Electrostatics:

Laboratory for Secondary Level Students

Student Manual

WS2

WOMEN SUPPORTING
WOMEN IN THE SCIENCES

Meet a Scientist

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About me:

I have a Master's in Chemical Safety Science and Engineering from Dalian University of Technology in China (2019). I studied Biology and Chemistry with Education in the University of Rwanda-College of Education (UR-CE) (2014). I am primarily interested in natural gas purification, and I've published scientific papers related to that topic. I am very passionate about science as a way to discover what's in the universe and how these things work.

My advice for students interested in science:

Being curious is good because it increases the research spirit and helps you learn and solve science problems. Ask questions because if you don't, you'll never know the treasure trove of information other people have.

When I was young ...

I grew up often saying that I would make things, like soaps and other items we usually use at home. My father always encouraged me on my path.

Mission Statement

This laboratory will teach electrical energy concepts to a target audience of middle and high school/secondary-aged students (ages ~12-18) through experiments related to static electricity.

Contents

1. Introduction to WS2 Laboratories

1.1. Information about WS2

Women Supporting Women in the Sciences (WS2), an international organization unifying and supporting graduate and professional-level women and allies in science, technology, engineering, and mathematics (STEM), was awarded an American Physical Society (APS) Innovation Fund in 2020 to form international teams to design and distribute low-cost physics and materials science lab kits to 5000 primary and secondary school students, predominantly in eastern Africa. The lab kits are intended to utilize local resources and include topics that are especially relevant to young girls in order to spur their interest in STEM subjects. The international teams, which designed the content found in these laboratory manuals, worked with WS2 Partners in eastern Africa in order to successfully deliver and teach the science lab kits to their local communities through 2022. WS2 gratefully acknowledges the hard work of the teams in the creation of this lab kit content. For more information about WS2, please visit our website at ws2global.org.

WS2 is sponsored by the APS Innovation Fund, Northwestern University Materials Research Science and Engineering Center, and Northwestern University Multicultural Student Affairs. WS2 Partners receiving lab kits are representatives from Makerere University (Uganda), Masinde Muliro University of Science and Technology (Kenya), Mbeya University of Science and Technology (Tanzania), Mkwawa University College of Education (Tanzania), Nelson Mandela African Institution for Science and Technology (Tanzania), University of Dar es Salaam (Tanzania), University of Dodoma (Tanzania), and University of Rwanda (Rwanda). The APS, Materials World Modules, SciBridge, and Projekt Inspire have provided valuable input on WS2 lab kit design. WS2 especially thanks WS2 Partner representatives (John Bakayana, Pendo Bigambo, Daudi Mazengo, Lawrence Robert Msalilwa, Celine Omondi, Marcellin Rutegwa), Tom Coon and students of Haile-Manas Academy (Debre Birhan, Ethiopia), and Carla Johnston and students of Frank Bergman Elementary School (Manhattan, KS, USA) for piloting the lab kits with small focus groups in late 2021. WS2 also tremendously thanks the virtual lab kit design team that created the content for this lab manual.

1.2. Key Vocabulary

- Electric charge: One of the basic properties of elementary particles of matter giving rise to electric and magnetic forces and interactions; the two types of charges are positive (+) and negative (-), and the negative charge is also known as an electron
- Static electricity: A stationary electric charge, typically produced by friction, which causes sparks, crackling, or the attraction of dust or hair
- Lightning: The occurrence of a natural electrical discharge between a cloud and the ground or within a cloud
- Lightning rod/ lightning conductor: A metal rod used to protect someone or something from being damaged by lightning

1.3. Key Questions

- How does lightning occur?
- What are the two types of charges?
- What are some general rules about static electricity?

- How can we design a device to protect a building from lightning?

1.4. Purpose

The purpose of this laboratory is to learn about electrostatics concepts, culminating in the learning about lightning rods or lightning conductors and how they work. Lightning rods or lightning conductors protect buildings and other structures against lightning strikes.

2. Background on Main Topics

2.1. Lightning

Have you ever witnessed a thunderstorm? If so, likely, this means that you have seen brilliant flashes of lightning and heard loud claps of thunder. Lightning has long interested humankind, and some of the earliest written reports described lightning as fire in the sky. Scientific understanding did not come until much later with some basic understanding of electricity. Lightning is the occurrence of a natural electrical discharge between a cloud and the ground or within a cloud. This discharge involves a large flow of electrical charges, and this flow of moving charges is known as current. Electrical charges can either be positively or negatively charged, and the negative charges are called electrons.

So how does lightning occur? In hot weather, water evaporates from the ground and is carried upwards into the atmosphere. At high altitudes, the air becomes cooler, which causes the water vapor in the air to condense, forming clouds that contain water droplets and ice crystals. The water droplets and ice crystals each contain electrical charges. As these water droplets and ice crystals move past each other, they rub into each other, and charges are exchanged between the two. Positive charges accumulate on the ice crystals which are generally located at the top of the cloud, and electrons accumulate on the water droplets which are generally located at the bottom of the cloud. If you could see the charges in the cloud, you would see that the top portion of the cloud is overall positively charged, while the bottom of the cloud is overall negatively charged. This built-up imbalance of charges in the cloud is a distinct feature of static electricity. This static electricity can be built up until there is a route for the discharge or release of the charges.

Opposite-sign charges (positive and negative) are attracted to each other, while the same-sign charges are repelled by each other. The build-up of negative charges at the bottom of the cloud in a thunderstorm cause an attraction of positive charges nearby. Eventually the charges between the two locations connect and a large and fast

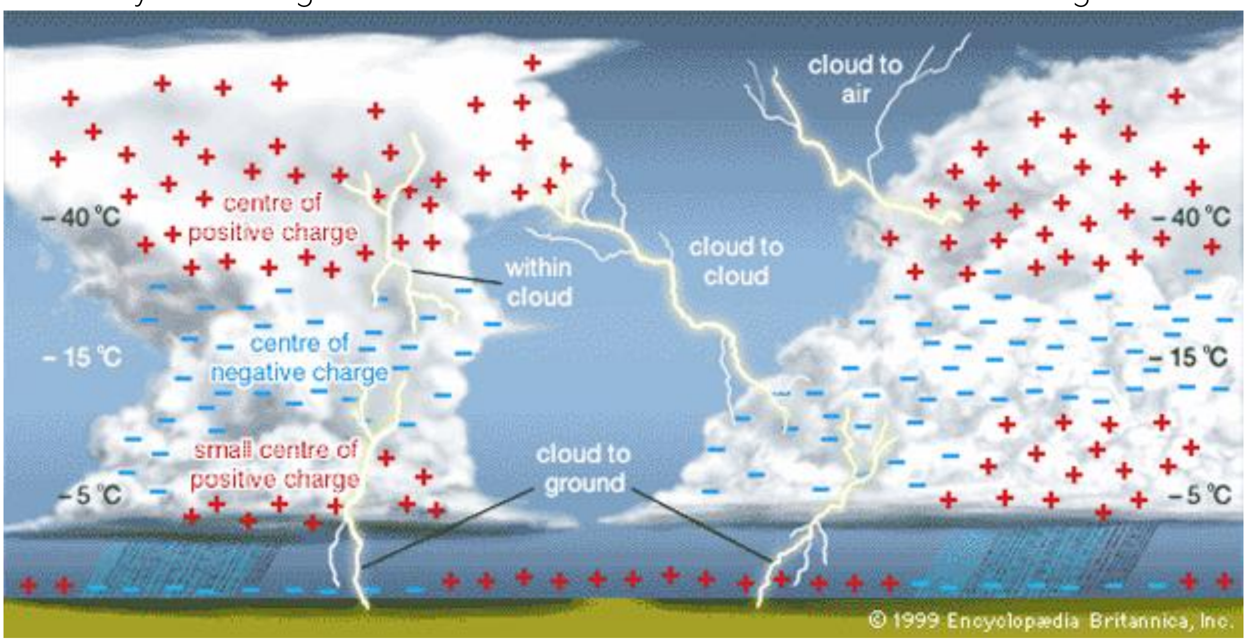

Figure 1. A schematic of the build-up of static charges in a thunderstorm. Cloud-to-cloud lightning and cloud-to-ground lightning are both shown, as well as typical temperatures in the cloud. This Photo by Encyclopedia Britannica is licensed under CC BY-SA-NC.

discharge occurs, resulting in the characteristic flash of lightning (see Figure 1)! This discharge can happen within the cloud itself, but sometimes the charges travel between the cloud and ground beneath it. This is how cloud-to-ground lightning strikes happen on earth, like those shown in the photograph below (see Figure 2). Lightning strikes on the earth every moment, often accompanied by heat during the discharge. In fact, lightning is approximately six times hotter than the surface of the Sun! This heat associated with lightning, along with the large static discharge, can cause destruction of property and life, so we have to be careful when we think that lightning may strike. As the earth's climate changes over time, extreme weather events, like lightning storms, may become more common in tropical regions of the world, such as in parts of East Africa. There are strategies to try to control where lightning strikes to prevent injury or destruction. One prominent strategy is the use of a lightning rod, which is a metal wire or object placed on the exposed part of a building or on a tall structure that can divert the lightning discharge safely into the ground, which protects people and objects.

Figure 2. Examples of cloud-to-ground lightning. Francois Loubser/Alamy via New York Times.

2.2. Supplies List

- Plastic (e.g., plastic pen, comb, straw, anything handheld and made of plastic)
- Paper
- Hair (e.g., on your student's head), wool, or fur
- Balloon
- Aluminum can (empty) or other metal object that can roll across the floor
- Sticky tape
- Metal (e.g., fork, spoon, metal pen, keys, anything handheld and made of metal)
- Pen or pencil

2.3. Safety Information

Before the students begin the laboratory, please take into consideration the following safety concerns:

- Students should be aware that they may get shocked while doing these electrostatics experiments. The experiments should not pose any harm to them, but it is advised to not complete these experiments around anything especially flammable (e.g., gasoline fumes).
- Students can cut paper using scissors for experiments, or teachers can cut the paper for students beforehand. Scissors should always be handled with care. As an alternative, students can rip paper by hand since the exact size of paper is not important to lab.

3. Experiments

3.1. Pre-Lab Questions

1. What are some examples of things that appear to “stick” together (without being sticky themselves)?

2. What are some reasons that objects can “stick” together?

3. What are some examples of things that don’t “stick” together no matter what you do?

4. Have you ever created a “shock” when you picked up a piece of metal or touched a wall? Why do you think this happened?

3.2. Part Ia. Static attraction!

3.2.1. *Summary*

In this experiment, we are going to test how a piece of plastic (a pen or a comb, for example) can become charged on its surface.

3.2.2. *Materials*

- Plastic (e.g., pen, comb, plastic straw)
- Piece(s) of paper
- Hair (or fur, wool, glass, or skin)

3.2.3. *Procedure (work in groups of 2-4)*

1. Lay several pieces of paper on a table (these should be small pieces of paper, about 1x1 or 2x2 cm).
2. Rub a plastic instrument through (or against) your hair, skin, wool/fur, or piece of glass.
3. Bring the plastic near the pieces of paper, but without touching them, and observe what happens.
4. Hold the plastic for 15 seconds near the paper and observe what happens.
5. Repeat steps 1-4 (you can use the same pieces of paper) by rubbing the piece of plastic against another recommended surface (air, skin, wool/fur, or piece of glass), and observe what happens.
6. Record your results in the table below, trying to rank the materials’ ability to generate an attraction based on your observations (rank in order with 1 being the best, 2 being the second best, and so on).

3.2.4. *<u>Results</u>*

Material 1	Material 2	Observation	Rank
Paper (neutrally charged)			

3.2.5. *<u>Post-Experiment Questions</u>*

1. What happened when you brought the plastic (after rubbing it) near the pieces of paper?

    a. <u>Extension question:</u> What happened as you continued to hold the plastic near the paper? Were there any changes over time?

2. What happened when you tried rubbing the plastic against different surfaces and bringing the plastic near the paper? Did different surfaces work better than others? What else can you do to improve the effect of attracting the paper?

3. Circle whether the following materials are charged or neutral:

Plastic at start of experiment	Charged	Neutral
Plastic after rubbing	Charged	Neutral
Other surface (hair, wool) after rubbing	Charged	Neutral
Paper at start of experiment	Charged	Neutral

4. Why do you think the attraction between the paper and plastic happens? What needs to happen to the surface of these materials to attract each other? Try answering this question using the words "electric charge", "positive" and "negative". <u>One hint:</u> the plastic surface can pick up negatively charged particles from the hair during rubbing.

3.3. Part Ib. Racing cans!

3.3.1. *Summary*

In this experiment, we are going to show how static attraction can induce movement in a nearby object.

3.3.2. *Materials*

- Balloon
- Aluminum can (empty) or other metal object that can roll across the floor

3.3.3. *Procedure (work in groups of 2-4)*

1. Blow up the balloon and tie a knot so that it stays inflated.
2. Rub the balloon on a volunteer student's hair several times.
3. Place the empty aluminum can on its side on a flat surface and have one student hold the can to prevent it from rolling.
4. Bring the balloon close to the side of the can (~2-3 cm).
5. Let go of the can gently. As the can rolls, keep moving the balloon to "guide" the can.
6. Move the balloon to the other side of the can and repeat steps 4-5. You may need to "recharge" the balloon by rubbing it on a volunteer student's hair several times.

   Extra challenge:

7. With the other groups in your class, try racing to see which group can move their can the fastest over a set distance without touching it and using only their balloon.

3.3.4. *Post-Experiment Questions*

1. What happened to the balloon after rubbing it on the hair? Try answering this question by explaining how charges move. Hint: the process is similar to Part Ia.

2. How was the balloon able to attract the can and cause it to move without touching it? Again, try answering this question by explaining how charged objects attract other objects. Hint: the process is similar to Part Ia.

3. Draw roughly how the charges are distributed on the balloon and can as the rubbed balloon is brought close to the can.

4. How can you make the can roll faster?

a. <u>Extension question:</u> How can you make the can roll slower?

3.4. Part II. Static repulsion!

3.4.1. *<u>Summary</u>*

In this experiment, we will be observing what happens when the same material develops the same (and opposite) types of charge.

3.4.2. *<u>Materials</u>*

- Sticky tape
- Pen or pencil

3.4.3. *<u>Procedure (work in groups of 2-4)</u>*

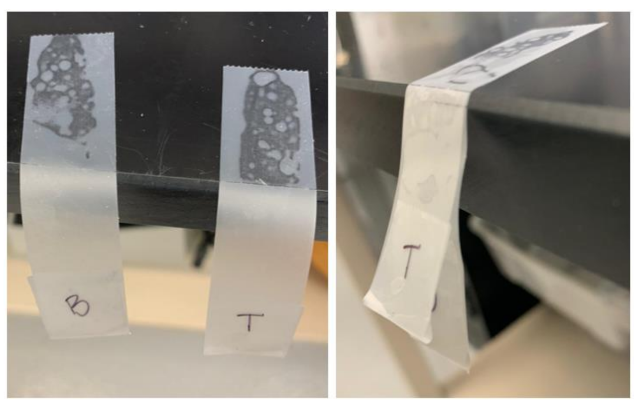

Figure 3. Experimental set-up for Part II before sticking tape together (left) and after (right).

1. Tear 4 pieces of tape, each about 10 cm long, or as long as your pen/pencil.
2. Fold ~1 cm (the top of your finger length) of each piece of tape onto itself so that you can easily hold it.
3. Stick two pieces of tape to a table with the folded over edge overhanging the table. The smooth part of the tape should be facing up toward you and the sticky part should be facing toward the table.
4. Label these pieces of tape with a “B” because they are on the bottom.

5. Stick the remaining two pieces of tape on top of the “B” pieces. The sticky parts of the top pieces of tape should be in contact with the smooth parts of the bottom pieces. Label the pieces on top “T”.
6. For both sets of tape, pull the “T” and “B” strips off the table while they are stuck together. You should have two sets of tape with a sticky side exposed of “B” and the smooth side exposed of “T”.
7. Using your fingers, rub each side of the tape so that the tape is no longer attracted to your hand (~5 times).
8. Then, pull apart the “T” and “B” strips quickly so you have two, single pieces of tape again. After doing this to both sets of tape, you should have four pieces of tape, two “T” and two “B”.
9. Using different combinations of “T” and “B”, bring two strips of tape close together (but not touching). Record your observations in the table below.

Figure 3 shows the set-up of this experiment.

3.4.4. *Results*

Tape Combination	Observations
T + B	
B + B	
T + T	

3.4.5. *Post-Experiment Questions*

1. How are the "T" and "B" strips different? What combinations of tape repel each other? Attract each other?

    a. Extension question: How do your observations with the tape combinations change over time?

2. Using the charged plastic or charged balloon from Part I, how might you figure out which piece of tape (top or bottom) is positively charged and which is negatively charged? (Advice for students: hold the charged plastic/balloon a few ~centimeters from the tape to see the effects)

3.5. Part III. Grounding effects

3.5.1. *Summary*

In this experiment, we will observe the effects of grounding. The process of electrons moving out of a charged object and into the ground (or earth or other material) is called grounding. After an object is grounded, the charged object returns to neutral so that it has no effect on (i.e., does not attract nor repel) the objects around it through electrostatic interactions. As you learned in the Background section, grounding is critical for success of lightning conductors or lightning rods, as the lightning's discharge can be routed harmlessly into the ground and prevent injury and destruction.

3.5.2. *Pre-Experiment Questions*

1. Why might grounding be helpful in everyday life?

2. What are some examples of materials that conduct electricity easily? These materials are called conductors.

3. What are some examples of materials that do not conduct electricity easily? These materials are called insulators.

3.5.3. *Materials*

- 2 pieces of plastic (e.g., pen, comb, plastic straw)
- Piece(s) of paper
- Hair (or fur, wool, glass, or skin)
- Piece of metal (e.g., fork, spoon, metal pen, key)

3.5.4. *Procedure (work in groups of 2-4)*

1. Lay several pieces of paper on a table (these should be small pieces of paper, about 1x1 or 2x2 cm).
2. Rub a plastic instrument through (or against) your hair, skin, wool/fur, or piece of glass.
3. Attempt to ground the charged plastic with a piece of metal by touching the metal to the charged plastic.
4. Bring the plastic near the pieces of paper, but without touching them, and observe what happens.
5. Repeat steps 1-4 (you can use the same pieces of paper), but instead use another piece of plastic, instead of metal, to try to ground the charged plastic and observe what happens.

3.5.5. *Post-Experiment Questions*

1. What did you observe when you used the metal to ground the charged plastic? What about when you used the second piece of plastic to ground the charged plastic? Try answering this question using the words “conductor” and “insulator”.

2. Which object works well to ground the charged plastic? Why do you think this is?

4. Design Challenge

The Challenge: Save yourself from lightning! Now that you have learned how to create static charges on the surface of objects and what happens when similarly charged or oppositely charged objects are brought close to each other, you have proven for yourself part of why lightning strikes! Since we know that opposite charges attract, the electrons in the negatively charged bottom of the cloud want to flow towards the positively charged earth. We also know that lighting tends to strike areas that are closest to the clouds, since that is the closest area of positive charges on the earth which means that the electrons don't have to travel as far. Since you've learned that grounding is an important technique to return charged objects to neutral, we are going to put everything together to design a "lightning-safe space".

4.1 Design Questions

1. If you were going to design a safe space to stay during a lightning storm, what materials would you use?
    a. Consider:
        i. How will the materials allow charges from the lightning bolt to flow away from you?
        ii. How will the materials react to the extreme heat of lightning?

2. How will the outside of your space be different from the inside of your space?

3. Will your structure be high off the ground or low to the ground?

4.2 Design Sketch

Try out your design by sketching it on paper. You can also color it in with markers, pens, pencils, and crayons. Be creative!

My lightning safe space:

5. Sources

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