Section 2
The Atom

Key Concept An atom is made of protons, neutrons, and electrons. Its properties are determined by these particles.

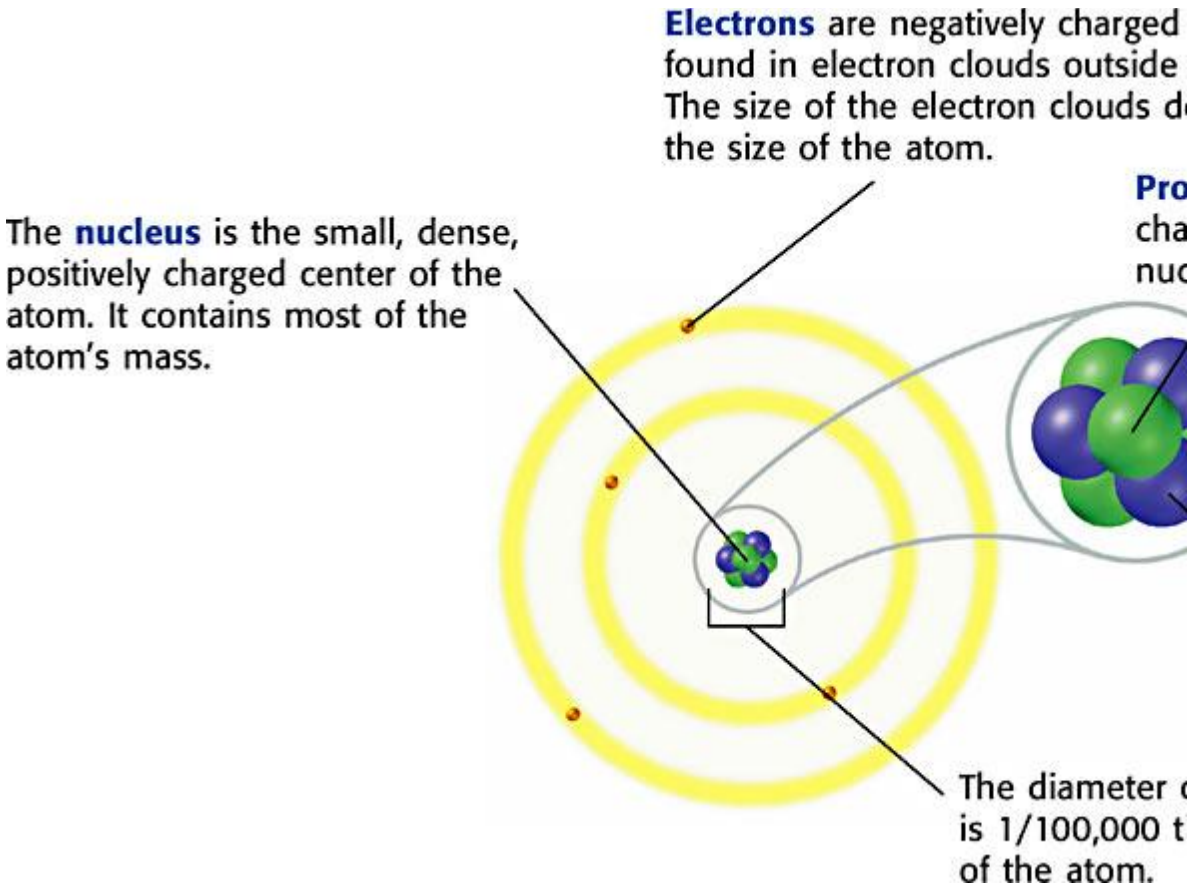
What You Will Learn
- Protons, neutrons, and electrons make up atoms.
- All atoms of a given element have the same number of protons in the nucleus.
- Isotopes of an element differ by the number of neutrons in the nucleus.
- Atomic mass is an average of the masses of all of the naturally occurring isotopes of an element.
- Four forces are at work in atoms.

Why It Matters
All matter is made up of atoms or subatomic particles.

Even though atoms are very small, they are made up of even smaller particles. You can learn a lot about the parts that make up an atom and what holds an atom together. In this section, you will learn about how atoms are alike and how they are different.

The Parts of an Atom
Almost all kinds of atoms are made of the same three particles. These particles are protons, neutrons, and electrons, as the model in **Figure 1** shows. The particles in the pictures are not shown in their correct proportions. If the particles were shown correctly, the electrons would be too small to see. Also, the electrons would be spaced much farther apart from one another and from the nucleus. Atoms are mostly empty space.

Figure 1 Parts of an Atom



Subatomic Particles

Protons, neutrons, and electrons are called *subatomic particles* because they are each much smaller than an atom. The number of subatomic particles that are in an atom and the way the particles interact determine the properties of the atom.

The Nucleus

In stars, such as those shown in **Figure 2,** atomic nuclei may collide and join. Thus, a new larger nucleus of a different element forms. But no matter what element you study, only two kinds of particles can make up a nucleus.

Figure 2 Stars are the birthplace of many atoms.

Protons are positively charged particles of the nucleus. The mass of a proton is about 1.7×10^{-24} g. This number can also be written as 0.000000000000000000000000017 g. Because the masses of particles in atoms are so small, scientists made a new unit for these particles. The SI unit that describes the mass of a particle in an atom is the **atomic mass unit** (amu). Each proton has a mass of about 1 amu. **Neutrons** are the particles of the nucleus that have no electric charge. Neutrons are a little more massive than protons. But the difference in mass is so small that the mass of a neutron can be thought of as 1 amu.

Protons and neutrons are the most massive particles in an atom. The volume of the nucleus is very small. So, the nucleus is very dense. If it were possible to have a nucleus that has the volume of a grape, that nucleus would have a mass greater than 9 million metric tons!

Standards Check Name the two kinds of particles that make up the nucleus of an atom.

Outside the Nucleus

Electrons are the negatively charged particles in atoms. Electrons are found outside the nucleus in electron clouds. Compared with protons and neutrons, electrons have a very small mass. It takes more than 1,800 electrons to equal the mass of 1 proton. The mass of an electron is so small that the mass is usually thought of as almost zero.

The charges of protons and electrons are opposite but equal, so the charges cancel out. Because an atom has no overall charge, an atom is neutral. If the numbers of electrons and protons become unequal, the atom becomes a charged particle called an *ion* (IE ahn). An atom that loses one or more electrons becomes a positively-charged ion. An atom that gains one or more electrons becomes a negatively-charged ion.

Atoms and Elements

There are more than 110 different elements. The atoms of each of these elements are different from the atoms of all other elements. What makes atoms different from each other? To find out, imagine that you could build an atom by putting together protons, neutrons, and electrons.

The Simplest Atom

To understand atoms, you should start with the simplest atom. Protons and electrons are found in all atoms. The simplest atom is made of just one of each. The atom is so simple that it doesn't even have a neutron. To "build" this atom, put just one proton in the center of the atom for the nucleus. To have a neutral charge, your atom will also need the same number of electrons as protons. So, you put one electron in the electron cloud outside the nucleus. Congratulations! You have just made a hydrogen atom.

The Role of Neutrons

Now, build an atom that has two protons. Both of the protons are positively charged, so they repel one another. You cannot form a nucleus with them unless you add some neutrons. For this atom, two neutrons will do. Then, add two electrons outside the nucleus. You have just made an atom of the element helium. A model of this atom is shown in **Figure 3.**

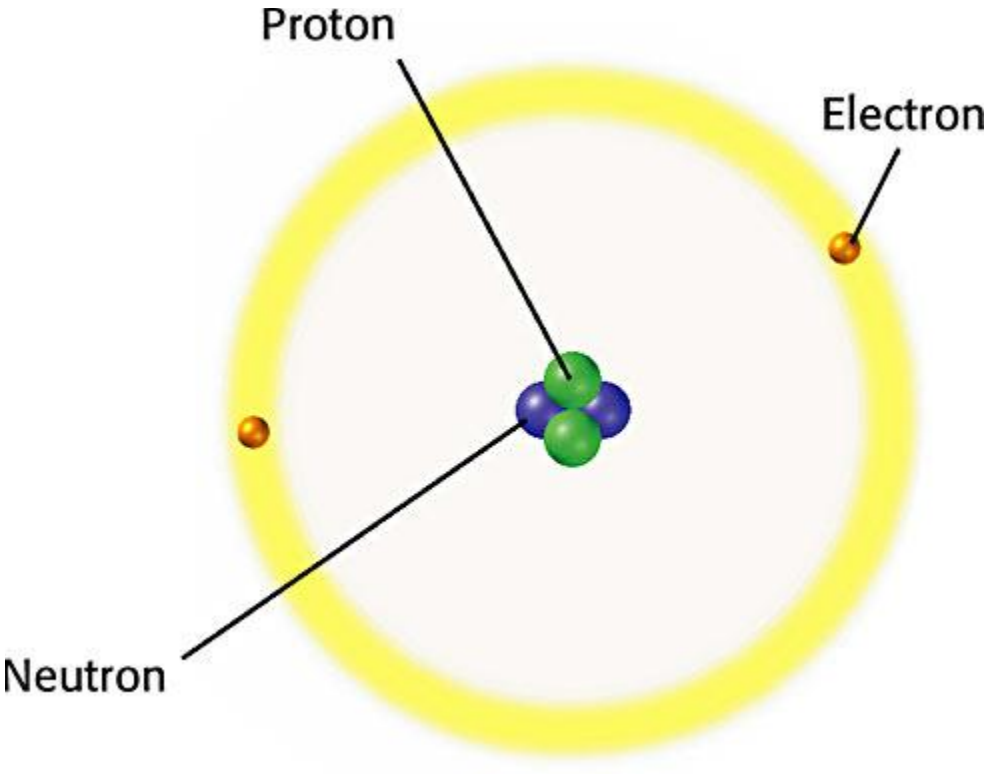


Figure 3 A helium nucleus must have neutrons in it to keep the protons from moving apart.

Building Bigger Atoms

You could build a carbon atom using 6 protons, 6 neutrons, and 6 electrons. You could build a fluorine atom using 9 protons, 10 neutrons, and 9 electrons. You could even build a gold atom using 79 protons, 118 neutrons, and 79 electrons! As you can see, an atom does not have to have equal numbers of protons and neutrons.

Protons and Atomic Number

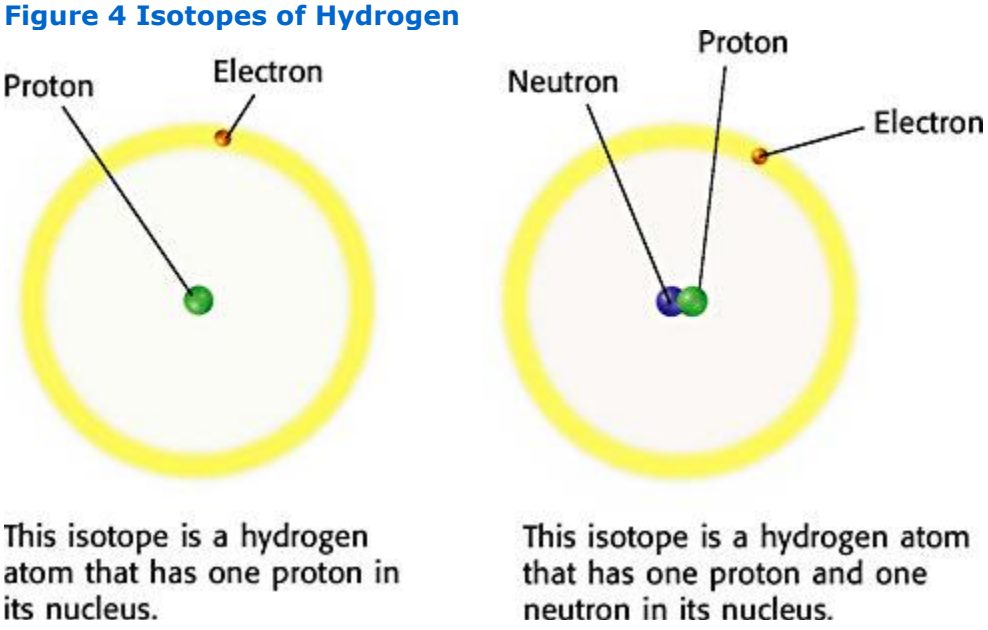
How can you tell which elements these atoms represent? The key is the number of protons. The number of protons in the nucleus of an atom is the **atomic number** of that atom. All atoms of an element have the

same atomic number. The element hydrogen has an atomic number of 1, which means that every hydrogen atom has only one proton in its nucleus. The element carbon has an atomic number of 6. So, every carbon atom has six protons in its nucleus. Similarly, if an atom has 8 protons, you know that it is an oxygen atom, because the element oxygen has an atomic number of 8. The atomic number of each element is listed on the periodic table.

Isotopes

Models of two kinds of hydrogen atoms are shown in **Figure 4.** They are both hydrogen atoms because they each have one proton. But one of the atoms also has a neutron in its nucleus.

Figure 4 Isotopes of Hydrogen



The two hydrogen atoms are isotopes of each other. **Isotopes** are atoms that have the same number of protons but have different numbers of neutrons. Atoms that are isotopes of each other are always the same element, because isotopes of the same element always have the same number of protons. They have different numbers of neutrons, however, which gives them different masses. Isotopes of the same element are similar to one another in many ways. However, some elements have isotopes whose properties differ in important ways.

Standards Check How do isotopes of the same element differ from one another?

Properties of Isotopes

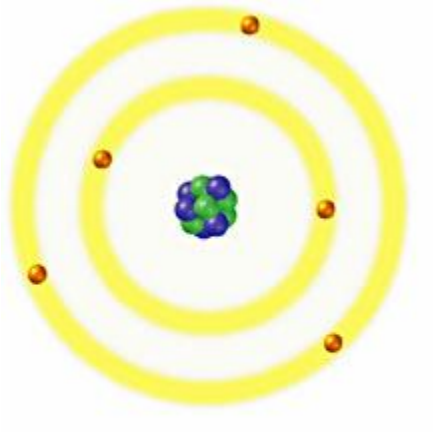
Each element has a limited number of isotopes that are found in nature. Some isotopes of an element have special properties because they are unstable. An unstable atom is an atom with a nucleus that will change over time. This type of isotope is *radioactive.* Radioactive atoms spontaneously fall apart after a certain amount of time. As they fall apart, they give off smaller particles and energy.

However, isotopes of an element share most of the same chemical and physical properties. For example, the most common oxygen isotope has 8 neutrons in its nucleus. Other isotopes of oxygen have 9 or 10 neutrons. All three kinds of oxygen are colorless, odorless gases at room temperature. Each one has the chemical property of combining with a substance as it burns. Different isotopes of an element even behave similarly in chemical changes in your body.

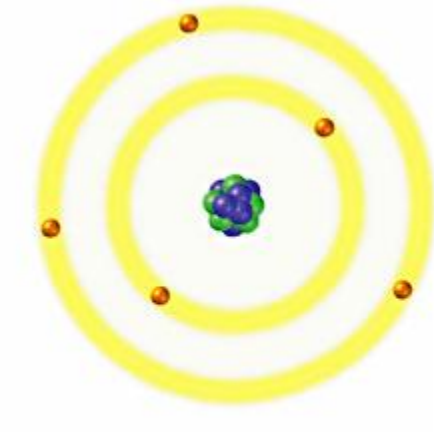
Standards Check In what cases are differences between isotopes important?

The Difference Between Isotopes

You can identify each isotope of an element by its mass number. The **mass number** is the sum of the protons and neutrons in an atom. Electrons are not included in an atom's mass number because their mass is so small that they have little effect on the atom's total mass. Look at the two boron isotope models shown in **Figure 5.** The isotope on the left has 5 protons and 5 neutrons. This isotope has a mass number of 10. The isotope on the right has a mass number of 11 because it has one more neutron than the one on the left.



Protons: 5
Neutrons: 5
Electrons: 5
Mass number =
protons + neutrons = 10



Protons: 5
Neutrons: 6
Electrons: 5
Mass number =
protons + neutrons = 11

Figure 5 Because each of these boron isotopes has a different number of neutrons, each isotope has a different mass number. **How can you tell that these two atoms are of the same element?**

[redacted]

Naming Isotopes

To identify a specific isotope of an element, write the name of the element followed by a hyphen and the mass number of the isotope. A hydrogen atom that has one proton and no neutrons has a mass number of 1. It is called hydrogen-1. Hydrogen-2 has one proton and one neutron. The carbon isotope that has a mass number of 12 is called carbon-12. If you know that the atomic number for carbon is 6, you can calculate the number of neutrons in carbon-12 by subtracting the atomic number from the mass number. For carbon-12, the number of neutrons is 12 – 6, which is equal to 6.

$$\begin{array}{r} 12 \text{ Mass number} \\ -\ 6 \text{ Number of protons (atomic number)} \\ \hline 6 \text{ Number of neutrons} \end{array}$$

Isotopes and Atomic Mass

Most elements contain a mixture of two or more isotopes. For example, copper is composed of atoms of copper-63 and of copper-65. The **atomic mass** of an element is the weighted average of the masses of all the naturally occurring isotopes of that element. A weighted average accounts for the percentages of each isotope that are present. Copper is 69% copper-63 and 31% copper-65. The atomic mass of copper is 63.6 amu.

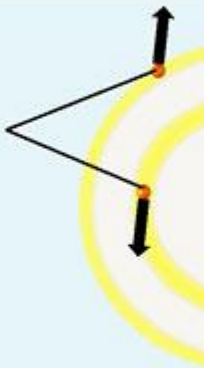
Forces in Atoms

You have seen that atoms are made of smaller particles. But what holds atoms together? What are the *forces* (the pushes or pulls between objects) acting between these particles? There are four basic forces that are at work everywhere in nature, even within the atom. These forces are gravitational force, electromagnetic force, strong force, and weak force. Each particle is acted on in a certain way by these basic forces. These forces work together to give an atom its structure and properties. Look at **Figure 7** to learn about each force.

Figure 7 Forces in the Atom

Gravitational Force Probably the most familiar of the four forces is *gravitational force*. Gravitational force acts between all objects all of the time. The amount of gravitational force between objects depends on their masses and on the distance between them. Gravitational force pulls objects, such as the sun, Earth, cars, and books, toward one another. However, because the masses of particles in atoms are so small, the gravitational force within atoms is very small.

Electromagnetic Force As mentioned earlier, objects that have the same charge repel each other, while objects that have opposite charges attract each other. This is due to the *electromagnetic force*. Protons and electrons are attracted to each other because they have opposite charges. The electromagnetic force holds the electrons around the nucleus.



Strong Force Protons push away from one another because of the electromagnetic force. A nucleus containing two or more protons would fly apart if the *strong force* did not hold them together. At the close distances between protons and neutrons in the nucleus, the strong force is greater than the electromagnetic force, so the nucleus stays together.

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

Section Summary

- Atoms consist of a nucleus, which has protons and usually neutrons, and electrons, which are located in electron clouds around the nucleus.
- The number of protons in the nucleus of an atom is that atom's atomic number. All atoms of an element have the same atomic number.
- Different isotopes of an element have different numbers of neutrons in their nuclei. Isotopes of an element share most chemical and physical properties.
- The mass number of an atom is the sum of the atom's neutrons and protons.
- Atomic mass is a weighted average of the masses of all natural isotopes of an element.
- The forces at work in an atom are gravitational force, electromagnetic force, strong force, and weak force.

Chapter Summary

The Big Idea

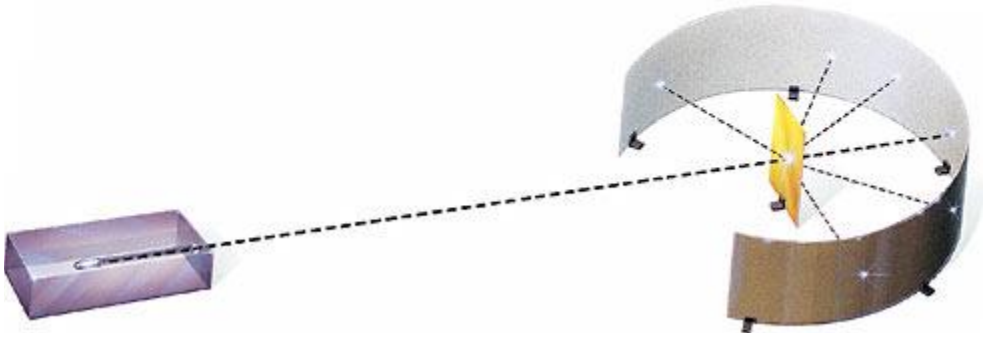
Atoms are composed of small particles that determine the properties of the atom.

Section 1
Development of the Atomic Theory

Key Concept Scientists have done experiments that have revealed important clues about the structure of atoms.

- There have been different models of the atom over time.
- The atomic theory has changed as scientists have experimented and dis covered new information about the atom.

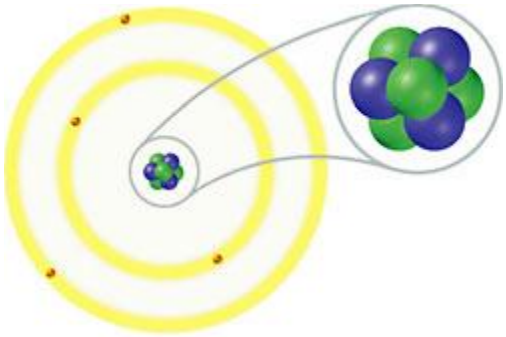
Ernest Rutherford's experiment with gold foil, which the diagram below represents, was one of many experiments that shaped the modern atomic theory.



Section 2
The Atom

Key Concept An atom is made of protons, neutrons, and electrons. Its properties are determined by these particles.

- Protons, neutrons, and electrons make up atoms.
- All atoms of a given element have the same number of protons in the nucleus.
- Isotopes of an element differ by the number of neutrons in the nucleus.
- Atomic mass is an average of the masses of all of the naturally occurring isotopes of an element.
- Four forces are at work in atoms.



In the model above, electrons are outside of the nucleus, which is composed of protons and neutrons.

[redacted]

[redacted]

[redacted]