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## Skill Sheet 7-A

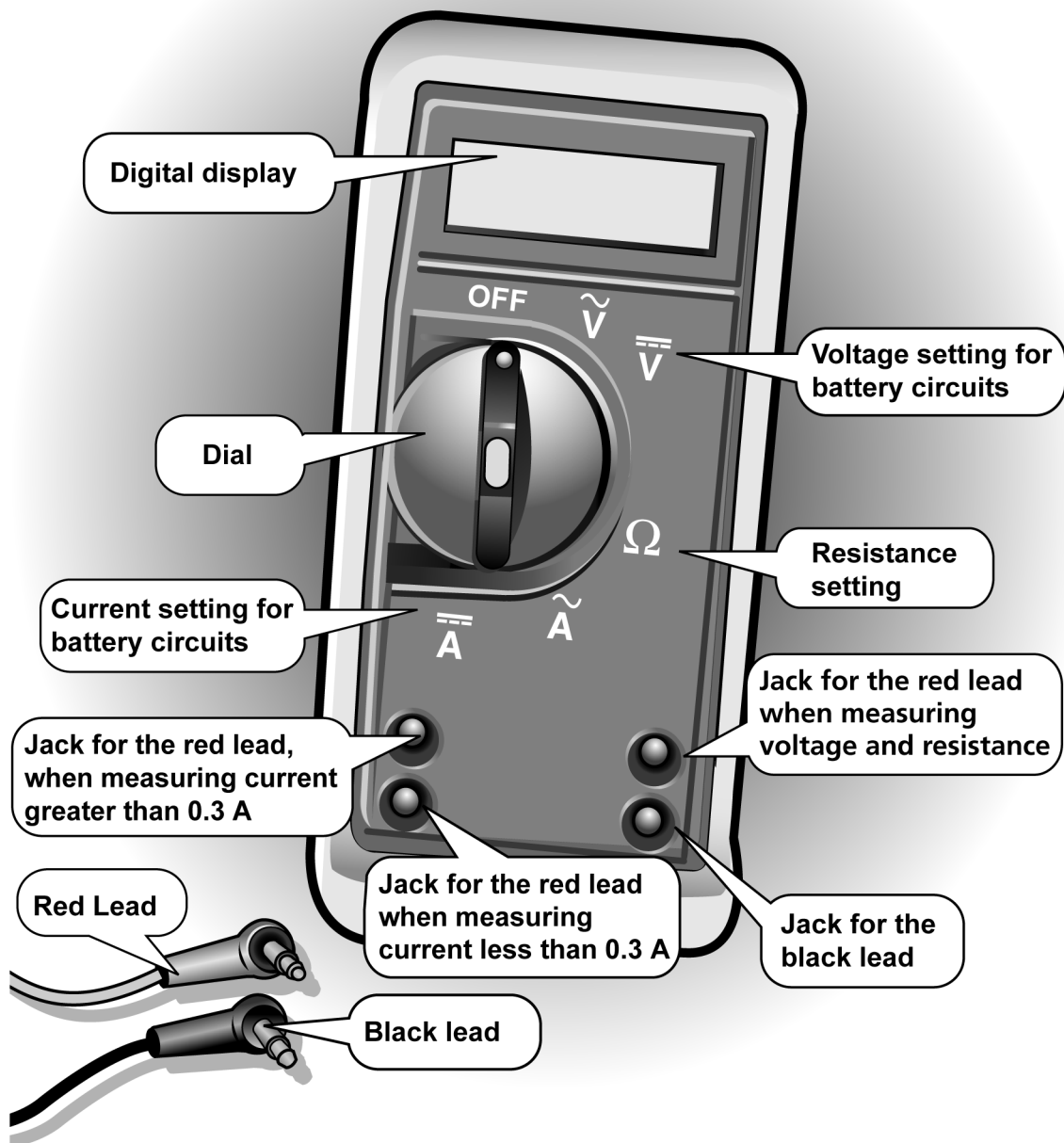
## Using an Electric Meter



What do you measure in a circuit and how do you measure it? This skill sheet gives you useful tips to help you use an electric meter and understand electrical measurements.

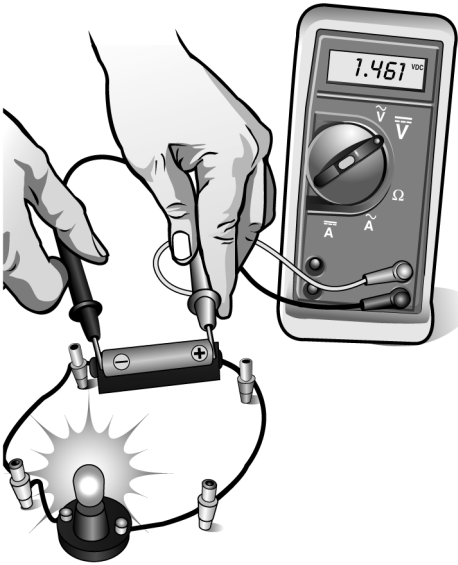
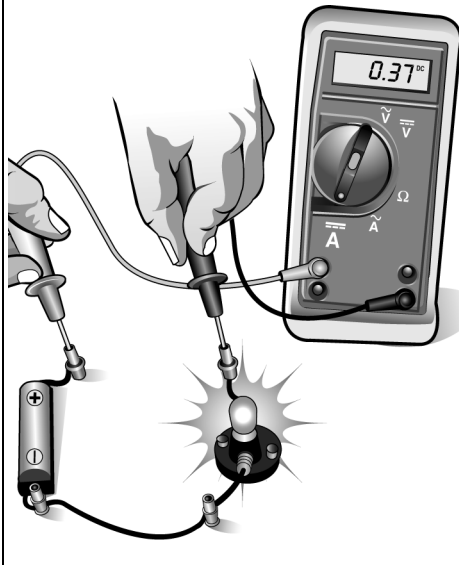
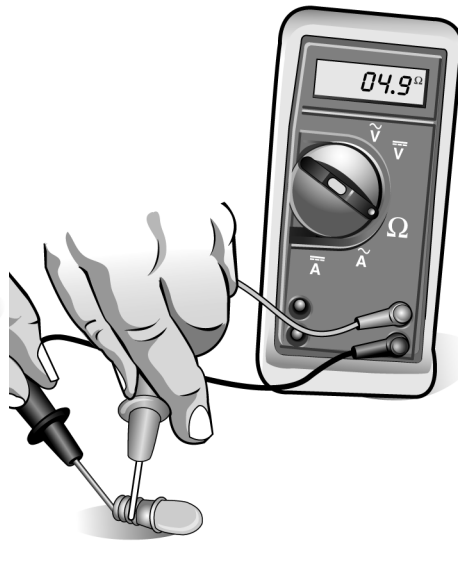
### 1. The digital multimeter

Most people who work with electric circuits use a *digital multimeter* to measure electrical quantities. These measurements help them analyze circuits. Most multimeters measure voltage, current, and resistance. A typical multimeter is shown below:



## 2. Using the digital multimeter

This table summarizes how to use and interpret any digital meter in a battery circuit. Note: A *component* is any part of a circuit, such as a battery, a bulb, or a wire.

Measuring Voltage	Measuring Current	Measuring Resistance
Circuit is ON	Circuit is ON	Circuit is OFF
Turn dial to voltage, labeled V, VDC, or $\overline{\overline{V}}$	Turn dial to current, labeled A, ADC, or $\overline{\overline{A}}$	Turn dial to resistance, labeled $\Omega$
Connect leads to meter following meter instructions	Connect leads to meter following meter instructions	Connect leads to meter following meter instructions
Place leads at each end of component (leads are ACROSS the component)	Break circuit and place leads on each side of the break (meter is IN the circuit)	Place leads at each end of component (leads are ACROSS the component)
Measurement in VOLTS (V)	Measurement in AMPS (A)	Measurement in OHMS ( $\Omega$ )
Battery measurement shows relative energy provided  Component measurement shows relative energy used by that component	Measurement shows the value of current at the point where meter is placed  Current is the flow of charge through the wire	Measurement shows the resistance of the component  When the resistance is too high, the display shows OL (overload) or $\infty$ (infinity)
		

### 3. Meter practice

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Build a series circuit with 2 batteries and 2 bulbs.

1. Measure and record the voltage across each battery:

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2. Measure and record the voltage across each bulb:

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3. Measure and record the voltage across both batteries:

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4. Draw a circuit diagram or sketch that shows all the posts in the circuit (posts are where wires and holders connect together).

5. Break the circuit at one post. Measure the current and record the value below. Repeat until you have measured the current at every post.

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# Skill Sheet 7-B

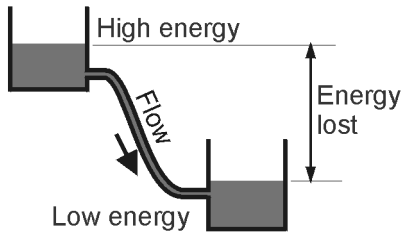
# Voltage, Current, and Resistance



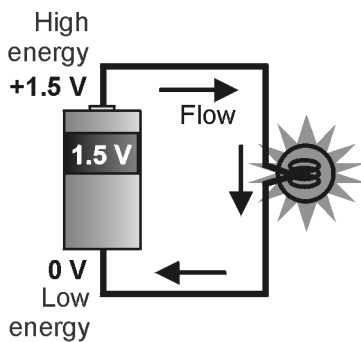
This skill sheet reviews the role of voltage, current, and resistance in an electric circuit, and provides practice in calculating these values using Ohm's Law. Understanding these three terms will greatly enhance your understanding of electricity. Let's begin our review!

## 1. What is voltage?

Water flows from high energy (height) to lower energy.



Electric charge flows from high energy (voltage) to lower energy.



You know that water will flow from a higher tank through a hose into a lower tank. The water in the higher tank has greater potential energy than the water in the lower tank. A similar thing happens with the flow of charges in an electric circuit.

Charges flow in a circuit when there is a difference in energy level from one end of the battery (or any other energy source) to the other. This energy difference is measured in volts. The energy difference causes the charges to move from a higher to a lower voltage in a closed circuit.

Think of voltage as the amount of “push” the electrical source supplies to the circuit. A meter is used to measure the amount of energy difference or “push” in a circuit. The meter reads the voltage difference (in volts) between the positive and the negative ends of the power source (the battery). This voltage difference supplies the energy to make charges flow in a circuit.

What is the difference between placing a 1.5-volt battery in a circuit and placing a 9-volt battery in a circuit?

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## 2. What is current?

Current describes the flow of electric charges. Current is the actual measure of how many charges are flowing through the circuit in a certain amount of time. Current is measured in units called *amperes*.

Just as the rate of water flowing out of a faucet can be fast or slow, electrical current can move at different rates. The type, length, and thickness of wire all effect how much current flows in a circuit. Resistors slow the flow of current. Adding voltage causes the current to speed up.

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1. What could you do to a closed circuit consisting of a battery, a light bulb, and a switch that would *increase* the amount of current? Explain your answer.
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2. What could you do to a closed circuit consisting of a battery, a light bulb, and a switch that would *decrease* the amount of current? Explain your answer.
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### 3. What is resistance?

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Resistance is the measure of how easily charges flow through a circuit. High resistance means it is difficult for charges to flow. Low resistance means it is easy for charges to flow. Electrical resistance is measured in units called *ohms* (abbreviated with the symbol  $\Omega$ ).

Resistors are items that reduce the flow of charge in a circuit. They act like “speed bumps” in a circuit. A light bulb is an example of a resistor.

Describe one thing that you could do to the wire used in a circuit to *decrease* the amount of resistance presented by the wire.

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### 4. How are voltage, current, and resistance related?

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When the voltage (push) increases, the current (flow of charges) will also increase, and when the voltage decreases, the current likewise decreases. These two variables, voltage and current, are said to be directly proportional.

When the resistance in an electric circuit increases, the flow of charges (current) decreases. These two variables, resistance and current, are said to be inversely proportional. When one goes up, the other goes down, and vice versa.

The law that relates these three variables is called Ohm’s Law. The formula is:

$$\text{Current (amps)} = \frac{\text{Voltage (volts)}}{\text{Resistance (ohms, } \Omega \text{)}}$$

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In your own words, state the relationship between resistance and current, as well as the relationship between voltage and current.

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## 5. Solving problems

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Now you will have the opportunity to demonstrate your understanding of the relationship between current, voltage and resistance. Answer each of the following questions and show your work. The first problem is done for you.

1. In a circuit, how many amps of current flow through a resistor such as a 6-ohm light bulb when using four 1.5-volt batteries as an energy supply?

$$\text{Current} = \frac{4 \times 1.5 \text{ volts}}{6 \text{ ohms}} = \frac{6 \text{ volts}}{6 \text{ ohms}}$$

$$\text{Current} = 1 \text{ amp}$$

2. How many amps of current flow through a circuit that includes a 9-volt battery and a bulb with a resistance of 6 ohms?
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3. How many amps of current flow through a circuit that includes a 9-volt battery and a bulb with a resistance of 12 ohms?
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4. How much voltage would be necessary to generate 10 amps of current in a circuit that has 5 ohms of resistance?
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5. How many ohms of resistance must be present in a circuit that has 120 volts and a current of 10 amps?
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# Skill Sheet 8-A

# Ohm's Law



Building and testing series circuits has helped you understand the relationship between voltage, resistance, and current. You know that if the voltage (energy) in a circuit increases, so does the current (flow of charges). You also understand that if the resistance increases, the current flow decreases. A German physicist, Georg S. Ohm, developed this mathematical relationship, which is present in most circuits. This relationship is known as Ohm's law:

$$\text{Current (amps)} = \frac{\text{Voltage (volts)}}{\text{Resistance (ohms, } \Omega)}$$

This skill sheet will provide you with an opportunity to test your knowledge of Ohm's law.

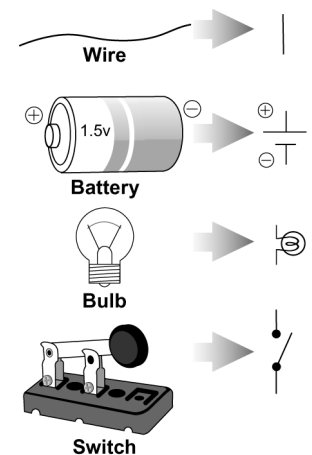
## 1. Using Ohm's Law to understand circuits

To work through this skill sheet, you will need the symbols used to depict circuits in diagrams. The symbols that are most commonly used for circuit diagrams are provided to the right.

All of the circuits discussed in this skill sheet are **series** circuits. This means the current has only one path through the circuit. Later you will learn about another kind of circuit in which the current has more than one possible path. This type of circuit is called a **parallel** circuit.

Note: For convenience, the symbol for battery is used to represent one *or more* batteries. The batteries you have used to build circuits are 1.5 volt batteries. Dividing the total voltage by 1.5 volts will tell you the number of batteries present in the circuit.

For example, the total voltage in the second diagram on the right is 6 volts. Divide 6 volts by 1.5 volts to find the number of batteries in the circuit.  $6 \div 1.5 = 4$ . There are four batteries in the circuit.



$$1.5 \text{ V } \frac{+}{-} = \text{[Battery Symbol]}$$

$$6 \text{ V } \frac{+}{-} = \text{[Four Batteries in Series Symbol]}$$

## 2. Solving problems

In this section, you will find some problems based on diagrams and others without diagrams. In all cases, you should show your work.

1. If a toaster produces 12 ohms of resistance in a 120-volt circuit, what is the amount of current in the circuit?

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2. What is the voltage of a circuit with 15 amps of current and toaster with 8 ohms of resistance?

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3. What is the current in a circuit containing two 1.5-volt batteries and a 6 ohm light bulb?

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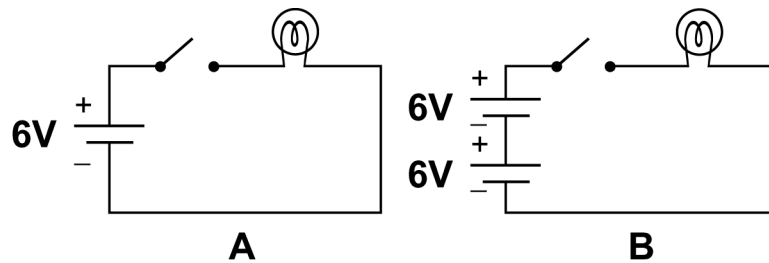
4. What is the resistance of a circuit in which a 9-volt battery produces a current of 3 amps?

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5. You have a large flashlight that takes 4 D-cell batteries. If the current in the flashlight is 2 amps, what is the resistance of the light bulb? (Hint: A D-cell battery has 1.5 volts.)

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6. Use the diagram below to answer the following problems.



a. What is the total voltage in each circuit?

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b. How much current would be measured in each circuit if the light bulb has a resistance of 6 ohms?

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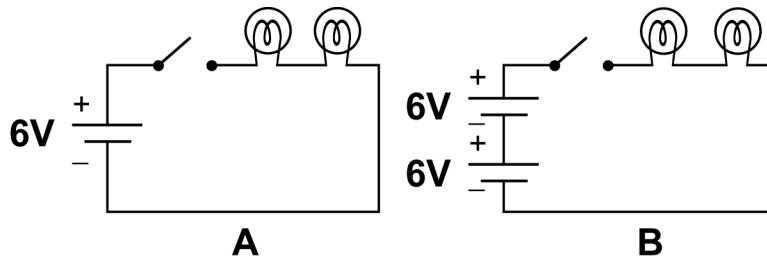
c. How much current would be measured in each circuit if the light bulb has a resistance of 12 ohms?

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d. What would happen to the brightness of the bulb if voltage is increased?

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7. Use the diagram below to answer the following problems.



a. How much current would be measured in each circuit if each light bulb has a resistance of 6 ohms?

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b. How much current would be measured in each circuit if each light bulb has a resistance of 12 ohms?

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c. What happens to the brightness of each bulb as you add bulbs to a series circuit? (Hint: Compare these diagrams to the diagrams in question 6 above.)

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8. What happens to the current in a series circuit as the number of batteries increases?

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9. What happens to the current in a series circuit as the number of bulbs increases?

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10. What happens to the current in a circuit as the voltage increases?

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11. What happens to the current in a circuit as the resistance increases?

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Which appliance in your kitchen uses the most power? The equation for electrical power is the tool you can use to answer this question. This skill sheet will help you sharpen your skills at calculating electrical power and analyzing the voltage, current, and power associated with electric circuits.

## 1. What is electrical power?

Power is the rate at which work is done or how much energy is being used per unit time. When you work with machines, power is calculated by dividing work by the amount of time it takes to perform the work. For electrical systems, the equation for power is:

$$\begin{aligned} \text{Current} \times \text{Voltage} &= \text{Power} \\ I \times V &= P \end{aligned}$$

This equation allows us to calculate the rate at which an appliance or other device is using energy or performing work.

The graphic below shows you why power is called a rate. The unit for voltage is joules per coulomb. The unit for current is coulombs per second. When you multiply voltage times current, the coulombs cancel so that the unit for power is joules per second.

$$\begin{array}{ccc} \text{Current} \times \text{Voltage} & = & \text{Power} \\ \downarrow & & \downarrow \\ \frac{\text{coulomb}}{\text{second}} \times \frac{\text{joules}}{\text{coulomb}} & = & \frac{\text{joules}}{\text{second}} \end{array}$$

## 2. The unit for electrical power

One joule per second is equal to one watt of power. The watt (W) is a familiar unit of power for most people. You can look at any appliance and see how many watts of power it uses. For example, the heating element on a coffee maker uses 1,050 watts of power. We can also say that the coffee maker has a power rating of 1,050 watts.

*One watt of power represents one joule of energy being used per second of time.*

$$\begin{aligned} \text{Power} &= \frac{\text{joules}}{\text{sec}} \\ 1 \text{ watt} &= \frac{1 \text{ joule}}{\text{sec}} \end{aligned}$$

The more watts of power a circuit or appliance has, the more energy it uses or the more work it can do per second of time. A 1,500-watt microwave oven can perform the same amount of work as a 900-W microwave; however, the rate at which the 1,500-watt microwave performs the work is faster. The 900-watt microwave takes more than one second to do the amount of work a 1,500-watt microwave can do in one second.

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### 3. Practice problems

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Complete the following problems. Be sure to show your work. The first problem has been done for you.

1. A toaster oven has a power rating of 750 W. If the oven heats a piece of pizza for 360 seconds, how many joules of energy have been used by the toaster oven?

$$\text{Power} = \frac{\text{joules of energy}}{\text{time}}$$

$$750 \text{ W} = \frac{\text{joules of energy}}{360 \text{ sec}}$$

$$750 \text{ W} \times 360 \text{ sec} = \text{joules of energy} = 270,000 \text{ joules}$$

2. The current flowing through an electric circuit is 9 amps. If the voltage in the same circuit is 120 V, what is the power of the circuit?

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3. A 7,200-watt electric clothes dryer operates with a current of 30 amps. What is the voltage associated with this circuit?

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4. A girl wants to build a radio that operates using a 9-volt battery. If the girl wishes the radio to function with 75 W of power, with what amount of current will she have to design her circuits?

- 
5. A CD player uses 85 joules of energy per second. If the voltage in the CD player is 170 V, what amount of current is required for the operation of player?

- 
6. You use your 60-watt DVD player to watch your favorite movie. If the player uses 324,000 joules of energy while playing the film, what is the running time of the movie?
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7. Your stereo has a power rating of 150 watts. Your friend buys a stereo with a power rating of 300 watts. If you both play your stereo for one hour, who will spend more money to listen to their music? Explain your answer.

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8. The voltage supplied to household circuits is generally 120 V. However, individual circuits (circuits supplying the kitchen as opposed to the dining room, for example) differ in the amount of current they carry. What does that tell you about the amount of power operating in different household circuits? Why do you think household circuits are designed in this way?

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#### 4. Comparing electrical power and mechanical power

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Power is a term that is used when you talk about machines that use electricity, like blenders, and mechanical machines, like pulleys. Look up the equation for mechanical power. Use this equation to answer the following questions.

1. Power can be calculated for electrical systems and mechanical systems. Write the equation for mechanical power. What are the units for mechanical power?

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2. Compare the equations for electrical power and mechanical power. How are they alike and different?

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## Skill Sheet 8-C

## Electrical Power and Ohm's Law



In this skill sheet you will review the relationship between electrical power and Ohm's law. As you work through the problems, you will practice calculating the power used by common appliances in your home.

### 1. How do you calculate electrical power?

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During everyday life we hear the word *watt* mentioned in reference to things like light bulbs and electric bills. The watt is the unit that describes how much power is used when electricity flows. Therefore, the definition of power is the “rate at which energy is flowing.” And since energy is measured in joules, power is measured in joules per second. In fact, one joule per second is equal to one watt.

You may also have heard of the word kilowatt. A kilowatt is 1,000 watts or 1,000 joules of energy flowing in one second. This term kilowatt is most often used with electrical use in houses and other large facilities. And on an electric bill you may have noticed the term kilowatt-hour. A kilowatt-hour means that one kilowatt of power has been used for one hour.

We can calculate the amount of electrical power by an appliance or other electrical component by multiplying the voltage by the current.

$$\text{Current} \times \text{Voltage} = \text{Power, or } P = I V$$

### 2. Solving problems

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Solve the following problems using the power equation and Ohm's law.

$$\text{Current (amps)} = \frac{\text{Voltage (volts)}}{\text{Resistance (ohms)}}$$

Remember, power is measured in watts.

1. Your hair dryer has a power rating of 1,200 watts.
  - a. How many kilowatts is this?

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b. If the hair dryer is used for 20 minutes per day, how many kilowatt-hours (kWh) per day is this? (Hint: convert 20 minutes to hours.)

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c. Find the kilowatt-hours used by the hair dryer each month (assume 30 days/month).

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d. If your town charges \$0.15/kWh, what is the cost to use the hair dryer per month?

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2. Using the formula for power, calculate the amount of current through a 75-watt light bulb that is connected to a 120-volt circuit in your home.
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3. What is the power rating of a home appliance (in kilowatts) that uses 8 amps of current when plugged into a 120-volt outlet.
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4. The following questions refer to the diagram.

a. What is the total voltage for the circuit?

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b. What is the total resistance for the circuit in ohms ( $\Omega$ )?

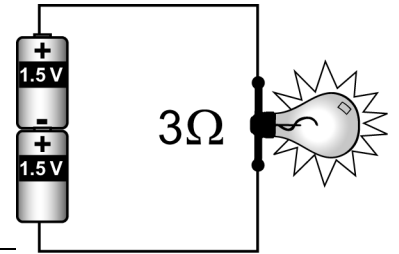
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c. What is the current that will flow through the circuit?

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d. What is the power (in watts) for this circuit?

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5. A toaster is plugged into a 120-volt household circuit. It draws 5 amps of current.

a. What is the resistance of the toaster in ohms ( $\Omega$ )?

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b. What is the power (in watts) of the toaster? What is this power in kilowatts?

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6. A clothes dryer in a home has a power of 4,500 watts and runs on a special 220-volt household circuit.

a. What is the current traveling through the dryer?

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b. What is the resistance of the dryer in ohms ( $\Omega$ )?

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7. A hair dryer is connected to a 120-volt household circuit. The current through the dryer is 10 amps.

a. What is the resistance of the hair dryer?

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b. What is the power rating (in kilowatts) of the dryer?

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c. If the dryer is used for 30 minutes per day, how many kilowatt-hours are used by the dryer each day?

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d. How many kilowatt-hours are used per month? (Assume 1 month = 30 days)

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e. If the town charges 14 cents per kWh, what is the cost to run the hair dryer per month?

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## Skill Sheet 9-A

## Parallel and Series Circuits



There are two major types of electric circuits: series and parallel. In a series circuit, current follows only one path. In a parallel circuit, the current has two or more possible paths. In both types of circuits, the current travels from the positive end of the battery toward the negative end. The amount of energy used by a circuit (series or parallel) must equal the energy supplied by the battery. In this way, electric circuits follow the law of conservation of energy. Understanding these facts will help you solve problems that deal with series and parallel circuits.

### 1. Solving series circuit problems

It is now time for you to test your knowledge of series and parallel circuits by answering the questions below. You will have to use Ohm's law to solve many of the problems, so remember that:

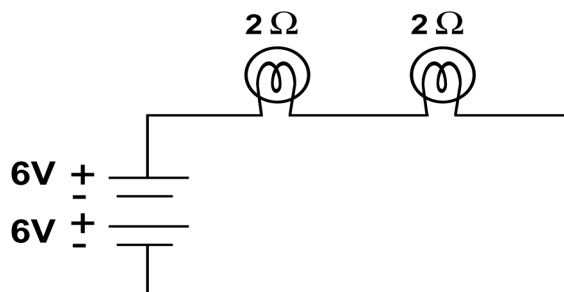
$$\text{Current (amps)} = \frac{\text{Voltage (volts)}}{\text{Resistance (ohms)}}$$

Some questions ask you to calculate a *voltage drop*. We often say that each resistor creates a separate voltage drop. As current flows along a series circuit, each resistor uses up some energy. As a result, the voltage gets lower after each resistor. If you know the current in the circuit and the resistance of a particular resistor, you can calculate the voltage drop using Ohm's law.

$$\text{Voltage drop (volts)} = \text{Current (amps)} \times \text{Resistance of one resistor (ohms)}$$

1. Use the series circuit pictured right to answer questions (a) - (e).

a. What is the total voltage of the circuit?



b. What is the total resistance of the circuit?

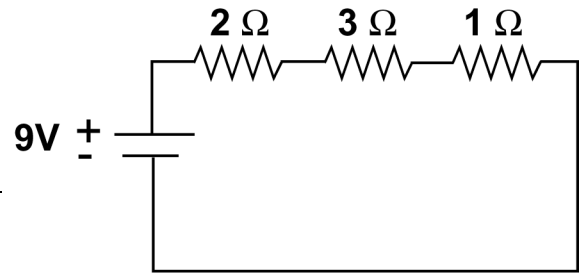
c. What is the current in the circuit?

d. What is the voltage drop across each light bulb? (Remember that voltage drop is calculated by multiplying current in the circuit by the resistance of a particular resistor:  $V = IR$ .)

e. Draw the path of the current on the diagram.

2. Use the series circuit pictured right to answer questions (a) - (d).

a. What is the resistance of the circuit?



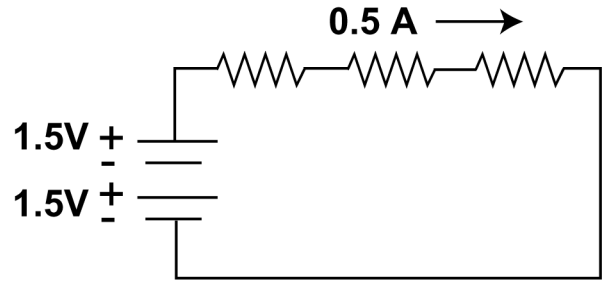
b. What is the current in the circuit?

c. What is the voltage drop across each resistor?

d. On the diagram, show the amount of voltage in the circuit before and after each resistor.

3. Use the series circuit pictured right to answer questions (a) - (c). Consider each resistor equal to all others.

a. What is the resistance of each resistor?



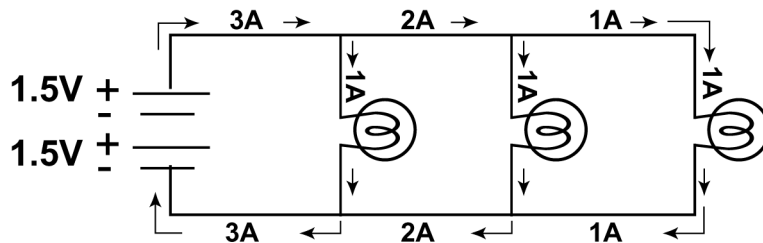
b. What is the voltage drop across each resistor?

c. On the diagram, show the amount of voltage in the circuit before and after each resistor.

## 2. Solving parallel circuit problems

A parallel circuit has at least one point where the circuit divides, creating more than one path for current. Each path is called a branch. The current through a branch is called branch current. Remember that if current flows into a branch in a circuit, the same amount of current must flow out again. This rule is known as **Kirchoff's current law**.

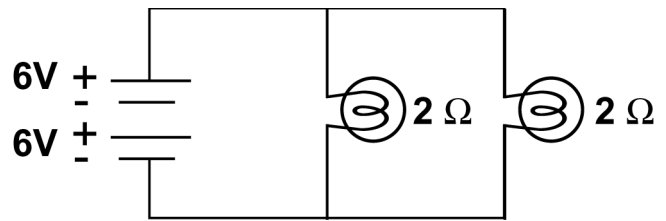
For example, suppose you have three light bulbs connected in parallel, and each has a current of 1 amp. The battery must supply 3 amps since each bulb draws 1 amp. Before the first branch point, 3 amps are flowing. One amp goes down the first branch to the first bulb, and 2 amps flow on to supply the next two bulbs.



1. Use the parallel circuit pictured right to answer questions (a) - (c).

a. What is the total voltage for the circuit?

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b. What is the voltage across each branch?

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c. What is the current through each branch?

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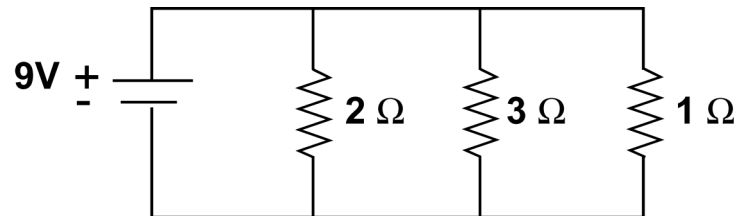
2. Compare the circuits in Part 1, question 1 and Part 2, question 1. What is the current through each bulb in the series circuit vs. the current through each bulb in the parallel circuit? Which bulbs would be brighter? Explain your reasoning.

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3. Use the parallel circuit pictured right to answer questions (a) - (d).

a. What is the voltage across each branch?

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b. What is the current through each branch?

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c. What is the power of each resistor? (Remember that power is current multiplied by voltage.)

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d. What is the power of the battery? (Hint: Add the branch currents to find the total current supplied by the battery.)

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## Skill Sheet 9-B

## Open and Closed Circuits



As you know, a circuit is a path for electric current. Electric current can move only through a closed circuit. A closed circuit provides a complete path with no breaks so that the current may travel out of and back to the power source. For this reason, the closed circuit is also known as a complete circuit.

An open circuit, on the other hand, has a break in it. No current flows and we say that the circuit is incomplete.

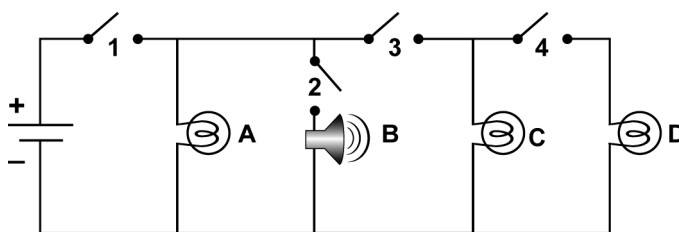
A familiar example of a closed and open circuit occurs when you turn a light switch on and off. When the switch is turned on, it closes the circuit and the lamp lights up. When the switch is turned off, the circuit is opened, and, therefore, the lamp turns off.

Open and closed circuits can be found in both series and parallel circuits. However, in a series circuit, it takes only one break in the current's path to open the entire circuit. This is because there is only one path for the current to flow. However, since a parallel circuit has more than one path for the electric current, a break in one path of the circuit may open that path but not the others.

### Solving problems

It is now time for you to test your knowledge of open and closed circuits in both series and parallel. You will use the circuit diagrams pictured below to answer the questions. You may wish to write on the diagrams in order to keep track where the current is flowing. As a result, each diagram is repeated several times.

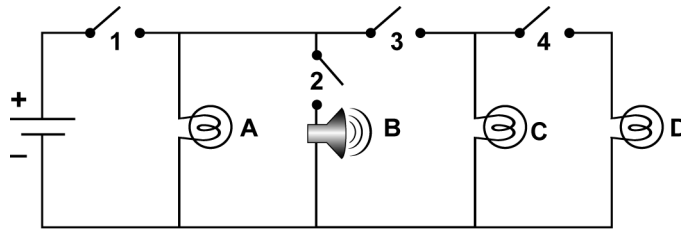
1. Which devices (A, B, C, or D) in the circuit pictured below will be *on* when the following conditions are met? For your answer, give the letter of the device or devices.



- a. Switch 3 is open, and all other switches are closed.

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- b. Switch 2 is open, and all other switches are closed.

- 
- c. Switch 4 is open, and all other switches are closed.
-



d. Switch 1 is open, and all other switches are closed.

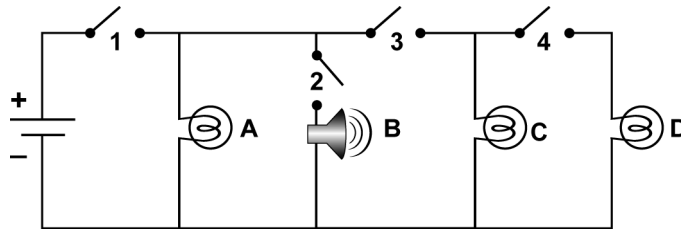
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e. Bulb C blows out, and all switches are closed.

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f. Bulb A blows out, and all switches are closed.

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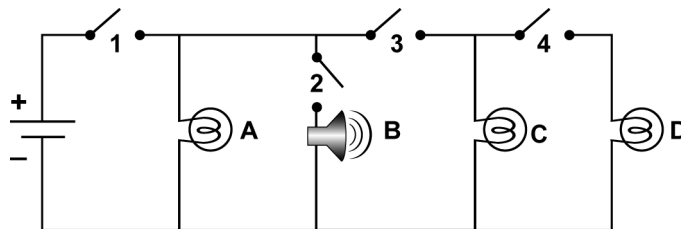


g. Switches 2 and 4 are open, and switches 1 and 3 are closed.

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h. Switches 2 and 3 are open, and switches 1 and 4 are closed.

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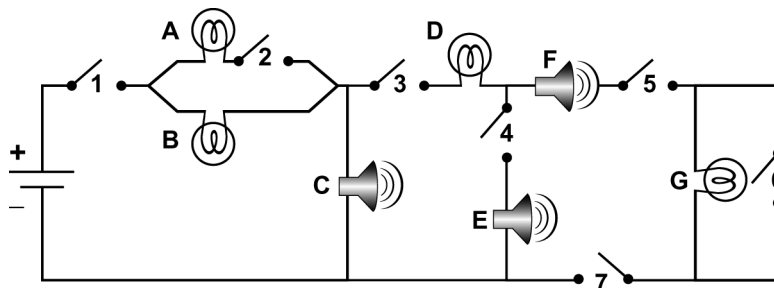
i. Switches 2, 3, and 4 are open, and switch 1 is closed.

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j. Switches 1 and 2 are open, and switches 3 and 4 are closed.

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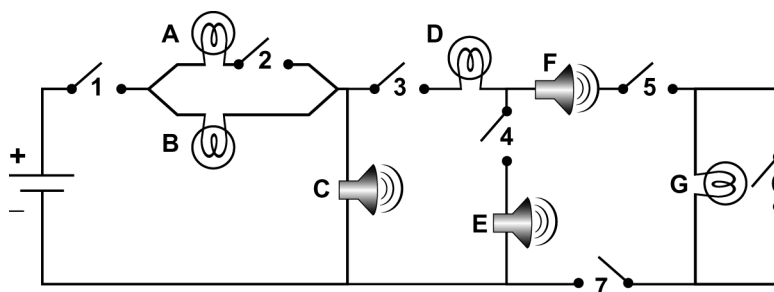
2. Which of the devices (A-G) in the circuit below will be *on* when the following conditions are met? For your answer, give the letter of the device or devices.



- a. Switch 5 is open, and all other switches are closed.

- 
- b. Switch 6 is open, and all others are closed.

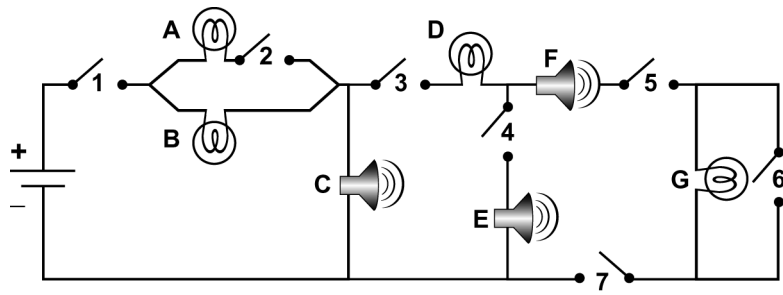
- 
- c. Switch 7 is open, and all others are closed.



- d. Switch 4 is open, and all others are closed.

- 
- e. Switch 3 is open, and all others are closed.

- 
- f. Switch 2 is open, and all others are closed.



g. Switch 1 is open, and all others are closed.

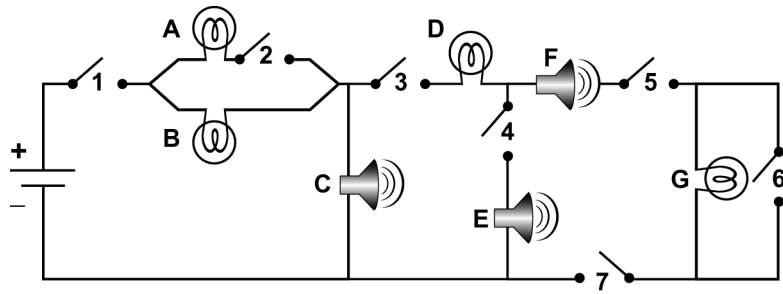
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h. Switches 2 and 4 are open, and all others are closed.

---

i. Switches 4 and 6 are open, and all others are closed.

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j. Switches 4 and 7 are open, and all others are closed.

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k. Switches 5 and 7 are open, and all others are closed.

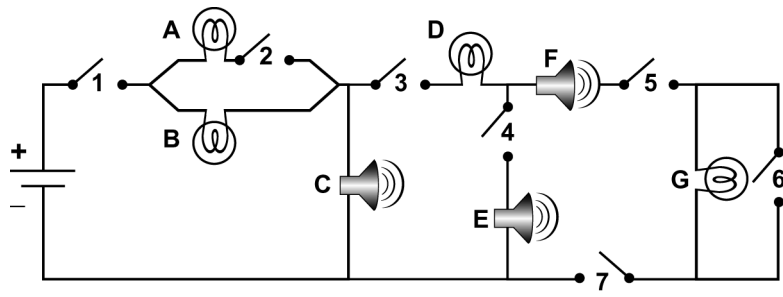
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l. Switches 2 and 3 are open, and all others are closed.

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m. Bulb D blows out with all switches closed.

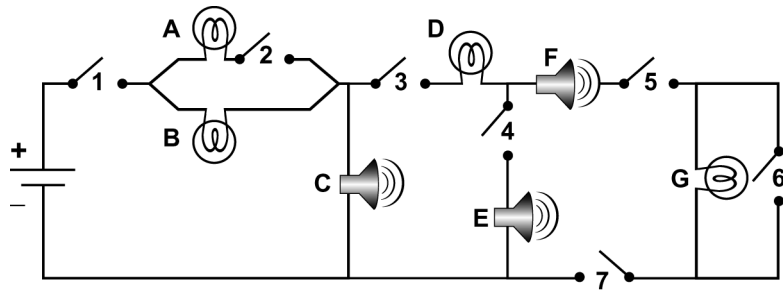
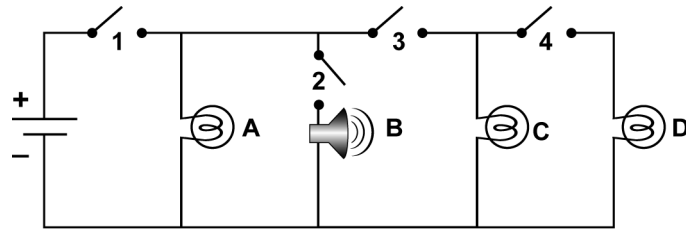
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n. Bulbs A and B blow out with all switches closed.

o. Bulbs A and D blow out with all switches closed.

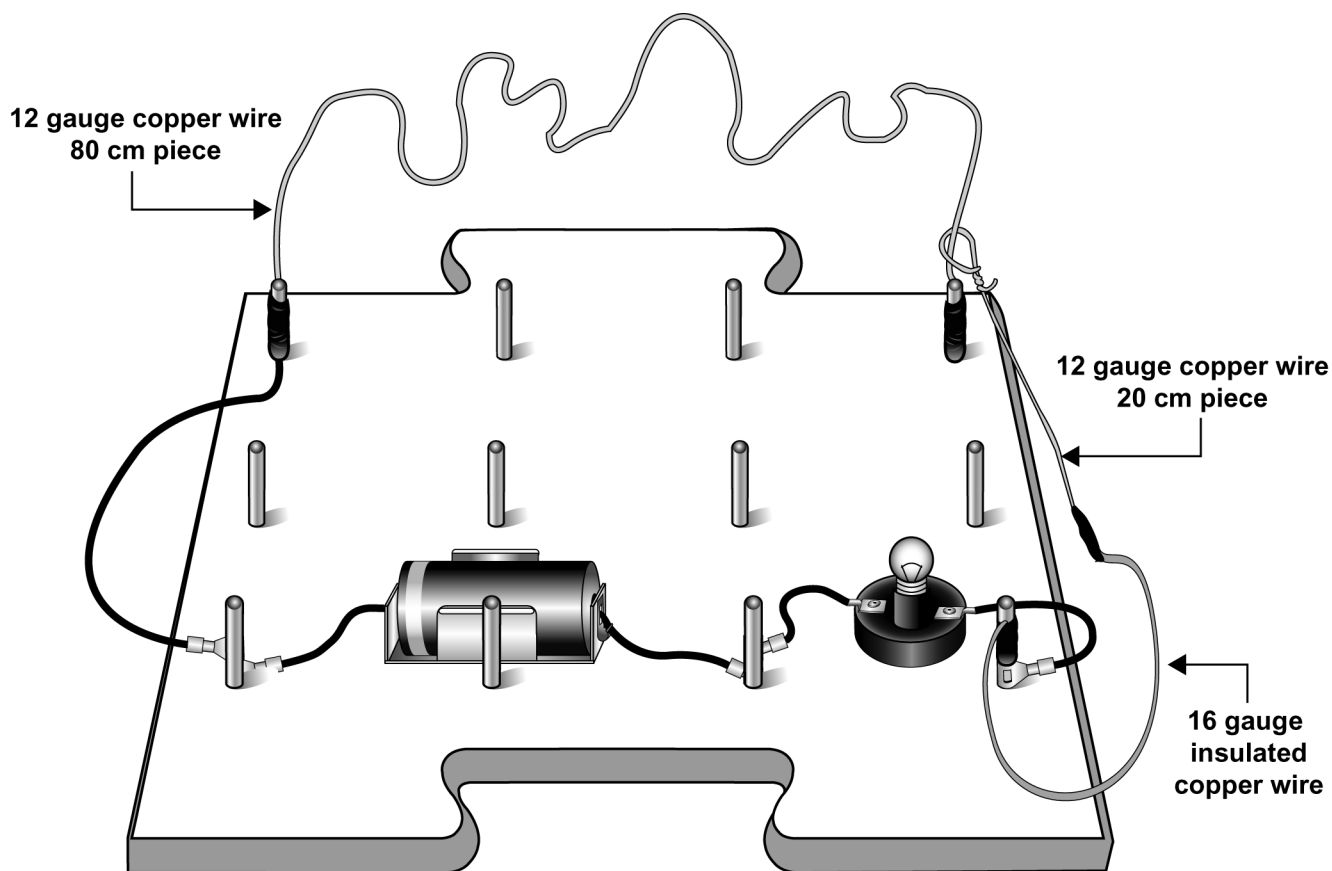
3. Use arrows to draw the direction of the current in each of the circuits below. Make sure to show current direction in all paths of the circuits within each diagram.



4. How many possible paths are there in circuit diagrams in questions (1) and (2)?

5. Draw a circuit of your own. Use one battery, show at least 4 devices (bulbs and bells), and use both parallel and series branches with switches in each. Finally, use arrows to show the direction of the current in all parts of your circuit.

Name: \_\_\_\_\_



### The Steady Hand Game

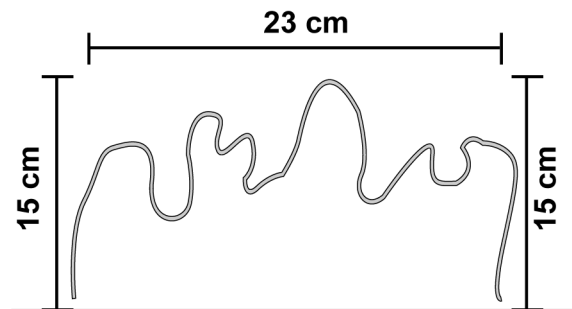
Do you have a steady hand? This easy-to-build game challenges your manual dexterity. Can you move a small loop of wire over a complicated maze without tripping the light bulb? Try it and see!

#### 1. Gather these materials

- Electric Circuits Set: electricity table, one battery with holder, one light bulb with holder, one long connecting wire (brown)
- 1 meter of 12-gauge copper wire. Wire must not have an insulated coating. This wire can be purchased where picture hanging supplies are sold.
- 50 centimeter-long piece of 16-gauge insulated copper wire. This wire can be purchased at a hardware store.
- Electrical tape
- Wire stripper tool
- Permanent-ink marking pen
- Metric ruler or measuring tape

## 2. How to build the game

1. Place the battery, light bulb, and long connecting wire on the electricity table as shown in the diagram on the previous page.
2. Cut a 20-centimeter piece from one end of the 1 meter-long piece of 12-gauge copper wire.
3. Bend one end of the 20-cm piece in to a loop with a diameter no larger than a dime. The smaller the loop, the more challenging the game! Twist the wire to secure the loop. You have just constructed the wand for your game board.
4. Strip 2 cm of plastic coating from each end of the 50 cm length of 16 gauge wire. (Your teacher may help with this part).
5. Wrap one end of the exposed wire around the base of your wand and secure with electrical tape.
6. Wrap the other end of the exposed copper wire around the right front corner post of the electricity table. (The light bulb wire should also be connected to this post). Secure with electrical tape.
7. Measure 15 cm in from each end of your remaining 80 cm piece of 12 gauge copper wire. Mark the two spots with permanent ink. DO NOT cut the wire.
8. Make a 90° bend in the wire at each spot so that the wire is shaped like a wide, upside-down U.
9. Bend the long horizontal section of the wire into a series of hills and valleys (see illustration). Adjust the bends until the two 15 cm “legs” of the wire are 23 cm apart.



10. Place one of the 15-centimeter “legs” alongside the left, rear post of the electricity grid. The long connecting wire should be attached to this post. Secure the leg with electrical tape.
11. Slide the loop of your wand over the other leg of the 12-gauge wire.
12. Use electrical tape to secure this leg to the right, rear post of the electricity grid. Make sure that the tape covers the entire post.
13. Make sure that the loop in the wand will slide down the post. The loop should be placed in this position when the game is not in use.
14. Now you are ready to play! Using one hand, move the loop in the wand over the hills and valleys—but don’t let the loop touch the copper wire! Try to make it all the way across without lighting the bulb.

Variation: Inexpensive buzzers can be purchased at electronic or hobby stores and placed in the circuit alongside the bulb.