5.1.2: Ions and the Octet Rule

Learning Objectives

- Use the octet rule and electron configurations to determine if an atom will gain or lose electrons forming anions or cations.

Ions are formed when an atom, usually on the left side of the periodic table, *reacts with* and *transfers* one or more electrons to another atom, usually on the right side of the periodic table. These electrons are usually *lost from* or *gained into* the **valence shell**, or outermost energy level (shell). Why do some atoms lose electrons and others gain electrons? How can we predict the number of electrons lost or gained? Which ions are stable and which ions do not form at all? These questions are best answered by looking at electron configurations and considering what is called the **octet rule**, which states that atoms gain or lose electrons to form a stable, noble gas configuration, i.e., a filled subshell containing *eight* electrons. Therefore, it is useful to take a closer look at electron configurations to further illustrate ion formation and electron transfer between atoms.

The electron configuration for sodium shows that there are ten core electrons and one valence electron in the third energy level. When sodium loses the single valence electron, forming the cation Na^+, the electron configuration is now identical to that of neon, a stable noble gas with eight valence electrons.

$$\begin{array}{ll} \mathrm{Na} & \rightarrow \quad \mathrm{Na^+ + e^-} \\ 1s^2\ 2s^2\ 2p^6\ 3s^1 & \quad\ 1s^2\ 2s^2\ 2p^6 \end{array} \tag{5.1.2.1}$$

Chlorine also has ten core electrons and valence electrons in the third energy level. However, chlorine has seven valence electrons, one less than the noble gas argon, which has eight valence electrons. Thus, chlorine will gain one electron, forming the anion, Cl^-, and achieving a stable noble gas configuration.

$$\begin{array}{ll} \mathrm{Cl + e^-} & \rightarrow \quad \mathrm{Cl^-} \\ 1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^5 & \quad\ 1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6 \end{array} \tag{5.1.2.2}$$

The octet rule and the periodic table can be used to predict what ions will form; main group elements on the left side of the periodic table (metals in groups 1, 2, and 13) tend to lose electrons (form cations) to achieve the same electron configuration as the noble gas just *before* them in the table. The number of electrons the atom will lose depends on what group the atom is in, i.e., how many valence electrons it has. Main group elements on the right side of the periodic table (nonmetals in groups 15-17) will gain electrons to achieve the same electron configuration as the noble gas just *after* them in the table. Again, the number of electrons the atom will gain depends on the number of valence electrons it has and how many are needed to reach the filled subshell, eight electrons.

Note Violation of the Octet Rule

It is *not impossible* to violate the octet rule. Consider sodium: in its elemental form, it has one valence electron and is stable. It is rather reactive, however, and does not require a lot of energy to remove that electron to make the Na^+ ion. We *could* remove another electron by adding even *more* energy to the ion, to make the Na^{2+} ion. However, that requires much more energy than is normally available in chemical reactions, so sodium stops at a 1+ charge after losing a single electron. It turns out that the Na^+ ion has a complete octet in its new valence shell, the $n = 2$ shell, which satisfies the octet rule. The octet rule is a result of trends in energies and is useful in explaining why atoms form the ions that they do.

Example 5.1.2.1

Write the electron configuration of aluminum atom ($Z = 13$) and underline the *valence electrons*. How many electrons are gained/lost to form an aluminum ion? Write the symbol and the electron configuration for an aluminum ion.

Solution

The electron configuration of Al atom is $1s^2\underline{2s^2 2p^6 3s^2 3p^1}$. Aluminum has three valence electrons in the third energy level, ($3s^2 3p^1$). The cation, Al^{3+}, is formed when these three valence electrons are **lost**, leaving the configuration for the noble gas neon, $1s^2 2s^2 2p^6$.

? Exercise 5.1.2.1

Write the electron configuration of oxygen atom (Z = 8) and underline the valence electrons. How many electrons are gained/lost to form an oxide ion? Write the symbol and electron configuration for oxide ion.

Answer

The electron configuration of O atom is $1s^2 2s^2 2p^4$. Oxygen has six valence electrons in the second energy level, ($2s^2 2p^4$). The anion O^{2-} is formed when two electrons are **gained** in the valence shell. The resulting electron configuration, $1s^2 2s^2 2p^6$, which is also identical to the configuration for the noble gas neon.

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