**Valence Electrons**

Mendeleev used similarities in the properties of elements to organize his periodic table. Scientists later learned that all of the elements within each group of the periodic table behave similarly because they have the same number of valence electrons. **Valence electrons** are the electrons in the highest occupied energy level of an element's atoms. The number of valence electrons largely determines the chemical properties of an element.

The number of valence electrons is related to the group numbers in the periodic table. To find the number of valence electrons in an atom of a representative element, simply look at its group number. For example, the elements of Group 1A (hydrogen, lithium, sodium, potassium, and so forth) all have one valence electron, corresponding to the 1 in 1A. Carbon and silicon, in Group 4A, have four valence electrons. Nitrogen and phosphorus, in Group 5A, have five valence electrons; and oxygen and sulfur, in Group 6A, have six. The noble gases (Group 8A) are the only exceptions to the group-number rule: Helium has two valence electrons, and all of the other noble gases have eight. Figure 7.1 shows some applications of Group 4A elements.
Valence Electrons

Use Visuals

Table 7.1  Have students identify the total number of electrons and the number of valence electrons in selected elements from Table 7.1. Reemphasize that the group number equals the number of valence electrons in an atom of a representative element.

Valence Electrons

Purpose  To model the valence electrons of an atom.

Materials  plastic egg, 11 marbles

Procedure  Hold up a plastic egg containing 10 marbles. State that the egg represents a sodium atom and that the marbles represent the 10 electrons making up the \( n = 1 \) and \( n = 2 \) energy levels. Explain that these electrons cannot be “removed” without “breaking” the egg. Now hold up one additional marble next to the egg. State that this marble represents the eleventh electron, and occupies the \( n = 3 \) energy level. This is the valence electron. Explain that if this electron is lost, the resulting atom has an overall 1+ charge.

Expected Outcome  Students should be able to distinguish valence electrons from nonvalence electrons.

The Octet Rule

Discuss

Have students determine the accuracy of this statement: All stable ions of elements result in electronic configurations that are isoelectronic with noble gases. (Most of the time this statement is true, but there are exceptions. Use Cu(I) as an example. Explain that a noble gas configuration is not generally possible with elements that would have to gain or lose many electrons to become stable.)

Word Origins

Octet  comes from the Greek word okto, meaning “eight.” There are eight electrons in the highest occupied energy level of the noble gases, except for helium. How do you think the term octet might also be applied to music or poetry?

Word Origins

In music, an octet refers to a group of eight performers, or a composition written for eight musicians. In poetry, an octet refers to a group of eight lines of verse.

Table 7.1  Electron Dot Structure of Some Group A Elements

<table>
<thead>
<tr>
<th>Period</th>
<th>1A</th>
<th>2A</th>
<th>3A</th>
<th>4A</th>
<th>5A</th>
<th>6A</th>
<th>7A</th>
<th>8A</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>H+</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>He</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Li+</td>
<td>Be+</td>
<td>B+</td>
<td>C+</td>
<td>N+</td>
<td>O2−</td>
<td>F−</td>
<td>Ne</td>
</tr>
<tr>
<td>3</td>
<td>Na+</td>
<td>Mg2+</td>
<td>Al3+</td>
<td>Si4+</td>
<td>P3−</td>
<td>S2−</td>
<td>Cl−</td>
<td>Ar</td>
</tr>
<tr>
<td>4</td>
<td>K+</td>
<td>Ca2+</td>
<td>Ga3+</td>
<td>Ge4+</td>
<td>As3−</td>
<td>Se2−</td>
<td>Br2−</td>
<td>Kr</td>
</tr>
</tbody>
</table>

Valence electrons are usually the only electrons used in chemical bonds. Therefore, as a general rule, only the valence electrons are shown in electron dot structures. Electron dot structures are diagrams that show valence electrons as dots. Table 7.1 shows electron dot structures for atoms of some Group A elements. Notice that all of the elements within a given group (with the exception of helium) have the same number of electron dots in their structures.

What is an electron dot structure?

The Octet Rule

You learned in Chapter 6 that noble gases, such as neon and argon, are unreactive in chemical reactions. That is, they are stable. In 1916, chemist Gilbert Lewis used this fact to explain why atoms form certain kinds of ions and molecules. He called his explanation the octet rule: In forming compounds, atoms tend to achieve the electronic configuration of a noble gas. An octet is a set of eight. Recall that each noble gas (except helium) has eight electrons in its highest energy level and a general electron configuration of \( n^2(n^2)^6 \). Thus the octet rule takes its name from this fact about noble gases.

Atoms of the metallic elements tend to lose their valence electrons, leaving a complete octet in the next-lowest energy level. Atoms of some nonmetallic elements tend to gain electrons or to share electrons with another nonmetallic element to achieve a complete octet. Although there are exceptions, the octet rule applies to atoms in most compounds.

Formation of Cations

An atom is electrically neutral because it has equal numbers of protons and electrons; an ion forms when an atom or group of atoms loses or gains electrons. An atom's loss of valence electrons produces a cation, or a positively charged ion. Note that for metallic elements, the name of a cation is the same as the name of the element. For example, a sodium atom (Na) forms a sodium cation (Na⁺). Likewise, a calcium atom (Ca) forms a calcium cation (Ca²⁺). Although their names are the same, there are many important chemical differences between metals and their cations. Sodium metal, for example, reacts explosively with water. By contrast, sodium cations are quite unreactive. As you may know, they are a component of table salt, a compound that is very stable in water.
The most common cations are those produced by the loss of valence electrons from metal atoms. Most of these atoms have one to three valence electrons, which are easily removed. Sodium, in Group 1A of the periodic table, is typical. Sodium atoms have a total of eleven electrons, including one valence electron. A sodium atom can lose an electron to become a positively charged sodium ion. The sodium ion has an electron configuration that is identical to the noble gas neon. When forming a compound, a sodium atom loses its one valence electron and is left with an octet (eight electrons) in what is now its highest energy level. Because the number of protons in the sodium nucleus is still eleven, the loss of one unit of negative charge (an electron) produces a cation with a charge of 1+. You can represent the electron loss, or ionization, of the sodium atom by drawing the complete electron configuration of the atom and of the ion formed.

\[
\text{Na} \quad \rightarrow \quad \text{Na}^+ + e^- \\
1s^22s^22p^63s^1 \rightarrow 1s^22s^22p^6 \\
\text{octet}
\]

Notice that the electron configuration of the sodium ion (1s22s22p6) is the same as that of a neon atom. The diagrams below help illustrate this point.

Both the sodium ion and the neon atom have eight electrons in their valance shells. Using electron dot structures, you can show the ionization more simply.

![Sodium and Neon Electron Configurations](image)

**Differentiated Instruction**

**Gifted and Talented**

Have students show how the atoms of transition elements become stable with pseudo-noble-gas configurations. These atoms would have to gain or lose too many electrons to achieve a noble-gas electron configuration. For example, show how Ag, Zn, and Ga lose 1, 2, and 3 electrons, respectively to form pseudo-noble-gas configurations.

**Formation of Cations**

**Use Visuals**

**Figure 7.2** Display the equation that goes with Figure 7.2 on an overhead projector. Point out that the interaction between atoms that produces bonding involves only the outermost electrons of the atoms. The inner electrons are locked tightly in filled energy levels and do not participate in bonding. Use a colored pen to circle the outermost electron in the sodium atom in this equation. Remind students that the outermost electrons are called valence electrons. Use a different colored pen to circle the octet of electrons in the sodium ion’s highest energy level. Circle the corresponding octet of electrons in neon to show the similarity in electron configurations. Have students draw a similar diagram for calcium.

**Answers to...**

**Figure 7.2** 8 electrons

**Checkpoint** A diagram that shows valence electrons as dots.
Discuss

One way to determine the number of valence electrons in an atom is to look at the electron configuration of the atom. Explain that any electron in an atom outside the noble-gas core is called a valence electron. Using diagrams such as those on pages 189 and 190, show students several examples of how various atoms of the representative elements form ions and gain a noble-gas electron configuration. Indicate the noble-gas core and valence electrons in your diagrams. Lay pieces of magnesium, zinc, copper, and aluminum on a dry surface in the lab to show that metals do not spontaneously form metal cations.

CLASS Activity

Forming Cations

Purpose Students model the formation of cations using equations.

Materials paper, pencil

Procedure Have students write equations similar to that for Mg on student page 190, showing the formation of metal cations from metal atoms. Students should show the electron dot structures for the metal atoms and metal cations that are formed. In addition, you may want students to write out the electron configurations for the metal atoms and cations. Check students’ equations to be sure the correct metal ion is formed.

Expected Outcome Students should be able to use electron dot structures to correctly write equations describing the ionization of metal atoms.

Figure 7.3 Walnuts are a good dietary source of magnesium. Magnesium ions (Mg\(^{2+}\)) aid in digestive processes.

Figure 7.4 Cations of Group 1A elements have a charge of 1\(^+\). Cations of Group 2A elements have a charge of 2\(^+\).

Differentiated Instruction

Special Needs

Ask students to work with a partner to practice drawing electron dot structures for Group A elements. Have one student randomly choose an element and write the symbol for that element on a piece of paper. Have another student fill in the electron dots for this element. Students can check their work by referring to Table 7.1. Make sure students understand that the electron dots represent only valence electrons, not the total number of electrons, and that valence electrons are the only electrons involved in chemical reactivity. Also, reinforce the stable octet dot structures for the noble gases and explain how ions of other elements will react to obtain this configuration.
### Formation of Anions

An anion is an atom or a group of atoms with a negative charge. The gain of negatively charged electrons by a neutral atom produces an anion. Note that the name of an anion of a nonmetallic element is not the same as the element name. The name of the anion typically ends in -ide. Thus a chlorine atom (Cl) forms a chloride ion (Cl\(^{-}\)), and an oxygen atom (O) forms an oxide ion (O\(^{2-}\)). Figure 7.5 shows the symbols of anions formed by some elements in Groups 5A, 6A, and 7A.

Because they have relatively full valence shells, atoms of nonmetallic elements attain noble-gas electron configurations more easily by gaining electrons than by losing them. For example, chlorine belongs to Group 7A (the halogen family) and has seven valence electrons. A gain of one electron gives chlorine an octet and converts a chlorine atom into a chloride ion.

\[
\text{Cl} \quad 1s^22s^22p^63s^23p^\xi \quad \rightarrow \quad \text{Cl}^- \quad 1s^22s^22p^63s^23p^\xi 1e^- \\
\]

The chloride ion is an anion with a single negative charge. Notice that it has the same electron configuration as the noble gas argon:

\[
\text{Ar} \quad 1s^22s^22p^63s^23p^6 \\
\]

Chlorine atoms, therefore, need one more valence electron to achieve the electron configuration of the nearest noble gas. The diagrams below illustrate how both the chloride ion and the argon atom have an octet of electrons in their highest energy levels.

---

**Figure 7.5** Atoms of nonmetallic elements form anions by gaining enough valence electrons so as to attain the electron configuration of the nearest noble gas.

**Interpreting Diagrams** In which group of the periodic table do the elements bromine and iodine belong?

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### Facts and Figures

#### Water Purification

Chlorine gas is often used to purify drinking water; it kills a variety of microorganisms, including those that carry diseases. But chlorine also reacts with organic substances in the water to produce chlorinated compounds such as chloroacetonitrile. Chloroacetonitrile has been shown to cause inflammation of the digestive tract in laboratory animals. As an alternative to chlorine, some countries have begun purifying water with ozone. Ozone kills microorganisms even more effectively than chlorine. About one percent of the water supply in the United States is now purified with ozone. It is estimated that it would cost $6 billion to switch completely to ozone for treating all the drinking water supplies.
Gifted and Talented

Many common anions are polyatomic ions. Have students infer what a polyatomic ion is, then confirm their definitions. Have them list some common polyatomic anions, such as sulfate (SO$_4^{2-}$), nitrate (NO$_3^{-}$), and phosphate (PO$_4^{3-}$). Tell them that polyatomic ions form ionic compounds and that polyatomic ions will be studied in Chapter 8.
CONCEPTUAL PROBLEM 7.1

Writing the Symbols and Names of Ions
The beaker shown on the right contains iodine vapor. Write the symbol and name of the ion formed when
a. an iodine atom gains one electron.
b. a strontium atom loses two electrons.

1 Analyze Identify the relevant concepts.
   a. An atom that gains electrons forms a negatively charged ion (anion). The name of an anion of a nonmetallic element ends in -ide.
   b. An atom that loses electrons forms a positively charged ion (cation). The name of a cation of a metallic element is the same as the name of the element.

2 Solve Apply concepts to this situation.
   a. $\text{I}^-$, iodide ion (an anion)
   b. $\text{Sr}^{2+}$, strontium ion (a cation)

Practice Problems
1. Write the name and symbol of the ion formed when
   a. a sulfur atom gains two electrons.
   b. an aluminum atom loses three electrons.
2. How many electrons are lost or gained in forming each ion?
   a. $\text{Ba}^{2+}$
   b. $\text{As}^{3-}$
   c. $\text{Cu}^{2+}$

7.1 Section Assessment
3. Key Concept How can you determine the number of valence electrons in an atom of a representative element?
4. Key Concept Atoms of which elements tend to gain electrons? Atoms of which elements tend to lose electrons?
5. Key Concept How do cations form?
6. Key Concept How do anions form?
7. How many valence electrons are in each atom?
   a. potassium
   b. carbon
   c. magnesium
   d. oxygen
8. Write the electron dot structure for each element in Question 7.
9. How many electrons will each element gain or lose in forming an ion?
   a. calcium (Ca)
   b. fluorine (F)
   c. aluminum (Al)
   d. oxygen (O)
10. Write the name and symbol of the ion formed when
    a. a potassium atom loses one electron.
    b. a zinc atom loses two electrons.
    c. a fluorine atom gains one electron.
11. Write the electron configuration of $\text{Cd}^{2+}$.

Assessment 7.1 Test yourself on the concepts in Section 7.1.

Ionization Energy Reread Section 6.3. How does the octet rule explain the large increase in energy between the first and second ionization energies of Group 1A metals?

Connecting Concepts
The amount of energy needed to remove the one valence electron of a Group 1A metal atom (first ionization energy) is low. After this electron is lost, the outer energy level contains an octet and is stable. If it loses another electron, it will be less stable, so the second ionization energy is high.

Section 7.1 Assessment
3. look up the group number of that element
4. Atoms of nonmetallic elements tend to gain electrons; atoms of metallic elements tend to lose electrons.
5. when an atom loses valence electrons
6. when an atom gains valence electrons
7. a. 1 b. 4 c. 2 d. 6
8. a. K b. Ç c. Mg d. O
9. a. lose 2 b. gain 1 c. lose 3 d. gain 2
10. a. potassium cation, $\text{K}^+$
    b. zinc cation, $\text{Zn}^{2+}$
    c. fluoride anion, $\text{F}^-$
11. $\text{Cd}^{2+}$: $1s^22s^22p^63s^23p^63d^{10}4s^24p^64d^{10}$

Checkpoints
1 electron