دانشگاه صنعتی امیرکبیر
(پلی تکنیک تهران)

Electrical and Electronic Circuits

chapter 10. Diodes

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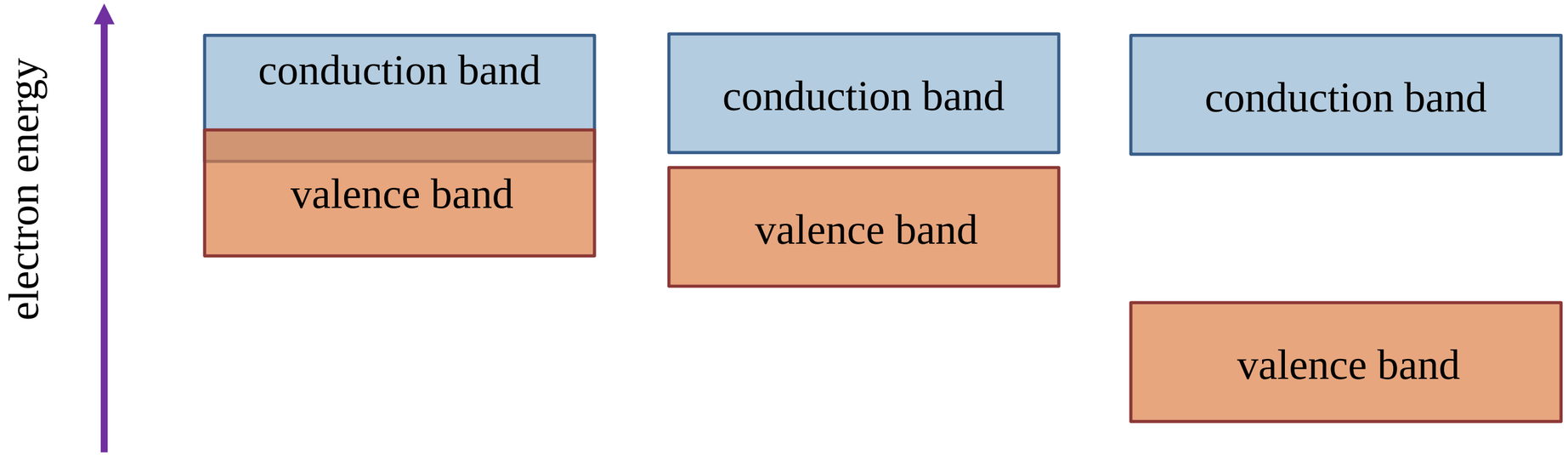
عظیم فرقدان

مهر ۱۴۰۳

Objectives of the Lecture

- Introduction to Diodes and Their Applications
- Voltage-Current Characteristics of Diodes and Their Models
- Analysis of Diode Circuits

semiconductor



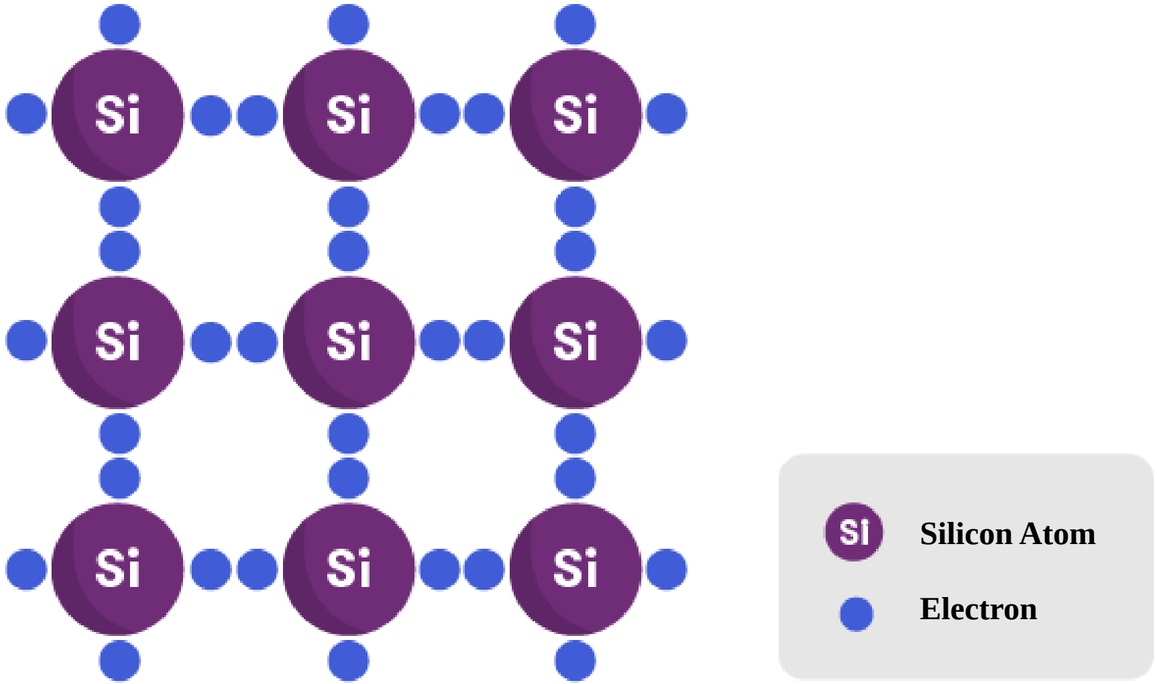
conductor
like **copper, silver, gold, aluminum,** etc.

Semiconductor
like **silicon, germanium,** etc.

Insulator
like **glass, ceramic, wood, plastic,** etc.

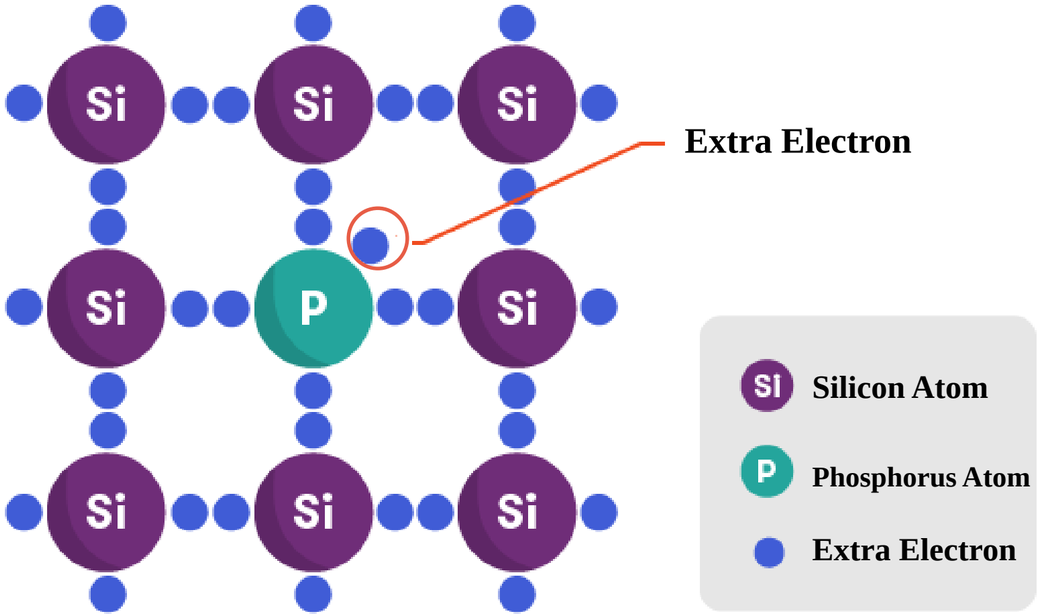
Silicon as a Semiconductor

- **Atomic Structure**
  - Contains 4 electrons in the valence shell



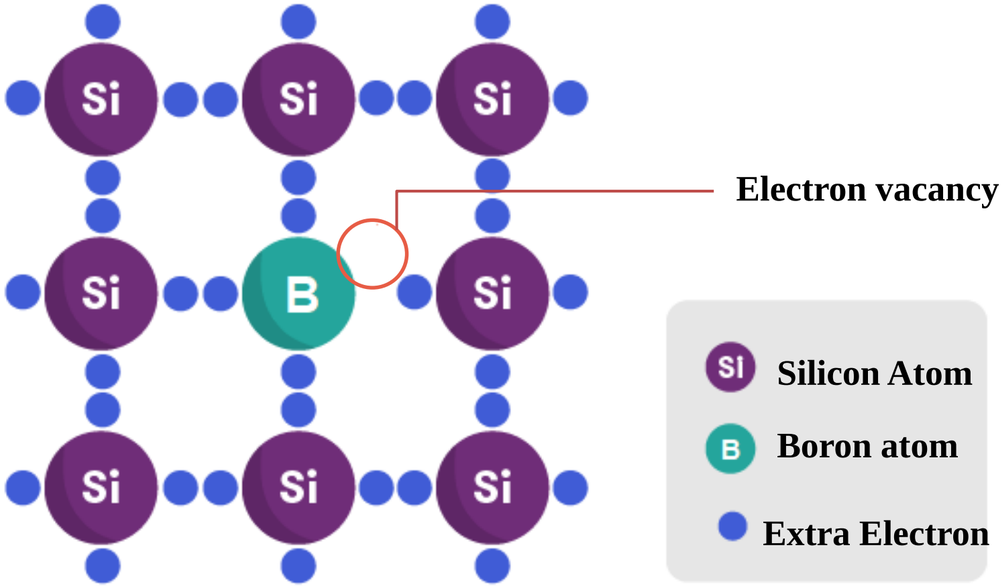
N-Type Semiconductor

- ✓ In an **N-type semiconductor**, several phosphorus atoms replace silicon atoms.
- ✓ A phosphorus atom has **5 electrons in its valence shell**, so one electron can move freely.



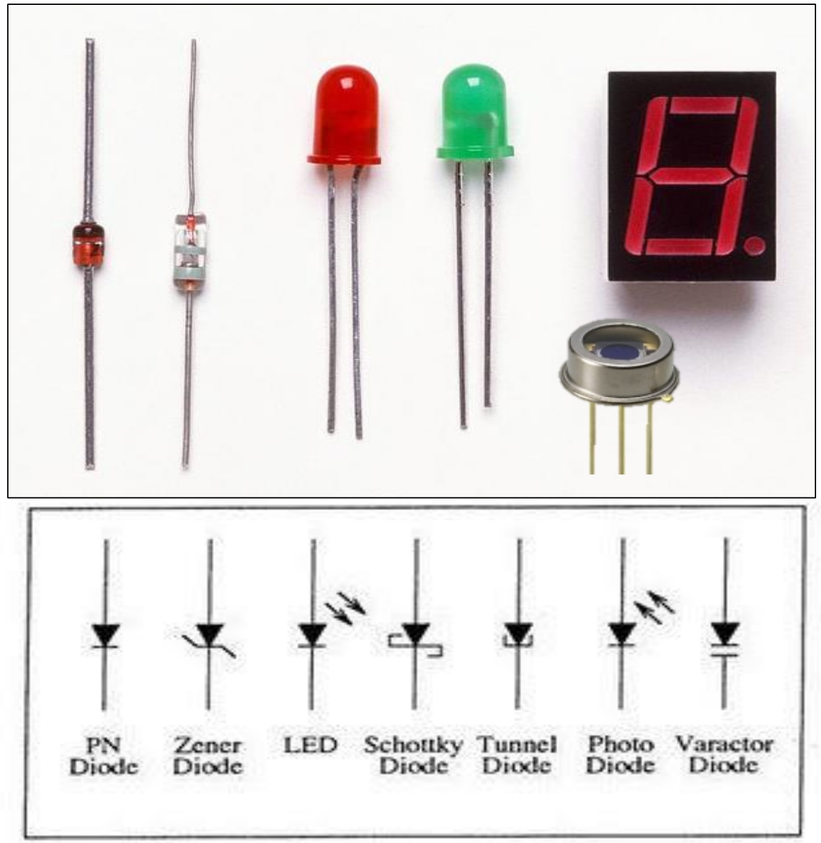
P-type semiconductor

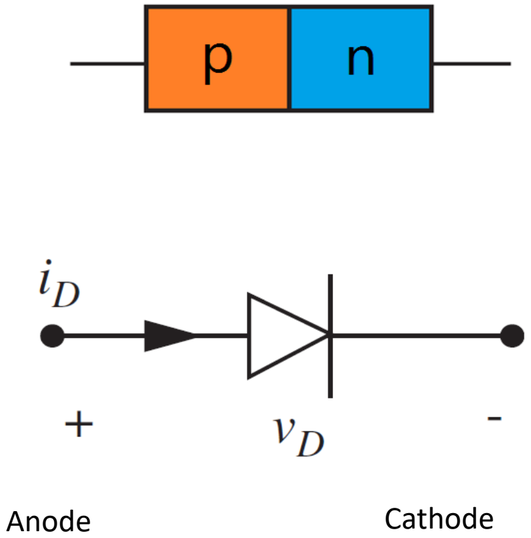
- ✓ In a p-type semiconductor, some boron atoms are substituted for silicon atoms.
- ✓ A boron atom has 3 electrons in its valence shell, resulting in a vacancy for one electron.



Diode

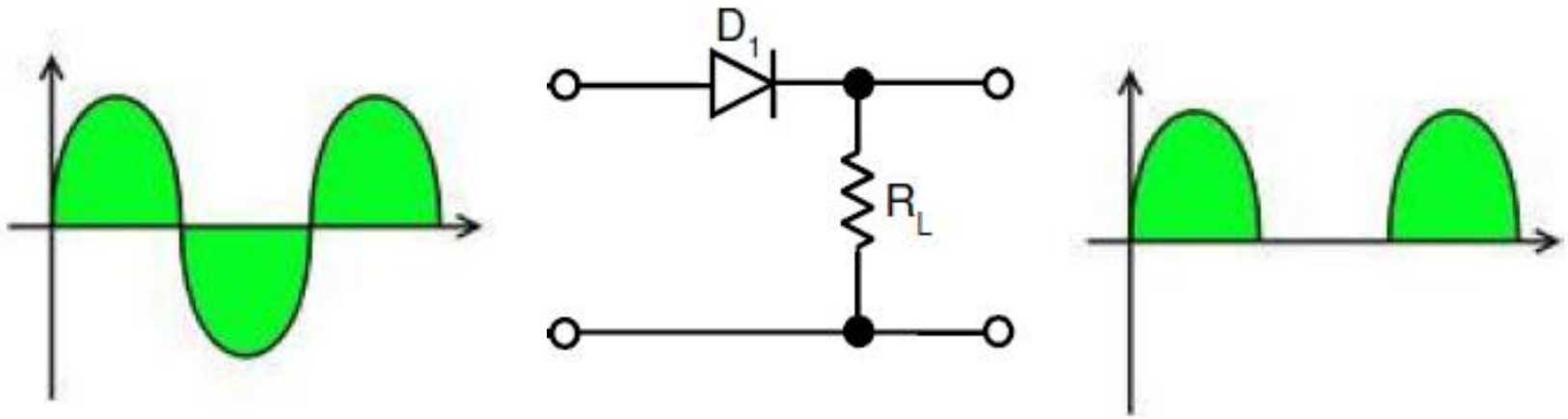
- A PN diode is a device formed by the junction of p-type and n-type semiconductors.





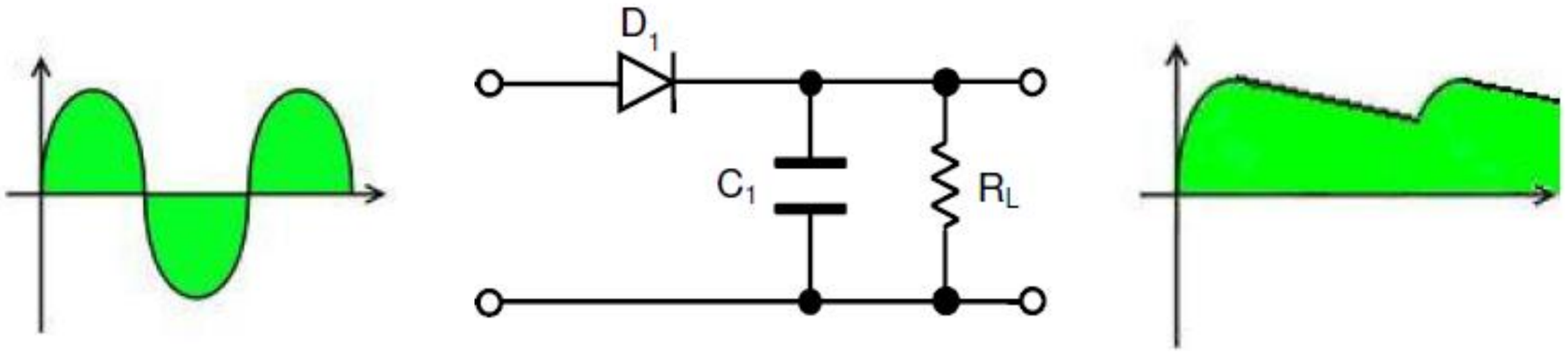
Applications of Diodes

- Rectifier Circuit



Applications of Diodes

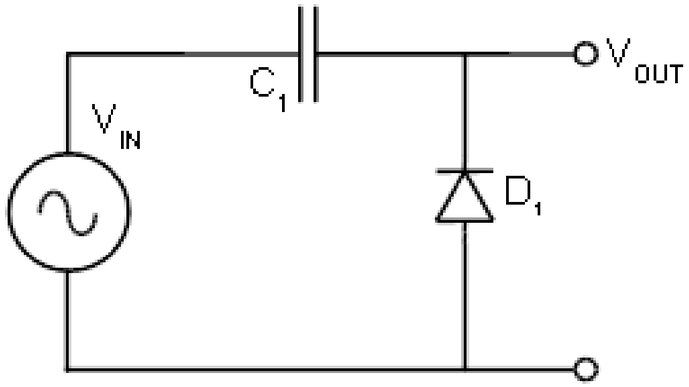
- Peak detector

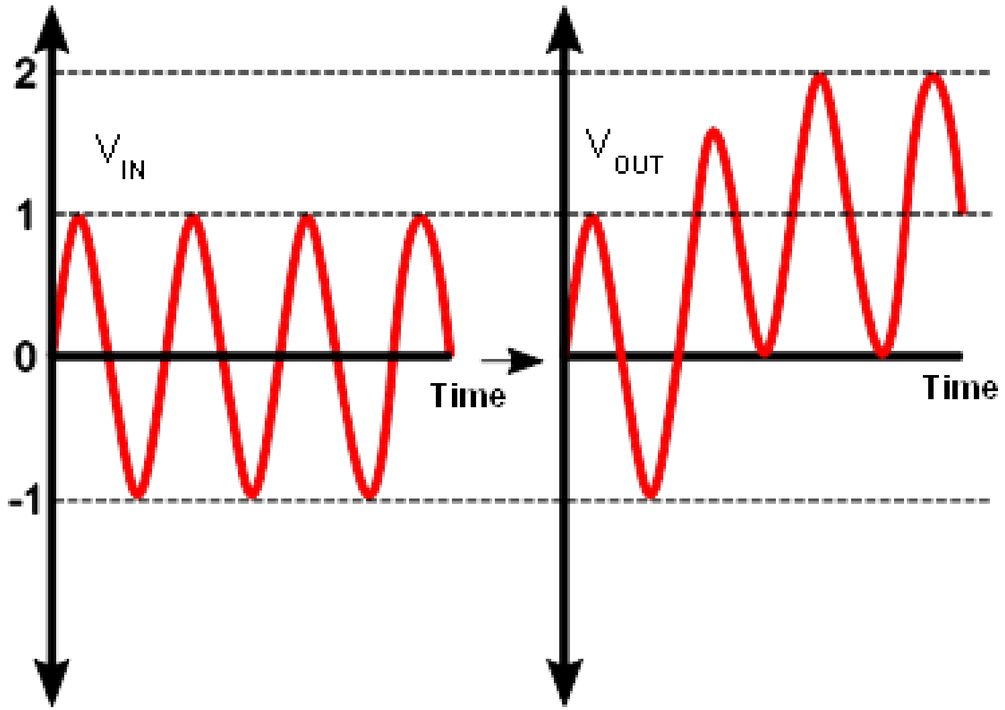


Example: For converting an AC wave to DC.

Applications of Diodes

➢Clamper Circuit

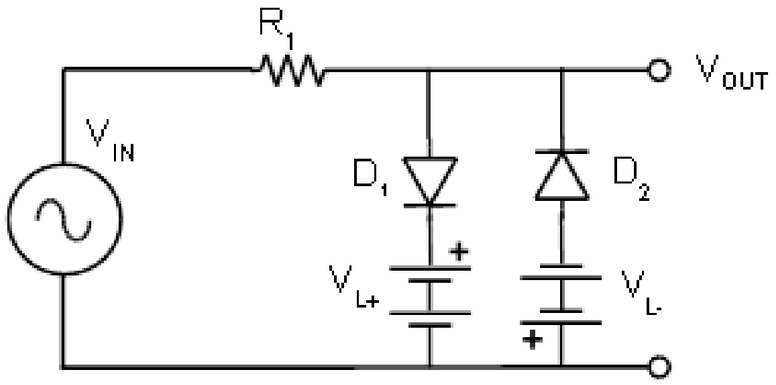


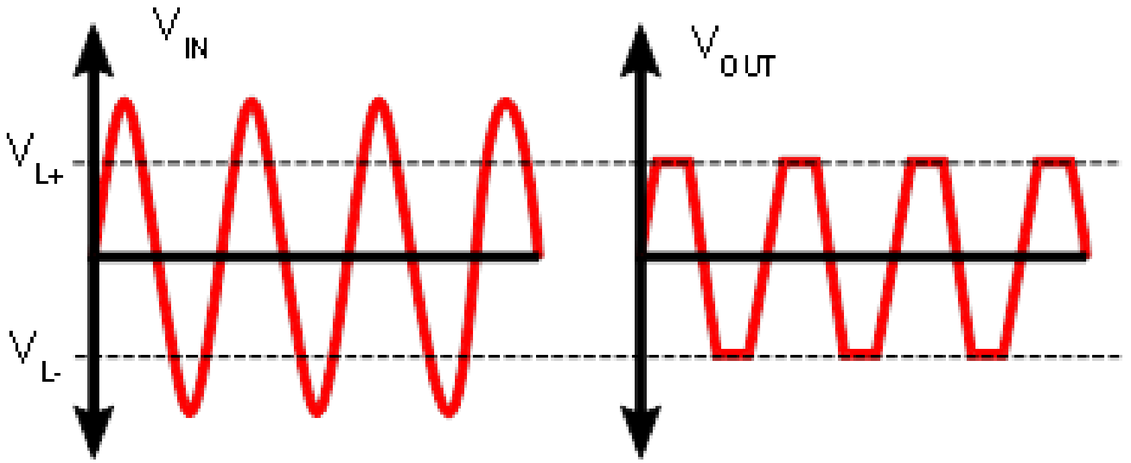


Example: For voltage multiplication.

Applications of Diodes

- Clipper/Limiter Circuit

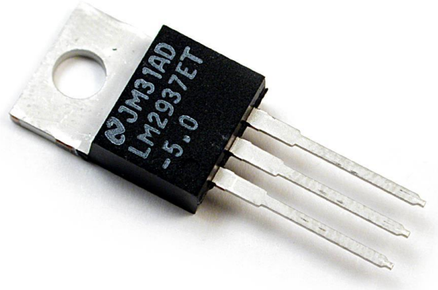


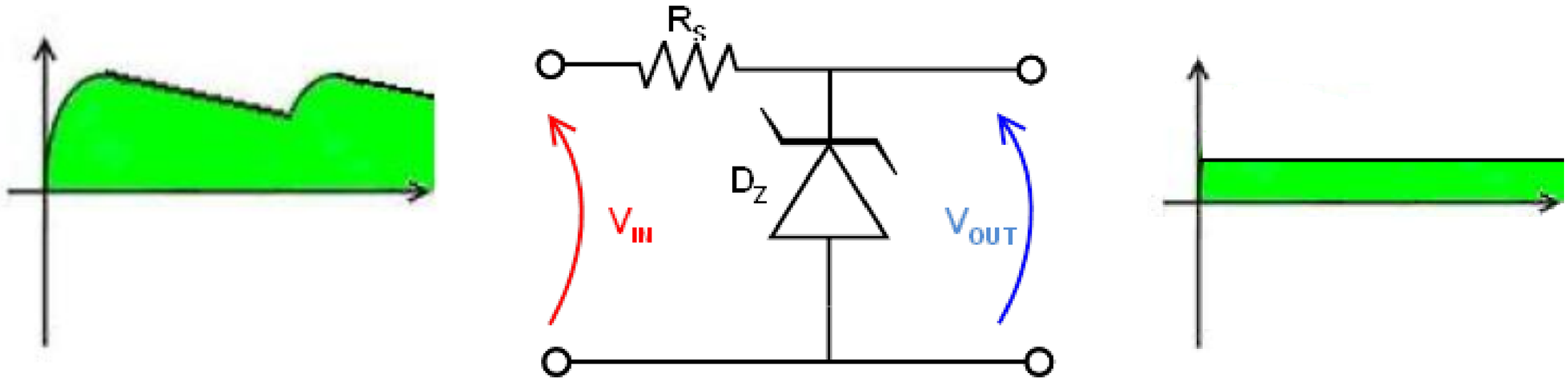


Example: For removing noise spikes.

Applications of Diodes

- Voltage Regulator

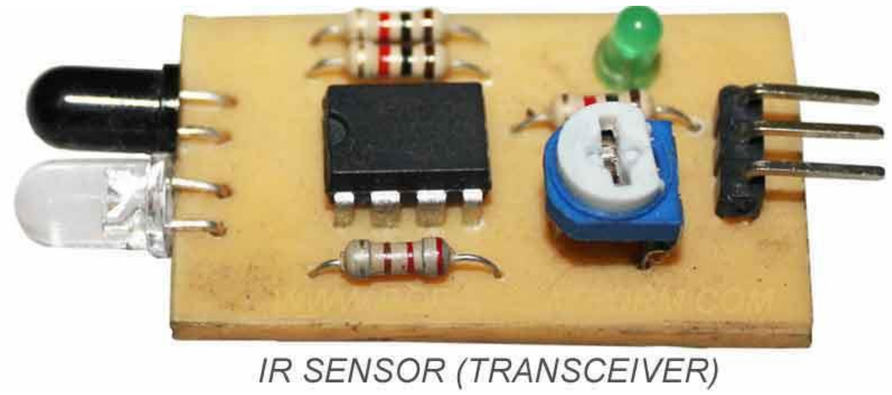




Applications of Diodes

- Infrared Transmitter/Receiver

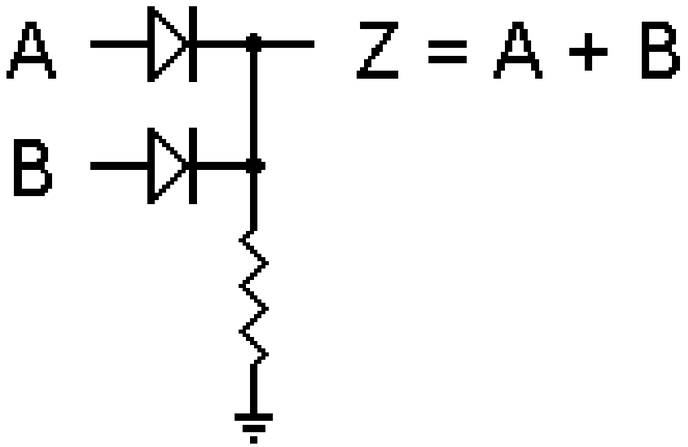
Light Emitting Diode (LED)

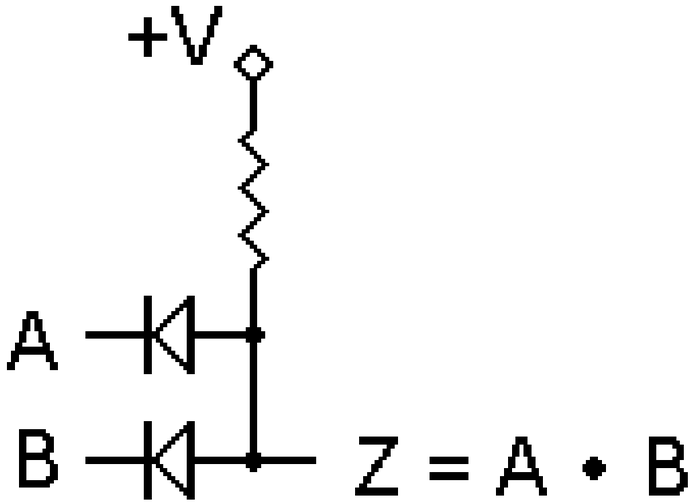


IR SENSOR (TRANSCEIVER)

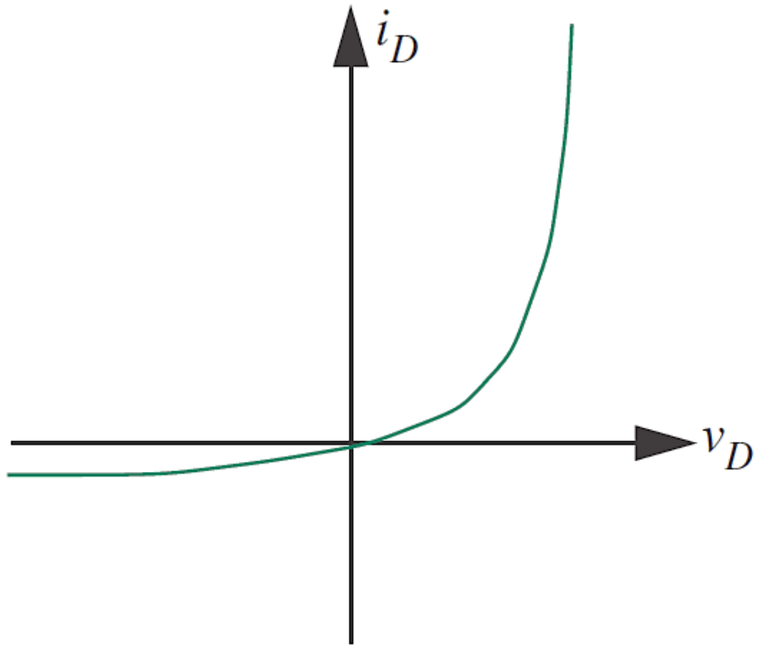
Applications of Diodes

- For constructing logic gates.

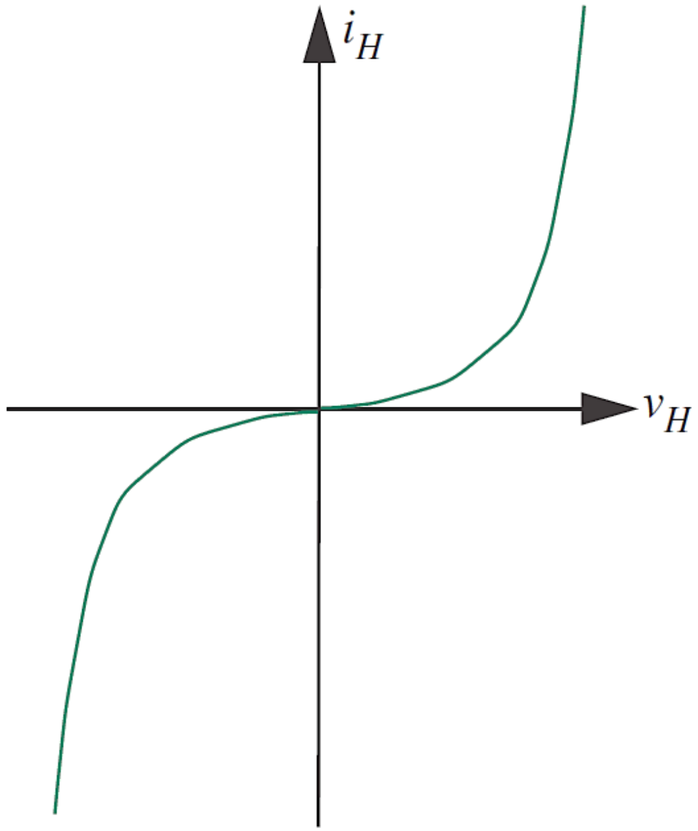




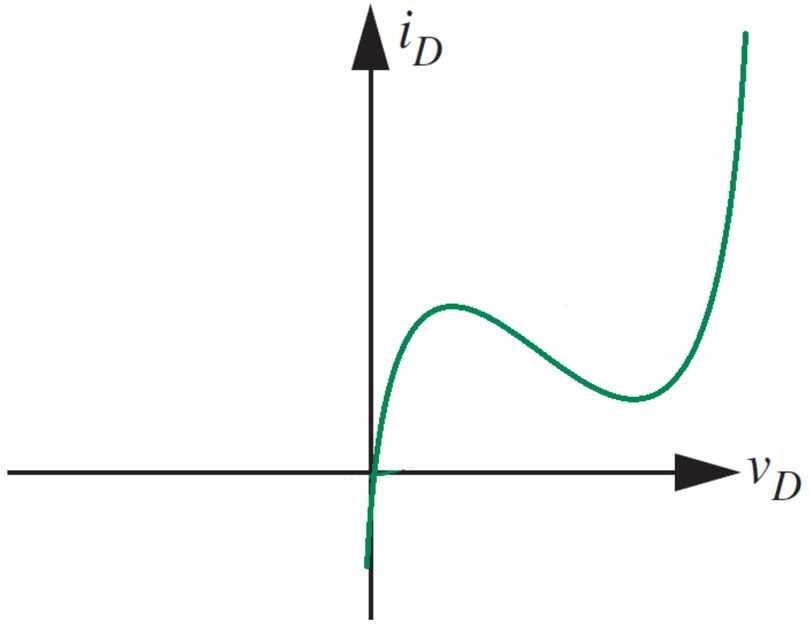
Voltage-Current Characteristic



PN Diode



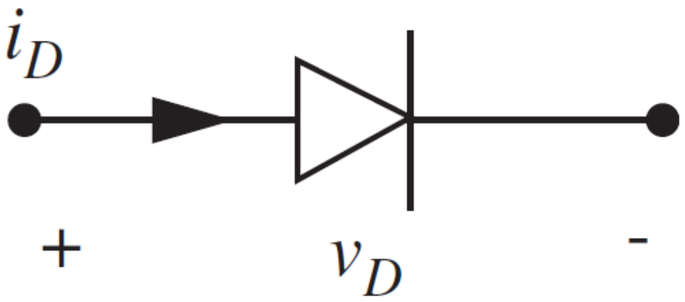
Zener Diode

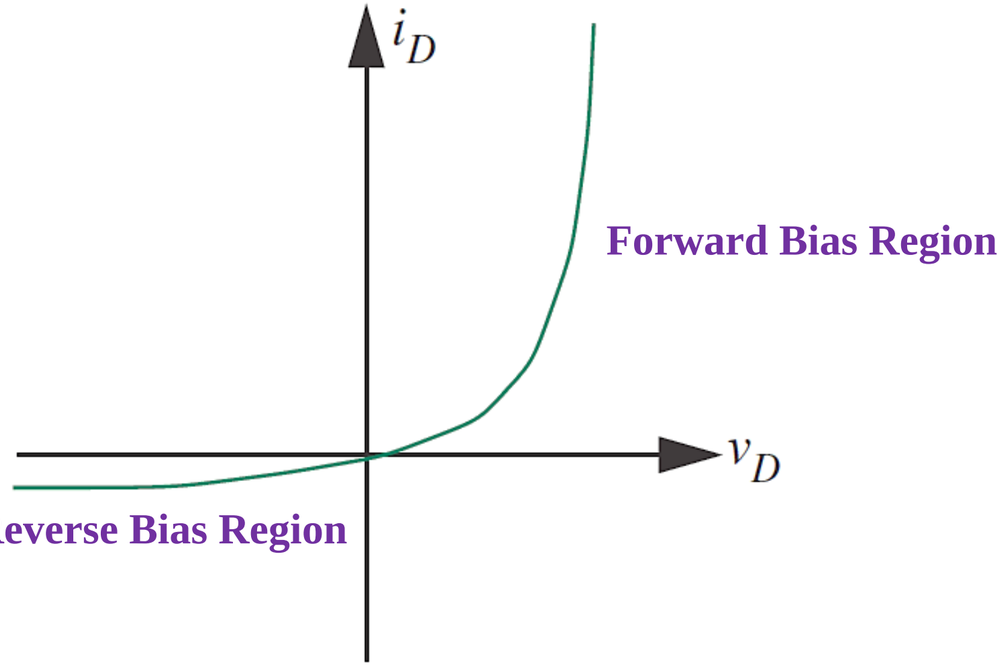


Tunnel Diode

Diode Models

❖Exact Model





$$i_D = I_s(e^{v_D/v_T} - 1)$$

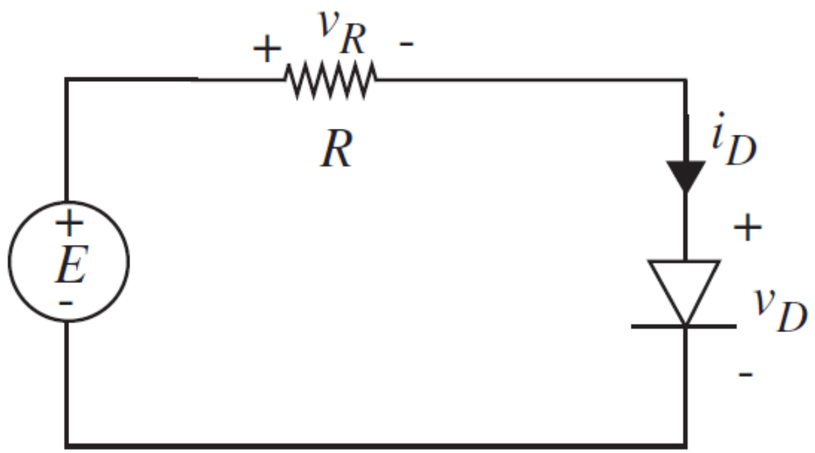
Saturation Current ≈ 10^{-12}

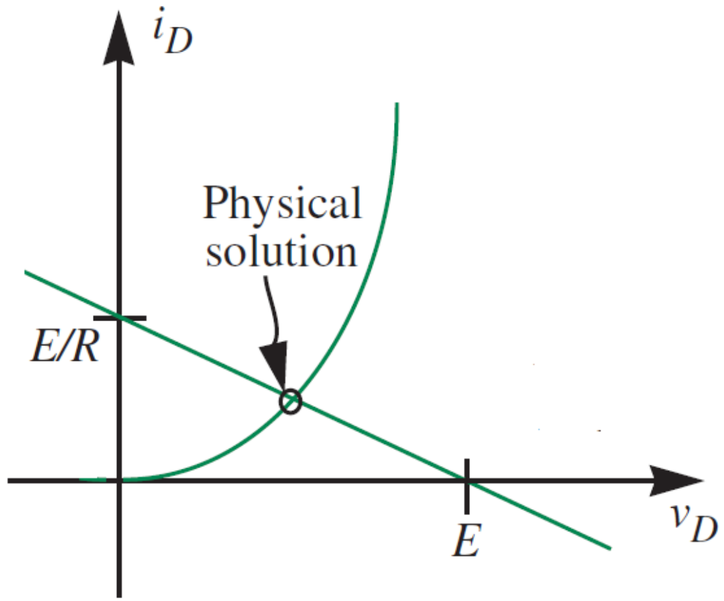
Thermal Voltage ≈ 25mv

Example

- Find the values of iD and vD.

  By applying Kirchhoff's Voltage Law (KVL), we have:





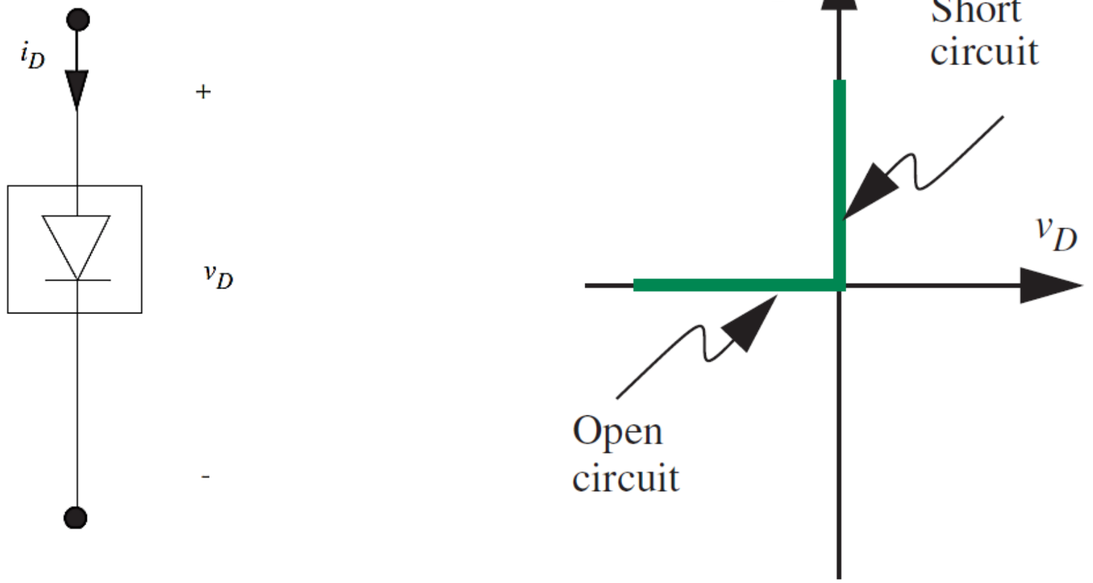
$$-E + Ri_D + v_D = 0$$

$$i_D = I_s(e^{v_D/v_T} - 1)$$

- ✓ The exact model complicates the analysis.
- ✓ Simpler models are needed.

Diode Models

- Ideal Model



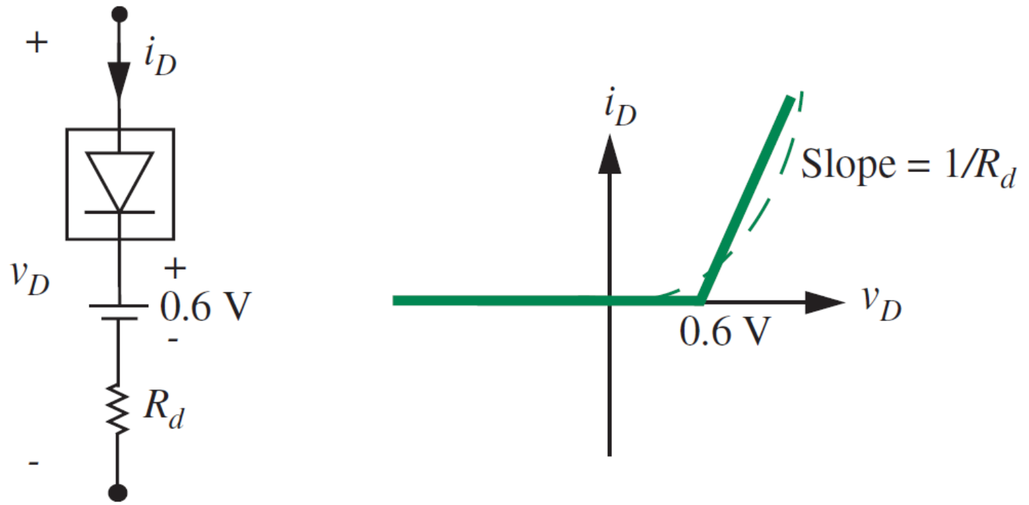
✓The diode is always in one of the two following states:

✓**On**: $(v_D = 0, i_D > 0)$ In this case, the diode behaves as a short circuit.

✓**Off**: $(i_D = 0, v_D < 0)$ In this case, the diode behaves as an open circuit.

Diode Models

➢Piecewise Linear



Threshold Voltage (v_{TH})

- ✓ The diode is always in one of the two following states:
- ✓ **On**: $v_D = RdiD + 0.6, \quad v_D > 0.6\,, \quad i_D > 0$
- ✓ **Off**: $i_D = 0, \quad v_D < 0.6$

Analysis of Diode Circuits

❖ Hypothetical Method

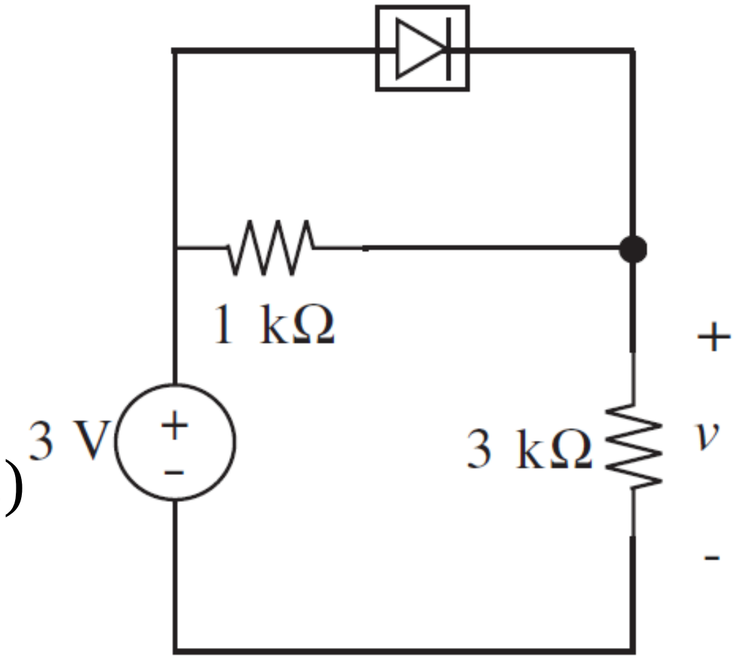
1. **For each diode, assume it is either on or off.**
   - ✓ For each assumption, draw the corresponding circuit (there will be 2^N possible states for N diodes).
2. **Analyze one of the circuits**:
   - ✓ Select one circuit and perform the analysis based on the given assumptions.
3. **Check the validity of assumptions**:
   - ✓ If the diode is assumed to be off, its voltage should be negative.
   - ✓ If the diode is assumed to be on, its current should be positive.
4. **Final verification**:
   - ✓ If all assumptions are correct, the analysis is complete.
   - ✓ If any assumption is incorrect, revisit and check the assumption again (repeat step 2).

Example 1

Assume the Diode is Ideal, Find the Voltage v

Assume the Diode is Off (Open Circuit)

- ✓ $i_D = 0,\ v_D < 0$
- ✓ $v_D = 0.75V$ (The diode voltage is positive. **Contradiction!**)

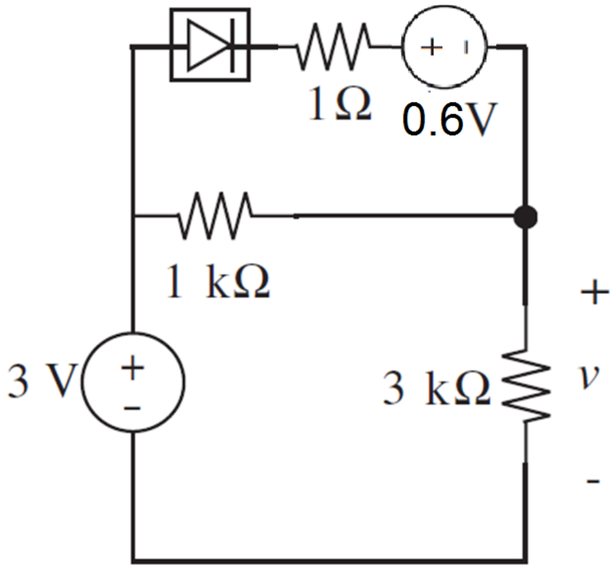


Assume the Diode is On (Short Circuit)

- ✓ $v_D = 0,\ i_D > 0$
- ✓ $i_D = 1mA \rightarrow v = 3V$ (The diode current is positive. **Correct.**)

Example 2

Assuming a piecewise-linear model, determine the voltage v.



- ✓ $R_d = 1,\ v_{TH} = 0.6$

Assume the diode is off (open circuit):

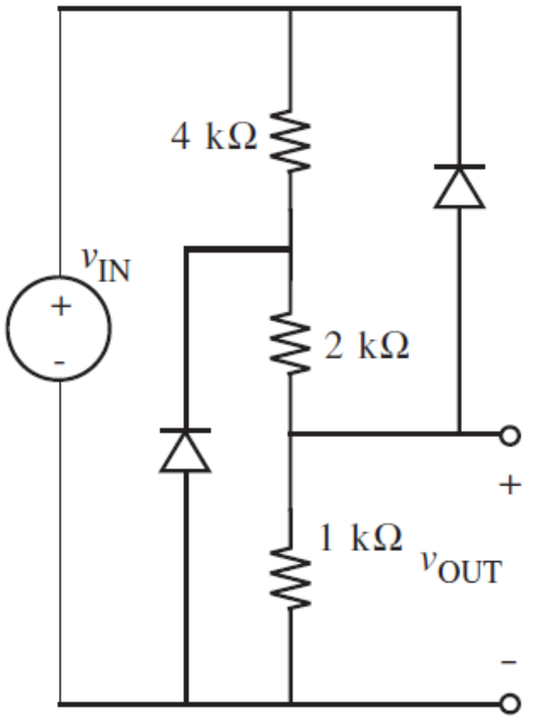
- ✓ $i_D = 0,\ v_D < 0.6$
- ✓ $v_D = 0.75V$ **(The diode voltage is positive. Contradiction!)**

Assume the diode is on (short circuit):

- ✓ $v_D = iD + 0.6,\ i_D > 0,\ v_D > 0.6$
- ✓ $i_D \approx 0.2mA \rightarrow v \approx 2.4V$ **(The diode current is positive. Correct.)**

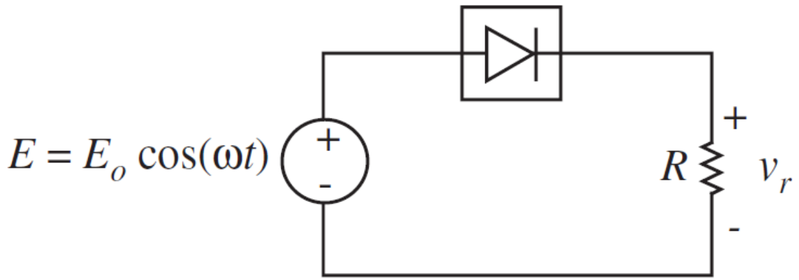
Example 3

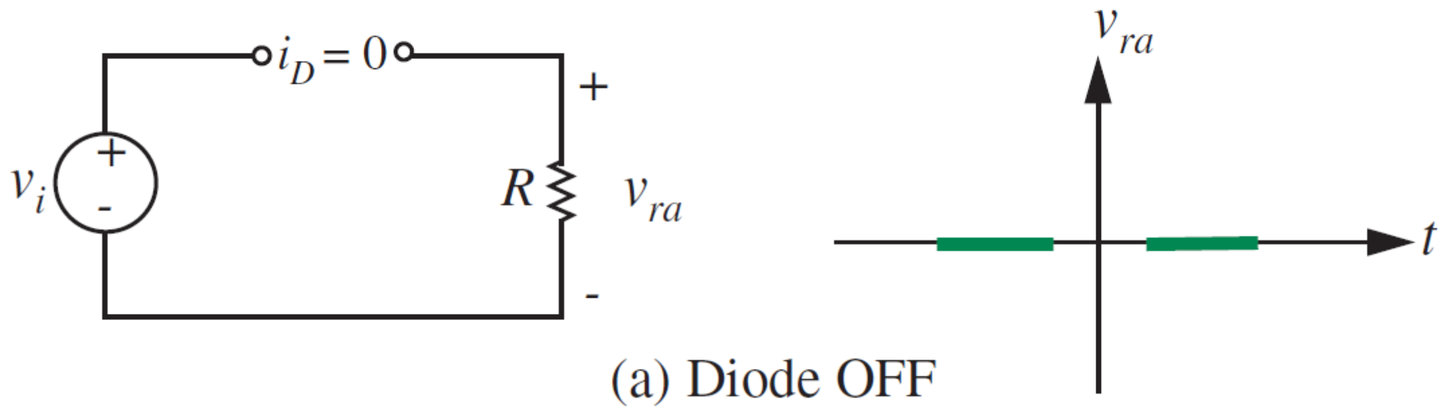
- Plot the output voltage v_{OUT} as a function of the input voltage v_{IN}.
- Four cases can be considered:
  - ✓ D_1 ON, D_2 ON
  - ✓ D_1 ON, D_2 OFF
  - ✓ D_1 OFF, D_2 ON
  - ✓ D_1 OFF, D_2 OFF
- Can you guess the correct case?
  - ✓ If $v_{IN} > 0$
  - ✓ If $v_{IN} < 0$



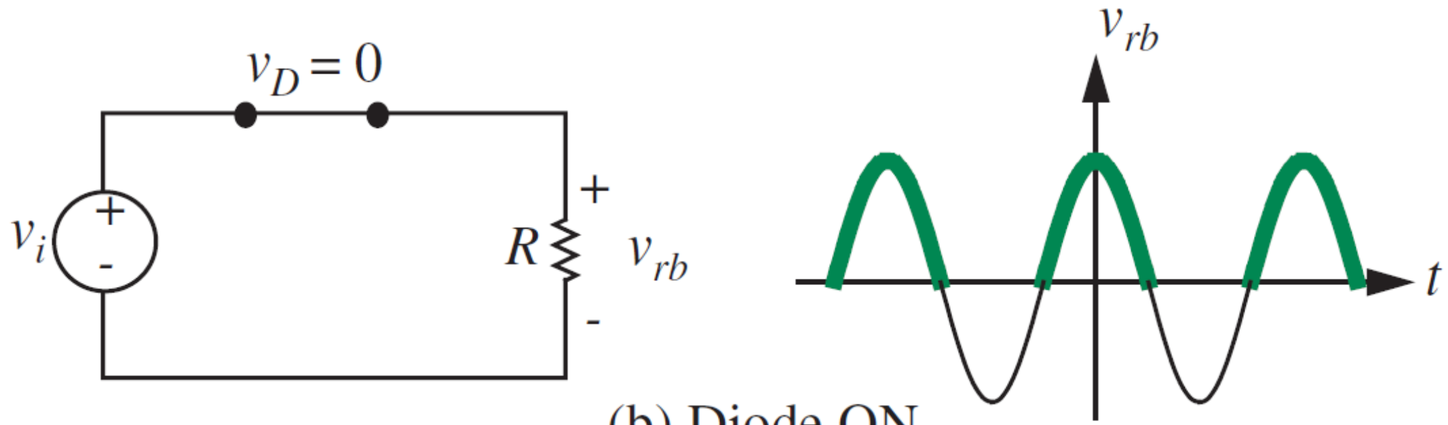
Example 4

- Rectifier

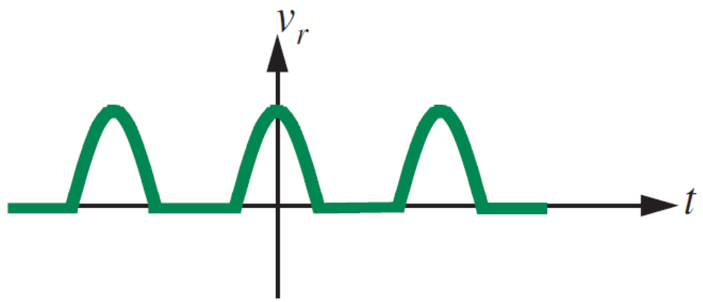




(a) Diode OFF

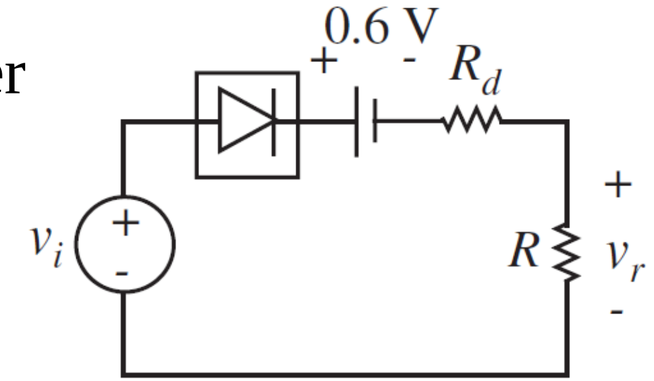


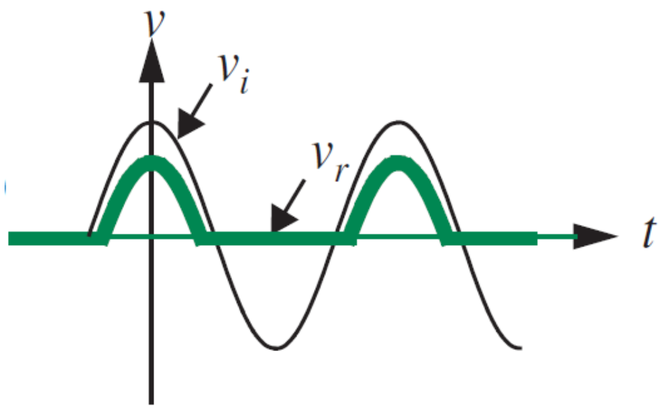
(b) Diode ON

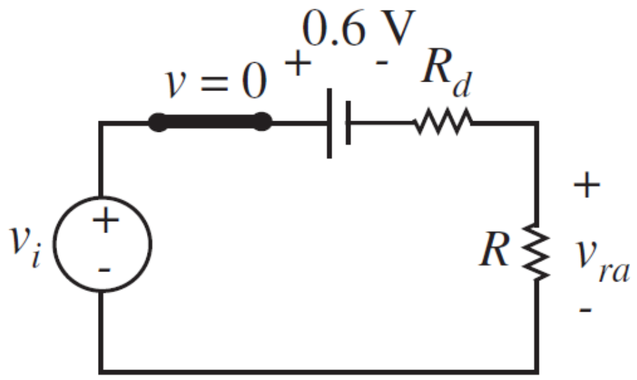


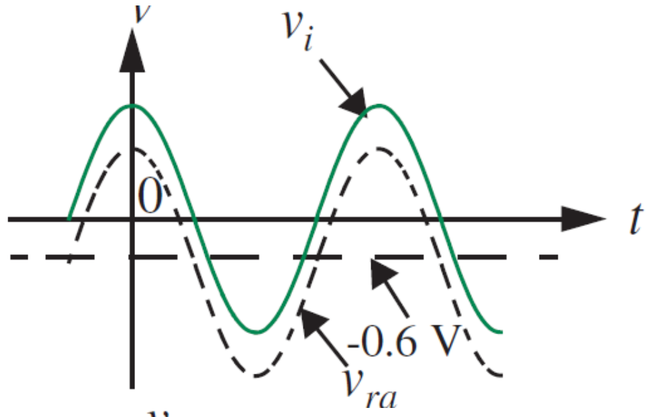
Example 5

- Rectifier



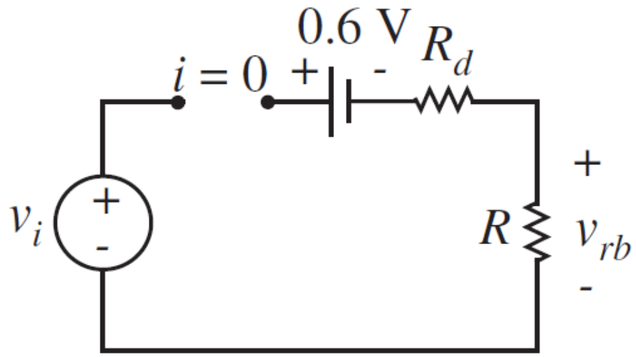


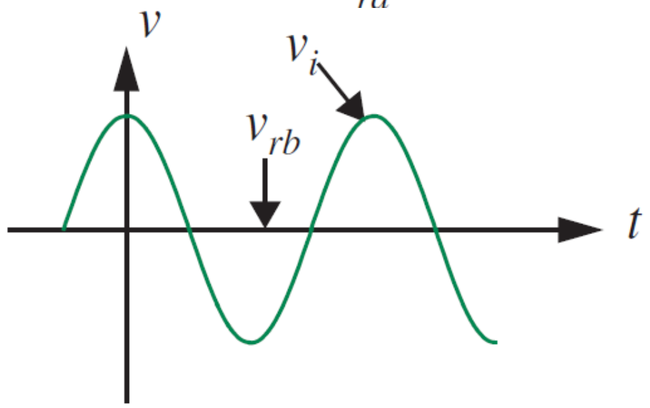




$$v_r = (v_i - 0.6)\frac{R}{R + R_d}$$

for $v_i > 0.6$



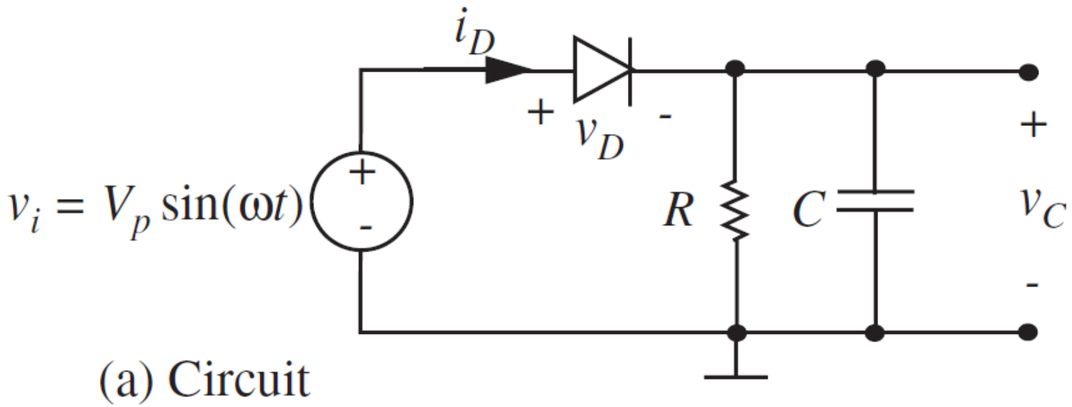


$$v_r = 0$$

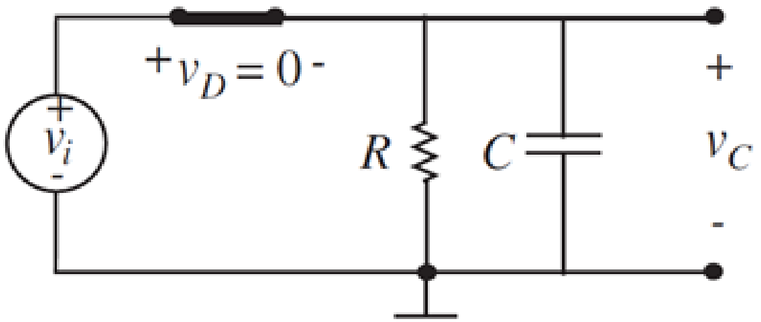
for $v_i < 0.6$

Example 6

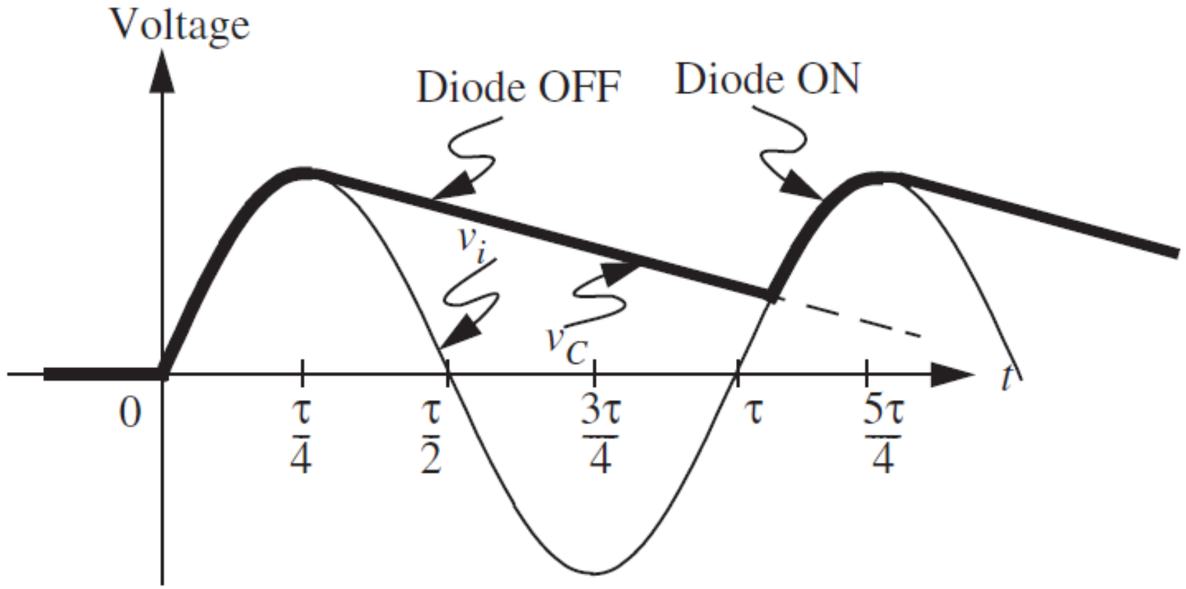
- Peak detector

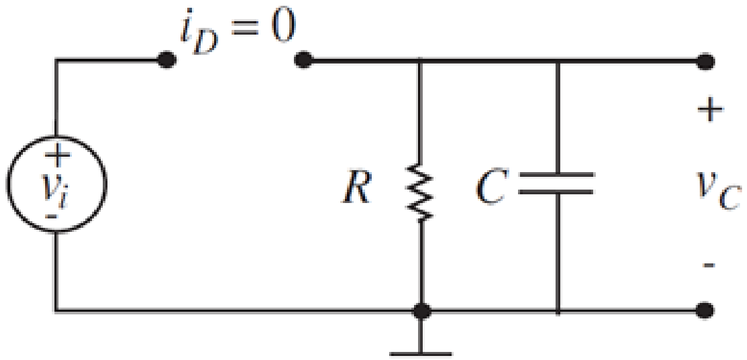


(a) Circuit



$$v_C = v_i$$



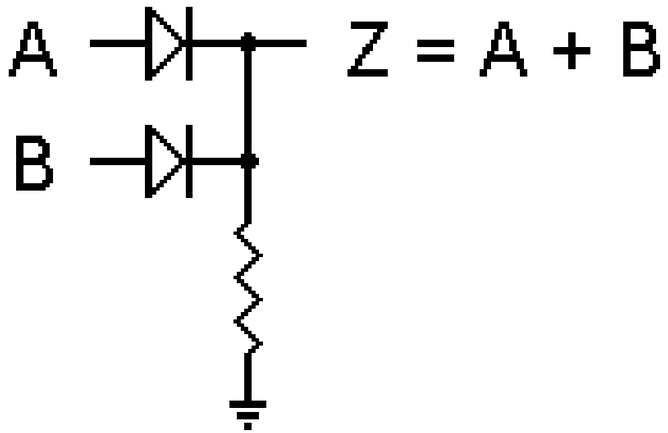


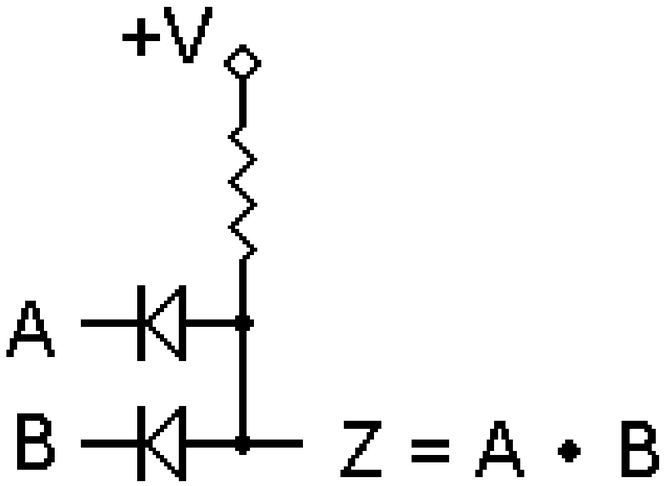
$$v_C = Ke^{-t/RC}$$

$$v_C = V_p e^{-(t-\tau/4)/RC}$$

Example 7

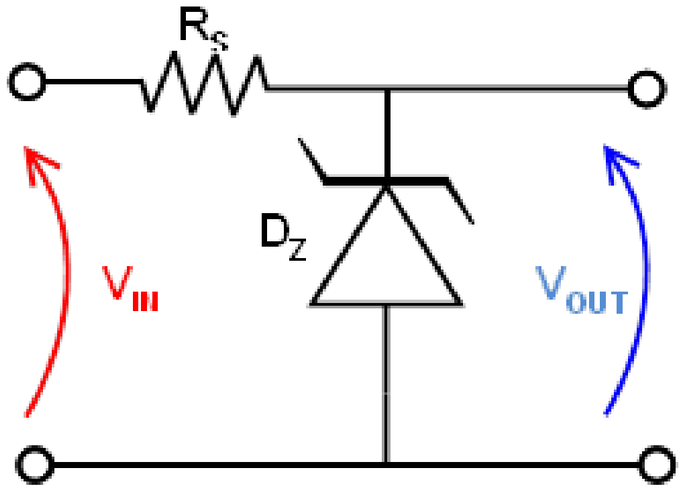
- Analyze the functionality of the following circuits.





Example 8

- In the circuit below, the threshold voltage of the Zener diode is -6 volts. Plot the output voltage v_{OUT} as a function of v_{IN}.



Thanks