Name ______________________ Class ______________ Date ______________

CHAPTER 6 Introduction to Atoms

SECTION 1

Development of the Atomic Theory

BEFORE YOU READ

After you read this section, you should be able to answer these questions:

- What is the atomic theory?
- How has the atomic theory changed?
- How do scientists observe atoms?

California Science Standards

8.3.a

What Is an Atom?

Imagine cutting something in half, then cutting again and again. Could you keep cutting forever? Around 440 BCE, a Greek philosopher named Democritus thought you would not be able to cut forever because you would eventually reach a smallest piece of matter. He called this particle an atom.

It was a long time before there was scientific evidence that Democritus was on the right track. We now know that all matter is made of tiny particles called atoms. An **atom** is the smallest particle into which an element can be divided and still keep its properties. ☑

STUDY TIP

Connect Concepts In your notebook, create a Concept Map about the scientists who studied atoms and what they learned.

READING CHECK

1. Identify What is an atom?

____

____

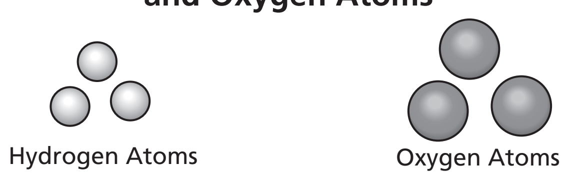
____

What Was the First Scientific Theory of Atoms?

The first scientific theory about atoms was published by John Dalton in 1803. Unlike Democritus, Dalton based his ideas on experiments. His theory helped explain observations that he and other scientists had made about elements and compounds. Dalton's theory stated the following ideas:

- Atoms are small particles that cannot be created, destroyed, or divided.
- All substances are made of atoms.
- All atoms of one element are exactly alike.
- Atoms of different elements are different.
- Atoms can join with other atoms to make different substances.

Dalton Model of Hydrogen Atoms and Oxygen Atoms



According to Dalton's theory, atoms cannot be divided or destroyed. Dalton's atoms can be modeled with hard metal balls.

TAKE A LOOK

2. Explain In the drawing, why do the oxygen atoms look different from the hydrogen atoms?

____

____

____

Is Dalton's Theory Still Used?

Dalton's theory explained many observations about matter. However, by the end of the 1800s, scientists had made observations that did not fit exactly with Dalton's theory. Scientists changed the atomic theory to include this new knowledge. While the modern atomic theory is based on Dalton's theory, it is also very different. ☑

READING CHECK

3. Discuss When would scientists need to change a theory?

____

____

____

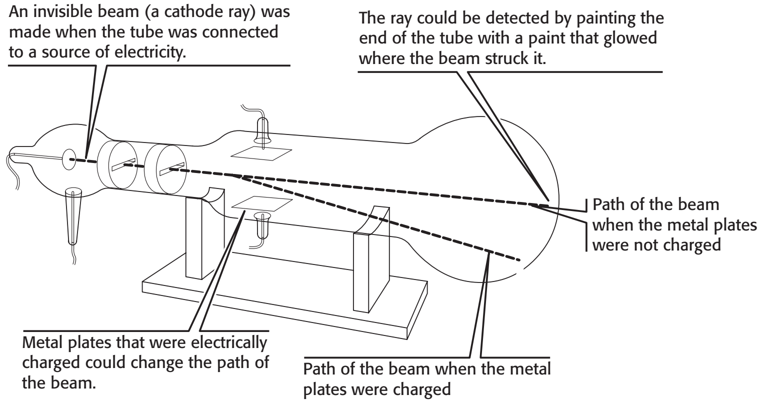
How Were Electrons Discovered?

In 1897, J. J. Thomson, a British scientist, discovered that atoms are not the smallest particles. There are even smaller particles inside the atom.

Thomson made this discovery when he was experimenting with mysterious invisible beams called cathode rays. Cathode rays were produced by connecting a special glass tube to a source of electricity. At the time, no one knew exactly what a cathode ray was made of.

To find out more about cathode rays, Thomson placed two metal plates inside the tube. He gave one plate a positive electrical charge and the other plate a negative charge. Thomson discovered that when he shot the cathode ray past the plates, it was attracted to the plate with the positive charge.

Thomson's Cathode-Ray Tube Experiment



TAKE A LOOK

4. Identify What is the electrical charge on the plate that causes the beam to bend toward that plate?

____

Thomson concluded that cathode rays must be made of tiny particles that come from atoms. Because the particles are attracted to a positively charged metal plate, the particles must have a negative charge. (Opposite charges attract each other.) The negatively charged particles found inside the atom are now called **electrons**. ☑

READING CHECK

5. Identify What type of electrical charge does an electron have?

____

What Were Thomson's Conclusions?

When Thomson discovered electrons, he was able to make several new conclusions about atoms. These conclusions included:

- There are particles (electrons) inside atoms.
- The particles have a negative charge.
- Because atoms have no electrical charge (they are neutral), they must also contain particles with positive charges that balance the negative charges. ☑

Notice that Thomson's conclusions do not fit exactly with Dalton's atomic theory. The atomic theory was changed to include a new description of atoms. However, other parts of Dalton's theory did not change. For example, scientists still knew that atoms of different elements are different. Scientists do not always need to discard a theory completely when new evidence is discovered.

READING CHECK

6. Explain How did Thomson know that atoms must contain particles with positive charges?

____

____

____

____

What Is the "Plum-Pudding" Model?

Thomson's experiment showed that atoms contain electrons. However, it did not show where electrons are located inside the atom. Thomson suggested that electrons might be scattered throughout the atom.

This new model of the atom was called the *plum-pudding model*, named after a dessert that was popular at the time. Today, we would probably call this a "chocolate chip ice-cream" model of the atom. Electrons are scattered throughout the atom as chocolate chips are scattered through ice cream.

Chocolate Chip Ice Cream Model of an Atom

Thomson proposed a model that has electrons mixed throughout the atom. The rest of the atom has a positive charge.

TAKE A LOOK

7. Compare What do the chocolate chips represent in a "chocolate chip ice cream model"?

____

How Did Rutherford Study the Atom?

In 1909, one of Thomson's former students designed a way to test his theory that electrons are scattered throughout the atom. Ernest Rutherford decided to shoot a beam of tiny, positively charged particles at a thin sheet of gold foil.

Rutherford assumed that atoms are soft blobs of matter with electrons and positively charged particles scattered through them. He thought that most of the particles he shot would pass right through the atoms of gold. Particles that hit other particles would stop or bounce off to the side.

When Rutherford performed the experiment, he found that most of the positively charged particles did pass through the gold foil. Some were deflected sideways, just as he expected. What surprised him was that some particles bounced straight back. ☑

READING CHECK

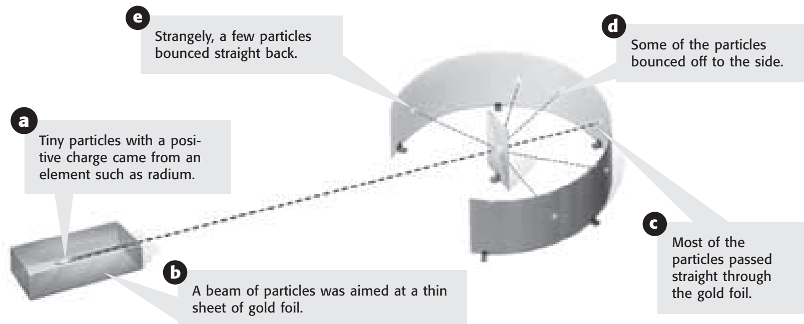
8. Identify What did Rutherford aim at the gold foil in his experiment?

____

____

____

Rutherford's Gold-Foil Experiment



TAKE A LOOK

9. Compare How did the number of particles that followed a straight path compare with the number that were deflected?

____

____

What Was Rutherford's Atomic Model?

The plum-pudding model did not explain what Rutherford saw. He reasoned that there was only one way that the positively charged particles could bounce straight back. That was if they hit a very dense part of the atom that also had a positive charge. (Like charges repel.) He concluded that most of the matter in the atom must be in a very small part of the atom, not scattered throughout it. Based on the results of his experiment, Rutherford proposed a new model of the atom, the *nuclear model*.

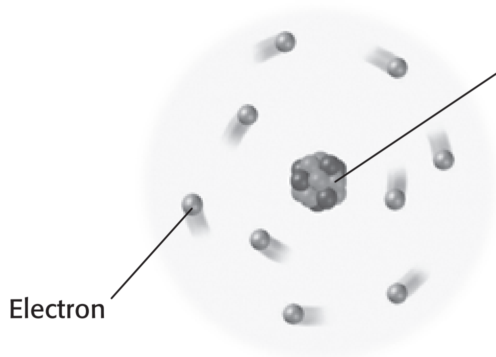
In his model, the center of the atom is a tiny, dense, positively charged area called the **nucleus**. The electrons move outside the nucleus in mostly empty space.

CALIFORNIA STANDARDS CHECK

8.3.a Students know the structure of the atom and know it is composed of protons, neutrons, and electrons

10. Describe Where are the electrons found in an atom?

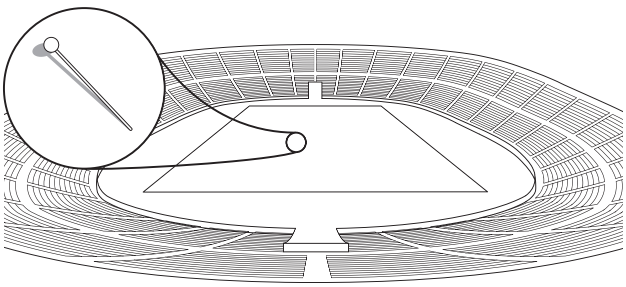
____



In Rutherford's model, the atom contains a nucleus. Electrons move around the nucleus.

How Big Is the Nucleus?

Rutherford concluded that the nucleus must be very small but very dense in order to deflect the fast-moving particles. He used his observations to calculate that the diameter of an atom is about 100,000 times greater than the diameter of its nucleus. The atom is mostly empty space. Electrons move in this space, around the nucleus.

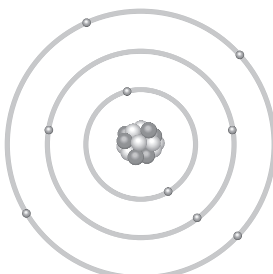


The stadium is about 100,000 times wider than a pinhead. This is about the same as the ratio of the diameter of an atom to its nucleus.

Where Are the Electrons?

In 1913, Niels Bohr, a Danish scientist, studied the way that atoms react to light. He made a slight change to Rutherford's model, based on his observations. Bohr proposed that electrons move around the nucleus in definite paths, or orbits. In Bohr's model, electrons could not exist between these orbits. However, the electrons could jump from one orbit to another as they gained or lost energy. Once again, the atomic theory was revised to account for new data. ☑

Bohr Model of the Atom



In the Bohr model, electrons move around the nucleus like planets around the sun.

Math Focus

11. Make Comparisons If an atom had a nucleus 1 ft in diameter, what would be the diameter of the atom, in miles? Show your work. Round to the nearest mile. (1 mi = 5,280 ft)

____

TAKE A LOOK

12. Identify In this comparison, what represents the nucleus of an atom?

____

☑ READING CHECK

13. List What three new ideas about electrons did Bohr propose?

____

____

____

____

____

TAKE A LOOK

14. Identify Label the nucleus and the electrons in the figures.

What Is the Modern Atomic Theory?

Atomic theory has changed over the past 100 years. Scientists such as Erwin Schrödinger from Austria, and Werner Heisenberg from Germany, have done important work. They have made observations that show that the Bohr model is not quite right.

Scientists still think that electrons are moving constantly around the nucleus. However, they now know that electrons do not orbit the nucleus, like planets orbit the sun. In fact, no one can ever know the exact path of an electron. No one can even predict the path an electron will follow as it moves around the nucleus. However, scientists can predict where electrons are likely to be found.

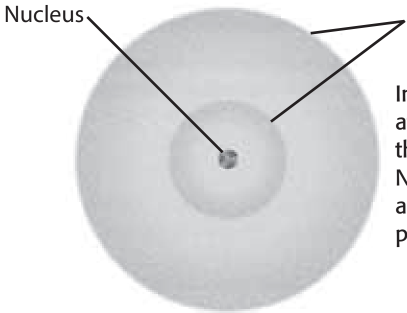
In the modern atomic model, the locations of electrons are described with **electron clouds**. Electron clouds are regions where electrons are most likely to be found. The figure below represents this model. ☑

READING CHECK

15. Define What are electron clouds?

____

____



In the current model of the atom, electrons move around the nucleus in electron clouds. No one can say exactly where a particular electron is at any particular time.

ENERGY LEVELS

Although electrons can't be found in any one particular place in an atom, there are certain *energy levels* that electrons can occupy. Electrons stay in motion because they have energy. As atoms gain and lose energy, electrons move from one energy level to another. The exact size and shape of a particular electron cloud depends on the energy of the electron.

TAKE A LOOK

16. Compare Fill in the table to compare the modern atomic model with the Bohr model.

Bohr model of the atom	Modern model of the atom
Electrons are tiny particles with a negative charge.	
Electrons are located outside the nucleus.	
Electrons orbit the nucleus in specific paths.	

Why Does a Theory Change?

As scientists learn more about the structure of atoms, the atomic theory is revised again and again. This does not mean that previous explanations were "wrong." Instead, it means that they provided a model of what was known about atoms at that time. These models were useful and helped scientists develop new experiments to learn more about atoms. Each of them led to a better understanding of the atoms.

The modern atomic theory has developed as scientists have learned more about the structure of these basic particles of elements. We know more about atoms today than Dalton did in 1803. The essential part of his theory is still the basic part of the modern atomic theory. The atoms of any particular element are different from the atoms of every other element. ☑

READING CHECK

17. Explain What was the essential part of Dalton's atomic theory?

____

____

____

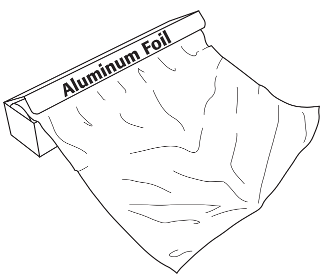
How Big Are Atoms?

Most of what we know about atoms was discovered without ever seeing an image of one. How small is an atom? The diameter of an atom is about one hundred-millionth of one centimeter (0.00000001 cm). Imagine a thin piece of aluminum foil. The foil is more than 100,000 atoms thick.

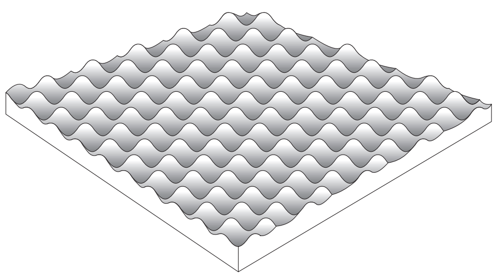
In fact, atoms are too small to be seen through a microscope. However, scientists today have tools that make images of atoms. One such tool is a scanning tunneling microscope (STM). This instrument uses the energy of electrons to make images. These images, like the one below, are not actual photographs. They are drawings made by a computer using information gathered by the STM.

Say It

Discuss There are about 100,000 atoms in the thickness of a piece of aluminum foil. In groups of two or three, discuss other things in your life that involve very large numbers. For example, how many people live in your city or town?



This piece of foil is more than 100,000 atoms thick.



Scientists today can make images of atoms such as these, but most of what we know about atoms was learned by observing them indirectly.

Math Focus

18. Calculate An aluminum can is about as thick as two pieces of aluminum foil. About how many atoms thick is an aluminum can?

____

____

Section 1 Review

8.3.a

SECTION VOCABULARY

atom the smallest unit of an element that maintains the properties of that element

<u>**Wordwise**</u> The prefix *a-* means "not." The root *tom* means "to cut."

electron a subatomic particle that has a negative charge

electron cloud a region around the nucleus of an atom where electrons are likely to be found

nucleus in physical science, an atom's central region, which is made up of protons and neutrons

1. **Describe** How does the size of the nucleus of an atom compare with that of its electron cloud?

____

____

2. **Recall** Finish the table below to summarize some of the advances in the development of atomic theory and those responsible for them.

Scientist	**Idea that was added to the atomic theory**
	Each element is made of a different type of atom.
Thomson	
Rutherford	
	Electrons are found in specific energy levels.
	You cannot predict exactly where an electron is or what path it will take.

3. **Apply Concepts** How did the discovery of electrons show that there are also positively charged parts of the atom?

____

____

4. **Evaluate Theories** What would cause scientists to change or replace the modern atomic theory?

____

____

5. **Identify** Label each of the models of the atoms as Dalton, Rutherford, Thomson, or Bohr.

Scientist	**Description of atomic model**
	electrons scattered throughout the atom
	electrons found in energy levels
	hard sphere that can't be broken apart
	atom with a nucleus

SECTION 2
The Atom

BEFORE YOU READ

After you read this section, you should be able to answer these questions:

- What are the three parts of an atom?
- How are atoms of different elements different?
- How are different atoms of the same element different?
- What forces work inside atoms?

California Science Standards

8.3a, 8.7.b

What Are the Parts of an Atom?

Atoms are made of three different types of particles: protons, neutrons, and electrons. As you have learned, electrons have a negative charge and are located in electron clouds outside the nucleus. You have also learned that the nucleus of an atom has a positive charge. **Protons** are the particles inside the nucleus of an atom that give the nucleus its positive charge.

There are other particles inside the nucleus as well. **Neutrons** are particles in the nucleus of an atom that do not have an electric charge. ☑

STUDY TIP

Compare In your notebook, make a table to compare various characteristics of subatomic particles. Include mass, charge, and location in an atom.

READING CHECK

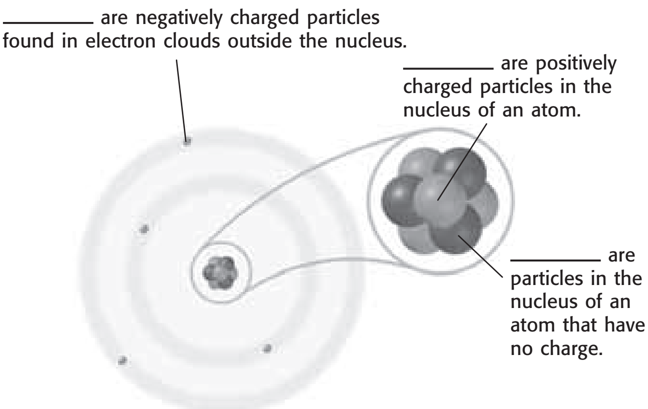
1. List What are the three types of subatomic particles in an atom?

____

____

____

Parts of an Atom



When the model of an atom is shown in a book, it does not show the correct scale of the particles in an atom. If protons were the size of those in an illustration, the electrons would need to be hundreds of feet away from the nucleus.

TAKE A LOOK

2. Identify Fill in the names of the subatomic particles on the blank lines in the illustration.

Because they are much smaller than an entire atom, protons, neutrons, and electrons are called *subatomic particles*. The properties of an element (such as its boiling point and the way it joins with other elements) depend on the number of subatomic particles in the atoms and the way that they interact.

CALIFORNIA STANDARDS CHECK

8.3.a Students know the structure of the atom and know it is composed of protons, neutrons, and electrons.

Word Help: structure
the arrangement of the parts of a whole

3. Describe Where are the three types of subatomic particles located in an atom?

____

____

____

MASSES OF SUBATOMIC PARTICLES

Protons, neutrons, and electrons are all tiny particles. However, protons and neutrons are much more massive than electrons. Therefore, most of the mass of the atom is in the nucleus.

Each individual nucleus has very little mass because the mass of one proton is only about 1.7×10^{-24} g. This can also be written as 0.0000000000000000000000017 grams. Because this number is so small, scientists use a unit called the atomic mass unit, instead of grams, when they describe the masses of subatomic particles.

One **atomic mass unit**, or *amu*, is equal to the mass of one proton. Every proton has a mass of 1 amu. Neutrons have a little more mass than protons, but the difference is very small. Therefore, we say that the mass of a neutron is also 1 amu. ☑

Electrons are much smaller than protons and neutrons. You would need about 1,840 electrons to equal the mass of a proton. Electrons are so small that they are usually not included in calculating the mass of an atom.

READING CHECK

4. Identify What is the SI unit for the mass of subatomic particles?

____

ELECTRIC CHARGES OF SUBATOMIC PARTICLES

Although the masses of an electron and a proton are very different, their electric charges are the same size. However, the signs of the charges are opposite. Electrons have a negative charge, and protons have a positive charge. Neutrons, on the other hand, have no charge at all. Because each atom has an equal number of electrons and protons, atoms are neutral (they have no charge).

If an atom gains or loses an electron, it becomes an *ion*. An ion formed by losing an electron has a positive charge because it has more protons than electrons. An ion formed by gaining an electron has a negative charge because it has more electrons than protons.

TAKE A LOOK

5. Identify Fill in the charge and mass of a neutron.

Particle	Charge	Mass (amu)
Proton	1^+	1
Neutron		
Electron	1^-	1/1,840

What Do the Neutrons Do?

Notice that a helium atom does not have just protons and electrons. The helium nucleus also contains neutrons. In fact, the nucleus of every element except hydrogen contains neutrons. Neutrons play an important role in an atomic nucleus.

Remember that like charges repel one another. Inside an atomic nucleus, protons with the same charge are very close together. If there were no forces to hold them together, electrical repulsion would cause the protons to fly away from one another. Neutrons allow protons to exist very close together. ☑

READING CHECK

8. Describe What is the role of neutrons in the nucleus of an atom?

____

____

____

How Many Protons and Neutrons Can a Nucleus Have?

Because the protons repel each other, the atoms of every element, except hydrogen, must have neutrons in their nuclei. For example, most helium atoms have two protons and two neutrons.

The number of protons is not always the same as the number of neutrons. In fact, except in atoms with only a few protons, nuclei have more neutrons than protons. For example, most fluorine atoms have 9 electrons, 9 protons, and 10 neutrons. Most uranium nuclei have 92 protons and 146 neutrons.

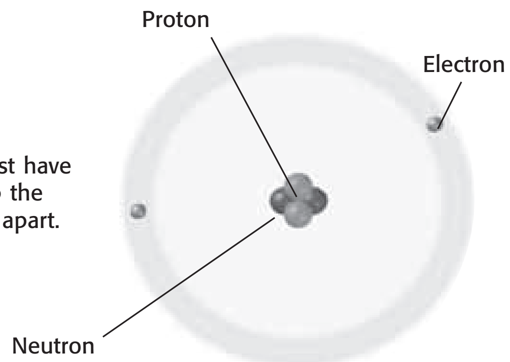
TAKE A LOOK

9. Predict What would happen to the helium atom if the neutrons were removed?

____

____

____



A helium nucleus must have neutrons in it to keep the protons from moving apart.

Notice that we said "most" uranium atoms have 146 neutrons. All uranium atoms have 92 protons. However, the number of neutrons can be different in different uranium atoms. There are also some uranium atoms that have 143 neutrons and some that have 142 neutrons. All atoms of the same element have the same number of protons, but they can have different numbers of neutrons.

How Are Atoms of Different Elements Different?

There are more than 110 elements known in the universe. Each element has atoms that are different from the atoms of all the other elements. All of the atoms of the same element have the same number of protons. Atoms of different elements have different numbers of protons.

For example, the simplest atom is hydrogen. Every hydrogen atom has one proton in its nucleus. An atom with two protons in its nucleus, however, is an atom of helium. Every helium atom has two protons.

The number of protons in the nucleus is called the **atomic number** of the atom. For example, because every oxygen atom has eight protons, the atomic number of oxygen is 8. The number of electrons is the same as the number of protons, so the atomic number also tells you how many electrons are in each atom. The periodic table lists the atomic number of each element. ☑

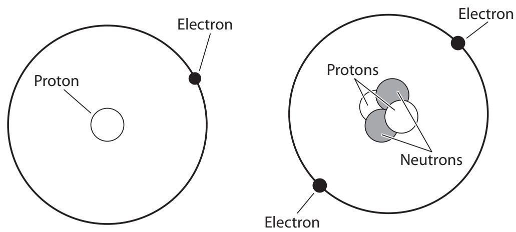
READING CHECK

6. Define What does atomic number tell you about an atom?

____

____

____



Comparison of a Hydrogen Atom and a Helium Atom		
Element	**Hydrogen**	**Helium**
Number of protons		
Number of neutrons		
Number of electrons		
Atomic number		

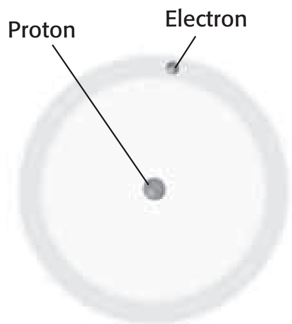
TAKE A LOOK

7. Organize In the table, fill in the blank boxes for each element.

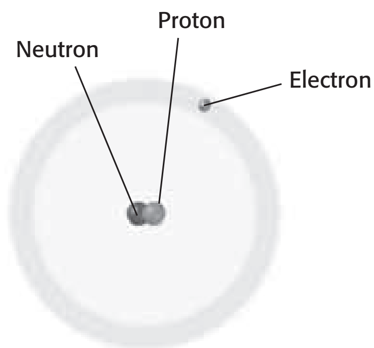
What Are Isotopes?

Just as there are three different kinds of uranium atoms, there are also three different kinds of hydrogen atoms. Most hydrogen nuclei consist of a single proton. However, about 1 hydrogen nucleus out of every 10,000 also contains a neutron. It is also possible for a hydrogen nucleus to have two neutrons, but these atoms are very rare. Atoms that have the same number of protons but a different number of neutrons are called **isotopes**.

The two hydrogen atoms in the figure below are isotopes of each other. They are both hydrogen because each has only one proton. Because they have a different number of neutrons, they have different masses.



This isotope is a hydrogen atom that has one proton in its nucleus.



This isotope is a hydrogen atom that has one proton and one neutron in its nucleus.

SIMILARITIES BETWEEN ISOTOPES

For each element, there is a certain number of isotopes that exist in nature. Isotopes share most of the same physical and chemical properties.

For example, there are three isotopes of oxygen. The most common isotope of oxygen has 8 neutrons in its nucleus. Other oxygen isotopes have 9 or 10 neutrons. All three kinds of oxygen are colorless, odorless gases at room temperature. Each one can combine with a substance as the substance burns. When you breathe, you take oxygen into your body. The oxygen is needed for the chemical changes that keep you alive. All of the isotopes of oxygen take part in the chemistry of your body in the same way. ☑

CALIFORNIA STANDARDS CHECK

8.7.b Students know each element has a specific number of protons in the nucleus (the atomic number) and each isotope of the element has a different but specific number of neutrons in the nucleus.

Word Help: specific
unique; peculiar to or characteristic of; exact

10. Describe How are isotopes of an element different from one another?

____

____

READING CHECK

11. Explain Why doesn't it matter which isotope of oxygen you breathe?

____

____

____

READING CHECK

12. Explain Can the mass number of an atom ever be smaller than its atomic number? Explain your answer.

____

____

____

____

READING CHECK

13. Identify Carbon has an atomic number of 6. How many protons and neutrons are in a nucleus of carbon-13?

____

____

Math Focus

14. Estimate We know that 99.985% of all hydrogen atoms are hydrogen-1. Only 0.015% are hydrogen-2 atoms. What is the approximate atomic mass of hydrogen?

____

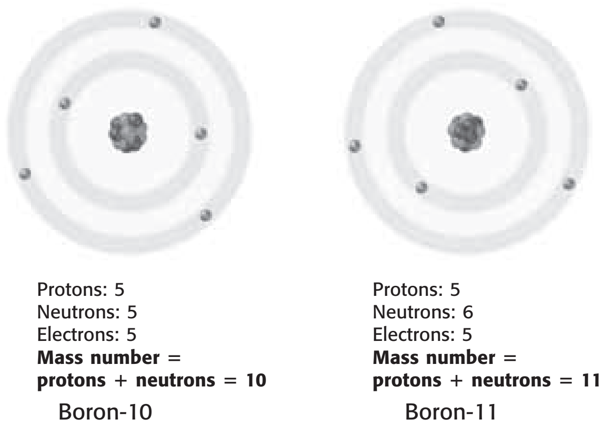
DIFFERENCES BETWEEN ISOTOPES

The chemical and physical properties of isotopes are generally the same. However, some differences between isotopes are important. For example, some isotopes are unstable, which means that their nuclei change over time. Atoms with this type of nucleus are called radioactive. The nuclei of radioactive atoms give off small particles along with energy.

Another important difference between isotopes is mass. Because isotopes contain different numbers of neutrons, they have different masses. In fact, scientists name isotopes by their mass. The **mass number** of an isotope is the sum of the protons and neutrons in an atom. (Electrons are not included in the mass number because they are so small that they have very little effect on the total mass of the atom.) ☑

The figure below shows two isotopes of boron. The isotope on the left has a mass number of 10. The isotope on the right has a mass number of 11 because it has one more neutron. To identify a specific isotope of an element, write the mass number after the element's name. The isotope on the left is called boron-10; the isotope on the right is called boron-11. ☑

Two Isotopes of Boron



What Is Atomic Mass?

The atomic mass of an element is the mass of one atom of the element. As you know, the mass of an atom equals the number of protons plus the number of neutrons. However, there are two or more isotopes of most elements. This means that the number of neutrons differs from atom to atom. The **atomic mass** of an element is the weighted average of the masses of all the natural isotopes of that element. For example, a sample of copper is about 69% copper-63 atoms and 31% copper-65 atoms. So, the atomic mass of copper is 63.6 amu.

What Forces Affect the Particles in Atoms?

Because charged particles attract and repel one another, there must be other forces that hold atoms and nuclei together. Scientists have discovered that there are four basic forces in nature. These forces work together to give atoms their structure and properties.

ELECTROMAGNETIC FORCE

The *electromagnetic force* causes objects with like charges to repel, and it causes objects with opposite charges to attract. Protons and electrons are attracted to one another because of the electromagnetic force. The electromagnetic force keeps the electrons and the nucleus together in an atom.

Say It

Discuss What would happen if each of the basic forces did not exist? Taking the forces one at a time, in a small group, discuss what would happen if that force didn't exist.

GRAVITATIONAL FORCE

Gravitational force pulls objects toward one another. It depends on the masses of the objects. Because subatomic particles are so small, the gravitational force has almost no effect within atoms.

STRONG FORCE

The *strong force* causes the protons and neutrons in the nucleus to be attracted to each other. It holds the nucleus together. Inside the nucleus, the attraction of the strong force is greater than the repulsion of the electromagnetic force. If there were no strong force, protons in the nucleus would repel one another, and the nucleus would fly apart.

Critical Thinking

15. Make an Inference In some radioactive nuclei, a neutron can change into an electron and a proton. The electron leaves the nucleus, but the proton does not. What happens to the identity of the atom when this happens?

____

____

____

____

WEAK FORCE

The *weak force* is important in radioactive atoms. In certain unstable atoms, a neutron can change into a proton and an electron. The weak force plays an important role in this change.

Forces in the Atom

Description	Force
Force that affects changes of particles in the nucleus.	
Attractive interaction between objects with mass.	
Attractive force between particles in the nucleus	
Attractive or repulsive force between objects with opposite charges.	

TAKE A LOOK

16. Identify Fill in the names of the four forces in the table.

Name ______________________ Class ______________ Date ______________

Section 2 Review

8.3.a, 8.7.b

SECTION VOCABULARY

atomic mass the mass of an atom expressed in atomic mass units

atomic mass unit a unit of mass that describes the mass of an atom or molecule

atomic number the number of protons in the nucleus of an atom; the atomic number is the same for all atoms of an element

isotope an atom that has the same number of protons (or the same atomic number) as other atoms of the same element do but that has a different number of neutrons (and thus a different atomic mass)

mass number the sum of the numbers of protons and neutrons in the nucleus of an atom

neutron a subatomic particle that has no charge and that is located in the nucleus of an atom

proton a subatomic particle that has a positive charge and that is located in the nucleus of an atom; the number of protons in the nucleus is the atomic number, which determines the identity of an element

subatomic

Wordwise The prefix *sub-* means "under."

1. **Compare** Why do two isotopes of an element have the same atomic number but different mass numbers?

____

____

____

2. **Organize** Fill in the table below with the properties of the subatomic particles.

Particle	Charge	Mass (amu)
Proton		
Neutron		
Electron		

3. **Apply Concepts** Why does every element except hydrogen need at least one neutron in its nucleus?

____

____

____

4. **Make Comparisons** Compare the particles in the nuclei of carbon-14 and nitrogen-14.

Atom	Atomic number	Number of protons	Number of neutrons
Carbon-14	6		
Nitrogen-14	7		