Engineering the Future
Science, Technology, and the Design Process

Engineer's Notebook: Project 4.0

Electricity and Communication Systems

National Center for Technological Literacy®
Museum of Science, Boston

Key Curriculum Press
Emeryville, CA

Project Team
Key Curriculum Press

Project Lead: Ladie Malek

Editorial Assistant: Christa Edwards

Production Director: Christine Osborne

Production Coordinator: Jennifer Young

Cover Designer: Jensen Barnes

Prepress and Printer: Versa Press

Textbook Product Manager: James Ryan

Publisher: Steven Rasmussen

Published by Key Curriculum Press.

Cover Photo Credit: PhotoDisc "Popular Objects" by Ryan McVay, PhotoDisc "Portfolio," PhotoDisc Volume 95 "Youth Culture," PhotoDisc Volume 4 "Science, Technology and Medicine" Version 2

Key Curriculum Press
1150 65th Street
Emeryville, CA 94608
510-595-7000
editorial@keypress.com
www.keypress.com

Printed in the United States of America

10 9 8 7 6 5 4 3 2 1 10 09 08 07

ISBN: 978-1-55953-969-2

Project Team
Museum of Science, Boston

Project Director: Cary I. Sneider

Program Manager: Julie Brenninkmeyer

Curriculum Developers: Johanna Bunn, Lee C. Pulis, Joel Rosenberg, Dan Tyman

Editor: Rebecca Pollard Pierik

Contributing Writers: Benjamin T. Erwin, Donald Foster, Chris Mrowka, John Ost

Content Reviewers: Kate Bielaczyc, Beth Miaoulis, Nancy Schalch, George Taliadouros, Laurette Viteritti, Camille Wainwright

Researchers: Kate Bielaczyc, Carol Symmons, Shih-Ying Yao

Assistants: Heather Hathaway, Katy Capo

Artist and Designer: Braden Chang

Interns: Bohn Barrayuga, Michael Habib, Christian Irwin, Jane Ko, Douglas Krause, Nancy Levoy, Richard Phannenstill, Ben Simms, and Shirley Theodore

Production Services: Publishing Solutions Group, Inc.

President of the Museum of Science and Director of the NCTL: Ioannis (Yannis) M. Miaoulis

Associate Director of the NCTL for Formal Education: Yvonne Spicer

Vice President of Publishing: Rich Blumenthal

This program was made possible through grants from the U.S. Small Business Administration, Massachusetts Technology Collaborative Renewable Energy Trust, Lockheed Martin, Cisco Systems, Inc., National Institute of Standards and Technology, and the Highland Street Foundation.

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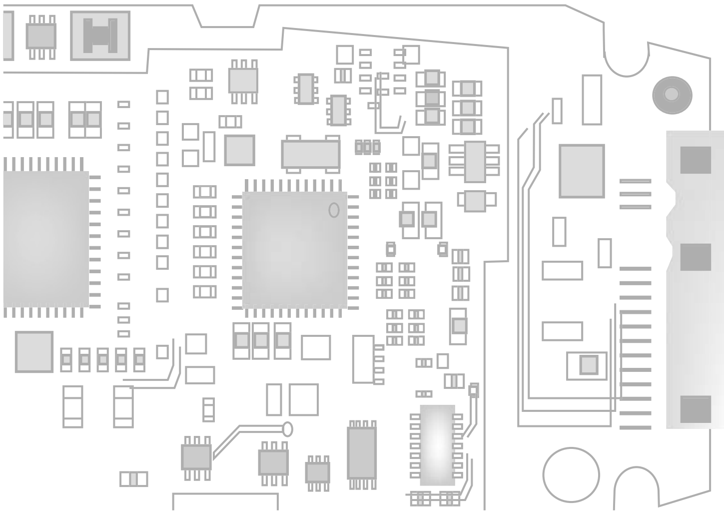
Project 4.0



Electricity and Communication Systems

People use electrical control systems dozens of times a day, from simple lighting systems to complex computer systems. Nonetheless, very few people understand what happens when they turn on a switch, and fewer still can use their creativity to design electrical circuits to solve problems. Surprisingly, understanding electricity and how it can be used for lighting, communication, and many other purposes is not as difficult as you might expect.

In Project 4 you'll learn how electrical engineers design systems by designing and building some yourself. You'll figure out a code to control a scoreboard, build a sound system and an FM radio, create a circuit to control the color of a light display, design and build a mouse detector, and a fan control system. You'll also find out how ammeters and voltmeters work, and how to generate your own electric current.

Teamwork

Engineers most often work in teams. A team shares resources, information, and talent to develop the best solutions to problems. In this course you will also frequently work as a member of a team. According to working engineers, you will be expected to:

1) Organize your team by designating co-leaders and specialists for critical objectives.

2) Apply the seven teamwork behaviors listed below, amending them as agreed.

3) Jointly agree upon your mission, objectives, and motivation to accomplish the challenge.

4) Schedule your team effort by setting a timeline of tasks, and delegate responsibilities.

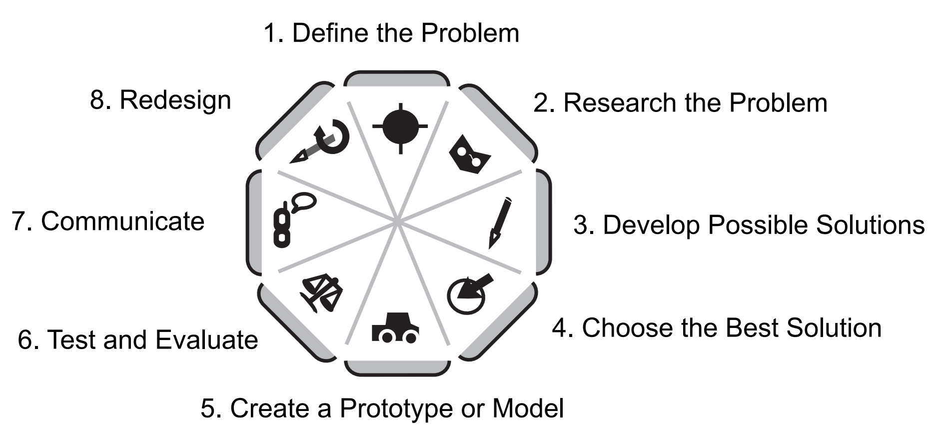
5) Carry out your plan on schedule, documenting procedure and results as you go.

6) Prepare for presentation of your conclusions and results.

There are seven behaviors that should be displayed by members of a team. They are the following:

Helping, offering assistance to others.	**Questioning,** interacting, discussing, and posing questions to all members of the team.
Listening, working from each others' ideas.	**Respecting,** encouraging and supporting the ideas and efforts of others.
Participating, contributing to the project.	**Sharing,** offering ideas, and reporting findings to each other.
Persuading, exchanging, defending, and rethinking ideas.	

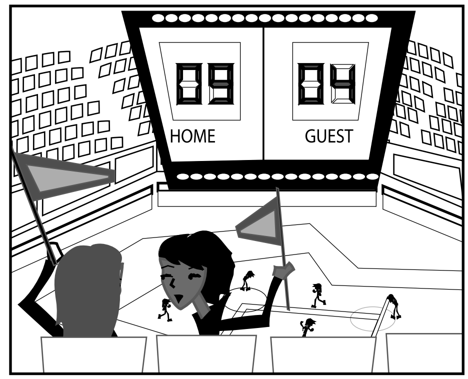
You will also need to keep in mind the eight steps of the Engineering Design Process.



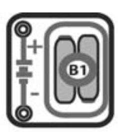
TASK 4.1 Create a Scoreboard Code

- Identify electrical components.
- Construct circuits and read schematic diagrams.
- Test insulators and conductors.
- Encode, decode, transmit, and receive signals.

Operating a scoreboard is easy. You just push buttons to display the score. However, each time you press a button you set off a complex series of events that opens and closes circuits in order to display the correct number. In Task 4.1 you will devise a code for displaying the numbers 0–9. First, however, you'll need to find out about simple circuits and schematic diagrams.



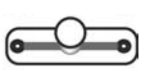
Explore Electrical Components



Battery holder with batteries

Slide switch

3-snap wire

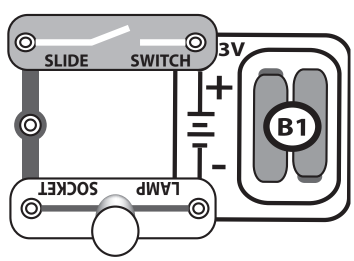


Light bulb in socket

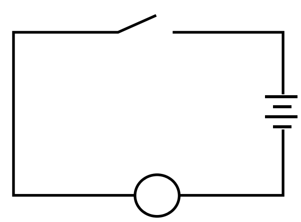
The actual components in your kit may look a little different from the representations shown here.

1) Find the following components in your electricity kit.

2) Build this circuit by snapping the parts together. Notice how the markings on the electrical components are similar to the diagram below.



Snap Circuits™ diagram



Schematic diagram

3) If you have not done so, twist a light bulb into the socket. Slide the switch and turn the circuit on. If the bulb does not light, troubleshoot the system.

Troubleshooting: Finding the reason why something doesn't work, and fixing it.

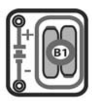
What's the Function?

At the bottom of the previous page, the diagram on the left shows the arrangement of **Snap Circuits™ parts** as they should be assembled. The diagram on the right is known as a **schematic diagram**.

> **Schematic diagram:** A simple diagram of how to construct an **electrical circuit.** Each component has a different **schematic symbol.** Lines between components show the path of electricity but not necessarily the physical arrangement of the components.

Examine Your Circuit

What do you think is the function of each of the components in the circuit you just assembled? Discuss it with your partner, and write what you think that component does in the circuit:

 **1)** Battery holder with batteries	
 **2)** Slide switch	
 **3)** 3-snap wire	
 **4)** Light bulb in socket	

Examine Your Circuit

Your kit has lots of different components. Their functions include

↓ **Input device:** A device that allows a circuit to sense a change in the physical world, like a switch or light resistor.

↑ **Output device:** A device that allows a circuit to create a change in the physical world, like a motor or a light bulb.

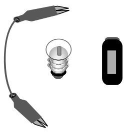
↔ **Controller:** Controls flow of electricity in a circuit, like a switch, relay, diode, or variable resistor.

Energy source: Provides energy to the circuit.

Connector: Provides a continuous conductivity path between components.

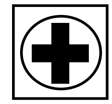
Initial ______________ Date ___________

Make a Bulb Light with a Wire



Light a bulb using only one wire and a single AA battery cell.
Do NOT use a bulb socket or battery holder to accomplish this.

- Try different arrangements, continuing until you find four different ways to light the bulb.
- In the left column, sketch each physical arrangement that works.
- In the right column, draw a schematic diagram of each arrangement that works.



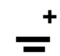
Burn Danger:

Do not connect the two ends of the battery directly. Only connect through the light bulb.

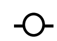
Sketch Arrangements

Draw Schematics

Schematic Drawing Hints

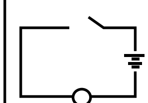


Represents a single battery cell with the longer line at the positive (+) end.



Is used when current can flow through a bulb and cause it to light.

Represents connector and may be long or short.



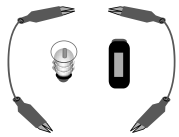
Schematic drawing with two battery cells, a switch, and a bulb.

1) What do you notice about the schematic diagrams of the arrangements that worked? Write your ideas below.

2) Discuss your answer with other ETF teams. Compare your arrangement sketches. Ask questions if you do not fully understand how to light the bulb. Below, write what you have to do to light the bulb.

Name ______________________________

Make a Bulb Light with Two Wires



Now light a bulb using two wires and a single AA battery.

Make a drawing and a schematic diagram of two arrangements that light the bulb.

Sketch	Schematic Diagram
1)	
2)	

How do the **schematic diagrams** you drew for the single-wire arrangements compare with the schematic diagram for the two-wire arrangement? How are they the same? How are they different? What does this tell you about how to build circuits from schematic diagrams?

Hint: Recall that schematics show the continuous path of electricity through a circuit, not necessarily the physical arrangements of components.

Conductors and Insulators

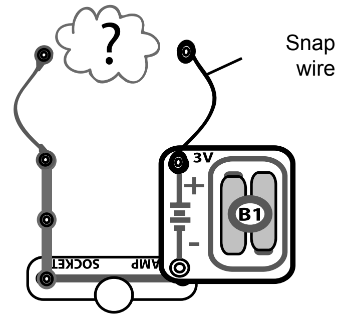
Different materials respond differently when subjected to heat or electricity. Engineers can use these properties when designing different devices and systems. Look at the definitions of thermal and electrical properties below. For each different property, give an example of a material and how it can be used. The first one is done for you.

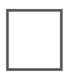
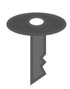
Thermal conductors allow heat energy to flow through them easily. **Example:** *Aluminum* **Use:** *Pots for cooking*	**Electrical conductors** allow electrical energy to flow through them easily. **Example:** **Use:**
Thermal insulators resist the flow of heat energy. **Example:** **Use:**	**Electrical insulators** resist the flow of electrical energy. **Example:** **Use:**

Initial ____________ Date __________

Electrical Conductors and Insulators

Build this circuit to see which materials are electrical conductors and which are insulators. Use two snap wires as test probes. If the bulb lights, the test object can be classified as a conductor; if the bulb doesn't light, the test object can be classified as an insulator. Predict whether an object will allow the bulb to light before testing it. Feel free to test other objects around you and record your observations.



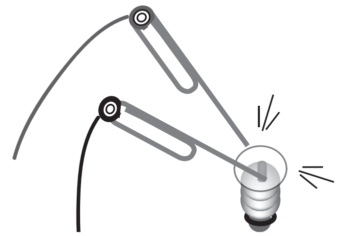
Test object	Prediction (insulator or conductor)	Observation (Did it light?)	Classification (insulator or conductor)
 **This paper**			
 **Your skin**			
 **Coins**			
 **Air**			
 **Paper clips (silver)**			
 **Clothing**			
 **Pencil lead**			
 **Key**			
Other (you choose)			

Examine the list of electrical conductors. What do they have in common?

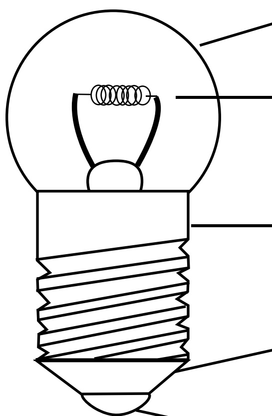
Examine the list of electrical insulators. What do they have in common?

Light Bulb Parts

To test individual parts of components, the snap wires themselves are too blunt. You can partially open two metal paper clips and touch them to the two snap wires to function as finer-tip probes for smaller areas. The picture shows the glass of another light bulb being tested.



Write "Conductor" or **"Insulator"** on the line for each part. (Take your best guess about the filament as you won't be able to test it directly.)



Glass bulb ____________________

Filament ____________________

Screw contact ____________________

Black base ____________________

Metallic tip ____________________

What Is a Circuit?

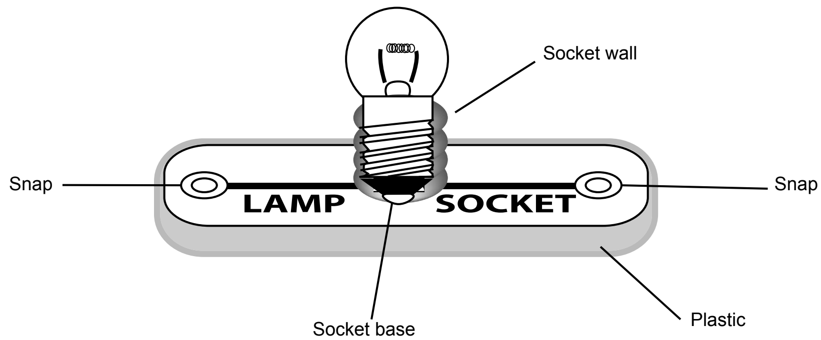
You have seen that a conducting path is necessary for the bulb to light, and that any break in that path causes the bulb to go out.

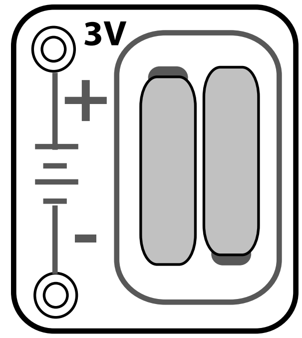
Circuit: A closed-loop continuous conducting path. From Latin, meaning "to go around."

- If a circuit has a break in it, it is an "open circuit."
- "Closing" a switch turns a circuit on, and "opening" that switch turns the circuit off.
- In a closed circuit all components have a continuous conducting path through them.

Initial ____________ Date ____________

Examine the lamp socket and battery holder closely, noting what appear to be insulators and conducting paths. Use the test circuit if you're unsure. Use a colored pencil to draw lines on the diagram below to show how you would connect them to make a continuous conducting path through each of the components to make a closed circuit that would turn on the light bulb.





How could you use a bulb in a socket, or batteries in a holder, as a switch?

Benchmark

1) In your own words, what is a circuit?

2) What is the difference between an electrical insulator and electrical conductor?

3) Although you cannot see inside the base of a light bulb, you can figure out what must be inside. Describe what the base of a light bulb would look like if you could see inside.

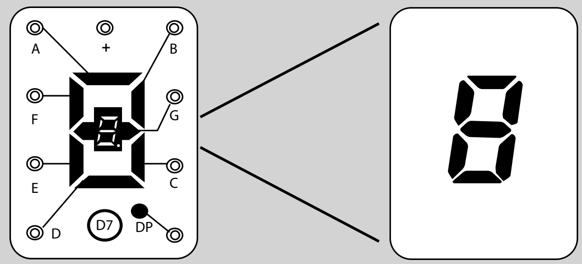
4) In your classroom, the electrical circuits are probably hidden in the walls. However, certain components of the circuits are visible. Name all of the components you can see and describe where they are in the room.

DESIGN CHALLENGE

Create a Digital Code

You might have a clock or a calculator that has a display like the one shown here. It is known as a “seven-segment display”; each number is made up of eight LEDs—seven for the segments, and one for the decimal point. The idea is simple: By turning on certain combinations of LEDs, letters and numbers can be displayed. The same kind of display is often used for scoreboards.

What are LEDs? The letters *LED* stand for “Light Emitting Diode.” They are used in many electronic devices, including alarm clocks, watches, stop lights, and so on. If an electric current passes through them, they light up; if there is no current, they do not light up.



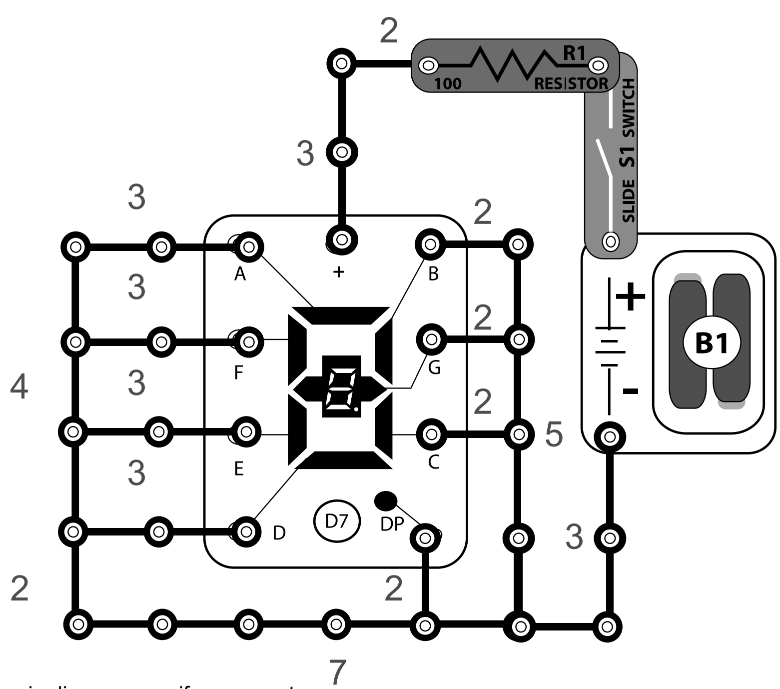
1) Shown here is a circuit for controlling the LEDs. What number is being displayed? Build the circuit to find out.

2) What happens if the connection to point G is removed? What number is displayed now?

3) Which point must be connected if any LEDs are to light up?

4) Will the circuit light any LEDs if the + and − connections to the battery holder are reversed? (Disconnect the battery and use snap wires to reverse the + and − connections to the circuit.)

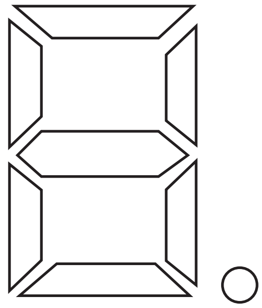
5) Although you cannot see inside the plastic, you can figure out where the wires inside must go, given what you learned about circuits. On the diagram below, use a colored marker to draw the path of the entire circuit in which just LED A (top LED) is connected.



Numbers in diagram specify snap part.

Initial ____________ Date ____________

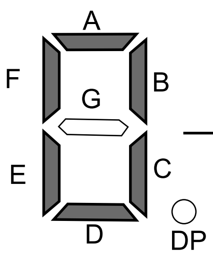
When the person operating the score board pushes a button for a certain number, it activates a code that consists of just ones and zeros built into the controller. A “1” means to turn the LED on, and a “0” means to turn it off. This is called a binary code sequence.



6) For the display as shown in question 1, the sequence would be 11111111, for the connectors A–G plus the decimal point (DP). If the decimal point is not on, the code would be 11111110. What would the code be if the number displayed were a 0?

____

7) Fill in the following binary code sequences to show how to display the digits 0, 1, 2, 3, 4, 5, 6, 7, 8, and 9.



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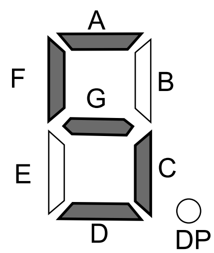

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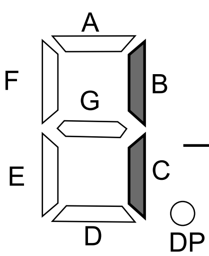

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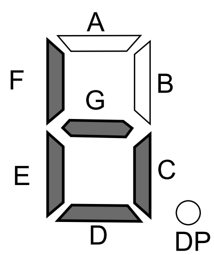

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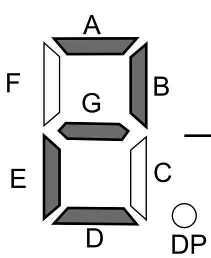

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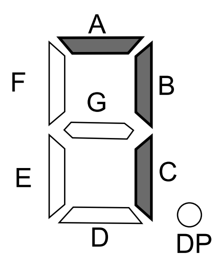

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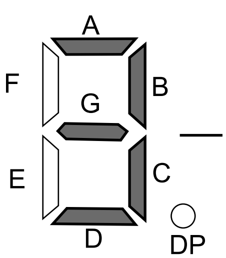

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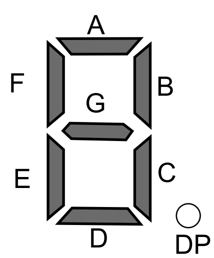

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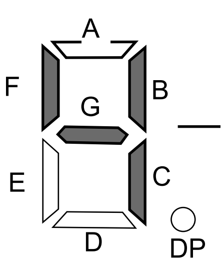

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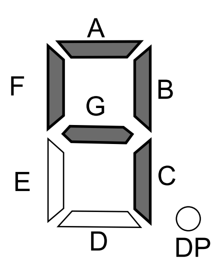

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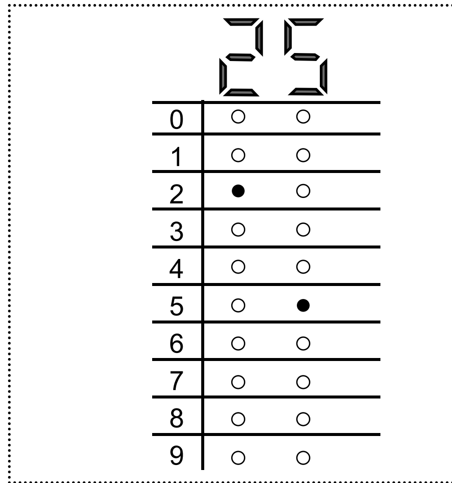
Communication Systems

A scoreboard is a communications device. The operator observes that a team has scored and wishes to communicate that information in an instant to thousands of fans. Suppose, for example, that the new score is 25. To light up "25" on the scoreboard, the operator pushes two buttons that encode the information. The information is now represented as a pattern of on-and-off electrical circuits, which is transmitted through wires. The pattern is called a **signal.** The scoreboard receives the coded information and decodes it by lighting up certain lights that make an easily understood message—the number twenty-five! How it looks as a diagram is shown to the right.



Control Booth

Encode
The operator hears that the new score is 25 and pushes two buttons, which turns 2 and 5 into a series of on-and-off electrical circuits.

Transmit
The information is transmitted in the form of code over a distance through wires.

Signal →

Scoreboard

Receive
The scoreboard is wired so that it senses the pattern of on-and-off electrical circuits.

Decode
The scoreboard transforms the on-and-off pattern into a series of lights that displays the number 25, and the fans roar with excitement.

In the space below, describe a communications device that you use frequently, using the terms "encode," "transmit," "receive," and "decode."

Encoding/Transmitting Device

Signal →

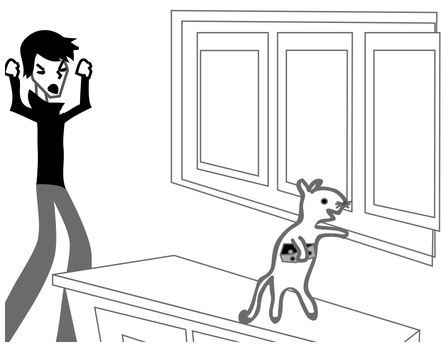
Receiving/Decoding Device

Read Chapter 24, "A Highway for Ideas," in the textbook *Engineering the Future* about the creation of the Internet. Use notebook paper to answer the questions at the end of the chapter. Sign, date, and number each page. Insert after this place in your *Engineer's Notebook.*

Initial ____________ Date ____________

TASK 4.2 Design a Mouse Detector

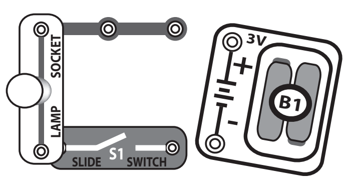
- Become familiar with Snap Circuits™.
- Use the Engineering Design Process.



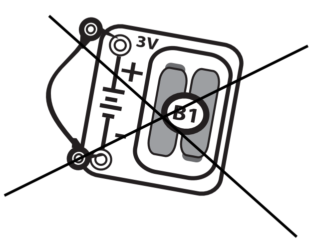
Employees at a company have reported seeing mice, but the exterminator came and said there was no evidence of them. Design a system that will be triggered by their activity. It should be inexpensive and reliable.

You will get a Snap Circuits™ kit with various types of circuit components that you can use to design and build a mouse detector. You will learn how to build and design circuits using this kit. There are many ways to do this, so there are many "right" answers. Before you start, there are a few rules you should know about.

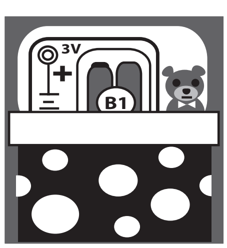
Rules to Follow



1. Disconnect the battery holder from the circuit when it's not in use to help the battery last longer. To do that easily, you could include an on/off switch in any **circuit** you build, and turn the circuit off when not in use.



2. Do not connect a wire to both ends of the battery holder, as in this diagram, because this greatly reduces the battery's life and can cause the exposed parts to get hot.

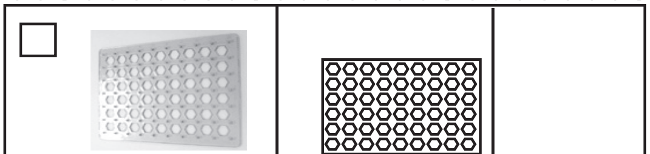


3. Take care of the parts in the kit and be sure to put them all back when finished. Anything you break or lose has to be replaced, and that takes time and money.

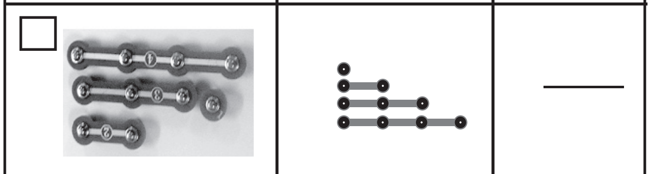
Name ______________________________

Snap Circuit™ Parts

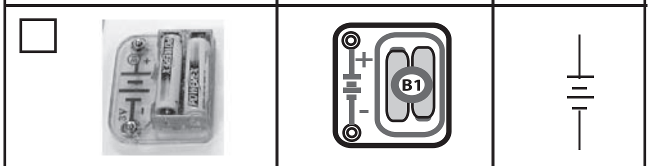
Photo | Illustration | Schematic



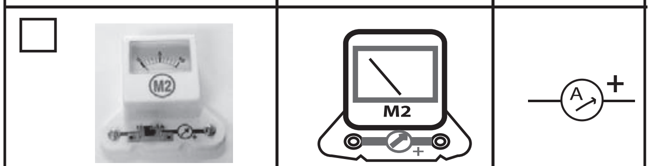
☐ Base grid



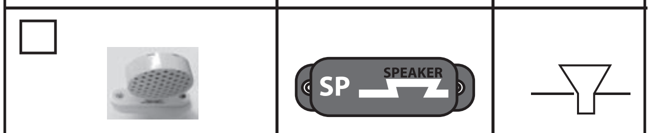
☐ Snap wires



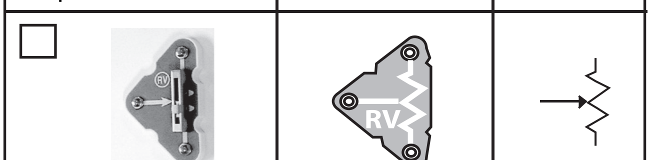
☐ Battery pack



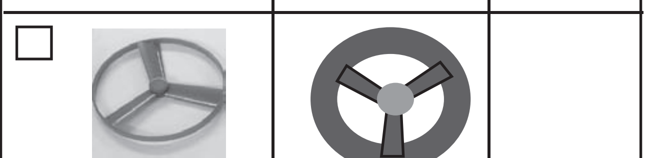
☐ Ammeter



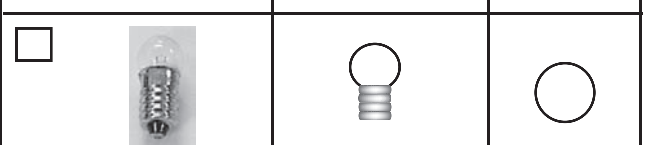
☐ Speaker



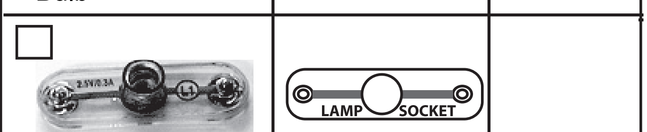
☐ Variable resistor



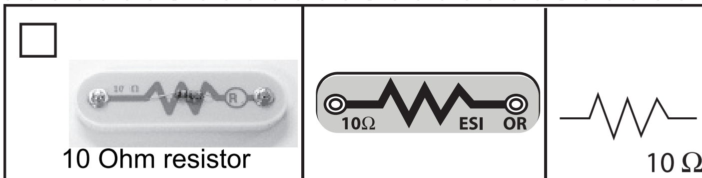
☐ Fan



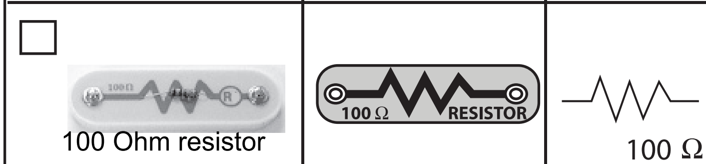
☐ Bulb



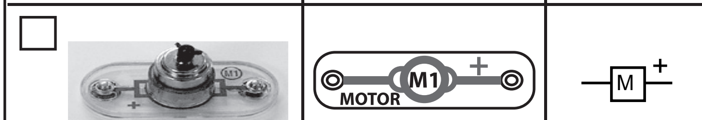
☐ Sockets



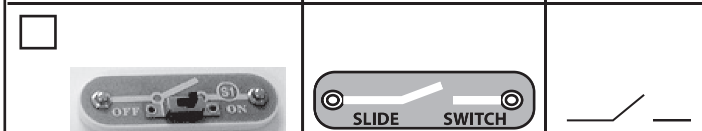
☐ 10 Ohm resistor



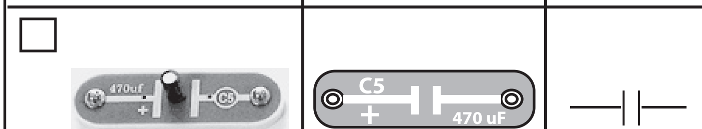
☐ 100 Ohm resistor



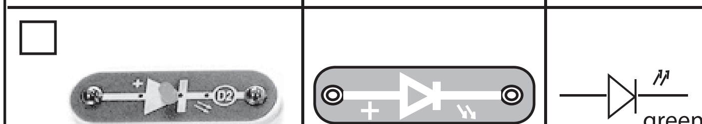
☐ Motor



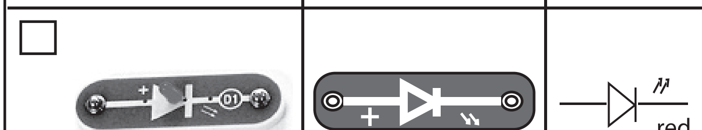
☐ Slide switch



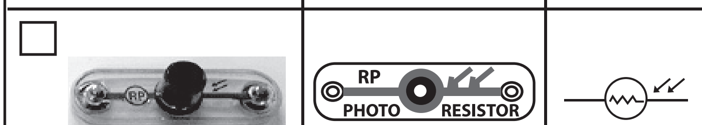
☐ 470 uf capacitor



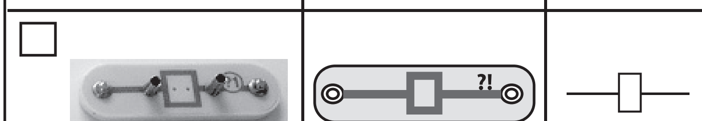
☐ Green LED



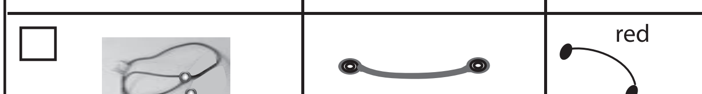
☐ Red LED



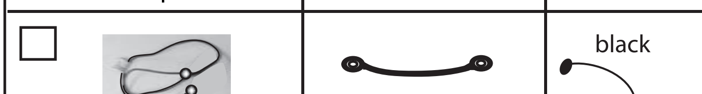
☐ Photoresistor



☐ 2 spring socket



☐ Red snap wire



☐ Black snap wire

Initial ______________ Date ____________

Explore Snap Circuit™ Components

Fill in the table below by testing the components in the circuit you made. It is best that you make just one change at a time so that you can observe how each component functions in the circuit. When filling in the first column, refer to the five functions listed previously (input, output, controller, energy source, or connector). For each component you should record the following:

- How it functions in the circuit? (Components may have more than one function.)
- How you might use it to accomplish some specific task?
- What happens when you reverse its connection to the circuit?
- Other observations, such as comparisons with similar devices, or combinations with other components that provide interesting results.

Component	Function	Specific use	Reversed?	Other observations
Press switch	Example: controller and input	temporarily on (only when button is pressed)	same	takes more than a mouse footstep to activate
Slide switch				
Motor				
Bulb				
Speaker				
Ammeter				
Green LED & resistor (100 Ohm)				must be used with a 100 Ω resistor
Red LED & resistor (100 Ohm)				must be used with a 100 Ω resistor
Photoresistor				
Red snap wire				
Black snap wire				
Batteries				

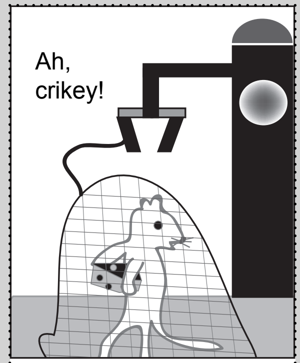
Initial _______________ Date ___________

Name ______________________________

DESIGN CHALLENGE

Design a Mouse Detector

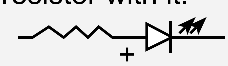
Your mouse detector circuit is going to be placed in strategic areas of a company's building, such as the basement, kitchen, or the boss's office. Think about how your Snap Circuit™ components can be rigged to detect movement, and how you could make use of food or other non-electrical items. Ask yourself, who will monitor the detector? Could someone who was blind or deaf monitor your detector? Follow the engineering design process listed below.



- **Define the problem.** List the criteria for success, and your constraints.
- **Research the problem.** How do similar devices, such as burglar alarms or door bells work?
- **Brainstorm ideas.** Sketch three or four different ideas for solving the problem.
- **Choose the best solution,** or combine the best parts of different ideas.
- **Create a prototype** using Snap Circuit™ components and non-electrical items.
- **Test and evaluate** the prototype to see how well it works.
- **Communicate** by writing a report showing how you followed each step of the engineering design process. Include a schematic diagram of your prototype.
- **Redesign.** Exchange drawings with another team and discuss the pros and cons of each solution. Add a paragraph and/or sketch to your report explaining how you might redesign your mouse detector to improve it.

CAUTION:

If you decide to use an LED, you MUST use the 100 Ohm resistor with it!



Rubric for Design a Mouse Detector

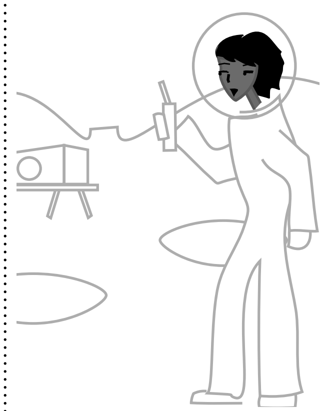
	⌖ ⌖ ⌖ ⌖	⌖ ⌖ ⌖	⌖ ⌖	⌖
Design Process	Clearly identifies thinking at each step.	Shows some thought at each step.	Few notes, sketches of steps followed.	No notes on steps followed.
Circuit Design	Innovative use of parts, thoughtful about potential use.	Good design chosen from several alternatives.	Simple design with no alternatives proposed.	No circuit designed.
Communication	Writing, drawings, and schematic diagrams are clear, comprehensive, accurate and easy to interpret.	Writing, drawings, and diagrams are adequate, but have some errors or omissions.	Writing, drawings, and diagrams are poorly done or incomplete.	Some attempt is made, but work is both poorly done and incomplete.

Initial ______________ Date ____________

TASK 4.3 Design a Communications System

- Explain the difference between an analog and digital signal.
- Recognize how radios receive AM and FM analog signals.

In 2006 NASA was given the task of establishing a permanent base on the moon. NASA engineers have since been busy designing every aspect of the moon base, including a system that will enable future moon residents to communicate with each other, with explorers in vehicles and on foot over the entire lunar surface, and with family and friends on Earth. Your task is to recommend the kinds of communications systems that will be needed for these various purposes. First you'll need to learn more about signals and how they get from one place to another.



What's a Signal?

Recall the sequence of communication involved in displaying numbers on a scoreboard. These steps are involved in communicating any message. Task 4.1 emphasized the process of encoding and decoding the message. This task focuses on the kind of signal you choose to carry the message. In each case, what form is the signal?

Encode → **Transmit** → **Signal** → **Receive** → **Decode**

1) When a scoreboard operator encodes and sends information to the scoreboard, the signal is in the form of...

2) When a mouse triggers a mouse detector, the device encodes the information. A signal is sent to the operator in the form of....

3) When two people are standing a few feet from each other, and one person says something to the other, the message is encoded by the person's voicebox in the form of vibrations. A signal is then sent to the other person in the form of....

Signal: A pattern of physical changes that carries a message. Note that it is not the message itself. If "hello" is the message, the vibrating air pressure pattern is the signal.

Encode: Convert a message into another representation.

Decode: Interpret coded information so the message can be "understood" and used.

Analog and Digital

There are two kinds of signals—analog and digital.

Digital signals carry information in the form of numbers. Digital signals carry information in two states, often on or off. Computers communicate using the binary system of numbers (0 and 1), where 0 is off and 1 is on. The communications code you developed for the scoreboard in Task 4.1 was transmitted as a digital signal.

Analog signals carry information in the form of a continuously (smoothly) changing pattern. Analog signals can be carried by sound, electrical current, fluid waves, and radio waves. A human voice is a good example of an analog signal.

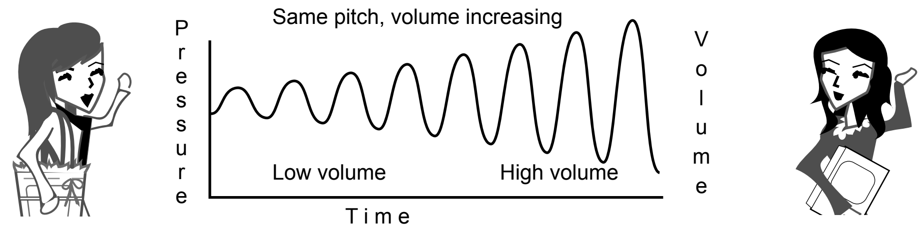
Analog Signals

Start with a very simple situation—a friend says "Hello!" To see how the sound is produced, place your fingers gently on the front of your throat and feel the vibration as you say "Hello." These vibrations cause pressure waves in the air that are shaped by your tongue as you speak. The pressure waves then spread out in all directions like ripples in a pond.

Your ears can detect sound pressure changes of less than one billionth of normal air pressure. If you could see the pressure waves in the air, you'd see that sounds vary in two ways: amplitude and frequency. Amplitude is how loud the waves are, and frequency is how high or low the sounds are. This is also called "pitch." If you could make a graph of the sound, it might look something like this:

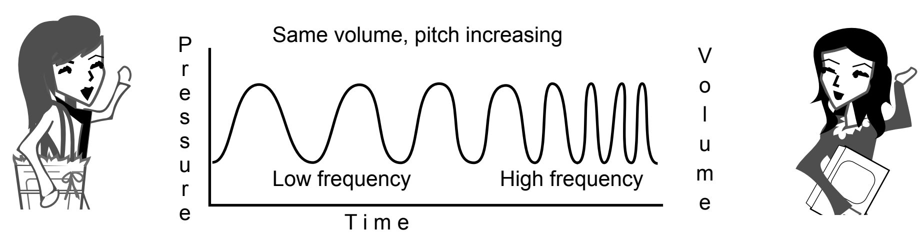
Change in Amplitude

The louder the sound, the greater or higher the height or amplitude of the waves. Her volume is increasing.



Change in Frequency

Now she starts on a low note and ends on a high note. The pitch is getting higher.



Read Chapter 25, "Teaching a Machine to Listen," in the textbook *Engineering the Future.* Sol Lerner explains how engineers are working to make computers recognize human speech. Read the chapter, then answer the questions at the end of the chapter on notebook paper. Don't forget to sign, date, and number each page. Insert the pages at this point in your *Engineer's Notebook.*

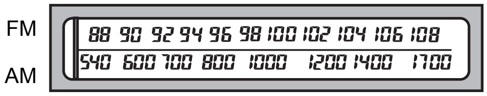
What Do AM and FM Mean?

Most AM-FM radios receive analog signals. What do AM and FM mean?

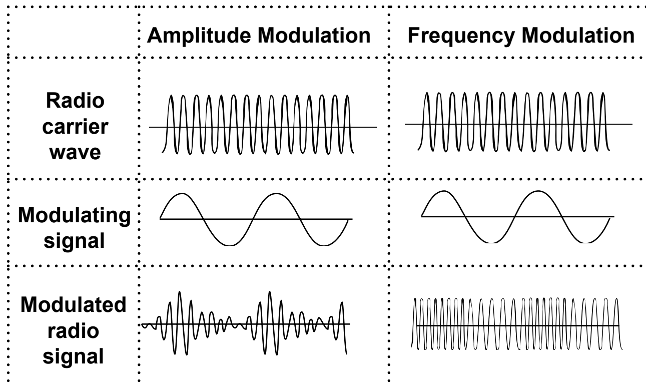
AM stands for “amplitude modulation.”
FM stands for “frequency modulation.”

Modulate means to “change” or “vary.” So to create an AM radio signal, the message is encoded by changing the amplitude (loudness) of a radio transmission called the “carrier wave.” To create an FM signal, the message is encoded by changing the frequency (pitch) of a carrier wave.

AM: 530 –1710 kHz FM: 88.1 to 107.9 MHz

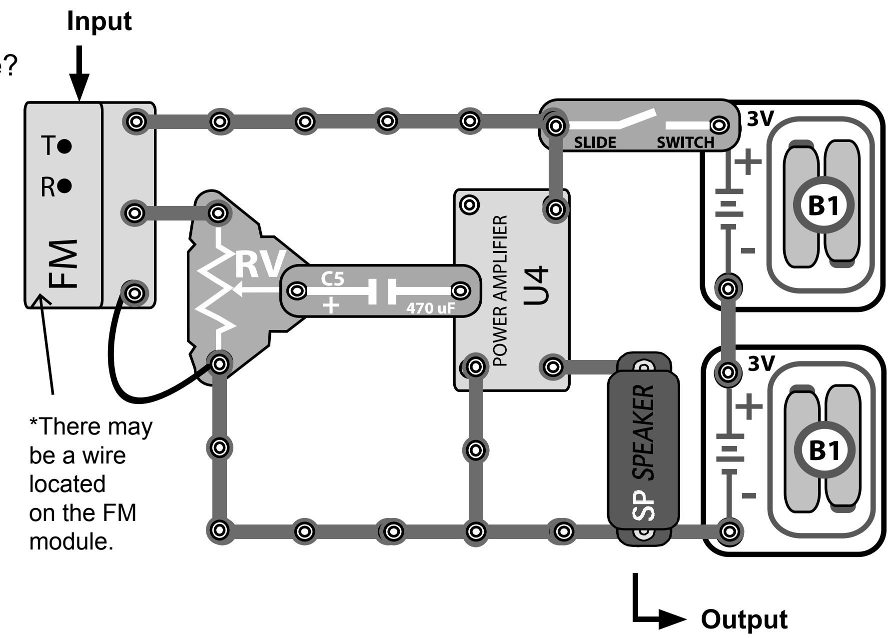


Different radio stations are assigned different frequencies for their carrier waves. When you tune your radio to an FM station, you are selecting the frequency of the carrier wave. Frequency is measured in cycles per second, also called “Hertz” after German physicist Heinrich Hertz.



Build an FM Radio Receiver

Build an FM radio receiver from Snap Circuit™ parts as shown in the diagram below. Two groups can work together. Your teacher will provide an FM transmitter and speaker.



1) How do you control the volume?

2) How do you change stations?

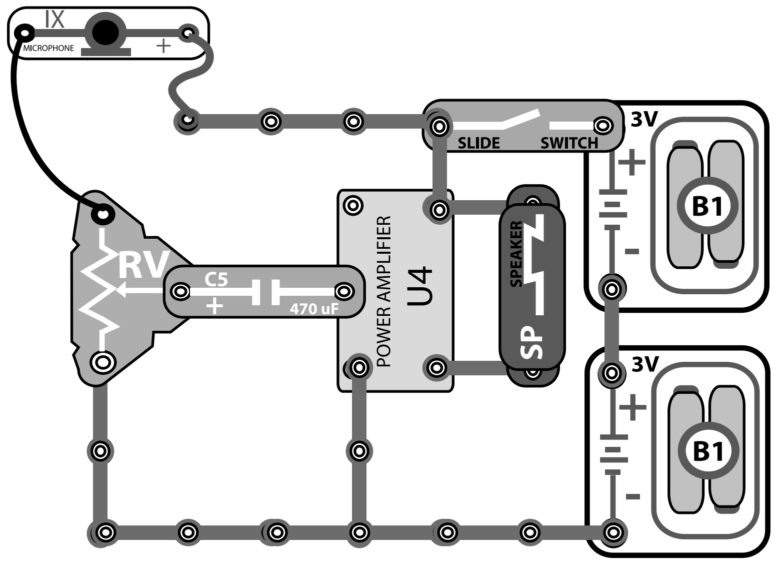
3) What does the wire attached to the FM module do?

4) Why is this called a “receiver”?

Build a Voice Amplifier

The radio receiver you built previously is really a radio receiver plus an amplifier. By changing the input device, you can amplify your own voice. You can use the same circuit that you used to build a radio receiver to build a voice amplifier. You only need to change the input device from an FM module to a microphone. Disconnect the FM module and connect the microphone provided by your teacher as shown below.

An **amplifier** is a device that adds energy to the signal.



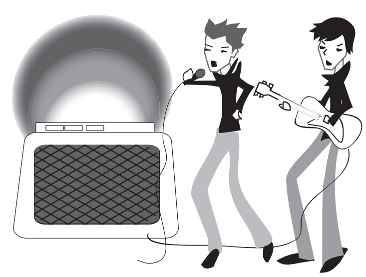
1) What happens when you speak into the microphone?

2) How do you control the volume?

Source: Produces a message to be communicated to the destination.

Destination: The person (or thing) for whom the message is intended.

3) What is the source of the signal?



4) What is the destination?

5) List some other situations when you have listened to sound that has been amplified.

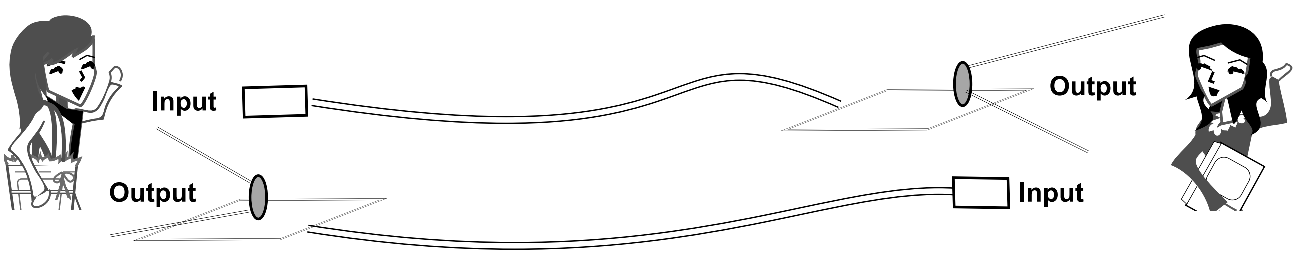
Initial ____________ Date ____________

How Does the Amplifier Circuit Work?

This is a complex circuit. There are several points where the current branches into smaller circuits, and there are some components, like the amplifier unit in your kit, that are enclosed so you cannot see what is inside. This is not unusual! Even electrical engineers sometimes use components that they do not fully understand. In the space below, list what you do understand about this circuit, and what you'd like to find out.

What I know about this circuit...	What I'd like to learn more about...

Collaborate with another team so that you'll have enough equipment. Build a telephone with two amplifiers and two long pairs of wires to attach the microphones.



1) What parts of this telephone correspond to parts of a telephone that you would buy?

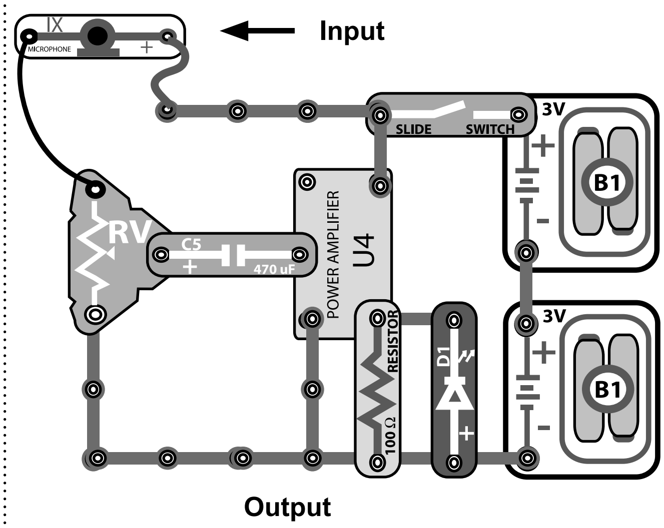
2) During a telephone conversation, what is happening when you are the source of a message?

3) What is happening when you are the destination of a message?

Communicate with Light

Replace the speaker in the previous circuit with an LED. Notice that you also have to snap a 100-Ohm (100 Ω) resistor in parallel with the LED.

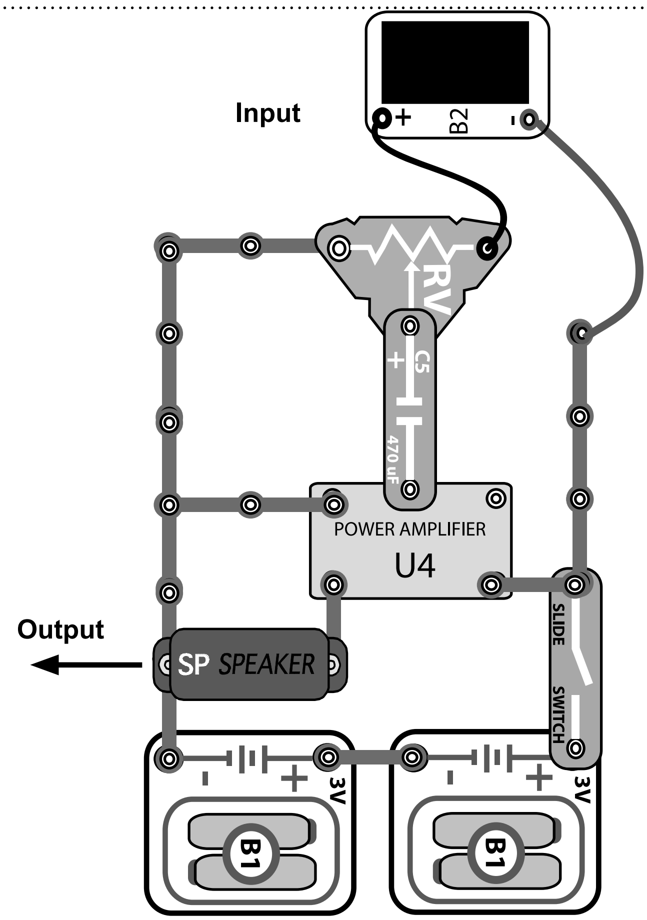
1) What happens to the LED when you speak into the microphone?



2) How does the output change if you adjust the volume control as you did when you used a speaker as an output device?

Collaborate with another group so that you'll have two amplifier circuits. Leave one of the amplifiers as shown above. On the other circuit, replace the microphone with the solar cell module and use a speaker as an output device.

Place the solar cell of this second system, provided by your teacher, about one inch above the LED from the first system. You may need to shield the solar cell from interference by overhead fluorescent lights. Adjust the variable resistor as needed to get the best output for both devices.



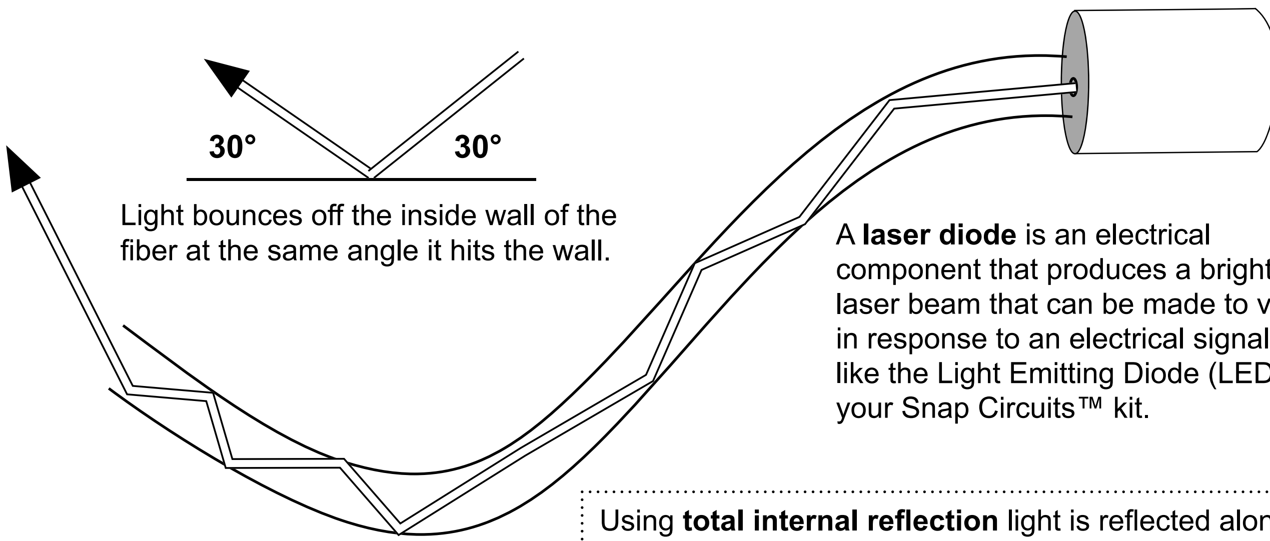
3) What happens when you speak into the microphone of the first system?

4) Describe the ways sound energy is transferred from the time it leaves the mouth of the person speaking in the microphone to the time it reaches the ears of the person listening to the speaker.

Fiber Optics

As you could see in the previous activity, either electricity or light can be used to carry signals. However, electrical signals traveling through wires next to each other may interfere with each other, causing static. As more and more telephones and computers have been added to communication systems, this problem has become much more important. That is why fiber optic cables have begun to replace copper cables. Fiber-optic cables placed between the transmitter and receiver allow the light signal to travel for hundreds of miles, even turning corners.

Fiber optics *(optical fibers)* are long, flexible strands of very clear glass about the diameter of a human hair. Fiber optics are bundled into optical cables. After a light beam enters an optical fiber, it is transmitted using total internal reflection. As the light travels in the optical fiber, if it strikes the inside wall of the fiber, the light is reflected and continues to travel down the fiber until it reaches the end. Below is an enlarged image of an optical fiber.



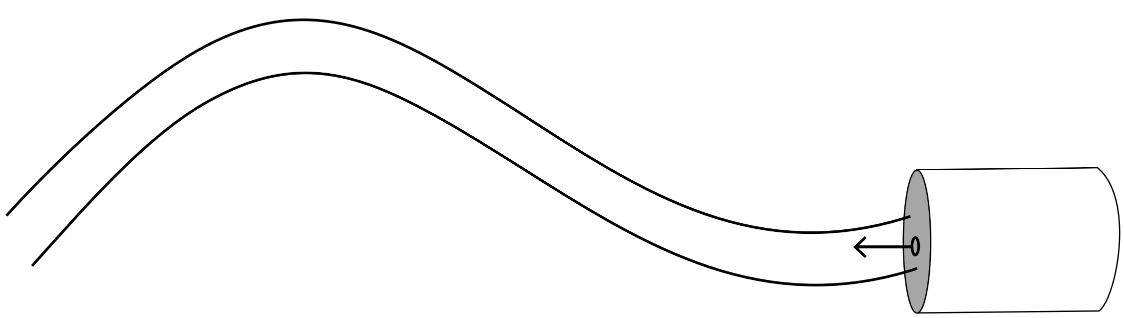
Light bounces off the inside wall of the fiber at the same angle it hits the wall.

A **laser diode** is an electrical component that produces a bright laser beam that can be made to vary in response to an electrical signal, like the Light Emitting Diode (LED) in your Snap Circuits™ kit.

Cladding is a plastic coating that covers the glass fibers to ensure 100% of the light is reflected back into the cable.

Using **total internal reflection** light is reflected along the optical fiber. In order for the light to be reflected entirely, the light must hit at an angle that is greater than the **critical angle.**

1) In the enlarged drawing of the optical fiber shown below, draw the path of a beam of light from the time it leaves the laser diode to the time it emerges from the other end of the fiber.



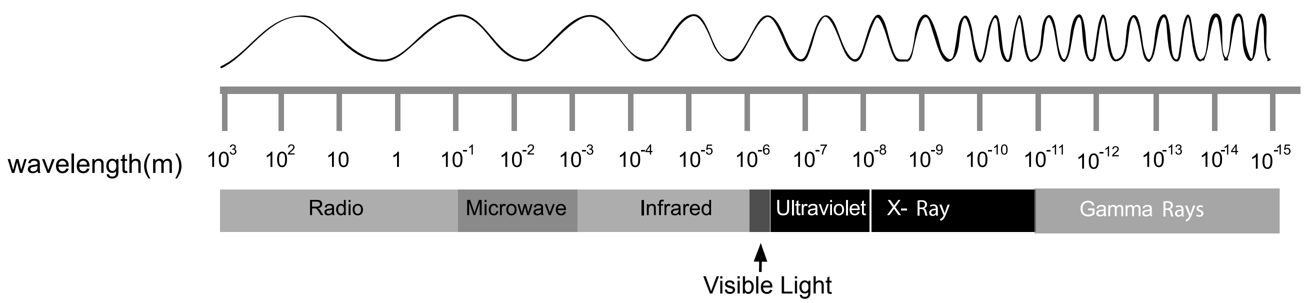
Read Chapter 26, "Shedding Light on Communications," in the textbook *Engineering the Future.* Nannette Haliburton describes how she uses fiber optics in her work. Read the chapter, then answer the questions at the end of the chapter on notebook paper. Don't forget to sign, date, and number each page. Insert the pages at this point in your *Engineer's Notebook.*

A Look at Remote Controls

When you press the “power” button on a remote control to turn on a TV, the device encodes your message (“on”) as a series of pulses of infrared light. The signal is decoded by the TV, which then responds to your command.

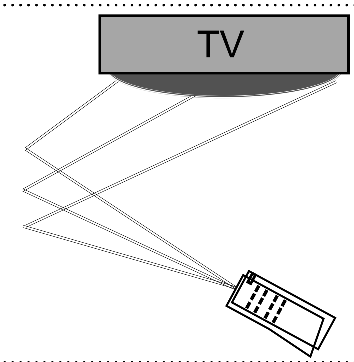
What is infrared light? Light can be thought of as a wave traveling through space. The distance between wave crests is the wavelength. Infrared light has a slightly longer wavelength than visible light. Microwaves and radio waves are also the same kind of waves, but with even longer wavelengths.

Ultraviolet waves, X-rays, and gamma rays are light waves with wavelengths that are shorter than visible light.

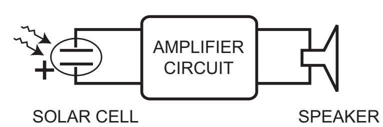


The entire range of wavelengths is called **the Electromagnetic Spectrum.**

1) **Reflect Infrared Light.** Like most kinds of light, infrared can be reflected. Try controlling a television by reflecting the light from the remote-control device off walls and ceilings. Describe what happens.



2) **Amplify the signal.** Use the amplifier circuit with the solar cell and speaker. Point the remote-control device at the solar cell and listen as the signal is decoded and transmitted as sound. Listen for the separate “beeps.” What are these “beeps”? Look at the next page to find out.

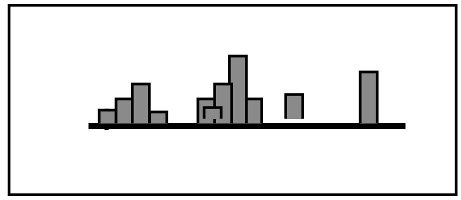


Read Chapter 27, “Riding the Waves,” in the textbook *Engineering the Future* to find out why Alex Hills needs to understand the electromagnetic spectrum in order to help people living in remote regions of Alaska communicate with each other. Read the chapter, then answer the questions at the end of the chapter on notebook paper. Don’t forget to sign, date, and number each page. Insert the pages at this point in your *Engineer’s Notebook.*

Initial ___ Date ___

Digital Signals

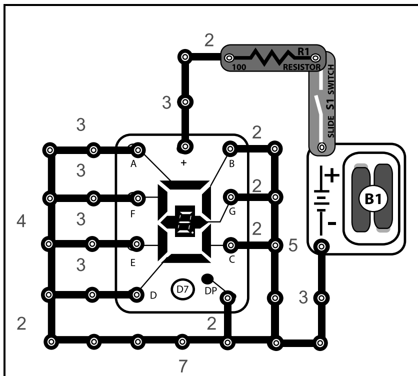
A remote-control device produces a digital light signal. Instead of changing smoothly like an analog signal, a digital signal changes abruptly between a fixed number of values. The signal is referred to as “digital” because you can assign a number to every value the signal takes.



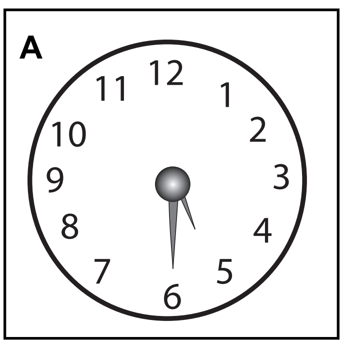
Why is the world “going digital”? Analog electrical signals are sensitive to interference from nearby electrical activity. That’s why analog TVs sometimes display “noisy” pictures, with static and distortion. Digital signals, on the other hand, are clear and sharp because the signal is in the form of a number. If there is a lot of inference, the signal does not get through at all; but if it is received, then it is decoded perfectly.

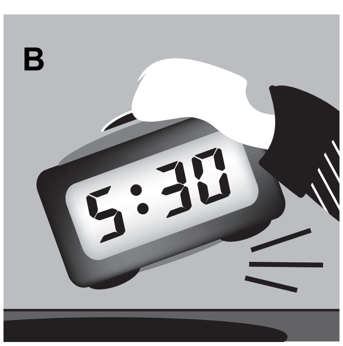
Digital signals carry information in the form of a discrete, limited set of elements. The binary system (0 and 1) used to communicate with computers is a base-two system of two elements.

An example of a digital communications system is the scoreboard in the first activity. The code indicates which circuits should be “on” and which should be “off.” This particular digital code is called “binary” code because it uses just two states. Computers communicate with binary code.



Numbers in diagram specify snap part.

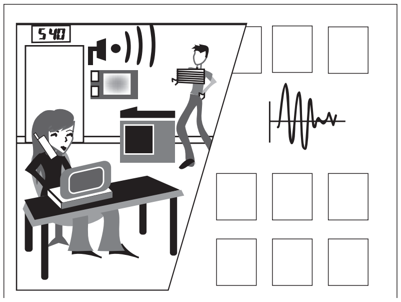




1) These two devices provide the same information, but one communicates with analog signals and the other with digital signals. What are the advantages and disadvantages of each?

2) What do you think the “beeps” are that come from the remote-control device? (See the previous page.)

DESIGN CHALLENGE



At the introduction of Task 4.3, you learned that NASA's next major mission is to establish a permanent base on the moon. Your challenge is to devise a communications system that will allow people to communicate within the base, to explorers on the moon outside the base, and to mission control on Earth.

- **Define the problem.** How many different communications systems are needed? List the criteria for success, as well as the constraints.
- **Research the problem.** How do NASA engineers communicate with spacecraft? What kinds of signals can travel without air?
- **Develop possible solutions.** Sketch three or four different ideas for solving the problem.
- **Choose the best solution,** or combine the best parts of different ideas.
- **Create a prototype.** Sketch your ideas. Make a drawing or diagram to show the different components of your design.
- **Test and evaluate** the prototype. Compare your ideas with another group. Discuss improvements for each other's ideas.
- **Communicate** by writing a report showing how you followed each step of the engineering design process. Include a sketch and/or diagram of your final solution.
- **Redesign.** After presenting your idea and getting feedback, list ways that it can be improved.

Rubric for Design a Communications System

	✦✦✦✦	✦✦✦	✦✦	✦
Design Process	Clearly identifies thinking at each step.	Shows some thought at each step.	Few notes, sketches of steps followed.	No notes on steps followed.
System Design	System plan meets challenge and uses communications concepts.	Adequate design chosen from several alternatives. Will meet criteria and constraints.	Simple design with no alternatives proposed.	System design is unclear or does not address challenge.
Communication	Writing, drawings, and schematic diagrams are clear, comprehensive, accurate, and easy to interpret.	Writing, drawings, and diagrams are adequate, but have some errors or omissions.	Writing, drawings, and diagrams are poorly done or incomplete.	Some attempt is made but work is both poorly done and incomplete.

TASK 4.4 Explore Circuits with an Ammeter

- Use an ammeter to explore circuits.
- Investigate direction and flow in circuits.

In order to design electrical devices that will solve various problems and meet people's needs, it's important to understand what's going on inside a circuit. We can't directly see what is happening in the wires because we are "electricity blind." But Danish physicist Hans Christian Oersted made a major discovery while doing a demonstration for his students. He noticed that a closed circuit caused a nearby compass needle to move.

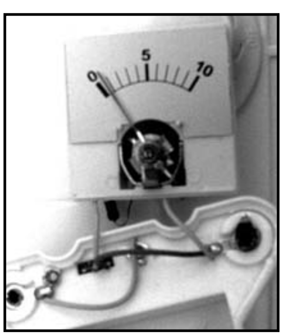
Hans Christian Oersted (1777–1851)

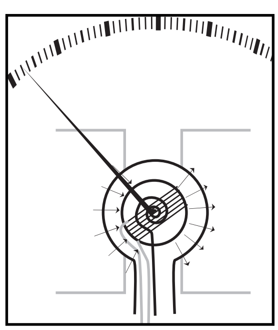
Andre Marie Ampere (1775–1836)

The Ammeter

A compass needle is a small magnet. The news that an electric current causes a magnet to move suggested that something was flowing through the wires. For now, this "something" will be called an electric current. By 1826 French physicist Andre-Marie Ampere had invented a device—now called an ammeter—to measure the direction and magnitude of the electric current in a circuit. Today the unit of electricity, the ampere, is named after him.

In an ammeter, a coil of wire with a needle attached is free to rotate near a fixed magnet. When the circuit is connected, current flows through the coil, creating a magnetic field. The coil and needle move away from the magnet. The stronger the electric current, the farther the needle moves. Two small pins limit the needle's rotation. The needle is "pinned" when it is pushing against either one of the pins. Here's how to avoid damaging the ammeter.

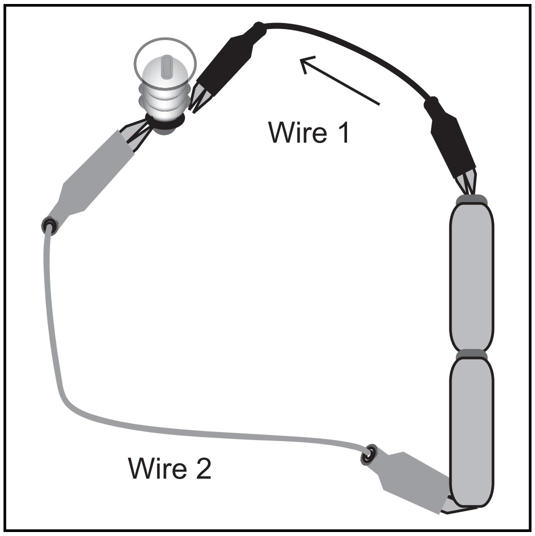




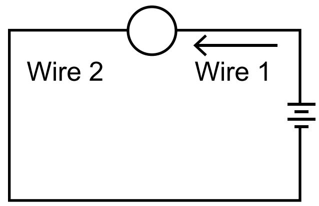
Clockwise Counter clockwise

- Always start with the ammeter at its high setting (0–1 A), connected to an open circuit.
- Momentarily close the circuit. If the needle swings and hits the far pin, try the low setting (0–0.3 mA or 0–300 µA).
- If the needle rotates counterclockwise (CCW), the ammeter is connected backward and the wires should be reversed.

Current in a Circuit



The arrow next to wire #1 in the circuit below shows the direction the electric current in that wire is flowing. What do you think is happening in wire #2? Without talking to your partner, write your answer to the following series of questions in the box next to each question. Don't worry if you are not too sure; this is just meant to help you know what you think about current



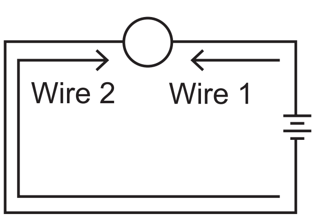
1) In wire #2, there is

A. an electric current flowing toward the bulb.
B. an electric current flowing away from the bulb.
C. no electric current flowing at all.

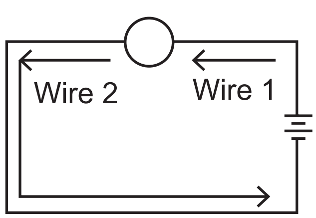
2) Compared to wire #1, wire #2 carries

A. more electric current.
B. the same amount of electric current.
C. no electric current at all.
D. some electric current, but less than wire #1.

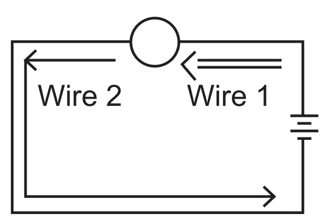
3) Which of these "mental models" about how current flows in the circuit do you think is correct? (Circle the best answer.)



A. Current flows from battery toward bulb.



B. Current flows in same direction and strength.



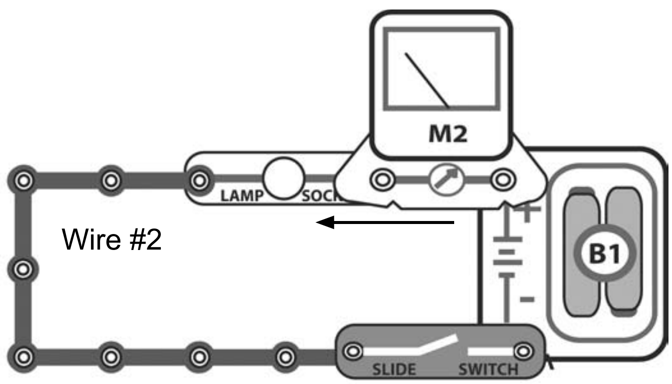
C. Current in wire 2 is less than in wire 1.

 Initial ____________ Date __________

Which Way Does the Current Flow?

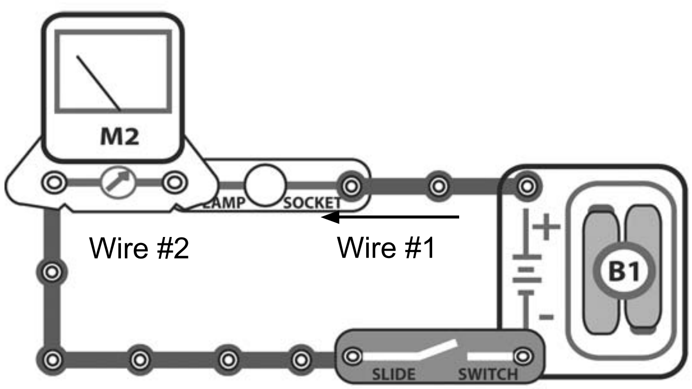
Build these circuits to test your answers to the questions on the previous page. Notice that the ammeter becomes part of the circuit. The + contact on the ammeter should always be connected closest to the + terminal of the battery and – contact to the – terminal. The direction of the current will be from the + side of the battery to the – side of the battery.

Take turns replacing each wire with an ammeter. Notice that the ammeter in the top diagram measures the magnitude of the current in wire #1, and that the ammeter in the bottom diagram measures the current in wire #2. In each case, start with the switch open (current off) and predict what will happen when the switch closes. Write predictions then close the switch and report the results.



1) Switch off: Predict the direction and magnitude of the needle deflection in wire #1.

2) Switch on: What does this result tell you about how the electric current moves in wire #1?



3) Switch off: Predict the directon and magnitude of the needle deflection in wire #2.

4) Switch on: What does this result tell you about how the electric current moves in wire #2?

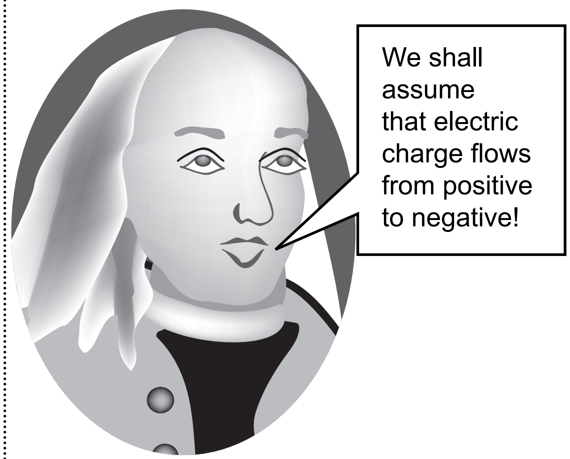
5) **Conclusion:** What does this tell you about the direction and magnitude of current in a circuit? (Hint: What is the correct answer to question 3 on the previous page?)

6) **In your opinion:** What is an electric current?

What Is an Electric Current?

An electric current transmits energy from one place to another—from a battery to a bulb, or from an electric power plant to all of the appliances in a house. But what carries electrical energy in the wires? Is it like water flowing through a hose? Or is it like particles of sand pouring down a slide? And which way does it flow?

One of the first people to develop a theory on electrical circuits was Benjamin Franklin. Franklin used the term "electric charge" for whatever it was that flowed through the wires in a circuit. He thought that electric charge flowed like a fluid, and he assumed that it flowed from the "positive" end of a battery to the "negative" end. Franklin's ideas were adopted for so long that even today, this model—that electric charge flows like a fluid from the positive to the negative end of a battery—is still used to design electric circuits.



Benjamin Franklin (1706–1790)

Today we know that electric charge is not a fluid. Electric charge is a property of invisibly small particles called **electrons.** These electrons move opposite to the way Franklin supposed—from negative to positive. However, because electrical engineers still use Franklin's "conventional flow" direction in actual design projects, in this course you will continue to assume (incorrectly!) that electric charge flows from positive to negative. Here are the important ideas to remember:

Electrical Energy: A property of matter that makes things happen by moving charge through a conductor.

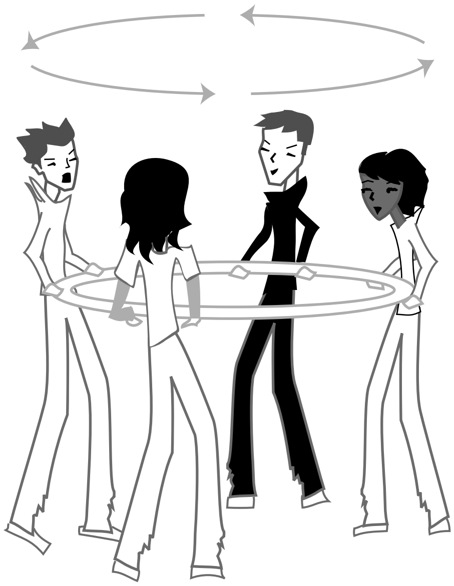
Charge: From a Latin word that means "vehicle." Charge is not energy—it carries the energy in a circuit.

Current: The flow of electrical charges through a circuit.

Conventional Flow Direction: An agreed-upon direction for charge flow, from the "positive" end of the battery toward the "negative" end.

Initial ___ Date ___

What's Happening Inside a Circuit?



A hula hoop makes a very good model for an electric circuit. Imagine a rigid hoop held by a group of students and a teacher. The teacher represents the "battery," and the hula hoop represents the wires or metal contacts in a circuit. The teacher has the energy to push the hoop in one direction—from positive to negative. The students let the hoop slide through their hands.

Imagine that the particles of charge are embedded in the plastic hoop.

Notice that when the teacher pushes the hoop, charge moves everywhere at once.

1) If the students holding the hoop represent light bulbs, which will light up first, the ones closest to the positive side of the "battery," or the "negative" side of the battery? Or will they all light up at the same time? Explain your answer.

2) No part of the hoop can move any faster than any other part of the hoop. What does that tell you about the direction and magnitude of the charge everywhere in the circuit?

3) Which statements are true and which are false? Be prepared to defend your answers.

A. A battery is the source of electric charge. __________

B. A battery is the source of energy that moves electric charge.__________

C. Lights in a circuit will go out when the electric charge is used up. _________

D. Lights in a circuit will go out when a battery runs out of energy._________

E. Electric charge is never used up—it is always present in all components of a circuit, even when the battery is dead. _________

How Much Is 1 Amp?

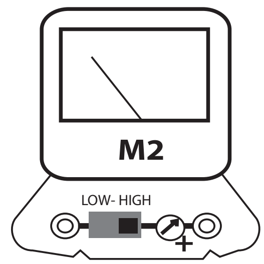
Amp is short for **Ampere,** the unit of electrical current.
The name "ammeter" is really a contraction of "amp meter."

If you were measuring a current of fluid such as air or water flowing through a tube, you'd be measuring the volume of air passing a given point in one second. So it might help to think of an amp as a certain volume of charge passing through a wire in a second. (But remember, it's only a model. Conductors are not hollow like pipes. Charge moves through the solid metal.)

Ampere → Amp

Ampere meter
Amp meter
→ Ammeter

At the HIGH setting of your ammeter's full-scale deflection is 1 amp, so each tic mark is 100 milliamps, or one-tenth of an amp (0.1 amp).



1) How much current flows through one light bulb when it is connected to two AA batteries? Build the circuit to find out and write the answer here. (Don't forget the decimal point!)

______ Amps

For very low currents, it is easier to use milliamps (mA).
1 amp (A) = 1,000 milliamps (mA)

At the LOW setting, your ammeter's full-scale deflection is 300 microamps, or 0.3 milliamps, so it is extremely sensitive to small currents. Each tic mark is 30 microamps, or 0.03 milliamps.

Types of Circuits

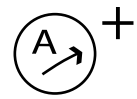
There are two major types of electrical circuits: series and parallel. As you'll see on the next page, whether bulbs are wired in series or parallel makes a big difference in how much electrical current runs through them, and therefore how bright the bulbs appear. It's important for you to learn the difference between these types of circuits.

Series Circuit: Components are in series if all the current that flows through one must flow through the others. There are no branches.

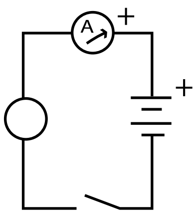
Parallel Circuit: Components are in parallel if the current branches on the way to the components then comes back together before returning to the battery.

Current and Brightness in Series and Parallel Circuits

Build the circuits shown on this page. Notice the symbol for the ammeter. Set the ammeter on HIGH. Before you turn on the switch, predict the current and how bright the bulbs will be in comparison with the simple circuit at the top. Write in your predictions, then turn on the switch to record your observations.



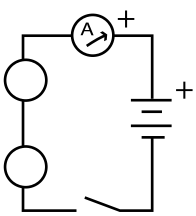
Predictions



Simple circuit

Current =

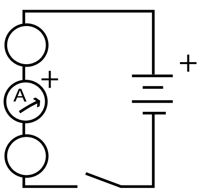
Brightness =



Series circuit

Current =

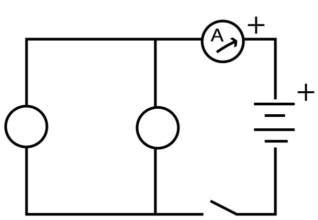
Brightness =



Series circuit

Current =

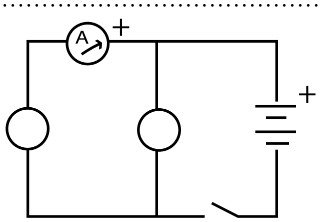
Brightness =



Parallel circuit

Current =

Brightness =

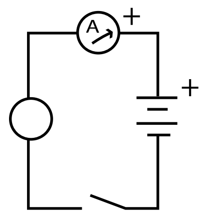


Parallel circuit

Current =

Brightness =

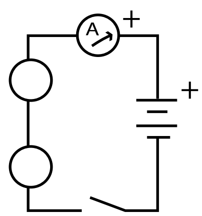
Observations



Simple circuit

Current =

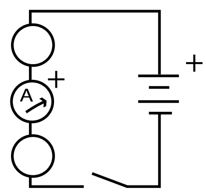
Brightness =



Series circuit

Current =

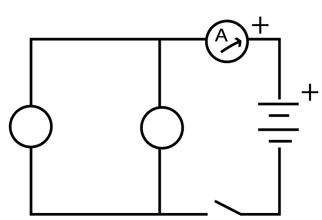
Brightness =



Series circuit

Current =

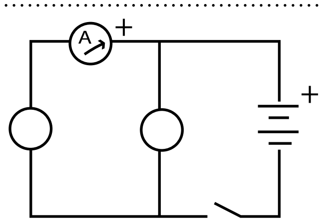
Brightness =



Parallel circuit

Current =

Brightness =



Parallel circuit

Current =

Brightness =

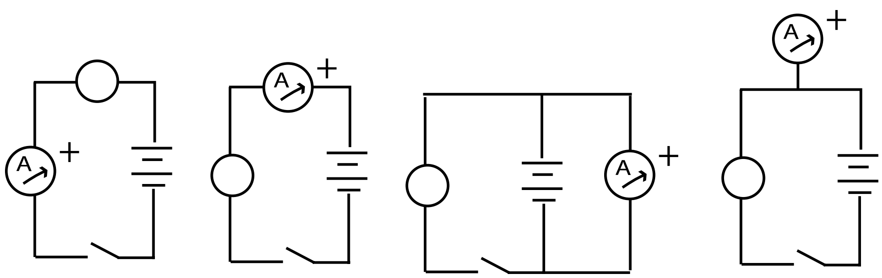
1) How does the current change when you add another bulb in a series circuit?

2) What happens to the current at the branch point in a parallel circuit?

Initial ______________ Date ___________

Benchmark

1) Circle the letter for each circuit that shows a correct way to connect an ammeter.

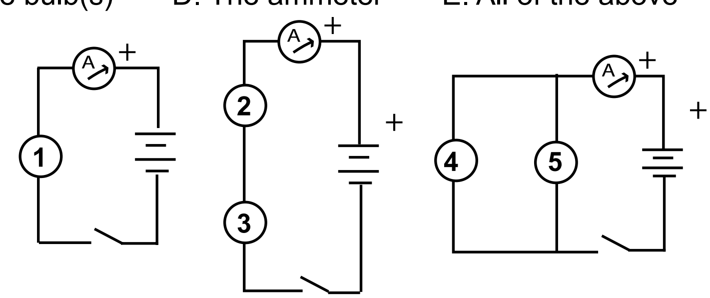


A. **B.** **C.** **D.**

2) An electric current is the flow of charges through a conductor. Where do these charges come from? (Circle the correct answer.)

A. The battery B. The wires C. The bulb(s) D. The ammeter E. All of the above

3) In the three circuits shown, the bulbs are all exactly the same. Which statements are true, and which are false? In each case explain why.



A. Bulb 1 is brighter than all the others. True or False? Explain.

B. Bulb 2 is brighter than bulb 3. True or False? Explain.

C. Bulb 4 is brighter than bulb 5. True or False? Explain.

D. Bulbs 2 and 3 are brighter than bulbs 4 and 5. True or False? Explain.

4) Some people like to think of a stream of water to help them remember what happens in series and parallel circuits. Explain how the stream idea represents what happens to the flow of charge (current) in these two kinds of circuits.

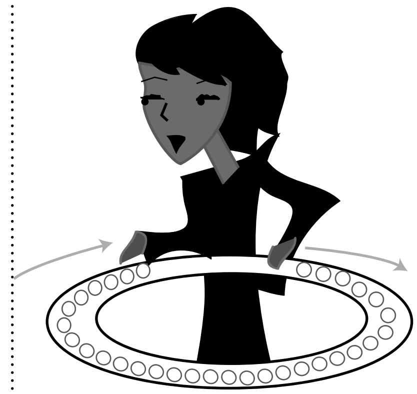
Read Chapter 28, "Designed Learning," in the textbook *Engineering the Future.* Joel Rosenberg talks about different models explaining electricity. Use notebook paper to answer the questions at the end of the chapter. Sign, date, and number each page. Insert after this place in your *Engineer's Notebook.*

Initial ______________ Date ___________

TASK 4.5 Explore Circuits with a Voltmeter

- Use a voltmeter to explore circuits.
- Apply Ohm's law to understand series and parallel circuits.

Current is the rate that charge flows through a circuit. But what is making the charge move? You've probably guessed that it's the battery. The battery pushes charge on one side of the circuit, while it pulls charge from the other side—like the teacher in the hula hoop model of a circuit. How a battery works is not mysterious. In fact, it's so simple you can make one in your kitchen.



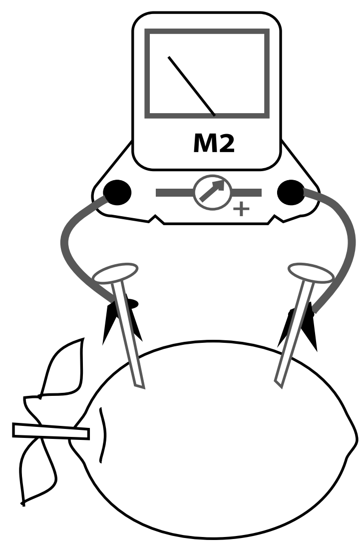
What Is a Battery?

A simple way to make an electric cell is with a lemon and nails or screws of two different metals, such as a copper nail and a galvanized (zinc-coated) nail. Use the ammeter in your kit on the LOW setting to measure the current. Try attaching the different metals to the positive and negative sides of the ammeter.

1) What was the maximum reading on the LOW setting? (Remember, each tic mark is 30 microamps.)

2) Was there a direction to the current?

3) Which metal was the + side? Which metal was the - side?



Strictly speaking, a "battery" is technically called an "electric cell." Two or more cells is a "battery." So by connecting two or more lemon cells together, you can produce a lemon battery. When you learn how to use a voltmeter, you can find out whether a lemon battery produces more voltage than a single cell.

Resistance

Alessandro Volta (1745–1827)

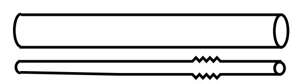
The unit of electric force is the volt (V), named in honor of the Italian physicist Alessandro Volta, who invented the battery. Volta's great discovery was that he could generate an electric current if he made a "sandwich" of two different kinds of metal with cardboard soaked with salt water in between. He used zinc and silver, but many other kinds of metals can be used. Each sandwich was an "electric cell." He stacked several "sandwiches" together and attached wires to the top and the bottom of this pile. The chemical reaction between the metals and salt water generated an electric current.

Voltage is measured by a voltmeter. In order to understand how a voltmeter works, you need to understand resistance first. Start with what you already know about resistance.

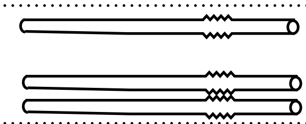
Resistance (symbol R): A measure of the ability of an object to hold back or partially block charge flow in circuits.

Resistance in Straws

1) Which is harder to blow through, a paper-towel tube or a straw?



2) Which is harder to blow through, one straw or two?



3) Which is harder to blow through, a short straw or a long straw?

Resistance in Electrical Circuits

You know from blowing through straws that the resistance of pipes depends on their diameter. Blowing through a paper-towel tube is easier than blowing through a stirrer straw because resistance increases as pipe diameter gets smaller.

1) The situation is similar for electric circuits. A thinner wire presents more resistance to the flow of charge than a thicker wire. Compare the strip of metal on the bottom of a snap wire to the filament in a bulb. Which do you think has more resistance?

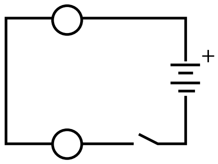
Snap wire or Filament

Explain why.

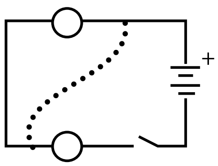
Initial ______ Date ______

Resistance in Electrical Circuits

Charge flows more easily if there is less resistance. Set up the circuit shown here. Turn on the switch and notice the brightness of the two bulbs.



2) Now use one of the wires to shorten the circuit as shown by the dotted line in the diagram. Observe what happens to the brightness of the two bulbs. Explain this result in terms of resistance.

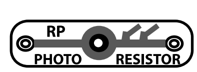


The resistance of an object depends on the material it is made of, its size, its shape, and external factors such as temperature. Resistance is measured in units of ohms (Ω, the Greek letter omega), in honor of German physicist Georg Ohm.

Wires are usually made of copper that has very low resistance. Other components, including LEDs and light bulbs, also have resistance. However, the resistance of these components changes with the voltage across them, so the graph of current versus voltage is not a straight line. These are called "non-linear" resistors.

Other resistors, like those in your kit, are made of a kind of material that does not change its resistance as voltage changes. These are very useful devices. For example, as you'll see on the next few pages, they are used for making voltmeters.

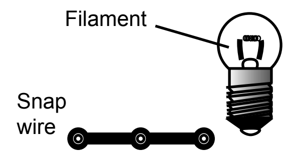
Resistors in Your Kit

What They're Called	What They Look Like	What to Do with Them
10 Ω (ten ohm) Resistor		These resistors are very useful because they keep their same value across a wide range of voltages and temperatures.
100 Ω (one hundred ohm) Resistor		
Variable Resistor, also called a Potentiometer or Adjustable Resistor		By adjusting a slider, you can change the resistance measured between positions A and B. This will be very useful in making a voltmeter.
Photoresistor		By changing the amount of light that falls on the photoresistor, you can change its resistance to the flow of current.

Initial ______________ Date ___________

Load

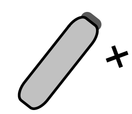
When charge flows through the thick wire of a snap circuit or through a thick copper wire, it flows easily. But when it is pushed through the thin filament of a light bulb it encounters high resistance, so it heats up the filament. It gets so hot that it glows. To an engineer, a light bulb is one kind of load that might be included in a circuit.



Load: A device that transfers electrical energy into some other form of energy. In addition to light bulbs, loads may be motors, television sets, radios, computers, or any device that receives its energy from electricity.

Voltage

A battery maintains a constant "electric pressure difference" between its two ends, and the difference doesn't disappear until the chemicals inside the battery have stopped reacting. This "electric pressure difference" is called **voltage.**



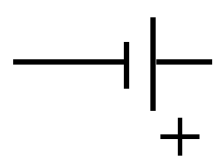
1) Look at what is printed on the batteries in your kit. What is the voltage difference (symbol ΔV) measured in volts?

[ ] **Volts**

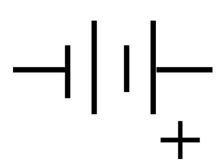
2) The number of volts printed on the battery indicates the difference in voltage between the two ends. If you connect two batteries in series, what will be the difference in voltage from the open end of one battery to the open end of the other?

[ ] **Volts**

3) Here are schematic diagrams of 1.5V batteries. Indicate the voltage next to each diagram.



[ ] **Volts**



[ ] **Volts**

Voltage difference (symbol ΔV): A measure of the "electric pressure" difference due to different charge concentrations maintained between the ends of a battery. It determines the tendency of the battery to establish an electric current flow. The voltage difference remains constant across the ends of a battery whether in a circuit or not.

Ohm's Law

Georg Simon Ohm was a high school physics teacher in Germany who enjoyed experimenting with electric circuits, which had been advanced a few years before by Volta's invention of the battery. Ohm discovered a very important relationship between voltage, current, and resistance that made it possible for engineers to analyze and design circuits. When he published his ideas in 1827, however, he was ridiculed. It took years before other scientists accepted his ideas.

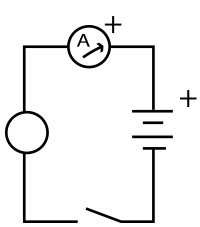
Georg Ohm (1789–1854)

Ohm's law is quite simple. It depends on the idea that where there is a difference in voltage in a circuit, charge will tend to flow. The greater the difference, the greater will be the flow of charge (also called current). Also, the flow of charge is inversely proportional to the resistance in a circuit. Ohm's law is stated mathematically as:

$$\Delta V = I \times R \quad \text{or} \quad I = \frac{\Delta V}{R} \quad \text{or} \quad R = \frac{\Delta V}{I}$$

Where:
ΔV = Voltage difference (measured in volts V)
I = Current (measured in amps A)
R = Resistance (measured in ohms Ω)

Ohm's Law can be used to find the value of ΔV, I, or R in a circuit if you know the value of the other two. Practice using Ohm's law by setting up the following circuits, using your ammeter on the HIGH (0–1 amp) setting to measure the current, and calculating the value of resistance. In each case, show how you found the value of *R*.



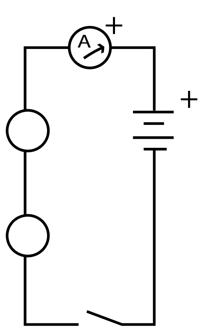
1) In this circuit:

What is the value of ΔV?

What is the value of *I*?

What is the value of *R*?

Show your work here.



2) In this circuit:

What is the value of ΔV?

What is the value of *I*?

What is the value of *R*?

Show your work here.

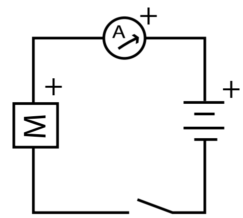
3) Set up this circuit using a motor as shown in the drawing and schematic diagram at right. In this circuit:

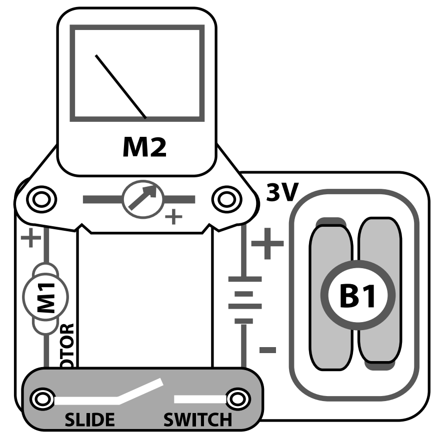
What is the value of ΔV?

What is the value of I?

What is the value of R?

Show your work below.





4) Now place a fan blade on top of the motor, and turn on the switch.

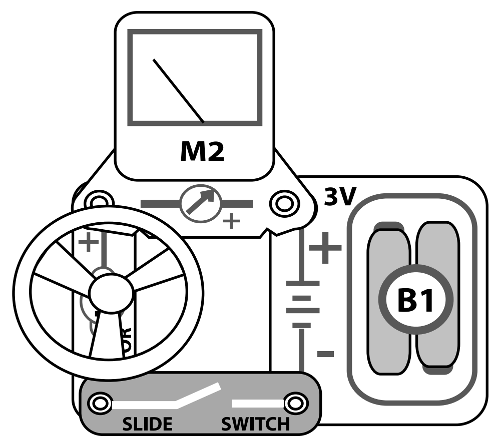
What is the value of ΔV?

What is the value of I?

What is the value of R?

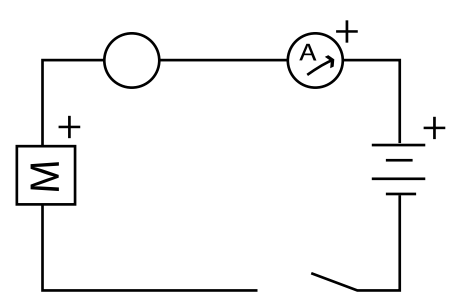
How did the fan blade change the circuit?

Why do you think that happened?



5) Add a light bulb in series with the motor. Compare the current with the fan blade and without the fan blade. Notice how the brightness of the light bulb changes as the current changes.

Describe and explain what you observed in terms of Ohm's law.



Initial ______________ Date __________

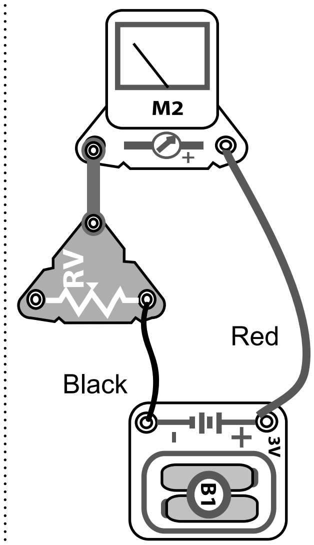
Make a Voltmeter

Just as an ammeter can be used to explore the current in a circuit, a voltmeter can be used to find the voltage across various places in a circuit. Your kit doesn't have a voltmeter, but you can make one with the help of Ohm's law. Start by setting up the circuit shown in the drawing below. Set the ammeter on LOW.

The triangular piece is called a **variable resistor.** A resistor is a component that provides a certain amount of resistance to the current. By moving the slider on the variable resistor, you can adjust the resistance.

Attach the red snap wire to the + side of the ammeter, and the black snap wire to the corner of the variable resistor as shown in the drawing. Attach the other ends of the snap wires to the battery holder, making sure to connect the red wire to the + side of the battery holder.

You know that the change in voltage across both batteries in the battery holder is 3 Volts. Carefully adjust the variable resistor so that the ammeter reads "3." You can now use the ammeter-variable resistor combo as a voltmeter. In fact, that's just what any voltmeter is—an ammeter in series with a resistor. The number value on the ammeter is the voltage.



One important thing to keep in mind: An ammeter is connected so that it is part of the circuit. A voltmeter is connected to two locations to measure the change in voltage between those locations. Try the practice problem below. The variable resistor has been set to find the correct voltage. Do not adjust it.

1) Predict the change in voltage across points **A and C.** Then connect the snap wires to see if you were right.

Prediction:

Observation:

2) Predict the change in voltage across points **A and B.** Then connect the snap wires to see if you were right.

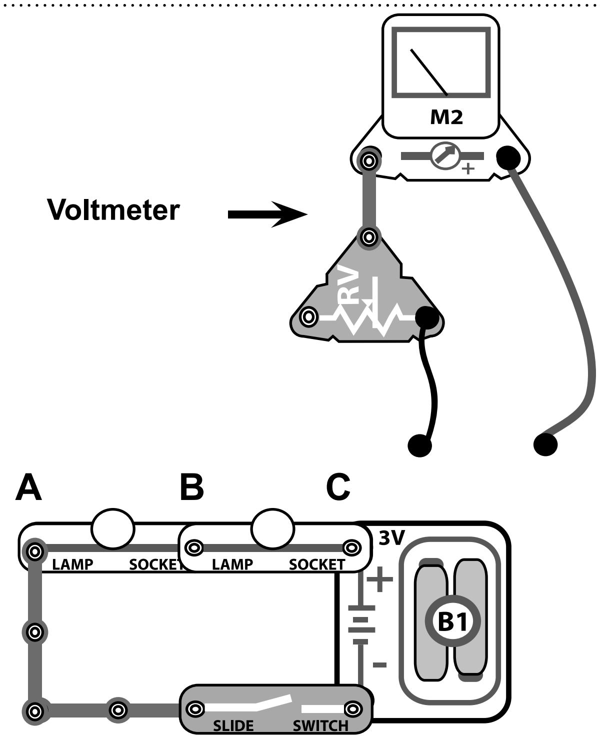
Prediction:

Observation:

3) Predict the change in voltage across points **B and C.** Then connect the snap wires to see if you were right.

Prediction:

Observation:

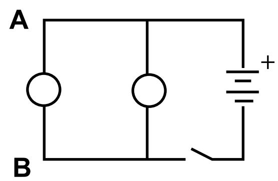


Voltage and Brightness in Parallel and Complex Circuits

Hold on to the voltmeter you built on the previous page. Build the two sets of circuits shown on this page. Before you turn on the switch, predict the voltage between the two lettered points and how bright the bulbs will be in comparison with the simple circuit. Write in your predictions, then turn on the switch and record your observations. (Before measuring each circuit, check the voltage across the battery to see whether your voltmeter needs adjustment.)

Predictions

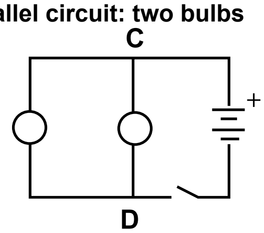
Parallel circuit: two bulbs



Voltage A to B =

Brightness =

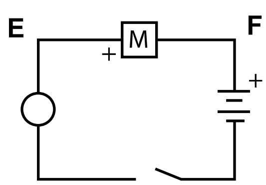
Parallel circuit: two bulbs



Voltage C to D =

Brightness =

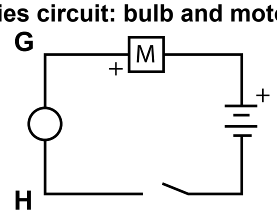
Series circuit: bulb and motor



Voltage E to F =

Brightness =

Series circuit: bulb and motor

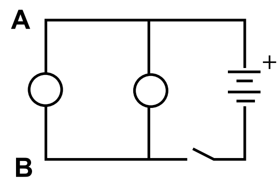


Voltage G to H =

Brightness =

Observations

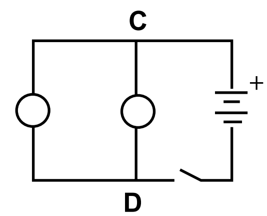
Parallel circuit: two bulbs



Voltage A to B =

Brightness =

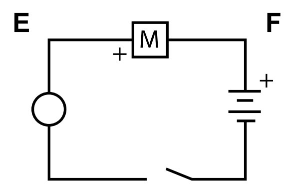
Parallel circuit: two bulbs



Voltage C to D =

Brightness =

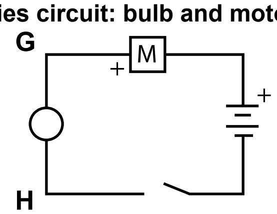
Series circuit: bulb and motor



Voltage E to F =

Brightness =

Series circuit: bulb and motor



Voltage G to H =

Brightness =

1) From what you have observed, how does the voltage change when you add another bulb in a parallel circuit?

2) From what you have observed, what happens to the voltage at a branch point in a complex circuit?

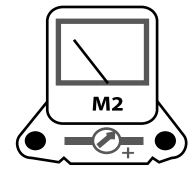
Initial ______________ Date __________

Use Ohm's Law to Measure Resistance

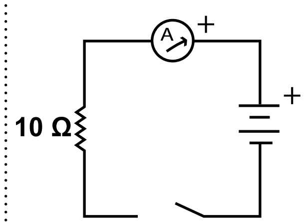
Earlier you learned that that the ammeter in your kit reads 1 amp (1A) on the HIGH setting, and 300 microamps (300 μA) on the LOW setting. Remember that:

1 amp (A) = 1,000 milliamps (mA)
1 amp (A) = 1,000,000 microamps (μA)

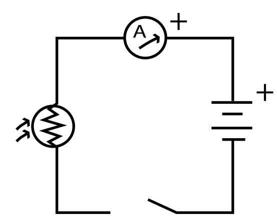
However, these meters are not perfectly accurate. You can find out how accurate your meter is by doing the first step, below.



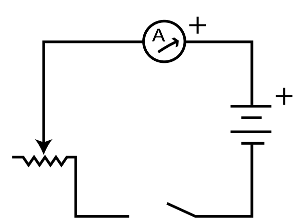
1) **Fixed Resistor.** Build the circuit shown here to test the accuracy of your meter. Use a resistor that you know to be 10 ohms (10 Ω). Set the ammeter on HIGH. **Before you close the switch, predict what the meter should say.** (Remember: *V=IR.*) Now close the switch and see how close it comes to the expected value. Give your results below.



2) **Photoresistor.** Replace the 10 Ω resistor with the photoresistor. Put it under a bright light and watch the ammeter. If the needle does not move, set the ammeter on LOW. Put your finger over the end so that no light enters, then take your finger off to see what happens. Based on what you have observed, does the photoresistor have more or less resistance than the 10 Ω resistor? Explain how you know that.

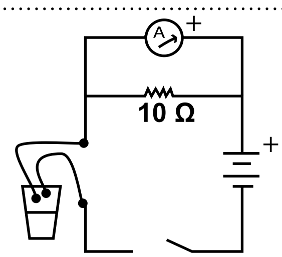


3) **Variable resistor.** Replace the photoresistor with the variable resistor connected to the circuit as shown in the diagram. Start with the ammeter on HIGH and notice where you have to place the slider so that it reads near the middle of the scale. Then change the resistance and switch scales on the ammeter to see the full range of resistance. What do you observe about where the slider must be to read on the LOW scale?



4) **What is the resistance of water?** Remove the variable resistor, leaving an open circuit. Snap a wire onto each side of the open circuit, and place the other ends of the wires into opposite sides of a glass of water

If the current is too high for the LOW scale and too low for the HIGH scale, you can change the sensitivity of your meter by adding a 10 Ω resistor as shown in the diagram. How does the resistance of water change if you add some salt?



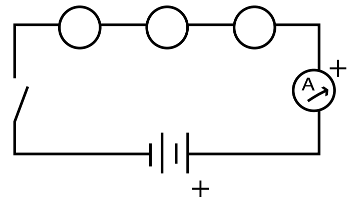
Benchmark

1) In this circuit, I = 0.1 amps, and the power source is 2 AA batteries.

What is the value of ΔV? [ ]

What is the value of R for the circuit? [ ]

What is the value of R for each bulb? [ ]



Don't forget to write units!

2) Some students are having an argument about the circuit above. For each statement, say whether you agree, or disagree, and why.

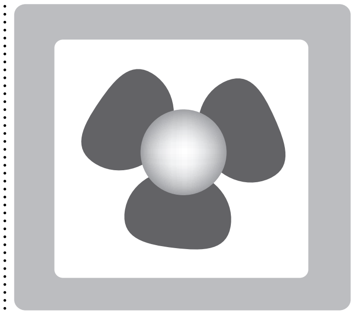
	Agree or disagree? Please explain.
Student A: "If I move the ammeter to the left side of the circuit, it will read zero because only the wire from the + side of the battery is needed."	
Student B: "Yes, it will read zero, but both wires are needed. It's just that the electricity is all worn out by the time it goes through all three bulbs."	
Student C: "You're both wrong. If you move the ammeter to the left side of the circuit, you'll see that the charges are moving in the opposite direction, so that the charges meet in the middle and light up the bulbs."	
Student D: "None of you are right. Wherever you put the ammeter, you'll see that the current keeps going in the same direction, and with the same current, all around the circuit."	

Read Chapter 29, "On the Grid," in the textbook *Engineering the Future* about the life and work of Soung-Sik Kim. Use notebook paper to answer the questions at the end of Chapter 26. Don't forget to sign, date, and number each page. Insert after this place in your *Engineer's Notebook.*

TASK 4.6 Design a Fan Control System

- Color code to analyze voltage differences.
- Use resistance in series and parallel circuits to control current flow.

Cooks in the cafeteria have been getting ill because of a poor ventilation system. They purchased fans for the two windows, but they came without switches. Your challenge will be to design a control system that will allow the two fans to be turned on and off independently, and to blow fresh air into the kitchen or blow smoke out of the kitchen. This will be your most complex design challenge yet, so you will first need to learn “color coding” to analyze complex circuits.

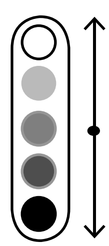


Color Coding in Electricity

Engineers do not design circuits by trial and error, but rather by using what they know to plan a circuit, and then build it and test it. In this task you’ll learn the method of color coding to analyze the voltage differences in complex circuits. Then you’ll apply what you know to design a fan control system to help the cooks stay healthy.

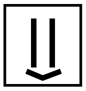
In an electric circuit, differences in voltage cause current to flow. The greater the difference in voltage, the more current will flow.

Use these five colors to show differences in voltage.

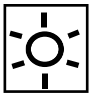


RED	High—above normal
ORANGE	Above normal
YELLOW	Normal
GREEN	Below normal
BLUE	Low—below normal

More Symbols

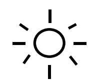
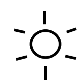
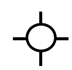


Arrowtails are used to represent the charge flow rate and direction through any part of a circuit. The charge flow rate is represented by the number of shafts in the tail, not by length of the arrow. If there is no charge flow, don't draw any arrows.



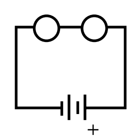
Starbursts are used to represent bulb brightness caused by charge flow rate through the filament. Brightness is represented by number of rays in the starburst, not by length or thickness of the rays.

These symbols show the relative brightness and strength of current and voltage in a given circuit. They do not represent numerical values. Increasing the voltage in a circuit will increase the strength of the current and the brightness of the bulbs. The following chart shows how to use colors and symbols to indicate the way voltage, current, and bulb brightness vary together.

Voltage	Current	Brightness
Large voltage difference (e.g., RED to BLUE)		
Medium voltage difference (e.g., YELLOW to BLUE)		
Small voltage difference (e.g., ORANGE to YELLOW)		

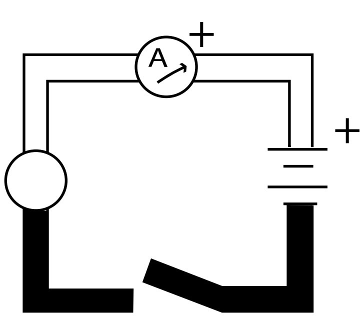
Color Code Series Circuits

Series Circuit: Circuit components are in series if all the current that flows through one must flow through the others. All of the moving charge passes through every resistance, and all of the charge is resisted every time it passes through a resistance.



The wires in Snap Circuits™ and the ammeter have very low resistance; you can color both sides of an ammeter in a circuit the same color—as if it was a simple wire.

Following is an example of how to use color coding and symbols to show what's happening in a circuit. Build the circuit to see how it compares with the diagram. (Make sure the ammeter is set to HIGH (0–1 amp) and connected correctly with "+" contact toward the positive battery terminal.) Record the ammeter reading.



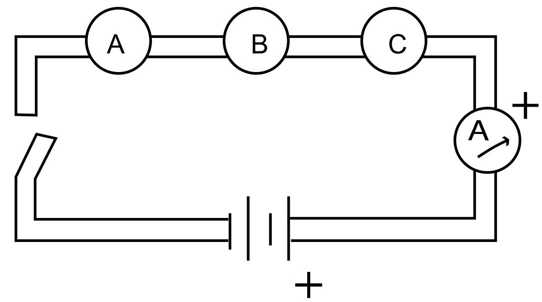
Describe what you observed about the voltage, current, and brightness. Did your observations agree or disagree with the symbols in the drawing at left?

Initial ____________ Date ___________

Series Circuits with Bulbs

1) Build this series circuit. Switch ammeter to HIGH (0–1 amp). **Before you turn on the switch, predict,** by writing below, how bright the bulbs will be, and what the current will be.

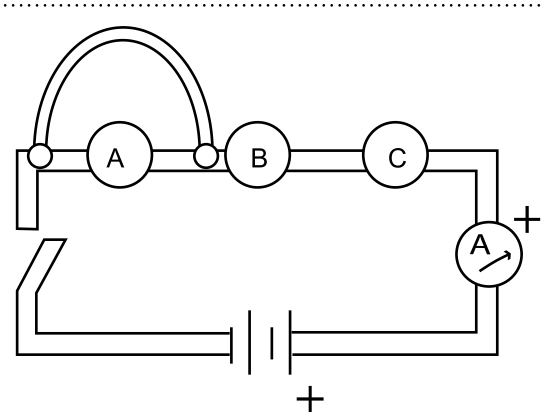
2) Close (turn on) the switch. Observe the brighness of the bulbs and read the current. Use the colors and symbols from the previous page to indicate differences in voltage, current, and brightness. Below the drawing, indicate what was right and wrong about your prediction.



How did results differ from your prediction?

3) Create a "short circuit" by connecting a "jump" wire across the snaps for bulb socket A, as shown in the drawing. **Before you turn on the switch, predict,** by writing below, how bright the bulbs will be, and what the current will be.

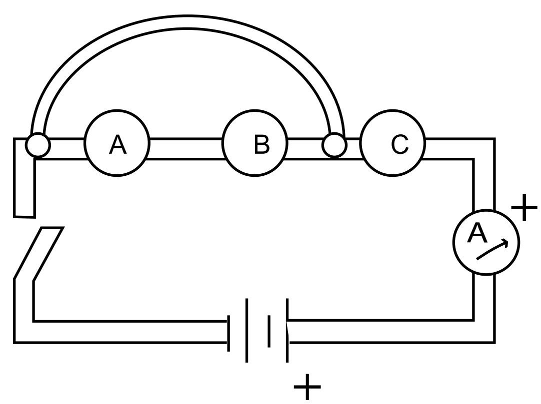
4) Close (turn on) the switch. Observe the brightness of the bulbs and read the current. Use the colors and symbols on the previous page to indicate differences in voltage, current, and brightness. Below the drawing, indicate what was right and wrong about your prediction.



How did results differ from your prediction?

5) Connect a jump wire across the snaps for bulb socket A and B, as shown in the drawing. **Before you turn on the switch, predict,** by writing below, how bright the bulbs will be, and what the current will be.

6) Close (turn on) the switch. Observe the brightness of the bulbs and read the current. Use the colors and symbols on the previous page to indicate differences in voltage, current, and brightness. Below the drawing, indicate what was right and wrong about your prediction.



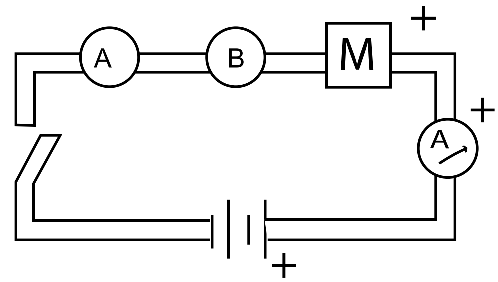
How did results differ from your prediction?

7) What can you conclude about the relationship between voltage, current, resistance, and the brightness of bulbs in series?

 Name ____________________

Color Code Series Circuits with a Motor

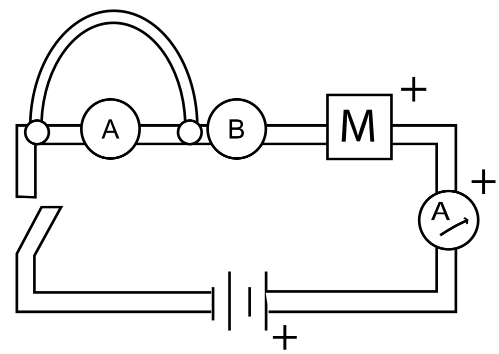
1) In the circuit on the previous page, replace bulb C with a motor. Switch ammeter to HIGH (0–1 amp). **Predict,** by writing below, how bright the bulbs will be, what the current will be, and what will happen to the motor.



How did results differ from prediction?

2) Close (turn on) the switch. Observe the motor, the brightness of the bulbs, and read the current. Use colors and symbols to indicate differences in voltage, current, and brightness. Below the drawing, indicate what was right and wrong about your prediction.

3) Create a "short circuit" by connecting a jump wire across the snaps for bulb socket A, as shown in the drawing. **Predict,** by writing below how bright the bulbs will be, what the current will be, and what will happen to the motor.

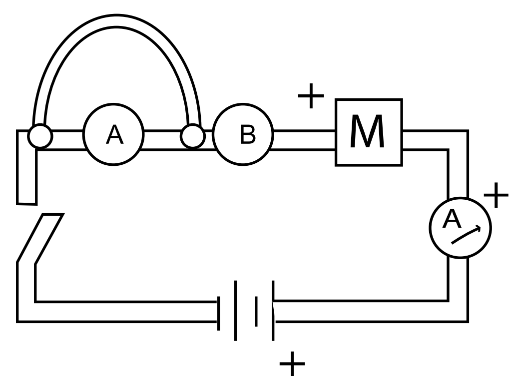


How did results differ from prediction?

4) Close (turn on) the switch. Observe the motor, the brightness of the bulbs, and read the current. Use colors and symbols to indicate differences in voltage, current, and brightness.

5) What happens to the motor if you connect a jump wire across both bulbs A and B?

6) Reverse the direction of the motor. **Predict,** by writing below, what will happen to the motor and the current.



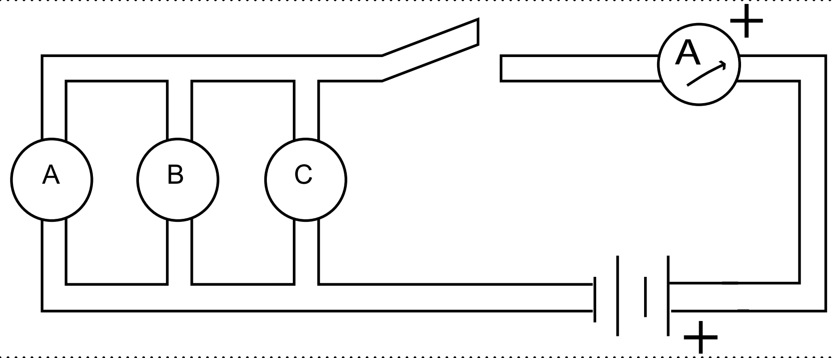
How did results differ from prediction?

7) Close (turn on) the switch. Use colors and symbols to indicate differences in voltage, current, and brightness. Indicate below what was right and wrong about your prediction.

8) What can you conclude about the relationship between voltage, current, and motor speed and direction?

 Initial ______________ Date ____________

Color Code Parallel Circuits



1) Build the circuit shown above. Set the ammeter on HIGH. Color code the diagram. Close (turn on) the switch. Predict what will happen if you unscrew bulb A.

A. How will the brightness of the other bulbs change? ____________________

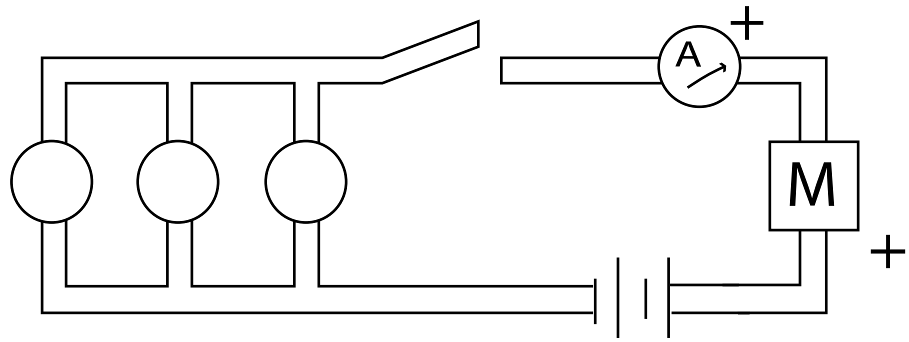
B. How will the current through the ammeter change? ____________________

2) Describe what actually happens if you unscrew bulb A.

A. How does the brightness of the other bulbs change? ____________________

B. How does the current through the ammeter change? ____________________

C. Explain why these changes occur. ____________________



3) Add the motor to the circuit as shown above and turn on the switch.

A. What happens to the bulbs when the motor is added? ____________________

B. What happens to the current? ____________________

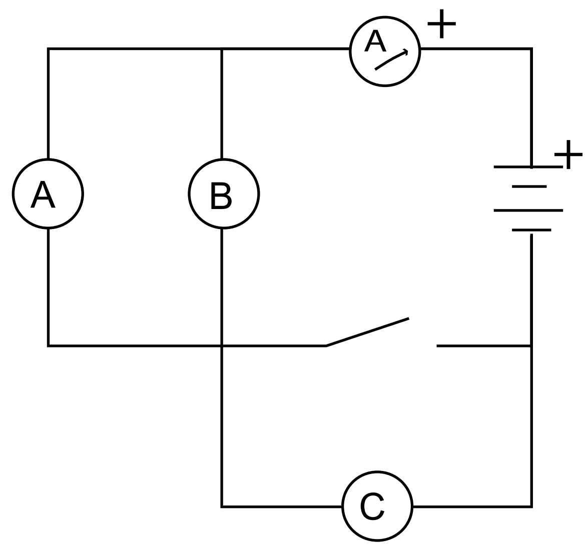
C. Unscrew the bulbs, one at a time. Describe and explain what happens.

Resistance in Complex Circuits

1) Build the circuit shown at right, but do not screw in any of the bulbs. Switch the ammeter to HIGH (0–1 amp).

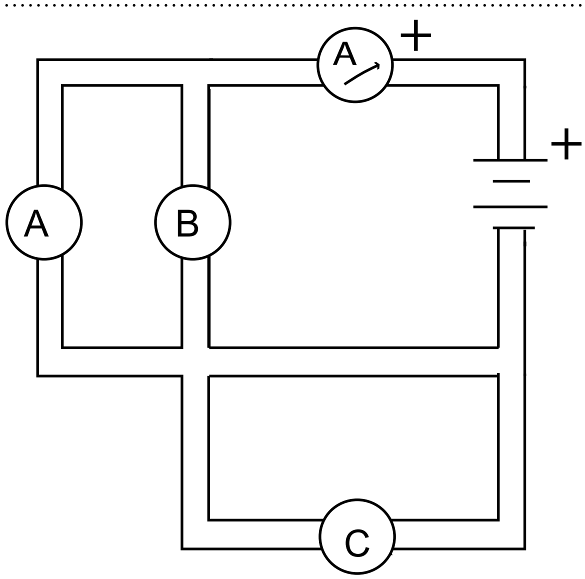
A. Predict which bulbs will light when all bulbs are screwed in, and the switch is open (off).

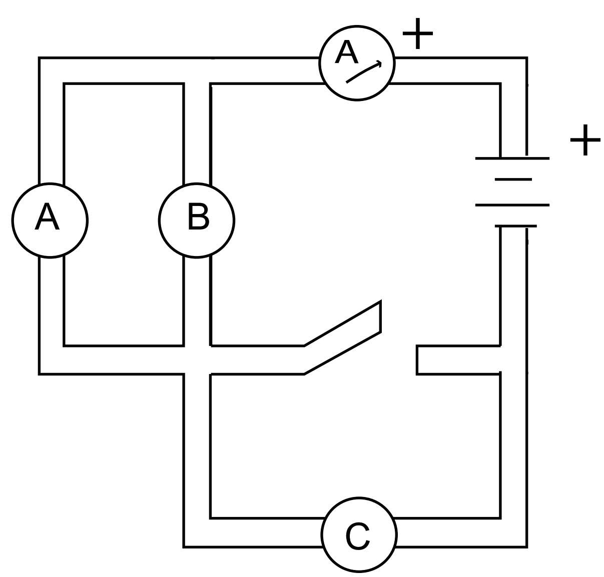
B. Predict which bulbs will light when all bulbs are screwed in, and the switch is closed (on).



2) Screw in the bulbs and see what happens when the switch is open and when the switch is closed. Were you surprised? Describe your observations below. Explain them if you can.

3) Color coding may sometimes help you understand what is happening in a circuit. Color code the circuit with the switch closed in the left schematic, and open in the right schematic.





Add any further insights that the color coding may have given you.

Initial ____________ Date ____________

4) In the circuit on the previous page:

A. What is the current when the switch is open (off)? [ ] Amps

B. What is the current when the switch is closed? [ ] Amps

C. Why does the current change?

If you had any difficulty answering question 4c, here are some ideas that might help.

Remember that the bulbs act as resistors. Also remember Ohm's law, *V=IR*.

Voltage Difference ΔV	**Current (*I*)**	**Resistance (R)**
$\Delta V = IR$	$I = \frac{\Delta V}{R}$	$R = \frac{\Delta V}{I}$

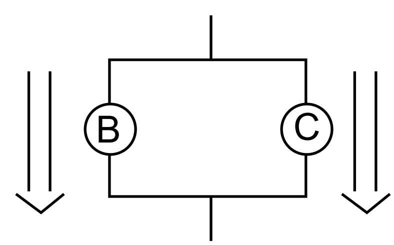
In a series circuit, the electricity must run through each resistor in turn (R_1, R_2, R_3, ...) so that total resistance (R_T) increases.

$$R_T = R_1 + R_2 + R_3 \ldots$$

In a parallel circuit, the electricity runs through all resistors at the same time, so that total resistance is reduced.

$$\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} \ldots$$

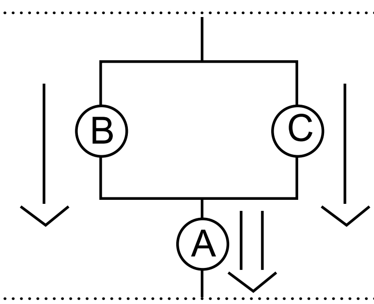
5) When the switch was closed (on), the current ran directly through bulbs B and C alone, as shown at right. Use the current values found previously to answer these questions.



A. What is the resistance of bulbs B and C in parallel?

R = Ω

B. When the switch was open (off), the current was forced to go through all of the bulbs, as shown at right. What is the resistance of all three bulbs in this arrangement?



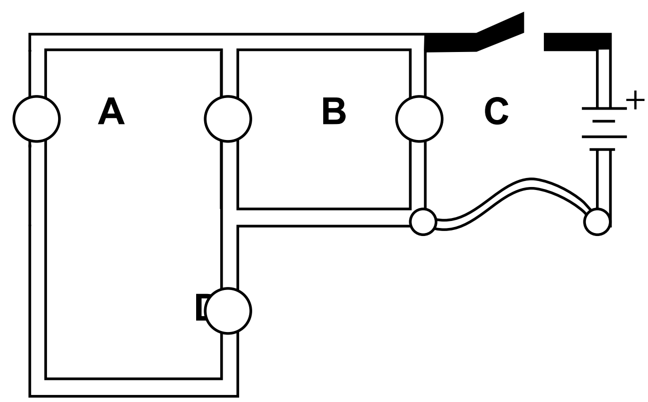
R = Ω

C. Why do bulbs B and C go out when the switch is turned off?

Color Code Complex Circuits

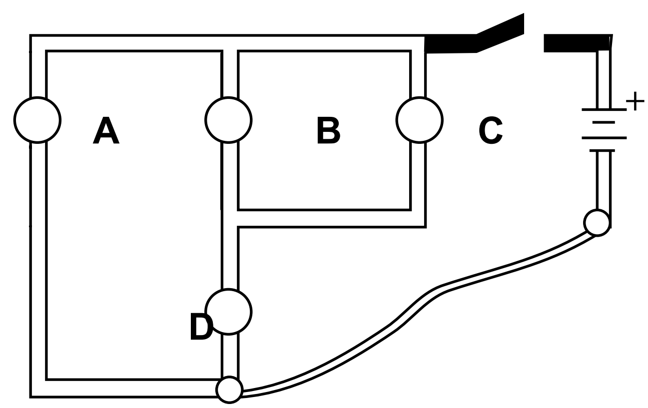
The advantages of color coding become clear when you start to design **complex circuits,** those with both serial and parallel parts, as you'll see when you build the circuit below.

1) Work with another group to build the circuit shown at right. It consists of a two-cell battery, four bulbs, snap connectors, a switch, and one snap wire. Before you turn on the switch, color code the drawing and predict the appearance of the four bulbs. Use the terms "bright," "dim," or "out," then turn on the switch and record what actually happened.



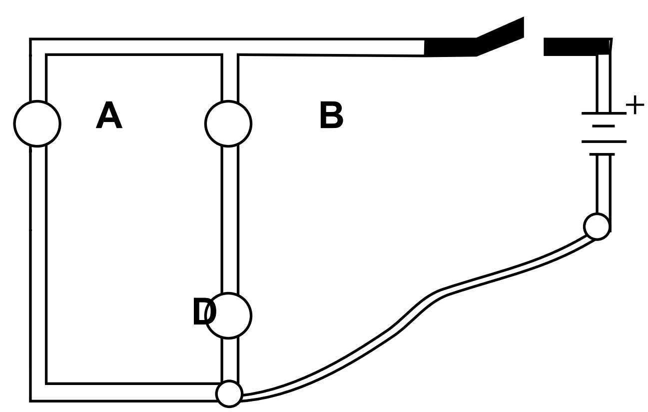
	Predicted	Actual
Bulb A		
Bulb B		
Bulb C		
Bulb D		

2) Switch the position of the snap wire as shown in the circuit diagram at right. Again, color code the circuit, make your predictions, and record what actually happens.



	Predicted	Actual
Bulb A		
Bulb B		
Bulb C		
Bulb D		

3) Unscrew bulb C. That breaks the connection, which does the same as removing the bulb and connectors attached to it. Again, color code the circuit, make your predictions, and record what actually happens.

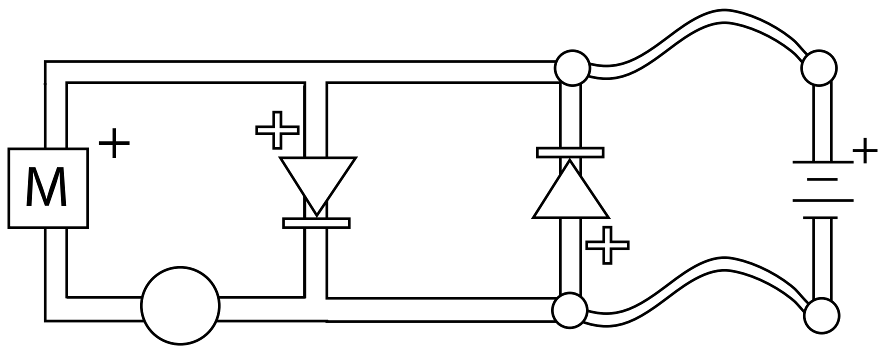


	Predicted	Actual
Bulb A		
Bulb B		
Bulb C		
Bulb D		

Color Code Circuits with Diodes

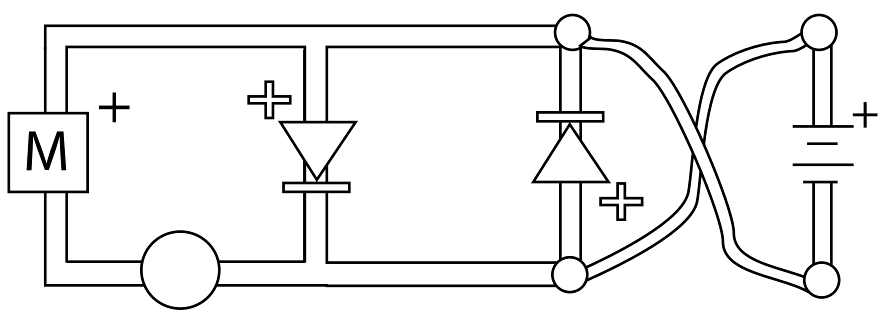
1) Build the following circuit, which uses two diodes, a motor, and a bulb. Use snap wires to connect the battery to the rest of the circuit. Describe what happens when you connect the battery to the rest of the circuit.

2) Color code the circuit and use the symbols from the previous pages to show the direction and magnitude of the current and what happens to the various components.



3) Switch the snap wires as shown, then describe what happens.

4) Color code the circuit and use symbols to show how the current has changed and what happened to the components.



Read Chapter 30, "Electrifying!," in the textbook *Engineering the Future.* Ken McAuliffe the Electrical Systems Coordinator at the Museum of Science, Boston, talks about different types of current and circuits. Use notebook paper to answer the questions at the end of the chapter. Don't forget to sign, date, and number each page. Insert after this place in your *Engineer's Notebook.*

Name ________________________________

DESIGN CHALLENGE

Design a Fan Control System

You now have enough knowledge about electric circuits to design a control system for the fans the cafeteria bought. You need each fan to have at least two speeds. It should also be reversible so that air can blow in or out, and it should have an on/off switch.

Each person should:

- sketch different design ideas and discuss with teammates before building anything.
- keep notes on separate pages and add them to their notebook demonstrating the design process steps.
- draw a set of schematic diagrams and write an explanation of how the design works.
- diagram and color code each setting of the circuit and draw arrowtails to indicate how current changes between fan settings.

Rubric for Design a Fan Control System

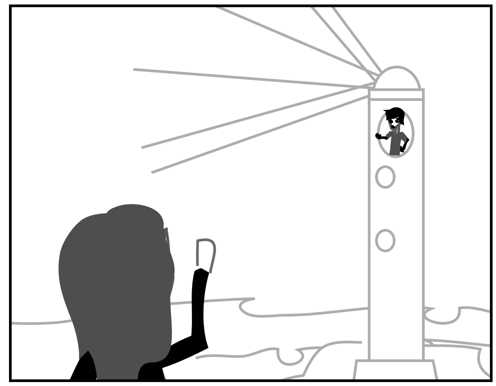
	⌖⌖⌖⌖	⌖⌖⌖	⌖⌖	⌖
Design Process	Clearly identifies thinking at each step.	Shows some thought at each step.	Few notes, sketches of steps followed.	No notes on steps followed.
Circuit Design	System plan meets challenge and uses communications concepts.	Adequate design chosen from several alternatives. Will meet criteria and constraints.	Simple design with no alternatives proposed.	System design is unclear or does not address challenge.
Communication	Writing, drawings, and schematic diagrams are clear, comprehensive, accurate, and easy to interpret.	Writing, drawings, and diagrams are adequate, but have some errors or omissions.	Writing, drawings, and diagrams are poorly done or incomplete.	Some attempt is made but work is poorly done and incomplete.

Initial ______________ Date __________

TASK 4.7 Provide Energy to a Lighthouse

- Understand power and energy.
- Explore alternative energy sources.
- Understand direct current (DC)/alternating current (AC).
- Understand the relationship between motors and generators.

The lives of thousands of sailors were lost until lighthouses were built to warn ships of rocks and reefs, and to help guide them into port. To be of any value, lighthouses must have very bright lights. Your next challenge is to select a power source for a 1,000-watt bulb in a lighthouse. The source you choose will need to work on an isolated island, to keep working all night long, and be as inexpensive and as easy to maintain as possible.



Power

Power and **energy** are two very important concepts you'll need to understand before choosing an energy source. Power and energy are closely related, but they are not the same.

How to picture it!
Just think of a car with a really powerful engine. It's a lot of fun to drive because it accelerates very fast, but it comes with a price. Powerful engines burn gasoline at a high rate. Each gallon of gasoline contains a certain amount of energy. The more powerful the engine, the faster it uses energy. Or think of a bright electric light. The brighter it is, the faster it uses electrical energy.

What is power?
Power *(P)* is the rate at which a device uses energy. Electric power is defined as the electric current *(I)* times the difference in voltage (ΔV).

$$P = \Delta V \times I$$

How is power measured?
The unit of power is the watt (W).

W = 1 amp × 1 volt

In designing a power system for a lighthouse, you will need to provide enough power to light a 1,000-watt bulb all night long. However, if it provides too much power it could burn out the light, or it would be too costly to run. In this task, you'll explore different ways to generate electric power to determine which would be best for this purpose.

Key Concepts of Energy

Watt = Unit of Power

James Watt
(1736–1819)

The unit of electric power—the watt—is named for James Watt, the inventor of the steam engine. You'll need to remember the following equation, which relates power to current and voltage:

$$P = \Delta V \times I$$

For example, typical house current is 120 V. If a light bulb draws a current of 0.5 A, what is the power of the lightbulb?

watts

Recall the term "Load" (a device that transfers electric energy into some other form of energy). In this case, the lighthouse bulb is the load that you need to power.

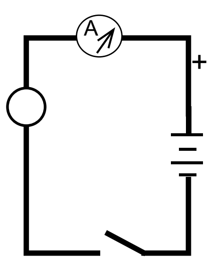
Box Diagrams

A good way to visualize power in a circuit is to draw a "box diagram."

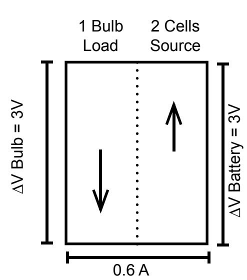
In a box diagram:

- the **width** of the box represents the **current.**
- the **height** of the box represents the **voltage.**
- the **power** of the circuit is the **area** of the box (width × height, or current × voltage).

Here is a schematic and a box diagram of a simple circuit, consisting of a two-cell battery, an ammeter, and a light bulb with connectors.



Schematic diagram



Corresponding box diagram

Notice that the box diagram has two sides. The right side represents the source of power and the left side represents the load.

The up arrow indicates the flow of current from the source, following the conventional direction of + to -.

The down arrow indicates the current flowing through the load back toward the source.

The power produced by the source always equals the power used by the load.

Build this circuit, note the current and voltage difference, then calculate the following:

What is the power generated by the source?

What is the power used by the load?

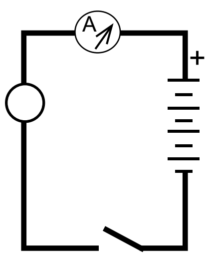
Initial ____________ Date ____________

Fuses

Lighthouse bulbs are very expensive. They are also fragile because the filament gets very hot and must stay lit for hours at a time. So they need to be protected by fuses.

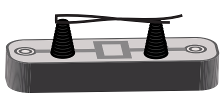
A **fuse** is a resistor designed to fail at a lower current than the load it is protecting.

1) To see how fuses work, start by building the following circuit and making a box diagram. Calculate the power of the bulb. Note how this circuit differs from the one on the previous page, in terms of the power and the brightness of the bulb. The box diagram should show this difference.

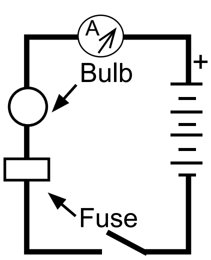


Draw box diagram here.

[ ] watts



Fuses come in different shapes and sizes, but they all have a wire or ribbon of metal in the middle that is connected in series with the rest of the circuit, and they will all melt if the current gets too high. Make a fuse by stretching one or two strands of fine steel wool between the springs on the spring socket module. Snap it into the circuit as shown below.



2) Close (turn on) the switch. If the fuse does not melt right away, blow gently on the fuse wire to cool it. What happens to the light and ammeter? What does this tell you about how changes in temperature can affect resistance?

3) Open (turn off) the switch and thin the fuse to just one strand of steel wool. Close the switch. Describe what happened to the fuse, the current and the brightness of the light, and explain how such a fuse can protect the lighthouse lamp.

Energy

How much energy do you need to light a 1,000-watt bulb? That depends on how long it's on. As defined on the previous page, power is the rate at which energy is used. If the bulb is on twice as long, it will use twice as much energy. So the units of energy are watt-hours (Wh). One thousand watt-hours is a kilowatt-hour (kWh).

$$E = P \times t$$

The relationship between power and energy is ____________________

If the 1,000 watt bulb is left on for a ten-hour night, how much energy will it use? [   ] **kWh**

How can you get electric energy on an island? In brief, there are three possible sources from which you will need to choose: batteries, solar cells, or generators. The following ideas about electrical energy apply to all three systems:

1) Electrical energy is like a substance—but it is not a substance. It can flow from one place to another and you can see its effects, but it is not a solid, liquid, or gas.

For each possible source of power, ask yourself the following:
- Where is the energy coming from?
- How is it being transferred?
- Where is it going? What are the effects?
- How can I "see" that energy is flowing?

2) It takes a difference (in chemical or mechanical energy) to make a difference (in voltage). When the difference disappears, or the circuit is broken, energy stops flowing.

What is causing the difference in voltage?

3) Increased resistance decreases the rate at which energy flows.

What is the load? What if it is increased?

Compare the pros and cons of each energy source.

Pros	**Cons**

Initial ______________ Date ___________

Will Batteries Provide a Good Source?

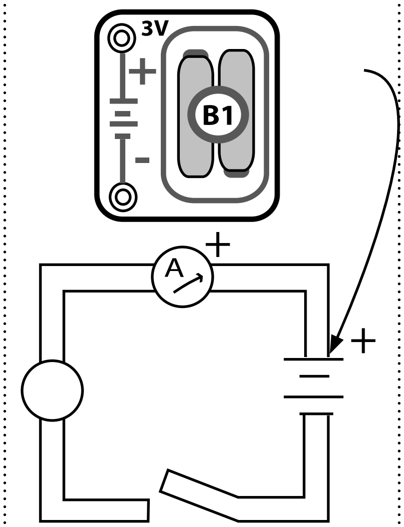
1) Electrical energy is like a substance—but it is not a substance. It can flow from one place to another and you can see its effects, but it is not a solid, liquid, or gas.

A. Build the circuit shown at right, with an ammeter set on HIGH, a two-cell battery holder, switch, and light bulb.

B. Close the switch. What effects of energy can you see (even though you can't see the electricity itself)?

C. As you look at the circuit try to imagine electrical charge flowing through all of the conductors in a continuous circle.

D. Electrical charge is not energy! Try to picture the charge carrying the energy from the battery to the bulb, and out into the world as heat and light.



2) It takes a difference (in chemical or mechanical energy) to make a difference (in voltage). When the difference disappears, or the circuit is broken, energy stops flowing.

A. Color code the circuit diagram to show the difference in voltage.

B. What current does the two-cell battery produce, in the above circuit? (Remember, full scale is 1.0 A.) _______ **amps**

C. What voltage does the two-cell battery produce? _______ **volts**

D. What is the power of the bulb in watts? _______ **watts**

E. What is inside the battery that maintains the difference in voltage?

3) Increased resistance decreases power.

A. Every circuit with a load offers some resistance. In the circuit above, what is the resistance of the light bulb?

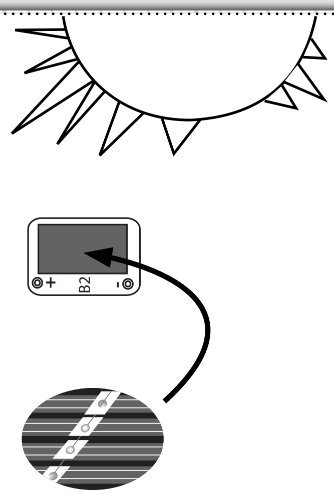
_______ **Ohms (Ω)**

4) Are batteries a good energy source for the lighthouse?

5) How many AA cells would you need to light a 1,000-watt bulb for one ten-hour night? (Show your work.)

The energy stored in a cell is usually marked on the outside. For example, a typical AA cell that produces 1.5 V may say 1,500 mAh (milliamp-hours). In terms of energy, that would be $E = (1.5\text{ V} \times 1.5\text{ Ah}) = 2.25\text{ Wh}$

Will Solar Cells Provide a Good Source?



You may have seen solar cell arrays used to power lighted street signs or emergency telephones on the highway. They appear to be large, flat boards with lots of little squares on their top surface. Now you can see those little squares up close.

When sunlight falls on a solar cell, charge moves from one side of the cell to the other. Look closely at the solar cell component and you'll see it's made up of smaller solar cells. Tiny wires (which may be hidden) connect these cells just like a battery holder. Many solar components can be used together to build a much larger and more powerful series called a **solar array.**

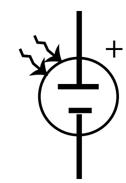
1) Electrical energy is like a substance—but it is not a substance. It can flow from one place to another and you can see its effects, but it is not a solid, liquid, or gas.

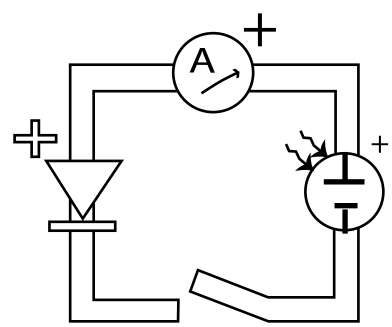
A. Solar energy comes to Earth across 93 million miles of space. What effects of solar energy can you sense (even though you can't see the energy itself)?

B. Build the circuit shown at right, with an ammeter set on LOW, an LED, and one solar cell module. Close the switch. What additional effects of energy transfer can you see?

C. Color code the circuit diagram above to show the difference in voltage when the solar cell is illuminated by light.

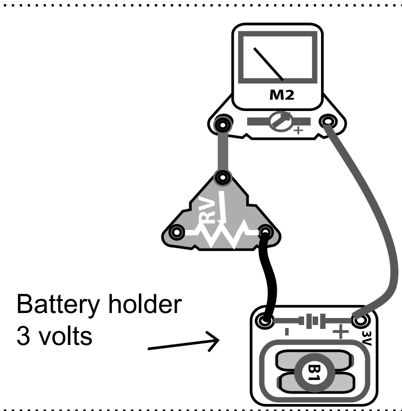
Symbol for a solar cell





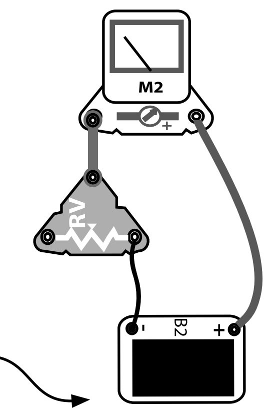
2) It takes a difference (in chemical, solar, or mechanical energy) to make a difference (in voltage). When the difference disappears, or the circuit is broken, energy stops flowing.

A. Use your ammeter and variable resistor to make a voltmeter. Remember to set the ammeter on the LOW setting, connect the snap wires to a battery holder with two cells, and adjust the variable resistor so the ammeter reads "3."

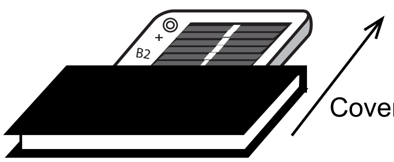


B. Replace the battery holder with a solar cell. What is the range of voltages you observe when the cell is in normal room light and when it is in bright sunlight (or close to a bright lamp)?

Low light ☐ volts ———— Bright light ☐ volts(V)



C. Place the solar cell and voltmeter in the brightest light possible and record the voltage. Use a book or thick stack of papers to cover one of the nine rows. Record the resulting voltage difference, and then cover the next rows and repeat until all rows are covered. Record the voltage in the table. (Actual positioning of solar cells may vary.)



Uncovered	ΔV
9	
8	
7	
6	
5	
4	
3	
2	
1	
0	

3) Increased resistance decreases the rate at which energy flows.

The 1,000-watt lighthouse bulb runs on 120 volts.

What current does it require? ☐ **amps (A)**

What is its electrical resistance? ☐ **ohms (Ω)**

4) Are solar cells a good energy source for the lighthouse?

In order to use solar cells to light the bulb for a lighthouse, you would need a solar cell array that produced 1,000 watts (1 kiloWatt) to energize batteries during the day, which would then be used to power the lighthouse bulb at night for ten hours.

Search the web to see what it would cost for a 1 kW solar cell array. Keep in mind that it cannot be connected to the power grid, since the lighthouse is on an island. Batteries will be needed to store ten kiloWatt-hours of energy for use at night.

Insert an additional sheet of paper here with the results of your search.

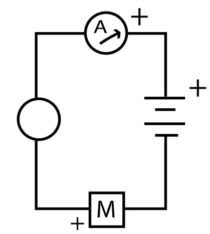
Read Chapter 31, "Sunny Side Up," in the textbook *Engineering the Future* to learn about solar energy from Christine Bordonaro. Use notebook paper to answer the questions at the end of the chapter. Don't forget to sign, date, and number each page. Insert the pages at this point in your *Engineer's Notebook.*

Will Generators Provide a Good Source?

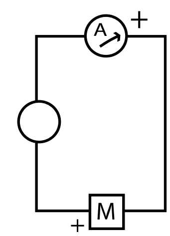
1) Energy is like a substance—but it is not a substance.

Generators and motors have a lot in common. You are going to build these two circuits and describe what happens.

A. The first circuit includes the motor in your kit, a battery holder, and an ammeter set on HIGH. Build the circuit. What happens?



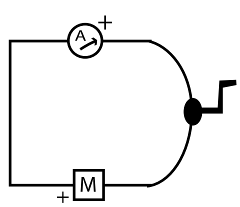
B. Remove the battery, replace it with a snap wire, and set the ammeter to LOW. Spin the rotator at the top of the motor while you're watching the ammeter needle. What happens?

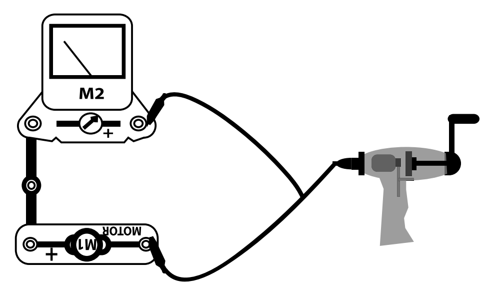


C. From what you have observed, what is the relationship between a generator and a motor?

Optional
Your instructor may provide your team with a more powerful hand-crank generator. If so, use it to build the circuit shown here and on the following two pages.

D. Connect the hand-crank generator to an ammeter set on HIGH and a motor as shown. Turn the crank. What happens?





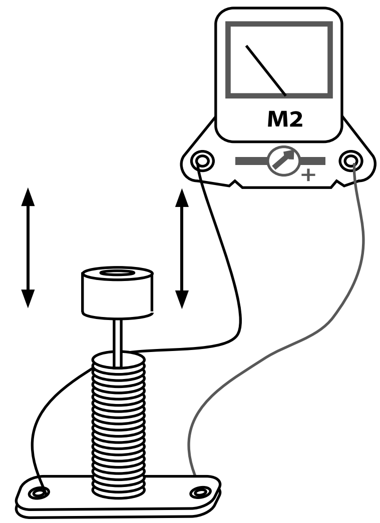
E. How are the motor and hand-crank generator similar? How are they different?

CAUTION! Turning the generator crank too fast will burn out components.

2) It takes a difference (in chemical, solar, or mechanical energy) to make a difference (in voltage). When the difference disappears, or the circuit is broken, energy stops flowing.

A. The source of the difference in the battery was chemical energy. The source of energy for the solar cell was solar energy. What is the source of energy for a generator?

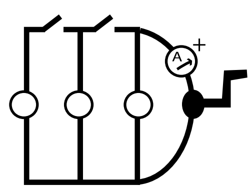
B. What's inside the generator that allows it to transfer energy of motion to electrical energy? To find out, make your own generator using the Snap Circuits™ coil and metal rod, and a strong magnet. Connect the coil to the ammeter, set on LOW. Hold a strong magnet in contact with the metal rod so that it too is magnetic. Move the rod in and out of the coil and watch the ammeter needle. Below, describe what happened and what you think is inside a generator.



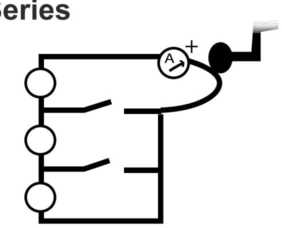
3) Increased resistance decreases the rate at which energy flows.

Set up the following circuits.

Parallel



Series



- Take turns using the generator so that everyone in the group has a chance to experience powering both circuits.
- Vary the load of the circuit while each person is turning the generator.
- Take turns using the ammeter set on HIGH to measure the current in both circuits.
- Record your observations and measurements.

A. Which circuit required you to push the hardest?

B. Which circuit required you to push the fastest?

C. Which circuit—series or parallel—do you think is used in home wiring? Why?

4) Is a generator a good energy source for the lighthouse?

A. Generators connected to diesel engines are available for purchase. Look on the Internet to see what it would cost for a 1 kW diesel-electric generator. See if you can find out how much fuel would be needed on the island each week to power the lighthouse for ten hours per night. Summarize the results of your search.

B. Generators can also be turned by wind. Look up "wind electric generators" on the Internet to see what a 1 kW generator would cost, and write the results here.

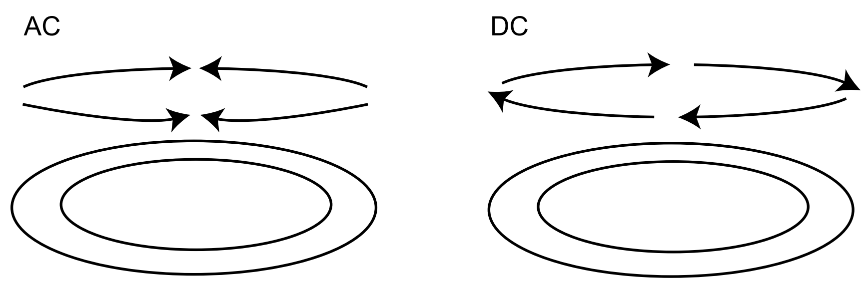
Which Is Better—AC or DC?

One of the choices you'll need to make in selecting a power source is whether it should be direct current (DC) or alternating current (AC).

Direct Current (DC): Current moves in one direction only. Batteries and solar cells produce direct current.

Alternating Current (AC): Current moves back and forth. Generators produce alternating current, although they may be modified to produce DC.

These two types of currents can easily be demonstrated with a hula hoop. If the hoop is pushed and pulled back and forth, it represents AC current. If the hoop continuously moves in the same direction, it represents DC current.



Small appliances like flashlights and calculators run on DC because they are energized by batteries. However, DC is not very good for transporting power long distances because it heats up the wires. AC can be changed to high voltage and low current so that very little energy is lost when transported many miles to homes and businesses.

A light bulb will work on AC or DC current because it lights up whenever the filament gets above a certain temperature. Although AC current stops for an instant before it reverses direction, it is such a short time that the filament doesn't have time to cool off.

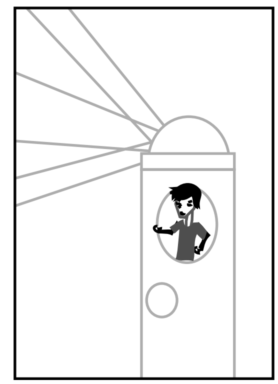
In your opinion, for the lighthouse, which do you think would be better: AC? DC? No difference?

Read Chapter 32, "Cape Wind," in the textbook *Engineering the Future* to see how Jim Gordon proposes using generators turned by the wind to replace power plants that burn coal, oil, or natural gas. Use notebook paper to answer the questions at the end of the chapter. Don't forget to sign, date, and number each page. Insert the pages at this point in your *Engineer's Notebook.*

Initial ____ Date ____

DESIGN CHALLENGE

Choose an Energy Source for a Lighthouse



Prepare a written proposal that shows your choice of an energy source for the lighthouse. Be sure your proposal has the following parts:

1) **Define the problem.** List at least three criteria for choosing the best energy source for a lighthouse.

2) **Conduct Research.** You have already done considerable research in completing this task. What are the pros and cons of each possible choice? Include a chart like the one below. You can also list any another possibility that may have occurred to you.

3) **Generate alternative solutions.** Select two of the choices that you think are best. Explain why you think those ideas would be best, and how you would go about comparing them further to determine which is the best way to provide energy to a lighthouse.

4) **Choose the best solution.** Which of the ideas do you think will be the best solution? Explain your choice. Write a report.

	Pros	Cons
Batteries		
Solar cells		
Diesel-electric generator		
Wind generator		
Other		

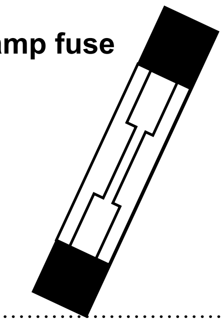
Rubric for Choose an Energy Source for a Lighthouse

	✧✧✧✧	✧✧✧	✧✧	✧
Design Process	Clearly defines the problem, with 3 or more criteria.	Problem definition acceptable, some criteria included.	Poor problem definition, some effort at criteria.	No problem definition or criteria.
Research	Pros and cons accurate and listed for each possible choice.	Chart filled out, some key information missing.	Chart poorly filled out, some correct information.	No comparison chart.
Alternative Solutions	Clearly describes alternatives and why they were rejected.	Alternatives described and some reasoning given for choice.	Alternatives briefly described.	Alternatives not considered.
Communication	Proposal clearly written, logical choice very well-supported.	Gives justification, but not why choice is better than others.	Proposal poorly written, choice not fully supported.	Poorly executed overall.

Initial ________________ Date ___________

Benchmark

An engineering student designed a system for a lighthouse with five 500-watt bulbs. She wired them in parallel so that if one burned out the others would stay on. She calculated that a 10-amp fuse would be needed to protect the circuit. However, when she switched the lights on, the fuse blew out. Check her calculations to see where she went wrong. Use a separate sheet of paper to show your work.



1) The student calculated that one 500-watt bulb would draw 4.17 A, given that the voltage supplied to the lighthouse was 120 volts. Write the correct formula and check her calculation.

2) The student calculated that each bulb must have a resistance of 28.8 Ω. Write the correct formula and check her calculation.

3) Finally, she found the resistance of five bulbs wired in parallel to be 144 Ω. She then calculated that a 10-amp fuse would be sufficient. Write the correct formula and check her calculation.

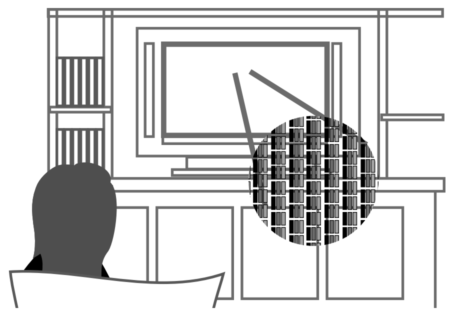
4) What would you tell the student to explain why the fuse blew out, and how to wire the lights properly so they will provide enough illumination for the lighthouse, without burning a fuse?

Initial ______________ Date ___________

TASK 4.8 Analyze Consumer Electronics

- Explain how a color TV display works.
- Analyze consumer electronics.
- Explain why LEDs are better than light bulbs for many applications.
- Use a multimeter to measure current, voltage, and resistance.

By now you know enough about electricity and communications to examine a wide variety of devices to see how they work. In this final task, you'll examine a television display and build a circuit for a single color pixel. You'll then learn how to use a multimeter to find out why LEDs are so important in today's electronics industries. Finally, you'll analyze competing consumer products to determine which are better and why.



Examine a TV Display

Use a magnifier to examine a color TV display or a color computer monitor. A fairly high-power magnifier is necessary, at least 10X (which means it makes things look ten times as large as they actually are). If you can do this in a store, you can compare the appearance of a LCD (Liquid Crystal Display) TV, a Plasma TV, and an older tube-type television. Pay careful attention to the colors that you see up close when the screen display is white.

1) Describe what you see when looking at a magnified view of a color TV display.

2) When the picture is white, what do you see under magnification?

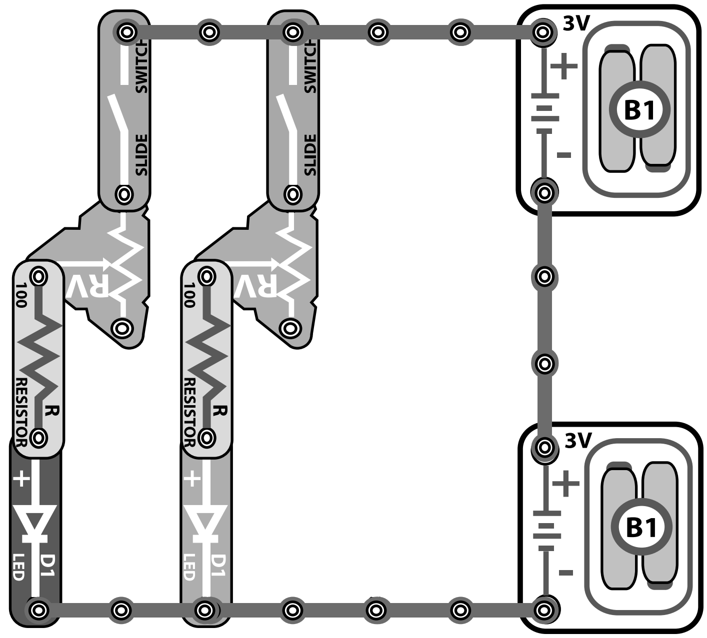
3) What colors do you actually see on the screen when you look up close?

4) How do you think color TV displays manage to show so many different colors at once?

Building the One-Pixel Circuit

As you probably observed, color TVs do not really display millions of colors. They display dots composed of just three colors. By changing the brightness of each of the three colors, the TV “fools your eye” into thinking it is looking at a different color.

Each element of three colored spots is called a “pixel.” Displays with more pixels appear sharper and clearer because all of the dots blend together so you don’t see the individual pixels. A 1-megapixel digital camera has 1 million pixels in each picture.



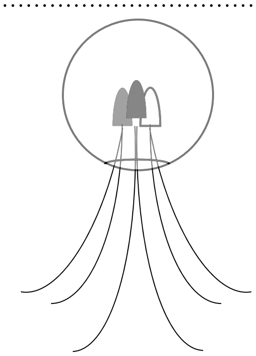
1) Build the circuit shown at the right using a red LED and a green LED. In an actual circuit you would have three colors, to display a pixel. Like a TV, there are two ways to control the LED. What are they?

2) Which colors would you combine to form a purple light pixel?

3) Is this a parallel circuit or a series circuit? __________

How do you know?

4) **Optional:** If you can obtain red, blue, and green LEDs that are not mounted in Snap Circuits™, a white ping pong ball, and wires, you can drill a hole in the ping pong ball, insert the LEDs, and connect them to the circuit with wires. With some adjustment, the ping pong ball will glow with different colors as you manipulate the controls. You could also experiment with other ways to combine the three colored LEDs into a single spot.



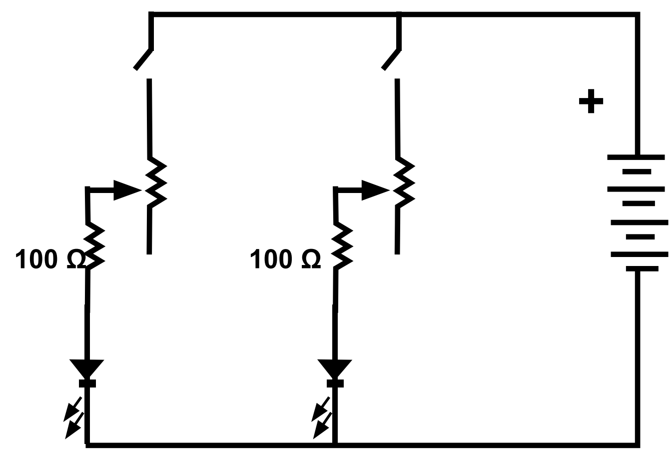
The One-Pixel Circuit

1) On the schematic diagram at right, draw a single position where you could connect the ammeter to measure the total current in the circuit with one or two LEDs lit up.

2) Connect the ammeter, set on HIGH. Turn the LEDs on one at a time, to their maximum brightness. How much current do they draw? (Remember, when set on HIGH the ammeter reads 1 amp, or 1,000 mA, so each of the ten divisions is 100 mA.)

- 1 LED __________ mA
- 1 Light bulb __________ mA
- 1 LED + 1 light bulb _________ mA

What do you think the current would be for 3 LEDs? _______ mA



Schematic diagram of the circuit

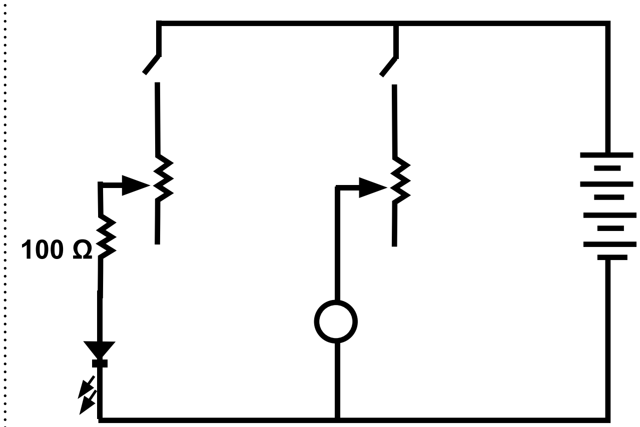
Why Are LEDs Replacing Bulbs?

Light Emitting Diodes (LEDs) are used in hundreds of different devices, from road signs to stop lights to televisions. To see why LEDs are replacing light bulbs in many applications, replace one of the LEDs and its 100Ω resistor with a light bulb.

1) Turn on all switches, and set both variable resistors to maximum. Turn down the variable resistor connected to the light bulb until the light bulb is approximately the same brightness as the LED.

2) Turn off all switches and connect the ammeter set on HIGH. Turn on each switch separately to see the current drawn by:

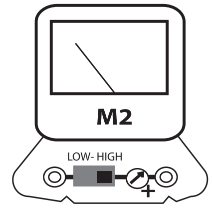
- 1 LED __________ mA
- 1 Light bulb __________ mA
- 1 LED + 1 light bulb _________ mA



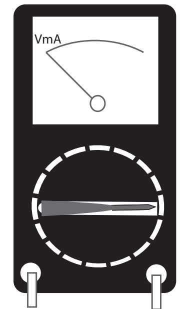
3) Look at the different values for current for the different circuits you created. What does this result suggest for why LEDs are replacing light bulbs in many applications?

Using a Multimeter

The basic ammeter in your kit measures current, but it is not very accurate. Multimeters can measure current, voltage, and resistance much more accurately. As soon as you learn how to use a multimeter, you will find it's handy for lots of applications.



Basic ammeter



Multimeter

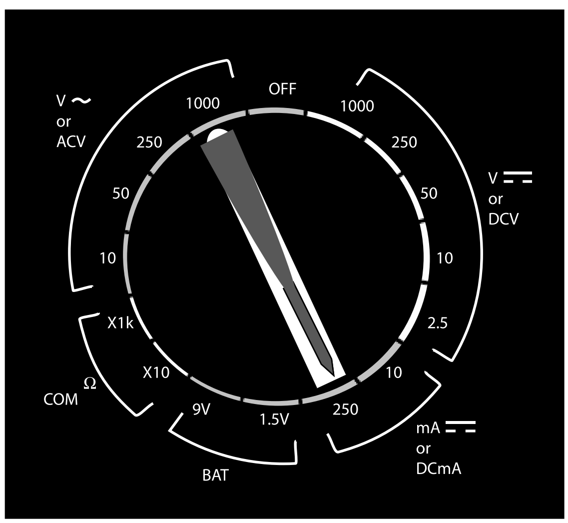
Multimeter: An instrument designed to measure current, voltage difference, and resistance.

Choose a Function

The first thing to do when using a multimeter is to set the dial, called the **range switch,** to measure current, voltage, or resistance, depending on what you want to measure. The different positions of the switch also allow you to choose a range (like the HIGH and LOW settings on the ammeter that comes in the Snap Circuit™ kit). An example of one multimeter is shown below.

Voltmeter (V~)
Measures alternating current (AC) voltage difference in volts.

Ohmmeter (Ω)
Measures resistance of an unconnected component (in ohms).



Battery (BAT)
Used to determine whether a battery is good or needs to be replaced.

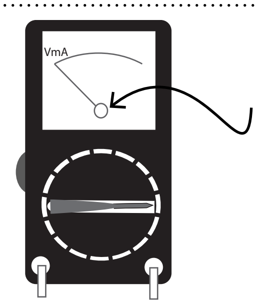
Voltmeter V (---)
Measures direct current (DC) voltage difference in volts.

Ammeter (mA)
Measures current in milliamps.

Safety Rules

Caution! These procedures are intended for low-voltage DC circuitry. DO NOT use with higher-voltage AC outlets!

Notice the "needle zero adjust," a screw at the bottom of the needle. Look at the multimeter your instructor gives you, and check to see that the needle is at zero when not connected to anything. If the needle is not at zero, adjust it using a screwdriver. It is good practice to check the zero when you start using any multimeter. The zero adjust knob on the side of the multimeter is for measuring resistance only.



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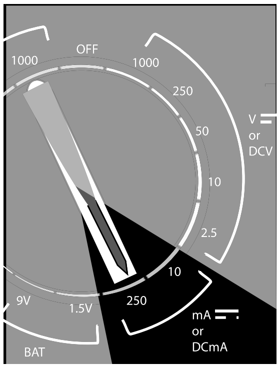
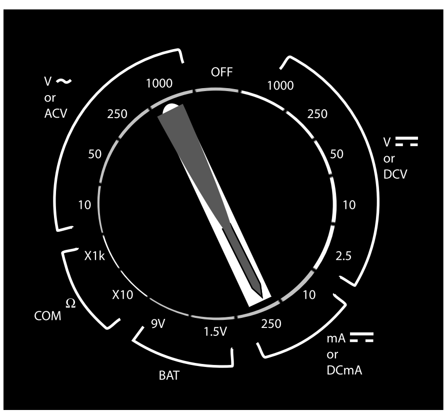
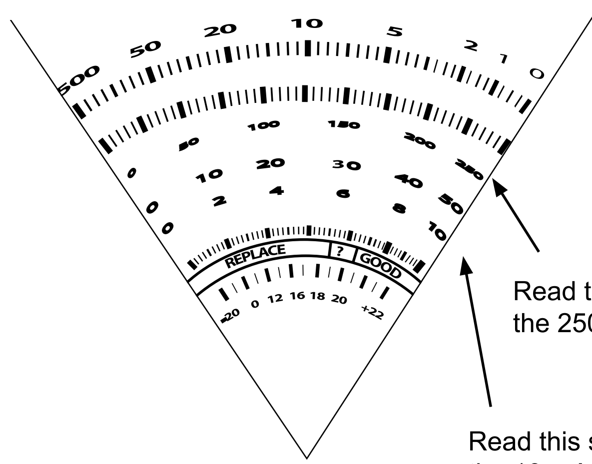
The Ammeter Function



The ammeter has a certain range, which goes from zero to some maximum amount of current. Most multimeters allow you to choose a range. Ranges of zero to 10 mA or 250 mA are common. If the current being measured is at the maximum of the range, the needle will swing all the way to the highest mark on the scale, called **full-scale deflection.** If the current is higher, the needle will swing past the highest mark and hit the pin. And if the contacts are reversed, the needle will swing to the left and hit the pin. Look at the range options on your multimeter. Set the range to 250 mA, or some value close to that.

Reading a multimeter can be quite confusing. There are lots of settings on the dial and lots of numbers printed on the display scale. The ammeter ranges are labeled "mA" (for "milliamp," 0.001 A) on most multimeters.





Read this scale for the 250 mA setting.

Read this scale for the 10 mA setting.

On the multimeter pictured here, there are two range settings:

- **250 mA** is the HIGH setting. It will measure currents from 0 to 250 mA.
- **10 mA** is the LOW setting. It will measure currents from 0 to 10 mA.

Read just the results on the scale that corresponds to the dial setting.

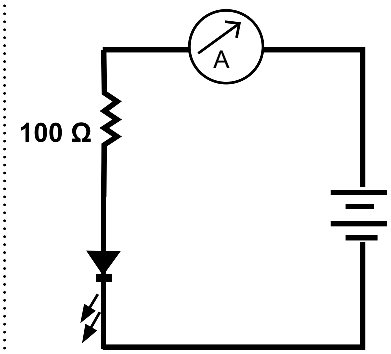
Start with the multimeter at the highest ammeter range. Briefly connect it in series with the circuit component whose current you want to measure, with the positive input (should be the red probe) connected to the positive side of the battery.

If the needle goes out of range, STOP! The current is too large to be measured by your multimeter. But if the needle barely moves, then try a lower setting.

If the needle rotates the "wrong" way, switch the probe connections. The ammeter is connected backward.

Practice Using the Ammeter

1) Build the circuit shown at right. First use the M2 ammeter to measure the current. Then use the multimeter to measure the current.



A. Which range did you use on the M2 ammeter, HIGH or LOW?

B. What is the current when the LED lights up?

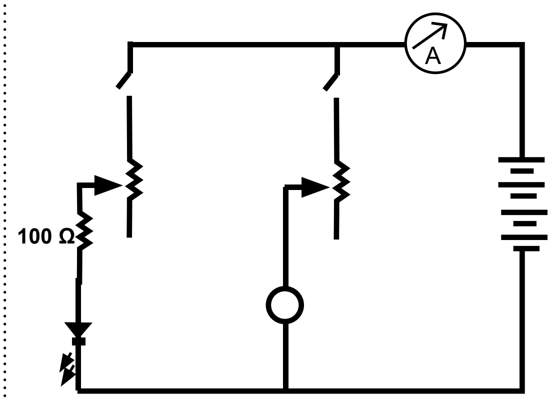
2) Now replace the M2 ammeter with the multimeter.

A. Which range did you use on the multimeter, 250 mA or 10 mA?

B. What is the current when the LED lights up?

C. Which gives you the most accurate measurement?

3) Connect the multimeter in the same place that you previously connected the M2 ammeter in the Snap Circuit™ kit, using the black and red probes to complete the circuit.



A. Try each separately to see the current drawn by:

- The LED ________mA
- The light bulb ________mA
- The LED and light bulb ________mA

B. How do these results differ from the measurements using the ammeter in the Snap Circuits™ kit?

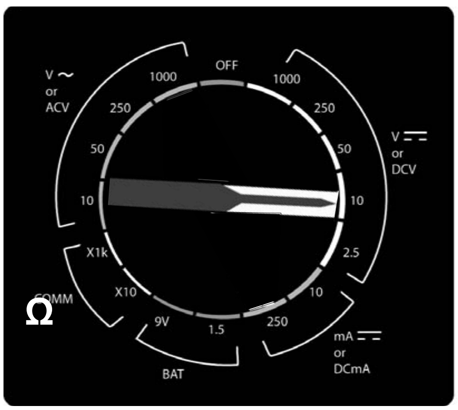
4) Put together a circuit of your own design, and use the milliamp range of the multimeter to measure current. Draw a schematic diagram of the circuit and write the results here.

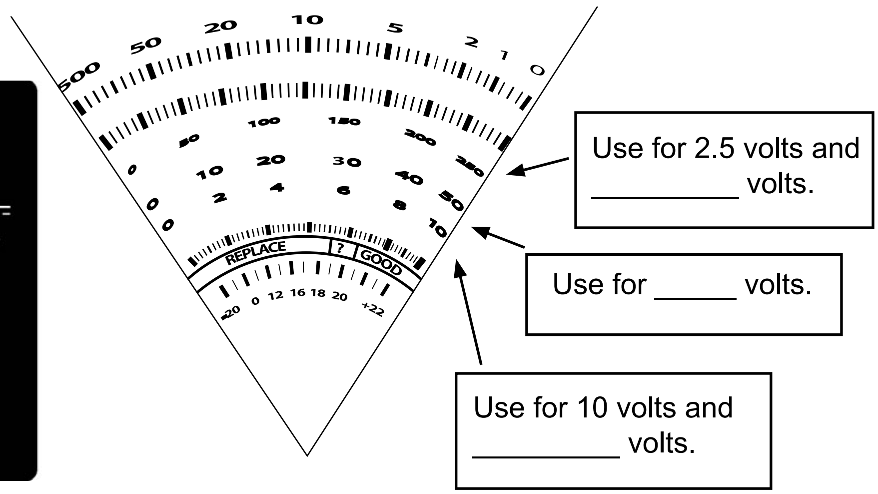
Initial ______________ Date __________

The Voltmeter Function

On the multimeter pictured below, there are five ranges for the voltmeter section. The lowest range is from zero to 2.5 volts, the highest is from zero to 1,000 volts. In the drawing below, the range switch is set to 10 volts.

1) As with the ammeter, changing the range also changes the scale used to read the voltage. For this multimeter, the printed voltmeter scale is the same one used for the ammeter, as there is both a “V” and a “mA” next to it. But there are five ranges and only three scales. Write in the boxes to show which scale you would use for the different voltage settings. The 2.5-volt and 10-volt scales are done for you.





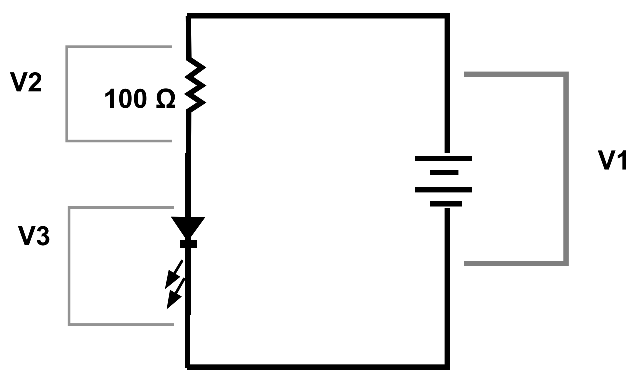
2) Build the circuit at right. The LED should light up. Use the multimeter voltmeter function to find the voltage differences: V1, V2, and V3.

V1 = _________

V2 = _________

V3 = _________

What do you notice about how these three voltages relate to each other? How can you explain it?

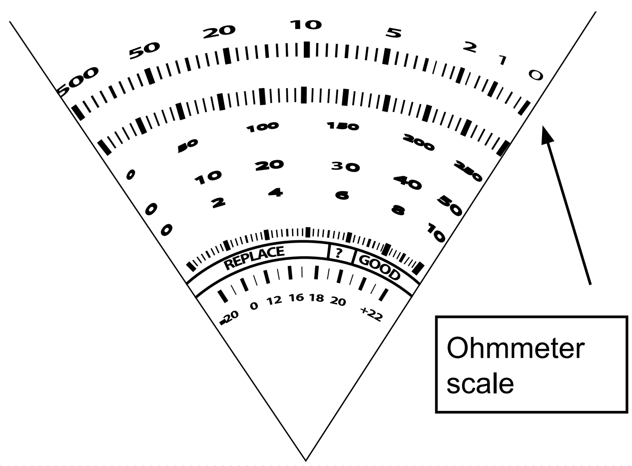


3) From previous activities, you know how a voltmeter is made. What is the object inside that allows the ammeter to be used as a voltmeter?

The Ohmmeter Function

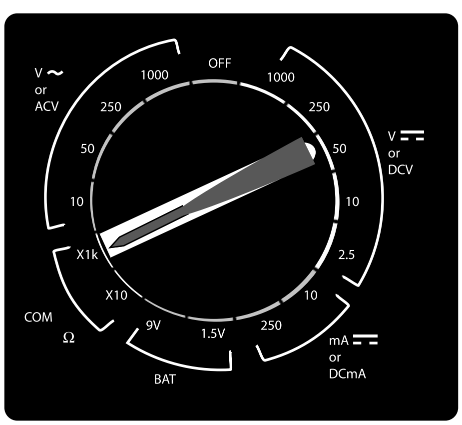
The ohmmeter function measures resistance. Unlike the ammeter and the voltmeter whose scales increase from left to right, the ohmmeter scale increases from right to left. Find the ohmmeter scale (also marked with an Ω).

Set the dial of the multimeter to the ohmmeter section (usually marked with an Ω), and then touch the probe tips to each other so that resistance is zero. This causes the needle to deflect all the way to the right. If the needle does not point to the zero on this scale, you will need to “zero” the Ohmmeter, as explained below.



While the probe tips are touching each other, turn the zero-ohm adjustment knob (usually marked “0ΩADJ”) until the needle points to zero. When you separate the probe tips, the circuit is opened, and there is now a resistance with “infinite ohms.” So the scale range is from 0Ω on the right, to infinite ohms on the left. Most conducting materials will test near the low end, while non-conducting materials will test near infinity.

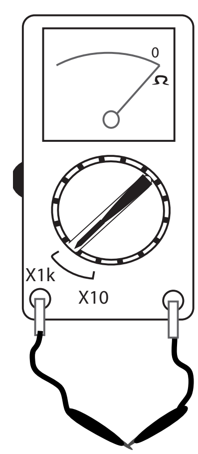
Beacuse the ohmmeter provides its own energy source, components should be tested when not connected to a circuit. **If the component you want to test is incorporated in a circuit, you will need to remove it from the circuit to test it.**



NOTE: You will need to zero-adjust the meter each time you change the ohm setting.

Practice Using the Ohmmeter

1) Switch the multimeter to the ohmmeter function, selecting a setting similar to “X1k” (which means that the ohmmeter reading is multiplied by 1,000, giving the answer in Ω). Touch the probes together and zero-adjust the needle to 0Ω.



Initial ______________ Date __________

2) Measure the resistance of the three different resistors in your kit. You'll know that you're using the correct scale if the reading on the ohmmeter corresponds to the value indicated on the components.

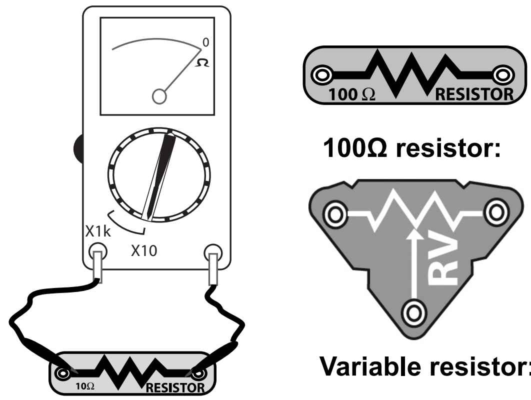
3) When you measure the resistance of the variable resistor (potentiometer), which scale do you find most helpful?

Ω × ________

4) How do you know that is the best scale to use?

5) What is the lowest resistance of the variable resistor?

________ Ω



6) What is the highest resistance of the variable resistor?

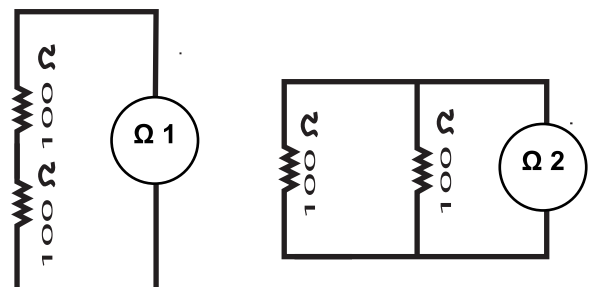
________ Ω

7) Use the ohmmeter function of your multimeter to measure the resistance of these circuits. Remember to disconnect the resistors from the battery.

First, predict what you think you'll observe.

A. What do you predict will be the total resistance of two resistors wired in series? What do you measure?

B. What do you predict will be the total resistance of two resistors wired in parallel? What do you measure?



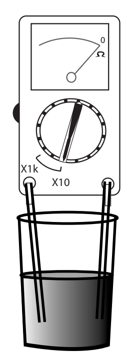
Ω 1 =

Ω 2 =

Predict	**Measure**
________ Ω	________ Ω
________ Ω	________ Ω

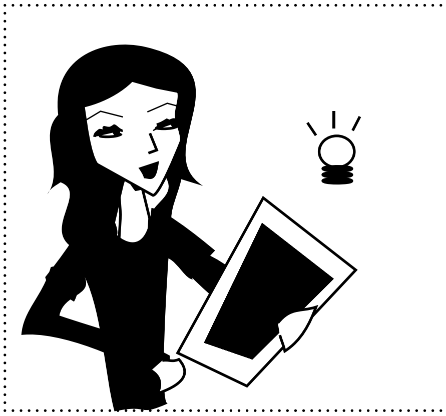
8) Explain why two resistors wired in parallel have a different resistance from two resistors wired in series.

9) Use your ohmmeter to measure the resistance of a glass of water. Then add some salt or vinegar to see if it changes the resistance. Describe your findings.



 Name ____________________

DESIGN CHALLENGE



Analyze Flashlight Designs

You have been hired by a major hardware store chain to determine which type of flashlight to purchase for sale in their company stores. This will be a million-dollar purchase, so you want to be thoughtful and thorough. Study the flashlights that have been submitted for your analysis. Use any of the materials in your kit and feel free to experiment with additional materials to make recommendations on how the designs might be improved.

- Make a list of criteria and constraints for an excellent flashlight.
- Take apart each device to see how it works. Draw a schematic diagram showing how the components are connected. Label each diagram with voltage, current, and resistance.
- Create a single chart that displays the information about each device.
- Discuss with your teammates which flashlight is best. You may modify your list of criteria and constraints.
- Write a brief summary of your analysis for each different flashlight. Include your diagram, and discuss how it meets or fails to meet the criteria and constraints. Conclude with a recommendation for which is the best flashlight and why.

Rubric for Analyze Flashlight Designs

	✧✧✧✧	✧✧✧	✧✧	✧
Design Process	Clearly identifies thinking at each step.	Shows some thought at each step.	Few notes, sketches of steps followed.	No notes on steps followed.
Circuit Design	Innovative use of a variety of parts, thoughtful about potential use.	Good design chosen from several alternatives.	Simple design with no alternatives proposed.	No circuit designed.
Communication	Schematic diagram accurate and easy to interpret. Functions and benefits clearly explained.	Schematic diagram is accurate. Explanation has errors or is incomplete.	Schematic diagram has errors. Explanation has errors or is incomplete.	Missing either schematic or written explanation.

Initial ____________ Date ____________

You Will Engineer the Future!

You might want to consider a career in engineering. If you do, you might have a wide variety of assignments. For example, you could be asked to compare different electronics for use by a rock band, to supply members of a mission to rescue someone from an underground cave, or to support troops on the battlefield. If you choose to become an engineer, you will be the person making those decisions. And as you know, there are many other kinds of engineers who make decisions about the world around us every day, from selecting material for a new paperclip, to designing a support structure for the world's biggest skyscraper.

As you consider what you may want to do in the future, keep in mind the following information:

- Next to teachers, engineers make up the largest profession in U.S. society today, and the percentage of engineering jobs will continue to grow in the forseeable future.
- Many organizations with science missions employ a large number of engineers. NASA, for example, employs ten engineers for every scientist.
- Engineers tend to be paid well—somewhat more, on average, than scientists.
- Becoming an engineer is not easy. Most engineering positions require a four-year college degree, and many engineers go on to earn graduate degrees.

If you decide that an engineering career is not for you, then the work you have done in this course will help you understand the world around you. And the choices you make as a citizen and consumer will determine what technologies are produced, and what they will be like. In a very real and important sense, you will engineer the future!