PROBLEM #1

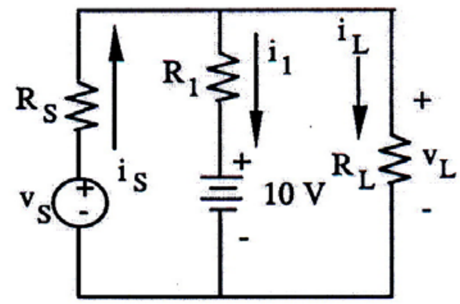
Three cases need to be considered:

(a) When $V_L > 10\text{ V}$, D_1 will conduct

(b) When $V_L < -5\text{ V}$, D_4 will conduct

(c) When $-5\text{ V} < V_L < 10\text{ V}$, all 4 diodes will be cut off.

For case (a), the circuit is shown on the right.



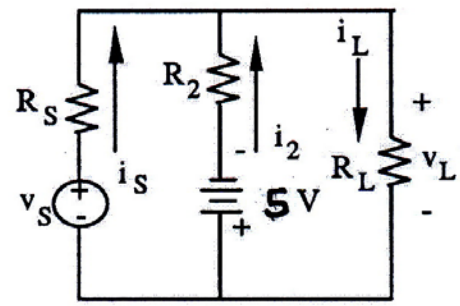
By KCL, $i_S = i_1 + i_l$, and

$$\frac{V_S - V_L}{10} = \frac{V_L - 10}{1} + \frac{V_L}{40}$$

Therefore, $V_L = \dfrac{4V_S + 400}{45}$ V

$V_S > 12.5\text{ V}$

For case (b), the circuit is shown on the right.



By KCL, $i_S + i_2 = i_L$, and

$$\frac{V_S - V_L}{10} + \frac{-5 - V_L}{10} = \frac{V_L}{40}$$

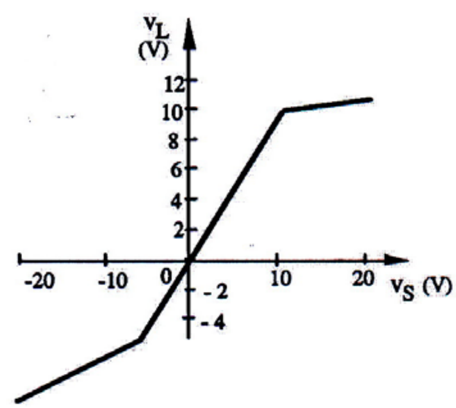
Therefore, $V_L = \dfrac{4V_S - 20}{9}$ V

$V_S < -6.25\text{ V}$

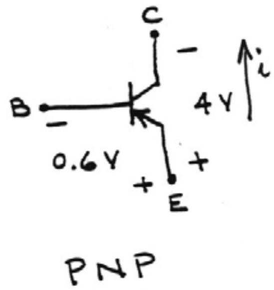
For case (c), we have $V_L = \dfrac{4}{5} V_S$ and

$-6.25\text{ V} < V_S < 12.5\text{ V}$

The v_L-v_S curve is shown on the right:

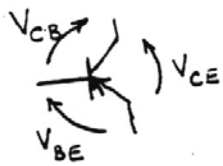


PROBLEM #2



a) $V_{BE} = -0.6\,V$

the EB junction is forward biased.



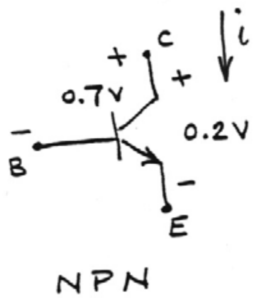
$V_{CE} = V_{BE} + V_{CB}$

$-4 = -0.6 + V_{CB}$

$\therefore\ V_{CB} = -3.4V$

The CB junction is reverse biased.

$\therefore$ the transistor is in the active region



b) $V_{CB} = 0.7\,V$

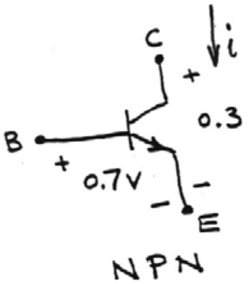
the BC junction is reverse biased.

$V_{CE} = V_{BE} + V_{CB}$

$0.2 = V_{BE} + 0.7 \quad \therefore\ V_{BE} = -0.5\,V$

$\therefore$ the BE junction is reverse biased.

$\therefore$ the transistor is in the cut-off region



c) $V_{BE} = 0.7\,V$

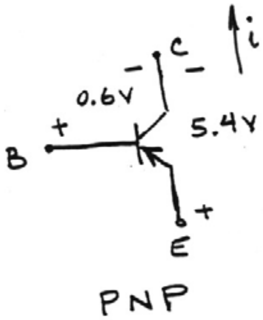
the BE junction is forward biased.

$V_{CE} = V_{BE} + V_{CB}$

$0.3 = 0.7 + V_{CB} \quad \therefore\ V_{CB} = -0.4\,V$

$\therefore$ the BC junction is forward biesed.

$\therefore$ the transistor is in the saturation region



d) $V_{CB} = -0.6\,V$

the CB junction is reverse biased.

$V_{CE} = V_{BE} + V_{CB}$

$-5.4 = V_{BE} - 0.6 \quad \therefore\ V_{BE} = -4.8\,V$

$\therefore$ the EB junction is forward biased.

$\therefore$ the transistor is in the active region.

PROBLEM #3

a) If all the input voltages are high at 5V, no current can flow from the base of Q_1 to the emitter of Q_1.

But the current from the base of Q_1 can flow through the collector of Q_1, which is the same as the base current of Q_2.

If Q_2 is assumed saturated ON, then the base plus collector current (equal to emitter current) of Q_2 flows through the 1kΩ resistor. If Q_3 is assumed saturated ON, then some of this current flows through the base of Q_3 to the emitter of Q_3.

Also, since Q_2 is saturated ON, all the collector current from the 5V source through the 1.6kΩ resistor flows through the CE of Q_2 and there is insufficient current to turn ON Q_4, which is therefore OFF.

Thus, Q_2 = saturated ON
Q_3 = saturated ON
Q_4 = cut-off OFF

$V_{B3} = 0.6\,V$

$V_{B2} = V_{BE2} + V_{B3} = 0.6 + 0.6 = 1.2V$

$V_{B1} = V_{BC1} + V_{BE2} + V_{B3} = 0.6 + 0.6 + 0.6 = 1.8V$

$V_{C2} = V_{CE2} + V_{B3} = 0.2 + 0.6 = 0.8V$

$V_{out} = V_{CE3} = 0.2\,V$

b) If $V_B = 0\,V$ then current from the 5V source flows through the 4kΩ resistor, through the base of Q_1 to the emitter of Q_1, and therefore Q_1 is saturated ON.

Thus,

$$Q_1 = \text{saturated ON}$$

$$V_{B1} = V_{BE1} = 0.6\,V$$

$$V_{B2} = V_{CE1} = 0.2\,V$$

There is insufficient current from Q_1 to the base of Q_2, and therefore Q_2 is OFF. Since there is no Q_2 emitter current, therefore Q_3 is OFF.

$$Q_2 = \text{cut-off OFF}$$

$$Q_3 = \text{cut-off OFF}$$

$$V_{B3} \approx 0\,V \quad (\text{small voltage due to leakage } I_{CEO})$$

If Q_2 is OFF, then the current from the 5V source through the 1.6kΩ resistor turns Q_4 ON.

Thus, since Q_4 is ON,

$$5 - i_{C4}(150\times10^3) - V_{CE4} - V_{D1} = V_{out}$$
$$5 - i_{B4}(1.6\times10^3) - V_{BE4} - V_{D1} = V_{out}$$

$$5 - i_{C4}(150\times10^3) - 0.2 - 0.6 = V_{out}$$
$$5 - i_{B4}(1.6\times10^3) - 0.6 - 0.6 = V_{out}$$

$$i_{C4} = \beta i_{B4} = 5\, i_{B4} \qquad (\text{assume saturated } \beta = 5)$$

$$4.2 - i_{B4}(750\times10^3) = V_{out}$$
$$3.8 - i_{B4}(1.6\times10^3) = V_{out}$$

$$0.4 = i_{B4}(748.4\times10^3)$$

$$\therefore \quad i_{B4} = 0.534\,\mu A$$
$$i_{C4} = 2.67\,\mu A$$

$$V_{out} = 3.8\text{ V}$$

$$V_{C2} \simeq V_{BE4} + V_{D1} + V_{out}$$
$$= 0.6 + 0.6 + 3.8$$
$$\simeq 5.0\text{ V}$$