TOPIC
2.4

How can we investigate and explain the composition of atoms?

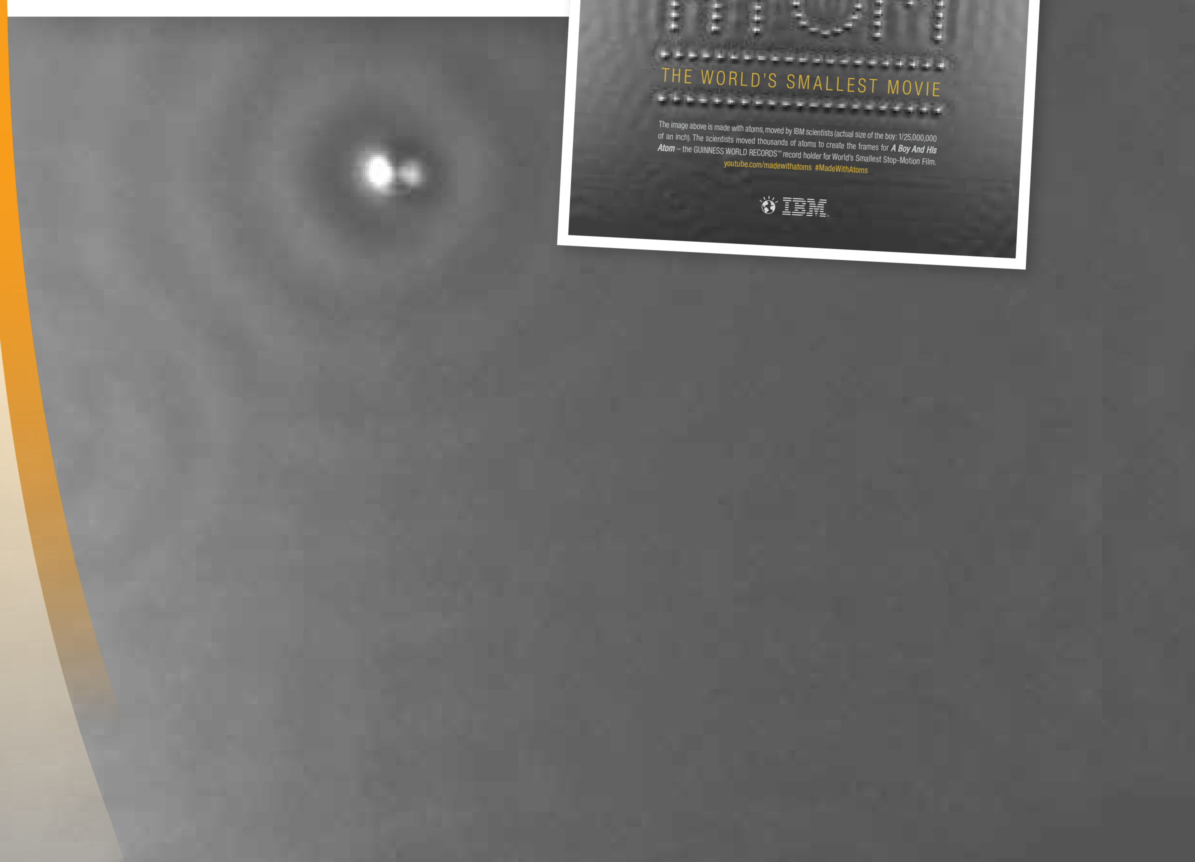
Key Concepts

- Dalton developed an early atomic theory.
- Many scientists contributed to the further development of atomic theory.
- An atom is made up of electrons, neutrons, and protons.
- Atomic theory continues to develop.

Curricular Competencies

- Seek patterns and connections in data from your own investigations and secondary sources.
- Transfer and apply learning to new situations.
- Generate and introduce new or refined ideas when problem solving.
- Communicate ideas using scientific language and representations.

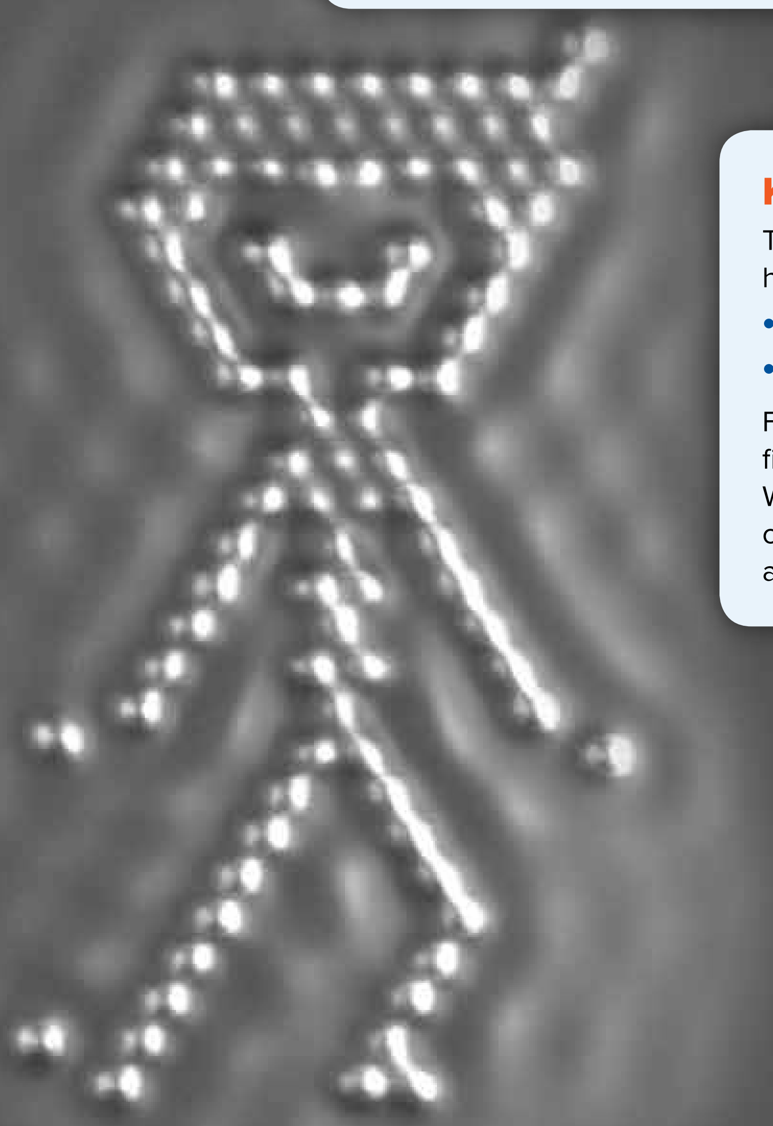
This is a frame from the smallest stop-motion animated movie in the world: "A Boy and His Atom." Just how small is the movie? The dots you see here are oxygen atoms, each one the visible portion of a carbon monoxide molecule. Scientists moved them bit by bit, frame by frame, capturing the images using a powerful high-tech microscope. Being able to capture images of individual atoms and move them around with precision would have been jaw-dropping to scientists working in the late 1800s and early 1900s. Even so, with the technologies and techniques available to them at that time, scientists were able to imagine, plan, and conduct experiments to probe the structure of the particles that make up matter. Even today, we use the ideas and theories they developed to explain the properties and behaviour of the matter all around us.



Starting Points

Choose one, some, or all of the following to start your exploration of this Topic.

1. **Identifying Preconceptions** The questions below involve scientific theories.
   - What is the difference between a scientific law and a scientific theory?
   - What is a hypothesis and how is it different from a scientific theory?
   - What is the relationship between a prediction and a theory?
2. **Questioning and Predicting** What questions do you have about how and why “A Boy and His Atom” was made? Record at least three questions and investigate them online.
3. **Evaluating** List two observations about matter that can be explained using kinetic molecular theory and two observations that cannot.



Key Terms

There are five key terms that are highlighted in bold type in this Topic:

- electrons
- nucleus
- protons
- neutrons
- atom

Flip through the pages of this Topic to find these terms. Add them to your class Word Wall along with their meaning. Add other terms that you think are important and want to remember.

CONCEPT 1

Dalton developed an early atomic theory.

Activity

Explaining Differences in Matter

Your teacher will provide you with three different white solids. Examine the solids using a magnifying glass. How would you describe each solid? How are they different and how are they the same? Add vinegar to a small amount of each and describe what you observe. With your teacher's permission, heat a scoopula-tip's worth of each substance on a piece of foil on a hot plate and describe what you observe. Summarize your observations in a table. Does kinetic molecular theory help you explain the differences you observed?

The kinetic molecular theory of matter is based on the idea that matter is made up of tiny particles in motion. This theory does a good job of explaining why substances can exist in different states, and what happens when matter changes from one state to another. But there are many observations about matter that it cannot explain. For example, it does not explain why water and mercury have such different properties, even though both are liquids. Water is essential to life, while even small amounts of mercury can be deadly. **Figure 2.20** shows the difference in their densities. What causes these differences?

Figure 2.20 The kinetic molecular theory of matter cannot explain why mercury and water are so different.

Greek Philosophers and *Atomos*

Various peoples throughout history have used storytelling, philosophical debate, and other modes of communication and analysis to share and explore ideas about the properties and changes of matter. The idea that matter is made up of different kinds of tiny particles is actually thousands of years old. A Greek philosopher named Democritus proposed the idea that matter was made up of tiny particles that exist in empty space. He called these particles *atomos*, which means "uncuttable," because they could not be created, destroyed, or divided any further. Although this idea is similar to the idea of atoms that was developed by scientists in the 19th and 20th centuries, Democritus did not use experiments to support his ideas. As a philosopher, he used only reason and logic.

Philosophies of Matter

A well-respected and very influential philosopher, Aristotle, disagreed with Democritus's ideas, in large part because he did not believe that empty space could exist. Like many disagreements on social media today, the argument was won partly by popularity (**Figure 2.21**). In fact, Aristotle's influence was so great that his denial of the existence of atoms persisted for 2000 years.

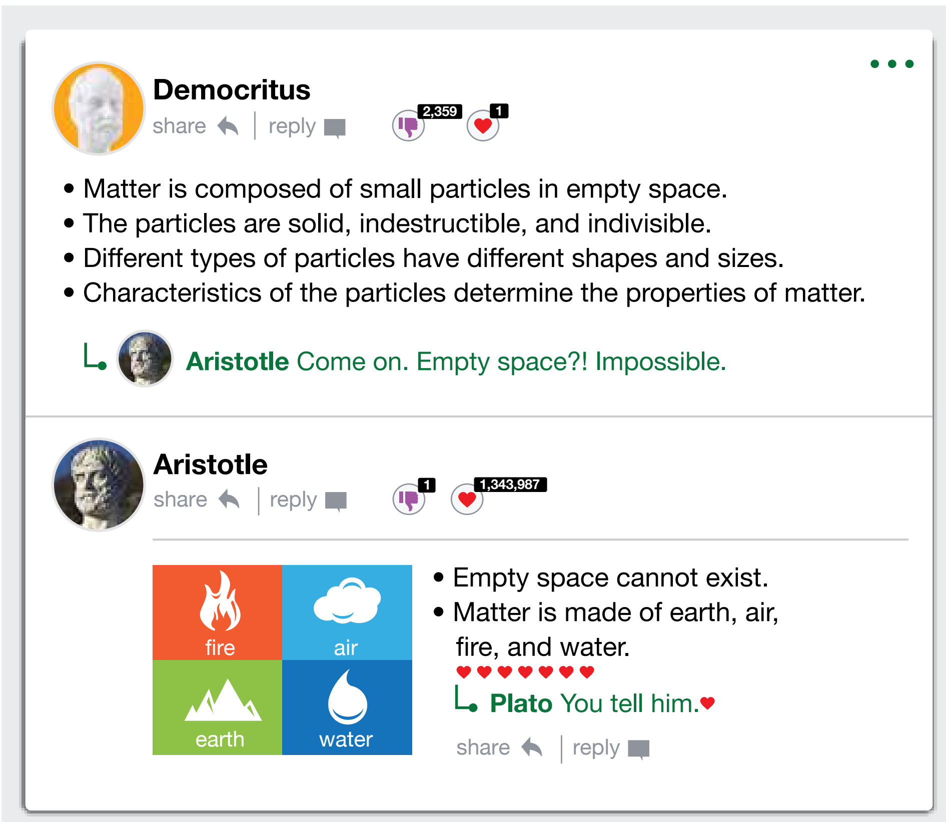


Figure 2.21 If Democritus and Aristotle had been able to use social media thousands of years ago, their posts might have looked like this.

Atomic Theory Begins

Over the centuries, people in different countries read about the idea of *atomos*, and many (including some scientists) agreed with it. However, it was not until the early 1800s in England that the *atomos* idea reappeared with the support of experimental results and analysis. John Dalton (1766–1844), shown in **Figure 2.22**, was a schoolteacher and scholar. Unlike Democritus, he was able to conduct controlled scientific experiments. He could do this because the general methods of scientific inquiry had already been developed. He also had access to instruments such as glassware and accurate balances that enabled him to measure changes in matter.

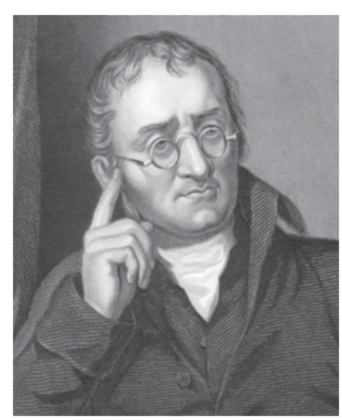


Figure 2.22 John Dalton

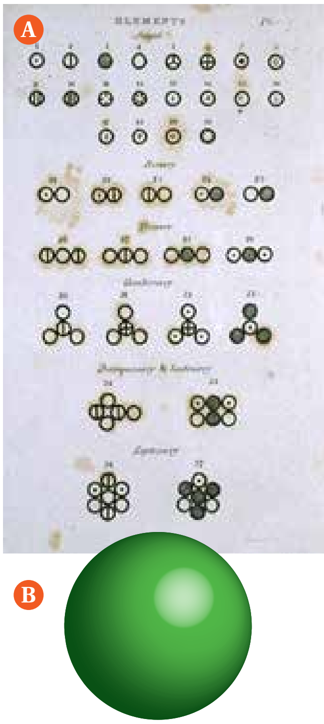


Figure 2.23 A This page from Dalton's book, *A New System of Chemical Philosophy*, shows the symbols he used to represent atoms of different elements. B According to Dalton's theory, atoms were solid, indestructible spheres.

Dalton's Theory of the Atom

Dalton's experiments allowed him to develop, refine, and support a hypothesis about matter. Studying many chemical reactions, he made careful observations and measurements that led him to propose in 1803 what has now come to be known as *Dalton's atomic theory*. He published his ideas in a book, a page from which is shown in **Figure 2.23**. The key points of his theory are described below.

Dalton's Atomic Theory

- All matter is made of extremely small particles called atoms.
- Atoms cannot be created, destroyed, or divided.
- All atoms of the same element are identical in size, mass, and chemical properties. Atoms of a specific element are different from those of another element.
- Different atoms combine in simple whole-number ratios to form compounds. In a chemical reaction, atoms are separated, combined, or rearranged.

Dalton's Theory Was Just the Beginning

Dalton's theory explained many existing observations about matter and its interactions. One example is the observation that mass is conserved in a chemical reaction—Lavoisier's law of conservation of mass. Since atoms were not created, destroyed, or divided in chemical reactions, it made sense that the mass of reactants and products in a chemical reaction did not change.

As scientists continued to study matter and to develop new technologies to allow them to perform different kinds of experiments, it became clear that Dalton's atomic theory could not explain all of the observations that scientists were making. Scientific theories are always subject to being changed or discarded if they prove insufficient to explain new observations. Dalton's atomic theory was just the beginning.

Before you leave this page . . .

1. Compare and contrast Democritus's *atomos* with Dalton's atomic theory.
2. How is a philosophical idea different from a scientific theory?

CONCEPT 2

Many scientists contributed to the further development of atomic theory.

Activity

Mystery Box

Your teacher will give your group a box, which you are not allowed to open. Using your skills of observation and the materials your teacher provides, perform as many tests as you can think of on the box to infer what is inside. How does this activity relate to the study of matter?

After Dalton got modern atomic theory rolling in the early 1800s, a series of discoveries followed that resulted in its adjustment and refinement. Throughout the remainder of the 19th century, many different scientists and inventors contributed to this work. A scientist named JJ Thomson was among the first.

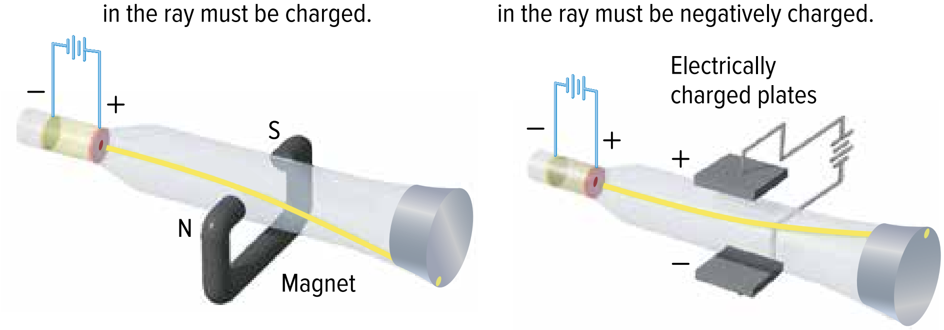
JJ Thomson and the Electron

Joseph John Thomson (1856–1940) was a British physicist who studied electric currents in cathode ray tubes, as shown in Figure 2.24. Scientists had discovered that when they attached a battery to the tube, a ray travelled through the tube. They called this ray a *cathode ray* because it appeared to originate from the negative terminal or *cathode* in the discharge tube. Further experiments revealed the following:

- Cathode rays were streams of negatively charged particles.
- All substances produced these particles.

A The cathode ray is deflected by the magnets. This means the particles in the ray must be charged.

The cathode ray is attracted to the positively charged plate. Opposites attract: the particles in the ray must be negatively charged.



The amount of deflection of the rays gave Thomson information about the ratio of the charge of the particles to their mass.

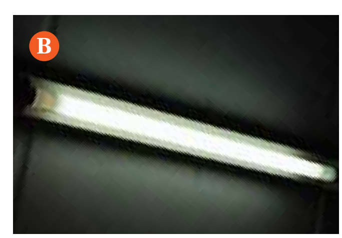


Figure 2.24 A Thomson used magnets and charged plates to manipulate cathode rays and measure the effects. B Fluorescent lights are familiar examples of cathode ray tubes.

Thomson's Model of the Atom

Connect to Investigation 2-H on pages 168–169

Thomson's key cathode ray tube experiments involved determining the charge-to-mass ratios of the negative particles. He did not determine the mass of the particles directly, but his experiments did allow him to compare their mass to that of a hydrogen atom, the lightest known atom. To his surprise, he found that the mass of the charged particles was much less than an atom of hydrogen. This meant that there were particles smaller than the atom! The conclusion was surprising because it contradicted the part of Dalton's theory that defined atoms as being indivisible. Based on the results of Thomson's experiment, Dalton's theory had to be revised, and a new model of the atom was developed.

Thomson proposed what he called a "plum-pudding" model of the atom. Plum pudding was a popular dessert in England at the time, but thinking of this model as a more familiar blueberry muffin gives the same results. Thomson's model, shown in **Figure 2.25**, pictured a positively charged ball (the "muffin") with negatively charged **electrons** embedded in it like blueberries. This model successfully explained the observations to date, but it soon had to be revised based on the findings of Thomson's student, Ernest Rutherford.

electrons negatively charged particles that are found in the space surrounding the nucleus

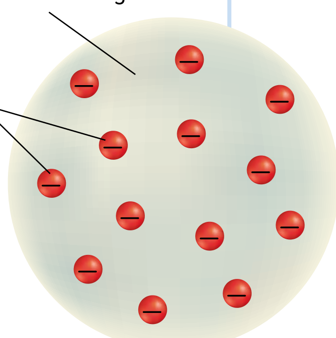


Figure 2.25 Thomson proposed a model of the atom similar to a blueberry muffin. Negatively charged particles (now called electrons) were embedded in matter with a positive charge that was evenly spread out.

Thomson's Contribution to Modern Atomic Theory

Atoms are not indivisible. They contain smaller, negatively charged particles, now known as electrons.

Ernest Rutherford and the Nucleus

Ernest Rutherford (1871–1937) was a scientist from New Zealand who worked for a while at McGill University in Montreal. In 1909 he designed an experiment to find out more about the structure of atoms. He exposed a very thin sheet of gold to a stream of high-speed particles with a positive charge, called alpha particles. The alpha particles acted like tiny bullets. Rutherford wanted to see what would happen to the alpha particles when they made contact with the gold atoms. He surrounded the gold foil with a detector screen. An alpha particle would become visible whenever it struck the screen. **Figure 2.26** shows how the experiment was set up.

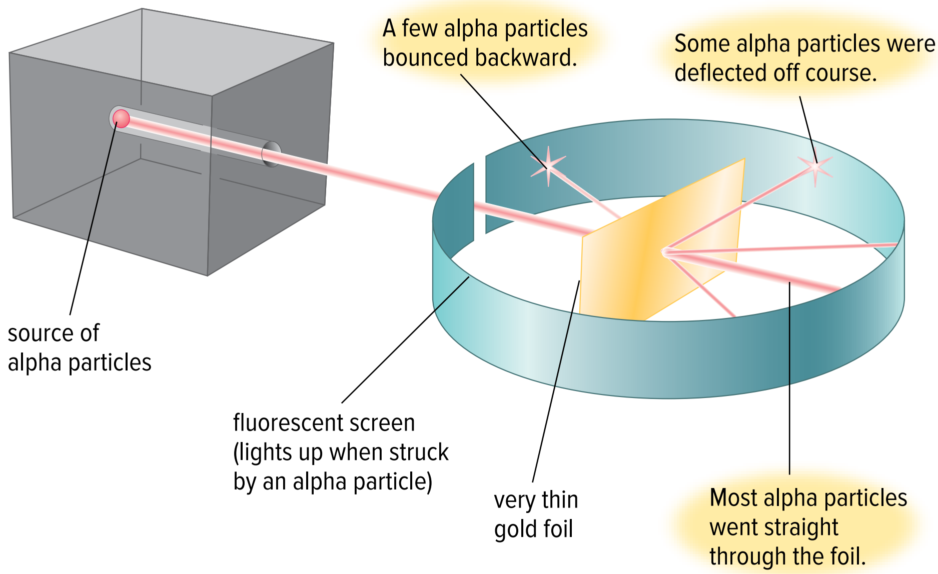


Figure 2.26 In Rutherford's experiment, most of the alpha particles went straight through the foil as expected. But a few bounced back, some at large angles. Rutherford had discovered the nucleus.

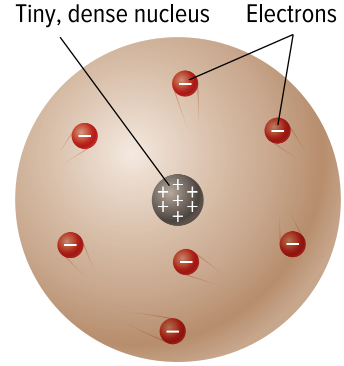


Figure 2.27 Rutherford revised the model of the atom to include a dense nucleus with a positive charge that was very tiny compared to the overall size of the atom. Electrons moved freely in the space surrounding the nucleus.

Most of the alpha particles went right through the gold atoms without their path being affected. This result was not surprising; it was consistent with Thomson's model. (Imagine a bullet going through a muffin.) The surprising result was that a small percentage of the alpha particles rebounded from the foil, much as a ball bounces off a wall. Rutherford had discovered the **nucleus**—the tiny, dense, positively charged centre of the atom.

Once again atomic theory had to be revised, and a new model of the atom, as shown in Figure 2.27, was proposed. According to Rutherford's model, virtually all of the mass of an atom was concentrated in the nucleus. The nucleus was so small compared to the volume occupied by the surrounding electrons that the majority of the atom's volume was empty space!

By 1920, it had been discovered that the nucleus contained positively charged particles that Rutherford called **protons**. James Chadwick (1891–1974), a coworker of Rutherford's, found that the nucleus also contained neutral particles called **neutrons**.

nucleus the positively charged centre of an atom that contains protons and neutrons; tiny compared with the size of the atom

protons positively charged particles found in the nucleus of an atom

neutrons particles with no charge that are found in the nucleus of an atom

Rutherford and Chadwick's Contribution to Modern Atomic Theory

The vast majority of an atom's volume is empty space occupied by very tiny negatively charged moving electrons.

The positive charge in an atom is contained in a tiny, dense nucleus. The nucleus is made up of two types of particles, each with about the same mass: protons, which are positively charged, and neutrons, which have no charge.

Niels Bohr and Energy Levels

Niels Bohr (1885–1962) was a Danish physicist. While working as a student in Rutherford's lab, he studied electrons and the region around the nucleus. Bohr analyzed the results of experiments on the light released by various gases. In the experiments, the gases had been made to glow by passing an electric current through a low-pressure sample contained inside a glass tube. Each gas produced a characteristic spectrum of light as a result, called a *line spectrum*. The line spectrum for hydrogen is shown in **Figure 2.28**.

Figure 2.28 This line spectrum for hydrogen provides evidence that electrons can have only certain allowed energies.

The colour or wavelength of light is related to its energy. Bohr knew that the light emitted by the gases was a result of high-energy electrons releasing energy. But why did the electrons of a given gas emit light only of certain wavelengths? Rutherford's model of the atom could not explain this result because electrons could possess any amount of energy in that model.

Electron Energy Levels

As shown in **Figure 2.29**, Bohr proposed that electrons surrounding the nucleus could occupy only specific "energy levels" or "energy shells." Each energy shell was associated with a certain amount of energy. The larger the shell, the higher the energy of an electron occupying it.

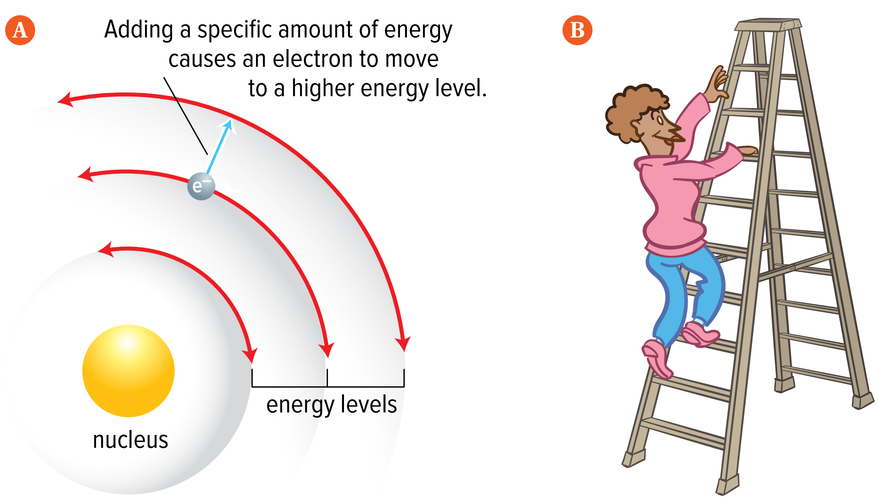


Figure 2.29 A In Bohr's model of the atom, electrons can have only certain amounts of energy. They occupy energy shells surrounding the nucleus. B The energy shells are like rungs on a ladder. When you climb a ladder, your foot can rest on any of the rungs but not in between.

Bohr's Contribution to Modern Atomic Theory

Electrons can have only certain amounts of energy. They occupy defined energy levels or shells in the space surrounding the nucleus.

Visible Effects of Electron Energy Shells

A neon light is an example of the visible effect of electrons jumping from one energy level to another. When electricity is added to the neon gas, the electrons in the neon atoms gain energy, causing them to jump to higher energy levels. Electrons can then fall back down to lower energy levels, releasing energy in the form of visible light of a characteristic colour. The light is the evidence that the electrons exist in specific energy levels and can move from one level to another. The characteristics of the line spectra of various elements can also be used to identify them, as shown in Figure 2.30.

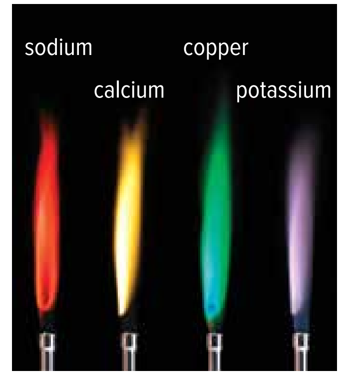


Figure 2.30 Flame tests work by placing a small sample of a compound containing a metal element in a flame. The added energy causes electrons in the atoms to jump up into higher shells and then fall back down, giving off light of characteristic colours.

Atomic Theory—A Group Effort

Bohr did not come up with his ideas in isolation—he built on the existing atomic model and theory, but also on work that Albert Einstein and others were doing regarding the nature of energy and light. Similarly, Thomson, Rutherford, and all of the other scientists who contributed to the development of modern atomic theory built on the work of scientists who had published results before them and who were working simultaneously on related ideas. They also depended on communication and teamwork with their colleagues, students, and laboratory assistants.

Activity

Atomic Theory Timeline

Working in groups, make a digital or paper timeline to show the development of atomic theory. Include the scientists and discoveries discussed in this book, but also research the contributions of additional scientists. You may wish to include some or all of the following people and events: Robert Boyle, William Crookes, Marie Curie, Robert Millikan, Eugen Goldstein, Lise Meitner, the first particle accelerator, the splitting of the uranium atom, the development of atomic weapons, the discovery of quarks and other particles, and the founding of CERN. Include any additional items you find through your research. You may also wish to include key historical events to anchor the events of the timeline, such as World Wars I and II.

Before you leave this page . . .

1. Compare and contrast models of the atom.
2. In your own words, describe Bohr's contribution to atomic theory.

CONCEPT 3

An atom is made up of electrons, neutrons, and protons

Activity

Cutting It Down to Size

Can you cut a piece of paper down to the size of an atom? Atoms vary in size, but a mid-sized atom is about 0.00000002 cm in diameter.

1. Take a strip of paper that is 25 cm long.
2. Predict how many times you would have to cut the strip in half to get a piece that is about 0.00000002 cm wide.
3. Start cutting. How many times were you able to cut your paper in half? How many more times would you have to cut to get your paper to the size of an atom?

atom the smallest particle of an element that retains the properties of that element

Today we know a lot about the nature and structure of atoms. An **atom** is defined as the smallest particle of an element that retains the properties of that element. All matter is made up of atoms, and atoms themselves are made up of smaller particles called *subatomic particles*. Key features of the atom are summarized in **Figure 2.31**.

nucleus

- The nucleus is the tiny region at the centre of the atom.
- The nucleus of most hydrogen atoms contains one proton.
- The nucleus of all other atoms contains both protons and neutrons.
- The number of protons in a nucleus determines the charge of the nucleus and the identity of an atom.

electron energy shell

- The region that electrons occupy accounts for well over 99.99 percent of the volume of an atom.
- Electrons occupy specific regions called energy levels that surround the nucleus.
- An electron is not like a fast-moving particle racing around the nucleus. It is more like a spread-out cloud of negative charge that exists in the whole region all at once.

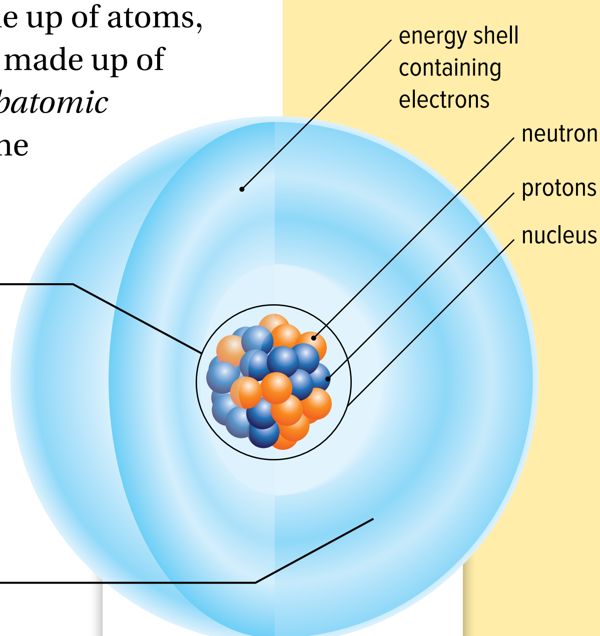


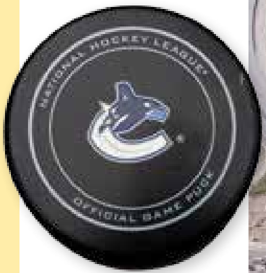
Figure 2.31 This model of the atom will help you explain the observations you make about matter in your study of chemistry.

Electric Charge

Electric charge comes in two types: positive and negative. Protons have a positive charge (1+ each), and electrons have a negative charge (1– each). The positive charge of the protons in the nucleus attracts the surrounding electrons. Neutrons have no charge. Atoms have equal numbers of protons and electrons, and so overall an atom is uncharged or neutral.

The Size of an Atom

Atoms are incredibly small. Suppose you enlarged everything on Earth so that an atom would become as big as a large apple. At this new scale, an apple would be as big as Earth!



The Size of the Nucleus Compared with an Atom

If a nucleus were the size of a hockey puck sitting at centre ice, the whole atom would include the entire rink, the seats, the building, and the surrounding streets and walkways or parking lot.

The Nuclear Force

Nuclei include multiple positively charged particles—protons—that are very close together. Normally, charged particles that have the same charge repel one another very strongly. But a force called the *nuclear force* (also called the *strong force*) acts within the nucleus to hold protons and neutrons together. It is very strong across very short distances—strong enough to counteract the repulsion between protons, keeping the nucleus from flying apart.

Connect to Investigation 2-I on pages 170–171

Subatomic Particles

Name	Symbol	Electric Charge	Relative Mass	Location in the Atom
proton	p^+	1+	1836	nucleus
neutron	n^0	0	1837	nucleus
electron	e^-	1–	1	surrounding the nucleus

Before you leave this page . . .

1. What are the three subatomic particles?
2. Compare and contrast the electron and the proton.
3. Use an analogy to describe the size or composition of an atom.
4. What does the existence of a nuclear force explain?

CONCEPT 4

Atomic theory continues to develop.

Activity

Atomic Theory in the Future

Do you think atomic theory is likely to change in the future? Write a brief blog post explaining your position. Support your ideas with examples.

According to Dalton's theory, atoms were indivisible and indestructible. Then Thomson discovered the electron and Rutherford discovered the nucleus, which was later found to be made up of neutrons and protons. The atom was not indivisible at all: it was made up of even smaller particles—*subatomic particles*. As scientists continued to study matter throughout the 20th century, they discovered that some of these subatomic particles were made up of still smaller particles.

Quarks

You may have heard the term "quark" before, perhaps in the title of CBC Radio's science program, Quirks and Quarks. According to current theories, quarks are *elementary particles*, meaning that they cannot be split apart into smaller particles. There are six different types, called *flavours* (really!) of quarks. They are classified based on their properties, which include mass and electric charge, and have the following creative names: *up*, *down*, *strange*, *charm*, *top*, and *bottom*.

Protons and neutrons are known as composite particles. As shown in **Figure 2.32**, they are both made up of quarks. Protons and neutrons also contain elementary particles called gluons. These act as a "glue" that binds quarks to one another.

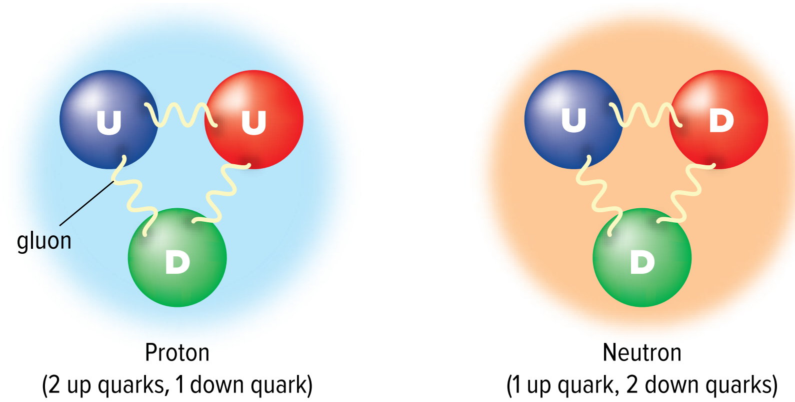


Figure 2.32 Protons and neutrons are made up of smaller elementary particles.

Leptons

Unlike protons and neutrons, electrons are themselves elementary particles. They are a type of elementary particle called *leptons*. Like quarks, leptons come in six flavours, as shown in Table 2.4. The key difference between quarks and leptons is that quarks experience the strong force, while leptons do not.

Table 2.4 Characteristics of Leptons

Lepton	Description
electron muon tau	• The electron is the lepton found in atoms. • Compared to the electron, muon and tau particles have the same charge (1^-) but a much greater mass.
electron neutrinos muon neutrinos tau neutrinos	• Neutrinos are very difficult to detect. They have no charge and are nearly massless. • Trillions of them pass through our bodies each second. • Neutrinos are produced by high-energy processes such as nuclear reactions in the Sun.

Research Continues

Today, engineers and scientists continue to work together to probe the atom even further. One local example, the TRIUMF cyclotron, is shown in Figure 2.33. Located in Vancouver, the cyclotron was built to research the particles that make up matter. Electromagnets in the cyclotron accelerate protons to extraordinary speeds. The resulting proton beam is allowed to collide with various materials, and specialized detectors provide data about the products of the collisions.

Figure 2.33 The TRIUMF cyclotron is a particle accelerator that produces a high-speed beam of protons. People come to Vancouver from all over the world to use it to run experiments.

Extending the Connections

Beyond the Atom

Choose one of these terms or another of your choice to research: dark matter, antimatter, the Higgs boson, superstring theory, or quantum mechanics.

Before you leave this page . . .

1. Describe the structure of a proton.
2. Compare neutrinos and electrons.

AT ISSUE How do you smash subatomic particles—and why?

What's the Issue?

Strange but true: the job of the largest machine in the world is to study the smallest particles in existence. The machine is the Large Hadron Collider (LHC). It is a particle accelerator located on the border of France and Switzerland and operated by CERN, which stands for the French words for the European Organization for Nuclear Research.

The Large Hadron Collider consists of a ring 27 km in circumference buried underground. Inside the ring, two particle beams are sent in opposite directions through two pipes. Powerful electromagnets accelerate the particles until they are travelling close to light speed. The beams are then made to collide, and special detectors gather information about the particles produced by the collision. The LHC was used in experiments that resulted in the discovery of the Higgs boson particle. The existence of this particle was first proposed in the 1960s, but it took the LHC to create a collision with enough energy to produce one.

The Large Hadron Collider did not come cheap. The machine took decades of time and billions of dollars to plan and build. And it costs billions more to maintain and operate. The cost of finding the Higgs boson alone has been estimated at over $13 billion. Is the research worth the price tag?

Dig Deeper

Collaborate with your classmates to explore one or more of these questions—or generate your own questions of interest to explore.

1. What is the Higgs boson particle? Why is its discovery significant?
2. Other than the Higgs boson, what other discoveries have been made using the LHC? Will these discoveries result in useful applications? Should that matter?
3. There are different types of particle accelerators. What are they and what are some characteristics and examples of each?
4. Are there environmental risks to using the Large Hadron Collider and other particle research facilities? Are the risks worth the benefits?

Check Your Understanding of Topic 2.4

QP Questioning and Predicting PC Planning and Conducting PA Processing and Analyzing E Evaluating AI Applying and Innovating C Communicating

Understanding Key Ideas

1. Democritus's ideas about matter were amazingly close to modern atomic theory. Why did thousands of years pass before most people accepted his view? PA C

2. Use Dalton's model of the atom to explain the law of conservation of mass. PA C

3. Thomson's experiments with cathode rays resulted in a revised model of the atom. PA C
   a) What did Thomson discover about cathode rays?
   b) Why did this discovery mean that Dalton's model had to be changed?

4. Make a Venn diagram to compare Thomson's and Rutherford's models of the atom. PA C

5. What evidence supports Bohr's hypothesis that electrons can exist only in certain specified energy shells surrounding the atom? E C

6. Draw a labelled sketch to represent the atom as described in Concept 3. PA C

7. Compare and contrast protons and neutrons. PA C

8. Neutrons, protons, and electrons are all subatomic particles, but not all of them are elementary particles. PA C
   a) What is an elementary particle?
   b) Which particle in an atom is an elementary particle, and what type is it?
   c) Describe the structure of the other two particles in an atom.

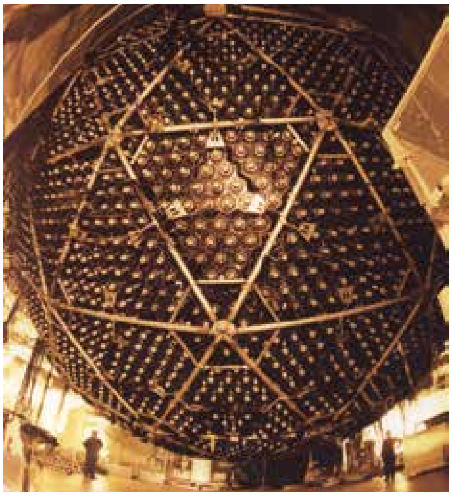
Connecting Ideas

9. If Thomson's model of the atom had been correct, how would the results of Rutherford's experiment have been different? Use diagrams to illustrate your answer. E C

10. Of the three main subatomic particles that make up the atom (protons, neutrons, and electrons), why do you think the neutron was the last to be discovered? E C

Making New Connections

11. This giant sphere is a highly sensitive neutrino detector. It is located 2 km underground at the Sudbury Neutrino Observatory in northern Ontario. AI C
    a) Based on what you know about neutrinos, why do you think they are so difficult to detect?
    b) Neutrinos, along with many other high-energy particles, are constantly streaming at Earth's surface from space. Since this is the case, why do you think the neutrino detector is located so far underground?



INVESTIGATION

2-H

STRUCTURED INQUIRY

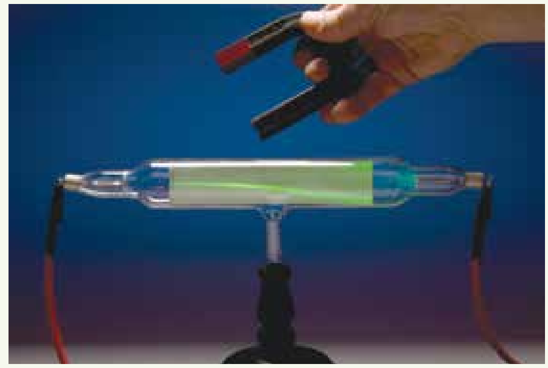
Skills and Strategies

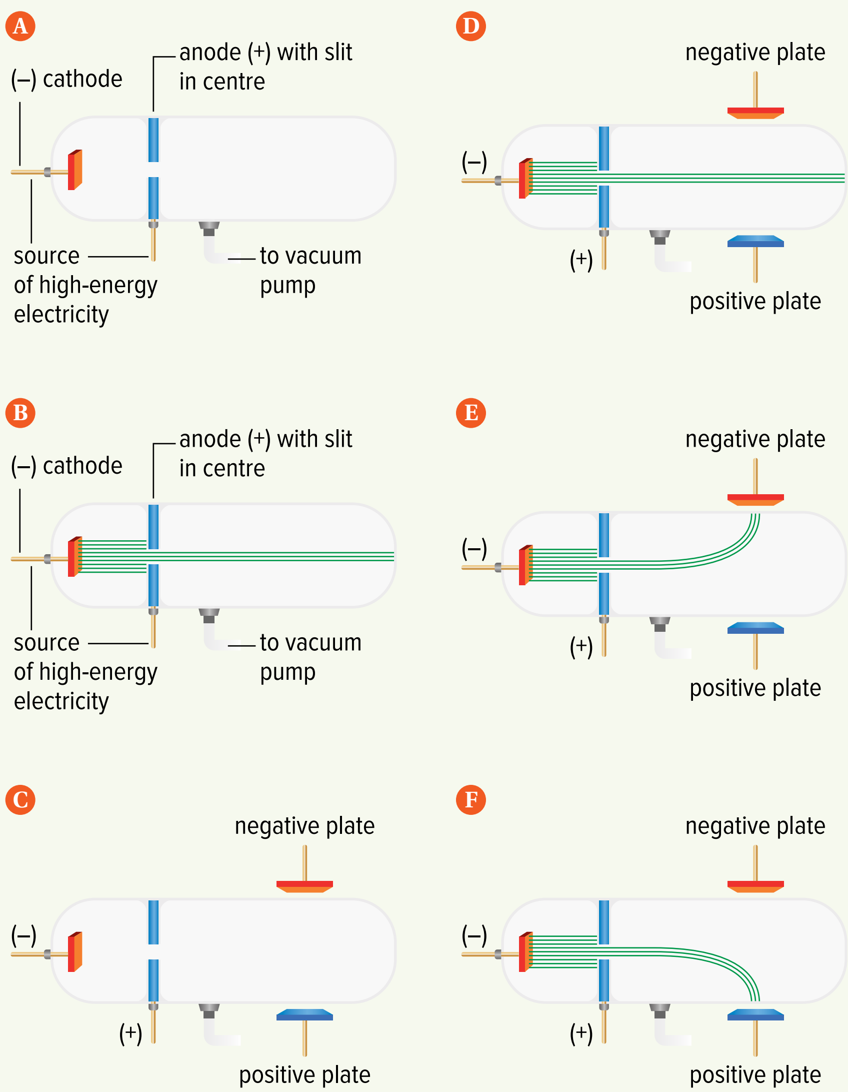
- Processing and Analyzing
- Evaluating
- Communicating

Interpreting Thomson's Results

Question

How can 2-dimensional models (images) help you analyze JJ Thomson's experiments and their results?





Procedure

1. Examine the photo and diagram A. The photo shows a cathode ray tube. (It is also called a Crookes tube after one of the scientists who invented it.)

   Compare and contrast the photo and the diagram.

2. Diagram B shows what happened when the source of high-energy electricity was turned on.
   a) In which of these directions do the rays travel?
      - from the anode to the cathode
      - from the left-hand edge of the tube to the anode
      - from the source of electricity to the anode
   b) Your answer to part a) is an example of an inference. An inference is a logical conclusion that you make based on evidence. What evidence supports your inference?
   c) What does the slit in the anode do to the rays?

3. Diagram C shows additions Thomson made to the cathode ray tube in order to investigate the nature of the rays further. Describe the new equipment.

4. Only one of diagrams D, E, and F shows what happened when the apparatus was in use. Which diagram do you think predicts the outcome correctly? Give reasons for your choice.

Process and Analyze

1. Draw a sketch to show what you think would have happened if the negative plate were on the bottom and the positive plate were on top. Give reasons for your answer.

2. Earlier scientists had concluded that cathode rays carried a negative charge. Did Thomson's experiment support this conclusion? Support your answer with specific evidence from this investigation.

Evaluate, Apply, and Communicate

3. By measuring the path of the cathode rays, Thomson was able to confirm the rays' charge. He was also able to work out a relationship between the charge and mass of the particles. This relationship led to the discovery that the charged particles have barely 1/2000 the mass of one hydrogen atom.
   a) Why was the mass of the particle significant?
   b) What changes were made to Dalton's model of the atom as a result of Thomson's experiment and why?

4. Are simplified 2D diagrams of Thomson's apparatus and results helpful in understanding the experiment? Explain why or why not.

INVESTIGATION

2-1

GUIDED INQUIRY

Skills and Strategies

- Planning and Conducting
- Processing and Analyzing
- Evaluating
- Communicating

Safety

- Have your plan for making your model approved by your teacher before you begin.
- Use care if you are working with scissors or other sharp tools.

What You Need

- craft materials to make models
- materials to make posters
- a device with a camera and video recorder

Modelling the Atom

Question

How can you use a variety of media to communicate the work of a scientist who advanced the understanding of atomic structure?

Procedure

1. Work in groups. Your teacher will assign your group one of the following scientists, or another of his or her choice:
   - John Dalton
   - William Crookes
   - JJ Thomson
   - Robert Millikan
   - Ernest Rutherford
   - Marie Curie
   - Niels Bohr
   - Henry Moseley
2. Your group's challenge is to produce a presentation about your scientist that includes a model of either the scientist's theory of the atom or a key experiment. Do research to find out about your scientist's contribution to atomic theory.
3. Collaborate to make a plan for doing the following:

   A. Making your model. Keep in mind the following criteria. The model should:
   - be detailed enough to show the key features of the scientist's atomic theory or experiment
   - be as dynamic as necessary, so that it can demonstrate the progress of an experiment, for example
   - illustrate the strengths and weaknesses of the scientist's work

   Your plan should include a list of materials you will need and sketches to show how you will make your model.

B. **Giving your presentation.** Consider including some of these features:

- a live or recorded simulated interview with your scientist
- a slideshow explaining the key points of your scientist's contributions
- a discussion of how your scientist fits into the larger picture of the development of atomic theory

You may wish to divide your group into two teams and have one team work on the model while the other works on the presentation. If you do this, decide how the two teams will communicate their progress to one another.

4. Check your plan with your teacher. Once it is approved, carry out your plan.

Analyze and Interpret

1. Practise your presentation and test your model. What improvements can you make?

Conclude and Communicate

2. Give your presentation to the class. Be prepared to answer questions and receive feedback from the audience.
3. Based on the feedback you received, how would you change your presentation if you were to give it again?
4. Which group, other than your own, got across the scientist's key ideas most effectively? Explain your answer.
5. How well did your model demonstrate your scientist's work? What aspects of your model could you improve? Were there some limitations of your model that you could not overcome? Explain your answer.