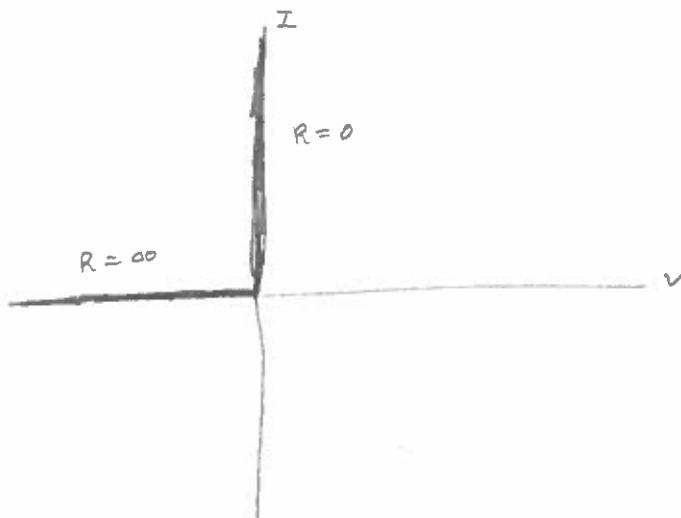


Diode Circuits

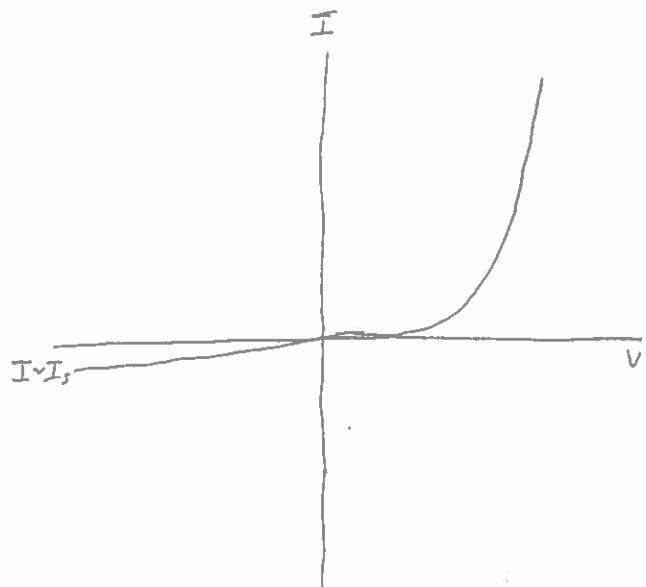
Diode is a pn junction that passes current in one direction but not in the other direction.



Ideal diode



Real diode



$$I = I_s [e^{\frac{V}{V_t}} - 1]$$

$$I_s = A g n_i^2 \left[\frac{D_p}{L_p N_p} + \frac{D_n}{L_n N_A} \right]$$

We will consider several different models for analyzing DC circuits with diode circuit elements.

Real diode model : Graphical / Iterative procedure



What is V_0 (voltage across diode?) .

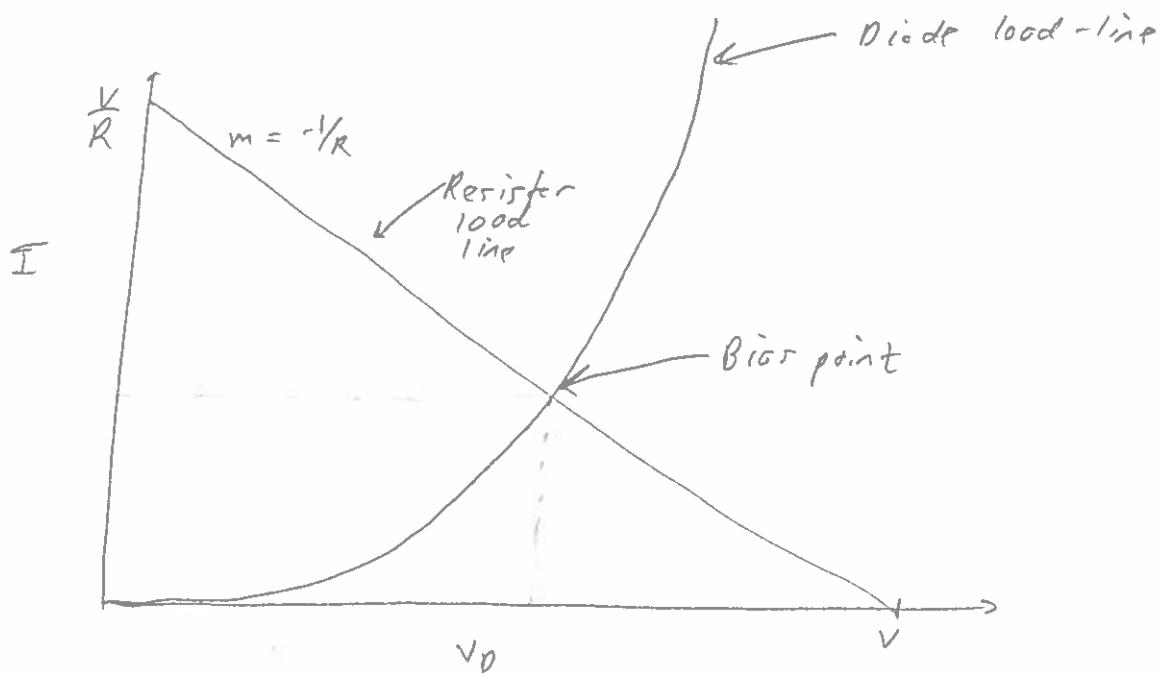
This is the voltage that will result in the same current through the resistor R as it will through the diode.

In other words:

$$\frac{V - V_0}{R} = I_s (\exp \frac{V_0}{V_t} - 1)$$

Graphical ("load-line") analysis

Plot I-V characteristics for each circuit device. Intersection point will give voltage bias point.



It is useful to derive an expression that relates an increase in voltage across a diode to an increase in current

$$I_d = I_s \left[\exp \left(\frac{V}{V_t} \right) - 1 \right]$$

$$\approx I_s \exp \left(\frac{V}{V_t} \right)$$

$$I_{d,1} = I_s \exp \left(\frac{V_1}{V_t} \right)$$

$$I_{d,2} = I_s \exp \left(\frac{V_2}{V_t} \right)$$

$$\frac{I_{d,2}}{I_{d,1}} = \exp \left(\frac{V_2 - V_1}{V_t} \right)$$

$$\ln \left(\frac{I_{d,2}}{I_{d,1}} \right) = \frac{V_2 - V_1}{V_t}$$

$$V_2 - V_1 = V_t \ln \left(\frac{I_{d,2}}{I_{d,1}} \right)$$

$$V_2 - V_1 = 2.3 V_t \log_{10} \left(\frac{I_{d,2}}{I_{d,1}} \right)$$

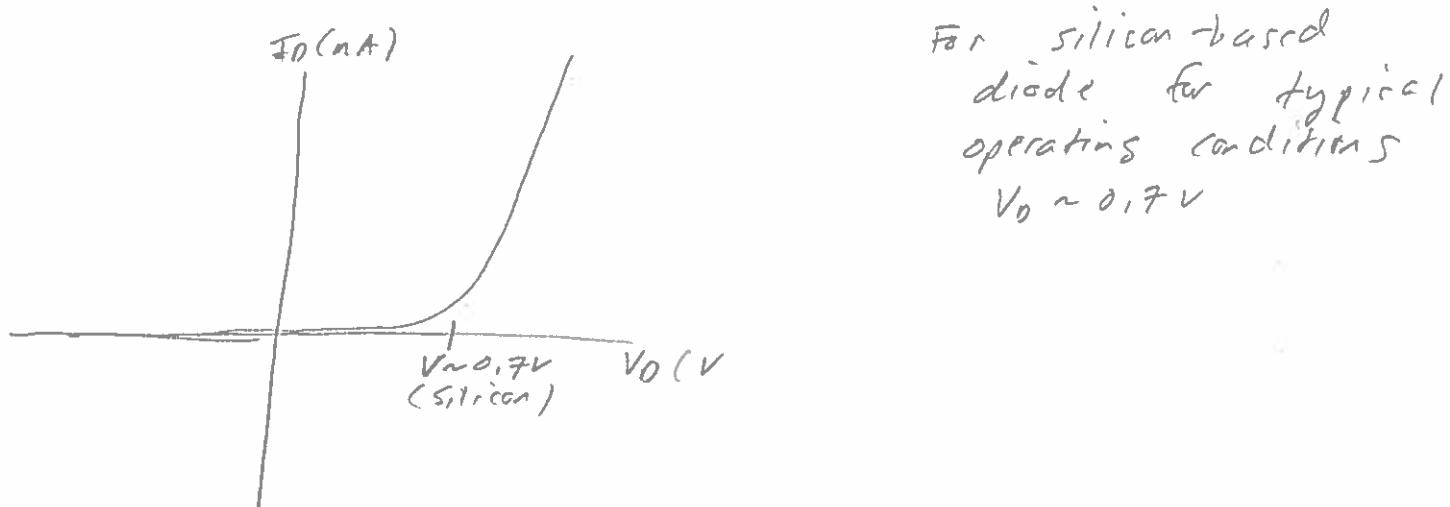
What does this say?

For a decade (factor of 10) increase in current, you need an additional voltage of $2.3 V_t = 60 \text{ mV}$.

Sometimes called the "swing" = 60 mV/decade

This is fundamental and NOT related to device constants or material constants!

We can also solve without graphical or computer-aided help by using an iterative approach.



If $V = 5.0\text{V}$ $R = 1\text{k}\Omega$
and I_R is such that
 $I_D = 1\text{mA}$ for $V_0 = 0.7\text{V}$

Iteration #1 : Assume $V_0 = 0.7\text{V}$
current through resistor

$$I = \frac{5 - 0.7}{1\text{k}\Omega} = 4.3\text{mA}$$

This is much larger
than 1mA \therefore our
assumption of $V_0 = 0.7\text{V}$
is too low.

Iteration #2 : plug in resistor current (4.3mA)
and determine diode voltage needed
to produce that current.

$$\text{Recall: } V_2 - V_1 = 2.3V \times \log_{10}\left(\frac{I_2}{I_1}\right)$$

$$V_2 - V_1 = 0.060 \log_{10}(4.3) = 0.038$$

$$\text{So, our new } V_0 = 0.738\text{V}$$

Let's recalculate the current through the resistor

$$I = \frac{5 - 0.738}{1k\Omega} = 4.264 \text{ mA} \quad (\text{really close to } 4.3 \text{ mA!})$$

Iteration #3

$$V_2 - V_1 = 2.3V_t \log 10 \left(\frac{4.264}{4.3} \right)$$

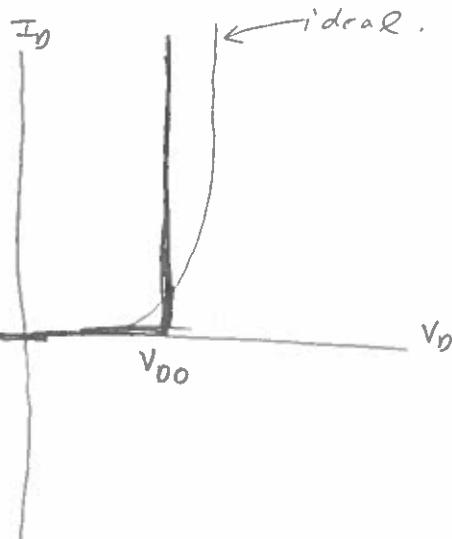
$$\text{New } V_D = 0.7368$$

$$\text{Current through resistor} = 4.2632 \text{ mA}$$

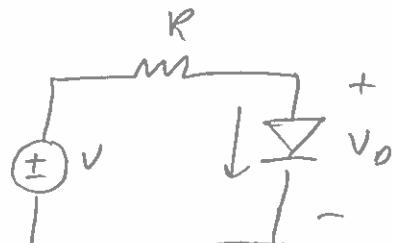
We can stop now since current through resistor and diode are almost identical.

Simplified models for diode

#1 constant voltage drop



$$R = \begin{cases} \infty & V_D < V_{D0} \\ 0 & V_D \geq V_{D0} \end{cases}$$

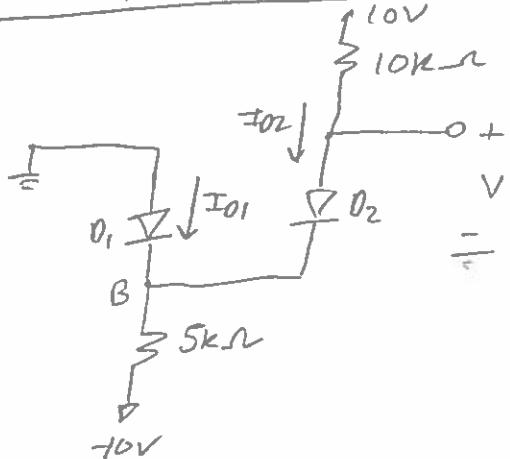


$$V = 5V \quad R = 1k\Omega$$

What is I_D ?

$$I_D = \frac{5 - 0.7}{1k\Omega} = 4.3 \text{ mA}$$

More complicated example:



what is I_{D1} , I_{D2} , and V ?

use constant voltage drop model for diode $V_{DD} = 0.7V$

Let's assume that both D_1 and D_2 are on.

$$\text{Then Node } B = -0.7V \quad // V$$

$$\text{and } I_{D2} = \frac{10 - (-0.7 + 0.7)}{10k\Omega}$$

$$= 1mA$$

$$\text{and } I_{D1} = \frac{-0.7 - -10}{5k\Omega} = 1mA = 0.86mA$$

Final result: $I_{D2} = 1mA$
 $I_{D1} = 0.86mA$

What if we change $10k\Omega$ to $5k\Omega$?
 $5k\Omega$ to $10k\Omega$?

Again, assume that both diodes are turned on.

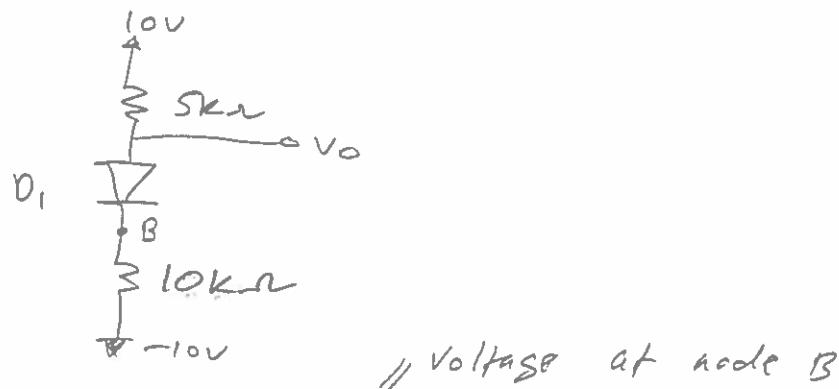
$$I_{D2} = \frac{10}{5k\Omega} = 2mA$$

$$I_{D1} = \frac{-0.7 - -10}{5k\Omega} - 2 = -0.14mA$$

(This can't be right!)

our first assumption was wrong, let's assume now that D_1 is off and D_2 is on.

Equivalent circuit:



$$I_{D1} = \frac{10 - (-10 + I_{D1} 10k\Omega \rightarrow, 7)}{5k\Omega}$$

$$5k\Omega I_{D1} = 10 + 10 - I_{D1} 10k\Omega \rightarrow, 7$$

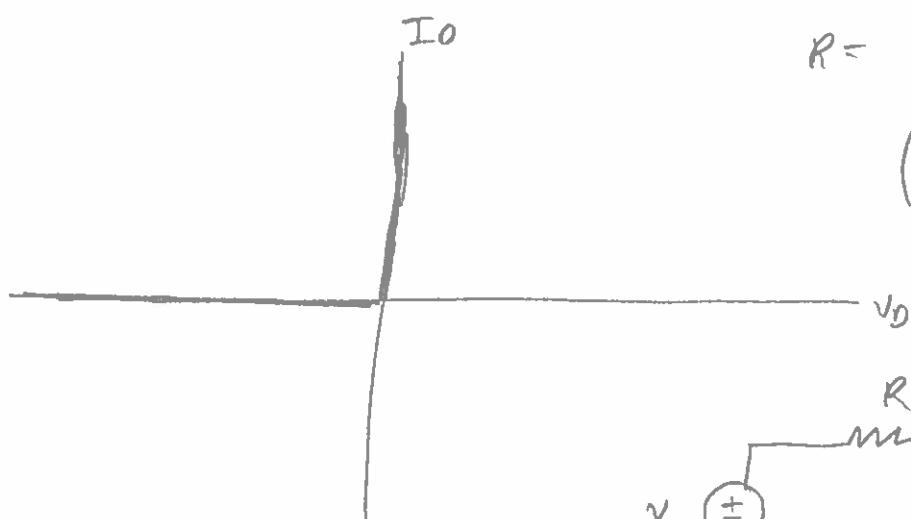
$$15k\Omega I_{D1} = 19,3$$

$$I_{D1} = \frac{19,3}{15k\Omega} = \boxed{1,29 \text{ mA}} \quad \text{Diode 1 is on!}$$

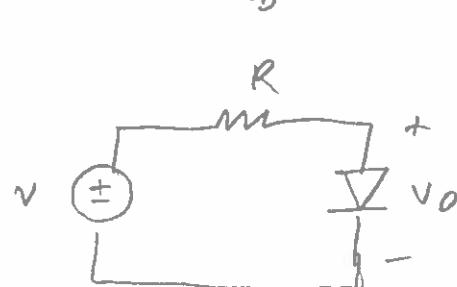
$$\begin{aligned} V_0 &= 10 - 5k\Omega I_{D1} \\ &= 10 - 6,45 \\ &= \boxed{3,55 \text{ V}} \end{aligned}$$

$V_B = 2,8 \text{ V} \rightarrow$ Diode 2 is reverse biased and is off!

#2 Ideal diode



$$R = \begin{cases} \infty & v_D < 0 \\ 0 & v_D \geq 0 \end{cases}$$



$$V = 5.0V \quad R = 1k\Omega$$

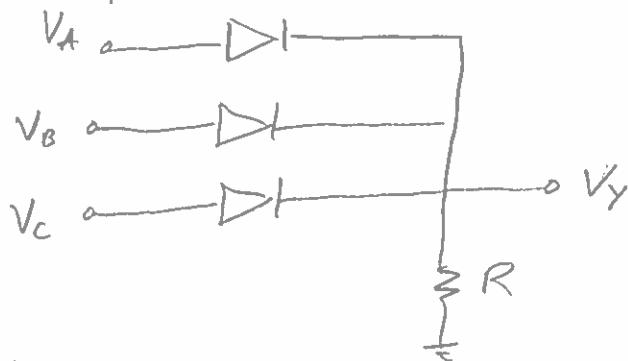
what is I_o ?

$$I_o = \frac{5}{1k\Omega} = 5mA$$

Diode Logic

Used for very early computers
but has largely fallen out of
favour due to major drawbacks.

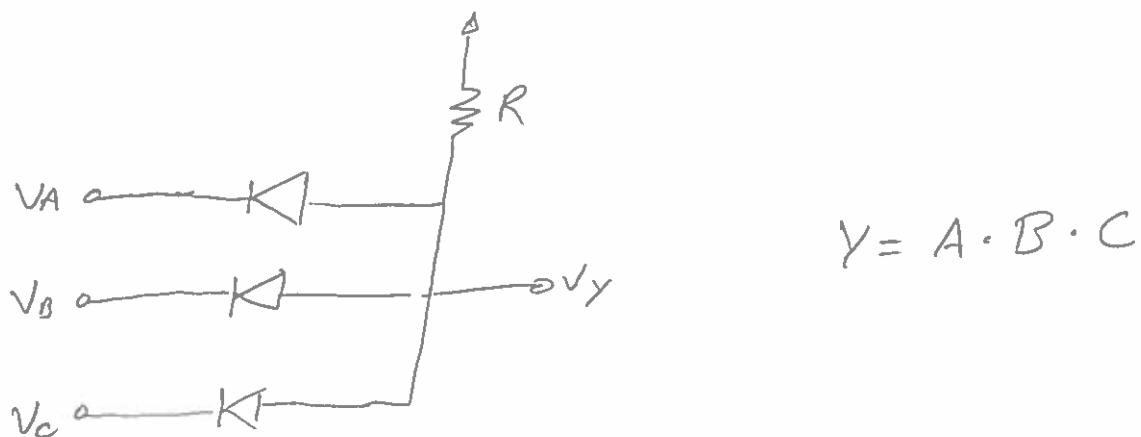
OR Gate



$$Y = A + B + C$$

111

AND Gate



$$Y = A \cdot B \cdot C$$

Downsides:

- Cascading not possible
- Large voltage drop across pull up / pull down resistor and diodes.