Chapter 4

Series Circuits

Topics Covered in Chapter 4

Topics Covered in Chapter 4

- 4-6: Total Power in a Series Circuit
- 4-7: Series-Aiding and Series-Opposing Voltages
- 4-8: Analyzing Series Circuits with Random Unknowns
- 4-9: Ground Connections in Electrical and Electronic Systems
- 4-10: Troubleshooting: Opens and Shorts in Series Circuits

4-1: Why *I* Is the Same in All Parts of a Series Circuit

- Characteristics of a Series Circuit
  - The current is the same everywhere in a series circuit.
  - The total resistance is equal to the sum of the individual resistance values.
  - The total voltage is equal to the sum of the *IR* voltage drops across the individual resistances.
  - The total power is equal to the sum of the power dissipated by each resistance.

4-1: Why *I* Is the Same in All Parts of a Series Circuit

- Current is the movement of electric charge between two points, produced by the applied voltage.
- The free electrons moving away from one point are continuously replaced by free electrons flowing from an adjacent point in the series circuit.
- All electrons have the same speed as those leaving the voltage source.
- Therefore, *I* is the same in all parts of a series circuit.

4-1: Why *I* Is the Same in All Parts of a Series Circuit

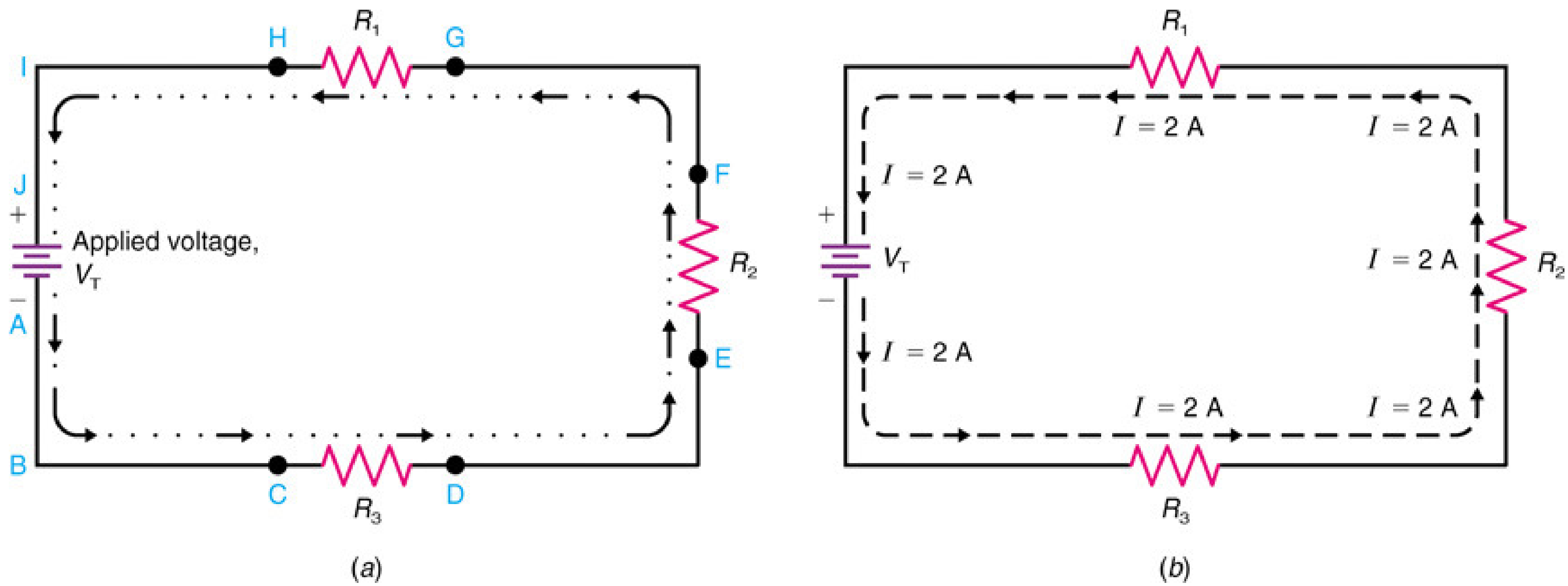


Fig. 4-2: There is only one current through R_1, R_2, and R_3 in series. (*a*) Electron drift is the same in all parts of a series circuit. (*b*) Current *I* is the same at all points in a series circuit.

4-1: Why *I* Is the Same in All Parts of a Series Circuit

- Series Current Formulas
  - Total current is the same as the individual currents in the series string:

$$I_T = I_1 = I_2 = I_3 = \ldots = \text{etc.}$$

  - Total current is equal to total voltage divided by total resistance:

$$I_T = \frac{V_T}{R_T}$$

4-2: Total *R* Equals the Sum of All Series Resistances

- When a series circuit is connected across a voltage source, the free electrons must drift through all the series resistances.
- There is only one path for free electrons to follow.
- If there are two or more resistances in the same current path, the total resistance across the voltage source is the sum of all the resistances.

4-2: Total *R* Equals the Sum of All Series Resistances

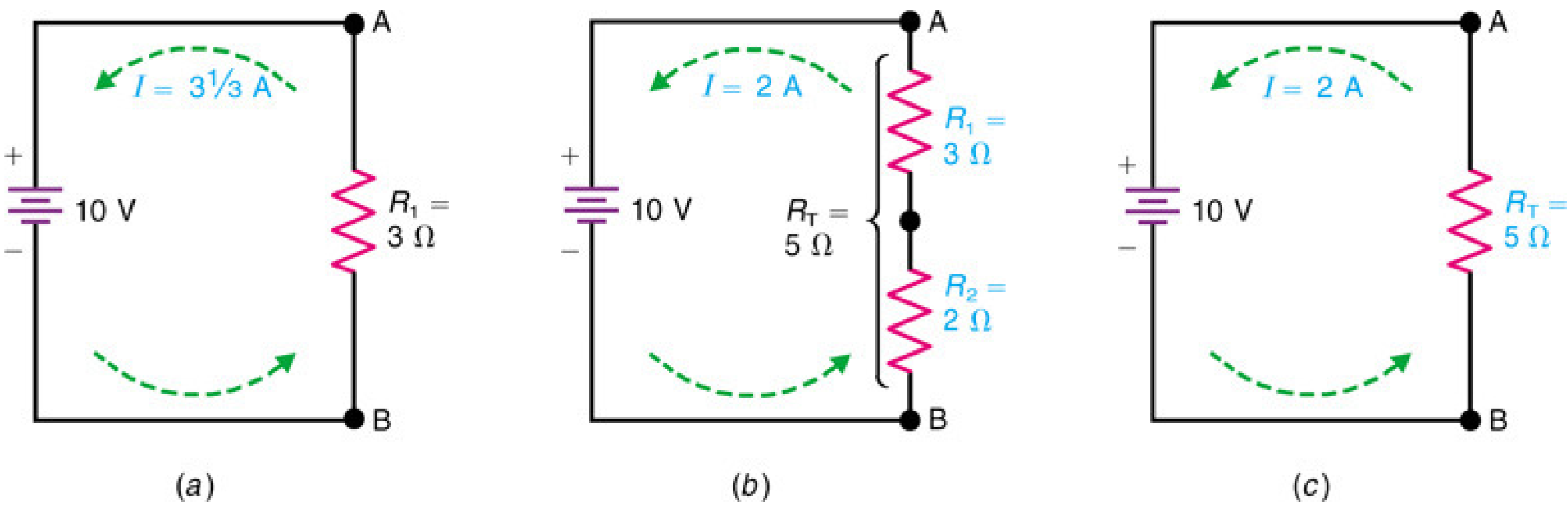
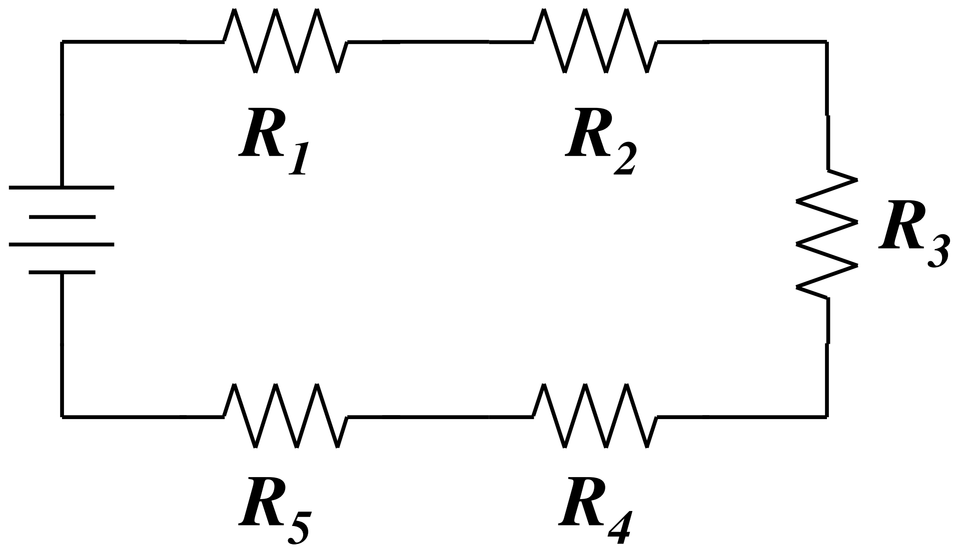


Fig. 4-4: Series resistances are added for the total R_T. (*a*) R_1 alone is 3 Ω. (*b*) R_1 and R_2 in series together total 5 Ω. (*c*) The R_T of 5 Ω is the same as one resistance of 5 Ω between points A and B.

4-2: Total *R* Equals the Sum of All Series Resistances

- Series Resistance Formulas
  - The total resistance is the sum of the individual resistances.



$$R_T = R_1 + R_2 + R_3 + R_4 + R_5$$

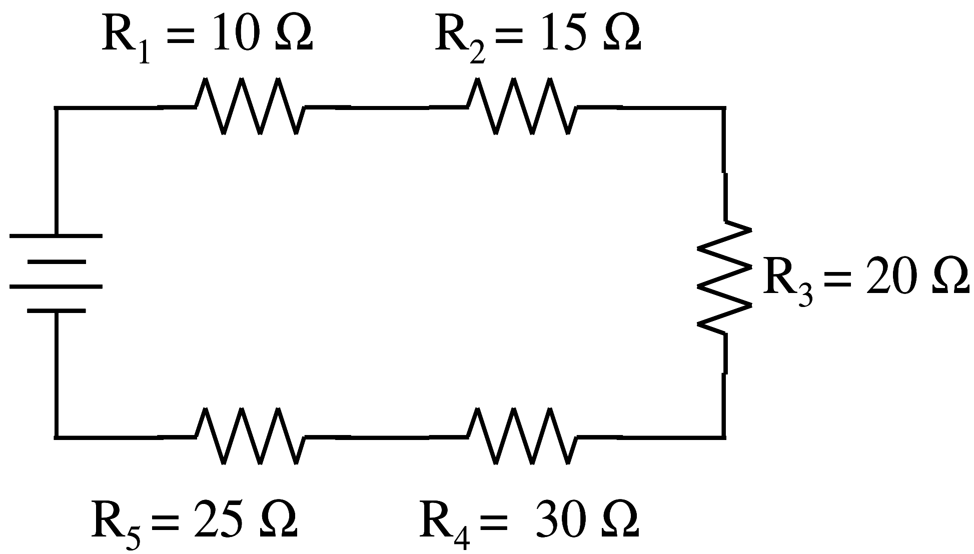
4-2: Total *R* Equals the Sum of All Series Resistances

- Series Resistance Formulas
  - Total resistance is equal to total voltage divided by the circuit current:

$$R_T = \frac{V_T}{I_T}$$

4-2: Total *R* Equals the Sum of All Series Resistances

- Determining the Total Resistance



$$R_T = R_1 + R_2 + R_3 + R_4 + R_5$$

$$R_T = 10\ \Omega + 15\ \Omega + 20\ \Omega + 30\ \Omega + 25\ \Omega = 100\ \Omega$$

4-3: Series *IR* Voltage Drops

- By Ohm's Law, the voltage across a resistance equals $I \times R$.
- In a series circuit, the *IR* voltage across each resistance is called an ***IR* drop** or **voltage drop**, because it reduces the potential difference available for the remaining resistances in the circuit.

4-3: Series *IR* Voltage Drops

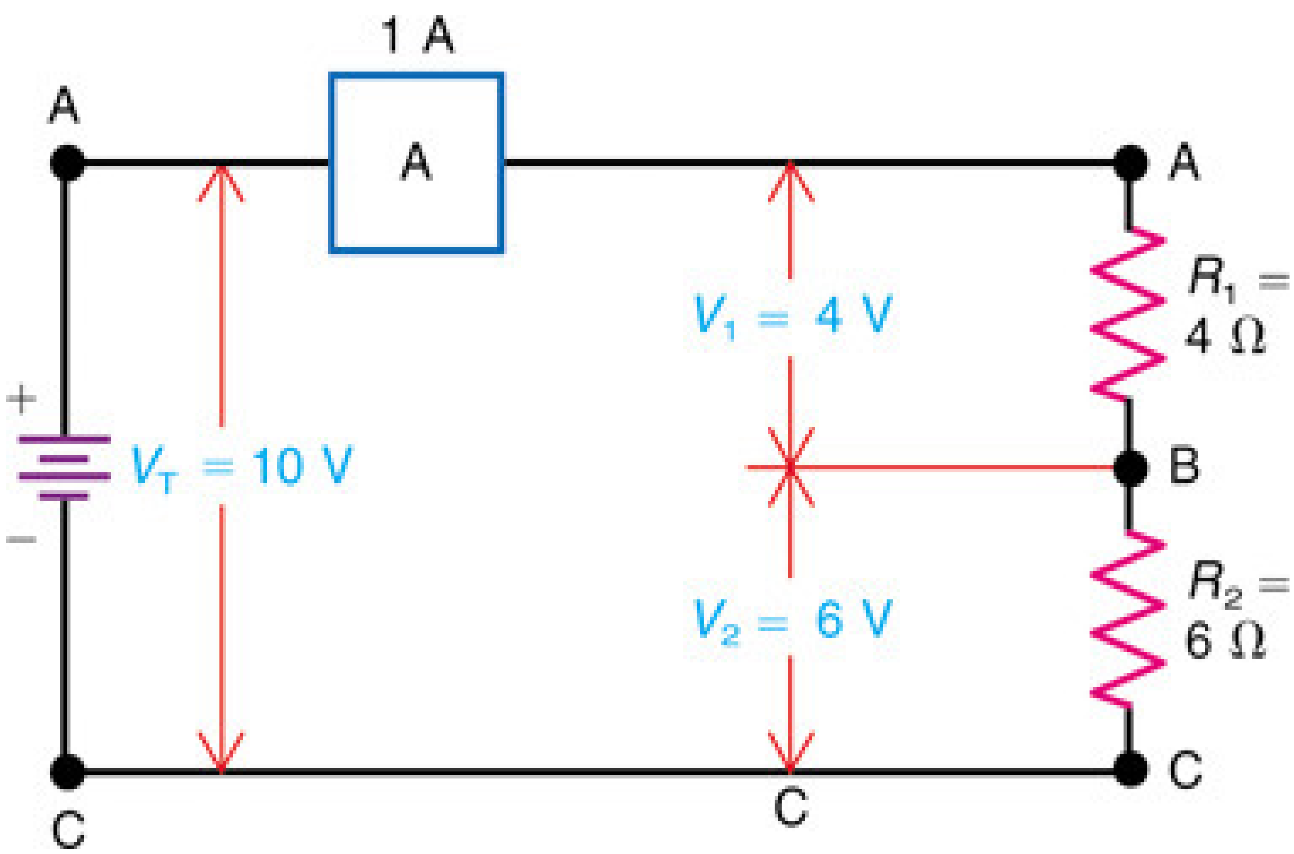
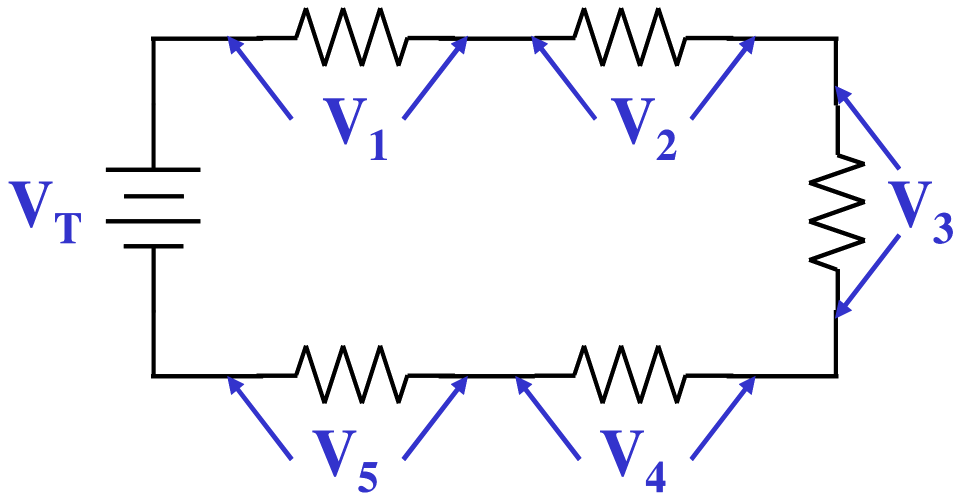


Fig. 4-5: An example of *IR* voltage drops V_1 and V_2 in a series circuit.

4-4: Kirchhoff's Voltage Law (KVL)

The total voltage is equal to the sum of the drops.

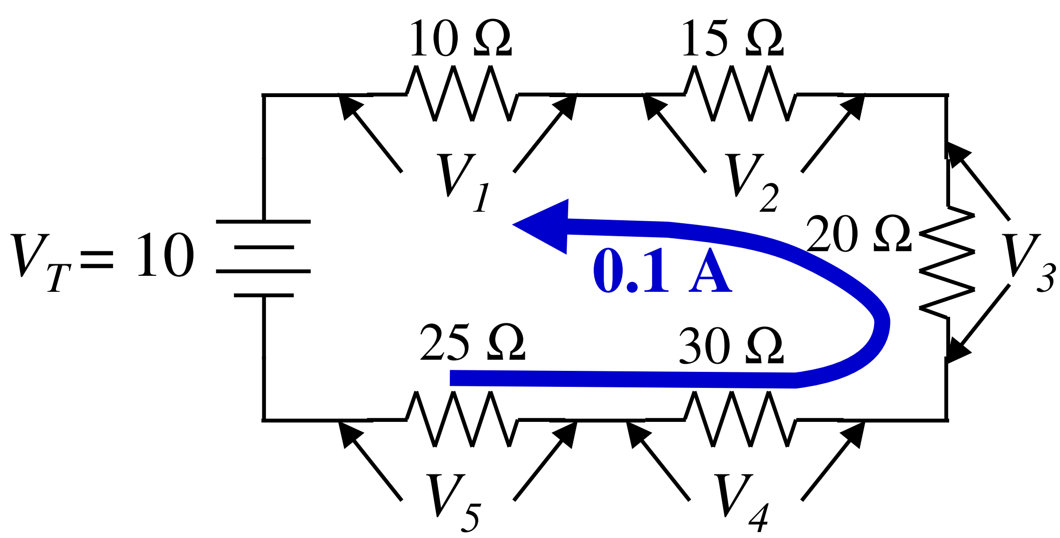


$$V_T = V_1 + V_2 + V_3 + V_4 + V_5$$

This is known as **Kirchhoff's voltage law (KVL).**

4-4: Kirchhoff's Voltage Law (KVL)

The *IR* drops must add to equal the applied voltage (KVL).



$$V_T = V_1 + V_2 + V_3 + V_4 + V_5$$
$$V_T = IR_1 + IR_2 + IR_3 + IR_4 + IR_5$$
$$V_T = 0.1 \times 10 + 0.1 \times 15 + 0.1 \times 20 + 0.1 \times 30 + 0.1 \times 25$$
$$V_T = 1\text{ V} + 1.5\text{ V} + 2\text{ V} + 3\text{ V} + 2.5\text{ V} = 10\text{ V}$$

4-5: Polarity of *IR* Voltage Drops

- When current flows through a resistor, a voltage equal to *IR* is dropped across the resistor. The polarity of this *IR* voltage drop is:
  - <u>Negative</u> at the end where the electrons enter the resistor.
  - <u>Positive</u> at the end where the electrons leave the resistor.

4-5: Polarity of *IR* Voltage Drops

- The rule is reversed when considering conventional current: positive charges move into the positive side of the *IR* voltage.
- The polarity of the *IR* drop is the same, regardless of whether we consider electron flow or conventional current.

4-5: Polarity of *IR* Voltage Drops

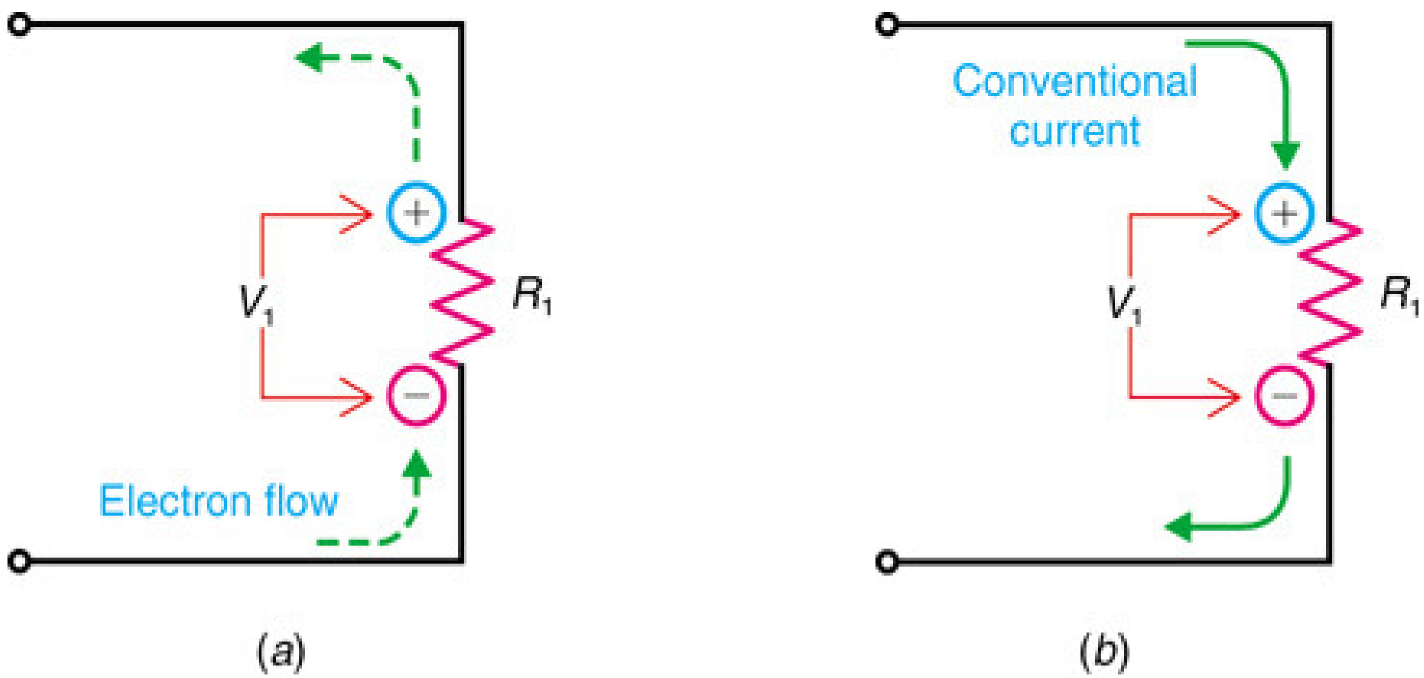


Fig. 4-8: Polarity of *IR* voltage drops. (*a*) Electrons flow into the negative side of V_1 across R_1. (*b*) Same polarity of V_1 with positive charges into the positive side.

4-6: Total Power in a Series Circuit

- The power needed to produce current in each series resistor is used up in the form of heat.
- The total power used in the circuit is equal to the sum of the individual powers dissipated in each part of the circuit.
- Total power can also be calculated as $V_T \times I$

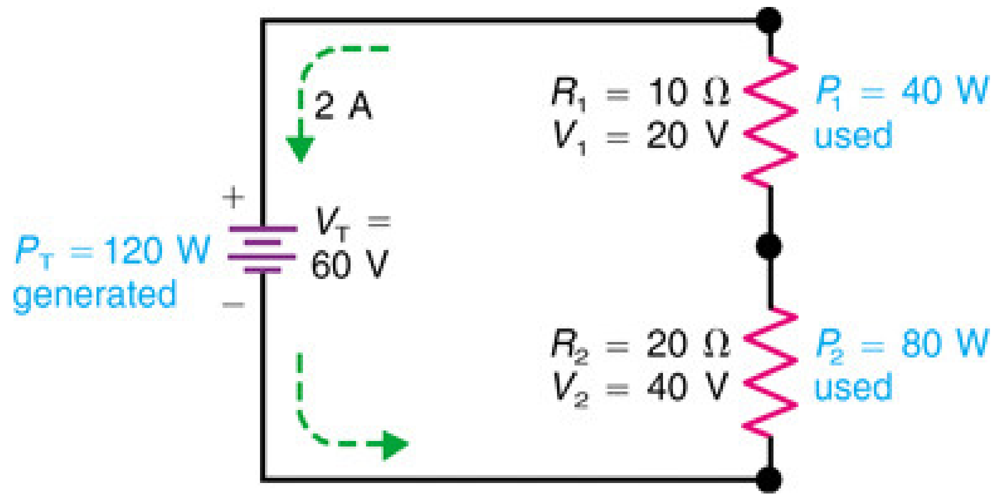
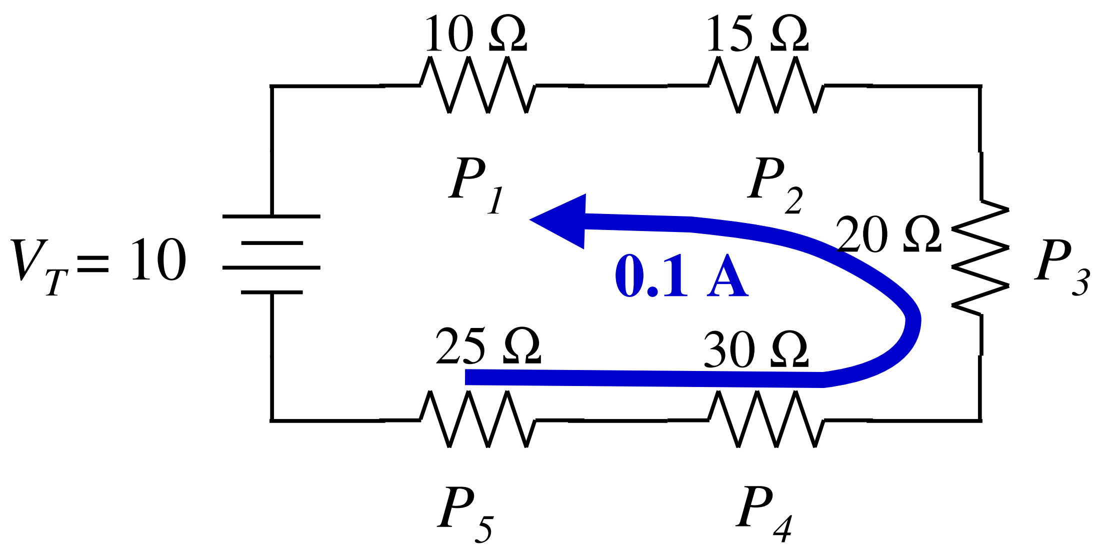


Fig. 4-10: The sum of the individual powers P_1 and P_2 used in each resistance equals the total power P_T produced by the source.

4-6: Total Power in a Series Circuit

Finding Total Power



$$P_T = P_1 + P_2 + P_3 + P_4 + P_5$$

$$P_T = I^2R_1 + I^2R_2 + I^2R_3 + I^2R_4 + I^2R_5$$

$$P_T = 0.1\text{ W} + 0.15\text{ W} + 0.2\text{ W} + 0.3\text{ W} + 0.25\text{ W} = 1\text{ W}$$

Check: $P_T = V_T \times I = 10\text{ V} \times 0.1\text{ A} = 1\text{ W}$

4-7: Series-Aiding and Series-Opposing Voltages

- Series-aiding voltages are connected with polarities that allow current in the same direction:
  - The positive terminal of one is connected to the negative terminal of the next.
- They can be added for the total voltage.

4-7: Series-Aiding and Series-Opposing Voltages

- Series-opposing voltages are the opposite: They are connected to produce opposing directions of current flow.
  - The positive terminal of one is connected to the positive terminal of another.
- To obtain the total voltage, subtract the smaller voltage from the larger.
- Two equal series-opposing voltage sources have a net voltage of zero.

4-7: Series-Aiding and Series-Opposing Voltages

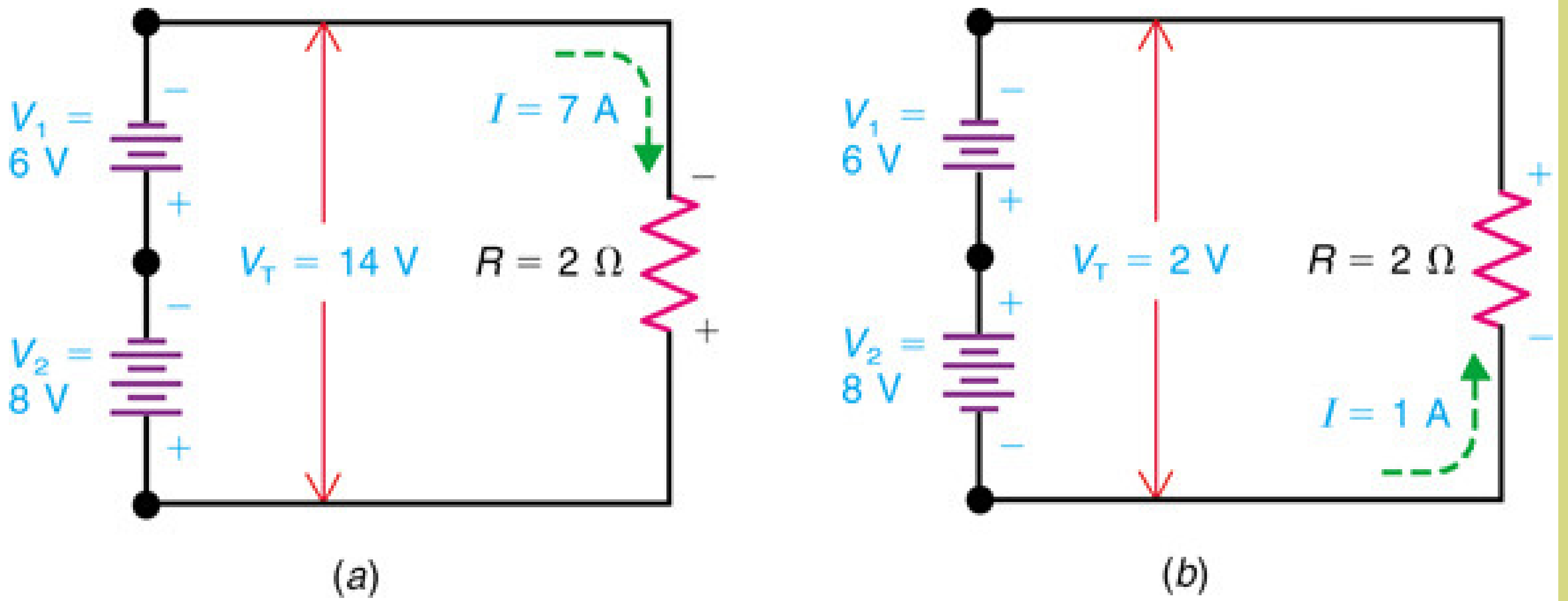


Fig. 4-11: Example of voltage sources V_1 and V_2 in series. (*a*) Note the connections for series-aiding polarities. Here 8 V + 6 V = 14 V for the total V_T. (*b*) Connections for series-opposing polarities. Now 8 V – 6 V = 2 V for V_T.

4-8: Analyzing Series Circuits with Random Unknowns

- When trying to analyze a series circuit, keep the following principles in mind:
  1. If *I* is known for one component, use this value in all components. The current is the same in all parts of a series circuit.
  2. If *I* is unknown, it may be calculated in one of two ways:
     - Divide V_T by R_T
     - Divide an individual *IR* drop by its *R*.
     - Remember not to mix a total value for an entire circuit with an individual value for part of the circuit.

4-8: Analyzing Series Circuits with Random Unknowns

3. If all individual voltage drops are known, add them to determine the applied V_T.

   - A known voltage drop may be subtracted from V_T to find a remaining voltage drop.

4-9: Ground Connections in Electrical and Electronic Systems

- In most electrical and electronic systems, one side of the voltage source is connected to ground.
- The reason for doing this is to reduce the possibility of electric shock.

4-9: Ground Connections in Electrical and Electronic Systems

- Figure 4-16 shows several schematic ground symbols:

- Ground is assumed to have a potential of 0 V regardless of the schematic symbol shown.
- These symbols are sometimes used inconsistently with their definitions. However, these symbols always represent a common return path for current in a given circuit.

4-9: Ground Connections in Electrical and Electronic Systems

- Voltages Measured with Respect to Ground
  - When a circuit has a ground as a common return, measure the voltages with respect to this ground.

4-9: Ground Connections in Electrical and Electronic Systems

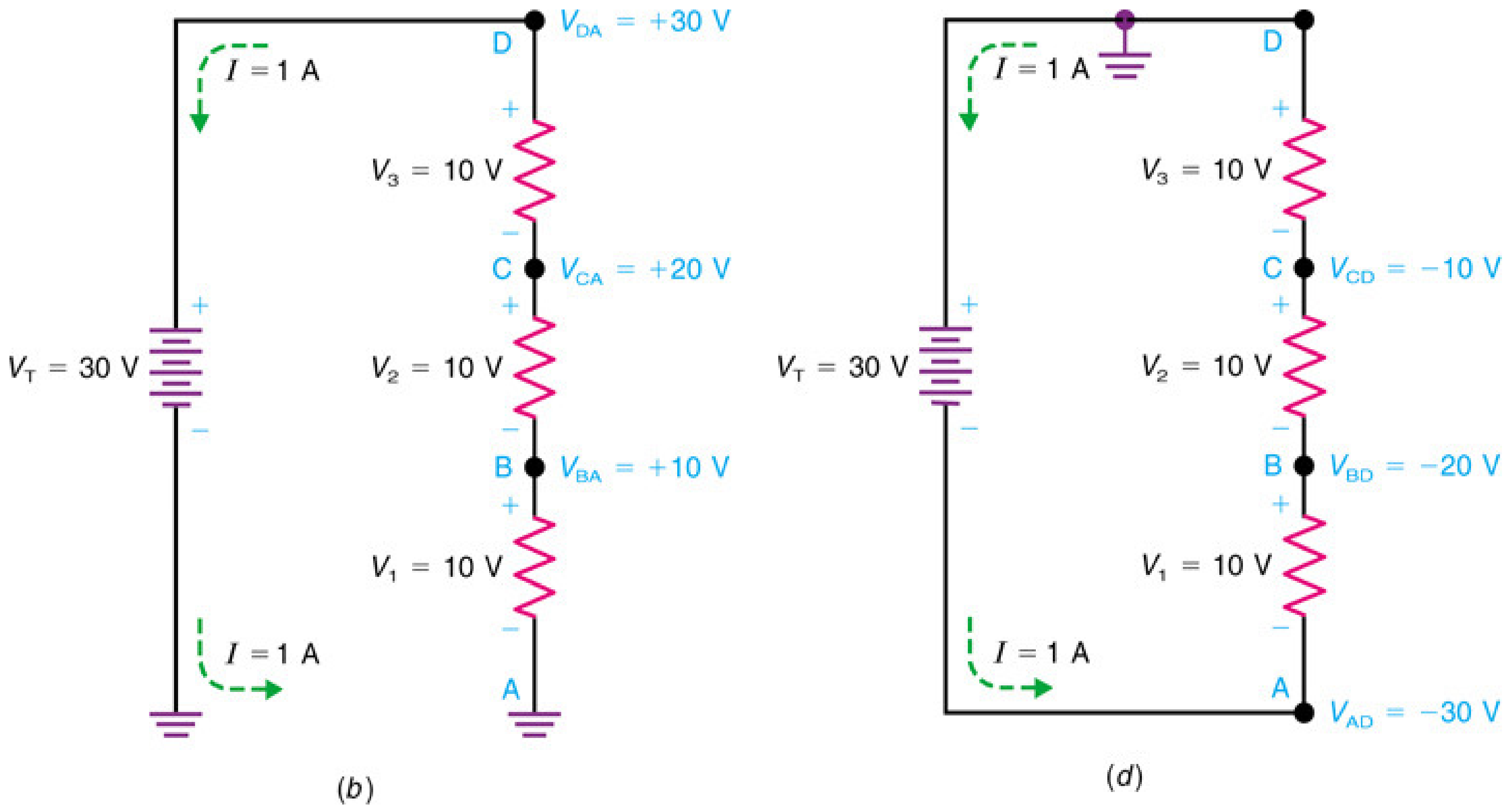


Fig. 4-18: An example of how to calculate dc voltages measured with respect to ground. (*b*) Negative side of V_T grounded to make all voltages positive with respect to ground. (*d*) Positive side of V_T grounded, all voltages are negative to ground.

4-10: Troubleshooting: Opens and Shorts in Series Circuits

- The Effect of an Open in a Series Circuit
  - An open circuit is a circuit with a break in the current path. When a series circuit is open, the current is zero in all parts of the circuit.
  - The total resistance of an open circuit is infinite ohms.
  - When a series circuit is open, the applied voltage appears across the open points.

4-10: Troubleshooting: Opens and Shorts in Series Circuits

- The Effect of an Open in a Series Circuit

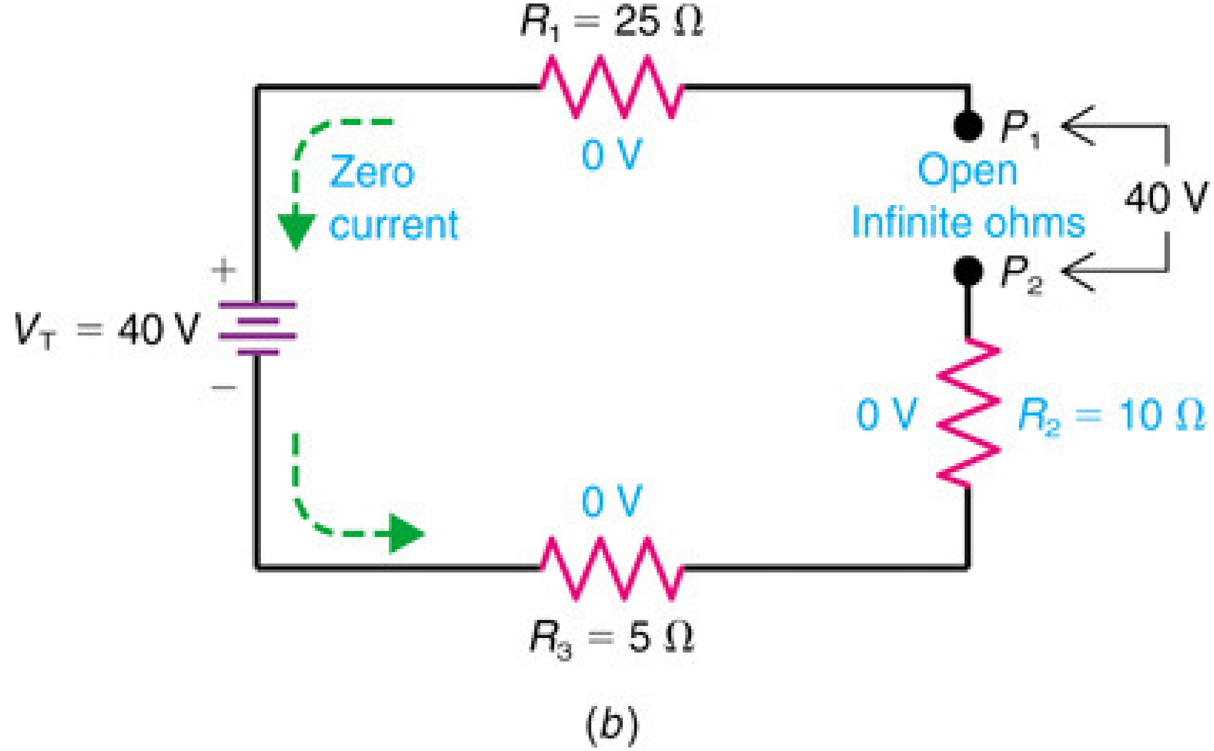


Fig. 4-19: Effect of an open in a series circuit. (*b*) Open path between points *P1* and *P2* results in zero current in all parts of the circuit.

4-10: Troubleshooting: Opens and Shorts in Series Circuits

- Applied voltage V_T is still present, even with zero current.
- The voltage source still has its same potential difference across its positive and negative terminals.
  - Example: The 120-V potential difference is always available from the terminals of a wall outlet.
    - If an appliance is connected, current will flow.
    - If you touch the metal terminals when nothing else is connected, you will receive a shock.

4-10: Troubleshooting: Opens and Shorts in Series Circuits

- The Effect of a Short in a Series Circuit
  - When part of a series circuit is shorted, the current flow increases.
  - When part of a series circuit is shorted, the voltage drops across the non-shorted elements increase.
  - The voltage drop across the shorted component drops to 0 V.

4-10: Troubleshooting: Opens and Shorts in Series Circuits

- The Effect of a Short in a Series Circuit

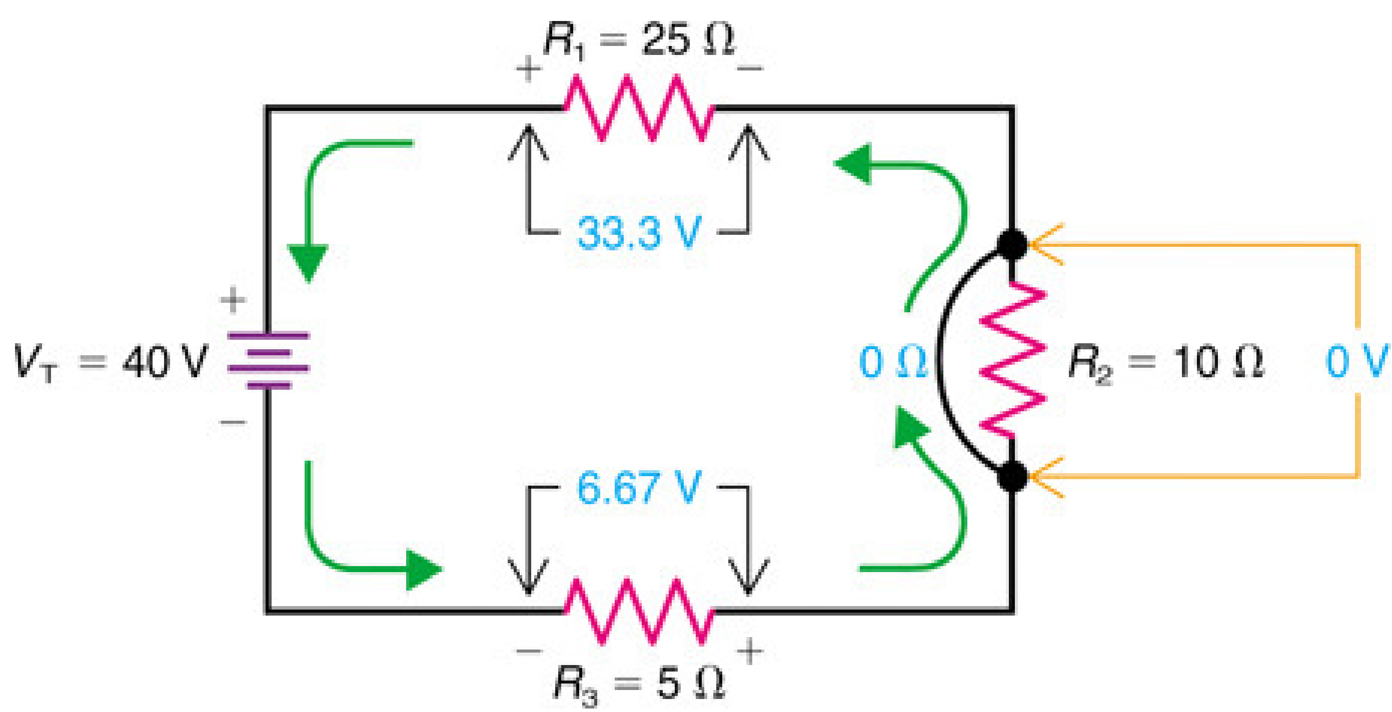


Fig. 4-21: Series circuit of Fig. 4-18 with R_2 shorted.

4-10: Troubleshooting: Opens and Shorts in Series Circuits

- When troubleshooting a series circuit containing three or more resistors, remember:
  - The component whose voltage changes in the opposite direction of the other components is the defective component.