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Introduction to Electronics

An introduction to electronic components and a study of circuits containing such devices.

School of Electrical and Computer Engineering

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Week 4:
Diodes Part 1

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Introduction to Electronics

Dr. Bonnie H. Ferri
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School of Electrical and
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Introduction To PN Junctions

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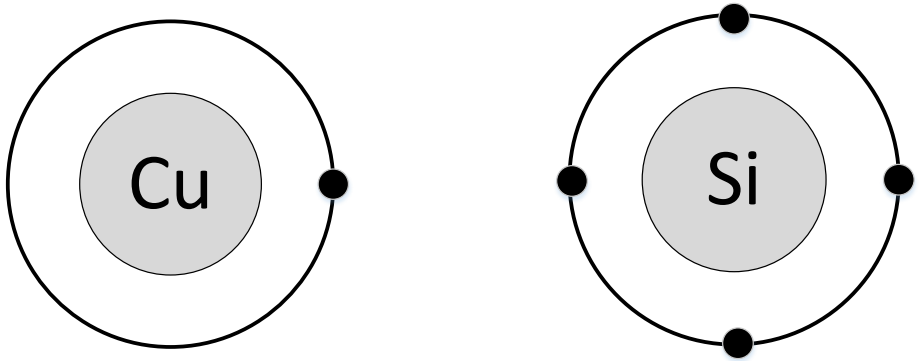
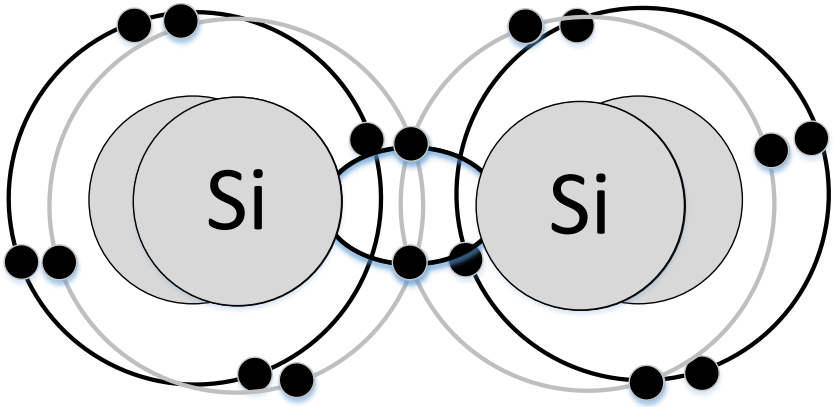
Introduce PN junctions and explain their physical behavior.

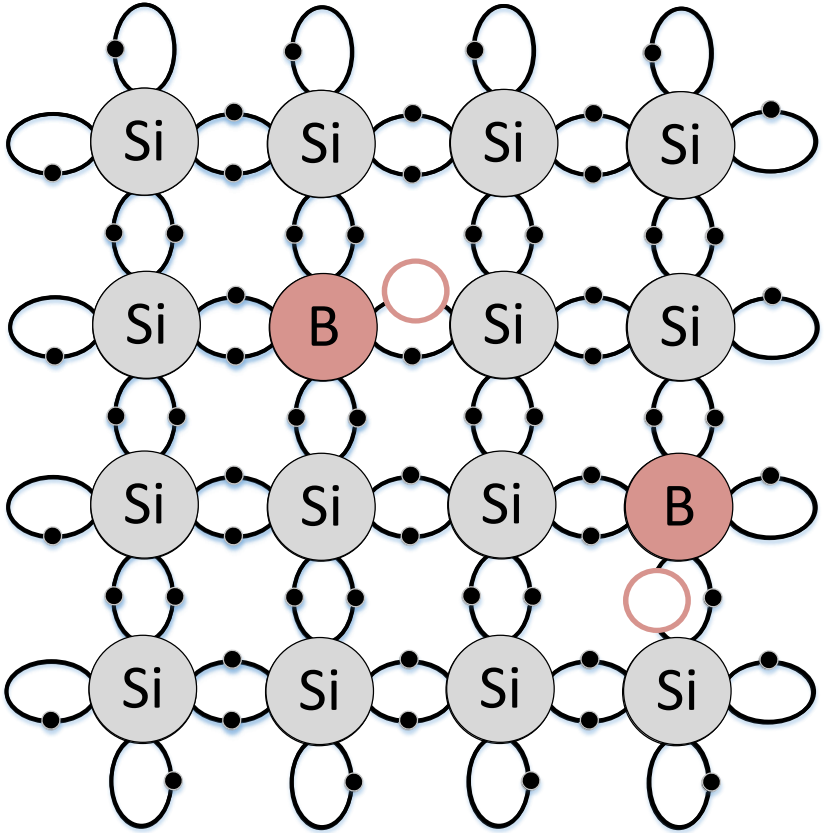
Lesson Objectives

- Demonstrate the physics of semiconductors
- Introduce PN Junctions



Semiconductor


Si
Si

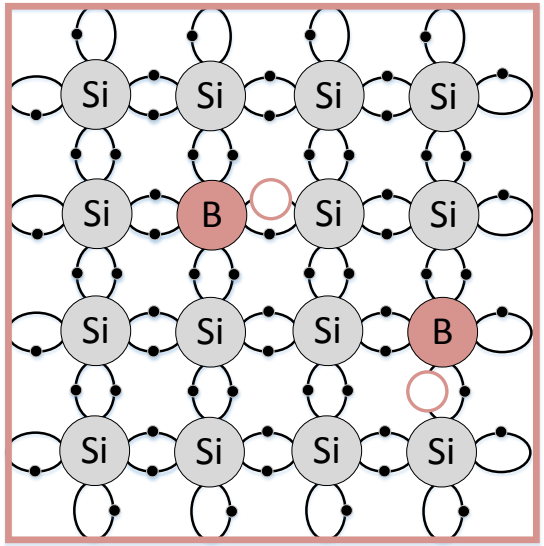


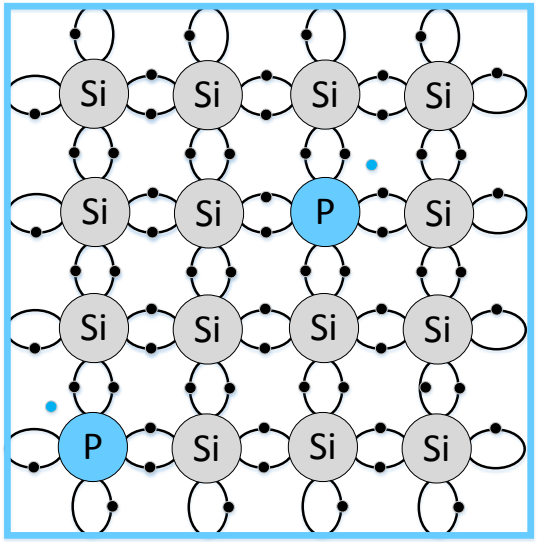
Doping - Add impurities such as Boron or Phosphorus

Number of electrons in outer shell:

- Boron has 3 electrons
- Phosphorus has 5 electrons

P-Type and N-Type Semiconductors

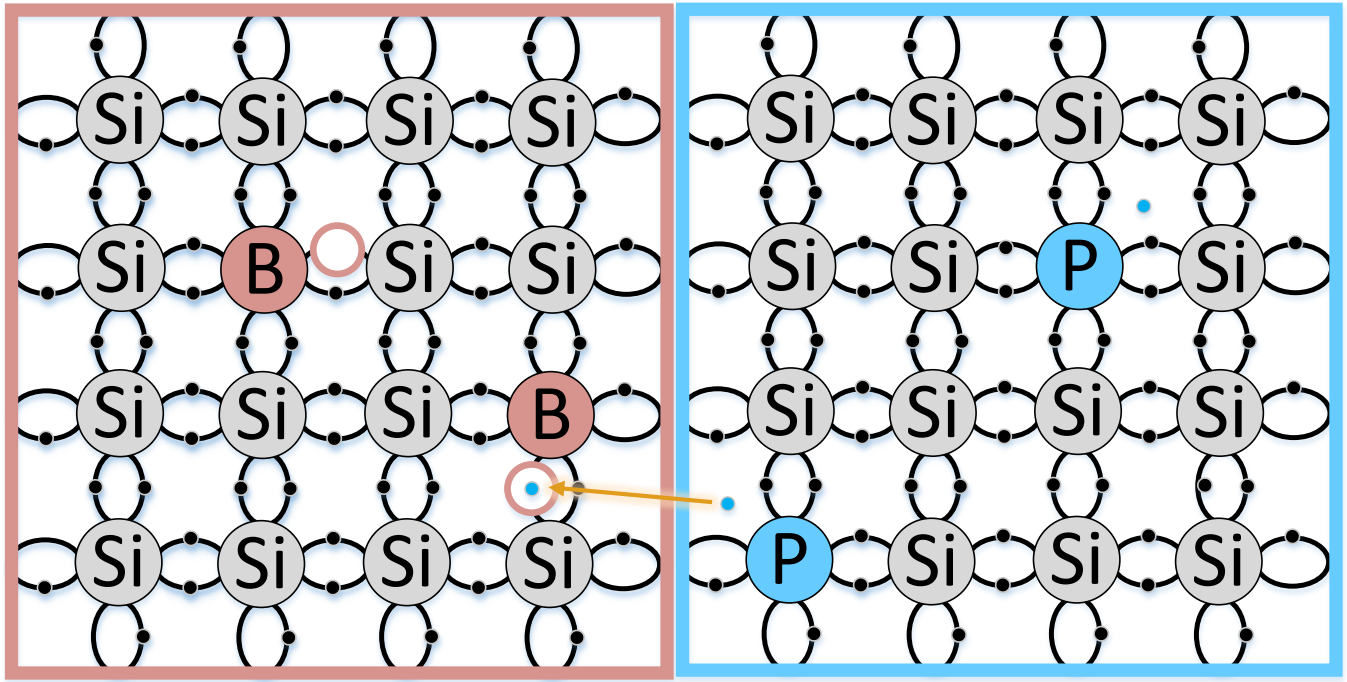




P-Type: extra holes

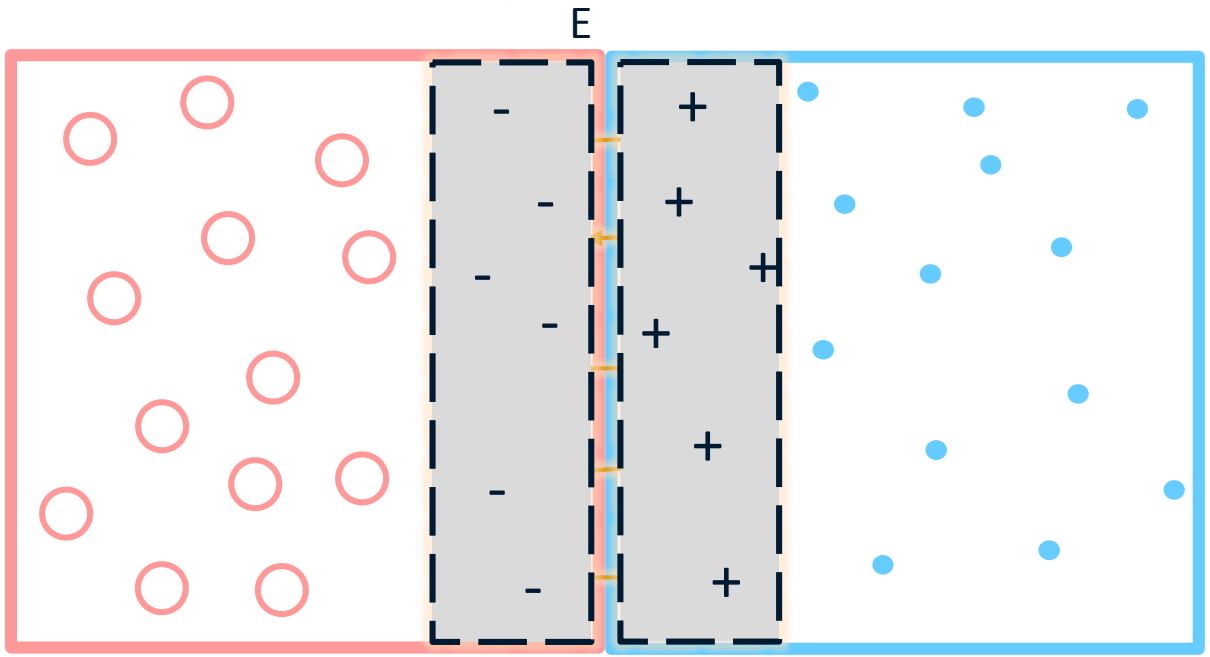
N-Type: extra free electrons

PN Junction



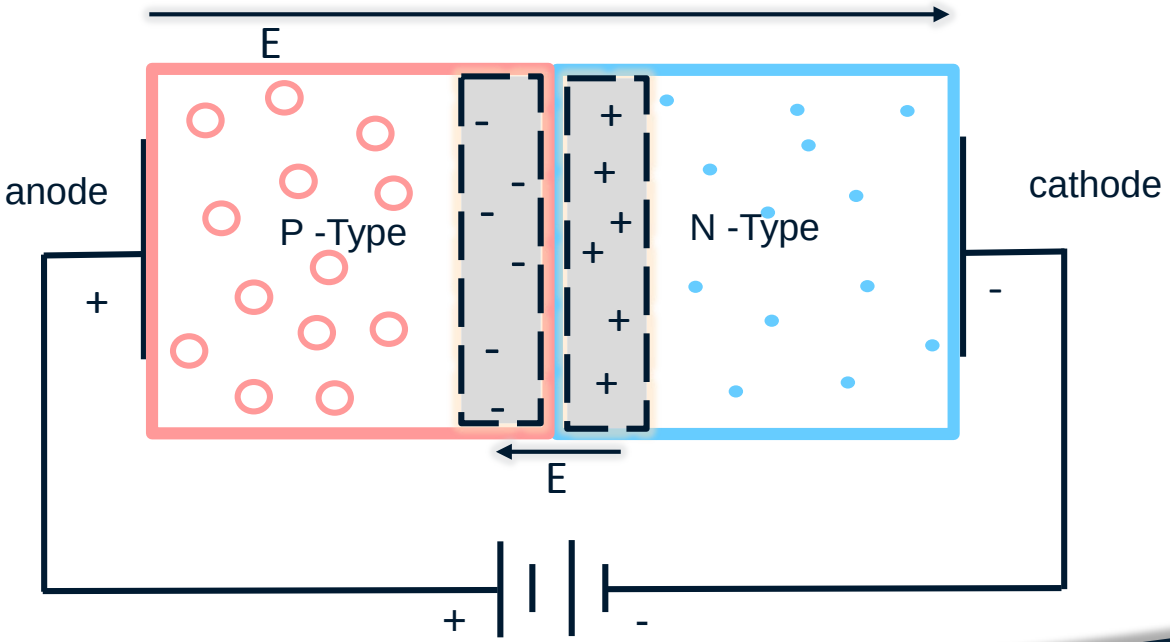
Energy – heat or light makes electrons at the junction diffuse to fill nearest holes

PN Junction

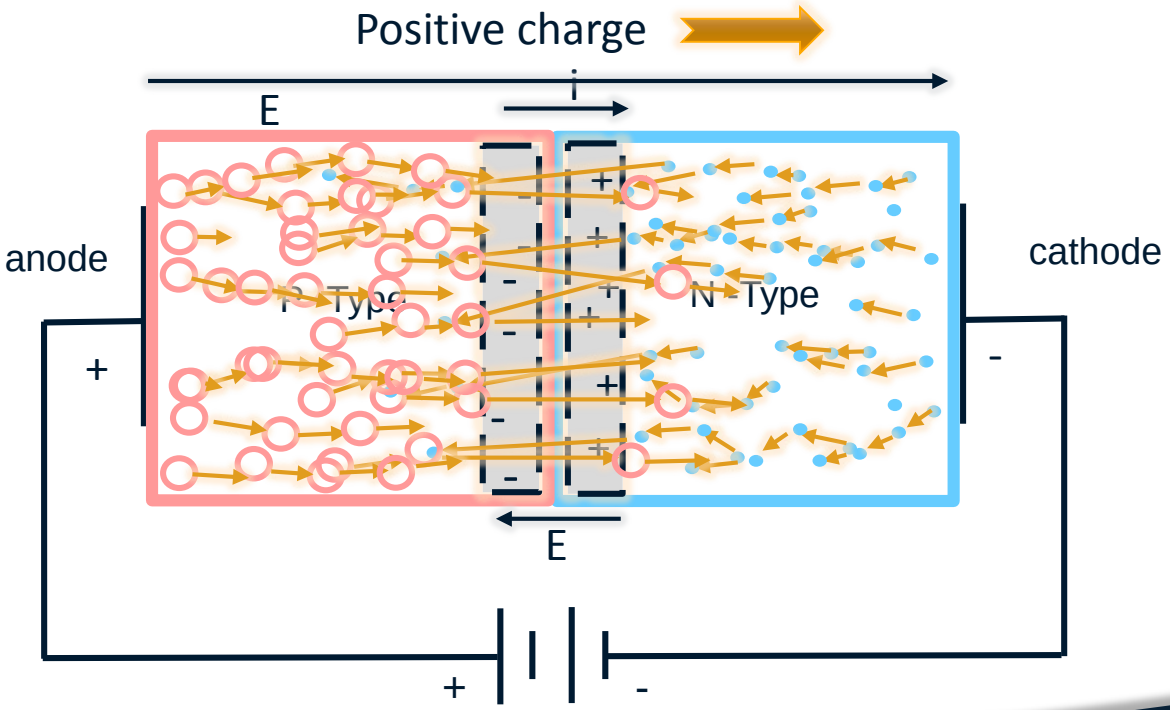


Depletion Region

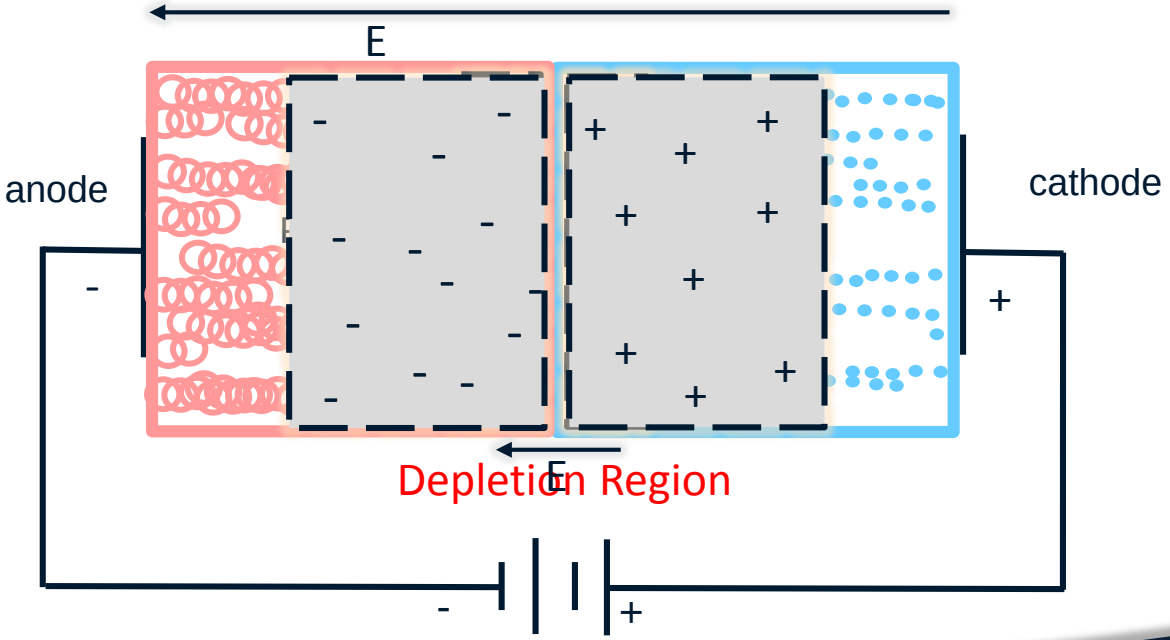
PN Junction: Conducting



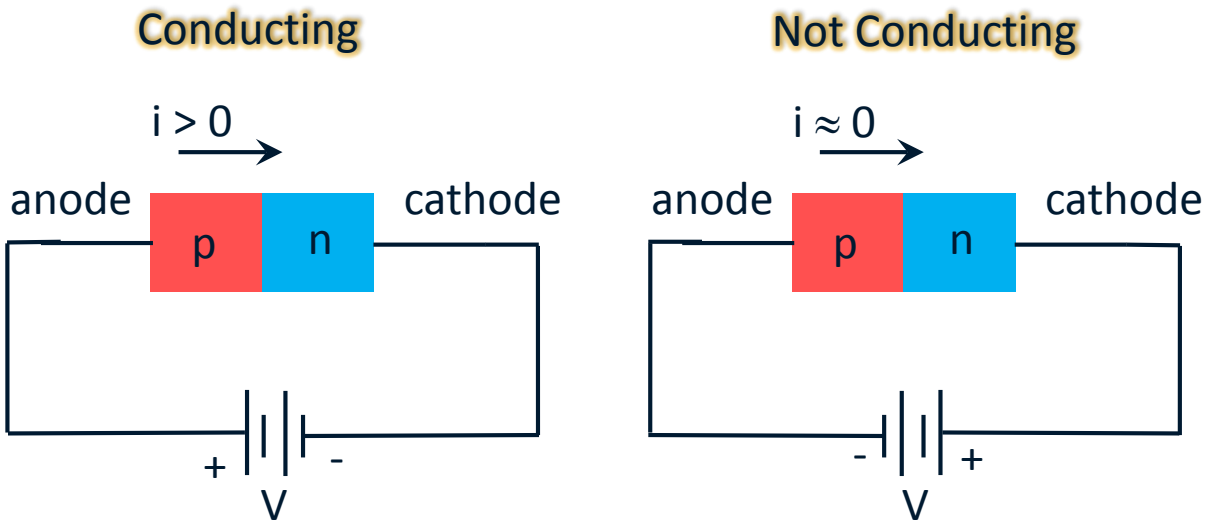
PN Junction: Conducting



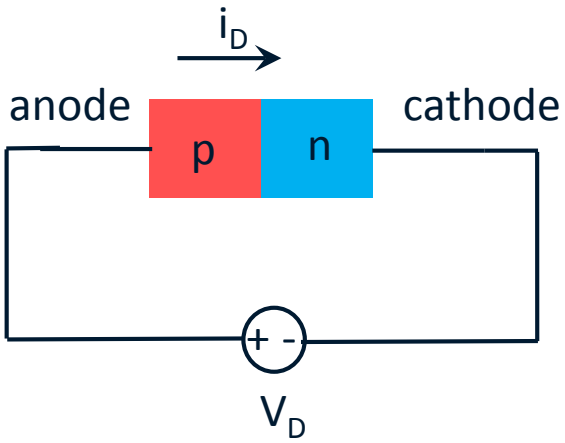
PN Junction: Not Conducting

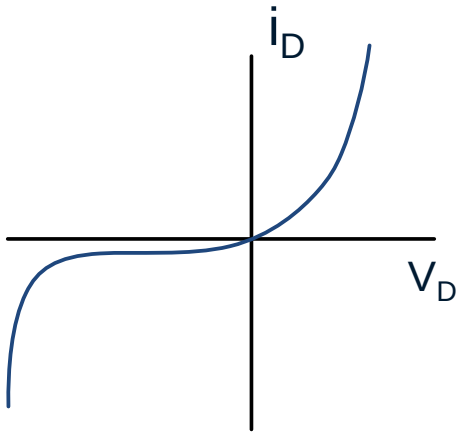


Summary of Behavior



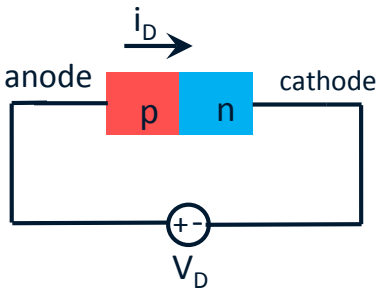
Diode

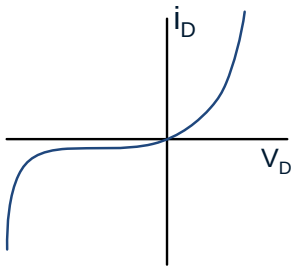




Summary

- Semiconductors become better conductors when
  - Doped
  - Exposed to heat or light
- PN Junctions (Diodes)





Remainder of Module 3: Diodes

- Circuit analysis with simple diode models
- Applications: rectifiers, AM detector, LEDs, voltage limiters, voltage regulators, AC to DC conversion

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Diode Behavior and Models

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Introduce ideal and non-ideal diode I-V curves

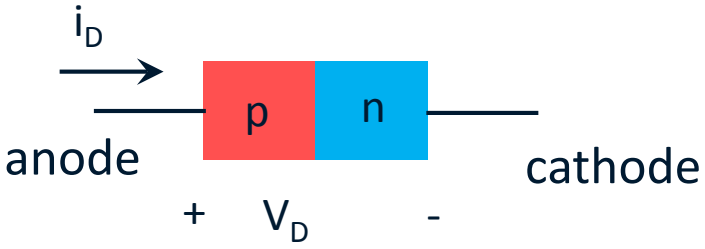
Previous Lesson

- The physics of PN junctions

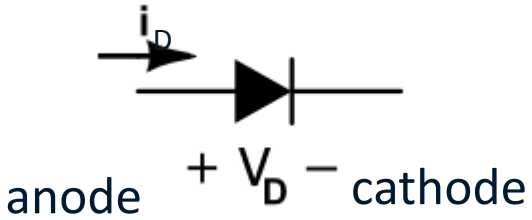
Lesson Objectives

- Analyze diode behavior
- Introduce diode applications
- Describe different operating regions
- Introduce simple diode models that approximate the actual device

Background



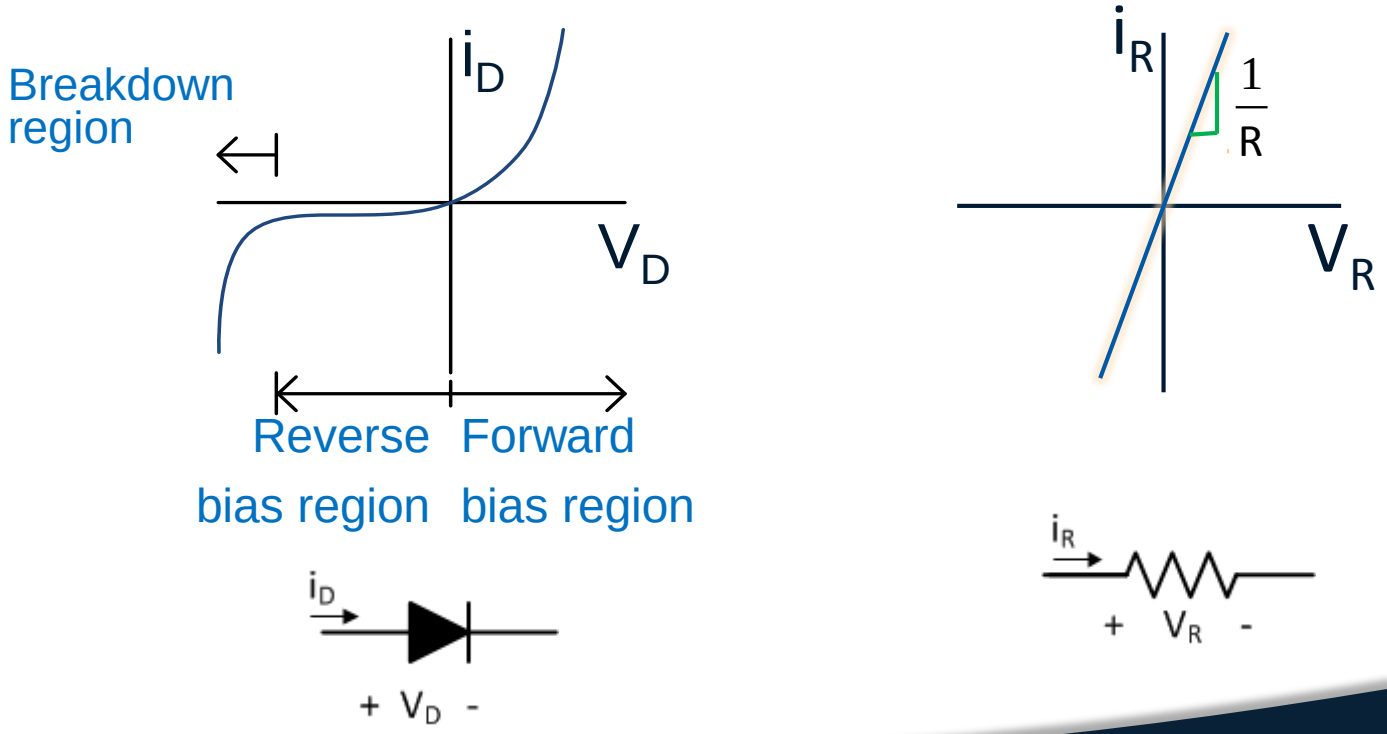
Circuit Symbol:



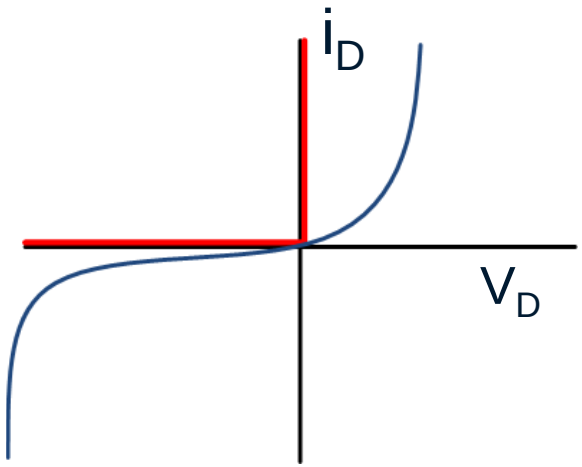
Uses:

- **Block current flow** in a specific direction
- **Rectifier** (AC to DC conversion)
- **Voltage regulator** and **limiter** (protection)
- **Light Emitting Diodes** (LEDs)
- **AM Detectors**
- **Electronic tuners**
- **Photodiodes**

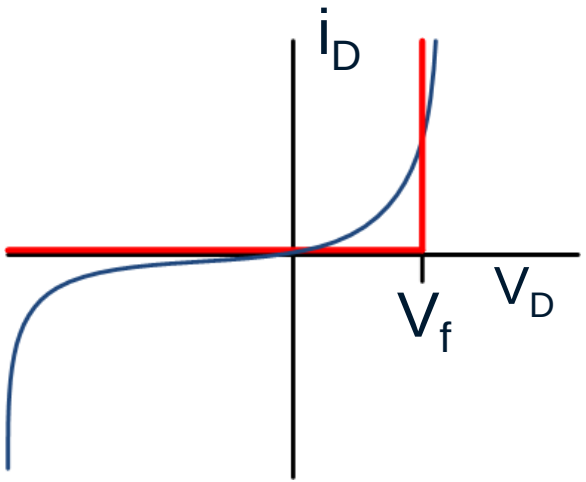
I-V Characteristics



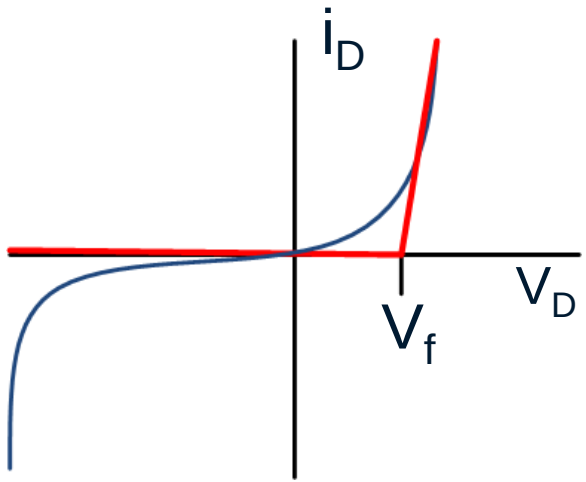
Simple Diode Models



Ideal Diode Model

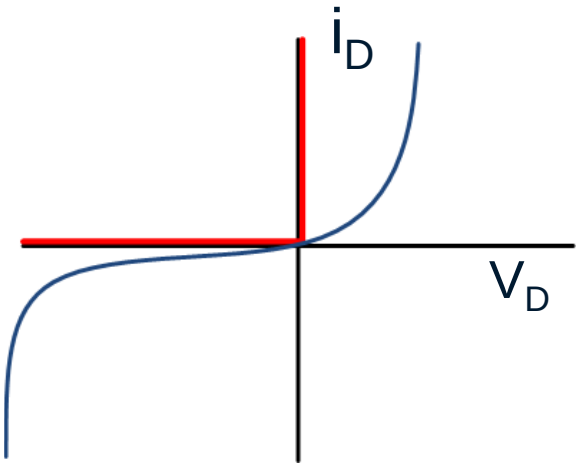


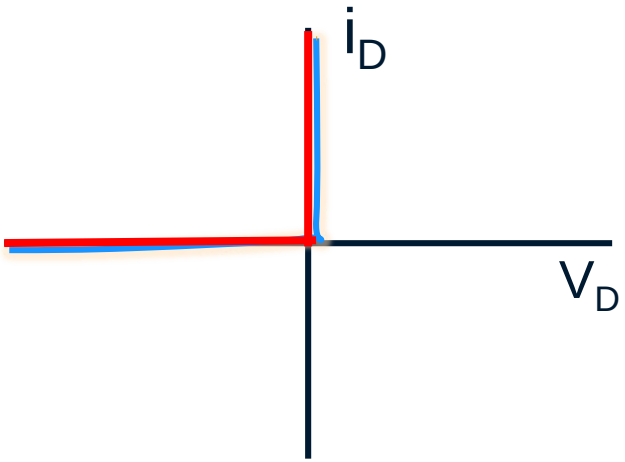
Ideal Diode + Voltage Source Model



Ideal Diode + Voltage Source + Resistor Model

Ideal Diode





Summary

- Diodes have three operating regions
  - Forward bias, $i_D > 0$
  - Reverse bias, $V_D < 0$
  - Breakdown
- Ideal diodes only allow current to flow in one direction
- Three models: ideal, ideal + voltage source, ideal + voltage source + resistor

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Ideal Diode Model

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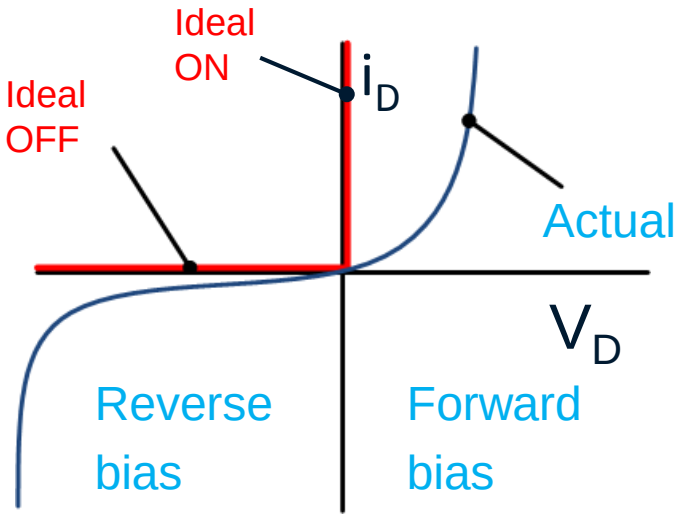
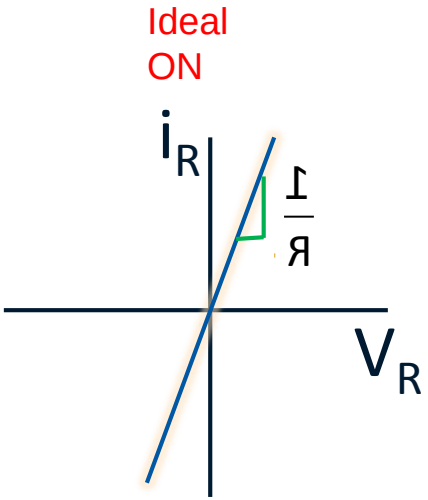
Introduce ideal diodes in circuits

Lesson Objectives

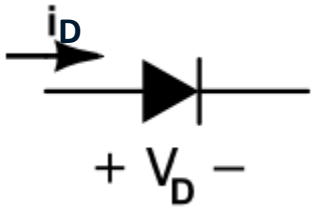
- Introduce ideal diode operation
- Describe how to analyze DC diode circuits

Ideal Diode Model

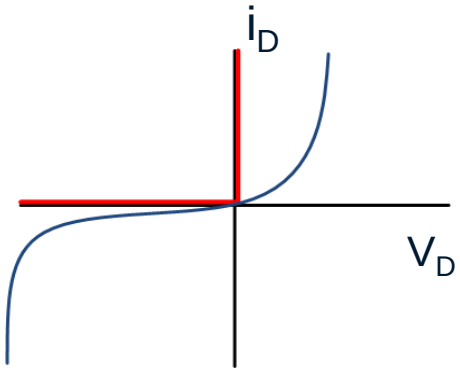




Ideal Diode Model



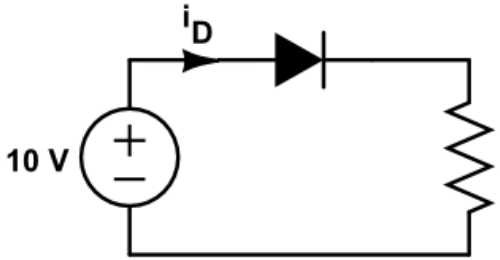
Two possible states: ON and OFF

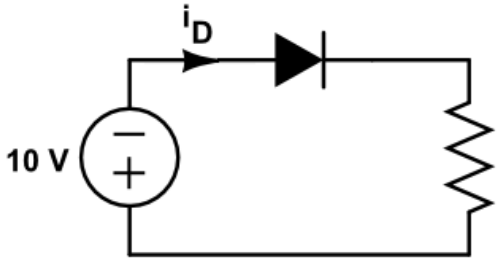


ON (conducting): if $i_D > 0$

OFF (blocking): if $V_D < 0$, $i_D = 0$

Example





Summary

- Diodes act as a short or an open, depending on the bias

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Assumed States Method

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Introduce ideal diode circuits with multiple diodes

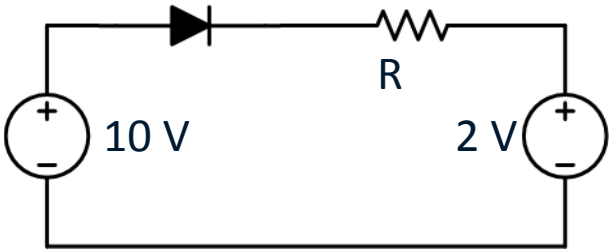
Lesson Objective

- Describe the procedure for handling multiple diodes in a single circuit

Assumed States Procedure

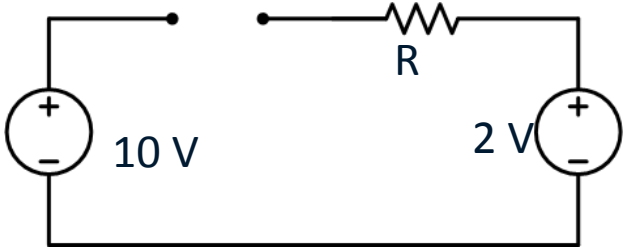
1) Identify all possible diode state combinations
   - 1 diode $\Rightarrow$ 2 states
   - 2 diodes $\Rightarrow$ 4 states
   - 3 diodes $\Rightarrow$ $2^3 = 8$ states
2) Analyze each state by replacing the diodes with the corresponding open or short.
3) Determine which state is consistent:
   - ON: $i_D > 0$
   - OFF: $V_D < 0$

Example



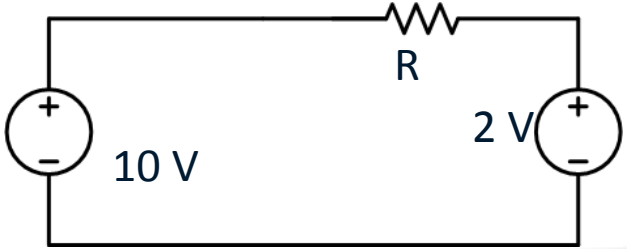
States	D1	Consistent?
A	OFF	
B	ON	

A) OFF:



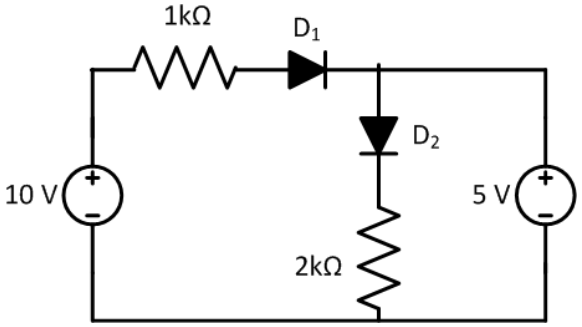
$-10 + V_D + 2 = 0, V_D > 0$
(not consistent)

B) ON:



$-10 + i_D 1k + 2 = 0, i_D = 0.008A > 0$
(consistent)

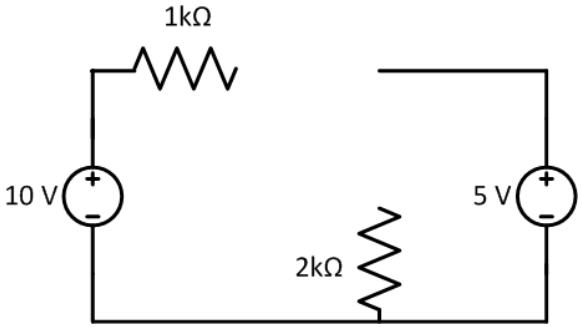
Two Diode Example



Find V_1

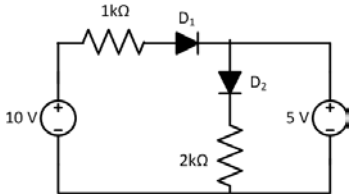
States	D1	D2	Consistent?
A	OFF	OFF	
B	OFF	ON	
C	ON	OFF	
D	ON	ON	

A)



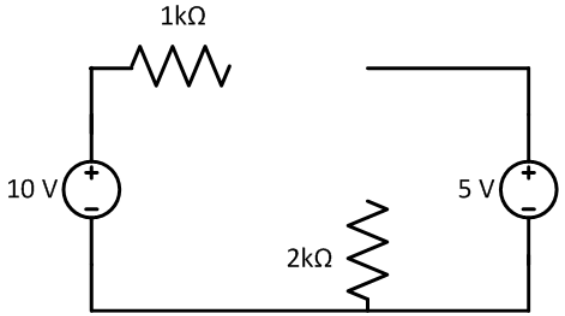
KVL: $-5 + V_{D2} = 0$ → $V_{D1} = 5 > 0$
(Not consistent)

Example continued



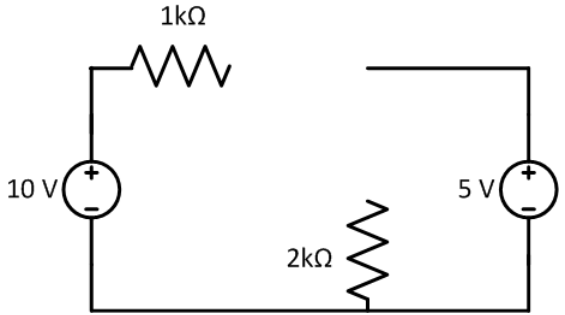
States	D1	D2	Consistent?
A	OFF	OFF	No
B	OFF	ON	
C	ON	OFF	
D	ON	ON	

B)



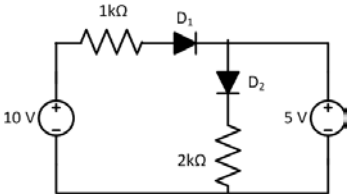
KVL: $-10 + V_{D1} + 5 = 0$, $V_{D1} = 5V > 0$
(Not consistent)

C)



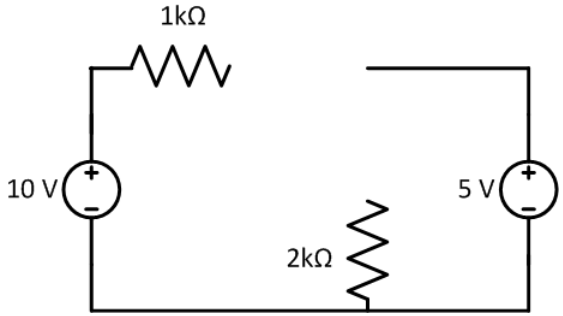
$V_{D2} = 5V > 0$
(Not consistent)

Example continued



States	D1	D2	Consistent?
A	OFF	OFF	No
B	OFF	ON	No
C	ON	OFF	No
D	ON	ON	

D)



KVL: $-10 + 1000i_{D1} + 5 = 0$
$i_{D1} = 0.005A > 0$
$i_{D2} = 5/2000 > 0$
(Consistent)

Operating state:
D_1 and D_2 are ON
$V_1 = 1000(0.005) = 5V$

Summary

- Diodes act as a short or an open, depending on the bias
- When solving a circuit, assume each possible state, and check to see if the behavior is consistent with that state

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Ideal Diode + Voltage Source Model

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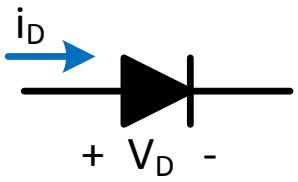
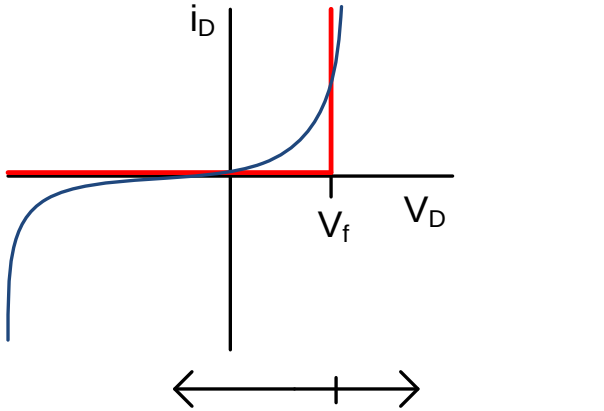
Introduce another diode model for circuit analysis

Lesson Objective

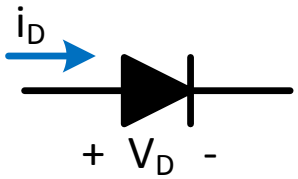
- Examine the ideal diode + voltage source model

Ideal Diode with a Voltage Source

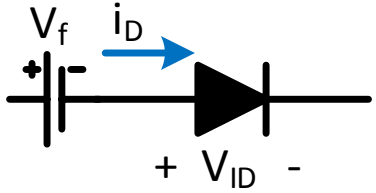




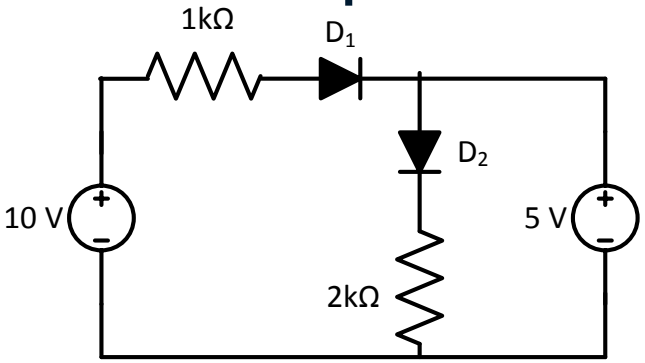
Replace



with

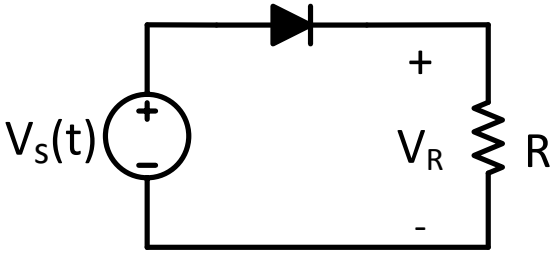


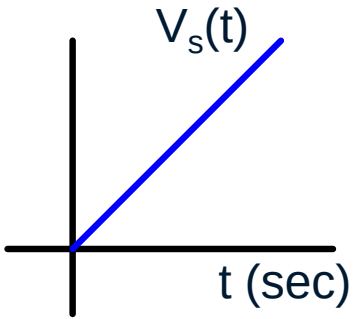
Example



States	D1	D2	Consistent?
A	OFF	OFF	
B	OFF	ON	
C	ON	OFF	
D	ON	ON	

Example





Summary

- Ideal diode + voltage source model has threshold voltage that must be surpassed before the diode is turned on.
  - 0.7 V Silicon
  - 0.3-0.4 V Germanium
  - 1- 4 V LED
- Replace diode with ideal diode + voltage source and analyze using ideal diode methods.