Chapter 11

Oxidations and Reductions

THE MAIN IDEA

Oxidation is the loss of electrons, and reduction is the gain of electrons.

Λ The chemical reactions going on in your body are quite similar to those going on within burning wood. In both cases, the products are carbon dioxide, water, and energy.

What do our bodies have in common with the burning of a campfire or the rusting of old farm equipment? Why does silver tarnish? How can aluminum restore tarnished silver? How are metals produced from minerals? How do batteries work, and what is their source of energy? What are fuel cells, and how do they generate electricity so efficiently? How do photovoltaic cells convert sunlight into electricity? Why is hydrogen such an environmentally friendly fuel but not itself a source of energy? The answers to all these questions involve a class of reactions called oxidation-reduction, sometimes "redox" for short. These reactions are similar to the acid-base reactions you learned about in the previous chapter in that they both involve the transfer of subatomic particles between reactants. For acid-base reactions, these subatomic particles are typically protons. Oxidation-reduction reactions, by contrast, involve the transfer of electrons.

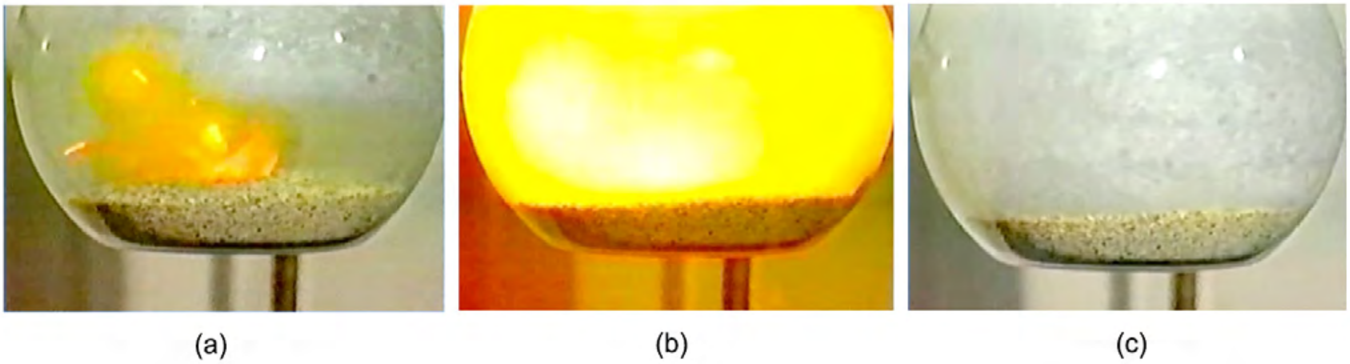
11.1 Losing and Gaining Electrons

Oxidation is the process whereby a reactant loses one or more electrons. **Reduction** is the opposite process, whereby a reactant gains one or more electrons. Oxidation and reduction are complementary processes that occur at the same time. They always occur together; you cannot have one without the other. The electrons lost by one chemical in an oxidation reaction don't simply disappear; they are gained by another chemical in a reduction reaction.

An oxidation-reduction reaction occurs when sodium and chlorine react to form sodium chloride, as shown in **Figure 11.1**. The equation for this reaction is

$$2Na(s) + Cl_2(g) \rightarrow 2NaCl(s) + heat$$

READING CHECK
Is it possible for oxidation to occur without reduction?



Λ Figure 11.1

(a) Chlorine gas, Cl_2, is introduced to a small lump of sodium, Na, resting on sand within a reaction flask. (b) The two chemicals react explosively. (c) The end product is chemically stable sodium chloride, NaCl, which can be seen coating the inner surface of the flask. Through this exothermic reaction, sodium metal is *oxidized* by the chlorine gas and the chlorine gas is *reduced* by the sodium metal.

To see how electrons are transferred in this reaction, we can look at each reactant individually. Each electrically neutral sodium atom changes to a positively charged ion. At the same time, we can say that each atom loses an electron and is therefore oxidized:

$$2Na(s) \rightarrow 2Na^{+} + 2e^{-} \quad \text{Oxidation}$$

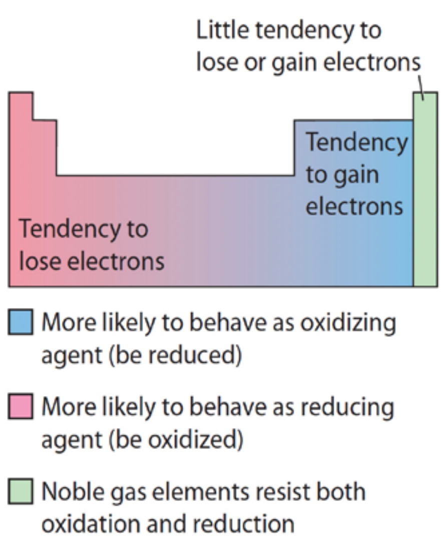
Each electrically neutral chlorine molecule changes to two negatively charged ions. Each of these atoms gains an electron and is therefore reduced:

$$Cl_2(g) + 2e \rightarrow 2Cl^{-} \quad \text{Reduction}$$

The net result is that the two electrons lost by the sodium atoms are transferred to the chlorine atoms. Therefore, each of the two equations shown actually represents one-half of an entire process, which is why they are each a **half-reaction**. In other words, an electron won't be lost from a sodium atom without the presence of a chlorine atom available to pick up that electron. Both half-reactions are required to represent the *whole* oxidation-reduction process. Half-reactions are useful for showing which reactant loses electrons and which reactant gains them, which is why half-reactions are used throughout this chapter.

Because the sodium causes reduction of the chlorine, the sodium is acting as a *reducing agent*. A reducing agent is any reactant that causes another reactant to be reduced. Note that sodium is oxidized when it behaves as a reducing agent—it loses electrons. Conversely, the chlorine causes oxidation of the sodium and so is acting as an *oxidizing agent*. Because it gains electrons in the process, an oxidizing agent is reduced. Just remember that loss of electrons is oxidation and gain of electrons is reduction. Here is a helpful mnemonic: OIL RIG—**o**xidation **i**s **l**oss and **r**eduction **i**s **g**ain.

Different elements have different oxidation and reduction tendencies. For example, metals lose electrons readily, while most nonmetals tend to gain electrons, as **Figure 11.2** illustrates.



Λ Figure 11.2

The ability of an atom to gain or lose electrons is indicated by its position in the periodic table. Those at the upper right (nonmetals) tend to gain electrons, and those at the lower left (metals) tend to lose them.

CONCEPT **CHECK**

True or false:

1. Reducing agents are oxidized in oxidation-reduction reactions.
2. Oxidizing agents are reduced in oxidation-reduction reactions.

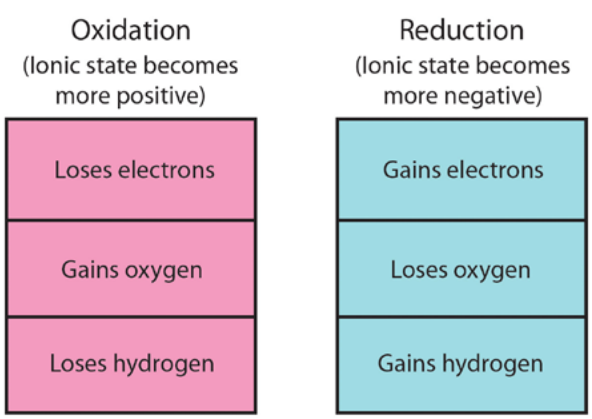
CHECK YOUR ANSWER Both statements are true

Whether a reaction is classified as an oxidation-reduction reaction is not always immediately apparent. The chemical equation, however, can provide some important clues. First, look for changes in the ionic states of elements. Sodium metal, for example, consists of neutral sodium atoms. In the formation of sodium chloride, these atoms transform into positively charged sodium ions; this occurs as sodium atoms lose electrons (oxidation). A second way to identify a reaction as an oxidation-reduction reaction is to determine whether an element is gaining or losing oxygen atoms. As the element gains the oxygen atom, it is losing electrons to that oxygen, because of the oxygen's high electronegativity. The gain of oxygen, therefore, is oxidation (loss of electrons), while the loss of oxygen is reduction (gain of electrons). For example, hydrogen, H_2, reacts with oxygen, O_2, to form water, H_2O, as follows:

$$\text{H-H} + \text{H-H} + \text{O=O} \rightarrow \text{H-O-H} + \text{H-O-H}$$

Note that the element hydrogen becomes attached to an oxygen atom through this reaction. The hydrogen, therefore, is oxidized losing an electron to the oxygen with which it partnered.

A third way to identify a reaction as an oxidation-reduction reaction is to see whether an element is gaining or losing hydrogen atoms. The gain of hydrogen is reduction, while the loss of hydrogen is oxidation. For the formation of water shown previously, we see that the element oxygen is gaining hydrogen atoms, which means that the oxygen is being reduced—that is, the oxygen is gaining electrons from the hydrogen, which is why the oxygen atom within water is slightly negative, as discussed in Section 6.8. The three ways of identifying a reaction as an oxidation-reduction type of reaction are summarized in **Figure 11.3.**



< Figure 11.3

Oxidation results in a greater positive charge, which can be achieved by losing electrons, gaining oxygen atoms, or losing hydrogen atoms. Reduction results in a greater negative charge, which can be achieved by gaining electrons, losing oxygen atoms, or gaining hydrogen atoms

CONCEPT **CHECK**

In the following equation, is carbon oxidized or reduced?

$$CH_4 + 2\,O_2 \rightarrow CO_2 + 2\,H_2O$$

CHECK YOUR ANSWER As the carbon of methane, CH_4, forms carbon dioxide, CO_2, it is losing hydrogen and gaining oxygen, which tells us that the carbon is being oxidized.