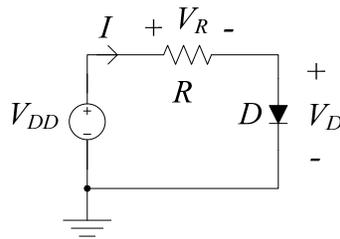


## Lecture 3: DC Analysis of Diode Circuits.

We'll now move on to the DC analysis of diode circuits. Applications will be covered in following lectures.

Let's consider this very simple diode circuit:



We will assume that the diode is forward biased. Using KVL

$$V_{DD} = IR + V_D \quad (4.7),(1)$$

From the characteristic equation for the diode

$$I = I_S \left( e^{\frac{V_D}{nV_T}} - 1 \right) \quad (4.1),(2)$$

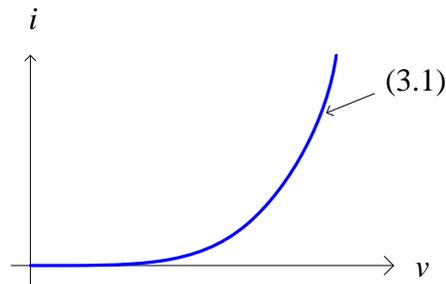
Assuming  $n$ ,  $I_S$ , and  $V_T$  are known, we have two equations for the two unknown quantities  $V_D$  and  $I$ . Substituting (2) into (1):

$$V_D = V_{DD} - I_S R \left( e^{\frac{V_D}{nV_T}} - 1 \right) \quad (3)$$

which is a transcendental equation for  $V_D$ . There is **no simple analytical solution** to this equation.

So how do we solve such a circuit problem? Over the next couple of pages we'll mention five methods.

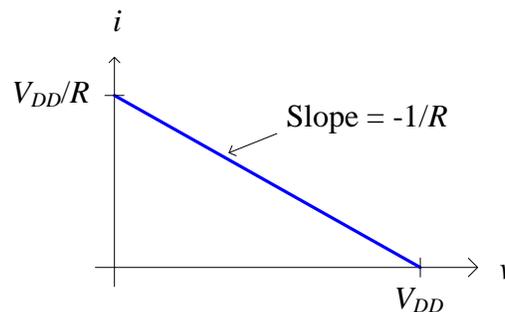
1. Graphical Analysis. Begin with the diode  $i$ - $v$  characteristic curve:



From (1), we can rearrange the equation in terms of  $I$  to also plot above. That is, from (1)

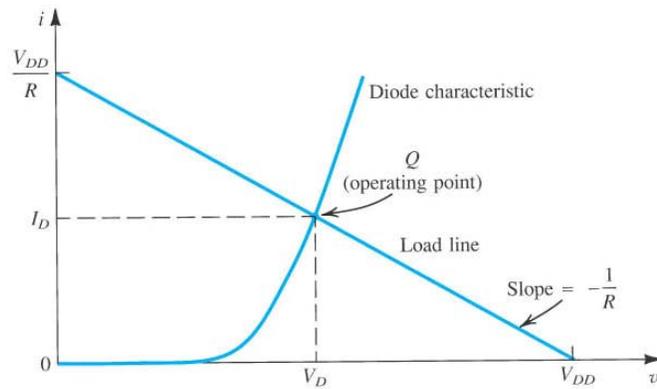
$$I = \frac{V_{DD}}{R} - \frac{V_D}{R} \quad (4)$$

which is an equation for a straight line ( $y = b + mx$ ):



We call this straight line the **load line**.

Now, plot both of these curves on the same graph:

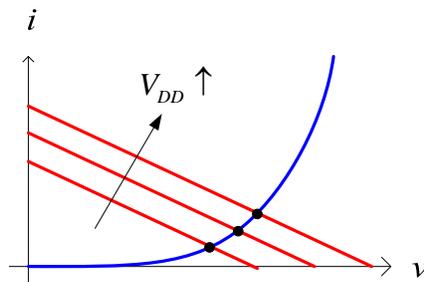


(Fig. 4.11)

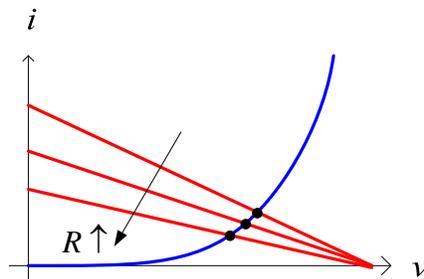
The point where these two curves intersect is the simultaneous solution to the two equations (1) and (2).

This graphical method is an impractical solution method for all but the simplest circuits. However, it is useful for a **qualitative understanding** of these circuits. For example, what happens when:

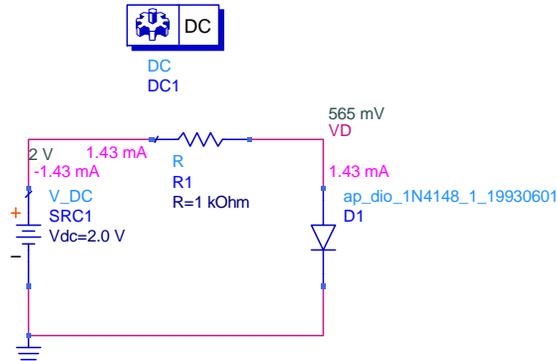
(a)  $V_{DD}$  increases?



(b)  $R$  increases?



## 2. Simulation packages. SPICE, Agilent's *Advanced Design System (ADS)*, etc. Here is a simple example using *ADS*:



## 3. Numerical methods. Use *Mathematica*, *Matlab*, *Mathcad*, etc. Here is a simple example from *Mathcad*:

### Solving a Nonlinear System of Equations for Diode Circuit

Enter the values of the circuit components and the characteristics of the diode:

$$R := 1000 \quad V_{DD} := 1.0 \quad I_S := 10^{-15} \quad n := 1.05 \quad V_T := 0.025$$

Enter guess values for the two unknowns:

$$V_D := 0.7 \quad I_D := 0.001$$

Enter the two equations:

Given

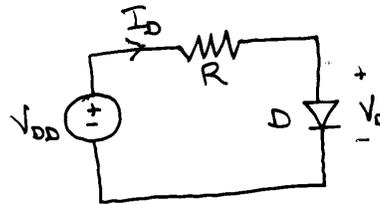
$$V_{DD} = I_D \cdot R + V_D$$

$$I_D = I_S \cdot \left( e^{\frac{V_D}{n \cdot V_T}} - 1 \right)$$

**Note:** Use the symbolic equals sign [Ctrl]= to define equations within the **Solve Block**.

$$\text{vec} := \text{Find}(V_D, I_D)$$

$$\text{Solution:} \quad \text{vec} = \begin{pmatrix} 0.694 \\ 3.058 \times 10^{-4} \end{pmatrix} = \begin{matrix} V_D \\ I_D \end{matrix}$$



4. Iterative analysis. See Example 4.4 in the text.
  5. Approximate analysis. This is by far the most widely used approach for hand calculations.
- 

## Approximate Diode Circuit Solutions

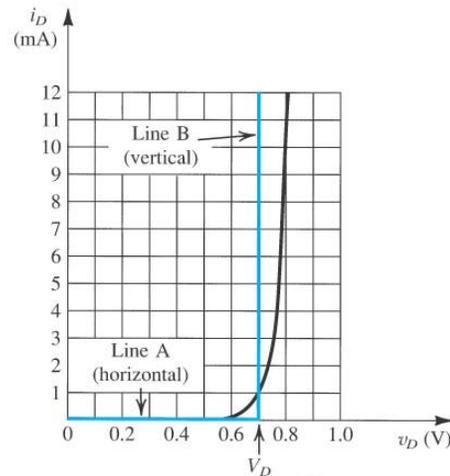
There is often a need for us to perform design with pencil and paper. Remember: simulation packages don't design for you, they only analyze circuits. There's a **big difference between design and analysis!**

There are **two very important approximate diode models** that allow easier paper designs:

1. Constant-Voltage-Drop (CVD) Model.
  2. Piecewise Linear (PWL) Model.
- 

## Constant-Voltage-Drop (CVD) Model

In this model, the characteristic curve is approximated as:

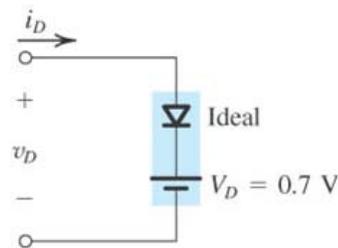


(Fig. 1)

In words, this model says that if the diode is forward biased, then the **voltage drop across the diode is  $V_D$** . If not forward biased, the diode is then reversed biased and the current is zero and  $V_D$  can be any value  $< V_D$ .

$V_D$  is often set to 0.7 V for silicon diodes, as shown above, while set to 0.2 V for Schottky diodes, for example.

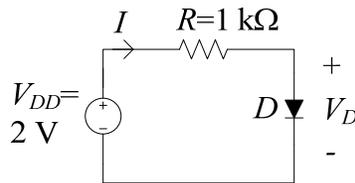
The CVD circuit model for diodes is



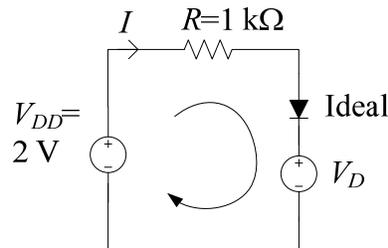
(Fig. 2)

This is probably the **most commonly used** diode model for hand calculations.

**Example N3.1.** Determine the current  $I$  in the circuit below using the CVD model and assuming a silicon diode.



Using the CVD model of Fig. 2, the **equivalent approximate circuit** is:



Assuming the diode is forward conducting (i.e., “on”) with  $V_D = 0.7\text{ V}$  and using KVL in this circuit:

$$2 = IR + V_D$$

or

$$I = \frac{2 - V_D}{R} = \frac{2 - 0.7}{1000} = 1.3\text{ mA}$$

The positive value of this current indicates our original assumption that the diode is “on” is correct.

What if  $V_{DD} = 0.5\text{ V}$ ? By KVL again,

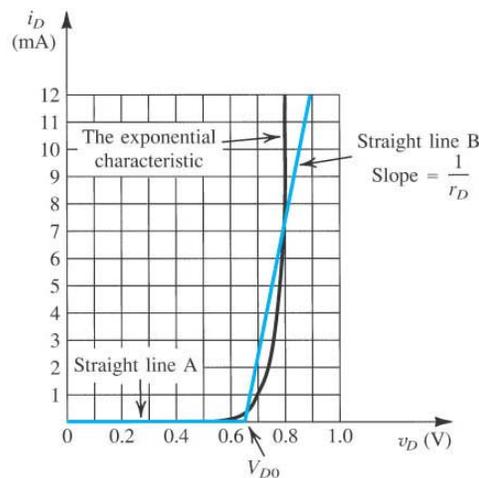
$$I = \frac{0.5 - V_D}{R} = \frac{0.5 - 0.7}{1000} = -0.2\text{ mA.}$$

Since  $I$  is negative, then D must be reversed biased. This means our initial **forward conducting assumption was incorrect**. Rather, in this situation  $I = 0$  and  $V_D = 0.5$  V.

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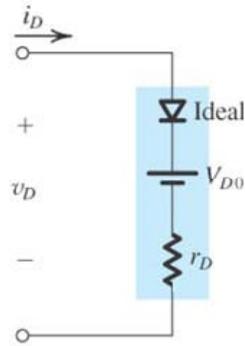
## Piecewise Linear (PWL) Diode Model

This is a “battery plus internal diode resistance model.” It is one step better than the CVD model by incorporating a slope to the interpolative line:



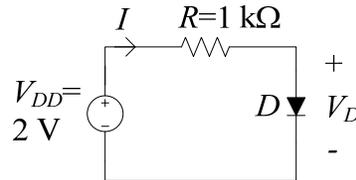
(Fig. 3)

The finite slope to this curve means that the diode has a **non-zero internal resistance**, which we will label as  $r_D$ . The equivalent circuit for the PWL diode model is then



(Fig. 4)

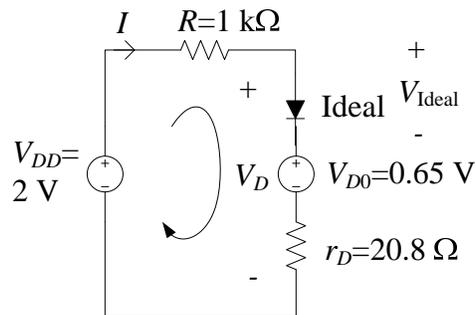
**Example N3.2.** Determine the current  $I$  in the circuit below using the PWL diode model shown in Fig. 3.



From Fig. 3, we can determine  $V_{D0}$  and  $r_D$  for the particular diode whose characteristic equation is shown:

- $V_{D0} = 0.65 \text{ V}$
- $r_D = \frac{\text{run}}{\text{rise}} = \frac{0.9 - 0.65}{12 \times 10^{-3}} = 20.8 \text{ } \Omega$ .

The equivalent circuit using the PWL model of the diode is then



Assuming the diode is “on,” then by KVL:

$$2 = I \cdot 1000 + 0.65 + 20.8 \cdot I$$

or

$$I = 1.32 \text{ mA.}$$

This is close to the 1.3 mA we computed in the last example using the cruder CVD model. Again, the positive value of this current indicates that we made the correct choice that the diode is “on.”

What’s the forward voltage drop across the diode?

$$V_D = 2 - 1000 \cdot 1.32 \times 10^{-3} = 0.68 \text{ V}$$

Is this enough to turn the diode on? Yes, referring to the equivalent circuit above

$$V_{\text{Ideal}} = V_D - 0.65 - 20.8 \cdot 1.32 \times 10^{-3} \approx 0^+ \text{ V}$$