

# ElectroCity (Grades 4-5)

## Unit Overview

This unit develops concepts of energy and electricity through design of circuits controlled by hidden switches. Opening or closing a box or card triggers lights and sounds, and sets color wheels and vibrators in motion. Students first learn to connect lights and buzzers to batteries, and then to control these circuits with homemade switches. To understand and troubleshoot their circuits, they develop strategies for making diagrams using standard symbols that everyone in the class can agree on. Subsequently, they add motors to their circuits and investigate series and parallel connections. Students use what they have learned to create their own “ElectroCities” – scenes that tell stories using circuits to provide light, sound and motion effects. In common devices such as refrigerators, automatic doors and alarms, switches are often hidden from view. Students create their own hidden switches, which are operated by doing other tasks, such as opening or closing a card or book. Magnets and Infrared remotes are introduced as ways of operating a switch at a distance. Students also learn to make noisemakers, vibrators, and fluorescent displays. Finally, students create automatic ElectroCities using any of the devices they have explored. The curriculum is summarized in Table 1.

Table 1: Summary of ElectroCity Curriculum

<b>Lesson</b>	<b>Title</b>	<b>Summary</b>
1	<b>Light &amp; Sound</b>	Turning on a LED and a buzzer
2	<b>Make a Switch</b>	Creating a switch from paper clips and fasteners
3	<b>Circuit diagrams</b>	Finding standard ways to represent circuits
4	<b>Motors, series &amp; parallel circuits</b>	Adding a motor to a circuit; connecting components in series and parallel
5	<b>Make a simple ElectroCity!</b>	Making a story come alive with light, sound & motion effects
6	<b>Hidden Switches</b>	Finding and making hidden switches
7	<b>Magnets &amp; Conductors</b>	Exploring electrical and magnetic properties of materials
8	<b>Magnetic proximity switches</b>	Incorporating magnets into switches that can be controlled from a distance
9	<b>Vibrators, Noisemakers, Remotes &amp; Things that Glow in the Dark</b>	Learning to make things that vibrate, make noise, operate via remote control, or glow in the dark.
10	<b>Design an Automatic ElectroCity</b>	Designing a mystery box or card with a surprise element, controlled by a hidden switch
11	<b>Make an Automatic ElectroCity</b>	Creating and troubleshooting the automatic ElectroCity
12	<b>Present your ElectroCity</b>	Students present their work to an audience

## Physical science & engineering concepts

1. Energy is needed to make things happen, such as getting something to move, light up, vibrate or make noise.
2. Energy can take many forms. Types include energy of sound, light, heat, position and motion; as well as elastic, chemical, magnetic and electric energy.
3. A **battery** stores energy in chemical form. Whenever the battery is part of a complete circuit, some of this energy changes to electric energy.
4. Electric energy can be converted to almost any form. For example, a **motor** changes electric energy to kinetic energy; a **lamp** changes it to light energy, and a **buzzer** or **speaker** changes it to sound energy. You can't see or hear electric energy at work, until it changes to light or sound.
5. A **circuit** transfers energy from a battery or other **source** to a lamp, motor, buzzer, speaker or other device that changes electrical energy to another form. Any device of this kind is called a **load**. A battery and a load each has two places to connect to, or **contacts**. Within a circuit, electricity must flow continuously between the source and the load.
6. A circuit needs at least one **conductor** that allows the electricity to flow from one contact of the battery to one contact of the load, and another conductor for the return path from the other contact of the load back to the other contact of the battery. Otherwise it is not a complete circuit, and the load will not do anything – for example, the light will not come on, or the motor will not turn.
7. Some loads are **polar**: it matters which way you connect them to the battery, which is also polar. A polar load has a (+) side that has to be attached to the (+) side of the battery, and a (–) side that has to be attached to the (–) side of the battery, or it won't work. An example is a Light Emitting Diode (LED). A motor is polar too, but not as obviously: it can be connected either way, but it will turn in opposite directions depending on which way it is connected to the battery.
8. A **control** tells a circuit what to do. The most common kind of control is a **switch**, which is needed to turn a circuit OFF, so it is not constantly ON. A switch works by breaking the flow of electricity from one side of the battery to one side of the load. Switches can be classified according to the type of mechanical action needed to operate them: **push button**, **pull chain**, **rotary**, **slide**, or **toggle**.
9. There are some **hidden switches** that you can't usually see, which are operated by taking some apparently unrelated action. For example, when you open a refrigerator, a hidden switch makes the light come on. Materials that allow electric current to flow are called **conductors**. Those that don't are referred to as **insulators**. A material that is attracted by a magnet is called a **ferromagnetic material**. Ferromagnetic materials are usually good conductors of electricity, but many conductors are not ferromagnetic.
10. If there is no direct mechanical connection between a hidden switch and the action that activates it, the switch is said to be a **proximity** switch. A simple proximity switch uses a ferromagnetic material to close the circuit when it comes near a magnet. This kind of switch is called a **magnetic proximity switch**.

11. An object that is spinning will **vibrate** if the weight is not **balanced**. Increasing the amount of an unbalanced weight, or its distance from the axis, will increase the amount of vibration. For example, a ceiling fan or car wheel will vibrate if the weight is not balanced.
12. Anything that strikes a stationary rigid object will make a **sound**, thereby changing its kinetic energy into sound energy.
13. Ultraviolet light cannot be seen directly, but it can make some materials glow while it is on. These materials are called **fluorescent**.

## User's Guide to ElectroCity

The unit is subdivided into 12 lessons. The most basic activities of a lesson can generally be completed in one class period, but additional time is typically needed for writing, further exploration and designing. Within each lesson, there are up to seven sections:

**Overview** provides a brief statement of the purpose of the lesson.

**Materials** shows a list of the supplies needed for the lesson, in classroom, group or individual student quantities. A group is assumed to consist of 4 – 6 students.

**Procedure** offers a basic lesson plan, including questions for discussion and prompts for writing entries in the Science Notebooks.

*⚡ Lightning bullets and italics indicate prompts for discussion, instructions for students and design challenges .*

Science Notebook entries are boxed.

*⚡* Writing prompts have lightning bullets.

**Homework** appears in some lessons – usually in the form of a scavenger hunt for students to conduct at home.

**Outcomes** provides a statement of the basic conclusions or generalizations to be developed through the lesson.

**Worksheets** provide structured alternatives to more open-ended writing in science notebooks. If worksheets are used, they should be taped or stapled into the science notebooks to provide a complete record of the unit.

**Troubleshooting** offers help to the teacher, pointing out common issues in construction, making things work or understanding how and why they work.

## Materials for ElectroCity

Item	Detail	Qty	Lessons
Penguin Race Toy	Alternatives: Dalmation Chase or Track Racer	1	1
Reclosable storage bag	2 gallon	30	all
CR 2032 Coin batteries		200	
LED, 10 mm.	Blue, green, red & yellow; 50 of each color	200	
Buzzer	Red & black wire leads	60	
Wire stripper		2	2-12
Mini-binder clips		60	
Masking tape	Roll, 1 in. x 60 ft.	10	
Aluminum foil	roll	1	
Rubber bands	¼ lb. bag, #64 3 ½ x ¼ in	1	
	¼ lb., #62, 2 ½ x ¼ in.	1	
cardstock	Pack of 250, assorted colors	2	
Paper clips	Box of 100, 1 ea., small & large	2	
Paper fasteners	Box of 100, 1 ½ in. brass plated	1	
	Box of 100, 1 in. brass plated	1	
	Box of 100, 1 ½ in. solid brass (Acco)	1	
Galvanized steel wire	100 ft. roll AWG #26	1	
AA Batteries		60	
Motors w/ 2 mm shafts		30	
Wheels w/ 4mm. holes		30	
Bushing 2 – 4 mm adapter		30	
Clothespins	Box of 50	1	6
Cardboard boxes	4 x 4 x 2 in. & 3 x 2 x 2 in., 30 of each	60	6, 9-12
Magnets	8 x 6 x 1.5 mm. #ZB5	60	7-12
Yellow highlighter	Box of 6	3	9-12
UV LED		15	
IR Transmitter (LED)	Osram SFH 313 FA / Digi-Key 475-1080-ND	15	
IR Receiver (Phototransistor)	Osram SFH 485 / Digi-Key 475-1112-ND	15	
Straw	¼" diameter	100	10-12
Foam blocks	2 ½ x 1 ½ x 1 in.	50	
Digital multimeter	Kelvin 50 LE	2	all

<b>Craft supplies</b>			
<b>Item</b>	<b>Detail</b>	<b>Qty</b>	<b>Lessons used in</b>
Tissue paper	13" x 20" sheet, assorted colors	6	11-12
Cellophane	5" x 25" roll, assorted colors	2	
Google eyes	Small bagful, assorted sizes	1	
Feathers	Small bagful, assorted shapes & colors	1	
Yarn	24 ft., assorted colors	1	
Felt	9" x 12" sheet, assorted colors	5	
Construction paper	9" x 12" sheet, assorted colors	40	
Foam stickers	Small bagful, assorted shapes & colors	1	
Craft sticks	Assorted colors	30	
Ribbon	Roll	1	
Pipe cleaner	Assorted colors	30	
Cocktail umbrella	Assorted colors, 4" diam.	30	

# Lesson 1: Light and Sound

## Overview

This lesson begins by revisiting the classic Batteries and Bulbs unit: students try to make a coin battery light up a LED and turn on a buzzer. Once they have addressed these basic challenges, students can explore lighting up two LEDs, or an LED and a buzzer, in parallel and/or series combinations. The Penguin Race toy is available to provide models of current, voltage, source and load.

## Materials

- ✦ LEDs – 10 per group (assorted colors)
- ✦ Buzzer – one per student
- ✦ The Penguin Race toy – one per class

## Procedure

1. The Penguin Race™ Toy: Lead a brief review of electric circuits. It is likely that students have already had experience with “Batteries and Bulbs” or an equivalent unit. Use chart paper to review what is needed to light a bulb from a battery. Use the Penguin Race Toy to illustrate the concepts: Use the Penguin Race Toy to illustrate the concepts (see Troubleshooting for a full discussion) :

- ✦ the escalator gives the penguins energy;
- ✦ they lose this energy as they travel down the slide;
- ✦ they need the escalator to get energy again, so they can go back up.

Ask students to think about how the Penguin Race Toy is similar to and different from an electric circuit:

- ✦ *In a circuit, what is traveling around?*
- ✦ *In the toy, what is traveling around?*
- ✦ *Why does the racetrack need to be attached to both the top and bottom of the escalator?*
- ✦ *Why does the light bulb need to be attached to both sides of the battery?*

Introduce the concept of a **model**: a simplified version of something that reveals important features of the real thing, without being exactly like the real thing. For example, a doll house is a model of a real house, showing rooms and furniture, but not as big as a real house.

Develop the idea that the Penguin Race toy is a model of an electric circuit.

- ✦ *In a circuit, **current** measures the rate at which electrons are flowing around. In the toy model, what plays the role of the current? What would I have to do to increase or decrease the current?*
- ✦ *In a circuit, **voltage** measures how much energy each electron has, and therefore how much it can do. You can increase the voltage by adding batteries. In the toy model,*

*what plays the role of the battery? What would you have to do to increase or decrease the voltage?*

2. Different kinds of batteries and bulbs: Many students have probably had experience with a unit on “Batteries and Bulbs.” If so, explain that we will be working with a different kind of battery and a different kind of bulb in this class. Provide each group with an assortment of LEDs and a coin battery per student. Ask:

- ✎ *What do you notice about the battery?*
- ✎ *What do you notice about the LED?*
- ✎ *How are they different from batteries and bulbs you have seen before?*

**Important safety note:** Like other batteries, these cannot give you a shock. However, other forms of electricity are extremely dangerous. Under no circumstances should any student attach anything to a wall outlet or to an electrical appliance that is plugged in.

3. Make the LED light up: There is a way to make the bulb light up, but you’re not going to tell them how – they will have to figure it out for themselves. Their challenge is to make the LED light up. Once students get it to work, introduce the word **polar** to describe the property of the LED: it will work only if it is connected to the battery in one direction.

Science Notebook or Worksheet:

- ✎ Describe and draw how you made the LED light up.
- ✎ How is the battery different from batteries you have used before? How is it similar?
- ✎ How is the LED different from light bulbs you have used before? How is it similar?
- ✎ What would you like to make using an LED?

4. Get the buzzer to sound:

Provide students with buzzers. The challenge is similar to the one with the LEDs – get it to make a sound.

Science Notebook or Worksheet:

- ✎ Describe and draw how you made the buzzer make a sound.
- ✎ How is the buzzer similar to the LED? How is it different?
- ✎ What would you like to make using a buzzer?

5. Batteries, loads and energy transformation: Introduce the term **load** for anything that electricity can run. The **input** to a load is electrical energy. The **output** from a load is energy in some other form, such as light, sound or motion.

- ✎ *What form of energy goes into a LED? What form of energy comes out?*
- ✎ *What form of energy goes into a buzzer? What form of energy comes out?*

Ask students for other examples of loads, besides LEDs and buzzers.

- ✎ *You’ve just gotten a battery to make a light and a buzzer work. What other things can you think of that electricity from a battery or wall outlet can run?*

6. Multiple Loads: Suggest that students continue experimenting with the batteries, LEDs and buzzers to find out:

✎ *What happens if you try to light two LEDs from one battery at the same time? What ways work and what ways don't work?*

✎ *Try to make an LED light up and a buzzer sound from the same battery. What happens?*

Science Notebook:

Record the results of these experiments

7. Are Two Batteries Better than One? Students might try lighting each color LED or sounding the buzzer using two batteries instead of one. The two batteries have to be stacked, — to +, as shown in the diagram below:



✎ *What changes when you use two batteries instead of one to light each color LED?*

✎ *What changes when you use two batteries instead of one to sound the buzzer?*

Science Notebook:

Record the results of these experiments

8. Switches: Gather students for a class meeting. Ask students:

✎ *In the circuits you have made so far, what did you have to do to turn them ON or OFF?*

✎ *When you turn a TV, light or hair dryer ON or OFF, what do you do?*

This discussion should pave the way for the Switch Hunt (see below).

## Homework

Switch Hunt: Provide the Worksheet, Part 2, for students to list switches they can find at home or elsewhere. For each one, they should list where it is located, what it controls, and what you have to do to operate it. For example, a light switch is located on the wall, it controls whether electrical energy will flow to a light fixture, and you operate it by pushing it up (on) or pulling it down (off). Other ways you might operate a switch could be by turning a knob, sliding something, or pushing a button down and holding it.

## Outcomes

- ‡ An electric circuit needs to have a battery (or other source of electricity), a load, and a complete path that connects each side of the load to a different side of the battery.
- ‡ An electrical load takes in energy in electrical form, and converts it to another form. Examples are: a LED or bulb converts electrical energy to light energy; a buzzer or speaker converts electrical energy to sound energy, and a motor converts electrical energy to mechanical or kinetic energy (energy of motion).
- ‡ The charges flowing in a circuit lose electrical energy in the load. They need to flow back to the battery to get more energy for operating the load – like the penguins in the toy, which get gravitational energy from the staircase.
- ‡ Both the LED and the buzzer are **polar** devices: they will not make a circuit unless they are connected in the right direction.

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

### Lesson 1, Part 1: Light and Sound

How I made the LED light up (draw and write)

	_____
	_____
	_____
	_____
	_____
	_____
	_____

What did you notice about the battery? \_\_\_\_\_

How is the LED different from other light bulbs you have used?

\_\_\_\_\_

How I made the buzzer sound off (draw and write)

	_____
	_____
	_____
	_____
	_____
	_____
	_____

How is the buzzer similar to the LED? \_\_\_\_\_

How are they different? \_\_\_\_\_

What would you like to make with them? \_\_\_\_\_

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

### Lesson 1, Part 2: **Switch Hunt**

List the switches you found in the classroom or remember from home.

Where I found it	What it controls	How to operate it (push, pull, turn, slide)

When do you use a switch? \_\_\_\_\_

\_\_\_\_\_

What does a switch do? \_\_\_\_\_

\_\_\_\_\_

Why does a circuit need a switch? \_\_\_\_\_

\_\_\_\_\_

## Troubleshooting (for teachers only)

### The Penguin Race™ Toy

The toy consists of a bunch of penguins, a slide and a motorized escalator that lifts the penguins to the top of the slide, so they can go back down again. Besides being fascinating to watch, this toy provides an excellent model for understanding how an electric circuit works. The penguins are like the electrons, which account for the flow of electricity in a circuit. The escalator lifts them up to a place where they have enough energy to travel down the slide by gravity. It is like the battery in a circuit, which gives the electrons an “energy kick” that is enough for them to travel on their own through the rest of the circuit. While traveling down the slide, the penguins speed up, but then stop when they hit the bottom. In a circuit, the electrons lose their energy in other ways: they may make a bulb light up, create a sound in a buzzer or make a motor turn.

Two basic circuit concepts are current and voltage. The amount of **current** counts the number of electrons that are flowing. In the toy model of a circuit, you could increase the current by adding penguins. If there were too many penguins to fit in the track, you would have to make it wider to accommodate them. Similarly, a wire may need to be bigger to contain more current. The reason an automotive jumper cable or air conditioner cord is so fat is that it takes a lot of current to start a car or run an air conditioner.

**Voltage** is a measure of how much energy kick the battery gives each electron as it passes through. The analogy to the battery in the toy model is the escalator. More voltage would correspond to a taller escalator, which would raise the penguins higher, and therefore give them more energy each time they went through.

The penguins make a **complete circuit**, because they have to return to the escalator on each go-round to get another energy boost. Similarly, the electrons in a circuit have to return to the battery to get the boost they will need to keep lighting the LED or sounding the buzzer. An analogy is often made between electric current and the flow of water, but this can be misleading, because in most water systems, we don't see the return flow. For example, when you turn on a faucet, you see the water go down the drain, but it's hard to visualize the entire water cycle that brings it back. The penguin toy makes it easier to understand an electric circuit, because it's obvious that the penguins have to get back to the beginning of the escalator to get the energy they'll need to go down the slide again.

### Coin batteries and LEDs

The battery has a larger flat side and a slightly smaller flat side. The large flat side is the positive (+) side – it has some writing and a “+” engraved into it. The smaller flat side is the “—“ side. LED stands for **light-emitting diode**. A diode is an electronic component that can pass current in only one direction – kind of like a one-way valve or “exit only” for electrons, and therefore, electric current. The LED has a long wire and a short wire. It will not light up unless the long wire is touching the “+” side of the battery, and the short wire is touching the “—“ side, and the two wires are not touching each other. With an ordinary light bulb, you could reverse the direction, and the bulb would still light up. Because the LED is actually a diode, which allows current to flow only one way, reversing the wires will not work.

### Making the buzzer sound

The buzzer is polar too. To make it work, the red wire has to touch the “+” side of the battery, and the black wire has to touch the “—“ side. If the wires are reversed, it will not work.

### If Nothing seems to Work

Begin by making sure each wire from the LED or buzzer is touching only one of the two terminals of the battery. The long wire from the LED, or the red wire from the buzzer, has to touch only the flat side of the battery; and the other wire from each has to touch only the round side of the battery. If the buzzer or LED is attached properly, and nothing works, the only possible problems are a bad battery or a bad LED or buzzer. It is more common to find a bad battery. Two ways to find out if a battery is bad are:

- ✦ Try another battery; or
- ✦ Test the battery using a **digital multimeter**; see the Appendix, Part 3.

### More than one load

To make two LEDs light up from the same battery, both LEDs need to be connected to the battery at the same time. The long wire of each LED should connect to the “+” contact of the battery and the short wire of each one should go to the “—“ side of the same battery. As circuits become more complex, the LED wires can get bent, so it is hard to know which one is long and which was short. To keep track, it is helpful to mark the (+) lead with a little piece of tape.

### What works with what

Only certain combinations will work. The red and yellow LEDs, will come on together, as will the green and blue LEDs, but if you try to mix and match, the red or yellow one will “steal” the current from the blue or green one. The reason is that the red and yellow LEDs come on at a lower voltage than the blue and green ones. Once the red or yellow LED comes on, it won’t allow the voltage to reach the point that will turn the green or blue one on. The buzzer will work with any of the LEDs.

To explore these issues further, you need a **digital multimeter**. See the Appendix, Part 6

### Are Two Batteries better than One?

The blue and green LEDs should light up more brightly from two batteries instead of one, while, there should be no change in the brightness of the red or yellow LEDs. Also, the buzzer should become louder when it is attached to two batteries, compared with one. If these results do not occur, check to see that the batteries are connected as shown in the diagram, — to +, as shown in the diagram:



For more information about using two batteries, see the Appendix, Part 5.

# Lesson 2: Make a Switch

## Overview

This lesson begins with a review of the **Switch Hunt** students have done for homework. Then they discuss the reasons for including a switch in a circuit, rather than turning it on by touching wires together. They then design and create as many types of switches as they can, and include them in circuits to control motors. Finally, students categorize switches according to the action needed to operate them. Basic categories are push button, slide, toggle and rotary switches.

## Materials

- ✎ AA batteries, motors (as in Lesson 1)
- ✎ Cardstock, paper clips, paper fasteners, aluminum foil, scissors, mini-binder clips, tape, wire
- ✎ Sample homemade switches: rotary slide, toggle, pushbutton

## Procedure

1. Switch hunt: Gather students for a class meeting. Review the results of the Switch Hunt students have done for homework. Then provide the worksheet for them to list switches they have found at home or can find in the classroom. For each one, they should list where it is located, what it controls, and what you have to do to operate it. For example, a light switch is located on the wall, it controls whether electrical energy will flow to a light fixture, and you operate it by pushing it up (ON) or pulling it down (OFF). Other ways you might operate a switch could be by turning a knob, sliding something, pulling a string or chain or pushing a button down and holding it. Ask students:

✎ *What is a switch?*

✎ *Where can you find one?*

✎ *What is the advantage of having a switch over touching two wires together?*

Without a switch, a circuit would be ON all the time. Develop the idea that you can use a switch to stop the flow of electricity. This will turn things OFF whenever you don't want them to be ON.

2. What does a switch do? A switch stops the flow of electricity to a load when it is off. It allows electricity to flow through the load when it is on. This means the switch must be placed in a circuit in such a way that all the electricity that flows through the load must also flow through the switch. On a drawing of a circuit with a battery and LED, ask:

✎ *Where could you place a switch in this circuit so it can turn an LED off?*

3. Make a switch: Explain that we'll next be making our own switches. Then ask:

✎ *What kind of parts does a switch need to have?*

Help students see that a switch needs to have two places, metal **contacts** where it connects to a circuit. The switch also has a conductor that can be moved to touch the two contacts and allow current to flow between them. The switch is then ON, and the circuit is **closed**. This conductor can also be moved so it doesn't touch both contacts. Then there

is no way for the current to flow from one contact to the other, the switch is OFF, and the circuit is **open**. No current will flow in the circuit.

Then engage students in thinking what they could use to make a switch:

- ✎ *What kinds of stuff do we have here that you could use to make your own switch?*
- ✎ *What kind of action would you want to take to turn your switch ON or OFF?*
- ✎ *What ideas do you have for making your switch?*

Provide materials and time for students to make and test their own switches. If necessary, provide sample homemade switches (see also [Troubleshooting](#)).

4. Add your switch to a circuit: In order for a switch to work, it has to be in one position for the light or buzzer to be ON, and in another position for the light or buzzer to be OFF. The next challenge is:

- ✎ *Put your switch inside a circuit so it controls the light or buzzer.*

Students should use the Worksheet to draw what they have made, and record the results of testing their switches.

5. Sorting switches by action needed to operate them: After students have made switches and gotten them to work, gather the class to think about types of switches, according to the action you have to take to operate them. Discuss the most common types:

- ✎ *To operate a **rotary** switch, you have to turn something, usually a knob. Switches with multiple ON positions are often of this type. For example, the speed control switch on a fan is usually a rotary switch.*
- ✎ *To use a **toggle** switch, you push a lever up or pull it down, and after you move it, it stays there. Most wall light switches are toggle switches.*
- ✎ *A **pushbutton** switch is one that you have to hold down to keep it ON. A computer mouse, keyboard and cell phone all use pushbutton switches.*
- ✎ *A **slide** switch is operated by pushing a tab back and forth. The ON/OFF switch on the Penguin Race Toy is an example of a slide switch.*

Ask students what kind of switch they have made.

- ✎ *How would you make one of the other types?*

## Outcomes

- ✎ A switch is a reliable way to control a circuit. Touching wires together is not reliable, and could even be dangerous.
- ✎ A switch can be made from common materials. It requires two metal contacts where it is connected in the circuit. It also requires a conductor that can touch both contacts to turn the circuit ON and a way the conductor can be moved so it doesn't touch both contacts, which will turn the circuit OFF.
- ✎ Switches can be operated by sliding, turning, pushing, pulling, or holding something down temporarily.

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

## Lesson 2: Make a Switch

How I made my switch (draw and write):


How I added my switch to a circuit (draw and write):


How I could tell if my switch was working : \_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

## Troubleshooting (for teachers only)

### What is a switch?

A switch requires a little bit of force and motion to turn ON or OFF the flow of electrical current. Students may wonder if other kinds of flow should be included. For example, a water faucet, toilet handle, drain plug, stove control knob, mouse trap trigger and the umbrella release button are all like switches, in that they interrupt or allow the flow of energy. However, each of these examples controls the flow of mechanical rather than electrical energy. A water faucet, toilet handle and drain plug allow water to flow or prevent it from flowing. The stove knob does the same for the flow of gas, and the umbrella release and mouse trap trigger each controls the motion of a much larger mechanism. Should these be considered switches?

The word “switch” seems more meaningful if it is restricted to something that controls the flow of electricity. A better word that describes all the devices mentioned above, and includes switches as well, is **control**. A switch is a control that affects the flow of electrical energy; all the others control mechanical energy flows, such as the flow of water, gas or part of a mechanism.

### Conductors and insulators

Some materials allow electricity to flow, while others don't. Those that do allow flow are called **conductors** and those that don't are **insulators**. All metals are conductors, and nearly all other materials are insulators.

### What a switch needs

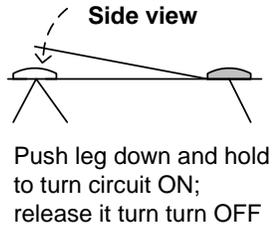
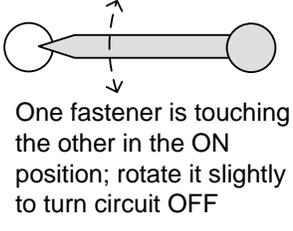
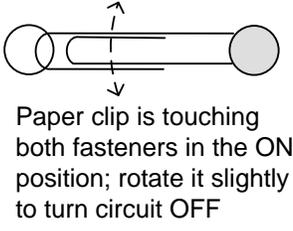
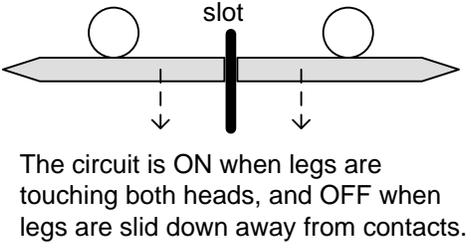
The basic requirements of a switch are two contacts, a way of moving one of them so the contact can be either touching (ON) or not touching (OFF), and a connection to each contact that puts the switch inside the loop of the circuit. Both contacts and the connections to them have to be made of conductors, or current won't flow through them. The switch has to interrupt the circuit when it is OFF, and connect the battery to the load (LED or buzzer) when it is ON. When the switch interrupts the circuit, the circuit is **open** and no current can flow. When the switch connects the circuit, it is **closed**, allowing current to flow.

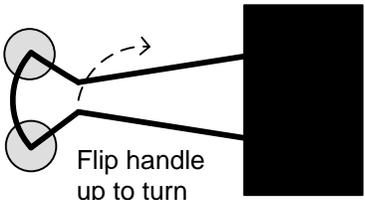
### Testing a switch

Testing a switch is easy: the light or buzzer should operate when the switch is in the ON position, but not when it is in the OFF position. Using a **digital multimeter**, you can test a switch without having a battery or LED connected. To find out how, see the Appendix, Part 7.

Ideas for making different kinds of switches

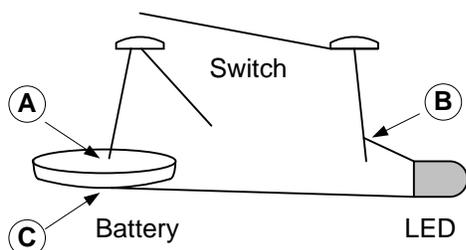
Each of these switches uses the heads of two paper fasteners as contacts. These fasteners should be pushed through a base made of cardstock or cardboard, with both heads up. Attach the wires from the circuit to the tails of these fasteners underneath the base to connect the switch to the rest of the circuit. The switches differ in the mechanisms used to join and separate the two paper fastener heads, and thereby turn the circuit ON and OFF.

Type	Materials	How to make it
Push-button	Two paper fasteners	<p>Attach the fasteners so that the leg of one can be pushed down to touch the head of the other, and will spring back up when released.</p> 
Rotary	Two paper fasteners	<p>Mount the fasteners so one leg of one is on the same side as the head of the other. Turn the circuit ON by rotating the leg so it touches the head, and turn it OFF by rotating it so they don't touch.</p> 
	Two paper fasteners and a paper clip	<p>Mount the fasteners on cardstock so all the legs are pointing down. Capture a paper clip under the head of one of the fasteners. Turn the paper clip so it touches the other fastener to turn the switch ON; turn it away to turn it OFF.</p> 
Slide	Three paper fasteners	<p>Cut a slot for one paper fastener, and poke holes for the other two. Mount two paper fasteners through the holes with heads up, and mount the third through the slot with both legs up. The legs turn the circuit ON by touching the two heads, and OFF by sliding away from them.</p> 

Type	Materials	How to make it
Toggle	Two paper fasteners	<p>Mount the heads of the fasteners so one leg of one is on the same side as the head of the other. Create a switch that is ON when this leg is captured under the head of the other fastener, and OFF when it is released.</p>  <p>Leg of one fastener is captured in the ON position; release it to turn the circuit OFF</p>
	Bulldog clip and two paper fasteners	<p>Use the snap action of the bulldog clip to touch and release it from the paper fasteners, and turn the circuit ON and OFF.</p>  <p>Flip handle up to turn circuit OFF</p>

### Troubleshooting circuits with switches

The diagram below show a simple circuit with a battery, LED and a push button switch; and three connections between them, labeled A, B and C.



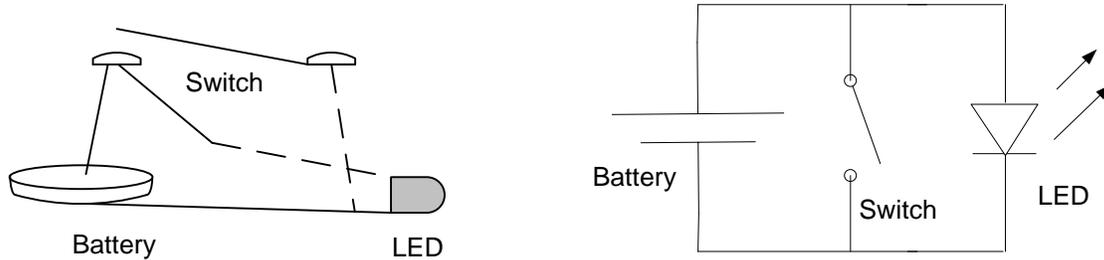
Key
A = switch contact attached to (+) side of the battery
B = (+) LED wire attached to other switch contact
C = (-) LED wire attached to (-) side of battery

If the circuit is attached as shown in the diagram, and the LED doesn't come on when the switch is closed, there are five possible **causes** for the trouble. The table below shows how to **test** for each one, and how to **fix** it:

Cause	Test	Fix
Battery or LED is bad	Attach LED directly to battery; if LED still won't turn on, either LED or battery is bad, or use <b>digital multimeter</b> (see the <a href="#">Appendix</a> , Part 3).	Try a new battery. If LED now comes on, old battery was bad. If LED still doesn't turn on, replace it.
Bad connection at A, B or C	Squeeze each connection in turn. If switch now operates LED, the connection you were squeezing was bad. You can also use the <b>digital multimeter</b> (see the <a href="#">Appendix</a> , Part 4).	Redo connection, making sure metal is touching metal.

## Short circuits

A “short circuit” is a conductor that connects two points that do not appear to be connected, and should not be. There are two common types of short circuits. The most serious type involves a switch that is connected across the battery, as in the drawing below, left. The two dashed lines show the wires that are reversed, compared with the correct circuit, which is shown on the further down for comparison. This looks similar to the circuit shown above, and it even appears to work, but it has a basic flaw!

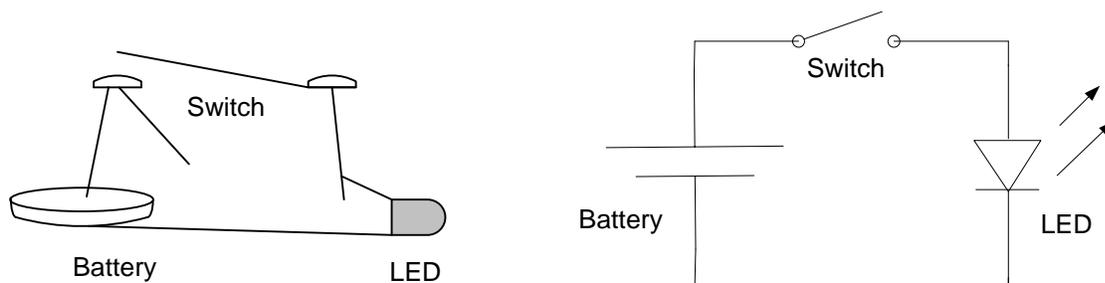


Switch short circuits battery when closed

The switch appears to control the LED, because pushing it down will turn the LED off, and releasing it will turn the LED ON. However, this is the reverse of the way the switch should work. The problem is that the switch is actually ON when the LED goes off, and vice versa. The diagram on the right uses symbols to show the problem more clearly. Lesson 3 develops electrical symbols and diagrams.

When the switch is closed, current flows from one side of the battery to the other with nothing in between. The current bypasses the LED completely, because the current follows the path of least resistance. When the switch is open, it allows the battery to supply the LED normally. If the switch is left closed for very long, the battery will first get warm and then soon go dead.

For comparison, the drawing and diagram below show the circuit that operates correctly.

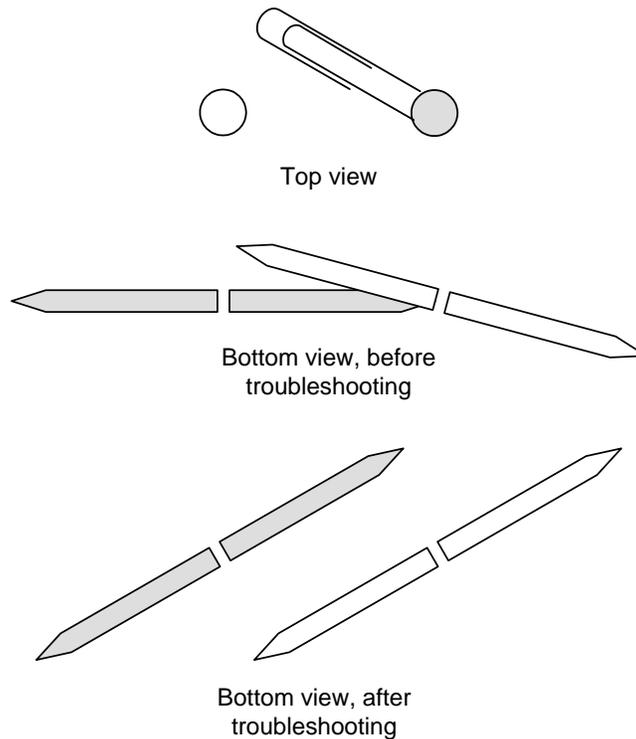


Switch interrupts circuit when open, turns LED ON when closed

This second circuit works correctly, because the switch interrupts the current when it is open, and allows current to flow from the battery to the LED and back when closed. In the first case, the, LED and switch are all said to be in **parallel**, because current can flow through either one if the other is removed. In the second case, the switch and LED are in **series**, because current has to flow through one to get the other. Lesson 4 develops series and parallel circuits.

**SAFETY NOTE: A short circuit across a battery can result in wires getting hot, and potentially causing a minor burn. If anything in a circuit gets warm or hot, disconnect it from the battery immediately. Find the short circuit, and remove it before reconnecting to the battery.**

Another type of short circuit can occur within a switch. In this case, a switch that appears to be open is actually never open due to the short circuit, because the two metal contacts are always touching, even when they don't seem to be. The drawing below shows one way this can happen. The rotary switch appears to be open until you look underneath. The two paper fasteners are actually touching! Fortunately, the solution is very simple – just turn the legs a little, so they no longer touch.



Even without looking underneath, you can detect this situation using a **digital multimeter**. See the [Appendix, Part 7](#), for details.

The table below summarizes the kinds of things that can go wrong in a circuit with a switch, and what to do about each one:

<b>Issue</b>	<b>Cause</b>	<b>Fix</b>
Load never turns ON	Load or battery is bad	Replace load or battery
	At least one connections is bad	Re-do connection, and secure with tape or rubber band
Load never turns OFF	Switch has short circuit	Separate contacts so they don't touch
Load turns on when switch is OFF, and <i>vice versa</i> ; battery gets warm	Switch is connected across battery, and can't interrupt circuit	Rewire circuit so switch can interrupt current path

# Lesson 3: Circuit diagrams

## Overview

Students represent their circuits by making drawings, and then conduct a Gallery Walk to evaluate the drawings. The drawings are likely to be hard to interpret. To solve this problem, students learn to use standard circuit symbols and rules for making diagrams, and use these for explaining their circuits, troubleshooting, and designing new circuits.

## Materials

- ✦ Circuits from Lesson 2
- ✦ Batteries, LEDs, buzzers, materials for making switches

## Procedure

1. Circuit drawings. Pose the challenge:

✦ *Suppose someone else wanted to make a circuit just like the one you made. Make a drawing of it so they will know what to do.*

Provide paper, but no further directions.

2. Gallery walk. Post the circuit drawings, and allow everybody to examine them. Then ask for comments:

✦ *What problems did you run into in making your drawing?*

✦ *How are these drawings different from each other?*

✦ *What problems would someone else have in using these drawings to make the actual circuits?*

Elicit the observation that different students used different symbols for representing the same items. If someone doesn't know what your symbol represents, they will not know how to make what you made.

3. Symbols. Standard symbols provide a way to give information in a very small space. If everyone agrees on what the symbols mean, there is no need to explain them each time. Brainstorm examples of how symbols are used to indicate ideas such as:

✦ MALE or FEMALE rest room

✦ Things you can find on maps

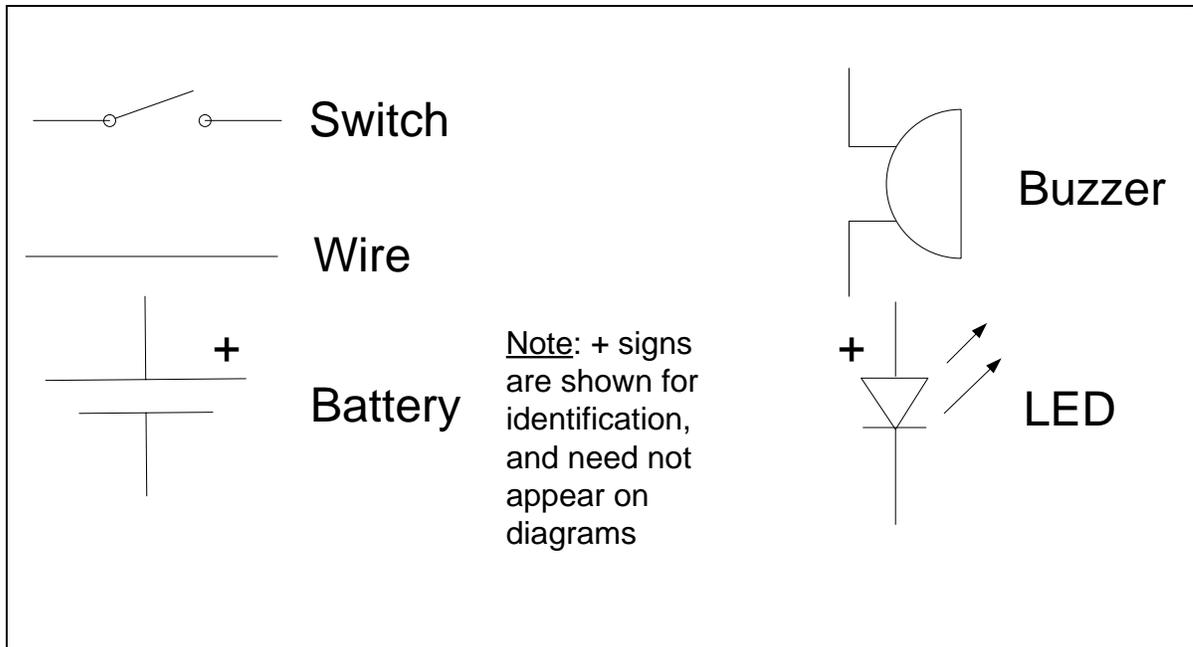
✦ Street signs (BUS STOP, HOSPITAL, NO U-TURN, DANGER)

✦ How to use appliances (ON/OFF, PLAY, REWIND, FAST FORWARD, etc.)

✦ How to take care of clothing (for DO NOT IRON, MACHINE WASH COOL, etc.)

✦ NO SMOKING

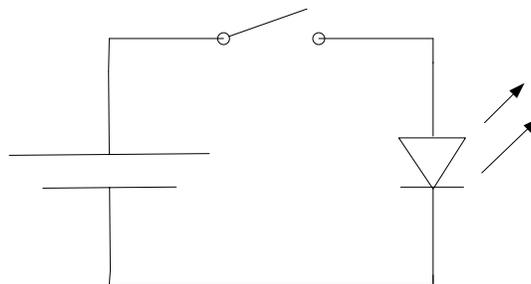
Then explain that there are **standard circuit symbols** that work the same way as all these other symbols. They save a lot of space, and are easy to understand, once everybody agrees on what they mean. Introduce the standard circuit symbols:



There are also some **standard rules** for using the circuit symbols. Following these rules makes the diagrams neat and easy to understand:

- ✎ Use horizontal or vertical straight lines to represent wires between circuit parts.
- ✎ Use square corners between horizontal and vertical lines.
- ✎ Put the battery on the left and the loads (LED and/ or buzzer) on the right.
- ✎ Put switches on top.

To provide practice in using the symbols and rules, draw this circuit, and ask students what parts it has and what it does. They can use the Worksheet to show their answers



4. Comparing diagrams with drawings: Ask each student to make a diagram of the same circuit they drew earlier, this time using the standard symbols and rules. Then conduct another Gallery Walk to compare the two representations for each circuit:
  - ✎ *How do they compare?*
  - ✎ *What makes one of them easier to follow?*
5. Using diagrams to design new circuits: Circuit diagrams make it possible to design new circuits without having to make them first. Here are three design challenges. In each one,

students use a diagram to design the circuit on paper. Later, they can make the circuit from the diagram:

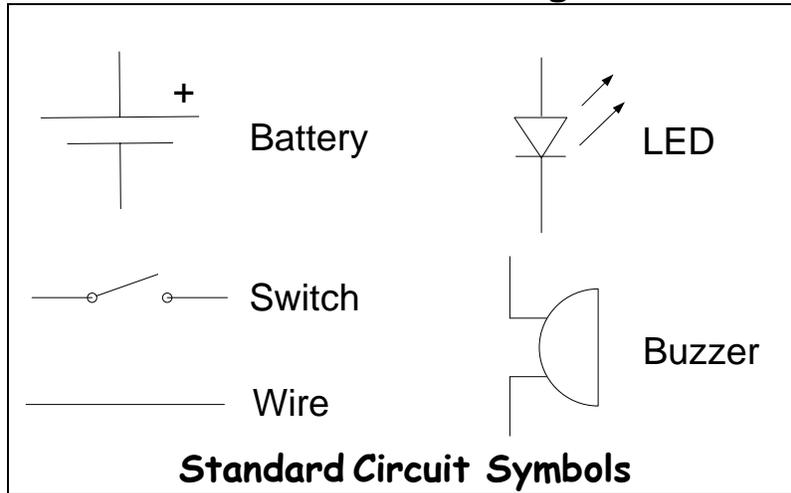
- ✎ *Make a diagram of a circuit that has both a LED and a buzzer and a switch that controls both together.*
- ✎ *Design a circuit that has both a LED and a buzzer, a switch that controls both together and a separate switch for each one.*
- ✎ *Design a circuit that has both a LED and a buzzer and a separate switch for each one, but no switch that controls both.*

## Outcomes

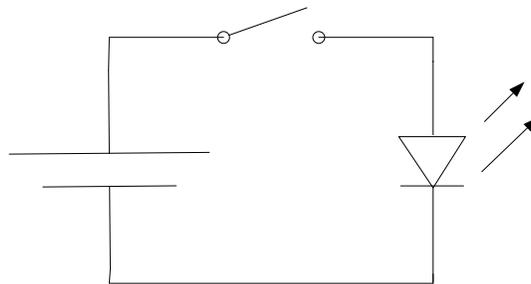
- ✎ Diagrams are different from drawings. A drawing tries to show what things look like, but a diagram reveals its structure. Electrical diagrams use a common set of symbols and rules, which make circuit operation clear.
- ✎ Standard diagrams make circuits easier to understand and troubleshoot.
- ✎ Electrical diagrams are also useful for trying out circuit ideas, before actually building the circuits. They are excellent **design tools**.

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

### Lesson 3: Circuit diagrams



1. Here is a circuit diagram made using the circuit symbols:



What parts does this circuit have? \_\_\_\_\_

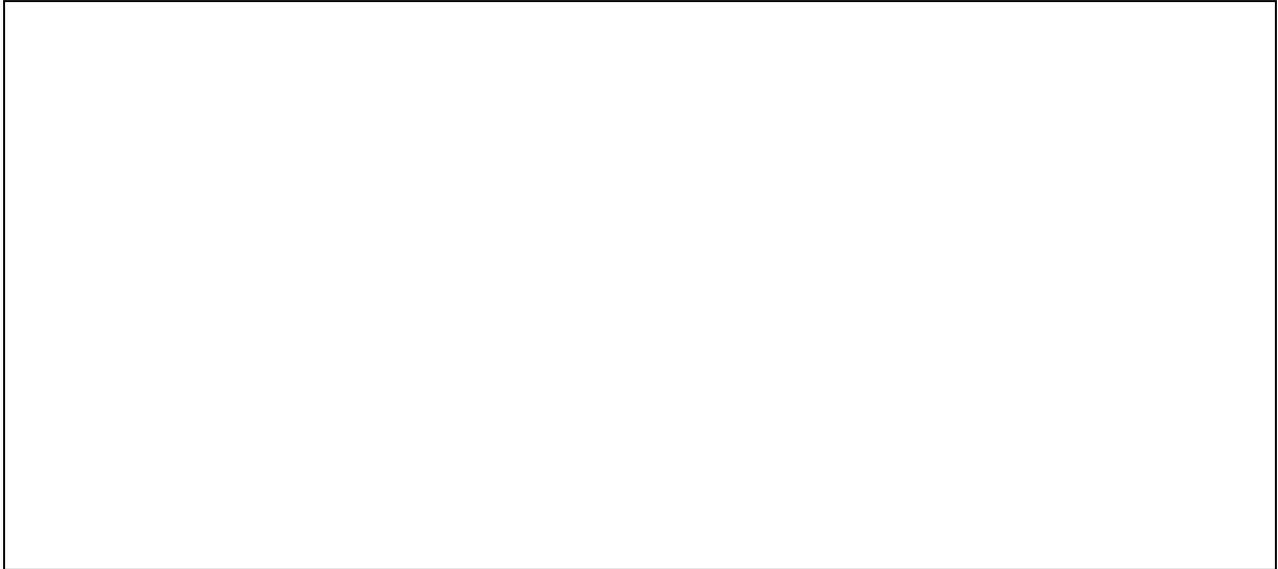
What does this circuit do? \_\_\_\_\_

2. Use the standard symbols to make a diagram of a circuit that has both a LED and a buzzer and a switch that controls both together:

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

### Lesson 3: **Circuit diagrams**, continued

3. Use the standard symbols to design a circuit that has both a LED and a buzzer, a switch that controls both together and a separate switch for each one:



4. Use the standard symbols to design a circuit that has both a LED and a buzzer and a separate switch for each one, but no switch that controls both:

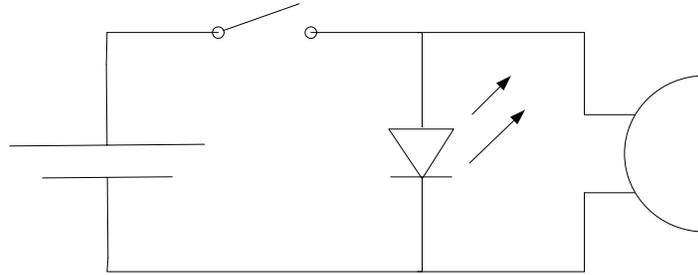


## Troubleshooting (for teachers only)

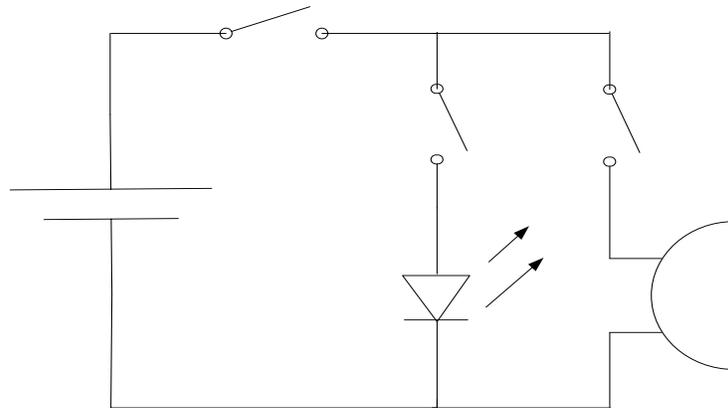
### Why use standard symbols?

Some students are likely to resist using the standard symbols. They will continue trying to make a circuit symbol that looks like the real part. Ask whether everyone would use the same symbol for that part. If not, how would someone else know what your diagram represents? It will take time for some students to accept the need for standard symbols – be patient!

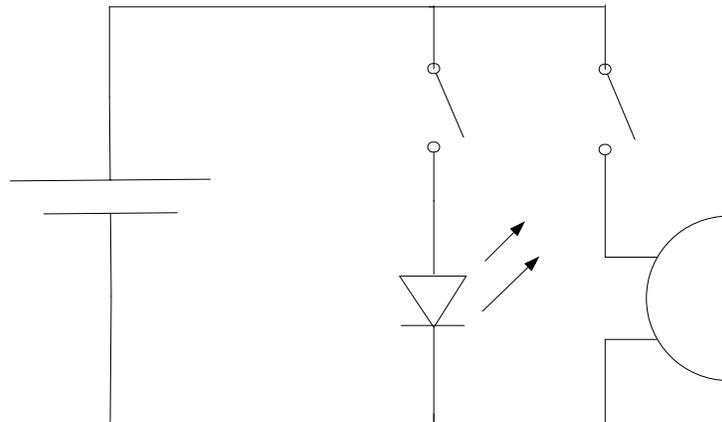
### Solutions to the three design challenges



A circuit that has both a LED and a buzzer and a switch that controls both together.



A circuit that has both a LED and a buzzer, a switch that controls both together and a separate switch for each one.



A circuit that has both a LED and a buzzer and a separate switch for each one, but no switch that controls both.

### Using diagrams for troubleshooting circuits

Besides being useful for designing new circuits, the diagrams are also useful for troubleshooting. If time is available for a student to make any of the circuits he or she has designed in part 5, the diagram can be used to troubleshoot the circuit. If the circuit doesn't work, compare the diagram with the circuit to make sure that:

- ✦ every line on the diagram corresponds to a connection in the real circuit,
- ✦ that every symbol on the diagram corresponds to the real component in the circuit, and
- ✦ nothing is in the circuit that isn't in the diagram.

If all of these are true, and the circuit still doesn't work, there are only two possibilities. Either:

- ✦ some of the connections are not being made (most likely), or
- ✦ one or more of the components is bad.

You can test the connections by squeezing them or redoing them. Test a battery by connecting it directly to a load that you know is working, and test a load by connecting directly to a battery that you know is good.

### Making a circuit that looks like its diagram

If students have difficulty translating between diagrams and circuits, here is an idea that might help. Make a circuit and its diagram, and then tape the components and wires of the circuit down in the same way as the diagram shows them. The correspondence between the circuit and the diagram should be obvious when these are put side-by-side. Then remove the tape, being careful not to undo any of the connections. Does the circuit work any differently? If not, shouldn't the same diagram still apply?

## Lesson 4: Motors, Series & Parallel Circuits

### Overview

Students learn about motors, how to use them and how to represent them on schematic diagrams. Students then explore how to connect circuit components in **series** vs. in **parallel**, and find differences in the ways these two types of circuits work.

### Materials

- ✦ Motors and AA batteries – one of each per student
- ✦ Bushings and wheels to attach to motors
- ✦ Materials for making switches, coin batteries, LEDs (as in Lessons 2 & 3)
- ✦ Wire stripper & wire cutter (one of each per class)

### Procedure

1. What is a motor? Ask students:

✦ *Where have you seen a motor?*

Students are likely to identify motors in cars, but explain that here we are talking about an **electrical motor**. Except for starter motors, most car motors get their energy from gasoline, but an electrical motor need electricity to work. Develop a brainstorming list of electrical motors that students have seen or know about. Here are some common places you can find electric motors:

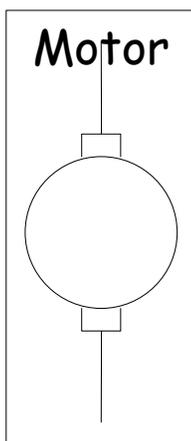
- ✦ *Electric fan*
- ✦ *Refrigerator*
- ✦ *Washing machine*
- ✦ *Dryer*
- ✦ *Vacuum cleaner*
- ✦ *Electric pencil sharpener*

Then ask:

✦ *What does a motor do?*

Develop the idea that a motor uses electrical energy to make something rotate. It converts electrical energy to **kinetic energy**, which means “energy of motion.”

2. Turning on a motor: Provide each student with a motor and an AA battery. Provide each group with tape, aluminum foil and rubber bands. Their challenge is to turn the motor



on, and then use the worksheet to describe what they did. Encourage them to use a schematic diagram rather than a drawing. The standard symbol for a motor is shown below and on the Worksheet:

Once the motors are working, you can use them to review concepts of energy and energy conversion:

✎ *What kind of energy goes into a motor?*

✎ *What kind of energy comes out?*

3. Is a motor polar? Review what it means for an electrical device to be **polar**: it matters which way it is connected. Review the directions in which something can rotate: **clockwise (CW)** or **counterclockwise (CCW)**.

✎ *Turn the motor ON. What direction does it go?*

It is probably hard to tell. Suggest that students attach a small piece of tape to the motor **shaft** (the part that rotates), and try connecting the motor to the battery two ways:

- a) Red wire of motor to the (+) side of the battery; other wire to the (—) side; and then,
- b) Red wire to (—) side; other wire to the (+) side.

Ask:

✎ *What happens differently when you reverse the wires?*

Students should use the Worksheet to record their observations.

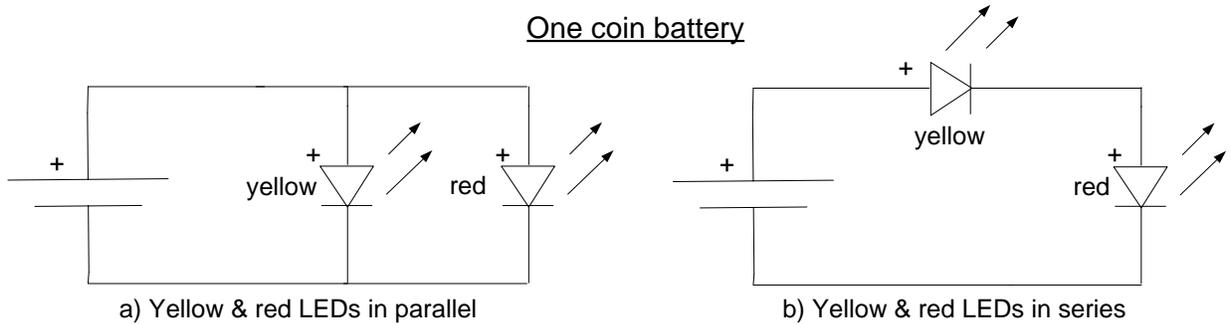
4. Turning a wheel: Provide bushings and wheels. A **bushing** is a small part that makes a tight fit between the motor and the wheel, so that when the motor turns, it makes the wheel turn too. Show students how to attach a bushing to a motor shaft, and then fit the wheel tightly on the bushing. Students can then decorate the wheel with cardstock, pom-poms, feathers, etc.:

✎ *How does the wheel look when it is not moving?*

✎ *What do you think it will look like when it is moving?*

Students use the Worksheet to record what they have found.

5. Series vs. Parallel Circuits: Here are two circuits. Each one has a coin battery, a yellow and a red LED. The parallel circuit in a) can be made simply by just pressing the wires from both LEDs against the coin battery, being careful to keep (+) with (+). To make the series circuit in b), it is helpful to tape the (+) wire from the red LED to the (+) side of the battery, and the (—) wire from the yellow LED to the (—) side of the battery. Complete the circuit by touching the two loose wires together. Ask students to make each one, observe what happens, and record their findings on the Worksheet, Part 2.

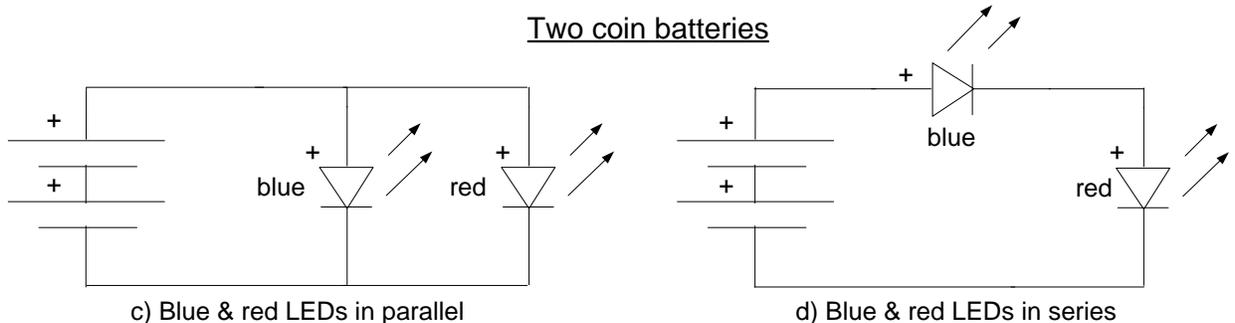


Ask:

- ✎ *What happens in each case?*
- ✎ *How are the series and parallel circuits similar?*
- ✎ *How are they different?*

Both LEDs should turn on when they are in parallel, but neither will light in series.

The next pair of experiments requires two coin batteries per circuit. These are most easily arranged in a stack, so the (+) side of the top battery is pressing against the (—) side of the bottom one. The parallel connection in c) is easy to make by pressing the wires from the two LEDs against the battery stack. The series connection in d) can be made by taping the (+) wire from the blue LED to the (+) side of the battery stack, and the (—) wire from the red LED to the (—) side of the battery stack, and then completing the circuit by touching the two loose wires together.



Ask students to compare these too, When they are in parallel, the red should be bright but the blue weak; while in series, both should come on equally.

The final questions get at the basic difference between series and parallel connections:

- ✎ *Remove one LED at a time from the parallel connection in c). What happens?*
- ✎ *Remove one LED from the series connection in d), leaving the extra wire from the other one loose. What happens?*

Students should observe that either LED will work without the other in the parallel connection, but in the series connection, each one depends on the other.

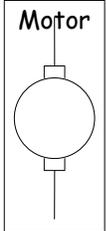
## Outcomes

- ✎ A motor converts electrical energy into kinetic energy. When you connect it to a battery, it should turn.
- ✎ The direction it turns depends on the way the wires are connected.
- ✎ When a wheel is spinning the details are blurred.
- ✎ When loads are connected in parallel, each one is connected directly to the source and doesn't depend on the others. A load in series will stop working if any of the other loads is removed or broken.

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

### Lesson 4, Part 1: **Motors**

How I turned on the motor (make a diagram and write)

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What happens differently when you reverse the wires?

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Add a wheel to your motor and decorate the wheel with a feather, piece of cardstock or craft material.

Draw and describe what you did:

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Predict what you think it will look like when the motor is on:

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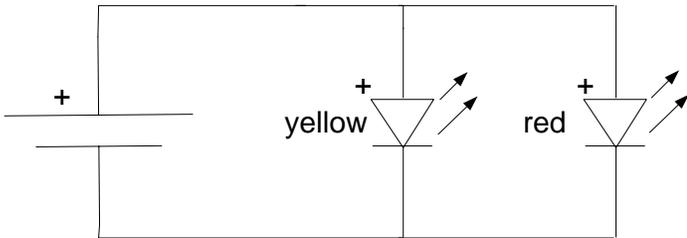
Turn the motor on. What does it actually look like?

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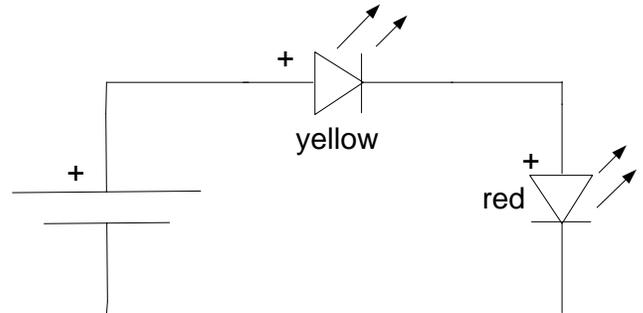
Name: \_\_\_\_\_ Date: \_\_\_\_\_

## Lesson 4, Part 2: Series and Parallel

1. A yellow and a red LED, one coin battery. Make each circuit:



a) Yellow & red LEDs in parallel



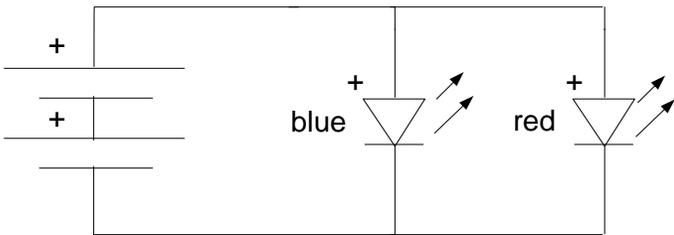
b) Yellow & red LEDs in series

What happens in a)? \_\_\_\_\_ What happens in b)? \_\_\_\_\_

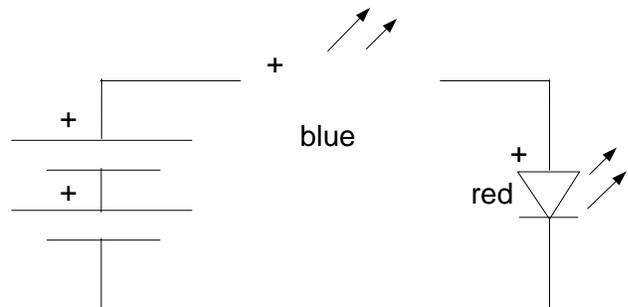
How are these two circuits similar? \_\_\_\_\_

How are they different? \_\_\_\_\_

2. A red and a blue LED, two coin batteries. Make each circuit:



c) Blue & red LEDs in parallel



d) Blue & red LEDs in series

What happens in c)? \_\_\_\_\_ What happens in d)? \_\_\_\_\_

Remove one LED from c). What happens to the other LED? \_\_\_\_\_

Remove one LED from d). What happens to the other LED? \_\_\_\_\_

### 3. Series vs. Parallel

What difference does it make whether two loads are connected in series or parallel? \_\_\_\_\_

## Troubleshooting (for teachers only)

### Why use AA batteries?

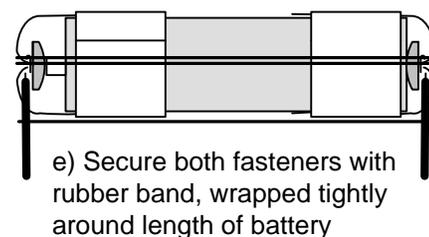
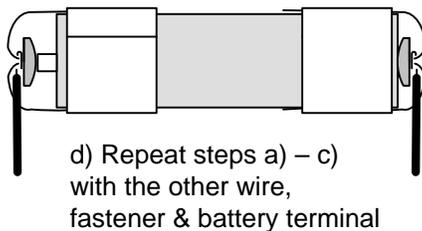
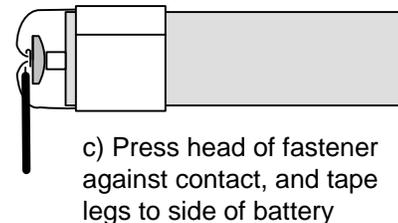
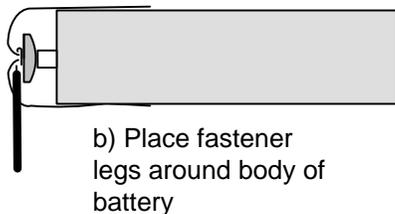
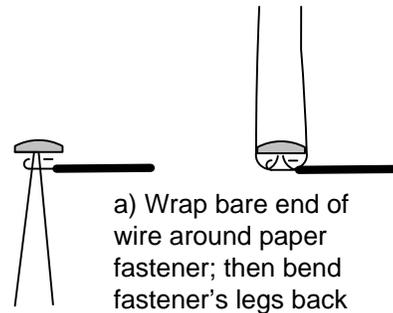
Students may wonder why we're not using coin batteries to operate motors. If you connect a coin battery to a motor, it will run the motor briefly, but within a minute or less the battery will go dead. The problem is that a motor requires a lot more current than a LED or buzzer. Current is the flow of electrons from the battery. The total number of electrons that can flow from a battery, from when it is new to when it goes dead, is called its **charge**. The total charge a battery can supply is sometimes rated in Ampere-Hours (AH) – the higher the better. A coin battery simply can't supply much charge. Once the charge stored in the battery is used up, the battery goes dead. The AA battery begins with a lot more charge than a coin battery, and can therefore run a motor a lot longer.

### Reversing the connections between the motor and the battery

When you reverse the way the motor is attached to the battery (red to “—“ instead of red to “+”), the motor will turn in the opposite direction. It can be hard to see which way the motor is turning, so it is helpful to add a little piece of tape (or better yet, a feather) to the shaft. The direction it is rotating – clockwise or counterclockwise – should be apparent from watching closely as it just begins to turn, or as it is stopping. Whether it is going clockwise or counterclockwise depends on your point of view. Clockwise viewed from one end is counterclockwise viewed from the other end.

### Making permanent connections to a AA battery

<u>Materials</u>
-- AA battery
-- two wires, bare or stripped at least ½ " back
-- two small paper fasteners (1")
-- tape
-- a rubber band.



### If there is too much insulation on the wires

The wires from the motor might have too much plastic insulation on them, making it hard to get a good electrical connection to the battery. Use a wire stripper to remove extra insulation

### Testing battery connections

The easiest way to see if battery connections are good is to use a **digital multimeter**. See the [Appendix](#), Part 4.

### Removing a bushing from a motor shaft or a wheel

The bushing fits tightly on the shaft and is too small to provide a good grip. To remove a bushing, close a wire stripper around the shaft, and use it to pry the bushing off. The same technique works if the bushing gets stuck inside the wheel – use a wire stripper to pry it out.

### Series and parallel connections

Series and parallel configurations offer two fundamentally different ways to attach two loads to the same battery, in this case LEDs. In the **parallel** connection (a), both LEDs are directly wired to the battery. Both turn on, and either one will also turn on without the other.

In the series connection (b), the LEDs split up the three volts from the battery. Recall from Lesson 1 that the **voltage** is the amount of energy kick each electron gets from the battery, while the **current** is the rate of flow of the electrons, which carry the energy. Both LEDs will light up in the parallel connection, but not in the series connection. The battery supplies three volts, which is only a little above the voltage required by each LED. Neither LED requires much current. In the parallel connection, each one gets the voltage it needs, so they both light up. However, in the series connection, the three volts from the battery gets split up, and neither LED gets enough voltage to work, so both remain dark.

The second pair of exercise, circuits c) and d) explores series and parallel circuits further. Each circuit uses two coin batteries, so there should be enough voltage to turn both LEDs on when they are in series. Sure enough, in series circuit d), both LEDs come on brightly. However, in circuit c), when both LEDs are in parallel, the red one comes on more brightly than the blue, because it needs less voltage.

What happens in each case when you remove one of the LEDs ?

- ✦ Removing either LED from the **parallel** circuit (c) will make the other LED bright, because each load is connected directly across the battery; while
- ✦ Removing either LED from the **series** circuit (d) will turn the other LED off, because its connection to the battery is now gone.

As an example of a parallel circuit, think about the row of lights above many medicine cabinets. One or more bulbs can blow, leaving the others on, because they are all connected in parallel across the house current, which plays the same role as a battery. An example of a series circuit is the old-fashioned string of Christmas tree lights, which would go out entirely if one of the bulbs was blown or removed. Pairs of fluorescent lights in old-fashioned ceiling fixtures were also sometimes connected this way – both bulbs had to be good for either one to turn on. \

# Lesson 5: Make a Simple ElectroCity!

## Overview

Each student designs and makes an **ElectroCity**: a decorated scene that includes a circuit to provide light, sound and/or motion.

## Materials

- ✎ Motors, AA batteries, bushings and wheels
- ✎ LEDs, coin batteries, buzzers, materials for making switches
- ✎ Aluminum foil, galvanized wire, rubber bands, tape
- ✎ Cardstock and craft materials

## Procedure

1. Planning an ElectroCity: Explain to students that they will next have an opportunity to design an **ElectroCity**, using any of the materials they have learned about. An ElectroCity is a scene that includes a circuit to make the scene come alive with light, sound and/or motion effects. The one rule is that:

✎ *Every circuit should be controlled by at least one switch.*

The first step is to write a description of the scene they would like to create, and draw a picture of what it will look like. Next they should explain how they will use a circuit to make their scene come alive.

### Science Notebook:

- ✎ Describe the scene you would like to create.
- ✎ Make a drawing showing what the scene will look like.
- ✎ How will you use an electric circuit to make your scene come alive?

2. The electrical design: Review the use of schematic symbols, conventions and diagrams. The next step is to make a design of the circuit(s) that will be at the heart of the ElectroCity. Encourage students to use the circuit symbols they have learned, and the conventions for connecting parts. See Lesson 3.
3. Making the ElectroCity: Provide time for students to create their ElectroCities, based on the designs they have already completed. As they are working, ask students to keep lists of **issues** – things that don't work.
4. Troubleshooting: It is likely that some aspects of some of the electrical circuits will not work. Ask students:

✎ *If something doesn't work the way you want it to, what should you do?*

Develop the idea that it doesn't make sense to start over, because most of what you made is probably OK. Also, if you start over, you might just run into the same issue again! It makes much more sense to:

- ✎ *Find out exactly what is preventing it from working, and*
- ✎ *Then solve only that problem.*

In engineering, this way of addressing issues is called **troubleshooting**.

Most of the problems will probably be due to bad connections, although there may also be failures due to bad components. For suggestions, see section on **Troubleshooting (for the Teacher)**.

## Homework

**A Hidden Switch Hunt.** In preparation for Lesson 6, list examples of **hidden switches** that you find at home. A hidden switch is one that you don't operate deliberately. You turn it ON or OFF by doing something else, which causes the switch to open or close. For example, a refrigerator contains a hidden switch. When you open the door, a light comes on, but you didn't turn the light on deliberately. Its switch is hidden, and operated by the opening and closing of the door.

The first row of the Worksheet, Part 2, is already filled in with the refrigerator example. Ask students to list their examples on the Worksheet. For each one, they should identify the device that contains the switch, what the switch controls and what has to happen to activate the switch.

## Outcomes

- ✎ Students use schematic diagrams to plan, build and troubleshoot their own circuits.
- ✎ Students apply the knowledge they have gained about electricity to create their own displays
- ✎ Students develop troubleshooting strategies and techniques to address issues as they arise.

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

### Lesson 5, Part 1: Making an ElectroCity

Make a schematic diagram of the circuits you will use:

Make a list of the issues that arose, and what you did to fix each one:

<b>Issue</b>	<b>Fix</b>
<hr/> <hr/> <hr/>	<hr/> <hr/> <hr/>
<hr/> <hr/> <hr/>	<hr/> <hr/> <hr/>
<hr/> <hr/> <hr/>	<hr/> <hr/> <hr/>

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

### Lesson 5, Part 2: Hidden Switch Hunt

List the hidden switches you found at home or in the classroom, or that you thought of afterwards. The first row is completed as an example.

<b>Where I found it</b>	<b>What it controls</b>	<b>What do you do to operate the switch ?</b>
Refrigerator	The light inside	Open or close the door

## Troubleshooting (for teachers only)

### Coming up with an idea for an ElectroCity

When students begin designing their ElectroCities, encourage them to be creative. They will likely come up with some very good ideas. If some students are having difficulty, conduct a brainstorming session, in which students call out ideas that come to them. In brainstorming, there are no bad ideas, and nobody is committed to pursuing any idea they come up with, so it should be a risk-free environment. The point of brainstorming is for students to get ideas from one another. Here are some ideas students have come up with in the past:

- ✎ A car, with a horn you can turn on or off with a switch.
- ✎ The night sky, with LEDs representing stars.
- ✎ A fireworks display.
- ✎ Fireflies.
- ✎ A thunderstorm, with the buzzer as thunder and LEDs representing lightning.
- ✎ An airplane or helicopter, with a motor operating the propeller.
- ✎ An intersection, using LEDs for the traffic light, and a buzzer for traffic sounds.

### Getting a circuit to work

The Troubleshooting sections of Lessons 1-4 provide numerous examples and suggestions about how to get a circuit to work. Here is a summary of what to look for and what to do. If a circuit doesn't work, there are three possible explanations:

- ✎ One or more of the connections is bad.
- ✎ One or more of the components is bad.
- ✎ The circuit was not designed properly.

Most circuit problems will probably be due to bad connections. A quick way to test a connection is to squeeze it – if it comes on when squeezed, it needs to be tightened, so the wires and terminals are making good contact. Another way to test for a bad connection is to run a separate wire that makes good contact. If the circuit now operates, the original connection was bad. See Troubleshooting sections for Lessons 1 & 2.

The next possibility is that some of the components are bad. One way to test a component is to substitute another of the same component at the same point in the circuit. If the new one works, but the old one didn't, and they are both connected the same way, the original component was probably bad. The **digital multimeter** is also very useful for troubleshooting. See the Appendix.

If the connections are all in place, and the circuit still doesn't work as it should, the fault may be in the wiring configuration. Use the schematic as a troubleshooting tool to make sure each connection that appears on the schematic is also in place in the actual circuit, and that no extra connections are made that do not appear on the schematic.

# Lesson 6: Hidden Switches

## Overview

A hidden switch is one that you normally activate by doing something else. For example, when you open the door of a refrigerator, you activate a switch that turns the light on. Students discuss the results of the **Hidden Switch Hunt** done for homework (see Lesson 5), and brainstorm additional examples of hidden switches. They then create their own circuits controlled by hidden switches, activated by opening a box or card.

## Materials

- ✦ Same materials as for Lesson 5: Motors, AA batteries, bushings and wheels, LEDs, buzzers, coin batteries, buzzers, paper fasteners, paper clips, aluminum foil, galvanized wire, rubber bands, cardstock, scissors, tape, craft supplies.
- ✦ Additional materials: Small cardboard boxes, clothespins.
- ✦ A few sample devices with hidden switches: money alarm, wind-activated chime, pop-up that lights up when opened, color wheel operated by opening a box.

## Procedure

1. The Hidden Switch Hunt: Debrief examples of hidden switches that students have found for Homework:

For example, a refrigerator contains a hidden switch. When you open the door, a light comes on, but you didn't turn the light on deliberately. Its switch is hidden, and operated by the opening and closing of the door.

2. What can you make that's controlled by a hidden switch? Show the students the small boxes and the clothespins (they have already seen the other materials). Conduct a brainstorming session, for students to come up with ideas of hidden-switch-controlled gadgets they could make that would be controlled by hidden switches. It is likely that they will come up with ideas on their own, but if necessary, you can show them the sample devices. They should use the Worksheet to record their ideas and plan what they will make.
3. Make your gadget: Provide students with materials and time to work on their gadgets. Much of their work is likely to be self-directed, and some students will probably be able to help others. Assist them only enough so that they don't become frustrated.

Science Notebook: Keep a record of what you did, things that didn't work, troubleshooting strategies you used, and how you fixed anything that didn't work

## Outcomes

- ✦ Students recognize that some switches are operated unintentionally, and come up with examples from their own experience.
- ✦ Students come up with their own ideas for hidden-switch-controlled gadgets they can make themselves.
- ✦ Students design, build, test and troubleshoot a device controlled by a hidden switch.

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

### Lesson 6: Make a Gadget Controlled by a Hidden Switch

What would you like to control with a hidden switch?

---

---

What will you have to do to make the switch turn ON and OFF?

---

---

Where will you hide the switch?

---

---

Make a drawing of what your gadget will look like:	Make a Schematic diagram of the circuit you will use:

## Troubleshooting (for teachers only)

### Hidden switch hunt

Here are some examples that students may not have come up with:

- ‡ Touch- or motion-activated lights in **light-up sneakers and pens**.
- ‡ An **electric pencil sharpener** switch has a switch inside that is activated by putting a pencil (or any other object that fits) into the hole.
- ‡ An **automobile dome light** is controlled by opening or closing any of the doors – similar to a refrigerator or oven light.
- ‡ An **automatic door** that opens when someone comes nearby.
- ‡ **Automatic faucets, soap dispensers, toilets and hand dryers** in public bathrooms.
- ‡ A **voice-activated toy** has a switch inside that responds to noise.
- ‡ **“Tickle-me” toys** have switches inside that are activated by pressure.
- ‡ A **car alarm** has a hidden switch that turns on when somebody touches the car.
- ‡ **Burglar alarms** are activated by opening or breaking a window.
- ‡ **Automatic street lights** come on when it gets dark. They have hidden switches that turn on when there isn't enough light.
- ‡ **Energy savers** turn the lights off when there isn't any motion in the room.

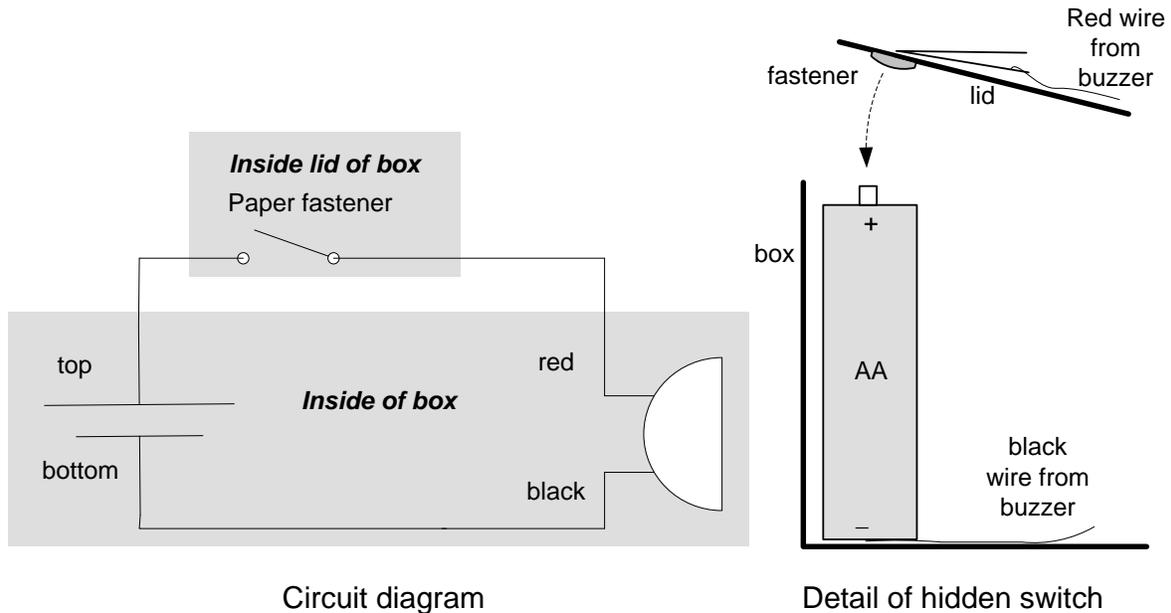
### Ideas for gadgets

Here are some ideas students and teachers have come up with:

- ✓ A dollar bill theft alarm (remove the dollar bill, and an alarm sounds)
- ✓ Cabinet alarm (same as dollar-bill alarm, except that cabinet door pulls a piece of cardstock from between contacts when door is opened)
- ✓ Upside-down alarm (turn the box upside down, and an alarm sounds)
- ✓ Wind alarm (alarm sounds when one contact is blown against another)
- ✓ Light box (close the box and see the light come on through the peephole)
- ✓ “Squeeze-me” toy (alarm sounds when you squeeze in the right place)
- ✓ Airplane or helicopter (close the lid of the box and the propeller starts turning)
- ✓ Car (lean back on the seat and the horn blows)
- ✓ Color wheel (open the box and the wheel spins; sections of colored paper, such as blue and red, blend when the motor is turning)

### A design for a simple gadget

Here is a very simple design for a box that makes a noise when the lid is closed. The hidden switch consists of a paper fastener attached to the top of a box, and an AA battery taped inside the box so it is standing up, (+) side up. The bottom (—) contact of the battery is taped to the black wire of the buzzer, and the red wire of the buzzer is attached to the paper fastener. See circuit diagram and construction detail below:



When the lid of the box is down, the paper fastener touches the top of the battery, closing the circuit, and making the buzzer sound.

### Finding problems with circuits hidden switches

Issues with hidden switches are similar to those with ordinary switches. See the Troubleshooting sections for Lessons 1-5, and the Appendix, Parts 3-7.

# Lesson 7: Magnets and Conductors

## Overview

Students experiment with magnets to find out what kinds of materials are attracted by them. Then they explore what kinds of materials will conduct an electric current. What's the connection between the two types of materials?

## Materials

- ✦ Small rare earth magnets, one per student
- ✦ Variety of small, thin metal objects, such as: coins, paper clips both coated and uncoated), solid-brass and brass-plated paper fasteners, aluminum foil, copper and steel wire
- ✦ Variety of small thin non-metal objects, such as: paper, cardboard, plastic, clay, rubber bands, cotton balls, felt, etc.
- ✦ Coin batteries and LEDs

## Procedure

1. What does a magnet attract? Show students a magnet and a paper clip. Ask:

✦ *Will this paper clip be attracted by a magnet?*

✦ *How could we find out?*

Students will probably suggest bringing the paper clip near the magnet. Try it, and of course, it will be attracted. Materials that are attracted by a magnet are called **ferromagnetic**.

2. What materials conduct electricity? Hold a coin battery and LED with two fingers so the LED lights up. Then show students a coin:

✦ *Will this coin conduct electricity? How could we use the coin battery and LED as a tester to find out?*

Students will probably come up with the idea of inserting the coin between one of the wires of the LED and the battery. Try it. Then repeat the same experiment with something that doesn't conduct electricity, such as a piece of paper. A material that allows electricity to flow is called a **conductor**. Materials that don't conduct electricity are called **insulators**.

✦ *What do these two tests tell us?*

✦ *Are all conductors also ferromagnetic?*

✦ *Are all ferromagnetic materials also conductors?*

Develop the idea that electricity and magnetism may not work the same with all materials. We won't know whether any particular material is a conductor and/ or ferromagnetic until we test it to find out.

3. Testing materials Distribute worksheets and materials. We will be testing materials to find out:

✎ *Does it conduct electricity?*

✎ *Is it attracted by a magnet?*

Students should predict what each material will do before they test it. On the Worksheet, record the predictions and the results of the tests for each type of material. Then they will try to answer these questions:

✎ *What do conductors seem to have in common?*

✎ *What do ferromagnetic materials seem to have in common?*

4. What can you do with a magnet? Provide time for students to experiment with their magnets, and record their findings in their Science Notebooks. Some focusing questions are:

✎ *How close does a magnet need to be to “feel” another magnet?*

✎ *What materials can be in between magnets, without preventing them from “feeling” each other?*

✎ *What other ways can magnets interact, besides attracting one another?*

#### Science Notebook

✎ What experiments did you try with your magnets?

✎ What did you learn?

✎ What can you do with a magnet?

## **Outcomes**

- ✎ All metals are conductors. Non-metals are generally insulators.
- ✎ Only some of the metals are ferromagnetic.
- ✎ Non-metals are not ferromagnetic, although a ferromagnetic material with a thin cover of a non-metal will be attracted by a magnet.
- ✎ A strong magnet may attract another magnet or a ferromagnetic material even though there are other materials in between, such as wood, paper or the human body.
- ✎ A magnet will not attract another magnet or a ferromagnetic material if it is too far away.
- ✎ While a ferromagnetic metal is attracted by a strong magnet, it will also act like a magnet itself.
- ✎ If magnets are turned in a particular way, they will sometimes repel one another.

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

### Lesson 7: Magnets and Conductors

Record your predictions (yes or no) and your results (yes or no) for each material you tested.

Material	Prediction		Test results	
	Attracted by magnet?	Conducts electricity?	Attracted by magnet?	Conducts electricity?

What do materials that are ferromagnetic seem to have in common?

---

What do materials that are conductors seem to have in common?

---

What materials are conductors, but not ferromagnetic?

---

What materials are ferromagnetic but not conductors?

---

## Troubleshooting (for teachers only)

### Conductors

All metals conduct electricity. Water conducts electricity too, unless it is pure – that’s why it’s dangerous for electrical components to get wet. There are a few non-metallic solids that conduct electricity, such as specialized plastics, but these are not common. A fast way to find out if a material conducts is to use a **digital multimeter**. See the Appendix, Part 7.

### Ferromagnetic materials

Anything made of iron or steel, except for some kinds of stainless steel, is ferromagnetic. Most other metals are not ferromagnetic. The magnets provided are made of a strong new ferromagnetic material called Neodymium/ Iron/ Boron, abbreviated NdFeB.

### Examples of ferromagnetic materials that are also conductors

- ✍ A coin battery
- ✍ The “—“ terminal of an AA battery
- ✍ The metal parts of a motor
- ✍ Scissor blades
- ✍ Bare paper clips
- ✍ Brass-plated steel paper fasteners (the steel is ferromagnetic not the brass coat)
- ✍ The tip of a ball point pen
- ✍ The metal wires attached to the LEDs
- ✍ The metal binding of a spiral or looseleaf notebook

### Examples of conductors that are not ferromagnetic

- ✍ Aluminum foil
- ✍ Coins
- ✍ Keys
- ✍ The wires attached to motors and buzzers
- ✍ The metal case around a pencil eraser
- ✍ Soda cans
- ✍ The “+“ terminal of an AA battery
- ✍ Solid brass paper fasteners

### Examples of ferromagnetic materials that are not conductors

All common ferromagnetic materials are metals, which therefore conduct electricity. However, Often, however, a ferromagnetic piece is covered by an insulator that is thin enough that the magnet will still attract it through the cover. Unless the insulator is scraped off, the material will appear to be both ferromagnetic and also an insulator. For example, plastic-coated paper clips & push pins will attract a magnet, because of the steel wire inside, but will not conduct electricity. because the plastic is an insulator.

# Lesson 8: Magnetic proximity switches

## Overview

Students are introduced to the **magnetic proximity switch**, which opens or closes when a magnet comes near it. These are inexpensive, common devices that are used in bicycles, exercise equipment, greeting cards, security systems and games. Students use what they have learned about magnets to create their own magnetic proximity switches, and test them in simple circuits.

## Materials

- ✦ Coin batteries and LEDs
- ✦ Magnets, paper clips, paper clips, solid-brass and brass-plated paper fasteners, aluminum foil, steel wire
- ✦ Sample homemade magnetic proximity switches
- ✦ Cardstock

## Procedure

1. Proximity switches: Introduce the idea that a hidden switch might be operated from a distance. For example, a washing machine needs a hidden switch to stop it from turning when the door is open. A seat belt in a car needs a switch to turn off the alarm when the seat belt is locked in place. Both washing machines and seat belts use switches that turn on or off when something is nearby – before it actually touches.

✦ *What could make a switch close when it is nearby, but not actually touching?*

If students don't come up with the idea that it could be a magnet, show them one of the magnets, and ask:

✦ *How could you use a magnet to operate a switch?*

If students can't think of a way, provide a further prompt:

✦ *Suppose you had made a pushbutton switch. How could you make it close by bringing a magnet nearby, instead of pushing it with your finger?*

✦ *Where would the magnet need to be to make the switch close?*

They can use the Worksheet to draw and explain their ideas.

2. Materials for a magnetic switch: Work out with students how their magnetic switch will work:

✦ *How many contacts does a switch have?*

✦ *What does a switch contact need to do (any switch – not necessarily magnetic)?*

✦ *When a magnet comes nearby, what should happen to these contacts?*

✦ *How many of them should move?*

✦ *How many of the contacts should be attracted by a magnet?*

A switch has two contacts. Both contacts have to be made of conductors, because otherwise the switch will never be able to turn ON. When a magnet comes nearby, one of

the contacts should move so it can touch the other, but the second contact should not move at all. Therefore, one contact will need to be made of a ferromagnetic material. The other contact will need to be made of a conductor that is not ferromagnetic.

Here's why: if neither contact is attracted by a magnet, the switch won't work, because the magnet will have no effect. If both contacts are attracted by a magnet, they will both go in the same direction when a magnet comes near, and won't touch in that case either. The solution is to use one contact that is attracted by a magnet, and another one that isn't. Once students understand this idea, review the outcomes of Lesson 7:

✎ *What kinds of materials are conductors?*

✎ *What materials are both conductors and ferromagnetic?*

✎ *What materials are conductors but are not ferromagnetic?*

3. Make a magnetic switch: Challenge students to come up with their own magnetic switches. If students have difficulty with this task, you can provide a simple example. Once their switch is complete, they should include it in a circuit, with a coin battery and LED, and test it with a magnet to see if the switch works.

## Outcomes

- 1. A switch has two contacts. Both need to be conductors, but only one contact should be ferromagnetic.
- 1. If a switch is controlled by a magnet, the magnet doesn't need to touch the switch directly in order to operate it. All it has to do is come close enough to move the ferromagnetic contact.
- 1. The magnet can pull the contact towards it, but not push it away. If a magnetic switch is based on a pushbutton switch, the magnet needs to operate on the opposite side from where your finger would have been.

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

## Lesson 8: Magnetic Proximity Switches

How you could use a magnet to activate a switch ? (draw and write)


What materials will you need for your switch?

\_\_\_\_\_

Show what will happen when a magnet comes near your switch.

Label each part.

--

**Troubleshooting (for teachers only)**

### Applications for magnetic switches

Students may have difficulty visualizing the bicycle example. Here are some other applications you can draw from:

### Materials for a magnetic switch

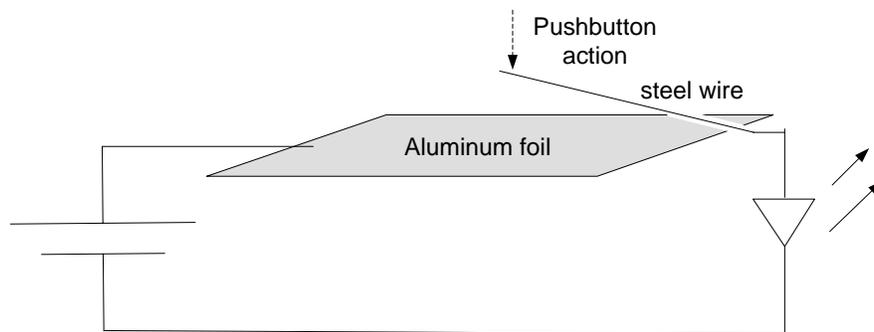
The **ferromagnetic contact** can be made of a paper clip, thin steel wire, or even the wire from one side of an LED.

The **non-ferromagnetic contact** can be made from aluminum foil or a solid brass paper fastener.

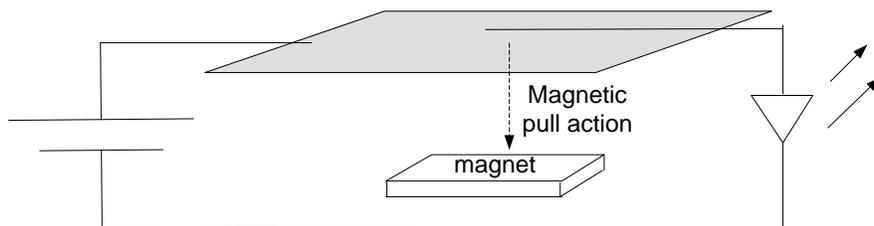
### How to make a magnetic switch

Figure a) shows the basic arrangement of a pushbutton switch, using steel wire for the movable conductor. The wire, which could be one of the leads from the LED, is bent so it is suspended slightly above the piece of foil, which is taped or glued to a piece of cardstock (not shown).

In Figure b), the same switch is configured as a magnetic switch. The magnet can only pull on the wire – not push it – so the magnet has to be below the foil to activate it. When a magnet passes slightly below the cardstock and foil, it attracts the wire so it touches the foil, completing the circuit, as shown in b).



a) Pushbutton switch



b) magnetic proximity switch

### Issues with magnetic switches

Problems with magnetic switches are similar to those with other kinds of switches, except for the mechanism of making the switch open and close. See the Troubleshooting section for Lesson 2, and the Appendix, Part 7.

# Lesson 9: Vibrators, Noisemakers, Remotes and Things that Glow in the Dark

## Overview

This lesson provides students with a variety of ideas they might include in their final ElectroCity designs (see Lessons 10-12). They explore how to create a vibrating device, by rotating an unbalanced wheel. They experiment with making a noisemaker by attaching a flap to a rotating wheel, and forcing it to hit an obstacle each time it comes around. They discover how an Ultraviolet (UV) LED will make a fluorescent pattern glow in the dark. Finally, they experiment with Infrared (IR) transmitters and receivers that can operate a switch from a distance.

## Materials

Per pair of students:

- ✦ AA battery, motor, bushing and wheel
- ✦ Three coin batteries, one UV LED, one IR transmitters and one IR receiver

General supplies

- ✦ Materials for making circuits: rubber bands, paper fasteners, wire, adhesive photosquares
- ✦ Fluorescent highlighters, blue or brown cardstock
- ✦ Small weights, such as coins or metal washers
- ✦ Craft materials

## Procedure

1. Working towards the final ElectroCity: Explain that in the final series of lessons, students will be making their own gadgets that include hidden switches, lights, buzzers, motors, magnetic switches – anything that we’ve learned about so far. Today we’ll look into a few more devices that they can use in their ElectroCities. These new devices are vibrators, noisemakers, remotes and things that glow in the dark.
2. Vibrators: Turn on a motor with a wheel attached. Hold the motor while it is turning -- it should run fairly smoothly. Then tape a nickel or washer near the edge of the wheel, as far out as it can go. Turn it on again, and let students hold the motor this time. They should feel it vibrating. Ask:
  - ✦ *What does it feel like now?*
  - ✦ *What is making it vibrate?*
  - ✦ *How could you make it vibrate more or less?*
  - ✦ *What kind of device has a vibrator inside?*

Students will probably point out that a cell phone has a vibrator, which you can use when you don’t want to hear the phone ring. It is actually made the same way as the vibrator you have just demonstrated – a little motor turns really fast with an off-center weight that makes it vibrate.

Provide materials for students to make and explore their own vibrators. Suggest adding beads or another small objects inside a vibrating box. They can use their Science Notebooks to record their ideas and findings.

3. Noisemakers: Use the same motor and wheel as before, but remove the weight. Make a flap by taping a rubber band or piece of paper so it extends beyond the edge of the wheel. Hold it so the flap just scrapes against the surface of a desk or table each time it comes around. Turn the motor on and ask students to listen. Can they hear it?

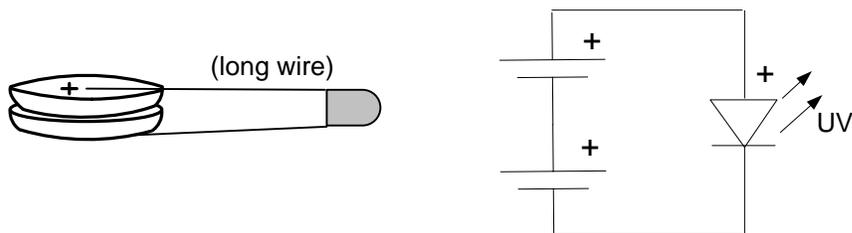
- ✎ What is making that noise?
- ✎ How would you make your own noisemaker?
- ✎ How can you change it to make the noise louder or softer?

Ask students for other ideas for making noise:

- ✎ a flap could hit a suspended string or rubber band instead of the side of the box,
- ✎ there could be a bead at the end of the flap,
- ✎ the motor could rotate a tube with beads inside, etc.

Provide materials and time for students to make their own noisemakers.

4. Things that glow in the dark: Ultraviolet light, sometimes called “black light,” is not visible, but has visible effects, such as sunburn. An Ultraviolet (UV) LED works like an ordinary LED, except that most of the light it produces is in the Ultraviolet range, and therefore not directly visible. Turn on a UV LED by pressing it against two coin batteries in series. Remember to alternate the two batteries: + — + — so the total voltage will be around six volts, as shown in the picture and diagram below:



You should see a faint purple glow. However, most of the light from the LED you can't see, because it is ultraviolet light – outside of the visible range. To demonstrate the effect of UV light, use a fluorescent highlighter to make a mark on a dark piece of paper or cardstock. Then ask someone to turn off the lights, and shine the UV LED on the fluorescent mark. It should glow an eerie yellow-green color. Try different paper colors to see which works best. Ask:

- ✎ What do you think is making this glow?
- ✎ What could you use this for?

5. Remotes: **Infrared** (IR) light, like Ultraviolet, is not visible but can be used to make visible things happen. For example, a TV remote sends Infrared light signals to turn and operate the TV set. Because IR is invisible, the TV set isn't fooled by ordinary visible light that happens to be in the room.

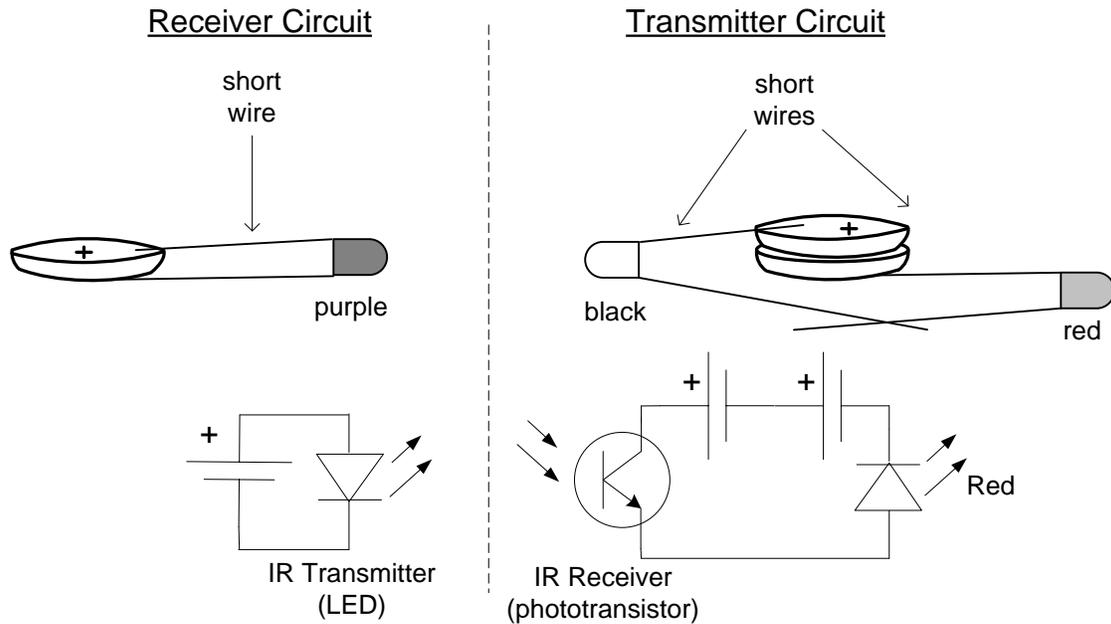
You can make your own remotes using IR transmitters and receivers. An **IR transmitter** is an LED that produces IR instead of visible or UV light. An **IR receiver** is a type of switch called a **phototransistor** that turns on when exposed to IR light.

Both the IR receiver and transmitter look like LEDs, but in different colors. The receiver is black, because it has a filter that keeps out visible light and lets only IR pass through – the same as in a TV set or DVD player, to prevent them from being activated by ordinary room light. The IR transmitter looks purple. Each of them has two wires, one (+) and one (—), but they are coded the opposite way from all the other LEDs. It's easy to forget this:

**On the IR transmitter and receiver, the short wire is (+) and the long wire is (—)**

To test the receiver and transmitter, you need a way to know that the receiver has detected the transmitter, and closed its switch as a result. The sample circuit below uses an ordinary red LED to show that the receiver has detected the IR light from the transmitter, and therefore the switch has closed. The red light should come on whenever this happens. (Instead of a red LED, we could have used any other color LED or a buzzer.) The drawing and diagram below show two circuits, separated by a dashed line:

- ✦ A transmitter circuit (right) that consists of a coin battery and an IR transmitter, or LED.
- ✦ A receiver circuit (left) that consists of two coin batteries, a red LED and a receiver, or switch, that closes when the IR light is detected.



The only connection between these two circuits is the IR light that passes from the transmitter to the receiver, closing the switch. Notice that the circuit symbol for the receiver has the arrows pointing inwards, to indicate that it receives light, unlike an LED, which transmits it.

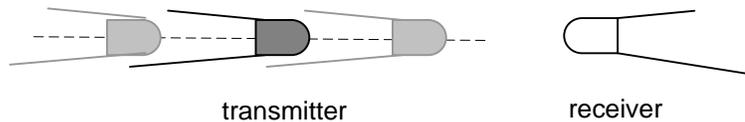
Provide materials and show students how to build a transmitter/ receiver set, as shown in the diagram. They should be able to make the red LED come ON by bringing the IR

transmitter in line with the receiver, and turn it OFF by moving the IR transmitter away so the receiver can't "see" it.

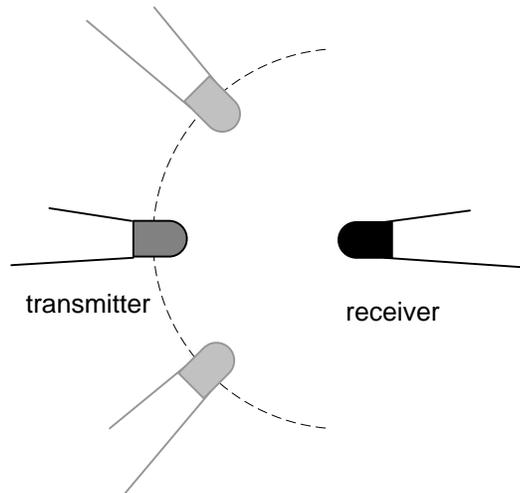
Extensions:

There are quite a few experiments you can do with an IR transmitter/ receiver set. Here are some things students might try, after they have gotten the basic circuit to work:

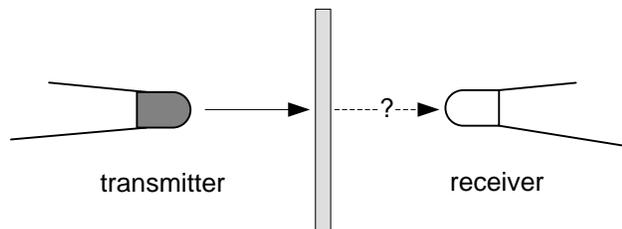
1. **What can you see when the IR transmitter is ON?** Turn on the transmitter, and look at it in a dark area, such as under a table or desk or inside a closet. What can you see? Is any of its output visible, and if so, what color?
2. **Distance between transmitter and receiver:** Move the transmitter gradually further and further from the receiver, as shown below. How close does the transmitter need to be to the receiver to turn it on?



3. **Alignment between transmitter and receiver:** Try changing the **angle** between the transmitter and receiver, as shown below. Does the receiver have to be looking at the transmitter head-on? How far off-center can it be?

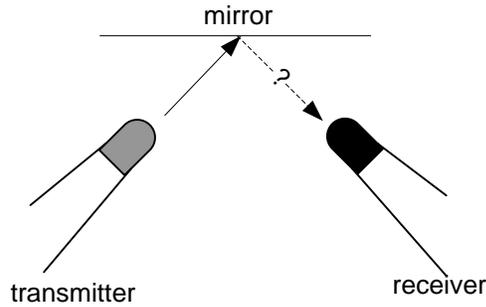


4. **Obstacles:** What happens if things get in the way between the transmitter and receiver? What kinds of things will let the IR light through and what materials will block the light? Try cellophane, transparency film, piece of paper, your hand, etc.

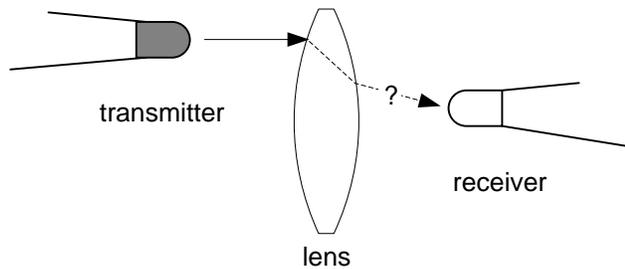


5. **Mirrors:** Set up a receiver and transmitter so the light from the transmitter has to bounce off a surface to get to the transmitter. What kinds of surface will reflect IR light? Try a

piece of aluminum foil (both sides), a piece of shiny plastic of any color, dull plastic, paper, transparency film, etc.

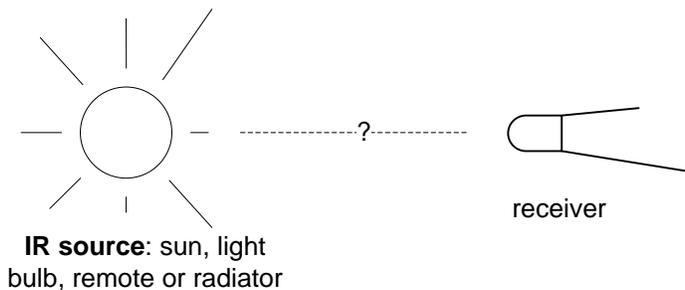


6. **Lenses:** Put a lens in front of the receiver. You can use a bug box, pair of glasses, glass ball, magnifying glass, or flat plastic magnifier as a lens. The receiver should be as close as possible to the **focal point** of the lens – the place where you would put whatever you’re magnifying, such as an insect or newspaper. Will a lens focus IR light? Find out by moving the transmitter off center, and see if the receiver will still detect it through the lens.



7. **Other sources of Infrared light:** Because IR light is invisible, we are not aware of the many other sources of IR in our environment. Set up the receiver circuit only, and see whether you can it to detect the following possible sources of IR:

- ✦ Sun light
- ✦ An incandescent light bulb
- ✦ A radiator
- ✦ A TV or DVD remote controller.



### Science Notebook

- ✎ How can you make a vibrator? Make a diagram. Label all parts.
- ✎ What experiments did you try with vibrators? What did you learn?
- ✎ How can you make a noisemaker? Make a diagram. Label all parts.
- ✎ What can you do with a UV LED?
- ✎ How does an IR transmitter/ receiver pair work? What can you use it to do?

### **Outcomes**

- ‡ An off-center weight on a rotating wheel will make the wheel vibrate.
- ‡ When one thing hits another repeatedly, it will keep making noise.
- ‡ Ultraviolet light is not visible, but it will make a fluorescent dye glow in the dark.
- ‡ Infrared light is not visible, but it can operate a switch.

## Troubleshooting

### Vibrators

Vibration occurs whenever a rotating disk is unbalanced. You can make a rotating wheel vibrate simply by taping a weight off-center. Any weight at all will work: a coin, paper clip, bead, button, etc. There are two ways to increase the amount of vibration:

- ↳ Add more weight, or
- ↳ Move the weight further from the center.

### Noisemakers

Almost anything that hits a barrier suddenly will make noise. The problem is that the motor has to keep turning, so the flap attached to the wheel has to be soft enough that it can continue to rotate, but hard enough to make an audible noise. If the motor stops turning, two solutions are to:

- ↳ Move the wheel and flap further from the obstacle; or
- ↳ Use a more flexible material for the flap.

If the sound isn't loud enough, the possible remedies are exactly the opposite:

- ↳ Move the wheel and flap closer to the obstacle; or
- ↳ Use a more rigid material for the flap.

Getting the right balance usually requires some trial-and-error.

### Different forms of light

Students may wonder about the relationships among visible light, IR and UV. Light is a form of electromagnetic radiation. Different forms of radiation vary in **wavelength**: the distance between crests of the wave at any moment. Radio waves, microwaves, light and x-rays are all forms of electromagnetic radiation, which are different because they have different wavelengths. There is only a narrow range of wavelengths that we can see and therefore call **visible light**. Within the visible range, different colors have different wavelengths, ranging from violet at the low end, to red at the high end, with the entire spectrum in between. Waves that have slightly lower wavelength than the visible range are called **ultraviolet (UV)**, and those that have slightly higher wavelength are **infrared (IR)**.

### Things that Glow in the Dark

An ultraviolet LED (UV LED) produces some visible light, which is why you can see it glow purple, but most of its radiation is in the UV range that you can't see. However, it has effects that you can't see directly. Ultraviolet light causes **fluorescence** in some materials. When a material fluoresces, it absorbs light at one wavelength, in this case UV, and re-transmits it at another wavelength. Some highlighters have a dye in them that absorbs UV light, and transmits light in the yellow-green part of the visible range. This light is easiest to see if there isn't too much background light competing, so the effect is best if the room lights are off, or if you look at it under a desk or table.

The effect changes with the color of the paper. The paper colors that seem to work best are blue, green or brown. Green has the advantage that the highlighter is nearly invisible until the UV light is turned on. Blue and brown provide better contrast, giving the mark an eerie glow in UV light.

## IR Remotes

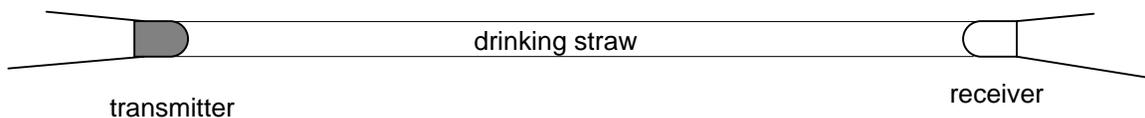
The receiver/transmitter circuits can be a little hard to troubleshoot, because both have to be working for the red LED to come on. Begin by checking the polarity of the IR receiver and transmitter. **The short wire of both the receiver and the transmitter is the (+) side.** It is easy to get this wrong, because it is the opposite from all the other LEDs.

If you have checked the polarity of both the receiver and transmitter, and the red LED still doesn't come on, place the receiver close to the transmitter and line them up so they are head to head. If it still doesn't come on, you will need to troubleshoot the receiver and transmitter circuits separately.

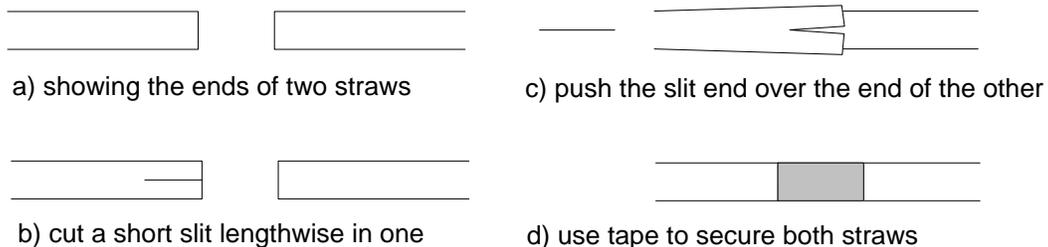
The transmitter circuit is simpler, because it has only two components: the IR LED and the coin battery. When the IR LED is on, if you look at it in a dark place you can see a faint red light glowing inside the purple case (see Extension 1, above). If this doesn't happen, either the polarity is wrong (see first paragraph of this section), the battery is dead or the LED is dead. The fastest way to find out which is to use the **digital multimeter** to test voltages, as described in the Appendix, Parts 3 & 6. Without the IR LED connected, a good coin battery should read about 3 Volts. Connecting a good IR should reduce the voltage reading to about 1.3 Volts.

An easy way to test the receiver circuit is to expose the black IR receiver to a known source of IR: the sun or an incandescent lamp (see Extension . Shield the red LED from the sun or the lamp, so its red light will be visible when it comes on. If the receiver circuit doesn't respond to sunlight or a lamp, check the wiring and the polarity of the IR receiver – again, see first paragraph above.

Once you have gotten the receiver/transmitter pair to work, try moving the transmitter away from the receiver (see Extension 2). They will operate from at least several feet away, as long as they are aligned properly (see Extension 3). The receiver has to see the transmitter head on, or it will not detect the IR light. You can use a straw to align them:



If you would like to place them further apart than one straw-length, you make a chain of straws, but cutting slits at the end of every other straw, and slipping the slit straws over the other straws. The diagram below shows how to connect two straws:



Two other ways to overcome the alignment problem are to use a lens or mirror, as suggested in Extensions 5 & 6.

## Lesson 10: Design an Automatic ElectroCity

### Overview

An Automatic ElectroCity is a mystery box or card that surprises you with sound, light or motion when you trip a hidden switch. Based on what they have learned so far, students design their own automatic ElectroCities, and begin to make them.

### Materials

- ✍ Same materials as for Lesson 6: Motors, AA batteries, bushings and wheels, LEDs, coin batteries, buzzers, paper fasteners, paper clips, aluminum foil, galvanized wire, rubber bands, cardstock, scissors, tape, small cardboard boxes, clothespins
- ✍ Same materials as for Lessons 8 & 9: Magnets, small weights, such as coins or metal, UV LEDs, fluorescent highlighters
- ✍ Craft materials: Ribbon, pom-poms, paper streamers, yarn, felt, pipe cleaners, beads, buttons, clay, cotton balls, cotton squares, toothpicks, push pins, cocktail umbrellas, etc. (as available).
- ✍ Additional: Cardboard tubes, small plastic wheels to fit, cardboard boxes,
- ✍ Storage bags to hold work-in-progress.

### Procedure

1. Brainstorming ideas for Automatic ElectroCities: Review all the devices available for making ElectroCities: batteries, LEDs, buzzers, motors, wheels, switches, hidden switches, magnets, magnetic switches, vibrators, noisemakers, infrared remotes, things that glow in the dark. Students may have already come up with ideas for their own ElectroCities. If not, conduct a brainstorming session in which students present their initial ideas for things they would like to make.

#### Science Notebook

- ✍ Describe what you plan to make.
- ✍ Make a drawing showing how the hidden switch will work. Explain what action will be needed to make the switch open and close.
- ✍ Make a drawing showing where all the parts will be.
- ✍ Make a diagram of the circuit you will use.

2. Starting to make Automatic ElectroCities: Provide students with materials, so they can begin working on their creations. Much of this work is likely to be self-directed, and students should be able to help one another. Intervene only when necessary to help students avoid frustration.
3. Clean-up: Provide storage bags so that students' work-in-progress will stay intact until the next lesson.

## Outcomes

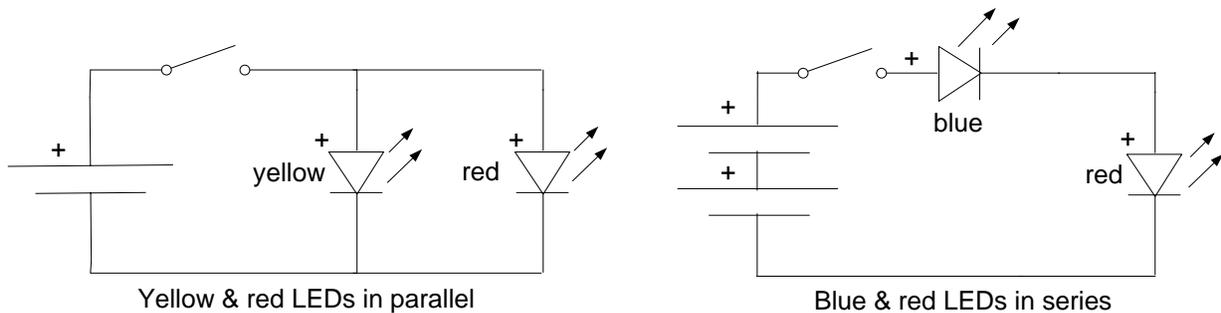
A complex design needs to be planned from beginning to end. For an electrical device with a hidden switch, the plan should include:

- ✦ a description of the project,
- ✦ a drawing of the hidden switch and discussion of how it will be activated,
- ✦ an overall drawing showing all the components, and
- ✦ an electrical diagram using standard symbols.

## Troubleshooting

### Ideas for Automatic ElectroCities

- ✦ **Buzz box:** This is a box that buzzes when you close it. The circuit idea is outlined in the Troubleshooting section of Lesson 6. In addition to the buzzer, there could be a motor in the box with an off-center wheel, causing the box to vibrate as well as buzz.
- ✦ **Light wheel:** The idea is to make a rotating wheel with two different-color LEDs attached. When the motor is on, the lights rotate, and their colors blend. Good combinations are red & yellow or red & blue. Red & yellow LEDs will both come one if attached in parallel across a single coin battery, but red & blue LEDs require two coin batteries and should be connected in series. See diagrams below, which are reproduced from Lesson 4, with switches added:

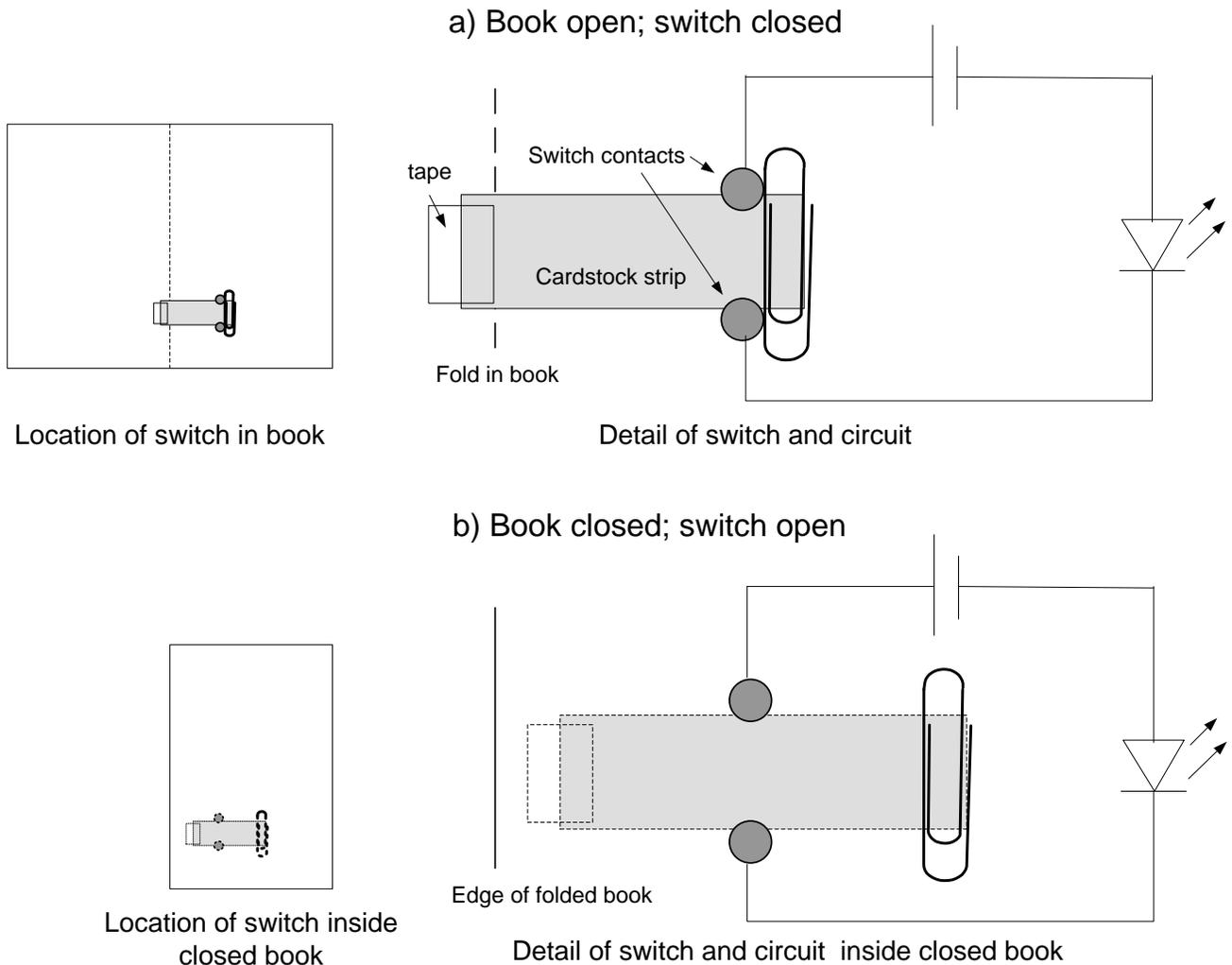


After the LED circuit is assembled, tape it to a wheel that is attached to the motor. The motor has to be powered by a separate AA battery, and the motor circuit should have its own switch, which could be the hidden switch. For the best effect, the LEDs should be side-by-side. When the motor and LEDs are turned on, a rotating pair of red and yellow LEDs should appear to be orange, while a blue and red LED pair should look purple.

- ✦ **Jitterbug:** Attach an unbalanced wheel to a motor, and mount the motor, a switch and a AA battery on a cardboard base. Support the base on wire legs made from paper clips. Decorate it to look like an animal. When the motor is on, the body should vibrate, causing it to move randomly on a smooth surface. For added effects, make an LED circuit with two wires that are close enough that the vibrations can make them touch, closing the circuit occasionally. If the LEDs are decorated to look like eyes, they will appear to be blinking as the animal is moving.

- Light up:** Make a pop-up card that has lights inside. Opening the card pulls a hidden slide switch that makes the LED come on. The light goes off when the card is closed. If students have not made pop-ups before, and would like to base their ElectroCities on pop-ups, you or they might consult the Pop-ups units at <http://www.citytechnology.org> – especially Lesson 9, which shows how to make an Angle Fold. The angle-fold construction is useful for hiding circuits inside, because it is closed on all but one side, and the triangular pop-up piece can come very close to the base when the book is open.

To make a slide switch, tape a paper clip to a piece of cardstock, shown below as a gray rectangle. Attach the strip to the left side of the book with a piece of tape, making sure that the strip is free to rotate as the book opens and closes – in other words the tape should act like a **hinge**. Capture the strip under the heads of two paper fasteners, and attach the circuit to the legs of these paper fasteners on the outside of the book. When the book is open as in diagram a), below, the left side of the book pulls the strip to the left, forcing the paper clip to touch the two paper fastener switch contacts. When the book closes – see diagram b) – the strip moves to the right, breaking the circuit.



- ‡ **Automatic maraca:** Attach a small cup or tube to a wheel off-center, or weight the wheel so it will vibrate. Put beads in the chamber and close it so the beads won't fly out. Then attach the wheel to the motor. When the motor rotates the wheel, the vibrations should cause the beads to make noise. You will need to tilt the wheel to the right angle to get this to happen. When the tube is vertical, the beads will fall to the bottom, and when it is horizontal, the motor probably won't be able to overcome gravity, and may not rotate at all. Start with the tube vertical, and gradually tilt it downward to find the angle where the noise is the loudest.
- ‡ **Automatic guitar:** Attach a bead to a motor-driven wheel by a rubber band. Stretch a rubber band across a box. Mount the motor so the bead strikes the rubber band each time it rotates. If the rubber band is fairly tight, the bead will make a guitar sound. To change the pitch, find a way to make the rubber band tighter (higher pitch) or looser (lower pitch).
- ‡ **Kitchen:** Make a set of toy appliances from small boxes. The stove could be a box that lights up when the door is opened. The dryer could have a color wheel inside that turns on when the door is closed. The wheel represents the clothes inside the dryer. The door should have a transparent window (made from cellophane or transparency film) so you can see the clothes spinning. The refrigerator could be a box with a fan inside that blows (cold) air when you open the door. The blender could be based on the same idea as the automatic maraca (see above).
- ‡ **Aquarium:** Glue or tape dark blue construction paper or cardstock on the inside walls of the box. Use the fluorescent marker to draw fish on one or more walls. Make a small window using transparent film or cellophane, so you will be able to see the fish. Use a hidden switch to turn on Ultraviolet LEDs that illuminate the fish, when the box is closed. Make a box with a peep-hole with an Ultraviolet LED inside that turns on when the box is closed. The LED should illuminate a design made with fluorescent marker, which the viewer can see glowing by looking through the peep hole.
- ‡ **Kaleidoscope:** This can be based built inside a cardboard tube from toilet paper or paper towels. Mount LEDs inside, and make a circuit that activates them by a hidden switch, which is located somewhere on the side of the tube. Make the tube light tight, except for the peephole. The user has to find the hidden switch, to make the lights come on.

# Lesson 11: Make an Automatic ElectroCity

## Overview

Students continue to work on their ElectroCities, and prepare for presenting their work in the next lesson.

## Materials

- ✦ Partially completed ElectroCities from Lesson 10
- ✦ Same materials as for Lesson 10: Motors, AA batteries, bushings and wheels, LEDs, buzzers, coin batteries, buzzers, paper fasteners, paper clips, aluminum foil, galvanized wire, rubber bands, cardstock, scissors, tape, small cardboard boxes, clothespins, magnets, small weights, such as coins or metal, UV LEDs, fluorescent highlighters; craft materials

## Procedure

1. Continuing work on ElectroCities: Students complete making their ElectroCities, test them, troubleshoot, and redesign as necessary.

### Science Notebook

- ✓ Write and draw what you made.
- ✓ List the problems that came up, and what you did to troubleshoot each one.
- ✓ What did you learn from doing this project?

2. Instructions for using your ElectroCity: Someone might not know what they would have to do to activate the device. Ask each student to attach a short instruction guide, such as “Close the Box and look through the hole,” which will tell the user what to do.

# Lesson 12: Present your ElectroCity

## Overview

Students design ways of presenting their ElectroCities to an audience.

## Materials

- ✦ ElectroCities completed in Lesson 11

## Procedure

1. Completing ElectroCities: Students complete their ElectroCities and prepare them for presentations
2. Presenting ElectroCities: This is the culminating lesson, where students will present their final products to an audience. The display could take one or more of several forms:
  - ✦ **Formal presentation**: each student shows his or her ElectroCity to an audience and explains what he or she did to make it.
  - ✦ **Museum**: Students create a display on tables, where visitors can view the ElectroCities and try them out for themselves
  - ✦ **Invention Convention**: Like a Science Fair, visitors come to view the ElectroCities, test them out and talk with the students who made them.

## Outcomes

- ✦ Students gain recognition for their ingenuity and hard work.

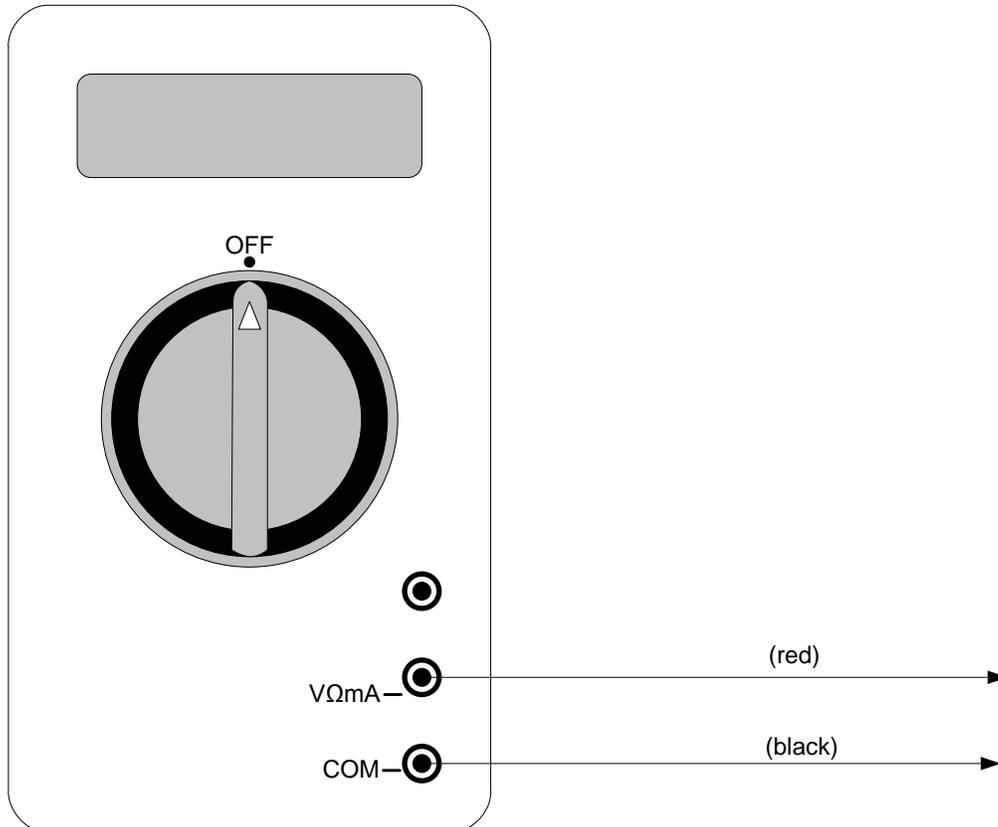
# The Digital Multimeter (DMM): A Guide for Teachers

## 1. What is a Digital Multimeter?

A meter is a device that measures electrical quantities. Your electric bill is based on the amount of electrical energy you used, which the electric company measures with a kilowatt-hour meter. When you are making and testing small circuits, the most important quantities are **voltage**, **current** and **continuity**. A **digital multimeter** (DMM) is a convenient handheld device that can measure any of these – therefore the prefix “multi” – and provide the results on a digital display. With a little practice, you can use it to check a battery, test a switch, discover why a red LED will turn a green one off when both are connected in parallel, learn about how a motor works, and much, much more. In the next few pages, we’ll show you how to set up a DMM, use to make some basic measurements, and then suggest some experiments you can do to learn a lot more about circuits.

## 2. Setting up a DMM

When the meter is not in use, it should be turned off. The switch has a little triangle on it, which should be pointing to the top center position marked “OFF,” as shown in the diagram below. In addition to the meter itself, there are only two other components that come in the box, and that you need to start making measurements: a red and a black **probe**. For nearly all measurements, these plug into the two **jacks** (receptacles) on the bottom right. The shrouded ends with the right-angle connectors are the ends that go into the jacks. Plug the black probe into the jack labeled “COM” (for “Common”) and the red probe into the jack labeled “VΩmA”. See diagram below.

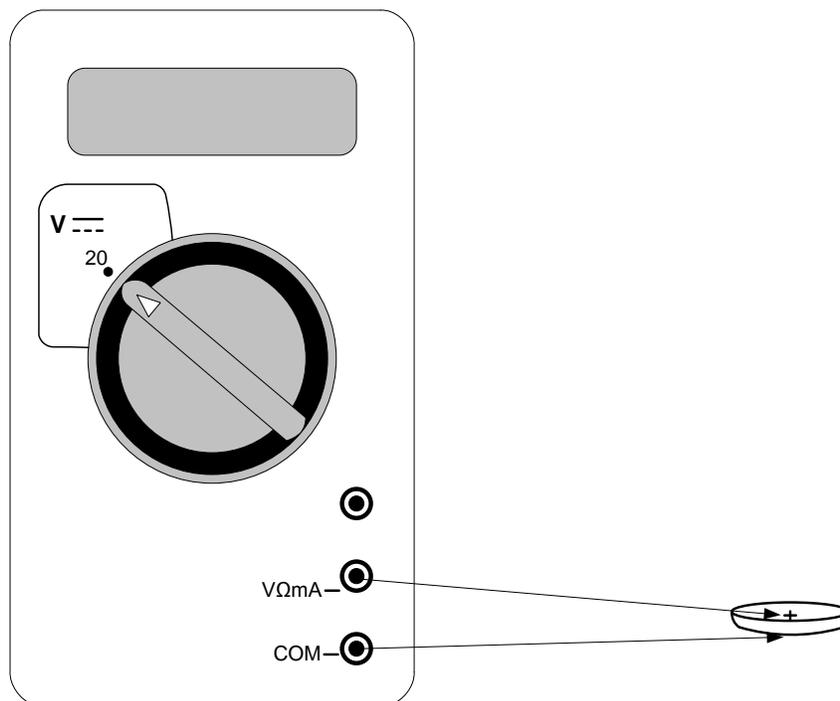


### 3. Using the Multimeter as a voltmeter: Testing a battery

Now you are ready to make your first measurement. Let's begin by checking a coin battery. a battery is a source of **direct current** (DC), which means that the direction of the current does not vary. A wall socket is a source of alternating current, which does vary in direction.

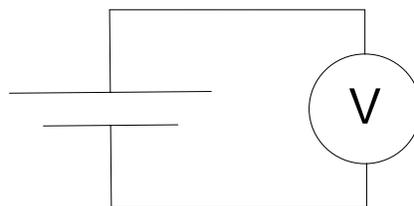
**SAFETY NOTE: DO NOT ATTACH ANYTHING TO A WALL SOCKET, IN THIS UNIT.**

The meter has a switch that allows you to select both a **function** – what quantity you are measuring – and a **range** – the maximum measurement you can make. Turn the switch to put the meter ON in the “20” range within the DV Voltage function. The maximum measurement will then be 20 Volts DC. The diagram shows how. The Voltage ranges are indicated by “V” and the DC ranges use the icon  $\text{---}$ . Then attach the red probe to the (+) side of the battery and the black probe to the (—) side of the same battery.



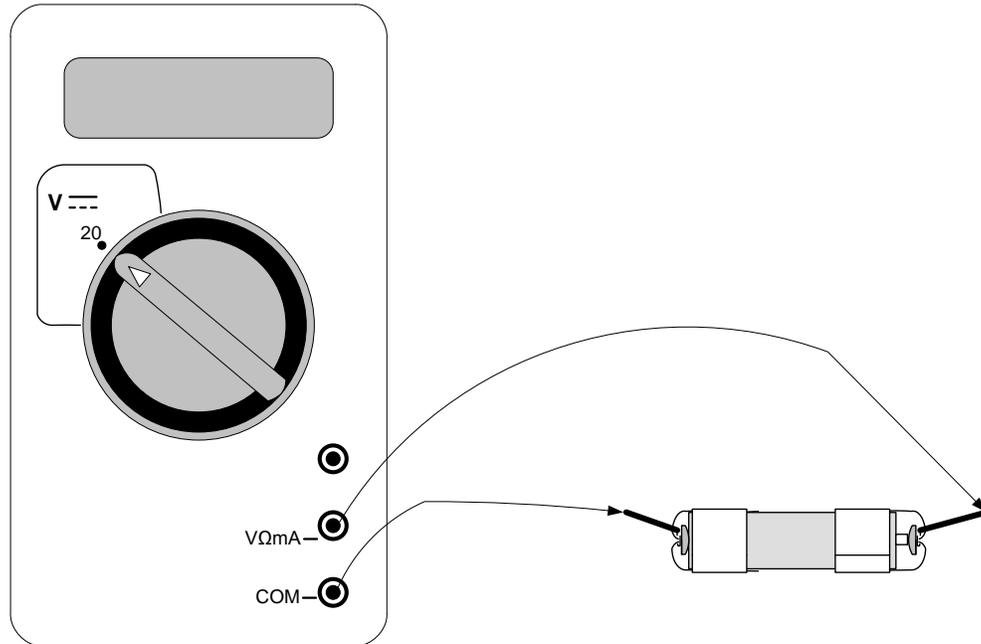
The meter should read around 3.0, which is the rated voltage of the battery. If the reading is zero, make sure the red and black connectors are pushed all the way down into the jacks, and that the probe ends are pressed hard against the battery terminals. If the reading is still zero, the battery may be dead. If there is a (—) sign in front of the reading, just reverse the two probes. Then use the same technique to measure the voltage of an AA battery, which is rated at 1.5 Volts.

A multimeter used to measure voltage is called a **voltmeter**. The circuit diagram symbol for a voltmeter is a circle with a “V” in it. Here is a diagram that shows the circuit pictured above:



#### 4. Testing for a bad connection to a battery

Often, a battery is good, but the wires to it are not making good contact. Using the same method as for testing a battery, you can find out if the connections are good, and even which one is bad. The drawing below shows the meter testing the connections to an AA battery:



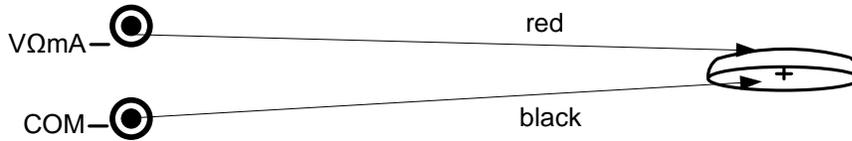
The reading on the meter should be close to 1.5 Volts. If not, touch the battery terminals directly, to see if the battery is good. If it is, but the voltage does not appear along the wires, then one or both of the connections are bad. Find out which one by moving one of the probes at a time. When the reading disappears, you have found the bad connection. The table below shows how:

Probe locations	Is there a voltage reading?	
	YES	NO
	All connections are good	Test each connection
	Left connection is probably bad	Test right connection and battery
	Right connection is probably bad	Test left connection and battery
	Battery is good	Battery is bad, or probe is not making contact

## 5. Learning more about batteries

Here are some experiments to try with a coin battery:

- ✦ **Turn the battery around**, as shown below. Predict the result of reading the voltage, and then check to see if you were right.



- ✦ **Test two batteries in series**. There are four ways to arrange these, as shown in the table below, which also includes circuit diagrams. Predict and record each result. Approximate expected values are given below the table.

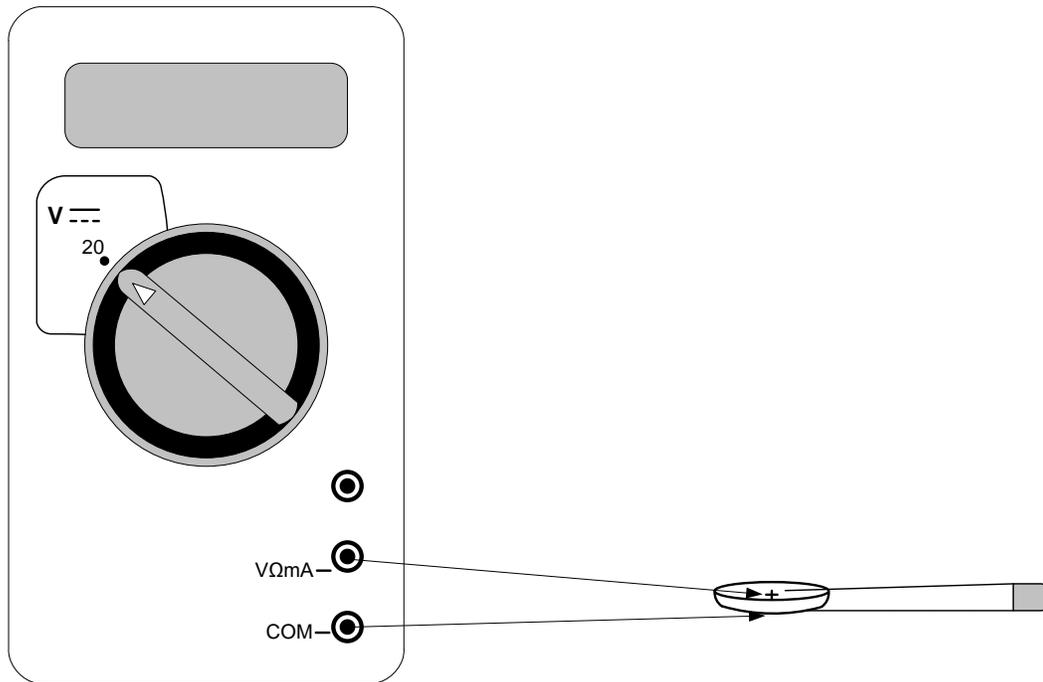
	Drawing	Diagram	Voltage Reading	
			Predicted	Actual
A				
B				
C				
D				

Expected results: A) + 6 Volts; B) 0 Volts; C) 0 Volts; D) – 6 Volts

## 6. Using a Voltmeter to learn more about LEDs

Students may have noticed that if you connect a red or yellow LED in parallel with a blue or green LED, only the red or yellow one will stay on. Why does this happen? Using a multimeter, it is easy to find out.

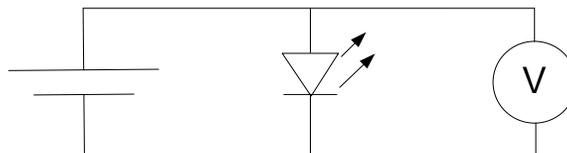
Use the same arrangement as you did to test a battery (see previous page), but this time also press the wires from a red LED against the battery so the LED comes on. Recall that the long wire has to be touching the (+) side of the battery. See the picture below:



The reading on the meter will tell you how much voltage the LED uses to turn on. Record this number. Now repeat the experiment with each of the other colors: yellow, green and blue. Record the voltage of each one. What do you notice?

Typically, a red or yellow LEDs will take only about 2.2 or 2.3 Volts – less than the full voltage of a coin battery, while the blue and green LED need about 2.9 Volts, which is nearly the full battery voltage. This helps to explain why a red or yellow LED will turn off a blue or green one when two are in parallel. The red or yellow LED will not allow the blue or green one to get to the greater voltage it needs to turn on. Also, an AA battery won't light any of the LEDs, because it only supplies 1.5 Volts, while the LEDs all need more than 2 Volts.

Something else to notice from this experiment is how a voltmeter needs to be connected. Here is a diagram of the circuit shown above:



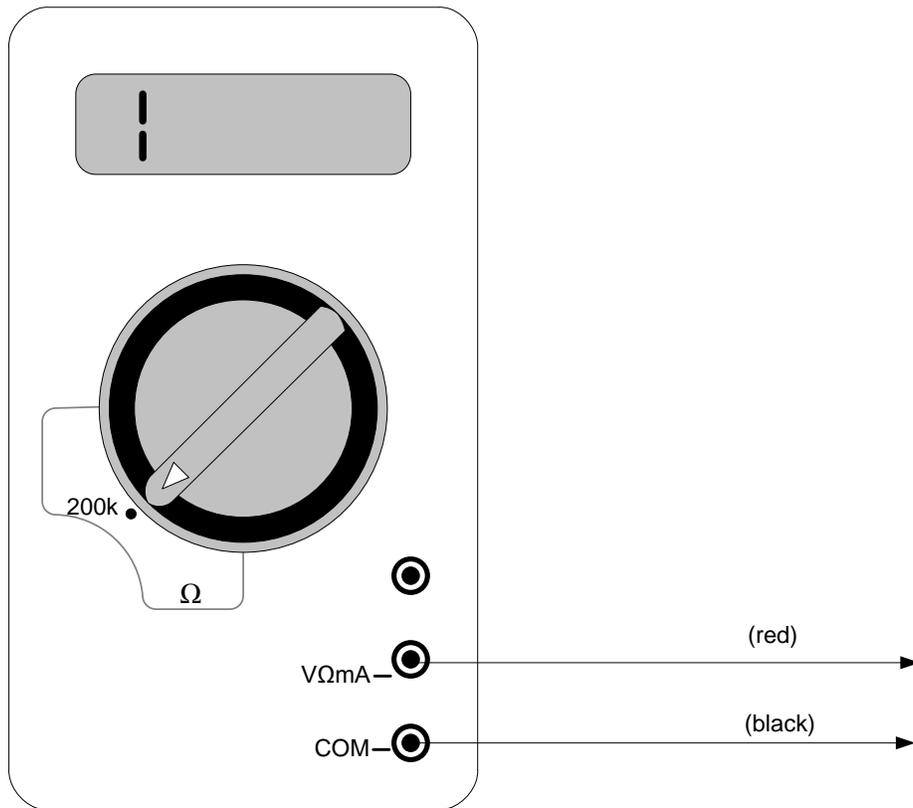
From this diagram, look at how the voltmeter is connected across the LED. A voltmeter has to be connected **in parallel** with the component whose voltage is being measured.

It may seem confusing that the components are shown in a different order in the diagram, compared with the picture. The convention in a diagram is to show the battery at the left, because it is the source or input, and the voltmeter at the right, because it is not an essential part of the circuit. The circuit works exactly the same way, regardless of which component is on the left or right, as long as they remain in parallel.

**7. Looking for continuity: Testing a switch and finding out if a material is a conductor**

You can also use a multimeter as a **continuity tester** – a device for checking whether or not parts of a circuit are actually connected electrically. To test for continuity, you use one of the ranges within the function group marked by a “Ω,” which is the Greek letter Omega. (Electrical resistance is measured in Ohms, Ω for short – but we need not worry about these details, because we will be using an Ω range only to find out if there is a connection or not.)

To test for continuity, keep the probes in the same place they were in for measuring voltage (see previous two pages) and turn the switch on the meter to the “200K” range within the Ω function. The picture shows how to set this up:



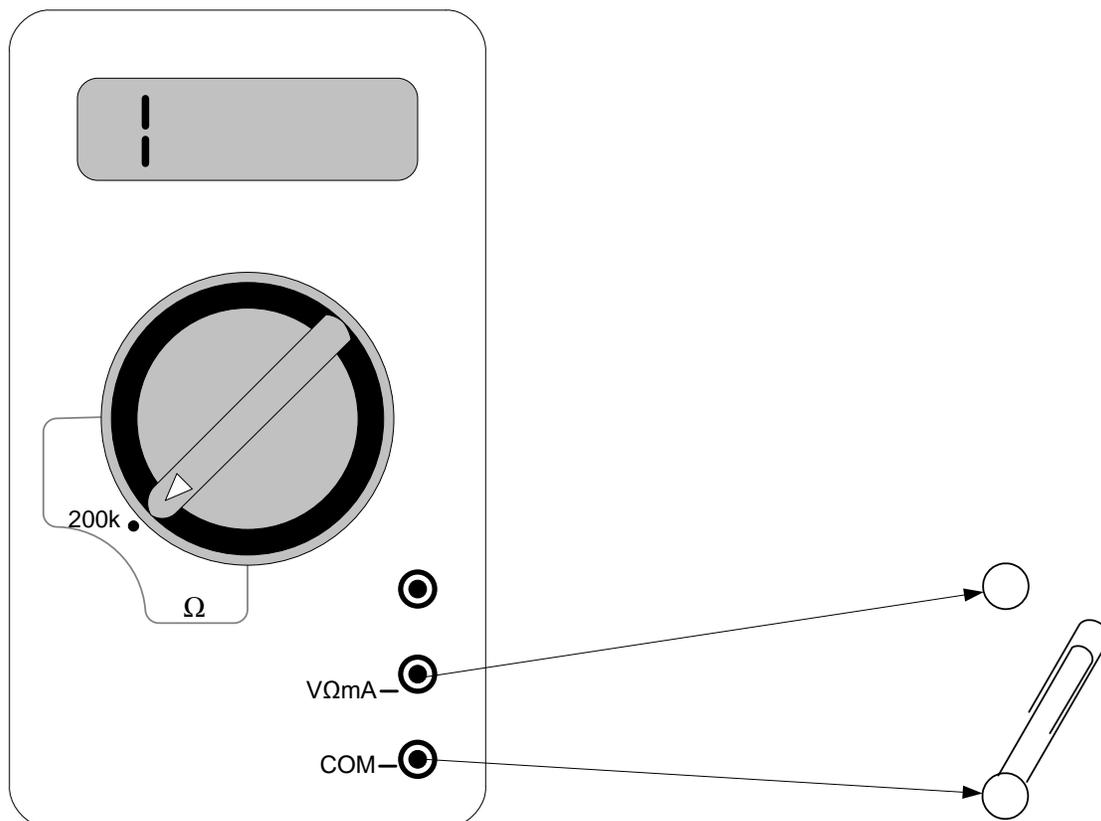
If you have done this correctly, the number “1” should appear in the display. Next touch the two metal probe ends together, and the display should change to “0.00”. The table below shows what what the numbers mean:

Display	Is there an electrical connection (continuity) between the two probes?
1	NO
0.00	YES

When a multimeter tests for continuity, it uses a battery, which is inside. To protect the battery, please observe these two rules:

- ⚡ **Test individual components only.** Do not test for continuity in a circuit that has a battery connected. Doing so can harm the battery inside the Multimeter.
- ⚡ **Do not leave the meter on for very long in one of the  $\Omega$  ranges.** Doing so can drain the battery inside the Multimeter.

Now you can use the continuity tester to find out whether there is a connection between circuit elements. Let's begin by testing a homemade switch. The drawing below shows an example of a meter being used to test rotary switch made from two paper fasteners and a paper clip:



When the switch is open, as shown above, there should be no connection between the two paper fasteners, and the meter should read “1”.

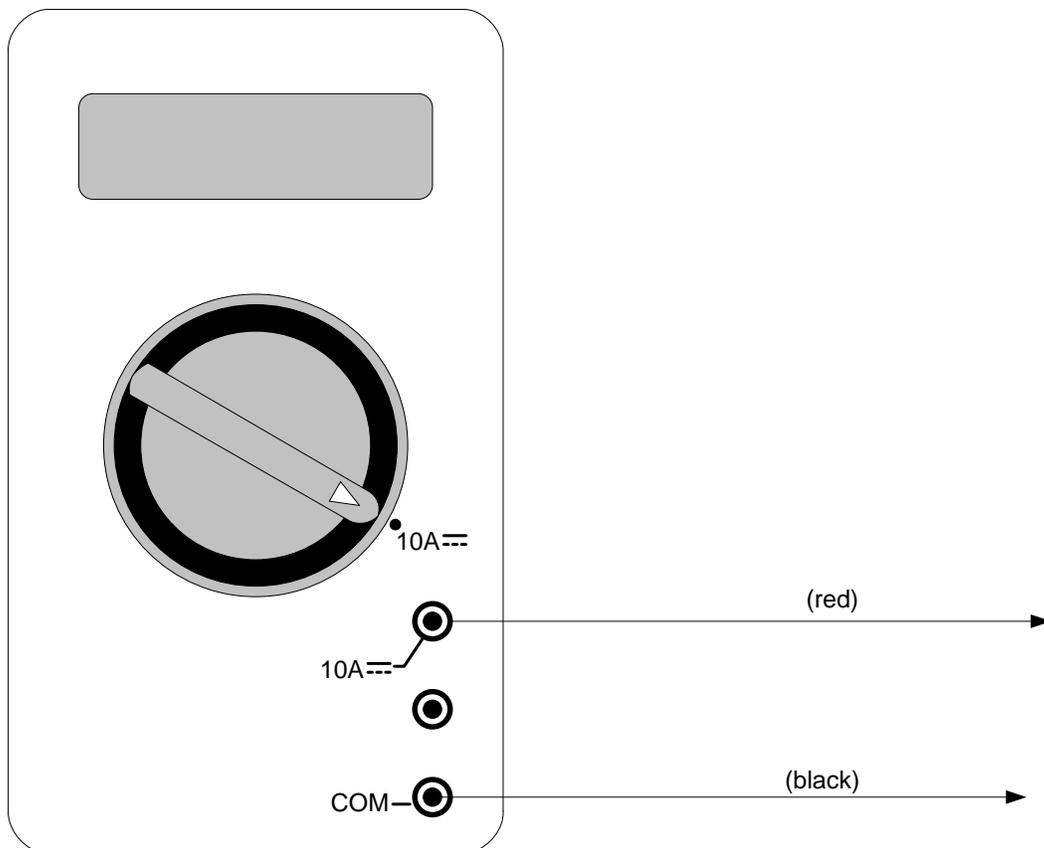
Now close the switch by touching the paper clip to both paper fasteners. The paper clip should make an electrical connection between them, so the meter should now read “0.00”. The meter provides an easy way to test a switch without using your own battery, LED or motor.

You can use the same method to test whether a material is a conductor or an insulator. Just touch one probe on each end. If it is a conductor, there will be electrical contact and the meter will read “0.00”; if it is an insulator, there will be no contact and it will read “1”.

## 8. Using a Multimeter to measure current: Comparing batteries and exploring motors

A multimeter can also serve to measure **current**, which is the rate of flow of electrical charges past a point. Since current is measured in **Amps**, which is short for “Amperes”, and is abbreviated A. Any device that measures current is called an **Ammeter**. When you use the multimeter as an Ammeter, there are a few precautions you need to take, not only to get an accurate reading, but also to protect the meter from damage. Here are the rules for measuring current:

- ✦ Once again, **DO NOT ATTACH ANYTHING IN THIS UNIT TO A WALL OUTLET.**
- ✦ **The Ammeter must be in series with the other circuit elements.** This is different from the voltmeter, which must be in parallel.
- ✦ **Use the highest current range, which is 10 Amps.** Set the meter switch on 10A as shown in the drawing below.
- ✦ **DO NOT USE THE MIDDLE JACK MARKED “VΩmA”.** The 10 Amp current range has a special jack labeled “10 A.” be. Move the red probe to the top jack, which is also shown in the drawing.

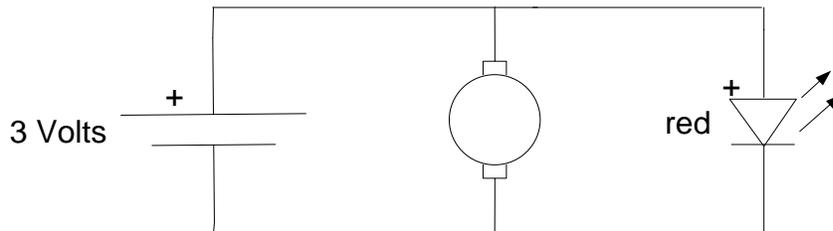


Now you are ready to make current measurements. These readings can help to answer the following questions, which may have come up while working with motors and LEDs:

- ✦ **What’s the difference between a little battery and a big one?** Some batteries are bigger than others, but the size doesn’t usually seem related to voltage. For example, a D cell is

bigger than an AA, but both supply 1.5 Volts, and a coin battery is even smaller, but provides 3 Volts.

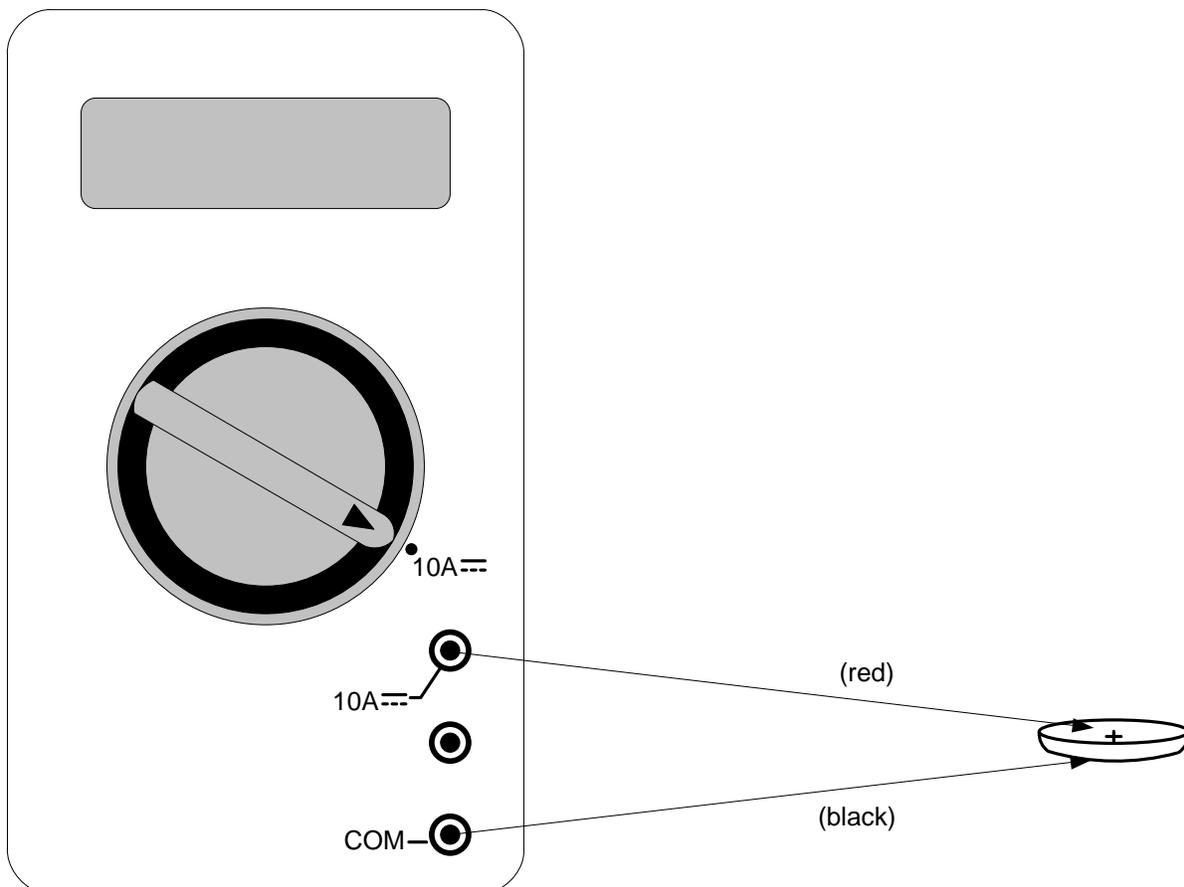
- ✦ **Why won't a coin battery run a motor?** As we will see, this question is closely related to the previous one.
- ✦ **What changes electrically when a motor is turning something?** Using two AA batteries you can operate both an LED and a motor in parallel, as shown in the diagram below:



Both the motor and LED should work fine, as long as the motor isn't turning a wheel or pulley. However, as soon as there is some weight on the motor shaft, the LED will begin to get dim. The weight could come from adding a wheel; or worse, driving a car or adding weight to the wheel; or worse yet, preventing the wheel from turning at all. If there is enough weight, the motor will continue trying to turn, but the LED will go out.

## 9. Comparing batteries

Attach the meter directly to a coin battery as shown below. Record the current reading.

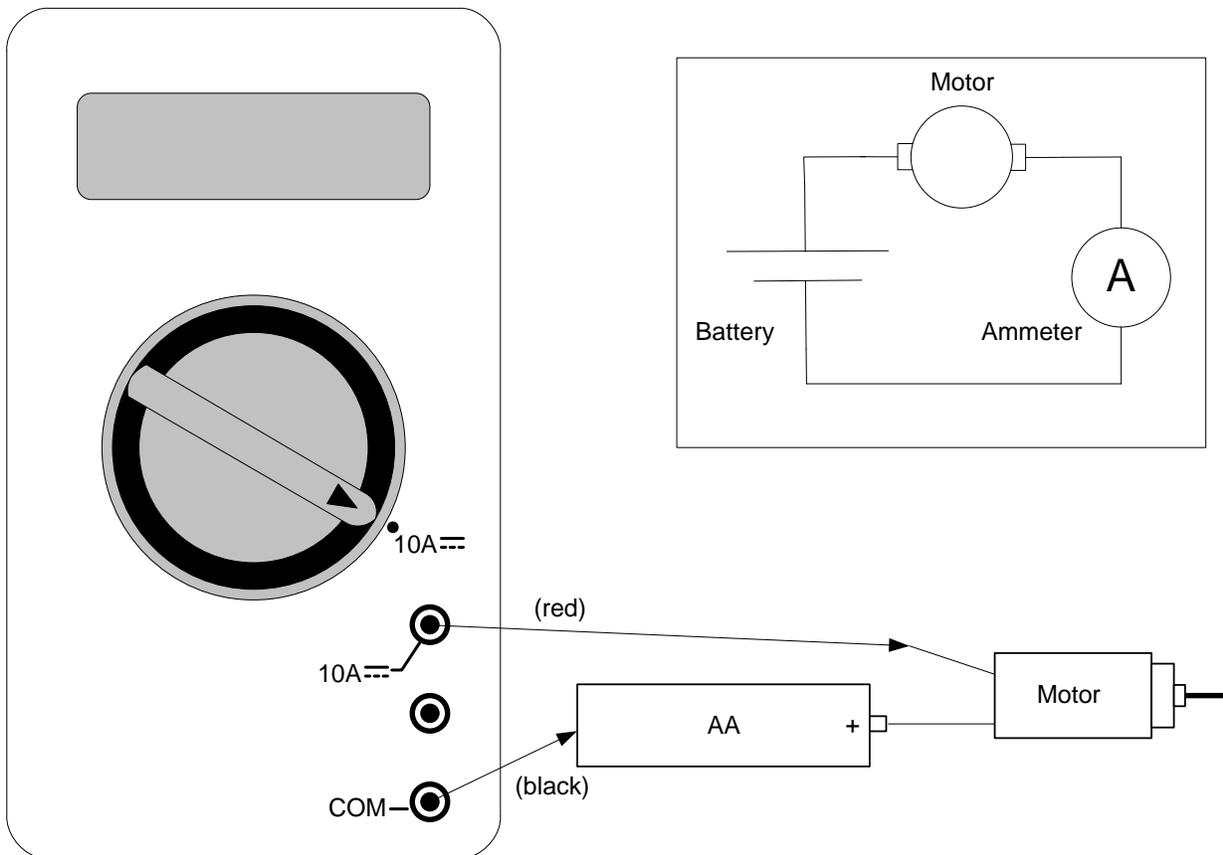


Next, use the same method to test any other battery you have available. For example you could measure the current supplied by a AAA, AA, C, D, 6-Volt square lantern battery or rectangular 9-Volt battery. Record the result of each measurement. What you obtain in each case is the maximum current the battery can provide. Typical results are that a coin battery can provide only about 0.1 A.; an AA supplies over 1 A., a D cell's maximum current is close to 2 A., and a 6-Volt lantern battery provides more than 5 A. How do these results shed light on why batteries come in different sizes?

If there is any **load** attached to the battery, such as a motor, LED or buzzer, the battery will provide less than the maximum current. The next set of experiments looks at the amount of current drawn by each type of load.

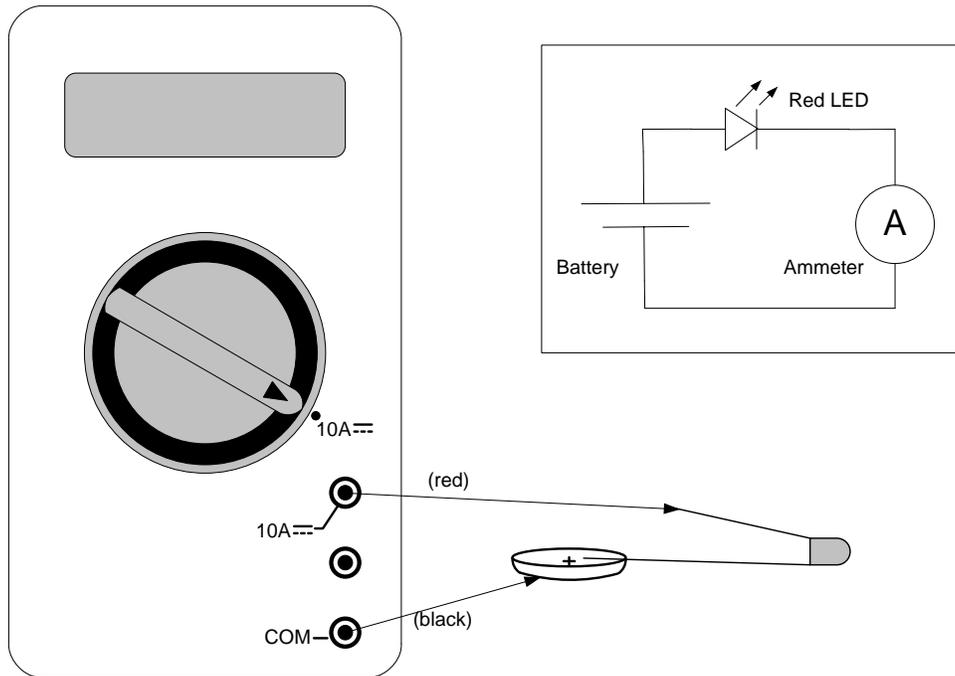
### 10. How much current do LEDs, buzzers and motors require?

The next step is to attach various loads to a battery, to see how much current each one is looking for. Let's begin with a motor. We already know that it won't work from a coin battery, so use an AA. Recall from before that an Ammeter has to be **in series** with a load – not in parallel, as with a voltmeter. The drawing and diagram below show how to attach the motor **in series** with the meter. The circuit diagram inside the box represents the same circuit. Notice the symbol for an Ammeter, which is a circle with an "A" inside.

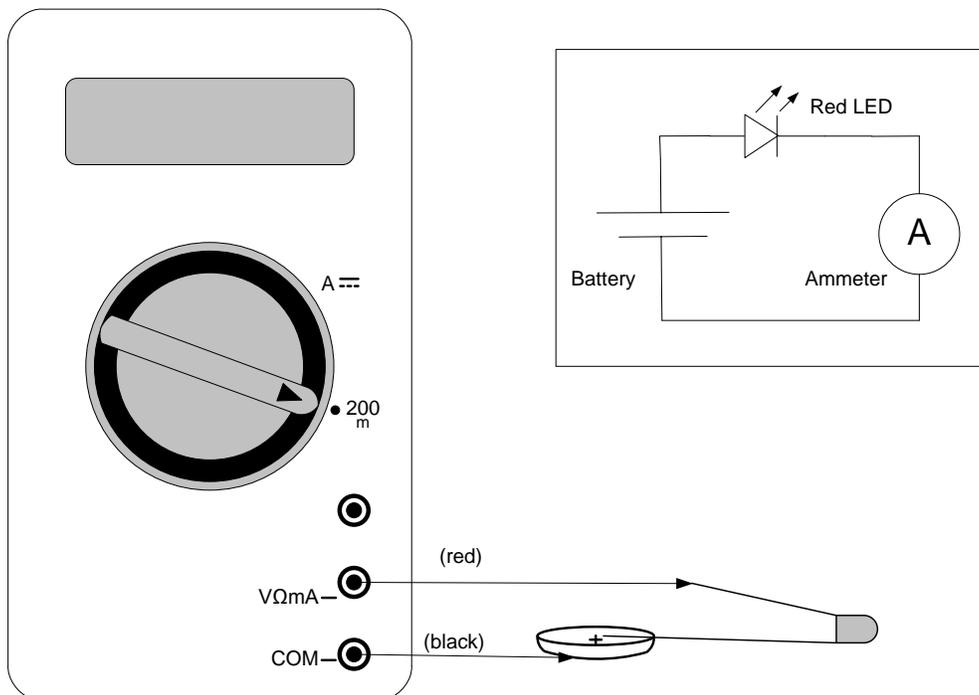


The motor is likely to draw between 0.1 and 0.2 Amps – much less than the maximum current a AA battery can supply.

Next, test a red LED. It won't run off of a AA battery, so this time use a coin battery. The circuit is shown in the drawing and diagram below.



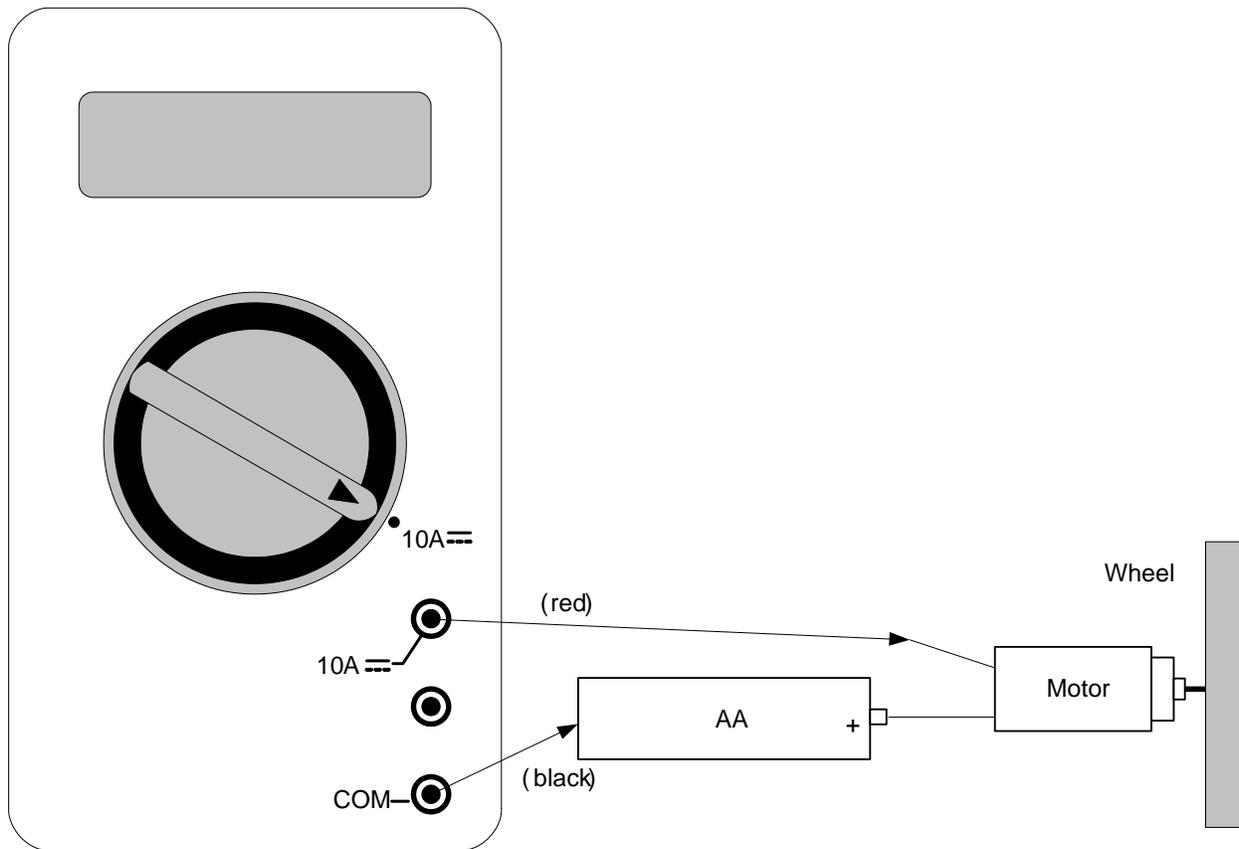
This time, the current will be much less – perhaps about 0.04 Amps. To get a more accurate reading, use the next lowest range of the meter, which is 200 mA, marked “200 m” on the switch. “m” stands for “milli,” which stands for “one thousandth” just as in millimeter or milligram. 200 mA. is the same as 0.2 A., which is considerably more than you are measuring, so it is safe to use the meter on that scale. **You will also need to move the red probe back to the “VΩmA” jack.** See diagram below:



You should get a reading, around 40 mA, which is the same as 0.04 A. Use the same method to test the yellow, green and blue LEDs, as well as the buzzer. The yellow LED should require roughly the same current as the red LED. The buzzer, blue and green LEDs use much less current, less than 10 mA. each. What do these results tell us about why LEDs and buzzers can run on coin batteries, but not motors?

### 11. What happens to a motor when it is working harder?

The last experiment explores the effect of adding weight to a motor. Restore the meter to the 10 A. range. **Be certain to move the red probe back to the 10A jack.** Then attach a wheel to the motor, using a bushing to get a tight fit. See the drawing below.



Now measure the current that motor uses. It will be much larger than the 0.1 – 0.2 Amps that measured before without the wheel – perhaps about 0.4 Amps or so. To see the current change even more, here are some things you can try:

- ✦ Add weight to the wheel, by taping a penny or other weight towards the edge.
- ✦ Slow the wheel and motor down, by forcing it to turn against something hard, such as a desk or table.
- ✦ Stop it completely, by holding it while it is still trying to turn.

Each of these actions should increase the current even more – possibly to 1 Amp or more, which is close to the maximum an AA battery can supply. What does this experiment reveal about how a motor uses current?