Problem 1.

\[ v_o = \left( 1 + \frac{R}{R} \right) v_i = 2v_i \] for \( v_i > 0 \)
\[ = 0 \] for \( v_i < 0 \)

a. \( v_i = +1 \) \( V \), diode is on. Hence \( v_o = 2v_i = 2 \) \( V \), \( v_A = v_o + V_{D_{off}} = 2.8 \) \( V \) and \( v_+ = v_i = 1 \) \( V \).

b. \( v_i = +2 \) \( V \), diode is on. Hence \( v_o = 2v_i = 4 \) \( V \), \( v_A = v_o + V_{D_{off}} = 4.8 \) \( V \) and \( v_+ = v_i = 2 \) \( V \).

c. \( v_i = -1 \) \( V \), diode is off. There is no current through \( R_L \) and \( R \), \( v_o = 0 \) and \( v_+ = 0 \). In the absence of feedback, opamp output voltage reaches the negative saturation limit and \( v_A = -12 \) \( V \).

d. \( v_i = -2 \) \( V \), diode is off. There is no current through \( R_L \) and \( R \), \( v_o = 0 \) and \( v_+ = 0 \). In the absence of feedback, opamp output voltage reaches the negative saturation limit and \( v_A = -12 \) \( V \).

Output waveform (Fig. 2) for a square wave input. Average output voltage \( v_{o_{avg}} = 5 \) \( V \).

Problem 2.

It is a non-inverting configuration. So,

\[ v_o = \left( 1 + \frac{R}{R} \right) v_i = 2v_i \] for \( v_i > 0 \)
\[ = 0 \] for \( v_i < 0 \)

a. \( v_i = +1 \) \( V \), diode is on. Hence \( v_o = 2v_i = 2 \) \( V \), \( v_A = v_o + V_{D_{off}} = 2.8 \) \( V \) and \( v_+ = v_i = 1 \) \( V \).

b. \( v_i = +2 \) \( V \), diode is on. Hence \( v_o = 2v_i = 4 \) \( V \), \( v_A = v_o + V_{D_{off}} = 4.8 \) \( V \) and \( v_+ = v_i = 2 \) \( V \).

c. \( v_i = -1 \) \( V \), diode is off. There is no current through \( R_L \) and \( R \), \( v_o = 0 \) and \( v_+ = 0 \). In the absence of feedback, opamp output voltage reaches the negative saturation limit and \( v_A = -12 \) \( V \).

d. \( v_i = -2 \) \( V \), diode is off. There is no current through \( R_L \) and \( R \), \( v_o = 0 \) and \( v_+ = 0 \). In the absence of feedback, opamp output voltage reaches the negative saturation limit and \( v_A = -12 \) \( V \).

Problem 3.

\[ v_o = \left( - \frac{R}{R} \right) v_i = -v_i \] for \( v_i < 0 \)
\[ = 0 \] for \( v_i > 0 \)

a. \( v_i = +1 \) \( V \), \( D_1 \) is on and \( D_2 \) is off. The negative feedback loop is closed via \( D_1 \). Hence, \( v_+ = 0 \), \( v_A = -0.8 \) and \( v_o = 0 \).
b. \( v_i = +2\ V, \) \( D_1 \) is on and \( D_2 \) is off. The negative feedback loop is closed via \( D_1 \).
   Hence, \( v_- = 0, v_A = -0.8 \) and \( v_o = 0 \).

c. \( v_i = -1\ V, \) \( D_1 \) is off and \( D_2 \) is on. The negative feedback loop is closed via \( D_2 \)
   and \( R \). Hence, \( v_- = 0, v_o = 1\ V \) and \( v_A = 1.8 \).

d. \( v_i = -2\ V, \) \( D_1 \) is off and \( D_2 \) is on. The negative feedback loop is closed via \( D_2 \)
   and \( R \). Hence, \( v_- = 0, v_o = 2\ V \) and \( v_A = 2.8 \).

**Problem 4.**

a. \( CR \gg T \).

(i) For \( v_i > 0 \), diode is on and \( v_o = 0 \).
   Voltage across the capacitor, \( v_c = +5\ V \).
   For \( v_i < 0 \), diode turns off and \( v_o = v_i - v_c = v_i - 5 \). The output waveform
   is as shown in the Fig. 4.

![Figure 4](image)

(ii) For \( v_i < 0 \), diode is on and \( v_o = 0 \).
   Voltage across the capacitor, \( v_c = -5\ V \).
   For \( v_i > 0 \), diode turns off and \( v_o = v_i - v_c = v_o + 5 \). The output waveform
   is as shown in the Fig. 5.

![Figure 5](image)

(iii) Even though there is a resistance \( (2R) \) present, the capacitor eventually
charges to \( v_c = 5\ V \), and the output is similar to (i) and shown in Fig. 4.

(iv) Here, there are two different time constants involved. To calculate the output
levels we shall exaggerate the discharge and charge waveforms as shown
in Fig. 6. During \( T_1 \), \( v_o(t) = v_1 \exp \left( \frac{-t}{2RC} \right) \).

![Figure 6](image)

At \( t = T_1 = T \), \( v_o(t) = v_1' = v_1 \exp \left( \frac{-T}{2RC} \right) \).
Where for \( T \ll RC \),
\( v_1' = v_1 (1 - \frac{T}{2RC}) = v_1 (1 - \alpha) \), where \( \alpha \ll 1 \).
During \( T_2 \), \( v_o(t) = v_1 \exp \left( \frac{T}{RC} \right) \).
At the end of \( T_2, t = T_2 = T \), \( v_o = v_2' \).
For \( T \ll RC \),
Now,

\[ v_2' = v_2 \left(1 - \frac{T}{RC}\right) = v_2 (1 - 2\alpha), \text{ where } \alpha \ll 1. \]

and,

\[ v_1' = \frac{v_1}{2} + v_2 = 10 \]
\[ \Rightarrow v_1(1 - \alpha) + v_2 = 10 \quad (1) \]

From eq. (1) and (2), we find that,

\[ v_1 = 2v_2 \]

Then using (1) and neglecting \( \alpha v_1 \) yields,

\[ 3v_2 = 10 \]
\[ \Rightarrow v_2 = 3.33 \text{ V} \]
\[ v_1 = 6.67 \text{ V} \]

The output waveform is as shown in the Fig. 7.

![Figure 7:](image)

(v) Using a method very similar to that employed for case (iv), we have,

\[ v_1 = 2v_2, \]

and the waveform is shown in Fig. 8.

![Figure 8:](image)

b. \( RC = T \).

(i) Since there is no \( R \), output waveform is same as in part (a).

(ii) Since there is no \( R \), output waveform is same as in part (a).

(iii) Even though there is a resistance \((2R)\) present, the capacitor eventually charges to \(+5 \text{ V}\) and the output waveform is same as in part (a).

(iv) Refer to Fig. 6.

During \( T_1 \), \( v_o(t) = v_1 \exp \left( \frac{-t}{2RC} \right) \).

At \( t = T_1 = T \),

\[ v_o(t) = v_1' = v_1 \exp \left( \frac{-T}{2RC} \right) \]
\[ = 0.606v_1. \]
During $T_2$, $v_o(t) = v_2 \exp\left(\frac{-t}{RC}\right)$.

At $t = T_2 = T$,

$$v_o(t) = v'_2 = v_2 \exp\left(-\frac{T}{RC}\right) = 0.606v_2.$$ 

Also,

$$v'_1 + v_2 = 10$$
$$v'_2 + v_1 = 10$$

On solving,

$$v_1 = 8.134, v'_1 = 4.929$$
$$v_2 = 5.071, v'_2 = 1.866.$$

![Figure 9](image)

(v) Similar to (iv), we can find that,

$$v_1 = 7.457, v'_1 = 5.808$$
$$v_2 = 4.192, v'_2 = 2.543.$$

![Figure 10](image)

**Problem 5.**

For $v_i$ close to 0, all four diodes $D_1 - D_4$ are on. This justifies 0.8 V voltage drops across diode. For such case (Fig. 11a), as long as the diodes are all conducting,

$$v_o = v_i.$$ 

However, as $v_i$ increases, current through $D_1$ and $D_4$ decreases and eventually diodes $D_1$ and $D_4$ get into off state. To determine the value of $v_i$ at which this happens, refer to Fig. 11b. Since $D_1$ and $D_4$ are off, $i_{D1} = i_{D4} = 0$.

$$i_{D2} = \frac{15 - 0.8}{15K + 15K}$$
$$v_o = i_{D2} \times 15K = 7.1\ V$$
$$v_i = v_o = 7.1\ V$$
Using a similar method for negative $v_i$, we get the output characteristics (Fig. 12).

**Problem 6.**
The circuit is a full wave rectifier with center-tapped secondary winding. Since the average value of each output is 15 V, the average value of the difference $V_{diff} = V_o^+ - V_o^-$ is 30 V.

\[
V_{diff, avg} = \frac{2}{\pi} V_{P, secondary} - 2V_{Don} \\
\Rightarrow \frac{(30 + 2 \times 0.8)\pi}{2} = V_{P, secondary} \\
V_{P, secondary} = 49.64 \text{ V}
\]

\[
PIV = V_{P, secondary} - V_{Don} \\
= 49.64 - 0.8 \\
= 48.84 \text{ V}
\]