Key Terms
circuit diagram
series circuit
parallel circuit

11.3 Measuring the Properties of Simple Circuits

On a hot afternoon in August 2003, the lights went out across Ontario, as shown in **Figures 11.18A** and **B**. Much of Ontario and parts of the northeastern and midwestern United States went without electricity for up to two days. In the end, 50 million people were affected. Eleven people died as a result of the blackout, and the event cost an estimated $6 billion.

A key cause of the event was a faulty alarm system at a utility company in Ohio that meant operators could not respond quickly to the failure of a power line. Reliable systems for measuring electric circuits both complex and simple are crucial to the safe operation of electrical systems at home and across the continent. **Figure 11.18C** below shows measurements of Ontario's electrical grid.

In this section, you will learn how to read and draw circuit diagrams and how to use a voltmeter and an ammeter.


B during the blackout


A before the blackout

Figure 11.18 The satellite images in **A** and **B** show the light visible from space before and during the vast blackout of August 2003. In **C**, the electrical energy distribution grid for Ontario is monitored in this control room in Mississauga. The operators rely on accurate measurements to keep Ontario supplied with electricity.

Circuit Diagrams

circuit diagram a diagram that uses standard symbols to represent the components in an electric circuit and their connections

A practical way to describe a circuit is to draw a circuit diagram. A **circuit diagram** uses standard symbols to represent the components of an electric circuit and their connections. **Figure 11.19** shows the components in a flashlight and the corresponding circuit diagram.

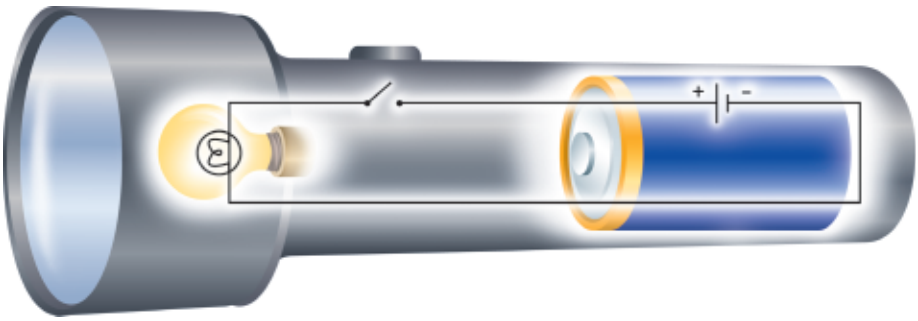


Figure 11.19 The symbol for a cell is two parallel lines of different lengths. The shorter line represents the negative terminal of the cell. The switch is usually shown in the open position so that it is not mistaken for a connecting wire. Note that straight lines are always used to represent the connecting wires.

One Pathway or Multiple Pathways

series circuit a circuit in which there is only one path along which electrons can flow

parallel circuit a circuit in which there is more than one path along which electrons can flow

Circuit diagrams show how the various components of a circuit are connected. In a **series circuit**, there is only one path along which electrons can flow. The specific places in a series circuit where components are connected to the conducting wires are called series connections. **Figure 11.20A** shows a series circuit with two light bulbs. Place your finger on the negative terminal of the cell in the circuit diagram. Trace your finger along the components in the circuit, back to the positive terminal of the cell. As you can see, there is only one way to trace the circuit from the negative terminal to the positive terminal. This is characteristic of all series circuits.

By comparison, in a **parallel circuit**, there is more than one path along which electrons can flow. **Figure 11.20B** shows a parallel circuit with two light bulbs. The specific parts of a parallel circuit where there are more than one pathway are called parallel connections. Most circuits are a combination of series and parallel connections.

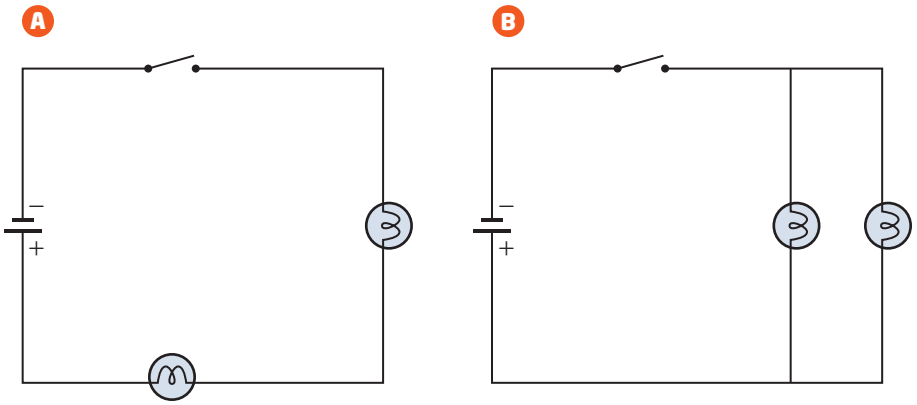


Figure 11.20 In **A**, there is only one path along which electrons can flow. This is a series circuit. In **B**, there is more than one path along which electrons can flow. This is a parallel circuit.

Symbols for Specific Components

Figure 11.21 shows images of the circuit components you will see in this chapter, as well as their symbols.

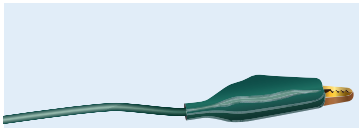
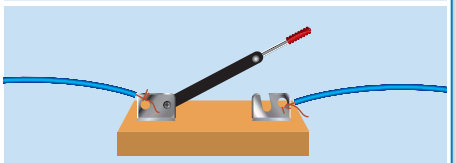
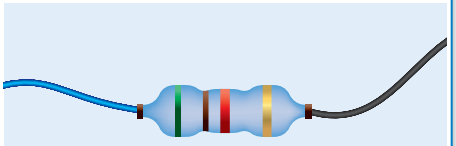
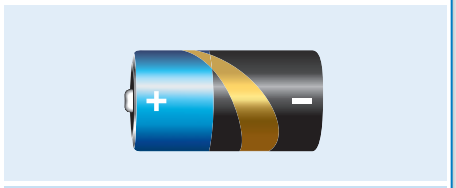
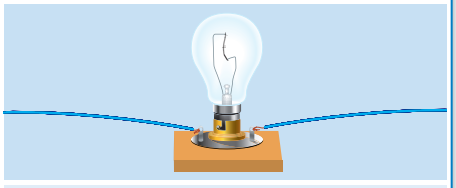
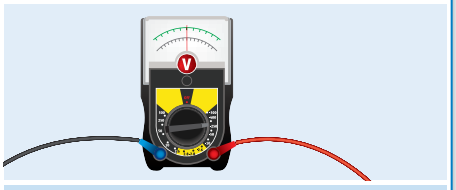
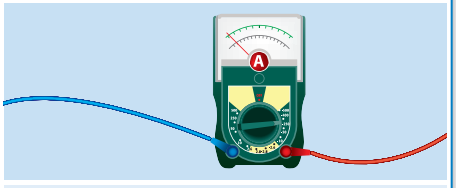
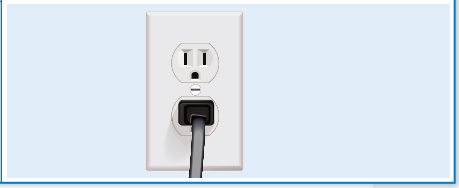
Symbol	Circuit Component
connecting wire	
switch	
resistor or load	
battery	
cell	
bulb	
voltmeter	
ammeter	
AC source	

Figure 11.21 Circuit symbols are used to represent the various components of a circuit. When joined together, the symbols make a circuit diagram. No special symbols for a multimeter or probeware (which can be used to measure voltage, current, and resistance) are shown because, when you use these meters, you must first select the property you need to measure. For example, when a circuit diagram shows the symbol for an ammeter, you need to select the current function on a multimeter.

Measuring Current and Potential Difference

An ammeter measures the current (in amperes, A) at *a particular location* in a circuit. Recall the analogy between electric current and the current of water in a river. If you were standing on a river bank, you could estimate the current, or total flow of water passing by in a certain amount of time. In a circuit, an ammeter measures the flow of electric charge (the current) at the point where the meter is connected in the circuit. Thus, *an ammeter is always connected in series*.

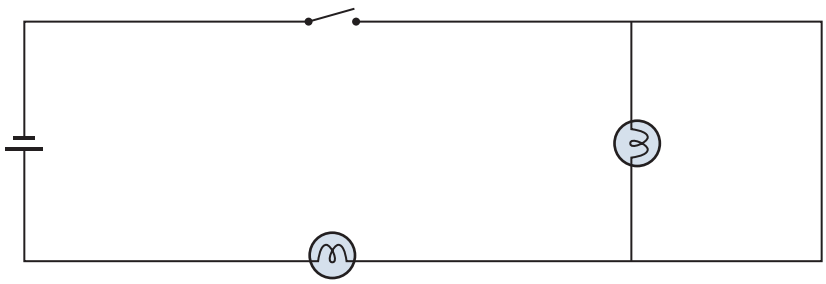
A voltmeter measures the potential difference (in volts, V) between two points in a circuit. The electric potential on one side of a load, such as a bulb or a resistor, is greater than the electric potential on the other side of the load. A voltmeter measures this difference. A voltmeter is *always connected in parallel* to measure the potential difference across the load.

Multimeters

A multimeter can be used as either an ammeter or a voltmeter. When the meter selection is set to read current, the meter must be connected in series. As you might expect, when the meter selection is set to read potential difference, the meter connection must be in parallel with the load. Many different meters are used in schools. In this textbook, instructions are given for ammeters and voltmeters.

Learning Check

1. Draw a symbol to represent each of the following components of a circuit. See **Figure 11.21** on page 457.
   - **a.** a cell (including labels for the positive and negative terminals)
   - **b.** a flashlight bulb
   - **c.** a load
   - **d.** a switch
2. Why must an ammeter be connected in series with a load, rather than in parallel, to correctly measure the current through the load?
3. Is this a parallel circuit or a series circuit? Explain your answer.



4. Write a brief analogy (two or three sentences) or draw a diagram to compare a road system with series and parallel connections in a circuit.

Activity 11-4

Measuring Current and Potential Difference in a Series Circuit

In this activity, you will build a basic circuit. Then you will measure current using an ammeter. You will also measure the potential difference between various points in the circuit using a voltmeter.

Safety Precautions

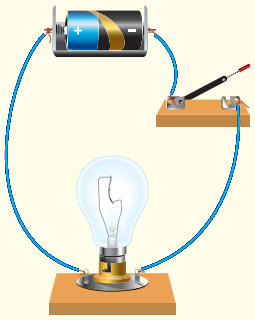
- Ask your teacher to check the connections to the ammeter and voltmeter before you close the switch.

Materials

- switch
- 6 connecting wires
- cell
- flashlight bulb
- voltmeter
- ammeter

Procedure

1. Make sure that the switch is in the open position. Use three wires to build the basic circuit on the right. Be sure to connect the switch to the negative pole of the cell. Check with your teacher, and then close the switch briefly to make sure that the flashlight bulb glows. Then open the switch.
2. Use two additional wires to connect a voltmeter across the cell. Make sure that the pole terminals on the meter connect to the same pole terminals on the cell.
3. Insert an ammeter in the circuit to measure the current leaving the cell. To do this, go to the switch and disconnect the wire between the cell and the switch.
4. Connect the loose wire to the negative pole of the ammeter. Use another wire to connect the positive pole of the ammeter to the switch.



5. After your teacher has checked your circuit connections, close the switch and record the current and potential difference. When you have done this, open the switch.
6. Connect the voltmeter across the switch and measure the potential difference when the switch is closed.
7. Measure and record the current entering the flashlight bulb and the potential difference across the bulb.

Questions

1. How does the voltage of the cell compare with the voltmeter reading across the flashlight bulb? Explain your observation.
2. Explain your reading of the potential difference across the switch when the switch was closed.
3. Explain the relationship between your two ammeter readings.

Electrical Energy and Gravitational Energy

A battery consists of cells that are connected. If you connect the cells in series, the positive terminal of one cell is connected to the negative terminal of another cell. This is what you do when you put two or more cells in a flashlight.

The potential difference across a battery of cells in series is the sum of the potential differences across each cell.

Sense of scale

The electric force between two protons is about 10^{36} times stronger than the gravitational force between them.

An Analogy for Potential Difference

As an analogy, think about a box on a table. The weight of the box represents an electric charge. The height of the box above the floor represents the potential difference between the terminals of a cell. Adding a second cell, which increases the potential difference in a circuit, is like stacking a second shelf on the first shelf and moving the box so that it is on top of the second shelf. This analogy is illustrated in **Figure 11.22**.

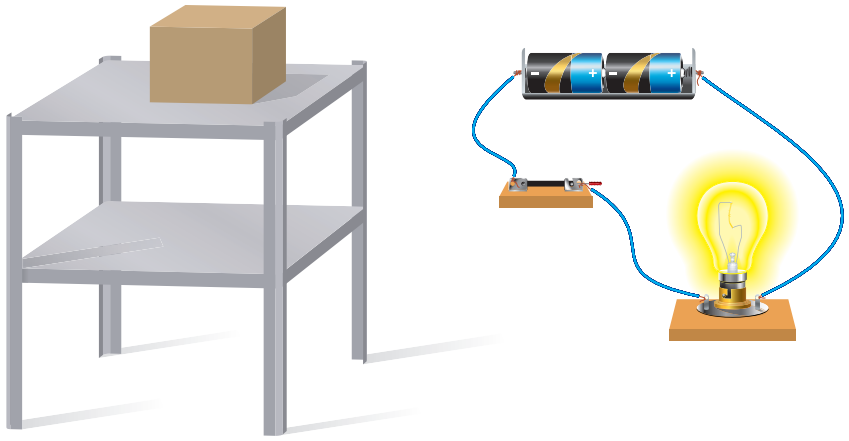


Figure 11.22 When a box is raised to a greater height, its gravitational potential energy is increased. When cells are connected in series, each cell increases the total potential difference across the battery.

Cells, Batteries, and Potential Difference

The potential difference that is generated by a cell is limited to a few volts because of the metals that are used for the electrodes. When a larger potential difference is required to operate a motorized toy or the starter motor on a car, several cells are connected in series to make a battery. As **Figure 11.23A** illustrates, a 9 V battery is made up of six smaller cells, each generating 1.5 V. The battery that is used to start a car is usually a 12 V battery, made up of six 2 V lead-acid cells, as shown in **Figure 11.23B**.

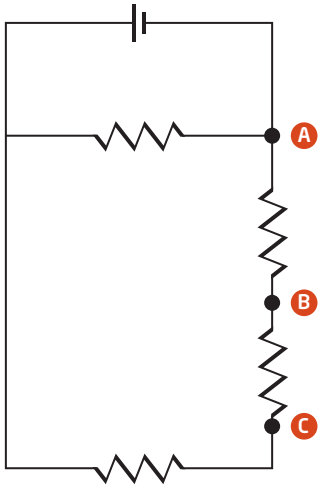
Figure 11.23 **A** The familiar 9 V battery contains six 1.5 V cells connected together. **B** An automobile battery contains six 2 V cells.

Section 11.3 Review

Section Summary

- Circuit diagrams use standard symbols to represent the components of an electric circuit and their connections in the circuit.
- At a series connection, there is only one path along which electrons can flow.
- At a parallel connection, there is more than one path along which electrons can flow.
- An ammeter measures current and is connected in series.
- A voltmeter measures potential difference and is connected in parallel between the terminals of a load.
- Each pole connection on a meter must trace back to the same type of terminal at the electrical source.
- The potential difference across a battery of cells in series is the sum of the potential differences across each cell.

Review Questions



K/U **1.** State the type of connection at each labelled point in the circuit on the right.

K/U **2.** Why is it important to be able to trace the pole connection on a meter back to the same type of pole at the electrical source?

C **3.** Draw the circuit symbol that would represent the 9 V battery shown in **Figure 11.23A**.

A **4.** Predict the potential difference that is generated by a battery with a 1.5 V cell in series with a 2.0 V cell.

C **5.** Draw a circuit diagram for the circuit shown on the lower right.

K/U **6.** Does gravity have an effect on the potential difference of a battery? Explain your answer.

T/I **7. a.** Consider a 6 V battery. How many cells would you expect to find inside the battery?

b. Why should you not connect a 6 V battery into a circuit that requires a D cell?

T/I **8.** In electric circuits, both electrons and energy are conserved.

a. What does it mean to say that something is conserved?

b. A certain battery can supply 6 J of energy to every coulomb of charge moving through a circuit. If the circuit consists of two identical flashlight bulbs in series, what can you predict about the total energy that is consumed by the bulbs?