Measuring static electricity: A classroom investigation to understand the triboelectric series

by Carrie Perry, Jill Nelson Granger, Arlene Vinion-Dubiel, and Hank Yochum

Static electricity results from a charge that transferred between two objects by touching the two objects together. The process of transferring charges by touching the two objects is known as triboelectric charging, with tribo referring to friction. Although every student has experienced static electricity, few understand how and why it happens.

Atoms have the same number of positively charged protons and negatively charged electrons, resulting in a neutral charge. Electrons can be transferred to other atoms, resulting in ions with an overall charge. Some atoms tend to lose electrons more easily and obtain a positive charge, whereas other atoms tend to gain electrons to obtain a negative charge. While subatomic structures are not discussed in depth until later grades, students should know about the forces between positive and negative charges.

A balloon rubbed on human hair gains electrons from the hair, resulting in a negatively charged balloon and many positively charged hairs. When the balloon and hair are separated, their opposing charges make them attract each other so that the hair stands up toward the balloon. Conversely, the positively charged strands of hair repel each other, resulting in the familiar halo of air as the hairs try to avoid contact with each other. When the opposite mechanism happens and a charged material quickly transfers electrons to become neutral again, an electric shock is experienced.

Different pairs of materials rubbed together will transfer different amounts of charge. In order to characterize the differences between pairs of materials, scientists developed the triboelectric series, a list of objects ordered by how likely they are to become positively or negatively charged. The farther apart two objects are on this chart, the larger the amount of charge transfer that results when they touch. Thus, a triboelectric series can help a scientist figure out which pairs of objects will create a static-electric charge when they touch each other. Discovering this series through a classroom investigation helps students answer questions such as, "Does a wool sweater have more static than a cotton one? How can you tell?"

The lesson described in this article is a structured inquiry during which students quantitatively measure the amount of charge transferred between two different materials. If students are familiar with inquiry activities, the teacher may allow the lesson to be more student-centered by providing less support. Suggestions are provided in the text.

Accessing students' prior knowledge is vital to determining how much teaching needs to be done prior to the investigation. Students may have some misconceptions about static electricity and how it is different from magnetism (Nabb and Henry 2009). Giving a pre-assessment on static electricity a few days before the lesson helps the teacher prepare for activities and plan discussions to dispel these misconceptions. A suggested pre-assessment, which can be modified as needed, is found with the lesson plan on the project website (see Resources).

At the beginning of the lesson, students are asked to begin a KWL (Know-Wonder-Learned) chart on what they think they know about static electricity. As a prompt, prior to completing the KWL, students are shown a video of children playing on a trampoline and a girl's hair responding comically as the static raises her hair. Then the teacher elicits student suggestions about why the girl's hair stands up and how this phenomenon works, as students fill in the K portion of their chart. Engaging students in discussions about their own shocking experiences (e.g., sweaters and hair on a cold day, touching a doorknob and receiving a spark) or using a demonstration or activity using transparent tape to address the charge nature of static, as described in Nabb and Henry (2009), can address misconceptions before the investigation begins.
Classroom investigation

Safety note: Students should wear goggles during this investigation. If any students have latex allergies, assign those individuals to track data or manage time rather than handle balloons.

After the initial discussion of the video and the KWL, students are placed into small groups, ideally made up of 4-6 students, and allowed to explore the provided materials for several minutes. These materials include an inflated balloon, a fabric square, and a ceramic or glass plate. It is important to inflate the balloons to approximately the same volume, so teachers should prepare the balloons prior to giving out the materials. Students are also given a paper plate, a small pile of confetti dots (which can be easily collected from any large three-hole puncher; the type of paper used to make the confetti does not matter as long as it is uniform), and a calculator. The teacher then shares the investigation question with the class: “What effect does the material used to make static electricity have on the amount of charge transferred?” The teacher then explains the experimental procedures, notably how to measure the amount of charge by averaging the number of confetti dots displaced by the static. Students can also be asked to suggest ways to use the given materials to measure the strength of the charge before the teacher gives the actual procedure.

As a simple way to measure the size of a charge, students scatter paper confetti on a paper plate within a small circle (the circles drawn on the paper plates may be any size as long as each group uses the same size; it is generally easier to trace a round item, such as a paper cup, than it is to draw this circle). Students rub the balloon with one of the materials to be tested (the independent variable) and hold the balloon above the plate at the same height. Each team should use a timer and rub the balloons on the materials for the same amount of time per item, per trial. The teacher may predetermine how long this interval should be or allow the students to make that decision with guidance. Fifteen to 30 seconds is adequate. Students then count the number of confetti dots the balloon picks up (the dependent variable) (Figure 1). After carefully removing the paper confetti by hand and ensuring that the balloon is no longer able to attract the pieces of paper, students repeat the trial three times using the same materials. Again, the teacher should exercise his or her judgment in determining if the number of trials should be prescribed or decided on by the students before beginning the experiment. If the class is less experienced with inquiry activities or has difficulty planning or working together, the teacher should provide more direct guidance.

On the triboelectric series, traditional pulp paper, such as notebook or printer paper, is close to zero (meaning that it has almost no charge, positive or negative), making it a good test material, whereas latex balloons are close to the negative end of the chart (able to take up electrons and obtain a negative charge). Most of the materials to be tested would be on the positive end of the chart (able to give electrons and obtain a positive charge), so the materials can be ranked based on how many confetti dots the balloon can pick up.

<table>
<thead>
<tr>
<th>Material</th>
<th>Trial 1</th>
<th>Trial 2</th>
<th>Trial 3</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wood</td>
<td>5</td>
<td>6</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>Cotton</td>
<td>18</td>
<td>16</td>
<td>14</td>
<td>16</td>
</tr>
<tr>
<td>Wool</td>
<td>26</td>
<td>31</td>
<td>27</td>
<td>28</td>
</tr>
<tr>
<td>Human hair</td>
<td>29</td>
<td>31</td>
<td>35</td>
<td>32</td>
</tr>
<tr>
<td>Polyester</td>
<td>38</td>
<td>34</td>
<td>45</td>
<td>39</td>
</tr>
</tbody>
</table>

(polar fleece)

Figure 1: Confetti dots are attracted to a balloon after being rubbed on human hair

Figure 2: Sample data of number of confetti dots picked up by latex balloon rubbed for 20 seconds with different materials
Sample data are shown in Figure 2.

Students should evaluate the experimental procedures to ensure that all variables are kept constant except for the materials that are being rubbed against the balloon. Asking simple questions such as “How are you rubbing the balloon against the material?” invites students to think about time, direction, distance between the balloon and plate, and other experimental variables. Some of these variables may have an effect (e.g., time), while others may not (e.g., direction). As time permits, students can be encouraged to design additional experiments to explore the effects of these other variables. Students should also consider why they are repeating trials for each material and how to keep conditions constant to ensure that their results are as consistent as possible. Visiting with groups and asking targeted questions create opportunities for the teacher to reinforce fundamental experimental-design principles. Common themes and questions from students should be added to the KWL chart from the beginning of the lesson under W (Wonder).

After the investigation is complete, ask students to use the data from their trials to find the average number of dots displaced for each material and create a graph to demonstrate the amount of charge generated by each material. Each group presents its findings to the class, comparing results and discussing ideas about static electricity. There will be variability in the data between trials and between groups. Discussing this variability with students encourages them to think about experimental design and how to reduce data variability. During targeted discussions and ongoing conversations that involve the entire class, students experience science as a collaboration. Typically students lead this conversation and begin asking their own questions. The teacher at this point should step back and serve as a guide rather than an instructor. The teacher may ask questions such as, “How would this experiment differ if we used...?” or “Why is it important to keep the times and materials the same for each group?” The question for investigation, “What effect does the material used to make static electricity have on the amount of charge transferred?” is emphasized during the discussion, with groups sharing their responses to the question using their own data.

After students have reached a consensus on the order of each material’s ability to transfer charge (thus creating their own mini-triboelectric series [Figure 3]), they compare their results to the scientific literature.
Connecting to the Next Generation Science Standards (NGSS Lead States 2010):

- The chart below makes one set of connections between the instruction outlined in this article and the NGSS. Other valid connections are likely, however space restrictions prevent us from listing all possibilities.
- The materials, lessons, and activities outlined in the article are just one step toward reaching the performance expectations listed below.

<table>
<thead>
<tr>
<th>Standard</th>
<th>Performance Expectations</th>
<th>Matching student task or question taken directly from the activity</th>
</tr>
</thead>
<tbody>
<tr>
<td>MS-PS2: Forces and Interactions</td>
<td>MS-PS2.3. Ask questions about data to determine the factors that affect the strength of electric and magnetic forces. MS-PS2.5. Conduct an investigation and evaluate the experimental design to provide evidence that fields exist between objects exerting forces on each other even though the objects are not in contact.</td>
<td>Students engage in an investigation answering the question “What effect does the material used to create static have on the amount of charge transferred?” Students analyze and compare their data with known information on the triboelectric series of materials.</td>
</tr>
</tbody>
</table>

| Dimension | Name or NGSS code/citation | |
|-----------|-----------------------------| |
| Science and Engineering Practices | Planning and Carrying Out Investigations Analyzing and Interpreting Data | Students find the average number of dots displaced by each material. Students generated a version of the triboelectric series with their own data. Students use data to support the measured magnitude of a static electricity charge. |
| Disciplinary Core Idea | PS2.B: Types of Interactions • Electric and magnetic forces can be attractive or repulsive, and their sizes depend on the magnitudes of the charges, currents, or magnetic strengths involved and existing in the distances between the interacting objects. | Students compare the patterns made by their data with known patterns of materials of the triboelectric series by answering the question “How does the order of your materials compare with the order from the published lists of materials?” |
| Crosscutting Concept | Patterns | |

Connections to the Common Core State Standards (NGAC and CCSSO 2010)

CCSS.ELA-Literacy.RST.6-8.3: Follow precisely a multistep procedure when carrying out experiments, taking measurements, or performing technical tasks
CCSS.ELA-Literacy.RST.6-8.9: Compare and contrast the information gained from experiments, simulations, video, or multimedia sources with that gained from reading a text on the same subject.
CCSS.Math.Content.6.SP.B.5.C: Giving quantitative measures of center (median and/or mean) and variability (interquartile range and/or mean absolute deviation), as well as describing any overall pattern and any striking deviations from the overall pattern with reference to the context in which the data were gathered.
(see Resources). At this time, the teacher should display several reputable images of the triboelectric series and allow students to point out the similarities or differences they notice. There is some variability among different charts, depending upon the materials used and how they were measured, which presents another opportunity for discussion of data variability. The teacher may ask students questions such as “How does the order of your materials compare with the order from the published lists of materials?” or “What are some factors that may have given us different results than the researchers who developed this series found?” or “How could we extend this experiment to get a bigger picture?” After students compare their data with known information, they finish the KWL chart by completing the L (Learned) section, answering any questions that may have arisen during the investigation and listed under W (Wonder). Completing this chart provides students with a visual representation of what they learned through the investigation.

Students who participated in this inquiry found that, although there were differences in findings across groups, everyone discovered that a balloon that had been rubbed on human hair picked up more confetti than one that had been rubbed on a cotton shirt. Thus, students were able to generate a version of a triboelectric series with their own data. They also learned that, although individual differences in experimenters may have an effect, scientific principles are universal and can be demonstrated by different people.

Assessment

The main learning objective is that students will recognize that a force can be quantitatively measured in an indirect way—in this case, through the number of confetti pieces a balloon can pick up. A simple rubric that can be modified as needed is provided on the project website (see Resources). The rubric allows students to peer-assess as the groups present the results of their investigation. Other summative assessment pieces include notes on the discussions in which students use their data to support their answer to the investigation question and the L (Learned) portion of the KWL chart, paying special attention to the use of vocabulary.

Conclusion

In this activity, students quantitatively measure the amount of static electricity made through charge transfer from different materials. In this way, students can rank the materials in terms of their charge-transfer ability. Comparing student lists with known lists of materials in the triboelectric series helps confirm student discoveries. Through inquiry and research into core principles, students can feel actively connected to static electricity, a science concept that would otherwise remain abstract and mysterious.

References


next-generation-science-standards.

Resources

In-depth information about static electricity—www.americanscientist.org/issues/feature/what-creates-static-electricity/1

Quantitative triboelectric series chart—www.trifield.com/content/tribo-electric-series/

Static electricity—www.sciencemadesimple.com/static_electricity.html

STEM4Teachers.org—http://www.stem4teachers.org/2014/02/24/measuring-static-electricity/

Carrie Perry (cperry@bedford.k12.va.us) is a special education teacher at Goodview Elementary School in Bedford, Virginia. Jill Nelson Granger is dean of the honors college at Western Carolina University in Cullowhee, North Carolina. Ariana Vinion-Dubiel is an independent education consultant, formerly of Sweet Briar College in Sweet Briar, Virginia. Hank Yochum is professor of engineering and physics at Sweet Briar College in Sweet Briar, Virginia.