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INVESTIGATION 5: How does an object become charged?

Overview

In Investigation 4, students constructed a model of atomic structure based on historical evidence. In Investigation 5, students will build upon that model by using simulations to collect evidence related to how changing the composition of an atom affects its identity. In addition, they will use simulations to explore the forces involved in maintaining an atom's structure, and to consider how introduction to an electric field affects an atom's electron distribution. Students will extend their conceptual model of electrostatic interactions to include 1) electron transfer as the mechanism for how an object becomes charged and 2) shifting electron distribution to explain how neutral objects can be attracted to both positively and negatively charged objects. Students will revise their models of some phenomena from earlier investigations to incorporate mechanistic ideas that explain why some things stick together and others do not.

The Performance Expectations (NGSS)

HS-PS1-1. Use the periodic table as a model to predict the relative properties of elements based on the patterns of electrons in the outermost energy level of atoms.[1]

Elements from NGSS (NGSS Lead States, 2013, p. 249 - 250)	**Connections to this investigation**
Elements of Disciplinary Core Idea	
Elements of the core idea from the NGSS Performance Expectation	How this investigation builds toward the core ideas
Structure and Properties of Matter • Each atom has a charged substructure consisting of a nucleus, which is made of protons and neutrons, surrounded by electrons. • The periodic table orders elements horizontally by the number of protons in the atom's nucleus and places those with similar chemical properties in columns. The repeating patterns of this table reflect patterns of outer electron states.	This investigation describes the characteristics that identify different types of atoms (elements) and provides an introduction to the periodic table. It prepares students for future application of the periodic table as a model that can be used to predict properties of the elements.
Crosscutting concept	
Crosscutting concept from the NGSS Performance Expectation	How this investigation builds toward the crosscutting concept

[1] Gray text indicates aspects of a Performance Expectation that are not directly addressed in these materials.

Overview

Patterns • Different patterns may be observed at each of the scales at which a system is studied and can provide evidence for causality in explanations of phenomena.	Students will use the periodic table, which is organized by patterns in the properties of elements, as a model to make predictions about the relationship between atomic structure and the elemental identity of an atom.
Science and engineering practice	
Science and engineering practice from the NGSS Performance Expectation	How this investigation builds toward the science and engineering practice
Developing and Using Models • Modeling in 9–12 builds on K–8 and progresses to using, synthesizing, and developing models to predict and show relationships among variables between systems and their components in the natural and designed worlds. ○ Use a model to predict the relationships between systems or between components of a system.	Students use simulations and hands-on activities to collect data that provide evidence for the structure of atoms.

HS-PS1-3. Plan and conduct an investigation to gather evidence to compare the structure of substances at the bulk scale to infer the strength of electrical forces between particles.

Elements from NGSS (NGSS Lead States, 2013, p. 249 - 250)	**Connections to this investigation**
Elements of Disciplinary Core Idea	
Elements of the core idea from the NGSS Performance Expectation	How this investigation builds toward the core ideas
Structure and Properties of Matter • The structure and interactions of matter at the bulk scale are determined by electrical forces within and between atoms.	This investigation expands the model of atomic structure to include the identity of an element. Students will apply this model as they use electric forces between particles to explain electric interactions observed between bulk objects.
Crosscutting concept	
Crosscutting concept from the NGSS Performance Expectation	How this investigation builds toward the crosscutting concept

Patterns: • Different patterns may be observed at each of the scales at which a system is studied and can provide evidence for causality in explanations of phenomena.	Students will use their models to provide an explanation of the aspects of an object's underlying structure that change when the object becomes charged.
Science and engineering practice	
Science and engineering practice from the NGSS Performance Expectation	How this investigation builds toward the science and engineering practice
Planning and carrying out investigations • Planning and carrying out investigations in 9-12 builds on K-8 experiences and progresses to include investigations that provide evidence for and test conceptual, mathematical, physical, and empirical models. ○ Plan and conduct an investigation individually and collaboratively to produce data to serve as the basis for evidence, and in the design: decide on types, how much, and accuracy of data needed to produce reliable measurements and consider limitations on the precision of the data (e.g., number of trials, cost, risk, time), and refine the design accordingly.	Students use data collected during investigations and the exploration of simulations as evidence to support claims about how the distribution of electrons within an atom affects interactions. In addition, students use this data to revise their models for explaining electrostatic phenomena.

Target Model: ***What should the students' conceptual model include?***

Students' models of the structure of matter should include the following:

- *All materials are made of particles called* atoms, *which are too small to be seen with the unaided eye.*
- *Atoms have a dense, positively charged nucleus that consists of neutrons and protons surrounded by much smaller, negatively charged electrons. The nucleus takes up only a small fraction of the volume of an atom.*
- *Every element consists of a different type of atom; the identity of an element is determined by the number of protons in the nucleus of an atom of that element.*
- *An atom has an electric charge when it contains an unequal number of protons and electrons.*

Students' models of electrostatic interactions should include the following:

- *Opposite charges attract; like charges repel.*
- *The strength of the interaction between charged objects depends on the distance between them and the amount of charge on each object (a qualitative understanding of Coulomb's law).*
- *Neutral objects are attracted to both positively and negatively charged objects.*
- *There is more than one way to charge an object.*
    - *An object can be rubbed with another material.*
    - *Charge can be transferred to or from an object when it touches another object.*
- *Charge is due to electrons from atoms of one object transferring to atoms of another object.*

Activities

Activity 5.1: What is the effect of changing the composition of an atom?

SUMMARY

In Investigation 4, students found that atoms are the basic building blocks of all materials, and that they consist of three types of smaller particles: protons, neutrons, and electrons. This activity introduces students to the periodic table at a very basic level. Students will explore a simulation to establish that the number of protons determines the type of element, and that an unequal number of protons and electrons leads to a charged atom. The understanding of how atoms become charged (by transfer of electrons, through rubbing objects together) will be used when students construct explanations of how clothes become charged in the dryer. In future activities, students will connect charged atoms with explanations of macroscopic, observed phenomena.

LEARNING GOALS

- Students will use a simulation and the periodic table to identify the number of protons in any element.
    - Atoms of different elements have different numbers of protons; the number of protons identifies an atom as a particular element.

Disciplinary core idea	Crosscutting concept	Science and engineering practice
Structures and Properties of Matter: Each atom has a charged substructure consisting of a nucleus, which is made of protons and neutrons, surrounded by electrons. The periodic table orders elements horizontally by the number of protons in the atom's nucleus and places those with similar chemical properties in columns. The repeating patterns of this table reflect patterns of outer electron states. (NGSS Lead States, p. 92)	*Structure and function:* Students investigate systems by examining the properties of different materials, the structures of different components, and their interconnections to reveal a system's function and/or solve a problem. (NGSS Appendix G p. 87)	*Obtaining, evaluating, and communicating ideas:* Communicate scientific and/or technical information or ideas (e.g. about phenomena and/or the process of development and the design and performance of a proposed process or system) in multiple formats (i.e., orally, graphically, textually, mathematically). (NGSS Appendix F p. 65)

- Students will interpret information from a simulation and use their model of atomic structure to explain the effect of changing the composition of an atom.
    - The number of protons determines the type of atom and can affect its charge.
    - Changing the number of electrons changes the charge of an atom.
    - There may be different numbers of neutrons in the same type of atom. The number of neutrons does not affect the charge of an atom.

Disciplinary core idea	Crosscutting concept	Science and engineering practice
Structures and Properties of Matter: Each atom has a charged substructure consisting of a nucleus, which is made of protons and neutrons, surrounded by electrons. The periodic table orders elements horizontally by the number of protons in the atom's nucleus and places those with similar chemical properties in columns. The repeating patterns of this table reflect patterns of outer electron states. (NGSS Lead States, p. 92)	*Structure and function:* Students investigate systems by examining the properties of different materials, the structures of different components, and their interconnections to reveal a system's function and/or solve a problem. (NGSS Appendix G p. 87)	*Constructing explanations and designing solutions:* Construct and revise an explanation based on valid and reliable evidence obtained from a variety of sources (including students' own investigations, models, theories, simulations, peer review) and the assumption that theories and laws that describe the natural world operate today as they did in the past and will continue to do so in the future. (NGSS Appendix F p. 61)

- Students will use the mechanism of electron transfer to explain how atoms become charged.
  - Protons are not easily added to or removed from an atom, so their number does not change when an atom becomes charged.
  - Electrons can move relatively easily between atoms. Therefore, the movement of electrons from one atom to another is responsible for changing the charge of atoms.

Disciplinary core idea	Crosscutting concept	Science and engineering practice
Structures and Properties of Matter: Each atom has a charged substructure consisting of a nucleus, which is made of protons and neutrons, surrounded by electrons. The periodic table orders elements horizontally by the number of protons in the atom's nucleus and places those with similar chemical properties in columns. The repeating patterns of this table reflect patterns of outer electron states. (NGSS Lead States, p. 92)	*Structure and function:* Students investigate systems by examining the properties of different materials, the structures of different components, and their interconnections to reveal a system's function and/or solve a problem. (NGSS Appendix G p. 87)	*Constructing explanations and designing solutions:* Construct and revise an explanation based on valid and reliable evidence obtained from a variety of sources (including students' own investigations, models, theories, simulations, peer review) and the assumption that theories and laws that describe the natural world operate today as they did in the past and will continue to do so in the future. (NGSS Appendix F p. 61)

POINT FOR CONSIDERATION

In this investigation, the periodic table will only be used to help students understand how a limited number of elements make up all substances, and to illustrate that each element is defined by its number of protons. The arrangement of the elements and periodic trends will not be introduced at this point.

PREPARATION

Class Time: 60 min.

Materials

- Worksheet 1 for Activity 5.1: Organizing the Elements

Activity 5.1 - Teacher Preparation

BASIC OUTLINE OF ACTIVITY

Use this space to make notes to prepare for your lesson

1. Introduction
    a. Discussion to review ideas about atoms and their structure
    b. Worksheet 5.1 and class discussion: Periodic table
2. Difference between elements
    a. Atom builder simulation in conjunction with Worksheet 5.1
    b. Optional discussion and model exploration
    c. Optional periodic table game
3. How atoms become charged
    a. Atom builder simulation
    b. Questions about protons, electrons, neutrons, and charges
    c. Concluding the lesson

Activity 5.1 (Student materials): What is the effect of changing the composition of an atom?

Reviewing the Homework
Discuss the reading from Activity 4.4.
Possible questions:

- *What was some of the evidence that informed our understanding of atoms?*
- *How does the model of atoms keep changing?*
- *Do you think scientists have arrived at the final model of atomic structure or do you think this model is still changing? Why?*
- *How could the probability model help us answer our driving question: Why do some clothes stick together when taken out of the dryer? What about our other questions: How do materials get charged? and Why are neutral and charged objects attracted to each other?*

Introducing the Lesson
Have a discussion to review what students know about atoms and their structure from previous investigations and experiences.

Possible questions:

- *How many types of atoms do you think there are?*
- *What do you think is different about different types of atoms?*

Note: Since the ideas of elements and the periodic table are important for future learning, it is important to discuss the definition of an element and how to read the periodic table as a class, rather than only having students read the introduction on their own.

Page title:

Introduction

In the last investigation, you learned that the particles that make up substances are either individual atoms or molecules. Incredibly, only slightly more than 100 types of atoms make up all substances. A substance that is made of a single type of atom is called an *element*.

Since all atoms contain protons, neutrons, and electrons, what makes one element different from another?

Worksheet 1 for Activity 5.1 : Organizing the Elements

Discussion

Hand out Worksheet 1 for Activity 5.1: Organizing the Elements, and help students interpret the periodic table.

- Explain that each box in the periodic table contains a symbol that represents a particular element.
  - *Possible question: What is the element symbol for helium?*
- Point to an atomic number (without telling students it is called an *atomic number*) and ask, *What does this number tell you about the atoms of this element?*
  - Ask students to explore the simulation alongside the Worksheet handout to see if they can figure out the significance of the atomic number.
  - Ask them to answer the questions on the worksheet after working with the simulation.

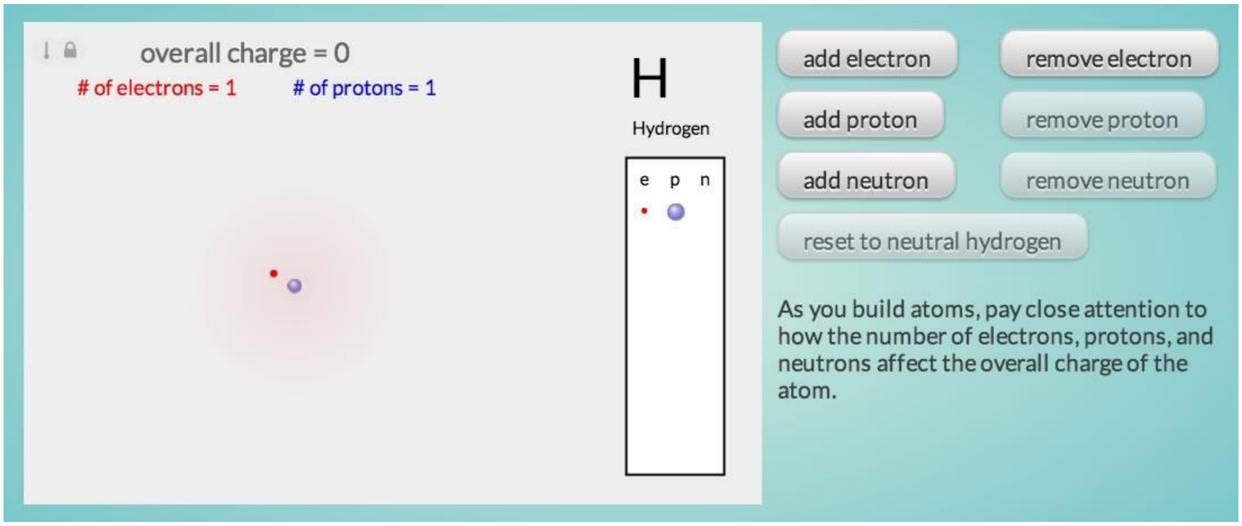
Note

Do ***NOT*** discuss the following ideas:

- Atomic weight (amu)
- Isotopes
- Electron configuration and its link to the organization of the periodic table
- Periodic trends
- Chemical properties leading to the organization of the periodic table

Page Title:
What makes one element different from another?

Explore the simulation of building atoms by changing the number of protons, electrons, and neutrons. Locate the elements you make on the Worksheet.



Simulation link: http://lab.concord.org/interactives.html#interactives/interactions/atom-builder.json

1. Explain what happens to an atom when the number of protons, neutrons, or electrons changes, while the number of the other two particles remains the same.

Student responses: In addition to answering the question, the goal here is for students to realize that they need to explore the simulation *systematically* in order to discover the answers, and then to recognize that this means altering one parameter at a time. You may need to use talk moves with students to elicit this behavior.

- If the number of electrons changes, the charge is different.
- If the number of protons changes, the charge is different and the identity of the atom is different.
- If the number of neutrons changes, nothing else changes.

2. Are there different ways to make an oxygen atom?

Student responses: Students may include only one alternative way to make an atom, but should also address the second part of the question.

- Yes. An oxygen atom can have different numbers of electrons and still be oxygen, so for example you could make oxygen with 7 electrons and it would still be oxygen. But making it have 7 protons changes it to Fluorine.
- Yes. If it had extra electrons it would have a negative charge, but still be oxygen. If it had extra protons it would change to another element.
- Yes, it could have extra neutrons, or fewer neutrons, but as long as it has eight protons it would still be oxygen.
- Yes. To change it to another element you would have to change the number of protons, so changing the number of electrons or neutrons would be another way to make oxygen.

3. What do you have to change in order to change the identify of an atom?

Student responses:

- To change it to another element you would have to change the number of protons, so changing the number of electrons or neutrons would be another way to make oxygen.
- Change the number of electrons.
    - *Ask them to return to the simulation and test out their ideas.*
- Change the number of neutrons.
    - *Ask students to return to the simulation and test out their ideas.*

4. Find oxygen on the periodic table on the Worksheet. Why do you think the 8 represents the number of protons and not the number of electrons or neutrons?

Student responses:

- Changing the number of protons makes it not oxygen anymore. Changing the number of electrons and neutrons doesn't matter. It's still oxygen.
- They just randomly chose protons.
    - *Ask students to return to the simulation and see if changing the electrons, protons or neutrons has different effects.*

Discussion and Model Exploration: Periodic Table

Lead a discussion to support students' use of the atom builder simulation and their understanding of the fundamentals of the periodic table.

Possible questions:

- *What are the combinations of protons, neutrons, and electrons that can make a helium atom?*
  - *What is the same about all of the combinations?*
- *What would you need to do to change the identity of an element?*
- *Find helium on the periodic table. What does the 2 above the element symbol, He, represent?*
- *Use the periodic table to determine the number of protons in carbon.*

Discuss their responses to the questions on the worksheet.

Make sure all students used the simulation and periodic table worksheet to understand the following:

- The number of protons identifies an element.
- The number above an element symbol (atomic number) represents the number of protons in each atom of that element.
- Therefore, if a proton could be added to or removed from any atom, that atom would become an atom of a different element.

Explain that scientists call the number above each element symbol an *atomic number*, and it represents the number of protons in each atom of that element.

As a class, look closely at the boxes in the periodic table and discuss them.

Possible questions:

- *How many protons are in a carbon (C) atom?*
- *If we had a special instrument to add or remove protons,*
  - *What would adding two protons do to a carbon (C) atom?*
  - *What would removing one proton do to a fluorine (F) atom?*

Optional Activity: Periodic Table Game

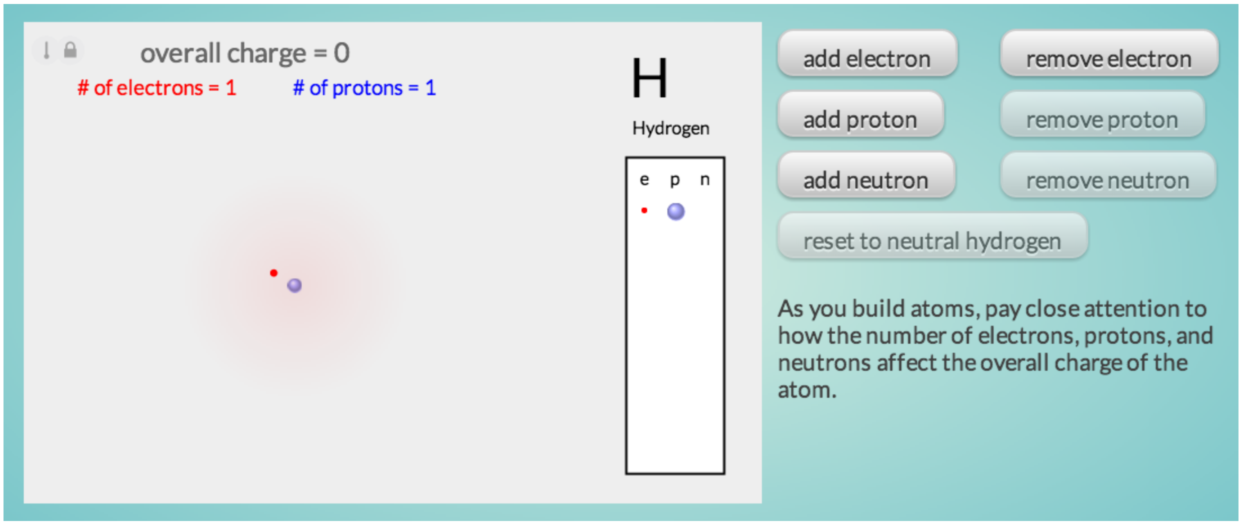
The class can play a periodic table game to reinforce understanding of how to read the periodic table. Groups can compete against each other to answer questions about the periodic table.

Possible questions:

- *What is the symbol for*
    - *nitrogen?*
    - *magnesium?*
    - *gold?*
- *Which element does the ______ represent?*
    - *Al*
    - *Na*
    - *Cu*
- *How many protons are there in*
    - *He?*
    - *C?*
    - *Cl?*
- *What element will the atom be if*
    - *a proton is added to a carbon nucleus?*
    - *a neutron is added to an oxygen nucleus?*
    - *an electron is added to a chlorine atom?*
    - *two protons are added to a neon nucleus?*
    - *an electron is removed from a lithium atom?*
    - *a neutron is removed from a fluorine nucleus?*

Note: Try to focus on the most common elements, which students may already be familiar with, so that students can connect terms they have already heard with new information from the periodic table.

Page title:
How do atoms become charged?



Simulation link: http://lab.concord.org/interactives.html#interactives/interactions/atom-builder.json
A charged atom has an unequal number of protons and electrons. Most atoms are neutral. How do neutral atoms become charged?

Use the simulation to help you answer the following questions.

Hint: *When you are using the simulation, build a neutral atom first. Then test various conditions to answer the question.*

5. **An atom that has an equal number of protons and electrons is:**

A. positively charged
B. negatively charged
C. neutral

Student responses:

- A. positively charged
    - *Ask students about the charge on a proton and on an electron.*
- B. negatively charged
    - *Ask students about the charge on a proton and on an electron.*
- **C. neutral**

6. An atom that has more protons than electrons is:

A. positively charged
B. negatively charged
C. neutral

Student responses:

- **A. positively charged**
- B. negatively charged
    - *Ask students what the charge on a proton is.*

7. An atom that has fewer protons than electrons is:

A. positively charged
B. negatively charged
C. neutral

Student responses:

- A. positively charged
    - *Ask students what the charge on an electron is.*
- **B. negatively charged**
- C. neutral
    - *Ask students how an atom becomes neutral.*

8. In real life, which is more likely to have caused a neutral atom to get a charge of +1?

A. A proton was added.
B. An electron was removed.
C. Either process equally likely to have happened.

Student responses:

- A. A proton was added.
    - *Ask students about the force holding the protons together in the nucleus. Or, ask students what happens if they add a proton to an atom.*
- **B. An electron was removed.**
- C. Either process could have happened just as easily.
    - *Ask students to compare the force holding the protons together in the nucleus with how electrons behave. Additionally, ask if they think the atoms change type when they are charged, what makes an atom change to a different type?*

9. In real life, which is more likely to have caused a neutral atom to get a charge of -1?

A. A proton was removed.
B. An electron was added.
C. Either process equally likely to have happened.

Student responses:

- A. A proton was removed.
  - *Ask students about the force holding the protons together in the nucleus. Or ask what happens if a proton is removed.*
- **B. An electron was added.**
- C. Either process could have happened just as easily.
  - *First, if they still aren't getting this right, do not kill yourself. Ask students to compare the force holding the protons together in the nucleus with how electrons behave.*

10. **What would happen to materials if they became charged by transferring protons?**

Student responses: Try to get students to extend their answers to include the atomic and the macroscopic levels.

- The identity of the atoms would change, which would change the material into something different.
- The atoms would become a different element.
  - *Ask students how that would play out in the material itself or "in the real world".*
- The material would become something else entirely.
  - *Ask students to explain why they think so.*

11. Explain the evidence that supports your claim about what causes a neutral atom to get a charge.

Student responses: Students should use the simulation to support their answer.

- In the simulation, if a proton is added or removed, a new atom is formed.
- Different atoms have different number of protons
  - *Ask students where they saw this pattern. Remind them that simulations are sources of data since they are models that allow us to explore relationships.*

Discussion

Return to the driving question for the unit, *Why do some clothes stick together when they come out of the dryer?* and the questions the class is working to answer in the next two activities:

- *How do objects become charged?*
- *What causes neutral objects and charged objects to interact with each other?*

Have students consider whether what they've learned about atomic structure so far helps them answer these questions. Ask students what additional questions they could explore in order to answer these questions.

Activity 5.2: How do objects become charged?

SUMMARY

In the previous activity, students learned that adding or removing electrons changes the charge of an atom. In this activity, as they further develop a mechanism for how things become charged, students will explore simple electrostatic phenomena from prior activities (rubbing rods with materials) to construct a model that includes electron transfer and conservation of charge.

LEARNING GOAL

- To explain how objects become charged, students will develop a more sophisticated model of atomic structure that includes electron transfer and conservation of charge. Students' models should include the following:
    - Electrons can transfer from one atom to another. The atom that loses one or more electrons becomes positively charged, and the atom that gains one or more electrons becomes negatively charged.
    - When two objects are rubbed against each other, electrons transfer between them. After being rubbed, if one object has an increase of electrons, then the number of electrons that object has gained will be the same as the number of electrons the other object has lost.
    - Charge is conserved. This means that the particles that have charge can be moved, but they cannot be created or destroyed.

Disciplinary core idea	Crosscutting concept	Science and engineering practice
Structures and Properties of Matter: Each atom has a charged substructure consisting of a nucleus, which is made of protons and neutrons, surrounded by electrons. The periodic table orders elements horizontally by the number of protons in the atom's nucleus and places those with similar chemical properties in columns. The repeating patterns of this table reflect patterns of outer electron states. (NGSS Lead States, p. 92)	*Structure and function:* Students investigate systems by examining the properties of different materials, the structures of different components, and their interconnections to reveal a system's function and/or solve a problem. (NGSS Appendix G p. 87)	*Analyzing and interpreting data:* Evaluate the impact of new data on a working explanation and/or model of a proposed process or system. (NGSS Appendix F p. 57)

POINT FOR CONSIDERATION

Because students know that a proton has a positive charge and an electron has a negative charge, they might believe that plus (+) and minus (-) signs associated with atoms or objects represent protons and electrons, not net charge.

Activity 5.2 - Teacher Preparation

PREPARATION

Class Time: 45 min.

Materials (for each group)

- teflon rod
- glass rod
- plastic bottle
- fur
- silk

BASIC OUTLINE OF ACTIVITY
Use this space to make notes to prepare for your lesson

1. Introduction
   a. Discuss the homework/reading

2. Investigate (patterns in data)
   a. Project and discuss data table
   b. Questions to identify and explain pattern
   c. Discussion - build consensus on the pattern

3. How do objects become charged?
   a. Questions to connect macroscopic and atomic levels
   b. Discussion - build consensus on mechanism (electron transfer)
   c. Conclude the lesson - apply to real life (class level multiple phenomena)

Activity 5.2 (Student materials): *How do objects become charged?*

Introducing the Lesson

Discuss how an atom becomes charged.

Possible questions:

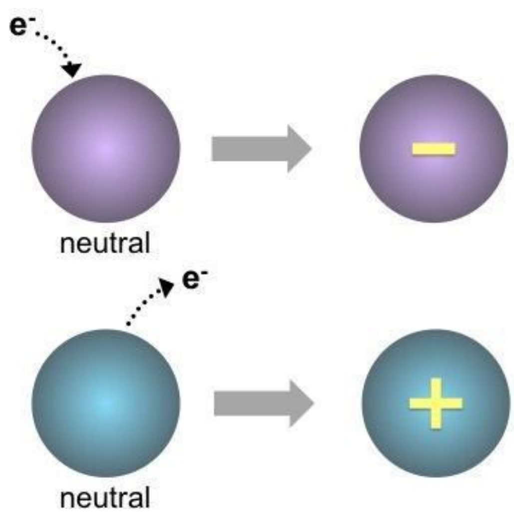
- *What effect does changing the number of electrons/protons/neutrons have on an atom?*
- *Which particles are easy/hard to remove and add? Why?*

To introduce the process of electron transfer, have students consider questions such as the following:

- *Where does the extra electron in a negatively charged atom come from?*
- *Where does an electron go when it is removed?*

Page title:
Introduction

In the last activity, you found that adding or removing electrons leads to an atom becoming negatively or positively charged. Where do these electrons come from, and where do they go?



Page title:
Investigate

In previous activities, you have established that objects are neutral unless you do something like rub them with fur to charge the objects. In Activity 1.4, you created one positively charged piece of tape and one negatively charged piece of tape, and determined the charge of each one. (Click on the sidebar to the right to see how to make the charged pieces of tape.)

Discussion
Return to the class data from Activity 1.4 when the class determined the charge of the T (top) and B (bottom) pieces of tape used throughout Investigation 1 to remind students of the objects being used as a reference.

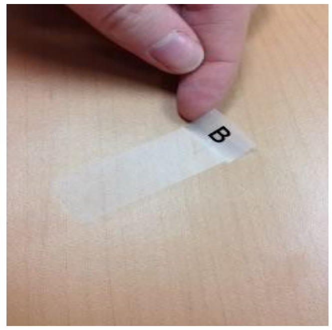
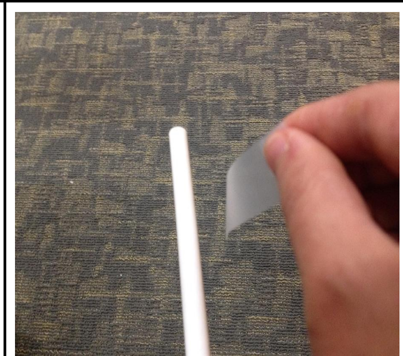
The data in the table below were collected using the positively and negatively charged pieces of tape to determine the charge of three pairs of objects.

- Test 1 (T1): a Teflon rod was rubbed with a piece of fur.
- Test 2 (T2): a glass rod was rubbed with a piece of silk.
- Test 3 (T3): a plastic bottle was rubbed with a piece of fur.
- Test 4 (T4): a plastic bottle was rubbed with a piece of silk.

Observations of the interaction between the pieces of tape and the objects after they were rubbed together are already entered in the table. Complete the table based on the data.

Object	interaction with positive tape before	interaction with negative tape before	charge before	interaction with positive tape after	interaction with negative tape after	charge after
T1- Teflon rod	attract	attract		attract	repel	
T1- fur	attract	attract		repel	attract	
T2- glass rod	attract	attract		repel	attract	
T2- silk	attract	attract		attract	repel	
T3- plastic bottle	attract	attract		attract	repel	
T3- fur	attract	attract		repel	attract	
T4- plastic bottle	attract	attract		attract	repel	
T4- silk	attract	attract		repel	attract	

Sidebar: Making the T and B Tape Strips

		
1. Get a strip of tape that is 1.5 to 2 inches long. Fold over one end of the tape as shown in the figure above. This will give you a non-sticky handle to hold the tape with.	2. Stick this piece of tape to the desk, and label the handle "B," for *bottom*.	3. Get a second strip of tape that is 1.5 to 2 inches long, and fold it in the same way. Place it directly on top of the first piece of tape, and label the handle "T," for *top*.
		
4. Using the handles, lift both pieces of tape off the desk at the same time. Then touch the entire length of the strip on both sides with your fingers several times. This will remove any electric charge on the surface of the tape.	5. Pull the pieces of tape apart, making sure to not touch the tape anywhere except on the non-sticky handles you made.	6. Both pieces of tape are now charged. Bring each piece of tape close to each object. **Tip:** *Try not to let the pieces of tape touch each other. If they do touch a little bit, they will lose some of their charge. So try to avoid it if possible.*

1. Take a snapshot of your completed table.

2. Review the data tables and look for a pattern in the charges of two objects after they were rubbed together. Describe the pattern.

Student responses: Make sure students go beyond identifying patterns for individual objects to focus on pairs of objects.

- The charges are always opposite: one is positive, and the other is negative.
- Fur is always positive.
    - *Ask how the charge on fur compares to the other objects. What is the charge of the object the fur rubbed?*

Discussion

Begin the discussion by exploring the phenomenon of neutrality as all of the objects start out neutral. Students may think that neutral means that no charges are present in an object, instead of seeing the object as composed of a balance of positive and negative particles.

Possible questions

- *What does it mean to say that an object is neutral?*
- *If an object is uncharged, does that mean it has no charges?*
- *Is there a difference between "uncharged" and "neutral"?*

Project the data table to the class and record class responses to fill out the table. Build a consensus of the patterns in the data:

- When two objects are rubbed together, If one becomes charged, the other will have the opposite charge.

Discuss how the data were obtained, supporting students in tracing the causal chain of events from rubbing an object to concluding whether it is positive or negative.

Possible questions:

- *What do you think is happening when two objects are rubbed together?*
- *Why do the objects end up with opposite charges no matter which two objects are rubbed together?*
    - *What does that say about the process of charging?*
    - *How do you think the objects become charged?*
- *Do you think electrons or protons transfer between the objects? Push for evidence from the last activity.*

3. **In the last investigation, you learned that all materials are made of atoms, and analyzed evidence that atoms contain positively charged protons and negatively charged electrons. If an object is neutral, what could you conclude about the charge of the atoms that make up that object?"**

Student answers:
- There must be an equal number of positively and negatively charged atoms in the object.
- All of the atoms are neutral.
  - *Ask students to consider the charge of an object by thinking about the number of positively and negatively charges in the object.*
- *There are the same number of electrons and protons.*
  - *Ask about what that might mean about the charge of the atoms?*

4. How could you change the overall charge of an atom without changing the atom's element?
a. Change the number of protons
b. Change the number of electrons
c. Change the number of neutrons

Student responses:
- A. change the number of protons
  - *Ask students to return to the simulation and observe what happens when protons are added or removed*
- **B. change the number of electrons**
- C. change the number of neutrons
  - *Ask students what charge neutrons have*

5. Use your understanding of the structure of atoms to explain what could make the fur become positive while the rod became negative when they are rubbed together.

Student answers:
- Electrons from the atoms that make up the fur moved to the atoms that make up the Teflon rod. So the fur is left with more protons than electrons, making it positive, and the rod now has more electrons than protons, making it negative
- Electrons moved.
  - *Push students to connect the changes at the atomic level to the macroscale.*

Discussion

As a class, build a consensus about the patterns in the data.

- Tabulate the data from rows 5 and 6 to share with the class.
- Encourage students to look at the collected data in terms of pairs of objects.
- Help students conclude that if one object becomes positively charged, then the other object becomes negatively charged.

Possible questions:

- *Why do you think each pair always has one positively charged object and one negatively charged object?*
- *What might be happening to account for this observation?*
- *Where do the electrons come from?*
- *Do protons or electrons move between objects? Explain why.*

Encourage students to support their ideas with evidence.

Page title:
How do objects become charged?

7. Do you think it is possible for two neutral objects to both become positively charged after they are rubbed together? Justify your answer.

Student answers:
- The positive charge has to result from losing electrons, because protons can't the transferred. So both cannot be positive.
- No, because the electrons move from one object to the other, so the charges must be opposite on the two objects.
- One object loses electrons to become positively charged, and the other object gains electrons to become negatively charged.

8. [drawing prompt] Choose one pair of objects from your data table. Imagine that you could zoom in and "see" the atoms they are made of. Draw a series of pictures that shows what you would see when one object becomes positively charged and the other object becomes negatively charged.

[text prompt] Label your drawings and explain what is happening at each step so that anyone can understand your drawings.

Student answers: In students' models, the objects should start out neutral, and electrons should move from one object to the other. If students include atoms in their models, some electrons from the atoms at the surface of one object should be transferred to the atoms at the surface of the other object. This results in the atoms of one object having an excess of electrons, so it becomes negatively charged. This also results in the atoms of the other object losing electrons, so that object becomes positively charged.
- *Students may make simple models with one proton and one electron, or just a nucleus in the middle with an electron surrounding it. Since this is a model that is representing electron transfer, there is no reason to draw an accurate model of the atoms contained in the substance.*

Discussion

Build a consensus model of electron transfer as the mechanism for how objects become charged. Share representative models with the class, perhaps one at the macroscopic level and one at the atomic level. Students should critique each other's models *based on evidence.*

Remind students that they should use evidence to evaluate their classmates' models.

The consensus model should include the following**:**

- When two neutral objects become charged due to being rubbed together, the result is always one positive and one negative object.
- Charge is conserved, so it cannot be created or destroyed. (Matter is conserved, so electrons and protons cannot be created or destroyed.)
- Electrons, not protons, move between objects.
- When charging by rubbing or contact, electrons come from atoms that make up the objects, not from the air.

Concluding the Lesson

Have students apply the consensus model to a real-life phenomenon, such as one of the following:

- clothes becoming charged in a dryer and sticking together
- hair sticking out after brushing or combing

Have students brainstorm what happens at the atomic level to cause the phenomenon to occur.

Activity 5.3: What causes neutral objects and charged objects to interact with each other?

SUMMARY

In Investigation 1, students observed that neutral objects and charged objects (both positive and negative) can attract each other. However, they could not explain why this happens. In this activity, students will use two simulations to explore how introducing atoms to an electric field can help explain the attraction between neutral and charged objects. They will apply their observations of what happens at the atomic level to explain why a balloon can stick to a wall.

LEARNING GOALS

Students will create models that incorporate atomic structure and electric fields to explain how neutral objects and charged objects (both positive and negative) can attract each other. Students' models should include the following:

- The electron distribution within an atom can shift in the presence of an electric field to create a separation of charge in which one end of an atom becomes slightly positively charged and the other becomes slightly negatively charged.
- Neutral objects contain an equal number of positive and negative charges; charged objects contain an unequal number of positive and negative charges.

Disciplinary core idea	Crosscutting concept	Science and engineering practice
Structures and Properties of Matter: Each atom has a charged substructure consisting of a nucleus, which is made of protons and neutrons, surrounded by electrons. The structure and interactions of matter at the bulk scale are determined by electrical forces within and between atoms (NGSS Lead States, p. 92)	*Cause and effect:* [Students] suggest cause and effect relationships to explain and predict behaviors in complex natural and designed systems. They also propose causal relationships by examining what is known about smaller-scale mechanisms within the system. They recognize changes in systems may have various causes that may not have equal effects. (NGSS Appendix G p. 83)	*Developing and using models:* Develop, revise, and/or use a model based on evidence to illustrate and/or predict the relationships between systems or between components of a system. (NGSS Appendix F p. 53)

POINT FOR CONSIDERATION

Interactions between neutral and charged objects are complex. There are several cause-and-effect relationships, so it may be difficult for students to grasp some of the ideas. Allowing students to talk through their thinking will help.

Activity 5.3 - Teacher Preparation

PREPARATION

Class Time: 60 min.

Materials

- balloon
- fur

BASIC OUTLINE OF ACTIVITY

Use this space to make notes to prepare for your lesson

1. How does a balloon stick to the wall without glue or tape?
    a. Discussion and revisit attraction between neutral and charged objects
    b. Questions
2. Interaction between a neutral atom and charged object
    a. Simulation: atom in an electric field
    b. Questions
3. Connecting observed phenomena to atoms
    a. Simulation: balloon and wall
    b. Questions and model
    c. Discussion - use evidence from the simulation

Activity 5.3 (Student materials): *What causes neutral objects and charged objects to interact with each other?*

Introducing the Lesson

Return to the DQ board, the driving question for the unit, and the other questions that students have raised. In the previous activity, the class answered the question, *How do objects become charged?* In this activity, they will work to answer the question, *What causes neutral objects and charged objects to interact with each other?*

Review the following phenomena from Investigation 1:

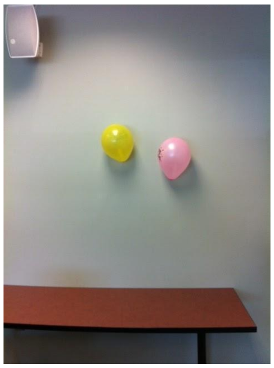
- Small pieces of paper "jumped" to a charged plastic bottle; a charged plastic bottle rolled toward a hand even though it was not touched.
- Charged rods and a variety of materials and objects were attracted and repelled.

Possible questions:

- *What observations have we made between neutral objects and charged objects?*
- *Have we developed any ideas that might help us explain this interaction?*
- *What do we still need to figure out to understand our observations?*

Page title:
How does a balloon stick to the wall without glue or tape?

In Investigation 1, you found that neutral and positively charged objects are attracted to each other, and that neutral and negatively charged objects are attracted to each other. In this activity, you will find out why this happens.



1. After a balloon is charged by being rubbed, it sticks to the wall. What do you think is happening to the wall where the balloon touches it?

Student responses: The goal in asking this question is to explore what students think. They are not expected to provide the “correct” answer at this point.

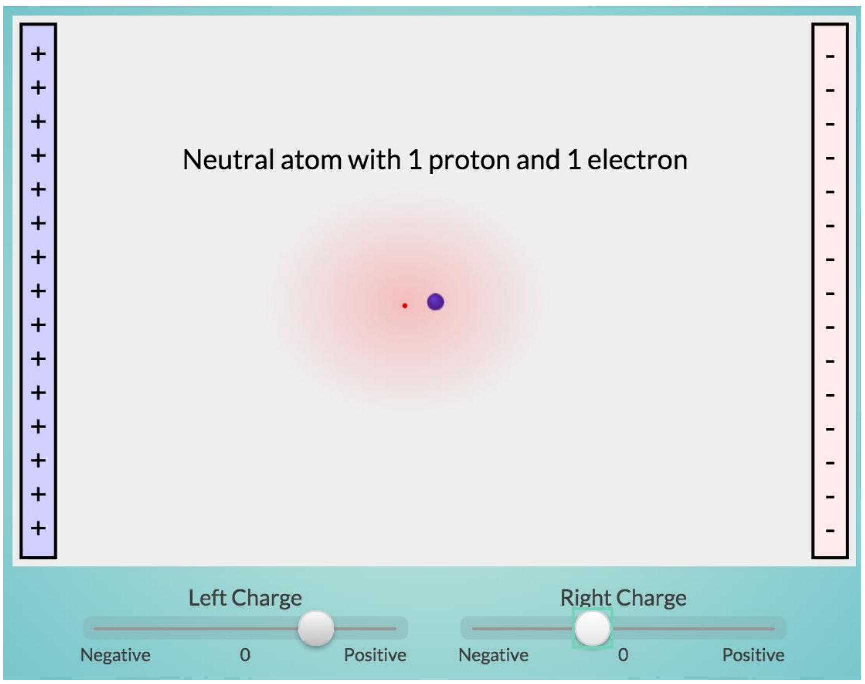
Page title:

Interaction between a neutral atom and charged object

Note: In the previous activity students saw that the structure of nucleus consists of positively charged protons and neutral neutrons. Depending on the identity of the atoms, their nuclei can have different number of protons and neutrons. For example, the simulation below uses a hydrogen atom that contains one proton and one electron. Most hydrogen atoms have no neutrons.

Investigate

Use the simulation to explore how the electric field of a charged object affects an atom.



Simulation link: http://lab.concord.org/interactives.html#interactives/interactions/deformedCloud.json

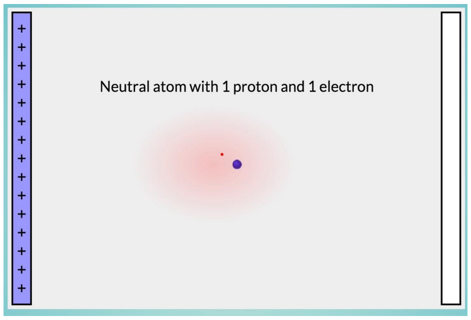
Use your observations of the simulation, as well as your models of atomic structure and electric forces, to answer the next two questions.

2. [snapshot prompt] Take a snapshot that shows what happens when a neutral atom interacts with a positively charged object.

[text prompt] Explain what happens to the atom.

Student responses:

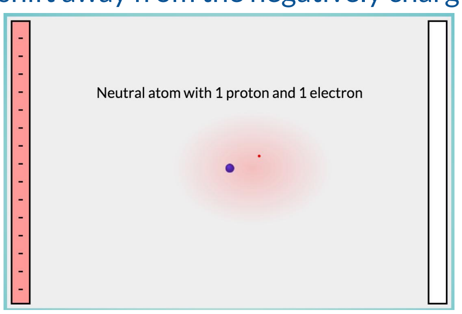
- The positive electric field causes the area where you are likely to find an electron to shift toward the positively charged plate.



3. [snapshot prompt] Take a snapshot that shows what happens when a neutral atom interacts with a negatively charged object.
[text prompt] Explain what happens to the atom.

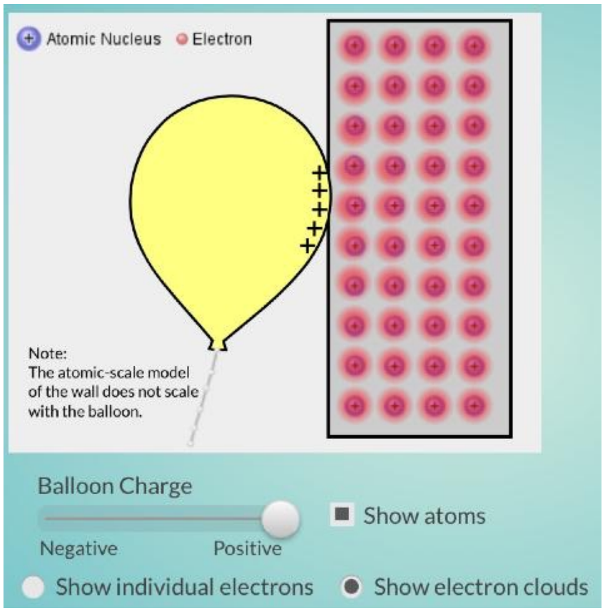
Student responses:

- The negative electric field causes the area where you are likely to find an electron to shift away from the negatively charged plate.



Page title:
Connecting observed phenomena to atoms

Use the simulation to explore what happens to the atoms that make up a wall when a charged balloon sticks to it.



Simulation link: http://lab.concord.org/interactives.html#interactives/interactions/balloonModelElectrons.json

4. [snapshot prompt] Take a snapshot of a negative balloon interacting with the wall.

[text prompt] Explain why the negatively charged balloon is attracted to the neutral wall.

Student responses:

- The negatively charged balloon repels the electrons around the atoms in the surface of wall, slightly exposing the positive nuclei in those atoms. Because opposites attract, the negative balloon and the positive nuclei of the atoms in the wall are now attracted to each other.

5. Take a snapshot of a positive balloon interacting with the wall.

[text prompt] Explain why the positively charged balloon is *also* attracted to the neutral wall.

Student responses:

- The positively charged balloon attracts the electrons around the atoms in the surface of wall, pulling them closer to the wall's surface. This causes the surface of the wall to be slightly negative. Opposites attract, so the positive balloon and the negative electrons of the atoms in the surface of the wall are now attracted to each other. Regardless of its charge, the balloon can be attracted to oppositely charged parts of atoms in the wall.

6. [drawing prompt] Draw a model that explains why both positively and negatively charged pieces of tape stick to the wall (on the non-sticky side of the tape).

[text prompt] Explain your model.

Student responses: The wall and a positively/negatively charged piece of tape are attracted to each other because the electric field around the charged tape causes the electrons of the atoms that make up the part of the wall nearest the tape to shift.

When positively charged tape is used, the electrons of the atoms that make up the part of the wall nearest the tape shift toward the positively charged tape. The positively charged tape and the negatively charged part of the wall are attracted to each other.

When negatively charged tape is used, the electrons of the atoms that make up the part of the wall nearest the tape shift away from the negatively charged tape, providing greater exposure to the positive nucleus. The negatively charged tape and the positively charged part of the wall are attracted to each other.

Note: Students may use a very simple model of an atom in these diagrams (for example, an atom that is made of just one proton and one electron). Since models are always simplifications, this is appropriate as it makes a complex relationship simple enough to be observed.

Note: The snapshot that students provide can be from either the electron cloud version or the particle version of the simulation.

However, make sure that students go through both the electron cloud version and the particle version.

Discussion
Have students use evidence from the simulation to explain what happens to the atoms that make up the wall when the balloon is brought close to it.

Possible questions:

- *Why does the balloon stick to the wall?*
  - *Does anyone have something to add to that?*
  - *What happens to the atoms on the surface of the wall?*
  - *Are there other possible explanations?*
- *What causes the changes to happen?*
  - *Do the changes happen to all of the atoms in the wall? Why or why not?*
  -

Return to the driving question for the unit: *Why do some clothes stick together when they come out of the dryer?* As a class, discuss how the ideas that students have incorporated into their models of atomic structure and electrostatic interactions can help them answer the question.

Return to other class questions students posed throughout this unit, and see if their models can help them answer those questions.

Post the final consensus model on the DQ board.

Activity 5.4: Revising our models of charge interactions

SUMMARY

In this activity, students will revisit some phenomena that they observed in previous investigations (aluminum pie pans flying off the Van de Graaff generator and Franklin's bells). Students will revise their previous models of these phenomena using their more sophisticated models of atomic structure and electrostatic interactions.

LEARNING GOAL

Students will apply their models of atomic structure and electrostatic interactions to provide a causal mechanism for explaining various electrostatic phenomena.

- Students' models of electrostatic interactions should include electrons transferring between objects, attraction between charged and neutral objects, and repulsion of like-charged objects.
- Students' models of atomic structure should include an electron cloud of electron density. (They will refer to the electron clouds as a region of high probability for finding an electron.)

Disciplinary core idea	**Crosscutting concept**	**Science and engineering practice**
Structures and Properties of Matter: Each atom has a charged substructure consisting of a nucleus, which is made of protons and neutrons, surrounded by electrons. The structure and interactions of matter at the bulk scale are determined by electrical forces within and between atoms (NGSS Lead States, p. 92)	*Cause and effect:* [Students] suggest cause and effect relationships to explain and predict behaviors in complex natural and designed systems. They also propose causal relationships by examining what is known about smaller-scale mechanisms within the system. They recognize changes in systems may have various causes that may not have equal effects. (NGSS Appendix G p. 83)	*Developing and using models:* Develop, revise, and/or use a model based on evidence to illustrate and/or predict the relationships between systems or between components of a system. (NGSS Appendix F p. 53)

POINTS FOR CONSIDERATION

- Students often have difficulty connecting macroscopic, observed phenomena with ideas at the atomic/molecular level. Be sure to encourage them to add atomic-level components to their former descriptions of charged objects. In addition, their models should be moving more toward an underlying causal account—a step-by-step process that shows what happens to explain a phenomenon.
- Students will not have direct evidence on which to base their ideas. Rather, they must form plausible explanations by applying models they have developed. Their models need to be consistent with the evidence they have and the principles they know. This is difficult,

and students may want some reassurance that their ideas are valid. If students ask whether one of their ideas is correct, respond by asking whether the idea is supported by evidence, and whether the idea accounts for all the evidence (i.e., explains the various phenomena).

PREPARATION

Class Time: 60 min.

Materials
(It is not mandatory to prepare the following materials because they are for optional demonstrations.)

- Van de Graaff generator with aluminum pie pans
- Van de Graaff generator with Franklin's bells

HOMEWORK

Worksheet for Activity 5.4: Controlling Electric Charge

Activity 5.4 - Teacher Preparation

BASIC OUTLINE OF ACTIVITY

Use this space to make notes to prepare for your lesson

1. Revising Pie Pan Models
   a. Introduction - videos
   b. Questions - review/revise model
   c. Discussion - compare and contrast student models, build consensus
2. Revising Franklin's Bells Model
   a. Optional activity - acting out Franklin's bells
   b. Questions - draw step-by-step model
   c. Discussion and revise models
   d. Questions - returning to the Unit Driving Question
   e. Discussion - conclude Unit 1

Activity 5.4 (Student materials): *Revising our models of charge interactions*

Introducing the Lesson

In this activity, students will apply ideas they have learned throughout the unit. In previous investigations, they created models to explain the aluminum pie pan demo and the Franklin's bells apparatus. Now they will return to those models to add information about atomic structure.

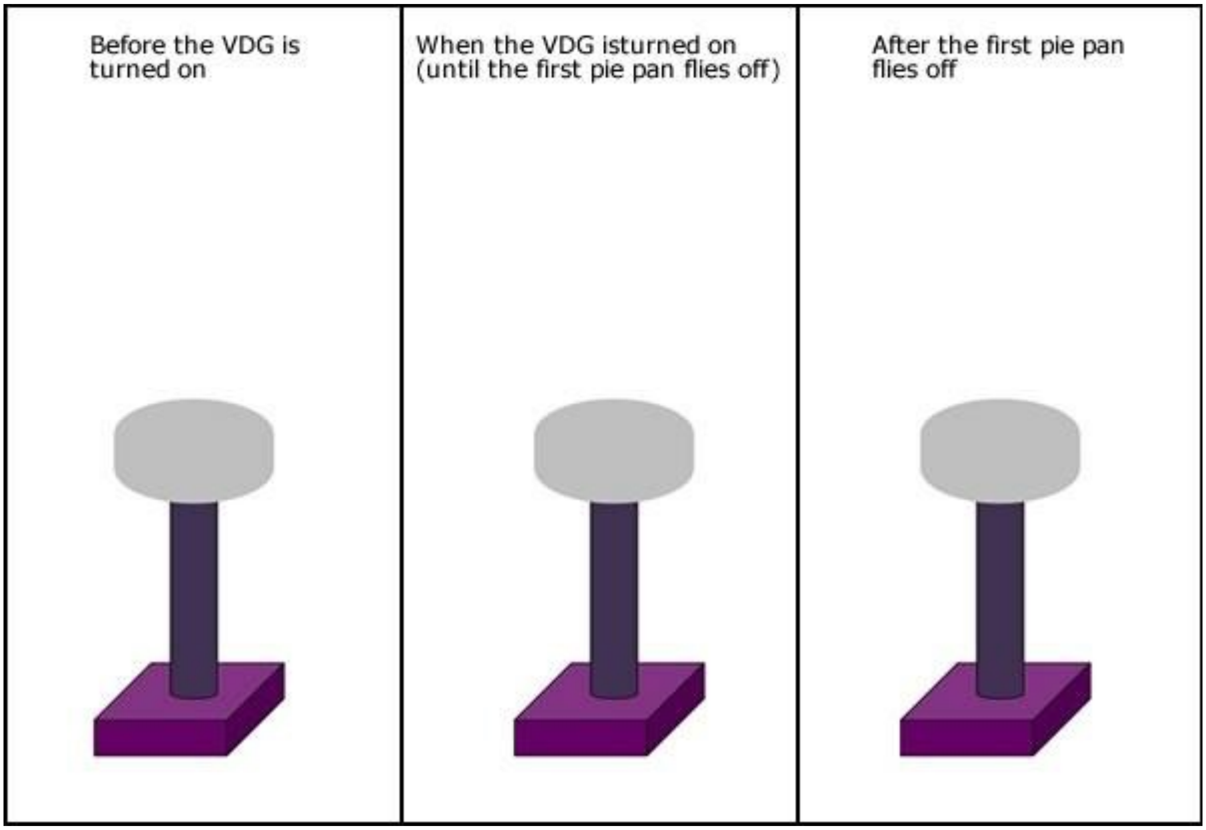
Remind students that they have developed models to explain these phenomena, and discuss why they need to come back to their models. For each phenomenon, have them brainstorm ideas about how they can provide a better explanation of what was happening that made the phenomenon occur.

Page title:
Revising pie pan models

Your teacher will show you videos of two phenomena that you have already observed and created models to explain. You will now revise those models using what you have learned about atomic structure and its role in the attraction, repulsion, and charging of objects.

1. [drawing prompt] Review your model of the pie pans and Van de Graaff generator from Investigation 1, and revise it by adding ideas that you have learned since then. Create a series of drawings that show why the pie pans behaved the way they did. Be sure your new drawings include some atomic-level details.
[text prompt] Explain your model.

If you want to see the demonstration again, click on the following link: Pie pan demonstration.



Student responses: Students models should show electrons being transferred between the VDG and pie pans, and between multiple pie pans. They should indicate attraction between charged and neutral objects as well as repulsion between like-charged objects. Keep in mind the three aspects of models: components, relationships, and connections to phenomena.

Discussion
Select a few students' models to post (representing the range of students' ideas). Have the class compare and contrast the different models. Ask students to choose aspects of each model that they agree with and disagree with using ideas, information, and evidence explored in the unit.

Have the class build a consensus model that best accounts for all the evidence. Make sure students can support the consensus model with evidence. The student model should now present a more causal explanation of the phenomenon.

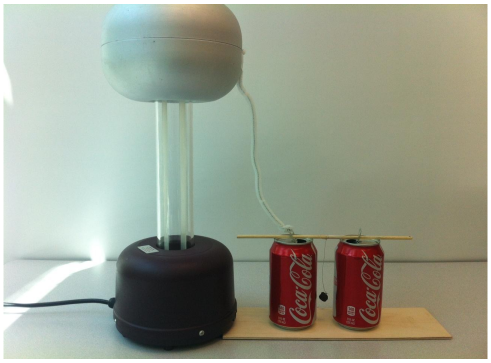
In addition, select two students' models, and compare their initial models (at the beginning of Inv. 1) with their revised versions (from the end of Inv. 1 and Inv. 4) and their current models. Discuss how their models have changed.

Possible questions:

- *Which models do you think best explain this phenomenon?*
- *Do the models present a causal mechanism to explain the phenomenon (i.e., a step-by-step process showing how the phenomenon occurred)?*
- *Are the models consistent with the evidence and information we have?*
- *Is there anything missing from this model that you would add?*
- *How would you change this model?*

Page title:
Revising Franklin's bells models

Watch the Franklin's bells demo that your teacher shows.



If you want to see the demonstration again, click on the following link: [Ringing "bells](#)" demonstration.

Optional Activity: Acting out Franklin's Bells

In this activity, students play the roles of pieces of the Franklin's Bells apparatus, while the teacher acts as the electrical outlet, handing out paper "electrons" to the van de Graaff (VDG) student. Students think through each step as electrons are passed along, and then back and forth, in order to grapple with this complex phenomenon in a step-by-step fashion.

To prepare:

- Cut several sheets of red and blue paper into 8 pieces each. Label them positive (blue) and negative (red) to match the color coding in the Interactions simulations. These will be the charges.
- Ask for four student volunteers. They will take on the roles of the two cans, the pith ball, and the VDG. You will act as the outlet.
- Have the volunteers "assemble" themselves into a Franklin's Bells apparatus at rest.

When assembled, but before "connecting to the outlet":

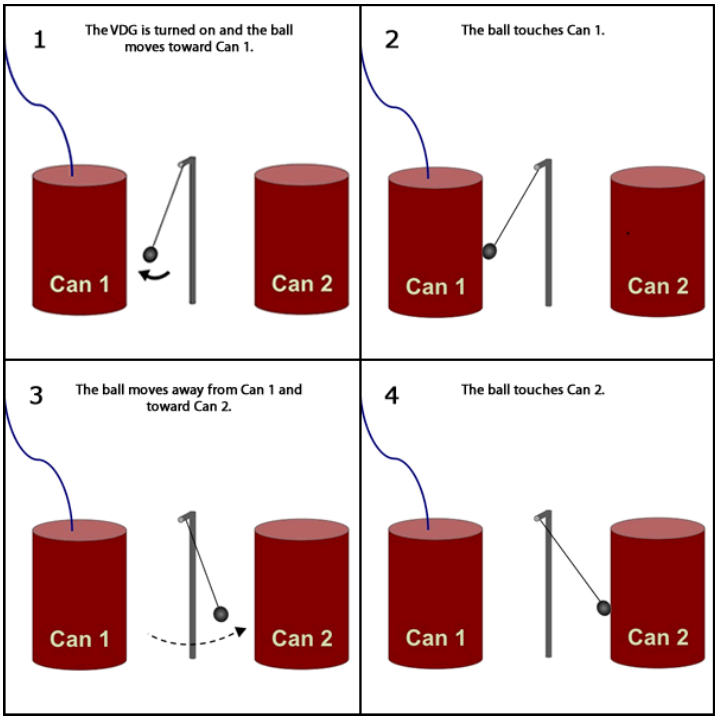
- Ask the class what charge each of the four parts of the apparatus (students) has before the VDG is turned on (neutral) and what it means (equal numbers of positive and negative charges.)
- Give each volunteer an equal number of red and blue paper charges to represent their neutral charge.
- Ask what happens when the VDG is plugged in. Treat the VDG as negative; the students should come to a consensus that electrons from the outlet move to the VDG.

Connect to the "outlet":

- Acting as the outlet, give a negative (red) paper (electron) to the student who is portraying the VDG.
- Ask the students what is going to happen next, and then have the students act out their answer(s) using their pieces of paper (charges).
    - Positive charges should be held close to the body since protons are stationary in the nucleus.
    - Negative charges can be held out toward or away from another object and/or passed on to another student, since electrons move and can be transferred.
    - When they receive a paper "electron" students should move in accordance with the resulting attraction and/or repulsion. When they bump into each other, they must pass an electron over to the student they bumped into.
    - Throughout this, acting as the outlet, continue handing more electrons to the VDG to keep the process running.
    - Continue until the class reaches a consensus that the motions of the students are mimicking the motions of the Franklin's Bells apparatus, and the motions of the electrons are logically causing the phenomenon.

2. [drawing prompt] Create a series of drawings that provide a step-by-step explanation of how the Franklin's bells device works. Include what you have learned about electric interactions and atomic structure in this unit.

[text prompt] Use your model to explain why the ball moves back and forth between the cans.



Student responses: Student models and explanations should include the transfer of electrons from the VDG to the first can, and then to the pith ball. When the electrons are transferred, they should indicate a repulsion between objects and the consequent movement of the ball. When the ball strikes the second can, again electrons should be shown transferring to it, and the resulting repulsion. Students should also indicate the repetitive nature of the transfer causing the phenomenon, with the electrons being continuously supplied by the VDG.

Discussion
Discuss what is happening at each point in the Franklin's bells demo. Then have students revise their previous model of this phenomenon to include their current model of atomic structure.

Possible questions:
- *How is the can that is attached to the Van de Graaff generator charged?*
- *When the VDG is turned on, why does the pith ball move toward the can attached to the VDG? Encourage students to include the ideas of charge and subatomic particles in their explanations.*
- *What happens when the pith ball touches a can? What can you conclude from that?*
- *Does your new model provide a causal mechanism to explain the phenomenon?*

3. Now let's return to the beginning of the unit. We started the unit by asking, *Why do some clothes stick together when they come out of the dryer?* Write a complete scientific explanation that answers this question. Be sure to include a claim, evidence, and reasoning in your answer.

Student responses: Make sure students include all aspects of the answer. In the example below, the claim, reasoning, and evidence are separated. However, students should eventually be writing one paragraph that includes all these ideas.
- Claim: Electric forces cause some of the clothes to be attracted to each other.
- Evidence: When clothes come out of the dryer, they stick together. If you pull them apart, sometimes you can hear or see sparks.
- Reasoning: Everything is made of atoms, which are themselves made of charged particles. When you rub materials together, they can exchange electrons. When clothes are put in a dryer, they rub together, so they exchange electrons. When some pieces of clothing gain electrons, they become negative, while other pieces of clothing lose electrons and become positive. Because opposites attract, the pieces of oppositely charged clothing are attracted to each other and stick together.

Concluding the Lesson
Return to the DQ board. Discuss the progress students made toward answering the unit-level driving question, and the information and evidence they gathered to help them answer it.
- Have students' share their responses to the unit-level driving question, *Why do some clothes stick together when they come out of the dryer?*
- Have students use the atomic model they developed to discuss the "rules" of interactions between charged and neutral objects.

Homework:

- Worksheet for Activity 5.4: Controlling electric charge