Spring 2019 Purdue University

ECE 255: L7

Ideal and Real Diodes

(Sedra and Smith, 4.1-4.2)

Mark Lundstrom
School of ECE
Purdue University
West Lafayette, IN USA

Announcements

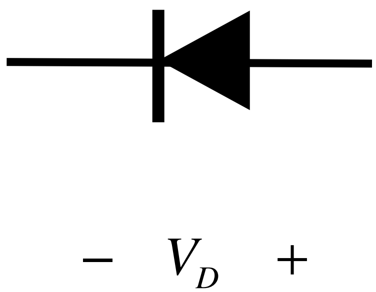
No office hours today.
(Remember, you can always email me to set up another time.)

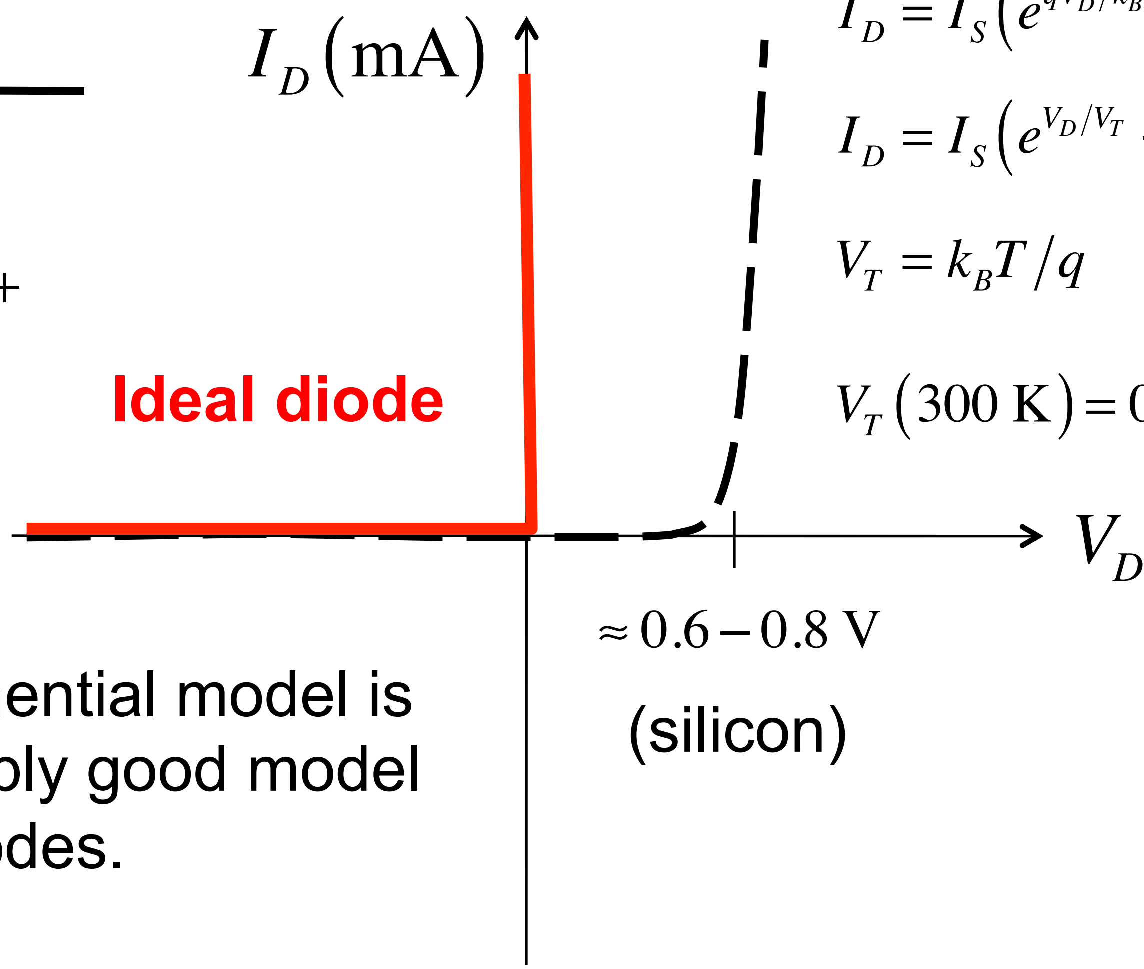
Exam 1: Thursday, Feb. 7, 6:30 PM, LILY 1105.
(Weeks -1- 4 topics, semiconductors, diodes, BJTs)

Ideal and Real Diodes

1) Ideal vs. real diodes
2) Circuit analysis using ideal diodes
3) Circuit analysis using “real” diodes

Ideal vs. real diodes





$$I_D = I_S\left(e^{qV_D/k_BT} - 1\right)$$

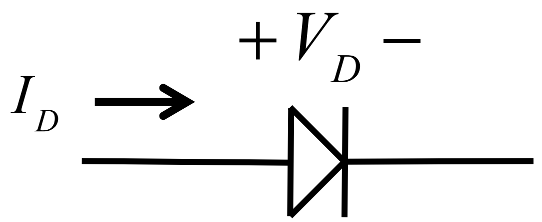
$$I_D = I_S\left(e^{V_D/V_T} - 1\right)$$

$$V_T = k_BT/q$$

$$V_T\left(300\ \mathrm{K}\right) = 0.026\ \mathrm{V}$$

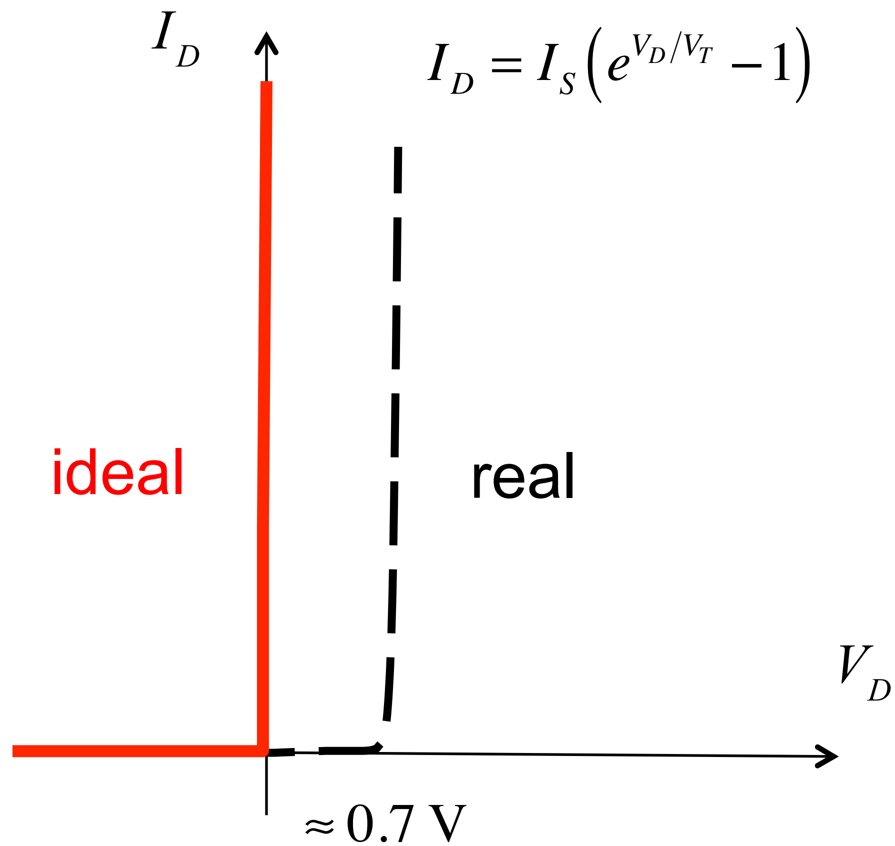
The exponential model is a reasonably good model for real diodes.

“Ideal” diode model

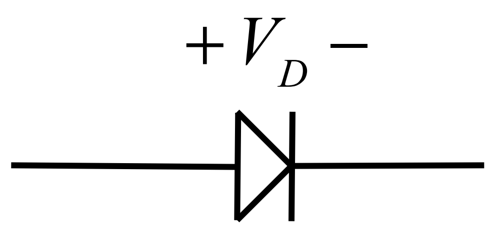


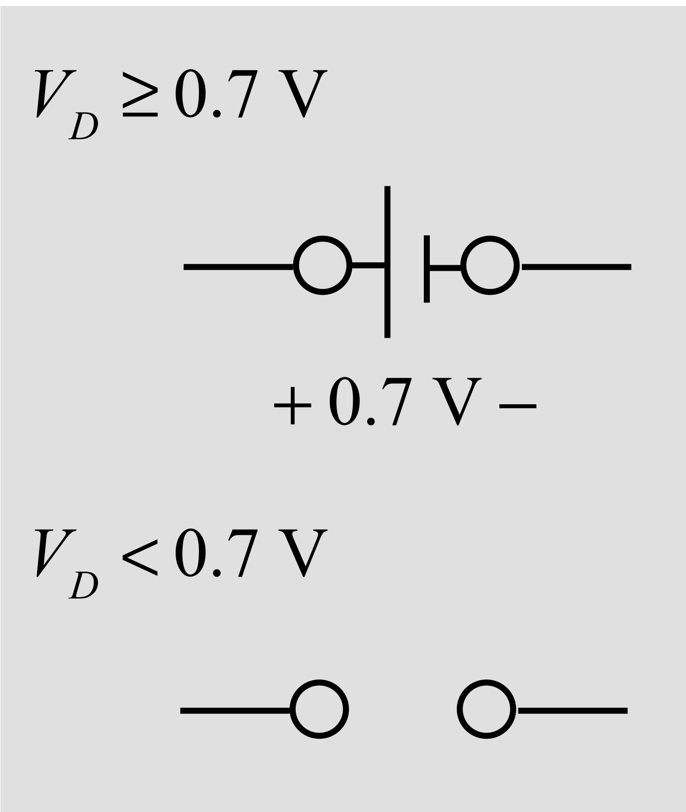
$V_D = 0$

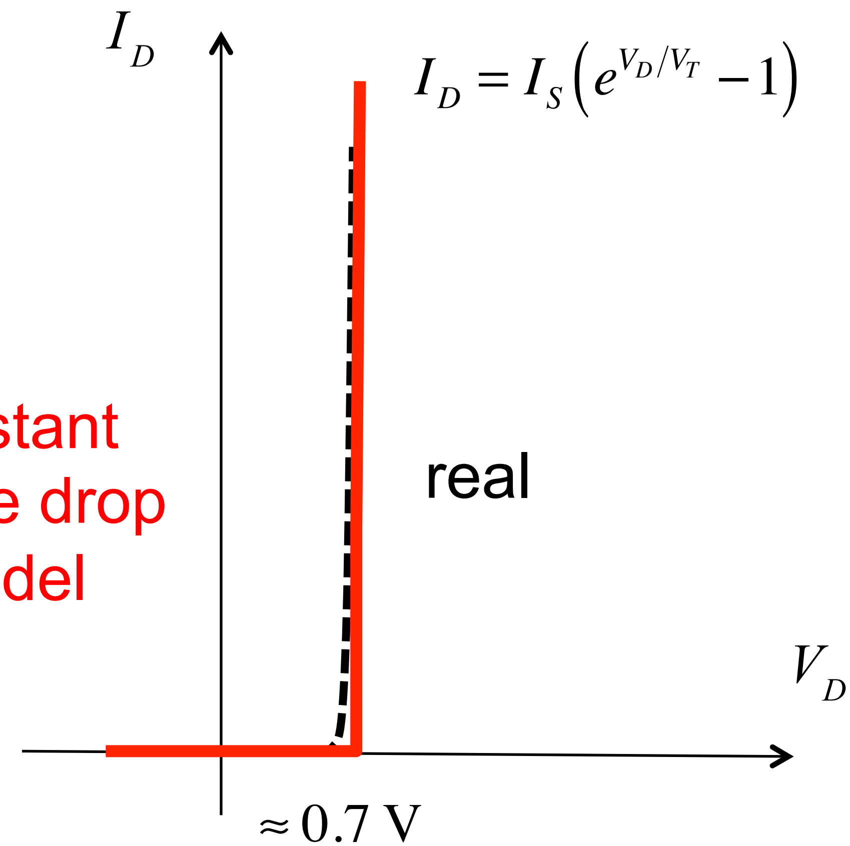
$V_D < 0$



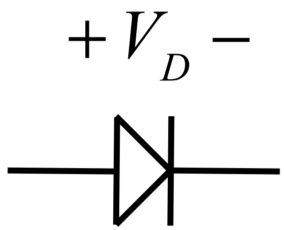
Constant-voltage-drop model

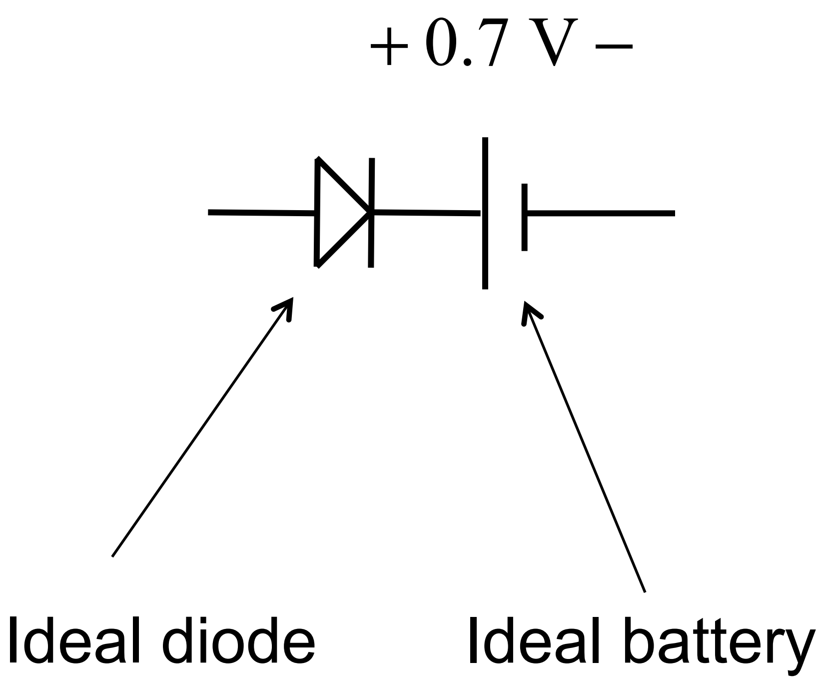


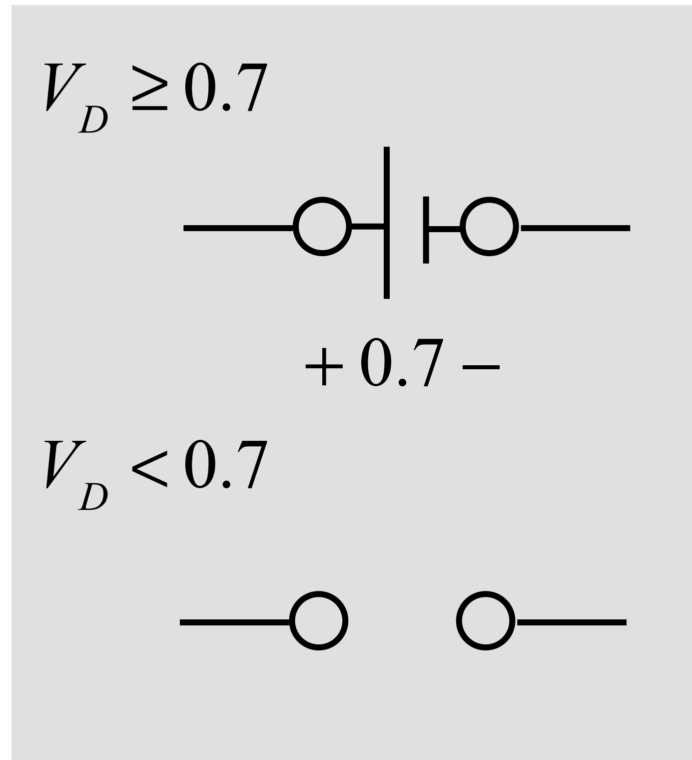




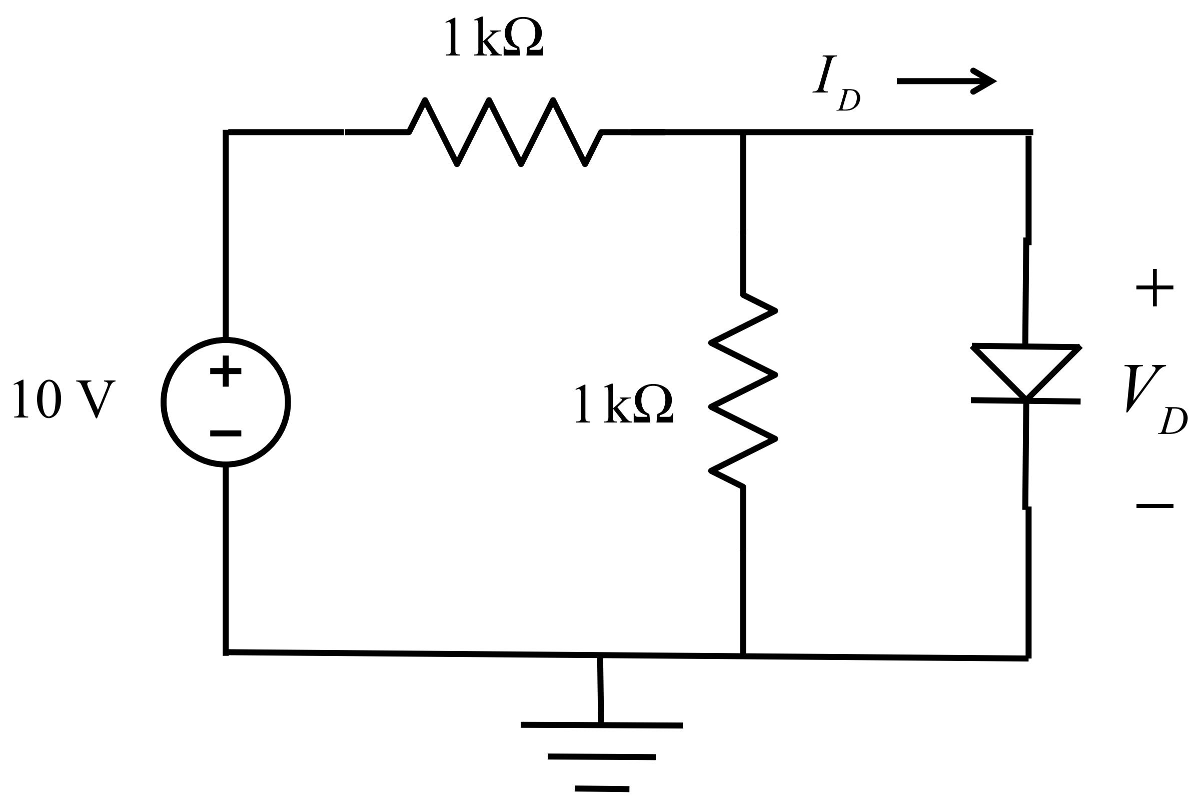
Constant-voltage-drop model



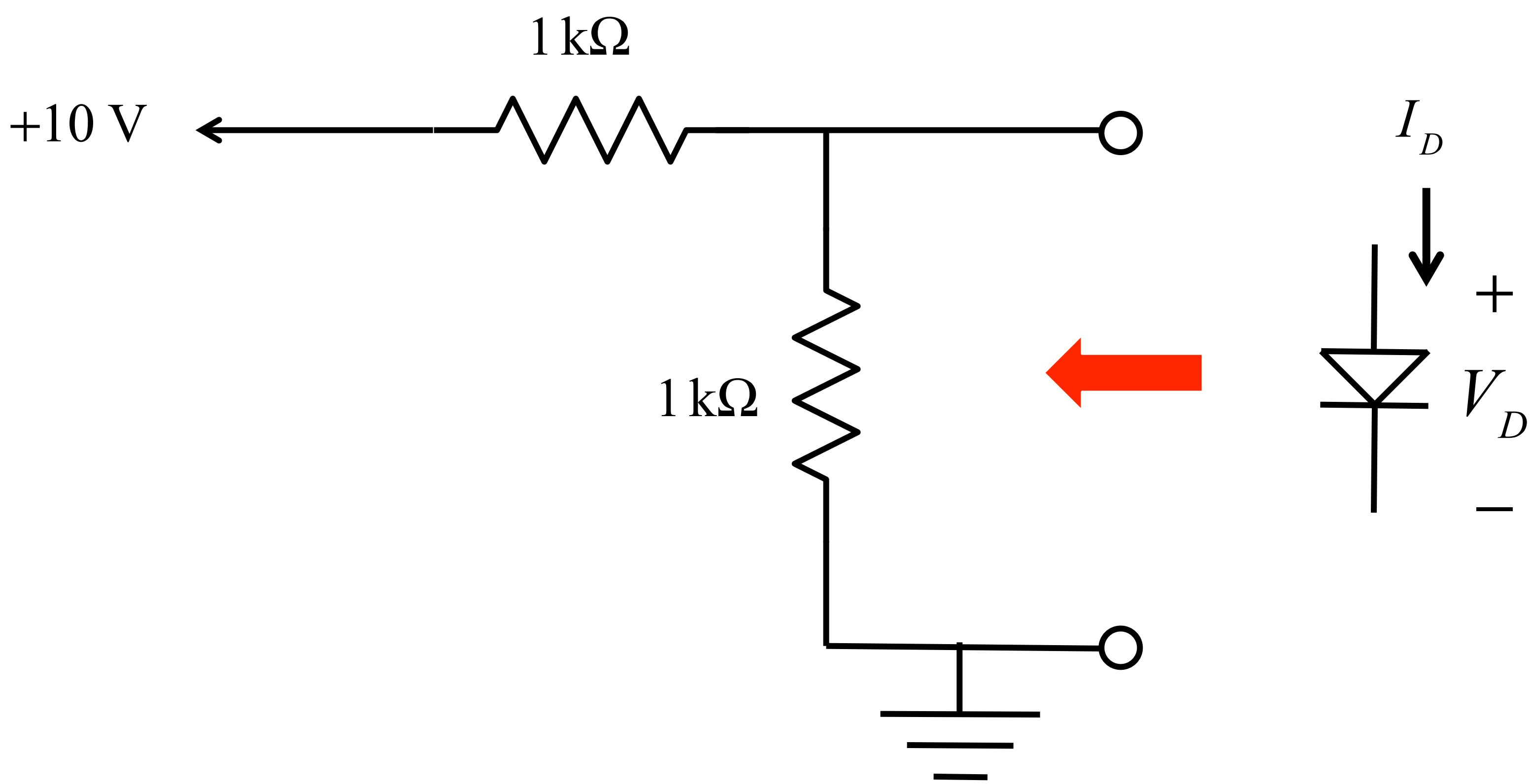




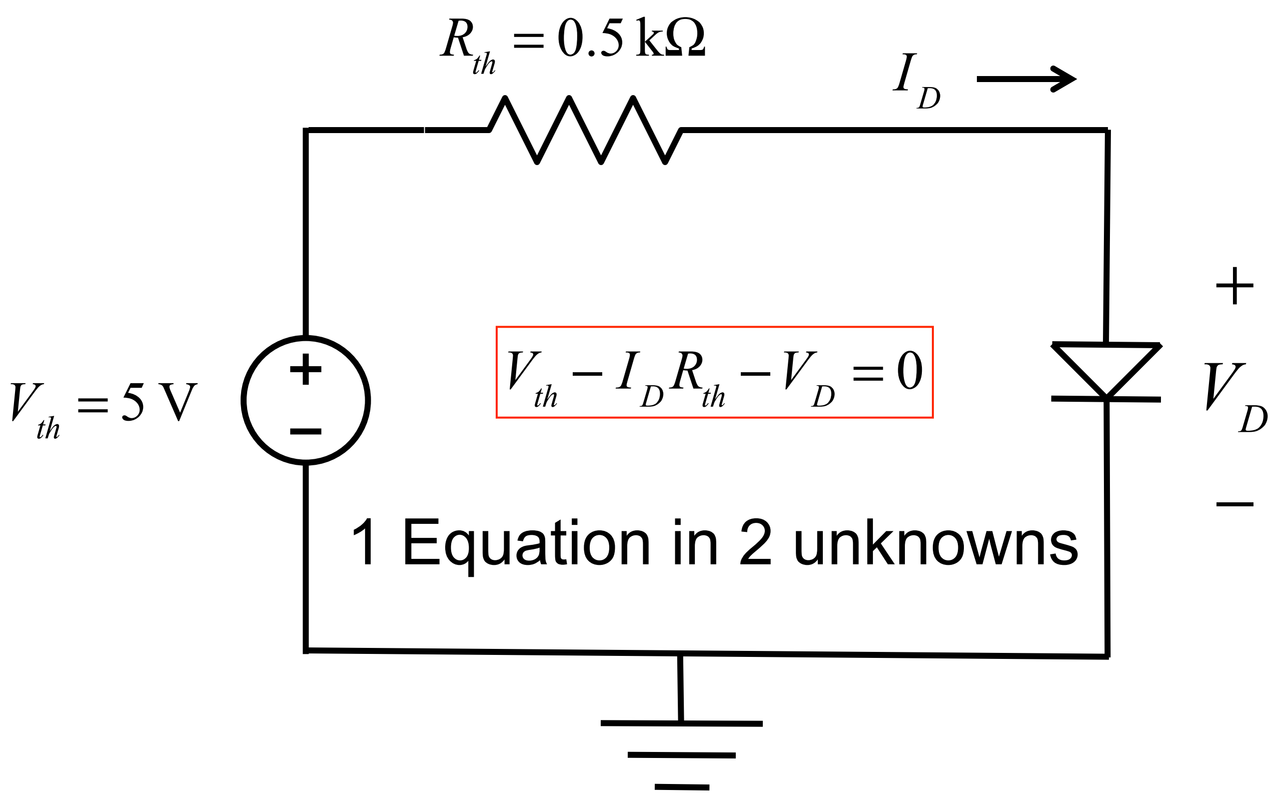
A simple circuit to analyze



Let's make it even simpler



Analyze the circuit

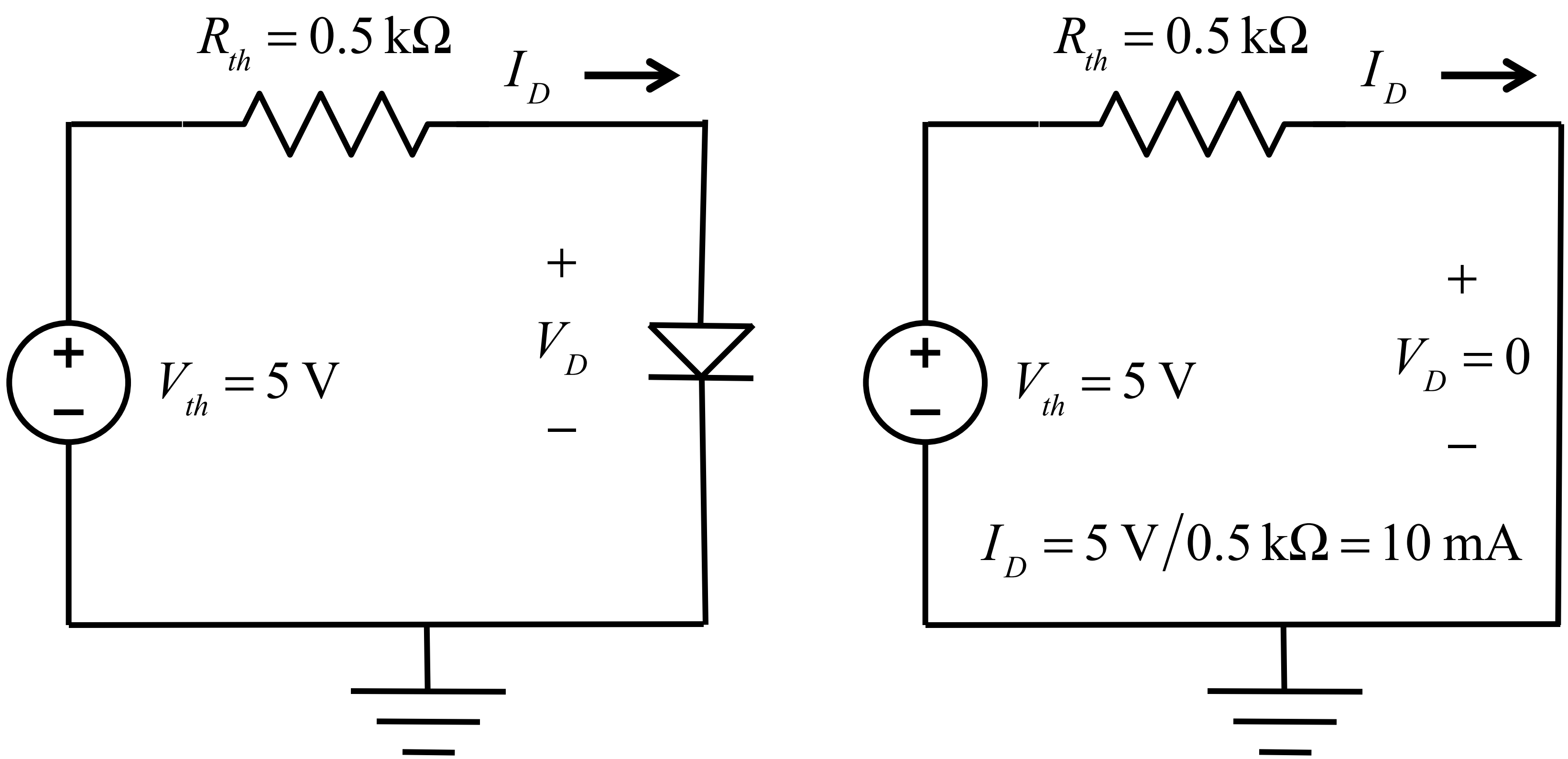


$$V_{th} - I_D R_{th} - V_D = 0$$

1 Equation in 2 unknowns

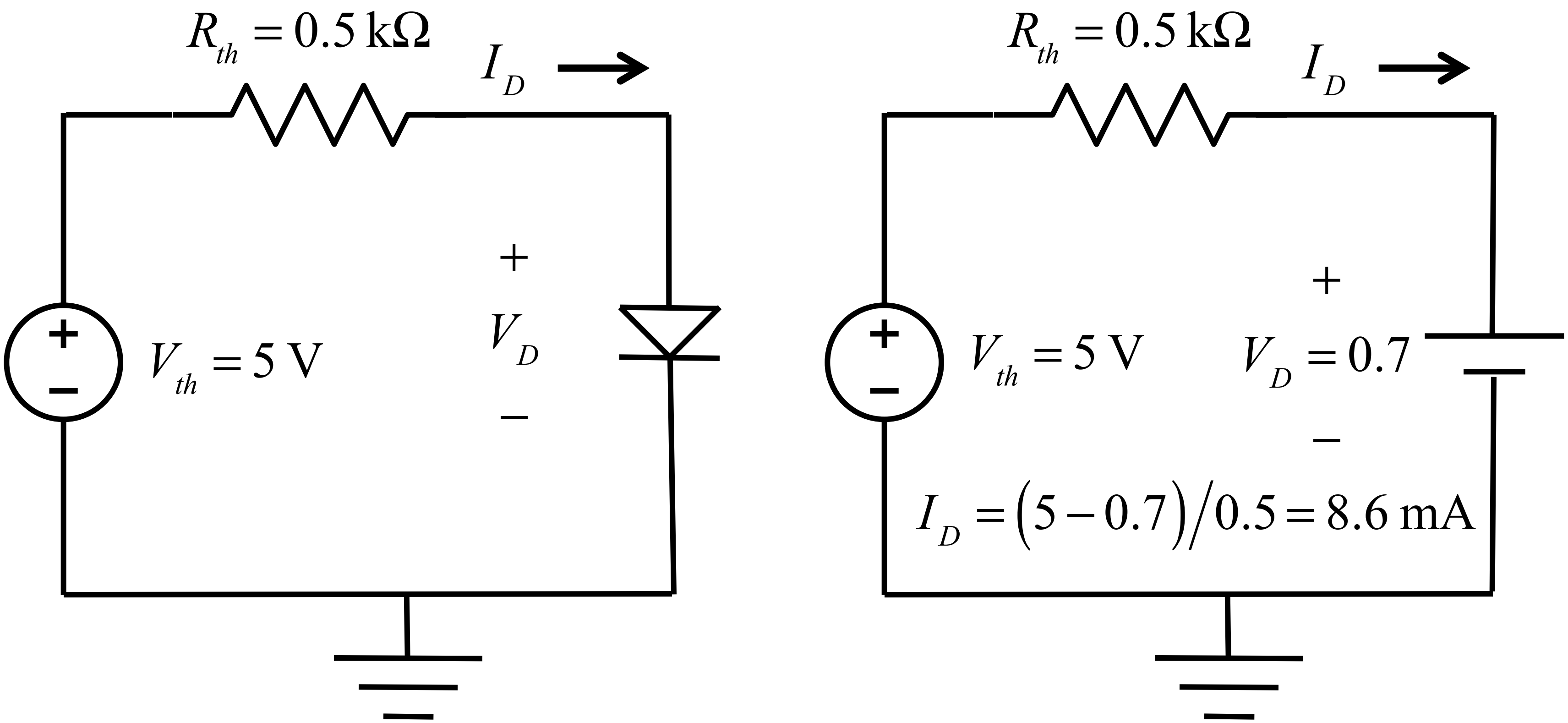
Need an equation for $V_D(I_D)$ or $I_D(V_D)$

1) Ideal diode analysis ($V_D = 0$)



$$\left(\text{Exact: } I_D = 8.61\ \mathrm{mA}\right)$$

2) Constant-voltage-drop model (V_D = 0.7 V)

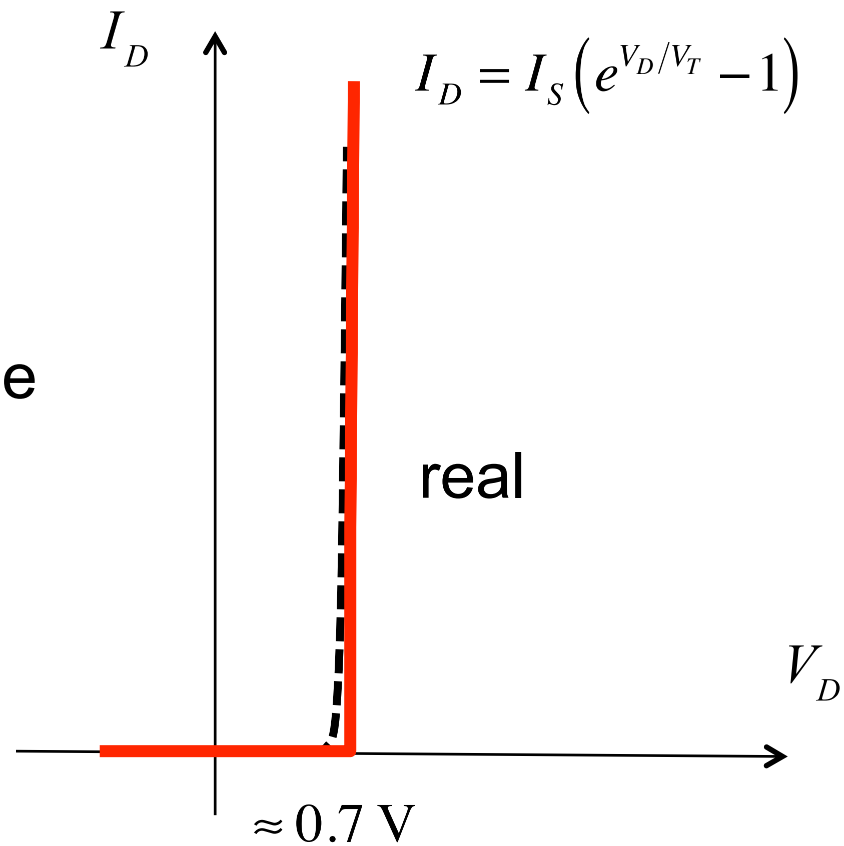


$$I_D = (5 - 0.7)\,\mathrm{V} / 0.5\,\mathrm{k\Omega} = 8.6\,\mathrm{mA}$$

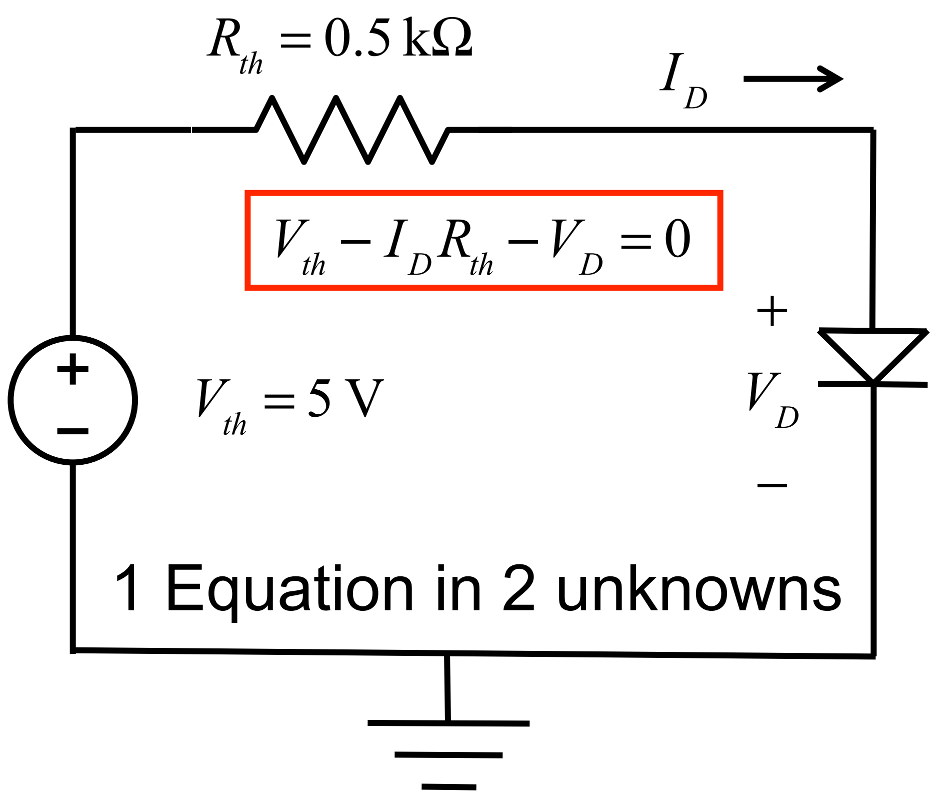
$$\left(\text{Exact: } I_D = 8.61\,\mathrm{mA}\right)$$

Constant-voltage-drop model

In this case, our model was a very good approximation to the actual diode.



Analyzing diode circuits



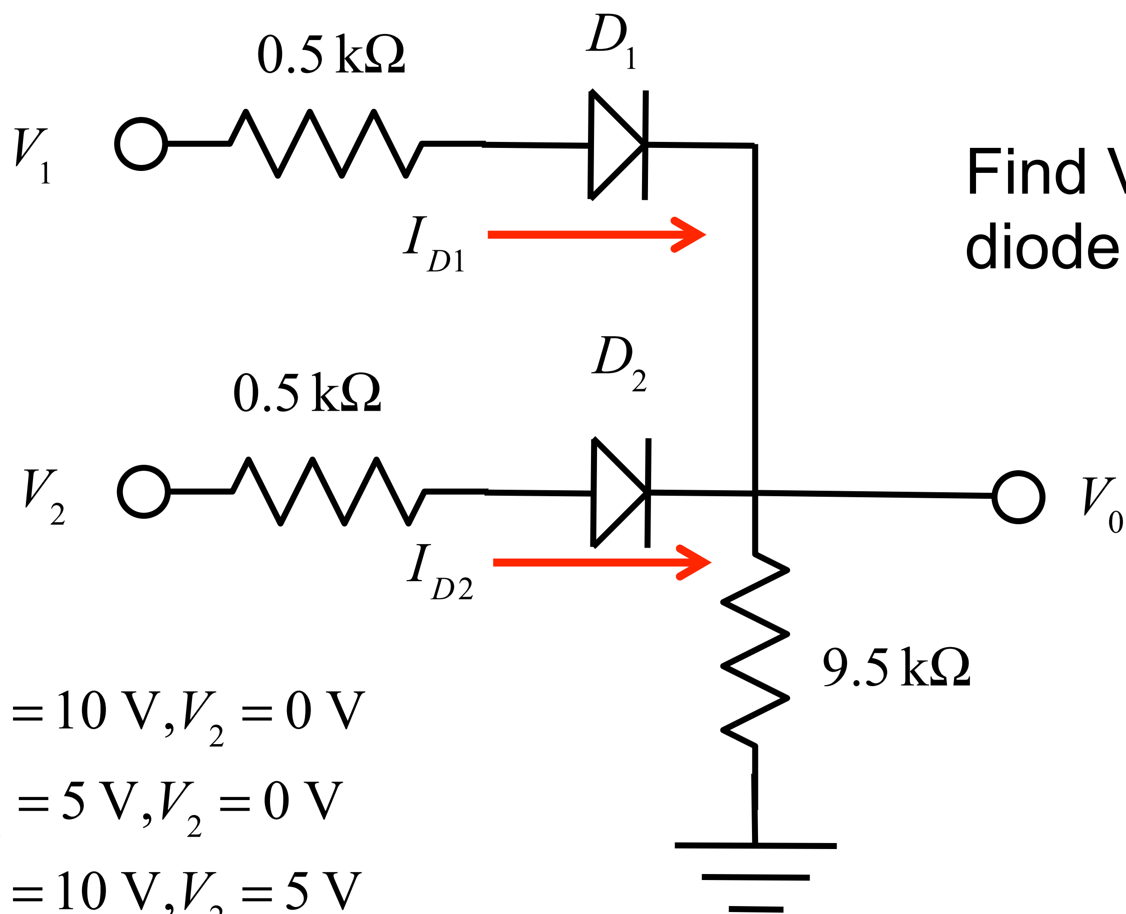
1) Ideal diode model (V_D = 0)

2) Constant-diode-drop model (V_D ~0.7)

3) Diode equation?

Need another equation for $V_D(I_D)$ or $I_D(V_D)$

Examples (assume the constant-V-drop model)



Find V_0 and the two diode currents

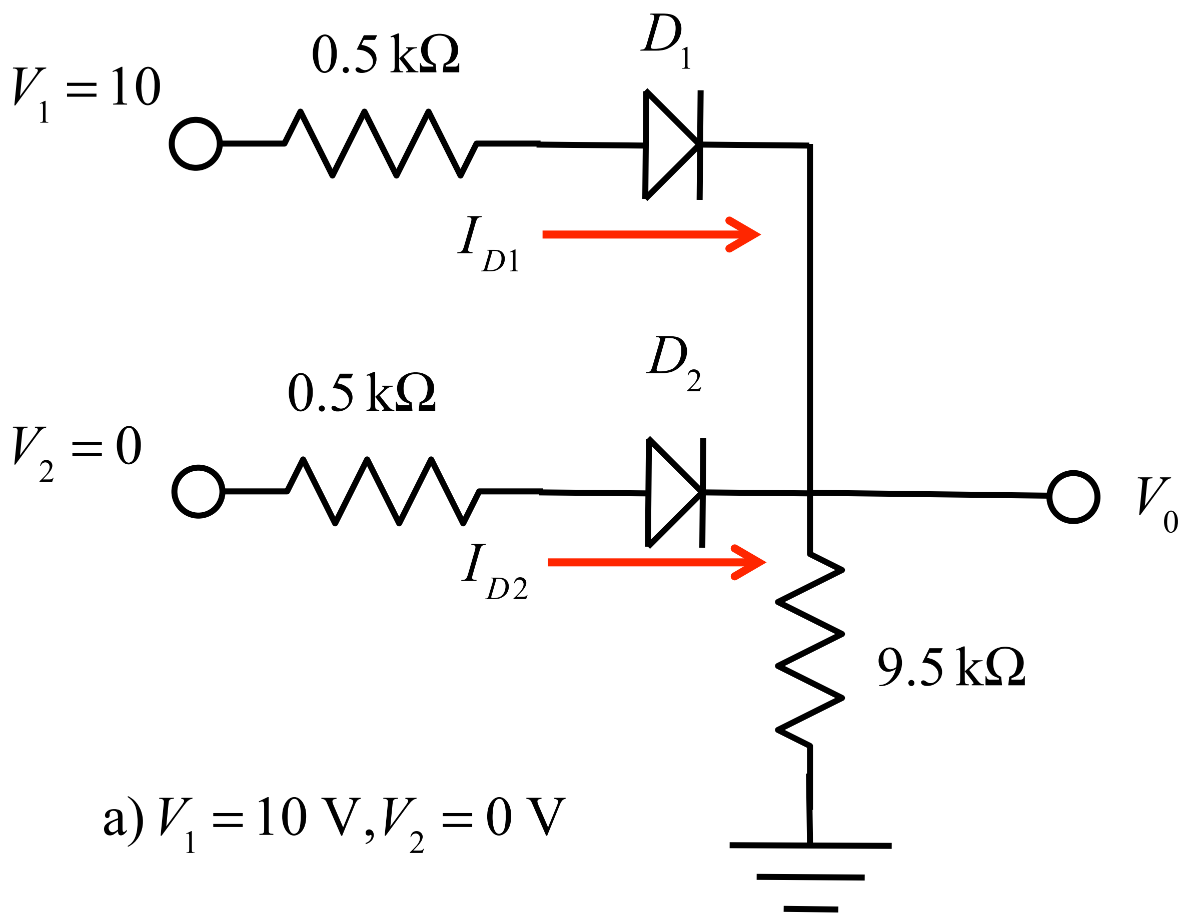
a) $V_1 = 10\text{ V}, V_2 = 0\text{ V}$

b) $V_1 = 5\text{ V}, V_2 = 0\text{ V}$

c) $V_1 = 10\text{ V}, V_2 = 5\text{ V}$

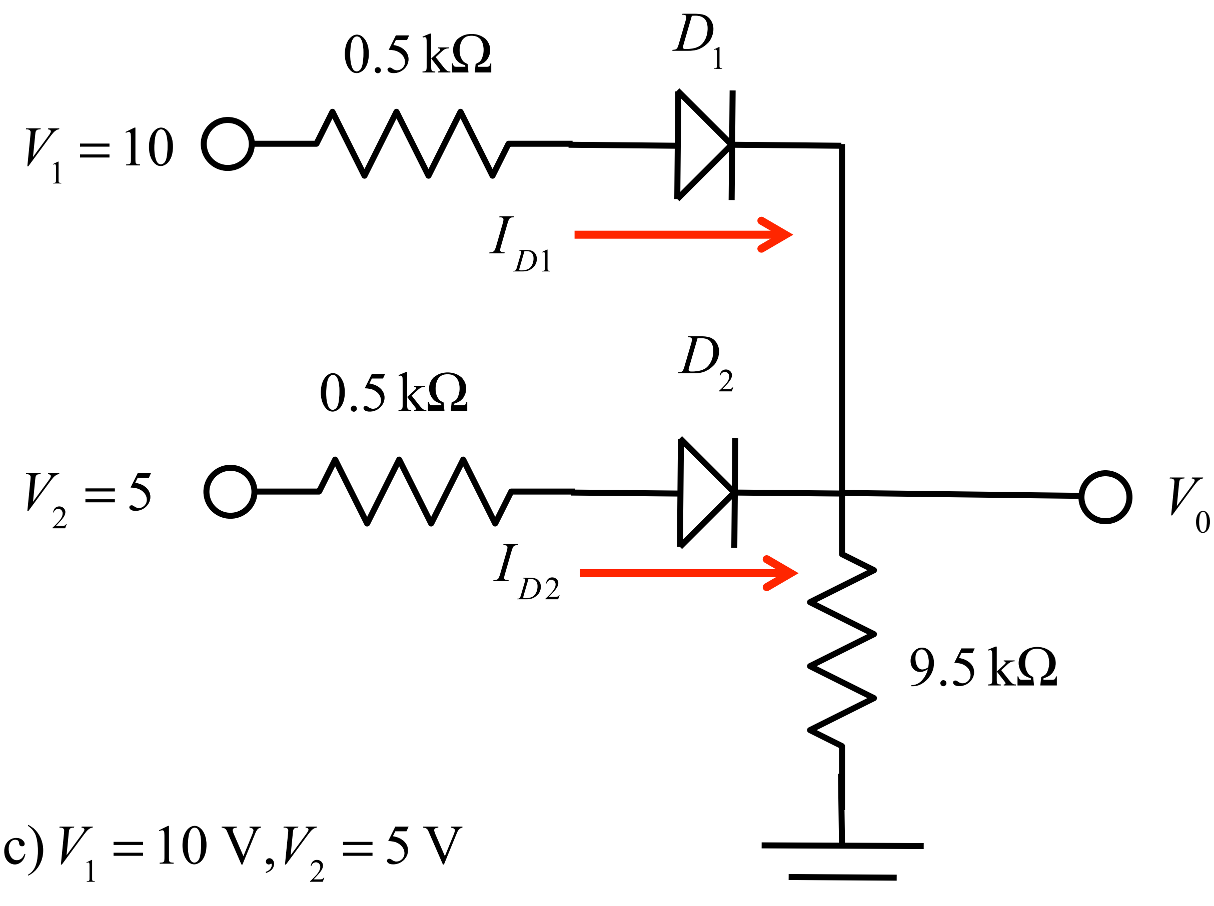
d) $V_1 = 10\text{ V}, V_2 = 10\text{ V}$

a)



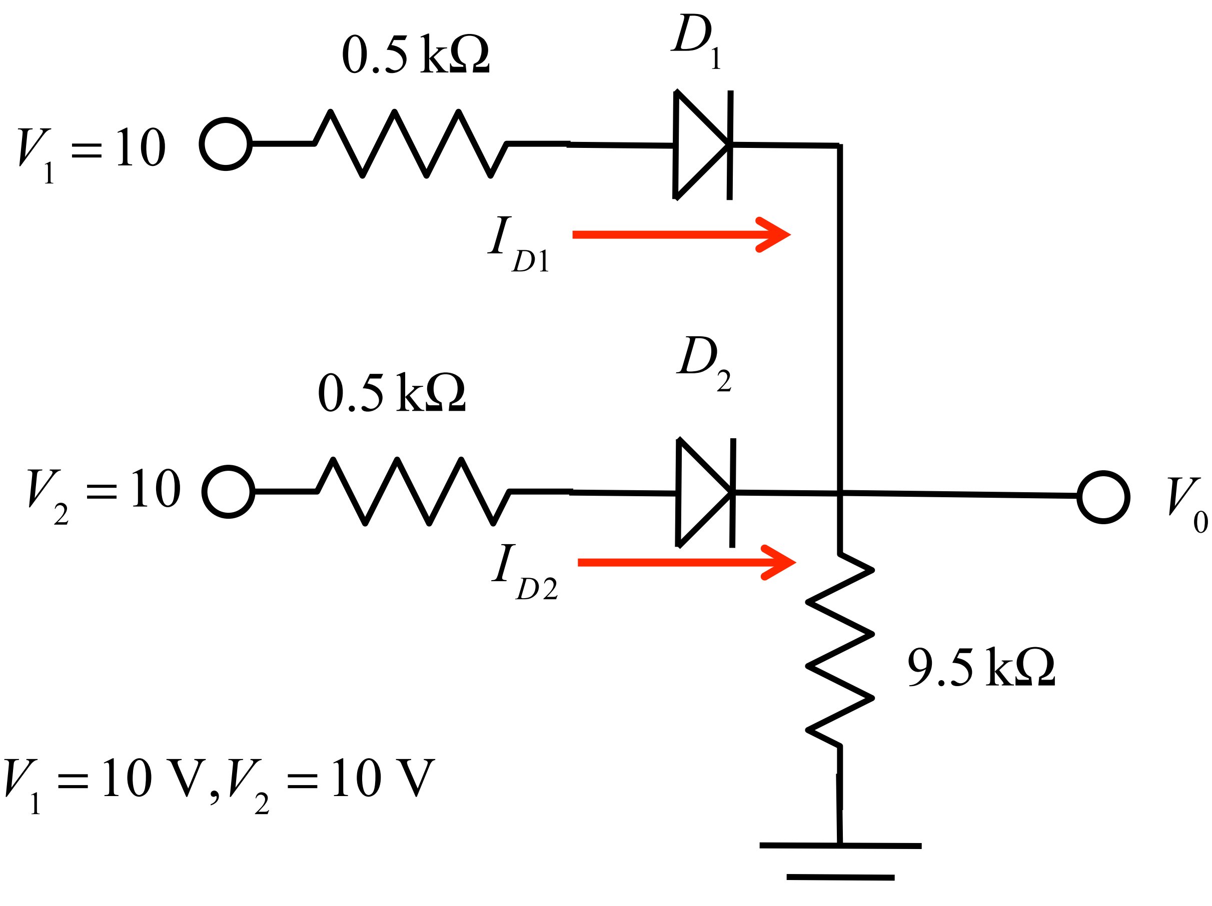
a) $V_1 = 10\ \text{V}, V_2 = 0\ \text{V}$

c)



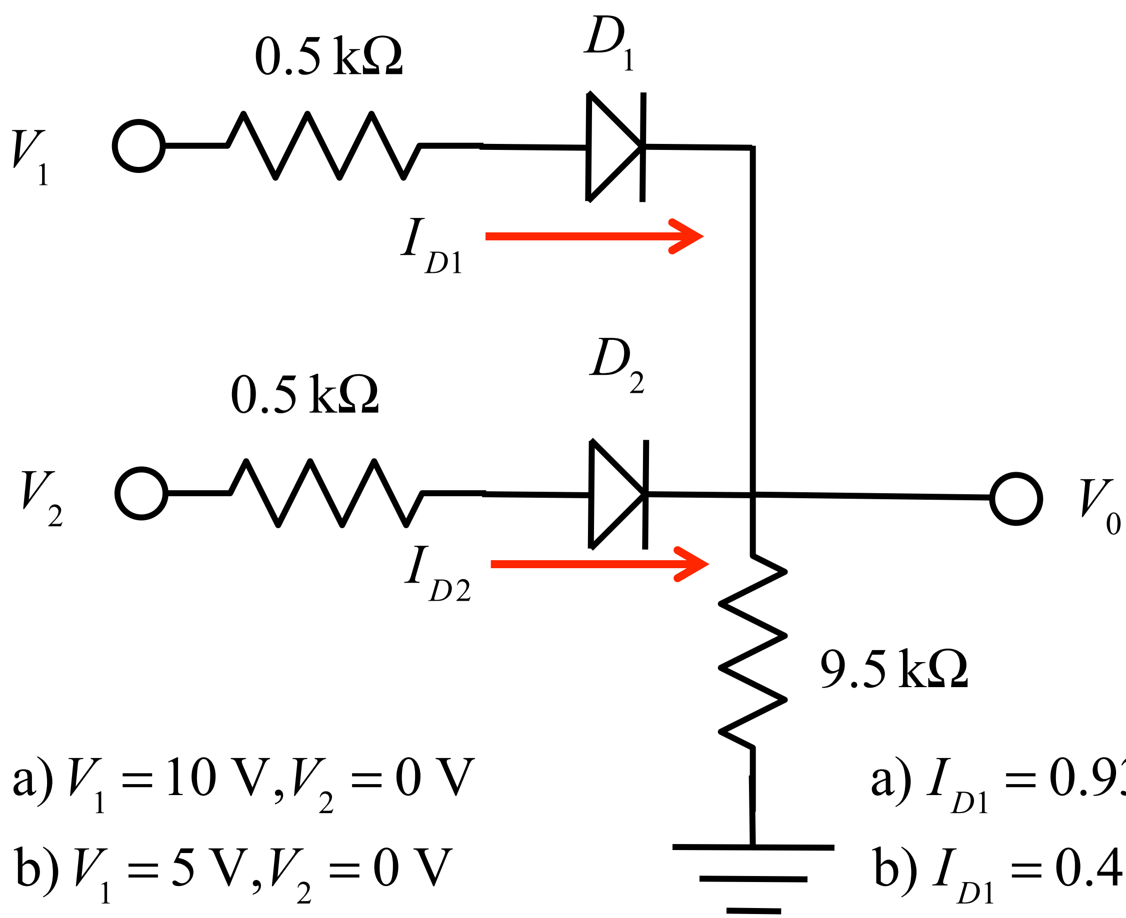
c) $V_1 = 10\ \mathrm{V}, V_2 = 5\ \mathrm{V}$

d)



d) $V_1 = 10\ \text{V}, V_2 = 10\ \text{V}$

Examples: Answers



Find V_0 and the two diode currents

a) $V_1 = 10\ \text{V}, V_2 = 0\ \text{V}$

b) $V_1 = 5\ \text{V}, V_2 = 0\ \text{V}$

c) $V_1 = 10\ \text{V}, V_2 = 5\ \text{V}$

d) $V_1 = 10\ \text{V}, V_2 = 10\ \text{V}$

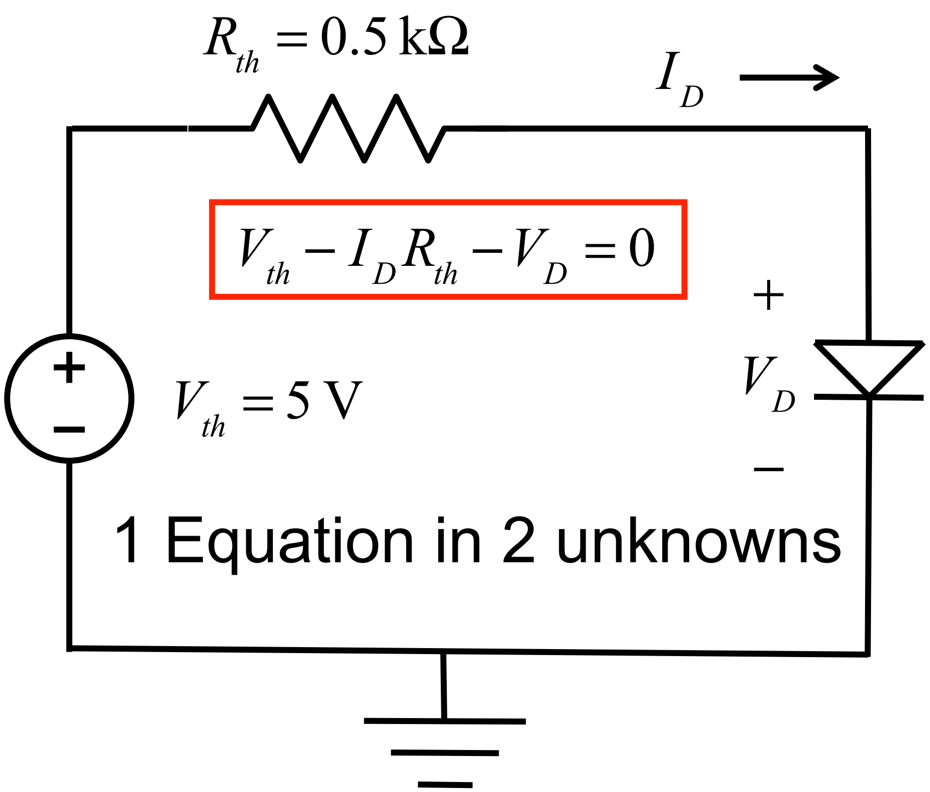
a) $I_{D1} = 0.93\ \text{mA}, I_{D2} = 0\ \text{mA}\ V_0 = 8.8\ \text{V}$

b) $I_{D1} = 0.43\ \text{mA}, I_{D2} = 0\ \text{mA}\ V_0 = 4.1\ \text{V}$

c) $I_{D1} = 0.93\ \text{mA}, I_{D2} = 0\ \text{mA}\ V_0 = 8.8\ \text{V}$

d) $I_{D1} = 0.48\ \text{mA}, I_{D2} = 0.48\ \text{mA}\ V_0 = 9.1\ \text{V}$

Analyze the circuit (exponential model)

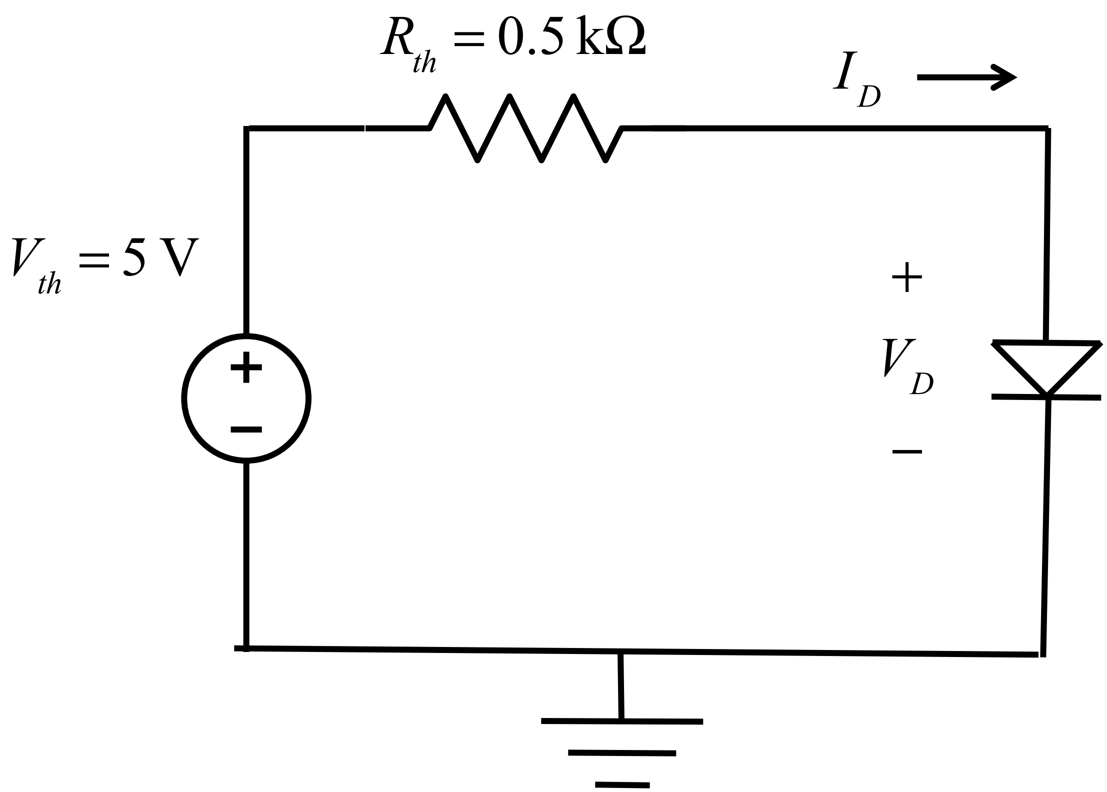


$$I_D = I_S\left(e^{V_D/V_T} - 1\right)$$

$$V_T = k_B T / q$$

Need another equation for $V_D(I_D)$ or $I_D(V_D)$

Analyze the circuit (exponential model)



$$V_{th} - I_D R_{th} - V_D = 0 \quad (1)$$

$$I_D = I_S\left(e^{V_D/V_T} - 1\right) \quad (2)$$

$$I_D = \left(V_{th} - V_D\right)/R_{th}$$

$$I_D = I_S e^{V_D/V_T}$$

$$I_S e^{V_D/V_T} = \left(V_{th} - V_D\right)/R_{th}$$

Graphical approach

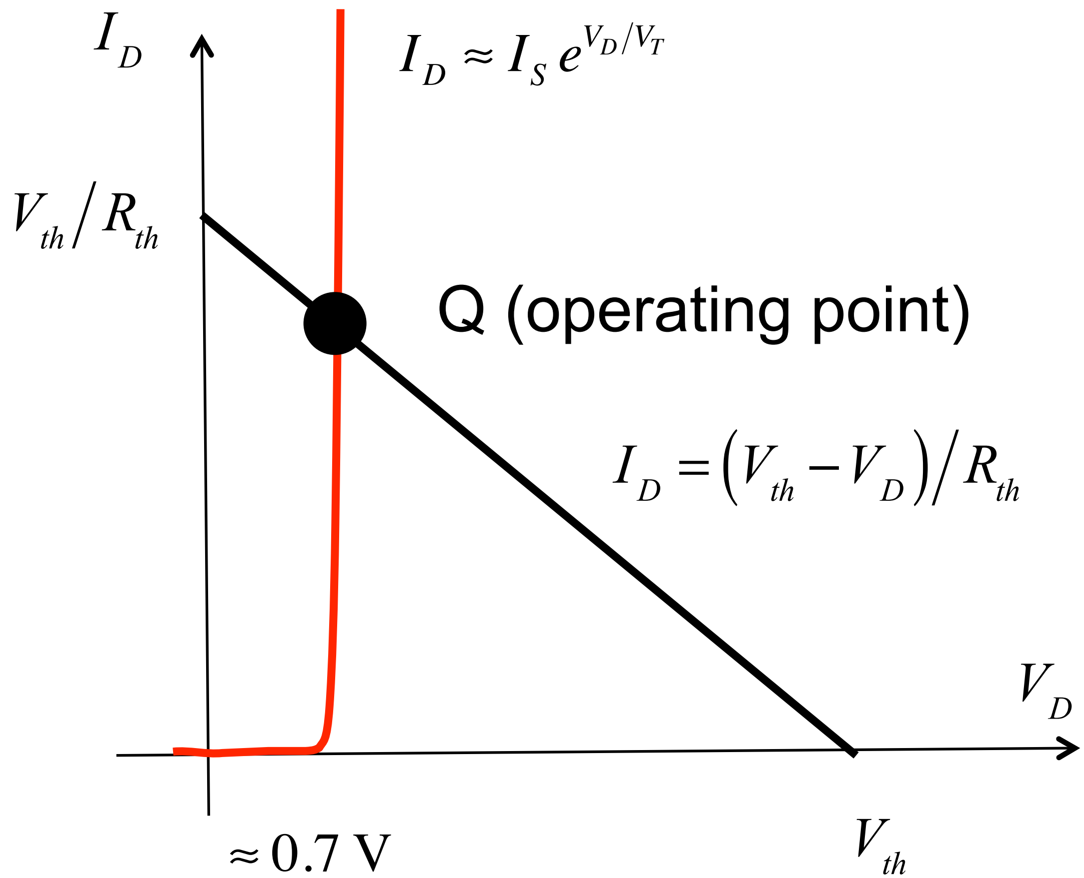
Circuit:

$$I_D = \left(V_{th} - V_D\right) / R_{th}$$

"load line"

Diode:

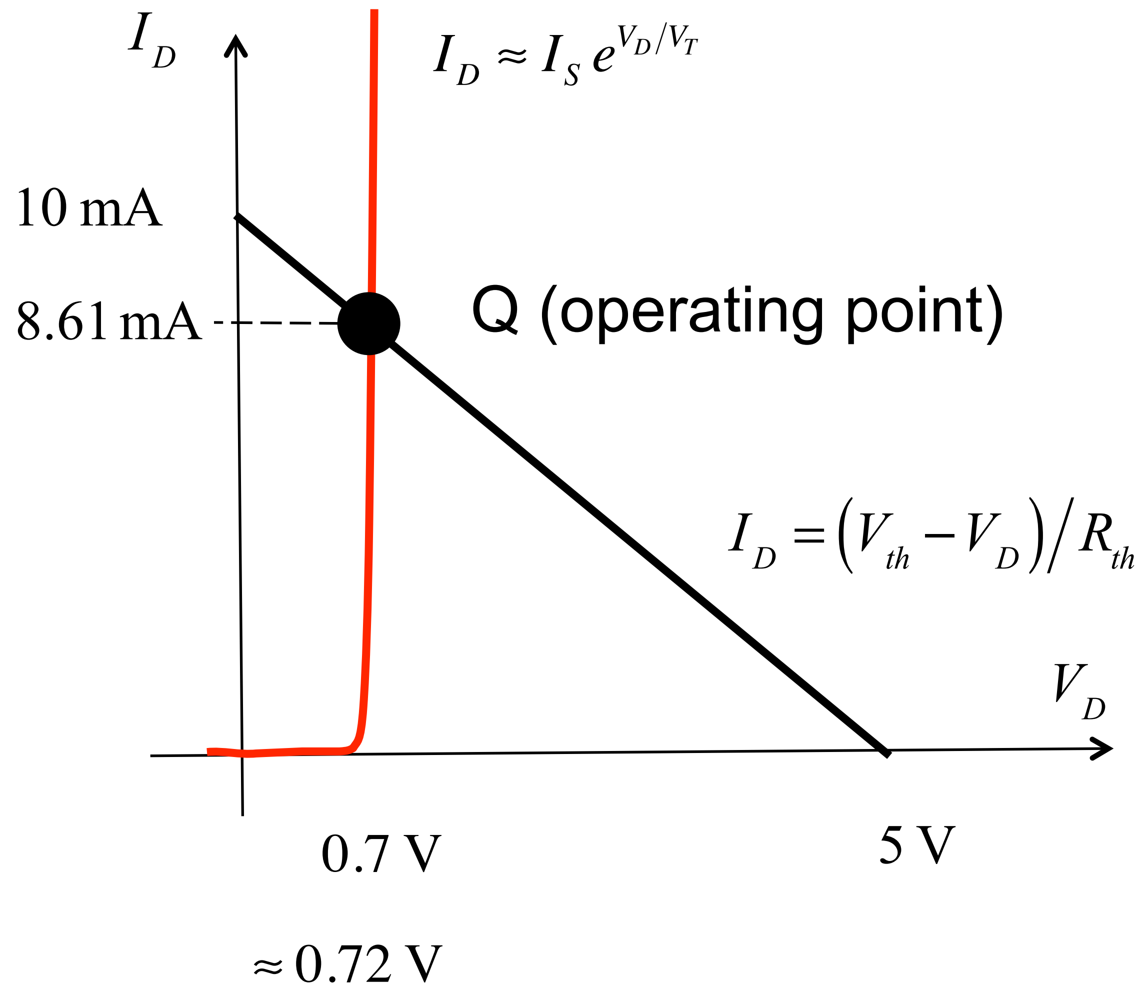
$$I_D = I_S\, e^{qV_D/k_BT}$$



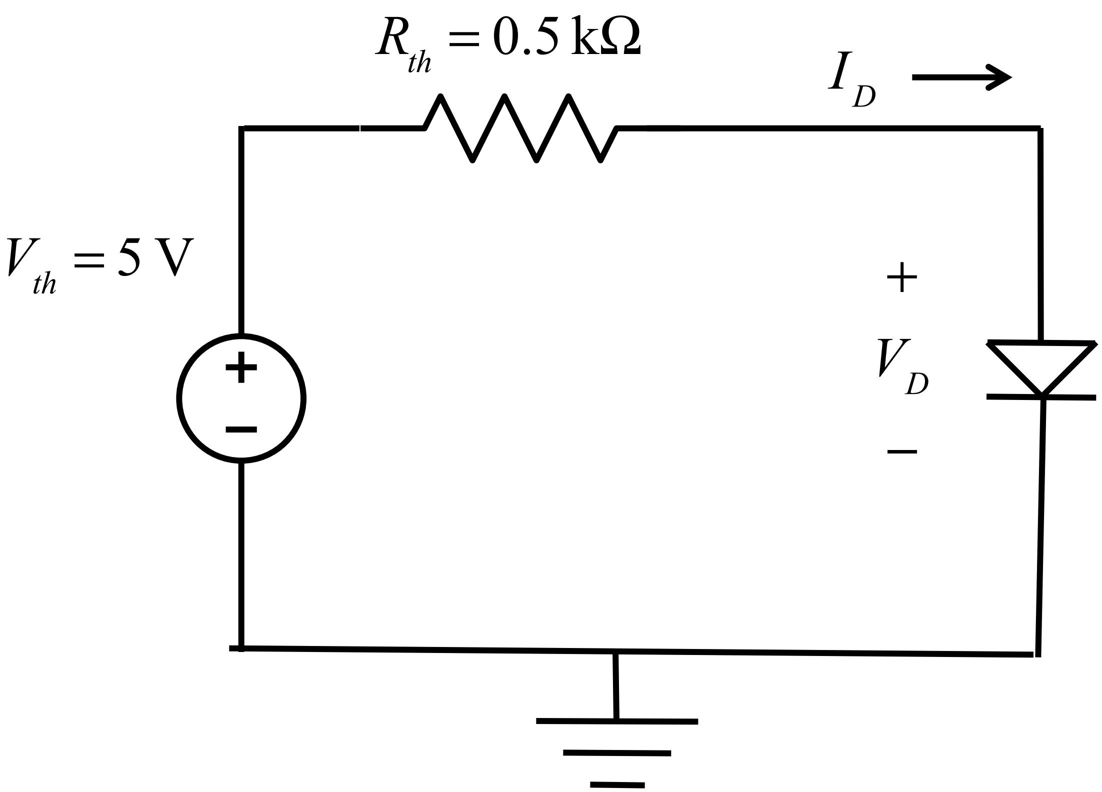
For our circuit...

$V_{th} = 5\text{ V}$

$R_{th} = 0.5\text{ k}\Omega$



Analyze the circuit (exponential model)



$$V_{th} - I_D R_{th} - V_D = 0 \quad (1)$$

$$I_D = I_S\left(e^{V_D/V_T} - 1\right) \quad (2)$$

$$I_D = \left(V_{th} - V_D\right)/R_{th}$$

$$I_D = I_S e^{V_D/V_T}$$

graphical analysis

numerical analysis →

$$I_S e^{V_D/V_T} = \left(V_{th} - V_D\right)/R_{th}$$

Numerical solution

$$V_{th} - \left(I_S\, e^{V_D/V_T}\right) R_{th} - V_D = 0$$

$$5 - \left(I_S\, e^{V_D/0.026}\right) 500 - V_D = 0$$

$$I_S = 10^{14}\ A$$

$$5 - \left(10^{-14}\, e^{V_D/0.026}\right) 500 - V_D = 0$$

Guess V_D
Compute LHS
Is LHS = 0?
Try new guess and repeat

V_D	LHS
0.7	+1.837
0.72	-1.036
0.71	0.671
0.713	0.226
0.714	0.065
0.715	-0.101
0.7145	-0.017

$$I_D = 10^{-14}\, e^{0.7145/0.026} = 8.61\,\text{mA}$$

Summary

The ideal diode is a very simple, sometimes good enough model for a diode.

The constant-voltage-drop model is better, usually acceptable for first-pass, analysis by hand. The one model parameter, V_D, is generally between 0.6 – 0.8 V for Si diodes.

The exponential model is the best. It is nonlinear which makes it harder to use for hand analysis. The one model parameter, I_S, needs to be specified.

Real and ideal diodes

1) Ideal vs. “real” diodes
2) Circuit analysis using ideal (or C-V-D) diodes
3) Circuit analysis using real diodes