ELECTRICITY

A comprehensive course that teaches the big ideas behind Faraday and Maxwell's ground-breaking work. Students will discover how to design and test circuits, detect electric charge, learn about electrochemistry as they construct batteries, play with the static electric field, and uncover the mysterious forces that redefined the entire field of chemistry and physics when they were first discovered.

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This curriculum is aligned with the National Standards and STEM for Science.

Table of Contents

Introduction

Greetings and welcome to the study of Electricity. This unit was created by a mechanical engineer, university instructor, airplane pilot, astronomer, robot-builder and real rocket scientist… me! I have the happy opportunity to teach you everything I know about electricity over the next set of lessons. I promise to give you my best stuff so you can take it and run with it… or fly!

The scientific principles we're going to cover were first discovered by a host of scientists in the 19^{th} century, each working on the ideas from each other, most prominently James Maxwell and Michael Faraday. This is one of the most exciting areas of science, because it includes one of the most important scientific discoveries of all time: how electricity and magnetism are connected. Before this discovery, people thought of electricity and magnetism as two separate things. When scientists realized that not only were they linked together, but that one causes the other, the field of physics really took off.

To get the most out of these labs, there are really only a couple of things to keep in mind. Since we are all here to have fun and learn something new, this shouldn't be too hard.

One of the best things you can do as the student is to cultivate your curiosity about things. *Why did that move? How did that spin? What's really going on here?*

This unit on Electricity is chock full of demonstrations and experiments for two big reasons. First, they're fun. But more importantly, the reason we do experiments in science is to hone your observational skills. Science experiments really speak for themselves much better than I can ever put into words or show you on a video. And I'm going to hit you with a lot of these science demonstrations and experiments to help you develop your observing techniques.

Scientists not only learn to observe what's going on in the experiment, but they also learn how to observe what their experiment is telling them, which is found by looking at your data. It's not enough to invent some new kind of experiment if you don't know how it will perform when the conditions change a bit, like on Mars. We're going to learn how to predict what we think will happen, design experiments that will test this idea, and look over the results we got to figure out where to go from there. Science is a process, it's a way of thinking, and we're going to get plenty of practice at it.

Good luck with this electricity unit!

For the Parent/Teacher:
Educational Goals for Electricity

The scientific principles we're going to cover were first discovered by a host of scientists in the 19th century, each working on the ideas from each other, most prominently James Maxwell and Michael Faraday. This is one of the most exciting areas of science, because it includes one of the most important scientific discoveries of all time: how electricity and magnetism are connected. Before this discovery, people thought of electricity and magnetism as two separate things. When scientists realized that not only were they linked together, but that one causes the other, the field of physics really took off.

<u>Here are the scientific concepts:</u>

Static Electricity

- The proton has a positive charge, the neutron has no charge, and the electron has a negative charge. These charges repel and attract one another kind of like magnets repel or attract. Like charges repel (push away) one another and unlike charges attract one another. Generally things are neutrally charged. They aren't very positive or negative, rather have a balance of both.
- Objects that are electrically charged can create a temporary charge on another object.
- The triboelectric series is a list that ranks different materials according to how they lose or gain electrons.

Electricity

- When electric current passes through a material, it does it by electrical conduction.
- Metals are conductors not because electricity passes through them, but because they contain electrons that can move.

Electrochemistry

- There are different kinds of conduction, such as metallic conduction, where electrons flow through a conductor (like metal) and electrolysis, where charged atoms (called ions) flow through liquids.

<u>By the end of the labs in this unit, students will be able to:</u>

- Design and build simple series and parallel circuits by using components such as wires, batteries, and bulbs.
- Know how to demonstrate that electrically charged objects attract or repel each other.
- Know electrical energy can be converted to heat, light, and motion.
- Differentiate observation from inference (interpretation) and know scientists' explanations come partly from what they observe and partly from how they interpret their observations.
- Measure and estimate the weight, length, or volume of objects.
- Formulate and justify predictions based on cause-and-effect relationships.
- Conduct multiple trials to test a prediction and draw conclusions about the relationships between predictions and results.
- Construct and interpret graphs from measurements.
- Follow a set of written instructions for a scientific investigation.

Master Materials List for All Labs

This is a brief list of the materials that you will need to do *all* of the activities, experiments and projects in each section. The set of materials listed below is just for one lab group. If you have a class of ten lab groups, you'll need to get ten sets of the materials listed below. For ten lab groups, an easy way to keep track of your materials is to give each group a number from one to ten, and make up ten separate lab kits using small plastic tubs or baskets. Put one number on each item and fill each tub with the materials listed below. Label the tubs with the section name, like *Static Electricity Study Kit* and you will have an easy way to keep track of the materials and build accountability into the program for the kids. Copy these lists and stick them in the bin for easy tracking. Feel free to reuse items between lessons and unit sections. Most materials are reusable year after year.

Materials for Standard Labs

- 9V battery with battery clip (RS#270-325)
- AA batteries
- AA battery case (RS#270-408)
- Activated charcoal (from a fish store)
- Alligator clip wires (RS#278-1157)
- Aluminum foil
- Baking soda
- Balloon
- Brass fasteners, 8
- Bubble solution with wands
- CdS cell (RS#276-1657)
- Clock with second hand (or stopwatch)
- Copper strips, 3
- Copper sulfate (www.hometrainingtools.com)
- Cotton cloth
- Digital Multimeter(RS#22-182 or similar)
- Disposable cups
- Distilled water
- Distilled white vinegar
- Dried dill (spice)
- Dull nail (iron)
- Fresh fruit
- Glass jar (like a pickle or jam jar) with lid
- Goggles
- Graphite from inside a pencil
- Hobby motor, 1.5-3V DC (RS#273-223)
- Index cards
- Laser pointer or flashlight
- LED (RS#276-012)
- Lemon juice
- Long match
- Packing peanuts
- Paper clips
- Paper confetti (you can make your own)
- Paper towel
- Ping pong ball
- Plastic grocery bags
- Popsicle sticks for stirring
- Potentiometer (RS#271-1714)
- Propeller or piece of tape for motor shaft
- Real silverware (not stainless)
- Salt
- Scissors
- Shiny metal key
- Shiny nail (galvanized)
- Skillet
- Soap
- Soup spoon
- Steel wire (6", like picture hanging wire)
- Styrofoam plate
- Sugar
- Tape
- Test tubes, glass or plastic, 2 (www.hometrainingtools.com)
- Thin sponge (about 2″ square)
- Tub or pie plate to catch the drips OR a sink
- Unpainted steel tacks, 2
- Vegetable or mineral oil
- Water bottle
- Wood clothespin
- Wood screw (brass)
- Wool sweater or cloth
- Yard stick
- Zinc strip (www.hometrainingtools.com)

Materials for Advanced Bonus Labs

- 9V battery clip (RS #270-325)
- AA batteries, 4 (RS#270-408)
- AA battery packs, 2 (RS#270-408)
- Black felt
- Dry ice
- Fishing line or sewing thread
- Flashlight
- Foam cup
- Foam meat tray
- Fun Fly Stick by Uniteach Toys (www.unitechtoys.com/funflystick.html)
- Goggles
- Heavy gloves for handling the dry ice
- Long straight pin (longer than the film cans)
- Magnet
- MPF 102 (RS#276-2062)
- Neon bulb (Radio Shack (RS)#272-712)
- Paper clips
- Penny
- Relay (RS#275-206)
- Rubbing alcohol
- Small aluminum pie tart tins
- Small Styrofoam ball
- Soup cans
- Three film canisters or small containers with tight-fitting lids or corks
- Wire coat hanger

Lab Safety

Goggles: These should be worn when working with chemicals, heat, fire, or projectiles. These protect your eyes from chemical splatter, explosions, and tiny fast-moving objects aimed at the eyes. If you wear glasses, you can find goggles that fit over them. Don't substitute eyeglasses for goggles, because of the lack of side protection. Eyeglasses don't provide this important side eye protection.

Clean up Messes: Your lab area should be neat, organized, and spotless before you start, during your experiment, and when you leave. Scientists waste more time hunting for lost papers, pieces of an experiment, and trying to reposition sensitive equipment… all of which could have easily been avoided had they been taught organizational skills from the start.

Dispose of Poisons: If a poisonous substance was used, created, or produced during your experiment, you must follow the proper handling procedures for disposal. You'll find details for this in the experiments as needed.

Special Notes on Batteries: Do not use alkaline batteries with your experiments. Find the super-cheap kind of batteries (usually labeled "Heavy Duty" or "Super Heavy Duty") because these types of batteries have a carbon-zinc core, which does not contain the acid that alkaline batteries have. This means when you wire up circuits incorrectly (which you should expect to do because you are learning), the circuits will not overheat or leak. If you use alkaline batteries (like Energizer and Duracell) and your students short a circuit, their wires and components will get super-hot and leak acid, which is very dangerous.

No Eating or Drinking in the Lab: All foods and drinks are banned from your classroom during science experimentation. When you eat or drink, you run the very real risk of ingesting part of your experiment. For electricity and magnetism labs, always wash your hands after the lab is over to rinse off the lead from the electrical components.

No Horse Play: When you goof around, accidents happen, which means chemicals spill, circuits short, and all kinds of hazards can occur that you weren't expecting. Never throw anything to another person and be careful where you put your hands – it could be in the middle of a sensitive experiment, especially with magnetism and electricity. You don't want to run the risk of getting shocked or electrified when it's not part of your experiment.

Fire: If you think there's a fire in the room (even if you're not sure), let your teacher know right away. If they are not around (they always should be), smother the fire with a fire blanket or use a fire extinguisher and send someone to find an adult. Stop, drop, and roll!

Questions: If you're not sure about something stop and ask, no matter what it's about. If you don't know how to properly handle a chemical, do part of an experiment, ask! If you're not comfortable doing part of the experiment, then don't do it.

Section 1: Static Electricity

Electrons are strange and unusual little fellows. Strange things happen when too many or too few of them get together. Some things may be attracted to other things or some things may push other things away.

Occasionally, you may see a spark of light and hear a sound. The light and sound may be quite small or may be as large as a bolt of lightning. When electrons gather, strange things happen. Those strange things are static electricity.

A lot of folks get nervous around electricity. You can't always "see" what's going on. *"Will I get a shock when I touch that?"* Many people have a certain level of fear around anything electrical in general. I mean, electrons are really small, and you can't see electricity directly, but you can certainly detect its effects when you turn on a blender, ring a doorbell, or set your alarm clock.

Electricity is predictable, and everything we're about to do is completely safe. The voltages and amperage we're working with are *way* below the "caution" limit, and the batteries we recommend won't leak acid or singe fingers if your students connect them the wrong way. (Which by the way you should expect them to do because it's part of the learning process.) I am going to help you set up a safe learning environment so your kids are free to experiment without you losing sleep over it.

I'm going to walk you through every step of the way, and by working through the discussion questions, worksheets, and exercises, you'll learn not only how electricity works, but also how to use electrical components like switches and motors, dimmers and lights and also how to connect them together to build useful things like burglar alarms and robots. It's not enough just to learn about these ideas – students will get to practice them in a way that's useful and practical. That's when the learning really sticks to their brain.

Lesson #1: Static Hair

Overview: Greetings, and welcome to the study of electricity! This first lesson is simply to get you to play with static electricity and decide what it is that you want to learn about electricity so we can do the really cool stuff later on.

What to Learn: When you are done today, you will need to know that electrons are too small for us to see with our eyes, but there are other ways to detect something's going on. You'll also get to learn that inside the atom, the proton has a positive charge, and the electron has a negative charge. By doing your experiments, you'll discover how like charges repel and opposite charges attract each other.

Materials

- 1 balloon
- Clock with second hand (or stopwatch)

Lab Time

1. Blow up your balloon and tie it off (if this isn't already done for you.)
2. Scrub your nearest lab partner's head with the balloon until you can get it to stand up. If it doesn't work, try another lab partner.
3. After a few laughs, look around the room and find eight things to try sticking your charged balloon to. Write them down on your worksheet under "Item/Object" before you start. You'll find your worksheet on the next page.
4. Important: Find the best lab partner head to use during the *entire* experiment that you collect data for. Be sure to charge your balloon the same way before testing each object. This means you use the same number of rubs on the same head for all ten items. Start timing as soon as the balloon sticks to your chosen object.

Static Electricity: Balloon Experiment

Item/Object	Did It Stick?	How Long Did It Stick? *(measure in seconds)*

Name of Head Used for Experiment____

Lab Partners____

Reading

Electrons are strange and unusual little fellows. Strange things happen when too many or too few of them get together. Some things may be attracted to other things or some things may push other things away. Occasionally you may see a spark of light and hear a sound. The light and sound may be quite small or may be as large as a bolt of lightning. When electrons gather, strange things happen. Those strange things are static electricity.

Different parts of the atom have different electrical charges. The proton has a positive charge, the neutron has no charge (neutron, neutral get it?) and the electron has a negative charge.

These charges repel and attract one another kind of like magnets repel or attract. Like charges repel (push away) one another and unlike charges attract one another. So if two items that are both negatively charged get close to one another, the two items will try to get away from one another. If two items are both positively charged, they will try to get away from one another. If one item is positive and the other negative, they will try to come together.

Blow up a balloon. If you rub a balloon on your head, the balloon is now filled up with extra electrons, and now has a negative charge. Try the following experiment to create a temporary charge on a wall: Bring the balloon close to the wall until it sticks.

Opposite charges attract, right? So, is the entire wall now an opposite charge from the balloon? No. In fact, the wall is not charged at all. It is neutral. So why did the balloon stick to it?

The balloon is negatively charged. It created a temporary positive charge when it got close to the wall. As the balloon gets closer to the wall, it repels the electrons in the wall. The negatively charged electrons in the wall are repelled from the negatively charged electrons in the balloon.

Since the electrons are repelled, what is left behind? Positive charges. The section of wall that has had its electrons repelled is now left positively charged. The negatively charged balloon will now "stick" to the positively charged wall. The wall is temporarily charged because once you move the balloon away, the electrons will go back to where they were and there will no longer be a charge on that part of the wall.

This is why plastic wrap, Styrofoam packing popcorn, and socks right out of the dryer stick to things. All those things have charges and can create temporary charges on things they get close to.

Exercises

1. Why does the hair stick to the balloon?
2. How do you get rid of electrons?
3. Can you see electrons? Why or why not?
4. Does it matter what kind of hair you rub the balloon on?
5. How long does the hair continue to stand up after you remove the balloon?
6. Does it matter what kind of balloon you use?
7. How fast or slow do you need to rub for the biggest charge on the balloon?
8. Does hair color matter?
9. This evening, find an article or story that describes how electricity improves our lives. Bring the article to school. If you bring in an article that no one else brings in, you get extra points.

Lesson #2: Electric Fields

Overview: Did you know that you can make things move using static electricity? You're going to be a detective and figure out how different objects interact when you stick them in an electric field.

What to Learn: We're going to use the concept that *like* charges repel (think two electrons, or two minus charges) and *opposite* charges attract (think plus and minus). You're also going to play with the idea of a force field, which can pull an object towards it or push an object away. A force field is an invisible area around an object within which that object can cause other objects to move.

Materials

- 7-9" latex balloon
- One full water bottle
- One tub or pie plate to catch the drips
- Ping pong ball
- Bubble solution with wands for blowing bubbles
- 10 packing peanuts
- Wool cloth or sweater
- Paper confetti

Lab Time

1. Charge your balloon by rubbing it on your head vigorously.

2. <u>The Wiggly Water:</u> Invert the full water bottle over the pie plate, holding it a good 1-2 feet above the plate so that a thin stream flows out from the bottle to the pie plate. (Note: If you're using a sink instead, put the water on the lowest setting so a thin stream trickles out.) Charge the balloon on your head and bring it close to the water stream – can you make it wiggle?
    a. Which way does the stream of water bend, toward (attracted) or away from (repelled) the balloon?

    b. How much water works best for this experiment: slow, medium or fast stream?

3. <u>Paper Hoppers:</u> Charge the balloon on your head again. Bring the charged balloon close to a pile of confetti. Can you pick up *all* the confetti?
    a. How long does it take before the confetti jumps off the balloon?

    b. Does this experiment work if the balloon is not charged first?

4. Dancing Bubbles: Charge the balloon on your head again while your lab partner blows bubbles about the size of your fist using the bubble solution and wand. Bring the charged balloon close to a floating bubble *slowly*.
    a. Is the bubble attracted to or repelled from the balloon?
    b. How long can you keep the bubble interacting with the balloon?
    c. If you keep a bubble on the wand and then bring the charged balloon close to it, can you distort the bubble's shape, or even pull it off the wand?

5. Chasing Balls: Bring the charged balloon close to a resting ping pong ball *slowly*. Make sure to do this on a smooth and level surface, where the ball has room to move around. You'll need a good charge on the balloon to make this one work well.
    a. Is the ping pong ball attracted to or repelled from the balloon?
    b. What is the charge on the balloon?
    c. What is the charge on the far side of the ping pong ball?

6. Ghost Poop: Rub a packing peanut with a piece of wool and stick them to the wall or your lab partner's back.
    a. How many different surfaces can hold ghost poop? Name them:

Reading

The four force fields are gravity, magnetic, electric, and electromagnetic. We're going to investigate the electromagnetic force field and how to create charge imbalances to make things stick, wiggle, dance, and move.

Force fields aren't just something for science fiction writers. They are actually a very real and very mysterious part of the world in which you live. So, what is a force field? Well, I can't tell you. To be honest, nobody can.

There's quite a bit that is still unknown about how they work. A force field is a strange area that surrounds an object. That field can push or pull other objects that wander into its area. Force fields can be extremely tiny or larger than our solar system.

A way to picture a force field is to imagine an invisible bubble that surrounds a gizmo. If some other object enters that bubble, that object will be pushed or pulled by an invisible force that is caused by the gizmo. That's pretty bizarre to think about, isn't it? However, it happens all the time.

As you sit there right now, you are engulfed in at least two huge force fields, the Earth's magnetic field and the Earth's gravitational field. Today, we're going to learn about the electric field.

An electric field is the space around an electrically-charged particle (think electron). This idea was first introduced by Michael Faraday. It's defined as the electric force you feel, and the direction of the field is taken to be the direction of the force the field exerts if you stick a positive charge in the field.

How do things get charged? Generally things are neutrally charged. They aren't very positive or negative. However, occasionally (or on purpose as we'll see later) things can gain a charge. Things get charged when electrons move. Electrons are negatively-charged particles. So if an object has more electrons than it usually does, that object would have a negative charge.

If an object has less electrons than protons (positive charges), it would have a positive charge. How do electrons move? It turns out that electrons can be kind of loosey goosey. Depending on the type of atom they are a part of, they are quite willing to jump ship and go somewhere else. The way to get them to jump ship is to rub things together.

Remember, in static electricity, electrons are negatively charged and they can move from one object to another. This movement of electrons can create a positive charge (if something has too few electrons) or a negative charge (if something has too many electrons). It turns out that electrons will also move around inside an object without necessarily leaving the object. When this happens the object is said to have a temporary charge.

When you rub the balloon on your head, you're stealing electrons from your scalp, creating a temporary positive charge on your head, and a temporary negative charge on the balloon. When you bring the negatively charged balloon close to something that has a balance of charges, like a ping pong ball, the electrons repel and move to the opposite side of the ball, leaving the positive charges to attract toward the balloon, so the ball rolls toward the balloon. The electric charge on the balloon can attract all sorts of interesting things, like paper strips, pencil shavings, soap bubbles, packing peanuts, and tissue paper. Remember, the positive particles move up and are drawn toward the negatively-charged balloon, which is where the movement comes from.

What about water? Water is like a bar magnet in that there are poles on a water molecule: there's a plus side and a minus side, and the water molecules line up their positive ends toward the balloon when you bring it close. Kids are going to hold the charged balloon near a thin stream of water to see if they can make the water wiggle without touching it. The bottom line? The charged balloon attracts the stream of water.

Exercises

1. Why did the ping pong ball move?
2. Why did the paper jump up?
3. Does the paper stick to the balloon forever? Why or why not?
4. What made the water move?
5. Does it matter if the water is hot or cold?
6. What other liquids do you think would work besides water?
7. Does it work with a full stream of rushing water? A pan full of water? Why or why not?
8. Which way (attracted or repelled) did the soap bubble move?
9. What holds the packing peanut to the wall?
10. Do these experiments work if it's raining? Why or why not?
11. What if you get the balloon wet first and then try these experiments again?
12. Does the paper stick to the balloon longer than the packing peanuts stick to the wall?

Lesson #3: Triboelectric Series

Overview: Today you are going to take a second look at static charge, exactly how it builds up, and which way the electrons move when materials are rubbed together.

What to Learn: When you finish today, you will need to know how a static charge is created and how to tell if it's a positive or negative charge that you've built up. Since you already know the hair-balloon experiment builds up a negative charge, you can use this to help you figure it out. Scientists do this experiment to create the *Triboelectric Series,* a chart that lists how the electrons tend to move, whether to or from the material.

Materials

- Styrofoam plate
- Wool sweater or cloth
- 2 plastic bags (clear plastic grocery bags work well)
- Cotton cloth
- Formica table or countertop or scrap piece
- 7-9" latex balloon
- Scissors
- Tape

Lab Time

1. Handy Static: Cut two 1" x 10" strips from a plastic grocery bag. Hold the strip firmly at one end and grasp the plastic with your other hand between your thumb and fingers. Working quickly, pull your hand so that the plastic runs through your fingers. Repeat several times to build up a large charge on the strip, leaving it hanging down when you're done.
    a. Place your hand near the strip and observe what happens:

    b. Name three objects that the strip is attracted to. Are any of these charged or are they neutral?

    c. Have a lab partner charge a second strip while you recharge the first and observe what happens when you bring the two charged strips close together.

1. Identifying Flying Objects: We're going to take advantage of this idea about repulsive forces by making a flying object.
   a. Cut out a two-inch section of the grocery bag. This can be in a ring shape, glider shape, or anything you want. Just be sure you have a small piece and not the whole bag. Also - the ink from the printing on the bag can possibly affect the way the bag charges up, so pick a blank spot to cut from.
   b. Blow up their balloon and tie it off.
   c. Test out your lab partners to find out who can give the balloon the best charge.
   d. A second lab partner is going to charge up the grocery bag scrap on a desk like this: place the bag on the Formica counter/desk and rub it with a cotton cloth. (If you're short on cloths, use a T-shirt.)
   e. Can you keep the bag piece floating above the balloon? For how long?
      Optional: If you want to upgrade to a glider shape, here's how you do it:
      i. Cut a 3.5" square from the plastic grocery bag
      ii. Fold in half
      iii. Place a small piece of tape on one of the open ends adjacent to the fold, starting from the fold and tape up only half way.
      iv. Charge it up the same way as you did with the plastic bag and see if you can get it to fly!
   f. Now let's see if there's a difference in the way we charge things up. Grab a foam plate and rub it with wool. Use the charged foam plate instead of the balloon. What happened?
   g. Charge the foam plate with a plastic bag, and try flying your object. What happened?
   h. Try rubbing other objects and fill out the table on the next page. You can try charging up the glider, balloon, or foam plate differently… it's up to you.

Identifying Flying Objects Date Table

Items Rubbed Together	What did you observe?	Was the charge positive or negative?
Cotton and Plastic Bag	*Floated above negatively-charged balloon*	*negative*
Balloon and Hair	*Glider floated above balloon*	*negative*
Plastic Bag and Foam Plate		
Wool and Foam Plate		

Reading

If you rub a balloon all over your hair, the *Triboelectric Effect* causes the electrons to move from your head to the balloon. But why don't the electrons go from the balloon to your head? The direction of electron transfer has to do with the properties of the material itself. And the balloon-hair combination isn't the only game in town.

The *Triboelectric Series* is a list that ranks different materials according to how they lose or gain electrons. A rubber rod rubbed with wool produces a negative charge on the rod: however, an acrylic rod rubbed with silk creates a positive charge on the rod. A foam plate often has a positive charge when you slide one off the stack, but if you rub it with wool it will build up a negative charge.

Near the top of the list are materials that take on a positive charge, such as air, human skin, glass, rabbit fur, human hair, wool, silk, and aluminum. Near the bottom of the list are materials that take on a negative charge, such as amber, rubber balloons, copper, brass, gold, cellophane tape, Teflon, and silicone rubber. Scientists developed this list by doing a series of experiments, very similar to the ones we're about to.

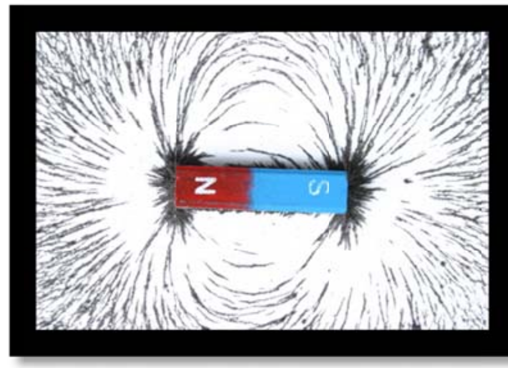
Exercises

1. What happened to the strip of plastic after you ran it through your fingers?
2. Is the strip attracted to neutral objects? Why or why not?
3. What happens if you charge two plastic strips – are they attracted or repelled from each other?
4. How long did you keep the bag floating above the balloon?
5. Why did the plastic bag piece float above the balloon?
6. What was the difference when you rubbed the foam plate with wool versus with a bag?
7. Which combination gave the best results for keeping your glider aloft?

Lesson #4: Visible Electric Fields

Overview: Time to figure out not only which way those electrons are moving, but what *fields* they are creating when they pile up. You know how to build up a static charge (balloons, anyone?), and how to tell if it's a positive or negative charge (gliders, anyone?), but now we're going to sneak a peek at the electrical field those pesky electrons generate. This is going to be important to know, especially when we get to magnetism.

What to Learn: Did you also know that electrical charges have an *electrical field*, just like magnets have a magnetic field? It's easy to visualize a magnetic field, because you've seen the iron filings line up from pole to pole. We're going to do a similar experiment with electric fields.



Materials

- 1 teaspoon dried dill (spice), depending on the size of your cup
- Vegetable or mineral oil (about ½ cup)
- 1 disposable cup
- 2 alligator wires or 2 strips of aluminum foil
- 1 balloon and/or other items to build up a static charge from previous lessons

Lab Time

1. Fill a cup with vegetable or mineral oil – you need about an inch.
2. Sprinkle small seeds or spices on top, about 1 tsp dill.
3. Build up an electric charge by rubbing a balloon on your head. You should be a pro at this by now.
4. Bring the balloon near the oil without touching the cup.
5. What happened to the spices? Be sure to look *carefully.* Write your observations:

6. Does it matter which end of the balloon you hold near the oil?

7. What if you move it a bit near the dish? Does this affect the dill at all?

8. Fill out the table below:

Charged Object Applied to Wire #1	Charged Object Applied to Wire #2	Observation (What did the seeds do?)
Balloon-Hair, Negative Charge	*Nothing*	*Seeds rotated and moved toward balloon.*

9. Draw a picture of your best experiment run that shows the electric field:

Reading

The dill leaves are all shaped like rods, which move to line up in the field (which is why round particles like cinnamon and pepper don't work as well). The dill has a balance of charges, meaning that there's an equal amount of both plus and minus charges.

When you bring a charged object like a negatively charged balloon up close, the negative charges in the dill are repelled and pushed away while the positive charges in the dill are attracted to the balloon, so one side of the dill becomes minus and the other plus. Since the dill is free to move in the liquid, the dill lines itself up in the electric field to indicate the charge direction. The positive end of the dill lines up to point at the negatively charged balloon.

Note: If your dill isn't moving at all, your object may not have a charge on it. This can happen simply by touching the object with your fingers (the little bit of oil from your fingers is enough to keep a charge from building up). Or if it has recently rained, or if you live in an area of high humidity, or your object leaks charge in any number of other ways. You can try to increase your chances of getting a static charge by cleaning it with rubbing alcohol after you use soap and water and drying it out completely, and you should see better results.

Exercises

1. What happened when you brought a charged balloon near the dill?
2. What side of the dill was attracted to the balloon?
3. What happened when you brought two negative charges near the dill?
4. Were you able to make the dill come out of the liquid and onto the balloon without touching the oil?

Lesson #5: Electroscope

Overview: Learn how to build a simple instrument for detecting electrostatic charge, either positive or negative, so you'll always have a way to know if you're in an electric field.

What to Learn: When high energy radiation strikes the Earth from space, it's called *cosmic rays*. To be accurate, a cosmic ray is not like a ray of sunshine, but rather is a super-fast particle slinging through space. Think of throwing a grain of sand at a 100 mph… and that's what we call a 'cosmic ray'. Build your own electroscope with this video!

Materials

- 1 large paperclip
- 1 piece of aluminum foil
- Tape
- Index card
- Small glass jar (like a pickle or jam jar) with lid
- 1 balloon and/or other items to build up a static charge from previous lessons
- Scissors

Lab Time

1. Take foil and cut a ½" strip. Fold it in half and snip the corners on both sides of the fold. Flatten well.
2. Open the paperclip to make an L-shape with a small hook on the end (to keep the foil from sliding off).
3. Trace the opening of the jar onto the index card and cut out the circle, making it a smidge larger than the jar (so it doesn't fall in when placed on top). Poke a hole in the center with the paperclip.
4. Drape the foil strip over the short end of the L-shape.
5. Insert the long end of the L-shape up through the hole in the index card.
6. Tape the index card to the jar opening, foil leaves dangling inside, not touching the bottom or sides of the jar.
7. Wad up a loose ball of foil and stick it on the end of the paperclip that is poking out of the top.

8. How will you test your electroscope? Explain:

9. How will you discharge your electroscope?

Electroscope Data Sheet

Static Charge Source	What did you observe with the electroscope?
Hair-Balloon	

Reading

This device is known as an *electroscope*, and its job is to detect static charges, whether positive or negative. When a static charge is brought close to the foil ball, the connected foil strips ("leaves") spread apart because like repels like charges.

The easiest way to make sure your electroscope is working is to rub your head with a balloon and bring it near the foil ball on top – the foil "leaves" inside the jar should spread apart into a V-shape.

If this doesn't happen (no V-shape), here are a few things to check into: It may be too humid of a day (close your windows and crank on the heat), there's not a good electrical connection between the foil ball and the foil leaves, or sometimes using a metal lid causes the charge to dissipate too quickly (use a cork and stick your wire through, or tape an index card over the mouth of the jar and glue the wire to the card).

Exercises

1. Why do the foil strips spread apart?
2. How do you discharge the electroscope?
3. Why did we use a glass jar?
4. Does the electroscope react the same way whether it's exposed to a positive or negative charge?
5. List four ways to charge the electroscope.

Lesson #6: Electrostatic Motor

Overview: Did you know that you can make a motor turn using static electricity? We're going to use the concept that like charges repel (think two electrons) and opposite charges attract.

What to Learn: How to make an electrostatic motor using the ideas of plus and minus charges to attract and repulse a charged object.

Materials

- Balloon (one per student)
- Soup spoon
- Flat table
- Yard stick

Lab Time

1. Set the spoon face-down on the table, near the edge.
2. Carefully balance the yardstick on the back of the spoon. You want the yardstick to be perfectly balanced and not touching the table or falling off the edge.
3. Blow up the balloon.
4. Charge the balloon by scrubbing it on your head.
5. Bring the balloon near the edge of the yardstick that's hanging off the table. The yardstick should begin to chase the balloon.
6. Can you position your lab team around the perimeter to see how fast you can make your yardstick go? Draw a diagram of your experiment and label each student participating.

7. What would happen if you use *both* a positively charged object *and* a negatively charged object to make the yardstick move?

Reading

The first electrostatic motors were designed and tested by Benjamin Franklin and Andrew Gordon in the 1750s. An electrostatic motor is based on electric charge, like we've been studying. It's dependent on the attraction of plus-minus and the repulsion of minus-minus and/or plus-plus in order to work. Electrostatic motors that you find on the shelf today usually require high voltage, so this experiment is a perfect demonstration of how it works without the kids getting shocked. These types of motors are found in tiny electronic systems that are way too small for ordinary magnetic motors to be used in.

Exercises

1. What happens if you rub the balloon on other things, like a wool sweater?
2. If you position other people with charged balloons around the table, how long can you keep the yardstick going?
3. Can we see electrons?
4. How do you get rid of extra electrons?
5. Why do you think the yardstick moved?
6. What would happen if you use *both* a positively charged object *and* a negatively charged object to make the yardstick move?

Lesson #7: Advanced Static Lab

Overview: Today is the day we pull all the pieces that we've been talking about together to make a really neat electrostatic lab. You're going to discover how an electrostatic motor can really spin fast by using both plus and minus charges, how to create a charge difference to ring Franklin bells, make pie plates fly, and how to light up a bulb without using batteries.

What to Learn: Pay special attention to see how a *difference* in charge can make things move, roll, spin, chime, fly, light up, and rotate. Plus and minus charges can be used as a push-pull force that works together in tandem.

Materials

- sheet of paper
- two empty, clean steel soup cans
- aluminum foil
- neon bulb
- small foil ball with fishing line or sewing thread attached
- foam cup
- dozen small aluminum pie tart tins
- foam meat tray or slab of Styrofoam
- Fun Fly Stick (also called "Wonder Fly Stick") OR a balloon and one piece of shaped tinsel

Optional: <u>*Electrostatic Motor*</u> *If you're making the electrostatic motor, you'll also need:*

- three film canisters or M&M containers
- long straight pin
- penny
- 2 paper clips
- hot glue gun with glue sticks
- drill with small drill bit
- scissors
- tape

Lab Time

1. Grab your Fly Stick and make your tinsel float. Does this remind you any experiments we've done before? Which experiment(s)?

2. Set the meat tray upside-down on your table. This will provide an insulating layer for the static charges while you work.

3. Flying Pans: Invert the Styrofoam cup on the meat tray, open-end down. Set a stack of pie tart pans on the bottom of the cup. Gently touch the Fly Stick to the pie pans and press the button. Ta-daa!

    a. Why did the pans fly off the cup?

    b. Where does the Fly Stick need to be for this experiment to work?

    c. Does the Fly Stick have to touch the pans for the pans to move?

4. Neon Bulb: Have one student hold one of the wires of a neon bulb (pictured left) in one hand. Another student brings the Fly Stick up close to the other wire and activates the wand.

    a. What happened?

    b. What if you don't hold the wire? Does this change how it works?

    c. What's inside the bulb?

    d. Why does the neon bulb light up?

5. Franklin Bell: Set two clean, steel soup cans with their bottoms about an inch apart on the meat tray. Hold the foam ball between the cans and have another student touch one of the cans with the Fly Stick.
   a. What happened?
   b. Is there a special spot to hold the ball and/or Fly Stick? If so, where?
   c. What happens if you place your hand on the metal part of the other can during your experiment?
   d. Why does holding your hand on the can do that to the experiment?
6. Wall Paper: Put a sheet of paper on the wall, and run your Fly Stick over the surface a couple of times, then remove it.
   a. What happened?
   b. Why does the paper do that?
   c. Fill out the data table:

Static Electricity Lab Data Sheet

Trial Number	How long did you charge the paper for?	How long did the paper stick to the wall?
1		
2		
3		
4		
5		

7. <u>Optional: Electrostatic Motor Build Steps:</u>
    a. Place three film canisters on the meat tray in a line, about a half inch apart. Make small marks on the tray so you know where they need to be spaced when you glue them.
    b. Glue the tops of the two outer film cans down onto the meat tray. Do not glue the film canister body to the tops.
    c. Wrap the body of a film can with aluminum foil using hot glue to secure into place (not tape). Open up one-half of a paperclip and tape it to the side the film canister you covered with foil. Make sure the metal paperclip is touching the metal foil. Make a small hook at the end of the paperclip for the charge to build up on. Repeat with a second film canister.
    d. Hot glue the pin, pointy-side up in the meat tray at the middle film can position.
    e. Drill a small hole in the bottom of the third film canister and set it right-side up onto the pin. Make sure it slides freely onto the pin.
    f. Now glue a penny inside the lid and drill a hole halfway through the penny. The tip of the pin should rest in the hole when assembled.
    g. Wrap the third film can with foil, gluing sparingly into place. Make three cuts (as shown in video) and fold the foil back a little bit so there are three foil sections not in contact with each other. You want three isolated foil areas for it to work right.
    h. Snap on lid of third canister and slide it on the pin, centering the pin in the hole in the penny. Spin it with your fingers and make sure there's little to no friction. If the rotor doesn't turn freely, add a tiny drop of oil on the penny and/or at the bottom hole.
    i. To activate, touch the Fly Stick to one of the stators (stationary film canister with the paper clip attached) and touch your finger to the other. The rotor will start to turn.

Reading

Hold a Fly Stick in your hand and wave it around, With your other hand, hold a piece of tinsel (which comes with the Fly Stick) and drop it over the Fly Stick as you press the button. The tinsel should fall uneventfully until it hits the wand's electrical field, and then *POOF!* it puffs into shape. What's going on?

Stop pressing the button and watch how the tinsel still reacts with the wand. Play around with the tinsel pieces for a bit until you get one stuck to the ceiling. Charge another piece of tinsel and point out how you are chasing the tinsel. What charge is on the tinsel? What charge is on the Fly Stick?

Flip the wand around and point the butt end of the stick at the tinsel, and can you notice how the tinsel chases you? What charge is on the bottom end of the wand?

The Fly Stick is like a BIG charged balloon, which also charges the tinsel with the same negative charge. Like repels like charges, so the tinsel tries to get as far away from itself as possible, just like the leaves from the electroscope. The tinsel sticks to the ceiling for the same reason the ghost poop stuck - the negative charges in the tinsel repel the wall's electrons, leaving the positive protons to be attracted to the tinsel.

Exercises

1. What is common throughout all these experiments that make them work?
2. What makes the neon bulb light up? What else would work besides a neon bulb?
3. Does it matter how far apart the soup cans are?
4. Why does the foil ball go back and forth between the two cans?
5. Why do the pans take on the same charge as the Fly Stick?
6. When sticking a sheet of paper to the wall, does it matter how long you charge the paper for?
7. Draw a diagram to explain how the electrostatic motor works. Label each part and show where the charges are and how they make the rotor turn.

Lesson #8: Alien Detector

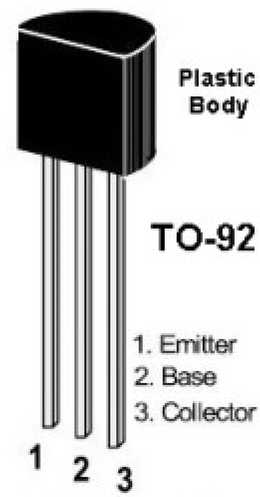
Overview: This experiment is for advanced students. This simple circuit can detect electric fields. Remember the electroscope experiment? This is an electronic version of it! After you've build one, hand it to your friends and announce that you've just been told there's an alien presence in the room, and challenge them to try to figure out where the aliens are hiding. (Let them know that aliens, like kids, never stay in one place either.)

What to Learn: This detector finds areas of positive charge, and is so sensitive that you can go around your house and discover pockets of static charge… even from your own footprints!

Materials

- 9V battery
- 9V battery clip with two wires (Radio Shack part #270-325)
- MPF 102 (Radio Shack part #276-2062)
- LED (any regular LED works fine, or Radio Shack part #276-012 is a great choice, because it will light up in both directions in case the kids hook it up backwards)
- 3 alligator clip leads (Radio Shack Part #278-1156)

Lab Time



1. Hold the MPF 102 transistor (image at left) with the flat side facing you. Be very careful with these, as it's easy to snap off the little wires, or zap them with too much heat or static which kills them. Here's how you identify the parts:
    a. Pin #1 is the one on the left, also called the *emitter* or *drain*.
    b. Pin #2 is in the middle, called the *base* or *source.*
    c. Pin #3 is on the right side, called the *collector*, or *gate.*
2. Gently spread apart the three leads into a W-shape, so you can get in there with alligator clips.
3. Bend the *gate* (pin #3 on the right side) upward. This is going to be your antenna, and will not be connected to anything. You can solder a longer wire if you're mounting it in a soapbox if needed.
4. Connect the *source* (middle lead) to an alligator clip lead. The other end of your alligator wire connects to the positive (red) wire of the battery clip.
5. Separate the two wires on the LED into a V shape so you can slip on alligator clip leads without them touching each other.
6. Connect the *drain* (pin #1 on the left side) to one of the LED wires using a second alligator clip wire.
7. Using the third alligator clip lead, connect the other LED wire to the black wire on the battery clip. Make sure the alligator clip lead is connected to the metal, not the insulation part of the wire. It's easy to have it connected on the last bit of the insulation, which raises it up a little and doesn't make metal-to-metal contact between the alligator jaws and the wire. Take your time and do it right.
8. Check all connections twice by repeating steps #1-9. Double-check *before* powering up.
9. Carefully insert the 9V battery into the battery clip. The LED should light up.
10. If the LED is dark, try running a plastic pen through your hair and waving the pen at the antenna gently. The LED should light up.

11. ***Do not touch the antenna!*** This will zap the circuit and fry the transistor, and then you will have to start all over. You can increase the antenna sensitivity by dangling an extra wire (like an alligator clip lead) to the end of the antenna.
12. Now walk around the room and find those aliens! And then fill out the worksheet.

If the detector doesn't work:

1. If it doesn't work, switch batteries with someone to see if you've got a good power source. It doesn't take much to power this circuit.
2. If it still doesn't work, disconnect everything and start over! You might have something not connected right.
3. If it *still* doesn't work, switch out your alligator wires for new ones. Sometimes there's a break between the wire and the alligator head, which breaks the circuit open.
4. If you're still reading this, my guess is that it STILL doesn't work… which means a couple of things:
    a. It's too humid. If you can't get a balloon to make your arm hair stand up, it's too humid for this experiment. You'll have to try this on another day, or close the doors and crank on t he heat.
    b. Transistor is connected wrong, so go through steps #1-9 again.
    c. Transistor is burned out, so grab a new one.

Alien Detective Table

Area/Object Tested	LED Light Up?	Comments
Ran a pen through my hair	*Yes!*	*Aliens might be on the pen or in my hair. Further testing needed on the different areas of my head.*
Near a tree / bush / living plant		
Near the ground (where specifically did you test?)		
Charged balloon on my hair		
Charged foam plate with wool		

Reading

This simple FET circuit is really an electronic version of the electroscope we built in a previous lesson. This "Alien Detector" is a super-sensitive static charge detector made from a few parts from Radio Shack. I originally made a few of these and placed them in soap boxes and nailed the lids shut and asked kids how they worked. (I did poke a switch and the LED so they would have some help as they figured it out.)

After you've made your charge detector, turn it on and comb your hair, holding the charge detector near your head and then the comb. You'll notice that the comb makes the LED turn off, and your head (in certain spots) makes the LED go on. So it's a positive charge static detector… this is important, because now you know when the LED is off, the space you're detecting is negatively charged, and when it's lit up, you're in a pocket of positively-charged particles. How far from the comb does your detector need to be to detect the charge? Does it matter how *humid* it is? You bet!

You can take your detector outdoors, away from any standing objects like trees, buildings, and people, and hold it high in the air. What does the LED look like? What happens when you lower the detector closer to the ground? Raise it back up again to get a second reading… did you find that the earth is negative, and the sky is more positive?

You can increase the antenna sensitivity by dangling an extra wire (like an alligator clip lead) from the end of the antenna. Because thunderstorms are moving electrical charges around (negative charges downwards and positive charges upwards), the earth is electrified negatively everywhere. During a thunderstorm, the friction caused by the moving water molecules is what causes lightning to strike! (But don't test your ideas outside in the wide open while lightning is striking!)

Exercises

1. When the LED is on, what do you think it means?
2. Does the LED turning off detect anything?
3. Do aliens like humidity?
4. How does this alien detector really work?

Lesson #9: Cosmic Ray Detector

Overview: You get to build a special cloud chamber that will make invisible particles visible. This cloud chamber works because it's filled with a super-saturated alcohol-water vapor mix. The alpha particles (ions) turn the vapor into microscopic clouds.

What to Learn: A cosmic ray is not like a ray of sunshine, but rather is a super-fast particle slinging through space. Think of throwing a grain of sand at 100 mph - that's what a "cosmic ray" is. Since these are tiny, charged particles and not grains of sand, we built the electroscope back in Lesson #5 to detect electrons. The Cosmic Ray Detector is a much better device for finding cosmic rays because it's going to catch negatively-charged particles (electrons, also called 'beta particles') *and* positively-charged particles (called 'alpha particles'). You'll actually get to see the thin, threadlike vapor trails appear and disappear, marking the path left by the particles. This type of detector was created by Charles Wilson in 1894, and Wilson later received a Nobel Prize (along with Arthur Compton) for their work on cloud chambers.

Materials

Safety Alert! *You'll be working with hot glue guns, toxic chemicals, glassware that can shatter, and finger-burning-cold dry ice. This is no time to mess around in the lab. Stay alert and work carefully to get your experiment to work.*

- rubbing alcohol
- clean glass jar
- black felt
- hot glue gun
- magnet
- flashlight
- scissors
- dry ice
- goggles
- heavy gloves for handling the dry ice (adults only)

Important Project Considerations: *After creating your detector:* You can bring your alpha particle detector near a smoke alarm, an old glow-in-the-dark watch dial or a Coleman lantern mantel. You can go on a hunt around your house to find where the particles are most concentrated. If you have trouble seeing the trails, try using a flashlight and shine it on the jar at an angle.

You will also be working with dry ice. The dry ice works with the alcohol to get the vapor inside the jar at just the right temperature so it will condense when hit with the particles. Note that you should **NEVER TOUCH DRY ICE WITH YOUR BARE HANDS.** Always use gloves and tongs and handle very carefully. **Keep out of reach of children** - the real danger is when kids think the ice is plain old water ice and pop it in their mouth.

If your dry ice comes in large blocks, the easiest way to break it into smaller pieces is to insert your hands into heavy leather gloves, wrap the dry ice block in a few layers of towels, and hit it with a hammer. Make sure you wrap the towels well enough so that when the dry ice shatters, it doesn't spew pieces all over. Use a metal pie plate to hold the chunks while you're working with them. Store unused dry ice in a paper bag in a cooler or the coldest part of the freezer. Dry ice freezes at -109 degrees Fahrenheit. Most freezers don't get that cold, so expect your dry ice to disappear soon.

Lab Time

1. Cut your felt to the size of the bottom of your jar. Glue the felt to the bottom of the jar.
2. Cut out another felt circle the size of the lid and glue it to the inside surface of the lid.
3. Cut a third felt piece, about 2 inches wide, and line the inside circumference of the jar, connecting it with the bottom felt. Glue it into place.
4. Strap goggles on your face. No exceptions.
5. Very carefully pour a tablespoon or two of the highest concentration of rubbing alcohol onto the felt in the jar. You don't need much. Swirl it around to distribute it evenly. Do the same for the lid. All the felt pieces should be thoroughly saturated. Cap the jar and leave it for ten minutes.
6. Unscrew the cap, and ask an adult to place a small piece of dry ice right on the lid. Invert the jar right over the lid. Leave the jar upside down. Do not handle dry ice yourself.
7. **DO NOT SCREW ON THE CAP TIGHTLY!** Leave it loose to allow the pressure to escape.
8. Sit and wait and watch carefully for the tiny, thin, threadlike vapor trails.
9. What do you think the magnet is for? (Hint: keep it *outside* the jar.)

Draw a picture of your experiment and describe how it works and label each part.

Reading

Cosmic rays have a positive charge, as the particles are usually protons, though one in every 100 is an electron (which has a negative charge) or a muon (also a negative charge, but 200 times heavier than an electron). On a good day, your cosmic ray indicator will blip every 4-5 seconds. These galactic cosmic rays are one of the most important problems for interplanetary travel by crewed spacecraft.

Most cosmic rays zoom to us from extra-solar sources (*outside* our solar system but *inside* our galaxy) such as high-energy pulsars, grazing black holes, and exploding stars (supernovae). We're still figuring out whether some cosmic rays started from outside our own galaxy. If they are from outside our galaxy, it means that we're getting stuff from quasars and radio galaxies, too!

Cosmic rays are fast-moving, high-energy, charged particles. The particles can be electrons, protons, the nucleus of a helium atom, or something else. In our case, the cosmic rays we're detecting are "alpha particles." Alpha particles are actually high-speed helium nuclei (helium nuclei are two protons and two neutrons stuck together). They were named alpha particles long before we knew what they were made of, and the name just kind of stuck.

Did you know that your household smoke alarm emits alpha particles? Most smoke detectors contain a small bit (around 1/5,000th of a gram) of Americium-241, which emits an alpha particle onto a detector. As long as the detector sees the alpha particle, the smoke alarm stays quiet. However, since alpha particles are easy to block, when smoke gets in the way and blocks the alpha particles from reaching the detector, you hear the smoke alarm scream.

Alpha particles are pretty heavy and slow, and most get stopped by just about anything, like a sheet of paper or your skin. Because of this, alpha particles are not something people get very excited about, unless you actually eat the smoke detector and ingest the material (which is not recommended).

The electroscope we made in Lesson #5 can detect alpha and beta particles. Both brick buildings as well as people emit beta particles. Beta particles are actually high-speed electrons or positrons (a positron is the antimatter counterpart to the electron), and they are quick, fast, and light. When an electron hit the foil ball, it traveled down and charged the foil leaves, which deflected a tiny bit inside the electroscope. A beta particle has a little more energy than an alpha particle, but you can still stop it in its tracks by holding up a thin sheet of plastic (like a cutting board) or tinfoil.

Exercises

1. How does this detector work?
2. Do all particles leave the same trail?
3. What happens when the magnet is brought close to the jar?

Static Electricity Evaluation

Student Worksheet

Overview: Today you're going to take two different tests: the quiz and the lab practical. You're going to take the written quiz first, and the lab practical at the end of this lab. The lab practical isn't a paper test – it's where you get to show your teacher that you know how to do something.

Lab Test & Homework

1. Your teacher will call you up so you can share how much you understand about electrical charges and how they interact with each other. Since science is so much more than just reading a book or circling the right answer, this is an important part of the test to find out what you really understand.
2. While you are waiting for your turn to show your teacher how much of this stuff you already know, you get to choose which homework assignment you want to complete. The assignment is due tomorrow, and half the credit is for creativity and the other half is for content, so really let your imagination fly as you work through it. Choose one:
    a. Write a short story or skit about static electricity from the perspective of the electron or proton. You'll read this aloud to your class.
    b. Make a poster that teaches the main concepts to static electricity. When you're finished, you'll use it to teach to a class in the younger grades and demonstrate each of the principles that you've learned.
    c. Write and perform a poem or song about static electricity. This will be performed to your class.

Static Electricity Quiz

Name____

1. What charge do the proton, neutron, and electron have?

2. What happens when you bring two like charges together?

3. What charge are most things?

4. How do I know if an object is positively or negatively charged?

5. Why does hair stick to a balloon when you rub it on your head?

6. Can you see electrons? Why or why not?

7. If you bring a charged balloon near a stream of orange juice, what happens and why?

8. I have a foam plate, plastic bag, a bottle of rubbing alcohol, and a piece of wool. How can I generate a positive electrical charge? How will I really know it's positive?

9. What does an electroscope detect? How do you know when it has detected it?

10. Why does a neon bulb light up when brought close to a static source?

11. Why do the leaves in the electroscope take on the same charge as the foil ball?

12. Draw a diagram that shows the yardstick Electrostatic Motor experiment set, and the location of the positive and negative charges on the balloon and the yardstick. Your diagram should clearly explain what's going on and why. You can use another sheet of paper if needed.

Static Electricity Lab Practical

Student Worksheet

This is your chance to show how much you have picked up on important key concepts, and if there are any holes. You also will be working on a homework assignment as you do this test individually with a teacher.

Materials:

- balloon
- ping pong ball
- paper

Lab Practical:

- Design and build an experiment that shows how electrically-charged objects attract each other.
- Design and build an experiment that shows how electrically-charged objects repel each other.
- Explain how objects that are electrically charged can create a temporary charge on another object.

Section 2: Electricity

Why study electricity? While it's true that you don't need to know how electricity works in order to flip on a light switch, you do need to know a thing or two about circuits before you start wiring up your own robot.

Electricity is all around you, from the tiny subatomic level of the electron to the gigantic solar storms from the sun.

When you're done with this lesson, you'll know how to wire up circuits for underwater vehicles, create your own robotics sensors, extract energy from fruit, split a water molecule, and really make sparks fly. Are you ready? This video will get you started on the right foot for your study into electricity.

Although we can't "see" electricity flow through wires, you can certainly see, hear, and feel its effects: the light bulb flashing on, the hair dryer blowing, the heat generated by a hot wire, and so forth. In order to understand electricity, though, we're going to talk about water because that's something that you already have experience with.

Electricity is like water going through a pipe. Imagine you have a big pipe connected in a circle, so it connects back to itself in a loop. The water needs a pump in order to move through the pipe. Electricity is like the water going through the pipe, and the battery is like the pump.

Now imagine breaking open your pipe to insert a waterwheel. Seal up the cracks and turn on your pump. Can you imagine what happens now? When the pump (battery) turns on, the water (electricity) flows through the pipe and turns the waterwheel. The waterwheel is like your motor or light bulb.

Suppose you add in a valve so you can turn the water on and off through your pipe. What is the valve like in your circuit? It's just like a switch in a circuit, because it interrupts the flow of electricity.

What would happen if you broke your pipe? Imagine you have a sledgehammer and you smashed open the pipe. Does it matter which side of the waterwheel you break it on? It does! If you break it before the waterwheel, the waterwheel won't turn. If you break it after the waterwheel, it might turn for a minute, but then it will stop because there's no more water going into the pump because you busted open the pipe, so the flow stops either way. That's what happens when you disconnect one of your wires in your circuit. No more electricity can flow.

Now imagine you've got a whole, complete pipe again. What would happen if we take out the pump, turn it around, and stick it back in again? The water goes the other way! What direction does the waterwheel go? It starts turning in the opposite direction also.

Some waterwheels are designed to go either forward or backward, while other waterwheels can only move forward due to the shape of their blades and how they were made. Some electrical components like buzzers and LEDs are polarized, meaning that they do not work backward. Other electrical components, like motors and light bulbs, do work forwards and backward. When you work with circuits, if you find a component that doesn't work, try turning it around in the circuit to see if that fixes it.

There are many different electrical components that make the electrons react in different ways, such as resistors (which limit current), capacitors (these collect a charge), transistors (these are like an electronic gate for electricity), relays (electricity itself activates a switch), diodes (which are a one-way street for electrons), solenoids (are an electrical magnet), switches (which are stoplights for electrons), and more. We're going to use a combination of LEDs, buzzers, and motors in our circuits in our unit together.

A CIRCUIT looks like a CIRCLE. When you connect the batteries to the LED with wire and make a circle, the LED lights up. If you break open the circle, electricity (current) doesn't flow and the LED turns dark. LED stands for "Light Emitting Diode". Diodes are one-way streets for electricity – they allow electrons to flow one way but not the other.

Remember when you scuffed along the carpet? You gathered up an electric charge in your body. That charge was static until you zapped someone else. The movement of electric charge is called electric current, and is measured in amperes ("A").

When electric current passes through a material, it does it by electrical conduction. There are different kinds of conduction, such as metallic conduction, where electrons flow through a conductor (like metal) and electrolysis, where charged atoms (called ions) flow through liquids.

Lesson #10: Basic Circuits

Overview: This lab will get you familiar with how to hook up a simple circuit so we can move to more complex stuff soon, like motors, switches, and remote controls. But first… the basics.

What to Learn: Remember when you scuffed along the carpet? You gathered up an electric charge in your body. That charge was static until you zapped someone else. The movement of electric charge is called electric current, and is measured in amperes (A). When electric current passes through a material, it does it by electrical conduction. There are different kinds of conduction, one of which is called *metallic conduction*, where electrons flow through a conductor, like metal.

Materials

- 2 AA batteries
- AA battery case
- 2 alligator wires
- LEDs

Safety Tip: I recommend using the super-cheap kind of batteries (usually labeled "Heavy Duty" or "Super Heavy Duty"), usually found at dollar stores. These types of batteries are carbon-zinc, which do not contain acid that can leak and expose you to toxic chemicals. When you short the circuits and overheats the batteries (which you should expect, by the way), it's not dangerous. Alkaline batteries (like Energizer and Duracell) will get super-hot and leak acid, so those aren't the ones you want to play with.

Lab Time

1. Following the video instructions, use the materials to wire up a simple circuit and get the LED to light up:
   a. Insert your batteries into the case. Flat side (minus) goes to the spring.
   b. Attach one alligator clip to each of the metal tips of the wires from the battery case. Make sure you've got a good metal-to-metal connection. You should now have two alligator clips attached to the battery pack.
   c. Attach the end of the alligator clips that's connected to the black wire (negative) from the battery case to the flat side of the LED. It doesn't matter what color the alligator clip wire is.
   d. Attach the other alligator clip that's connected to the red wire (positive) from the battery case to the longer LED wire. Again, it doesn't matter what color the alligator clip wire is.
   e. Your LED should light up!
2. Once your LED is illuminated, what happens if you take it out and insert it in the opposite way into the circuit? (Reverse the polarity.) Does it still work?
3. Troubleshooting a circuit that doesn't work:
   a. Batteries inserted into the case the wrong way? (Flat side of the battery should go to the metal spring inside the case.)
   b. LED is in the circuit the wrong way? Remember, LEDs are picky about plus and minus, meaning that it matters which way they are in the circuit. If you choose a bipolar LED, then you don't have to

worry about this one, since there are two LEDs, one in each direction, in one LED package which will illuminate no matter which way you have it in your circuit. LEDs are polarized.

c. Is there a metal-to-metal connection? You're not grabbing the plastic insulation, are you? Not even a tiny bit? Sometimes kids have the edge of the alligator clip lead propped up on the edge of the plastic insulation, which will make your connection not work.
d. Once in awhile, you'll get a bad alligator wire. There's an easy to check this: remove your alligator clip leads from the circuit and touch each of the metal tips from the battery pack wires to the LED wires. If the LED lights up, swap out your alligator clip lead wires for new ones and that should fix it.

Reading

When electric current passes through a material, it does so by electrical conduction. There are different kinds of conduction, such as metallic conduction, where electrons flow through a conductor, like metal, and also by electrolysis, where charged atoms called ions flow through liquids (we'll be getting to that later).

Although we can't see electricity flow through wires, you can certainly see, hear, and feel its effects: the light bulb flashing on, the hair dryer blowing, the heat generated by a hot wire, and so forth. In order to understand electricity, though, we're going to talk about water, because that's something that you already have experience with.

Electricity is like water going through a pipe. Imagine you have a big pipe connected in a circle, so it connects back to itself in a loop. The water needs a pump in order to move through the pipe. Electricity is like the water going through the pipe, and the battery is like the pump.

Now imagine breaking open your pipe to insert a waterwheel. Seal up the cracks and turn on your pump. Can you imagine what happens now? When the pump (battery) turns on, the water (electricity) flows through the pipe and turns the waterwheel. The waterwheel is like your motor or light bulb.

Suppose you add in a valve so you can turn the water on and off through your pipe. What is the valve like in your circuit? It's just like a switch in a circuit, because it interrupts the flow of electricity.

What would happen if you broke your pipe? Imagine you have a sledgehammer and you smashed open the pipe. Does it matter which side of the waterwheel you break it on? It does! If you break it before the waterwheel, the waterwheel won't turn. If you break it after the waterwheel, it might turn for a minute, but then it will stop because there's no more water going into the pump because you busted open the pipe, so the flow stops either way., That's what happens when you disconnect one of your wires in your circuit. No more electricity can flow.

Now imagine you've got a whole, complete pipe again. What would happen if we take out the pump, turn it around, and stick it back in again? The water goes the other way! What direction does the waterwheel go? It starts turning in the opposite direction also.

Some waterwheels are designed to go either forward or backward, while other waterwheels can only move forward due to the shape of their blades and how they were made. Some electrical components like buzzers and LEDs are polarized, meaning that they do not work backward. Other electrical components, like motors and light bulbs, do work forward and backward. When you work with circuits, if you find a component that doesn't work, try turning it around in the circuit to see if that fixes it.

If you look around the room, do you notice the different kinds of light bulbs you have? You might find a fluorescent bulb, an incandescent light bulb, a neon bulb an LED, or even a halogen lamp. What's the difference in how these produce light?

The incandescent light bulb uses a wire that glows when electric current runs through it. To keep the wire from burning itself up, the air is removed from the bulb and replaced with an inert gas. The wire is made from the element *tungsten*.

Neon bulbs light up because the electrical field excites the gas, which then gives off a pinkish-orange light.

A fluorescent tube is lined with white stuff called phosphor, which gives off light whenever it's struck by UV rays. The tube is filled with a gas that gives off UV rays when placed in an electrical field. When the bulb is brought close to a static charge, electrons rip through the tube and go out the other side. As they go through, they smack into the gas vapor which releases light rays (UV in a fluorescent tube) that hit the phosphor on the inside of the tube, which then emits light. Fluorescent lights, or any tube of gas from the noble gases column on the periodic table, like neon, will also glow in an electrically-charged field.

LED stands for "Light Emitting Diode." They don't have a filament so they don't get hot. They light up by the movement of electrons in a semiconductor material (more on this later), and they last a long time, like thousands of hours.

For halogen lamps, instead of creating a vacuum like with incandescent bulbs, they fill the bulb with a halogen gas so that the filament will burn brighter. It's not the gas that's illuminating, but rather the filament itself.

Exercises

1. What does LED stand for?
2. Does it matter which way you wire an LED in a circuit?
3. Does the longer wire on the LED connect to plus (red) or minus (black)?
4. Do you need to hook up batteries to make a neon bulb light up? Why or why not?
5. What's the difference between a light bulb and your LED?
6. What is the difference between a bolt of lightning and the electricity in your circuit?
7. What is the charge of an electron?

Lesson #11: Conductivity Testers

Overview: Today you get to wire up a simple circuit and test a variety of objects to figure out if they are insulators or conductors of electricity.

What to Learn: Take special note as to which *kinds* of materials are insulators and which are conductors of electricity. Metals are conductors not because electricity passes through them, but because they contain electrons that can move.

Materials

- 2 AA batteries
- AA battery case
- 3 alligator wires
- LEDs

Lab Time

1. It's time to wire up your detector. Here's what you need to do:
    a. Remove one of the alligator clips from the LED (it doesn't matter which one) and let it dangle.
    b. Add a *third* alligator clip to the LED – right in the same spot as the one you just removed. The other end should be dangling also.
    c. Hold the circuit by the two dangling alligator clips, and touch their tips together. The LED should light up.
    d. Break contact and the LED goes dark. Touch them together again and the LED lights up. On. Off. On. Off. On. This is the world's simplest switch.
    e. Now touch each of the two alligator clips to either side of an object you think will conduct electricity. What did you test and what happened?

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2. Fill out the data table:

Conductivity & Insulator Testers Data Table

Object	Is it a Conductor?	Is it an Insulator?	Notes:

Reading

Metals are conductors not because electricity passes *through* them, but because they contain electrons that can move. An insulator does not allow electrons to move.

Think of the metal wire like a hose full of water. The water can move through the hose. An insulator would be like a hose full of cement - no charge can move through it.

All metals conduct electricity: however, some metals like copper and gold conduct better than others because they have less internal resistance (which relates to how the metal is structured.) Metals have free electrons which can move from atom to atom, allowing the electricity to conduct through them. Paper, rubber, and plastics make great insulators, because sometimes you don't want electricity to flow unless you say so. We're going to talk about switches when we make our burglar alarms later on.

Exercises

1. Name six materials that are electrically conductive.
2. What kinds of materials are conductors and insulators?
3. Can you convert an insulator into a conductor? How?
4. Name four instances when insulators are a bad idea to have around.
5. When are insulators essential to have?

Lesson #12: Switches & Motors

Overview: When you turn on a switch, it's difficult to really see what's going on. So you're going to make your own from paperclips, brass fasteners, and index cards. And you get to play with real motors, too.

What to Learn: Think of this switch like a train track. When you throw the switches one way, the train (electrons) can race around the track at top speed. When you turn the switch to the OFF position, it's like a bridge collapse for the train – there's no way for the electrons to jump across from the brass fastener to the paper clip. When you switch it to the ON position (both sides), you've rebuilt the bridges for the train (electrons).

Materials

- 2 AA batteries
- AA battery case
- 2 alligator wires
- 1.5-3V DC hobby motor
- 1 index card
- 2 brass fasteners
- 1 large paperclip
- propeller or piece of tape for the motor shaft

You decide if you want to complete Part 3. If that's the case, you'll also find these items set out for you:

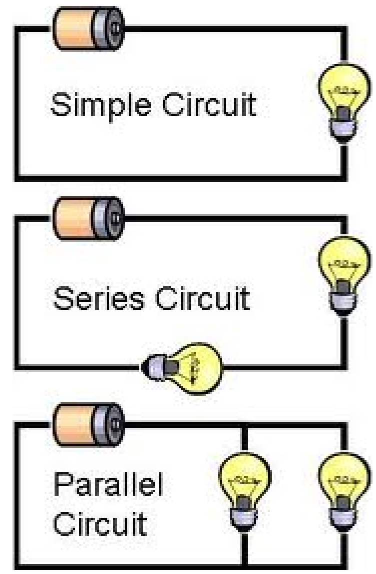
- 6 brass fasteners
- 1 index card
- 2 large paper clips
- 6 alligator clip lead wires

Lab Time

1. Today, we're going to learn how to turn a *motor* on and off by controlling when the electricity goes through the circuit by using a switch. The motors we're using are one of those special electrical components which are not polarized, meaning if you stick it in backward; it will still run… but backward.
2. SPST stands for Single Pole Single Throw, which means that the switch turns on only one circuit at a time. When the switch is engaged, current flows. When it's not, the circuit is broken open and electricity stops. SPST stands for Single Pole, Single Throw, which means that the switch turns on only one circuit at a time. This is a great switch for turning one motor on and off.
3. DPDT stands for Double Pole Double Throw, and you need this kind of switch to handle the circuitry required to make a motor go in reverse. That's in Part 3 of this experiment.
4. There are three different parts to this experiment – you'll be doing Parts 1 & 2 for sure, but Part 3 is totally optional.

Lab Time

Part 1: Making a motor turn.



1. Grab hold of your materials and make the motor turn on. Do you see those two little terminals on the back of the motor? That's where you hook up the alligator wires. It's just like lighting up an LED, only instead of wires, there are tabs.
2. Since these motors spin quickly and the shaft is tiny, add a piece of tape (unless you're using propellers) to the shaft to see the spinning action more clearly.
3. Can you make your motor go in reverse? (Hint: remember the waterwheel?)
4. Can you hook up both the LED and motor at the same time?

Part 2: Switching the motor on and off using a switch. Follow your instructor through these steps:

1. Making the SPST switch:
    a. Open the paperclip into a V-shape.
    b. Stick the brass fastener through the paperclip and through the index card, making sure the smaller loop of the paperclip is on the bottom.
    c. Open the brass fastener up on the other side.
    d. Measure where the second brass fastener needs to go in order to miss the lower loop but hit the larger loop when the paper clip is pressed. Insert the brass fastener at the mark and open it up on the other side. The paper clip should not be touching the second brass fastener yet.
    e. Make sure the brass fasteners aren't touching on the underside of the card, or you'll bypass the switch.
    f. Press down on the upper loop to be sure it touches the brass fastener, and springs back up when you let go. You've just made a NO (normally open) switch, meaning that the switch is open (no current flows) until it's activated. Now let's hook it up in a circuit.
2. Now remove one wire from the motor terminal and replace it with a third alligator wire like we did with the conductivity tester experiment, only this time it's a motor and not an LED. When you touch the two free ends, make sure the motor still runs.
3. Instead of having the alligator clip leads touching each other, connect each one to a brass fastener on the underside of the index card.
4. Press the switch – the motor should turn. Ta-daa!
5. Trace the path the electricity takes with their finger. What did you find out? Write it here:

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Part 3: Making the motor go forward and reverse using a single switch. Follow your instructor's directions:

1. Making the DPDT switch:
   a. We're going to put six brass fasteners on the card, three in each row. Insert the two middle brass fasteners first, each with their own paperclip attached. Open them up on the other side and tape them down on the underside so they are out of reach of other fasteners but can still be attached to alligator clip leads.
   b. Move both the paperclips up and mark the next location for the fasteners. Insert two fasteners, one on each side, and open them up on the underside of the card. Tape into place.
   c. Move the paperclips down and mark the last set of points for the last two fasteners. Insert fasteners, open up, and tape.
   d. Show the kids how to operate the switch and have them practice *before* wiring it up. Both paperclips up means forward, both down is reverse. No contact is off.
   e. Working on the underside of the card: use two alligator clips to make the "X." Connect one alligator clip to a corner (it doesn't matter which) and the other end connects to the fastener in the opposite diagonal corner. If you grab the stems that are peeking out of the tape, it's easier to connect to. Do this for both diagonals.
   f. Connect one alligator clip wire to the negative wire on the battery back and then to one of the middle brass fasteners.
   g. Connect one alligator clip wire to the positive wire on the battery back and then to the other middle brass fastener.
   h. Connect one alligator wire to each motor terminal (you should have two wires connected to your motor). Connect the other ends of the wires to two brass fasteners on one end of the switch (it doesn't matter which), but they must be on the same end.
   i. Test your motor and see how it works! If it doesn't work, remove all the wires and redo steps f-h. If you still have trouble, grab a new set of wires and see if this helps.
2. Trace the path the electricity takes with your finger. What did you find out? Write it here:

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Reading

Do you remember how the yardstick moved around in a circle using a balloon way back in Lesson #6: The Electrostatic Motor? Using static charge attraction, the yardstick followed the balloon around in a circle.

Imagine modifying the experiment so that there was a charged balloon physically attached to the end of the yardstick, so that you could use a positively charged object to attract and pull the yardstick toward you, and then just as the stick was close, you quickly switched to a negatively charged object to push the object away. That's how the electrostatic bottle motor worked in a previous experiment.

Now place those statically charged objects with magnets. You've got a magnet on something which can move in a circle, and another magnet you can flip North-South depending on where the rotating magnet is. That's how a motor works! We're going to actually build a motor using these principles when we get to electromagnetism, and we have to wait a bit before making one because we're going to make a magnet that we can turn on and off for that project, and there's a few more things we need to learn how to do first.

Remember the water analogy? Suppose you add in a valve so you can turn the water on and off through your pipe. What is the valve like in your circuit? It's just like a switch in a circuit, because it interrupts the flow of electricity. There are different kinds of switches, but they all do the same thing: allow you to control when electricity flows through the circuit.

Think of this switch like a train track. When you throw the switches one way, the train (electrons) can race around the track at top speed. When you turn the switch to the OFF position, it's like a bridge collapse for the train – there's no way for the electrons to jump across from the brass fastener to the paper clip. When you switch it to the ON position (both sides), you've rebuilt the bridges for the train (electrons).

Exercises

1. If you want to reverse the spin direction of a motor without using a switch, what can you do?
2. A simple switch can be made out of what kinds of materials?
3. How would you make your SPST switch an NC (normally closed) switch?
4. How did you have to connect your circuit in order for both the LED and motor to work at the same time? Draw it here:
5. Draw a picture of your experiment that explains how the SPST switch works, and show how electricity flows through your circuit:

Extra Credit (for students who have completed Part 3):

6. Draw a picture of your experiment that explains how the DPDT switch works in your circuit and show how to wire up the circuit.

Lesson #13: Digital Multimeters

Overview: Today you're going to learn how to use one of the most important tools that scientists use. You'll get to "see" electricity as you test them. And you'll never have to wonder if a battery is good or bad again.

What to Learn: Although these are the most common electrical testers, there's more than one device in that box. It measures volts, amps (current), and resistance (how easy it is for electricity to get through a wire). We're going to learn how to use it in a useful, practical way to measure volts and detect problems with non-working circuits.

Materials

- Digital Multimeter (DMM)
- Circuit equipment from Experiments 10-12 for testing

Lab Time

1. Plug your probes into the DMM. The black lead goes to ground. Push it in all the way.
2. Put the red lead in the hole that says "V" for volts. It usually has the "Ω" symbol (pronounced "omega") which stands for ohms, or it might say "ohms," or even "mA" for milli-amps. Don't put it in the hole that says "10A" – that's for testing large currents like in your house.
3. Turn the dial. Feel how it clicks?
4. You can test two different kinds of voltage: DC and AC. AC is the kind inside your house wiring. We're going to test DC with our circuit. Set your arrow on the meter to the DC voltage, which is the V with a straight line on top of it (the V with a squiggling line is AC volts). Set the knob in the DC volt area to the mark that says "20."
5. Take an AA battery and touch one probe end to the plus, and the other probe to the minus. You should get a reading. What did you get for a reading on your DMM? (Remember to write V after the number for "volts".)

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6. Test your second battery and write the reading here:

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   If the battery is good, it should read between 1.4 – 1.6 volts, depending on how fresh they are. Brand new batteries give a higher reading. Generally, if AA, AAA, C, or D cell batteries read 1.3 volts or higher, they are good and will work in your circuit. If they read between 1 – 1.3 volts, they may or may not work, depending on the type of circuit you're using them in. Anything less than 1 volt won't work and should be disposed of. 9V batteries are good between 7-9 volts.

7. Insert your batteries into the battery case. Touch the probe test leads to the ends of the wires from the battery case. What do you read?

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8. Wire up a circuit that uses a battery pack and a motor.
9. Using your probes, touch a test probe to each terminal of the motor and read how many volts you have at the motor. The motor is using a bunch of volts, so it's going to vary. So here's how you read how many volts the motor is really getting: disconnect the alligator clip wires from the back of the motor (so the motor no longer in the circuit) and attach them instead to just the probes. What do you read?

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10. Discuss with the students about how to differentiate observation from inference (interpretation). Scientists' explanations come partly from what they observe and partly from how they interpret their observations. After they take their data, ask them if they notice any patterns in their data.

Taking turns, have one lab partner wire up *one part* of a circuit incorrectly, like putting two alligator clip wires on one LED lead, putting a battery in backward, etc. Keep it simple, but the circuit shouldn't work at first. Use the DMM to figure out where the problem is. Now fill out the data table:

DMM Data Table

Type of Circuit Tested	Component Tested	Result	Notes
Simple circuit with a motor and battery pack.	*Battery pack*	*Zero volts.*	*Battery was not pushed in all the way.*

Reading

A DMM (Digital Multi-Meter) or DVOM (Digital Voltage Ohm Meter) is a handheld device that scientists pull out when things go wrong. This handy tool can detect problems with electronics, motor controls, appliances, power supplies, and circuits in no time.

It's not enough to know how to use the buttons and dial. You also have to know *how* to test your circuit. That's what we're going to do with this lab.

If you like history, the first device to detect current was a galvanometer (we're making one of these later on) way back in 1820. It wasn't until the 1920s when vacuum-tube electronics were common that the first multimeter was invented by an upset engineer who was frustrated that he had to carry around so many different devices to do his job maintaining telecommunication circuits with the British Post Office.

Exercises

1. If you measure 2.65 volts from your battery pack, do you need new batteries or will they work?

2. How do you think you would measure the resistance of an LED?

3. Reset your meter for a quick practical test: Remove the wires from your DMM and set the dial at OFF. Wave your hand wildly and show how you can use the meter (you can add probes and turn it on now) to test the voltage on your LED in a simple circuit doing the steps from the experiment.

Lesson #14: Motor Speed Controllers

Overview: You already know how to turn the LED on and off. You can even make a motor go forward and reverse. But what if you want to change the speed of the motor? Or how bright or dim the LED lights up. Today you'll be able to do just that.

What to Learn Once you understand how to use this potentiometer in a circuit, you'll be able to control the speed of your laser light show motors as well as the motors and lights on your robots.

Materials

- 2 AA batteries
- AA battery case
- 3 alligator wires
- potentiometer (1k works best)
- 1.5-3V DC hobby motor
- LED
- Optional: DMM

Lab Time

1. Wire up a simple circuit with the LED and make it light up.
2. Replace one of the LED alligator clip leads with a third wire, as we did in *Experiment 11: Conductivity Testers.*
3. Take the two free alligator clips ends and connect one to the middle tab of the potentiometer, and the other to one of the remaining tabs.
4. Turn the knob. What happened?

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5. Move the second alligator clip to the other terminal. How does this change the circuit?

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6. Can you use a motor instead of an LED? Try it now. What happened?

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7. If you have trouble with the motor, here's an alternative circuit you can try that is a Voltage Divider circuit, using a variable voltage supply for the motor:
   a. Connect the positive battery wires to one of the potentiometer's resistive terminals (*not* the middle terminal) using an alligator clip lead.
   b. Connect the negative battery wire to the other resistive terminal on the potentiometer (again, *not* the middle wiper terminal) using another alligator clip lead.
   c. Connect a third alligator clip lead between one of the motor terminals and the wiper.
   d. Connect a fourth alligator clip lead to the last motor terminal and right on top of the negative battery wire. You will have two alligator clip leads attached at this point. Make sure they all make good contact.
   e. Turn the knob… does the motor turn?

1. Optional: You can do this as a demo piece if you're short on equipment or time.
   a. Disconnect your potentiometer from the circuit. Use your DMM, turning your dial to the "Ω" symbol to measure the resistance in ohms.
   b. Touch your probes to the wiper and one of the resistive ends and read a measurement. What happens to your reading when you turn the knob? How high and low do the numbers go (what is the range of the potentiometer)?

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   c. With a pencil, draw a long line on a sheet of paper. Touch one of the probes to the end of the line. Touch the other probe to a spot anywhere else on the line. What do you read?

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   d. What if you move your pencil further down the line? Does this change the reading? How?

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Reading

A potentiometer (sometimes referred to as *pot*) is a resistor with three terminals that has a sliding contact to vary the resistance. Resistance is a measure of how easily current flows through a wire. The more the resistance, the less current flows through the circuit. We're going to use ours as a variable resistor. In everyday life, potentiometers are everywhere: volume controls, old radio dials, and inside joysticks as a way to detect position.

If you have an extra, pull it apart so you can see the sliding contact (called a 'wiper') that moves along the resistive element. The wiper is the middle contact and the resistive elements are the terminals on either side.

Exercises

1. How does a potentiometer work?
2. Does the potentiometer work differently on the LED and the motor?
3. Name three places you've used potentiometers in everyday life.
4. How do you think you might wire up an LED, switch, and potentiometer?

Lesson #15: Electric Eye Sensor

Overview: Photoresistors are very inexpensive light detectors, and you'll find them in cameras, street lights, clock radios, robotics, and more. We're going to play with one and find out how to detect light using a simple series circuit.

What to Learn: This is the first of many different burglar alarms we're going to make with our simple circuits and switches knowledge. Pay special attention to how this gets inserted in your circuit. Notice any similarities to the switch circuit? We're going to use the idea of wiring up components in *series* over the next couple of Burglar Alarm lessons.

Materials

- AA battery case with batteries
- one CdS cell
- three alligator wires
- LED
- Optional: Laser pointer or flashlight (or both)
- Optional: DMM (Digital Multimeter)

Lab Time

1. Separate the wires of your CdS cell.
2. Light up your LED in a simple circuit. Don't put in the CdS cell yet – we want to be sure everything works before introducing a new electronic element.
3. Remove one of the alligator clips from an LED wire and replace it with a third alligator clip lead.
4. Attach each one of the two free ends of alligator wires to either end of the CdS cell. You should now have a complete circuit that looks a lot like a circle when you stretch it out.
5. Put your hand over the CdS light detector and the LED should go dark.
6. Shine a flashlight or laser pointer on the CdS cell (or just go outside in the sun) and the LED will light up. If you used the sun for a light source, you'll need to cup your hands around the LED because it's going to look dark or dim outdoors.
7. Optional: Using your DMM set to DC volts and "20," measure the voltage of the LED. How many volts does the LED receive? (Don't forget to write "V" after the number you read.)

   ____

8. Set your DMM to "ohms" or the "Ω" symbol. Touch one probe to each side of the CdS cell. If this is too difficult, then attach an alligator wire to a probe and the other end to one of the wires on the CdS cell. Do this for both sides. Make sure your dial is set to measure resistance. What do you read? (Don't forget to write "Ω" or "ohms" after the number you write down.)

   ____

9. Fill in the data table below. Note that your values will not be the same as mine, since you have different lighting, different batteries, and a different size cell than I do. Feel free to go outside, hide it under the table, close the cell in a book, put it next to the window, etc… when taking your data. Be creative!

CdS Photocell Data Table

Lighting Condition	**CdS Cell Resistance**	**LED Voltage**
CdS Cell completely covered up	*7.1 MΩ (or 7,100,000 Ω)*	*0.5 volts*
Laser pointer beam dead center on the cell	*3.8 kΩ (or 3,800 Ω)*	*2.9 volts*

Reading

This is the first of many different burglar alarms we're going to make with our simple circuits and switches knowledge. This particular one is a good one to start with, since it's relatively simple to make and you probably have experience with the *buzz* you hear when you enter a store that's armed with one of these.

A *photoresistor* or *light dependent resistor* limits the amount of current that flows through it in proportion to the light it receives. This effect is called *photoconductivity*. The more light that falls on the resistor, the more electricity flows through the wire. Photoresistors are also called *photocells*.

Exercises

1. How is a CdS cell like a switch? How is it *not* like a switch?
2. When is the LED the brightest?
3. How could you use this as a burglar alarm?

Lesson #16: Trip Wire Burglar Alarm

Overview: This alarm has a thin wire that someone "trips," which pulls out the paper, closes a switch, and lights up the LED!

What to Learn: This particular burglar alarm is an NC (Normally Closed) switch, and today you get to learn how to wire it up in a circuit and pull the trigger.

Materials

- AA battery case
- 2 AA batteries
- 3 alligator clip wires
- wood clothespin
- 4-6″ piece of steel wire, like picture hanger wire OR use un-insulated copper wire
- 2 unpainted steel tacks scrap of paper
- LED

Lab Time

1. Make the NC trip wire switch:
    a. Cut a 3" piece of steel wire. Wrap the steel wire around the stem of the tack. Do this twice – once for each tack.
    b. Open the clothespin all the way, and insert one of the tacks inside the jaw, like you're inserting teeth. Do this for the upper and lower jaw of the clothespin.
    c. Orient the wires so that one steel wire comes off to the left of the clothespin and the other off to the right. This will make sure that the wires don't touch during your experiment.
    d. Open up your paperclip, and grab a scrap of a sheet of paper. When you release the clothespin, the two metal tacks should be on either side of the paper.
2. Make the Trip Wire Circuit:
    a. Use your batteries, wires, and LED to make the LED light up. (No trip wire yet.)
    b. Remove one of the alligator wires from the LED and replace it with a third alligator wire.
    c. Attach one of the free alligator wire ends to one of the steel wires coming from the clothespin.
    d. Attach the remaining alligator wire to the last steel wire from the clothespin.
    e. Yank the paper away – did the LED light up?
    f. Attach string to the paper. The length of string you need is going to depend on where you install the trip wire alarm.
3. Installation Tip: Hide this switch down low by the door frame and use fishing line instead of string to make this burglar alarm virtually invisible. Use a tack in the frame or tie the line to the door hinge to secure and wait for the action…

Reading

Do you need a little help protecting your stuff, like from younger siblings or nosy friends? This burglar alarm relies on a special kind of switch: an NC (normally closed) switch. This means that when the switch is just sitting there, it allows current to flow. When it's activated, electricity stops. The opposite kind if switch is an NO (normally open) switch, which doesn't turn on the electricity until you push the button. (The burglar alarm in the next experiment uses an NO switch.)

This switch works because paper doesn't conduct electricity – it's an insulator, just like plastic. Since the trip wire is an NC switch, this circuit works *until* you trigger the switch. We need a way to stop the current (flow of electrons) until we want the LED to activate. When you stick the paper index card between the two tacks in the clothespin, it breaks the electrical connection and the switch goes in the OFF position. Remove the paper and your switch moves to the ON position, and electrons are flowing around and around your circuit, and you see the LED light up.

This is a *silent alarm*, but if you'd like a *loud* alarm, substitute a buzzer for the LED. Make sure to select a buzzer that is low voltage (under 6V), like Radio Shack part #273-053.

Installation Tip: Hide this switch down low by the door frame and use fishing line instead of string to make this burglar alarm virtually invisible. Use a tack in the frame or tie the line to the door hinge to secure and wait for the action…

Exercises

1. How does this work?
2. What type of switch is the trip wire?
3. Name three places you can install this alarm.

Lesson #17: Pressure Sensor

Overview: You've about to make an NO burglar alarm switch, which is similar to the Trip Wire Burglar Alarm, only this one is triggered by squeezing it. If you're using the special black foam without the hole, it works because the foam conducts more electricity when squished together, and less when it's at the normal shape.

What to Learn: Switches control the flow of electricity through a circuit. There are different kinds of switches. NC (normally closed) switches keep the current flowing until you engage the switch. The SPST and DPDT switches are NO (normally open) switches. Today's switch is also an NO switch.

Materials

- thin sponge or foam square (about 1″ square)
- AA battery case
- 2 AA batteries
- 3 alligator clip wires
- 2 large paper clips
- scissors
- aluminum foil
- LED

Lab Time

1. Make the Pressure Sensor:
   a. Cut the foil so it's slightly smaller than the foam square. You need two pieces.
   b. Carefully cut an open hole through the middle of your square. Make it bigger than you think you need.
   c. Place one piece of foil in the top of the sponge with the other piece on the bottom.
   d. Place a paperclip on top of each piece of foil. Point the paperclips in opposite directions so they don't touch when you're squeezing the sensor later.
   e. Wrap the whole thing in a single piece of tape.
2. Make the Pressure Sensor Circuit:
   a. Use your batteries, wires, and LED to make the LED light up. (No trip wire yet.)
   b. Remove one of the alligator wires from the LED and replace it with a third alligator wire.
   c. Attach one of the free alligator wire ends to one of the paperclips.
   d. Attach the remaining alligator wire to the other paperclip.
   e. Press *hard* on the sensor. *GOTCHA!*
3. When you squeeze the foam, the LED lights up! It's ideal for under a doormat or carpet rug where lots of weight will trigger it. You'll always know when mom's on her way into your room.

Troubleshooting: There are a few problem areas to watch out for when building this sensor. First, make sure the hole in your foam is big enough to stick a finger (or thumb) through easily. The foam keeps the foil apart until stepped on, then it squishes together to allow the foil to make contact through the hole. The second potential problem is if the switch doesn't turn the LED off. If this happens, it means you're bypassing the switch entirely and keeping the circuit in the constant ON position. Check the two foil squares, alligator clips, and paperclips – are they touching around the outside edges? Lastly, make sure your foam is the kind that pops back into shape when released.

Bonus Idea: Stick just the sensor under a rug and run longer wires from the sensor to your room. When someone comes down the hallway, they'll trigger the sensor and alert you before they get there!

Reading

By controlling how and when a circuit is triggered, you can easily turn a simple circuit into a burglar alarm – something that alerts you when something happens. By sensing light, movement, weight, liquids, even electric fields, you can trigger LEDs to light and buzzers to sound. Your room will never be the same.

The pressure sensor we're building is small, and it requires a fair amount of pressure to activate.

Now is a good time to introduce the idea of *pressure*. Pressure is force (like weight) over a given area (like a footprint). If you weighed 200 pounds, and your footprint averaged 10" long and 2" wide (so the area of your footprint is 10 x 2 = 20 square inches), you'd exert 200 / 20 = 10 psi (pounds per square inch) on the ground when standing on both feet. Or 5 psi per foot.

However, if you walked around on stilts instead of feet, and the "footprint" of each stilt averaged 1" by 1" square, you'd now exert 200 / (1 x 1) = 200 psi, or 100 psi per foot. Why such a difference?

The secret is in the area of the footprint. In our example, your foot is about 20 square inches, but the area of each stilt was only 1 square inch. Since you haven't changed your weight, you're still pushing down with 200 pounds. In the stilts' case, you're pressing the same weight into a much smaller spot… and hence the pressure applied to the smaller area shoots up by a factor of 20. Imagine how the floor feels under the spike of a high-heeled shoe.

So how do we use pressure in this experiment? You need to exert pressure on the sensor for it to activate. How much pressure is going to depend on how large or small your sensor is, how stiff your sponge is, how large the hole is, and so forth.

Bonus Idea: Stick just the sensor under a rug and run longer wires from the sensor to your room. When someone comes down the hallway, they'll trigger the sensor and alert you before they get there!

Exercises

1. How does this sensor work?
2. What makes this an NO switch?
3. How can you use both the trip wire and the pressure sensor in the same circuit? Draw it out here:

Lesson #18: Latching Circuits

Overview: Once you've made the Pressure Sensor burglar alarm, you might be wondering how to make the alarm stay on after it has been triggered, the way the Trip Wire Sensor does naturally. That's what we're going to do today using another type of switch and a more complex circuit.

What to Learn: A relay is a switch you can turn on and off using electricity. It uses an electromagnet to activate the switch inside of it.

Materials

- relay (you'll want one that has a coil voltage of 12V DC or less)
- your completed Pressure Sensor circuit
- 3 AA battery packs with 6 AA batteries
- 7 additional alligator clip wires
- Optional: SPST switch

Lab Time

1. Hook up your battery packs like this: connect the positive lead from battery pack #1 to the negative lead on battery pack #2 using an alligator clip wire. Connect the positive lead from #2 to the negative of #3 using a second alligator wire. You should now have two free ends: the negative from #1 and the positive from #3. Those are the two you are going to use to power your relay in the next step. (If you use your DMM set to 20 volts and DC, you'll find you have about 9V between those two leads. That's usually enough to get the relay to click.
2. Connect the alligator lead from battery pack #1 to one side of the relay coil. The coil terminals are usually the two tabs that are orientated differently than the rest. Touch (don't connect) the alligator lead from battery pack #3 to the other coil terminal. Tap it a few times to hear the relay click. If you don't get a click, stop and redo your wiring until you do before moving on.

3. Connect the alligator clip lead from battery pack #3 (in the video, it's white) to one side of the SPST switch. You can use your index card SPST switch if you like, or simply skip the switch and connect it to a free alligator clip lead (in the video, this one is yellow).
4. Connect the switch to the pressure sensor using another alligator clip lead (yellow in the video).
5. Connect the other paperclip of the pressure sensor to the relay coil (a second white wire in the video).
6. Connect the other side of the relay coil to the batteries (in the video, it's green).
7. Recheck your connections: You should have the relay connected to the SPST to the pressure sensor and back to the relay, like a big loop.
8. Squeeze the pressure sensor – do you hear the relay click once? If not, redo steps #3-9.
9. The video uses a buzzer. You can use your LED instead (it's a much quieter lab if you do). Connect one alligator wire to each lead of the LED (in the video, they are green and white). Connect each of the alligator wires from the LED to the coil, one on each terminal, right on top of the ones that are already clipped on.
10. Connect a fresh alligator clip lead to one side of the pressure sensor right onto the paper clip (red wire in the video). The other side of this alligator clip goes to the middle contact on the relay.

11. Connect another new alligator clip lead to either the top or the bottom contact. Here's how to tell which one: look at your relay. Do you see which contact (top or bottom) the small metal lever is touching when it's not activated? That's not the one you want. Choose the other one and clip the wire onto that terminal. The other end of this alligator wire (white in the video) goes to the other side of your pressure sensor right onto the paperclip. You should have two wires on each paperclip.
12. Press the sensor to trigger the LED, and the relay should also click on. Does the LED stay lit? If not, go back and try hooking up your circuit again, carefully following the steps in the video.

Reading

A relay is switch you can turn on and off using electricity. It uses an electromagnet to active the switch inside of it. We'll talk more about how the relay works when we discuss Magnetism.

Once you've made the Pressure Sensor burglar alarm, you might be wondering how to make the alarm stay on after it has been triggered, the way the Trip Wire Sensor does naturally.

The reason this isn't as simple as it seems is that the trip wire is a normally closed (NC) switch while the pressure sensor is a normally open (NO) switch. This means that the trip wire is designed to allow current to flow through the tacks when there's no paper insulating them, while the pressure sensor stops current flowing in its un-squished state. It's just the nature of the two different types of switches.

However, we can build a circuit using a relay which will "latch on" when activated and remain on until you reset the system (by cutting off the power). This super-cool latching circuit video will show you everything you need to know

Exercises

1. What is a relay?
2. What does the relay do in this circuit?
3. Draw out a picture that shows how everything is connected in your circuit:

Lesson #19: Nerve Tester

Overview: Today's lesson is mostly playtime, since you already know everything you need to in order to create this project. You're going to start with a simple circuit, then modify it a bit and turn it into an electrical roller coaster.

What to Learn: How to modify your simple circuit into something fun and entertaining! And probably hone your troubleshooting skills when things go wrong.

Materials

- AA battery case
- 2 AA batteries
- 2 alligator wires
- LED
- bare wire OR you can use a wire coat hanger, but be aware you may have to use sandpaper if it's is coated with clear enamel
- popsicle stick
- paperclip
- tape
- wood block with wood 2 wood screws and a drill and/or screwdriver OR dense foam block

Lab Time

1. Insert batteries into cases and connect an LED so that it works. Set aside as you make the next part.
2. Using a paper clip, form a loop and secure to a popsicle stick so that it looks like a bubble wand, with the ends poking out of the bottom of the tape. Bend the ends up so you can clip onto them with your alligator clips later. (You should have ¼ – ½" poking upward.)
3. Bend and twist an un-insulated coat hanger wire into spirals and dizzy roller-coaster shapes. When you've got it right, make a small loop at each end. If you're using a wood base, insert one screw into each small loop and screw into the wood base, about 10" apart (be sure to thread the bubble wand loop onto the wire first!). Your roller coaster wire should stand up on its own.
4. Disconnect the clip lead wire from your positive battery terminal and clip it to the exposed paper clip end on your popsicle-stick bubble-wand. Wrap the exposed end of the positive terminal around one end of the coat hanger near the screw and seal with tape.
5. If it doesn't work:
    a. Make sure the batteries are fresh and inserted the right way.
    b. Make sure your coat hanger is really just a bare rod of metal. If it's got a coating on it, you'll need to use sandpaper on the entire length before using it in the project.
    c. Use a block of wood or foam for best results… they are both excellent insulators for the wire track.
    d. Places where kids most often forget to hook up:
        i. connect the wire to a bare spot on the track itself, near the base
        ii. be sure your loop also has a good metal wire connection

Reading

Electrical circuits are used for all kinds of applications, from blenders to hair dryers to cars. And games! Here's a quick and easy game using the principles of conductivity. This experiment is a test of your nerves and skill to see if you can complete the roller coaster circuit and make it from one end to the other. You can opt to make a noisy version (more fun) or a silent version (for stealth).

Exercises

1. Can you travel the entire path without turning on the light?
2. Where in your circuit can you add a switch to turn the game on and off?

Electricity Evaluation

Student Worksheet

Overview: Today you're going to take two different tests: the quiz and the lab practical. You're going to take the written quiz first, and the lab practical at the end of this lab. The lab practical isn't a paper test – it's where you get to show your teacher that you know how to do something.

Lab Test & Homework

1. Your teacher will call you up so you can share how much you understand about electricity and how it works. Since science is so much more than just reading a book or circling the right answer, this is an important part of the test to find out what you really understand.
2. While you are waiting for your turn to show your teacher how much of this stuff you already know, you get to choose which homework assignment you want to complete. The assignment is due tomorrow, and half the credit is for creativity and the other half is for content, so really let your imagination fly as you work through it. Choose one that you didn't choose from the Static Electricity homework assignment last time:
   a. Write a short story or skit about electricity from the perspective of the wire or the electrical component. You'll read this aloud to your class.
   b. Make a poster that teaches the main concepts to electricity. When you're finished, you'll use it to teach to a class in the younger grades and demonstrate each of the principles that you've learned.
   c. Write and perform a poem or song about electricity. This will be performed to your class.

Electricity Quiz

Name____

1. What is the difference between a bolt of lightning and the electricity in your circuit?

2. How does electricity pass through a material?

3. What kinds of materials are conductors and insulators? Name three of each.
   a. Conductor:
   b. Conductor:
   c. Conductor:
   d. Insulator:
   e. Insulator:
   f. Insulator:

4. What is an NC SPST switch? How does it work when placed in a circuit?

5. What's the difference between an incandescent light bulb, a fluorescent light, and the LED?

6. If you measure 2.85 volts from your battery pack, do you need new batteries or will they work?

7. Where have you used potentiometers in everyday life?

8. How is a CdS cell like a switch? How is it not like a switch?

9. Is the trip wire an NO or NC switch without the paper inserted?

10. What is a relay?

11. Imagine your teacher just asked you to hook up a simple circuit to power a motor. Draw the circuit as a diagram below, and show how electricity flows through your circuit (indicate the direction with an arrow). Label every part of your diagram, including every component used. For bonus points, also show where you would put your DMM probes to measure how much voltage the motor is receiving.

Electricity Lab Practical

Student Worksheet

This is your chance to show how much you have picked up on important key concepts, and if there are any holes. You also will be working on a homework assignment as you do this test individually with a teacher.

Materials:

- AA battery case
- 2 AA batteries
- 4 alligator wires
- switch
- LED
- 1.5-3VDC motor

Lab Practical:

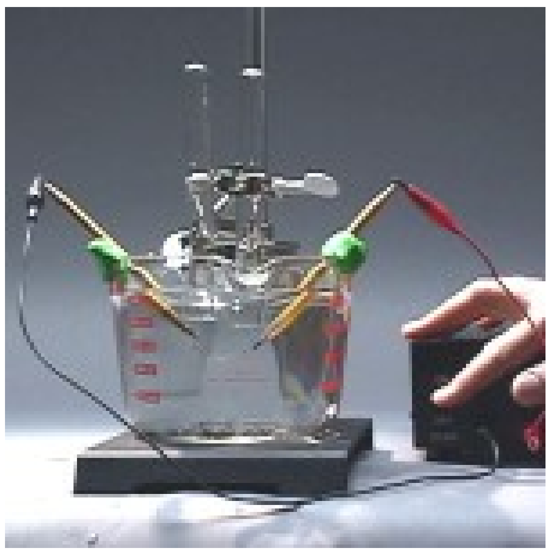
- Design and build a simple series circuit which lights up an LED and includes a switch.
- Design and build a simple parallel circuit which powers both LED and motor at the same time.
- Explain how electrical energy can be converted to light or motion.

Section 3: Electrochemistry

When electric current passes through a material, it does so by electrical conduction. There are different kinds of conduction, such as metallic conduction, where electrons flow through a conductor (like metal) and electrolysis, where charged atoms (called ions) flow through liquids.

When an atom (like hydrogen) or molecule (like water) loses an electron (negative charge), it becomes an ion and takes on a positive charge.   When an atom (or molecule) gains an electron, it becomes a negative ion. An electrolyte is any substance (like salt) that becomes a conductor of electricity when dissolved in a solvent (like water).

This type of conductor is called an "ionic conductor" because once the salt is in the water; it helps along the flow of electrons from one clip lead terminal to the other so that there is a continuous flow of electricity.



Lesson #20: Electrolytes

Overview: Electricity. Chemistry. Nothing in common, have nothing to do with each other…right? Wrong! Electrochemistry has been a fact since 1774. Once electricity was applied to particular solutions, changes occurred that scientists of the time did not expect… and you get to play detective again and figure out what's going on.

What to Learn: An electrolyte is any substance (like salt) that becomes a conductor of electricity when dissolved in a solvent (like water). This type of conductor is called an "ionic conductor" because once the salt is in the water, it helps along the flow of electrons from one clip lead terminal to the other so that there is a continuous flow of electricity.

Materials

- 2 AA batteries
- AA battery case
- 3 alligator clip wires
- LED
- Water
- Sugar
- Salt
- Vinegar
- Baking soda
- Lemon juice
- Oil
- Soap
- 10 disposable cups
- 10 popsicle sticks for stirring
- Optional: DMM

Lab Time

1. Connect the alligator clip leads to the wires from the battery case, one on each.
2. Connect the other ends to the LED to make a simple circuit. This makes sure everything is working before trying something new.
3. Disconnect one of the wires from the LED and insert a third alligator wire.
4. Touch the two free ends of the alligator clip leads together. The LED should light up.
5. Fill the jar with water.
6. Insert the free ends of the alligator clip leads into the jar. What happened? Write it here:

   ____

7. Add a couple tablespoons of salt and stir.

8. Insert the free ends of the alligator clip leads into the jar. What happened? Write it here:

____

9. Optional: Turn on the DMM to “20” volts DC and insert the probes into the jar.

   How much voltage do you read? ____

10. Fill out the data table.
11. When you’ve got a couple of minutes of lab time left, ask yourself this question: What happens if you mix an electrolyte and non-electrolyte together? Test it and record your results in the last box on the data table.
12. Cleanup: Clean everything thoroughly after you are finished with the lab. After cleaning with soap and water, rinse thoroughly. Chemists use the rule of “three” in cleaning glassware and tools. After washing, chemists rinse out all visible soap and then rinse three times more.
13. Storage: Place all chemicals, cleaned tools, and glassware in their respective storage places.
14. Disposal: Dispose of all solid waste in the garbage. Liquids can be washed down the drain with running water. Let the water run awhile to ensure that they have been diluted and sent downstream.

Electrolyte Data Table

Substance Tested	Did it conduct electricity?	How much voltage is present?
Plain Water		
Water + Salt		
Electrolyte: *Non-electrolyte:*		

15. When you've got a couple of minutes of lab time left, run one more test, and you'll record your result in the last box on the data table.

Reading

Our first part of the experiment uses a saturated solution of table salt that is just sitting in a container minding its own business.

The batteries push voltage through the saltwater. That electric current tears the sodium from the chlorine. These positively and negatively charged ions rush about, looking for something they are attracted to. Opposites attract, so positively charged sodium ions find spending time with the negative electrode a treat. They are very happy together. Negatively charged chlorine ions are attracted to the positive electrode.

Sodium chloride decomposes into sodium and chlorine ions: $NaCl \rightarrow Na^{+} + Cl^{-}$

When the salt sodium chloride (NaCl) mixes with water, it separates into its positively (Na+) and negatively (Cl-) charged particles (ions). When a substance mixes with water and separates into its positive and negative parts, it's called a "salt."

Salts can be any color of the rainbow, from the deep orange of potassium dichromate to the vivid purple of potassium permanganate to the inky black of manganese dioxide. Did you know that MSG (monosodium glutamate) is a salt? Most salts are not consumable, as in the lead poisoning you'd get if you ingested lead diacetate.

If you pass a current through the solution of salt and water, opposites attract: the positive ions are attracted to the negative pole and the negative ions go toward the positive pole. These migrations ions allow electricity to flow, which is why "salt" solutions conduct electricity.

Exercises

1. Why does electricity flow through some solutions but not all of them?
2. What is a salt?
3. How are electrolytes used today in real life?
4. Which substance was your top conductor?
5. Which substance didn't conduct anything at all?
6. What happens if you mix an electrolyte and non-electrolyte together?

Lesson #21: Electrolysis

Overview: This lab is a lot of fun, because we're breaking apart molecules and setting them on fire. Pay close attention to how to do this one safely so your eyebrows stay attached.

What to Learn: A water molecule is two hydrogen atoms and one oxygen atom. You're going to use electricity to split apart the water molecule into smaller pieces: hydrogen ions (positively charged hydrogen) and oxygen ions (negatively charged oxygen). The positive hydrogen ions zip over to the negative terminal and form tiny bubbles right on the wire. Same thing happens on the positive battery wire. After a bit of time, the ions form a larger gas bubble.

Materials

- 2 test tubes, glass or plastic
- 2 alligator clip leads
- 1 disposable cup
- Distilled water
- One 9 volt battery with battery clip
- Salt or sodium sulfate

Lab Time: Have fun and please follow the directions carefully. This could be dangerous if you're not careful.

1. Have fun and please follow the directions carefully. This could be dangerous if you're not careful.
2. Fill the cup two-thirds with water.
3. Fill your test tubes with water. Place your thumb over the end, and invert and insert into the water cup. You want an entire test tube filled with water. Do this for both test tubes. A few bubbles are okay.
4. Connect your battery to two alligator clip leads, one lead for each terminal.
5. Insert one alligator clip into each test tube.
6. You should now have two inverted test tubes filled with water, each with their own alligator clip wire.
7. Put a tablespoon or so of salt into the water and stir it up. The salt allows the electricity to flow better through the water. If you have access to sodium sulfate, use it, as the reaction will progress faster.
8. You should see bubbles rising into the test tube. If you don't see bubbles, check the wires and battery connection.
9. When the test tube is mostly full of gas, ask an adult to test for flammability. Before they do, which tube do you think is filled with oxygen and which is hydrogen? Write down your guess here:
    a. Positive wire:____________________________________
    b. Negative wire:____________________________________
10. What did you *really f*ind?
    a. Positive wire:____________________________________
    b. Negative wire:____________________________________

11. Cleanup: Clean everything thoroughly after you are finished with the lab. After cleaning with soap and water, rinse thoroughly. Chemists use the rule of “three” in cleaning glassware and tools. After washing, chemists rinse out all visible soap and then rinse three times more.
12. Storage: Place all chemicals, cleaned tools, and glassware in their respective storage places.
13. Disposal: Dispose of all solid waste in the garbage. Liquids can be washed down the drain with running water. Let the water run awhile to ensure that they have been diluted and sent downstream.

Reading

If you guessed that this has to do with electricity and chemistry, you’re right! But you might wonder how they work together. Back in 1800, William Nicholson and Johann Ritter were the first ones to split water into hydrogen and oxygen using electrolysis. (Soon afterward, Ritter went on to figure out electroplating.) They added energy in the form of an electric current into a cup of water and captured the bubbles forming into two separate cups, one for hydrogen and the other for oxygen.

It takes energy to split a water molecule. (On the flip side, when you combine oxygen and hydrogen together, it makes water and a puff of energy. That’s what a fuel cell does.) Back to splitting the water molecule – as the electricity zips through your wires, the water molecule breaks apart into smaller pieces: hydrogen ions (positively charged hydrogen) and oxygen ions (negatively charged oxygen). Remember that a battery has a plus and a minus charge to it, and that positive and negative attract each other.

So, the positive hydrogen ions zip over to the negative terminal and form tiny bubbles right on the wire. Same thing happens on the positive battery wire. After a bit of time, the ions form a larger gas bubble. If you stick a test tube over each wire, you can capture the bubbles and when you’re ready, ignite each to verify which is which.

If the match burns brighter, the gas is oxygen. If you hear a *POP!,* the gas is hydrogen. Oxygen itself is not flammable, so you need a fuel in addition to the oxygen for a flame. In one case, the fuel is hydrogen, and hence you hear a pop as it ignites. In the other case, the fuel is the match itself, and the flame glows brighter with the addition of more oxygen.

When you put the match to it, the energy of the heat causes the hydrogen to react with the oxygen in the air and *“POP*,” hydrogen and oxygen combine to form what? That’s right, more water. You have destroyed and created water! (It’s a very small amount of water, so you probably won’t see much change in the test tube.)

The chemical equations going on during this electrolysis process look like this:

A reduction reaction is happening at the negatively charged cathode. Electrons from the cathode are sticking to the hydrogen cations to form hydrogen gas:

$2\ H^+_{(aq)} + 2e^- \text{-->}\ H_{2(g)}$

$2\ H_2O_{(l)} + 2e^- \text{-->}\ H_{2(g)} + 2\ OH^-_{(aq)}$

The oxidation reaction is occurring at the positively charged anode as oxygen is being generated:

$2\ H_2O_{(l)}\ \text{-->}\ O_{2(g)} + 4\ H^+_{(aq)} + 4e^-$

$4\ OH^-_{(aq)} \rightarrow O_{2(g)} + 2\ H_2O_{(l)} + 4\ e^-$

Overall reaction:

$2\ H_2O_{(l)} \rightarrow 2\ H_{2(g)} + O_{2(g)}$

Note that this reaction creates twice the amount of hydrogen as oxygen molecules. If the temperature and pressure for both are the same, you can expect to get twice the volume of hydrogen to oxygen gas. (This relationship between pressure, temperature, and volume is the Ideal Gas Law principle.)

This is the idea behind vehicles that run on sunlight and water. They use a solar panel (instead of a 9V battery) to break apart the hydrogen and oxygen and store them in separate tanks, then run them both back together through a fuel cell, which captures the energy (released when the hydrogen and oxygen recombine into water) and turns the car's motor. Cool, isn't it?

Exercises

1. Why are bubbles forming?
2. Did bubbles form at both wires, or only one? What kind of bubbles are they?
3. What would happen if you did this experiment with plain water? Would it work? Why or why not?
4. Which terminal (positive or negative) produced the hydrogen gas?
5. Did the reaction create more hydrogen or more oxygen?

Lesson #22: Electroplating

Overview: People use this technique to add material to undersized parts, for placing a protective layer of material on objects, and to add aesthetic qualities to an object.

What to Learn: You're going to use electrolytes to deposit metal ions and make them stick to objects by using by positive and negative electrical charges.

Materials

- one shiny metal key (ask for these at a hardware store that makes keys and keeps a bucket of mistakes)
- copper strip, copper pipe or shiny copper penny (shine it up with ketchup and a toothbrush)
- 2 alligator clips
- 9V battery with clip
- water
- copper sulfate
- disposable cup
- paper towel
- popsicle stick

Lab Time

1. Wipe your key with a few swipes of a wet paper towel to get rid of the oils and dirt from your fingers.
2. Brush up your penny or copper pipe until it's shiny. You can use sandpaper or a clean paper towel.
3. Place a teaspoon of copper sulfate into your container. Don't touch this chemical with your hands. Cap it and set it aside.
4. Add a thin stream of water, just enough so that the bits on the bottom dissolve. Go slowly and stir continuously until all the copper sulfate is dissolved. (Do not heat the solution.)
5. Connect the wires to your battery.
6. Connect one end of an alligator wire to the copper strip and the other end to the positive (red) wire from your battery.
7. Connect the other alligator wire to the key and the negative (black) lead.
8. Place the copper strip and the key in the solution without touching each other. If they touch, you'll short your circuit and blow up your battery. Let this sit for a few minutes… and notice what happens and how long it took to happen (glance at the clock when you put the wires in the solution). Write down your observations.
9. Working with another lab group, use a second battery in your circuit.
    a. Connect the batteries in series: connect the second battery by removing the wire attached to the positive terminal of the original battery, and attaching a third alligator clip lead. The other end of this alligator clip lead goes to the new battery's negative terminal. Reattach the clip lead to the new positive terminal and perform your experiment. Does the reaction happen faster or slower now?

   b. Connect the batteries in series: twist together the red wires from both batteries. Twist the negative wires from both. Now insert this where the original battery was in your circuit using alligator clip leads. Does the reaction happen faster or slower now?

10. Remove the key and the copper strip from the solution and set on the paper towel. Attach one paperclip to each lead and put them (without touching) in the solution. What happens?
11. Complete the data table. Be sure to note what kind of copper piece you used, and how many batteries were in your circuit. If you had more than one battery, also include how they were connected (series or parallel). For "Time to Electroplate," you can enter two numbers: first number is the time that you first put the wires in to when you first start to see a color change beginning to appear. The second number is how long it took to electroplate the whole thing, measured when you took it out of the solution.

Electroplating Data Table

Positive Electrode	Negative Electrode	Time to Electroplate	Battery	Notes/Observations

12. Cleanup: Clean everything thoroughly after you are finished with the lab. After cleaning with soap and water, rinse thoroughly. Chemists use the rule of "three" in cleaning glassware and tools. After washing, chemists rinse out all visible soap and then rinse three times more.
13. Storage: Place all chemicals, cleaned tools, and glassware in their respective storage places.
14. Disposal: Dispose of all solid waste in the garbage. Strain out the solution through a piece of paper towel and throw the paper towel in the trash. Liquids can be washed down the drain with running water or flushed down the toilet. If using a sink, let the water run awhile to ensure that they have been diluted and sent downstream.

Reading

Electroplating was first figured out by Michael Faraday. The copper dissolves and shoots over to the key and gets stuck as a thin layer onto the metal key. During this process, hydrogen bubbles up and is released as a gas. People use this technique to add material to undersized parts, for placing a protective layer of material on objects, and to add aesthetic qualities to an object.

This experiment can be tricky. The problem areas include:

1. Solution is not saturated, meaning there's too much water mixed in. If this happens, add more copper sulfate.
2. Wires aren't making good contact with the battery or metal pieces.
3. Not enough voltage or amps available to drive the circuit. If this happens, you can add a second battery to your circuit either in series or parallel.
4. No copper sulfate? You can use salt and vinegar, although this is a much slower reaction and you'll probably want to leave it for a couple of hours.

Exercises

1. Look at your key. What color is it?

2. Where did the copper on your key come from?

3. What happened when you added a second battery?

4. Which circuit (series or parallel) did the reaction accelerate faster with?

Lesson #23: Fruit Battery

Overview: Today you get to raid the refrigerator and test several different kinds of fruits and veggies to create the best battery with the highest voltage. Do *not* eat anything that was used in the lab.

What to Learn: This experiment shows how a battery works using electrochemistry. The copper electrons are chemically reacting with the lemon juice, which is a weak acid, to form copper ions (cathode, or positive electrode) and bubbles of hydrogen. These copper ions interact with the zinc electrode (negative electrode, or anode) to form zinc ions. The difference in electrical charge (potential) on these two plates causes a voltage, which kids will measure with your digital multi-meter.

Materials

- zinc strip
- copper strip
- two alligator wires
- digital multimeter (DMM)

You can use a galvanized nail and a copper penny (preferably minted before 1982) for additional electrodes and connect them all the way around the fruit.

Fruit to experiment may include:

- lemon
- lime
- apple
- potato
- tomato
- bananas
- grapes
- pineapple
- oranges
- tangerines

Lab Time

1. Roll and squish the lemon around in your hand so you break up the membranes inside, without breaking the skin or leaking any juice. If you're using non-membrane foods, such as an apple or potato, you are all ready to go.
2. Insert the copper and zinc strips into the lemon, making sure they do not contact each other inside.
3. Clip one test wire to each metal strip using alligator wires to connect to the digital multimeter.
4. Turn on the DMM to 20 VDC. Read the multimeter and record your results in the data table.
5. What happens when you gently squeeze the lemon? Does the voltage vary over time?
6. Fill in the data table as you test these different ideas:
    a. Try potatoes, apples, or other fruit or vegetable containing electrolytes. Record your measurements in the data table.
    b. What if you use one electrode in one fruit and one in the other? What do you measure?

Fruit Batteries Data Table

Trial #	Fruit Type	Volts Generated (V)
1		
2		
3		
4		
5		
6		
7		
8		
9		
10		

Reading

The basic idea of electrochemistry is that charged atoms (ions) can be electrically directed from one place to another. If we have a glass of water and dump in a handful of salt, the NaCl (salt) molecule dissociates into the ions Na^+ and Cl^-.

When we plunk in one positive electrode and one negative electrode and crank up the power, we find that opposites attract: Na^+ zooms over to the negative electrode and Cl^- zips over to the positive. The ions are attracted (directed) to the opposite electrode and there is current in the solution.

Electrochemistry studies chemical reactions that generate a voltage and vice versa (when a voltage drives a chemical reaction), called oxidation and reduction (redox) reactions. When electrons are transferred between molecules, it's a redox process.

Fruit batteries use electrolytes (solution containing free ions, like salt water or lemon juice) to generate a voltage. Think of electrolytes as a material that dissolves in water to make a solution that conducts electricity. Fruit batteries also need electrodes made of conductive material, like metal. Metals are conductors not because electricity passes through them, but because they contain electrons that can move. Think of the metal wire like a hose full of water. The water can move through the hose. An insulator would be like a hose full of cement – no charge can move through it.

You need two different metals in this experiment that are close, but not touching inside the solution. If the two metals are the same, the chemical reaction doesn't start and no ions flow and no voltage is generated – nothing happens.

This experiment produces around one volt of electricity, and the amps are in the micro-to-milli scale. For comparison, you'll need about 557 lemons to light a standard flashlight bulb.

Exercises

1. What kinds of fruit make the best batteries?

2. What happens if you put one electrode in one fruit and one electrode in another?

3. What happens if you stick multiple electrode pairs around a piece of fruit, and connect them in series (zinc to copper to zinc to copper to zinc…etc.) and measure the voltage at the start and end electrodes?

Lesson #24: Salty Battery

Overview: In the last experiment (Fruit Batteries), we experimented with different electrolyte solutions for the electrodes. This time, we're keeping the solution the same, but changing the electrodes.

What to Learn: The basic idea of electrochemistry is that charged atoms (ions) can be electrically directed from one place to the other. If we have a glass of water and dump in a handful of salt, the NaCl (salt) molecule dissociates into the ions Na+ and Cl-. When we plunk in one positive electrode and one negative electrode and add electricity, we find that opposites attract: Na+ zooms over to the negative electrode and Cl- zips over to the positive. The ions are attracted (directed) to the opposite electrode and there is current in the solution.

Materials

- water
- salt
- distilled white vinegar
- Goggles and gloves if you have an adult to handle bleach (do not handle this yourself – your adult will do this part for you)
- Disposable cup
- Popsicle stick

Electrodes to experiment may include:

- real silverware (not stainless)
- shiny nail (galvanized)
- dull nail (iron)
- wood screw (brass)
- large paper clip
- copper penny or copper pipe
- graphite from inside a pencil
- 2 alligator wires
- digital multimeter (DMM)

Lab Time

1. Fill your cup partway with water.
2. Add a teaspoon of vinegar.
3. Add a teaspoon of salt.
4. Optional: add a couple of drops of bleach, cap it and put it away out of reach of kids. If you are using bleach, make sure every kid is wearing a pair of goggles.
5. Connect the nail with one alligator clip lead.
6. Connect the penny with another alligator clip lead.
7. Dip both nail and penny in the water, and make sure they are not touching each other.
8. Connect the other ends of alligator clip leads to the probes on the DMM, one alligator wire to each probe.

9. Turn on the DMM to 20 VDC. What do you read? Write it here:______________________________
10. What happens if you pull the two electrodes as far apart from each other as possible? What happens to your voltage? Write it here:

____

11. Replace the penny with a paperclip, and dip it in the solution. What do you read? Write it in your data table.
12. What about a brass screw? What other things can you try? What different combinations are there to test? Fill in the data table with your measurements.

Reading

Using ocean water (or make your own with salt and water), you can generate enough power to light up your LEDs, sound your buzzers, and turn a motor shaft. We'll be testing out a number of different materials such as copper, aluminum, brass, iron, silver, zinc, and graphite in a small sample of salt water to find out which works best for your solution.

Electrochemistry studies chemical reactions that generate a voltage and vice versa (when a voltage drives a chemical reaction), called oxidation and reduction (abbreviated "redox") reactions. When electrons are transferred between molecules, it's a redox process.

Electrolytes (a solution containing free ions, like salt water or lemon juice) can be used to generate a voltage. Think of electrolytes as a material that dissolves in water to make a solution that conducts electricity. Did you notice how in *Lesson #23: Fruit Batteries*, we also needed electrodes made of conductive material, like metal? Metals are conductors not because electricity passes through them, but because they contain electrons that can move. Think of the metal wire like a hose full of water. The water can move through the hose. An insulator would be like a hose full of cement – no charge can move through it. You need two different metals in this experiment that are close, but not touching inside the solution. If the two metals are the same, the chemical reaction doesn't start and no ions flow, no voltage is generated… nothing happens. But don't take my word for it – try it for yourself!

Exercises

1. Which combination gives the highest voltage?
2. What happens if you use two strips of the same material?
3. What would happen if we used non-metal strips?

Salty Battery Data Table

Trial #	Electrode #1	Electrode #2	Voltage (V)
1			
2			
3			
4			
5			
6			
7			
8			
9			
10			
11			
12			
13			
14			
15			
16			
17			
18			
19			
20			

Lesson #25: Silver Battery

Overview: We'll be using electrochemistry to make a battery that reverses the chemical reaction that puts tarnish on grandma's good silver. Never polish your tarnished silver-plated silverware again! Instead, set up a "silverware carwash" where you earn a nickel for every piece you clean. (Just don't let grandma in on your little secret!) It's safe, simple, and just needs help with the stove.

What to Learn: This is a very simple battery that works using electrochemistry.

Materials

- stove (with adult help)
- skillet
- aluminum foil
- water
- baking soda
- salt
- real silverware (not stainless)

Lab Time

You can safely dip your silverware into a self-polishing solution. Here's how to do it:

1. Line your skillet with aluminum foil.
2. Add one to two cups of water to your skillet (depending on the size of your pan.)
3. Add a teaspoon of salt.
4. Add 1 teaspoon baking soda.
5. When your solution bubbles, place the tarnished silverware directly on the foil. Start with a small, really tarnished piece so you can see the cleaning effects the best.
6. Use tongs to flip it over. This reaction happens quickly.
7. Only the parts touching the foil will get cleaned, so you'll want to move the foil around (or add more) so it comes in good contact with the silver.
8. Lift out the silverware, run under cool water, and wipe dry.
9. Toss the foil in the trash (or recycling) when you're done, and the liquids go down the drain with plenty of water.

Reading

Your silver turns black because of the presence of sulfur in food. Here's how the cleaning works: The tarnished fork (silver sulfide) combines with some of the chemicals in the water solution to break apart into sulfur (which gets deposited on the foil) and silver (which goes back onto the fork). Using electricity, you've just relocated the tarnish from the fork to the foil. Just rinse clean and wipe dry.

This is a very simple battery, believe it or not! The foil is the negative charge, the silverware is the positive, and the water-salt-baking-soda solution is the electrolyte.

Exercises

1. Where is the electrolyte in this experiment?
2. Where does the black stuff that was originally on the silverware go?
3. Where's the electricity in this experiment?
4. Where would you place your DMM probes to measure the generated voltage?

Lesson #26: Air Battery

Overview: It's easy to use chemistry to generate electricity, once you understand the basics. With this experiment, you'll use aluminum foil, salt, air, and a chemical from an aquarium to create an air battery. We'll be using a digital multimeter to find out just how much voltage your battery cell generates (and this will also tell you how many of these batteries you need to make to power a LED or motor.)

What to Learn: This "aluminum air battery" uses a chemical reaction between the foil and air (well, specifically the oxygen in the air). The combination of oxygen and foil produces aluminum oxide and energy. If you build your battery well, you can see the energy when this battery lights up an LED or turns a motor shaft, but the oxide layer will be invisible to your eye.

Materials

- salt
- bowl of water
- activated charcoal (from an aquarium supply store)
- aluminum foil
- paper towel
- 2 alligator clip leads

Lab Time

1. Fill your bowl with water.
2. Make a saturated salt solution by dissolving as much salt as you can into the water. When you start to see bits floating on the bottom, you've added the perfect amount.
3. Fold your paper towel in half and dip it in your solution.
4. Lay a sheet of aluminum foil on the table.
5. Pull out the towel and lay it on top of the foil.
6. Pour a layer of charcoal over the towel, about ½-inch thick. Completely cover the paper towel.
7. Remove the plastic insulation from one of the alligator clip lead so the metal head is completely exposed. (You may have already done this in your lab preparation.)
8. Lay the exposed lead in the middle of the charcoal pile.
9. Clip the second alligator clip lead onto one end of the foil, so that the wire is coming out of other end of the foil.
10. Roll the paper towel *first* around the exposed alligator lead. You don't want this lead touching the foil, but rather completely surrounded by the charcoal. Wrap it up and then wrap the foil around it like a large burrito with one wire sticking out of each end.
11. Close the ends off so you don't leak carbon bits everywhere.
12. Connect the free alligator clip lead ends to your DMM.

13. Turn on your DMM to 20 V DC. What do you read? (Don't forget to write "volts" after your number!)

____

14. Squish the battery to make good contact between the carbon, salt, and foil. Your voltage should change when you do this.
15. If your answer is higher than 2.5V, then try using this in place of your battery pack and attaching an LED in a simple circuit.
16. If it's less than 2.5 volts, you'll need to team up with another lab group and hook your batteries up together to generate enough power. Here's how:
    a. Connect the alligator clip lead attached to the foil on your battery to the alligator clip lead coming from the center of their battery.
    b. Connect your probe to their foil alligator wire.
    c. You should still have the other probe attached to the alligator wire coming from the center of yours. If not, hook it up.
    d. What do you read?____

Reading

This "aluminum air battery" uses a chemical reaction between the foil and air (well, specifically the oxygen in the air). The combination of oxygen and foil produces aluminum oxide and energy. If you build your battery well, you can see the energy when this battery lights up an LED or turns a motor shaft, but the oxide layer will be invisible to your eye.

Your battery should last between 4 – 10 minutes, depending on how well you build it. You can get a larger amount of voltage by using larger wires (with more surface area contacting the charcoal). What do you have that would be a larger electrode for the battery?

The more salt you use, the better your air battery will work! You'll notice there's a point, though, where no matter how much more salt you add, you can't increase the voltage… due to the saturation point of the water. It's better to have an over-saturated solution (meaning that there are still bits at the bottom of the bowl). You can heat the water to increase its capacity to dissolve the salt.

Exercises

1. How many air batteries does it take for your LED to light up?

2. Which electrode is positive? Which is negative? (Hint: Use the DMM to figure this out.)

3. What is the electrolyte in this experiment?

4. What could you use instead of an exposed alligator clip lead to make this battery last longer?

Electrochemistry Evaluation

Student Worksheet

Overview: Today you're going to take two different tests: the quiz and the lab practical. You're going to take the written quiz first, and the lab practical at the end of this lab. The lab practical isn't a paper test – it's is where you get to show your teacher that you know how to do something.

Lab Test & Homework

1. Your teacher will call you up so you can share how much you understand about electrochemistry and how it works. Since science is so much more than just reading a book or circling the right answer, this is an important part of the test to find out what you really understand.
2. While you are waiting for your turn to show your teacher how much of this stuff you already know, you get to get started on your homework assignment. The assignment is due next week, and half the credit is for creativity and the other half is for content, so really let your imagination fly as you work through it.

   Here it is: Your classroom is going to be converted into an interactive science museum next week. You will be in charge of one of the stations. Your audience knows nothing about electricity. Your job is to design and build an experiment that teaches the students in lower levels an important concept in one of the following areas: static electricity, electricity, or electrochemistry. You will get to explain to your students what's going on as you demonstrate your experiment. You can have them watch or actively do something at your station. You will be graded based on content and creativity, so really let your mind go wild. (Hint: If you were the audience, what would *you* want to learn about most?)

Electrochemistry Quiz

Name____

1. Name three kinds of electrolytes we've used in our electrochemistry experiments.
2. Where would you place your DMM probes to measure the generated voltage?
3. What happens if you use two strips of the same material? What would happen if we used non-metal strips?
4. What kinds of fruit make the best batteries and why?
5. What happens if you put one electrode in one fruit and one electrode in another?
6. Where did the copper on your key come from?
7. What kind of bubbles formed when we split the water molecule?
8. Does plain water conduct electricity?
9. Why does electricity flow through some solutions but not all of them?
10. What is a salt?

Electrochemistry Lab Practical

Student Worksheet

This is your chance to show how much you have picked up on important key concepts, and if there are any holes. You also will be working on a homework assignment as you do this test individually with a teacher.

Materials:

- AA battery case
- 2 AA batteries
- 2 alligator wires
- Disposable cup
- popsicle stick
- Digital Multimeter

Electrolyte Options:

- Distilled white vinegar
- Salt
- Sugar

Electrode options:

- 2 pennies
- 2 nails
- 2 piece of plastic
- popsicle stick

Lab Practical:

- Design and build a battery and show how much voltage it produces.

- Explain from your experiment above how chemical energy can be converted into electrical energy.

Answers to Exercises and Quizzes

Lesson #1: Static Hair
1. Why does the hair stick to the balloon? (The balloon steals electrons from your head, making your head positively charged, which is now attracted to the negatively charged balloon.)
2. How do you get rid of electrons? (Ground the balloon by touching it to something metal.)
3. Can you see electrons? Why or why not? (No – they are too small!)
4. Does it matter what kind of hair you rub the balloon on? (Yes – fine hair without any hair products added works best.)
5. How long does the hair continue to stand up after you remove the balloon? (Anywhere between 2 seconds and 2 minutes.)
6. Does it matter what kind of balloon you use? (Yes and no. Yes: material that the balloon is made out of, and thickness of the rubber. No, the shape does not matter.)
7. How fast or slow do you need to rub for the biggest charge on the balloon? (Fast, as in vigorously.)
8. Does hair color matter? (No. The texture of the hair, how fine the hair is, and whether you've gooped it up or not *will* affect this experiment.)

Lesson #2: Electric Fields
1. Why did the ping pong ball move? (The ping pong ball has no charge on it, meaning it has an equal, balanced number of electrons and protons. The balloon has a large negative charge on it, so when you bring it close to the ping pong ball, the electrons in the balloon repel the electrons in the balloon, leaving the positive protons exposed to the balloon. Those ping pong ball protons are attracted to the balloon's electrons so the ball rolls toward the balloon.)
2. Why did the paper jump up? (The balloon has a large negative charge. The paper has an equal balance of negative and positive charges, so it's currently neutral. The electrons in the paper are quickly repelled by the electrons in the balloon, leaving the positive protons to be attracted to the negative electrons in the balloon.)
3. Does the paper stick to the balloon forever? Why or why not? (Nope. The paper bits begin to steal electrons from the balloon when they get stuck to it, making the paper negative all over. Since negative charges repel each other, the paper jumps off the balloon.)
4. What made the water move? (The water molecule is a polar molecule, meaning that it acts like a tiny bar magnet in that it has a positive and negative end. Water is a liquid, which means that these little water molecules can rotate and move easily. The charged balloon influences the direction that the mini-magnets line up as they flow past.)
5. Does it matter if the water is hot or cold? (Nope, not really.)
6. What other liquids do you think would work besides water? (Any water-based liquid will work, like vinegar, juice, etc.)
7. Does it work with a full stream of rushing water? A pan full of water? Why or why not? (A small, thin, steady stream works best because the balloon needs to influence the molecules. If too many are rushing past, the balloon needs to have a stronger charge to influence it.)
8. Which way (attracted or repelled) did the soap bubble move? (Attracted.)
9. What holds the packing peanut to the wall? (The charged packing peanut's negative charge is caused by having too many electrons. When you stick the foam peanut on the wall, the electrons in the foam repel the electrons in the wall, leaving the positive protons exposed, but those protons don't care at all, because they are attracted to the negative electrons, and this attractive force keeps the foam stuck in place.)

10. Do these experiments work if it's raining? Why or why not? (No –humidity is extra water molecules in the air, and these water molecules allow electrons that are piling up to bleed off into the air, preventing a charge from building up.)
11. What if you get the balloon wet first and then try these experiments again? (See answer #10)
12. Does the paper stick to the balloon longer than the packing peanuts stick to the wall? (No, because the paper takes on the negative electric charge and is quickly repelled by the negative charge in the balloon, whereas the wall and the packing peanuts are happily attracted to each other.)

Lesson #3: Triboelectric Series
1. What happened to the strip of plastic after you ran it through your fingers? (The plastic is attracted to your hand and moves not only toward your hand, but your arm and clothes!)
2. Is the strip attracted to neutral objects? Why or why not? (Yes. The strip moves toward desks, chairs, and the wall. The plastic has a huge negative charge on it. When the plastic gets close to the desk, the negative charges repel the electrons on the object, leaving the surface near the plastic positively charged and attracted to the plastic.)
3. What happens if you charge two plastic strips – are they attracted or repelled from each other? (Repelled because they both have the same negative charge.)
4. How long did you keep the bag floating above the balloon? (Time varies.)
5. Why did the plastic bag piece float above the balloon? (They are both charged with a huge negative charge.)
6. What was the difference when you rubbed the foam plate with wool versus with a bag? (When you rub the foam plate with the wool, the plate takes on electrons and creates a negative charge on the plate. To give the plate a positive charge, rub it with a plastic bag.)
7. Which combination gave the best results for keeping your glider aloft? (Answer varies – ask the kids for their best test results after they've finished their experiments and record them for everyone to see.)

Lesson #4: Visible Electric Fields
1. What happened when you brought a charged balloon near the dill? (The negative charges in the dill are attracted to the balloon and the positive charges are repelled, so the dill lines up to indicate the field direction.)
2. What side of the dill was attracted to the balloon? (Positive)
3. What happened when you brought two negative charges near the dill? (The dill will move less than if you had placed a positive and negative charge at the wires/aluminum foil.)
4. Were you able to make the dill come out of the liquid and onto the balloon without touching the oil? (If you move the balloon just right, the attractive electrical charge will pull the lightweight dill right up out of the oil and onto the balloon.)

Lesson #5: Electroscope
1. Why do the foil strips spread apart? (Like repels like. The charge from the balloon is picked up by the foil ball, which conducts it to down the paperclip and to the foil leaves. The foil spreads apart because they are both negatively charged.)
2. How do you discharge the electroscope? (Touch it with your hands to balance the plus and minus charges.)
3. Why did we use a glass jar? (Glass is a great insulator against wind currents and not as easy to tip over as a plastic bottle.)
4. Does the electroscope react the same way whether it's exposed to a positive or negative charge? (Yes – it detects both equally well.)
5. List four ways to charge the electroscope. (Balloon-hair, wool-PVC pipe, two foam plates rubbed together, plastic baggie and foam plate.)

Lesson #6: Electrostatic Motor

1. What happens if you rub the balloon on other things, like a wool sweater? (You get a positive charge on the balloon, which doesn't affect the experiment. The balloon will still make the yardstick move whether it's positively or negatively charged.)
2. If you position other people with charged balloons around the table, can you keep the yardstick going? (Yes.)
3. Can we see electrons? (Nope. The radius of an electron is approximately 0.000000000000002 meters)
4. How do you get rid of extra electrons? (Ground yourself or the object by touching something like the floor or a water pipe that's buried into the earth.)
5. Why do you think the yardstick moved? (The negative charge in the balloon repels the electrons in the yardstick, exposing those positive protons, which are attracted to the balloon. Since the stick is free to rotate, it chases the balloon around in a circle.)
6. What would happen if you use *both* a positively charged object *and* a negatively charged object to make the yardstick move? (Nothing – the charges in the yardstick get confused and it stays put. Or, if you're really careful about where you place each one, you could possibly get it to move a bit.)

Lesson #7: Advanced Static Lab

1. What is common throughout all these experiments that make them work? (Opposite charges attract, like charges repel.)
2. What makes the neon bulb light up? What else would work besides a neon bulb? (Neon bulbs light up because the electrical field excites the gas, which then gives off a pinkish-orange light. A fluorescent tube is lined with white stuff called phosphor, which gives off light whenever it's struck by UV rays. The tube is filled with a gas that gives off UV rays when placed in an electrical field. When the bulb is brought close to a static charge, electrons rip through the tube and go out the other side. As they go through, they smack into the gas vapor which releases light rays (UV in a fluorescent tube) that hit the phosphor on the inside of the tube, which then emits light. Fluorescent lights, or any tube of gas from the noble gases column on the periodic table… like neon will also glow in an electrically-charged field.)
3. Does it matter how far apart the soup cans are? (Yes – if they are too far apart, the ball isn't attracted to the opposite can.)
4. Why does the foil ball go back and forth between the two cans? (The ball takes on the charge of the negatively charged can (charged by the Fly Stick), and is then repelled since they are both the same charge.
It swings to the opposite can where the charge balance is restored. Then the positive protons see the negatively-charged soup can and are attracted to it and the cycle starts all over.)
5. Why do the pans take on the same charge as the Fly Stick? (Aluminum conducts electricity.)
6. When sticking a sheet of paper to the wall, does it matter how long you charge the paper for? (Yes, but only up to a point. See results from table to determine where this point is.)
7. Draw a diagram to explain how the electrostatic motor works. Label each part and show where the charges are and how they make the rotor turn.
    a. The Fly Stick charges one of the stators with a big negative charge, which is very different from the ground (balance) charge of the opposite stator. The charge is conducted through the paperclip and onto the foil area, which picks up the same charge as the paperclip. Like charges repel, so the rotor starts to turn, bringing a new foil area under the paperclip hook. Tiny sparks jump to the new areas and charge them, which make them attract/repel from the stators and it continues to turn. The foil on the rotor under the paperclip hook is always charged with the same charge as the paperclip, so it's being repelled or attracted sideways. If you put a positive charge instead of grounding it, the rotor will spin even faster.

b. You can also think of the rotor like a waterwheel. Imagine turning the whole thing sideways and on one side, the negative charge is pouring into the side of the rotor that is falling toward the grounding film can.

Lesson #8: Alien Detector

1. When the LED is on, what do you think it means? (It detects a positive charge region.)
2. Does the LED turning off detect anything? (Yes – a negative charge region.)
3. Do aliens like humidity? (No – this experiment doesn't work in high humidity.)
4. How does this alien detector really work? (It's a positive charge static detector… this is important, because now you know when the LED is off, the space you're detecting is negatively charged, and when it's lit up, you're in a pocket of positively-charged particles.)

Lesson #9: Cosmic Ray Detector

1. How does this detector work? (When the particle enters the chamber, it smacks into the alcohol vapor and makes free ions. The vapor in the chamber condenses around these ions, forming little droplets which form the cloud trail.)
2. Do all particles leave the same trail? (No. Different types of particles leave different trails. Alpha particles are heavy and create straight, thick trails. Beta particles, which are light, will leave light, wispy, trails. If you see any curly trails or straight paths that take a sharp turn, those are particles that have smacked into each other.)
3. What happens when the magnet is brought close to the jar? (You can use a magnet to deflect the cosmic rays if the magnet is strong enough and positioned just right.)

Lesson #10: Basic Circuits

1. What does LED stands for? ("Light Emitting Diode.")
2. Does it matter which way you wire an LED in a circuit? (Yes, LEDs are polarized.)
3. Does the longer wire on the LED connect to plus (red) or minus (black)? (Longer lead is positive, and the flat side on the lens is negative.)
4. Do you need to hook up batteries to make a neon bulb light up? Why or why not? (No. The neon bulb (from *Lesson #7* will light up from static electricity. No batteries required. The neon lamp requires very little amps, but high voltage to illuminate, which you can get by charging yourself up. Simply hold one lead and scuff along the carpet and touch the other lead to your cat's nose. Or hold one lead and slide down a non-metal slide.)
5. What's the difference between a light bulb and your LED?
6. What is the difference between a bolt of lightning and the electricity in your circuit? (One one: quantity.)
7. What is the charge of an electron? (Negative)

Lesson #11: Conductivity Testers

1. Name six materials that are electrically conductive. (Soda cans, quarters, paper clips, braces, unpainted eyeglasses, and your tongue.)
2. What kinds of materials are conductors and insulators? (Materials with free electrons, like metals, are conductors. Insulators are like paper, ceramics, and rubber.)
3. Can you convert an insulator into a conductor? How? (Yes, that's what a semiconductor is. It's like a switch in a black box. Sometimes it conducts and sometimes it doesn't. If it's a dimmer switch, then it conducts to different degrees depending on the position of the dimmer.)
4. Name four instances when insulators are a bad idea to have around. (When you need to conduct electricity, like to a bulb, motor, relay, buzzer, etc. Also when static charge can harm a circuit, you need a way to discharge regularly to avoid build-up.)
5. When are insulators essential to have? (When you want to turn off a light.)

Lesson #12: Switches & Motors

1. If you want to reverse the spin direction of a motor without using a switch, what can you do? (Switch the wires on the back of the motor.)
2. A simple switch can be made out of what kinds of materials? (You need to be able to control when it conducts and insulates. Take the two wires (one from the battery and the other from the motor) and touch them together – ON – OFF – ON – OFF. Simplest switch in the world! Air is the insulator and metal is the conductor. But you can also use index cards, paper clips, and brass fasteners.)
3. How would you make your SPST switch an NC (normally closed) switch? (Leave the paperclip in its normal shape (don't bend into a V) and touch the paperclip to the brass fastener. The motor will run until you move the paperclip away.)
4. How did you have to connect your circuit in order for both the LED and motor to work at the same time? (If they wire it up in series (plus to minus), they'll find it doesn't work. If they hook it up in parallel (plus to plus), then both will work with one battery pack.)
5. Draw a picture of your experiment that explains how the SPST switch works, and show how electricity flows through your circuit.

Extra Credit (for students who have completed Part 3):

6. Draw a picture of your experiment that explains how the DPDT switch works in your circuit and show how to wire up the circuit.

Lesson #13: Digital Multimeters

1. If you measure 2.65 volts from your battery pack, do you need new batteries or will they work? (You have to test each battery individually to see if they are both above 1.3 volts.)
2. How do you think you would measure the resistance of an LED? (Turn the dial to the "Ω" mark to measure ohms and put each of the probes on one of the LED's wires and read the value.)
3. Reset your meter for a quick practical test: Remove the wires from your DMM and set the dial at OFF. Wave your hand wildly and show your teacher how you can use the meter (you can add probes and turn it on now) to test the voltage on your LED in a simple circuit doing the steps from the experiment.

Lesson #14: Motor Speed Controllers

1. How does a potentiometer work? (A potentiometer is a resistor with three terminals that has a sliding contact to vary the resistance. Resistance is a measure of how easily current flows through a wire. The more the resistance, the less current flows through the circuit. We're going to use ours as a variable resistor.)
2. Does the potentiometer work differently on the LED and the motor? (No, but the range may differ since the motor draws much more current than the LED.)
3. Name three places you've used potentiometers in everyday life. (Potentiometers are everywhere: volume controls, dimmer switches, radio dials.)
4. How do you think you might wire up an LED, switch, and potentiometer? (They are all in series with each other.)

Lesson #15: Electric Eye Sensor

1. How is a CdS cell like a switch? How is it *not* like a switch? (The flow of current is controlled by the amount of light that falls on the detector. It's unlike a switch in that it never really stops the current completely.)
2. When is the LED the brightest? (In full sun.)
3. How could you use this as a burglar alarm?

Lesson #16: Trip Wire Burglar Alarm

1. How does this work? (The LED lights up as you "push" (squeeze, really) the switch by opening the clothespin. We've reversed this so the LED is also dark until you yank the paper away. To arm the trip wire, insert a small scrap of paper between the tacks. This works because paper does not conduct electricity. When the paper gets yanked out, the tacks touch and… *GOTCHA!!!*)
2. What type of switch is the trip wire? (The trip wire is an NC [normally closed] switch.)
3. Name three places you can install this alarm. (Across the bottom of a doorway, inside a drawer, or attached to a cupboard door.)

Lesson #17: Pressure Sensor

1. How does this sensor work? (When you squeeze it, you're getting the two foil squares to touch through the hole, which allows current to flow to your LED. When you release it, the foil spreads apart again because they are on opposite sides of the foam square, which insulates and interrupts the flow of electricity, and the LED goes dark.)
2. What makes this an NO switch? (A normally open switch doesn't allow current to flow when it's sitting there by itself. When you activate it (in our case, stepping on it), then it allows electricity to flow.)
3. How can you use both the trip wire and the pressure sensor in the same circuit? Draw it out here:

Lesson #18: Latching Circuits

1. What is a relay? (A relay is a switch you can turn on and off using electricity.)
2. What does the relay do in this circuit? (The relay keeps the electricity flowing to the LED after the pressure sensor shuts it off. The SPST switch resets the relay.)
3. Draw out a picture that shows how everything is connected in your circuit:

Lesson #19: Nerve Tester

1. Can you travel the entire path without turning on the light? (Answers vary)
2. Where in your circuit can you add a switch to turn the game on and off? (Answers vary)

Lesson #20: Electrolytes

1. Why does electricity flow through some solutions but not all of them? (Salt mixes with water and separate into positively ($Na+$) and negatively (Cl^-) charged particles (ions). If you pass a current through the solution of salt and water, opposites attract: the positive ions are attracted to the negative pole and the negative ions go toward the positive pole. These migrations ions allow electricity to flow, which is why salt solutions conduct electricity.)
2. What is a salt? (When a substance mixes with water and separates into its positive and negative parts, it's called a "salt.")
3. How are electrolytes used today in real life? (One example: the body uses electrolytes such as sodium, calcium, potassium, chloride, magnesium, and more to regulate the nerve and muscle function, keep your body hydrated, and maintain the right pH in the blood.)
4. Which substance was your top conductor? (Check data for result.)
5. Which substance didn't conduct anything at all? (Check data for result.)
6. What happens if you mix an electrolyte and non-electrolyte together? (Check data for result.)

Lesson #21: Electrolysis

1. Why are bubbles forming? (Bubbles form as the gases are produced. As the water molecule breaks apart into smaller pieces: hydrogen ions [positively charged hydrogen] and oxygen ions [negatively charged oxygen], they bubble up into the test tube.)

2. Did bubbles form at both wires or only one? What kind of bubbles are they? (Hydrogen bubbles formed at one of the wires and oxygen formed at the other.)
3. What would happen if you did this experiment with plain water? Would it work? Why or why not? (You need the electrolytes to carry the current through the water and separate the water molecule into its ions. Without it, the water acts like a weak insulator and no bubbles will form.)
4. Which terminal (positive or negative) produced the hydrogen gas? (The positive hydrogen ions zip over to the negative terminal and form tiny bubbles right on the wire.)
5. Did the reaction create more hydrogen or more oxygen? (Since water is two hydrogen atoms and one oxygen atom, this experiment generates twice as much hydrogen as oxygen.)

Lesson #22: Electroplating
1. Look at your key. What color is it? (Black until you wipe it off, then copper or dull brown underneath.)
2. Where did the copper on your key come from? (The copper ions in the solution.)
3. What happened when you added a second battery? (The reaction happens much faster.)
4. Which circuit (series or parallel) did the reaction accelerate faster with? (Check data results.)

Lesson #23: Fruit Battery
1. What kinds of fruit make the best batteries? (Citrus, because of the acid.)
2. What happens if you put one electrode in one fruit and one electrode in another? (The ions are not able to be attracted to the different electrodes, so there's no current flowing.)
3. What happens if you stick multiple electrode pairs around a piece of fruit, and connect them in series (zinc to copper to zinc to copper to zinc…etc.) and measure the voltage at the start and end electrodes? (You'll get a high voltage at first, which runs out more quickly than using only a single pair.)

Lesson #24: Salty Battery
1. Which combination gives the highest voltage? (Check data for result.)
2. What happens if you use two strips of the same material? (You won't have a difference. These copper ions interact with the zinc electrode to form zinc ions. The copper electrons are chemically reacting with the lemon juice to form copper ions. The difference in electrical charge (potential) on these two plates causes a voltage.)
3. What would happen if we used non-metal strips? (They don't break into ions, and don't work.)

Lesson #25: Silver Battery
1. Where is the electrolyte in this experiment? (The water + salt + baking soda solution.)
2. Where does the black stuff that was originally on the silverware go? (On the foil.)
3. Where's the electricity in this experiment? (The solution is heated, adding the needed energy make this chemical reaction take place. The current flows from plus (silverware) to minus (foil).)
4. Where would you place your DMM probes to measure the generated voltage? (The black probe on the foil and the red probe on the silverware.)

Lesson #26: Air Battery
1. How many air batteries does it take for your LED to light up? (Check data results.)
2. Which electrode is positive? Which is negative?
3. What is the electrolyte in this experiment? (Salt water.)
4. What could you use instead of an exposed alligator clip lead to make this battery last longer? (Zinc, copper…etc.)

Vocabulary for the Unit

If an **atom** has more electrons spinning in one direction than in the other, that atom has a magnetic field. Atoms are made of a core group of neutrons and protons, with an electron cloud circling the nucleus.

The proton has a positive **charge**, the neutron has no charge (neutron, neutral get it?) and the electron has a negative charge. These charges repel and attract one another kind of like magnets repel or attract. Like charges repel (push away) one another and unlike charges attract one another. Generally things are neutrally charged. They aren't very positive or negative, but rather have a balance of both.

When electric current passes through a material, it does it by electrical **conduction**. There are different kinds of conduction, such as metallic conduction, where electrons flow through a conductor (like metal) and electrolysis, where charged atoms (called ions) flow through liquids. Metals are **conductors** not because electricity passes through them, but because they contain electrons that can move.

LED stands for "Light Emitting Diode." A **diode** is like a one-way valve for electricity. It lets current go through it one way, but not the other. They have two leads, called the **anode** and the **cathode**.

Electricity is a flow of electrons. A flow of electrons creates a magnetic field. Magnetic fields can cause a flow of electrons. Magnetic fields can cause electricity.

Electrons can have a "left" or "right" spin in addition to "going around" the nucleus. Electrons technically don't orbit the core of an atom. They pop in and pop out of existence. Electrons do tend to stay at a certain distance from a nucleus. This area that the electron tends to stay in is called a shell. The electrons move so fast around the shell that the shell forms a balloon-like ball around the nucleus.

A **field** is an area around an electrical, magnetic or gravitational source that will create a force on another electrical, magnetic or gravitational source that comes within the reach of the field. In fields, the closer something gets to the source of the field, the stronger the force of the field gets. This is called the inverse square law.

Objects that are electrically charged can create a **temporary charge** on another object.

A **schematic** is a simple line-drawing of an electrical circuit.

A **transistor** is kind of like an electronic dimmer switch. Think of a light dimmer – you know, the kind that you might have on the lights in a room in your house, or a friend's house. You turn a knob or slide a lever, and all the lights dim.

The **triboelectric** series is a list that ranks different materials according to how they lose or gain electrons.