

# Chapter 9

## Chemical Bonds

### Opening Essay

Diamond is the hardest natural material known on Earth. Yet diamond is just pure carbon. What is special about this element that makes diamond so hard?

Bonds. Chemical bonds.

In a perfect diamond crystal, each C atom makes four connections—bonds—to four other C atoms in a three-dimensional matrix. Four is the greatest number of bonds that is commonly made by atoms, so C atoms maximize their interactions with other atoms. This three-dimensional array of connections extends throughout the diamond crystal, making it essentially one large molecule. Breaking a diamond means breaking every bond at once.

Also, the bonds are moderately strong. There are stronger interactions known, but the carbon-carbon connection is fairly strong itself. Not only does a person have to break many connections at once, but also the bonds are strong connections from the start.

There are other substances that have similar bonding arrangements as diamond does. Silicon dioxide and boron nitride have some similarities, but neither of them comes close to the ultimate hardness of diamond.

How do atoms make compounds? Typically they join together in such a way that they lose their identities as elements and adopt a new identity as a compound. These joins are called *chemical bonds*. But how do atoms join together? Ultimately, it all comes down to electrons. Before we discuss how electrons interact, we need to introduce a tool to simply illustrate electrons in an atom.

### 9.1 Lewis Electron Dot Diagrams

## LEARNING OBJECTIVE

1. Draw a Lewis electron dot diagram for an atom or a monatomic ion.

In almost all cases, chemical bonds are formed by interactions of valence electrons in atoms. To facilitate our understanding of how valence electrons interact, a simple way of representing those valence electrons would be useful.

A **Lewis electron dot diagram** (or electron dot diagram or a Lewis diagram or a Lewis structure) is a representation of the valence electrons of an atom that uses dots around the symbol of the element. The number of dots equals the number of valence electrons in the atom. These dots are arranged to the right and left and above and below the symbol, with no more than two dots on a side. (It does not matter what order the positions are used.) For example, the Lewis electron dot diagram for hydrogen is simply



Because the side is not important, the Lewis electron dot diagram could also be drawn as follows:



The electron dot diagram for helium, with two valence electrons, is as follows:



By putting the two electrons together on the same side, we emphasize the fact that these two electrons are both in the  $1s$  subshell; this is the common convention we will adopt, although there will be exceptions later. The next atom, lithium, has an

electron configuration of  $1s^22s^1$ , so it has only one electron in its valence shell. Its electron dot diagram resembles that of hydrogen, except the symbol for lithium is used:



Beryllium has two valence electrons in its  $2s$  shell, so its electron dot diagram is like that of helium:



The next atom is boron. Its valence electron shell is  $2s^22p^1$ , so it has three valence electrons. The third electron will go on another side of the symbol:



Again, it does not matter on which sides of the symbol the electron dots are positioned.

For carbon, there are four valence electrons, two in the  $2s$  subshell and two in the  $2p$  subshell. As usual, we will draw two dots together on one side, to represent the  $2s$  electrons. However, conventionally, we draw the dots for the two  $p$  electrons on different sides. As such, the electron dot diagram for carbon is as follows:



With N, which has three  $p$  electrons, we put a single dot on each of the three remaining sides:



For oxygen, which has four  $p$  electrons, we now have to start doubling up on the dots on one other side of the symbol. When doubling up electrons, make sure that a side has no more than two electrons.



Fluorine and neon have seven and eight dots, respectively:



With the next element, sodium, the process starts over with a single electron because sodium has a single electron in its highest-numbered shell, the  $n = 3$  shell. By going through the periodic table, we see that the Lewis electron dot diagrams of atoms will never have more than eight dots around the atomic symbol.

### EXAMPLE 1

What is the Lewis electron dot diagram for each element?

1. aluminum
2. selenium

Solution

1. The valence electron configuration for aluminum is  $3s^23p^1$ . So it would have three dots around the symbol for aluminum, two of them paired to represent the  $3s$  electrons:



2. The valence electron configuration for selenium is  $4s^24p^4$ . In the highest-numbered shell, the  $n = 4$  shell, there are six electrons. Its electron dot diagram is as follows:



### *Test Yourself*

What is the Lewis electron dot diagram for each element?

1. phosphorus
2. argon

### *Answer*



For atoms with partially filled  $d$  or  $f$  subshells, these electrons are typically omitted from Lewis electron dot diagrams. For example, the electron dot diagram for iron (valence shell configuration  $4s^23d^6$ ) is as follows:



Elements in the same column of the periodic table have similar Lewis electron dot diagrams because they have the same valence shell electron configuration. Thus the electron dot diagrams for the first column of elements are as follows:



Monatomic ions are atoms that have either lost (for cations) or gained (for anions) electrons. Electron dot diagrams for ions are the same as for atoms, except that some electrons have been removed for cations, while some electrons have been added for anions. Thus in comparing the electron configurations and electron dot diagrams for



the Na atom and the  $\text{Na}^+$  ion, we note that the Na atom has a single valence electron in its Lewis diagram, while the  $\text{Na}^+$  ion has lost that one valence electron:

Lewis dot diagram:



Electron configuration:



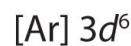
Technically, the valence shell of the  $\text{Na}^+$  ion is now the  $n = 2$  shell, which has eight electrons in it. So why do we not put eight dots around  $\text{Na}^+$ ? Conventionally, when we show electron dot diagrams for ions, we show the original valence shell of the atom, which in this case is the  $n = 3$  shell and empty in the  $\text{Na}^+$  ion.

In making cations, electrons are first lost from the *highest numbered shell*, not necessarily the last subshell filled. For example, in going from the neutral Fe atom to the  $\text{Fe}^{2+}$  ion, the Fe atom loses its two  $4s$  electrons first, not its  $3d$  electrons, despite the fact that the  $3d$  subshell is the last subshell being filled. Thus we have

Lewis dot diagram:



Electron configuration:

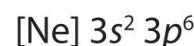


Anions have extra electrons when compared to the original atom. Here is a comparison of the Cl atom with the  $\text{Cl}^-$  ion:

Lewis dot diagram:



Electron configuration:



## EXAMPLE 2

What is the Lewis electron dot diagram for each ion?

1.  $\text{Ca}^{2+}$
2.  $\text{O}^{2-}$

### Solution

1. Having lost its two original valence electrons, the Lewis electron dot diagram is just  $\text{Ca}^{2+}$ .



2. The  $\text{O}^{2-}$  ion has gained two electrons in its valence shell, so its Lewis electron dot diagram is as follows:



### *Test Yourself*

The valence electron configuration of thallium, whose symbol is Tl, is  $6s^2 5d^{10} 6p^1$ . What is the Lewis electron dot diagram for the  $\text{Tl}^+$  ion?

### *Answer*



## KEY TAKEAWAYS

- Lewis electron dot diagrams use dots to represent valence electrons around an atomic symbol.
- Lewis electron dot diagrams for ions have less (for cations) or more (for anions) dots than the corresponding atom.



## EXERCISES

1. Explain why the first two dots in a Lewis electron dot diagram are drawn on the same side of the atomic symbol.
2. Is it necessary for the first dot around an atomic symbol to go on a particular side of the atomic symbol?
3. What column of the periodic table has Lewis electron dot diagrams with two electrons?
4. What column of the periodic table has Lewis electron dot diagrams that have six electrons in them?
5. Draw the Lewis electron dot diagram for each element.
  - a. strontium
  - b. silicon
6. Draw the Lewis electron dot diagram for each element.
  - a. krypton
  - b. sulfur
7. Draw the Lewis electron dot diagram for each element.
  - a. titanium
  - b. phosphorus

8. Draw the Lewis electron dot diagram for each element.

- a. bromine
- b. gallium

9. Draw the Lewis electron dot diagram for each ion.

- a.  $\text{Mg}^{2+}$
- b.  $\text{S}^{2-}$

10. Draw the Lewis electron dot diagram for each ion.

- a.  $\text{In}^+$
- b.  $\text{Br}^-$

11. Draw the Lewis electron dot diagram for each ion.

- a.  $\text{Fe}^{2+}$
- b.  $\text{N}^{3-}$

12. Draw the Lewis electron dot diagram for each ion.

- a.  $\text{H}^+$
- b.  $\text{H}^-$

## ANSWERS

1. The first two electrons in a valence shell are *s* electrons, which are paired.

3. the second column of the periodic table

5. a.

Sr:

b.



7. a.

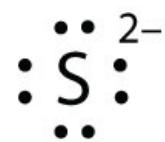
Ti :

b.



9. a.  $Mg^{2+}$

b.



11.a.  $\text{Fe}^{2+}$

b.

