Cornerstone Electronics Technology and Robotics I Week 15
Combination Circuits (Series-Parallel Circuits)

- Administration:
  - o Prayer
  - o Turn in quiz
- Electricity and Electronics, **Chapter 8**, Introduction:
  - o In this lesson, we will learn to analyze circuits with resistors in both series and parallel together and compute the total resistance (equivalent resistance) for those circuits. From there, we can calculate the voltage drop and current for each resistor in the circuit.
  - o Series-parallel circuits are also called combination circuits.
  - o Examples:

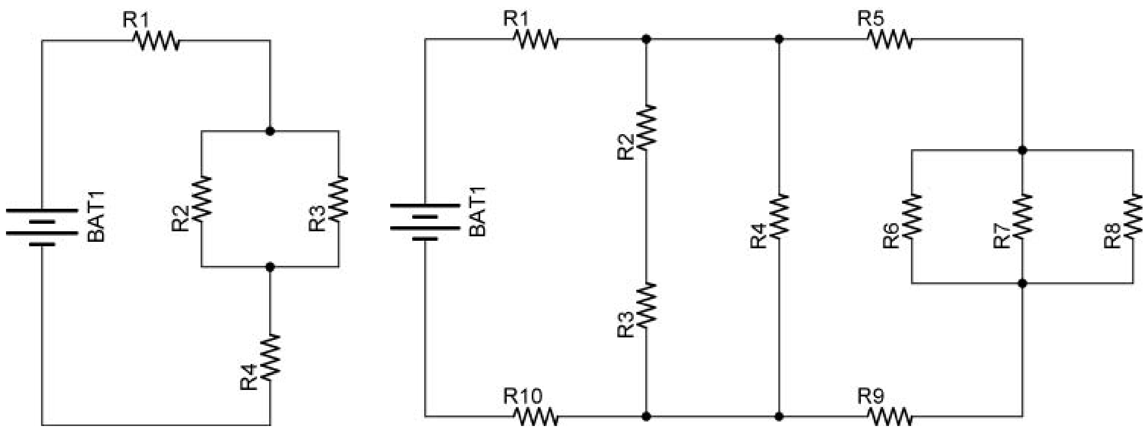


Figure 1 – Examples of Combination Circuits

  - o See applets:
    - http://www.falstad.com/circuit/e-resistors.html
    - http://webphysics.davidson.edu/physlet_resources/bu_semester2/c10_combo.html
  - o Regardless of the complexity of a series-parallel circuit, it can be solved when broken down into steps of individual series and parallel circuits.
  - o Review:
    - Four equations are used to solve series resistor circuits. They are:

$$\mathbf{R_T = R_1 + R_2 + R_3 + \ldots + R_N}$$
$$\mathbf{V_T = V_1 + V_2 + V_3 + \ldots + V_N}$$
$$\mathbf{I_T = I_1 = I_2 = I_3 = \ldots I_N}$$
$$\mathbf{V = I \times R}$$

V = I x R can be applied to the total circuit ($V_T = I_T \times R_T$) and to individual resistors ($V_1 = I_1 \times R_1$).

See Lesson 13, Series Circuits for details. Link:
http://cornerstonerobotics.org/curriculum/lessons_year1/ER%20Week13,%20Series%20Circuits.pdf

- Four equations are used to solve parallel resistor circuits. They are:

  $$1/R_T = 1/R_1 + 1/R_2 + 1/R_3 + \ldots\ldots\ldots\ldots + 1/R_N$$
  $$V_T = V_1 = V_2 = V_3 = \ldots\ldots V_N$$
  $$I_T = I_1 + I_2 + I_3 + \ldots + I_N$$
  $$V = I \times R$$

  See Lesson 14, Parallel Circuits for details. Link:
http://cornerstonerobotics.org/curriculum/lessons_year1/ER%20Week14,%20Parallel%20Circuits.pdf

- Power in Combination Circuits: The total power in a combination circuit is equal to the sum of the individual powers.
- The variables used in Ohm's Law equations must be *common* to the same two points in the circuit under consideration. This rule cannot be overemphasized. This is especially important in series-parallel combination circuits where nearby components may have different values for both voltage drop *and* current.

- Electricity and Electronics, **Section 8.1,** Solving a Complex Circuit:
  - The goal of series-parallel resistor circuit analysis is to be able to determine all voltage drops, currents, and power dissipations in a circuit.
  - **Contracting the Circuit:** Finding the total resistance and total current: In this section, you will combine series and parallel resistors in a step by step process until the entire circuit is reduced to one equivalent resistor.
    - **Step 1:** Assess which resistors in a circuit are connected together in simple series or simple parallel.
    - **Step 2:** Re-draw the circuit, replacing each of those series or parallel resistor combinations identified in step 1 with a single, equivalent-value resistor.
    - **Step 3:** Repeat Steps 1 and 2 until the entire circuit is reduced to one equivalent resistor.
    - **Step 4:** Find the total current for the circuit.
  - **Expanding the Circuit:** In this section, you will proceed step-by-step from the simplified version of the circuit back to its original form, plugging in values of voltage and current where appropriate until all values of voltage and current are known.
    - **Step 5:** Taking total voltage and total current values, go back to last step in the circuit reduction process and insert those values where applicable.
    - **Step 6:** From known resistances, total voltage, and total current values from step 5, use Ohm's Law to calculate unknown values (voltage or current)
    - **Step 7:** Repeat steps 5 and 6 until all values for voltage and current are known in the original circuit configuration. Essentially, you will proceed step-by-step from the simplified version of the circuit back to its original, complex form, plugging in values of voltage and current where appropriate until all values of voltage and current are known.
    - **Step 8:** Calculate power dissipations from known voltage, current, and/or resistance values.

Contracting a combination circuit to determine the one equivalent resistor:

Expanding a combination circuit to determine the circuit currents and voltages:

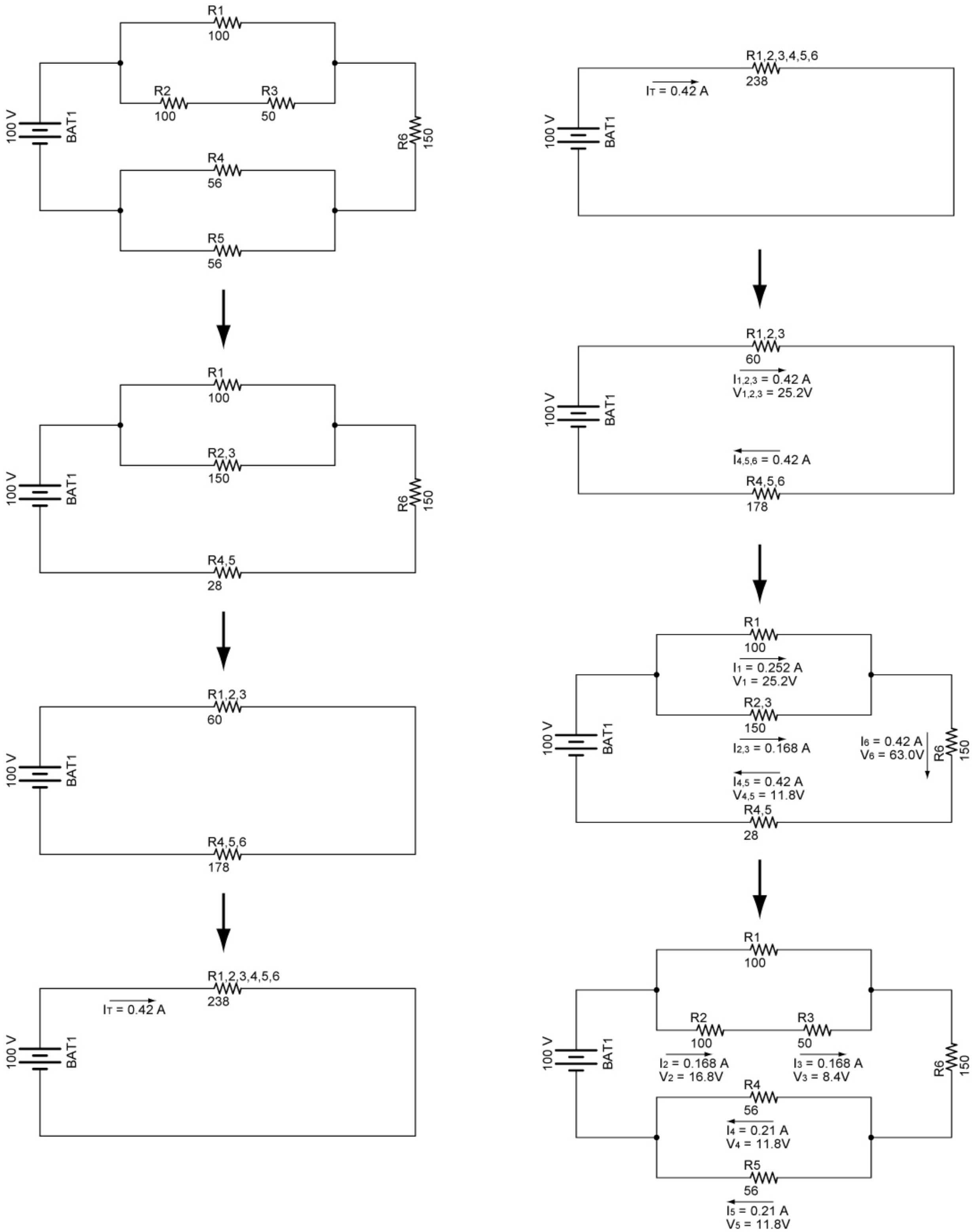


Figure 2 – Example of Contracting and Expanding a Combination Circuit

Example 1: Parallel resistors R_1 and R_2 are in series with resistor R_3. See Figure 3.

(Note: In the following examples, when you encounter a resistor labeled $R_{1,2}$, it is an equivalent resistor for resistors R_1 and R_2. $R_{1,2,3,4,5}$ is the equivalent resistor for resistors R_1, R_2, R_3, R_4, and R_5. Similarly, $V_{4,5}$ is the voltage drop across the equivalent resistor $R_{4,5}$.)

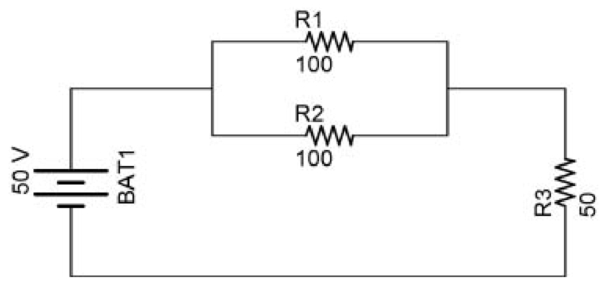


Figure 3

Solve for the all of the unknowns in Table 1.

	Resistance	Voltage	Current
R_1	100 Ω	V_1	I_1
R_2	100 Ω	V_2	I_2
R_3	50 Ω	V_3	I_3
Total	R_T	50 V	I_T

Table 1

- **Contracting the Circuit:** Finding the Total Resistance, R_T and Total Current, I_T :
  - **Step 1:** Assess which resistors in a circuit are connected together in simple series or simple parallel. In our circuit, R_1 and R_2 are in a simple parallel configuration.
  - **Step 2:** Re-draw the circuit, (Figure 4), replacing each of those series or parallel resistor combinations identified in Step 1 with a single, equivalent-value resistor. In this circuit, R_1 and R_2 are replaced with $R_{1,2}$.

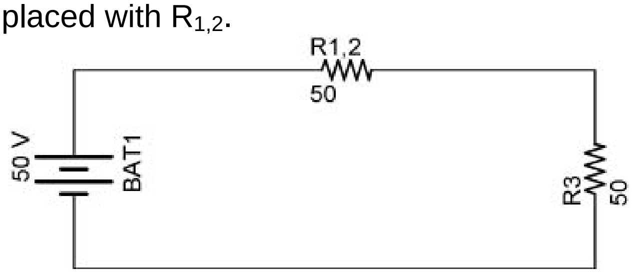


Figure 4

$R_{1,2} = R/N$
$R_{1,2} = 100\ \Omega / 2$
$R_{1,2} = 50\ \Omega$

- **Step 3:** Repeat Steps 1 and 2 until the entire circuit is reduced to one equivalent resistor. (Step 1) - $R_{1,2}$ and R_3 are in a simple series configuration. (Step 2) - Re-draw the circuit, (Figure 5), with $R_{1,2,3}$ replacing $R_{1,2}$ and R_3. Enter R_T, ($R_{1,2,3}$), into the solution table (Table 2).

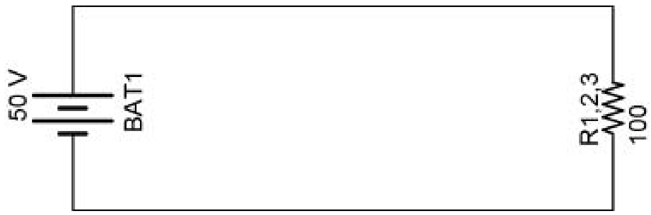


Figure 5

$R_T = R_{1,2,3}$
$R_T = R_{1,2} + R_3$
$R_T = 50\ \Omega + 50\ \Omega$
$R_T = 100\ \Omega$

	Resistance	Voltage	Current
R1	R1 = 100 Ω	V1	I1
R2	R2 = 100 Ω	V2	I2
R3	R3 = 50 Ω	V3	I3
Total	**R_T = 100 Ω**	V_T = 50 V	I_T

Table 2

- **Step 4:** Find the total current for the circuit.

$I_T = V_T / R_T$
$I_T = 50\ V / 100\ \Omega$
$I_T = 0.5\ A$

See Table 3:

	Resistance	Voltage	Current
R1	R1 = 100 Ω	V1	I1
R2	R2 = 100 Ω	V2	I2
R3	R3 = 50 Ω	V3	I3
Total	R_T = 100 Ω	V_T = 50 V	**I_T = 0.5 A**

Table 3

- **Expanding the Circuit:** Find all remaining values of voltage and current.
  - **Step 5:** Taking total voltage and total current values, go back to last step in the circuit reduction process, (Figure 6), and insert those values where applicable. We can now determine the current through each series resistor in the equivalent circuit in Figure 8.4.

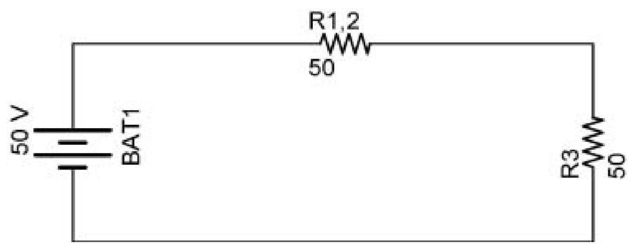


Figure 6

$I_T = I_{1,2} = I_3 = 0.5$ A

Enter the value of I_3 into the solution table (Table 4).

	Resistance	Voltage	Current
R1	R1 = 100 Ω	V1	I1
R2	R2 = 100 Ω	V2	I2
R3	R3 = 50 Ω	V3	**I3 = 0.5 A**
Total	R_T = 100 Ω	V_T = 50 V	I_T = 0.5 A

Table 4

  - **Step 6:** From known resistances, total voltage, and total current values from Step 5, use Ohm's Law to calculate unknown values (voltage or current). In our example, calculate the voltage drop V_3 across the series resistor R_3 and the voltage drop $V_{1,2}$ across the parallel combination (equivalent resistor, $R_{1,2}$).

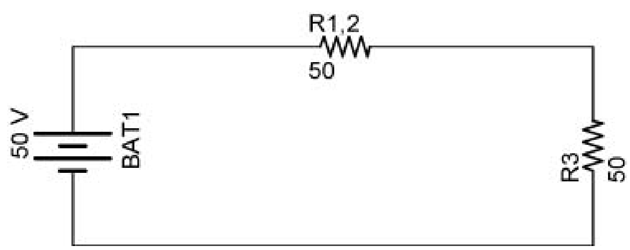


Figure 7

$V_3 = I_3 \times R_3$
$V_3 = 0.5 \text{ A} \times 50\ \Omega$
$V_3 = 25 \text{ V}$
$V_{1,2} = I_{1,2} \times R_{1,2}$
$V_{1,2} = 0.5 \text{ A} \times 50\ \Omega$
$V_{1,2} = 25 \text{ V}$

Since R_1 and R_2 are parallel resistors, the voltage drops V_1 and V_2 are the same value and equal to $V_{1,2}$.

$$V_1 = V_2 = V_{1,2} = 25 \text{ V}$$

We can now enter V_1, V_2, and V_3 into the solution table (Table 5).

	Resistance	Voltage	Current
R1	R1 = 100 Ω	**V1 = 25 V**	I1
R2	R2 = 100 Ω	**V2 = 25 V**	I2
R3	R3 = 50 Ω	**V3 = 25 V**	I3 = 0.5 A
Total	R_T = 100 Ω	V_T = 50 V	I_T = 0.5 A

Table 5

- **Step 7:** Repeat steps 5 and 6 until all values for voltage and current are known in the original circuit configuration. Essentially, you will proceed step-by-step from the simplified version of the circuit back into its original, complex form, plugging in values of voltage and current where appropriate until all values of voltage and current are known. Here, calculate the current through each parallel resistor (R_1 and R_2) in the parallel resistor combination. Use Ohm's Law.

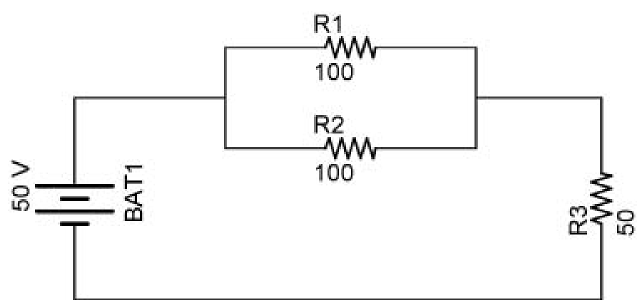


Figure 8

$I_1 = V_1 / R_1$
$I_1 = 25 \text{ V} / 100 \ \Omega$
$I_1 = 0.25 \text{ A}$

$I_2 = V_2 / R_2$
$I_2 = 25 \text{ V} / 100 \ \Omega$
$I_2 = 0.25 \text{ A}$

Enter I_1 and I_2 into the solution table (Table 6).

	Resistance	Voltage	Current
R1	R1 = 100 Ω	V1 = 25 V	**I1 = 0.25 A**
R2	R2 = 100 Ω	V2 = 25 V	**I2 = 0.25 A**
R3	R3 = 50 Ω	V3 = 25 V	I3 = 0.5 A
Total	R_T = 100 Ω	V_T = 50 V	I_T = 0.5 A

Table 6

- **Step 8:** Calculate power dissipations from known voltage, current, and/or resistance values.

$P_1 = V_1 \times I_1$
$P_1 = 25\ V \times 0.25\ A$
$P_1 = 6.25\ W$

$P_2 = V_2 \times I_2$
$P_2 = 25\ V \times 0.25\ A$
$P_2 = 6.25\ W$

$P_3 = V_3 \times I_3$
$P_3 = 25\ V \times 0.5\ A$
$P_3 = 12.5\ W$

$P_T = V_T \times I_T$
$P_T = 50\ V \times 0.5\ A$
$P_T = 25\ W$

The final solution table (Table 7):

	Resistance	Voltage	Current	Power
R1	R1 = 100 Ω	V1 = 25 V	I1 = 0.25 A	**P1 = 6.25 W**
R2	R2 = 100 Ω	V2 = 25 V	I2 = 0.25 A	**P2 = 6.25 W**
R3	R3 = 50 Ω	V3 = 25 V	I3 = 0.5 A	**P3 = 12.5 W**
Total	R_T = 100 Ω	V_T = 50 V	I_T = 0.5 A	**P_T = 25 W**

Table 7

Summary of Values:

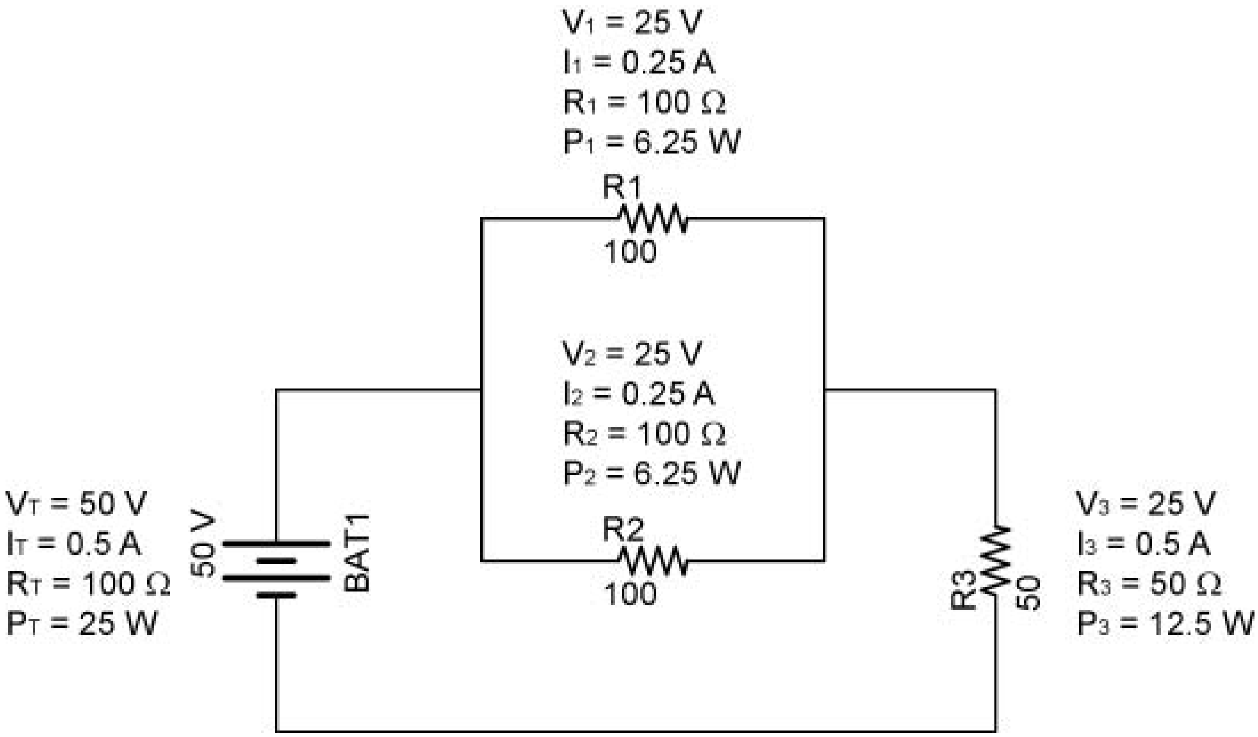


Figure 9

- **Example 2:** This combination circuit is a more complicated set of series and parallel resistors. See Figure 10.

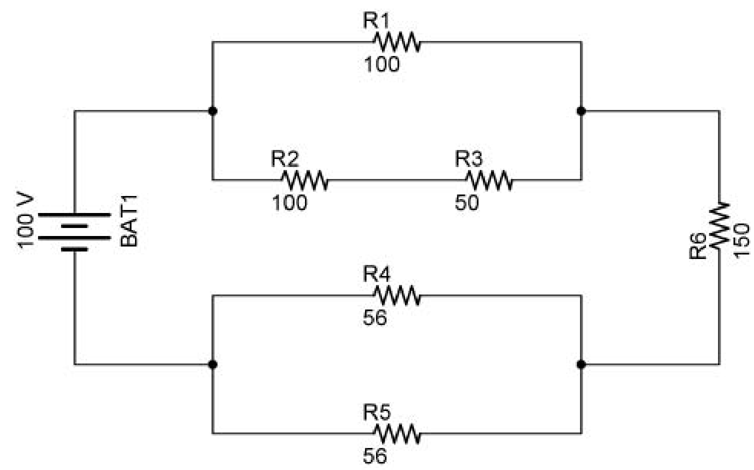


Figure 10

Solve for the all of the unknowns in Table 8.

Resistor	Resistance	Voltage	Current
R1	R1 = 100 Ω	**V1**	**I1**
R2	R2 = 100 Ω	**V2**	**I2**
R3	R3 = 50 Ω	**V3**	**I3**
R4	R4 = 56 Ω	**V4**	**I4**
R5	R5 = 56 Ω	**V5**	**I5**
R6	R6 = 150 Ω	**V6**	**I6**
Totals	**R_T**	V_T = 100 V	**I_T**

Table 8

- **Contracting the Circuit:** Finding the Total Resistance, R_T and Total Current, I_T :
  - **Step 1:** Assess which resistors in a circuit are connected together in simple series or simple parallel. In this circuit, R_2 and R_3 are in simple series in a parallel branch. Also, R_4 and R_5 are in simple parallel configuration.
  - **Step 2:** Re-draw the circuit, (Figure 11), replacing each of those series or parallel resistor combinations identified in Step 1 with a single, equivalent-value resistor.

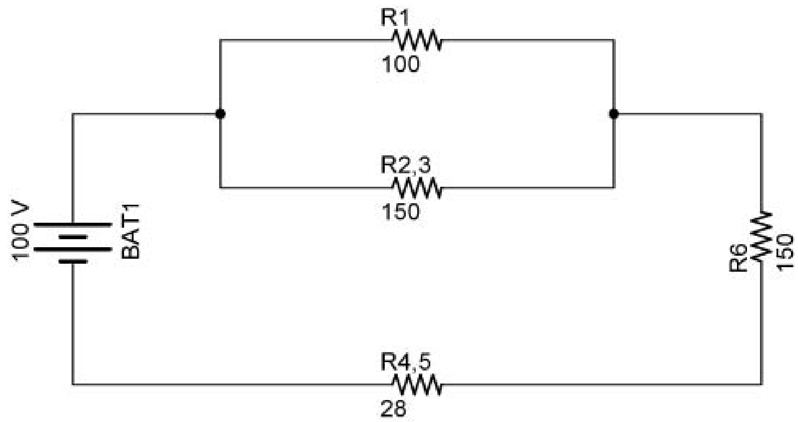


Figure 11

To determine the equivalent resistance $R_{2,3}$, add the series resistors R_2 and R_3 together.

$R_{2,3}$:

$R_{2,3} = R_2 + R_3$
$R_{2,3} = 100\ \Omega + 50\ \Omega$
$R_{2,3} = 150\ \Omega$

Also determine the equivalent resistor $R_{4,5}$ for the parallel resistors, R_4 and R_5, using the formula for parallel resistors of equal value.

$R_{4,5}$:

$R_{4,5} = R/N$
$R_{4,5} = 56\ \Omega / 2$
$R_{4,5} = 28\ \Omega$

- **Step 3:** Repeat Steps 1 and 2 until the entire circuit is reduced to one equivalent resistor. (Step 1) - R_1 and $R_{2,3}$ are in a simple parallel configuration. $R_{4,5}$ and R_6 are in a simple series configuration. (Step 2) - Re-draw the circuit, (Figure 12), with $R_{1,2,3}$ replacing R_1 and $R_{2,3}$ and $R_{4,5,6}$ replacing $R_{4,5}$ and R_6.

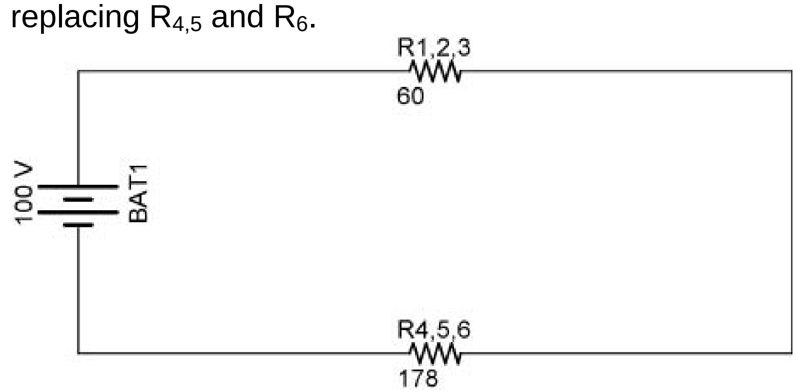


Figure 12

Determine the equivalent resistor $R_{1,2,3}$ for the parallel resistors, R_1 and $R_{2,3}$, using the formula for two parallel resistors.

$R_{1,2,3}$:

$$R_{1,2,3} = R_1 \times R_{2,3} / R_1 + R_{2,3}$$
$$R_{1,2,3} = 100\ \Omega \times 150\ \Omega / 100\ \Omega + 150\ \Omega$$
$$R_{1,2,3} = 15{,}000\ \Omega^2 / 250\ \Omega$$
$$R_{1,2,3} = 60\ \Omega$$

Determine the equivalent resistor $R_{4,5,6}$ for the series resistors, $R_{4,5}$ and R_6, using the formula series resistor formula.

$R_{4,5,6}$:

$$R_{4,5,6} = R_{4,5} + R_6$$
$$R_{4,5,6} = 28\ \Omega + 150\ \Omega$$
$$R_{4,5,6} = 178\ \Omega$$

- **Step 3 again:** Repeat Steps 1 and 2 until the entire circuit is reduced to one equivalent resistor. (Step 1) - $R_{1,2,3}$ and $R_{4,5,6}$ are in a simple series configuration. (Step 2) - Re-draw the circuit, (Figure 13), with $R_{1,2,3,4,5,6}$ replacing $R_{1,2,3}$ and $R_{4.5.6}$.

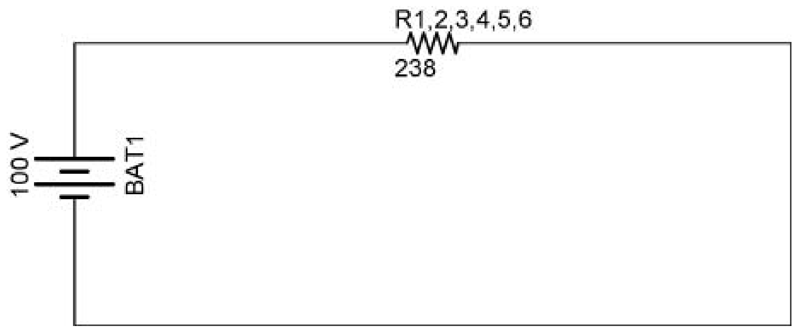


Figure 13

Determine the equivalent resistor $R_{1,2,3,4,5,6}$ for the series resistors $R_{1,2,3}$ and $R_{4,5,6}$ using the formula series resistor formula.

$$R_{1,2,3,4,5,6} = R_{1,2,3} + R_{4,5,6}$$
$$R_{1,2,3,4,5,6} = 60\ \Omega + 178\Omega$$
$$R_{1,2,3,4,5,6} = 238\ \Omega$$
$$R_{1,2,3,4,5,6} = R_T$$

Enter R_T, ($R_{1,2,3,4,5,6}$), into the solution table (Table 9).

Resistor	Resistance	Voltage	Current
R1	R1 = 100 Ω	V1	I1
R2	R2 = 100 Ω	V2	I2
R3	R3 = 50 Ω	V3	I3
R4	R4 = 56 Ω	V4	I4
R5	R5 = 56 Ω	V5	I5
R6	R6 = 150 Ω	V6	I6
Totals	**R_T = 238 Ω**	V_T = 100 V	I_T

Table 9

- **Step 4:** Find the total current for the circuit.

  $I_T = V_T / R_T$
  $I_T = 100\ V / 238\ \Omega$
  $I_T = 0.42\ A$

  See Table 10:

Resistor	Resistance	Voltage	Current
R1	R1 = 100 Ω	V1	I1
R2	R2 = 100 Ω	V2	I2
R3	R3 = 50 Ω	V3	I3
R4	R4 = 56 Ω	V4	I4
R5	R5 = 56 Ω	V5	I5
R6	R6 = 150 Ω	V6	I6
Totals	R_T = 238 Ω	V_T = 100 V	**I_T = 0.42 A**

Table 10

- **Expanding the Circuit:** Find all remaining values of voltage and current.
  - **Step 5:** Taking total voltage and total current values, go back to last step in the circuit reduction process, (Figure 8.12), and insert those values where applicable.

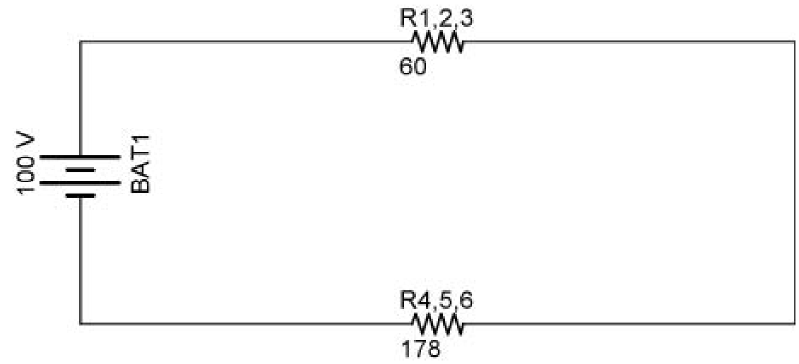


Figure 14

Determine the current through each series resistor in the equivalent circuit in Figure 14.

$$I_T = I_{1,2,3} = I_{4,5,6} = 0.42 \text{ A}$$

Also, we can calculate the voltage drop $V_{1,2,3}$ across resistor $R_{1,2,3}$.

$$V_{1,2,3} = I_{1,2,3} \times R_{1,2,3}$$
$$V_{1,2,3} = 0.42 \text{ A} \times 60\ \Omega$$
$$V_{1,2,3} = 25.2 \text{ V}$$

- **Step 6:** From known resistances and total voltage / total current values from Step 5, use Ohm's Law to calculate unknown values (voltage or current). See Figure 15.

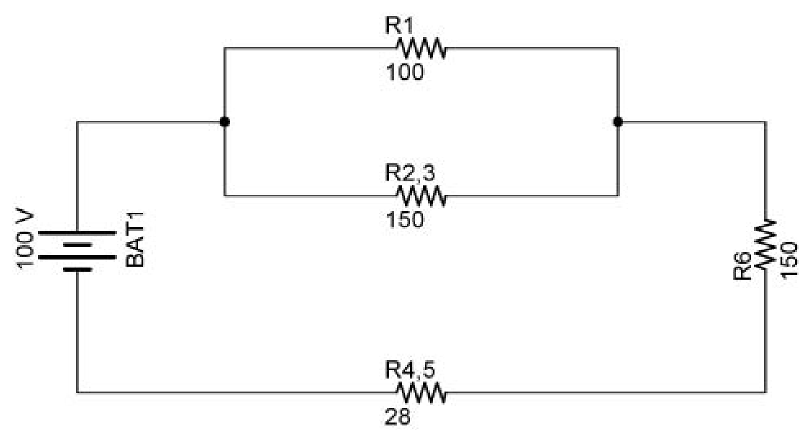


Figure 15

R_1 and $R_{2,3}$:

Since R_1 and $R_{2,3}$ are parallel resistors, the voltage drops V_1 and $V_{2,3}$ are the same value and equal to $V_{1,2,3}$.

$$V_1 = V_{2,3} = V_{1,2,3} = 25.2 \text{ V}$$

Knowing V_1 and R_1, solve for I_1:

$$I_1 = V_1 / R_1$$
$$I_1 = 25.2\ V / 100\ \Omega$$
$$I_1 = 0.25\ A$$

The current through $R_{2,3}$ is the total current I_T less I_1.

$$I_{2,3} = I_T - I_1$$
$$I_{2,3} = 0.42\ A – 0.252\ A$$
$$I_{2,3} = 0.168\ A$$

$I_{2,3}$ could have been solved using Ohm's Law, $I_{2,3} = V_{2,3} / R_{2,3}$

$R_{4,5}$ and R_6:

$R_{4,5}$ and R_6 are in series so they have the same current through them as $R_{4,5,6}$.

$$I_{4,5,6} = I_{4,5} = I_6 = 0.42\ A$$

Knowing I_6 and R_6, solve for V_6:

$$V_6 = I_6 \times R_6$$
$$V_6 = 0.42\ A \times 150\ \Omega$$
$$V_6 = 63\ V$$

Knowing $I_{4,5}$ and $R_{4,5}$, solve for $V_{4,5}$:

$$V_{4,5} = I_{4,5} \times R_{4,5}$$
$$V_{4,5} = 0.42\ A \times 28\ \Omega$$
$$V_{4,5} = 11.8\ V$$

Update the solutions table with the values of V_1, I_1, V_6 and I_6 (Table 11).

Resistor	Resistance	Voltage	Current
R1	R1 = 100 Ω	**V1 = 25.2 V**	**I1 = 0.252 A**
R2	R2 = 100 Ω	V2	I2
R3	R3 = 50 Ω	V3	I3
R4	R4 = 56 Ω	V4	I4
R5	R5 = 56 Ω	V5	I5
R6	R6 = 150 Ω	**V6 = 63 V**	**I6 = 0.42 A**
Totals	R_T = 238 Ω	V_T = 100 V	I_T = 0.42 A

Table 11

- **Step 7:** Repeat steps 5 and 6 until all values for voltage and current are known in the original circuit configuration.

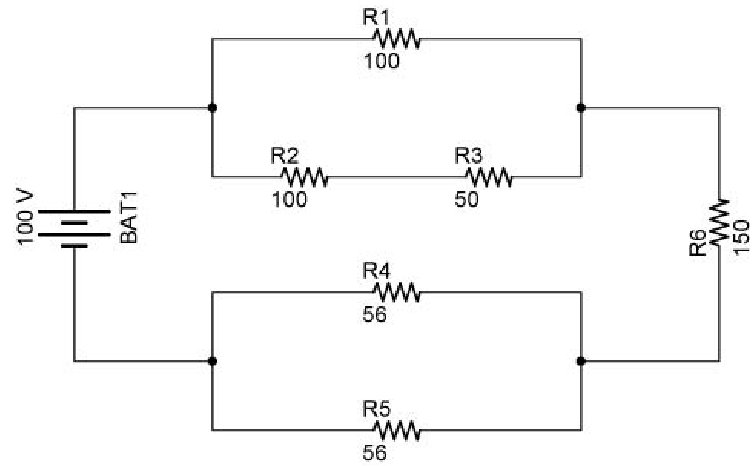


Figure 16

R_2 and R_3:

R_2 and R_3 are in series so they have the same current through them as $R_{2,3}$.

$$I_{2,3} = I_2 = I_3 = 0.168\text{ A}$$

Knowing I_2 and R_2, solve for V_2:

$$V_2 = I_2 \text{ x } R_2$$
$$V_2 = 0.168\text{ A x } 100\ \Omega$$
$$V_2 = 16.8\text{ V}$$

Knowing I_3 and R_3, solve for V_3:

$$V_3 = I_3 \text{ x } R_3$$
$$V_3 = 0.168\text{ A x } 50\ \Omega$$
$$V_3 = 8.4\text{ V}$$

R_4 and R_5:

Since R_4 and R_5 are parallel resistors, the voltage drops V_4 and V_5 are the same value and equal to $V_{4,5}$.

$$V_4 = V_5 = V_{4,5} = 11.8\text{ V}$$

Knowing V_4 and R_4, solve for I_4:

$$I_4 = V_4 / R_4$$
$$I_4 = 11.8\text{ V} / 56\ \Omega$$
$$I_4 = 0.21\text{ A}$$

Since R_4 and R_5 are equal,

$I_4 = I_5$

Record voltages and currents into the solution table (Table 12).

Resistor	Resistance	Voltage	Current
R1	R1 = 100 Ω	V1 = 25.2 V	I1 = 0.252 A
R2	R2 = 100 Ω	**V2 = 16.8 V**	**I2 = 0.168 A**
R3	R3 = 50 Ω	**V3 = 8.4 V**	**I3 = 0.168 A**
R4	R4 = 56 Ω	**V4 = 11.8 V**	**I4 = 0.21 A**
R5	R5 = 56 Ω	**V5 = 11.8 V**	**I5 = 0.21 A**
R6	R6 = 150 Ω	V6 = 63 V	I6 = 0.42 A
Totals	R_T = 238 Ω	V_T = 100 V	I_T = 0.42 A

Table 12

- **Step 8:** Calculate power dissipations from known voltage, current, and/or resistance values.

$P_1 = V_1 \times I_1$
$P_1 = 25.2\ V \times 0.252\ A$
$P_1 = 6.3\ W$

$P_2 = V_2 \times I_2$
$P_2 = 16.8\ V \times 0.168\ A$
$P_2 = 2.8\ W$

$P_3 = V_3 \times I_3$
$P_3 = 8.4\ V \times 0.168\ A$
$P_3 = 1.4\ W$

$P_4 = V_4 \times I_4$
$P_4 = 11.8\ V \times 0.21\ A$
$P_4 = 2.5\ W$

$P_5 = V_5 \times I_5$
$P_5 = 11.8\ V \times 0.21\ A$
$P_5 = 2.5\ W$

$P_6 = V_6 \times I_6$
$P_6 = 63\ V \times 0.42\ A$
$P_6 = 26.5\ W$

$P_T = V_T \times I_T$
$P_T = 100\ V \times 0.42\ A$
$P_T = 42\ W$

Check power total:

$P_T = P_1 + P_2 + P_3 + P_4 + P_5 + P_6$
$P_T = 6.3\ W + 2.8\ W + 1.4\ W + 2.5\ W + 2.5\ W + 26.5\ W$
$P_T = 42.0\ W$

The final solution table (Table 13):

Resistor	Resistance	Voltage	Current	Power
R1	R1 = 100 Ω	V1 = 25.2 V	I1 = 0.252 A	**P1 = 6.3 W**
R2	R2 = 100 Ω	V2 = 16.8 V	I2 = 0.168 A	**P2 = 2.8 W**
R3	R3 = 50 Ω	V3 = 8.4 V	I3 = 0.168 A	**P3 = 1.4 W**
R4	R4 = 56 Ω	V4 = 11.8 V	I4 = 0.21 A	**P4 = 2.5 W**
R5	R5 = 56 Ω	V5 = 11.8 V	I5 = 0.21 A	**P5 = 2.5 W**
R6	R6 = 150 Ω	V6 = 63 V	I6 = 0.42 A	**P6 = 26.5 W**
Totals	R_T = 238 Ω	V_T = 100 V	I_T = 0.42 A	**P_T = 42.0 W**

Table 13

Summary of Values:

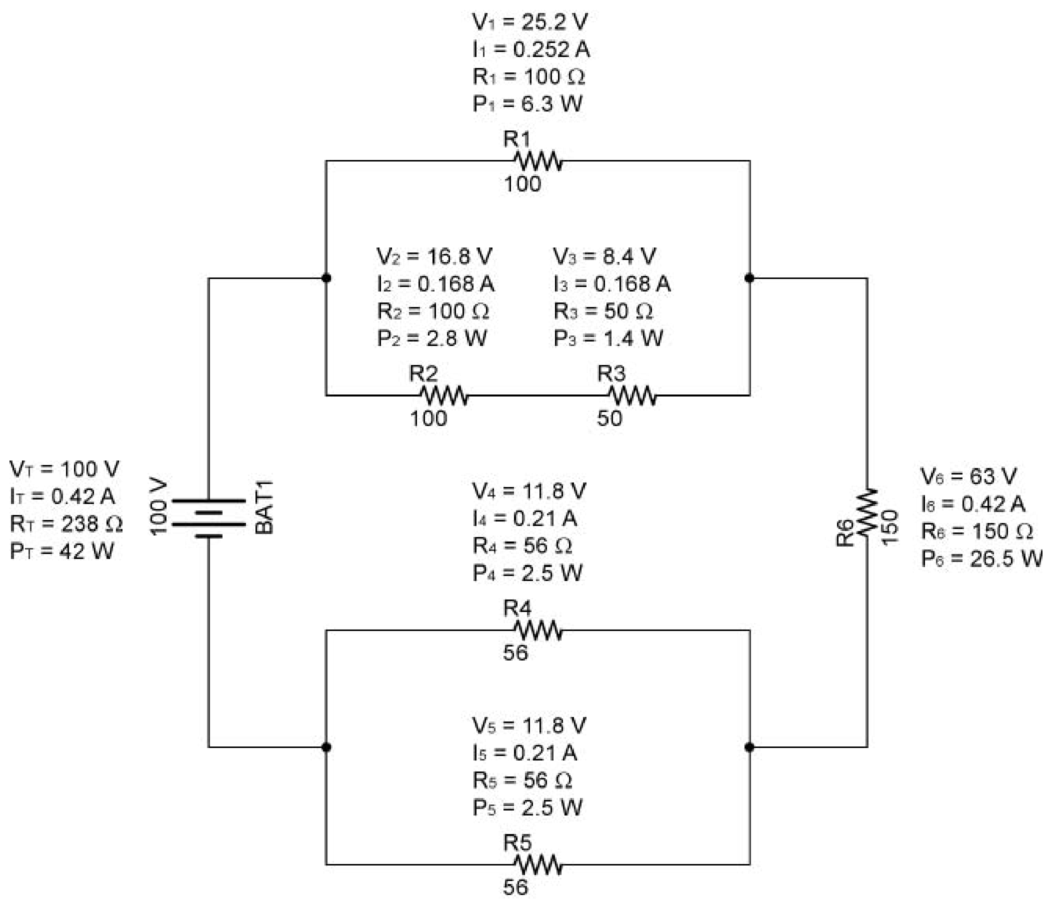
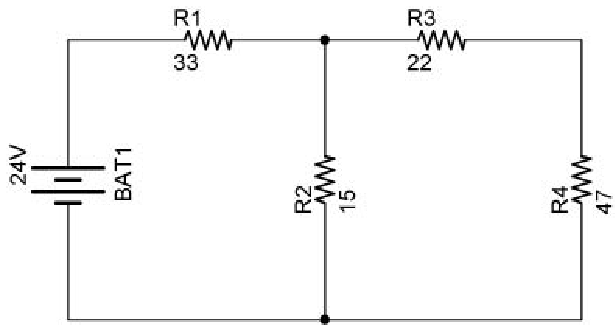


Figure 17

- Example Problem 1:
  - Solve for all of the unknowns in the following circuit. Fill in each unknown in the table below the circuit.



	Resistance	Voltage	Current	Power
R1	R1 = 33 Ω			
R2	R2 = 15 Ω			
R3	R3 = 22 Ω			
R4	R4 = 47 Ω			
Total		V_T = 24 V		

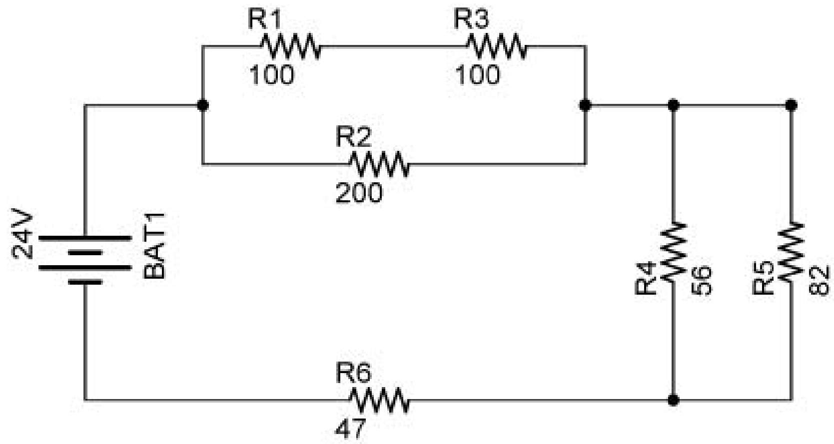
- Remember, to solve **series circuit** problems, you can use any or all of the following equations:

$$\mathbf{R_T = R_1 + R_2 + R_3 + \ldots + R_N}$$
$$\mathbf{V_T = V_1 + V_2 + V_3 + \ldots + V_N}$$
$$\mathbf{I_T = I_1 = I_2 = I_3 = \ldots I_N}$$
$$\mathbf{V = I \times R}$$

- Remember, to solve **parallel circuit** problems, you can use any or all of the following equations:

$$\mathbf{1/R_T = 1/R_1 + 1/R_2 + 1/R_3 + \ldots\ldots\ldots\ldots + 1/R_N}$$
$$\mathbf{V_T = V_1 = V_2 = V_3 = \ldots\ldots V_N}$$
$$\mathbf{I_T = I_1 + I_2 + I_3 + \ldots + I_N}$$
$$\mathbf{V = I \times R}$$

- Example Problem 2:
  - Fill in the known values then solve for all of the unknowns in the following circuit.



	Resistance	Voltage	Current	Power
R1				
R2				
R3				
R4				
R5				
R6				
Total				

- Remember, to solve **series circuit** problems, you can use any or all of the following equations:

$$R_T = R_1 + R_2 + R_3 + \dots + R_N$$
$$V_T = V_1 + V_2 + V_3 + \dots + V_N$$
$$I_T = I_1 = I_2 = I_3 = \dots I_N$$
$$V = I \times R$$

- Remember, to solve **parallel circuit** problems, you can use any or all of the following equations:

$$1/R_T = 1/R_1 + 1/R_2 + 1/R_3 + \dots\dots\dots + 1/R_N$$
$$V_T = V_1 = V_2 = V_3 = \dots\dots V_N$$
$$I_T = I_1 + I_2 + I_3 + \dots + I_N$$
$$V = I \times R$$

- You are given a black box with two terminals. The box is known to contain six 1-ohm resistors. Using ohm-meter, you measure the resistance between the terminals to be the following:

    - 0.75 Ohms
    - 1.5 Ohms
    - 2.25 Ohms
    - 3 Ohms
    - 4.5 Ohms
    - 6 Ohms

  Determine the configurations of the six resistors inside the box that create each resistance value.

- Example Problem Solutions:

    - Example Problem 1:

	Resistance	Voltage	Current	Power
R1	R1 = 33 Ω	V1 = 17.48 V	I1 = 0.530 A	P1 = 9.25 W
R2	R2 = 15 Ω	V2 = 6.52 V	I2 = 0.435 A	P2 = 2.84 W
R3	R3 = 22 Ω	V3 = 2.08 V	I3 = 0.095 A	P3 = 0.20 W
R4	R4 = 47 Ω	V4 = 4.44 V	I4 = 0.095 A	P4 = 0.42 W
Total	R_T = 45.3 Ω	V_T = 24 V	I_T = 0.53 A	P_T = 12.71 W

    - Example Problem 2:

	Resistance	Voltage	Current	Power
R1	R1 = 100 Ω	V1 = 6.66 V	I1 = 0.0666 A	P1 = 0.443 W
R2	R2 = 200 Ω	V2 = 13.31 V	I2 = 0.0666 A	P2 = 0.886 W
R3	R3 = 100 Ω	V3 = 6.66 V	I3 = 0.666 A	P3 = 0.443 W
R4	R4 = 56 Ω	V4 = 4.43 V	I4 = 0.079 A	P4 = 0.350 W
R5	R5 = 82 Ω	V5 = 4.43 V	I5 = 0.054 A	P5 = 0.239 W
R6	R6 = 47 Ω	V6 = 6.26 V	I6 = 0.1331 A	P6 = 0.833 W
Total	R_T = 180.28 Ω	V_T = 24 V	I_T = 0.1331 A	P_T = 3.194 W