Charge Transfer

SCIENCE NSPIRED

Science Objectives

- Students will explore relationships among distance, charge, and time.
- Students will measure and describe charge transfer by induction and by contact.

Vocabulary

- charge polarity
- dielectric material
- electric conductor
- static electricity

About the Lesson

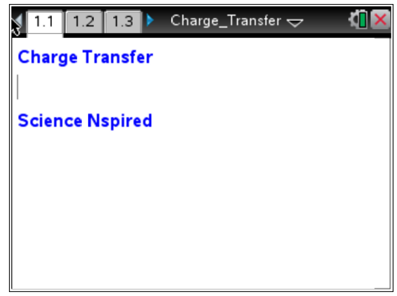
- In this activity, students explore and compare various processes of charge transfer by induction and by contact.
- As a result, students will:
  - Explore how the magnitude of an induced charge depends on the distance between the charged object and metal.
  - Investigate the process of discharging or “leakage” of charge over time.
  - Model each of these relationships mathematically.

TI-Nspire™ Navigator™

- Send out the *Charge_Transfer.tns* file.
- Monitor student progress using Screen Capture.
- Use Live Presenter to spotlight student answers.

Activity Materials

- *Charge_Transfer.tns* document
- TI-Nspire™ technology
- Vernier Charge Sensor
- Vernier EasyLink™or Go!®Link interface
- cellophane “invisible” tape
- copy of student worksheet
- glass jar or beaker
- heavy-duty aluminum foil
- metal can, such as a clean, empty soup can
- pen or pencil
- ruler



TI-Nspire™ Technology Skills:

- Download a TI-Nspire document
- Open a document
- Move between pages
- Collect Data with Probes

Tech Tip:

Access free tutorials at http://education.ti.com/calculators/pd/US/Online-Learning/Tutorials

Lesson Files:

Student Activity

- Charge_Transfer_Student.doc
- Charge_Transfer_Student.pdf

TI-Nspire document

- Charge_Transfer.tns

Discussion Points and Possible Answers

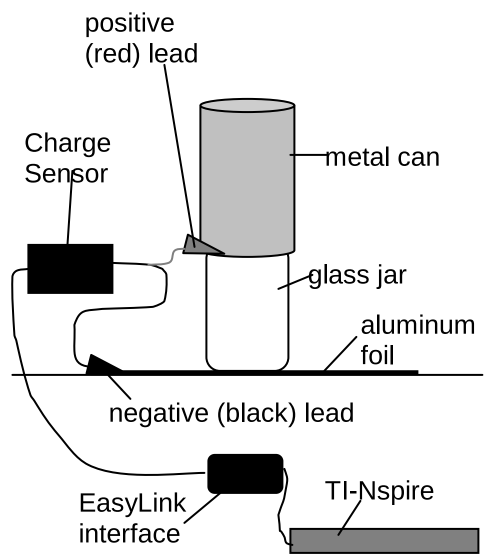
Before carrying out this activity, review with students the concepts of charge transfer by contact, induction between conductors and dielectrics, and electric discharge. Students should be familiar with static electricity, charge polarity, electric conductors, and dielectric materials.

The following questions are the focus of the student exploration:

- What happens when a positively or negatively charged object is brought near a metal can without touching it? Does this effect depend on the distance between the charged object and the can?
- What happens when a positively or negatively charged object is placed inside a can without touching it? What if you brought it in contact with the can?
- Does induced or transferred charge change over time? Why? What factors affect this process?

Problem 1: Exploring Charge by Contact and Induction

1. Students will use a Vernier EasyLink (if using a handheld) or Go!Link (if using a computer) interface. They should connect the sensor cable leads to the Charge Sensor and then connect the sensor to the EasyLink or Go!Link interface. (Students should not connect the interface to the handheld or computer yet.)
2. Students should slide the switch on the Charge Sensor to the ±10V position. At the beginning of each experiment, students should press the **Reset** button for a few seconds with the leads shorted together to make sure all charge is depleted from the internal capacitor.
3. Students should connect the black lead of the sensor to the edge of a piece of aluminum foil. This will act as the grounding plane.
4. Next, students should balance a metal can on top of an inverted glass jar in the center of the aluminum foil. They should connect the red lead to the bottom lip of the metal can. Make sure students are using a metal can that has a lip on both the top and the bottom, rather than a can that has a beveled bottom edge. The diagram to the right shows how to set up the equipment for this investigation.



Have students answer the questions on the activity sheet.

Q1. How can objects be charged by contact?

Answer: An insulator can be charged by rubbing it with a cloth. A neutral conductor will acquire charge if placed in contact with a charged conductor or insulator.

Q2. How can charge be induced?

Answer: If a charged object is brought near a neutral conductor, the positive and negative charges in the conductor will separate. The net charge of the conductor will remain zero. Another way to induce a net charge on a metal object is to first ground it. If, for example, a negatively charged object is brought close to the metal, free electrons in the metal are repelled and many of them move to the ground. Disconnect the metal from the ground, and it will have a positive induced charge on it.

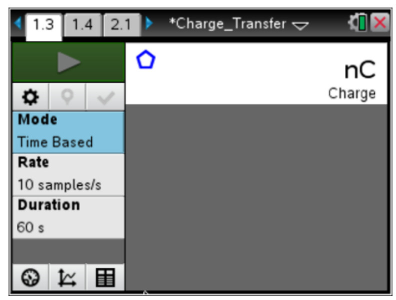
Q3. Explain the law of conservation of charge.

Answer: The net amount of electric charge produced in any process is zero; no net electric charge can be created or destroyed.

5. Next, students tape two short pieces of cellophane tape to pieces of paper and then charge the tape by sticking the sticky side of one to the smooth side of the other. They should rub them lightly between their fingers to neutralize any overall charge.

Move to pages 1.2 and 1.3.

6. Students should read page 1.2, and then move to page 1.3. They should connect the Charge Sensor to their handheld or computer. The charge reading should be very close to zero. If it is not, students should press the **Reset** button on the Charge Sensor to zero the sensor.



7. Students should bring the pieces of tape near the can to check for neutrality. If they have successfully removed any stray charge from the tape, the charge reading will not change when they bring both pieces of tape near the can. After they have checked for neutrality, they should separate the pieces of tape and then answer Questions 4 and 5.

Have students answer the questions on the activity sheet.

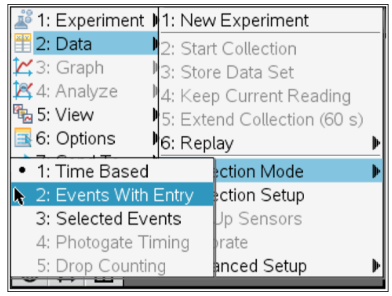
Q4. What happens to the pieces of tape now when you bring them near each other?

Answer: They attract one another, since they are oppositely charged.

Q5. Explain how the pieces of tape became charged.

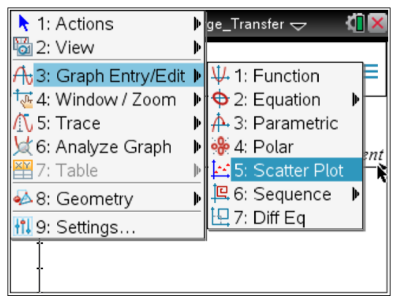
Answer: Rubbing (sticking) the pieces of tape against each other causes loose electrons to move from one piece to another. This causes one piece to become positively charged and the other one to become negatively charged.

8. Next, students should set up the data collection as **Events with Entry**.



Move to page 1.4.

9. Students should observe and record the charge reading as they bring one piece of tape near to but not touching the can, inside but not touching the can, and touching the can. Students should use a specific number to represent each position (e.g., 1 for outside the can, 2 for inside the can, and 3 for touching the can). They should press **Start Collection** to start, and then **Keep data button** to collect a measurement.
10. Next, students repeat Step 9 for the other piece of tape. (Make sure students use different numbers—such as 4, 5, and 6—to represent the positions of the second piece of tape, and make sure they zero the Charge Sensor before beginning.) After data are collected, students can click on **Stop Data Collection** and disconnect the sensor. Then they can graph their data and answer Questions 6 and 7.
11. Page 1.4 contains a blank *Graph & Geometry* application. Students should change the graph type to a scatter plot (**Menu > Graph Entry/Edit > Scatter Plot**) and use the entry line to set the *x*-axis to the variable run1.event and the *y*-axis to run1.charge. Students should use **(Window/Zoom > Zoom-Data)** to ensure that all of the data are visible.



Have students answer the questions on the activity sheet.

Q6. Explain why measuring the charge on the can allows you to determine the charge on each piece of tape.

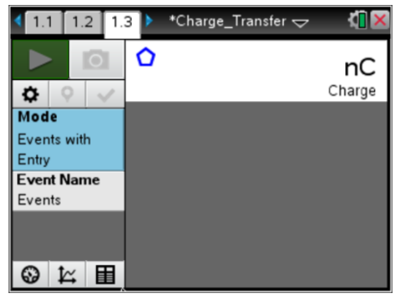
<u>**Answer**</u>**:** The charge on the tape induces a charge on the can when the tape is placed near the can, outside or inside. The amount of induced charge is slightly less than the amount of charge on the tape. When the tape touches the can, any excess charge is transferred from the tape to the metal.

Q7. Can you compare all three measurements? Which one do you think is most precise?

Answer: Answers will vary. The values should be similar, but not identical. In general, placing the tape inside the can, but not touching it, gives the most precise measurement of the charge on the tape. You may also wish to discuss with students the relative sizes and signs of the charges on the two pieces of tape. The two pieces should have nearly equal but opposite charges. Discuss with students why the law of conservation of charge requires this to be so.

Problem 2: Induced Charge Change with Distance

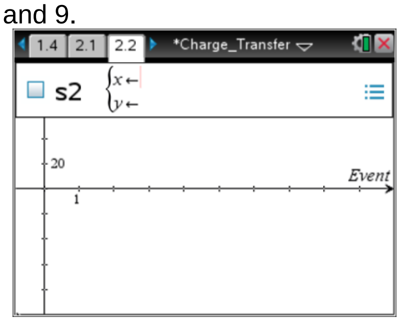
Move to page 2.1.



1. Next, students explore how the distance from the charged object affects the amount of induced charge on the metal can. They should move to page 2.1 and set up the experiment for **Events with Entry**. They should also zero the Charge Sensor again.
2. Students should measure and record the induced charge produced by holding a positively charged piece of tape about 1 cm from the can. Students should use a ruler to estimate the distance between the can and the tape. The distance measurements will not be completely accurate, but as long as students use sufficient care, they should be precise enough to give usable results. Students can determine which piece of tape is positively charged by holding the tape in the center of the can and reading the charge from the data collection box. A negatively charged piece of tape should give similar results, but students often have difficulty dealing with negative data, so it is recommended that they use positively charged tape for this part of the investigation.
3. Students should move the tape 1 cm farther from the can and collect another data point.
4. Students should repeat Step 3 three or four more times, until they have a total of at least five or six data points.

   Note: Make sure students enter the correct distance in the **Events with Entry** dialog box each time they record a data point.
5. After the data are collected, students should click on **Stop Data Collection** and disconnect the sensor and graph their data. They should then answer Questions 8 and 9.

Move to page 2.2.



6. Page 2.2 contains a blank *Graph & Geometry* application. Students should change the graph type to scatter plot and set the *x*-axis to the variable run1.event and the *y*-axis to run1.charge. Use (**Window/Zoom > Zoom-Data**) to ensure that all of the data are visible.

Have students answer the questions on the activity sheet.

Q1. Explain why the magnitude of induced charge changes as you move the tape away from the can.

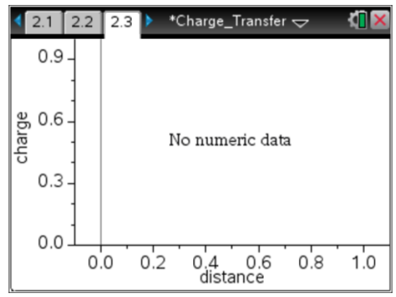
Answer: The electric field around a charged object decreases in magnitude as the distance from the object increases. Therefore, as the charged tape is moved away from the can, the can is exposed to a weaker electric field. As a result, the force causing the free charges in the metal to separate is smaller, thus causing less charge separation.

Q2. What mathematical function appears to best fit the data that describe the change of induced charge as the tape moves away from the can?

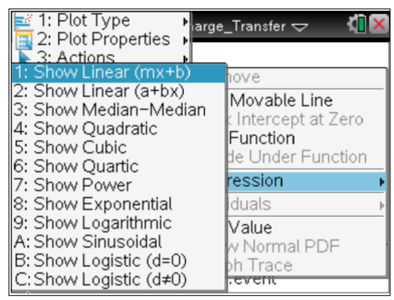
Answer: Student answers will vary. Encourage student discussion of the shape of the curve.

Move to page 2.3.

7. Page 2.3 contains a *Data & Statistics* application. Students should use it to make a plot of charge vs. distance with their data.



8. Students should use the **Regression** tool to find the type of equation that best fits the data. They should try several different types of regression and identify the two functions that seem to fit the data best.



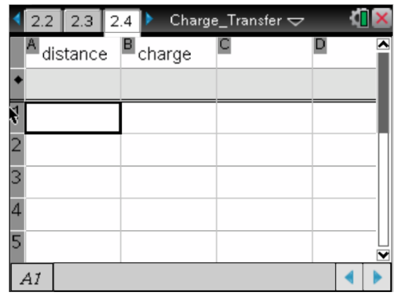
Have students answer the question on the activity sheet.

Q3. Which two functions appear to fit the data best?

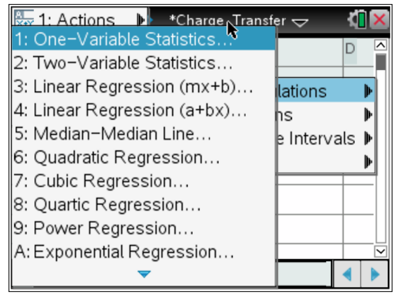
Answer: Student answers will vary. Encourage student discussion of the fit of each curve. Students should be able to justify their answers.

Move to page 2.4.

9. Page 2.4 contains a *Lists & Spreadsheet* application. Students should assign their collected distance values to column A and their collected charge values to column B.
   Note: The TI-Nspire may automatically overwrite columns A and B with the collected data. If this occurs, students should rename column A **distance** and column B **charge** and then assign the data to the respective columns.



10. Students should highlight columns A and B and use the **Regression** tool to find the r^2 values for the two functions they identified in Step 8. They should display the results of the regressions in separate columns on page 2.4.
    Make sure students do not overwrite any data when they carry out the second regression.



Have students answer the question on the activity sheet.

Q4. Based on the r^2 values for the two regressions, which one fits the data best? What is the best-fit equation for the data? Do both models make physical sense?

Answer: Student Answers will vary. For the sample data shown, the best-fit curve has the equation $y = -0.69 - 0.54 \ln x$. Encourage students to discuss the physical implications of each equation.

Problem 3: Process of Charge Leakage with Time

Have students answer the questions on the activity sheet.

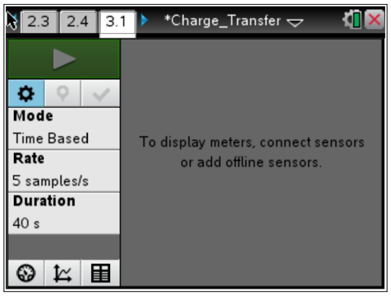
Q1. What happens over time to the charge of an object that has been charged by rubbing?

Answer: In general, the charge “leaks off” due to contact with objects or water molecules in the air.

Q2. How does humidity affect static electricity? Why?

Answer: On a dry day, static electricity is more noticeable because air contains fewer water molecules to allow leakage. On a humid or rainy day, it is hard to make any object hold a net charge for long. This is because the water molecules are polar. Thus, the extra electrons, for example, are attracted to positive ends of water molecules.

Move to page 3.1.



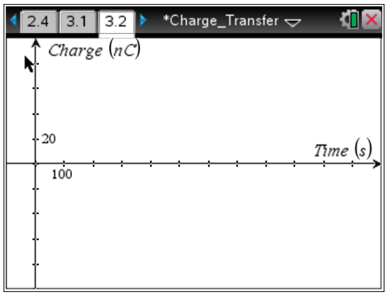
1. Next, students connect the sensor and set up data collection for **Time Based** mode. They should set the device to record one data point every 60 sec for 1,200 sec.
   Note: This part of the investigation will require about 20 minutes. Also, note that high humidity will significantly affect the results of this part of the investigation. If possible, carry it out on a relatively dry day.
2. To collect data, students should first reset the sensor, then charge one piece of tape positively and drop it into the can. They can then begin data collection.
   Note: Students should periodically press the **arrow keys** on the NavPad to prevent the TI-Nspire from automatically powering down. Pressing arrow keys will not interfere with data collection.

Have students answer the questions on the activity sheet.

Q3. Predict how charge will change with time. What type of function do you think will fit the data?

Answer: Student answers will vary. Students should reason that the charge will leak off the tape over time, so they should predict some form of inverse curve. The rate of discharge is proportional to the initial charge on the tape, so some students may be able to reason that the discharge should follow an exponential curve.

Move to page 3.2.



3. After data are collected, students can click on **Stop Data Collection** and disconnect the sensor.
4. Page 3.2 contains a blank *Graph & Geometry* application. Students can set the *x*-axis to the variable run1.time and the y-axis to run1.charge and use **(Window/Zoom > Zoom-Data)** to ensure that all of the data are visible.

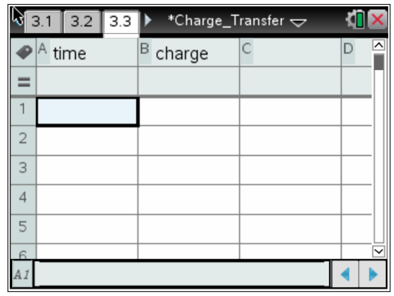
Have students answer the questions on the activity sheet.

Q4. What mathematical function appears to best fit the data that describe the change of charge over time?

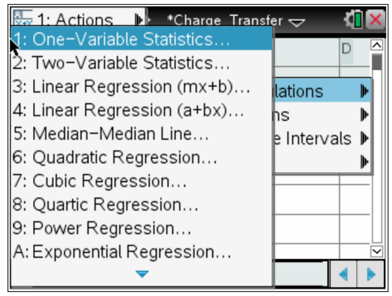
Answer: Answers will vary. Students should be able to justify their Answers.

Move to page 3.3.

5. Page 3.3 contains a *Lists & Spreadsheet* application. Students should assign the time data they collected to column A and the charge data they collected to column B.



6. Students should use the **Regression** tool to determine the best-fit equation for the charge vs. time data. They should use an exponential or linear regression to fit the data.



Return to page 3.2.

7. Students should move back to page 3.2, change the graph to a function graph, and display the regression equation along with the scatter plot of the data. They should then answer Questions 5 and 6.

   Note: If time allows, students can carry out additional investigations. For example, they can charge different lengths of tape and determine the charge per unit length. Students can also use other materials to explore charging by contact and induction. For example, they can use small PVC pipe, a plastic comb, or a ruler. Other options include evaluating the effect of removing the ground plane, or of the students' charging themselves (e.g., by scuffing their feet on a carpet) before carrying out the activity.

Have students answer the questions on the activity sheet.

Q5. Write the mathematical equation for the best-fit curve for your data.

Answer: Answers will vary. For the sample data, the best-fit exponential line has the equation $y = 9.5 \cdot (0.9998)^x$.

Note: that this is extremely close to a linear function. Students may also choose to perform a linear regression on the data. Encourage students to compare the r^2 values for these two functions. You may wish to discuss these results with students. The "true" decay relationship should be exponential in form. However, if the sampling time is short relative to the decay rate, then students will see only a small portion of the decay curve. This portion can be approximated by a linear function. You should also discuss with students the importance of thinking about the physical implications of a mathematical model. For example, in this case, although a linear equation appears to fit the data, the physical implications of the linear model are not realistic. A linear model suggests that as time increases, electric charge eventually becomes negative—that is, that the object continues to lose charge even after it has lost all of its excess positive charge. This is not a physically plausible model.

Q6. Do your results agree with the prediction you made in Question 3? If not, identify any errors in reasoning that you made.

Answer: Answers will vary. Encourage metacognitive thinking to help students identify errors in their reasoning.

TI-Nspire Navigator Opportunity

Use Screen Capture to view student progress through the lab.

Wrap Up

Upon completion of the lab and discussion, the teacher should ensure that students are able to understand:

- The importance of accurately setting up the lab.
- How to gather and analyze data.
- The model of the discharge of a capacitor.

Assessment

Students should answer questions on the student activity sheet.