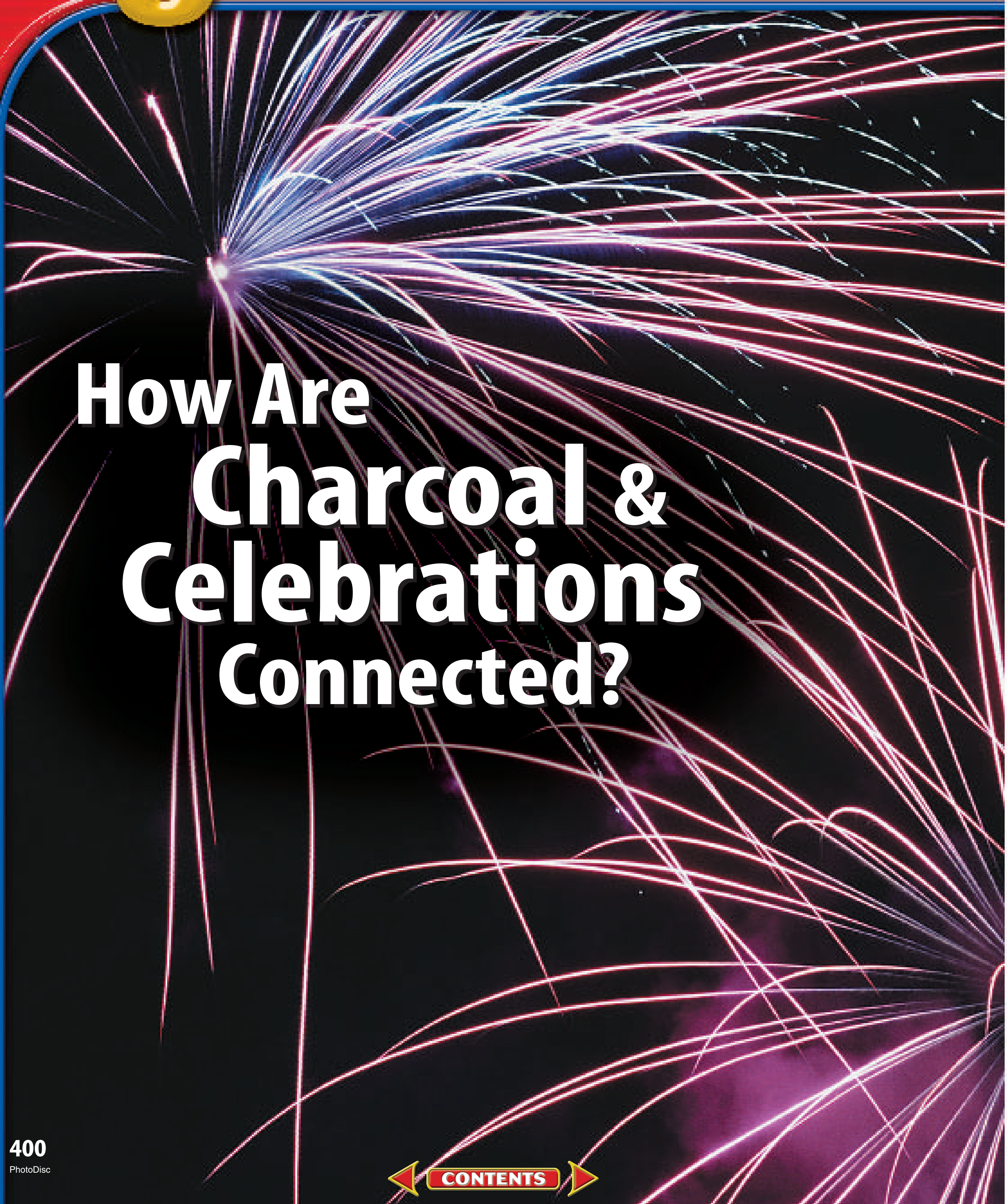


How Are Charcoal & Celebrations Connected?

PhotoDisc

CONTENTS

NATIONAL GEOGRAPHIC

According to one report, one day in the tenth century in China, a cook combined charcoal with two other ingredients that were common in Chinese kitchens. The result was a spectacular explosion of sparks. Whether or not that story is true, most experts agree that fireworks originated in China. The Chinese discovered that if the ingredients were put into a bamboo tube, the force of the reaction would send the tube zooming into the sky. The spectacular light and noise were perfect for celebrations. Traders carried the art of firework making westward to Europe. The Europeans added new colors to the bursts by mixing various chemicals into the explosive powder. Today, people all over the world use colorful fireworks to celebrate special occasions.

unit projects

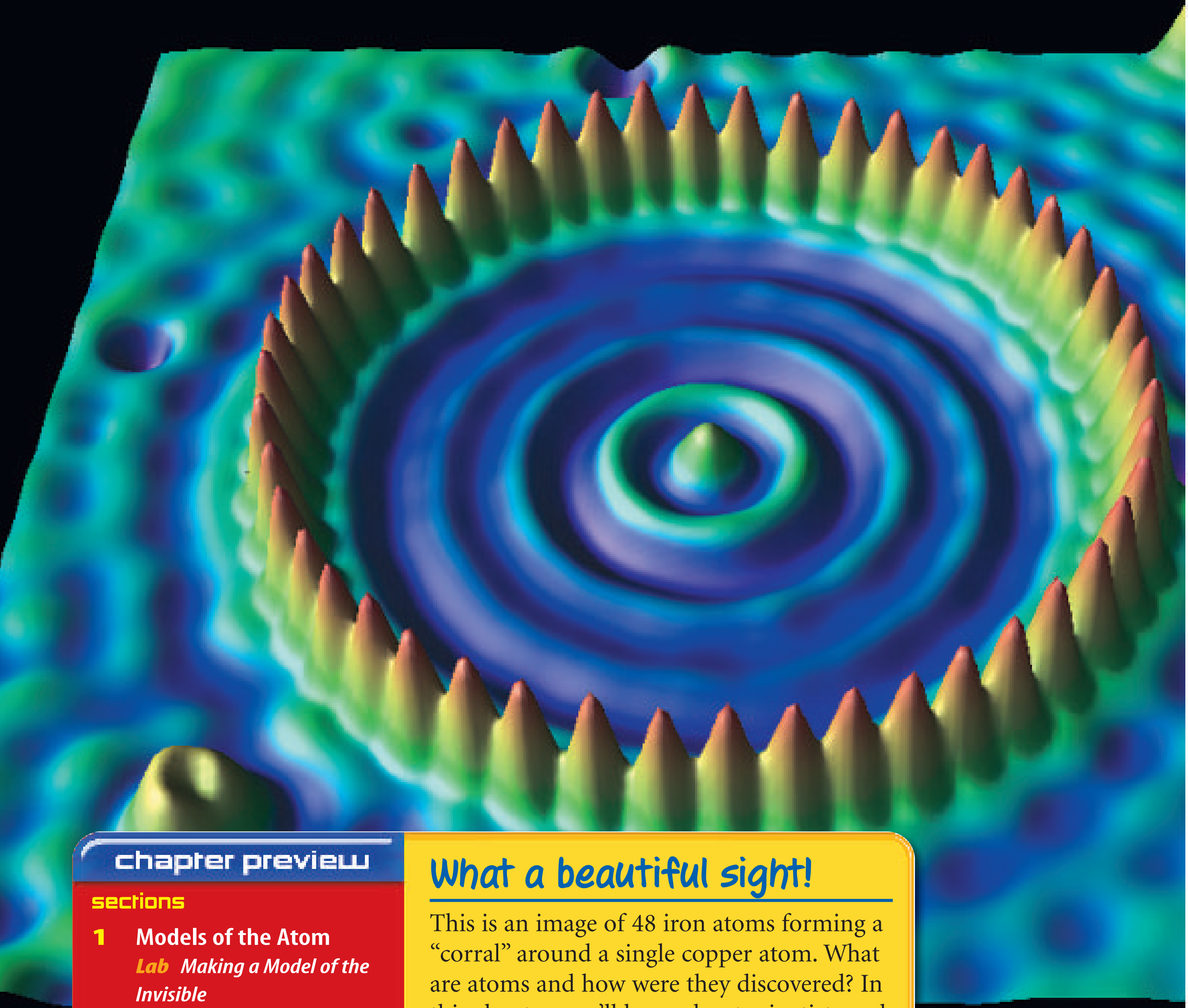
Visit **blue.msscience.com/unit_project** to find project ideas and resources. Projects include:

- **Career** Discover polymers and their uses. Brainstorm a list of questions for a polymer chemist about these new materials.
- **Technology** Investigate the chemical makeup of your breakfast cereal or snack food. Design a circle graph showing the percentages of each chemical ingredient in your food sample.
- **Model** Demonstrate to the class a common chemical reaction. Compile a class collection of these simple chemical reactions to share with others.

WebQuest *Chemistry of Fireworks* explores the chemical compounds of fireworks, what chemicals are used, and how firework displays are created.

(inset)Stephen Frisch/Stock Boston/PictureQuest, (bkgd)PhotoDisc chapter 14

Inside the Atom



chapter preview

sections

1 **Models of the Atom**
Lab *Making a Model of the Invisible*

2 **The Nucleus**
Lab *Half-Life*

Virtual Lab *How can you simulate the radioactive half-life of an element?*

What a beautiful sight!

This is an image of 48 iron atoms forming a "corral" around a single copper atom. What are atoms and how were they discovered? In this chapter, you'll learn about scientists and their amazing discoveries about the nature of the atom.

Science Journal Describe, based on your current knowledge, what an atom is.

courtesy IBM

Start-Up Activities

Launch LAB

Model the Unseen

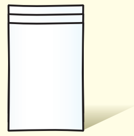
Have you ever had a wrapped birthday present that you couldn't wait to open? What did you do to try to figure out what was in it? The atom is like that wrapped present. You want to investigate it, but you cannot see it easily.

1. Your teacher will give you a piece of clay and some pieces of metal. Count the pieces of metal.
2. Bury these pieces in the modeling clay so they can't be seen.
3. Exchange clay balls with another group.
4. With a toothpick, probe the clay to find out how many pieces of metal are in the ball and what shape they are.
5. **Think Critically** In your Science Journal, sketch the shapes of the metal pieces as you identify them. How does the number of pieces you found compare with the number that were in the clay ball? How do their shapes compare?

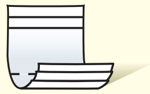
FOLDABLES™ Study Organizer

Parts of the Atom Make the following Foldable to help you organize your thoughts and review the parts of an atom.

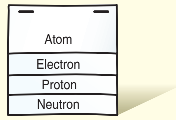
STEP 1 **Collect** two sheets of paper and layer them about 2 cm apart vertically. Keep the edges level.



STEP 2 **Fold** up the bottom edges of the paper to form four equal tabs.



STEP 3 **Fold** the papers and crease well to hold the tabs in place. Staple along the fold. **Label** the tabs *Atom, Electron, Proton,* and *Neutron* as shown.



Read and Write As you read the chapter, describe how each part of the atom was discovered and record other facts under the appropriate tabs.

Science Online
Preview this chapter's content and activities at blue.msscience.com

section 1

Models of the Atom

as you read

What You'll Learn

- **Explain** how scientists discovered subatomic particles.
- **Explain** how today's model of the atom developed.
- **Describe** the structure of the nuclear atom.
- **Explain** that all matter is made up of atoms.

Why It's Important

Atoms make up everything in your world.

Review Vocabulary

matter: anything that has mass and takes up space

New Vocabulary

- element
- anode
- cathode
- electron
- alpha particle
- proton
- neutron
- electron cloud

First Thoughts

Do you like mysteries? Are you curious? Humans are curious. Someone always wants to know something that is not easy to detect or to see what can't be seen. For example, people began wondering about matter more than 2,500 years ago. Some of the early philosophers thought that matter was composed of tiny particles. They reasoned that you could take a piece of matter, cut it in half, cut the half piece in half again, and continue to cut again and again. Eventually, you wouldn't be able to cut any more. You would have only one particle left. They named these particles *atoms*, a term that means "cannot be divided." Another way to imagine this is to picture a string of beads like the one shown in **Figure 1.** If you keep dividing the string into pieces, you eventually come to one single bead.

Describing the Unseen Early philosophers didn't try to prove their theories by doing experiments as scientists now do. Their theories were the result of reasoning, debating, and discussion—not of evidence or proof. Today, scientists will not accept a theory that is not supported by experimental evidence. But even if these philosophers had experimented, they could not have proven the existence of atoms. People had not yet discovered much about what is now called chemistry, the study of matter. The kind of equipment needed to study matter was a long way from being invented. Even as recently as 500 years ago, atoms were still a mystery.

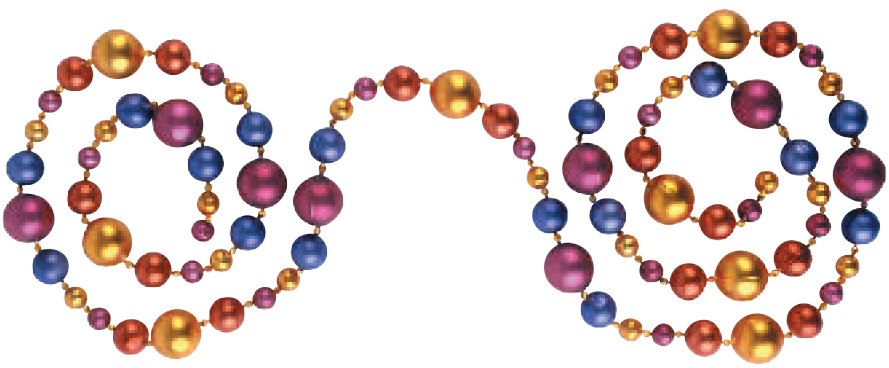


Figure 1 You can divide this string of beads in half, and in half again until you have one, indivisible bead. Like this string of beads, all matter can be divided until you reach one basic particle, the atom.

EyeWire

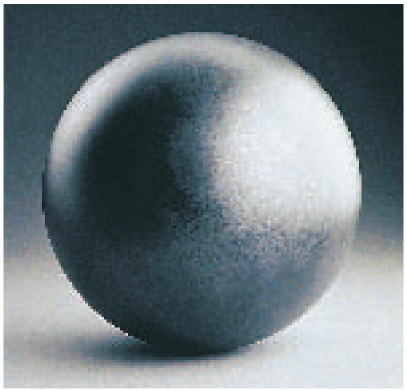
A Model of the Atom

A long period passed before the theories about the atom were developed further. Finally during the eighteenth century, scientists in laboratories, like the one on the left in **Figure 2,** began debating the existence of atoms once more. Chemists were learning about matter and how it changes. They were putting substances together to form new substances and taking substances apart to find out what they were made of. They found that certain substances couldn't be broken down into simpler substances. Scientists came to realize that all matter is made up of elements. An **element** is matter made of atoms of only one kind. For example, iron is an element made of iron atoms. Silver, another element, is made of silver atoms. Carbon, gold, and oxygen are other examples of elements.

Figure 2 Even though the laboratories of the time were simple compared to those of today, incredible discoveries were made during the eighteenth century.

Dalton's Concept John Dalton, an English schoolteacher in the early nineteenth century, combined the idea of elements with the earlier theory of the atom. He proposed the following ideas about matter: (1) Matter is made up of atoms, (2) atoms cannot be divided into smaller pieces, (3) all the atoms of an element are exactly alike, and (4) different elements are made of different kinds of atoms. Dalton pictured an atom as a hard sphere that was the same throughout, something like a tiny marble. A model like this is shown in **Figure 3.**

Figure 3 Dalton pictured the atom as a hard sphere that was the same throughout.



Scientific Evidence Dalton's theory of the atom was tested in the second half of the nineteenth century. In 1870, the English scientist William Crookes did experiments with a glass tube that had almost all the air removed from it. The glass tube had two pieces of metal called electrodes sealed inside. The electrodes were connected to a battery by wires.

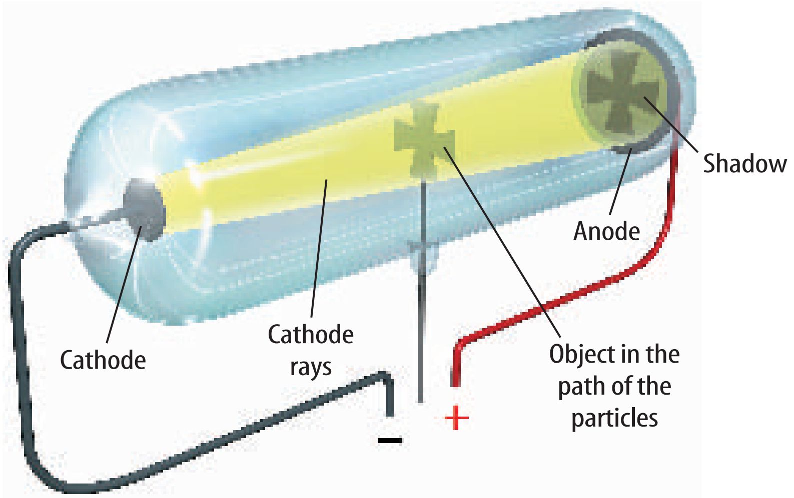


Figure 4 Crookes used a glass tube containing only a small amount of gas. When the glass tube was connected to a battery, something flowed from the negative electrode (cathode) to the positive electrode (anode).
Explain *if this unknown thing was light or a stream of particles.*

A Strange Shadow An electrode is a piece of metal that can conduct electricity. One electrode, called the **anode,** has a positive charge. The other, called the **cathode,** has a negative charge. In the tube that Crookes used, the metal cathode was a disk at one end of the tube. In the center of the tube was an object shaped like a cross, as you can see in **Figure 4.** When the battery was connected, the glass tube suddenly lit up with a greenish-colored glow. A shadow of the object appeared at the opposite end of the tube—the anode. The shadow showed Crookes that something was traveling in a straight line from the cathode to the anode, similar to the beam of a flashlight. The cross-shaped object was getting in the way of the beam and blocking it, just like when a road crew uses a stencil to block paint from certain places on the road when they are marking lanes and arrows. You can see this in **Figure 5.**

Figure 5 Paint passing by a stencil is an example of what happened with Crookes's tube, the cathode ray, and the cross.

Cathode Rays Crookes hypothesized that the green glow in the tube was caused by rays, or streams of particles. These rays were called cathode rays because they were produced at the cathode. Crookes's tube is known as a cathode-ray tube, or CRT. **Figure 6** shows a CRT. They were used for TV and computer display screens for many years.

Reading Check

What are cathode rays?

Elena Rooraid/PhotoEdit, Inc.

Discovering Charged Particles

The news of Crookes's experiments excited the scientific community of the time. But many scientists were not convinced that the cathode rays were streams of particles. Was the greenish glow light, or was it a stream of charged particles? In 1897, J.J. Thomson, an English physicist, tried to clear up the confusion. He placed a magnet beside the tube from Crookes's experiments. In **Figure 7,** you can see that the beam is bent in the direction of the magnet. Light cannot be bent by a magnet, so the beam couldn't be light. Therefore, Thomson concluded that the beam must be made up of charged particles of matter that came from the cathode.

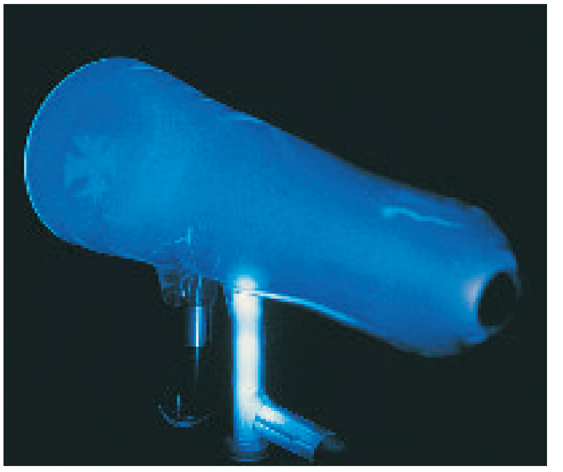


Figure 6 The cathode-ray tube got its name because the particles start at the cathode and travel to the anode. At one time, a CRT was in every TV and computer monitor.

The Electron Thomson then repeated the CRT experiment using different metals for the cathode and different gases in the tube. He found that the same charged particles were produced no matter what elements were used for the cathode or the gas in the tube. Thomson concluded that cathode rays are negatively charged particles of matter. How did Thomson know the particles were negatively charged? He knew that opposite charges attract each other. He observed that these particles were attracted to the positively charged anode, so he reasoned that the particles must be negatively charged.

These negatively charged particles are now called **electrons.** Thomson also inferred that electrons are a part of every kind of atom because they are produced by every kind of cathode material. Perhaps the biggest surprise that came from Thomson's experiments was the evidence that particles smaller than the atom do exist.

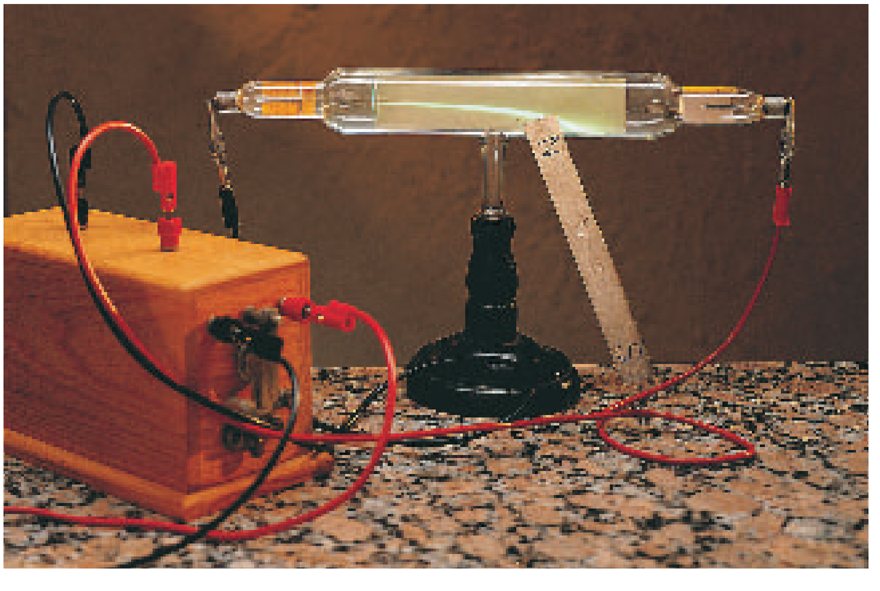


Figure 7 When a magnet was placed near a CRT, the cathode rays were bent. Since light is not bent by a magnet, Thomson determined that the cathode rays were made of charged particles.

Figure 8 Modeling clay with ball bearings mixed through is another way to picture the J.J. Thomson atom. The clay contains all the positive charge of the atom. The ball bearings, which represent the negatively charged electrons, are mixed evenly in the clay.
Explain *what made Thomson include positive particles in his atomic model?*

Thomson's Atomic Model Some of the questions posed by scientists were answered in light of Thomson's experiments. However, the answers inspired new questions. If atoms contain one or more negatively charged particles, then all matter, which is made of atoms, should be negatively charged as well. But all matter isn't negatively charged. Could it be that atoms also contain some positive charge? The negatively charged electrons and the unknown positive charge would then neutralize each other in the atom. Thomson came to this conclusion and included positive charge in his model of the atom.

Using his new findings, Thomson revised Dalton's model of the atom. Instead of a solid ball that was the same throughout, Thomson pictured a sphere of positive charge. The negatively charged electrons were spread evenly among the positive charge. This is modeled by the ball of clay shown in **Figure 8.** The positive charge of the clay is equal to the negative charge of the electrons. Therefore, the atom is neutral. It was later discovered that not all atoms are neutral. The number of electrons within an element can vary. If there is more positive charge than negative electrons, the atom has an overall positive charge. If there are more negative electrons than positive charge, the atom has an overall negative charge.

Reading Check *What particle did Thomson's model have scattered through it?*

Rutherford's Experiments

A model is not accepted in the scientific community until it has been tested and the tests support previous observations. In 1906, Ernest Rutherford and his coworkers began an experiment to find out if Thomson's model of the atom was correct. They wanted to see what would happen when they fired fast-moving, positively charged bits of matter, called alpha particles, at a thin film of a metal such as gold. Alpha particles, which come from unstable atoms, are positively charged, and so they are repelled by particles of matter which also have a positive charge.

Figure 9 shows how the experiment was set up. A source of alpha particles was aimed at a thin sheet of gold foil that was only 400 nm thick. The foil was surrounded by a fluorescent (floo REH sunt) screen that gave a flash of light each time it was hit by a charged particle.

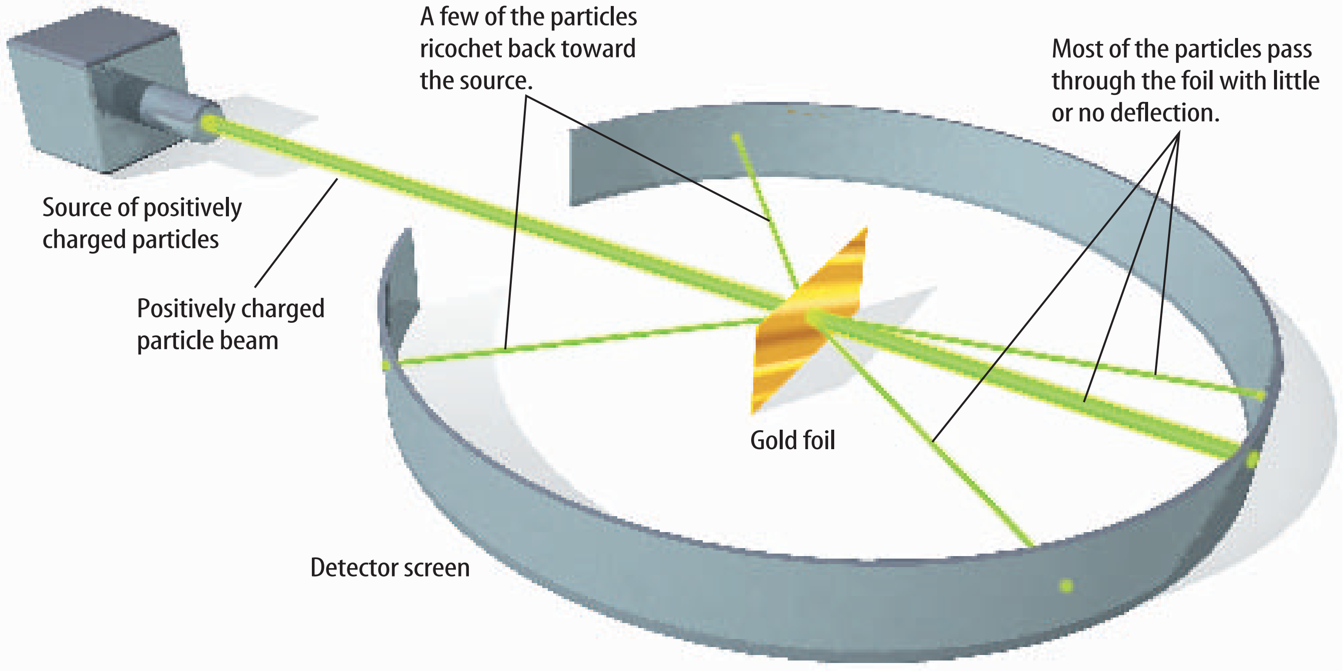
Aaron Haupt

Expected Results Rutherford was certain he knew what the results of this experiment would be. His prediction was that most of the speeding alpha particles would pass right through the foil and hit the screen on the other side, just like a bullet fired through a pane of glass. Rutherford reasoned that the thin, gold film did not contain enough matter to stop the speeding alpha particle or change its path. Also, there wasn't enough charge in any one place in Thomson's model to repel the alpha particle strongly. He thought that the positive charge in the gold atoms might cause a few minor changes in the path of the alpha particles. However, he assumed that this would only occur a few times.

That was a reasonable hypothesis because in Thomson's model, the positive charge is essentially neutralized by nearby electrons. Rutherford was so sure of what the results would be that he turned the work over to a graduate student.

The Model Fails Rutherford was shocked when his student rushed in to tell him that some alpha particles were veering off at large angles. You can see this in **Figure 9.** Rutherford expressed his amazement by saying, "It was about as believable as if you had fired a 15-inch shell at a piece of tissue paper, and it came back and hit you." How could such an event be explained? The positively charged alpha particles were moving with such high speed that it would take a large positive charge to cause them to bounce back. The uniform mix of mass and charges in Thomson's model of the atom did not allow for this kind of result.

Figure 9 In Rutherford's experiment, alpha particles bombarded the gold foil. Most particles passed right through the foil or veered slightly from a straight-line path, but some particles bounced right back. The path of a particle is shown by a flash of light when it hits the fluorescent screen.



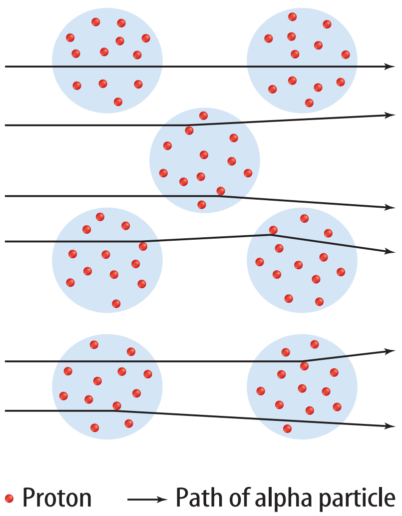


Figure 10 Rutherford thought that if the atom could be described by Thomson's model, as shown above, then only minor bends in the paths of the particles would have occurred.

A Model with a Nucleus

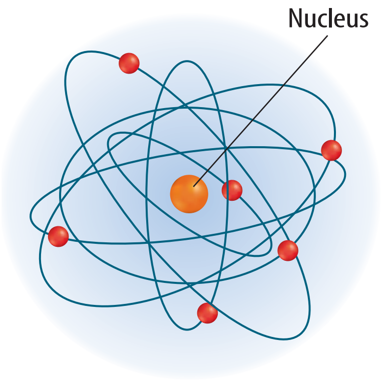
Now Rutherford and his team had to come up with an explanation for these unexpected results. They might have drawn diagrams like those in **Figure 10,** which uses Thomson's model and shows what Rutherford expected. Now and then, an alpha particle might be affected slightly by a positive charge in the atom and turn a bit off course. However, large changes in direction were not expected.

The Proton The actual results did not fit this model, so Rutherford proposed a new one, shown in **Figure 11.** He hypothesized that almost all the mass of the atom and all of its positive charge are crammed into an incredibly small region of space at the center of the atom called the nucleus. Eventually, his prediction was proved true. In 1920 scientists identified the positive charges in the nucleus as protons. A **proton** is a positively charged particle present in the nucleus of all atoms. The rest of each atom is empty space occupied by the atom's almost-massless electrons.

Reading Check *How did Rutherford describe his new model?*

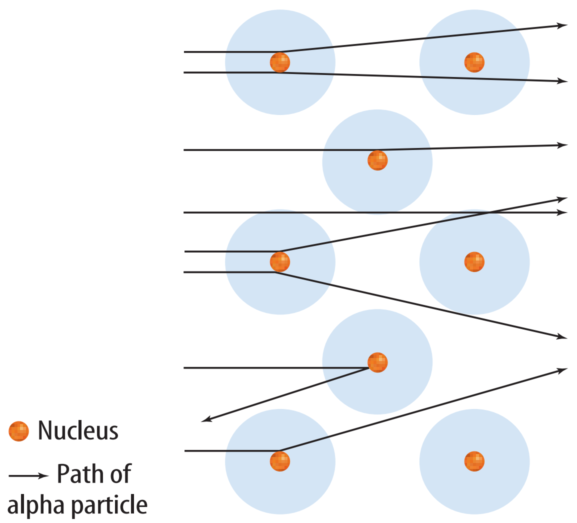
Figure 12 shows how Rutherford's new model of the atom fits the experimental data. Most alpha particles could move through the foil with little or no interference because of the empty space that makes up most of the atom. However, if an alpha particle made a direct hit on the nucleus of a gold atom, which has 79 protons, the alpha particle would be strongly repelled and bounce back.

Figure 11 The nuclear model was new and helped explain experimental results.



Rutherford's model included the dense center of positive charge known as the nucleus.

Figure 12 This nucleus that contained most of the mass of the atom caused the deflections that were observed in his experiment.



The Neutron Rutherford's nuclear model was applauded as other scientists reviewed the results of the experiments. However, some data didn't fit. Once again, more questions arose and the scientific process continued. For instance, an atom's electrons have almost no mass. According to Rutherford's model, the only other particle in the atom was the proton. That meant that the mass of an atom should have been approximately equal to the mass of its protons. However, it wasn't. The mass of most atoms is at least twice as great as the mass of its protons. That left scientists with a dilemma and raised a new question. Where does the extra mass come from if only protons and electrons made up the atom?

It was proposed that another particle must be in the nucleus to account for the extra mass. The particle, which was later called the **neutron** (NEW trahn), would have the same mass as a proton and be electrically neutral. Proving the existence of neutrons was difficult though, because a neutron has no charge. Therefore, the neutron doesn't respond to magnets or cause fluorescent screens to light up. It took another 20 years before scientists were able to show by more modern experiments that atoms contain neutrons.

Reading Check *What particles are in the nucleus of the nuclear atom?*

The model of the atom was revised again to include the newly discovered neutrons in the nucleus. The nuclear atom, shown in **Figure 13,** has a tiny nucleus tightly packed with positively charged protons and neutral neutrons. Negatively charged electrons occupy the space surrounding the nucleus. The number of electrons in a neutral atom equals the number of protons in the atom.

Mini LAB

Modeling the Nuclear Atom

Procedure

1. On a sheet of **paper,** draw a circle with a diameter equal to the width of the paper.
2. Small dots of **paper in two colors** will represent protons and neutrons. Using a dab of **glue** on each paper dot, make a model of the nucleus of the oxygen atom in the center of your circle. Oxygen has eight protons and eight neutrons.

Analysis

1. What particle is missing from your model of the oxygen atom?
2. How many of that missing particle should there be, and where should they be placed?

Try at Home

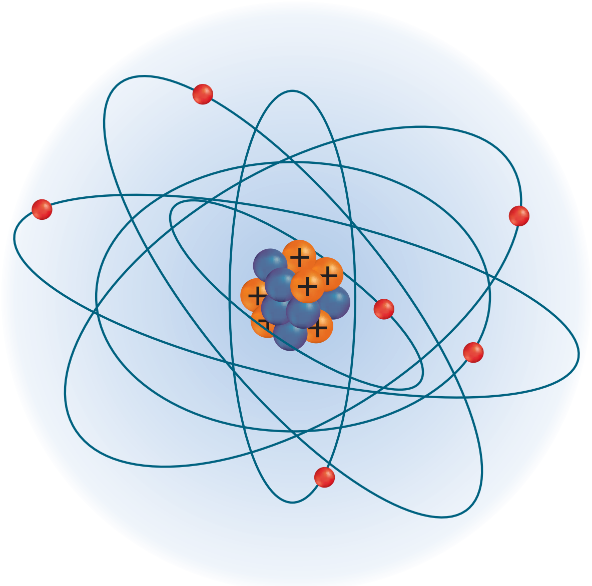


Figure 13 This atom of carbon, atomic number 6, has six protons and six neutrons in its nucleus.
Identify *how many electrons are in the "empty" space surrounding the nucleus.*

Figure 14 If this Ferris wheel in London, with a diameter of 132 m, were the outer edge of the atom, the nucleus would be about the size of a single letter *o* on this page.

Size and Scale Drawings of the nuclear atom such as the one in **Figure 13** don't give an accurate representation of the extreme smallness of the nucleus compared to the rest of the atom. For example, if the nucleus were the size of a table-tennis ball, the atom would have a diameter of more than 2.4 km. Another way to compare the size of a nucleus with the size of the atom is shown in **Figure 14.** Perhaps now you can see better why in Rutherford's experiment, most of the alpha particles went directly through the gold foil without any interference from the gold atoms. Plenty of empty space allows the alpha particles an open pathway.

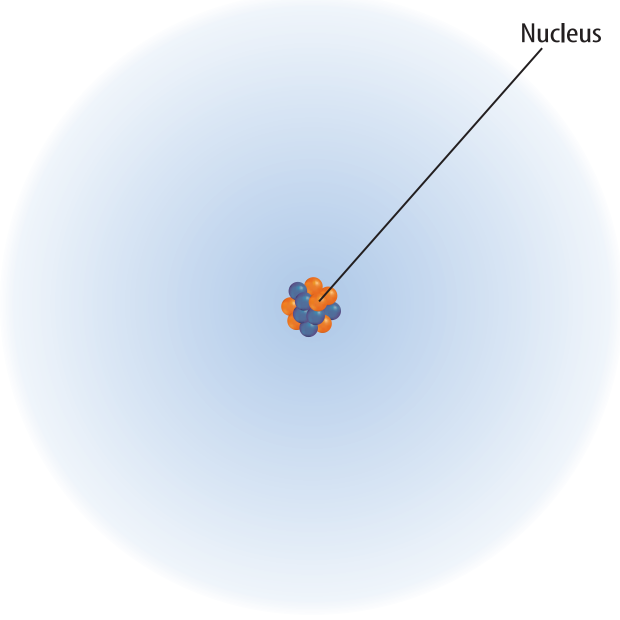
INTEGRATE History

Protons Rutherford finally identified the particles of the nucleus as discrete positive charges of matter in 1919. Using alpha particles as bullets, he knocked hydrogen nuclei out of atoms from boron, fluorine, sodium, aluminum, phosphorus, and nitrogen. Rutherford named the hydrogen nuclei *protons,* which means "first" in Greek because protons were the first identified building blocks of the nuclei.

Further Developments

Even into the twentieth century, physicists were working on a theory to explain how electrons are arranged in an atom. It was natural to think that the negatively charged electrons are attracted to the positive nucleus in the same way the Moon is attracted to Earth. Then, electrons would travel in orbits around the nucleus. A physicist named Niels Bohr even calculated exactly what energy levels those orbits would represent for the hydrogen atom. His calculations explained experimental data found by other scientists. However, scientists soon learned that electrons are in constant, unpredictable motion and can't be described easily by an orbit. They determined that it was impossible to know the precise location of an electron at any particular moment. Their work inspired even more research and brainstorming among scientists around the world.

Electrons as Waves Physicists began to wrestle with explaining the unpredictable nature of electrons. Surely the experimental results they were seeing and the behavior of electrons could somehow be explained with new theories and models. The unconventional solution was to understand electrons not as particles, but as waves. This led to further mathematical models and equations that brought much of the experimental data together.



The Electron Cloud Model The new model of the atom allows for the somewhat unpredictable wave nature of electrons by defining a region where electrons are most likely to be found. Electrons travel in a region surrounding the nucleus, which is called the **electron cloud.** The current model for the electron cloud is shown in **Figure 15.** The electrons are more likely to be close to the nucleus rather than farther away because they are attracted to the positive charges of the protons. Notice the fuzzy outline of the electron cloud. Because the electrons could be anywhere, the cloud has no firm boundary. Interestingly, within the electron cloud, the electron in a hydrogen atom probably is found in the region Bohr calculated.

Figure 15 The electrons are more likely to be close to the nucleus rather than farther away, but they could be anywhere.

section 1 review

Summary

The Models of the Atom

- Some early philosophers believed all matter was made of small particles.
- John Dalton proposed that all matter is made of atoms that were hard spheres.
- J.J. Thomson showed that the particles in a CRT were negatively charged particles, later called electrons.
- Rutherford showed that a positive charge existed in a small region of the atom, which he called the nucleus.
- In order to explain the mass of an atom, the neutron was proposed as an uncharged particle with the same mass as a proton, located in the nucleus.
- Electrons are now believed to move about the nucleus in an electron cloud.

Self Check

1. **Explain** how the nuclear atom differs from the uniform sphere model of the atom.
2. **Determine** how many electrons a neutral atom with 49 protons has.
3. **Think Critically** In Rutherford's experiment, why wouldn't the electrons in the atoms of the gold foil affect the paths of the alpha particles?
4. **Concept Map** Design and complete a concept map using all the words in the vocabulary list for this section. Add any other terms or words that will help create a complete diagram of the section and the concepts it contains.

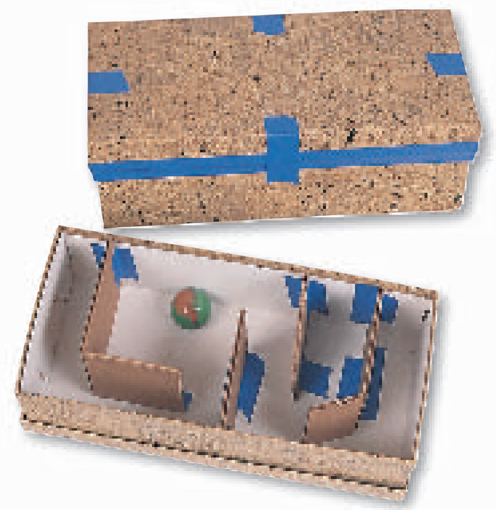
Applying Math

5. **Solve One-Step Equations** The mass of an electron is 9.11×10^{-28} g. The mass of a proton is 1,836 times more than that of the electron. Calculate the mass of the proton in grams and convert that mass into kilograms.

LAB

Making a Model of the Invisible

How do scientists make models of things they can't see? They do experiments, gather as much information as possible, and then try to fit the information together into some kind of pattern and make inferences. From the data and inferences, they create a model that fits all their data. Often they find that they must revise their model when more data come to light.



Real-World Question

How can you determine the inside structure of a box?

Goals

- **Observe** the motion of a marble inside a closed box.
- **Infer** the structure of the divisions inside the box.

Materials

sealed box
paper and pencil

Procedure

1. **Record** the number of the box your teacher gives you. Don't take the lid off the box or look inside.
2. Lift the box. Tilt the box. Gently shake it. In your Science Journal, record all your observations. Make a sketch of the way you think the marble in the box is rolling.
3. Use your observations to infer what the inside of the box looks like.
4. **Compare** your inferences with those of students who have the same box as you do. Then you might want to make more observations or revise your inferences.
5. When you have gathered all the information, sketch your model in your Science Journal.
6. Open your box and compare your model with the actual inside structure of the box.

Conclude and Apply

1. **Compare and Contrast** How did your model of the inside of the box compare with the actual inside?
2. **Draw Conclusions** Could you have used any other test to gather more information?
3. **Describe** how your notes in your Science Journal might be more helpful in this lab.
4. **Explain** how an observation is different from an inference.

Communicating Your Data

Create a data table and set of instructions that would help another student systematically test a new sealed box. **For more help, refer to the Science Skill Handbook.**

Aaron Haupt

section 2

The Nucleus

Identifying Numbers

The electron cloud model gives you a good idea of what the average nuclear atom looks like. But how does the nucleus in an atom of one element differ from the nucleus of an atom of another element? The atoms of different elements contain different numbers of protons. The **atomic number** of an element is the number of protons in the nucleus of an atom of that element. The smallest of the atoms, the hydrogen atom, has one proton in its nucleus, so hydrogen's atomic number is 1. Uranium, the heaviest naturally occurring element, has 92 protons. Its atomic number is 92. Atoms of an element are identified by the number of protons because this number never changes without changing the identity of the element.

Number of Neutrons The atomic number is the number of protons, but what about the number of neutrons in an atom's nucleus? A particular type of atom can have a varying number of neutrons in its nucleus. Most atoms of carbon have six neutrons. However, some carbon atoms have seven neutrons and some have eight, as you can see in **Figure 16.** They are all carbon atoms because they all have six protons. These three kinds of carbon atoms are called isotopes. **Isotopes** (I suh tohps) are atoms of the same element that have different numbers of neutrons. The isotopes of carbon are called carbon-12, carbon-13, and carbon-14. The numbers 12, 13, and 14 tell more about the nucleus of the isotopes. The combined masses of the protons and neutrons in an atom make up most of the mass of an atom.

as you read

What You'll Learn

- **Describe** the process of radioactive decay.
- **Explain** what is meant by half-life.
- **Describe** how radioactive isotopes are used.

Why It's Important

Radioactive elements are beneficial, but must be treated with caution.

Review Vocabulary
atom: the smallest particle of an element that retains all the properties of that element

New Vocabulary
- atomic number
- isotope
- mass number
- radioactive decay
- transmutation
- beta particle
- half-life

Figure 16 The three isotopes of carbon differ in the number of neutrons in each nucleus.

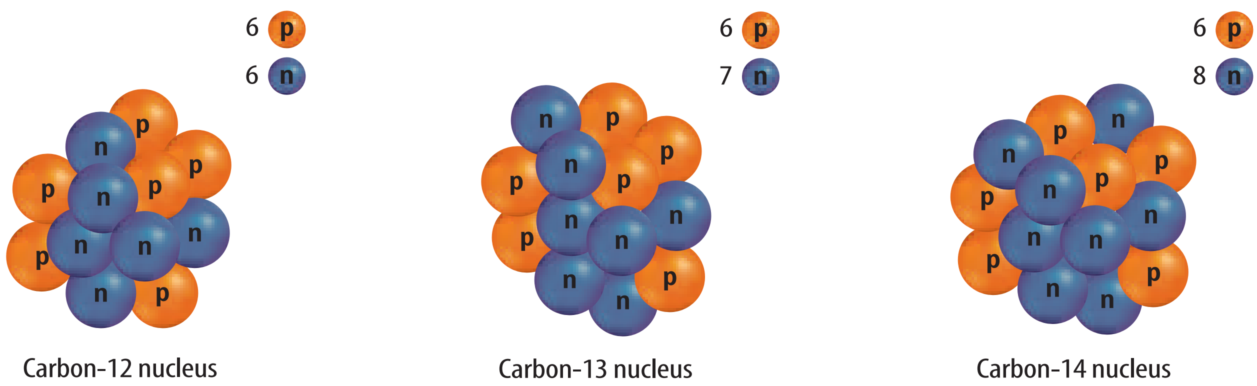


Table 1 Isotopes of Carbon

	Carbon-12	Carbon-13	Carbon-14
Mass number	12	13	14
Number of protons	6	6	6
Number of neutrons	6	7	8
Number of electrons	6	6	6
Atomic number	6	6	6

Mass Number The **mass number** of an isotope is the number of neutrons plus protons. **Table 1** shows the particles that make up each of the carbon isotopes. You can find the number of neutrons in an isotope by subtracting the atomic number from the mass number. For example, carbon-14 has a mass number of 14 and an atomic number of 6. The difference in these two numbers is 8, the number of neutrons in carbon-14.

Strong Nuclear Force When you need to hold something together, what do you use? Rubber bands, string, tape, or glue? What holds the protons and neutrons together in the nucleus of an atom? Because protons are positively charged, you might expect them to repel each other just as the north ends of two magnets tend to push each other apart. It is true that they normally would do just that. However, when they are packed together in the nucleus with the neutrons, an even stronger binding force takes over. That force is called the strong nuclear force. The strong nuclear force can hold the protons together only when they are as closely packed as they are in the nucleus of the atom.

Science Online

Topic: Radioactive Decay

Visit blue.msscience.com for Web links to information about radioactive decay.

Activity Explain how radioactive decay is used in home smoke detectors.

Radioactive Decay

Many atomic nuclei are stable when they have about the same number of protons and neutrons. Carbon-12 is the most stable isotope of carbon. It has six protons and six neutrons. Some nuclei are unstable because they have too many or too few neutrons. This is especially true for heavier elements such as uranium and plutonium. In these nuclei, repulsion builds up. The nucleus must release a particle to become stable. When particles are released, energy is given off. The release of nuclear particles and energy is called **radioactive decay.** When the particles that are ejected from a nucleus include protons, the atomic number of the nucleus changes. When this happens, one element changes into another. The changing of one element into another through radioactive decay is called **transmutation.**

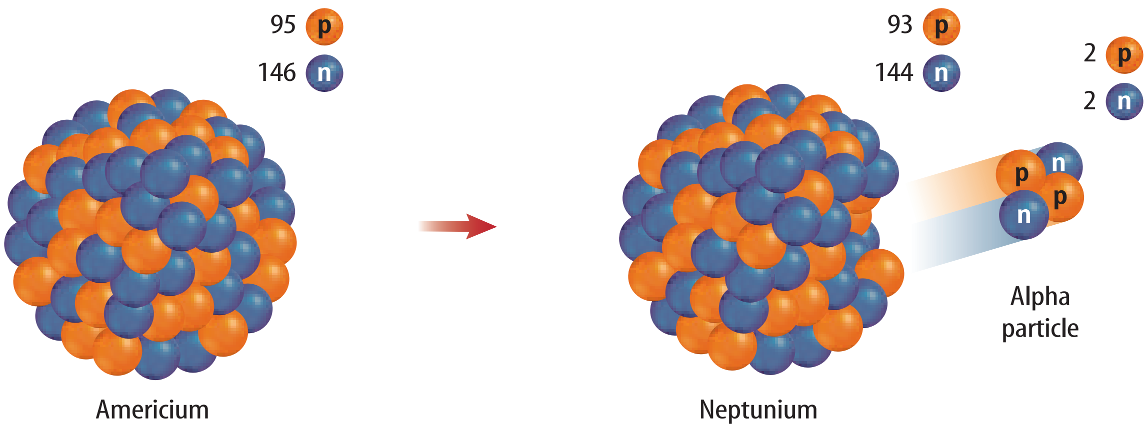
Reading Check *What occurs in radioactive decay?*

Figure 17 This lifesaving smoke detector makes use of the radioactive isotope americium-241. The isotope is located inside the black, slotted chamber. When smoke particles enter the chamber, the alarm goes off.

Loss of Alpha Particles Transmutation is occurring in most of your homes right now. **Figure 17** shows a smoke detector that makes use of radioactive decay. This device contains americium-241 (a muh RIH shee um), which undergoes transmutation by ejecting energy and an alpha particle. An **alpha particle** consists of two protons and two neutrons. Together, the energy and particles are called nuclear radiation. In the smoke detector, the fast-moving alpha particles enable the air to conduct an electric current. As long as the electric current is flowing, the smoke detector is silent. The alarm is triggered when the flow of electric current is interrupted by smoke entering the detector.

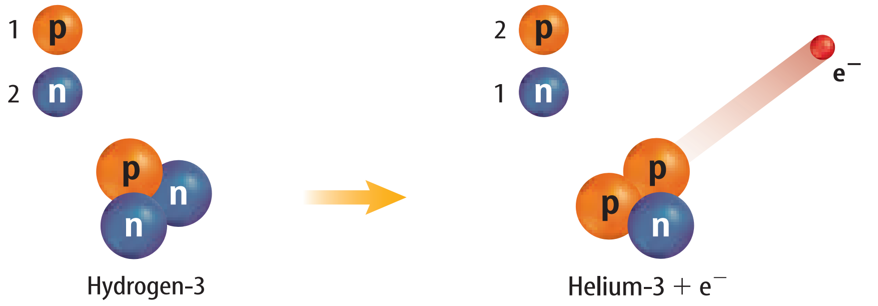
Changed Identity When americium expels an alpha particle, it's no longer americium. The atomic number of americium is 95, so americium has 95 protons. After the transmutation, it becomes the element that has 93 protons, neptunium. In **Figure 18,** notice that the mass and atomic numbers of neptunium and the alpha particle add up to the mass and atomic number of americium. All the nuclear particles of americium still exist after the transmutation.

Figure 18 Americium expels an alpha particle, which is made up of two protons and two neutrons. As a result, americium is changed into the element neptunium, which has two fewer protons than americium.



Timothy Fuller

Figure 19 Beta decay results in an element with an atomic number that is one greater than the original.



Loss of Beta Particles Some elements undergo transmutations through a different process. Their nuclei emit an electron called a beta particle. A **beta particle** is a high-energy electron that comes from the nucleus, not from the electron cloud. However, the nucleus contains only protons and neutrons. How can it give off an electron? During this kind of transmutation, a neutron becomes unstable and splits into an electron and a proton. The electron, or beta particle, is released with a large amount of energy. The proton, however, remains in the nucleus.

Reading Check *What is a beta particle?*

Because a neutron has been changed into a proton, the nucleus of the element has an additional proton. Unlike the process of alpha decay, in beta decay the atomic number of the element that results is greater by one. **Figure 19** shows the beta decay of the hydrogen-3 nucleus. With two neutrons in its nucleus, hydrogen-3 is unstable. One neutron is converted to a proton and a beta particle by beta decay, and an isotope of helium is produced. The mass of the element stays almost the same because the mass of the electron that it loses is so small.

Rate of Decay

Is it possible to analyze a nucleus and determine when it will decay? Unfortunately, you cannot. Radioactive decay is random. It's like watching popcorn begin to pop. You can't predict which kernel will explode or when. But if you're an experienced popcorn maker, you might be able to predict how long it will take for half the kernels to pop. The rate of decay of a nucleus is measured by its half-life. The **half-life** of a radioactive isotope is the amount of time it takes for half of a sample of the element to decay.

Mini LAB

Graphing Half-Life

Procedure

1. Make a table with three columns: *Number of Half-Lives, Days Passed,* and *Mass Remaining.*
2. Mark the table for six half-lives.
3. Thorium-234 has a half-life of 24 days. Fill in the second column with the total number of days after each half-life.
4. Begin with a 64-g sample of thorium and calculate the mass remaining after each half-life.
5. Make a graph with *Number of half-lives* on the *x*-axis and *Mass remaining* on the *y*-axis.

Analysis

1. During which half-life does the most thorium decay?
2. How much thorium was left by day 144?

Calculating Half-Life Decay Iodine-131 has a half-life of eight days. If you start with a sample of 4 g of iodine-131, after eight days you would have only 2 g of iodine-131 remaining. After 16 days, or two half-lives, half of the 2 g would have decayed and you would have only 1 g left. **Figure 20** illustrates this process.

The radioactive decay of unstable atoms goes on at a steady pace, unaffected by conditions such as weather, pressure, magnetic or electric fields, and even chemical reactions. Half-lives, which are different for each isotope, range in length from fractions of a second to billions of years.

February		4 grams iodine-131	1	2	3	4
5	6	7	8 2 grams iodine-131	9	10	11
12	13	14	15	16 1 gram iodine-131	17	18
19	20	21	22	23	24 0.5 grams iodine-131	25
26	27	28	1 March	2	3	4 ?

Figure 20 Half-life is the time it takes for one half of a sample to decay.
Calculate *how much of the sample you expect to find on March 4.*

Applying Math — Use Numbers

FIND HALF-LIVES Tritium has a half-life of 12.5 years. If you start with 20 g, how much tritium would be left after 50 years?

Solution

1 *This is what you know:*
- half-life = 12.5 years
- initial weight = 20 g

2 *This is what you need to find out:*
- the number of half-lives in 50 years
- final weight after 50 years

3 *This is the procedure you need to use:*
- Determine the number of half-lives.
  number of years/half life = number of half-lives
  50 years/12.5 years = 4 half-lives
- Determine the final weight.
  final weight = initial weight/$2^{(\text{number of half-lives})}$
  final weight = 20 g/2^4 = 20 g/16 = 1.25 g

4 *Check your answer:* Substitute the number of half-lives and the final weight into the second equation and solve for initial weight. You should get the same initial weight.

Practice Problems

1. Carbon-14 has a half-life of 5,730 years. Starting with 100 g of carbon-14, how much would be left after 17,190 years?
2. Radon-222 has a half-life of 3.8 days. Starting with 50 g of radon-222, how much would be left after 19 days?

Science Online — For more practice, visit blue.msscience.com/math_practice

Carbon Dating Scientists have found the study of radioactive decay useful in determining the age of artifacts and fossils. Carbon-14 is used to determine the age of dead animals, plants, and humans. The half-life of carbon-14 is 5,730 years. In a living organism, the amount of carbon-14 remains in constant balance with the levels of the isotope in the atmosphere or ocean. This balance occurs because living organisms take in and release carbon. For example, animals take in carbon from food such as plants and release carbon as carbon dioxide. While life processes go on, any carbon-14 nucleus that decays is replaced by another from the environment. When the plant or animal dies, the decaying nuclei no longer can be replaced.

When archaeologists find an ancient item, such as the one in **Figure 21,** they can find out how much carbon-14 it has and compare it with the amount of carbon-14 the animal would have had when it was alive. Knowing the half-life of carbon-14, they can then calculate when the animal lived.

INTEGRATE Environment

Energy Conversion Nuclear power plants convert the nuclear energy from the radioactive U-235 to electrical energy and heat energy. Research how the plants dispose of the heat energy, and infer what precautions they should take to prevent water pollution in the area.

INTEGRATE Earth Science

When geologists want to determine the age of rocks, they cannot use carbon dating. Carbon dating is used only for things that have been alive. Instead, geologists examine the decay of uranium. Uranium-238 decays to lead-206 with a half-life of 4.5 billion years. By comparing the amount of uranium to lead, the scientist can determine the age of a rock. However, there is some disagreement in the scientific community about this method because some rocks might have had lead in them to start with. In addition, some of the isotopes could have migrated out of the rock over the years.

Figure 21 Using carbon-14 dating techniques, archaeologists can find out when an animal may have lived.

Disposal of Radioactive Waste Waste products from processes that involve radioactive decay are a problem because they can leave isotopes that still release radiation. This radioactive waste must be isolated from people and the environment because it continues to produce harmful radiation. Special disposal sites that can contain the radiation must be built to store this waste for long periods. One such site is in Carlsbad, New Mexico, where nuclear waste is buried 655 m below the surface of Earth.

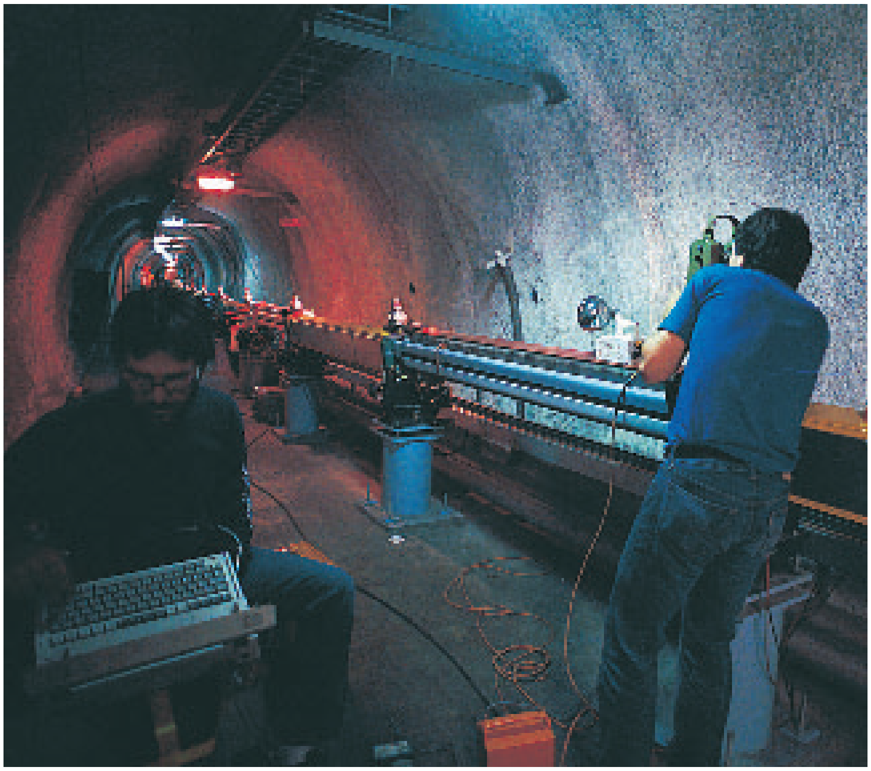


Figure 22 Giant particle accelerators, such as this linear accelerator at Stanford, are needed to speed up particles until they are moving fast enough to cause an atomic transmutation.

Making Synthetic Elements

Scientists now create new elements by smashing atomic particles into a target element. Alpha and beta particles, for example, are accelerated in particle accelerators like the one in **Figure 22** to speeds fast enough that they can smash into a large nucleus and be absorbed on impact. The absorbed particle converts the target element into another element with a higher atomic number. The new element is called a synthetic element because it is made by humans. These artificial transmutations have created new elements that do not exist in nature. Elements with atomic numbers 93 to 112, and 114 have been made in this way.

Uses of Radioactive Isotopes The process of artificial transmutation has been adapted so that radioactive isotopes of normally stable elements can be used in hospitals and clinics using specially designed equipment. These isotopes, called tracer elements, are used to diagnose disease and to study environmental conditions. The radioactive isotope is introduced into a living system such as a person, animal, or plant. It then is followed by a device that detects radiation while it decays. These devices often present the results as a display on a screen or as a photograph. The isotopes chosen for medical purposes have short half-lives, which allows them to be used without the risk of exposing living organisms to prolonged radiation.

Science Online

Topic: Isotopes in Medicine and Agriculture

Visit blue.msscience.com for Web links to information about the use of isotopes in medicine and agriculture.

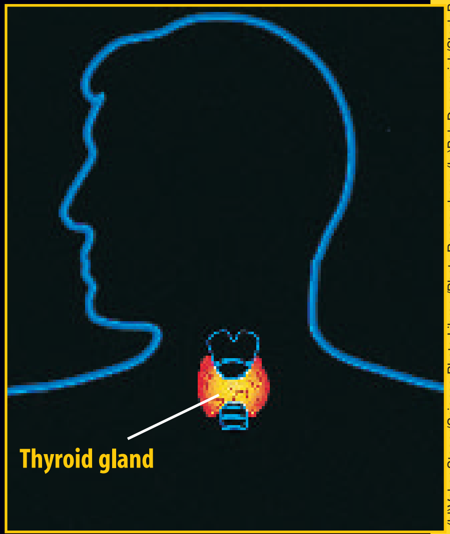
Activity List the most commonly used radioactive elements and their isotopes used in medicine and agriculture.

Peter Menzel/Stock Boston

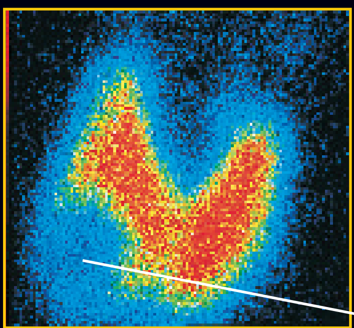
VISUALIZING TRACER ELEMENTS

Figure 23

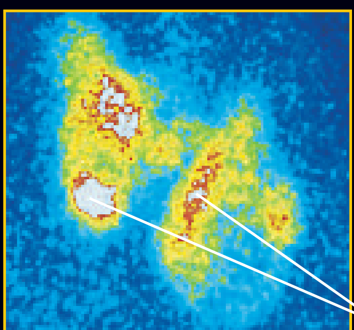
Typically, we try to avoid radioactivity. However, very small amounts of radioactive substances, called radioisotopes or "tracer elements," can be used to diagnose disease. A healthy thyroid gland absorbs iodine to produce two metabolism-regulating hormones. To determine if a person's thyroid is functioning properly, a radioisotope thyroid scan can be performed. First, a radioactive isotope of iodine—iodine-131—is administered orally or by injection. The thyroid absorbs this isotope as it would regular iodine, and a device called a gamma camera is then used to detect the radiation that iodine-131 emits. A computer uses this information to create an image showing thyroid size and activity. Three thyroid images taken by a gamma camera are shown below.



NORMAL
A healthy thyroid gland manufactures hormones that regulate a person's metabolism, including heart rate.



ENLARGED
Although rarely life threatening, an enlarged thyroid, or goiter—caused by too little iodine in the diet—can form a grapefruit-size lump in the neck.



OVERACTIVE
In the condition known as hyperthyroidism, an overactive thyroid speeds up metabolism, causing weight loss and an increased heart rate.

A gamma camera traces the location of iodine-131 during a thyroid scan procedure.

(tl)T. Youssef/Custom Medical Stock Photo, (tr)Alfred Pasieka/Science Photo Library/Custom Medical Stock Photo, (cl)CNRI/PhotoTake, NYC, (bl)Voker Steger/Science Photo Library/Photo Researchers, (br)Bob Daemmrich/Stock Boston/PictureQuest

Medical Uses The isotope iodine-131 has been used to diagnose problems with the thyroid, a gland located at the base of the neck. This is discussed in **Figure 23.** Other radioactive isotopes are used to detect cancer, digestion problems, and circulation difficulties. Technetium-99 is a radioisotope with a half-life of 6 h that is used for tracing a variety of bodily processes. Tumors and fractures can be found because the isotope will show up as a stronger image wherever cells are growing rapidly.

Environmental Uses In the environment, tracers such as phosphorus-32 are injected into the root system of a plant. In the plant, the radioactive phosphorus behaves the same as the stable phosphorus would. A detector then is used to see how the plant uses phosphorus to grow and reproduce.

Radioisotopes also can be placed in pesticides and followed to see what impact the pesticide has as it moves through an ecosystem. Plants, streams, insects, and animals can be tested to see how far the pesticides travel and how long they last in the ecosystem. Fertilizers containing small amounts of radioactive isotopes are used to see how well plants absorb fertilizers. Water resources can be measured and traced using isotopes, as well. This technique has been used in many developing countries that are located in arid regions as they search for sources of water.

INTEGRATE Life Science

Cell Division in Tumors When a person has cancer, cells reproduce rapidly, causing a tumor. When radiation is focused directly on the tumor, it can slow or stop the cell division while leaving healthy, surrounding tissue largely unaffected. Find out more about radiation therapy and summarize your findings in your Science Journal.

section 2 review

Summary

Identifying Numbers

- The atomic number is the number of protons in the nucleus of an atom.
- The mass number is the total of protons and neutrons in the nucleus of an atom.
- Isotopes of an element have different numbers of neutrons.

Radioactivity

- Radioactive decay is the release of nuclear particles and energy.
- Transmutation is the change of one element into another through radioactive decay. One form of transmutation is the loss of an alpha particle and energy from the nucleus. Another is the loss of a beta particle from the nucleus.
- Half-life of a radioactive isotope is the amount of time it takes for half of a sample of the element to decay.

Self Check

1. **Define** the term *isotope*. What must you know to calculate the number of neutrons in an isotope of an element?
2. **Compare and contrast** two types of radioactive decay.
3. **Infer** Do all elements have half-lives? Why or why not?
4. **Explain** how radioactive isotopes are used to detect health problems.
5. **Think Critically** Suppose you had two samples of the same radioactive isotope. One sample had a mass of 25 g. The other had a mass of 50 g. Would the same number of particles be ejected from each sample in the first hour? Explain.

Applying Skills

6. **Make Models** You have learned how scientists used marbles, modeling clay, and a cloud to model the atom. Describe the materials you might use to create one of the atomic models described in the chapter.

LAB Design Your Own

Half-Life

Mark Burnett

Goals

- **Model** isotopes in a radioactive sample. For each half-life, determine the amount of change that occurs in the objects that represent the isotopes in the model.

Possible Materials

pennies
graph paper

Design an experiment to test the usefulness of half-life in predicting how much radioactive material still remains after a specific number of half-lives.

Real-World Question

The decay rates of most radioactive isotopes range from milliseconds to billions of years. If you know the half-life of an isotope and the size of a sample of the isotope, can you predict how much will remain after a certain amount of time? Is it possible to predict when a specific atom will decay? How can you use pennies to create a model that will show the amount of a radioactive isotope remaining after specific numbers of half-lives?

Form a Hypothesis

Using the definition of the term *half-life* and pennies to represent atoms, write a hypothesis that shows how half-life can be used to predict how much of a radioactive isotope will remain after a certain number of half-lives.

Test Your Hypothesis

Make a Plan

1. With your group, write the hypothesis statement.
2. **Write** down the steps of the procedure you will use to test your hypothesis. Assume that each penny represents an atom in a radioactive sample. Each coin that lands heads up after flipping has decayed.
3. **List** the materials you will need.
4. In your Science Journal, make a data table with two columns. Label one Half-Life and the other Atoms Remaining.
5. **Decide** how you can use the pennies to represent the radioactive decay of an isotope.
6. **Determine** (a) what will represent one half-life in your model, and (b) how many half-lives you will investigate.
7. **Decide** (a) which variables your model will have, and (b) which variable will be represented on the *y*-axis of your graph and which will be represented on the *x*-axis.

Follow Your Plan

1. Make sure your teacher approves your plan and your data table before you start.
2. Carry out your plan and record your data carefully.

Analyze Your Data

1. The relationship among the starting number of pennies, the number of pennies remaining *(y)*, and the number of half-lives *(x)* is shown in the following equation:

$$y = \frac{\text{(starting number of pennies)}}{2^x}$$

2. **Graph** this equation using a graphing calculator. Use your graph to find the number of pennies remaining after 2.5 half-lives.
3. **Compare** the results of your activity and your graph with those of other groups.

Conclude and Apply

1. Is it possible to use your model to predict which individual atoms will decay during one half-life? Why or why not?
2. Can you predict the total number of atoms that will decay in one half-life? Explain.

Communicating Your Data

Display your data again using a bar graph. **For more help, refer to the Science Skill Handbook.**

CONTENTS

Pioneers in Radioactivity

A Surprise on a Cloudy Day

Most scientific discoveries are the result of meticulous planning. Others happen quite by accident. On a cloudy day in the spring of 1896, physicist Henri Becquerel was unable to complete the day's planned work requiring the sun as the primary energy source. Disappointed, he wrapped his experimental photographic plates and put them away in a darkened drawer along with some crystals containing uranium. Imagine Becquerel's surprise upon discovering that the covered plates had somehow been exposed in complete darkness! The unplanned discovery that uranium emits radiation ultimately led to a complete revision of theories about atomic structure and properties.

Marie Curie's Revolutionary Hypothesis

One year before this revolutionary event, physicist Wilhelm Roentgen discovered a type of ray that could penetrate flesh, yielding photographs of living people's bones. Were these "X" rays, as Roentgen named them, and the radiation emitted by uranium in any way related? Intrigued by these findings, scientist Marie Curie began studying uranium compounds. Her research led her to hypothesize that radiation is an atomic property of matter which causes atoms of some elements to emit radiation, changing into atoms of another element. Her revolutionary hypothesis challenged current beliefs that the atom was indivisible and unchangeable.

"The Miserable Old Shed"

Marie Curie's husband became interested in her research, shelving his own magnetism studies to partner with her. Together, in the laboratory she referred to as "the miserable old shed," they experimented with a uranium ore called pitchblende. Strangely, pitchblende proved to be more radioactive than pure uranium. The Curies hypothesized that one or more undiscovered radioactive elements must also be part of this ore. By eventually isolating the elements radium and polonium from pitchblende, they achieved the dream of every scientist of the day: adding elements to the periodic table. In 1903, Marie and Pierre Curie shared the Nobel prize in physics with Henri Becquerel for contributions made through radiation research. The first female recipient of a Nobel prize, Marie Curie was awarded a second Nobel in 1911 in chemistry for her work with radium and radium compounds.

Investigate **Research the work of Ernest Rutherford, who won the Nobel prize in Chemistry in 1908. Use the link to the right to describe some of his discoveries dealing with transmutation, radiation, and atomic structure.**

Science Online
For more information, visit blue.msscience.com/time

Reviewing Main Ideas

Section 1 Models of the Atom

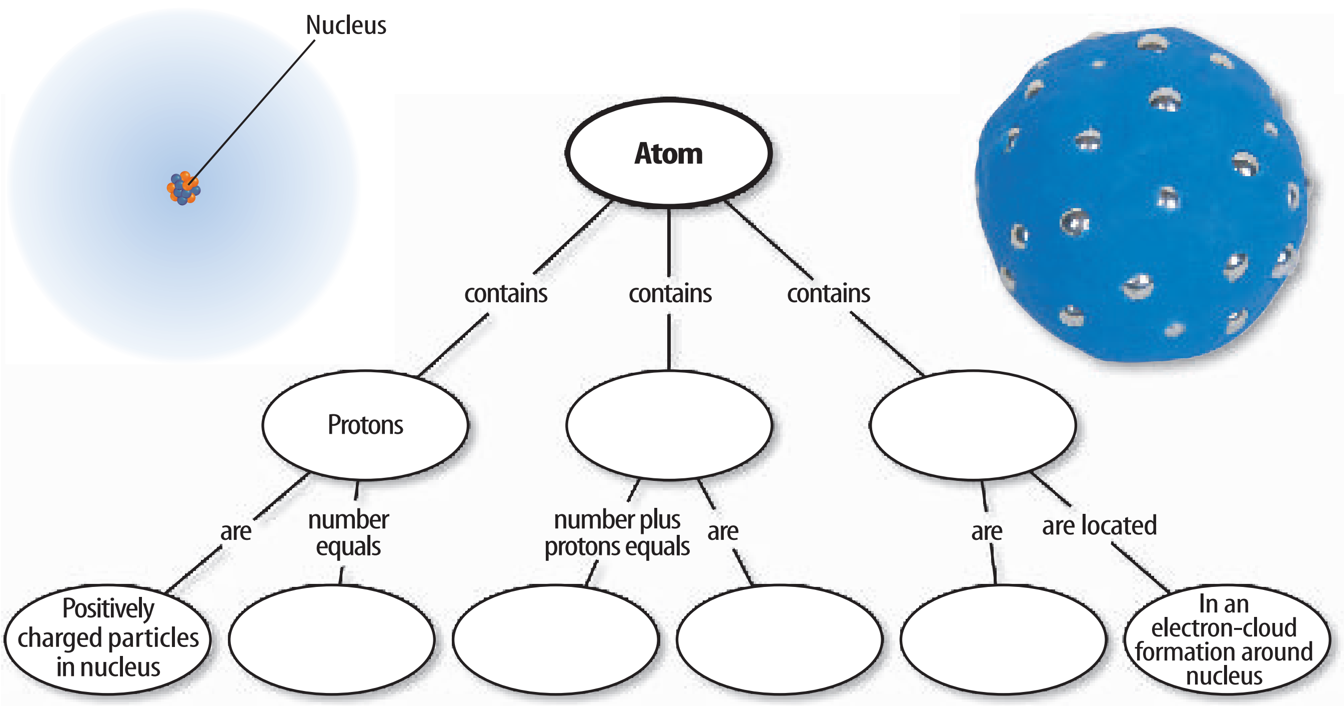
1. John Dalton proposed that an atom is a sphere of matter.
2. J.J. Thomson discovered that all atoms contain electrons.
3. Rutherford hypothesized that almost all the mass and all the positive charge of an atom is concentrated in an extremely tiny nucleus at the center of the atom.
4. Today's model of the atom has a concentrated nucleus containing the protons and neutrons surrounded by a cloud representing where the electrons are likely present.

Section 2 The Nucleus

1. The number of protons in the nucleus of an atom is its atomic number.
2. Isotopes are atoms of the same elements that have different numbers of neutrons. Each isotope has a different mass number.
3. An atom's nucleus is held together by the strong nuclear force.
4. Some nuclei decay by ejecting an alpha particle. Other nuclei decay by emitting a beta particle.
5. Half-life is a measure of the decay rate of a nucleus.

Visualizing Main Ideas

Copy and complete the following concept map about the parts of the atom.



Aaron Haupt

chapter 14 Review

Using Vocabulary

alpha particle p. 408
anode p. 406
atomic number p. 415
beta particle p. 418
cathode p. 406
electron p. 407
electron cloud p. 413
element p. 405
half-life p. 418
isotope p. 415
mass number p. 416
neutron p. 411
proton p. 410
radioactive decay p. 416
transmutation p. 416

Each phrase below describes a science term from the list. Write the term that matches the phrase describing it.

1. a nuclear particle with no charge
2. a substance made up of only one type of atom
3. the number of protons and neutrons in the nucleus of an atom
4. a negatively charged particle
5. the release of nuclear particles and energy
6. the number of protons in an atom

Checking Concepts

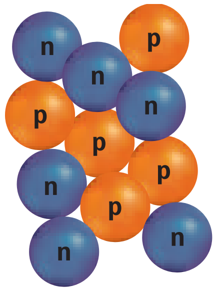
Choose the word or phrase that best answers the question.

7. In beta decay, a neutron is converted into a proton and which of the following?
   A) an isotope **C)** an alpha particle
   B) a nucleus **D)** a beta particle

8. What is the process by which one element changes into another element?
   A) half-life
   B) chemical reaction
   C) chain reaction
   D) transmutation

9. What are atoms of the same element that have different numbers of neutrons called?
   A) protons **C)** ions
   B) electrons **D)** isotopes

Use the illustration below to answer questions 10 and 11.



Boron nucleus

10. What is the atomic number equal to?
    A) energy levels **C)** neutrons
    B) protons **D)** nuclear particles

11. If the atomic number of boron is 5, boron-11 contains
    A) 11 electrons.
    B) five neutrons.
    C) five protons and six neutrons.
    D) six protons and five neutrons.

12. How did Thomson know that the glow in the CRT was from a stream of charged particles?
    A) It was green.
    B) It caused a shadow of the anode.
    C) It was deflected by a magnet.
    D) It occurred only with current.

13. Why did Rutherford infer the presence of a tiny nucleus?
    A) The alpha particles went through the foil.
    B) No alpha particles went through the foil.
    C) The charges were uniform in the atom.
    D) Some alpha particles bounced back from the foil.

14. What did J.J. Thomson's experiment show?
    A) The atom is like a uniform sphere.
    B) Cathode rays are made up of electrons.
    C) All atoms undergo radioactive decay.
    D) Isotopes undergo radioactive decay.

Thinking Critically

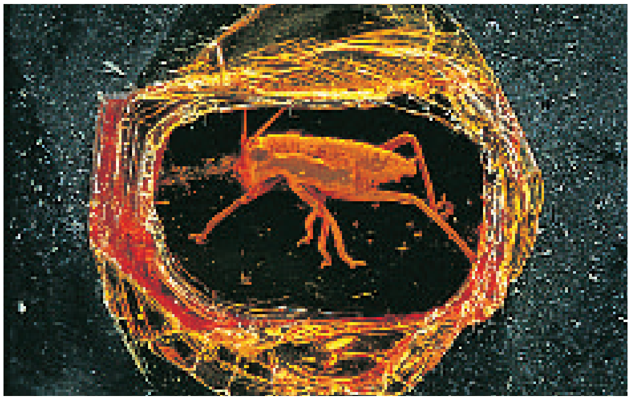
15. **Explain** how it is possible for two atoms of the same element to have different masses.

16. **Explain** Matter can't be created or destroyed, but could the amounts of some elements in Earth's crust decrease? Increase?

17. **Describe** why a neutral atom has the same number of protons and electrons.

18. **Compare and contrast** Dalton's model of the atom to today's model of the atom.

Use the figure below to answer question 19.



19. **Explain** how carbon-14 dating can provide the age of a dead animal or plant.

20. **Predict** If radium-226 releases an alpha particle, what is the mass number of the isotope formed?

21. **Concept Map** Make a concept map of the development of the theory of the atom.

22. **Predict** Given that the mass number of an isotope of mercury is 201, how many protons does it contain? Neutrons?

23. **Draw Conclusions** An experiment resulted in the release of a beta particle and an isotope of curium. What element was present at the beginning of this experiment?

Performance Activities

24. **Poster** Make a poster explaining one of the early models of the atom. Present this to your class.

25. **Game** Invent a game that illustrates radioactive decay.

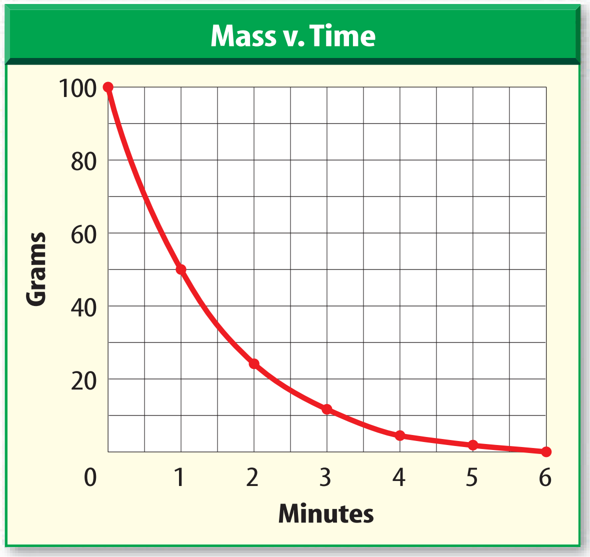
Applying Math

26. **Half Life** A radioactive isotope has a half-life of two years. At the end of four years, how much of the original isotope remains?

    A) one half　　**C)** one third

    B) one fourth　　**D)** none

Use the graph below to answer question 27.



27. **Radioactive Decay** The radioactive decay of an isotope is plotted in the graph. What is the half-life of the isotope? How many grams of the isotope remain after three half-lives?

28. **Mass Number** An atom of rhodium-100 (^{100}Rh) has

    A) 45 protons, 45 neutrons, 45 electrons.

    B) 45 protons, 55 neutrons, 45 electrons.

    C) 55 protons, 45 neutrons, 45 electrons.

    D) 55 protons, 45 neutrons, 55 electrons.

chapter 14 Standardized Test Practice

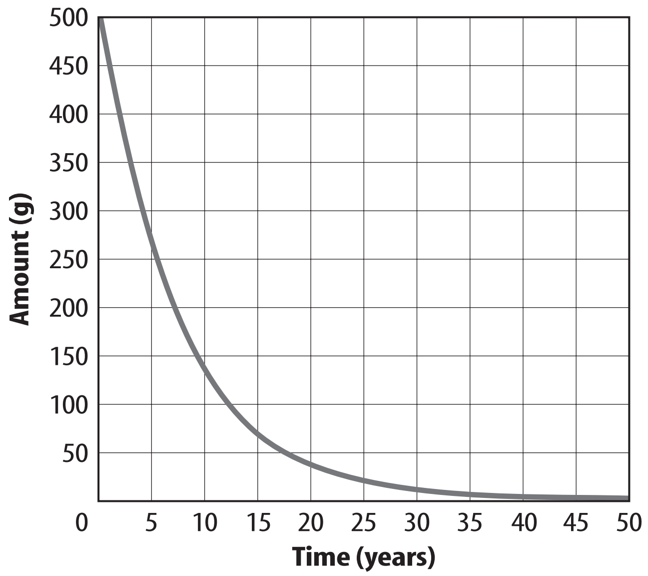
Part 1 Multiple Choice

Record your answers on the answer sheet provided by your teacher or on a sheet of paper.

1. Which of the following is not an element?
   A. iron **C.** steel
   B. carbon **D.** oxygen

Use the graph below to answer questions 2 and 3.

Radioactive Decay of Cobalt-60



2. The graph above shows the radioactive decay of 500 g of cobalt-60. What is the half-life of cobalt-60?
   A. 5.27 years **C.** 21.08 years
   B. 10.54 years **D.** 60.0 years

3. About how much of the original 500 g of cobalt-60 will be left after 20 years?
   A. 30 g **C.** 90 g
   B. 60 g **D.** 120 g

Test-Taking Tip

Use Recall Remember to recall any hands-on experience as you read the question. Base your answer on the information given on the test. What did you do in the pennies experiment?

Use the table below to answer questions 4 and 5.

Isotopes of Nitrogen		
Isotope	**Mass Number**	**Number of Protons**
Nitrogen-12	12	7
Nitrogen-13	13	7
Nitrogen-14	14	7
Nitrogen-15	15	7

4. The table above shows properties of some nitrogen isotopes. How many neutrons does nitrogen-15 have?
   A. 7 **C.** 14
   B. 8 **D.** 15

5. Which of the isotopes listed in the table would you expect to be the least stable?
   A. nitrogen-15 **C.** nitrogen-13
   B. nitrogen-14 **D.** nitrogen-12

6. Which of the following is the smallest?
   A. electron **C.** proton
   B. nucleus **D.** neutron

7. What is the heaviest naturally occurring element?
   A. actinium **C.** polonium
   B. americium **D.** uranium

8. Ruthenium has an atomic number of 44 and a mass number of 101. How many protons does ruthenium have?
   A. 44 **C.** 88
   B. 57 **D.** 101

9. Which of the following could not be dated using carbon-14 dating?
   A. wooden bowl **C.** bone fragments
   B. plant remains **D.** rock tools

10. What is all matter made of?
    A. dust **C.** atoms
    B. sun rays **D.** metal alloys

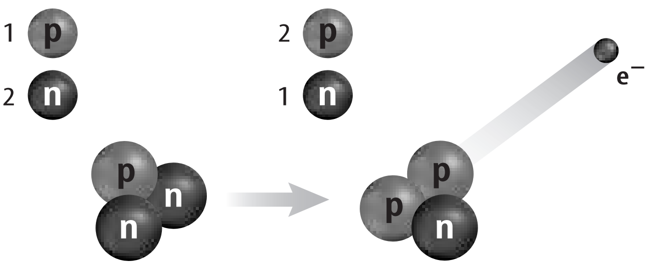
Part 2 Short Response/Grid In

Record your answers on the answer sheet provided by your teacher or on a sheet of paper.

11. What is an element?

12. What is the modern-day name for cathode rays?

Use the illustration below to answer questions 13 and 14.



13. The figure above illustrates the beta decay of hydrogen-3 into helium-3 and an electron. What is a beta particle? From what part of the atom do beta particles originate?

14. Describe the transmutation that occurs during the beta decay shown in the illustration.

15. Describe Thomson's idea about the composition of an atom.

16. Are electrons more likely to be close to the nucleus or far away from the nucleus? Why?

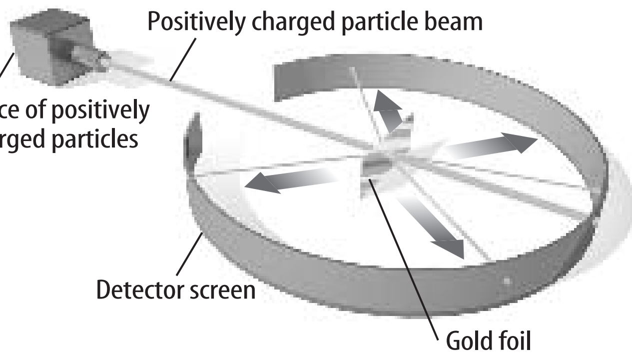
17. Cesium-137 has a half-life of 30.3 years. If you start with 60 g, how much cesium would be left after 90.9 years?

18. Explain how the half-life of C-14 is used to date American Indian, Greek, and Roman artifacts, but cannot be used to date fossil remains from the Cretaceous Period.

Part 3 Open Ended

Record your answers on a sheet of paper.

Use the illustration below to answer questions 19 and 20.



19. The illustration above shows Rutherford's gold foil experiment. Describe the setup shown. What result did Rutherford expect from his experiment?

20. What is the significance of the particles that reflected back from the gold foil? How did Rutherford explain his results?

21. Describe Dalton's ideas about the composition of matter, including the relationship between atoms and elements.

22. Describe the discovery of cathode rays.

23. Describe how was able to show Thomson that cathode rays were streams of particles, not light.

24. Some smoke detectors contain small radioactive sources. Explain how these detectors use radioactive decay to detect smoke.

25. Manganese-54 has a half-life of about 312 days. Draw a graph of the radioactive decay of a 600-g sample of manganese-54.

26. Describe the uses of radioactive elements in medicine, agriculture, and industry.