Learning Objectives

• Describe how electrons are grouped within atoms.

Although we have discussed the general arrangement of subatomic particles in atoms, we have said little about how electrons occupy the space about the nucleus. Do they move around the nucleus at random, or do they exist in some ordered arrangement?

The modern theory of electron behavior is called quantum mechanics. It makes the following statements about electrons in atoms:

• Electrons in atoms can have only certain specific energies. We say that the energies of the electrons are quantized.

• Electrons are organized according to their energies into sets called shells (labeled by the principle quantum number, \( n \)). Generally the higher the energy of a shell, the farther it is (on average) from the nucleus. Shells do not have specific, fixed distances from the nucleus, but an electron in a higher-energy shell will spend more time farther from the nucleus than does an electron in a lower-energy shell.

• Shells are further divided into subsets of electrons called subshells. The first shell has only one subshell, the second shell has two subshells, the third shell has three subshells, and so on. The subshells of each shell are labeled, in order, with the letters \( s \), \( p \), \( d \), and \( f \). Thus, the first shell has only a single \( s \) subshell (called \( 1s \)), the second shell has \( 2s \) and \( 2p \) subshells, the third shell has \( 3s \), \( 3p \), and \( 3d \) and so forth.

<table>
<thead>
<tr>
<th>Shell</th>
<th>Number of Subshells</th>
<th>Names of Subshells</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>( 1s )</td>
</tr>
<tr>
<td>2</td>
<td>2</td>
<td>( 2s ) and ( 2p )</td>
</tr>
<tr>
<td>3</td>
<td>3</td>
<td>( 3s ), ( 3p ) and ( 3d )</td>
</tr>
<tr>
<td>4</td>
<td>4</td>
<td>( 4s ), ( 4p ), ( 4d ) and ( 4f )</td>
</tr>
</tbody>
</table>

• Different subshells hold a different maximum number of electrons. Any \( s \) subshell can hold up to 2 electrons; \( p \), 6; \( d \), 10; and \( f \), 14.

<table>
<thead>
<tr>
<th>Subshell</th>
<th>Maximum Number of Electrons</th>
</tr>
</thead>
<tbody>
<tr>
<td>( s )</td>
<td>2</td>
</tr>
<tr>
<td>( p )</td>
<td>6</td>
</tr>
<tr>
<td>( d )</td>
<td>10</td>
</tr>
<tr>
<td>( f )</td>
<td>14</td>
</tr>
</tbody>
</table>

It is the arrangement of electrons into shells and subshells that most concerns us here, so we will focus on that.
We use numbers to indicate which shell an electron is in. As shown in Table 2.6.1, the first shell, closest to the nucleus and with the lowest-energy electrons, is shell 1. This first shell has only one subshell, which is labeled 1s and can hold a maximum of 2 electrons. We combine the shell and subshell labels when referring to the organization of electrons about a nucleus and use a superscript to indicate how many electrons are in a subshell. Thus, because a hydrogen atom has its single electron in the s subshell of the first shell, we use $1s^1$ to describe the electronic structure of hydrogen. This structure is called an electron configuration. Electron configurations are shorthand descriptions of the arrangements of electrons in atoms. The electron configuration of a hydrogen atom is spoken out loud as “one-ess-one.”

Helium atoms have 2 electrons. Both electrons fit into the 1s subshell because s subshells can hold up to 2 electrons; therefore, the electron configuration for helium atoms is $1s^2$ (spoken as “one-ess-two”).

The 1s subshell cannot hold 3 electrons (because an s subshell can hold a maximum of 2 electrons), so the electron configuration for a lithium atom cannot be $1s^3$. Two of the lithium electrons can fit into the 1s subshell, but the third electron must go into the second shell. The second shell has two subshells, s and p, which fill with electrons in that order. The 2s subshell holds a maximum of 2 electrons, and the 2p subshell holds a maximum of 6 electrons. Because lithium’s final electron goes into the 2s subshell, we write the electron configuration of a lithium atom as $1s^22s^1$. The shell diagram for a lithium atom is shown below. The shell closest to the nucleus (first shell) has 2 dots representing the 2 electrons in 1s, while the outermost shell (2s) has 1 electron.

**Figure 2.6.1** Shell diagram of lithium (Li) atom.

The next largest atom, beryllium, has 4 electrons, so its electron configuration is $1s^22s^2$. Now that the 2s subshell is filled, electrons in larger atoms start filling the 2p subshell. Thus, the electron configurations for the next six atoms are as follows:

- B: $1s^22s^22p^1$
- C: $1s^22s^22p^2$
- N: $1s^22s^22p^3$
- O: $1s^22s^22p^4$
- F: $1s^22s^22p^5$
- Ne: $1s^22s^22p^6$
With neon, the $2p$ subshell is completely filled. Because the second shell has only two subshells, atoms with more electrons now must begin the third shell. The third shell has three subshells, labeled $s$, $p$, and $d$. The $d$ subshell can hold a maximum of 10 electrons. The first two subshells of the third shell are filled in order—for example, the electron configuration of aluminum, with 13 electrons, is $1s^22s^22p^63s^23p^1$. However, a curious thing happens after the $3p$ subshell is filled: the $4s$ subshell begins to fill before the $3d$ subshell does. In fact, the exact ordering of subshells becomes more complicated at this point (after argon, with its 18 electrons), so we will not consider the electron configurations of larger atoms.

A fourth subshell, the $f$ subshell, is needed to complete the electron configurations for all elements. An $f$ subshell can hold up to 14 electrons.

Electron filling always starts with $1s$, the subshell closest to the nucleus. Next is $2s$, $2p$, $3s$, $3p$, $4s$, $3d$, $4p$, etc., shown in the electron shell filling order diagram in Figure 2.6.2. Follow each red arrow in order from top to bottom. The subshells you reach along each arrow give the ordering of filling of subshells in larger atoms.

![The diagonal rule for electron filling order.](image)

**Figure 2.6.2** The order of electron filling in an atom.

Example \(\PageIndex{1}\): Electronic Configuration of Phosphorus Atoms

What is the electron configuration of a neutral phosphorus atom?

**Solution**

A neutral phosphorus atom has 15 electrons. Two electrons can go into the $1s$ subshell, 2 can go into the $2s$ subshell, and 6 can go into the $2p$ subshell. That leaves 5 electrons. Of those 5 electrons, 2 can go into the $3s$ subshell, and the remaining 3 electrons can go into the $3p$ subshell. Thus, the electron configuration of neutral phosphorus atoms is $1s^22s^22p^63s^23p^3$.

Exercise \(\PageIndex{1}\): Electronic Configuration of Chlorine Atoms

What is the electron configuration of a neutral chlorine atom?

**Answer**

A neutral chlorine atom has 17 electrons. Two electrons can go into the $1s$ subshell, 2 can go into the $2s$ subshell, and 6 can go into the $2p$ subshell. That leaves 7 electrons. Of those 7 electrons, 2 can go into the $3s$ subshell, and
the remaining 5 electrons can go into the 3p subshell. Thus, the electron configuration of neutral chlorine atoms is $1s^22s^22p^63s^23p^5$.

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Valence Electrons

In the study of chemical reactivity, we will find that the electrons in the outermost principal energy level are very important and so they are given a special name. **Valence electrons** are the electrons in the highest occupied principal energy level of an atom. In the second period elements, the two electrons in the \(1s\) sublevel are called **inner-shell electrons** and are not involved directly in the element's reactivity or in the formation of compounds. Lithium has a single electron in the second principal energy level and so we say that lithium has one valence electron. Beryllium has two valence electrons. How many valence electrons does boron have? You must recognize that the second principal energy level consists of both the \(2s\) and the \(2p\) sublevels and so the answer is three. In fact, the number of valence electrons goes up by one for each step across a period until the last element is reached. Neon, with its configuration ending in \(2s^22p^6\), has eight valence electrons.

A chemical reaction results from electron removal, electron addition, or electron sharing of the valence electrons of the different atoms. The path a specific element will take depends on where the electrons are in the atom and how many there are. Thus, it is convenient to separate electrons into two groups. Valence shell electrons (or, more simply, the **valence electrons**) are the electrons in the highest-numbered shell, or valence shell, while core electrons are the electrons in lower-numbered shells. We can see from the electron configuration of a carbon atom—$1s^22s^22p^2$—that it has 4 valence electrons ($2s^22p^2$) and 2 core electrons ($1s^2$). You will see in the next chapters that the chemical properties of elements are determined by the number of valence electrons.

**Example \(\PageIndex{2}\): Counting Valence Electrons in Phosphorus Atoms**

From the electron configuration of neutral phosphorus atoms in Example \(\PageIndex{1}\), how many valence electrons and how many core electrons does a neutral phosphorus atom have?

**Solution**

The highest-numbered shell is the third shell, which has 2 electrons in the 3s subshell and 3 electrons in the 3p subshell. That gives a total of 5 electrons, so neutral phosphorus atoms have **5 valence electrons**. The 10 remaining electrons, from the first and second shells, are core electrons.

**Exercise \(\PageIndex{2}\): Counting Valence Electrons in Chlorine Atoms**

From the electron configuration of neutral chlorine atoms (Exercise \(\PageIndex{1}\)), how many valence electrons and how many core electrons does a neutral chlorine atom have?

**Answer**

The highest-numbered shell is the third shell, which has 2 electrons in the 3s subshell and 5 electrons in the 3p subshell. That gives a total of 7 electrons, so neutral chlorine atoms have **7 valence electrons**. The 10 remaining electrons, from the first and second shells, are core electrons.
Exercise Counting Valence Electrons in Sodium Atoms

What is the electron configuration of a neutral atom of sodium (Na)? How many core electrons are there? How many valence electrons? How do you draw the shell diagram of sodium atom?

Answer

Sodium (Na) has atomic number 11, hence, 11 electrons. The electron configuration is: \(1s^22s^22p^63s^1\). This means the first shell (1s) has 2 electrons. The second shell (2s and 2p) has a total of 8 electrons. And, the third (last) shell has 1 electron.

The first and second shells comprise the core (inner) electrons = 2 + 8 = 10 electrons. The outermost (valence) has 1 electron.

The shell diagram of the Na atom is shown here. The shell nearest the nucleus (first shell) has 2 electrons, the second shell has 8 electrons and the last (outermost) shell has 1 electron (2.8.1)

Concept Review Exercises

1. How are electrons organized in atoms?
2. What information does an electron configuration convey?
3. What is the difference between core electrons and valence electrons?

Answers

1. Electrons are organized into shells and subshells around nuclei.
2. The electron configuration states the arrangement of electrons in shells and subshells.
3. Valence electrons are in the highest-numbered shell; all other electrons are core electrons.

Key Takeaway

- Electrons are organized into shells and subshells about the nucleus of an atom.
- The valence electrons determine the reactivity of an atom.
Exercises

2.6: Arrangements of Electrons

1. What is the maximum number of electrons that can fit in an s subshell? Does it matter what shell the s subshell is in?

2. What is the maximum number of electrons that can fit in a p subshell? Does it matter what shell the p subshell is in?

3. What is the maximum number of electrons that can fit in a d subshell? Does it matter what shell the d subshell is in?

4. What is the maximum number of electrons that can fit in an f subshell? Does it matter what shell the f subshell is in?

5. What is the electron configuration of a carbon atom?

6. What is the electron configuration of a sulfur atom?

7. What is the valence shell electron configuration of a calcium atom?

8. What is the valence shell electron configuration of a selenium atom?

9. What atom has the electron configuration 1s\(^2\)2s\(^2\)2p\(^5\)?

10. What atom has the electron configuration 1s\(^2\)2s\(^2\)2p\(^6\)3s\(^2\)3p\(^3\)?

11. Draw a representation of the electronic structure of an oxygen atom.


13. A potassium atom has ____ core electrons and ____ valence electrons.

14. A silicon atom has ____ core electrons and ____ valence electrons.

Answers

1. 2; no

2. 6; no
3. 10; no
4. 14; no
5. 1s²2s²2p²
6. 1s²2s²2p⁶3s²3p⁴
7. 4s²
8. 4s²4p⁴
9. fluorine
10. phosphorus
11.
12.
13. 18; 1
14. 10; 4