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INVESTIGATION 4 - What are nature's building blocks?

Overview

This investigation builds on the particle model of matter by identifying the particles that make up all substances as either individual atoms or groups of atoms held tightly together (molecules). To answer the question of how objects become charged, students need a model of atoms that includes electrons and protons. The investigation follows the historical development of models of atomic structure. Based on evidence collected through the exploration of simulations of the experiments scientists used to further understand aspects of the atomic model, students develop their own models of atomic structure. In addition, students gain an understanding of the relative size of atoms as compared with other small objects, and they learn how indirect evidence can be used to study phenomena that cannot be directly observed. In later investigations, students will apply the model of atomic structure to explain how materials become charged through electron transfer and polarization.

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]

Note: The gray coloring indicates that this investigation helps build toward this performance expectation, but does not directly address it. See below for a detailed explanation.

Elements of the NGSS (NGSS Lead States, 2013 p. 92 - 93)	**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 provides an introduction to atomic structure. 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	

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

Overview

Crosscutting concept from the NGSS Performance Expectation	How this investigation builds toward the performance expectation
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.	The periodic table is a model organized by patterns in the properties of the elements and therefore atomic structure. The investigation does not get into the organization of the periodic table. However, students are analyzing evidence that they use to develop their own model of atomic structure. Students will need to identify patterns in this data. Additionally, after students have a model of atomic structure, they can identify patterns in properties of elements and relate them to patterns in atomic structure in later classes.
Science and Engineering Practice	
Scientific practice from the NGSS Performance Expectation	How this investigation builds toward the performance expectation
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 of historical experiments to collect data that provides evidence for the structure of atoms. Students use data collected during investigations and using simulations as evidence to support claims about the structure and composition 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 of the NGSS (NGSS Lead States, 2013 p. 92 - 93)	**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

Overview

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 provides an introduction to atomic structure that includes protons and electrons. In later investigations, students will apply this model to explain electrical forces that occur between objects. This model prepares students for using the concept of electrical forces between particles to explain the properties of bulk substances, which is the focus of Unit 3.
Crosscutting Concept	
Crosscutting concept from the NGSS Performance Expectation	How this investigation builds toward the performance expectation
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 analyze several sources of data to identify patterns and develop models of atomic structure that can explain observations. Additionally, this investigation includes several activities that relate to the crosscutting concept: scale, proportion, and quantity. Students gain an understanding of the relative size of atoms and other small, important scientific objects (e.g., red blood cell, virus).
Science and Engineering Practice	
Scientific practice from the NGSS Performance Expectation	How this investigation builds toward the performance expectation

Overview

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 from simulations as evidence to support claims about the structure and composition of atoms. Students also engage in the practice of developing and using models as they use the evidence from simulations to revise and develop their models of atomic structure. Students then use these models to explain observations.

Objective: Target Model

What should the students' conceptual model include?

- *All materials are made of particles that are too small to be seen.*
- *These particles are called* atoms.
- *Atoms have a dense, positively charged nucleus that consists of neutrons and protons; the nucleus is surrounded by much smaller, negatively charged electrons.*
- *Electrons can be modeled as a "cloud" surrounding the nucleus and are best represented in terms of probability maps.*

It is important to stress that in addition to providing a description of a phenomenon, models can also represent what causes a phenomenon to happen. The ability to connect the sub-microscopic structure of matter to observable phenomena is an important part of understanding the underlying mechanisms of the behavior of matter.

Background Knowledge

In 1911, Ernest Rutherford performed an experiment that involved firing positively charged alpha particles (helium nuclei) at a thin sheet of gold foil. Unexpectedly, he observed that some of the alpha particles were deflected, indicating an intense electric field caused by very concentrated positive charge. At the time, the prevailing model of atomic structure was the plum pudding model, which described electrons as being suspended in a diffuse, uniform positive charge. Rutherford's results were inconsistent with this model. The observed deflection of positively charged particles could only result from a small, dense, positive charge with a strong electric field. Based on Rutherford's results, the model of atomic structure was revised to include an extremely dense, positively charged center surrounded by electrons. In this model, most of the volume of the atom has a very low density.

Activities

Activity 4.1	*What are the particles that make up all substances, and how small are they?*	*45 min.*
Activity 4.2	*If you can't see it, how do you know it's there?*	*120 min.*
Activity 4.3	*How do we know what's inside an atom?*	*90 min.*
Activity 4.4	*Where are the electrons?*	*45 min.*

Activity 4.1: What are the particles that make up all substances, and how small are they?

SUMMARY

Investigation 3 provided evidence that materials are made of tiny particles. This activity defines those particles as *atoms* or *molecules* (groups of atoms). Students will explore the relative sizes of important scientific objects (e.g., cells and atoms) and learn how to communicate and describe small sizes. In the following activity, students will learn how indirect evidence can be used to study things that cannot be directly observed, linking this to the study of atoms, which are too small to be seen with optical microscopes.

LEARNING GOAL

- Students will describe in a qualitative or semi-quantitative way the relative size of atoms by using macroscopic objects to represent microscopic ones.

Disciplinary Core Idea	Crosscutting Concept	Scientific and Engineering Practice
Structure and properties of Matter: The structure and interactions of matter at the bulk scale are determined by electrical forces within and between atoms. (NGSS Lead States, p. 92)	*Scale, Proportion, and Quantity:* Some systems can only be studied indirectly as they are too small, to large, too fast, or too slow to observe directly. Students use orders of magnitude to understand how a model at one scale relates to a model at another scale. (NGSS Appendix G p. 84)	*Obtaining, Evaluating, and Communicating Information:* Compare, integrate and evaluate sources of information presented in different media or formats (e.g., visually, quantitatively) as well as in words in order to address a scientific question or solve a problem. (NGSS Appendix F p. 65)

POINTS FOR CONSIDERATION

- In this activity, students draw their initial models of the atom. Make sure *not* to correct their drawings at this point. They will learn about the structure of atoms throughout this investigation.
- Although scientific notation and metric units are *not* included in the above learning goals, this activity does provide a context that makes both of these topics relevant. Thus, this may be a good opportunity to introduce these topics or to give students practice with them. Optional supports for learning about these topics are provided.
- Students often use the terms *particle*, *atom*, and *molecule* interchangeably when they first develop a particle model of matter. That is fine now, but by the end of the investigation, students should be able to definitively identify atoms.
- Students often struggle to comprehend the sizes of objects that are outside their daily frame of reference (both small and large).
- Learners tend to underestimate the magnitude of the range of sizes outside their daily experience—both small (micro and atomic scales) and large (planetary and astronomical scales). For example, students often underestimate the difference in size between atoms and cells, believing they are close in size.

Activity 4.1 - Teacher Preparation

PREPARATION

Class Time: 45 min.

Materials

- For optional activity, “Understanding Size by Using Representative Objects”: (for each group)
    - piece of PVC pipe (~10 cm diameter)
    - cinnamon red hot candy
    - long-grain rice (~1 mm in diameter)
- For main activity:
    - meter stick
    - 2.5 cm (1 in.) diameter wood rod
    - beach ball (~1 m in diameter)
    - measuring tape (60 meters)

Activity Setup

- For optional activity, “Understanding Size by Using Representative Objects”:
    - Print out the student worksheet - Understanding Size by Using Representative Objects. (Student version starts on page 4)
    - Put together a materials kit for each group.
- For main activity:
    - Print out copies of the student worksheet - Comparing the size of some important scientific objects
    - Teacher version: Comparing the size of some important scientific objects-Teacher

HOMEWORK

- (Optional) Reading 1 for Activity 4.1: How Are Very Small Numbers Defined?
- (Optional) Reading 2 for Activity 4.1: Scientific Notation: Keeping Track of Very Big and Very Small Numbers

Note: Reading 1 for Activity 4.1 introduces metric units, and Reading 2 for Activity 4.1 introduces scientific notation. Although both topics are outside the learning goals for the unit, this activity provides a context that makes them relevant. Thus, if either topic is part of a learning goal for your curriculum, this may be a good time to introduce it.

Activity 4.1 - Teacher Preparation

BASIC OUTLINE OF ACTIVITY

Use this space to make notes to prepare for your lesson

1. What is matter made of?
    a. Introducing the lesson
    b. Students' initial drawings of atomic structure
    c. Discussion
2. History of the atom
    a. Timeline
    b. Optional scientific notation activity
3. How small are atoms?
    a. Initial ideas
    b. Discussion
    c. Building a scale analogy
    d. Concluding the lesson

Activity 4.1 (Student materials): What are the particles that make up all substances, and how small are they?

Introducing the Lesson

Start the discussion by reminding students of their conclusion from the last investigation:

- The particle model explains observations of the behavior of matter better than the continuous model.

Discuss students' ideas about the particles that make up matter by introducing the investigation-level driving question, *What are nature's building blocks?* and the activity-level driving question, *What are the particles that make up all substances, and how small are they?*

Possible questions:

- *What do you think the particles are?*
- *What is the same/different about the particles that make up air and those that make up water?*

Encourage students to share their ideas and ask additional questions. Add their ideas and questions to the driving question board.

Tell students that questions like this have been asked for centuries and that scientists continue to refine their answers even now by looking deeper into how to explain the behavior of matter. In this investigation, students will explore some of these ideas and some of the progress scientists have made in characterizing these particles.

Page title:

What is matter made of?

In the last investigation, you found that the particle model of matter helps explain how materials behave. According to the particle model, all substances are made of tiny particles that are too small to be seen with the naked eye. Each of these single particles is either an *atom* or a *molecule*, which is a group of atoms held tightly together.

1. [drawing prompt] Draw what you think an atom looks like. Make sure to label your model so that anyone can understand it.

[text prompt] How does your model explain your observations of substances?

Student responses: The point of this question is to gauge students' current understanding, as well as to foster discussion about how we might learn about atoms and their internal structure.

- Simple ball
- Small dots
- Iconic representation such as the Bohr model or Johnny Neutron
    - *Ask students how they know this represents the structure of the atom. Where did this image come from?*

Discussion

After students answer this question individually, have them share their answers with the class. The goal of the discussion should just be to generate a variety of ideas, not to evaluate any of them at this point. Consider adding some students' initial models to the DQ board.

Students may have heard of protons, electrons, and neutrons in other classes. However, they may or may not remember that these are parts of an atom. If students bring up these terms during the discussion, consider asking questions such as the following:

- *What is a ______?*
- *How do we know they are part of atoms?*
- *What characteristics do ______ have (or need to have) that might help explain how objects become charged?*

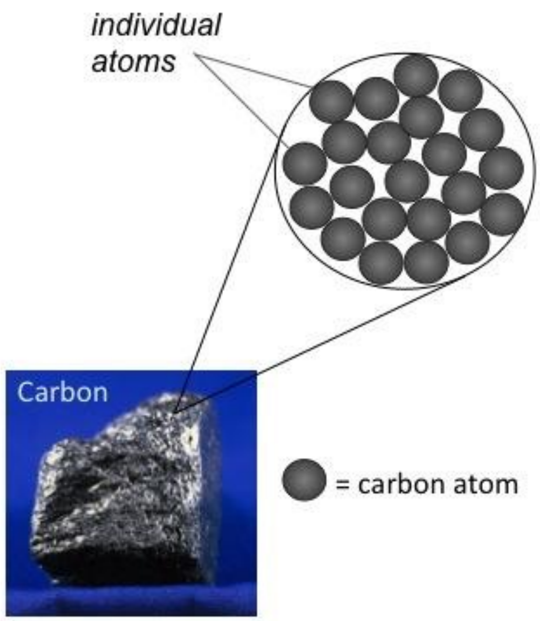
Students may not be able to answer these questions, which is fine. This is what students will be exploring during this investigation.

Note: Do not evaluate or try to guide students' responses. The purpose here is just to elicit students' initial ideas about atoms.

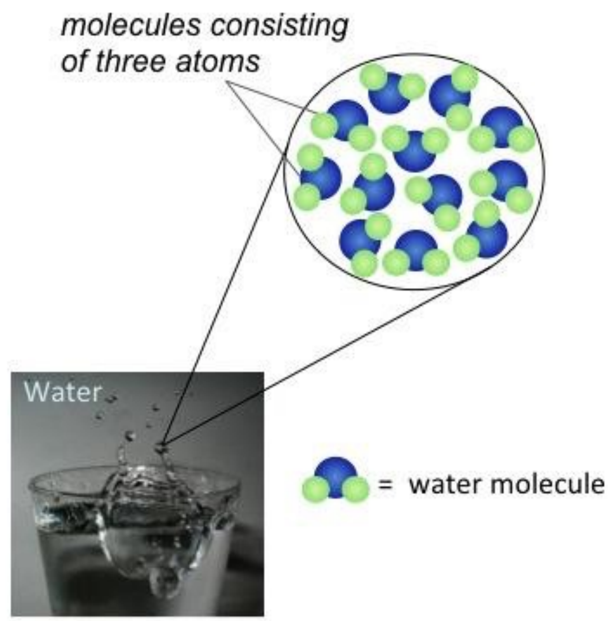
Page Title:

History of the atom

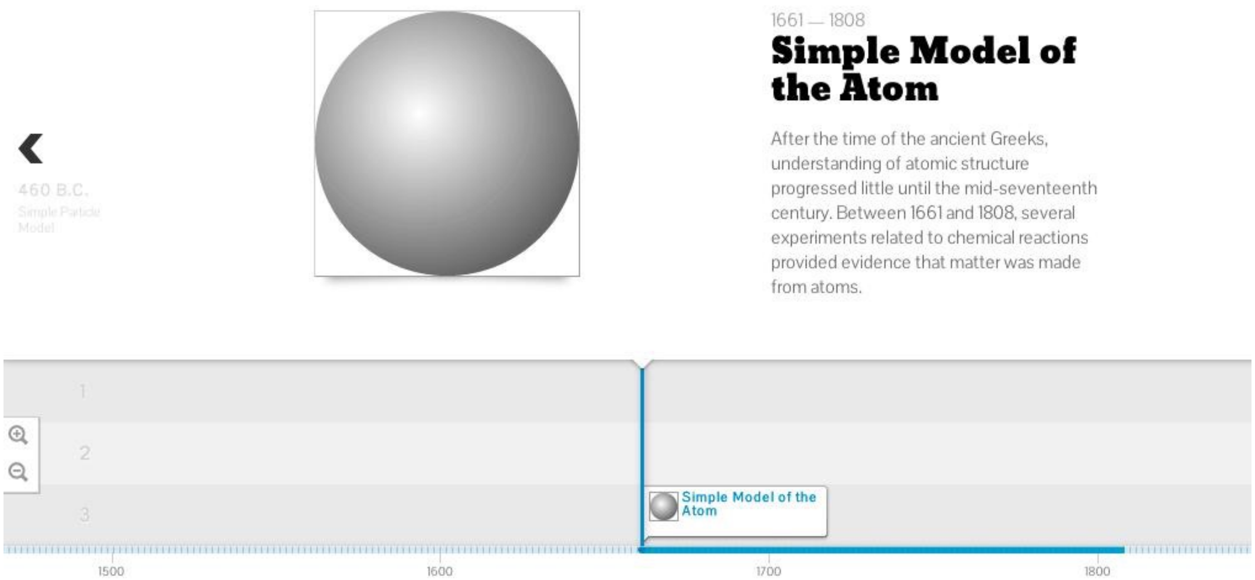
The small particles that make up substances are either individual atoms or molecules. As shown in the figure below, the particles that make up the chunk of carbon are individual carbon atoms. The particles that make up water and ethanol are molecules. Each water molecule shown in the figure is formed by a group of three atoms.



Carbon image credit: USGS
License: Public domain
Image source: http://commons.wikimedia.org/wiki/File:GraphiteUSGOV.jpg



Water image credit: Roger McLassus
License: Creative Commons Attribution-Share Alike 3.0
Image source: http://commons.wikimedia.org/wiki/File:2006-02-13_Drop-impact.jpg



[Click here for link to live timeline.]

Use the timeline to determine how long it took between the time the Greeks proposed the existence of atoms, and the time when experiments first indicated that matter is made of atoms.

2. How long did people have to wait for evidence of the existence of atoms?

a. approximately 100 years
b. approximately 500 years
c. approximately 2000 years
d. approximately 5000 years

Automated "Check answer" feedback:

a. Use the back arrow on the left side of the timeline to see when the Greeks first suggested that atoms exist.
b. Use the back arrow on the left side of the timeline to see when the Greeks first suggested that atoms exist.
c. **Yes, it took many years before experiments provided evidence to support the existence of atoms.**
d. Use the back arrow on the left side of the timeline to see when the Greeks first suggested that atoms exist.

Page Title:

How small are atoms?

Optional Activities: Metric Units and Scientific Notation
While metric units and scientific notation are not part of the learning goals for this investigation, this is a good opportunity for students to learn about these topics—in the context of learning about the sizes of important scientific objects. If you choose to review or introduce metric units and/or scientific notation, you may wish to assign this activity's optional readings and worksheet, which provide support for understanding these topics..

Investigate
Atoms are too small to be seen, but how small are they? You will explore how atoms compare in size with various other objects you might study in science class. Because atoms are so small, you will use objects you can see to represent atoms and other small objects. These comparisons will help you understand how small atoms really are.

3. [prediction question] Eight pennies can be lined up across a dollar bill.

What would happen if we made a similar measurement with atoms?

Imagine lining atoms up across the thickness of a strand of hair (about 0.0001 m). How many atoms do you think would line up across a piece of hair?

Supplemental content: The exact number depends on both the type of atom that are being lined up next to each other and the thickness of the hair. In general the answer would be in the millions range.

- *Clarification - this is just an initial prediction, students' answers may include a huge range.*

Student responses: Do not evaluate students' responses, this is just a prediction question.

- 100 atoms
- 1 billion atoms
- Bigger than a billion

.

Discussion

Discuss students' estimations of how many atoms it would take to form a line one thousandth of a meter long. Have students consider the relative size of atoms as compared with other important scientific objects (e.g., bacteria or other cells, DNA). Post the overall distribution of students' estimations.

In this activity, students will use various objects to represent things that are too small to be seen with the naked eye. Encourage students to think about how the representative objects relate to the target objects they represent. In general, when an object is used to represent something else, the representative object will have some characteristics in common with the target object, as well as some characteristics that are different. The purpose of the representation determines what needs to be similar and what can be different. Some examples that you may wish to discuss with students are as follows:

- Model cars and airplanes show how the real machines look, but not how they work.
- A box that is used to represent a building might show where the windows and doors are, but not the internal structure, electricity, or plumbing.
- Using a baseball to represent the moon and a basketball to represent Earth illustrates the relative sizes of Earth and the moon. Each ball is similar in shape to the object it represents (spherical), but none of the other features of the actual objects are represented. For the purposes of this representation, what is most important is that the relative sizes are accurate.

In this activity, the focus is on size. So it is the relative sizes that are accurate, not necessarily how the objects look.

Pass out the student worksheet - Comparing the size of some important scientific objects.
Teacher version: Comparing the size of some important scientific objects-Teacher

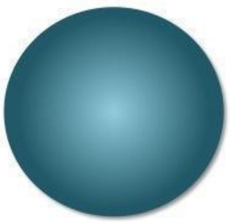
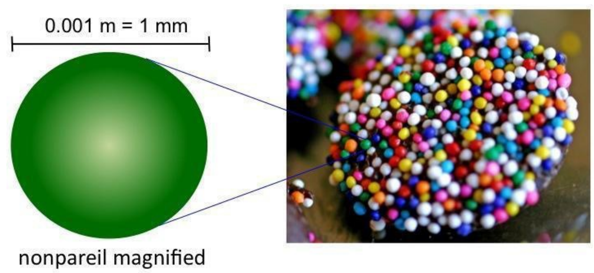
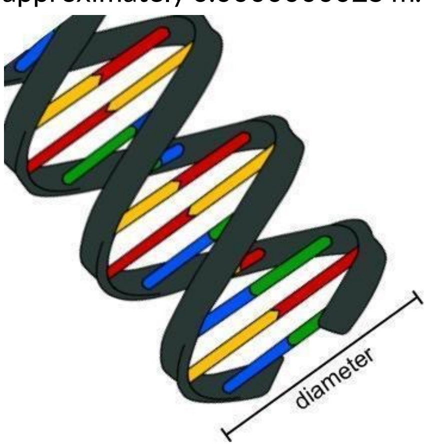
Students should complete the calculations and identify representative objects for each comparison. You could give groups the materials and have them match them with the appropriate items, or fill in the table as a whole class.
If possible, have the class go to a space where they can experience a distance of 60 m (outside, the gymnasium, a hallway). A classroom should be adequate for the 10 m size.

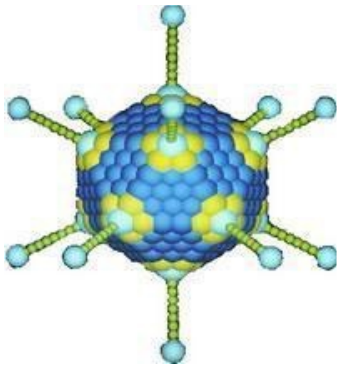
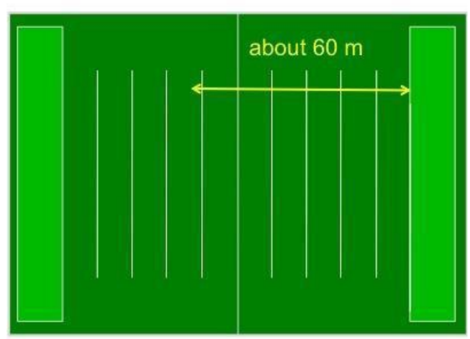
- Give each student a nonpareil and tell them that if they magnified an atom 10,000,000 times, it would be this size.
- Then have students calculate the diameter of a strand of DNA if it were also magnified 10,000,000 times. Either have groups select the appropriate item to match their calculation or show them the wooden dowel and explain that the width of the dowel represents the width of a strand of DNA magnified the same amount.
- Repeat this with the additional comparisons:
    - virus - beach ball
    - red blood cell - 60 meters (measure out in hallway, gym, outside, or other large space)

human hair - 10 football fields (students could identify a landmark that is a similar distance from the school)NOTE: These are representative objects. For instance, all atoms are not the same size, but they are all much, much smaller than a red blood cell.

Page title:

Comparing the size of some important scientific objects

Object	Representative Object (size of original object magnified about 10,000,000 times)
Atom  The diameter of an atom is approximately 0.0000000001 m.	Nonpareils are the little colored balls used to decorate candy and baked goods. They are about 0.001 m in diameter (1 mm). For this activity, a single nonpareil will represent an atom. 
DNA While DNA can be quite long, its diameter is approximately 0.0000000025 m.  	If an atom were as big as a nonpareil, the diameter of a strand of DNA would be about as wide as the diameter of a wooden rod that is 0.025 m (2.5 cm) across. 

Virus Viruses are responsible for causing a variety of diseases, from AIDS to the common cold. The diameter of a virus is approximately 0.00000012 m. 	If an atom were as big as a nonpareil, a virus would be about the same size as a beach ball with a diameter of 1 m. 
Red Blood Cell The diameter of a red blood cell is about 0.000006 m. 	If a an atom were as big as a nonpareil, a red blood cell would have a diameter of about 60 m. The arrow illustrates approximately 60 m on a football field. 

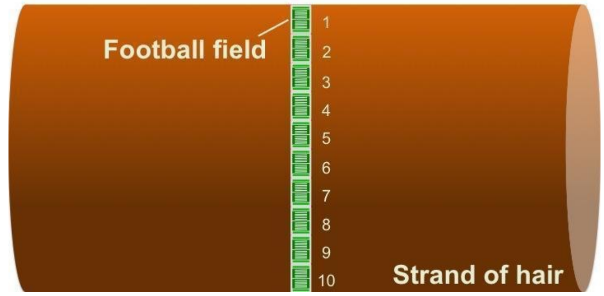
Strand of Hair A strand of hair is approximately 0.0001 m in diameter.	If an atom were as big as a nonpareil, a strand of hair would be about 10 football fields across. 

Image credits. See source for author and licensing info. *Nonpareil*: http://commons.wikimedia.org/wiki/File:Nonpareils.jpg; *DNA*: http://commons.wikimedia.org/wiki/File:Difference_DNA_RNA-EN.svg; *Virus*: http://commons.wikimedia.org/wiki/File:Adenovirus_weis.jpg; *Beachball*: http://commons.wikimedia.org/wiki/File:Blender259BeachBall.png; *Blood cell*:http://commons.wikimedia.org/wiki/File:Red_blood_cell.png

4. Consider how small an atom is, based on the activity you just finished. Estimate again how many atoms it would take to form a line across the diameter of a strand of hair (0.0001 m long)?

Supplemental content: Again, the amount would vary significantly depending on the type of atom and the thickness of the strand of hair. However, using the numbers provided in the activity, it would take ten hairs lined up side by side to equal a millimeter. Ten million atoms would also be a millimeter wide (the nonpareil is a millimeter and it is 10,000,000 times larger than the atom in the analogy). Therefore, the number of atoms that could be lined up across a human hair would be 10,000,000 divided by 10, or 1,000,000.
Student responses: Students may need support to connect the analogies from the activity to answer the question. They could either imagine lining up nonpareils up along ten football fields (note students may overestimate using this method), measure how many nonpareils line up to make a centimeter then calculate how many would line up to make ten football fields, or complete the calculations from the expert answer above.

- 1,000,000

Activity 4.2: If you can't see it, how do you know it's there?

SUMMARY

In this activity, students will develop a model based on indirect evidence to gain insight into how scientists study objects (e.g., atoms) that are too small to observe or measure directly. The teacher will lead a mystery box activity, in which the class collects indirect evidence related to what is inside the box. Using that evidence, students will draw a model of what they think is inside the box. Students will also explore simulations of Thomson's cathode ray tube experiments to collect evidence suggesting that all materials contain negatively charged particles with a mass that is much lower than that of a hydrogen atom. Establishing that atoms contain charged particles is a step toward understanding how objects become charged. In the next activity, students will continue to explore simulations of historically significant experiments to continue to develop more scientifically accurate models for atomic structure.

LEARNING GOALS

Students will communicate the benefits and limitations of using indirect evidence for studying atomic structure.

- Atoms cannot be directly observed, so using indirect evidence is the only way to investigate atomic structure.
- Indirect evidence can provide some information about an object that cannot be observed directly, but it cannot provide an exact image of that object.

Disciplinary Core Idea	Crosscutting Concept	Scientific and Engineering Practice
Structure and properties of matter: Matter of any type can be subdivided into particles that are too small to see, but even then the matter still exists and can be detected by other means. (NGSS Lead States, p. 43)	*Patterns:* Students observe patterns in systems at different scales and cite patterns as empirical evidence for causality in supporting their explanations of phenomena. They recognize classifications or explanations used at one scale may not be useful or need revision using a different scale; thus requiring improved investigations and experiments. (NGSS Appendix G p. 82)	*Analyzing and interpreting data:* • Analyze data using tools, technologies, and/or models (e.g. computational, mathematical) in order to make valid and reliable scientific claims or determine an optimal design solution. • Consider limitations of data analysis (e.g., measurement error, sample selection) when analyzing and interpreting data. (NGSS Appendix F p. 57)

Students will use historical evidence to develop and defend a model of atomic structure that explains the results of experiments done historically to better understand the nature of matter.

- By the end of this activity, students' models of atomic structure should include the following:
  - Atoms have positive and negative parts.
  - The negative parts, called *electrons*, have very little mass.
- Evidence for the model should include the following:
  - Thomson showed that negatively charged particles are part of all atoms. He

determined that the mass of each negative particle was approximately 1/2000 the mass of a hydrogen atom. The particles were attracted to positively charged plates. (Students will not see this specific quantity in their experimentation, but they will see that electrons have a *much* smaller mass than the least massive atom—hydrogen.)
  - Because atoms have negative parts, atoms must also have positive parts to balance out the charge, or everything would repel and fly apart.

Disciplinary Core Idea	**Crosscutting Concept**	**Science and Engineering Practice**
Structure and properties of matter: Each atom has a charged sub-structure consisting of a nucleus, which is made of protons and neutrons, surrounded by electrons. (NGSS Lead States, p. 92)	*Patterns:* Students observe patterns in systems at different scales and cite patterns as empirical evidence for causality in supporting their explanations of phenomena. They recognize classifications or explanations used at one scale may not be useful or need revision using a different scale; thus requiring improved investigations and experiments. (NGSS Appendix G p. 82)	*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. • Develop and/or use a model (including mathematical and computational) to generate data to support explanations, predict phenomena, analyze systems, and/or solve problems. (NGSS Appendix F, p. 53)

POINT FOR CONSIDERATION

Do not open the box during or at the conclusion of this activity! Students will want to know what is inside the box; however, scientists do not get the opportunity to "open the box" to see what atoms actually look like. For the full effect of this activity, it is important that students *not* be given the opportunity to see or be told what is actually in the box. As they collect more evidence, they can be more confident in their ideas, but they will never be 100 percent certain.

PREPARATION

Class Time: 120 min.

Materials

- mystery box (See below for details about how to make it.)
- laser pointer
- projector screen or white wall
- plastic water bottle (**Note:** The bottle needs to fit inside the mystery box.)

Activity Setup

- How to make a mystery box:
  a. Prepare a box with two opposite open sides.
  b. Draw a grid on a sheet of paper, and poke small holes in each cell of the grid (see picture below).
  c. Attach the sheet of paper to one open side of the box. This side will face the

class. The opposite side will remain open and face the projector screen or a white wall.

d. Place the plastic bottle inside the box.

- Do not allow students to see inside the box through the open side.
- The teacher will demonstrate the activity with the laser pointer while students observe.

SAFETY ISSUES

Laser pointers can be harmful to the eyes (potentially causing blindness) if pointed directly at a person's eyes.

HOMEWORK

- Reading 1 for Activity 4.2: What If It Is Impossible to Directly Measure or Make Observations?
- Reading 2 for Activity 4.2: What Types of Tools Are Useful for Visualizing Small Objects?

Activity 4.2 - Teacher Preparation

BASIC OUTLINE OF ACTIVITY

Use this space to make notes to prepare for your lesson

1. The mystery box
    a. Introducing the lesson
    b. Testing the mystery box
    c. Students' ideas about object inside the mystery box
    d. Discussion
    e. Homework
2. Cathode rays
    a. Introducing the lesson
    b. Thomson's experiment
3. Learning more about cathode ray particles
    a. Analyze relationships between components to evaluate Thomson's results
    b. Discussion
4. Discovering the electron
    a. Evaluating Thomson's evidence and conclusion
    b. Students' revised models of atomic structure
    c. Discussion of revised models
5. The plum pudding model
    a. Timeline

Activity 4.2 (Student materials): If you can't see it, how do you know it's there?

Introducing the Lesson
Remind students that they have learned that materials are made of particles called *atoms* and that these particles are extremely small.

Lead a short discussion asking students to recall whether they have ever placed their hands inside a mystery box at a museum or haunted house. Brainstorm strategies for gathering information about things one cannot see. Discuss using other senses to "see" and make observations.

Possible questions:

- *What can you find out about what's in a completely dark room or a mystery box?*
- *How can you determine what the objects are without seeing them?*
- *What can't you find out?*

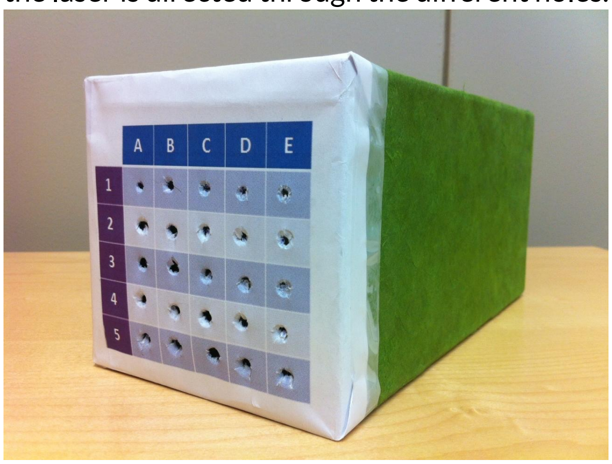
Page title:

The mystery box

Imagine walking into a completely dark room. How would you figure out what is in the room?

Scientists often study things they cannot see *or* touch. In this activity, you will explore ways to collect information about an object without actually seeing it—or even touching it!

Investigate
Your teacher will shine a laser through each of the holes in a box containing an unknown object (see figure below). To collect evidence about what is inside the box, observe what happens when the laser is directed through the different holes.



Tip: Suggested Pre-activity
Have students evaluate how the outgoing light changes when shining a laser pointer through various materials. This will help them evaluate the evidence the class collects regarding the mystery box. For example, you can shine the laser through a full and empty drinking glass and then a book to see what happens each time. Have students characterize and compare the results of shining the light through different materials. Students can then use these observations to help them evaluate the evidence and make inferences about the object inside the mystery box.

Note: In the pre-activity, make sure none of the materials are the same as what the object in the mystery box is made of, and tell students that the materials are not the same. Otherwise, students will make assumptions about what is in the mystery box.

Procedure

1. Direct the laser beam through the holes punched in the grid. Let students know where on the grid you are shining the laser. For example, if you shine the laser in the hole at the top left side, tell students that you are testing cell A1 on the grid. Have one student record the class consensus regarding observations for each point on the grid. This will save time and help the class focus on collecting data.
2. Direct the laser through a few cells of your choice, and then ask students which additional cells they want you to test so that they can build their model.
3. Optional: After about half the cells have been tested, tell students that you will do a limited number of additional tests. Have them discuss what they think might be inside the box and which cells they think would be most informative to test. Have them construct an argument for which cell they want tested and make a prediction of what they expect to see.

1. Based on the evidence your class collected, draw a picture on the grid to illustrate the size and shape of the object in the mystery box.

	A	B	C	D	E
1					
2					
3					
4					
5					

Student responses: Students should indicate the shape, size, and location of an object that would account for the evidence. Students may also speculate about what the object is or what it is made of. Students may need help understanding the instruction and what to put in the box.

- Trace of an object (could be a general shape and location or a specific item).
- Coloring in the boxes to indicate whether the light was blocked or fuzzy.
  - *Push students to trace the outline of an object that would leave this type of pattern*

NOTE: Do NOT tell students what you put in the box! The idea of the activity is to experience the affordances and limitations of indirect evidence. It is an analogy to studying the structure of atoms. Given this goal, telling students what is in the box is disingenuous since their is no way to look inside an atom.

2. Explain what evidence you used when considering what to draw.

Student responses: The illustration is the student's "claim." Student explanations should include reference to the data generated by the laser pointer (evidence) and provide a rationale for how that leads them to a particular conclusion (reasoning).

- Something solid must be in the area where the light was blocked. There must be something plastic or glass in the area where the light was blurred.

Discussion

Have students share their initial models in small groups so that they can critique them and build on each other's models. Display or present some of the models at the front of class and discuss their similarities and differences. Ask students to defend their ideas, but do not evaluate their drawings. Rather, ask students to explain how their models are consistent with **all** the observations they have made so far. This is an opportunity to explore how the same data can sometimes be interpreted in different ways. This happens in science as well, especially when experiments push the boundaries of what is known.

Possible questions:

- *Is there an object inside?*
- *How do we know?*
- *What can we tell about the object?*
- *What is it made of? What is it not made of?*

Note: ***Be sure you do not tell students what is inside the box.***

Homework: Reading 1 for Activity 4.2
What If It Is Impossible to Directly Measure or Make Observations?

Page title:

Cathode rays

Introducing the Lesson
Before the lesson, review the reading on indirect evidence.

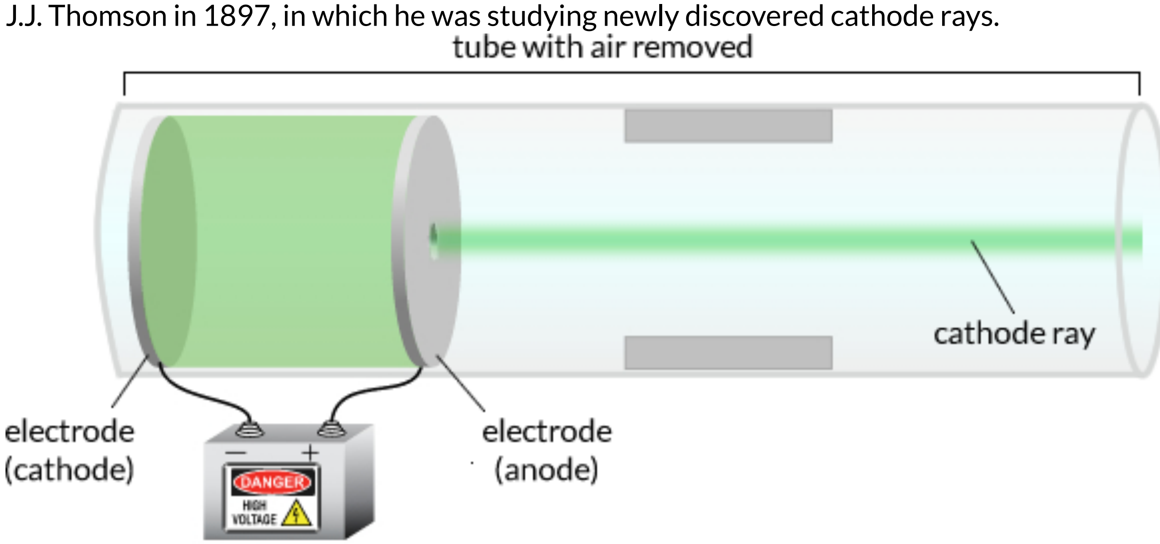
Possible questions:
- *What is indirect evidence?*
- *What are some examples of indirect evidence in the reading?*
- *Can anyone think of a different example of indirect evidence?*
- *Why might indirect evidence be important for studying atoms?*

Projecting the DQ board and showing the activity-level question: *If you can't see it, how do you know it's there?* and the unanswered questions how materials become charged and why neutral and charged objects interact.

Possible questions:
- *How might understanding atoms help us answer our questions about how materials become charged and why neutral and charged objects interact?*
- *How can we learn about atoms?*

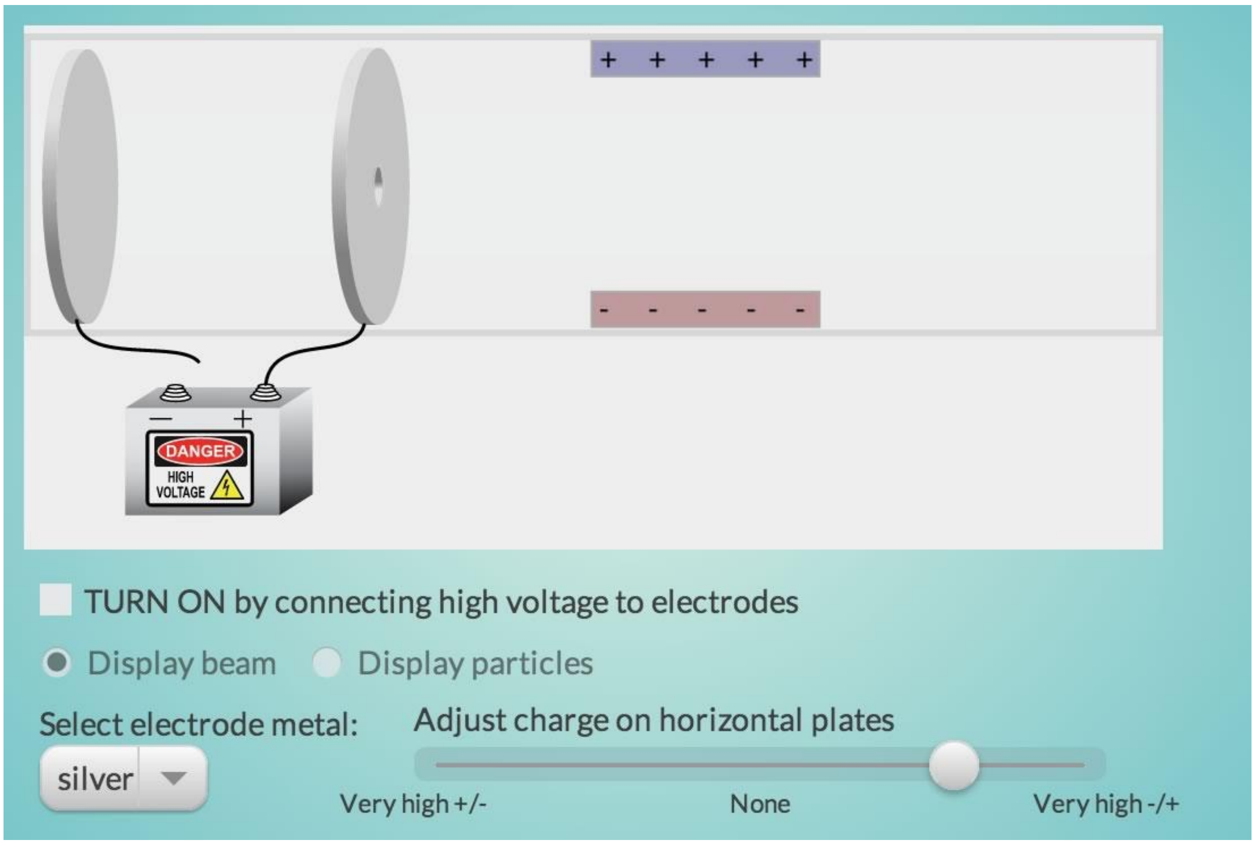
Demo (optional)
- *If you have a Crookes tube take it out and demonstrate how a charged object (like a balloon or wand connected to a Van de Graaff generator) can deflect the beam inside the apparatus.*

The first hint that atoms might be made of even smaller particles came from experiments done by J.J. Thomson in 1897, in which he was studying newly discovered cathode rays.



If all the air is removed from a sealed glass tube, and electrodes inside the tube are connected to a high-voltage electrical source, a beam of light called a *cathode ray* will shoot across the tube.

This simulation is an animation of the experiment that J.J. Thomson conducted, which provided a first glimpse into the structure of the atom and led to one of the most important discoveries in history. Use the simulation to collect data, and see if you come to the same conclusions about cathode rays as Thomson did.



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

Note: Students may not realize the significance of the simulation showing the same outcome when the metal is changed. Ask students what is different, what they observe, and what that tells them.

3. Thomson believed that cathode rays were made up of tiny particles. Based on the simulation, what charge did these particles have?

A. Positive
B. Negative
C. Neutral

Automated "Check answer" feedback:

A. Try charging the plates, and observe whether the particles are pushed or pulled toward a specific charge. If the tiny particles were positive, would they be attracted to or repelled by the positively charged plate?
B. Think about what evidence from the simulation supports this answer.
C. Try charging the plates, and observe whether the particles are pushed or pulled toward a specific charge. How do neutral objects interact with charged objects?

4. What evidence from the simulation supports your claim about whether the cathode ray particles were positive, negative, or neutral?

Student responses: :

- The particles move (the ray bends) toward the positive charge and away from the negative charge.

5. Thomson thought the cathode ray particles were coming from the electrodes, so he tried using different metals for the electrodes. Did changing the electrode material change the way the cathode ray particles behaved?

A. Yes, the behavior of the particles changed when the metal was changed.
B. No, the particles behaved the same when the metal was changed.

Student responses:

- A. Yes, the behavior of the particles changed when the metal was changed.
    - *Ask students to change the metal. Do you observe changes? What is different? Does the beam change?*
- **B. No, the particles behaved the same when the metal was changed.**

Page title:

Learning more about cathode ray particles

We know that cathode ray particles have a negative charge no matter what material they come from. What other properties of cathode ray particles can we discover?

This simulation allows you to test how particles with different masses behave as they pass through an electric field created by charged plates. See if you can identify any trends in their behavior.

NOTE: Unlike the simulation on the previous page, this does not represent an actual experiment that was done, rather it allows you to test components and relationships in order to test the properties of the particles that were discovered in the experiments Thomson did with Cathode-Ray tubes.

Hint: *Watching the particles in slow motion may make it easier to compare the different particles.*

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

6. Charge the plates so that the electric field between them is strong enough to deflect positive or negative atoms. How does the mass of an atom affect the amount a charged atom gets deflected?

A. The mass has no effect on the amount of deflection.
B. Atoms with less mass get deflected more.
C. Atoms with more mass get deflected more.

Automated "Check answer" feedback:

A. Make sure the charge on the plates is high enough by checking the "Increase charge on plates 1000x" box, and compare atoms of low and high mass.
B. Think about what evidence from the simulation supports this answer.
C. Try comparing hydrogen (the atom with the lowest mass in this simulation) and carbon (the atom with the highest mass in this simulation).

7. Using evidence from the simulation, explain why you selected the previous answer.

Supplemental content: Changing direction (making a curve) requires an outside force. The more mass an object has, the more force is required to cause it to change direction. This is reflected in the simulation as the same amount of force (the electric field) causes the lighter atoms (Hydrogen) to curve more than the heavier atoms (Carbon).

Clarification - students should reference observations from the simulation; they are not expected to use Newton's laws to explain the relationship.

Student responses: Check to see if students' responses are consistent with both with their answer choice and with the simulation.

- Hydrogen is the lightest atom and it curves the most in the electric field.
- All the atoms go straight through
    - *Note: this answer is logical if the student selected A. Point out the "Increase charge 1000x" button and have students retest the atoms.*

8. Thomson was able to calculate the mass of the particles he discovered. Based on the simulation, how does the mass of a cathode ray particle compare with the mass of a hydrogen atom (the atom with the lowest mass)? Support your answer with evidence.

Supplemental content: The particle Thomson discovered is affected much more than hydrogen atom. If the same force is applied to both the particle and a hydrogen atom, the particle will bend much more significantly than the hydrogen atom. In fact, that field needs to be magnified by about 1,000 times in order to get the hydrogen atom to bend, indicating the particle is around 1,000 times lighter than the hydrogen atom.

Clarification - students only need to state that the particles are smaller than atoms, they do not need to compare the relative masses. Students should support their answer with the simulation.

Student responses:

- The particle has a much lower mass than the hydrogen atom. The simulation shows that objects with lower mass curve more and the particle curves more than any of the atoms.

Discussion

These are complex simulations, so it is helpful to review what students learned each time they finish exploring one. Below are some questions to use when helping students evaluate and understand each simulation in this activity. You might put this into a table on the board and fill it in as a class.

- What are the components/variables shown in the simulation?
- What are the relationships between those components? (What are you trying to test?)
- What are some connections between the simulation and the results of Thomson's experiment?

The two simulations used to provide students with evidence related to Thomson's Cathode-Ray Tube experiments are doing very different things. The first simulation (on the previous page) is a representation of what Thomson actually did. This simulation allows students to explore relationships, but goes beyond Thomson's actual experiment. Help students differentiate between these two simulations.

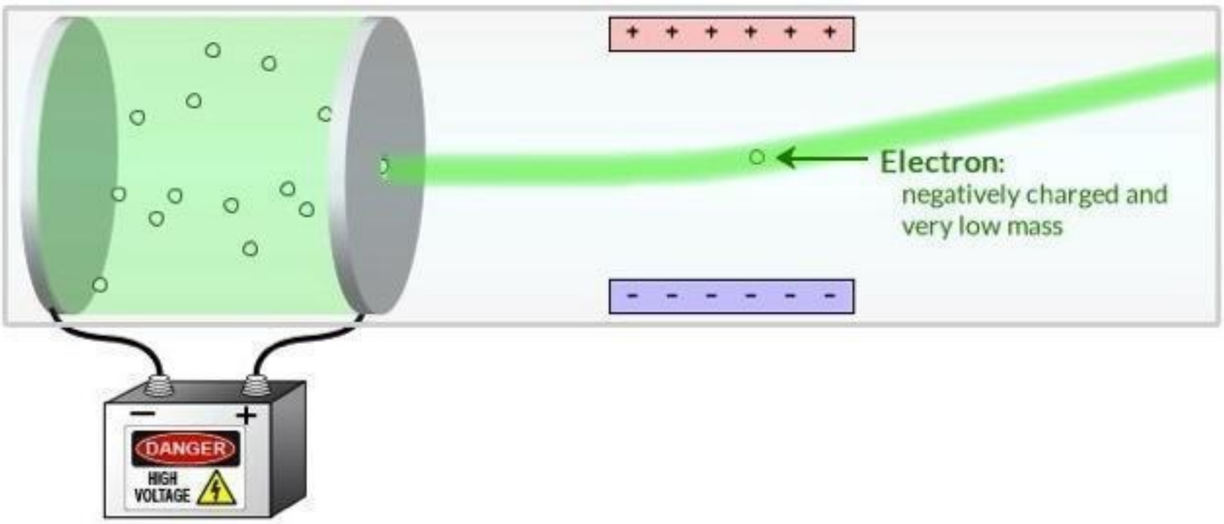
Possible questions:

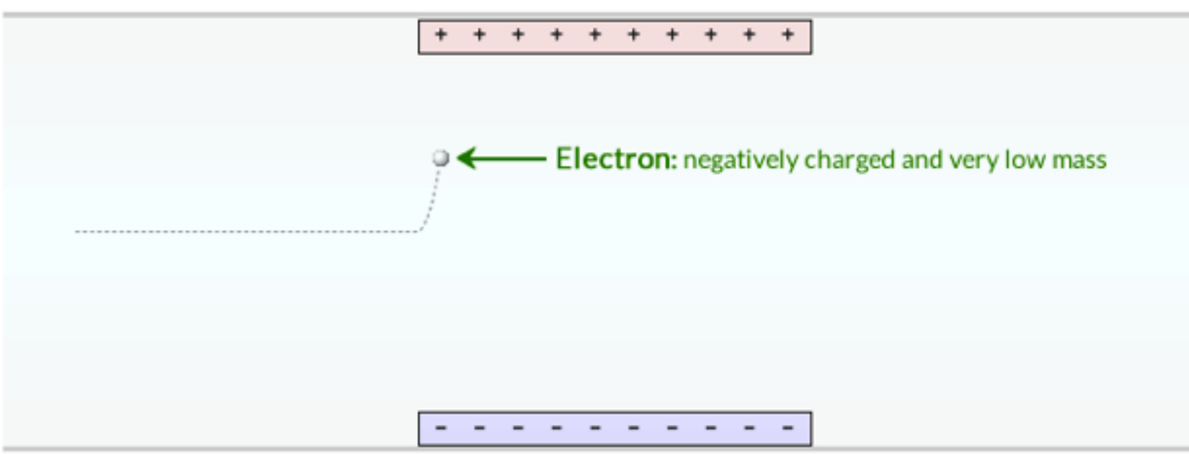
- *What did Thomson actually do in his test?*
- *Did Thomson send atoms through the Cathode-Ray Tube?*
- *What is the purpose of each of these simulations?*

Page title:

Discovering the electron

From these experiments, Thomson concluded that the particles in the beam were *pieces* of atoms, and that they had a negative charge and a much smaller mass than atoms. Eventually, these particles were named *electrons* because they were discovered from experiments using high-voltage electricity.





Use your observations from *both* simulations in this activity to answer the following questions.

9. Thomson was able to calculate that the mass of the electron was significantly lower than the mass of any atom. How does the evidence from the simulation align with this calculation?

Supplemental content: Thomson was able to calculate the mass of the particle using the strength of the electric field and the arc of the curve. The mass of the particles was significantly less than the mass of a hydrogen atom (at the time, the mass of a hydrogen atom was known and believed to be the smallest atom).

Clarification - students should base their answer on the relationship between mass, the curve of atoms, and the curve of the mystery particles in the simulation.

Student responses:

- Electrons were deflected much more by the same electric field than even the lowest mass atom.

10. What evidence did Thomson have to support his conclusion that electrons were negatively charged?

Supplemental content: Electrons (particles that make up a cathode ray) always move toward the positively charged plate and away from the negatively charged plate.

Clarification - students should connect the observation and Thomson's conclusion.

Student responses:

- The simulation shows that the particles always bend toward the positive plate (and away from the negative plate).
- Electrons also behaved like negatively charged atoms in the electric field between the charged plates.

11. What evidence did Thomson have to support his conclusion that electrons were part of all atoms?

Supplemental content: The electrons (cathode ray particles) seemed to be coming from the electrodes, regardless of the type of metal from which the electrodes were made. Because electrodes made of any metal produced cathode ray particles that behaved the same way, Thomson concluded that the particles were the same regardless of the type of metal that produced them. Therefore, if everything is made of atoms, if electrons are smaller than atoms, and if the same type of particles come from different metals (which are made from different atoms), then electrons must be part of all atoms.

Clarification - Students may have a hard time putting together that the metals are made of atoms and those atoms are the source of the electrons. Students may also point out that we only have evidence that the atoms of silver, gold, and iron have electrons, which is a very valid point.

Student responses:

- All the metals in the simulation (silver, gold, iron) produced the beam and small negatively charged particles.

12. [drawing prompt] Draw a model of the atom that could explain the evidence from Thomson's experiment.

[text prompt] Describe how your model explains Thomson's evidence.

Student responses: The purpose of this drawing is to continue eliciting their conceptual model of an atom as more evidence is gathered, and to provide an example of the process of scientific modeling. Their model should reflect new evidence by including tiny charged particles. Their description should explain that their model of the atom now includes electrons because Thomson discovered that negatively charged particles called electrons were part of all atoms. Students may or may not include positives as well.

- Students may draw a circle with negative electrons in it.
- Students may draw iconic models such as the Bohr model or the image from Jimmy Neutron.
    - *Make sure students are connecting some aspect of this model to the evidence from Thomson (electrons). Students may identify the "wrong" component as the electron; they just need to identify something as the electron.*
- Students may not change their model from before
    - *Make sure students are connecting their old model with the new evidence.*
- Students may still draw a solid sphere or circle.
    - Ask students where the electrons would come from in their model.

13. Revisit your previous model of the atom, which you drew in Activity 4.1. If your model has not changed, what evidence supports your original idea? If your model has changed, what evidence convinced you that you needed to change it?

Student responses: If students included negative particles in their first model, they can cite as evidence the results of Thomson's experiment that there are small negatively charged particles as part of the atom. For students who drew something simpler in their first model, such as a ball with no internal structure, they should have negative parts included in their new model and connect this new representation with the particles found by Thomson.

- I included electrons in my first model, Thomson's experiment showed that all atoms have small negative pieces in them.
- At first I just drew a ball, but now I have small negative pieces (electrons) inside the atom.

Reviewing Student Models
Review different student models.
- Note the variety of representations, and ask students what they think about the different models.
- If a model seems confusing, ask if any students think they can explain it. (Or if students are willing to have names attached to their models, ask the author of the model to explain it.)

Add to the DQ board a few models selected by the class.

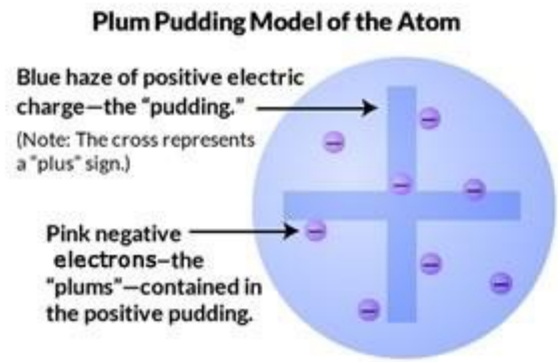
Possible questions:
- *How do you think adding negatively charged particles to the model of the atom helps explain how objects become charged?*
    - *If there are models in which the atom contains one or more positive parts, ask why the positive parts were included. Try to steer the conversation toward a logical need for positive charge to keep the negative particles from just repelling each other and flying apart. There is no need for the term protons (or neutrons) at this point. You just want to help students understand the plum pudding model that will be tested in the next activity.*
- *If all objects are made of atoms and all atoms are made of negative pieces, how could we explain our observations that some objects become positively charged and some objects have a neutral charge?*
- *What else would atoms have to contain to explain how objects become charged?*
- *What questions do you have about how the structure of the atom relates to the charge of objects?*

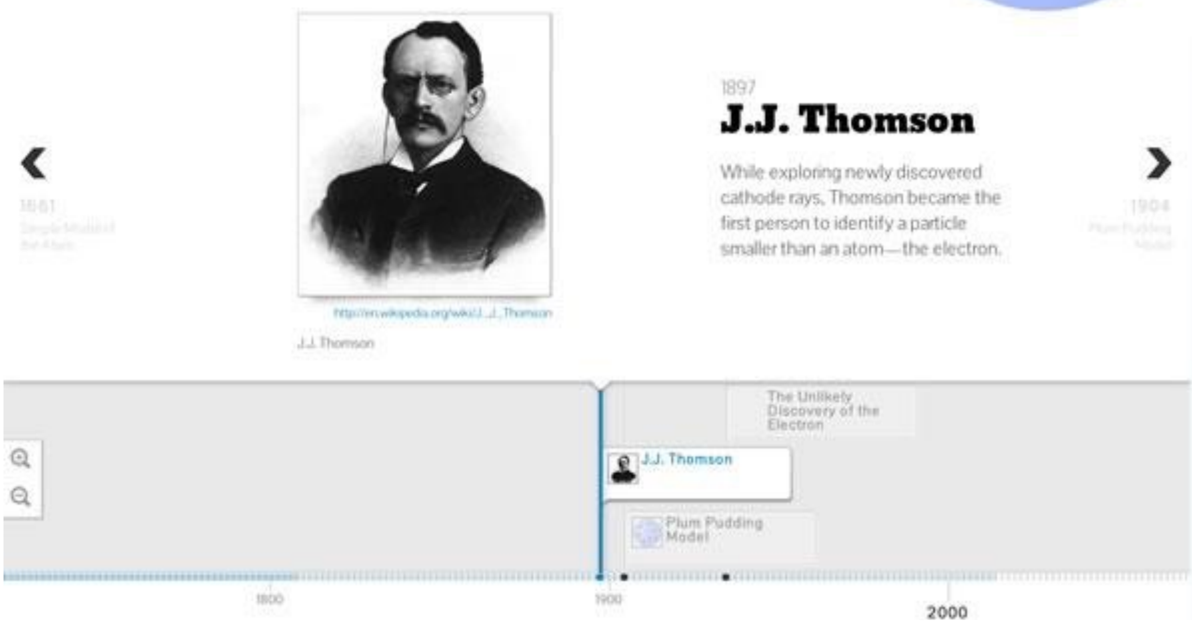
Post relevant questions and comments on the DQ board.

Page title:

The plum pudding model

The discovery of the electron led to models that described the atom's internal structure. One of the first of these models was called the *plum pudding model*, because it was thought that the atom might consist of a positive "pudding" in which negative electron "plums" were embedded. A more modern-day analogy might be the *raisin bread model*, in which the "bread" is the positive part of the atom and the "raisins" are the negative electrons.





[Click here for link to live timeline.]

14. How does the evidence from Thomson's experiments support the plum pudding model of the atom?

Supplemental content: The scientific community was never really satisfied with the so called "Plumb pudding" model, but Thomson's evidence had to be accounted for in the updated model of atomic structure. Thomson found that negative electrons were part of atoms, and the plum pudding model shows electrons as part of atoms. Additionally, evidence shows most atoms are neutral not negative, so there must be some positive charge to balance out the negative electrons. The idea behind the plumb pudding model is that atoms are made of a positive gel-like substance with negative electrons floating in it. The electricity bumped the negative electrons out of the positive gel and the electrons floated from one end of the Cathode-Ray tube to the other creating the glowing beam.

Clarification - Students do not need to know the history of the development of this mode, but they should evaluate how well this model matches with the evidence they have. *Students may use in their answer some of what the class discussed.*

Student responses:

- This model has positives and negative pieces. The negative pieces explain Thomson's observations that negative particles could fly out from atoms. If there are negative pieces, positives are also needed, because not all objects are negatively charged.
- This model is missing neutrons and protons
  - Ask students if there is any evidence at this point to support the idea that atoms have other pieces.

15. Notice that, in the timeline, from 460 B.C. all the way up till the late 1800s the "simple model of an atom" or the idea that an atom was a sphere was maintained. Why do you think it took so long before the simple model of the atoms was changed to include smaller pieces?

Supplemental content: Thomson did not actually set out to discover pieces of atoms, he was just exploring new technologies: electricity and vacuums. No one realized atoms had smaller pieces before, because we did not have the technology to observe those smaller pieces. Since we have to rely on indirect evidence to study atomic structure, we have to wait for technological discoveries that allow us to make observations for that indirect evidence.

Clarification - Students are not expected to know the specifics of the history and how it all fit together, but they should be able to speculate about the need for indirect evidence and the development of the technology that Thomson used in that discovery. You may want to provide some of the historical context for students.

Student responses:

- They had to wait till someone developed the tube that Thomson used.
- We cannot see atoms so we have to wait till some indirect evidence comes up.

Homework: Reading 2 for Activity 4.2
[What Types of Tools Are Useful for Visualizing Small Objects?]

Activity 4.3: How do we know what's inside an atom?

SUMMARY

In the previous activity, students collected evidence that suggested atoms contain negatively charged particles with a mass much lower than that of any atom. In this activity, they will use a simulation of Rutherford's gold foil experiment to test whether the positive charge distribution within an atom is consistent with the plum pudding model. This simulation will provide evidence for a small, dense, positive nucleus surrounded by electrons. This model helps prepare students for understanding electron transfer as a mechanism for charging objects.

LEARNING GOAL

Students will use evidence collected from simulations to develop and defend a model of atomic structure that explains the results of historically significant experiments.

- By the end of this activity, students' models of atomic structure should include the following:
  - Atoms are made of smaller particles: electrons, protons, and neutrons.
  - Atoms have a small, dense, positively charged center called a *nucleus*.
- Evidence for the model should include the following:
  - Thomson showed that atoms of all materials contained particles that were attracted to positively charged plates; therefore, the particles were negatively charged. He also determined that the mass of each particle was much lower than the mass of a hydrogen atom.
  - Rutherford found that when positively charged alpha particles were shot at a thin sheet of gold foil, most of the alpha particles passed straight through, but some were deflected back. This deflection suggested that the positive part of a gold atom was concentrated into a small, dense volume and had an intense electric field. This dense, positive center of the atom is called the *nucleus*.

Disciplinary Core Idea	Crosscutting Concept	Scientific and Engineering Practice
Structure and properties of matter: Each atom has a charged sub-structure consisting of a nucleus, which is made of protons and neutrons, surrounded by electrons. (NGSS Lead States, p. 92)	*Patterns:* Students observe patterns in systems at different scales and cite patterns as empirical evidence for causality in supporting their explanations of phenomena. They recognize classifications or explanations used at one scale may not be useful or need revision using a different scale; thus requiring improved investigations and experiments. (NGSS Appendix G p. 82)	*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. • Develop and/or use a model (including mathematical and computational) to generate data to support explanations, predict phenomena, analyze systems, and/or solve problems. (NGSS Appendix F, p. 53)

PREPARATION

Class Time: 90 min.

HOMEWORK

Reading Activity 4.3: Why Doesn’t an Atomic Nucleus Fly Apart?

BASIC OUTLINE OF ACTIVITY

Use this space to make notes to prepare for your lesson

1. Gold foil experiment and prediction
    a. Student predictions
    b. Discussion of predictions
2. Testing the plum pudding model
    a. Results
    b. Role of electrons
3. Investigate
    a. Simulation
    b. Students' revised models
    c. Discussion of simulation
    d. Discussion of students' revised models
4. A nuclear model of the atom
5. One more mystery to solve
6. Explore the timeline

Activity 4.3 (Student materials): ***How do we know what's inside an atom?***

Discussion:

Review the reading about atomic force microscopes.

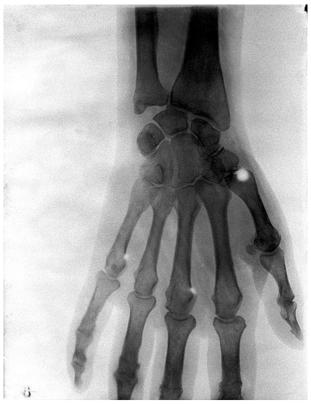
Possible questions:

- *How does an atomic force microscope work?*
- *Do you think atoms are little bumps, or could additional evidence continue to change our ideas about atoms?*
- *Are the images in this reading actual pictures of atoms or actual proof of atoms?*

Page title:

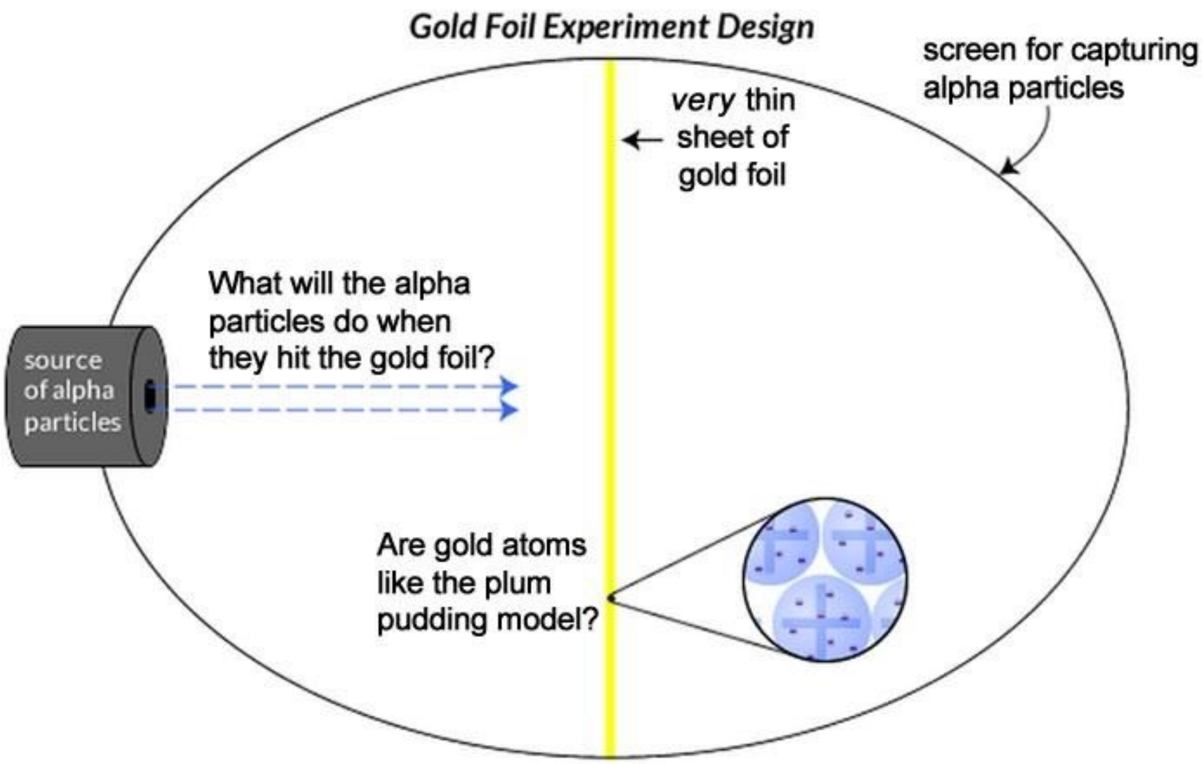
Gold foil experiment and prediction

X-rays are a form of radiation. They can go through skin, but bone is too dense. When x-rays hit a special plate, the plate turns white. Since x-rays can't go through bone as easily as flesh, this leaves an image of the bones on the plate.



X-Ray of hand
Credit: Wellcome Library, London
License: Creative Commons Attribution 4.0 International
Image source: http://wellcomeimages.org/indexplus/image/L0026315.html

Ernest Rutherford studied a type of radiation called alpha particles. Like x-rays these high energy particles are positively charged and can pass through very thin materials, but not thicker or more dense materials. The positively charged alpha particles, are much, much smaller than gold atoms. Rutherford shot these particles at an extremely thin sheet of gold foil to see how the alpha particles and gold atoms would interact.



1. [prediction question] Make a prediction about what you think might be the results of Rutherford's test? If the atoms making up the gold foil do have the structure described by the plum pudding model, what do you think will happen when the alpha particles reach the foil? Why?

Student responses: Students may have a range of predictions. Ask students to support their predictions.

- The particles will pass right through because the gold sheet is too thin
- The particles will bounce off because the atoms are made of positive gel and the alpha particles are also positive
- The particles will hit the foil and stop
  - Some students may interpret the lines in the image as showing that the alpha particles stop. Clarify that the question is asking students what they think will happen next.

Bring students together, and ask them to share their predictions of what will happen to the alpha particles in the experiment. Remind students to give reasons for their predictions.

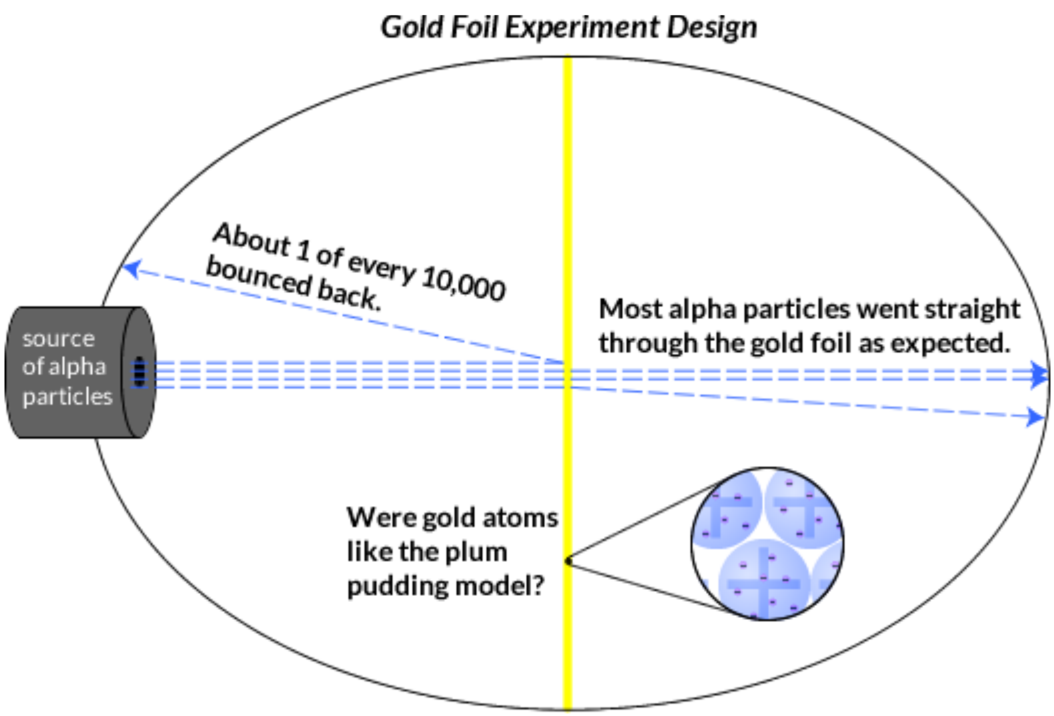
For an analogy, you could tell students a story about a person who uses a slingshot to shoot stones at a snowbank covering a thin, scraggly shrub. Ask the following questions:

- *What do you predict will happen to the stones? Why?*
- *What if some of the stones bounce back? What could explain this?*

Page title:

Testing the plum pudding model

If the plum pudding model had been correct, all of the particles would have gone straight through the sheet. Most of particles did go straight through, as expected, but a few particles—just 1 out of 10,000—were deflected and bounced back. This result was extremely surprising. Rutherford said it was like firing a cannon at a piece of tissue paper and having the cannonball come back and hit you!



2. In doing this experiment, Rutherford assumed the electrons in the gold atoms would have almost no effect on the alpha particles. Why was it reasonable to assume the electrons would have almost no effect?
As you answer your question use the following information about the mass of each of these particles -
Gold atom: 197 atomic mass units (amu); electron: 0.000549 amu; alpha particle: 4 amu

Supplemental content: The electrons had very little mass compared with the alpha particles, so it was reasonable to assume the alpha particles would just push the electrons out of the way.

Clarification - this is an important point before moving on to the simulation. Students may need help connecting all the relationships and interactions. Students may want to add to or edit their answer during or after the whole class discussion of this question.

Student responses:

- The electrons are too small and light to affect the alpha particles.

Discussion:
Make sure students agree that it was reasonable for Rutherford to ignore the electrons, why this is reasonable, and set up the upcoming simulation. It might be helpful to build an analogy to think about the different sized objects interacting.

Possible questions:

- *Do you think it was reasonable for Rutherford to ignore the electrons in his calculations? Why?*
- *What would happen an alpha particle ran into an electron?*
- *What would happen if a basket ball ran into a paperclip? How does this relate to the alpha particle and electron?*

Page title:

Investigate

Rutherford used his observations to calculate the strength of the electric field in the atom and that must mean about the positive charges inside the atom. Use the simulation to test the relationships between the distribution of the positive charges, the electric field, and the path of the alpha particles. Adjust the way the positive charge is distributed, and then shoot alpha particles at it. How does the way the positive charge is distributed affect the behavior of the positive alpha particles?

Simulation link: http://lab.concord.org/interactives.html#interactives/interactions/rutherford-no-electrons.json

3. How does changing the concentration of the positive charge affect the electric field generated by it?

Supplemental content: Earlier we saw that more charge created a stronger field. Packing more charge into a smaller area increases the amount of charge in that region and therefore increases the strength of the electric field around that region.

Clarification - students just need to summarize the pattern they observe in the simulation; they do not need to support their answer.

Student responses:

- There is a stronger field around the positive charge when it is more concentrated. This is shown by the model because the pointers are brighter around a more concentrated positive charge.

4. What happens to the alpha particles when the positive region is spread out?

Supplemental content: The alpha particles pass through the positive region. Since the positive charges are spread out, the electric field is weak, and the alpha particles pass through the positive region. An analogy would be thinking about gravitational fields in space. If an asteroid passes through a dust cloud, the gravitational field of those dust particles is too weak to affect the movement of the asteroid significantly. However, if all those dust particles were collected into a planet, the gravitational field would then be strong enough to affect the path of the asteroid. If you carefully observe the alpha particles in the simulation, you will notice that the ones at the top and bottom of the screen do curve slightly. The field is strongest around the edges of the positive region. Thus the alpha particles that happen to pass along the edge are affected the most by the electric field. However, it is not strong enough to turn those alpha particles around and send them back in the direction of the source and Rutherford observed that a few alpha particles returned in the direction of the source.

Clarification - students just need to summarize the pattern they observe in the simulation; they do not need to support their answer.

Student responses:

- None of the alpha particles bounce back
- The alpha particles pass through the spread out positive region

5. [snapshot prompt] Set up the model so that a small number of alpha particles bounce back, similar to what happened in Rutherford's experiment. Take a snapshot of your setup.

Student responses: Student images should show that the positive charge in the simulation is highly concentrated.

6. What do Rutherford's results and the relationships shown in the simulation tell you about the positive charges inside an atom?

Supplemental content: The electric field generated by the atom's positive charge repels the alpha particles. The field has to be strong enough to have a significant effect. In order to create a strong enough field to deflect some of the alpha particles, the positives within an atom must be concentrated.

Clarification - students should connect the results from Rutherford's experiment with the observations of the simulation to make a claim about the concentration of positive charges within atoms. This is a difficult concept, students may need support, to discuss their ideas, and revised their answers in order to connect all these ideas.

Student responses: Students may need to edit their answers during or after the class discussion in order to put all the concepts together.

- In the simulation, alpha particles are only deflected if the positive area is really concentrated. Rutherford saw that some alpha particles were deflected when he shot them at gold atoms, so the positive area in the gold atoms must be really concentrated.

Discussion

After students had some time to explore the simulation, discuss the simulation as a class. This is a complex simulation and concept and students will need time to work through the relationships shown in the simulation and how the connect with Rutherford's observations.

Use the aspects of models to discuss the simulation and relationships shown in the simulation first.

- What are the components/variables shown in the simulation?
- What are the relationships between those components? (What are you trying to test?)
- What are some connections between the simulation and the results of Rutherford's experiment?

Similar to the simulations related to Thomson's experiment, make sure students are clear about what is represented in the simulation and how it is different from what Rutherford did.

Possible questions:

- *What is the purpose of this simulation?*
- *How does this simulation relate to what Rutherford did?*
  - *Is the simulation representing an actual atom?*
  - *Did Rutherford change the the concentration of an atom?*

Once students agree on the relationships shown in the simulation, discuss some of the questions and the connection to Rutherford's observations.

Possible questions:

- *What does Rutherford's experiment tell us about the Plum pudding model?*
  - *In the Plum pudding model are the positive charges spread out or concentrated? According to the simulation, what should have happened in that case?*
- *What do the results from Rutherford's experiment and the relationships shown in the simulation tell us about what must be true about the positive charges inside the gold atoms?*
- *What do you think you would observe if you tried this experiment with other atoms (for example, aluminum foil or a sheet of paper - mostly carbon, hydrogen, oxygen, and nitrogen atoms)?*

7. In what ways did Rutherford's experiment NOT support the plum pudding model?

Supplemental content: In the plum pudding model, the positive charge is evenly spread out. So if the plum pudding model were correct, the electric field around the positive charge would not be strong enough to deflect alpha particles. Since some alpha particles were deflected in Rutherford's experiment, the plum pudding model could not be correct.

Clarification - This is a complicated question and concept, students may need support to connect the simulation, the plum pudding model, and the hypothetical question about how the result would have come out differently.

Student responses:

- In the plum pudding model, the positive is spread out. The results of Rutherford's experiment did not match with this because spread out positive charge could not have been able to deflect any alpha particles.

8. [drawing prompt] Draw a model of the atom that could explain Rutherford's observations. Keep in mind, models must account for all evidence, so your model should still account for Thomson's observations.

[text prompt] Describe how your model explains Rutherford's and Thomson's observations.

Student responses: Students' drawings will still vary significantly. In particular, they may not know where to place the electrons, and that is fine at this point. However, the atoms students draw should include both positive and negative parts, and the positive parts should be concentrated in one location.

9. Revisit your previous model of the atom, which you drew in Activity 4.2. If your model has not changed, how does it explain Rutherford's results? If your model has changed, what evidence convinced you that you needed to change it?

Student responses: Students should now have both negative and positive parts included in their model, and they should connect their new representation with evidence from Rutherford's experiment.

- If students had positive charges spread out in their previous model, they should discuss how the evidence from Rutherford and the simulation showed that the positive charges must be concentrated.
- If students only included negative charges in their previous model, they should discuss how Rutherford's results provided information about the inclusion and location of the positive charges.
- If students included one or more positive parts concentrated together in their previous model, they can cite as evidence the results of Rutherford's experiment, which showed that there is a positive part of the atom that repels the positive alpha particles.

Reviewing Student Models

Review students' latest atomic models.

- Note the variety, and ask students what they think about the different representations.
- Be sure students make connections between their models and evidence from the simulation. It would be useful to have the simulation projected.
- If a model seems confusing, ask if any students think they can explain it. (Or if students are willing to have names attached to their models, ask the author of the model to explain it.)
- Add to the DQ board a few models selected by the class.

Discussion

Relate student models to the activity-level driving question: *What else makes up an atom?* Also make connections to the question of how objects become charged.

Possible questions:

- *How does this model of the structure of the atom, which is based on Rutherford's experiments, help explain how objects become charged?*
- *What questions do you have about how the structure of atoms relates to the charge of objects?*

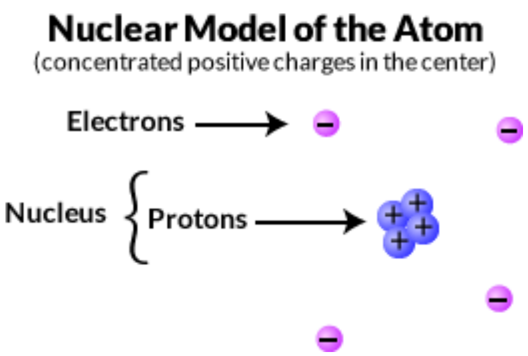
Post relevant questions and comments on the DQ board.

Page title:

A nuclear model of the atom

Based on the results of the gold foil experiment, Rutherford suggested that atoms have a very small, dense, positive core.

As a result of Rutherford's experiments, the plum pudding model of atomic structure had to be revised. Rutherford determined that instead of being spread throughout the atom, the positive part of an atom must be concentrated into a tiny space. The positive parts got the name *protons*. The area where the protons are concentrated together in the center of the atom was named the *nucleus*.



10. Recall that Rutherford observed that about 1 out of every 10,000 alpha particles bounced back. What does this tell you about the relative size of the small dense, positive nucleus compared to the size of the rest of the atom?

Supplemental content: The size of the nucleus is several orders of magnitude smaller than the size of the rest of the atom. This relationship makes it very difficult to represent atoms as it is impossible to provide an accurate representation of these relative sizes. In fact, if the image above were accurate, the small, dense, positive nucleus would be too small to be seen.

Clarification - students should use the fact that relatively few alpha particles bounced back to conclude that the nucleus must be significantly smaller.

Student responses:

- The nucleus must be really small compared to the size of the atom
- The nucleus must be like 10,000 times smaller than the atom

11. Rutherford was really surprised by the results of his experiment and calculations. Based on what you know about interactions between charged particles, why would scientists be surprised that a nucleus consists of positive charged protons packed closely together in a tiny space?

Supplemental content: Positive charges repel each other, especially when close together. It surprised Rutherford that the positive charges in an atom would group together in a concentrated area. He speculated that there must be something else in the atom to hold those positives close together.

Clarification - students should pull in their previous understanding about interactions between charged objects and distance.

Student responses:

- Positive charges should repel, not clump together in a tight space

Page title:

One more mystery to solve

The model suggested by Rutherford's experiments puzzled scientists. Why would positive protons with all the same charge pack closely together?

Hydrogen with a single proton made sense, as did the expected mass of a hydrogen atom. However, other atoms presented a challenge both in charge and mass.

12. [Prediction question] Given the information in the table, predict what the mass of a helium atom should be.

Particle	Mass
proton	about 1 atomic mass unit (amu)
electron	much, much less than 1 amu
hydrogen atom (1 proton & 1 electron)	about 1 amu
helium atom (2 protons & 2 electrons)	?????

Supplemental **content:** Since the mass of the electron is so insignificant, the mass of the whole atom should be equal to the mass of the number of protons, therefore the mass of a helium atom should be 2 amu.

Clarification - students should use the masses and the patterns to predict the mass of helium.

Student responses:

- 2 amu

[prediction reveal] The mass of helium atoms are higher than predicted given the number of protons. Helium atoms have a mass of about 4 amu. In fact, most atoms seem to be too heavy. Lithium is known to have 3 protons, but a mass of 7 amu, carbon atoms have 6 protons and a mass of 12 amu. What could account for the extra mass?

Discussion:
Review the idea of the nucleus, protons, the size of the nucleus and the puzzle about the mass of atoms.

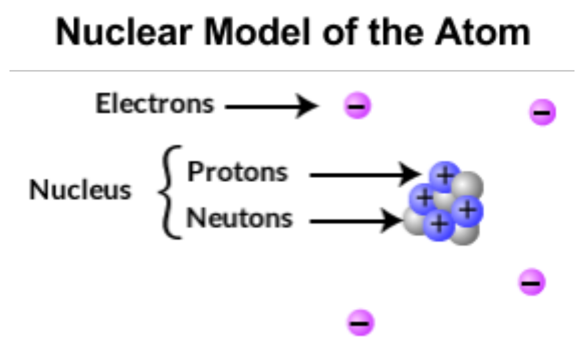
Possible questions:

- *What is the nucleus? What is it made of?*
- *Why is it surprising that protons would clump tight together?*
- *How much space within the atom do the protons/does the nucleus take up? How do you know?*
- *What do you think is in the rest of the atom?*
- *There is also the puzzle about the mass, what do you think could account for the mass of the atom?*

Page title:

Nuclear model of the atom

Rutherford proposed the idea that there could also be another particle in the nucleus with the protons. He thought these particles would be neutral and named them neutrons. Through additional experiments, scientists determined that atoms do in fact have neutral particles that are about the same mass as protons. An atom generally has the same number of protons and electrons.



Note: Neutrons are neutral particles. Neutral particles are different from neutral objects. Neutral objects are made of several atoms and are neutral because they have the same number of protons and electrons. Neutrons, however, have no charge at all. While we saw that neutral objects are attracted to charged objects, there is no electrostatic interaction between neutral particles and charged particles. This idea will be developed in the next investigation, but students may confuse these ideas at this point.

13. [Prediction question] How does the idea of a neutron help address the puzzles about the protons in the nucleus and the mass of atoms?

Student responses: Students should be able to connect the extra mass with the existence of neutrons. Students may also think that the neutral neutrons and positive protons would be attracted, while this is not accurate, it does match the students' earlier observations and they have not yet differentiated between neutral objects and neutral particles.

- The extra mass could have come from the neutrons
- The neutrons could lessen the repulsions between the protons
- The neutrons could be attracted to the neutrons

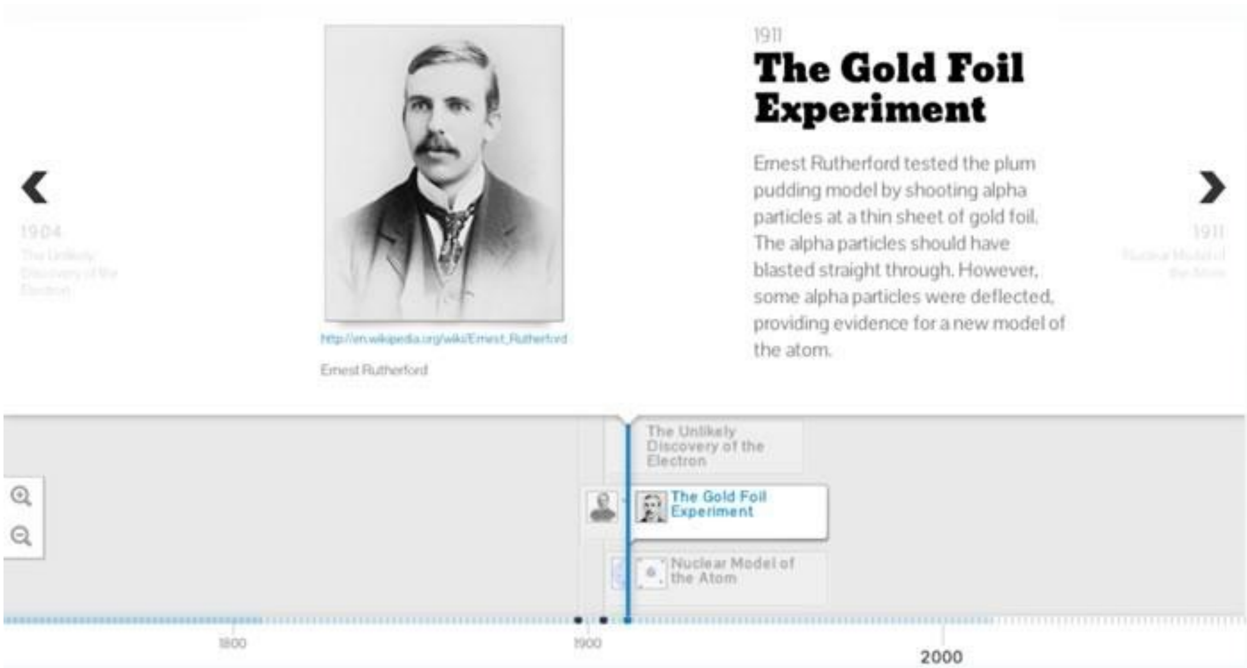
[prediction reveal] While the idea and later discovery of neutrons did explain the extra mass in atoms, it still seemed that the positive protons would repel each other. Neutral particles could act as a "buffer" but in such a small space, the repulsion between the protons should be really strong. It turns out that a special type of force, which is called the *strong nuclear force*, exists between protons and neutrons in the nucleus. This force is about 100 times stronger than the electric force. It also only acts over very short distances.

Discussion:
Review the idea of the nucleus, protons, neutrons, and the strong force.

Possible questions:
- *How does the idea of neutron help explain why many atoms seem too heavy?*
- *What does the strong nuclear force do?*

Page title:

Explore the timeline



[Click here for link to live timeline.]

Homework: Reading for Activity 4.3 [Why Doesn't an Atomic Nucleus Fly Apart?]

Activity 4.4: Where are the electrons?

SUMMARY

The experimental evidence thus far has helped establish a model of atomic structure that contains negatively and positively charged particles, as well as a dense, positively charged nucleus at the center. At this point, the model contains little information about the electrons except that they surround the nucleus. To help students understand the probability (or electron cloud) model of the atom, this activity provides students with experiences that help them make sense of a probabilistic electron density representation of electrons.

LEARNING GOAL

Students will use mathematical thinking to describe probability and to analyze cloud representations of electrons in atoms.

Disciplinary Core Idea	Crosscutting Concept	Scientific and Engineering Practice
Structure and properties of matter: Each atom has a charged sub-structure consisting of a nucleus, which is made of protons and neutrons, surrounded by electrons. (NGSS Lead States, p. 92)	*Patterns:* Students observe patterns in systems at different scales and cite patterns as empirical evidence for causality in supporting their explanations of phenomena. They recognize classifications or explanations used at one scale may not be useful or need revision using a different scale; thus requiring improved investigations and experiments. (NGSS Appendix G p. 82)	*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

- In this activity, students will not connect atomic structure to phenomena because the phenomena related to probability models of atomic structure are related to waves, light, and complex mathematical thinking, which are all beyond the scope of this curriculum. The Appendix provides some information about some of this evidence that led to the probability model and the evolution of the atomic model.
- Students are often familiar with the Bohr and sometimes have a difficult time moving past or letting go of this model. Emphasize that all models have shortcomings and you have to select the model that is most appropriate for problem you are working on. The Bohr model is useful for some situations, but the questions we are answering the Bohr model is NOT very useful, but the probability model is.
- Most historical experimentation will be glossed over in moving through the Bohr model to the orbital model. Some students may have been taught the Bohr model previously. These students may have more difficulty transitioning to the probability map view of electrons around a nucleus. Focusing on the two representations as models and the fact that they each have value, depending on their use, can help students.

PREPARATION

Class Time: 45 min.

Materials (for each group)

- pencil
- lab handout for Activity 4.4: Describing probability

HOMEWORK

Reading for Activity 4.4: A Short History of the Atom

BASIC OUTLINE OF ACTIVITY

Use this space to make notes to prepare for your lesson

1. The Bohr model
2. Describing probability
    a. Pencil drop test
3. Predicting random events
    a. Bullseye simulation
4. Representing electrons with probability maps
    a. Interpreting electron cloud representation
    b. Discussion
5. The changing model of the atom
    a. Timeline

Activity 4.4 (Student materials): Where are the electrons?

Discussion: Review the reading from the homework for Activity 4.3: Why Doesn't an Atomic Nucleus Fly Apart?

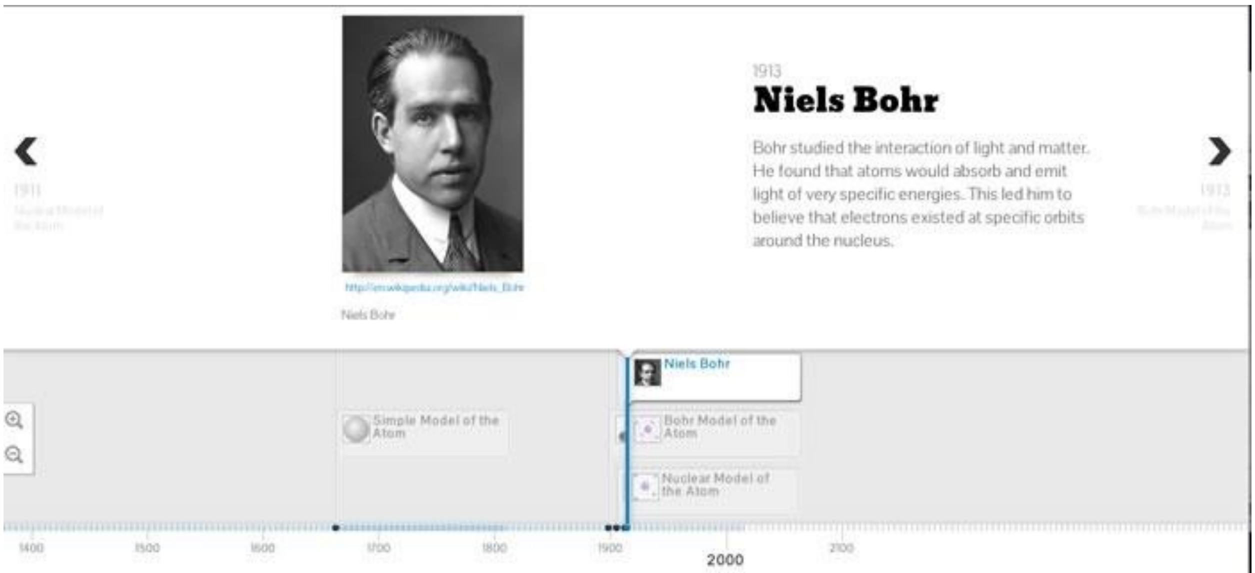
Possible questions:

- *Why doesn't the nucleus fly apart?*
- *Do you think it would be easy to change the number of protons or neutrons in a given atom? Why?*
- *What did you get for the calculations in Table 2?*
    - *Do others agree or disagree with that?*
    - *What object did you identify as about that size?*

Page title:

The Bohr model

Read about Niels Bohr who created the model of the atom you are probably most familiar with. Then, click on the arrow at the right side of the timeline to see the Bohr model, and answer the questions below.



[Click here for link to live timeline.]

1. The Bohr model is a model that is commonly shown in many science textbooks. How does this model align with the evidence we have analyzed about atomic structure (from Thomson's and Rutherford's experiments)?

Student responses: Students are not expected to relate the correct name to the discovery.

- The Bohr model includes negative particles and the positives are clumped together.

2. What is inaccurate about the way atomic structure is represented in this model?

Student responses: Students may identify a variety of issues.

- The nucleus is too big
- Electrons should not be purple
  - *Since negative is always red in the simulation, students may have associated red with electrons. Ask them if we have evidence about the colors of the parts of atoms.*

Discussion: Discuss the Bohr model. Students may be familiar with this model and often get very attached to this model. Be sure to emphasize the limits of this model.

Possible questions:

- *What is represented in this model?*
- *How does this fit with Thomson's evidence? Rutherford's?*
- *What are the limitations of this model?*
- *How do we decide if a particular model is a good one?*

Models are evaluated based on how well the align with the available evidence and how well the help explain answers or solve problems. Emphasize that this means some models might be great for one problem but not work well for a different problem. The Bohr model is like this. It is very useful in certain situations, but it is not helpful for explaining how objects become charged or why charged and neutral objects interact.

For our questions, the probability model is most useful, we will not be using the Bohr model.

Page title:

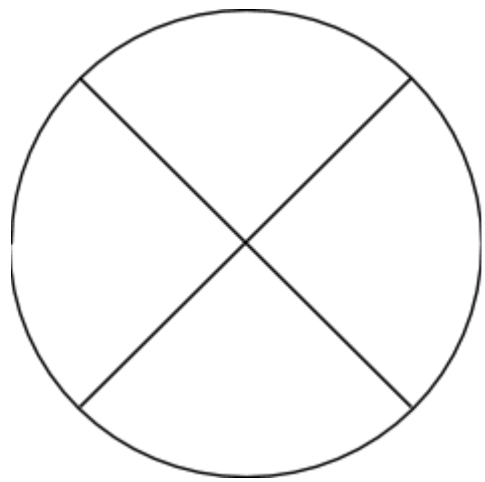
Describing probability

The Bohr model is common because it is very useful for specific problems However, the Bohr model does not help answer our questions: How do objects become charged? Why do neutral and charged objects interact?

For these questions, the probability model of atomic structure is more useful. In the probability model, instead of having electrons in orbits, you represent the regions within an atom where electrons are most likely to be found.

But how do you draw a representation of a region where an electron is likely to be found? By following the steps below, you will see how this kind of representation can be built.

1. Draw the target symbol shown here on a piece of paper.
2. Place the paper on a table, a desk, or the floor.
3. Hold a pencil about 1 foot directly above the center of the circle with the point of the pencil facing downward.
4. While aiming the tip directly at the center of the "X," drop the pencil.
5. Repeat this many times (at least 25 times, even more is better), dropping the pencil from the same place each time.



Tip: If you have a ring stand, you might have students set up a small ring or test tube holder on the stand to act as a guide for dropping the pencil from the same location each time.

Discussion: Have students share their papers. Students could all stick their paper up on the wall, or you could have several students volunteer to share theirs.

Possible questions:

- *What patterns do you notice?*
- *What is similar across these papers?*

3. Describe the pattern of marks on the paper.

Student responses: Students should describe what they observed.

- There are a lot of dots on the paper, with more of them concentrated in the middle and fewer far from the center.

4. If you dropped the pencil one more time, do you think it would be more likely to land near the center or near the edge of the circle? Include evidence to support your answer.

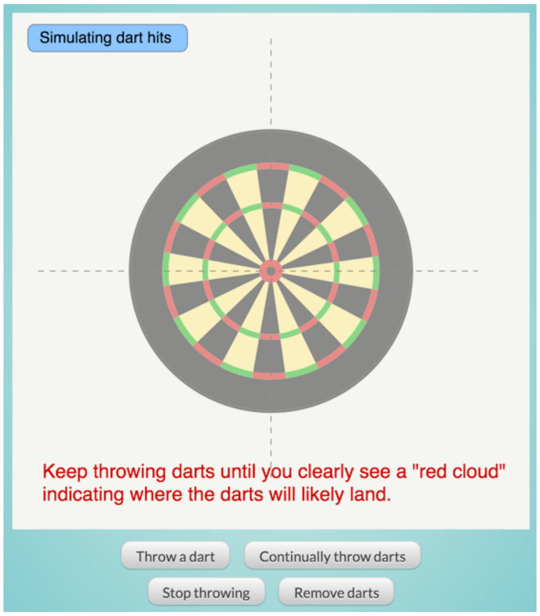
Student responses: Students should use the pattern on their paper to make a general prediction about where the next mark is more likely or less likely.

- It is most likely to land near the center. Using the dot pattern on the paper, you can see that the pencil usually landed near the center rather than near the edge of the circle.
- It is more likely to land near the edge - one has not hit there in awhile.
    - *Help student differentiate between the likelihood that a mark will be made near one of the edges and the likelihood that the next mark will be made near the end.*

Page title:

Predicting random events

Try building your own probability map using the simulation below.



Simulation link: http://lab.concord.org/interactives.html#interactives/interactions/electron-darts.json

5. [drawing prompt]After throwing many darts, take a snapshot of the dart board. Assuming the same person threw all of the darts, draw a circle on your snapshot to indicate where the next dart is likely to land.

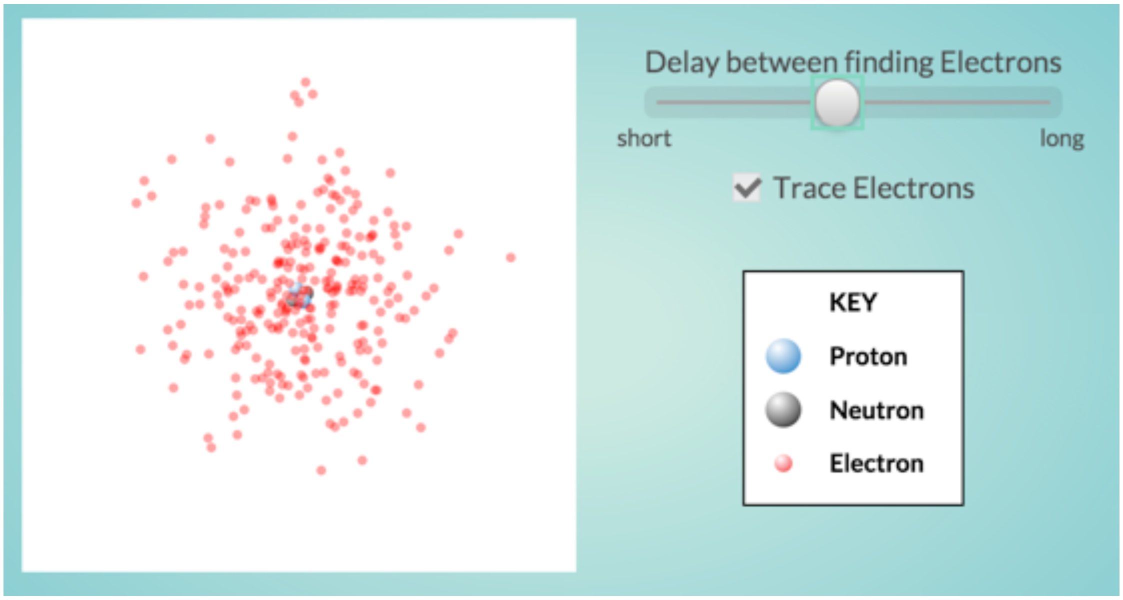
[text prompt] Explain why you think the next dart will land where you indicated.

Student responses: Students may make a variety of predictions depending on how "daring" they want to be. A conservative prediction would include making a large circle around the whole area. A more risky prediction would be to make a smaller circle near the center of the circle. In either case, students should be able to support their idea.

- It is most likely to land near the center. Using the dot pattern on the target you can see most hit there.
- All the targets hit somewhere inside this area.
- Some students may pick a specific point.
  - *Ask students if they would be willing to bet $100 that the next dart would land in that exact place. Is there area that you would be willing to bet $100 on?*

Page title:
Representing electrons with a probability map

In the animation, watch as an electron's location is traced out.



http://lab.concord.org/interactives.html#interactives/interactions/structure-of-an-atom.json

6. Notice, as you watch the animation that the red color gets dark in the region of the atom right over the nucleus. What does this represent?

Student responses:
- The darker color represents that the electron is most likely to be close to the nucleus
- The electron goes back to the space near the nucleus most often

7. Why would the electrons spend most of their time close to the nucleus?

Supplemental content: Due to the attractive forces between positive protons and negative electrons, electrons are most likely to be close to the nucleus. The electrons also repel other electrons and they have an extremely high amount of energy. Due to the high energy and the repulsion with other electrons, the electrons move throughout a very large area. In fact, there is no limit to how far away the electron could move. The attractive forces between the protons and electrons pulls the electrons back closer to the nucleus.

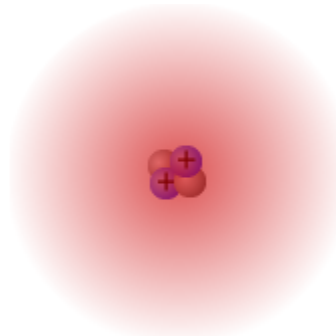
Clarification - students should use the interactions between charges that they have learned to speculate about why electrons are most likely to be found near the nucleus. However, they are not expected to know more about the properties and behavior of electrons.

Student responses:
- Electrons are negative, protons are positive, and opposite charges attract.

Page title:

Interpreting electron probability maps

The region where electrons are likely to be located around an atom's nucleus is shown in much the same way as the probability map you created with the pencil and the probability map shown on the dartboard.



8. [drawing prompt] Draw on this image of an atom to indicate where you are more likely and where you are less likely to find electrons.

Student responses: Students should indicate that electrons are more likely to be found near the center of the circle than near the edge.

Discussion: Discuss the probability model. Students who are familiar with the Bohr model may be resistant to the idea that the electrons are most likely to be found close to the nucleus. Push students to interpret the representation and connect with their understanding of how charged objects interact.

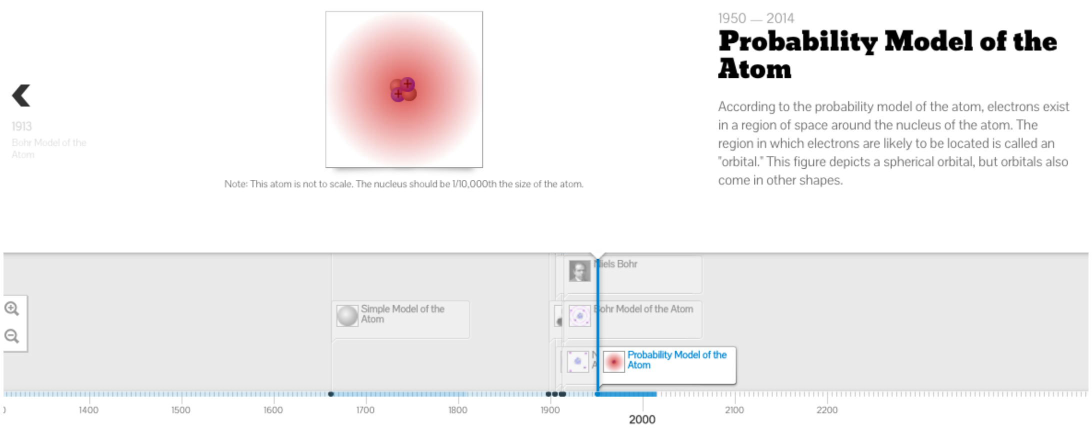
Possible questions:

- *According to this model, where are electrons most likely to be found?*
- *Is that the only place where the electrons can be?*
- *How is this model different from the Bohr model?*
- *How does this model fit with what we already know about how charged objects interact?*

Page title:

The changing model of the atom

Throughout history, the accepted model of the atom has changed many times as a result of new data and experiments. The probability model, which has been in use since the 1950s, is the currently accepted model of the atom. What do you think might come next on the timeline?



[Click here for link to live timeline.]

Homework

- Reading for Activity 4.4: A Short History of the Atom