Diode circuits

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What is a diode?

Simplest view (no physics):

— a unidirectional device that allows current to flow in one direction but not the other.

Ideally, we regard a diode as short circuit when voltage applied to it in the forward manner is positive.
Ideal characteristic

Bias conditions

Forward bias: $v_d > 0$ — current can flow and $i_d > 0$.
Reverse bias: $v_d < 0$ — current cannot flow and $i_d = 0$. 

Ideal diode

with finite forward drop (more realistic)

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Take a closer look at the characteristic around the turning point.

The $i$-$v$ characteristic is an exponential function.

From physics, we have

$$i_d = I_{ss} \left( e^{\frac{q v_d}{kT}} - 1 \right)$$

Also, the diode can only stand the negative voltage up to a certain threshold $V_{BD}$, beyond which the diode conducts reverse current (breakdown).
Which model to use?

The choice depends on the external voltage magnitudes.

Ideal model:

1. For a voltage of 100V:
   \[ i_d = \frac{100}{100} = 1 \text{ A} \]
   With 0.7V drop:
   \[ i_d = \frac{(100-0.7)}{100} = 0.997 \text{ A} \]

2. For a voltage of 10V:
   \[ i_d = \frac{10}{100} = 100 \text{ mA} \]
   With 0.7V drop:
   \[ i_d = \frac{(10-0.7)}{100} = 93 \text{ mA} \]

3. For a voltage of 2V:
   \[ i_d = \frac{2}{100} = 20 \text{ mA} \]
   With 0.7V drop:
   \[ i_d = \frac{(2-0.7)}{100} = 13 \text{ mA} \]
Example: rectifier circuit

The ideal model is valid if the external voltages are well above 0.7V.

What is the magnitude of $v_r$?
- Crude — 50 V
- Better — $50 - 1.4 = 48.6$ V
Application examples

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A nonlinear circuit problem

Suppose we wish to find $v_d$, given that the external voltage $V_s$ is not large enough to validate the use of the ideal diode model.
Step 1 : locating the operating points

Recall: The characteristic curve/line for a device actually defines where the point \((v, i)\) can lie.

We know

1. the operating point \((v_d, i_d)\) is somewhere on the diode characteristic curve

2. the operating point \((v_R, i_R)\) is somewhere on the resistor characteristic curve
Step 2 : KVL & KCL constraints

We also know

from KCL : \( i_d = i_R \)  \hspace{1cm} \text{AND} \hspace{1cm} \text{from KVL} : \( v_d + v_R = V_s \)
Step 3: enforcing KVL & KCL

Method: flip the resistor curve horizontally; and push the two curves together horizontally until the y-axes are $V_s$ apart.
Solution: load line

The flipped resistor line is called the LOAD LINE.
General problem

How to find $v_d$ and $i_d$?
Basic load line construction

\[ + v_R - \]
\[ R \]
\[ + i_d \]
\[ - v_d \]
\[ i \]
\[ V_s \]

slope = \(-\frac{1}{R}\)

device characteristic

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Alternative construction

\[ V_s \quad + \quad v_R \quad - \quad i_R \]

\[ R \]

\[ i_d \quad + \quad v_d \quad - \quad i \]

Nonlinear device

Load line

\( i_d \) when device is short-circuit

\( v_d \) when device is open-circuit

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Tutorial problem

Find the operating point.