Chapter 4

Conductors and Insulators

Introduction

We have seen in earlier activities that electricity flows through a complete path called a circuit. Within a circuit, electricity flows through conductors. Conductors are materials through which electricity can flow. Insulators, on the other hand, block the flow of electricity. Insulators are materials through which electricity *cannot* flow.

The properties of both types of materials—conductors and insulators—are useful.

In this chapter we'll investigate which kinds of materials and objects are good conductors and which are insulators.

Goals of this Activity

When you have completed this Activity, you will be able to:

1. Describe the difference between electrical conductors and insulators.
2. Identify electrical conductors and insulators through experimentation.
3. Describe why it is important to have both conductors and insulators.

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Chapter 4

In this chapter you will introduce your students to the concepts and practical uses of conductors and insulators. We learned earlier that electricity flows through a circuit. But what is a circuit made of? Here we'll explore what circuits are made of (conductors and insulators) in order for electricity to safely flow.

As you work through this chapter, keep in mind that:

1. Electricity flows through Conductors which are usually made of metal.
2. Electricity does not flow through Insulators which are usually non-metallic.

National Science Education Standard (NSES) K-4 Content Standard B, Light, Heat, Electricity, and Magnetism:

- *Electricity in circuits can produce light, heat, sound, and magnetic effects. Electrical circuits require a complete loop through which an electrical current can pass.*

NSES 5-8 Content Standard B, Transfer of Energy:

- *Energy is a property of many substances and is associated with heat, light, electricity, mechanical motion, sound, nuclei, and the nature of a chemical. Energy is transferred in many ways.*
- *Electrical circuits provide a means of transferring electrical energy when heat, light, sound, and chemical changes are produced.*

Ask your students to read the passage "To Flow or Not to Flow" before starting a discussion. Start the discussion by revisiting the definition of a circuit: A path through which electricity flows.

Your students may recall you've already used the word **conductor** in your discussion of circuits. So you can ask, "Physically, what does the electricity flow through in a circuit?" You may get a variety of answers such as the wires, snaps, metal, loads, etc. They are all correct because they are all conductors.

Conductors are typically made of metal. However, there are some non-metallic conductors such as the graphite in pencils and salt solutions such as salt water which you'll have the chance to demonstrate at the end of the chapter.

We learned earlier that electricity is the flow of electrons. Electrons are negatively charged sub-atomic particles (extremely tiny parts of an atom). They travel in orbits around the protons and neutrons of an atom's nucleus much like the planets in our solar system travel in orbits around the sun. Metals don't hang on to their outermost electrons very strongly. So, when an electrical charge is applied across a conductor it causes these loosely held electrons to move from one atom to another to another, etc. thus creating a flow of electrons.

As mentioned in Chapter 3, charge is often referred to as electrical potential and is measured in volts (V) and the current flow is measured in amps (A).

We'll learn in Chapter 8 that the flow of electrons also produces an electromagnetic field around the conductor.

All materials, even conductors, impede (oppose) the flow of electrons, some more than others. This opposition to flow is called

To Flow or Not To Flow

We know that electricity flows in a path called a circuit. Without a complete circuit, electricity cannot flow. If it does not flow, electricity cannot do work such as lighting a lamp, powering a computer, or turning a motor.

However, experience tells us that electricity doesn't flow through everything. If it did, we'd get an electric shock every time we turned on a lamp, touched a computer keyboard, or picked up a battery.

Electricity flows through objects that are conductors and doesn't flow through objects that are insulators. Good conductors are generally made of metal such as copper, aluminum, silver, gold, brass, tin, and lead. Good **insulators** are often made of glass, plastic, rubber, ceramic, or cloth.

Insulators are useful for separating electricity from objects and living things that it could damage. In the picture at the left, power lines are separated from the metal tower by a stack of ceramic insulators.

Insulators also protect electric circuits from objects that could interfere with the proper functioning of the circuit. Most importantly, insulators are necessary for health and safety because they separate people from electricity. For example, the conductor in most appliance power cords is copper wire, but it is surrounded by insulating plastic so that we can safely touch a plugged-in cord.

In this Activity we experiment with different kinds of materials and objects to identify good conductors of electricity, poor conductors of electricity, and insulators.

We will build a working circuit using a lamp as our load. Then we will test different objects to see if they are conductors or insulators. Some of the objects have been supplied in this KitBook. You will also be asked to find other objects to test and record your results. If the lamp lights up with the object in the circuit, then the object is a conductor. If the lamp doesn't light up, the object is an insulator.

Definitions and Symbols

Conductor

Electricity flows through conductors. Conductors are usually made of metal. Copper, aluminum, silver, and gold are good conductors. The PowerPage in this KitBook uses copper wire and steel snaps for conductors. A conductor is the opposite of an insulator.

Insulator

An insulator is a material, usually non-metallic, that partially or completely blocks the flow of electricity (and heat, too). Plastic, rubber, leather, glass, and ceramic are good insulating materials. An insulator is the opposite of a conductor.

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resistance and is measured in Ohms, symbol Ω (the Greek letter Omega). It is named for German physicist Georg Simon Ohm (1789-1854) who discovered the relationship between current, voltage, and resistance. Good conductors have low resistance.

Ask your students, "If current flows through conductors, what does it not flow through?" The answer is **insulators.** Insulators are materials that hold on to their electrons tightly. Good insulators have a very high resistance and block the flow of electrons completely, thus there is no current.

Now ask your students, "What good is an insulator if it cannot conduct electricity?" The answer is that insulators can be used to separate conductors from each other and from living things. For example, insulators protect electrical circuits from coming in contact with conductive objects that could damage or alter the operation of the circuit. Similarly, insulators safely protect objects, people, and animals from coming in contact with electrical current that could be harmful. Without insulators we could not safely plug in electric appliances or touch them when they are plugged in.

It is also interesting to note that materials which are good conductors and insulators of electricity are also good conductors and insulators of heat. For example, coffee cups are not generally made of metal but of ceramic, glass, Styrofoam, or plastic so they can be comfortably held.

Activity 5

STEP 5: Use a jumper wire to connect the right side of position 1 to its left side. Does the lamp light up? **Yes.** Is the jumper wire a good conductor? **Yes, the wire is copper and the alligator clips are steel.**

Activity 5 Conductors and Insulators

You will need these parts in order to complete this Activity:

- 1 Battery
- 1 Lamp
- 1 Penny
- 1 Slide switch
- 2 Jumper wires with alligator clips
- 1 Rubber band
- Conductors
- Insulators

1 Place the battery in Position 5 with the positive terminal on the right.

2 Place the slide switch in Position 4.

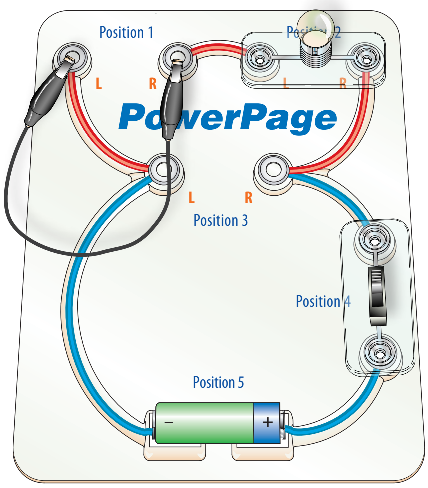
3 Make sure the switch is in the ON position.

4 Place a lamp in Position 2.

5 Use a jumper wire to connect the right side of Position 1 to its left side. Does the lamp light up? Is the jumper wire a good conductor?

6 Remove the alligator clip from Position 1L and clip the other jumper lead into 1L.

This is where we will connect objects to determine whether they are conductors or insulators, as shown in the figure on the next page.



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Activity 5 Conductors and Insulators (continued)

7 Attach the alligator clips to a penny. Does the lamp light up? Is the penny a conductor or insulator?

8 Remove the penny and replace it with a rubber band. Does the lamp light up? Is the rubber band a conductor or an insulator?

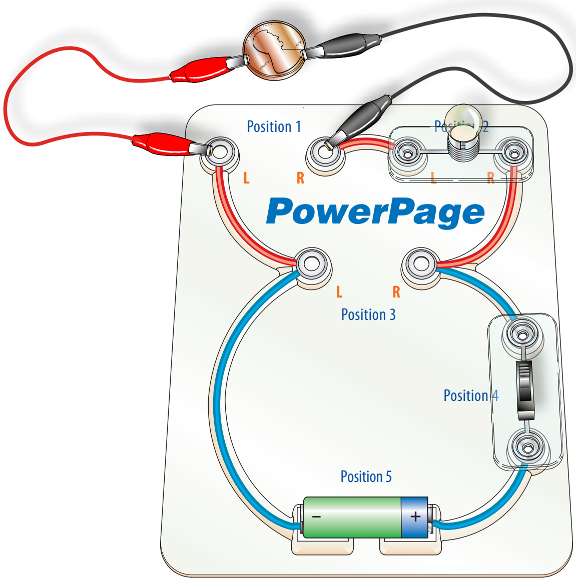
9 Remove the rubber band and replace it with the straw, then a paper clip, and then the craft stick. Does the lamp light up? Which of these objects are conductors? Which are insulators?

10 Now try at least four different objects available in the classroom.

Record your observations on a separate sheet of paper. Draw a picture of each object and label whether it is a conductor or an insulator.

11 Turn off the switch. Remove all parts and return them to the tray. Put all the conductors and insulators you tested back where you found them.

12 Go on to the reading and questions at the end of the chapter when you are ready.



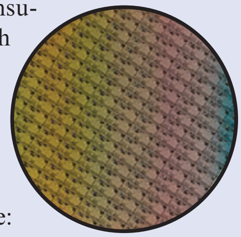
STEP 7: Attach the alligator clips to a penny. Does the lamp light up? **Yes.** Is the penny a conductor or insulator? **Conductor, the outside of a new (since 1982) penny is copper and the inside is zinc.**

STEP 8: Remove the penny and replace it with a rubber band. Does the lamp light up? **No.** Is the dubber band a conductor or an insulator? **Insulator.**

STEP 9: Remove the rubber band and replace it with the straw, then a paper clip, and then the craft stick. Does the lamp light up? **No, Yes, No.** Which of these objects are conductors? **Paper clip.** Which are insulators? **Straw and craft stick.**

STEP 10: A reproducible Conductors and Insulators Worksheet can be found at the end of the book and can be freely copied for classroom use.

Did You Know?



Some materials are good conductors and some are good insulators. But there is also an important class of materials with unique electrical properties known as *semiconductors.* These materials have physical properties somewhere in between a conductor and an insulator. They carry electricity moderately well—not well enough to be called a conductor like copper wires, but not poorly enough to be called an insulator like a piece of glass. Hence, their name: semi-conductor. Examples include germanium and silicon.

Because of their unique properties, semiconductors can perform special functions that have led them to become the basic building blocks of modern electronics.

Transistors, invented in 1947, were the first practical applications of semiconductors. Since then, every major electronic invention has been made possible by the transistor. In 1958, a huge breakthrough took place with the invention of the integrated circuit—the microchip—consisting of thousands of interconnected transistors. Microchips took the transistor innovation to an exciting new level and gave rise to the Information Age.

Questions

1. Can you tell if an object will be a good conductor or insulator just by looking at it? How?
2. Why is it just as important to have insulators as it is to have conductors?
3. Name three examples of insulators used in electrical devices at home and in the classroom.

Challenges

1. Who was Georg Ohm and for what is he best known?
2. Research and write a short paper (less than one page in length) about the history of the transistor. Who invented it and why?
3. Who was Jack Kilby and what was his most important contribution to society?

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Questions

1. Yes, most of the time. If it is metallic it is likely to be a good conductor. If it is non-metallic it is likely to be a good insulator. Most metals are solids at room temperature, except mercury. It is a good conductor and has many unique uses.
2. Insulators protect us and other living things from electric current flowing in conductors. Without insulators we wouldn't dare touch a car battery, screw in a light bulb, or flip on a switch.
3. 1. Plastic insulation on electrical cords; 2. plastic housings on appliances, phones, computers, and monitors; 3. plastic buttons and knobs used on switches; 4. glass on light bulbs

Challenges

1. George Simon Ohm was born in Erlangen, Germany March 16, 1789 and died at the age of 65 on July 6, 1854 in Munich, Germany. He expanded on the work of Volta and discovered that the current passing through a conductor is directly proportional to the voltage across it and inversely proportional to the resistance of the conductor. He was the first to describe this fundamental relationship between current, voltage, and resistance, hence it is known as Ohm's law. Simply put, Ohm's law states that the Voltage (V) in a circuit equals the Current (I) times the Resistance(R). Stated algebraically, $V=IR$. It can also be represented as $I=V/R$ and $R=V/I$. So if we know any two values we can solve for the third. This formula is one of the most useful and widely used formulas in electric circuit design and analysis.

2. Semiconductors are materials with unique electrical properties somewhere in between conductors and insulators. They are neither insulators nor conductors. They carry electricity moderately well, hence their name: *semi*-conductors. Examples include germanium and silicon.

   Dr. John Bardeen, Dr. William Brattain, and Dr. William Shockley discovered the transistor effect and developed the first transistor device while members of the technical staff at Bell Labs in Murray Hill, New Jersey in December 1947. Thus, the first important use of transistors was in telephone equipment.

   Transistors have the ability to control their own semiconducting ability. They can act like a conductor when needed or as an insulator when that is needed. Because of this they are used for two basic functions: as switches and as modulators (often used as amplifiers).

   The transistor is the basic building block of the modern electronic devices that define our age and has spawned innumerable new products, companies, and even whole industries.

   Many useful sources of information about the transistor can be found in the library and on the internet, including
   www.alcatel-lucent.com. Alcatel-Lucent is the most recent successor of the original Bell Labs.

3. Jack St. Clair Kilby (November 8, 1923–June 20, 2005) invented the first semiconductor integrated circuit (IC) commonly referred to as a micro chip or just chip. The invention occurred on September 12, 1958 while Kilby was working for Texas Instruments.

   Kilby built upon the semiconductor and transistor Innovations of Bell Labs. His initial major work leading to the invention occurred during his first year as an employee. Interestingly and inspiringly enough, he was not yet eligible for a summer vacation and made good use of his time by making his breakthrough discoveries while others were on vacation.

   He was a prolific inventor throughout his career with over 60 patents to his credit including the first handheld calculator in 1967.

   Because of his inventiveness and contributions to society he earned numerous awards and public recognition including: the National Medal of Science in 1970, induction into the National Inventors Hall of Fame in 1982, and the Nobel Prize in Physics in 2000.

   He was born on November 8, 1923 in Jefferson City, MO. He held degrees in electrical engineering from the University of Illinois and the University of Wisconsin-Milwaukee. He died in Dallas, Texas at the age of 81 on June 20, 2005 after a short bout with cancer.

Chapter 4 Extension Activity

Metals aren't the only materials that conduct electricity. Salt solutions often make conductors as well. For safety reasons, electrical devices are kept away from water. Many appliances, such as hair blow dryers, have warnings on them about safe use near water. In this extension you can show your students why it is important for them to be careful with electricity around water.

CAUTION: Although this extension experiment is completely safe, it is important to point out to your students that this is not an experiment they should try themselves. Only the teacher or other responsible adult should attempt it so students don't get the idea that it is OK to work with electricity around water.

Also, do not collect the hydrogen gas and do not perform this experiment near an open flame.

You will demonstrate to your class that water can be a conductor. Since the average human body is around 70% water, it is important for all of us to be careful around electricity.

What you'll need:

- **1** glass jar (the size of a measuring cup or small jelly jar)
- **2** fresh AA batteries
- **4** jumper wires from KitBooks
- **1** full shaker of table salt.
- **2** conductors such as metal spoons (that you won't care ruining!)–or–two short lengths (at least 10cm [~4 inches]) of bare (un-insulated) copper wire from home or a hardware store,–or–two nails from KitBooks

STEP 1: Build a circuit similar to the insulator/conductor testing circuit in this chapter except instead of a fixed switch in Position 4 use two jumper wires to connect a second battery in Position 4 (as you did in Activity 4).

STEP 2: Touch the jumper wires together in Position 1 to make sure the bulb comes on. If not, make sure the batteries are pointing in the same direction such that the positive side of the first battery is electrically connected to the negative side of the second battery.

STEP 3: Connect a spoon to each jumper wire.

STEP 4: Fill the glass jar about two-thirds full with tap water.

STEP 5: Ask your students to predict what will happen when you insert the two spoons into the water. Will the lamp come on? **Answer: No, unless the spoons touch each other.**

STEP 6: Observe that the light is not on. Explain to your students that pure water alone is not a good conductor. But when impurities are added to the water they can become carries of the electric current. For example, sea water is about a million times more conductive than de-ionized water.

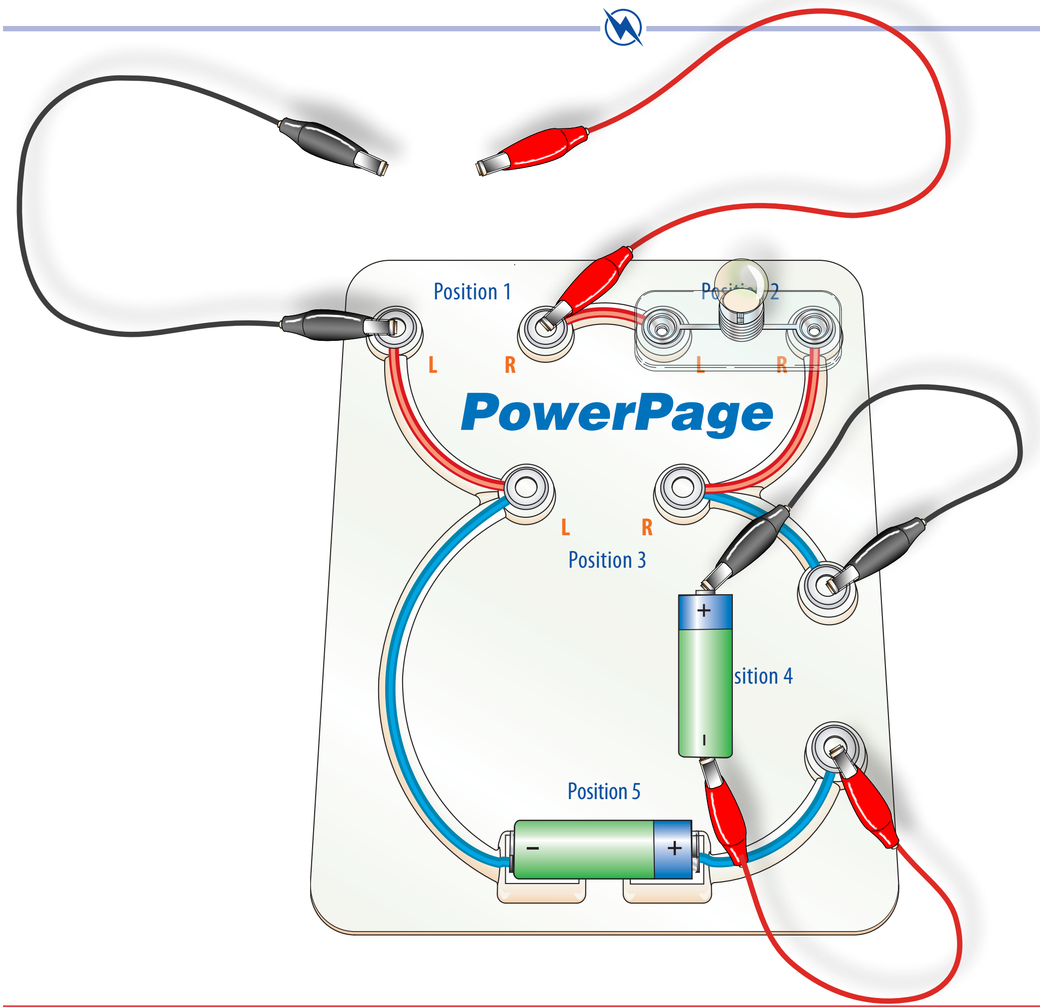
STEP 7: Now begin pouring salt into the water and stirring it with one of the spoons. The salt will dissolve into solution. The chemical composition of table salt is sodium chloride (NaCl). This experiment actually splits the salt into positive sodium ions Na^+ and negative chloride ions Cl^-. These ions become the charge carriers in the water.

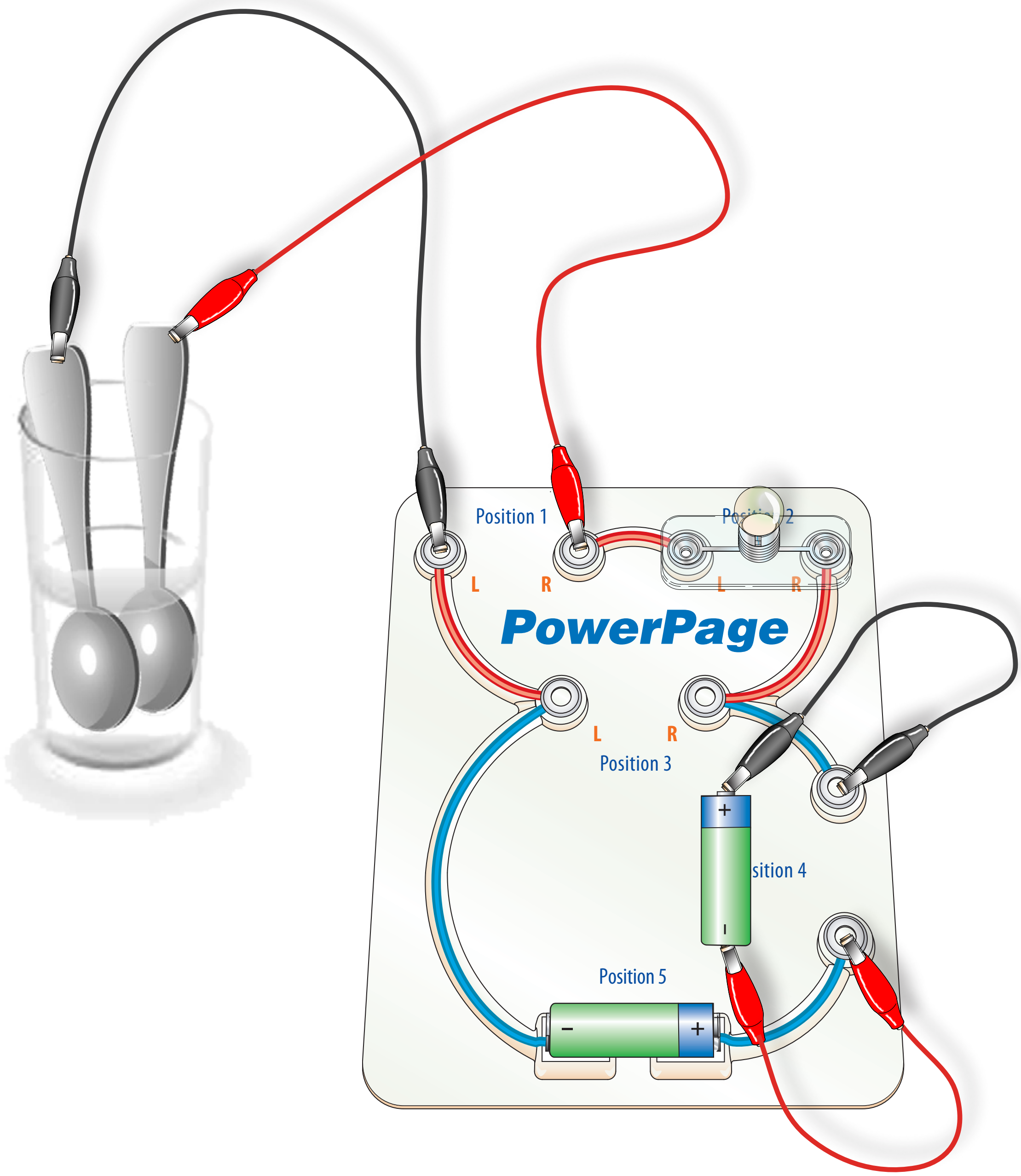
STEP 8: Have your students watch carefully (you may even want to dim the lights in the room), when enough salt is added to the water, the light will begin to come on and becomes brighter as more salt dissolves in the water.

STEP 9: When the bulb is lit, ask your students to predict what will happen when you move the spoons closer together but not touching. Answer: The lamp should burn brighter because of less resistance.

Your students may also observe bubbles forming around the spoons n the water. The water (H_2O) is being broken down into hydrogen gas at the cathode (spoon connected to the negative side of the battery) and oxygen gas at the anode (spoon connected to the positive side of the battery). Twice as much hydrogen will produced as oxygen and the total is proportional to the amount of charge through the water.

STEP 10: Disconnect the batteries, dispose of the water, and put all the parts away.

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