5.2 The Structure of the Atom

Key Terms
atomic number
mass number
isotope

The next time you see someone talking on a tiny cellphone, stop and think about atoms. Understanding atoms has helped to make electronic devices smaller and more powerful than they were just a few years ago. **Figure 5.8** shows the change in cellphones over time. In the past, electronic devices relied on circuits made from metal wires and circuit components that were large and bulky. As scientists learned more about atoms, however, they developed ways to build up layers of atoms of different elements on a wafer-thin piece of silicon. This allowed them to build very small circuit components. Thus, scientists have used their understanding of the structure of atoms to create new materials that have helped to make the miniaturization of cellphones possible.

Figure 5.8 Due to advances in our knowledge of atoms, today's portable cellphones are much smaller and have many more features than earlier models. Imagine what phones will be like in the future!

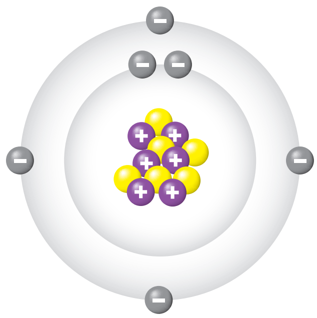


Figure 5.9 This diagram represents an atom of the element carbon.

Inside the Atom

An atom, such as the one drawn in **Figure 5.9**, is the smallest particle of an element that has the same properties of the element. We now know that the atom is composed of many subatomic particles. There are three main types of subatomic particles: protons and neutrons, which make up the nucleus, and electrons, which move in specific regions around the nucleus. Each type of subatomic particle has its own set of properties. Some of these properties are summarized in **Table 5.1**.

Table 5.1 Subatomic Particles

Name	Relative Mass	Electric Charge	Location in the Atom
proton	1836	+	nucleus
neutron	1837	0	nucleus
electron	1	–	energy levels surrounding the nucleus

Study Toolkit

Suffixes Identify three words on this page that end with a suffix. Identify each base word, then define the whole word. Use the Glossary at the end of this textbook or a dictionary to check your definition. This will help you to remember the meaning of each word.

Protons and Neutrons

Protons and neutrons contribute nearly all the mass of an atom. Neutrons have slightly more mass than protons, but both neutrons and protons have about 1840 times more mass than electrons. This is often referred to as the relative mass of protons and neutrons, compared to electrons. Neutrons have no charge, so they neither attract nor repel protons due to electric charge. Neutrons and protons do attract each other, however, by a force called the *strong force.* This force is the strongest in nature and overcomes the repulsion between positively charged protons. Otherwise, nuclei with more than one proton would never form. Because both protons and neutrons make up the nucleus of an atom, they are often referred to as *nucleons.*

The number of protons in the nucleus of an atom is the **atomic number**. The atomic number identifies an atom as a particular element. For example, there are six protons in the atom shown in **Figure 5.9**, making this atom an element with an atomic number of 6. The element with an atomic number of 6 is carbon. No matter where that atom is in the universe, it will always be carbon. If a proton is added or removed by some type of nuclear reaction, the atom is no longer carbon—it is a completely different element.

The sum of the number of protons and the number of neutrons in an atom is called the **mass number**. The mass number is always a whole number. By knowing the mass number and the atomic number of an atom, you can determine the number of protons, the number of neutrons, and the number of electrons that make up that atom.

atomic number the number of protons in the nucleus of an atom

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

Calculating the Number of Subatomic Particles

atomic number = number of protons
mass number = number of protons + number of neutrons
number of neutrons = mass number - atomic number
number of protons = number of electrons (neutral atom)

Representing Elements

The development of chemical symbols to represent the elements allowed chemists to communicate their findings more easily. Just as it is easier to write "4378" instead of "four thousand three hundred and seventy-eight," it is easier and much less time consuming for chemists to write "Mg" instead of "magnesium." Also, every language has its own way of saying and spelling the names of the elements. The symbols that are used to represent the elements, however, are the same throughout the world—the system is international. So, while a French Canadian scientist may say "hydrogène" and an Italian scientist may say "idrogeno," both use the symbol H to represent hydrogen.

A common notation that scientists use to represent atoms of elements is shown in **Figure 5.10**. This notation, called the *standard atomic notation*, includes the atomic number and mass number of an atom of an element. The mass number is always placed to the top and left of the symbol for the element. The atomic number is always placed to the bottom and left of the symbol. In the next activity, you will practise using symbols to represent elements and you will learn how to use this type of notation properly.

mass number — 11; atomic number — 5; $^{11}_{5}B$ — symbol for boron

Figure 5.10 This notation provides information about an atom of an element, such as boron.

Activity 5-4

What's Your Number?

Symbols were assigned to the elements as an international way to represent the elements, regardless of language. Standard atomic notation of the elements also provides a universal method of representing atoms of elements. Can you determine some of the rules that are used for assigning symbols to the elements?

Materials

- Appendix A: Properties of Common Substances

Questions

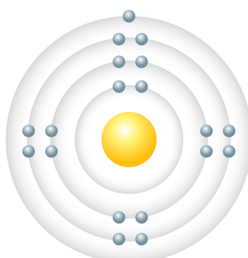
1. The most common elements in your body are oxygen, carbon, hydrogen, and nitrogen. What are the symbols for these elements? Write a rule that might have been used to create these symbols.
2. Calcium is another important element in your body. It is present in your bones, teeth, and blood.
   a. What is the symbol for calcium? Write a rule that might have been used to create this symbol.
   b. What would be the symbol for calcium if you used the rule you wrote in step 1? Why can this not be the symbol for calcium?
3. The Latin names of some metals were used for centuries: *argentum* for silver, *aurum* for gold, *cuprum* for copper, *ferrum* for iron, *hydrargyrum* for mercury, *plumbum* for lead, and *stannum* for tin. Infer possible symbols for these elements. Use Appendix A to check your inferences. Are there exceptions to the rules you wrote in steps 1 and 2 for these symbols? If so, identify them.
4. Copy and complete the table below. Provide a title for your table.

Standard Atomic Notation	Name of Element	Atomic Number	Mass Number	Number of Electrons	Number of Protons	Number of Neutrons
$^{12}_{6}C$						
$^{65}_{30}Zn$						
	sulfur	16				16
	calcium		40		20	
	nitrogen	7	14			

Representing Atoms

The Bohr-Rutherford model that was introduced in the previous section is a convenient way of representing the atomic structure of an element. According to this model, electrons occupy specific energy levels, which are sometimes called *shells*. Electrons in levels that are farther from the nucleus have more energy than electrons in levels that are closer to the nucleus. The number of electrons that can occupy each energy level changes as you move outward from the nucleus. You will learn more about the distribution of electrons in energy levels in later science courses. The box below provides a step-by-step description of how to draw Bohr-Rutherford models for atoms with atomic numbers between 1 and 20.

The diagrams in **Figure 5.11** are examples of Bohr-Rutherford models of the atom potassium, which has 19 electrons. Bohr-Rutherford models that you will draw should resemble the diagram on the right.



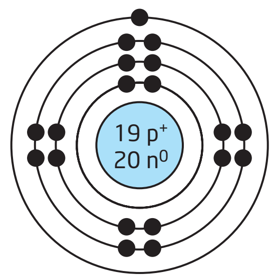
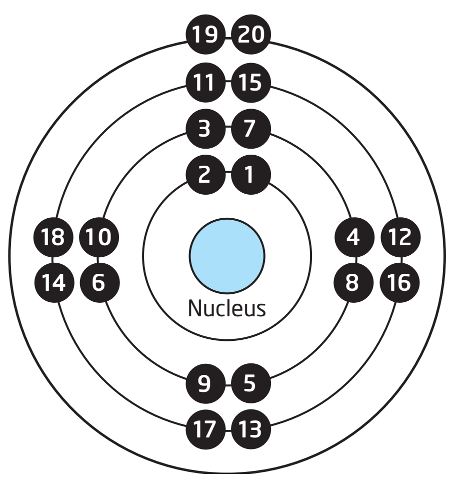


Figure 5.11 Both of these diagrams represent an atom of potassium.

How to Draw Bohr-Rutherford Models

1. Draw a circle that represents the nucleus. Indicate the number of protons and neutrons in the nucleus. You can use the symbols "p$^+$" to represent protons and "n^0" to represent neutrons.
2. Determine the number of electrons in the atom. Draw the different energy levels using circles around the nucleus.
3. Starting with the energy level nearest the nucleus, put in up to two electrons. Once the first energy level is full, fill the second one with up to eight electrons. Add up to eight electrons to the third energy level, and then the final two electrons to the fourth energy level.
4. Electrons should be placed according to the sequence depicted in the diagram. When filling the first energy level, place the first electron where the 12:00 position is on a clock. Then add the next electron beside it. For the second energy level, begin at the 12:00 position. Then, continue adding electrons at the 3:00 position, then the 6:00 position, and then the 9:00 position. If there are more than four electrons to be added, repeat this pattern. Adding electrons to the third and fourth energy levels is done in the same manner.



The numbers indicate the sequence to follow when adding the first 20 electrons to Bohr-Rutherford models.

Activity 5-5

Make Your Own Atom

Making a three-dimensional model of an atom can help you remember that atoms are not fixed structures, as they appear to be in diagrams. Electrons move in three-dimensional paths, not simple circles. How accurate can you make your model of an atom?

Suggested Materials

- metal rings (3 different sizes) or wire
- Styrofoam® ball
- clay (3 different colours)
- string

Procedure

1. Work in groups of four. Your teacher will assign your group the atom of an element and tell you the atomic number and mass number of the atom.
2. Determine the number of protons, neutrons, and electrons in the atom.
3. Draw a Bohr-Rutherford model of the atom. Make sure that your teacher has approved your diagram before you proceed to the next step.
4. Build a three-dimensional model of the atom using the materials provided and your diagram as a guide. Use the Styrofoam® ball to represent the nucleus, and use two different colours of clay to represent the protons and neutrons. Use the third colour of clay to represent the electrons. Attach the electrons to the rings made of wire, matching the electron arrangement in your diagram.
5. Make a mobile by hanging your model with string. This will help to hold together the different parts of your model and allow you to manipulate it.

Questions

1. What were some important details you needed to consider when building your three-dimensional model?
2. In what ways is your three-dimensional model a better representation of the atom than the diagram you drew on paper?
3. In what ways do you think your model does not represent an atom accurately?

Isotopes

In **Figure 5.12**, notice that both of the atoms have one proton, but the atom on the right also has a neutron. Even though these atoms are not identical, they are both atoms of the same element, hydrogen, because they have the same number of protons. Atoms of an element that have the same number of protons but a different number of neutrons are called **isotopes** of the element. The atoms shown in **Figure 5.12** are isotopes of hydrogen. Since each isotope has a unique mass number, you can specify an isotope of an element by placing its mass number after the name of the element. For example, the names of these isotopes of hydrogen are hydrogen-1 and hydrogen-2.

Suggested Investigation

Inquiry Investigation 5-A, The Bohr-Rutherford Model of the Atom, on page 212

isotope one of two or more forms of an element that have the same number of protons but a different number of neutrons

Figure 5.12 These atoms are different isotopes of hydrogen because they have different numbers of neutrons.

Learning Check

1. An atom has an atomic number of 8 and a mass number of 16. How many protons and neutrons does the atom have? Explain.
2. Draw a Bohr-Rutherford model to show how the electrons in an atom of argon (atomic number 18, with 22 neutrons) are arranged.
3. Draw Bohr-Rutherford diagrams of two different isotopes of carbon.
4. What does taking a neutral position about an issue mean? Relate this to the term *neutron*.

Sense of place

The Large Hadron Collider at CERN is the largest particle accelerator in the world. It is used to accelerate subatomic particles and observe what happens when they collide. Here, scientists are hoping to re-create the big bang to better understand the origins of our universe.

A Simple Model of a Complex System

Although models of an atom usually show electrons orbiting around a nucleus, the actual structure of an atom is much more complex. Electrons are thought to exist in cloud-like regions surrounding the nucleus, with different probabilities of finding an electron in a given cloud. In addition, scientists have discovered that protons, neutrons, and electrons are not the only subatomic particles. Since the discovery of the neutron, over 200 other subatomic particles have been identified. Protons and neutrons are actually composed of different types of smaller subatomic particles called quarks.

As scientific technologies continue to improve, the model of the atom will continue to evolve. An exceptional facility that supports this type of research is CERN (Conseil Européen pour la Recherche Nucléaire), shown in **Figure 5.13**. It is the largest laboratory in the world for studying the atom and interactions between subatomic particles. At CERN, thousands of scientists and engineers from more than eight different countries and hundreds of universities work together to uncover even more information about the atom.

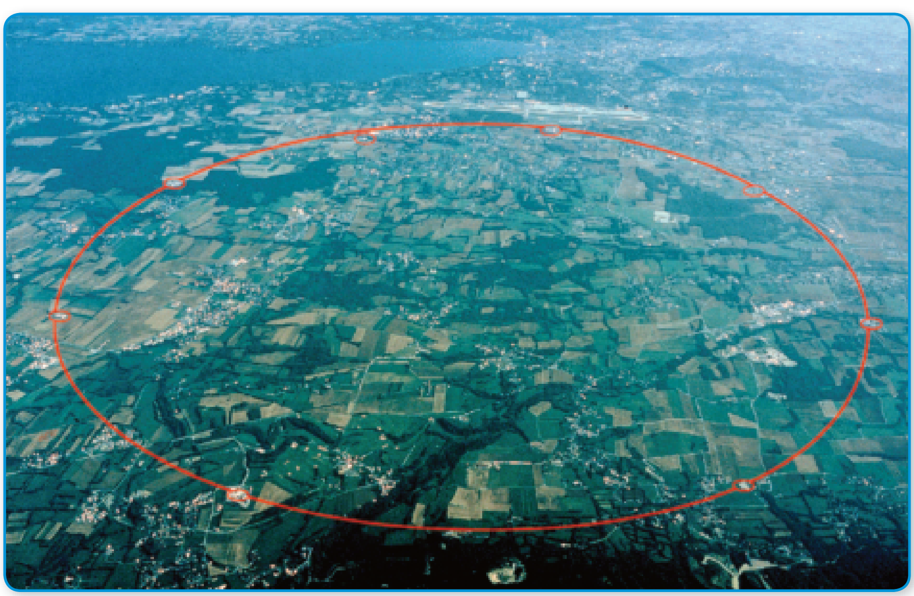


Figure 5.13 CERN is located on the border between France and Switzerland. The circle on this photo indicates where the Large Hadron Collider is. This particle accelerator lies about 100 m underground in a tunnel with a circumference of 27 km.

Section 5.2 Review

Section Summary

- Atoms are made up of protons, neutrons, and electrons. Protons are positively charged, neutrons have no charge, and electrons are negatively charged.
- The atomic number of an atom is the number of protons in the nucleus. It is always a whole number and identifies the element. The mass number of an atom is the total number of protons and neutrons. Like the atomic number, it is always a whole number.
- Protons and neutrons make up the nucleus and account for most of the mass of the atom. Electrons occupy energy levels outside the nucleus.
- Bohr-Rutherford models are used to depict the atomic structures of elements.
- An element is made up of isotopes, which are atoms that have the same number of protons but different numbers of neutrons.

Review Questions

K/U **1.** What are three types of subatomic particles in the atom? Compare and contrast the properties of these particles, based on information in **Table 5.1**.

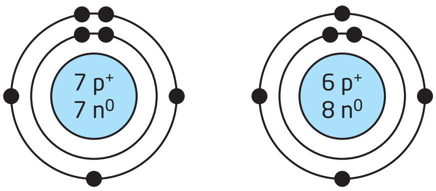
K/U **2.** Which particle in the atom has almost no mass?

T/I **3.** If you know the atomic number and the mass number of an isotope of an element, how can you determine the number of protons and neutrons in that atom?

K/U **4.** An istope of oxygen (O) has an atomic number of 8 and a mass number of 16. What is the standard atomic notation for this isotope?

T/I **5.** If an atom has 12 electrons, how many energy levels are occupied?

A **6.** Do the following diagrams show atoms of the same element? Explain.



Bohr-Rutherford models provide information that is needed to identify an element.

C **7.** An atom has 8 protons, 9 neutrons, and 8 electrons. Draw a Bohr-Rutherford model of this atom.

T/I **8.** How is a hydrogen-1 atom different from a hydrogen-2 atom? How are they the same?