11.5 Series and Parallel Circuits

There is electric current through all the bulbs around the mirror shown in **Figure 11.28**, except for the bulb that is not glowing. The bulb that is not glowing has probably "burned out," but it could be loose. In either case, the result is an open circuit. Since the other bulbs are on, the bulb that is not glowing must be in parallel with them. Otherwise, the circuit through those bulbs would be broken and charges would not be able to flow through them. The bulbs are turned on or off by a single switch. Thus, the switch must be in series with the circuit for the bulbs. The source of electricity, the switch, and the bulbs are an example of a circuit that combines series and parallel connections.

Loads in Series

The potential difference (in volts) between the terminals of a cell is the energy required (in joules) to move one coulomb of charge around the circuit. Loads, such as bulbs, transform electrical energy into other forms of energy. The total energy that is transformed by the current through the entire circuit must equal the work that is done by the cell. The current is the same at all points in a series circuit, and the potential difference between the terminals of a cell must equal the sum of the potential differences between the connections to all the loads in series with the cell (**Figure 11.29**).

$$I_T = I_1 = I_2 = I_3 \qquad V_T = V_1 + V_2 + V_3 \qquad R_T = R_1 + R_2 + R_3$$

Adding loads in series is similar to increasing the length of a wire. If length is the only difference between two wires, the longer wire has greater resistance. Thus, you can use Ohm's law to predict that the resistance will increase as more loads are added to a series circuit.

Figure 11.28 Circuits that contain both series and parallel connections are found in almost every application that uses electric current.

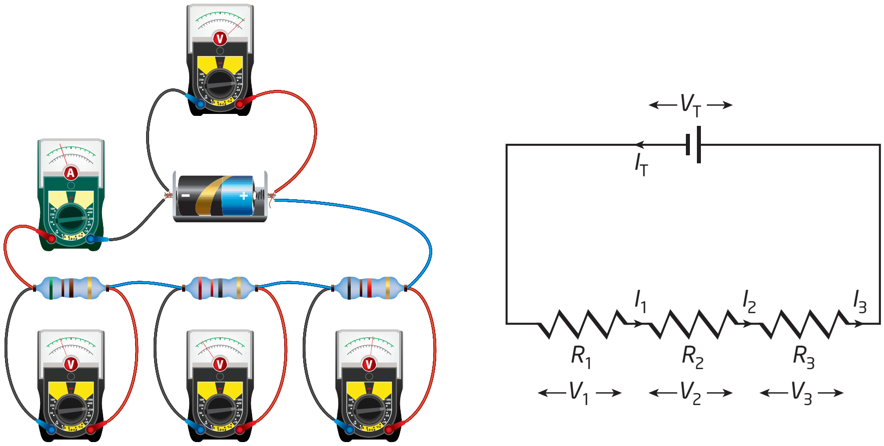

Figure 11.29 When loads are connected in series, the sum of the individual resistances is equal to the total resistance. Note that ammeters connected at I_1, I_2, and I_3 would all show the same reading as the ammeter at I_T.

Suggested Investigation

Inquiry Investigation 11-B, Loads in Series, on page 474

Decreased Current, Decreased Glow

Adding more bulbs in series to a circuit increases the total resistance of the circuit. This has an effect on the intensity of light bulbs in the circuit, as is shown in **Figure 11.30**.

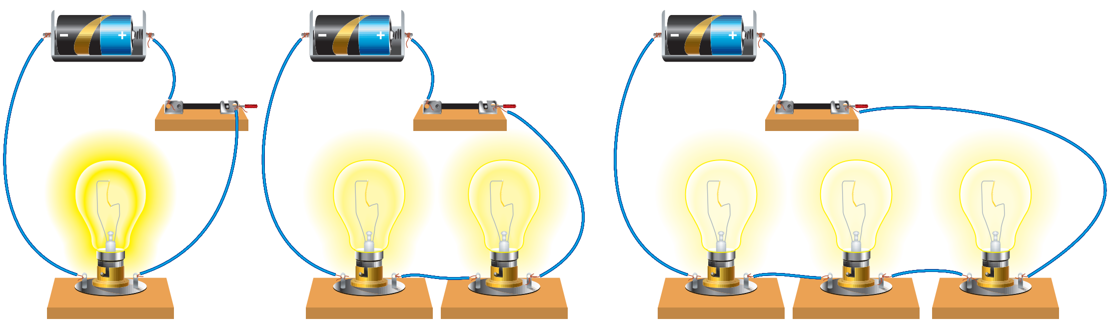

Figure 11.30 As more bulbs in series are added to this circuit, each bulb will glow with less intensity. All the bulbs in each arrangement will glow with the same intensity as each other *if they are identical*.

Loads in Parallel

At a parallel connection, there is more than one path along which electrons can flow. If you drink a liquid through two straws, more liquid will reach your mouth in the same amount of time than if you drank through one straw. The analogy between two straws in a drink and a parallel connection in a circuit suggests that the total resistance of two loads connected in parallel is less than the resistance of either load. **Figure 11.31** shows a series-parallel circuit that can be used to operate two bulbs independently. If only one switch is closed, the circuit operates as a simple series circuit. The bulb in series with the closed switch will glow, while the bulb in series with the open switch will not glow. Now imagine that both switches are closed, and place a finger on the negative terminal of the cell. Move your finger along the connecting wire. At the point marked P, you can choose which path you trace with your finger. This is characteristic of a parallel connection. The current entering a parallel connection divides. Thus, the sum of the currents through each path of a parallel connection equals the current entering the connection.

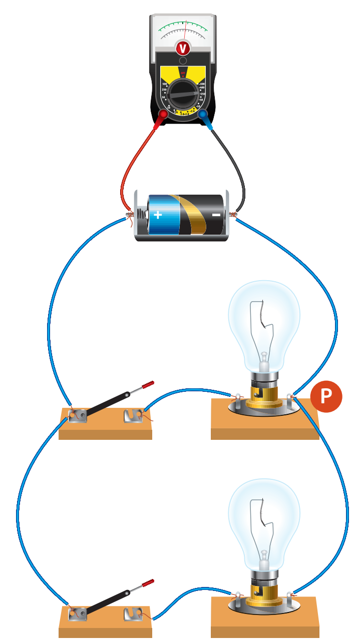

Figure 11.31 You can measure the potential difference and current in this circuit to find out the characteristics of a parallel connection.

Measuring Potential Difference

Now think about how you would measure the current and potential difference in the circuit in **Figure 11.31**. Recall that a voltmeter must be connected in parallel between the ends of a load. When you connect a voltmeter, the basic circuit does not change. You might connect the voltmeter between the terminals of the cell or between the connections to a bulb. Each bulb is connected to the cell with a switch and connecting wires. There is negligible potential difference across these components when the switch is closed, because their resistance is negligible. Thus, allowing for experimental error, the voltmeter will measure the same potential difference across each bulb and between the terminals of the cell.

Study Toolkit

Identifying Cause and Effect Drawing a cause-and-effect map can help you understand how inserting an additional parallel connection into a circuit affects the current and resistance in each parallel path.

Measuring Current

Recall that an ammeter must be connected in series at a point in a circuit. Connecting an ammeter always involves disconnecting the basic circuit at the point where you want to measure the current. Imagine that you have a pair of scissors and you could cut the basic circuit to insert the ammeter. To measure the current through a bulb, imagine making a cut in the circuit at different points, as shown in **Figure 11.32**. The points where you decide to cut the circuit do not matter, because the current in a series connection is the same at any point. To "cut" the circuit in **Figure 11.32**, trace along a wire to a connection, disconnect the circuit at the connection, and insert the ammeter.

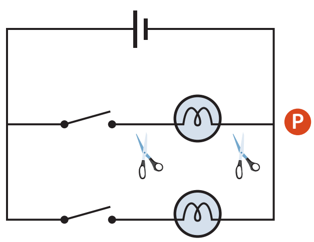

Figure 11.32 An ammeter can be inserted at different points in this circuit.

The resitance of the ammeter is very small, so adding it to the circuit does not affect the current. The easiest connection for an ammeter is between the switch and the bulb. You could make the ammeter connection, however, at point P. At this point, two connecting wires would be attached to the negative terminal of the ammeter. As in **Figure 11.33**, a wire from the positive terminal on the ammeter to the bulb would complete the series connection. **Figure 11.33** shows the relationships among the current, potential difference, and resistance of loads that are connected in parallel.

Suggested Investigation

Inquiry Investigation 11-C, Loads in Parallel, on page 476

$$I_T = I_1 + I_2 + I_3 \qquad V_T = V_1 = V_2 = V_3$$

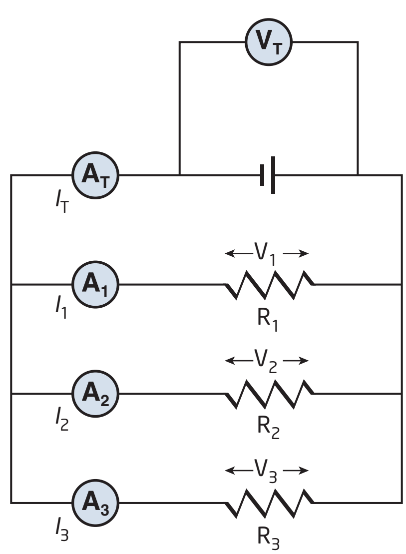

Figure 11.33 This diagram shows the relationships among the current, potential difference, and resistance in a circuit that contains loads in parallel.

Section 11.5 Review

Section Summary

- The current is the same at any point in a series connection: $I_T = I_1 = I_2 = I_3$.
- The potential difference across loads in series is the sum of the potential differences across all the loads: $V_T = V_1 + V_2 + V_3$.
- The resistance of loads that are connected in series is equal to the sum of the resistances of all the loads: $R_T = R_1 + R_2 + R_3$.
- The potential difference is the same between the terminals of any load in a parallel connection: $V_T = V_1 + V_2 + V_3$.
- The current entering loads that are connected in parallel is equal to the sum of the currents entering all the loads: $I_T = I_1 + I_2 + I_3$.
- The resistance of loads that are connected in parallel is less than the resistance of the smallest load: $R_T < R_1$; $R_T < R_2$; $R_T < R_3$.

Review Questions

K/U **1.** Two loads are connected in series. Must the potential differences between the connections on the loads be the same? Must the current through each load be the same? Explain.

K/U **2.** Two loads are connected in parallel. Must the potential differences between the connections on the loads be the same? Must the current through each load be the same? Why?

C **3.** Draw the diagram for the circuit shown in **Figure 11.30**.

C **4.** Draw a circuit diagram that contains three cells connected in series to a flashlight bulb. If each cell is 1.5 V, what is the potential difference across the bulb?

K/U **5.** How does the current leaving the cell in a parallel circuit compare with the current in a series circuit, if both circuits have the same type of cell and the same number of identical flashlight bulbs?

T/I **6.** Will each of two bulbs connected in parallel be as bright as a single bulb connected to a cell? Why? In this question, assume that all bulbs are identical and both cells are identical.

A **7.** A set of lights has a bulb that can be inserted near the plug to make all the lights flash on and off. If one of the regular bulbs burns out, the other bulbs still operate. Explain why.

T/I **8.** In the circuit diagram on the right, the flashlight bulbs are identical. Describe what you would expect to observe in each of the following situations.

a. switch 1 closed, switches 2 and 3 open

b. switches 1 and 2 closed, switch 3 open

c. switches 1 and 3 closed, switch 2 open

d. all switches closed