EE-110 – Basic Electronics

Lecture #2

Diodes

Subtopics

1.0 Semiconductor diodes (3 hours)

1.1 Introduction to semiconductors materials

1.2 Introduction to diode

1.3 Introduction to Zener diode and LED

2.0 Diode applications (6 hours)

2.1 Load line analysis and diode approximation

2.2 Series-Parallel Configuration

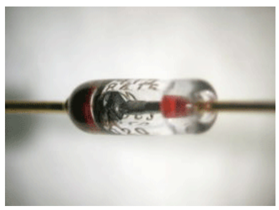
2.3 Half-wave and Full-wave rectification

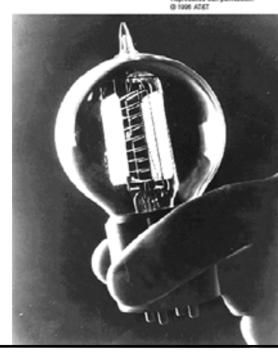
2.4 Clippers and Clampers

2.5 Zener diode application

Early Diodes

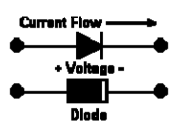
- Thermionic diodes are thermionic valve devices (also known as vacuum tubes)
- Electrodes surrounded by a vacuum within a glass envelope, similar in appearance to incandescent light bulbs.





Semiconductor Diodes

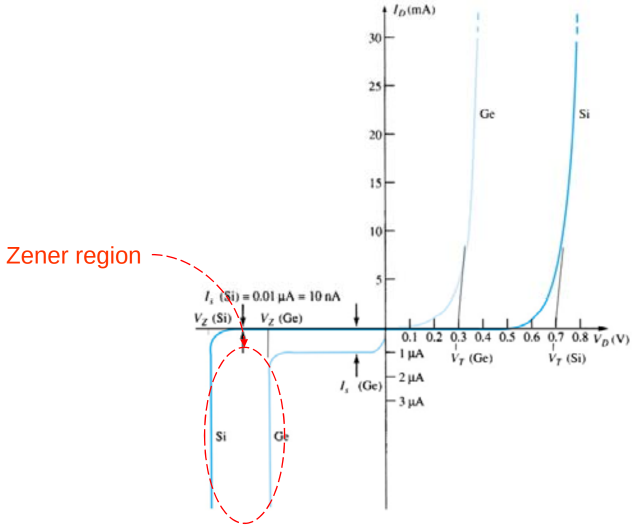
- Most modern diodes are based on semiconductor p-n junctions
- In a p-n diode, conventional current can flow from the p-type side (the anode) to the n-type side (the cathode), but cannot flow in the opposite direction.



Diode symbol

Semiconductor Diodes

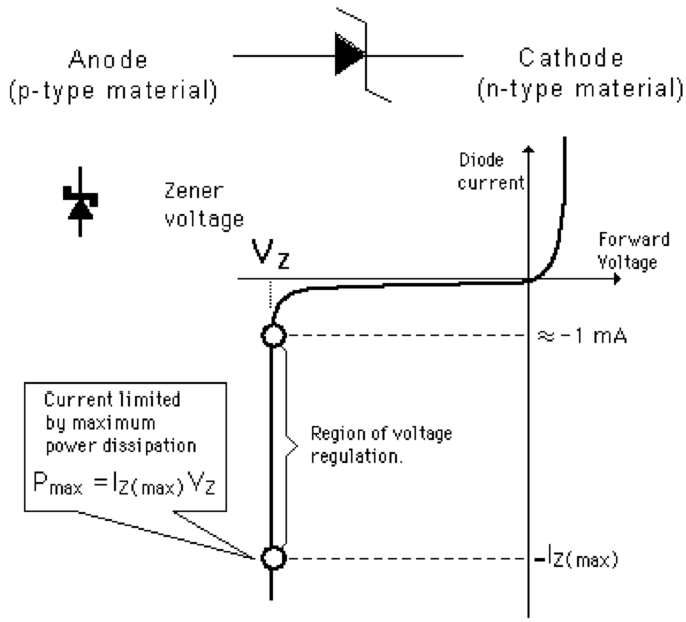
- Comparison of Ge, Si and GaAs diodes



Zener Diode

- A special type of diode that is supposed to be reversed biased
- Zener diode works in zener region where the diode start to breakdown at breakdown avalanche voltage (VZ), and the current is avalanche current (IZ)
- It limits a voltage to a certain point to pass through the zener diode

Zener Diode

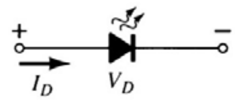


LED (Light-Emitting Diode)

- In a forward-biased p-n junction, recombination of the holes and electrons requires energy possessed by the unbound free electrons
- In Si and Ge, most of the energy is dissipated in the form of heat and photons
- But in other material such as GaAs, the energy generate light but it is invisible for the eye to see (infrared)
- Other materials that emit light during forward-bias operation

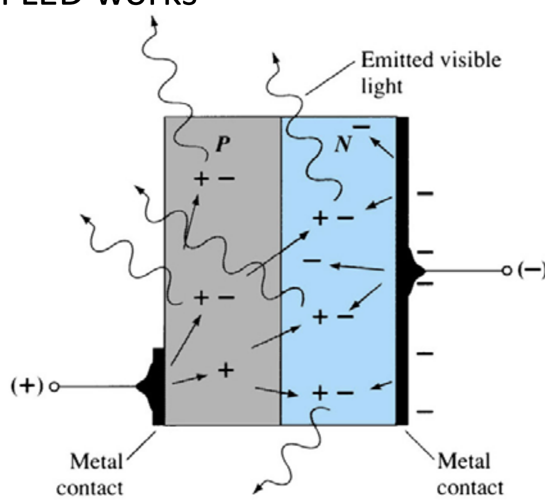
LED (Light-Emitting Diode)

Color	Construction	Forward Voltage
Amber	AlInGaP	2.1
Blue	GaN	5.0
Green	GaP	2.2
Orange	GaAsP	2.0
Red	GaAsP	1.8
White	GaN	4.1
Yellow	AlInGaP	2.1



LED (Light-Emitting Diode)

- How an LED works

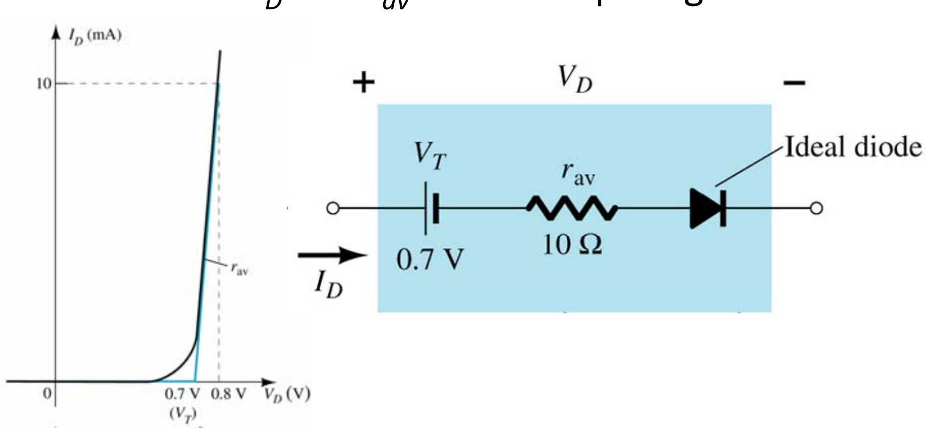


Diode Approximation

- Diode equivalent circuits:
  - Ideal Equivalent Circuit
  - Simplified Equivalent Circuit
  - Piecewise-Linear Equivalent Circuit
- Purpose: to represent diode

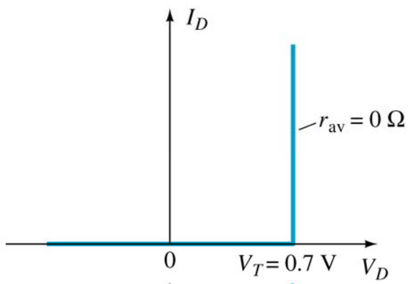
Piecewise-Linear Equivalent Circuit

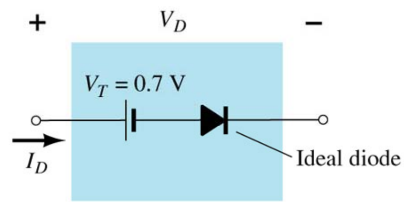
- Approximation representation of the actual diode
- Diode have V_D and r_{av} for the slope region



Simplified Equivalent Circuit

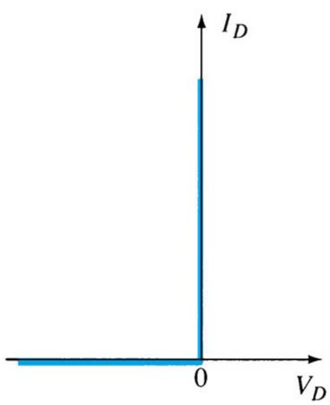
- Assume straight vertical line of I_D at V_D
- No r_{av}

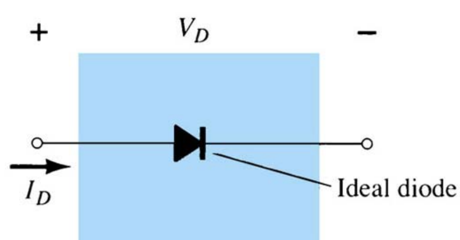




Ideal Equivalent Circuit

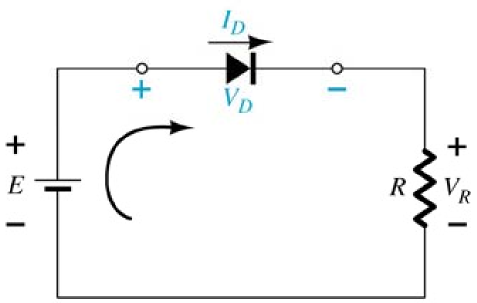
- Diode as an ideal switch
- No V_D or r_{av}

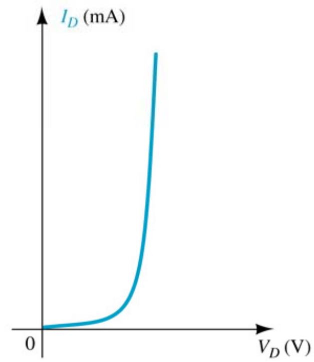




Load-Line Analysis

- A simple analysis which used the diode characteristic to obtain the Q-point (operation point)
- A series diode circuit and characteristic:

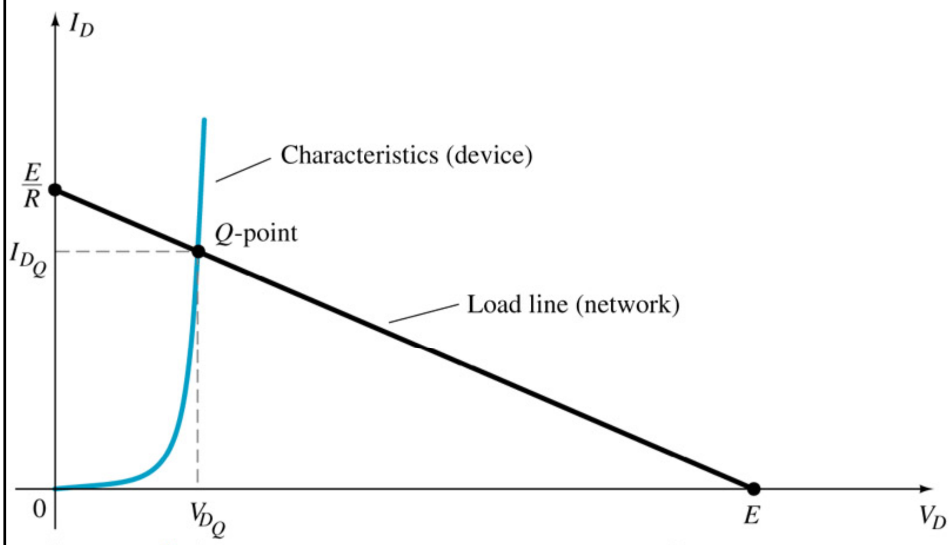




Load-Line Analysis

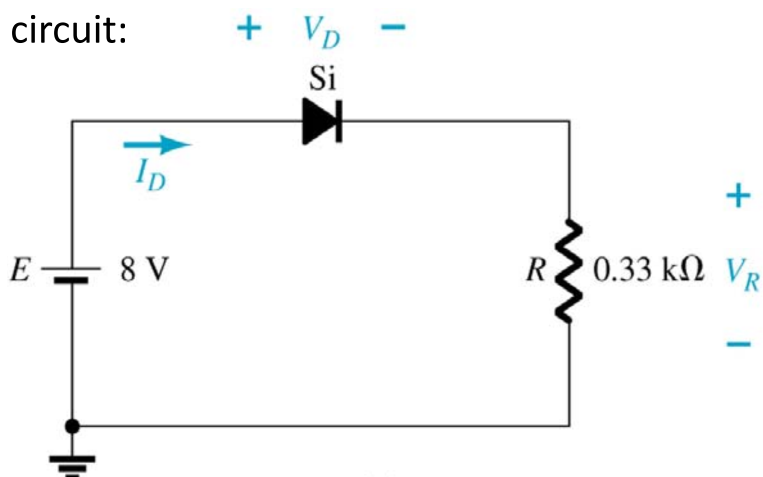
- $E = V_D + V_R = V_D + I_R$
- For $V_D = 0, \quad E = 0 + I_D R = I_D R, \quad \therefore I_D = E/R$
- For $I_D = 0, \quad E = V_D + (0)R = V_D, \quad \therefore V_D = E$
- Connect a line between E / R and E
- The overlap of the lines becomes the Q-point of the diode and I_{DQ} and V_{DQ} will be obtained

Load-Line Analysis



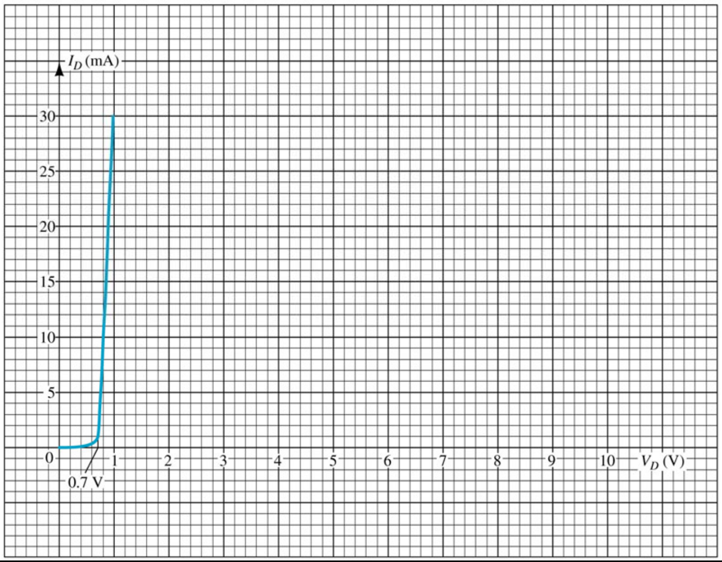
Problem 2.1a

- Determine I_D, V_D & V_R
- The circuit:



Problem 2.1a

- The diode characteristic:



Problem 2.1a

- Solution:
  - The circuit representation:
  - For

$$E = V_D + V_R = V_D + I_D R$$

$$V_D = 0, \quad E = 0 + I_D R$$

$$\therefore I_D = E/R = 8/0.33k = 24.24\ \text{mA}$$

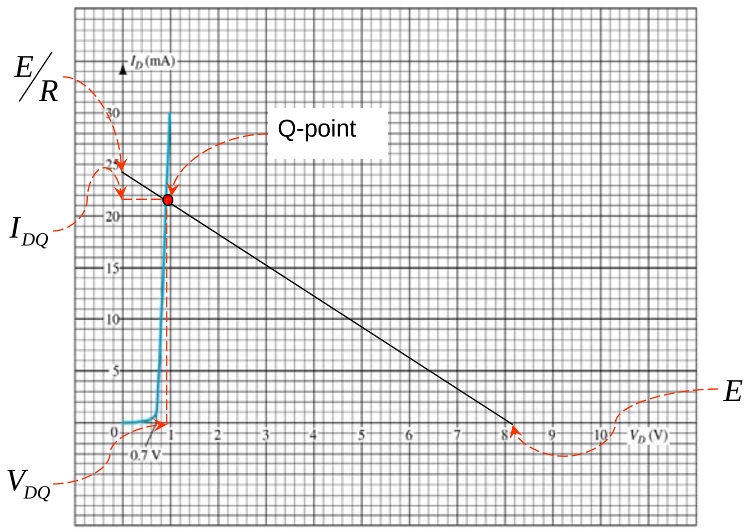
  - For

$$I_D = 0, \quad E = V_D + (0)R$$

$$\therefore V_D = E = 8\ \text{V}$$

Problem 2.1a

- The load-line analysis becomes:



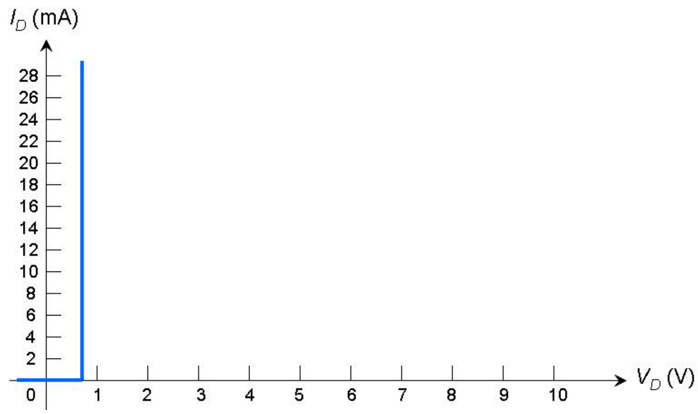
Problem 2.1a

- From the analysis:
  - $V_{DQ} = V_D \approx 0.9$ V
  - $I_{DQ} = I_D \approx 21.5$ mA
  - For V_R

$$\begin{aligned} V_R &= I_D R \\ &= (21.5m)(0.33k) \\ &= 7.095\text{ V} \end{aligned}$$

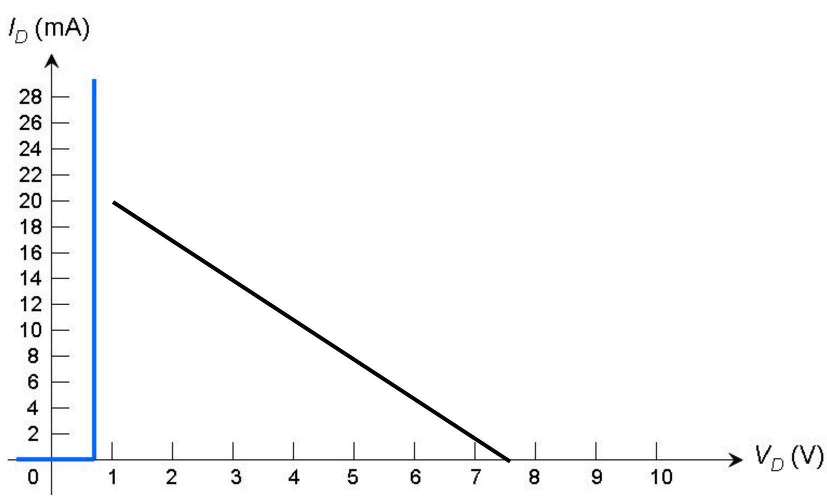
Problem 2.1b

- Re-do Problem 2.1a using approximate (simplified) model for diode and compare the result
- The diode characteristic becomes:



Problem 2.1b

- The solution:



Problem 2.1b

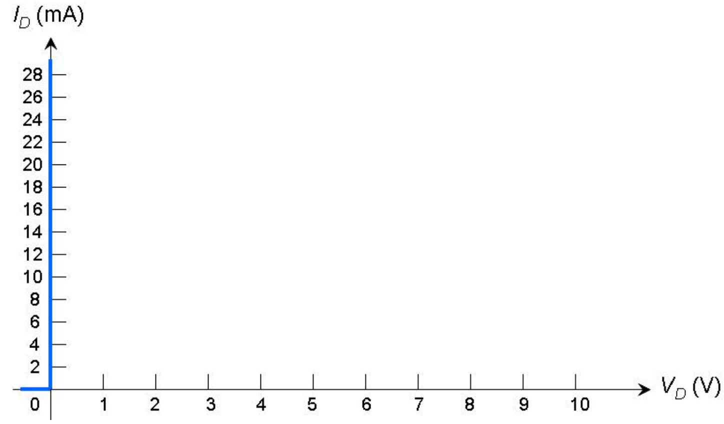
- VD is always 0.7 V, so VD = VDQ = 0.7 V
- From the graph, IDQ = ID ≈ 22 mA
- So, we get VR = (22m)(0.33k) = 7.26 V ≈ 7.3 V
- Using Kirchoff's voltage law, E = VD + VR

$$8 = 0.7 + V_R$$
$$\therefore V_R = 7.3\ \mathrm{V}$$

- The answer are the same

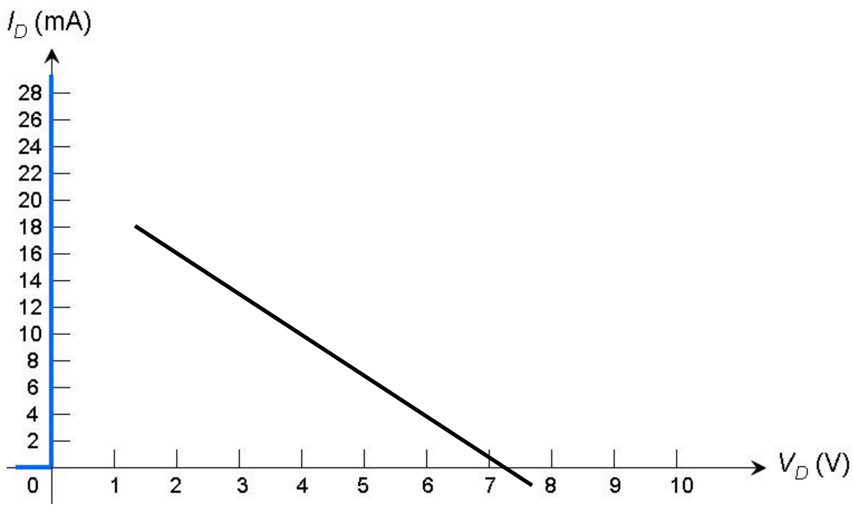
Problem 2.1c

- Re-do Problem 2.1a using ideal model for diode and compare the result
- The diode characteristic becomes:



Problem 2.1c

- The solution



Problem 2.1c

- VD is always 0 V, so VD = VDQ = 0 V
- It acts like an ideal switch
- From the graph, IDQ = ID ≈ 24.24 mA
- So, we get VR = (24.24m)(0.33k) = 7.9992 V ≈ 8 V
- Using Kirchoff's voltage law, E = VR
- The answer are the same

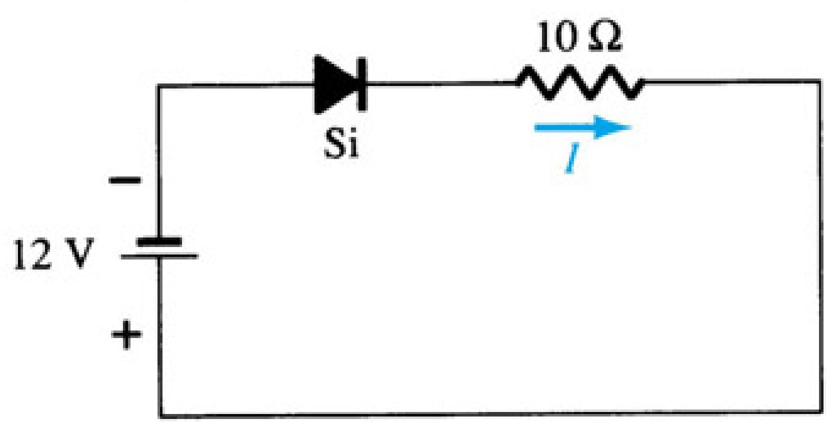
$$\therefore V_R = 8\text{ V}$$

Series-Parallel Configuration

- Diode can be applied to any circuits
- Usually diode is represented as an approximated (simplified) model diode
- To keep the calculation simple, just use the Kirchoff's voltage & current law
- Hint: it is easier to use nodal analysis technique for circuit representation
- Important: strong knowledge in CIRCUIT THEORY!!!!!

Problem 2.5a

- Find *I*
- The circuit:

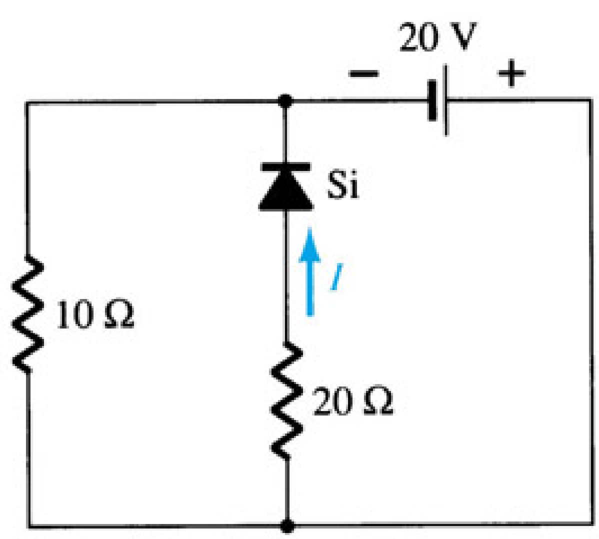


Problem 2.5a

- For Si, V_D = 0.7 V
- Notice that the diode is in reverse-bias configuration
- So, no current will flow, I = 0 A

Problem 2.5b

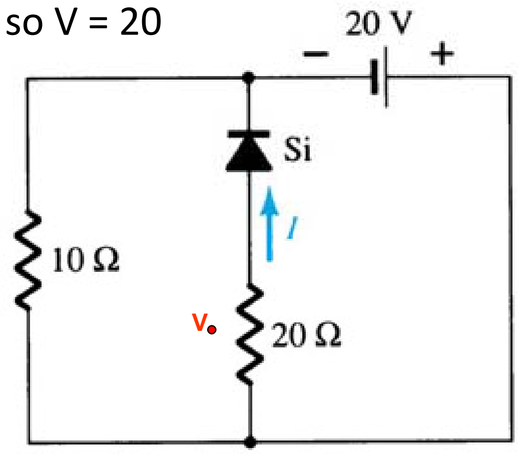
- Find I
- The circuit:



Problem 2.5b

Solution:

- Using nodal analysis, node V is equal to the voltage supplied, so V = 20



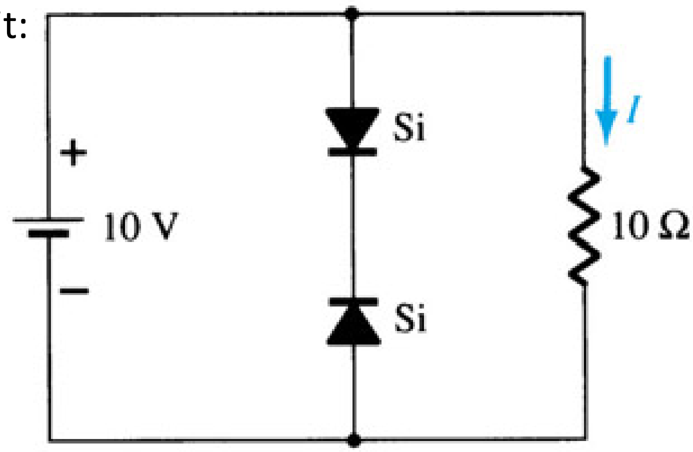
Problem 2.5b

- Using the simple Ohm's law:

$$I = \frac{V}{R} = \frac{20 - 0.7}{20} = 0.965\ \text{A}$$

Problem 2.5c

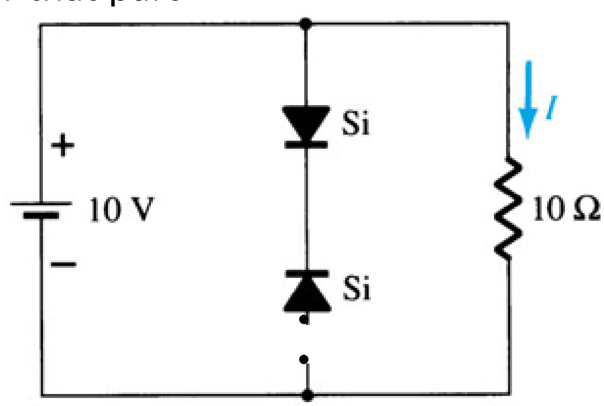
- Find *I*
- The circuit:



Problem 2.5c

Solution:

- One of the diode is in reverse-bias resulting in open circuit for that part



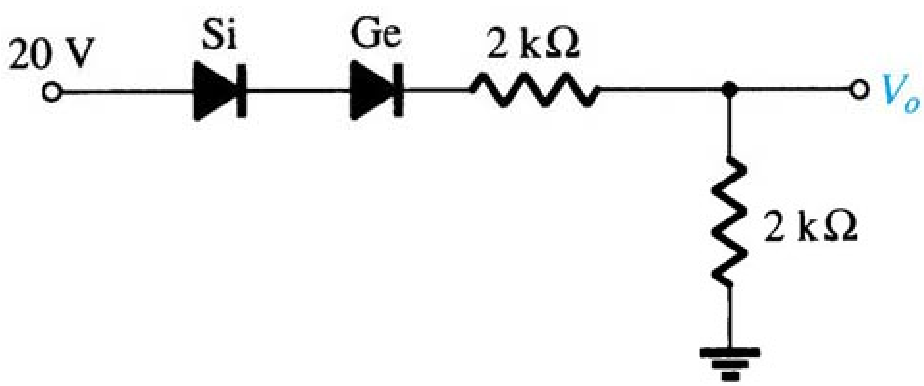
Problem 2.5c

- So, by using the simple Ohm's law:

$$I = \frac{V}{R} = \frac{10}{10} = 1\,\text{A}$$

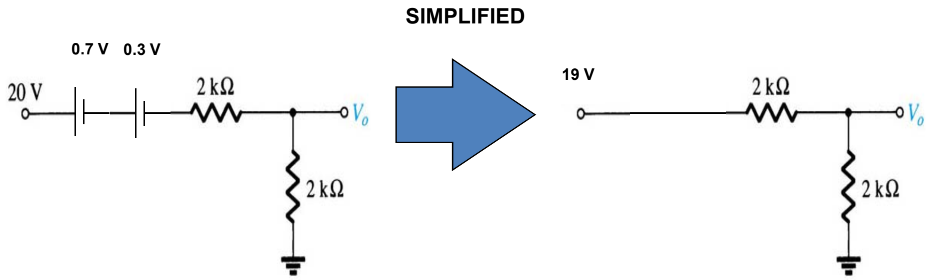
Problem 2.7a

- Find V_o
- The circuit:



Problem 2.7a

- Both the diode are in forward-bias, so both are short-circuited
- For Si, VD = 0.7 V
- For Ge, VD = 0.3 V
- The circuit becomes:



Problem 2.7a

Solution:

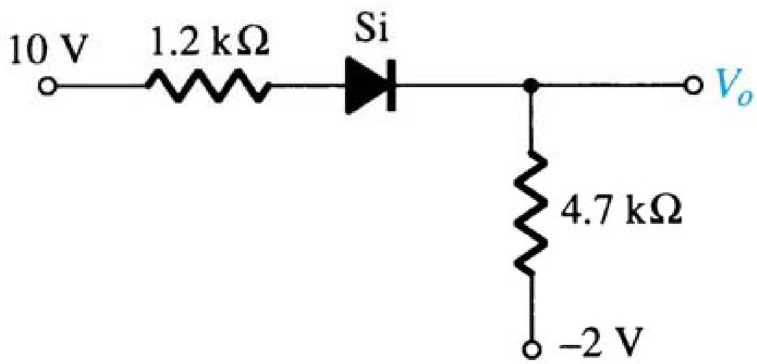
- Using nodal analysis, voltage at Vo:

$$\frac{19 - V_0}{2k} = \frac{V_0}{2k}$$

$$\therefore V_0 = 9.5 \text{ V}$$

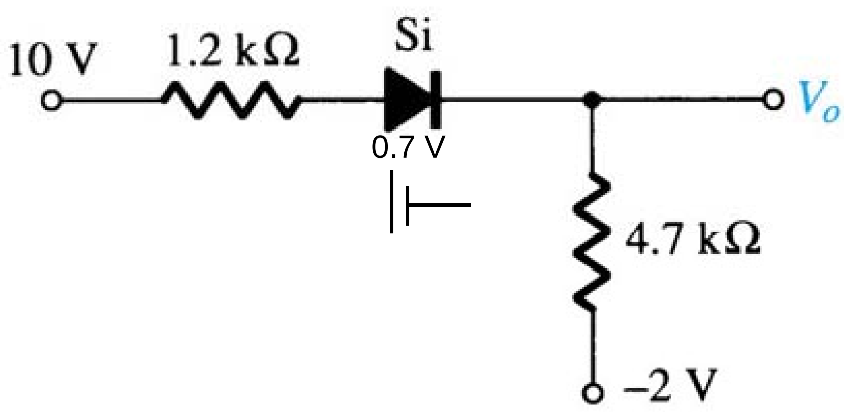
Problem 2.7b

- Find V_o
- The circuit:



Problem 2.7b

- The circuit becomes:



Problem 2.7b

Solution:

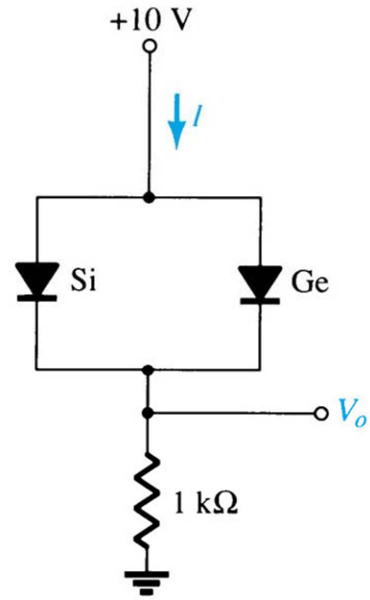
- The nodal analysis of node Vo:

$$\frac{10-0.7-V_0}{1.2k}=\frac{V_0-(-2)}{4.7k}$$

$$\therefore V_0 = 7\text{ V}$$

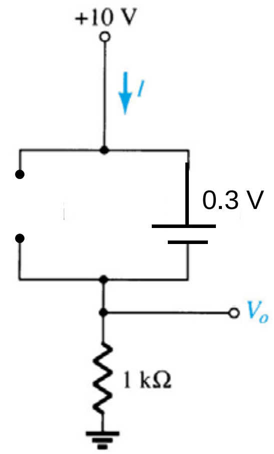
Problem 2.11a

- Find V_o & I:
- The circuit:



Problem 2.11a

- For Si, V_D = 0.7 V
- For Ge, V_D = 0.3 V
- Because of this, current will flow in the Ge's diode route
- Naturally, current will select the easiest/fastest route
- So, the circuit becomes:



Problem 2.11a

Solution:

- Using Kirchoff's voltage law:

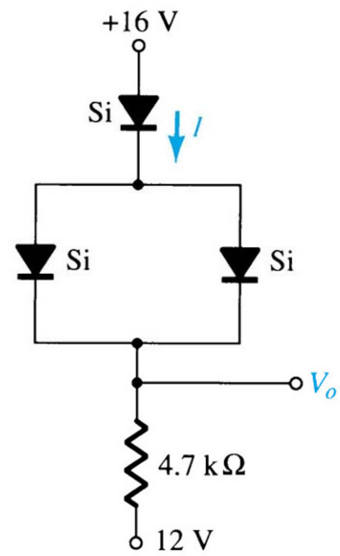
$$V_0 = 10 - 0.3 = 9.7 \text{ V}$$

- For *I*, by using basic Ohm's law:

$$I = \frac{V_0}{R} = \frac{9.7}{1k} = 9.7 \text{ mA}$$

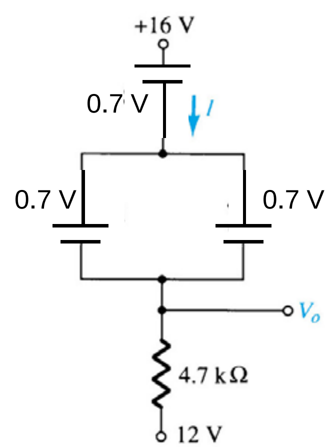
Problem 2.11b

- Find V_o & I:
- The circuit:



Problem 2.11b

- For the same type of diode, the circuit will becomes:
- Because there is no resistor exist in the parallel route of the diode, current will flow in only one of the diode's route



Problem 2.11b

Solution:

- Using Kirchoff's voltage law:

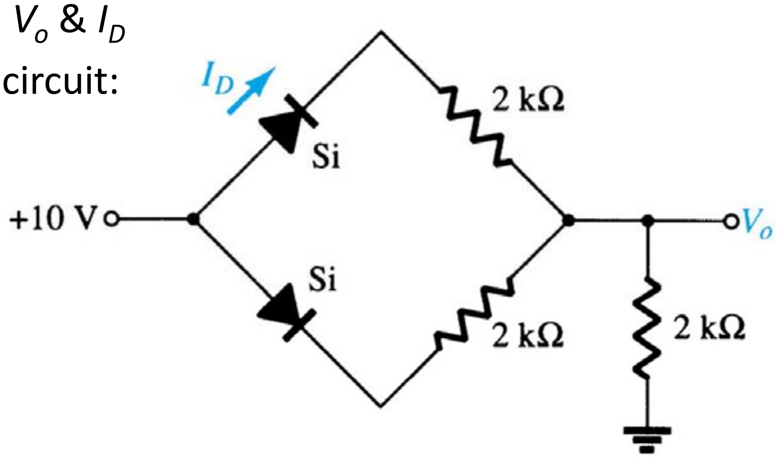
$$V_0 = 16 - 0.7 - 0.7 = 14.6\text{ V}$$

- For I, by using Ohm's law:

$$I = \frac{14.6 - 12}{4.7k} = 0.553\,\text{mA}$$

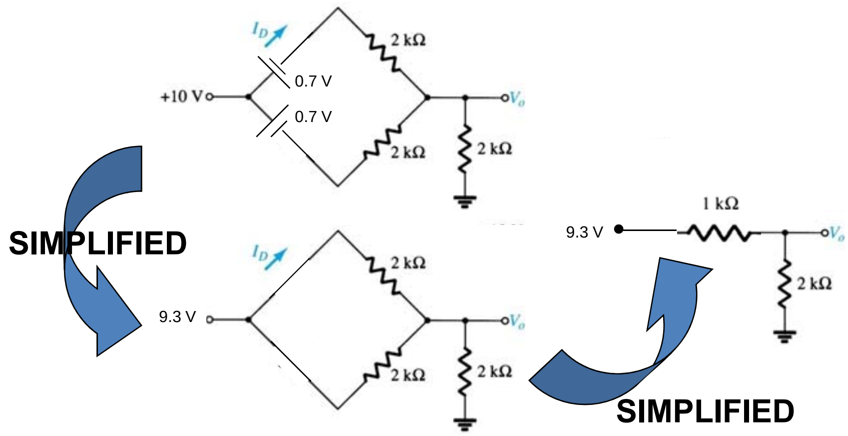
Problem 2.13

- Find V_o & I_D
- The circuit:



Problem 2.13

- The circuit becomes:



Problem 2.13

Solution:

- The nodal analysis for node Vo:

$$\frac{9.3 - V_0}{1k} = \frac{V_0}{2k}$$

$$\therefore V_0 = 6.2\ \text{V}$$

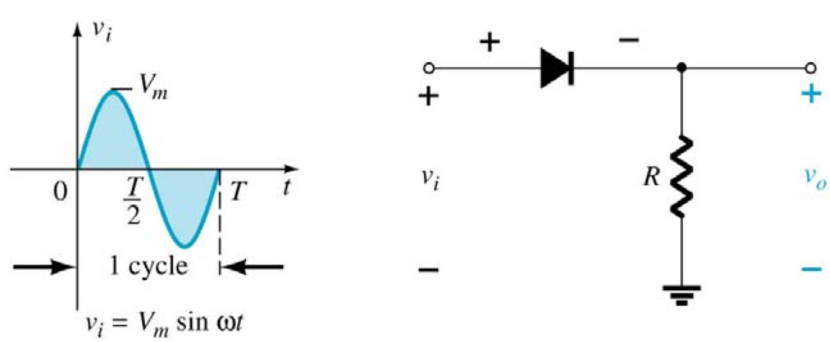
- For ID: $$I_D = \frac{9.3 - 6.2}{2k} = 1.55\ \text{mA}$$

Rectification

- Rectify means improvement, cure healing (pembaikan, penambahbaikan)
- For a sinusoidal waveform or any supply that has a variation of input value, diode can be used for rectification
- Rectification are used to modified the input value to become only the signal that we want

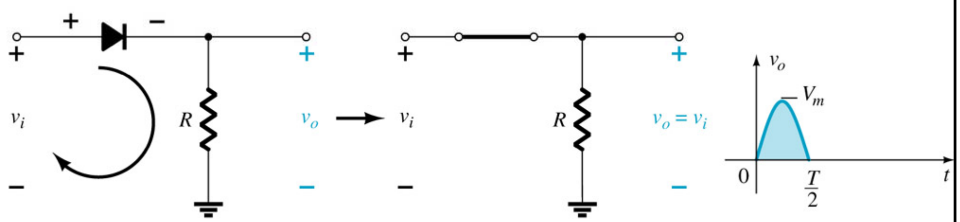
Half-Wave Rectification

- For a full cycle of a sinusoidal or continuous waveform, only half of the waveform is taken to be rectified



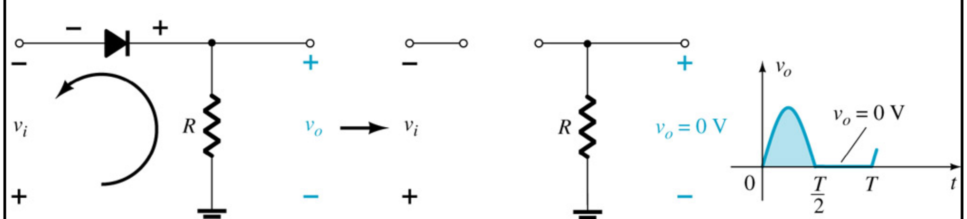
Half-Wave Rectification

- For the period 0 → T/2, the sinusoidal input will give a forward bias supply to the circuit
- The diode will "on" and current will pass through
- Assume that the diode is ideal



Half-Wave Rectification

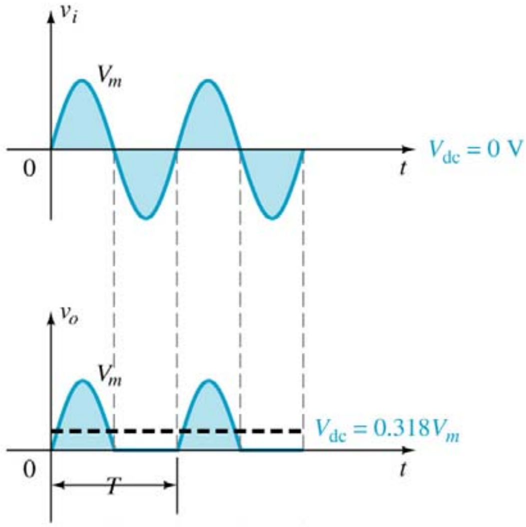
- For the period T/2 → T, the sinusoidal input will give a reverse bias supply to the circuit
- The diode will "off" and no current can pass through
- Assume that the diode is ideal



Half-Wave Rectification

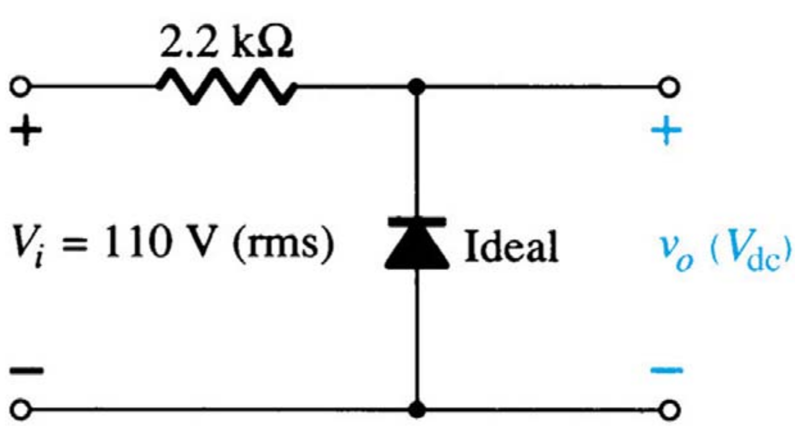
- For a continuous periodic waveform, the rectified waveform will become:
- Where as:

$$V_{dc} = 0.318V_m$$



Problem 2.25

- Sketch V_o and determine V_{dc}:



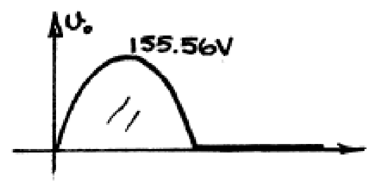
Problem 2.25

Solution:

- To obtain Vm from Vrms:

$$V_m = \sqrt{2}V_{rms}$$
$$= \sqrt{2}(110) = 155.56 \text{ V}$$

- The output Vo will be:

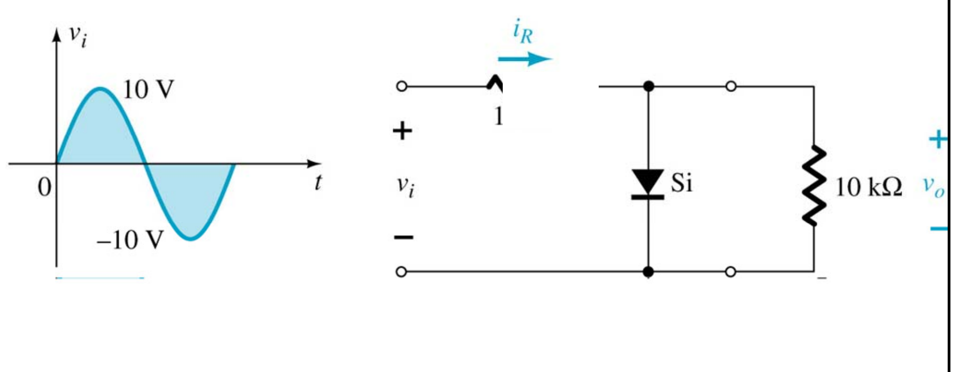


- Vdc will be: $V_{dc} = 0.318V_m$

$$= 0.318(155.56) = 49.47 \text{ V}$$

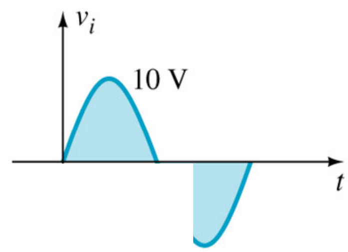
Problem 2.26

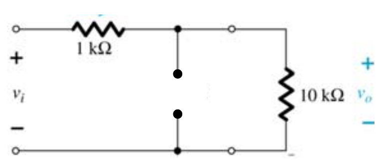
- Sketch V_o

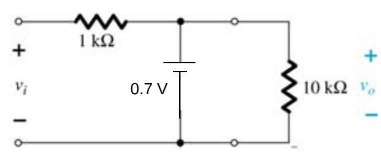


Problem 2.26

- Solution:
- For the positive input supply:
- The circuit becomes:
- For Vi < 0.7V:
  For Vi ≥ 0.7V:

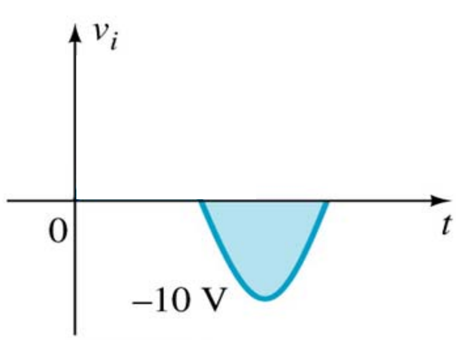


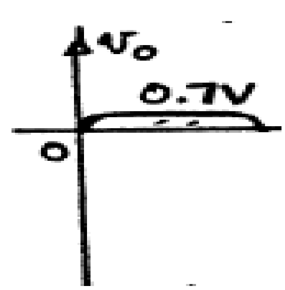




Problem 2.26

- The output for the positive input supply becomes:
- For the negative input supply:



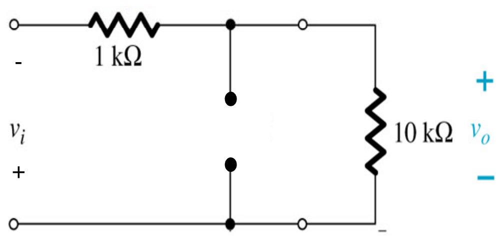


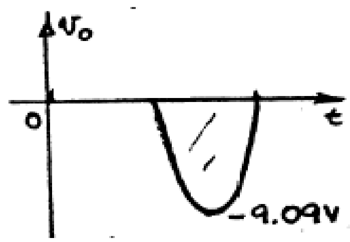
Problem 2.26

- The circuit becomes:
- For maximum Vo: The output becomes:

$$\frac{-10 - V_0}{1k} = \frac{V_0}{10k}$$

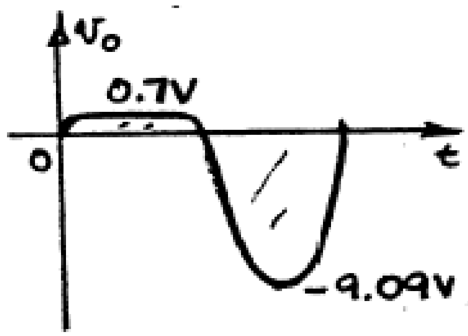
$$\therefore V_o = -9.091V$$





Problem 2.26

- Combine both the output becomes:



PIV or PRV

- Peak Inverse Voltage (PIV) or Peak Reverse Voltage (PRV)
- It is a rating to make sure for the reverse-bias operation, the diode didn't enter the Zener region
- PIV is set according to the circuit and the input voltage

$$\text{PIV rating} \geq V_m$$ for half-wave rectifier

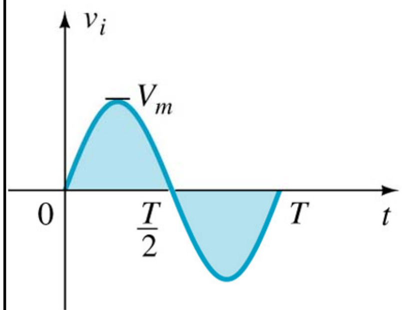
Full-Wave Rectification

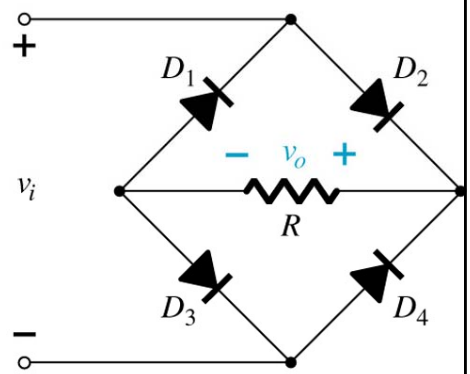
- The whole cycle of input signal is used and rectified
- Two commonly types of full-wave rectifier:
  - Bridge Network
  - Center-Tapped (CT) Transformer
- The dc level from a sinusoidal input can be improved 100%. So the V_{dc} becomes:

$$V_{dc} = 0.636V_m$$

Full-Wave Rectifier: Bridge Network

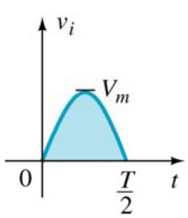
- The most commonly bridge network configuration are build with 4 diodes

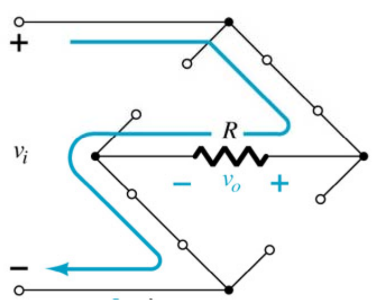


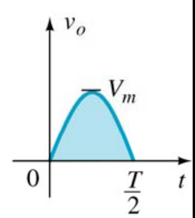


Full-Wave Rectifier: Bridge Network

- For the positive input supply, the current will take the route as shown below, and the output will becomes:

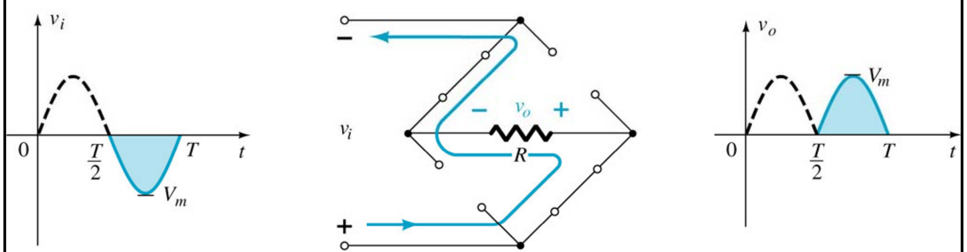






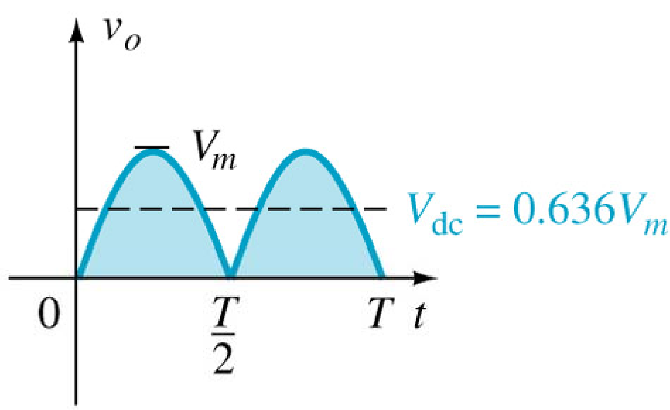
Full-Wave Rectifier: Bridge Network

- For the negative input supply, the current will take the route as shown below, and the output will becomes:



Full-Wave Rectifier: Bridge Network

- Combine both of the output becomes:



Full-Wave Rectifier: Bridge Network

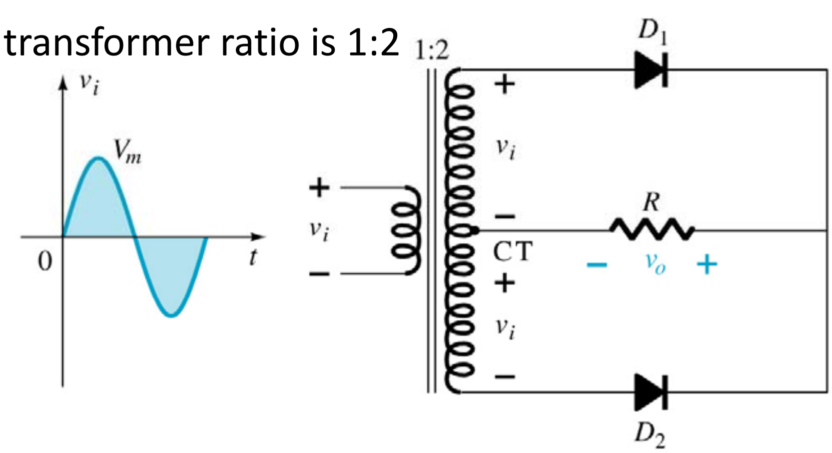
- Due to the maximum voltage from the input supply is V_m, to keep the diode away from the Zener region, the PIV rating is:

$$\text{PIV rating} \geq V_m$$

for full-wave rectifier: bridge network

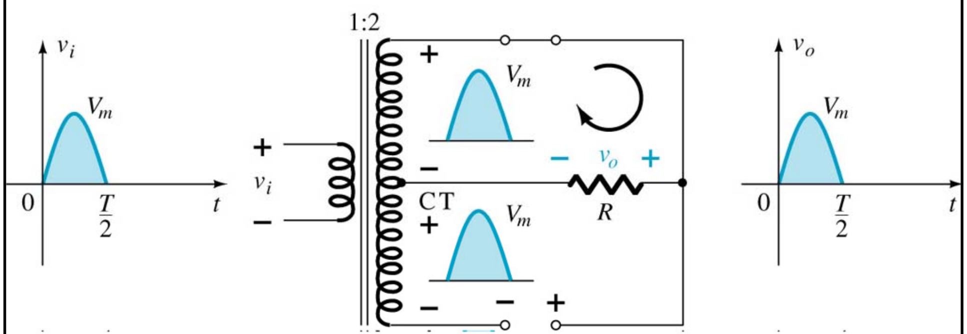
Full-Wave Rectifier: Center-Tapped (CT) Transformer

- It is constructed with 2 diodes and a center-tapped transformer
- The transformer ratio is 1:2



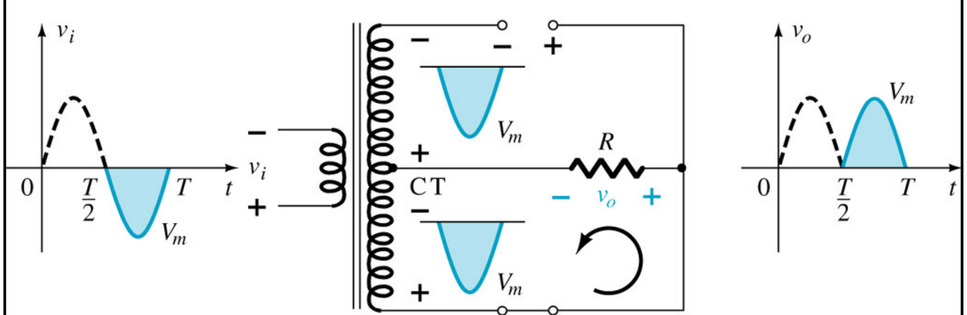
Full-Wave Rectifier: Center-Tapped (CT) Transformer

- For the positive input supply:



Full-Wave Rectifier: Center-Tapped (CT) Transformer

- For the negative input supply:



Problem 2.28

- The circuit: