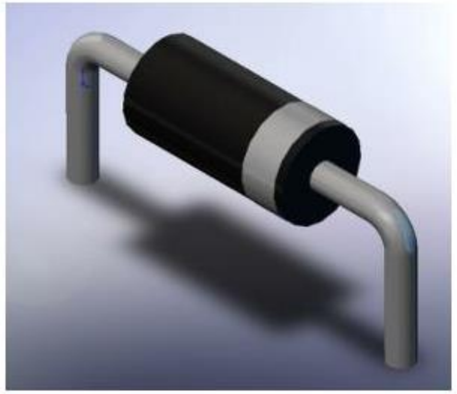
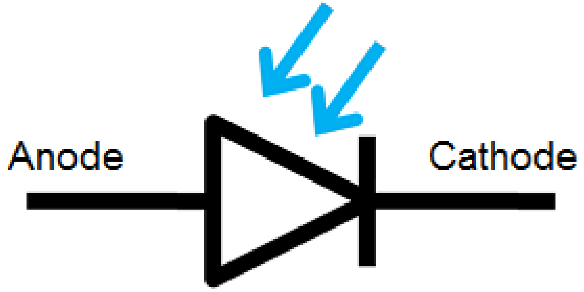
Lecture 16: Introduction to Diodes

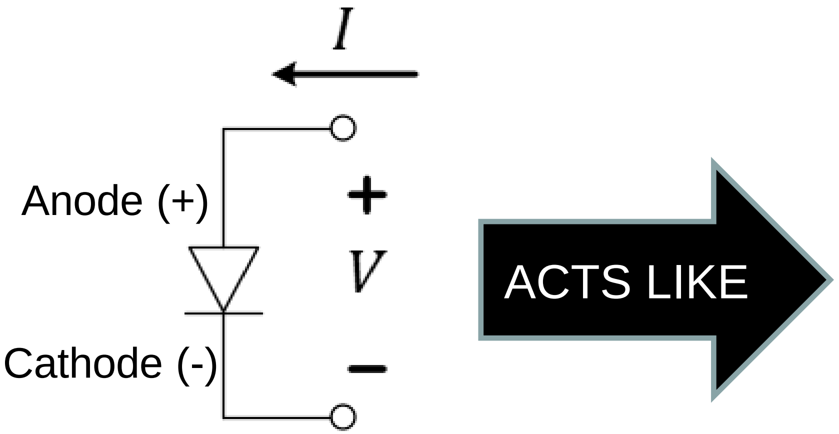
- Diode IV characteristics
- Connecting diode to a linear circuit
- Piecewise linear models of diodes





Recommended: https://learn.sparkfun.com/tutorials/diodes

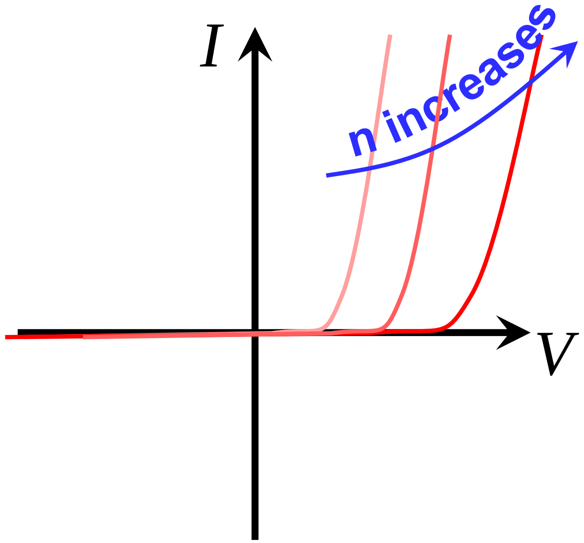
- **IV characteristics**



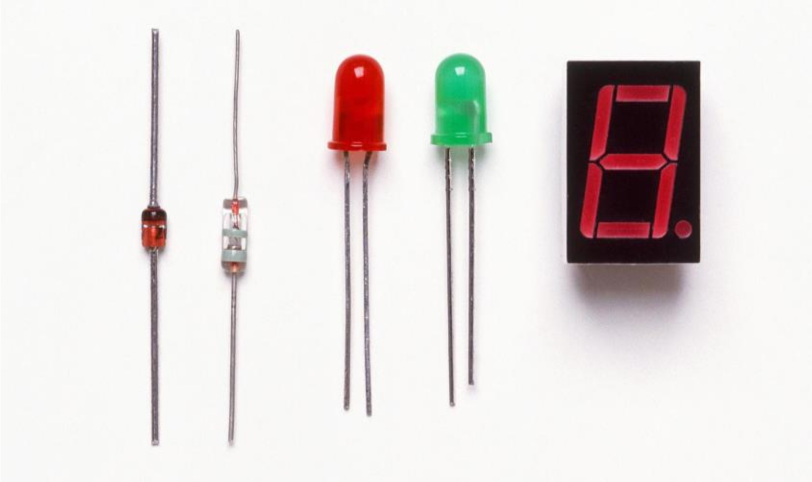
Mathematical expression

$$I \approx I_S\left(e^{V/nV_{therm}} - 1\right)$$

$$V_{therm} = k_B T/q$$



- **Major applications: lighting, electronics**



Made of *semiconductor* materials like Si, Ge, GaN with some additives called *dopants.*

Date sheet

$$I \approx I_S\left(e^{V/nV_{therm}} - 1\right)$$

$V_{therm} = \frac{k_B T}{q}$ (thermal voltage)

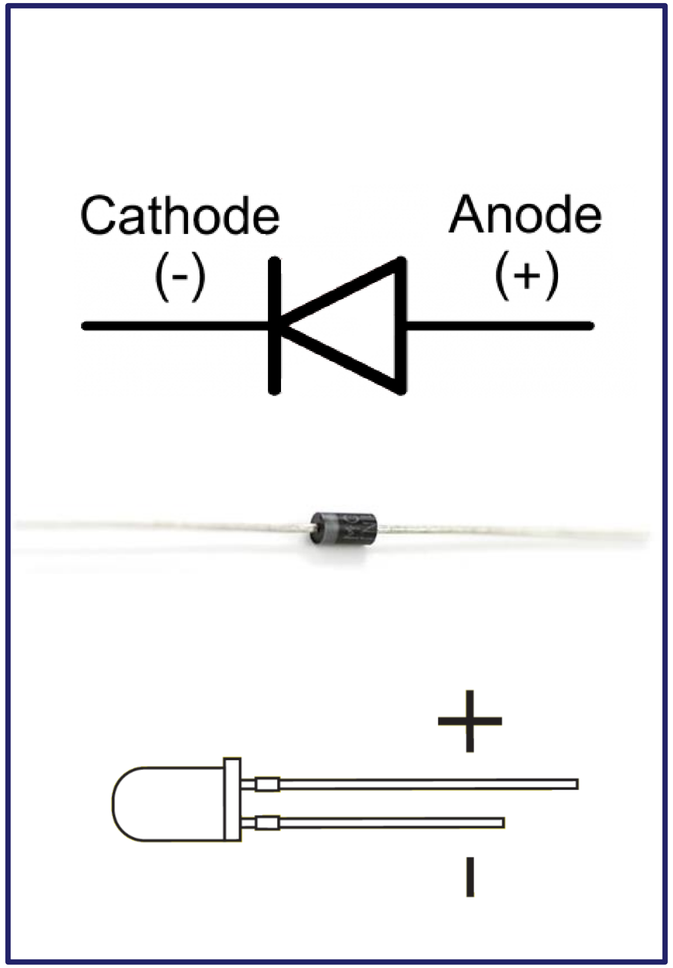
$\frac{k_B}{q} = 8.617 \times 10^{-5} eV \cdot K^{-1}$ (Boltzmann’s constant)

$T =$ temperature (Kelvin)

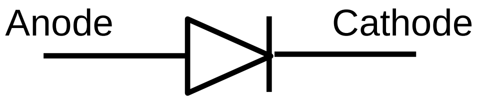
$\frac{k_B T}{q} = 25.85 mV$ at 300K

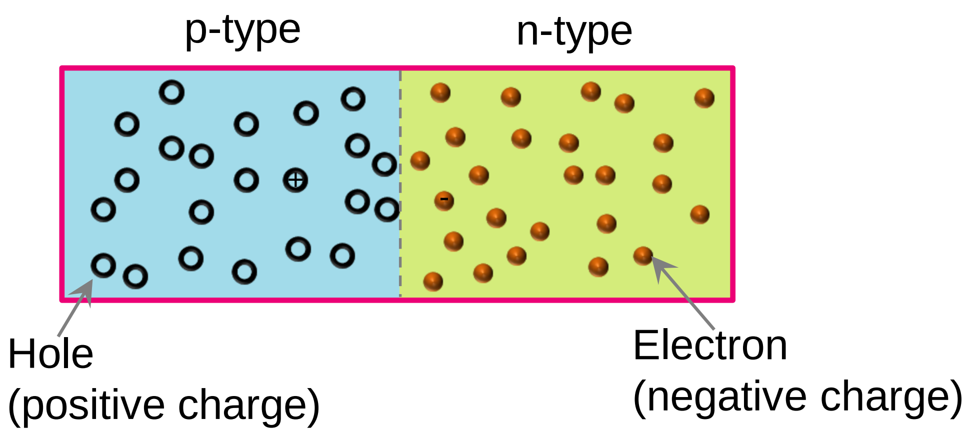
$n =$ ideal factor
(depends on device fabrication parameters)

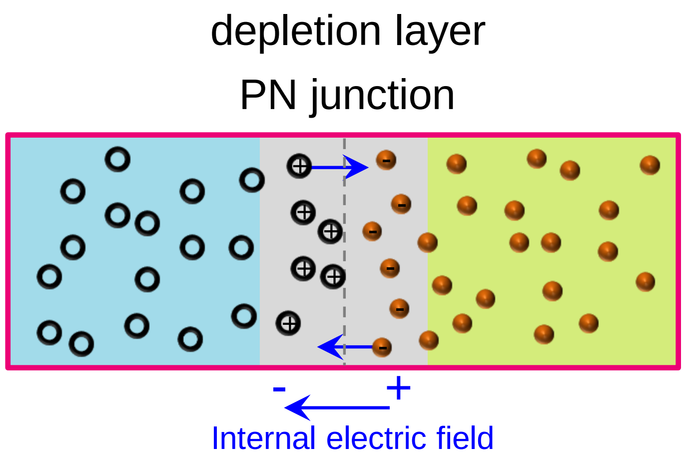
Circuit model



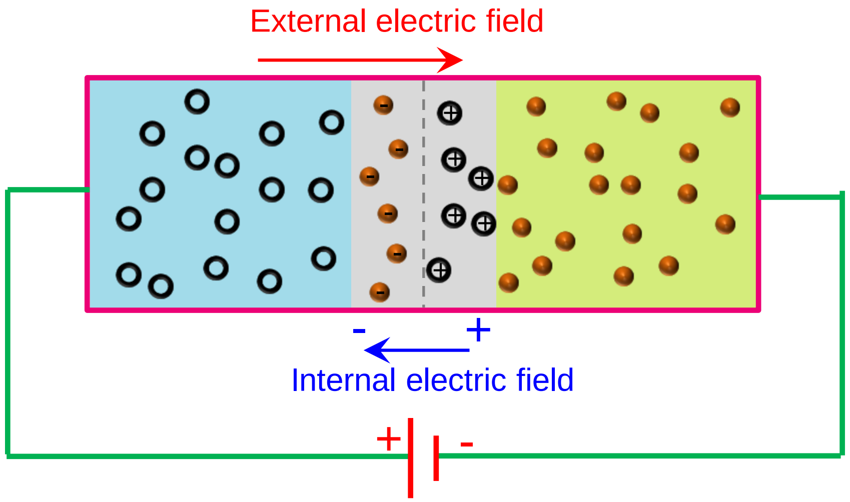
Working principle – Supplementary Note



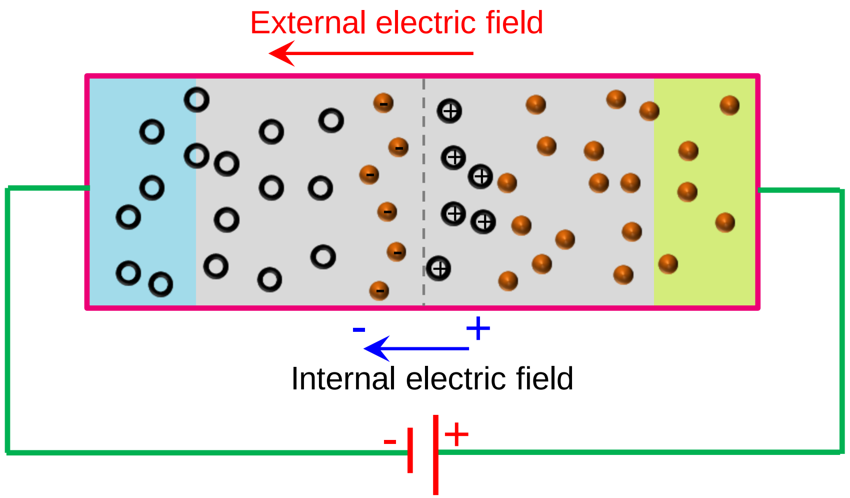




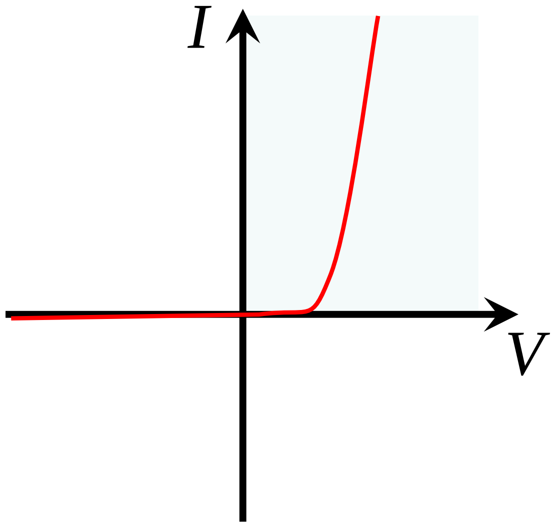
Case 1: forward bias (conductive)

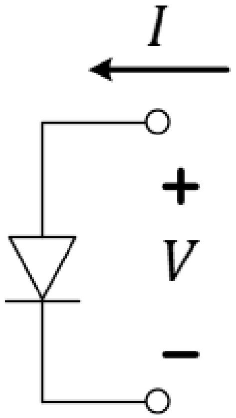


Case 2: reverse bias (cut-off)



L16Q1: Based on the exponential equation for IV, can the diode supply power?



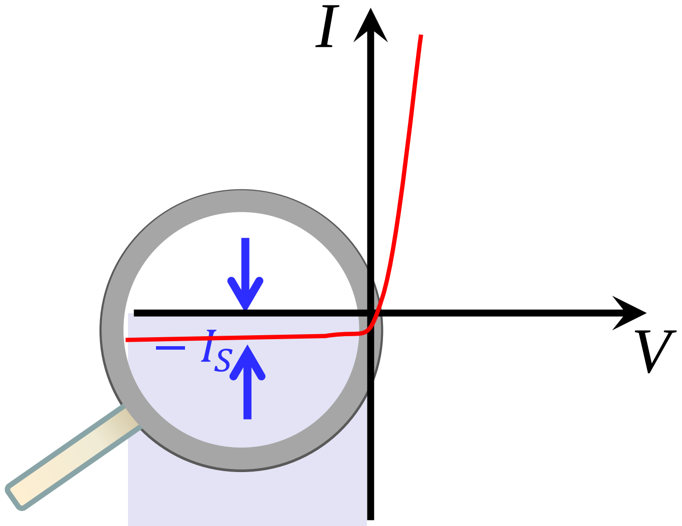


Case 1: **forward bias** $(V > 0)$

$$e^{V/nV_{therm}} > 1$$

$$I \approx I_S\left(e^{V/nV_{therm}} - 1\right) > 0$$

$$\underline{P = IV > 0}$$



Case 2: **reverse bias** $(V < 0)$

$$e^{V/nV_{therm}} < 1$$

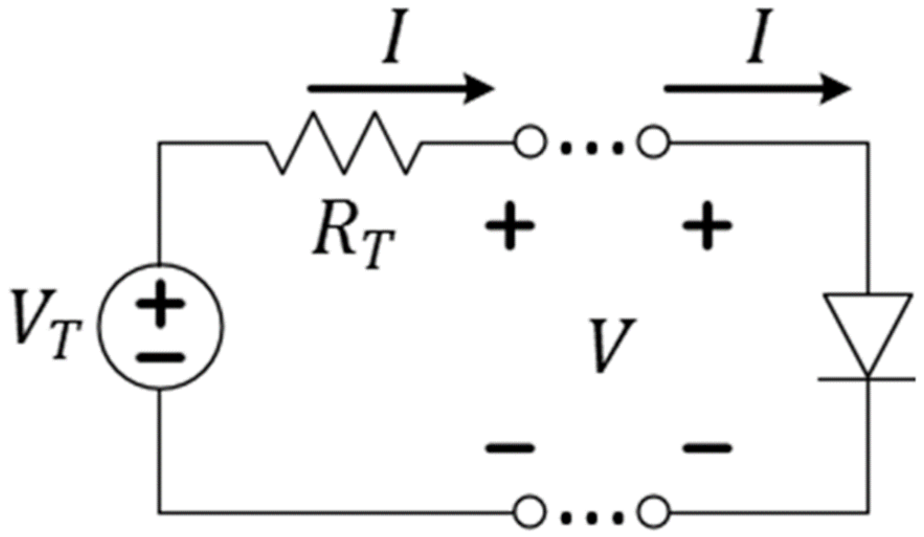
$$I \approx I_S\left(e^{V/nV_{therm}} - 1\right) < 0$$

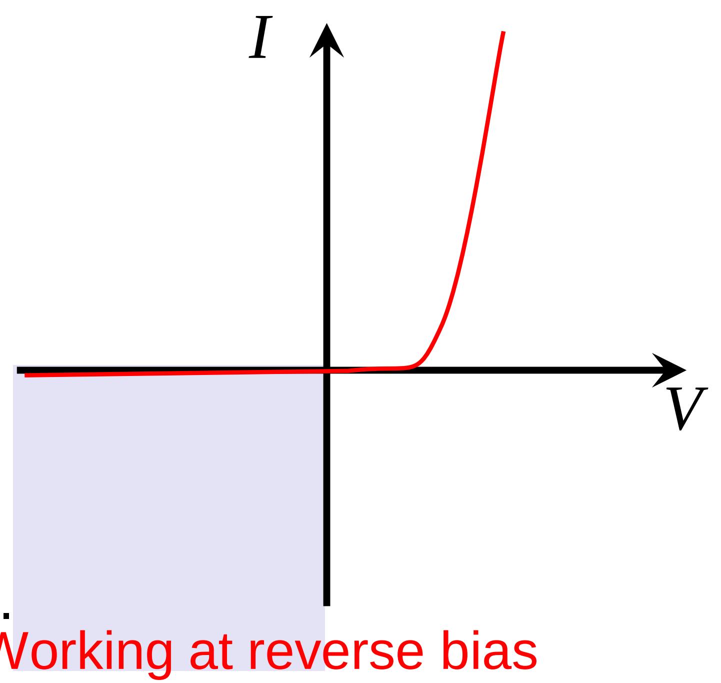
$I \approx -I_S$ (for large enough $|V|$)

$$\underline{P = IV > 0}$$

No, the curve exists only in two quadrants where the “signed” P is > 0.

Connecting diode to a linear circuit





We can solve graphically for an operating point.
For an LED more current means more light.

Working at reverse bias

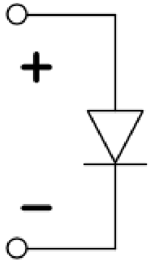
L16Q2: What is the current flowing through the diode if $V_T < 0$?

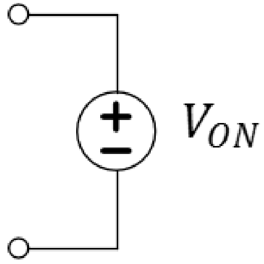
small and negative…nearly 0

Instead of looking for graphical solutions, we can approximate the diode with two linear segments, corresponding to diode's regimes of operation.

Case 1: **forward bias** $(V > V_{ON})$

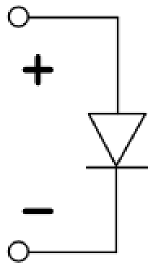
$I > 0$

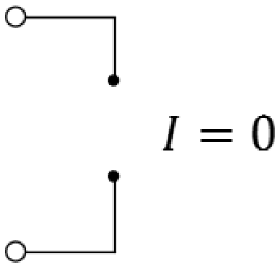




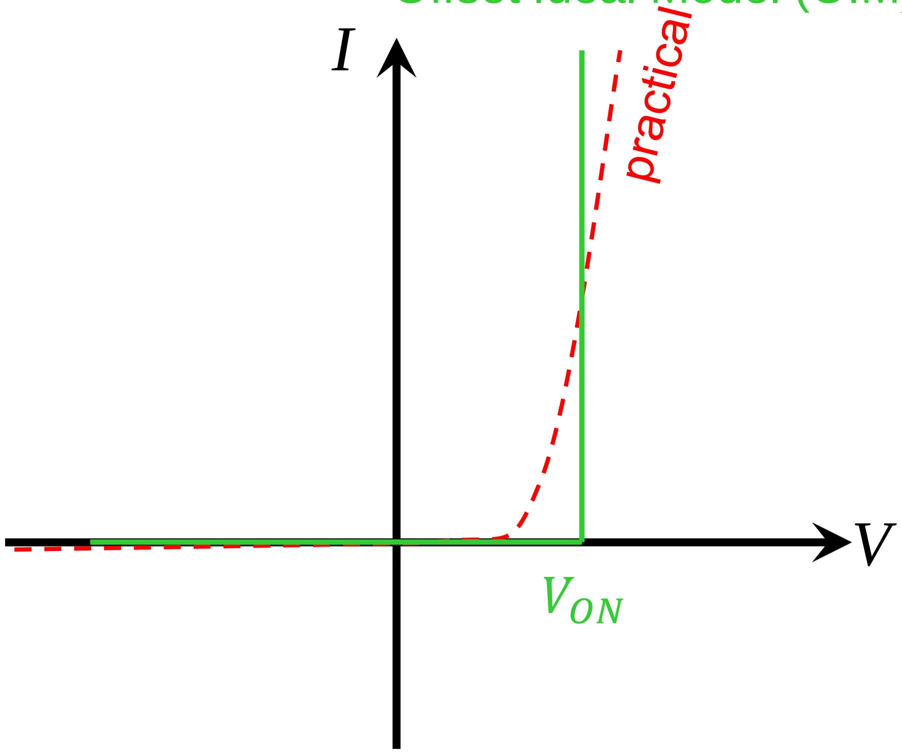
Case 2: **reverse bias** $(V < V_{ON})$

$I = 0$

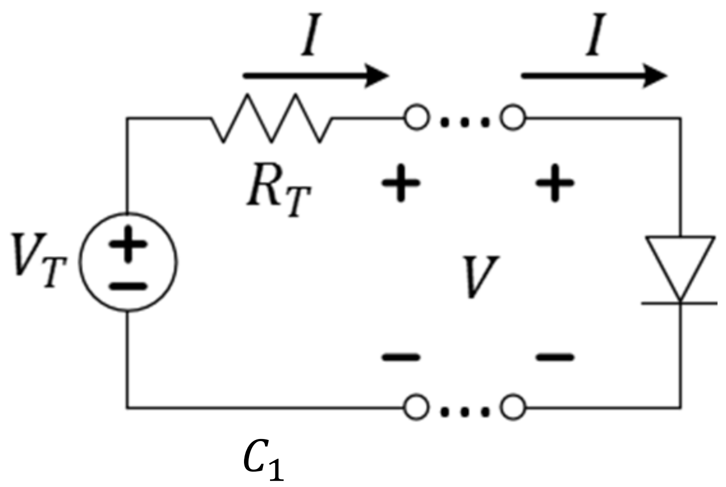


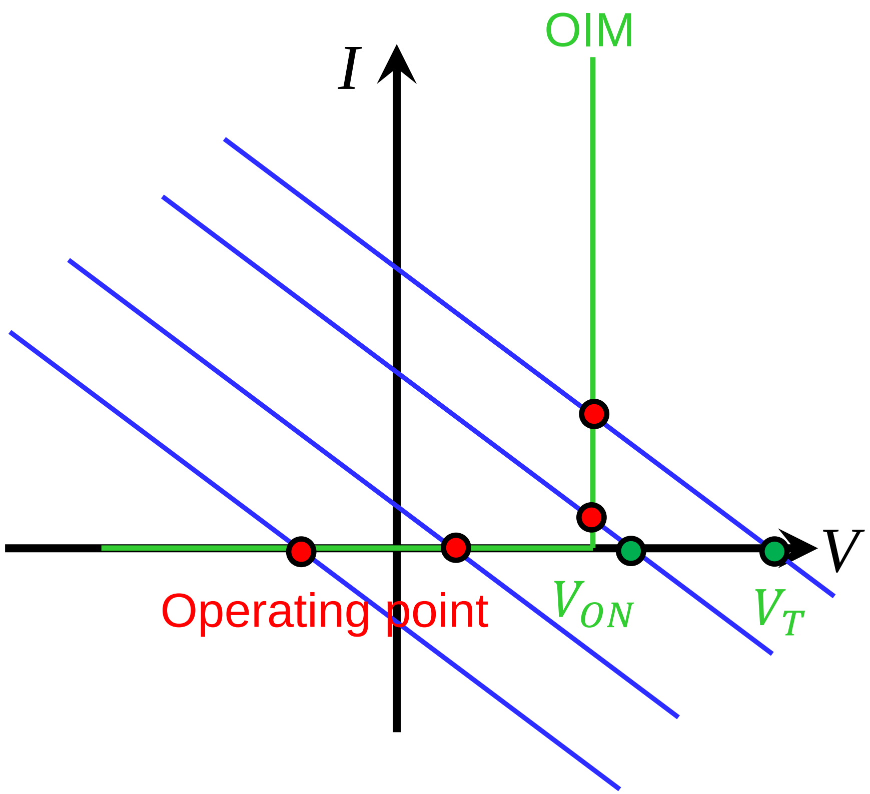


Offset Ideal Model (OIM)



L16Q3: What is the minimum V_T of the connected linear circuit which causes current to flow through the diode if the piecewise linear model above is used?





For the resistor R_T, the IV characteristic is,

$$I = \frac{V_T - V}{R_T} = \frac{V_T}{R_T} - \frac{V}{R_T}$$

$$I > 0 \implies V_T > V_{on}$$

Different diode types have different V_{ON}

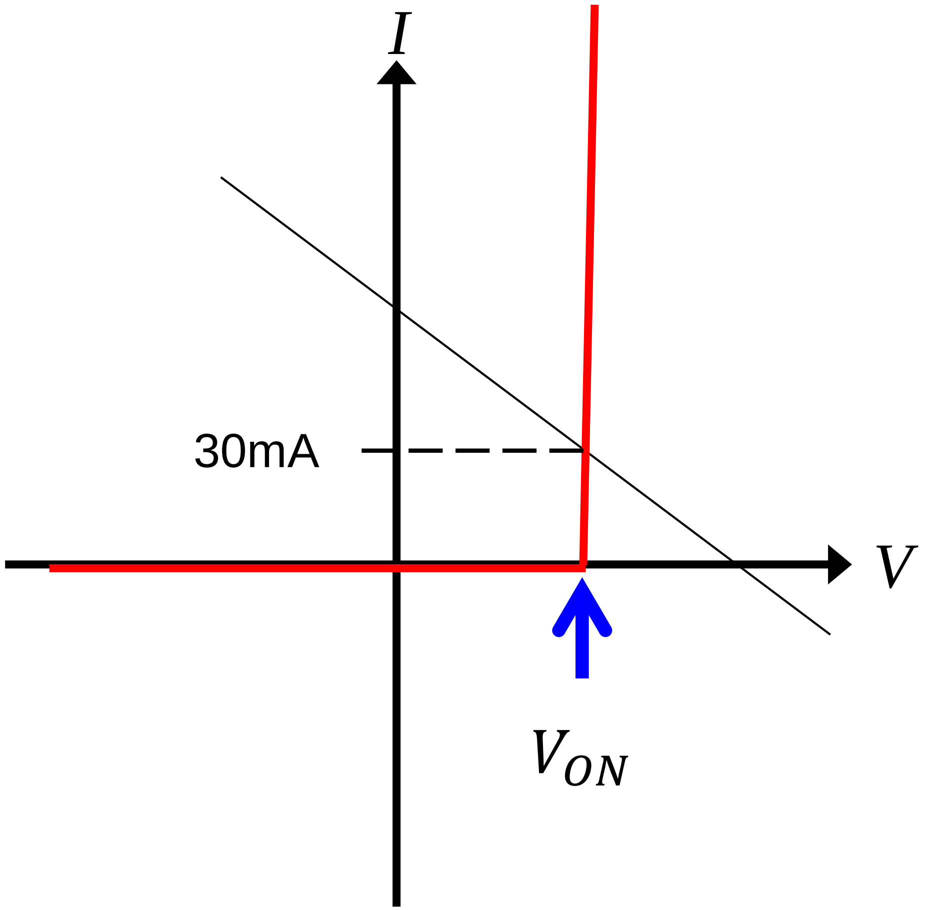
Diode Type	V_{ON}(V)	Applications
Silicon	0.6-0.7	General; integrated circuits; switching, circuit protection, logic, rectification, etc.
Germanium	~0.3	Low-power, RF signal detectors
Schottky	0.15-0.4	Power-sensitive, high-speed switching, RF
Red LED (GaAs)	~2	Indicators, signs, color-changing lighting
Blue LED (GaN)	~3	Lighting, flashlights, indicators
"Ideal"	0	Can neglect V_{ON} for high voltage applications

L16Q4: What is the power dissipated by a Ge diode if 30 mA is flowing through it?

Germanium:

$V_{on} \sim 0.3V$

$$P = V_{on} \times I$$
$$= 0.3 \times 30mA$$
$$= 9mW$$



Q4:

A. $3\ mW$

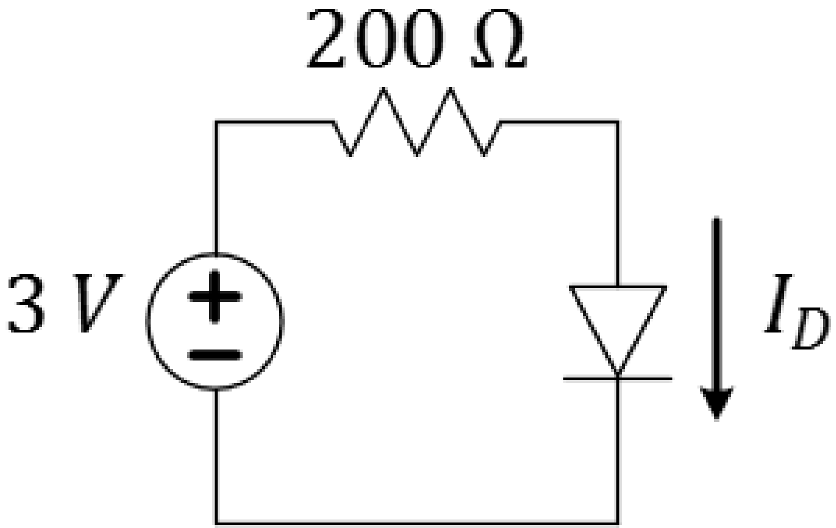
$\boxed{B.\ 9\ mW}$

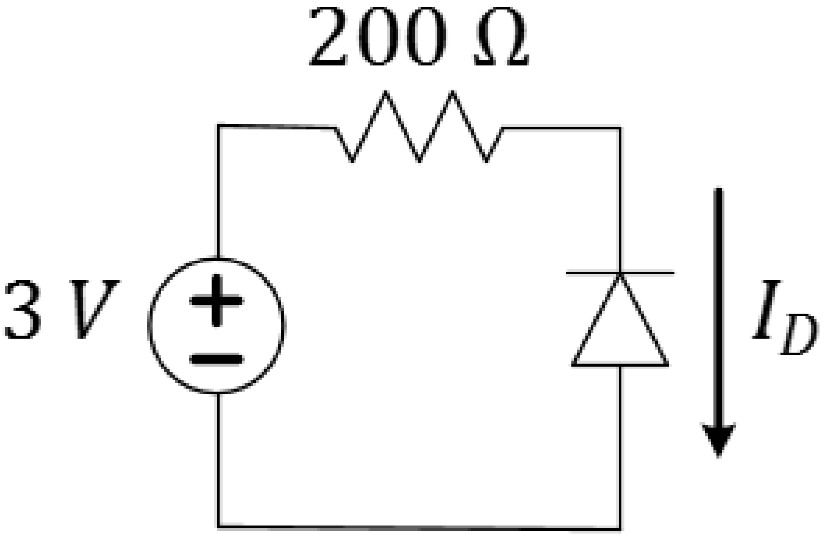
C. $30\ mW$

D. $90\ mW$

E. $900\ mW$

Diode circuit examples (offset ideal model)

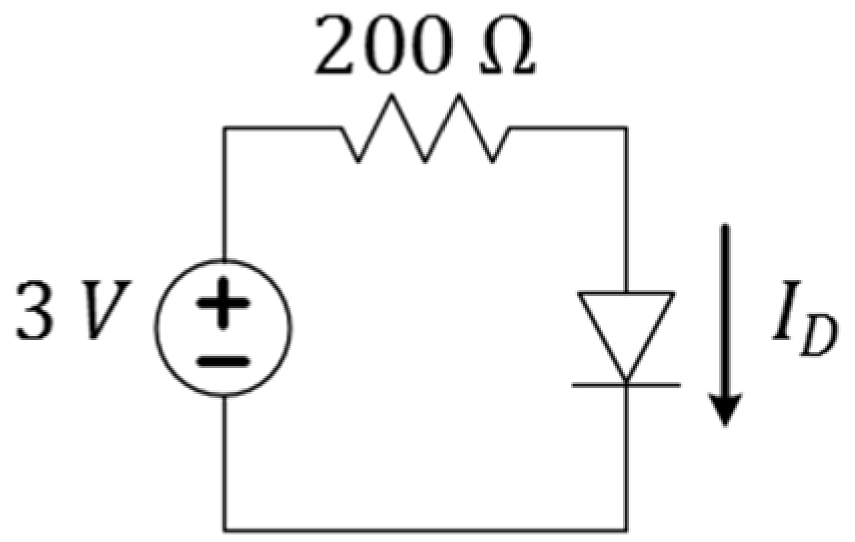


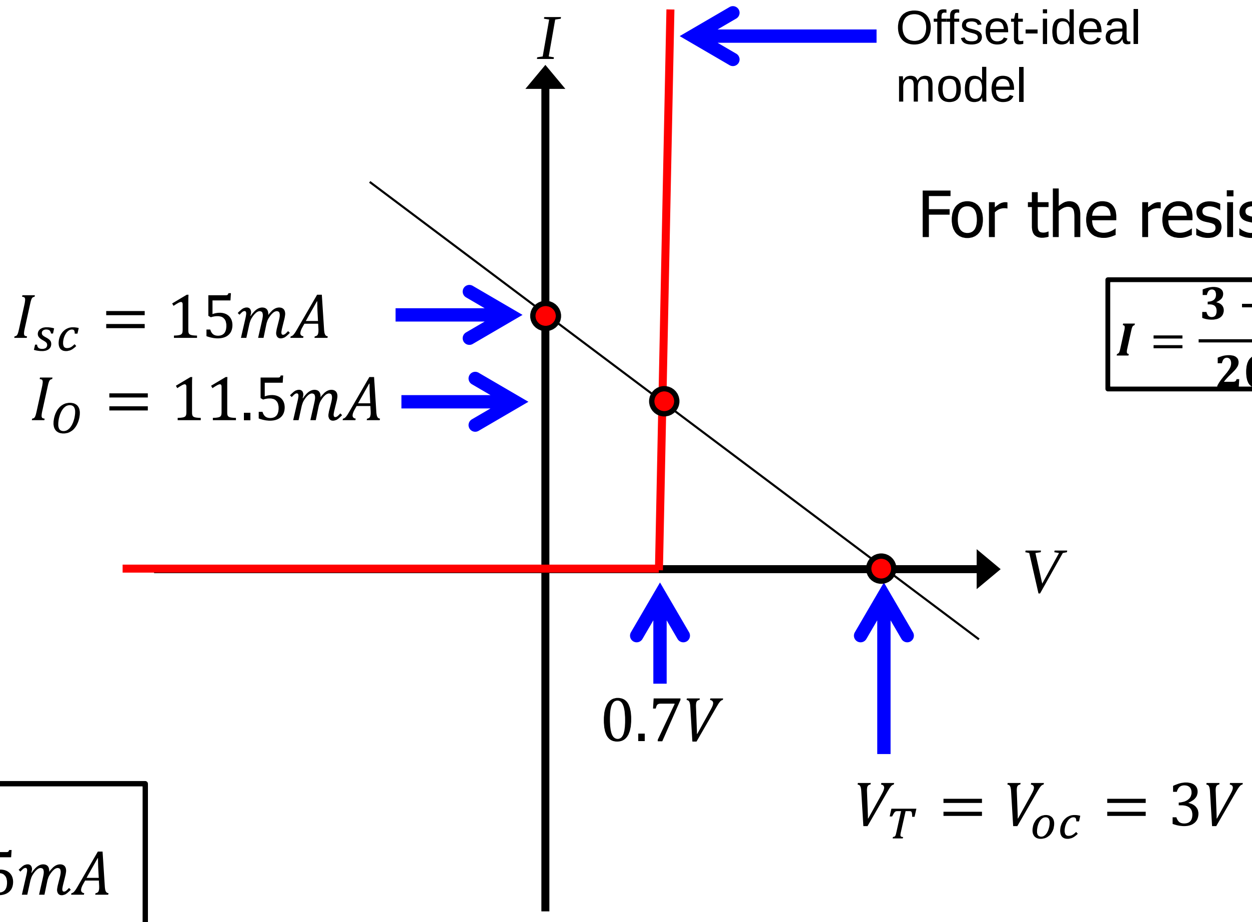


Assume offset-ideal model with V_{ON} = 0.7 (common Si diodes)
L16Q5: What is the current through the diode in the top left circuit?
L16Q6: What is the current through the diode in the top right circuit?

L16Q5: What is the current through the diode?

Assume offset-ideal model with V_{ON} = 0.7 (common Si diodes)





For the resistor

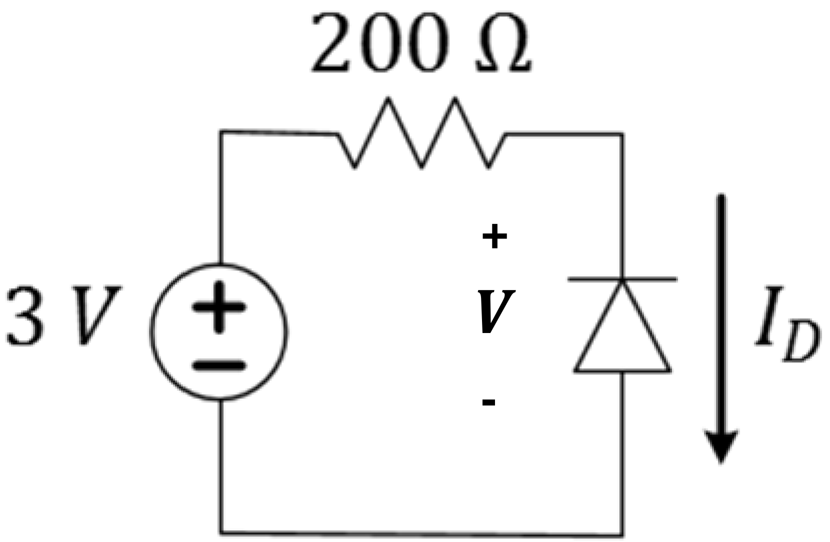
$$\boxed{I = \frac{3 - V}{200}}$$

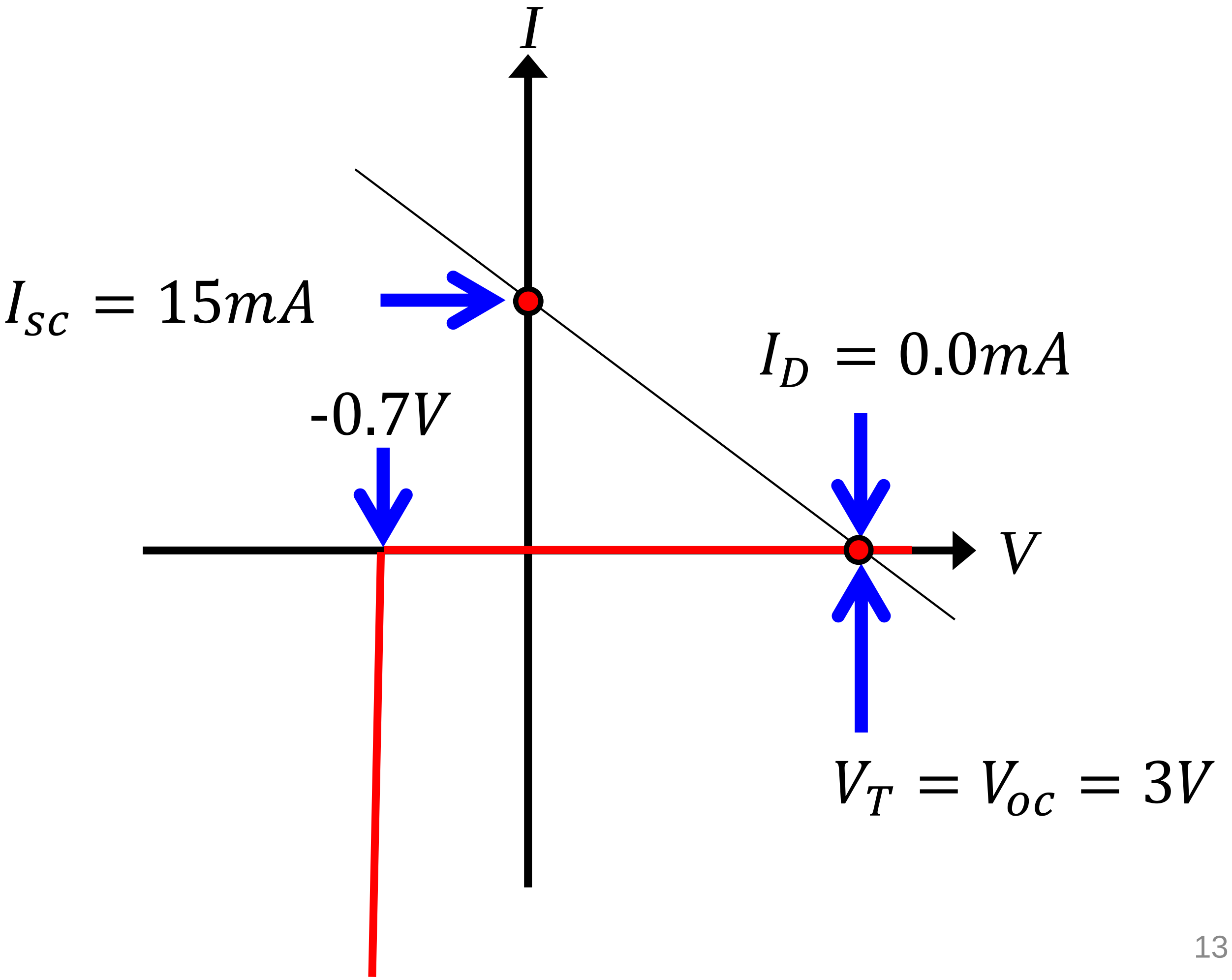
FORWARD BIAS

$$\boxed{I_O = I_{sc} - \frac{V_{ON}}{R} = 0.015 - \frac{0.7}{200} = 11.5mA}$$

L16Q6: What is the current through the diode?

Assume offset-ideal model with V_{ON} = 0.7 (common Si diodes)



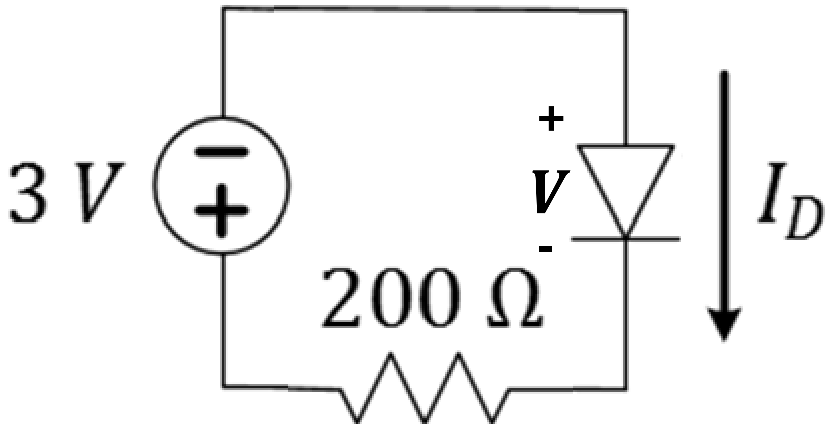


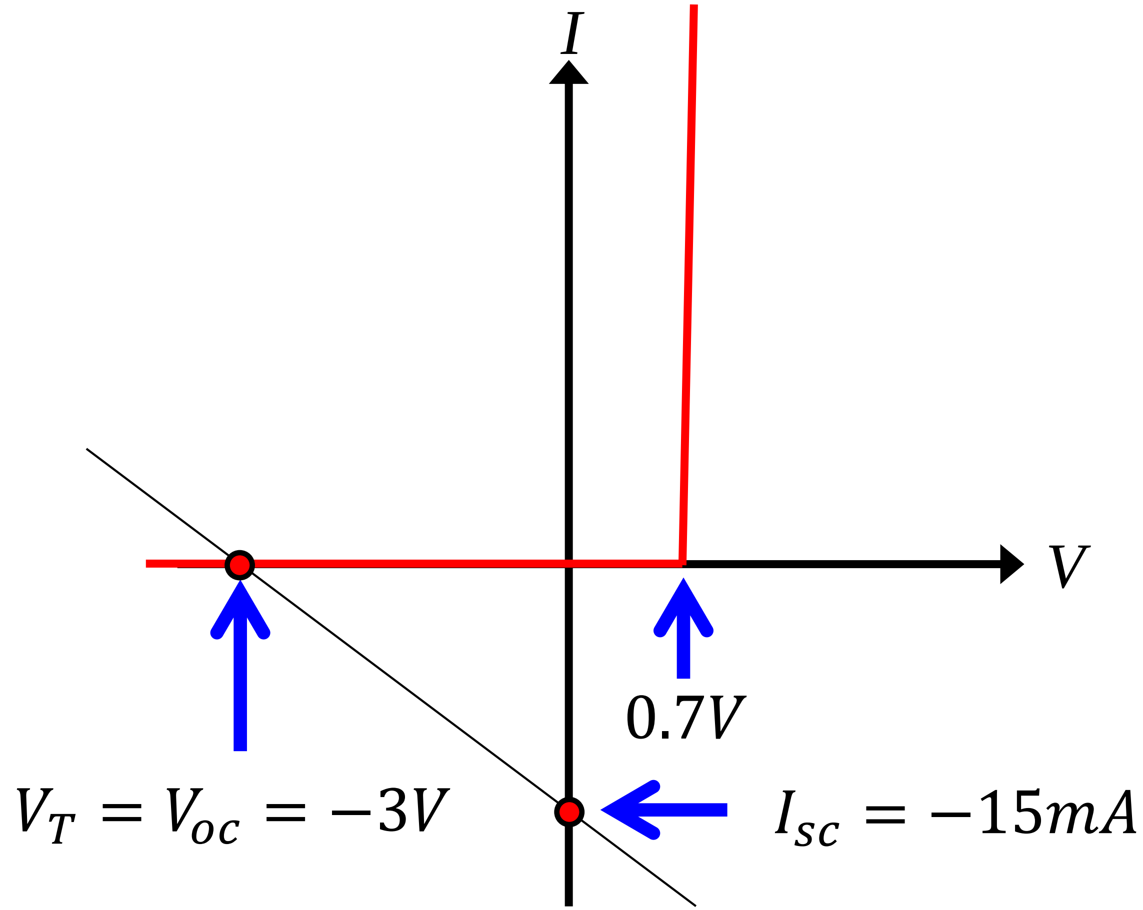
REVERSE BIAS

$$\boxed{I_D = \frac{3 - V}{200}}$$

L16Q6: What is the current through the diode?

Assume offset-ideal model with V_{ON} = 0.7 (common Si diodes)

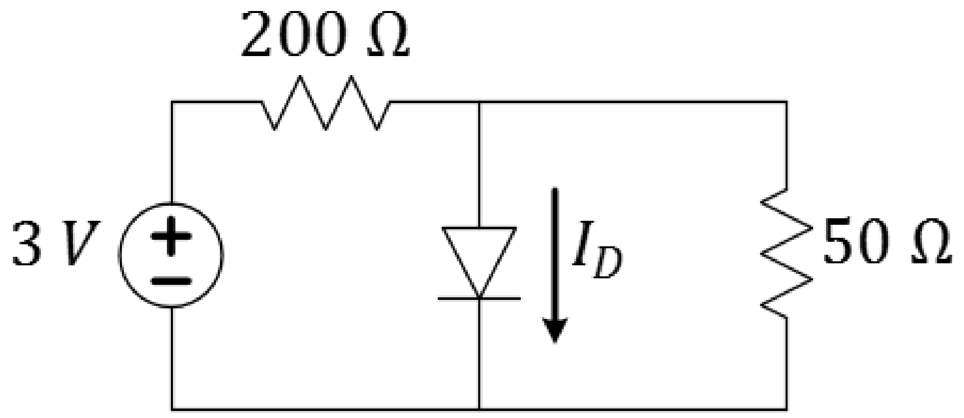




REVERSE BIAS

$$\boxed{I_D = \frac{-3 - V}{200}}$$

Diode circuit examples (offset ideal model)



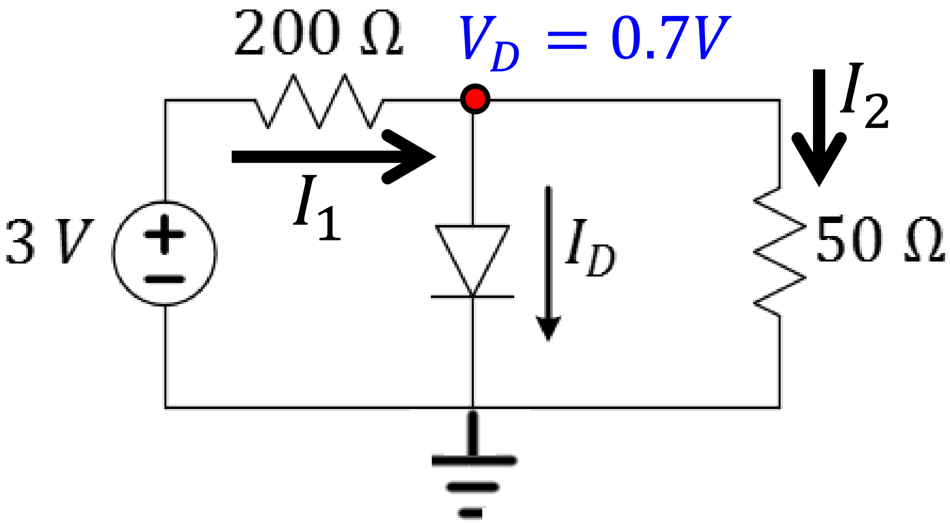
Assume offset-ideal model with V_{ON} = 0.7V (common Si diodes)

L16Q7: What is the current through the diode in the circuit?

$I_D =$

A. $-11.5\ mA$
B. $-2.5\ mA$
C. $0\ mA$
D. $+2.5\ mA$
E. $+11.5\ mA$

L16Q7: What is the current through the diode in the circuit?



Assume offset-ideal model with V_{ON} = 0.7V

Assume diode is conducting:

$$I_1 = \frac{(3-0.7)}{200} = \frac{2.3}{200} = 11.5mA$$

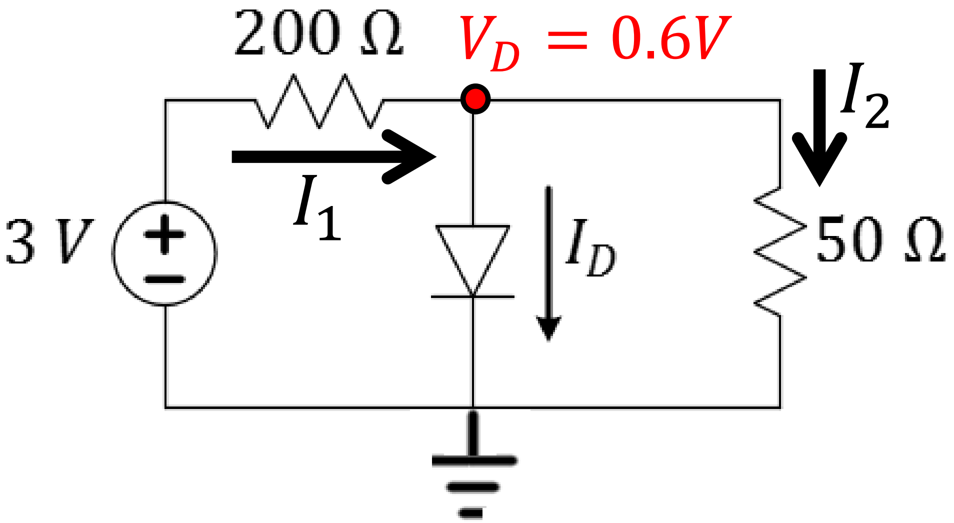
$$I_2 = \frac{0.7}{50} = 14mA$$

From KCL

$$I_D = I_1 - I_2 = -2.5mA$$

NOT PHYSICAL → diode does not conduct

L16Q7: What is the current through the diode in the circuit?



Assume offset-ideal model with V_{ON} = 0.7V

Assume diode is reverse biased:

$$I_D = 0\text{A}$$

$$I_1 = I_2 = \frac{3}{250} = 12mA$$

$$V_D = I_2 \times 50 = 0.6V$$

$I_D =$

A. $-11.5\ mA$

B. $-2.5\ mA$

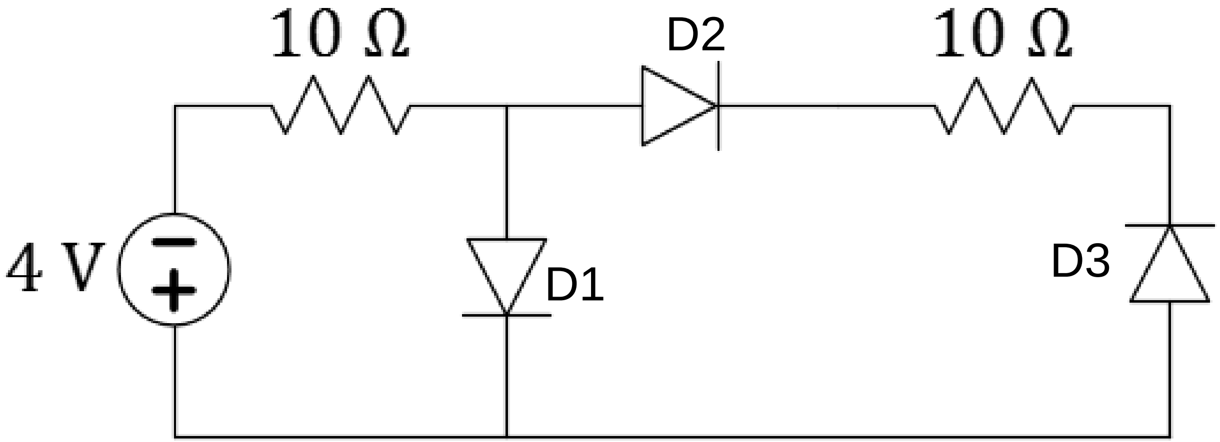
C. $0\ mA$

D. $+2.5\ mA$

E. $+11.5\ mA$

I-V operating point of the diode is (0A,0.6V)

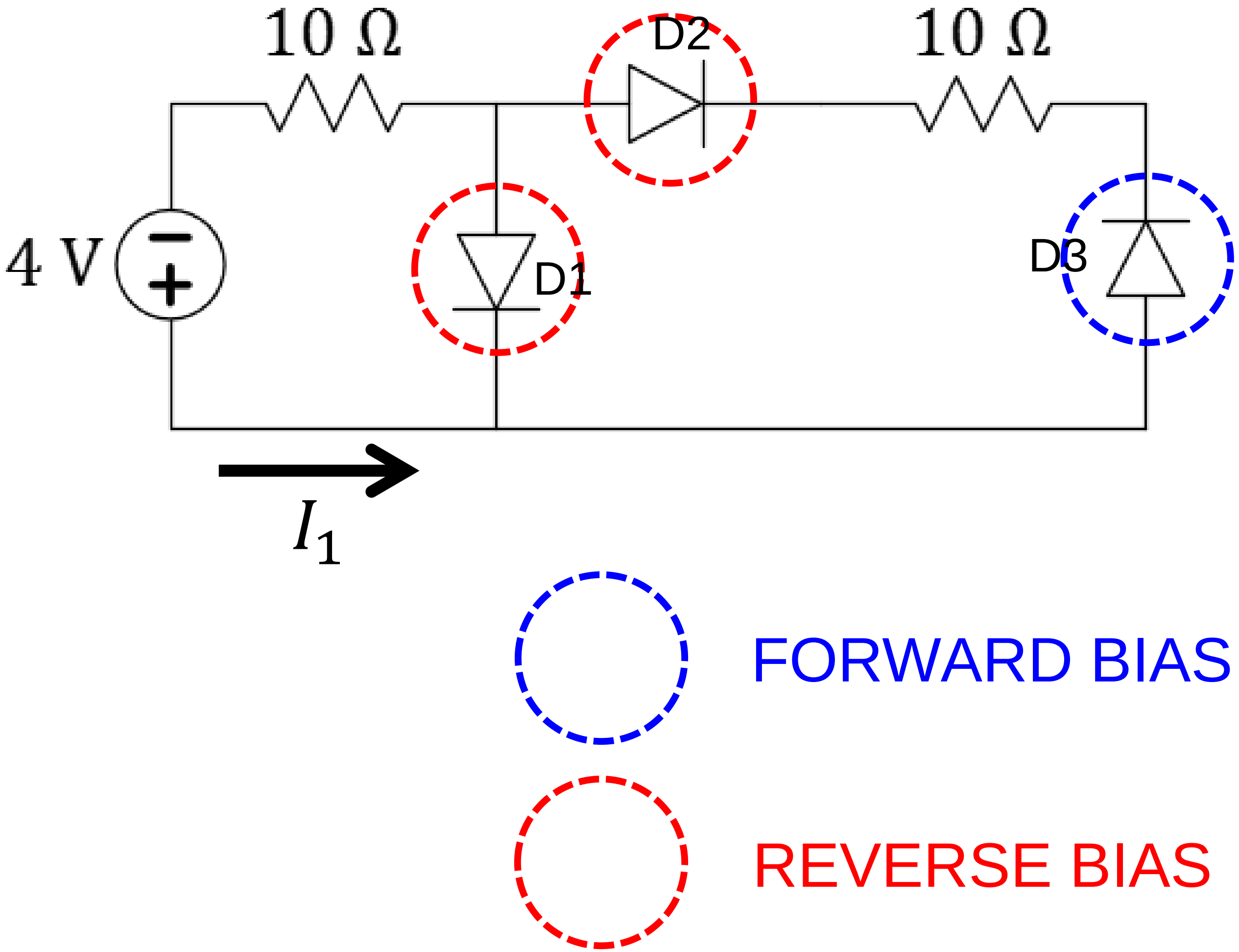
Back-to-back diodes in series are modeled by OIM as an open circuit



L16Q8: Assume OIM with V_{ON} = 0.7 V (Si) What is the current through the left-most diode?

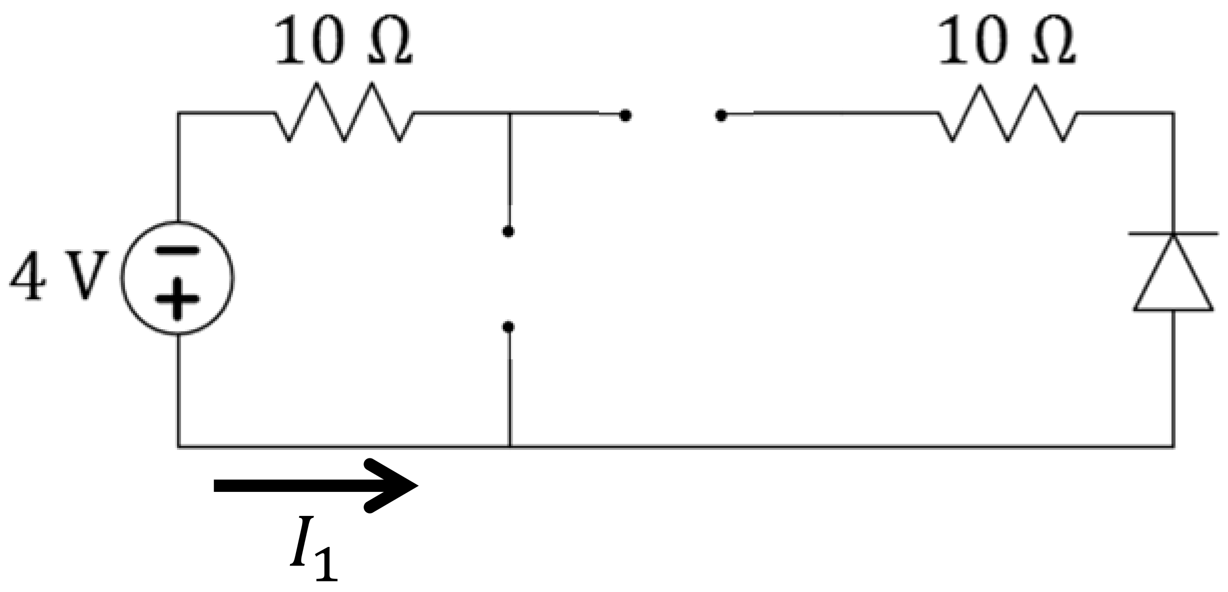
A. 0 *Amps*
B. 0.2 *Amps*
C. 0.33 *Amps*
D. 0.4 *Amps*
E. 3.3 *Amps*

L16Q8: Assume OIM with V_{ON} = 0.7 V (Si)
What is the current through the left-most diode?



A. $0\ Amps$
B. $0.2\ Amps$
C. $0.33\ Amps$
D. $0.4\ Amps$
E. $3.3\ Amps$

L13Q8: Assume OIM with V_{ON} = 0.7 V (Si)
What is the current through the left-most diode?



A. $0\ Amps$
B. $0.2\ Amps$
C. $0.33\ Amps$
D. $0.4\ Amps$
E. $3.3\ Amps$

L16 Learning Objectives

a. Draw a "typical" diode IV curve and describe its shape

b. Explain how to use graphical analysis to find the operating point of a diode connected to a linear circuit

c. Describe the offset ideal diode model (open, V-source)

d. Solve simple circuit problems with one diode, given V_{ON}