

# Circuits Lab

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$$R_2 = 40\ \Omega$$

## 1. Purpose

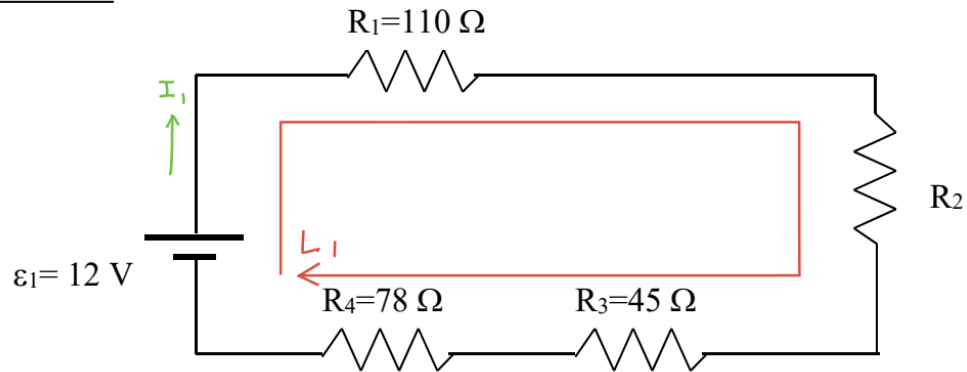
The goal of the exercise was to use Kirchhoff's rules to analyze 7 different circuits and calculate current, voltage, and power for each circuit element. For the first 4 circuits, the voltage and current calculations were compared to results obtained using an online circuit simulator.

## 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

Circuit 1



**Figure 1.** Circuit 1

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

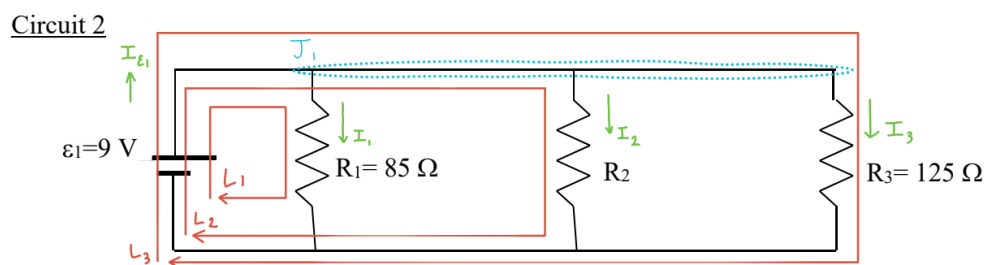
	$V$ (V)	$I$ (A)	$P$ (W)
$\mathcal{E}_1$	12.0	0.0440	0.527
$R_1$	4.84	0.0440	0.213
$R_2$	1.76	0.0440	0.0773
$R_3$	1.98	0.0440	0.0869
$R_4$	3.43	0.0440	0.151

$$L_1 : \mathcal{E}_1 - I_1 R_1 - I_1 R_2 - I_1 R_3 - I_1 R_4 = 0$$

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

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

## 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

$$J_1 : \quad \begin{aligned} I_{\mathcal{E}_1} &= I_1 + I_2 + I_3 \\ I_1 + I_2 + I_3 - I_{\mathcal{E}_1} &= 0 \end{aligned}$$

$$L_1 : \quad \begin{aligned} \mathcal{E}_1 - I_1 R_1 &= 0 \\ I_1 R_1 &= \mathcal{E}_1 \end{aligned}$$

$$L_2 : \quad \begin{aligned} \mathcal{E}_1 - I_2 R_2 &= 0 \\ I_2 R_2 &= \mathcal{E}_1 \end{aligned}$$

$$L_3 : \quad \begin{aligned} \mathcal{E}_1 - I_3 R_3 &= 0 \\ I_3 R_3 &= \mathcal{E}_1 \end{aligned}$$

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

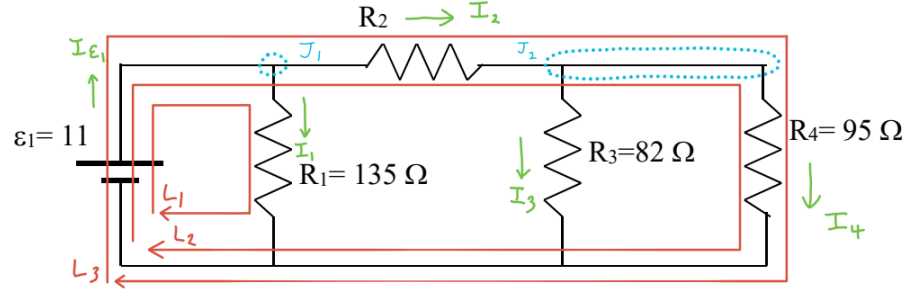
$$I_1 = 0.106 \text{ A}$$

$$I_2 = 0.225 \text{ A}$$

$$I_3 = 0.0720 \text{ A}$$

$$I_{\mathcal{E}_1} = 0.403 \text{ A}$$

## 2.3. Circuit 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

$$\begin{aligned} J_1 : \quad & I_{\mathcal{E}_1} = I_1 + I_2 \\ & I_1 + I_2 - I_{\mathcal{E}_1} = 0 \end{aligned}$$

$$\begin{aligned} J_2 : \quad & I_2 = I_3 + I_4 \\ & I_2 - I_3 - I_4 = 0 \end{aligned}$$

$$\begin{aligned} L_1 : \quad & \mathcal{E}_1 - I_1 R_1 = 0 \\ & I_1 R_1 = \mathcal{E}_1 \end{aligned}$$

$$\begin{aligned} L_2 : \quad & \mathcal{E}_1 - I_2 R_2 - I_3 R_3 = 0 \\ & I_2 R_2 + I_3 R_3 = \mathcal{E}_1 \end{aligned}$$

$$\begin{aligned} L_3 : \quad & \mathcal{E}_1 - I_2 R_2 - I_4 R_4 = 0 \\ & I_2 R_2 + I_4 R_4 = \mathcal{E}_1 \end{aligned}$$

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

$$I_1 = 0.0815 \text{ A}$$

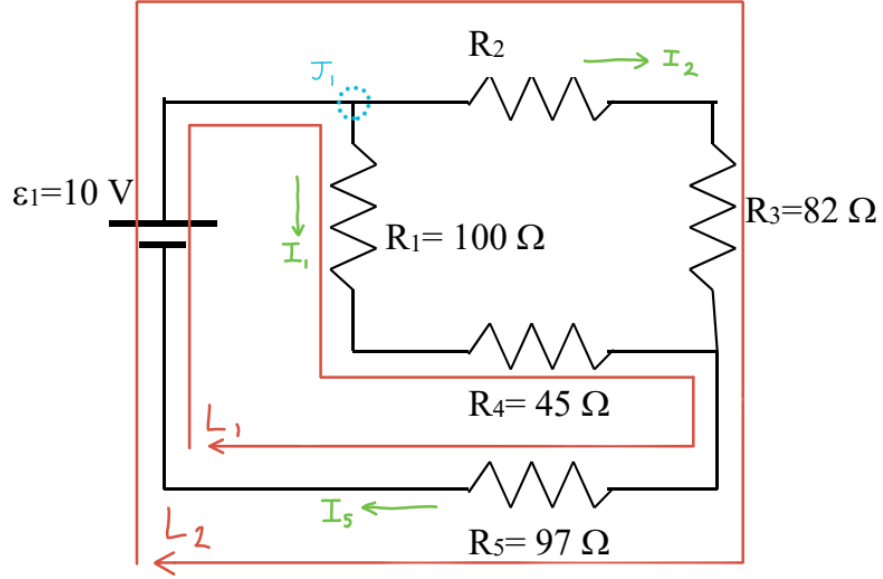
$$I_2 = 0.131 \text{ A}$$

$$I_3 = 0.0703 \text{ A}$$

$$I_4 = 0.0607 \text{ A}$$

$$I_{\mathcal{E}_1} = 0.212 \text{ A}$$

## 2.4. Circuit 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

$$J_1 : \quad I_5 = I_1 + I_2$$

$$I_1 + I_2 - I_5 = 0$$

$$L_1 : \mathcal{E}_1 - I_1 R_1 - I_1 R_4 - I_5 R_5 = 0$$

$$I_1 (R_1 + R_4) + I_5 R_5 = \mathcal{E}_1$$

$$L_2 : \mathcal{E}_1 - I_2 R_2 - I_2 R_3 - I_5 R_5 = 0$$

$$I_2 (R_2 + R_3) + I_5 R_5 = \mathcal{E}_1$$

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

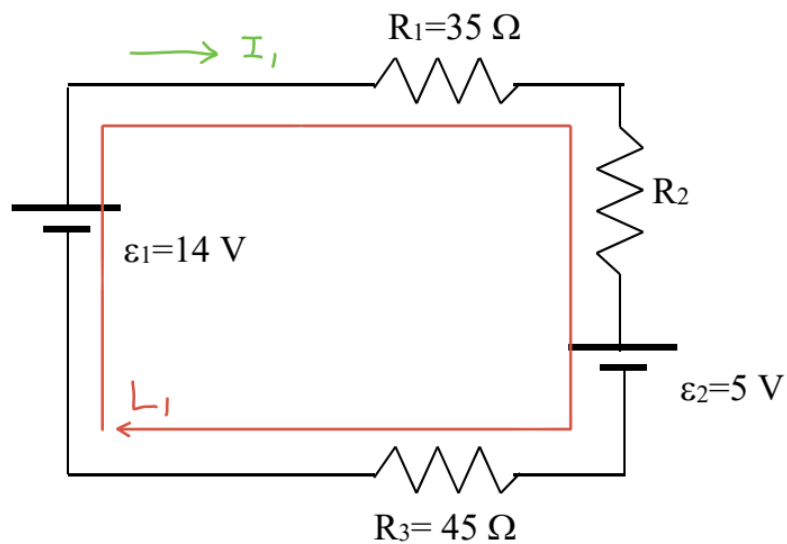
$$I_1 = 0.0280 \text{ A}$$

$$I_2 = 0.0333 \text{ A}$$

$$I_5 = 0.0613 \text{ A}$$



## 2.5. Circuit 5

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

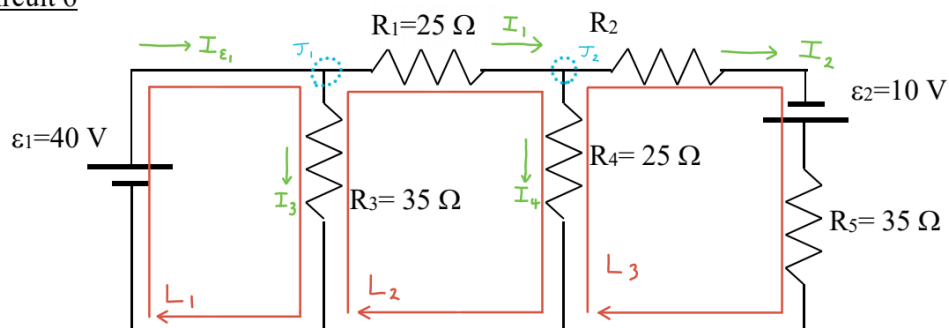
	$V$ (V)	$I$ (A)	$P$ (W)
$\mathcal{E}_1$	14.0	0.0750	1.05
$\mathcal{E}_2$	5.00	0.0750	0.375
$R_1$	2.62	0.0750	0.197
$R_2$	3.00	0.0750	0.225
$R_3$	3.38	0.0750	0.253

$$L_1 : \mathcal{E}_1 - I_1 R_1 - I_1 R_2 - \mathcal{E}_2 - I_1 R_3 = 0$$

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

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

## 2.6. Circuit 6

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

$$\begin{aligned} J_1 : \quad & I_{\mathcal{E}_1} = I_1 + I_3 \\ & I_1 + I_3 - I_{\mathcal{E}_1} = 0 \end{aligned}$$

$$\begin{aligned} J_2 : \quad & I_1 = I_2 + I_4 \\ & I_1 - I_2 - I_4 = 0 \end{aligned}$$

$$\begin{aligned} L_1 : \quad & \mathcal{E}_1 - I_3 R_3 = 0 \\ & I_3 R_3 = \mathcal{E}_1 \end{aligned}$$

$$\begin{aligned} L_2 : \quad & -I_1 R_1 - I_4 R_4 + I_3 R_3 = 0 \\ & I_1 R_1 - I_3 R_3 + I_4 R_4 = 0 \end{aligned}$$

$$\begin{aligned} L_3 : \quad & \mathcal{E}_2 - I_2 R_2 - I_2 R_5 + I_4 R_4 = 0 \\ & I_2(R_2 + R_5) - I_4 R_4 = \mathcal{E}_2 \end{aligned}$$

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

$$I_1 = 0.971 \text{ A}$$

$$I_2 = 0.343 \text{ A}$$

$$I_3 = 1.14 \text{ A}$$

$$I_4 = 0.629 \text{ A}$$

$$I_{\mathcal{E}_1} = 2.11 \text{ A}$$

## 2.7. Circuit 7

Circuit 7 (It is recommended to solve this circuit using a matrix.)

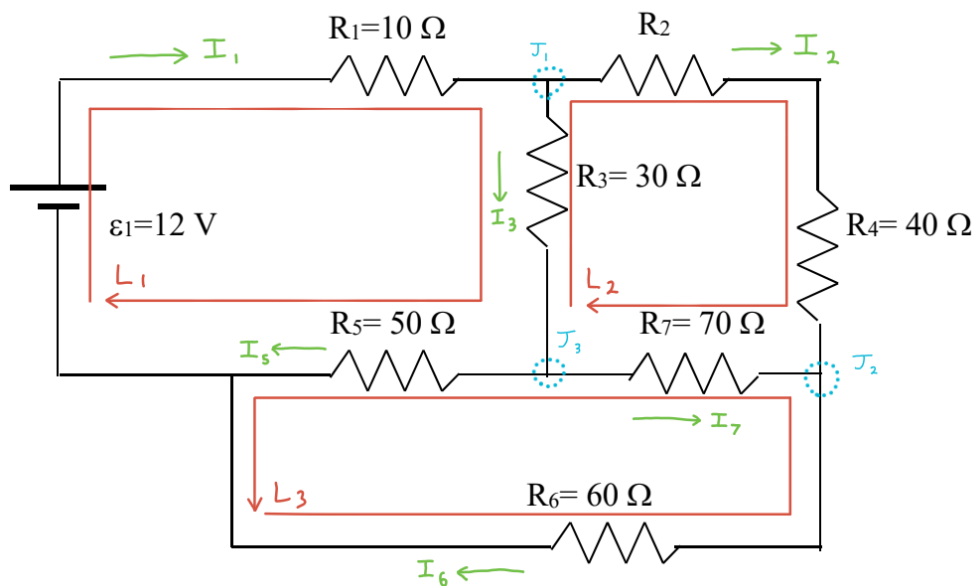


Figure 7. Circuit 7

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

$$\begin{aligned} J_1 : \quad & I_1 = I_2 + I_3 \\ & I_1 - I_2 - I_3 = 0 \end{aligned}$$

$$\begin{aligned} J_2 : \quad & I_2 + I_7 = I_6 \\ & I_2 - I_6 + I_7 = 0 \end{aligned}$$

$$\begin{aligned} J_3 : \quad & I_3 = I_5 + I_7 \\ & I_3 - I_5 - I_7 = 0 \end{aligned}$$

$$\begin{aligned} L_1 : \quad & \mathcal{E}_1 - I_1 R_1 - I_3 R_3 - I_5 R_5 = 0 \\ & I_1 R_1 + I_3 R_3 + I_5 R_5 = \mathcal{E}_1 \end{aligned}$$

$$\begin{aligned} L_2 : \quad & -I_2 R_2 - I_2 R_4 + I_7 R_7 + I_3 R_3 = 0 \\ & I_2 (R_2 + R_4) - I_3 R_3 - I_7 R_7 = 0 \end{aligned}$$

$$\begin{aligned} L_3 : \quad & -I_5 R_5 + I_6 R_6 + I_7 R_7 = 0 \\ & I_5 R_5 - I_6 R_6 - I_7 R_7 = \mathcal{E}_2 \end{aligned}$$

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

$$I_1 = 0.200 \text{ A}$$

$$I_2 = 0.0646 \text{ A}$$

$$I_3 = 0.135 \text{ A}$$

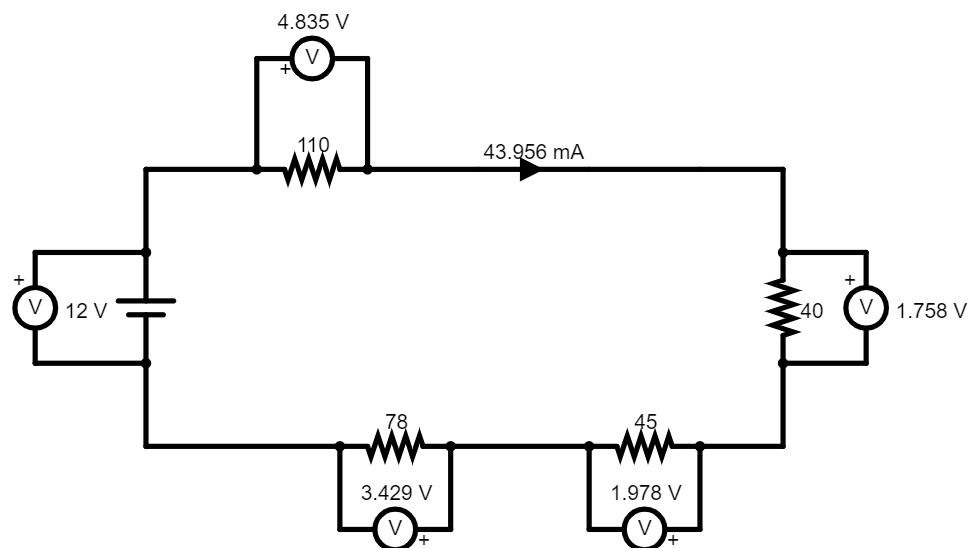
$$I_5 = 0.119 \text{ A}$$

$$I_6 = 0.0806 \text{ A}$$

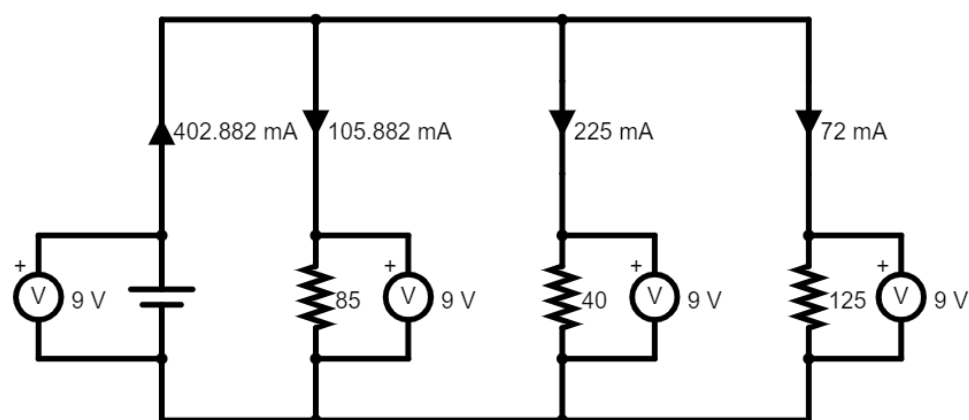
$$I_7 = 0.0160 \text{ A}$$

### 3. Simulations

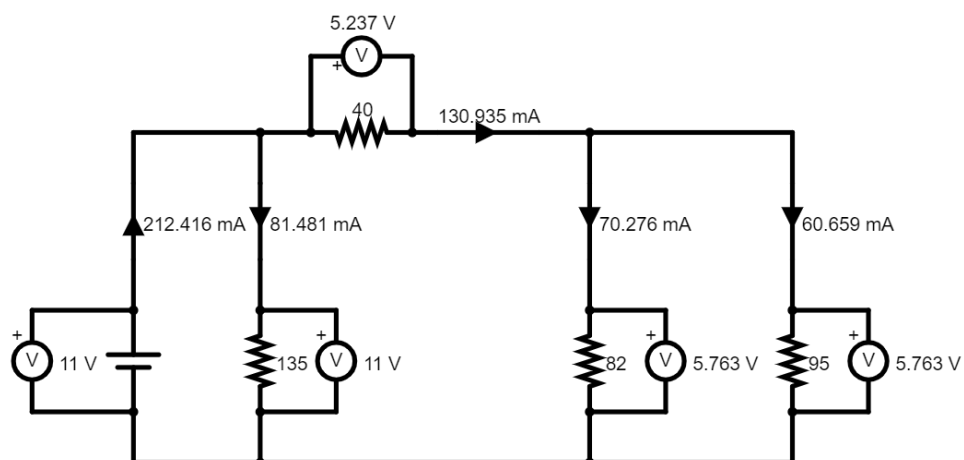
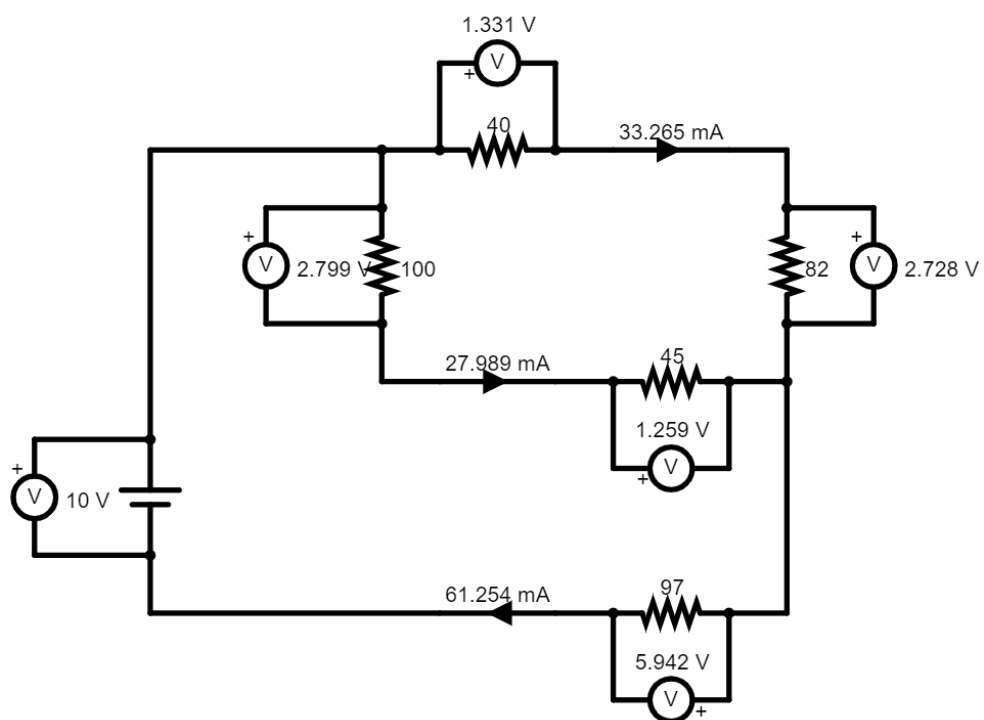
Circuits 1 through 4 were simulated using the Circuit Simulator Applet (located at <https://www.falstad.com/circuit/> ). All the voltage and current values match the calculations to 3 significant figures (Yay!).



**Figure 8.** Circuit 1 Simulation



**Figure 9.** Circuit 2 Simulation

**Figure 10.** Circuit 3 Simulation**Figure 11.** Circuit 4 Simulation

## **4. Conclusion**

## **5. 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.
- [3] Paul Falstad, *Circuit Simulator Applet*, <https://www.falstad.com/circuit/> Accessed 26 April 2023.