Charge Transfer – ID: 10542

By Irina Lyublinskaya

Time required
45 minutes

Topic: Electricity and Magnetism

- *Solve problems using the relationship between current, charge, and time.*
- *Measure and describe charge transfer by induction and by contact.*

Activity Overview

In this activity, students explore and compare various processes of charge transfer by induction and by contact. They explore how the magnitude of an induced charge depends on the distance between the charged object and metal and determine mathematical models for this process. Students will also investigate the process of discharging or "leakage" of charge over time and compare that with an exponential decay model.

Materials

To complete this activity, each student will require the following:

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

TI-Nspire Applications

Graphs & Geometry, Data & Statistics, Lists & Spreadsheet, Notes

Teacher Preparation

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

- *A good resource for teachers is the article "Electrostatics with Computer-Interfaced Charge Sensors" by Robert A. Morse, published in the journal* The Physics Teacher, *Vol. 44, November 2006, p. 498–502.*
- *The screenshots on pages 2–10 demonstrate expected student results. Refer to the screenshots on page 11 for a preview of the student TI-Nspire document (.tns file). The student worksheet is shown on pages 12–15.*
- ***To download the .tns file and student worksheet, go to education.ti.com/exchange and enter "10542" in the search box.***

Classroom Management

- *This activity is designed to be* ***student-centered****, with the teacher acting as a facilitator while students work cooperatively. The student worksheet guides students through the main steps of the activity and includes questions to guide their exploration. Students may record their answers to the questions on blank paper or answer in the .tns file using the Notes application.*
- *The ideas contained in the following pages are intended to provide a framework as to how the activity will progress. Suggestions are also provided to help ensure that the objectives for this activity are met.*
- *In some cases, these instructions are specific to those students using TI-Nspire handheld devices, but the activity can easily be done using TI-Nspire computer software.*

The following questions will guide student exploration during this activity:

- 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?

The purpose of this activity is for students to explore the processes of charging by contact and induction and the process of discharging, also known as leakage. In the first problem, students will use cellophane tape as a charged object to either induce a charge on a metal can or charge it by direct contact. In the second problem, students will explore how induced charge on a metal can depends on the distance between the tape and the can. In the third problem, students will measure the charge transferred to the metal can by direct contact from a tape over time. In problems 1 and 2, students are expected to develop mathematical models of the processes by using statistical regressions.

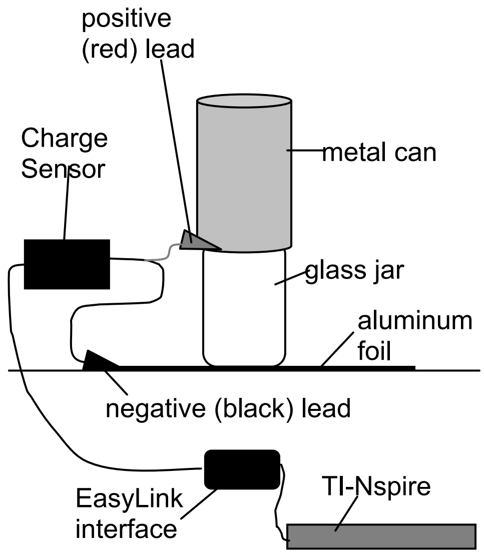
Problem 1 – Exploring charge by contact and induction

Step 1: Students will use a Vernier EasyLink (if using a handheld) or Go!Link (if using a computer) interface. They should connect the sensor lead cable 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.)

Step 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.

Step 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.

Step 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 an older style metal can that has a lip on both the top and the bottom, rather than a newer style can that has a beveled bottom edge. The diagram to the right shows how to set up the equipment for this investigation. Note: This diagram is also shown in the student worksheet, but it is not labeled. Once students have set up the equipment, they should answer questions 1–3.



Q1. How can objects be charged by contact?

A. *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.*

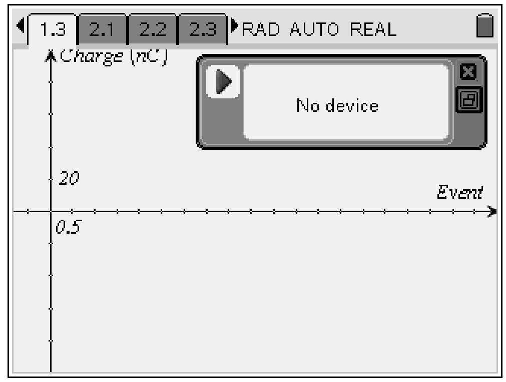
Q2. How can charge be induced?

A. *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 meaning of the law of conservation of charge.

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

Step 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 stray charge.



Step 6: Students should open the file **PhysWeek30_ChargeTransfer.tns**, read the first two pages, and then move to page 1.3. When students reach page 1.3, they should insert a data collection box and then 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.

Step 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.

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

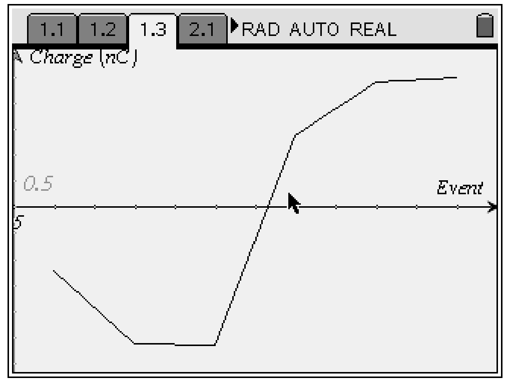
A. *They attract one another, since they are oppositely charged.*

Q5. Explain how the pieces of tape become charged.

A. *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.*

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

Step 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).



Step 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 should close the data collection box and disconnect the sensor. They should then answer questions 6 and 7.

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

A. *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?

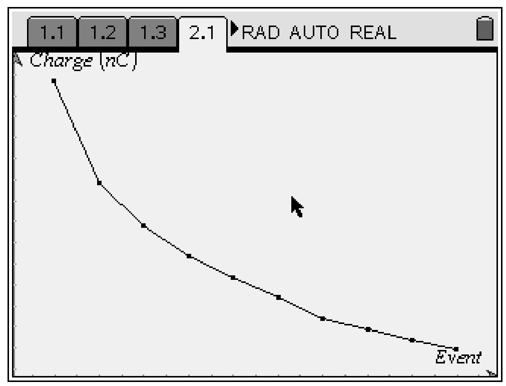
A. *Answers will vary. The values should be similar, but not identical. In general, placing the tape inside the can, but not touching it, gives the most precise measurement of the charge on the tape. You may also wish to discuss with students the relative sizes and signs of the charges on the two pieces 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

Step 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, insert a new data collection box, and set up the experiment for **Events with Entry**. They should also zero the Charge Sensor by pushing the Reset button and discharge the metal can by quickly connecting it to the grounding plane.

Step 2: Next, 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.

Step 3: Next, students should move the tape 1 cm farther from the can and collect another data point.



Step 4: Students should repeat step 3 three or four more times, until they have a total of at least five or six data points. A graph should appear on page 2.1 as they collect data. Note: Make sure students enter the correct distance in the **Events with Entry** dialog box each time they record a data point.

Step 5: After the data are collected, students should close the data collection box and disconnect the sensor. They should then answer questions 8 and 9.

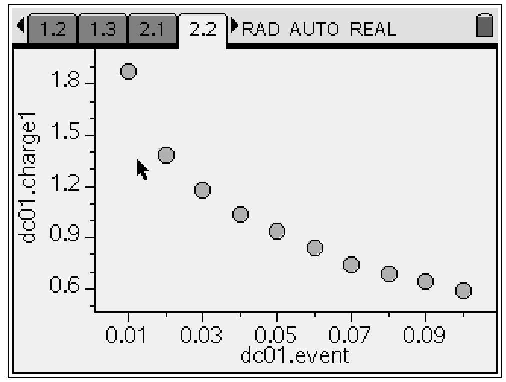
Q8. Explain why the magnitude of induced charge changes as you move the tape away from the can.

A. *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.*

Q9. What mathematical function appears to best fit the data that describe the change of induced charge as the tape moves away from the can?

A. *Student answers will vary. Encourage student discussion of the shape of the curve.*

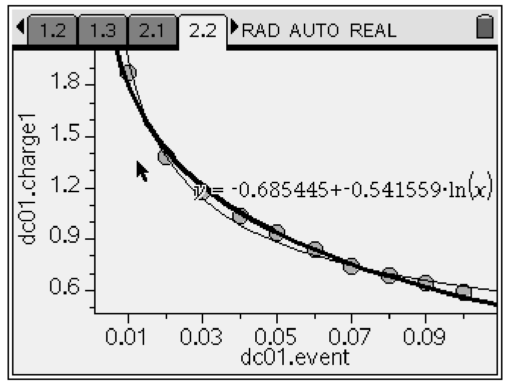
Step 6: Next, students move to page 2.2, which contains a *Data & Statistics* application. They will use the application to make a plot of charge vs. distance for the data they collected.



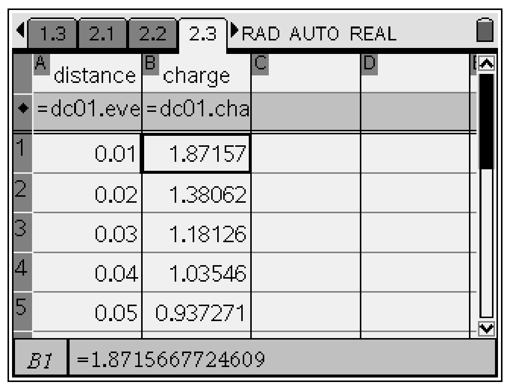
Step 7: Students should use the **Regression** tool to find the type of equation that best fits the data. They should try several different types of regression and identify the two functions that seem to fit the data best.

Q10. Which two functions appear to fit the data best?

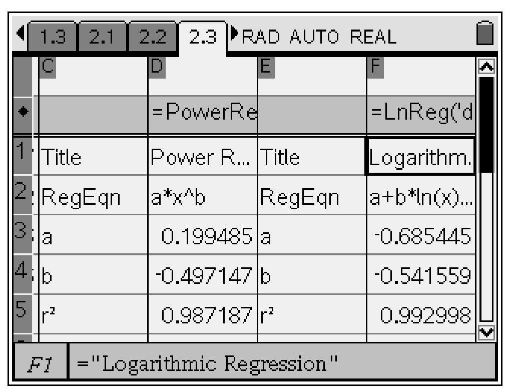
A. *Student answers will vary. Encourage student discussion of the fit of each curve. Students should be able to justify their answers.*



Step 8: Next, students move to page 2.3, which contains a *Lists & Spreadsheet* application. They 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.



Step 9: Students should use the **Regression** tool to find the r^2 values for the two functions they identified in step 7. Make sure students do not overwrite any data when they carry out the second regression.



Q11. 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?

A. *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

Q12. What happens over time to the charge of an object that has been charged by rubbing?

A. *In general, the charge "leaks off" onto water molecules in the air. This is because the water molecules are polar. Thus, the extra electrons, for example, are attracted to positive ends of water molecules.*

Q13. How does humidity affect static electricity?

A. *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.*

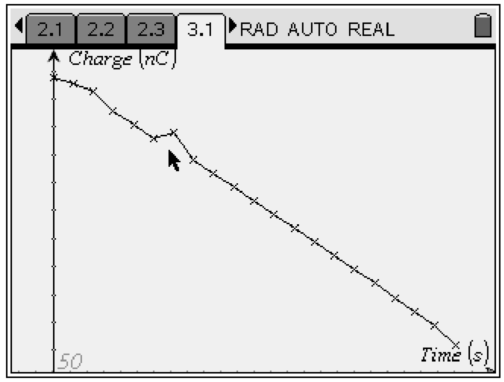
Step 1: Next, students move to page 3.1, add a new data collection box, connect the sensor, and set up data collection for **Time Graph** mode. They should set the device to record one data point every 60 sec for 1,200 sec. Note: This part of the investigation will require a significant amount of time. You may wish to assign it as homework or allow students additional class time to complete it. 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.

Step 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.

Q14. Predict how charge will change with time. What functional form do you think the data will have?

A. *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.*

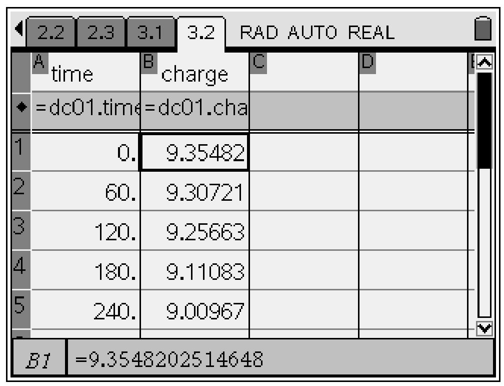
Step 3: After data are collected, students should close the data collection box and disconnect the sensor and then answer question 15.



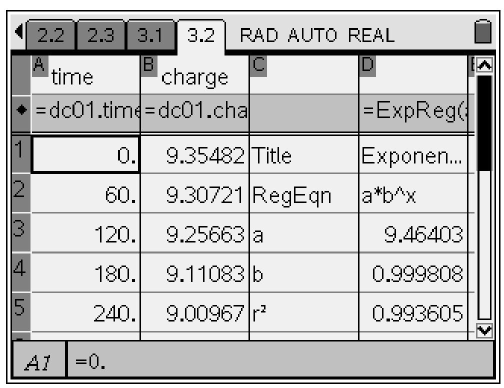
Q15. What mathematical function appears to best fit the data that describe the change of charge over time?

A. *Answers will vary. Students should be able to justify their answers.*

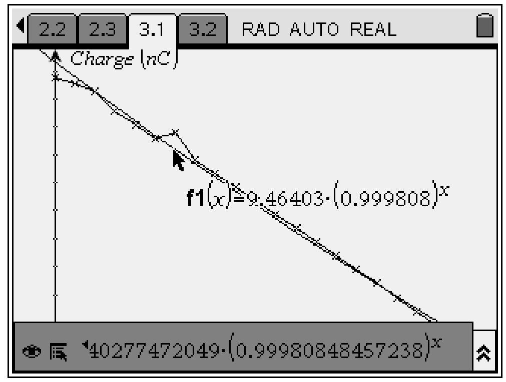
Step 4: Next, students move to page 3.2, which contains a *Lists & Spreadsheet* application. They should assign the time data they collected to column A and the charge data they collected to column B.



Step 5: 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.



Step 6: Students should move back to page 3.1, 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 16 and 17. 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.



Q16. Write the mathematical equation for the best-fit line for your data.

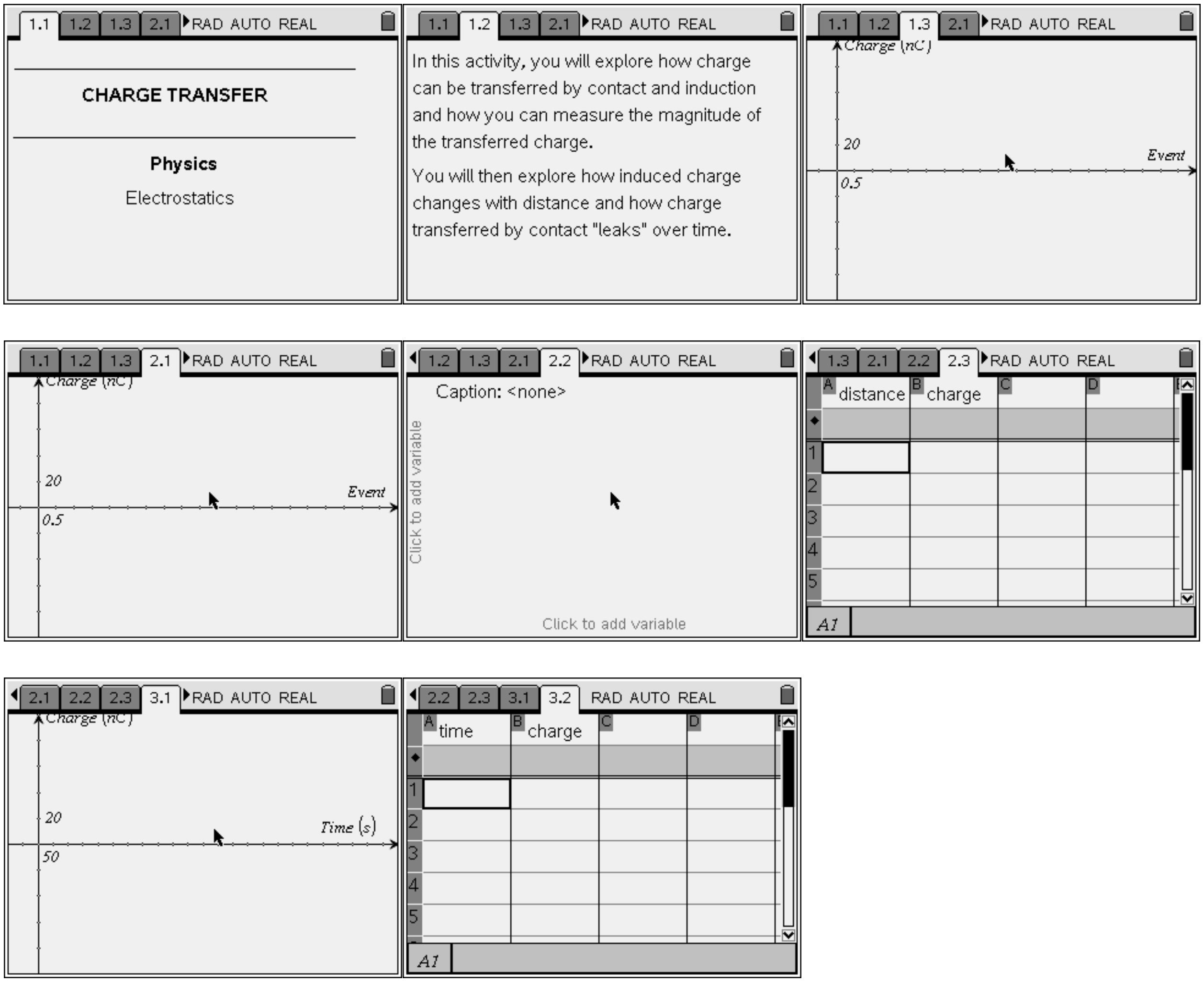
A. *Answers will vary. For the sample data, the best-fit exponential line has the equation $y = 9.5 \cdot (0.9998)^x$. Note that this is extremely close to a linear function. Students may also choose to perform a linear regression on the data. Encourage students to compare the r^2 values for these two 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.*

Q17. Do your results agree with the prediction you made in question 14? If not, identify any errors in reasoning that you made.

A. *Answers will vary. Encourage metacognitive thinking to help students identify their errors in reasoning.*

Charge Transfer – ID: 10542

(Student)TI-Nspire File: *PhysWeek30_ChargeTransfer.tns*



Charge Transfer

ID: 10542

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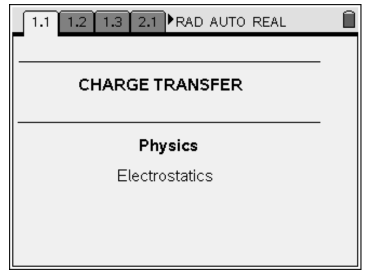


In this activity, you will explore the following questions:

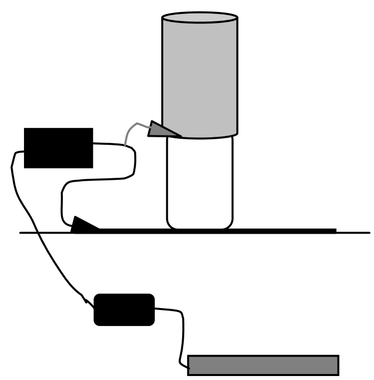
- *What happens when a positively or negatively charged object is brought near a metal can without touching it? Does this effect depend on the distance between the charged object and the metal can?*
- *What happens when a positively or negatively charged object is placed inside a metal can without touching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

In this activity, you will measure the charge transferred by induction and by contact onto a metal can from charged cellophane tape. You will measure the charge transferred from different distances and over time. You will then analyze these data and develop mathematical models for charge as a function of distance and as a function of time.

Problem 1: Exploring charge by contact and induction

Step 1: Connect the sensor leads cable to the Charge Sensor and then connect the sensor to the EasyLink (if working with TI-Nspire handheld) or Go!Link (if working with computer) interface.

Step 2: Slide the switch on the Charge Sensor to the ±10V position. Press the Reset button for a few seconds with the leads shorted together to make sure all charge is depleted from the internal capacitor.



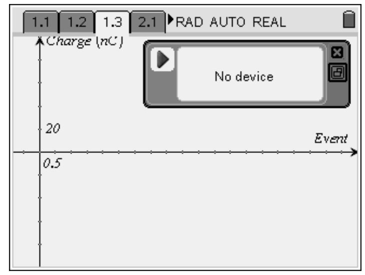
Step 3: Place a square sheet of heavy-duty aluminum foil on the table. Fold the edge of the sheet over several times to form a thicker edge on one side. This will prevent tearing. Connect the black (grounded) lead of the sensor to the folded edge. This sheet of foil is the grounding plane.

Step 4: Place an inverted glass jar in the middle of the aluminum foil. Place the metal can on top of the glass jar. The opening of the can should be facing upward. Connect the red (positive) lead of the sensor to the bottom lip of the can, as shown in the diagram to the right. Note: Begin all experiments by grounding the positive lead and then zeroing the charge sensor.

Q1. How can objects be charged by contact?
Q2. How can charge be induced?
Q3. Explain the meaning of the law of conservation of charge.

Step 5: Stick two pieces of cellophane tape to short pieces of paper or card stock. Make sure most of each piece of tape is hanging off the paper. Charge the tape by sticking the two pieces together—the sticky side of one piece to the smooth side of the other. To get rid of any excess charge, run the pieces of tape gently through your fingers. Try to minimize your handling of the tape.

Step 6: Open the file **PhyAct39_ChargeTransfer_EN.tns**, read the first two pages, and then move to page 1.3. When you reach page 1.3, insert a new data collection box by pressing ctrl D. Then, connect the EasyLink or Go!Link interface to your handheld or computer. A charge reading should show up in the data collection box.

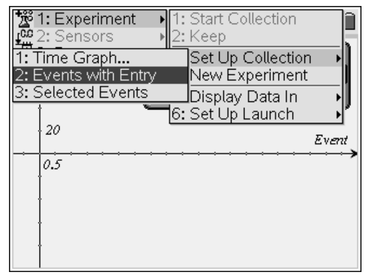


Step 7: To check that the tape is not carrying any excess charge, bring the tape near the metal can (do not touch the can with the tape). The charge sensor reading should not change if the tape is not holding excess charge. Once you have checked for neutrality, separate the pieces of tape.

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

Q5. Explain how the pieces of tape become charged.

Step 8: Set up the data collection as an **Events with Entry** experiment (**Menu > Experiment > Set Up Collection > Events with Entry**). Click the "play" button (►) to start the data collection.



Step 9: Observe and record the charge reading as you bring one of the pieces of tape near the can, inside but not touching the can, and touching the can. To collect a data point, click the button in the lower right corner of the data collection box. A dialog box will appear. In the dialog box, enter a number representing which data point you are collecting (for example, you may use 1 for the tape near the can, 2 for the tape inside the can, and 3 for the tape touching the can). A graph should appear on page 1.3 as you collect your data.

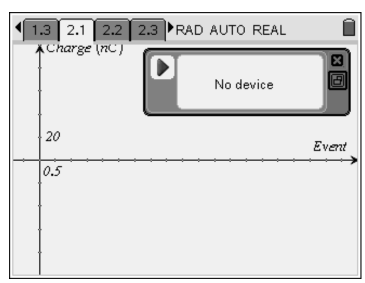
Step 10: Repeat step 9 for the other piece of tape. (Make sure to zero the Charge Sensor and ground the metal can by touching it to the aluminum foil before collecting the data.) After data are collected, close the data collection box and disconnect the sensor.

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

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

Problem 2: Induced charge change with distance

Step 1: Next, you will explore how induced charge changes with distance. Move to page 2.1, insert a new data collection box, and set up data collection for **Events with Entry**. Connect the sensor to the TI-Nspire. Zero the Charge Sensor by pressing the Reset button, and ground the can by touching it to the aluminum foil.



Step 2: Hold a positively charged piece of tape about 1 cm from the can. (Use a ruler to measure the approximate distance between the tape and the can, but do not allow the ruler to touch the tape or the can.) Once the charge reading has stabilized, collect the data point. Enter 0.01 in the dialog box.

Step 3: Move the tape approximately 1 cm farther away from the can, wait for the reading to stabilize, and record another data point. Enter 0.02 in the dialog box.

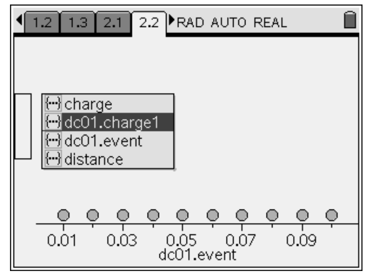
Step 4: Repeat step 3 three or four more times.

Step 5: After data are collected, close the data collection box and disconnect the sensor.

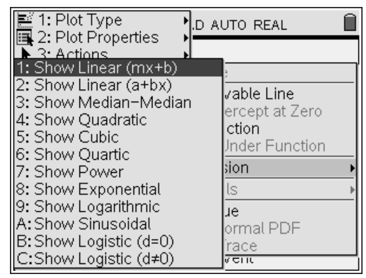
Q8. Explain why the magnitude of induced charge changes as you move the tape away from the can.

Q9. What mathematical function appears to best fit the data that describe the change of induced charge as the tape moves away from the can?

Step 6: Move to page 2.2, which contains a *Data & Statistics* application. Use this application to plot charge vs. distance for the data you collected.

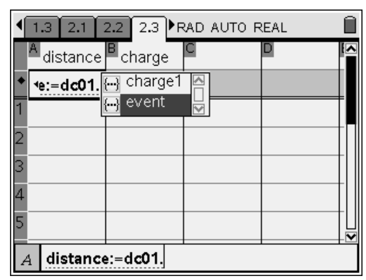


Step 7: Use the **Regression** tool (**Menu > Analyze > Regression**) to identify a best-fit line for the data you collected. Try several different types of regressions to determine which best fits the data. Identify the two functions that appear to fit the data best.

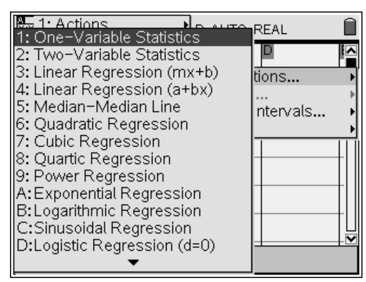


Q10. Which two functions appear to fit the data best?

Step 8: Move to page 2.3, which contains a *Lists & Spreadsheet* application. Assign the distance values you collected to column A (**distance**) by typing **=dc01.event** in the formula bar. Assign the charge values you collected to column B (**charge**) by typing **=dc01.charge1** in the formula bar.



Step 9: Highlight columns A and B and use the **Regression** tool (**Menu > Stat Calculations**) to calculate the two best-fit regressions you identified in step 7. Display the results of the regressions in separate columns on page 2.3.

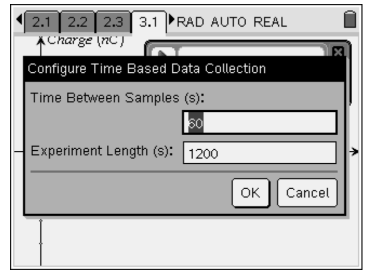


Q11. Based on the r^2 values for the two regressions, which one fits the data best? What is the best-fit equation for the data? Do both models make physical sense?

Problem 3: Process of charge leakage with time

Q12. What happens over time to the charge of an object that has been charged by rubbing?

Q13. How does humidity affect static electricity?



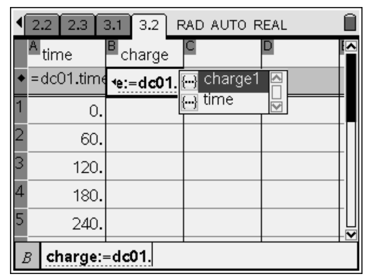
Step 1: Next, you will explore how the charge on the tape changes over time. To do this, you will need to collect time series data. Move to page 3.1, insert a new data collection box, and set up the data collection for a time graph (**Menu > Experiment > Set Up Collection > Time Graph**). Set the time between samples to 60 seconds and the experiment length to 1,200 seconds. Connect the sensor to the TI-Nspire.

Step 2: To collect data, first press Reset on the sensor. Then, charge one piece of tape positively, drop it into the can, and press the "play" button (►) on the data collection box. While the experiment is running, answer question 14.

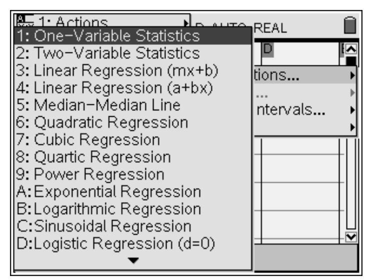
Q14. Predict how charge will change with time. What functional form do you think the data will have?

Step 3: After data are collected, close the data collection box and disconnect the sensor.

Q15. What mathematical function appears to best fit the data that describe the change of charge over time?



Step 4: Move to page 3.2, which contains a *Lists & Spreadsheet* application. Assign the time values you collected to column A (**time**) by typing **=dc01.time** in the formula bar. Assign the charge values you collected to column B (**charge**) by typing **=dc01.charge1** in the formula bar.



Step 5: Use the **Regression** tool (**Menu > Stat Calculations**) to carry out a regression on your data.

Step 6: Move back to page 3.1, change the graph to a function graph, and display the regression equation along with the scatter plot of the collected data.

Q16. Write the mathematical equation for the best-fit line for your data.

Q17. Do your results agree with the prediction you made in question 14? If not, identify any errors in reasoning that you made.