Exercise 4.5

The load lines for $v_{in} = -0.8 \, \text{V}$ and $0.8 \, \text{V}$ are shown below.

![Diagram](image)

The results are $V_{CEmax} = 9.0 \, \text{V}$, $V_{CEQ} = 5.0 \, \text{V}$, $V_{CEmin} = 1.0 \, \text{V}$. 

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Exercise 4.6

The load lines are shown below.

From the load lines we find $V_{CE\text{Max}} \approx 9.8 \, \text{V}$, $V_{CEQ} \approx 7.0 \, \text{V}$, and $V_{CE\text{Min}} \approx 3.0 \, \text{V}$.
Exercise 4.9
(a) $V_{BE} = -0.2 \text{ V}$ and $V_{CE} = 5 \text{ V}$, because we have $v_{BE} < 0.5$, the transistor is in cutoff.

(b) $I_B = 50 \text{ } \mu\text{A}$ and $I_C = 2 \text{ mA}$, because we have $I_C < \beta I_B$ the transistor is in saturation.

(c) $V_{CE} = 5 \text{ V}$ and $I_B = 50 \text{ } \mu\text{A}$, because we have $V_{CE} > 0.2$ and $I_B > 0$, the transistor is in the active region.

Exercise 4.10

(a) Let us assume operation in the active region. Then we have $I_B = (V_{CC} - 0.7)/R_B = 71.5 \text{ } \mu\text{A}$, $I_C = \beta I_B = 3.575 \text{ mA}$, and $V_{CE} = V_{CC} - R_C I_C = 11.4 \text{ V}$. Because we found $V_{CE} > 0.2 \text{ V}$, the active-region assumption is valid and the results are correct.

(b) Again let us assume operation in the active region. Then we have $I_B = (V_{CC} - 0.7)/R_B = 71.5 \text{ } \mu\text{A}$, $I_C = \beta I_B = 17.9 \text{ mA}$, and $V_{CE} = V_{CC} - R_C I_C = -2.9 \text{ V}$. Because we found $V_{CE} < 0.2 \text{ V}$, the active-region assumption is invalid, and the results are not correct.

Therefore let us assume operation in saturation. Then we have $I_B = (V_{CC} - 0.7)/R_B = 71.5 \text{ } \mu\text{A}$, $I_C = (V_{CC} - 0.2)/R_C = 14.8 \text{ mA}$. Because we have $\beta I_B > I_C$ the saturation-region assumption is valid.

Exercise 4.11

The load-line equation is

$$V_{CC} = R_C I_C + V_{CE} \quad \text{or} \quad 20 = 5000 I_C + V_{CE}$$
(b) As in part (a) we have $I_B = 19.3 \ \mu A$. We start by assuming operation in the active region resulting in

$$I_C = \beta I_B = 2.90 \ mA$$

$$V_{CE} = -20 + R_C I_C = 9 \ V$$

Because $V_{CE} > -0.2 \ V$, the active region assumption is not valid. Therefore assume operation in saturation, in which case we have

$$I_B = \frac{V_{CC} + V_{BE}}{R_B} = \frac{20 - 0.7}{1 \ \text{M}\Omega} = 19.3 \ \mu A$$

$$V_{CE} = -0.2 \ V$$

$$I_C = \frac{V_{CC} - 0.2}{R_C} = 1.98 \ mA$$

Then because $\beta I_B > I_C$ the transistor is operating in saturation, and the problem is solved.

**Exercise 4.13**

$$R_1 = 100 \ \text{k}\Omega \quad R_2 = 50 \ \text{k}\Omega$$

$$R_B = \frac{1}{\frac{1}{R_1} + \frac{1}{R_2}} = 33.3 \ \text{k}\Omega$$

$$V_B = V_{CC} \frac{R_2}{R_1 + R_2} = 5 \ V$$

$$I_B = \frac{V_B - V_{BE}}{R_B + (\beta + 1)R_E} = \frac{5 - 0.7}{33.3k + (\beta+1)1k}$$

$$I_C = \beta I_B$$

$$I_E = I_C + I_B$$

$$V_{CE} = V_{CC} - R_C I_C - R_E I_E$$

<table>
<thead>
<tr>
<th>$\beta$</th>
<th>$I_B$ (µA)</th>
<th>$I_C$ (mA)</th>
<th>$I_E$ (mA)</th>
<th>$V_{CE}$ (V)</th>
</tr>
</thead>
<tbody>
<tr>
<td>100</td>
<td>32.0</td>
<td>3.20</td>
<td>3.23</td>
<td>8.57</td>
</tr>
<tr>
<td>300</td>
<td>12.9</td>
<td>3.86</td>
<td>3.87</td>
<td>7.27</td>
</tr>
</tbody>
</table>

In Example 4.7 the ratio of the collector currents is $4.24/4.12 = 1.029$. For the higher resistor values in this exercise the ratio is $3.86/3.20 = 1.21$. In general higher resistance values in the four-resistor bias circuit lead to
greater changes in the bias point with changes in \( \beta \). The SPICE simulation is stored in the file named Exer4_13.

**Exercise 4.14**

For the four-resistor bias circuit we have:

\[
R_B = \frac{1}{1/R_1 + 1/R_2}
\]

\[
V_B = V_{CC} \frac{R_2}{R_1 + R_2}
\]

\[
I_B = \frac{V_B - V_{BE}}{R_B + (\beta + 1)R_E}
\]

\[
I_C = \beta I_B
\]

\[
V_{CE} = V_{CC} - R_C I_C - R_E I_E
\]

(a) An increase in \( R_C \) has no effect on \( I_C \) (provided that operation remains in the active region).
(b) An increase in \( R_E \) decreases \( I_B \) and \( I_C \).
(c) An increase in \( R_1 \) decreases \( V_B \), \( I_B \) and \( I_C \).
(d) An increase in \( R_2 \) increases \( V_B \), \( I_B \) and \( I_C \).
(e) An increase in \( \beta \) increases \( I_C \).

**Exercise 4.15**

(a) An increase in \( R_C \) reduces \( V_{CE} \).
(b) An increase in \( R_1 \) increases \( V_{CE} \).
(c) An increase in \( R_2 \) decreases \( V_{CE} \).
(d) An increase in \( \beta \) decreases \( V_{CE} \).

**Exercise 4.16**

Because \( V_{BE} \approx 0.7 \text{ V} \) for \( Q_1 \) and \( Q_2 \) and because the bases are grounded, the voltage at the top node of the 2-mA current source is \(-0.7 \text{ V}\).