# Circuits Lab

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$R_2 = 40\ \Omega$

## 1. Purpose

The goal of the exercise was to use Kirchhoff's rules to analyze 7 different circuits and calculate current, voltage, and power for each circuit element. For the first 4 circuits, the voltage and current calculations were compared to results obtained using an online circuit simulator.

## 2. Results

The following sections contain the theoretical voltage, current, and power for each circuit element for each of the 7 circuits. In addition, there is an annotated circuit diagram for each circuit. In each case, the voltage across a resistor was calculated with $V = IR$, and the power dissipated by a circuit element with $P = VI$.

### *2.1. Circuit 1*

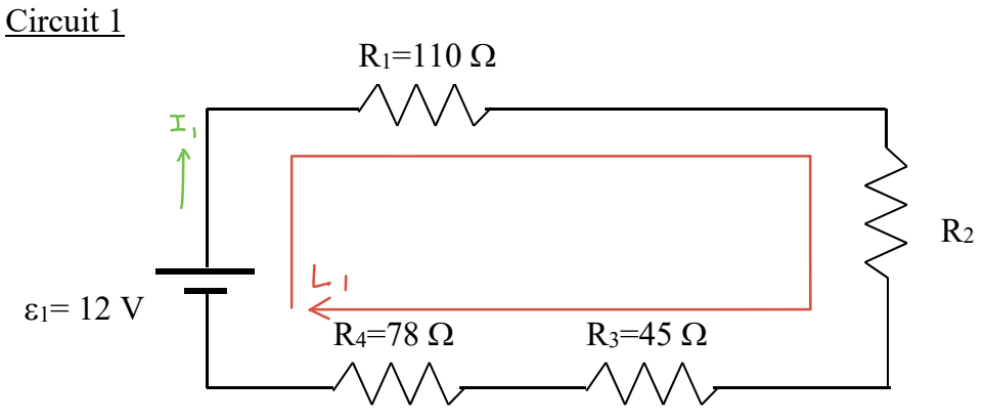


**Figure 1.** Circuit 1

**Table 1.** Circuit 1 $V$, $I$, and $P$

| | $V$ (V) | $I$ (A) | $P$ (W) |
|---|---|---|---|
| $\mathcal{E}_1$ | 12.0 | 0.0440 | 0.527 |
| $R_1$ | 4.84 | 0.0440 | 0.213 |
| $R_2$ | 1.76 | 0.0440 | 0.0773 |
| $R_3$ | 1.98 | 0.0440 | 0.0869 |
| $R_4$ | 3.43 | 0.0440 | 0.151 |

$$\mathrm{L}_1 : \mathcal{E}_1 - I_1 R_1 - I_1 R_2 - I_1 R_3 - I_1 R_4 = 0$$

$$I_1 = \frac{\mathcal{E}_1}{R_1 + R_2 + R_3 + R_4}$$

$$I_1 = 0.0440 \text{ A}$$

### *2.2. Circuit 2*

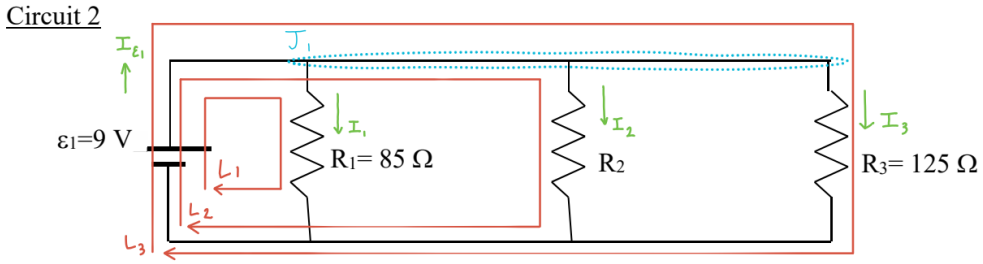


**Figure 2.** Circuit 2

**Table 2.** Circuit 2 $V$, $I$, and $P$

| | $V$ (V) | $I$ (A) | $P$ (W) |
|---|---|---|---|
| $\mathcal{E}_1$ | 9.00 | 0.403 | 3.63 |
| $R_1$ | 9.00 | 0.106 | 0.953 |
| $R_2$ | 9.00 | 0.225 | 2.02 |
| $R_3$ | 9.00 | 0.0720 | 0.648 |

$$\begin{aligned} \text{J}_1: \quad I_{\mathcal{E}_1} &= I_1 + I_2 + I_3 \\ I_1 + I_2 + I_3 - I_{\mathcal{E}_1} &= 0 \end{aligned}$$

$$\begin{aligned} \text{L}_1: \quad \mathcal{E}_1 - I_1 R_1 &= 0 \\ I_1 R_1 &= \mathcal{E}_1 \end{aligned}$$

$$\begin{aligned} \text{L}_2: \quad \mathcal{E}_1 - I_2 R_2 &= 0 \\ I_2 R_2 &= \mathcal{E}_1 \end{aligned}$$

$$\begin{aligned} \text{L}_3: \quad \mathcal{E}_1 - I_3 R_3 &= 0 \\ I_3 R_3 &= \mathcal{E}_1 \end{aligned}$$

$$\begin{bmatrix} 1 & 1 & 1 & -1 \\ R_1 & 0 & 0 & 0 \\ 0 & R_2 & 0 & 0 \\ 0 & 0 & R_3 & 0 \end{bmatrix} \begin{bmatrix} I_1 \\ I_2 \\ I_3 \\ I_{\mathcal{E}_1} \end{bmatrix} = \begin{bmatrix} 0 \\ \mathcal{E}_1 \\ \mathcal{E}_1 \\ \mathcal{E}_1 \end{bmatrix}$$

$$I_1 = 0.106 \text{ A}$$
$$I_2 = 0.225 \text{ A}$$
$$I_3 = 0.0720 \text{ A}$$
$$I_{\mathcal{E}_1} = 0.430 \text{ A}$$

### *2.3. Circuit 3*

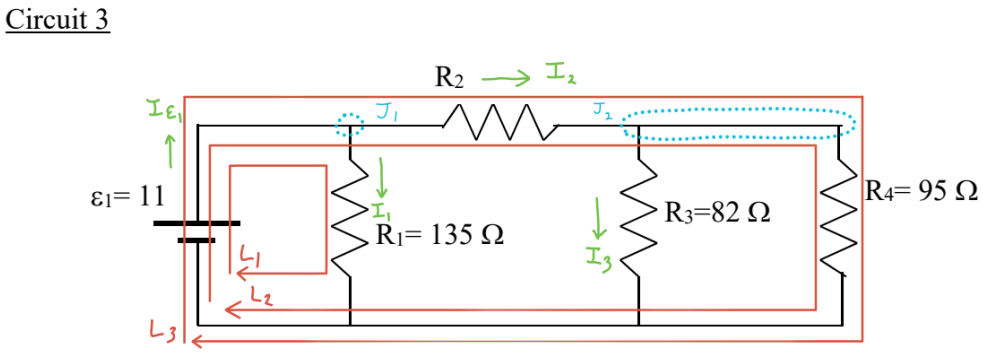


**Figure 3.** Circuit 3

**Table 3.** Circuit 3 $V$, $I$, and $P$

| | $V$ (V) | $I$ (A) | $P$ (W) |
|---|---|---|---|
| $\mathcal{E}_1$ | 11.0 | 0.212 | 2.34 |
| $R_1$ | 11.0 | 0.0815 | 0.896 |
| $R_2$ | 5.24 | 0.131 | 0.686 |
| $R_3$ | 5.76 | 0.0703 | 0.405 |
| $R_4$ | 5.76 | 0.0607 | 0.350 |

$$\begin{aligned} \text{J}_1: \quad I_{\mathcal{E}_1} &= I_1 + I_2 \\ I_1 + I_2 - I_{\mathcal{E}_1} &= 0 \end{aligned}$$

$$\begin{aligned} \text{J}_2: \quad I_2 &= I_3 + I_4 \\ I_2 - I_2 - I_4 &= 0 \end{aligned}$$

$$\begin{aligned} \text{L}_1: \quad \mathcal{E}_1 - I_1 R_1 &= 0 \\ I_1 R_1 &= \mathcal{E}_1 \end{aligned}$$

$$\begin{aligned} \text{L}_2: \mathcal{E}_1 - I_2 R_2 - I_3 R_3 &= 0 \\ I_2 R_2 + I_3 R_3 &= \mathcal{E}_1 \end{aligned}$$

$$\begin{aligned} \text{L}_3: \mathcal{E}_1 - I_2 R_2 - I_4 R_4 &= 0 \\ I_2 R_2 + I_4 R_4 &= \mathcal{E}_1 \end{aligned}$$

$$\begin{bmatrix} 1 & 1 & 0 & 0 & -1 \\ 0 & 1 & -1 & -1 & 0 \\ R_1 & 0 & 0 & 0 & 0 \\ 0 & R_2 & R_3 & 0 & 0 \\ 0 & R_2 & 0 & R_4 & 0 \end{bmatrix} \begin{bmatrix} I_1 \\ I_2 \\ I_3 \\ I_4 \\ I_{\mathcal{E}_1} \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \\ \mathcal{E}_1 \\ \mathcal{E}_1 \\ \mathcal{E}_1 \end{bmatrix}$$

$$\begin{aligned} I_1 &= 0.0815 \text{ A} \\ I_2 &= 0.131 \text{ A} \\ I_3 &= 0.0703 \text{ A} \\ I_4 &= 0.0607 \text{ A} \\ I_{\mathcal{E}_1} &= 0.212 \text{ A} \end{aligned}$$

### *2.4. Circuit 4*

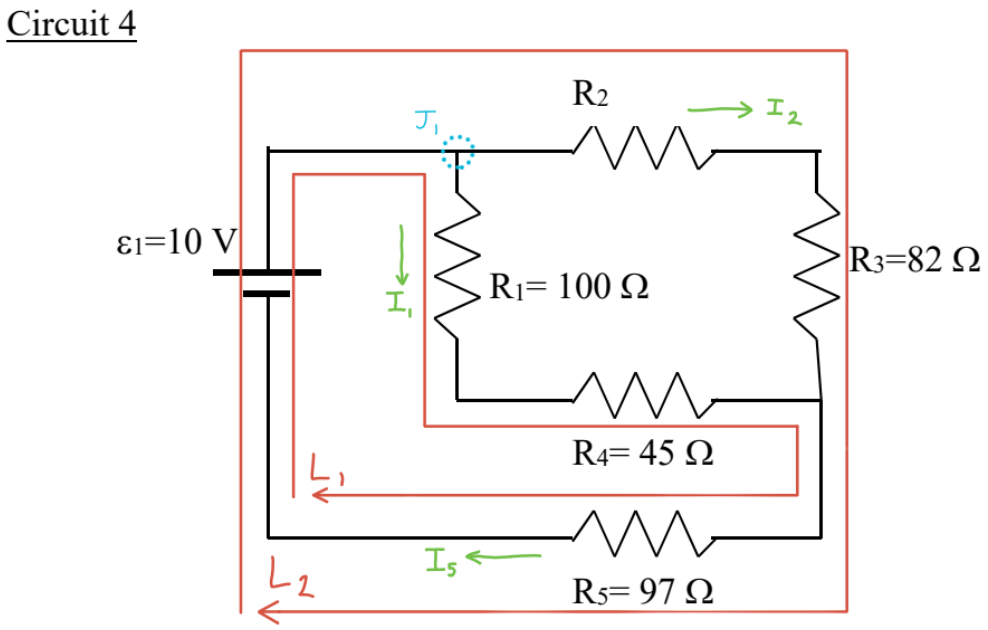


**Figure 4.** Circuit 4

**Table 4.** Circuit 4 $V$, $I$, and $P$

| | $V$ (V) | $I$ (A) | $P$ (W) |
|---|---|---|---|
| $\mathcal{E}_1$ | 10.0 | 0.0613 | 0.613 |
| $R_1$ | 2.80 | 0.0280 | 0.0783 |
| $R_2$ | 1.33 | 0.0333 | 0.0443 |
| $R_3$ | 2.73 | 0.0333 | 0.0907 |
| $R_4$ | 1.26 | 0.0280 | 0.0353 |
| $R_5$ | 5.94 | 0.0613 | 0.364 |

$$\text{J}_1: \quad I_5 = I_1 + I_2$$
$$I_1 + I_2 - I_5 = 0$$

$$\text{L}_1: \mathcal{E}_1 - I_1R_1 - I_1R_4 - I_5R_5 = 0$$
$$I_1(R_1 + R_4) + I_5R_5 = \mathcal{E}_1$$

$$\text{L}_2: \mathcal{E}_1 - I_2R_2 - I_2R_3 - I_5R_5 = 0$$
$$I_2(R_2 + R_3) + I_5R_5 = \mathcal{E}_1$$

$$\begin{bmatrix} 1 & 1 & -1 \\ R_1 + R_4 & 0 & R_5 \\ 0 & R_2 + R_3 & R_5 \end{bmatrix} \begin{bmatrix} I_1 \\ I_2 \\ I_5 \end{bmatrix} = \begin{bmatrix} 0 \\ \mathcal{E}_1 \\ \mathcal{E}_1 \end{bmatrix}$$

$$I_1 = 0.0280 \text{ A}$$
$$I_2 = 0.0333 \text{ A}$$
$$I_5 = 0.0613 \text{ A}$$

### *2.5. Circuit 5*

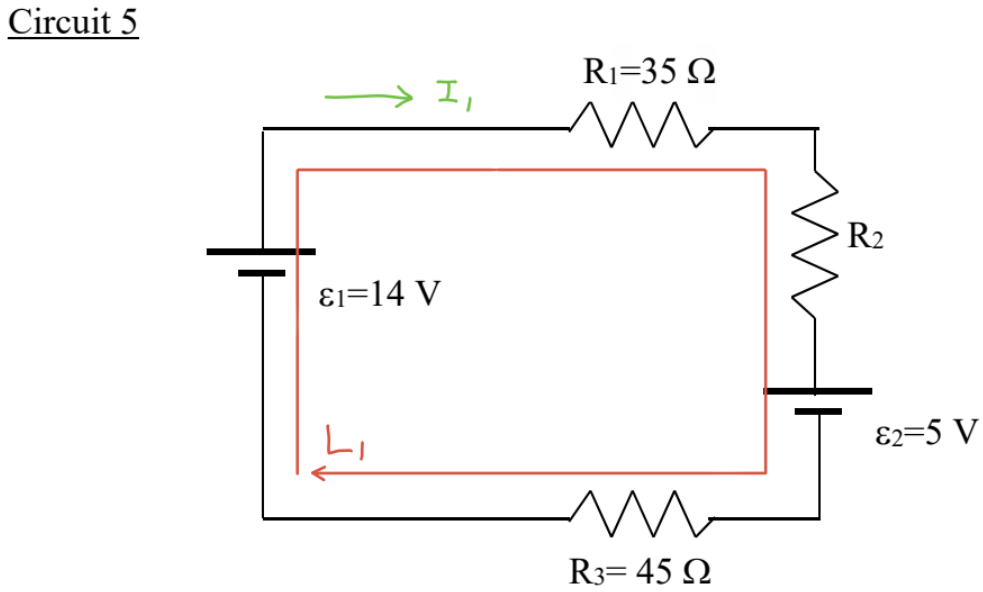


**Figure 5.** Circuit 5

**Table 5.** Circuit 5 $V$, $I$, and $P$

| | $V$ (V) | $I$ (A) | $P$ (W) |
|---|---|---|---|
| $\mathcal{E}_1$ | 14.0 | 0.0750 | 1.05 |
| $\mathcal{E}_2$ | 5.00 | 0.0750 | 0.375 |
| $R_1$ | 2.62 | 0.0750 | 0.197 |
| $R_2$ | 3.00 | 0.0750 | 0.225 |
| $R_3$ | 3.38 | 0.0750 | 0.253 |

$$\mathrm{L}_1 : \mathcal{E}_1 - I_1 R_1 - I_1 R_2 - \mathcal{E}_2 - I_1 R_3 = 0$$

$$I_1 = \frac{\mathcal{E}_1 - \mathcal{E}_2}{R_1 + R_2 + R_3}$$

$$I_1 = 0.0750 \text{ A}$$

### *2.6. Circuit 6*

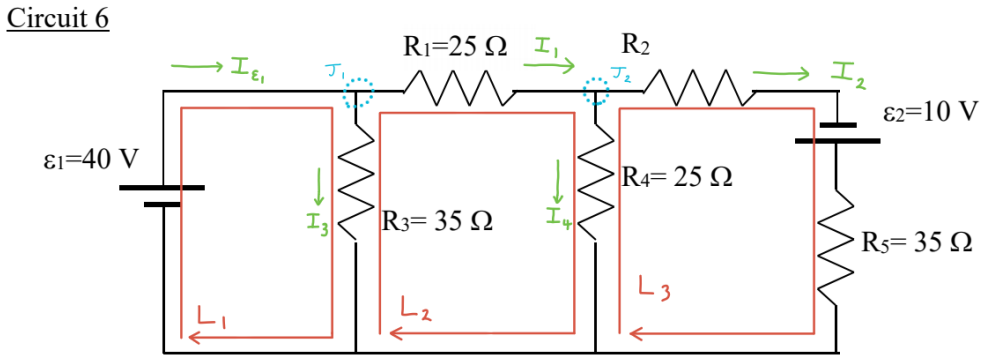


**Figure 6.** Circuit 6

**Table 6.** Circuit 6 $V$, $I$, and $P$

| | $V$ (V) | $I$ (A) | $P$ (W) |
|---|---|---|---|
| $\mathcal{E}_1$ | 40.0 | 2.11 | 84.6 |
| $\mathcal{E}_2$ | 10.0 | 0.343 | 3.43 |
| $R_1$ | 24.3 | 0.971 | 23.6 |
| $R_2$ | 13.7 | 0.343 | 4.70 |
| $R_3$ | 40.0 | 1.14 | 45.7 |
| $R_4$ | 15.7 | 0.629 | 9.88 |
| $R_5$ | 12.0 | 0.343 | 4.11 |

$$\begin{aligned}
\text{J}_1: \qquad I_{\mathcal{E}_1} &= I_1 + I_3 \\
I_1 + I_3 - I_{\mathcal{E}_1} &= 0
\end{aligned}$$

$$\begin{aligned}
\text{J}_2: \qquad I_1 &= I_2 + I_4 \\
I_1 - I_2 - I_4 &= 0
\end{aligned}$$

$$\begin{aligned}
\text{L}_1: \qquad \mathcal{E}_1 - I_3 R_3 &= 0 \\
I_3 R_3 &= \mathcal{E}_1
\end{aligned}$$

$$\begin{aligned}
\text{L}_2: \qquad -I_1 R_1 - I_4 R_4 + I_3 R_3 &= 0 \\
I_1 R_1 - I_3 R_3 + I_4 R_4 &= 0
\end{aligned}$$

$$\begin{aligned}
\text{L}_3: \mathcal{E}_2 - I_2 R_2 - I_2 R_5 + I_4 R_4 &= 0 \\
I_2(R_2 + R_5) - I_4 R_4 &= \mathcal{E}_2
\end{aligned}$$

$$\begin{bmatrix} 1 & 0 & 1 & 0 & -1 \\ 1 & -1 & 0 & -1 & 0 \\ 0 & 0 & R_3 & 0 & 0 \\ R_1 & 0 & -R_3 & R_4 & 0 \\ 0 & R_2 + R_5 & 0 & -R_4 & 0 \end{bmatrix} \begin{bmatrix} I_1 \\ I_2 \\ I_3 \\ I_4 \\ I_{\mathcal{E}_1} \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \\ \mathcal{E}_1 \\ 0 \\ \mathcal{E}_2 \end{bmatrix}$$

$$\begin{aligned}
I_1 &= 0.971 \text{ A} \\
I_2 &= 0.343 \text{ A} \\
I_3 &= 1.14 \text{ A} \\
I_4 &= 0.629 \text{ A} \\
I_{\mathcal{E}_1} &= 2.11 \text{ A}
\end{aligned}$$

*2.7. Circuit 7*

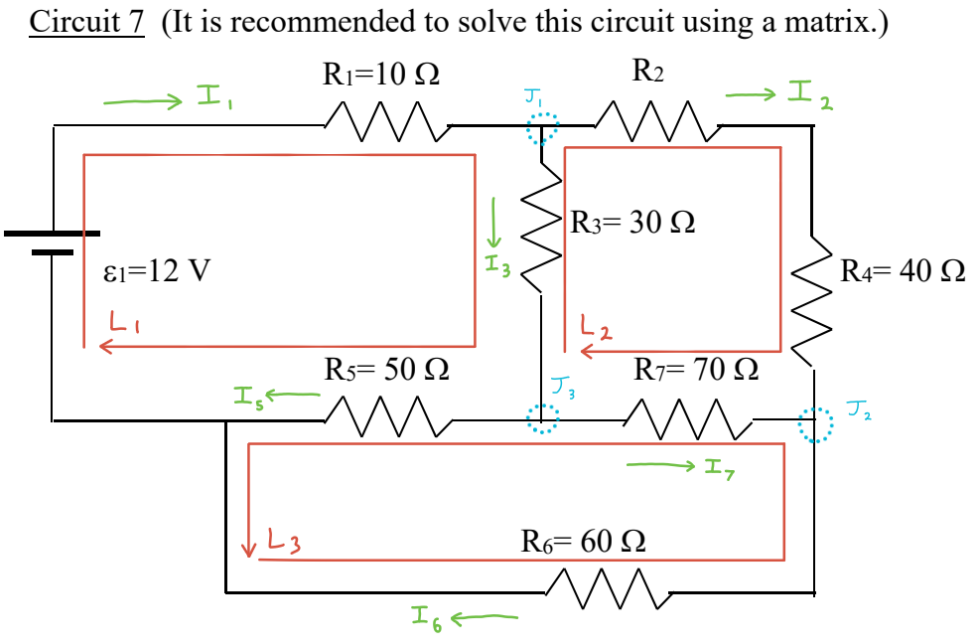


**Figure 7.** Circuit 7

**Table 7.** Circuit 7 $V$, $I$, and $P$

| | $V$ (V) | $I$ (A) | $P$ (W) |
|---|---|---|---|
| $\mathcal{E}_1$ | 12.0 | 0.200 | 2.40 |
| $R_1$ | 2.00 | 0.200 | 0.399 |
| $R_2$ | 2.58 | 0.0646 | 0.167 |
| $R_3$ | 4.05 | 0.135 | 0.547 |
| $R_4$ | 2.58 | 0.0646 | 0.167 |
| $R_5$ | 5.95 | 0.119 | 0.709 |
| $R_6$ | 4.83 | 0.0806 | 0.390 |
| $R_7$ | 1.12 | 0.0160 | 0.0179 |

$$\begin{aligned}
\text{J}_1: \qquad I_1 &= I_2 + I_3 \\
I_1 - I_2 - I_3 &= 0
\end{aligned}$$

$$\begin{aligned}
\text{J}_2: \qquad I_2 + I_7 &= I_6 \\
I_2 - I_6 + I_7 &= 0
\end{aligned}$$

$$\begin{aligned}
\text{J}_3: \qquad I_3 &= I_5 + I_7 \\
I_3 - I_5 - I_7 &= 0
\end{aligned}$$

$$\begin{aligned}
\text{L}_1: \qquad \mathcal{E}_1 - I_1R_1 - I_3R_3 - I_5R_5 &= 0 \\
I_1R_1 + I_3R_3 + I_5R_5 &= \mathcal{E}_1
\end{aligned}$$

$$\begin{aligned}
\text{L}_2: -I_2R_2 - I_2R_4 + I_7R_7 + I_3R_3 &= 0 \\
I_2(R_2 + R_4) - I_3R_3 - I_7R_7 &= 0
\end{aligned}$$

$$\begin{aligned}
\text{L}_3: \qquad -I_5R_5 + I_6R_6 + I_7R_7 &= 0 \\
I_5R_5 - I_6R_6 - I_7R_7 &= \mathcal{E}_2
\end{aligned}$$

$$\begin{bmatrix}
1 & -1 & -1 & 0 & 0 & 0 \\
0 & 1 & 0 & 0 & -1 & 1 \\
0 & 0 & 1 & -1 & 0 & -1 \\
R_1 & 0 & R_3 & R_5 & 0 & 0 \\
0 & R_2 + R_4 & -R_3 & 0 & 0 & -R_7 \\
0 & 0 & 0 & R_5 & -R_6 & -R_7
\end{bmatrix}
\begin{bmatrix} I_1 \\ I_2 \\ I_3 \\ I_5 \\ I_6 \\ I_7 \end{bmatrix}
=
\begin{bmatrix} 0 \\ 0 \\ 0 \\ \mathcal{E}_1 \\ 0 \\ 0 \end{bmatrix}$$

$$\begin{aligned}
I_1 &= 0.200 \text{ A} \\
I_2 &= 0.0646 \text{ A} \\
I_3 &= 0.135 \text{ A} \\
I_5 &= 0.119 \text{ A} \\
I_6 &= 0.0806 \text{ A} \\
I_7 &= 0.0160 \text{ A}
\end{aligned}$$

## 3. Conclusion

## 4. Citations

[1] Karen Schnurbusch, *Physics 4B Lab Book*, Mt. San Antonio College, 2023, pp. 71-74.
[2] Karen Schnurbusch, *Physics 4B Equations*, Mt. San Antonio College, 2023, pp. 4, 5.