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# **Ideal Diodes**

**ECE 320 Electronics I (Digital Electronics)**

**Jake Glower - Lecture #6**

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# Diodes

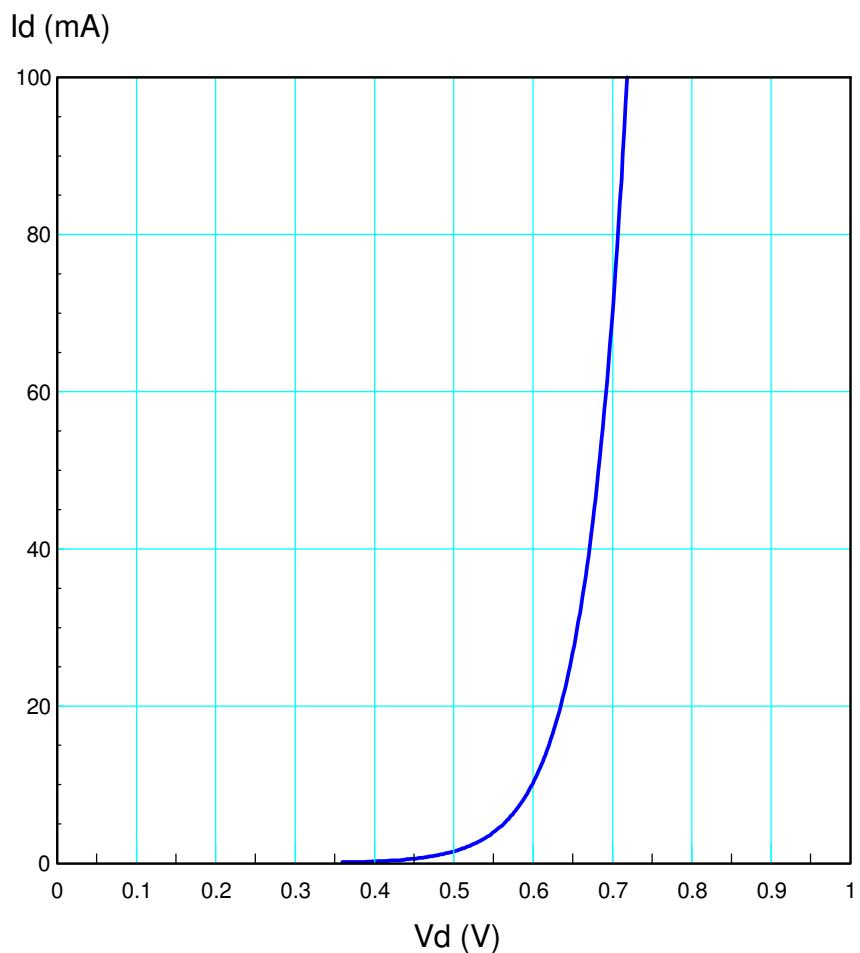
The VI characteristics for a diode are:

$$I_d = I_{dss} \cdot \left( \exp\left(\frac{V_d}{nV_t}\right) - 1 \right)$$

$$V_d = nV_t \cdot \ln\left(\frac{I_d}{I_{dss}} + 1\right).$$

Problem:

- These are nonlinear equations
- Circuit analysis is difficult
- You have to solve N nonlinear equations for N unknowns



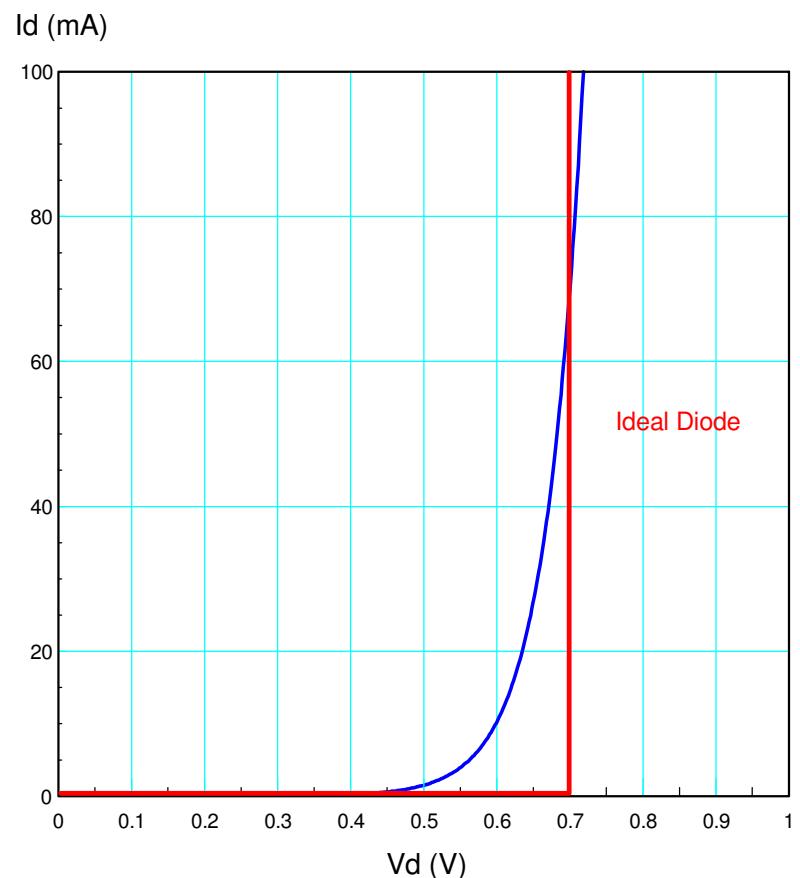
# Ideal Diode

Approximate the diode VI characteristics with a model which is

- Simple, and
- Accurate

Use a piecewise linear model

State	Model	Condition
On	$V_d = 0.7V$	$I_d > 0$
Off	$I_d = 0$	$V_d < 0.7V$



# Digikey & Ideal Diodes

- Vf tries to describe a nonlienar curve with a single number
- Ideal Diode:  $V_d = V_f$  if  $I_d > 0$

The screenshot shows the Digi-Key website interface. At the top, there is a navigation bar with the Digi-Key logo, a search bar labeled "All Products", and menu options for "PRODUCTS", "MANUFACTURERS", and "SEARCH". Below the navigation bar, the URL path is shown as "Product Index > Discrete Semiconductor Products > Diodes - Rectifiers - Single". The main content area displays the search results with a title "Results: 34,259". A search bar "Search Within Results" is present. The results are listed in three columns: "Voltage - DC Reverse (V<sub>r</sub>) (Max)", "Current - Average Rectified (I<sub>o</sub>)", and "Voltage - Forward (V<sub>f</sub>) (Max) @ If". The "Voltage - Forward (V<sub>f</sub>) (Max) @ If" column has a blue border around the first few items, indicating they are selected or highlighted.

Voltage - DC Reverse (V <sub>r</sub> ) (Max)	Current - Average Rectified (I <sub>o</sub> )	Voltage - Forward (V <sub>f</sub> ) (Max) @ If
-	-	620mV @ 7A
4V	3mA	625mV @ 8A
5V	10mA	630mV @ 1A
6V	10mA (DC)	630mV @ 100A
8V	15mA	630mV @ 10A
10V	15mA (DC)	630mV @ 120A
12V	20mA (DC)	630mV @ 16A
15V	30mA	630mV @ 1A
20V	30mA (DC)	630mV @ 20A
23V	33mA	630mV @ 25A

# Solving Diode Circuits Using the Ideal Diode Model: Take 1

Nonlinear Solution:

$$I_d = I_{dss} \cdot \left( \exp\left(\frac{V_d}{nV_t}\right) - 1 \right)$$

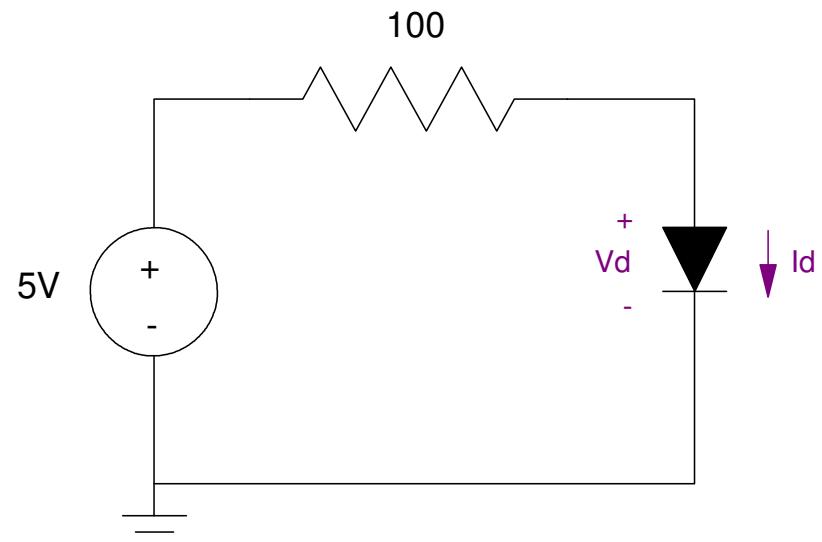
$$\left( \frac{V_d - 5}{100} \right) + I_d = 0$$

If

- $I_{dss} = 7.65e-11$
- $nV_t = 0.0377$

then

- $V_d = 0.7590V$
- $I_d = 42.41mA$



## Ideal Diode Model Solution:

Guess the diode is "on"

$$V_d = 0.7V.$$

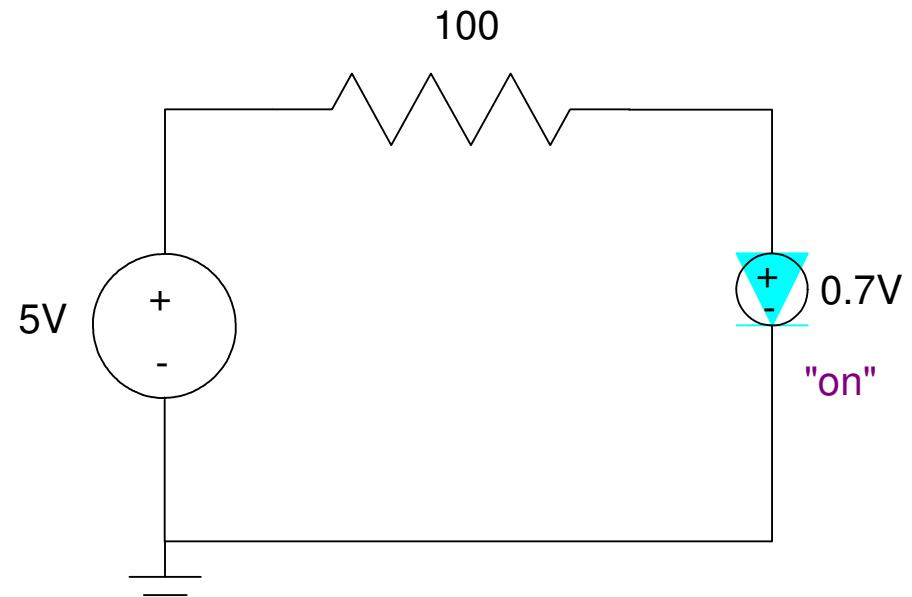
Solve for  $I_d$

$$I_d = \left( \frac{5-0.7}{100} \right) = 43mA$$

Check:  $I_d > 0$  when on

Note:

- The answer is close
- But slightly different from the nonlinear solution



# One Problem, 3 answers

Nonlinear Solution

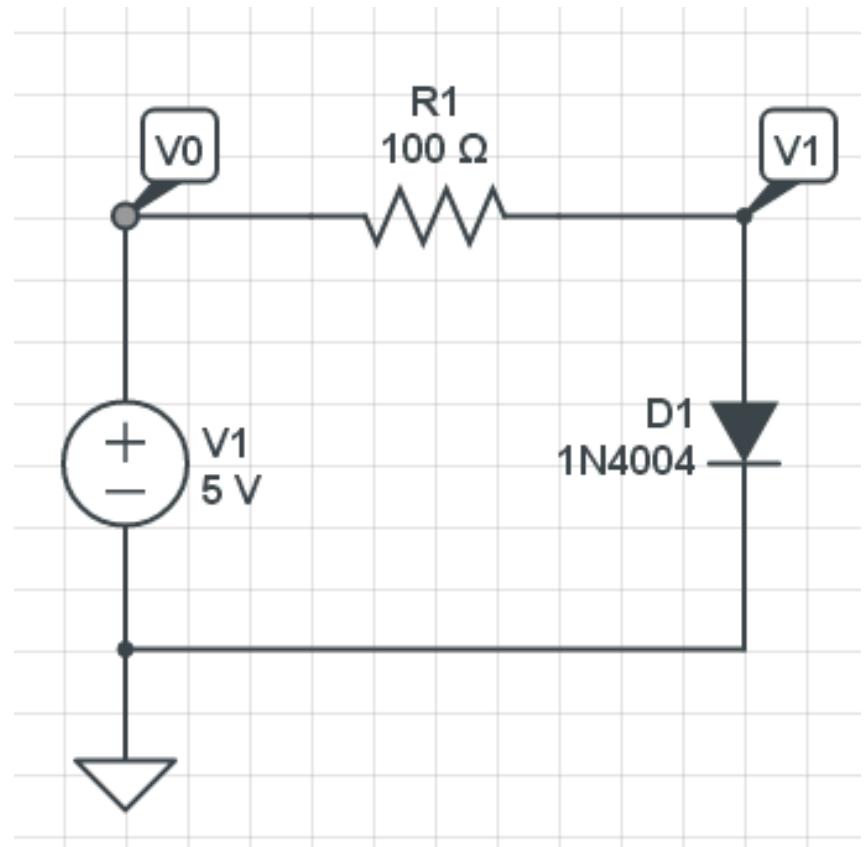
- $V_d = 0.7590V$
- $I_d = 42.41mA$

Ideal Diode

- $V_d = 0.7V$
- $I_d = 43mA$

CircuitLab

- $V_d = 0.7517V$
- $I_d = 42.48mA$



## Diode Circuits (take 2)

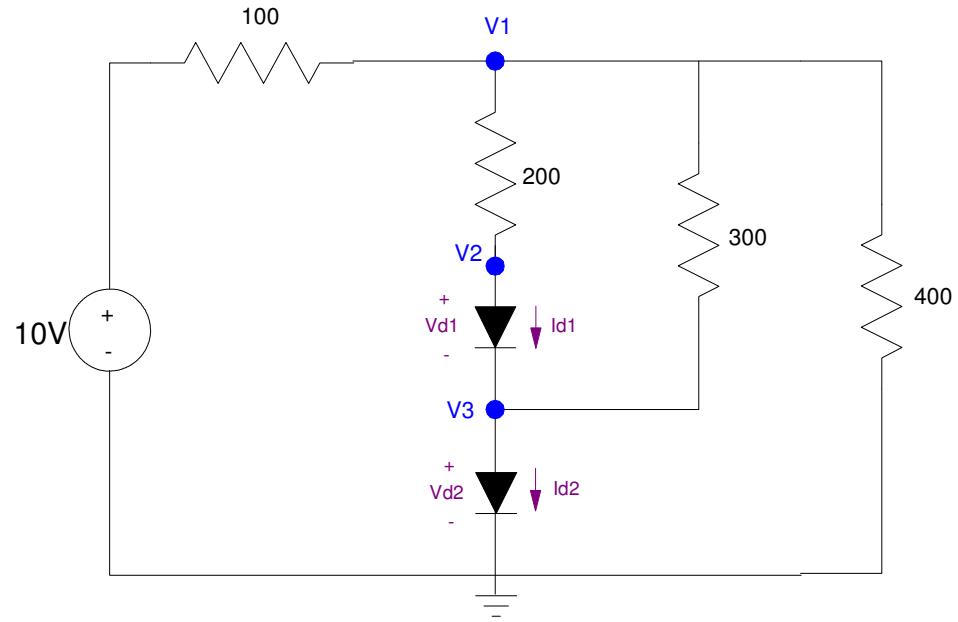
Guess which diodes are on and off

- $2^n$  permutations
- One is correct
- If you build the circuit, it does *something*

Replace the diodes with their ideal-diode model

Check your results

- On diodes have  $I_d > 0$
- Off diodes have  $V_d < 0.7V$



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Guess #1: Both diodes are on

- $V3 = +0.7V$
- $V2 = +1.4V$

$V_1$  is solved using voltage nodes:

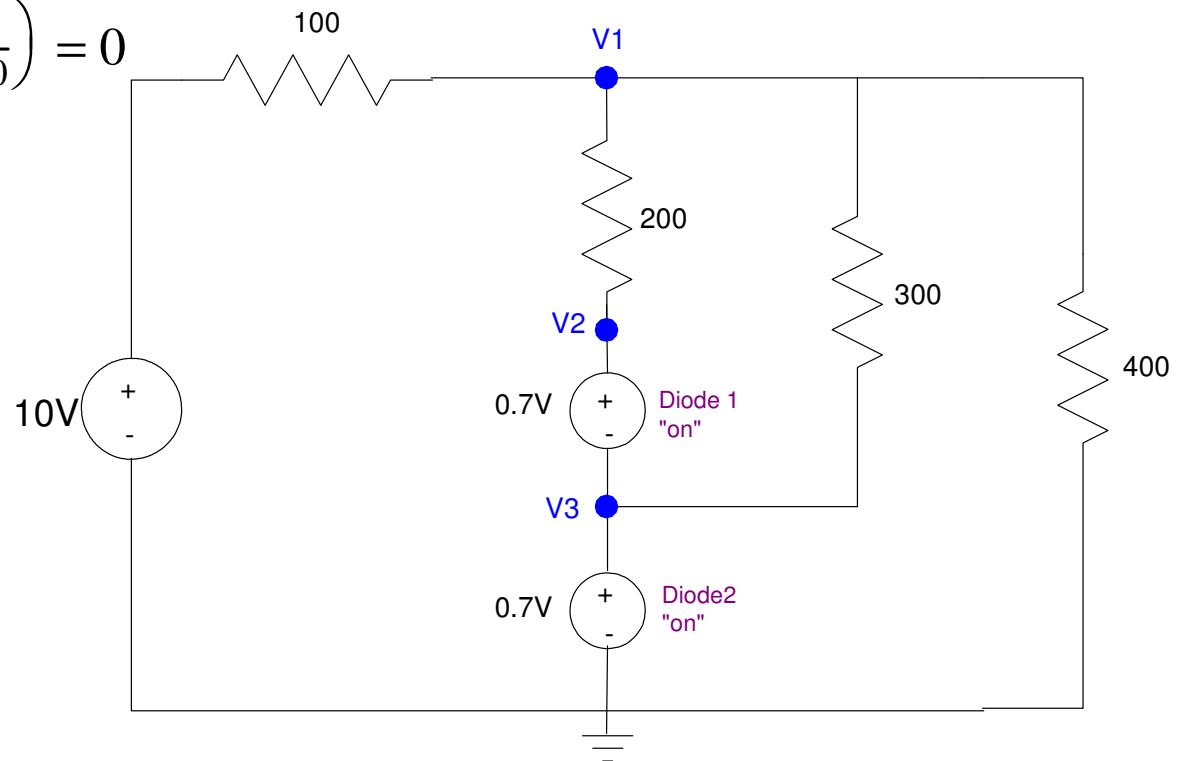
$$\left(\frac{V_1-10}{100}\right) + \left(\frac{V_1-1.4}{200}\right) + \left(\frac{V_1-0.7}{300}\right) + \left(\frac{V_1}{400}\right) = 0$$

- $V_1 = 5.248V$

Check:

$$I_{d1} = \left(\frac{V_1-1.4}{200}\right) = 19.2mA > 0$$

$$I_{d2} = I_{d1} + \left(\frac{V_1-0.7}{300}\right) = 32.1mA > 0$$



# One Circuit, 3 Answers (take 2)

Nonlinear Model:

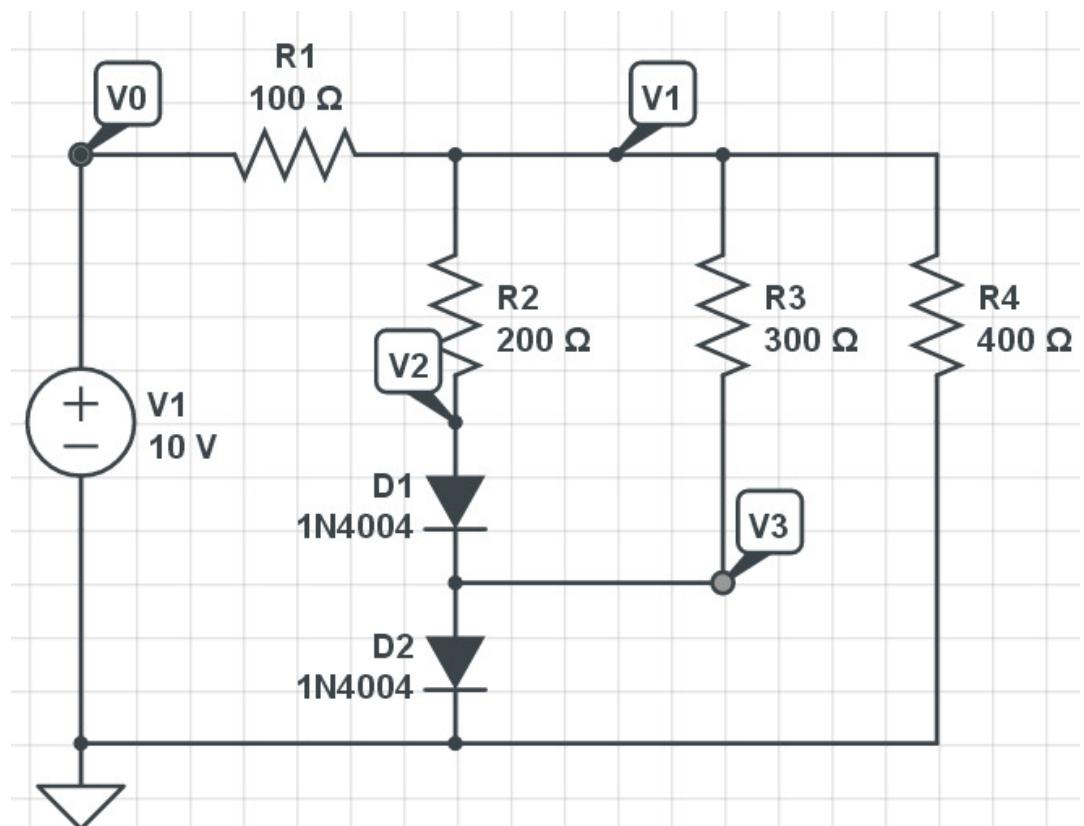
- $V_1 = 5.2528V$
- $V_2 = 1.4006V$
- $V_3 = 0.7291V$

Ideal Diode

- $V_1 = 5.248 V$
- $V_2 = 1.4 V$
- $V_3 = 0.7 V$

CircuitLab

- $V_1 = 5.270V$
- $V_2 = 1.464V$
- $V_3 = 0.7432V$



## Diode Circuit (take 3)

Repeat if the input voltage drops to 0.2V

Guess both diodes are off

- $I_{d1} = 0$
- $I_{d2} = 0$

Solve:

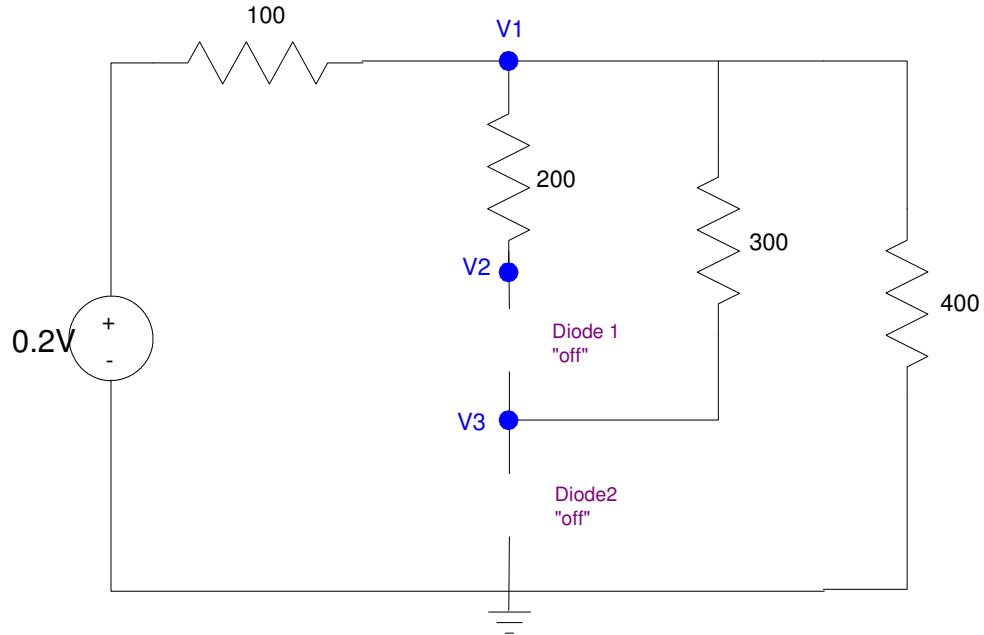
$$\left(\frac{V_1 - 0.2}{100}\right) + 0 + 0 + \left(\frac{V_1}{400}\right) = 0$$

$$V_1 = 0.16V$$

$$V_2 = 0.16V$$

$$V_3 = 0.16V$$

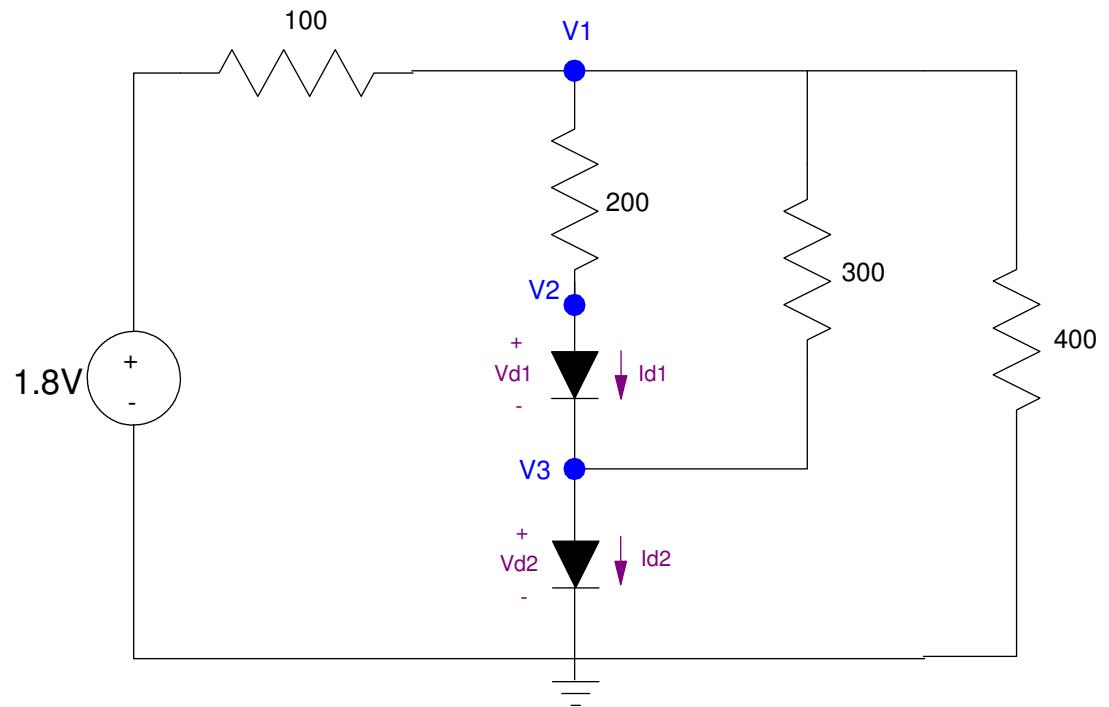
Check:  $V_d < 0.7$



## Diode Circuits (take 4)

Repeat when the input becomes 1.8V

- 4 permutations for diode 1 & 2
- One is correct
- *if you build the circuit, it does something*



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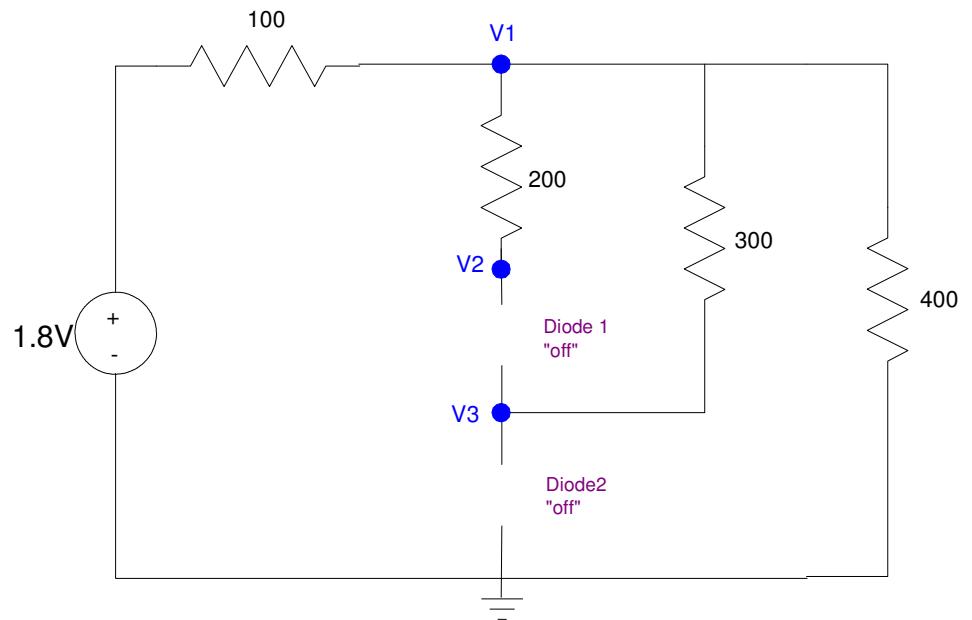
## Guess 1: Assume Both Diodes Off:

By voltage division

$$V_1 = \left( \frac{400}{400+100} \right) 1.8V = 1.44V$$

$$V_{d2} = 1.44V$$

This is too much: 1.44V will turn on diode 2. So, both diodes are not off.



## Guess 2: Assume Both Diodes On:

This results in

- $V_3 = 0.7V$
- $V_2 = 1.4V$

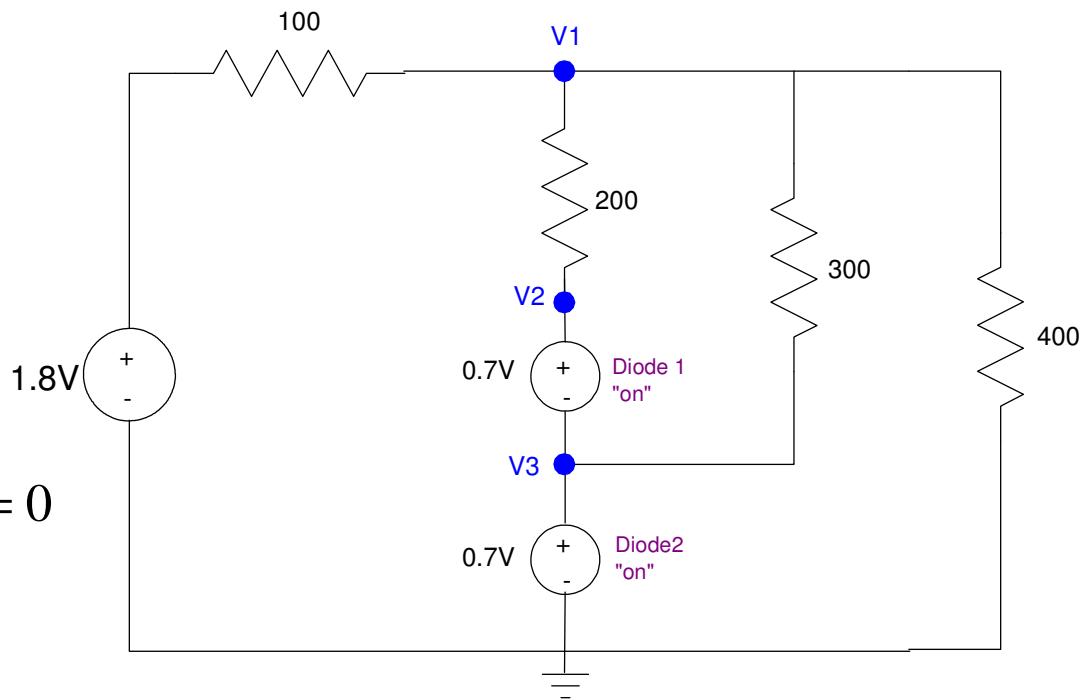
By voltage nodes:

$$\left(\frac{V_1 - 1.8}{100}\right) + \left(\frac{V_1 - 1.4}{200}\right) + \left(\frac{V_1 - 0.7}{300}\right) + \left(\frac{V_1}{400}\right) = 0$$

$$V_1 = 1.312V$$

Check:

$$I_{d1} = \left(\frac{V_1 - V_2}{200}\right) = -0.44mA$$



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### Guess 3: Assume Diode2 is on, Diode1 is off:

Solve using voltage nodes:

$$\left(\frac{V_1 - 1.8}{100}\right) + 0 + \left(\frac{V_1 - 0.7}{300}\right) + \left(\frac{V_1}{400}\right) = 0$$

This gives

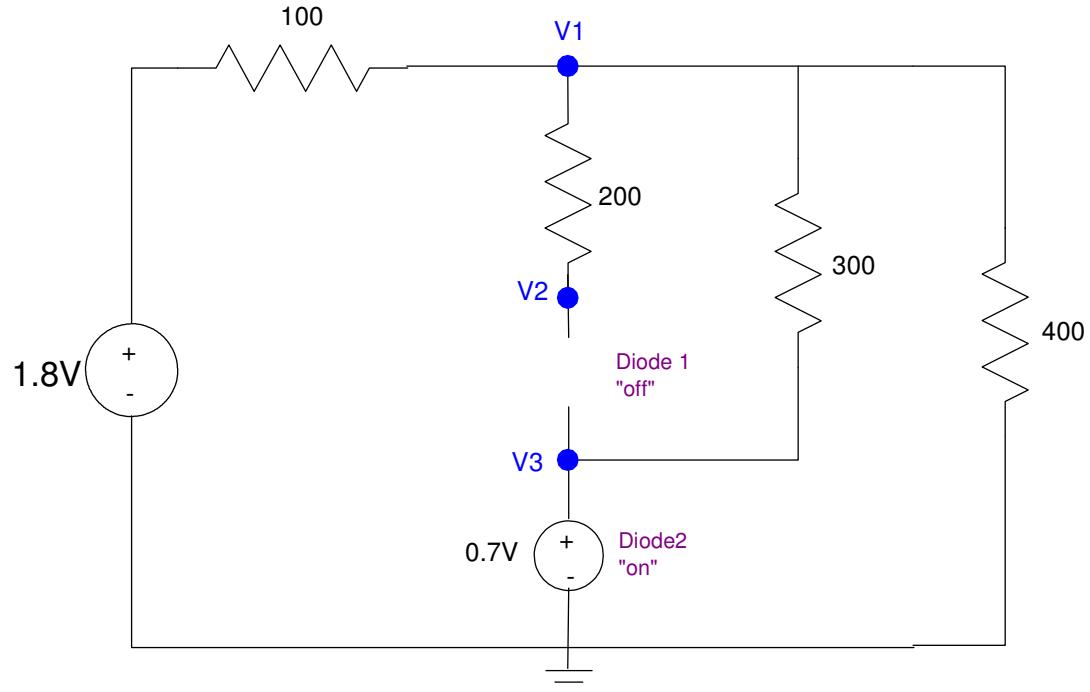
- $V_1 = 1.2842 \text{ V}$
- $V_2 = 1.2842 \text{ V}$
- $V_3 = 0.7 \text{ V}$

Check: Diode 1 is off:

$$V_{d1} = V_2 - V_3 = 0.5842 \text{ V} < 0.7 \text{ V}$$

Diode2 is on

$$I_{d2} = \left(\frac{V_1 - 0.7}{300}\right) = 0.263 \text{ mA} > 0$$



# One Circuit, Three Solutions

Ideal Diode:

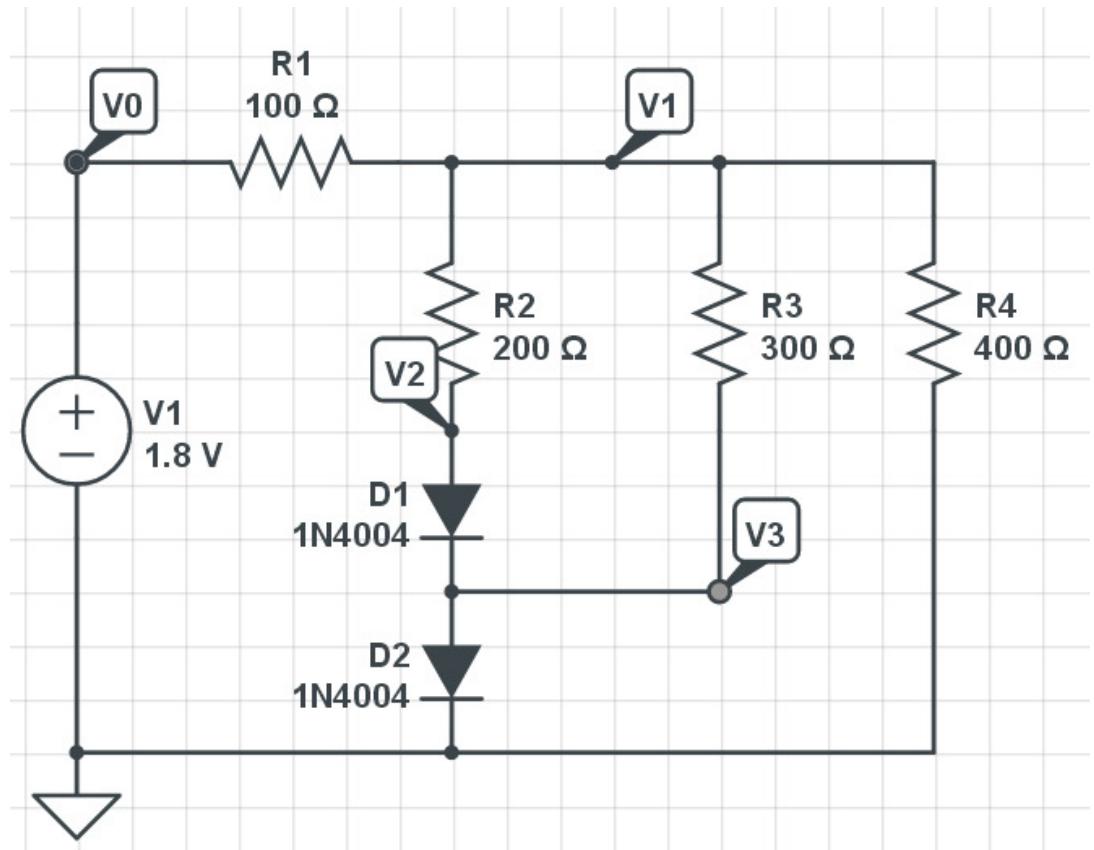
- $V_1 = 1.2842V$
- $V_2 = 1.2842V$
- $V_3 = 0.7V$

Nonlinear

- $V_1 = 1.2585$
- $V_2 = 1.2115$
- $V_3 = 0.6484$

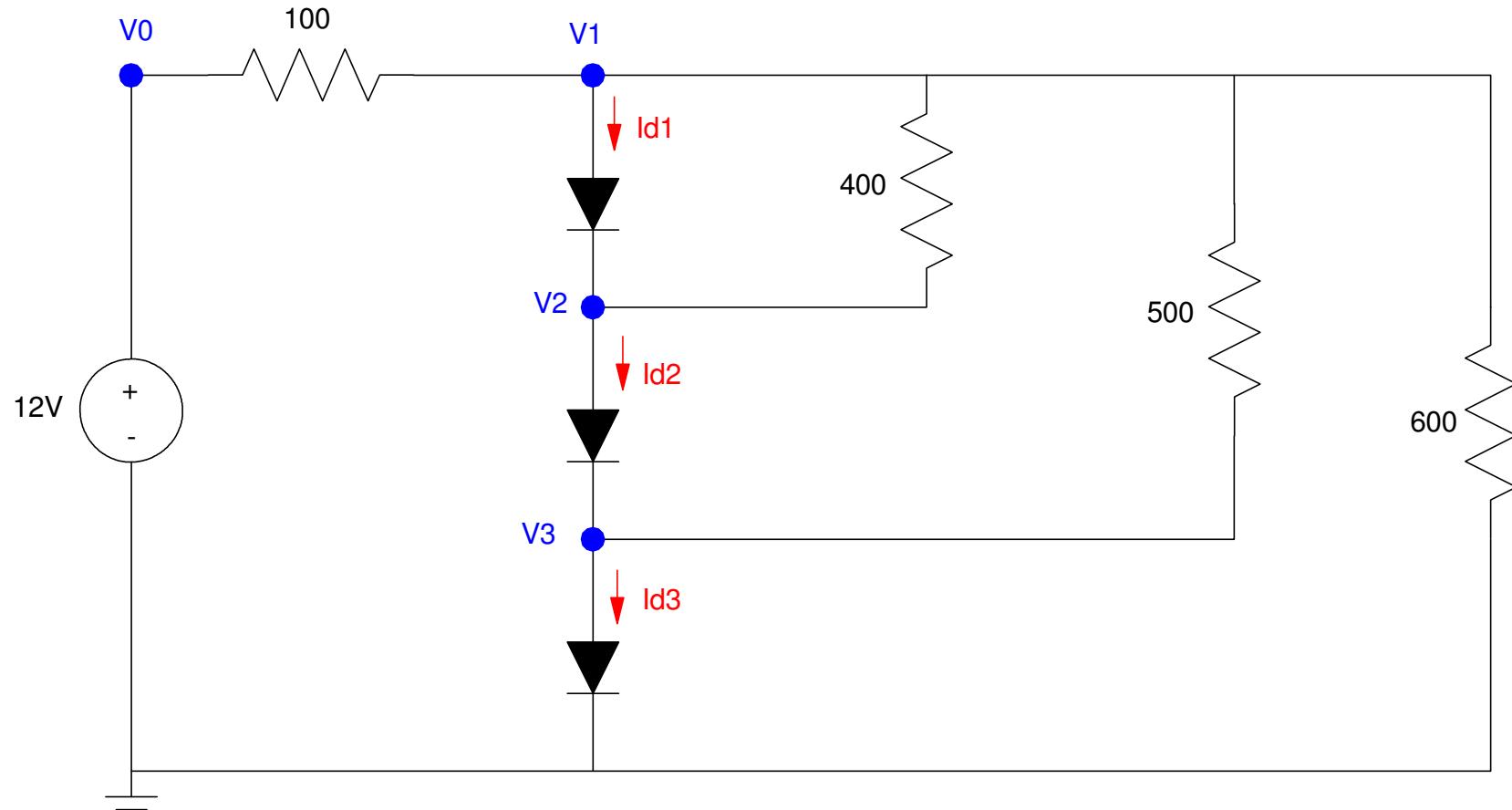
CircuitLab

- $V_1 = 1.255V$
- $V_2 = 1.202V$
- $V_3 = 0.6415V$



Handout:

Determine the voltages and currents assuming ideal silicon diodes



# Summary

Ideal diodes simplify circuit analysis

- Result is a linear circuit
- Results will be slightly off

Ideal diodes give better intuition for how diode circuits work

- The diode is a valve that's either on or off

They are a little annoying

- There are  $2^n$  possible circuits to analyze
- One is correct (the diode will do something)

