2.3 The Periodic Table and Atomic Theory

In a Bohr model diagram, electrons are arranged in shells in a specific pattern around the nucleus. The electrons in the outermost electron shell are called valence electrons. The number of valence electrons in an atom determines many of its chemical and physical properties. The atoms of all alkali metals have one valance electron; an atom of each alkaline earth metal has two valence electrons; and an atom of each halogen has seven valence electrons. Noble gas atoms have filled valence shells, which makes them chemically stable. All noble gas elements have eight valence electrons except helium, which is stable with two valence electrons.

Words to Know

Bohr model
electron shells
valence electron
valence shell

The periodic table is full of patterns. For example, non-metals appear on the right. This is no accident. Patterns occur as a result of regular changes in the structure of the atoms of these elements. Elements with similar properties line up in columns because all those elements are similar in the arrangement of their electrons.

One way to show the arrangement of electrons in an atom is with a Bohr model diagram. A **Bohr model** diagram shows how many electrons are in each shell surrounding the nucleus (Figure 2.21). This type of diagram is named after Niels Bohr (Figure 2.22), the Danish physicist whose model of the atom you studied in section 1.3. The regions surrounding the nucleus of an atom are sometimes called **electron shells**. The shell nearest the nucleus can hold 0, 1, or 2 electrons. The next two shells outward can each hold up to 8 electrons. Any remaining electrons will fill the fourth shell, to a maximum of 18. This pattern of 2, 8, 8, and 18 applies to all atoms, although not all atoms have that many electrons.

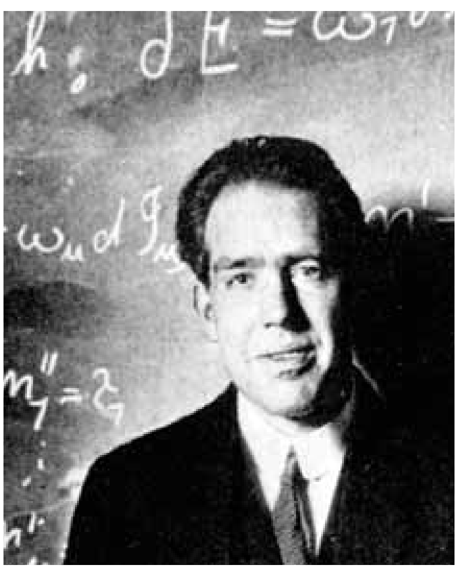


Figure 2.22 Niels Bohr

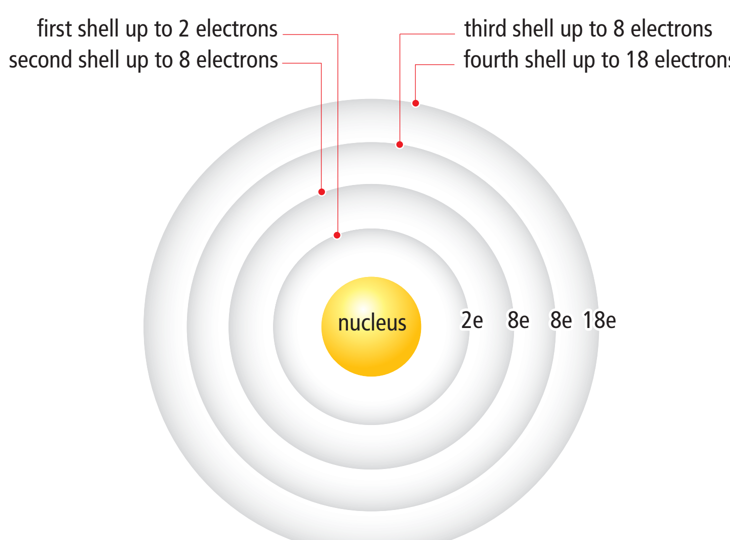
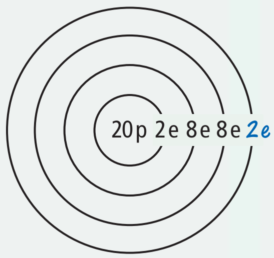


Figure 2.21 A Bohr model showing electron shells

2-3A Looking for Patterns in Atoms

Think About It

The number of electrons in an atom is always equal to the number of protons. The protons are in the nucleus, while the electrons surround the nucleus in energy levels or shells. In this activity, you will compare the electron arrangements in various atoms.



The arrangement of electrons in a calcium atom

Material

- coloured pencils or felt pens

What to Do

1. Your teacher will assign you several atoms to sketch using a Bohr model diagram. Use a periodic table to look up the atomic number of each atom. Record this number in the centre of the paper to represent the nucleus of the atom, as shown in the diagram.
2. Determine the number of electrons in the atom. Start with the shell nearest the nucleus and put in up to two electrons. Once the first shell is full, fill the second shell with up to eight electrons. The third shell can also have up to eight electrons. Put any remaining electrons into the last shell, which will hold up to 18 electrons.
3. Highlight the circle containing the outermost electrons with a distinctive colour or a heavy line.
4. Highlight the number of electrons in the outermost circle that contains electrons.
5. Compare your atoms with those of others in the class. Look for similarities between atoms of the same family.
6. Arrange all the sketches on the wall just as they appear in the periodic table.

What Did You Find Out?

1. What is the pattern in the arrangement of electrons as you move down a family?
2. What is the pattern in the arrangement of electrons as you move across a period from left to right?

Bohr Model Diagrams

A Bohr model diagram usually contains the element symbol, the number of protons in the atom, and a way to show where the electrons are. Some diagrams show the electrons as dots. Others just have figures indicating the number of electrons in each shell. Figure 2.23 shows three ways you could draw a Bohr model diagram for the element potassium (atomic number 19).

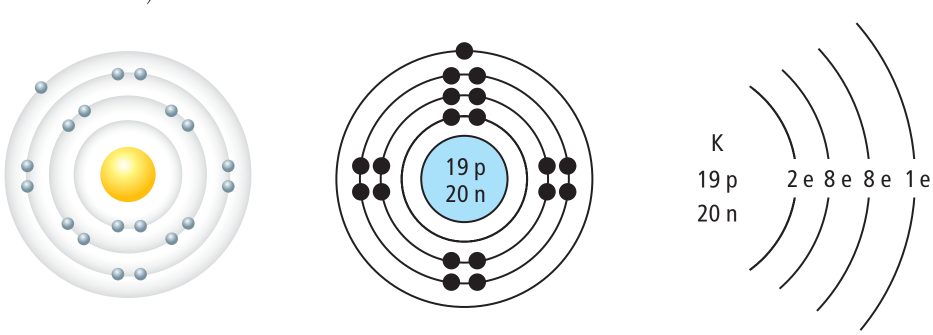


Figure 2.23 Each of these diagrams representing an atom of potassium is a Bohr model diagram.

Did You Know?

Alchemists could not turn lead into gold, but in 1980, Nobel Prize winning physicist Glen Seaborg did just that. He used nuclear reactions to make microscopic amounts, and the cost was much greater than mining for gold. His remarkable achievement added to our understanding of how atoms work.

Valence Electrons and Chemical Families

Figure 2.24 below shows how the electrons are arranged in each atom of the first 18 elements. Notice that the first electron shell is filled (2 electrons) before the second electron shell is filled. Likewise, the second electron shell is filled (8 electrons) before the third shell. The third shell is filled (8 electrons) before the fourth shell, which can hold up to 18 electrons.

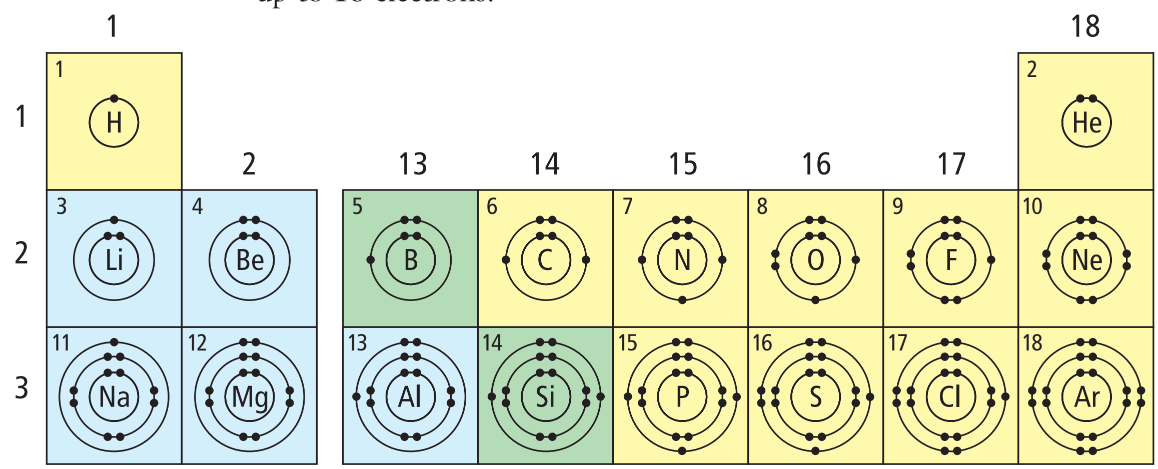


Figure 2.24 Electron arrangements in the first 18 elements

Did You Know?

Dalton was not quite correct when he said that all atoms of an element are identical. For instance, all carbon atoms have six protons, but the number of neutrons can vary from six to eight. These different varieties are called "isotopes."

The electrons in the outermost shell (those farthest from the nucleus) have the strongest influence on the properties of an atom. These electrons in the outermost shell are called **valence electrons**. The shell that contains the outermost electrons is called the **valence shell**.

You will notice several striking patterns in Figure 2.24.

- Most elements in the same family have the same number of valence electrons. For example, halogens have seven valence electrons. Helium, a noble gas, is an exception to the pattern with only two valence electrons.
- Elements in the same period have valence electrons in the same shell.
- The period number indicates the number of shells that have electrons.

Noble Gas Stability

The noble gases (He, Ne, Ar, Kr, Xe, Rn) are normally unreactive, which means the atoms do not form new substances with other atoms. Why? Because their atoms have filled valence shells—the maximum number of electrons in their outermost shells. That makes them stable. For two atoms to join together to make a new substance, atoms must gain, lose, or share electrons. But atoms with filled valence shells will not easily trade or share electrons. They have what we call noble gas stability.

Atoms from other families often try to achieve a kind of stability similar to the noble gases. To do this, they will gain or lose electrons. For example, metals, which usually have one, two, or three valence electrons, will often lose them all. When metals lose their valance electrons, their remaining electrons will have the same arrangement as the noble gas in their row in the periodic table.

What about non-metals? They gain one, two, or three extra electrons in order to achieve noble gas stability. They will gain exactly enough electrons to achieve the same electron arrangement as the noble gas in their row in the periodic table.

How Atoms Become Ions

Recall that an atom that has gained or lost electrons is called an ion. Ions carry an electric charge, because the number of protons (positive) in them is not equal to the number of electrons (negative). Note that:

- an atom of any metal can lose electrons and form positive ions
- an atom of any non-metal except a noble gas can gain electrons and form negative ions
- ions have the same electron arrangement as the nearest noble gas

The charge on an ion is shown on the symbol of an element by adding a superscript number followed by a plus or minus sign. Table 2.3 shows some examples of Bohr model diagrams for atoms and their ions.

Table 2.3 Bohr Model Diagrams of Lithium, Magnesium, and Chlorine

	lithium	magnesium	chlorine
Atom	Li 3 p 2, 1	Mg 12 p 2, 8, 2	Cl 17 p 2, 8, 7
Ion	Li^{+} 3 p 2	Mg^{2+} 12 p 2, 8	Cl^{-} 17 p 2, 8, 8

The charge on an ion is equal to the sum of the charges on its protons and electrons. For example, the magnesium ion Mg^{2+} has 12 protons (12+) and 10 electrons (10−) for a total charge of 2+.

Reading Check

1. How many electrons can there be in each of the first four shells surrounding an atom?
2. Draw a simple Bohr model diagram for the following elements: (a) hydrogen, (b) lithium, (c) sodium, and (d) potassium.
3. List the number of valence electrons in atoms from each family: (a) alkali metals, (b) alkaline earth metals, (c) halogens, and (d) noble gases.

Suggested Activity

Conduct an Investigation 2-3B on page 68

Explore More

Atomic radius is an estimate of the distance from the atom's nucleus to its "edge." The larger the radius, the larger the atom. But having more electrons does not always mean a larger atom. As usual with the periodic table, there is a pattern. Find out more about trends in the atomic radii of the elements at **www.bcscience9.ca.**

2-3B Flaming Metal Ions

Conduct an INVESTIGATION

Inquiry Focus

SkillCheck

- Observing
- Predicting
- Measuring
- Working co-operatively

Safety

- Handle chemicals safely.
- Be careful around open flames.
- Tie back long hair.
- Wash your hands thoroughly after doing this investigation.

Materials

- felt pen
- 9 small test tubes
- test tube rack
- wooden splints that have been soaked in a selection of solutions containing metal ions
- Bunsen burner
- diffraction-grating glasses

In this activity, you will heat several compounds in the flame of a Bunsen burner until the flame takes on a colour characteristic of the metal ion in the compound. The colours are related to the arrangement of electrons in each ion.

Question

How can you use a flame test to identify metal ions?

Procedure

1. Label the top of each test tube with the symbol of the metal ion that is in solution: Na, Ca, K, Li, Ba, Sr, Cu, Unknown 1, and Unknown 2.
2. Your teacher will set out a supply of wooden splints that have been soaked in solutions of metal ions. Take one splint per group for each metal ion, and place it in the appropriate test tube.
3. Light a Bunsen burner. Set it so that it has a blue flame. Have one person put on diffraction-grating glasses.

4. Place the wooden splints in the flame, one at a time, and note the colour of the metal ion.
5. Test the two unknown solutions. Both are metal ions from the seven you have tested. Try to identify them.
6. Clean up and put away your equipment.

Analyze

1. How did you identify the ions in your unknown solutions?
2. Which metal ions were difficult to distinguish?
3. Suggest how the diffraction-grating glasses can help in identifying metal ions using the flame test.

Conclude and Apply

1. Describe how the flame test enabled you to identify the unknown metal ions.

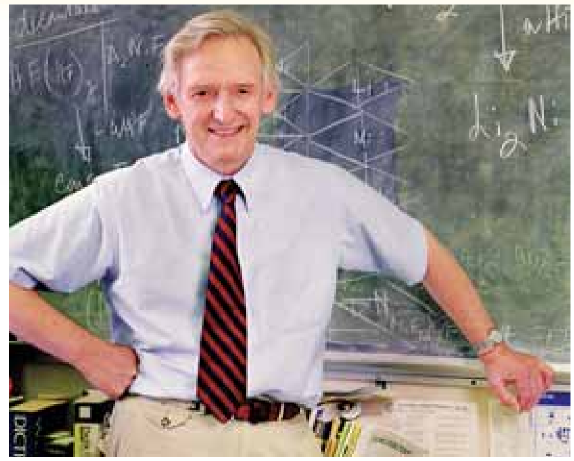
Science Watch

Compounds of the Noble Gases

Until 1962, chemists thought the noble gas elements were unreactive and unable to form a connection with any other kind of atom. This means they could not combine with other elements to form compounds. Then Neil Bartlett, a young British-born professor at the University of British Columbia, mixed a platinum–fluorine compound with the noble gas xenon. As Bartlett had imagined, the two materials reacted. They formed a new substance containing xenon.

Before long, news of Bartlett's discovery was heard around the world. Other scientists repeated his experiment and were also able to demonstrate that xenon could react chemically. Since xenon's new-found reactivity had broken the family mould, you might think that xenon would no longer be a part of the noble gas chemical family. However, xenon's place in the family was actually strengthened a short time later by the discovery of compounds involving other noble gases, including radon and argon. The noble gases were still a family. Science had simply found out something new about them.

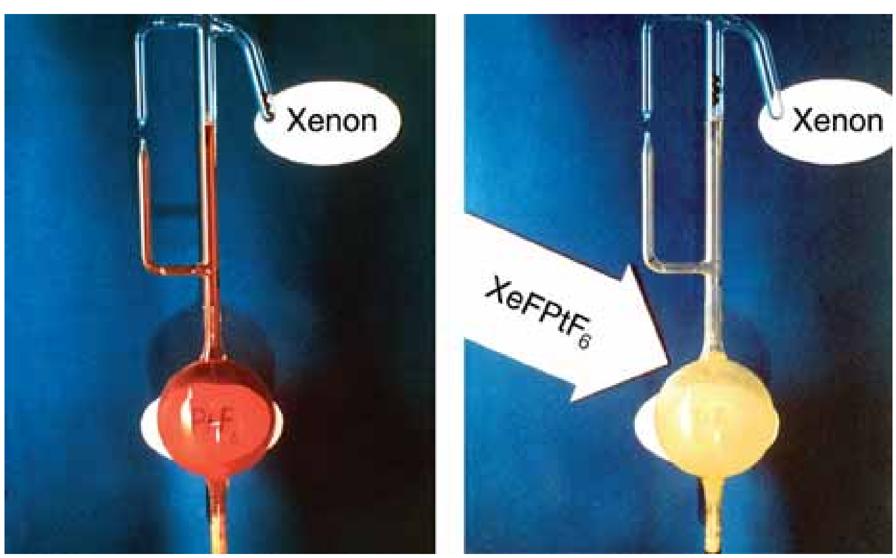
Compounds made from noble gases have proven extremely useful. They have been used in lasers and in the production of anti-tumour agents to fight cancer.



Neil Bartlett discovered that some noble gases could react chemically. After that, every chemistry book in the world had to be rewritten.

Questions

1. Before 1962, what property of noble gases led scientists to think that these elements could not form compounds?
2. What noble gas did Neil Bartlett use to form the first noble gas compound? What two other noble gases were later found to be able to form compounds?
3. Describe one way in which noble gas compounds have been used.



The yellow substance is the first noble gas compound discovered.

Wild, Weird, Wonderful

www Science

Helium—More Than Just Balloons

Helium has more uses than just inflating balloons.

Helium is a noble gas used in arc welding to prevent the metal reacting with the air.

Have you ever watched a helium balloon drift high into the sky and wondered what it would be like to soar along with it? Helium is an element that is lighter than air, which gives large balloons the ability to fly high and even to take passengers with them. The photograph shows a balloonist at a height of 2000 m being held aloft by 30 balloons. How did he get down? By breaking some of the balloons to release the helium. The helium eventually drifted into the upper atmosphere and floated off into space.

Only about 10 percent of the helium in the world is used to fill balloons. Its other uses are very down to Earth. About 20 percent is used as liquid helium to supercool magnets in magnetic resonance imaging (MRI) machines. MRI machines make images of the insides of our bodies like the one shown here. Another 20 percent of the world's helium is used in arc welding. Helium and other unreactive gases are released during the welding. This keeps the melting metal from reacting with the air.

An MRI image of a human head.

Helium is used in many other applications, including in deep sea breathing systems to reduce the risk of decompression sickness, and in nuclear reactor coolant systems, refrigeration systems, and lasers.

Where does all the helium come from? Helium is produced deep inside Earth by the radioactive decay of elements such as uranium and thorium. It is usually held inside rocks but can also become trapped with natural gas. There it builds up over millions of years. When the natural gas is extracted from wells, up to 8 percent of the gas can be helium. In the early days of natural gas drilling, the helium was just released into the air without being used.

Our consumption of helium is now so great that some scientists fear that Earth's helium resources could be used up in the next century. After that, the nearest sources may be the Moon or one of our neighbouring planets, such as Neptune.

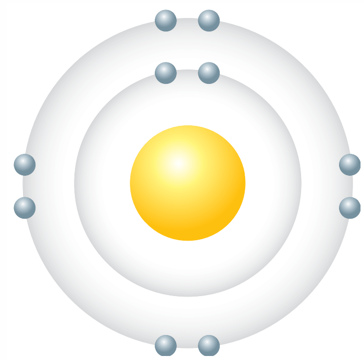
Check Your Understanding

Checking Concepts

1. On the periodic table on page 54, locate the metalloid with the lowest atomic number. What is its name and symbol?
2. Draw a Bohr model diagram for atoms of each of the following elements:
   (a) lithium
   (b) fluorine
   (c) magnesium
   (d) sulphur
3. (a) What is an electron shell?
   (b) How many electrons can each of the four shells nearest the nucleus hold?
4. How many electrons are in each electron shell in an atom of argon?
5. (a) Do metals gain or lose electrons as they form ions?
   (b) Do metals form negative ions or positive ions?
6. Is the electron arrangement in a sodium ion similar to neon or to argon?
7. Is the electron arrangement in an ion of chlorine similar to neon or argon?
8. Explain the difference between a valence electron and a valence shell.
9. What is similar about the electron arrangements of all the alkaline earth metals?
10. Describe the pattern in the way the electron arrangement changes going left to right across the third period.

Understanding Key Ideas

11. What feature of the electron arrangements in noble gases causes them to be chemically unreactive?
12. (a) How can a metal atom achieve noble gas stability?
    (b) How can a non-metal atom achieve noble gas stability?
13. Draw a Bohr model diagram for each of the following atoms:
    (a) Ne
    (b) S
    (c) K
    (d) Be
14. Use the Bohr model diagram below to answer the following questions. This diagram shows the number of electrons, but not the number of protons.
    (a) If this diagram represents an atom, not an ion, what element is it?
    (b) If this diagram represents an ion with a charge of 3−, what element is it?
    (c) If this diagram represents an ion with a charge of 2+, what element is it?



15. Draw a Bohr model diagram for each of the following atoms or ions:
    (a) Ar
    (b) P and P^{3-}
    (c) S and S^{2-}
    (d) Cl and Cl^{-}
    (e) K and K^{+}
    (f) Ca and Ca^{2+}
16. What do you notice about the arrangement of electrons of the ions in parts (b) to (f) of question 15?

Pause and Reflect

The hydrogen atom is the only atom that can either lose or gain an electron. Draw Bohr model diagrams for hydrogen when it gains and when it loses an electron. How does this ability to lose or gain an electron make hydrogen unique among all other elements?

Prepare Your Own Summary

In this chapter, you investigated the periodic table as a means of organizing the elements according to their physical and chemical properties. Create your own summary of the key ideas of this chapter. You may include graphic organizers or illustrations with your notes. (See Science Skill 12 for help with using graphic organizers.) Use the following headings to organize your notes:

1. Characteristics of Some Common Elements
2. Information Given in the Periodic Table
3. Chemical Families
4. Bohr Model Diagrams
5. How Valence Electrons Relate to Chemical Families

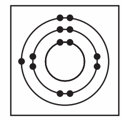
Checking Concepts

1. What is an element?
2. List three common objects that contain one or more elements.
3. Write the names of the elements corresponding to the following symbols:
   (a) P
   (b) Be
   (c) K
   (d) Co
4. Provide the chemical symbol for each of the following elements:
   (a) helium
   (b) lithium
   (c) boron
   (d) magnesium
   (e) calcium
5. Name two elements that are liquids at room temperature.
6. List six properties typical of metals.
7. Iron is a very strong metal.
   (a) What element(s) can be added to it to make it even stronger?
   (b) What is this new metal called?
8. List two ways in which mercury is different from silver.
9. What is the name of the chart that organizes the elements according to their physical and chemical properties?
10. What does the atomic mass of an element measure?
11. What is the relationship between the number of protons in an atom and its atomic number?
12. What is a chemical family?
13. Name the chemical families in groups 1, 2, 17, and 18.
14. Compare the alkaline earth metals to the alkali metals according to their reactivity with water.
15. What is the most important chemical property of the noble gases?
16. What does a Bohr model diagram represent?
17. Define each of these terms:
    (a) valence shell
    (b) valence electron
18. List the number of valence electrons in atoms of each of the following elements:
    (a) potassium
    (b) aluminum
    (c) oxygen
    (d) argon
19. (a) Which chemical family is composed of elements with filled valence shells?
    (b) How does having filled valence shells affect the reactivity of these elements?

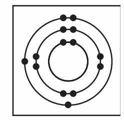
Understanding Key Ideas

20. How is a physical property different from a chemical property?
21. Describe the pattern of the atomic numbers in the periodic table.
22. What is the atomic number of each of these elements?
    (a) antimony
    (b) arsenic
    (c) manganese
    (d) selenium
23. Use the periodic table to find the atomic mass of hydrogen, oxygen, nitrogen, and rhenium.
    (a) Which of these elements has the heaviest atoms?
    (b) Which has the lightest?
24. Locate the following elements in the periodic table: nickel, neodymium, neptunium, and germanium.
    (a) Which two have only one common ion charge?
    (b) Which has the greatest number of common ion charges?
    (c) Which is a metalloid?
    (d) Which two are in period 3?
    (e) Which is in column 10?
25. Locate the following elements in the periodic table: iron, americium, ruthenium, uranium.
    (a) Which has the heaviest atoms?
    (b) Which two are in column 8?
    (c) Which does not have a common ion charge of 3+?
26. Explain why H is listed in the same column as the metals Li, Na, and K, even though H is a non-metal.
27. Draw Bohr model diagrams for Be, Mg, Ca.
28. Identify the following atoms

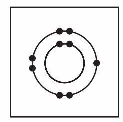
(a)



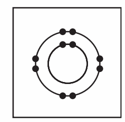
(b)



(c)



(d)



Pause and Reflect

In this chapter, you have investigated how elements are the building blocks of matter. The elements are organized into the periodic table. Why is the periodic table an important tool for anyone studying chemistry?