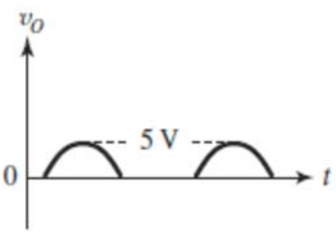
University of Southern California
Ming Hsieh Department of Electrical Engineering
EE 348L - Electronic Circuits
Spring 2016

Homework 3 Solutions

At the end of the chapter complete the following 12 problems: 4.4, ~~4.9~~, ~~4.10~~, ~~4.17~~, ~~4.20~~, 4.26, ~~4.27~~, ~~4.28~~, ~~4.59~~, ~~4.86~~, ~~4.87~~, and ~~4.90~~.

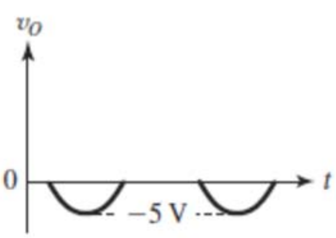
4.4

(a)



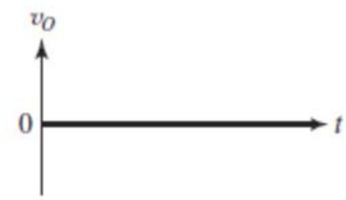
$V_{p^+} = 5$ V $\quad V_{p^-} = 0$ V $\quad f = 1$ kHz

(b)



$V_{p^+} = 0$ V $\quad V_{p^-} = -5$ V $\quad f = 1$ kHz

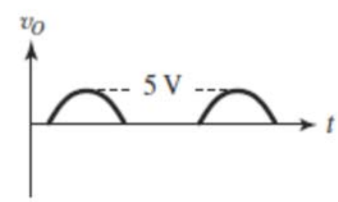
(c)



$v_O = 0$ V

Neither D_1 nor D_2 conducts, so there is no output.

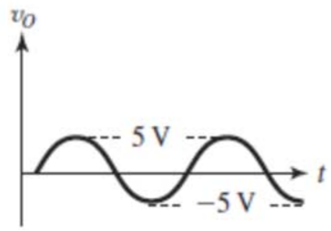
(d)



$V_{p^+} = 5$ V, $\quad V_{p^-} = 0$ V, $\quad f = 1$ kHz

Both D_1 and D_2 conduct when $v_I > 0$

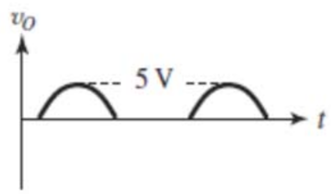
(e)



$V_{p^+} = 5\text{ V}, \quad V_{p^-} = -5\text{ V}, \quad f = 1\text{ kHz}$

D_1 conducts when $v_I > 0$ and D_2 conducts when $v_I < 0$. Thus the output follows the input.

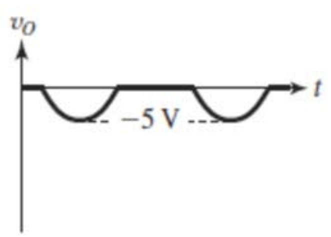
(f)



$V_{p^+} = 5\text{ V}, \quad V_{p^-} = 0\text{ V}, \quad f = 1\text{ kHz}$

D_1 is cut off when $v_I < 0$

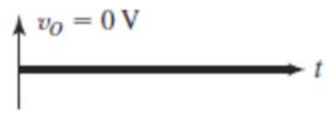
(g)



$V_{p^+} = 0\text{ V}, \quad V_{p^-} = -5\text{ V}, \quad f = 1\text{ kHz}$

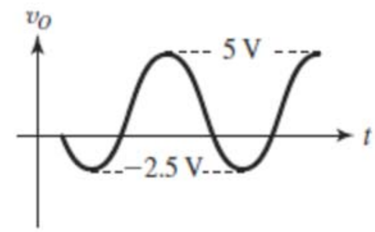
D_1 shorts to ground when $v_I > 0$ and is cut off when $v_I < 0$ whereby the output follows v_I.

(h)



$v_O = 0\text{ V} \sim$ The output is always shorted to ground as D_1 conducts when $v_I > 0$ and D_2 conducts when $v_I < 0$.

(i)



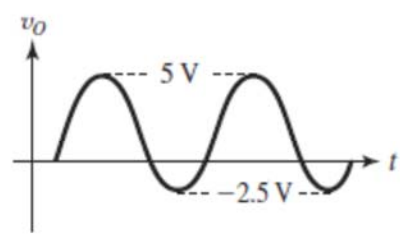
$V_{p^+} = 5\text{ V}, \quad V_{p^-} = -2.5\text{ V}, \quad f = 1\text{ kHz}$

When $v_I > 0$, D_1 is cut off and v_O follows v_I.

When $v_I < 0$, D_1 is conducting and the circuit becomes a voltage divider where the negative peak is

$$\frac{1\text{ k}\Omega}{1\text{ k}\Omega + 1\text{ k}\Omega} \times -5\text{ V} = -2.5\text{ V}$$

(j)

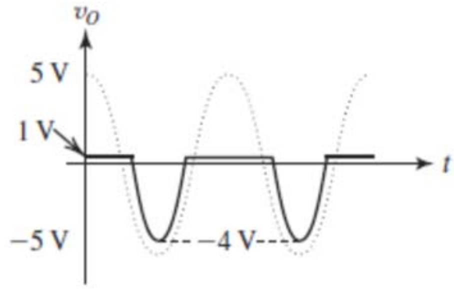


$V_{p^+} = 5\text{ V}, \quad V_{p^-} = -2.5\text{ V}, \quad f = 1\text{ kHz}$

When $v_I > 0$, the output follows the input as D_1 is conducting.

When $v_I < 0$, D_1 is cut off and the circuit becomes a voltage divider.

(k)



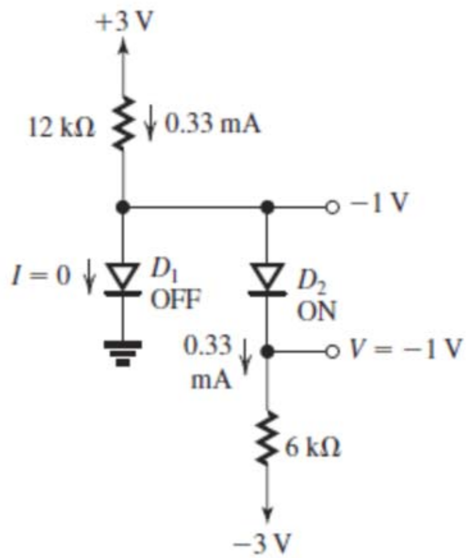
$V_{p^+} = 1$ V, $V_{p^-} = -4$ V, $f = 1$ kH$_3$

When $v_I > 0$, D_1 is cut off and D_2 is conducting. The output becomes 1 V.

When $v_I < 0$, D_1 is conducting and D_2 is cut off. The output becomes:

$v_O = v_I + 1$ V

4.9

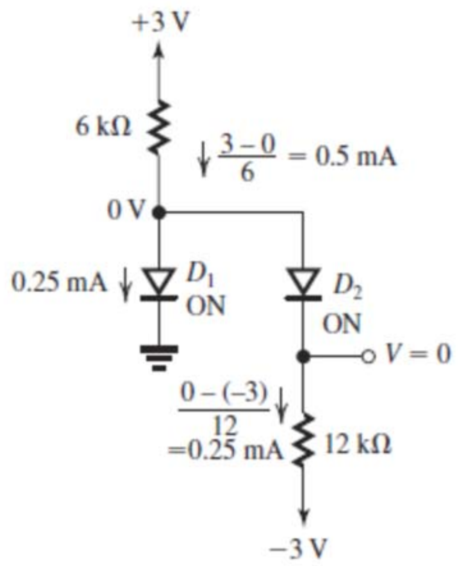


(a)

(a) If we assume that both D_1 and D_2 are conducting, then $V = 0$ V and the current in D_2 will be $[0 - (-3)]/6 = 0.5$ mA. The current in the 12 kΩ will be $(3 - 0)/12 = 0.25$ mA. A node equation at the common anodes node yields a negative current in D_1. It follows that our assumption is wrong and D_1 must be off. Now making the assumption that D_1 is off and D_2 is on, we obtain the results shown in Fig. (a):

$I = 0$

$V = -1$ V



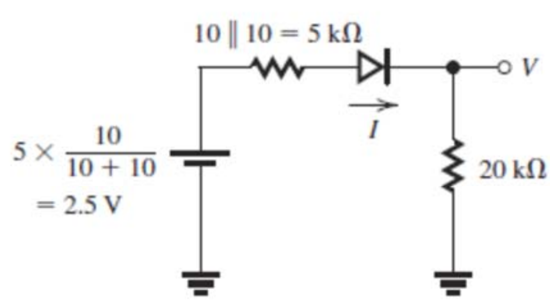
(b)

(b) In (b), the two resistors are interchanged. With some reasoning, we can see that the current supplied through the 6-kΩ resistor will exceed that drawn through the 12-kΩ resistor, leaving sufficient current to keep D_1 conducting. Assuming that D_1 and D_2 are both conducting gives the results shown in Fig. (b):

$I = 0.25$ mA

$V = 0$ V

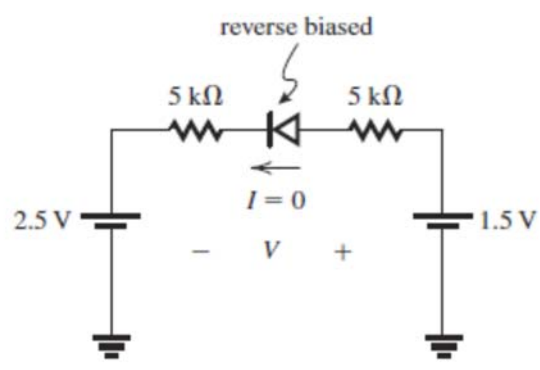
4.10 The analysis is shown on the circuit diagrams below.



$$I = \frac{2.5}{5+20} = 0.1 \text{ mA}$$

$$V = 0.1 \times 20 = 2 \text{ V}$$

(a)



$$V = 1.5 - 2.5 = -1 \text{ V}$$

(b)

4.17 $V_T = \dfrac{kT}{q}$

where

$k = 1.38 \times 10^{-23}$ J/K $= 8.62 \times 10^{-5}$eV/K

$T = 273 + x°C$

$q = 1.60 \times 10^{-19}$C

Thus

$V_T = 8.62 \times 10^{-5} \times (273 \times x°\text{C})$, V

x [°C]	V_T [mV]
−55	18.8
0	23.5
+55	28.3
+125	34.3

for $V_T = 25$ mV at 17°C

4.20 $I = I_S e^{V_D/V_T}$

$10^{-3} = I_S e^{0.7/V_T}$ (1)

For $V_D = 0.71$ V,

$I = I_S e^{0.71/V_T}$ (2)

Combining (1) and (2) gives

$I = 10^{-3} e^{(0.71 - 0.7)/0.025}$

$= 1.49$ mA

For $V_D = 0.8$ V,

$I = I_S e^{0.8/V_T}$ (3)

Combining (1) and (3) gives

$I = 10^{-3} \times e^{(0.8 - 0.7)/0.025}$

$= 54.6$ mA

Similarly, for $V_D = 0.69$ V we obtain

$I = 10^{-3} \times e^{(0.69 - 0.7)/0.025}$

$= 0.67$ mA

and for $V_D = 0.6$ V we have

$I = 10^{-3} e^{(0.6 - 0.7)/0.025}$

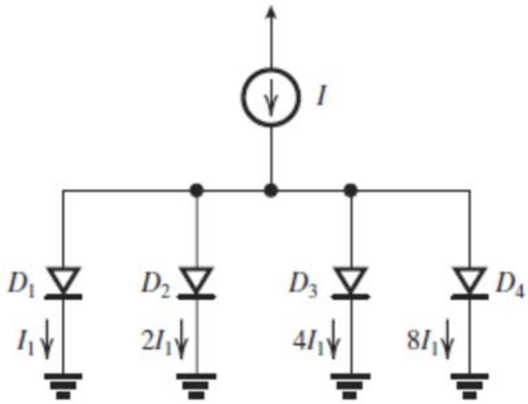
$= 18.3$ µA

To increase the current by a factor of 10, V_D must be increased by ΔV_D,

$10 = e^{\Delta V_D/0.025}$

$\Rightarrow \Delta V_D = 0.025 \ln 10 = 57.6$ mV

4.26



$I_1 = 0.1$ mA

The junction areas of the four diodes must be related by the same ratios as their currents, thus

$A_4 = 2A_3 = 4A_2 = 8\ A_1$

With $I_1 = 0.1$ mA,

$I = 0.1 + 0.2 + 0.4 + 0.8 = 1.5$ mA

4.27 We can write a node equation at the anodes:

$I_{D2} = I_1 - I_2 = 7$ mA

$I_{D1} = I_2 = 3$ mA

We can write the following equation for the diode voltages:

$V = V_{D2} - V_{D1}$

If D_2 has saturation current I_S, then D_1, which is 10 times larger, has saturation current $10I_S$. Thus we can write

$I_{D2} = I_S e^{V_{D2}/V_T}$

$I_{D1} = 10I_S e^{V_{D1}/V_T}$

Taking the ratio of the two equations above, we have

$$\frac{I_{D2}}{I_{D1}} = \frac{7}{3} = \frac{1}{10}e^{(V_{D2}-V_{D1})/V_T} = \frac{1}{10}e^{V/V_T}$$

$$\Rightarrow V = 0.025\ \ln\left(\frac{70}{3}\right) = 78.7\ \text{mV}$$

To instead achieve $V = 60$ mV, we need

$$\frac{I_{D2}}{I_{D1}} = \frac{I_1 - I_2}{I_2} = \frac{1}{10}e^{0.06/0.025} = 1.1$$

Solving the above equation with I_1 still at 10 mA, we find $I_2 = 4.76$ mA.

4.28 We can write the following node equation at the diode anodes:

$$I_{D2} = 10\ \text{mA} - V/R$$

$$I_{D1} = V/R$$

We can write the following equation for the diode voltages:

$$V = V_{D2} - V_{D1}$$

We can write the following diode equations:

$$I_{D2} = I_S e^{V_{D2}/V_T}$$

$$I_{D1} = I_S e^{V_{D1}/V_T}$$

Taking the ratio of the two equations above, we have

$$\frac{I_{D2}}{I_{D1}} = \frac{10\ \text{mA} - V/R}{V/R} = e^{(V_{D2}-V_{D1})/V_T} = e^{V/V_T}$$

To achieve $V = 50$ mV, we need

$$\frac{I_{D2}}{I_{D1}} = \frac{10\ \text{mA} - 0.05/R}{0.05/R} = e^{0.05/0.025} = 7.39$$

Solving the above equation, we have

$$R = 42\ \Omega$$

4.59 $V_Z = V_{Z0} + I_{ZT} r_z$

(a) $10 = 9.6 + 0.05 \times r_z$

$\Rightarrow r_z = 8\ \Omega$

For $I_Z = 2I_{ZT} = 100$ mA,

$V_Z = 9.6 + 0.1 \times 8 = 10.4$ V

$P = 10.4 \times 0.1 = 1.04$ W

(b) $9.1 = V_{Z0} + 0.01 \times 30$

$\Rightarrow V_{Z0} = 8.8$ V

At $I_Z = 2I_{ZT} = 20$ mA,

$V_Z = 8.8 + 0.02 \times 30 = 9.4$ V

$P = 9.4 \times 20 = 188$ mW

(c) $6.8 = 6.6 + I_{ZT} \times 2$

$\Rightarrow I_{ZT} = 0.1$ A

At $I_Z = 2I_{ZT} = 0.2$ A,

$V_Z = 6.6 + 0.2 \times 2 = 7$ V

$P = 7 \times 0.2 = 1.4$ W

(d) $18 = 17.6 + 0.005 \times r_z$

$\Rightarrow r_z = 80\ \Omega$

At $I_Z = 2I_{ZT} = 0.01$ A,

$V_Z = 17.6 + 0.01 \times 80 = 18.4$ V

$P = 18.4 \times 0.01 = 0.184$ W $= 184$ mW

(e) $7.5 = V_{Z0} + 0.2 \times 1.5$

$\Rightarrow V_{Z0} = 7.2$ V

At $I_Z = 2I_{ZT} = 0.4$ A,

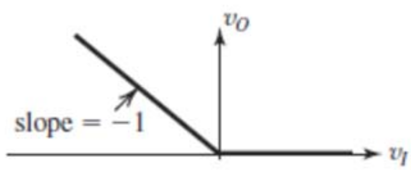
$V_Z = 7.2 + 0.4 \times 1.5 = 7.8$ V

$P = 7.8 \times 0.4 = 3.12$ W

4.86 $v_I > 0$: D_1 conducts and D_2 cutoff

$v_I < 0$: D_1 cutoff,

D_2 conducts $\sim \dfrac{v_O}{v_I} = -1$



(a) $v_I = +1$ V

$v_O = 0$ V

$v_A = -0.7$ V

Keeps D_2 off so no current flows through R

$\Rightarrow v_- = 0$ V

Virtual ground as feedback loop is closed through D_1

(b) $v_I = +3$ V

$v_O = 0$ V

$v_A = -0.7$ V

$v_- = 0$ V

(c) $v_I = -1$ V

$v_O = +1$ V

$v_A = 1.7$ V

$v_- = 0$ V

$\sim$ Virtual ground as negative feedback loop is closed through D_2 and R.

(d) $v_I = -3\text{ V} \Rightarrow v_O = +3$ V

$v_A = +3.7$ V

$v_- = 0$ V

4.87 (a) See figure (a) on next page. For $v_I \leq 3.5$ V, $i = 0$ and $v_O = v_I$. At $v_I = 3.5$ V, the diode begins to conduct. At $v_O = 3.7$ V, the diode is conducting $i = 1$ mA and thus

$$v_I = v_O + i \times 1\ \text{k}\Omega = 4.7\ \text{V}$$

For $v_I > 4.7$ V the diode current increases but the diode voltage remains constant at 0.7 V, thus v_O flattens and v_O vs. v_I becomes a horizontal line.

In practice, the diode voltage increases slowly and the line will have a small nonzero slope.

(b) See figure (b) on next page. Here $v_O = v_I$ for $v_I \geq 2.5$ V. At $v_I = 2.5$ V, $v_O = 2.5$ V and the diode begins to conduct. The diode will be conducting 1 mA and exhibiting a drop of 0.7 at $v_O = 2.3$ V. The corresponding value of v_I

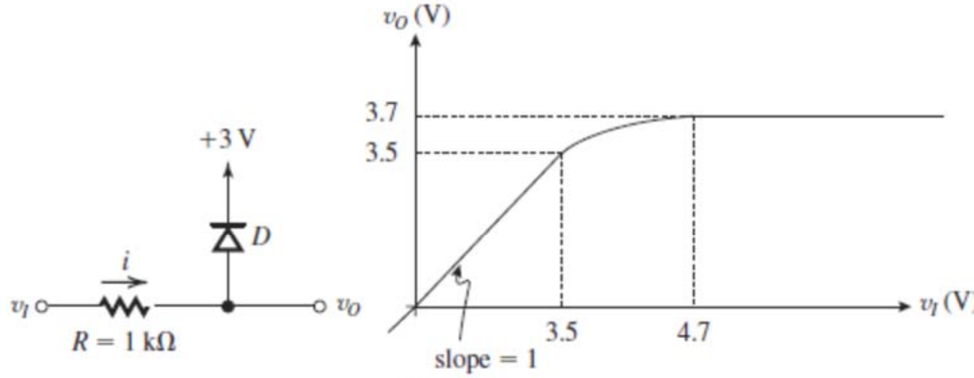
$$v_I = v_O - iR = 2.3 - 1 \times 1 = +1.3\ \text{V}$$

As v_I decreases below 1.3 V, the diode current increases, but the diode voltage remains constant at 0.7 V. Thus v_O flattens at about 2.3 V.

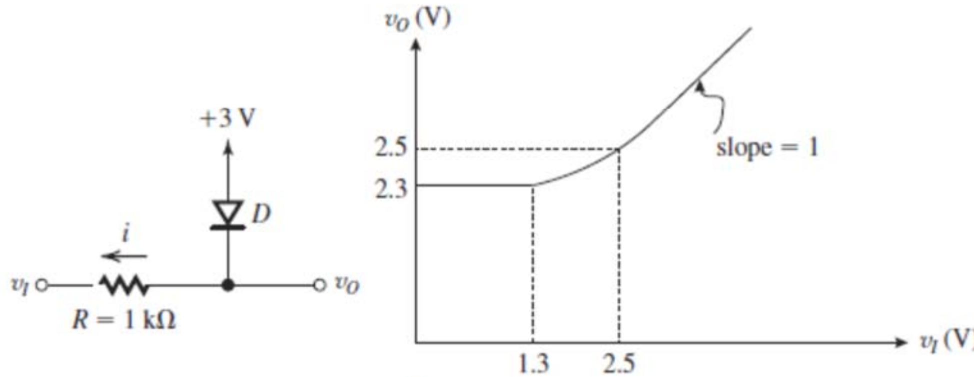
(c) See figure (c) on next page. For $v_I \leq -2.5$ V, the diode is off, and $v_O = v_I$. At $v_I = -2.5$ V the diode begins to conduct and its current reaches 1 mA at $v_I = -1.3$ V (corresponding to $v_O = -2.3$ V). As v_I further increases, the diode current increases but its voltage remains constant at 0.7 V. Thus v_O flattens, as shown.

(d) See figure (d) on next page.

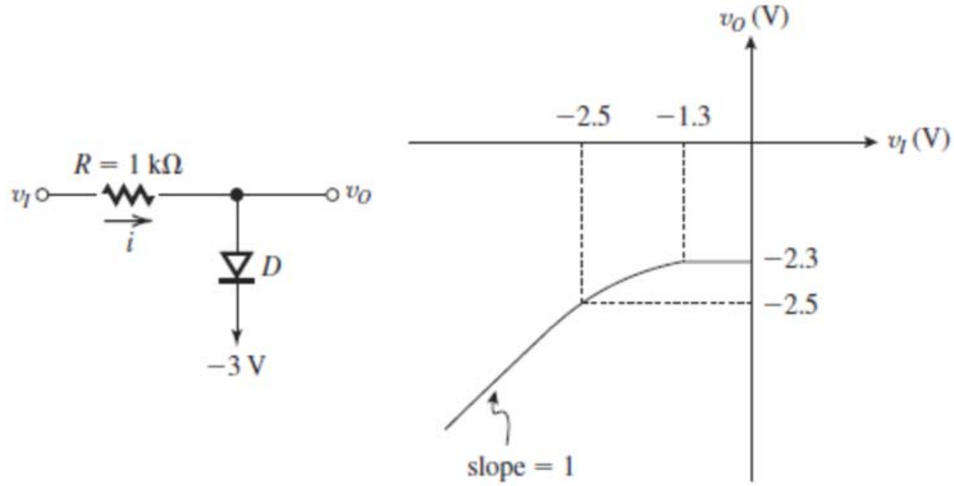
These figures belong to Problem 4.87.



(a)

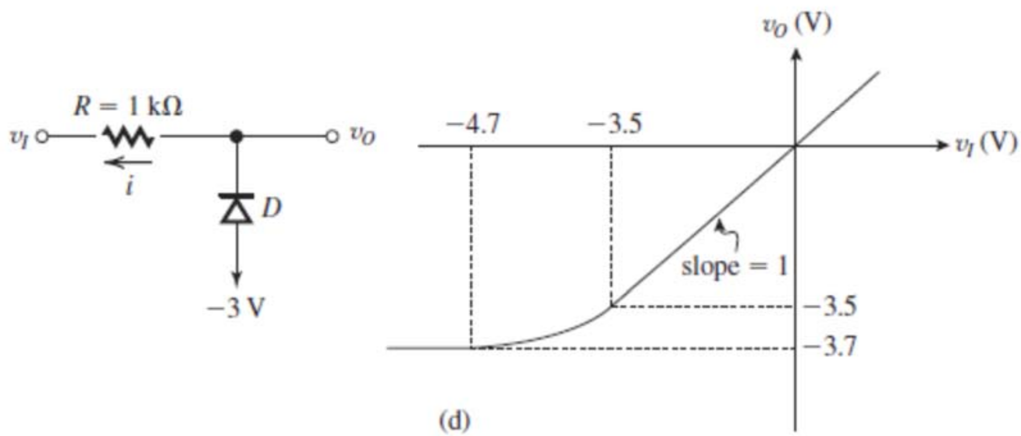


(b)



v_O (V)
−2.5
−1.3
v_I (V)
$R = 1\ \text{k}\Omega$
v_I
v_O
i
D
−2.3
−2.5
−3 V
slope = 1

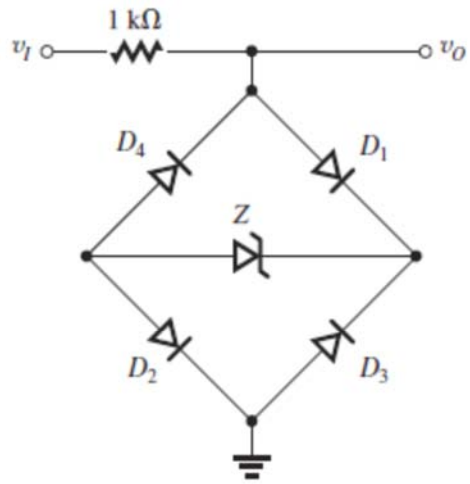
(c)



v_O (V)
$R = 1\ \text{k}\Omega$
−4.7
−3.5
v_I
v_O
v_I (V)
i
D
slope = 1
−3 V
−3.5
−3.7

(d)

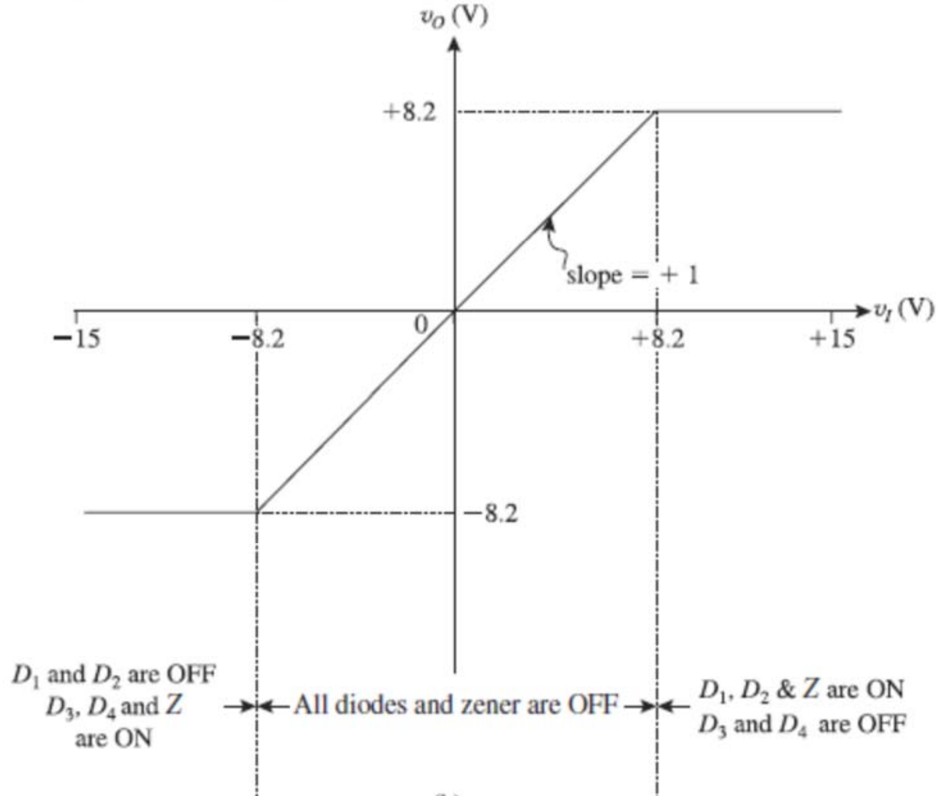
4.90



(a)

The limiter thresholds and the output saturation levels are found as $2 \times 0.7 + 6.8 = 8.2$ V. The transfer characteristic is given in Fig. (b). See figure on next page.

This figure belong to Problem 4.90, part b.



(b)