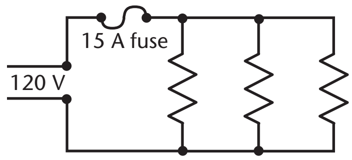


FIGURE 23–10 This parallel wiring arrangement permits the use of more than one appliance simultaneously, but if all three appliances are used at once, the fuse could melt.

that detects small differences in current caused by an extra current path and opens the circuit, thereby preventing dangerous shocks.

Electric wiring in homes uses parallel circuits, such as the one diagrammed in **Figure 23–10,** so that the current in any one circuit does not depend upon the current in the other circuits. The current in a device that dissipates power, P, when connected to a voltage source, V, is represented by $I = P/V$. Suppose, that in the schematic diagram shown in **Figure 23–10,** a 240-W television is plugged into a 120-V outlet. The current that flows is represented by $I = (240\ \text{W})/(120\ \text{V}) = 2\ \text{A}$. Then, a 720-W curling iron is plugged in. The current through the curling iron is $I = (720\ \text{W})/(120\ \text{V}) = 6\ \text{A}$. Finally, a 1440-W hair dryer is plugged in. The current through the hair dryer is $I = (1440\ \text{W})/(120\ \text{V}) = 12\ \text{A}$.

The current through these three appliances can be found by considering them as resistors in a parallel circuit in which the current through each appliance is independent of the others. The value of the resistance is found by calculating the current the appliance draws and then using the equation $R = V/I$. The equivalent resistance of the three appliances is

$$\frac{1}{R} = \frac{1}{10\ \Omega} + \frac{1}{20\ \Omega} + \frac{1}{60\ \Omega} = \frac{1}{6\ \Omega}$$

$$R = 6\ \Omega.$$

The 15-A fuse is connected in series with the power source so the entire current passes through it. The current through the fuse is

$$I = \frac{V}{R} = \frac{120\ \text{V}}{6\ \Omega} = 20\ \text{A}.$$

The 20-A current exceeds the rating of the 15-A fuse, so that the fuse will melt, or blow, cutting off current to the entire circuit.

A **short circuit** occurs when a circuit is formed that has a very low resistance. The low resistance causes the current to be very large. If there were no fuse or circuit breaker, such a large current could easily start a fire. A short circuit can occur if the insulation on a lamp cord becomes old and brittle. The two wires in the cord could accidentally touch. The resistance of the wire might be only 0.010 Ω. When placed across 120 V, this resistance would result in the following current.

$$I = \frac{V}{R} = \frac{120\ \text{V}}{0.010\ \Omega} = 12\ 000\ \text{A}$$

HELP WANTED

ELECTRICIAN

Electrical contractor needs electricians who have successfully completed a 5-year apprenticeship program conducted by a union or professional builder's association. You must be a high school grad, be in good physical condition, have excellent dexterity and color vision, and be willing to work when and where there is work. You will do all aspects of the job, including reading blueprints, dealing with all types of wires, conduits, and equipment. Safety and quality work must be your highest priorities. For information contact:

International Brotherhood of Electrical Workers
1125 15th Street, N.W.
Washington, DC 20005

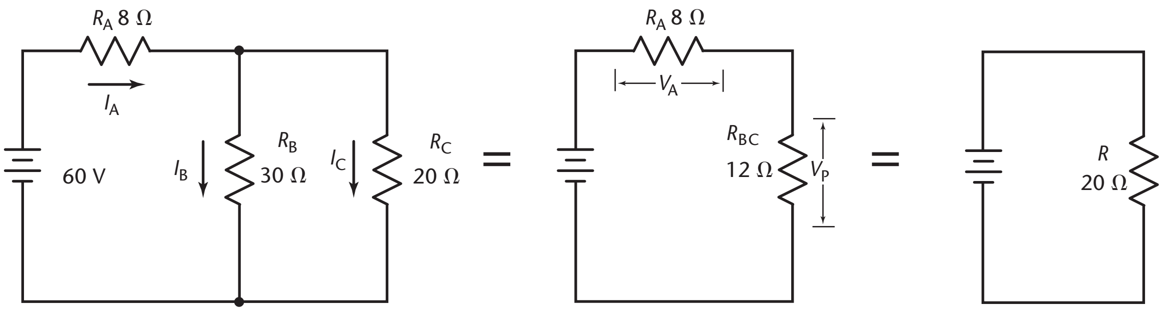


FIGURE 23–11 Use these diagrams as you study the following Problem Solving Strategy.

Such a current would cause a fuse or a circuit breaker to open the circuit immediately, thereby preventing the wires from becoming hot enough to start a fire.

Combined Series-Parallel Circuits

Have you ever noticed the light in your bathroom dim when you turned on a hair dryer? The light and the hair dryer were connected in parallel across 120 V. This means that the current through the lamp should not have changed when you plugged in the dryer. Yet the light dimmed, so the current must have changed. The dimming occurred because the house wiring had a small resistance in series with the parallel circuit. This is a **combination series-parallel circuit.** The following is a strategy for analyzing such circuits. Refer to **Figure 23–11** which illustrates the procedure described in steps 1, 2, and 3 of the Problem Solving Strategy.

PROBLEM SOLVING STRATEGIES

Series-Parallel Circuits

1. Draw a schematic diagram of the circuit.
2. Find any parallel resistors. Resistors in parallel have separate current paths. They must have the same potential differences across them. Calculate the single equivalent resistance that can replace them. Draw a new schematic using that resistor.
3. Are any resistors (including the equivalent resistor) now in series? Resistors in series have one and only one current path through them. Calculate a single new equivalent resistance that can replace them. Draw a new schematic diagram using that resistor.
4. Repeat steps 2 and 3 until you can reduce the circuit to a single resistor. Find the total circuit current. Then go backwards through the circuits to find the currents through and the voltages across individual resistors.

Circuits

Problem

Suppose that three identical lamps are connected to the same power supply. Can a circuit be made such that one lamp is brighter than the others and stays on if either of the others is loosened in its socket?

Hypothesis

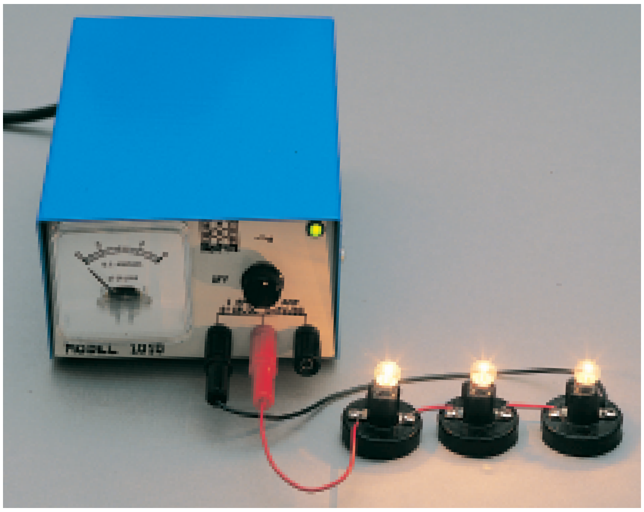
One lamp should be brighter than the other two and remain at the same brightness when either of the other two lamps is loosened in its socket so that it goes out.

Possible Materials

power supply with variable voltage
wires with clips
3 identical lamps and sockets

Plan the Experiment

1. Sketch a series circuit and predict the relative brightness of each lamp. Predict what would happen to the other lamps when one is loosened so that it goes out.
2. Sketch a parallel circuit and predict the relative brightness of each lamp. Predict what would happen to the other lamps when one is loosened so that it goes out.
3. Draw a combination circuit. Label the lamps A, B, and C. Would the bulbs have the same brightness? Predict what would happen to the other two lamps when each lamp in turn is loosened so that it goes out.
4. **Check the Plan** Show your circuits and predictions to your teacher before starting to build the circuits.
5. When you have completed the lab, dispose of or recycle appropriate materials. Put away materials that can be reused.



Analyze and Conclude

1. **Interpreting Data** Did the series circuit meet the requirements? Explain.
2. **Interpreting Data** Did the parallel circuit meet either of the requirements? Explain.
3. **Formulating Hypotheses** Explain the circuit that solved the problem in terms of current.
4. **Formulating Hypotheses** Use the definition of resistance to explain why one lamp was brighter and the other two were equally dim.
5. **Making Predictions** Predict how the voltages would compare when measured across each lamp in the correct circuit.
6. **Testing Conclusions** Use a voltmeter to check your prediction.

Apply

1. Can one wall switch control several lights in the same room? Are the lamps in parallel or series? Are the switches in parallel or series with the lamps? Explain.

Example Problem

Series-Parallel Circuit

A hair dryer with a resistance of 12.0 Ω and a lamp with a resistance of 125 Ω are connected in parallel to a 125-V source through a 1.50-Ω resistor in series.

a. Find the current through the lamp when the hair dryer is off.

b. Find the current when the hair dryer is on.

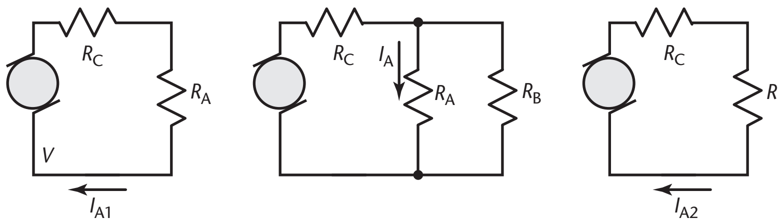
c. Explain why the lamp dims when the hair dryer is on.

Sketch the Problem

- Draw a diagram of the simple series circuit when the dryer is off.
- Draw the series-parallel circuit including the dryer and lamp.
- Replace R_A and R_B with a single equivalent resistance, R_p.

Calculate Your Answer

Known:	Unknown:
$R_A = 125\ \Omega$	$I_{A1} = ?$
$R_B = 12.0\ \Omega$	$R = ?$
$R_C = 1.50\ \Omega$	$I_{A2} = ?$
$V_{source} = 125\ \text{V}$	$I_2 = ?$



Strategy:

a. When the hair dryer is off, the circuit is a simple series circuit.

b. Find the equivalent resistance for parallel circuit.

Find the equivalent resistance for entire circuit.

Use equivalent resistance to determine the current when the hair dryer is on.

c. The greater current when the hair dryer is on means a greater voltage drop across R_C, which causes less voltage across R_A. A decrease in voltage means current decreases, which is less power.

Calculations:

$$I_{A1} = \frac{V}{R_A + R_C} = \frac{125\ \text{V}}{125\ \Omega + 1.50\ \Omega} = 0.988\ \text{A}$$

$$\frac{1}{R_p} = \frac{1}{R_A} + \frac{1}{R_B},\ \text{so}\ R_p = \frac{R_A R_B}{R_A + R_B}$$

$$R = R_C + R_p = R_C + \frac{R_A R_B}{R_A + R_B}$$

$$R = 1.50\ \Omega + \frac{(125\ \Omega)(12.0\ \Omega)}{125\ \Omega + 12.0\ \Omega} = 12.5\ \Omega$$

$$I_{A2} = \frac{V_{source}}{R} = \frac{125\ \text{V}}{12.5\ \Omega} = 1.00 \times 10^1\ \text{A}$$

$$V_C = IR_C = (1.00 \times 10^1\ \text{A})(1.50\ \Omega) = 15.0\ \text{V}$$

$$V_A = V_{source} - V_C = 125\ \text{V} - 15.0\ \text{V} = 1.10 \times 10^2\ \text{V}$$

$$I_A = \frac{V_A}{R_A} = \frac{1.10 \times 10^2\ \text{V}}{125\ \Omega} = 0.880\ \text{A}$$

Current drops from 0.988 A to 0.880 A. Power, $P = I^2R$, is smaller, consequently the light dims.

Check Your Answer

- Are the units correct? Current is in amps, potential drops are in volts.
- Is the magnitude realistic? Decreased parallel resistance increases the current, causing a voltage drop in the series resistor. This leaves less voltage across the combination, so the current is smaller.

Pocket Lab

Ammeter Resistance

Design an experiment using a power supply, a voltmeter, an ammeter, a resistor, and some wires to determine the resistance of the ammeter. Make a sketch of your setup and include measurements and equations.

Communicating Results What is the resistance of the ammeter? Be prepared to present your experiment to the class.

Practice Problems

13. Two 60-Ω resistors are connected in parallel. This parallel arrangement is connected in series with a 30-Ω resistor. The combination is then placed across a 120-V battery.

a. Draw a diagram of the circuit.

b. What is the equivalent resistance of the parallel portion of the circuit?

c. What single resistance could replace the three original resistors?

d. What is the current in the circuit?

e. What is the voltage drop across the 30-Ω resistor?

f. What is the voltage drop across the parallel portion of the circuit?

g. What is the current in each branch of the parallel portion of the circuit?

Ammeters and Voltmeters

An **ammeter** is used to measure the current in any branch or part of a circuit. If, for example, you want to measure the current through a resistor, you would place an ammeter in series with the resistor. This requires opening a current path and inserting an ammeter. The use of an ammeter should not change the current in the circuit you wish to measure. Because current would decrease if the ammeter increased the resistance in the circuit, the resistance of an ammeter should be as low as possible. **Figure 23–12** shows a real ammeter as an ideal, zero-resistance meter placed in series with a 0.01-Ω resistor. The ammeter resistance is much smaller than the values of the resistors. The current decrease would be from 1.0 A to 0.9995 A, too small to notice.

Another instrument, called a **voltmeter,** is used to measure the voltage drop across some part of a circuit. To measure the potential drop across a resistor, connect the voltmeter in parallel with the resistor. A voltmeter should have a very high resistance so that it causes the smallest possible change in currents or voltages in the circuit. Consider the circuit shown in **Figure 23–13.** A typical inexpensive voltmeter consists of an ideal, zero-resistance meter in series with a 10-kΩ resistor. When it is connected in parallel with R_B, the equivalent resistance of the combination is smaller than R_B alone. Thus, the total resistance of the circuit decreases, increasing

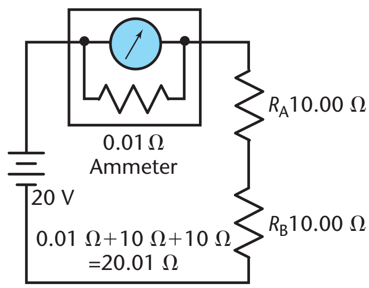
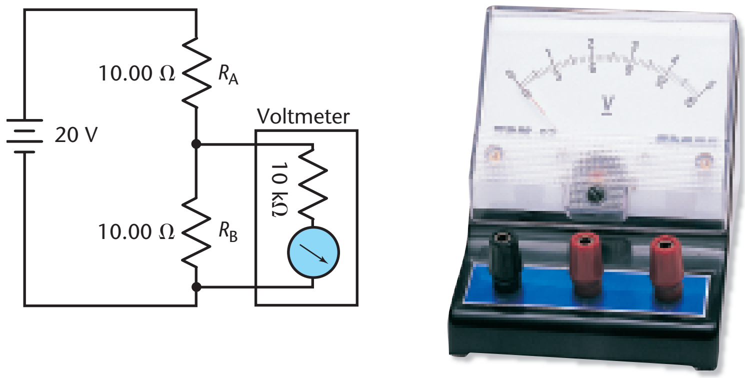


FIGURE 23–12 An ammeter measures current and so it is always placed in series in a circuit.

CONTENTS

FIGURE 23–13 A laboratory voltmeter such as this one measures potential difference. Voltmeters are placed in parallel.



the current. R_A has not changed, but the current through it has increased, increasing the potential drop across it. The battery, however, holds the potential drop across R_A and R_B constant. Thus, the potential drop across R_B must decrease. The result of connecting a voltmeter across a resistor is to lower the potential drop across it. The higher the resistance of the voltmeter, the smaller the voltage change. Using a voltmeter with a 10 000-Ω resistance changes the voltage across R_B from 10 V to 9.9975 V, too small a change to detect. Modern electronic multimeters have even higher resistances, 10^7 Ω, and so produce even smaller changes.

23.2 Section Review

1. Consider the circuit in **Figure 23–14** made with identical bulbs.
   - **a.** Compare the brightness of the three bulbs.
   - **b.** What happens to the brightness of each bulb when bulb 1 is unscrewed from its socket? What happens to the three currents?
   - **c.** Bulb 1 is screwed in again and bulb 3 is unscrewed. What happens to the brightness of each bulb? What happens to the three currents?
   - **d.** What happens to the brightness of each bulb if a wire is connected between points B and C?
   - **e.** A fourth bulb is connected in parallel with bulb 3 alone. What happens to the brightness of each bulb?
2. Research and describe the connection between the physics of circuits and future careers.
3. **Critical Thinking** In the circuit in **Figure 23–14,** the wire at point C is broken and a small resistor is inserted in series with bulbs 2 and 3. What happens to the brightness of the two bulbs? Explain.

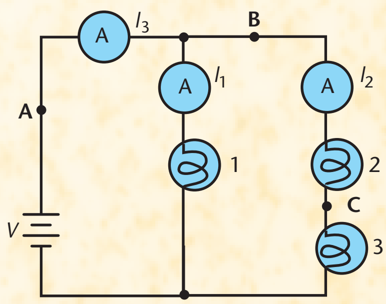


FIGURE 23–14

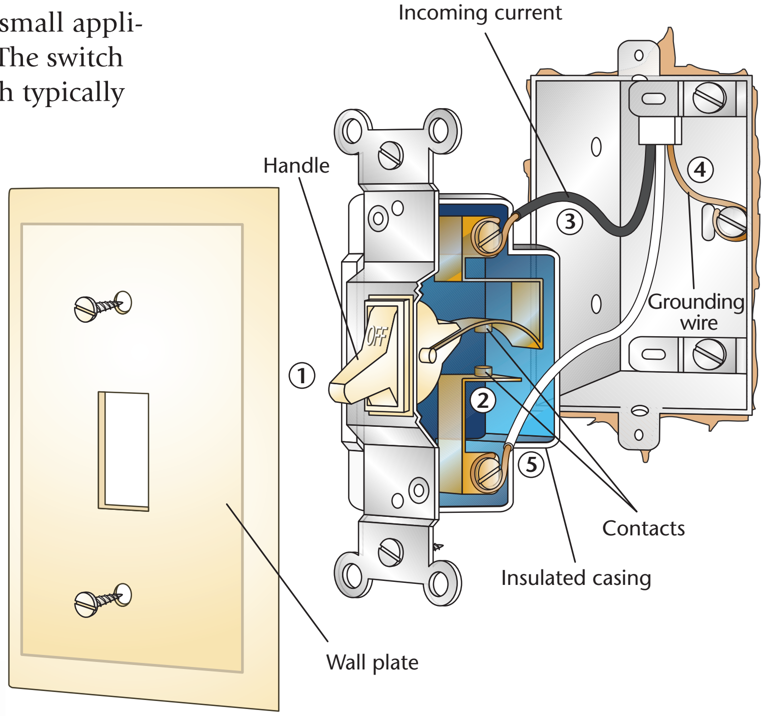
How It Works

Electric Switch

An electric switch is a device that is used to interrupt, complete, or divert an electrical current in a circuit. Switches are found on everything from hair dryers and toaster ovens, to calculators and video games, to computers and airplane instrument panels. Some switches are simple mechanical switches. In certain devices, such as computers, however, mechanical switches are too slow and are replaced by electronic switches made from semiconducting materials.

Probably the most common type of switch is the mechanical switch you use to operate the small appliances and lights in your home or school. The switch shown below is a snap-action toggle switch typically used to turn lights off and on.

1. The insulated handle of a snap-action toggle switch can be flipped in either of two positions–off or on.
2. When the handle is in the off position, as it is in this diagram, metal contacts within the switch are separated, interrupting the path of the current.
3. When the handle is in the on position, the metal contacts, which are linked by wires, come together to complete the circuit.
4. One wire leads to a grounding location. Then if a problem occurs with the wires or switch contacts, the current is routed to the ground, not to the person touching the switch.
5. The switch casing is insulated, so if a wire becomes loose or frayed and touches the casing, current will not flow.



Thinking Critically

1. Circuit breakers are automatic switches. Explain why this is so.
2. Why must the contacts in a switch be metal? Why are switch handles often plastic?