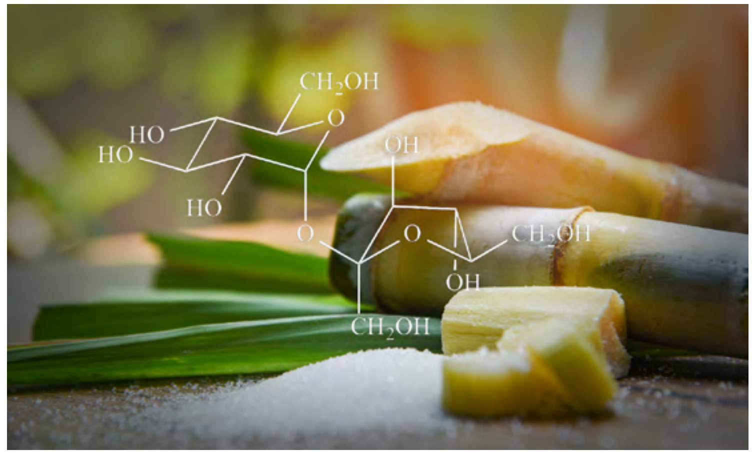
Chapter 2

# The Chemistry of Life






## 2.5 Types of Chemical Reactions

Two main classes of chemical reactions include: *acid–base* reactions and *oxidation–reduction* reactions. Acid–base reactions involve the transfer of hydrogen ions, $H^+$, from one reactant to another. These sorts of reactions occur within your stomach helping you digest your food. They also play a key role in global climate. Most consumer goods can trace their origins to acid–base chemical reactions.

Oxidation–reduction reactions involve the transfer of one or more *electrons* from one reactant to another. The burning of wood is an oxidation–reduction reaction, as are the reactions your body uses to transform the food you eat into biochemical energy. Oxidation–reduction reactions are responsible for the rusting of a car and the release of electrical energy from a battery.

What are the most important acid-base and oxidation-reduction concepts that a biology student might need to know? From the world of acids and bases, it's important to understand the concept of pH. From the world of oxidations and reductions, it's important to understand how oxygen atoms have such a strong affinity for electrons. Let's take a closer look at these main ideas.

### Acids and Bases

We can define an **acid** as any chemical that donates a hydrogen ion, $H^+$, and a **base** as any chemical that accepts a hydrogen ion. Because a hydrogen atom consists of one electron surrounding a one-proton nucleus, a hydrogen ion formed from the loss of an electron is nothing more than a lone proton. Thus, it is also sometimes said that an acid is a chemical that donates a proton and a base is a chemical that accepts a proton. Consider what happens when hydrogen chloride is mixed into water:

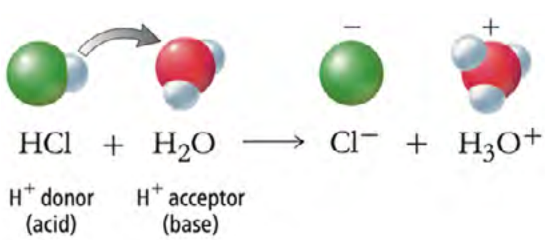
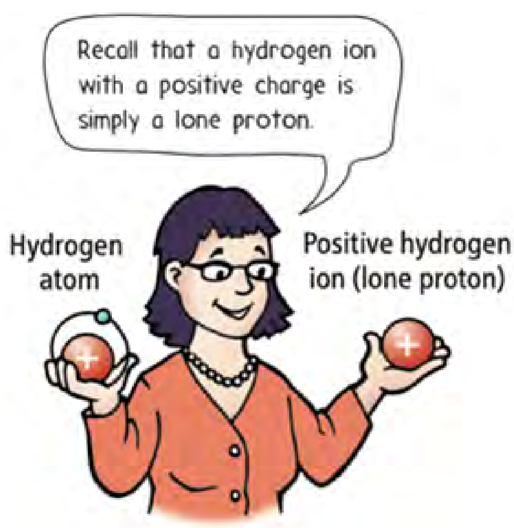



**FIGURE 2.24**

Acid-base reaction.



Hydrogen chloride donates a hydrogen ion to the water molecule, resulting in a third hydrogen bonded to the oxygen. In this case, hydrogen chloride behaves as an acid (proton donor) and water behaves as a base (proton acceptor). The products of this reaction are a chloride ion, $Cl^-$, and a **hydronium ion**, $H_3O^+$, which is a water molecule with an extra proton.

When added to water, ammonia behaves as a base as it accepts a hydrogen ion from water, which, in this case, behaves as an acid:

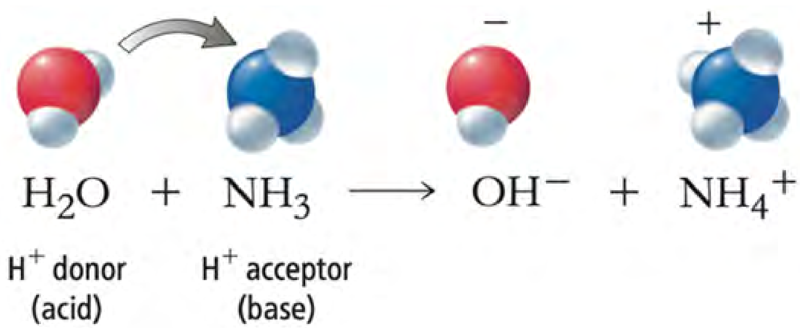



**FIGURE 2.25**
Ammonia added to water.

This reaction results in the formation of an ammonium ion, $NH_4^+$, and a **hydroxide ion**, $OH^-$, which, is a water molecule without the nucleus of one of the hydrogen atoms.

How might these concepts apply to biology? Consider what happens when the drug pseudoephedrine is exposed to the acid hydrogen chloride. In the presence of hydrogen chloride, the pseudoephedrine behaves as a base by accepting $H^+$ from a hydrogen chloride. The negative $Cl^-$ then joins the pseudoephedrine-$H^+$ ion to form the salt pseudoephedrine hydrochloride, which is a decongestant, shown in Figure 2.26.

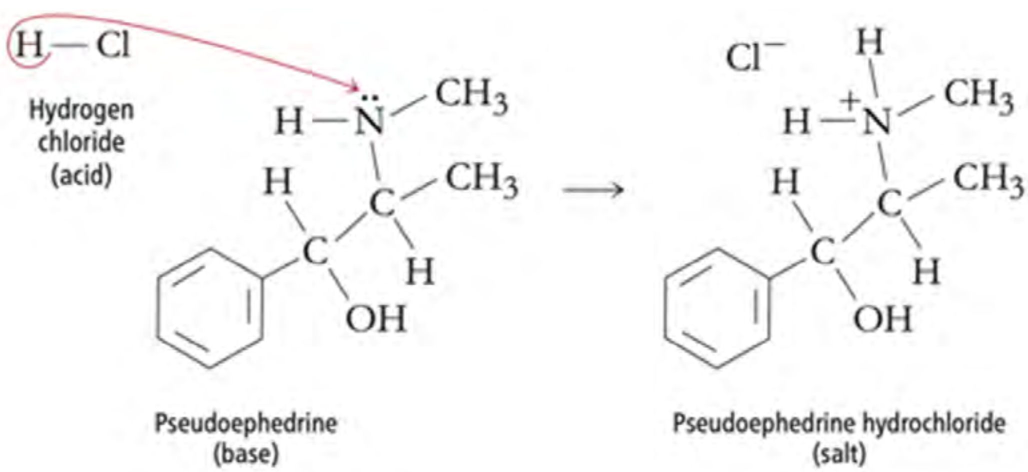



**FIGURE 2.26**

Hydrogen chloride and pseudoephedrine react to form the salt pseudoephedrine hydrochloride, which, because of its solubility in water, is readily absorbed into the body. Many pharmaceuticals, especially those taken orally, are similarly provided in a salt form so that they are easily absorbed.

Notice that the pseudoephedrine hydrochloride salt has both negative and positive charges, much like table salt, NaCl. The pseudoephedrine molecule itself is an oil and doesn't mix very well in water. Its salt, by contrast, has these positive and negative charges, which means it can be dissolved in water, much like table salt. This means that the drug can be taken orally. It will dissolve in your stomach fluids and then be absorbed into your body (as a salt) through your intestines.

**pH** is a measure of the concentration of hydronium ions, $H3O^+$, within a solution. In this sense, it's a measure of the solution's "acidity". Interestingly, the concentration of hydronium ions, $H3O^+$, is intimately tied into the concentration of hydroxide ions, $OH^-$. As one goes up, the other necessarily goes down, much like two ends of a see-saw, as shown in Figure 2.27. At a pH of 7 the concentration of the two are equal and the solution is said to be *neutral*. As the hydronium ion, $H3O^+$, concentration increases, the pH goes down and the solution is *acidic*. As the hydronium ion, $H3O^+$, concentration decreases, the pH goes up and the solution is *basic* (sometimes called *alkaline*).

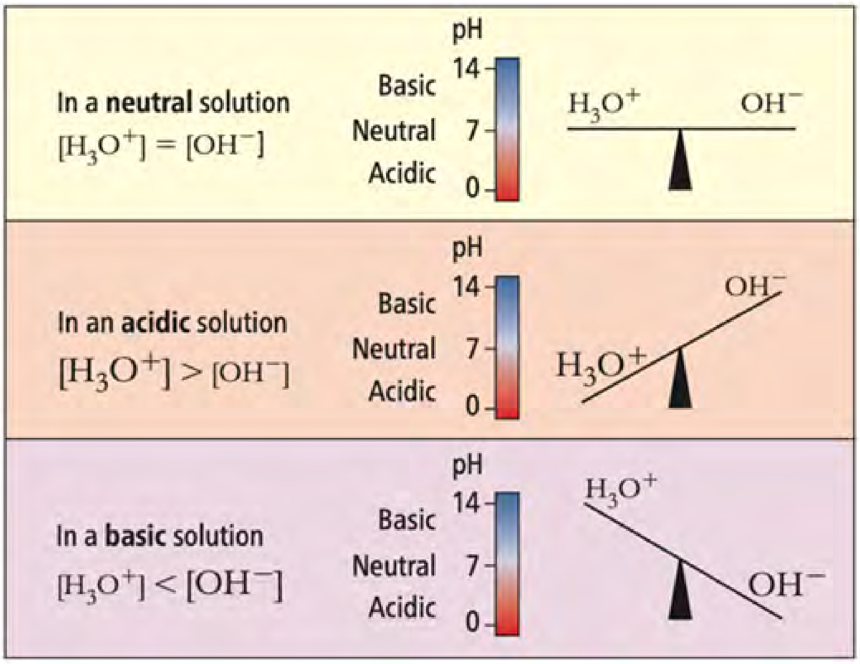



**FIGURE 2.27**

The relative concentrations of hydronium and hydroxide ions determine whether a solution is acidic, basic, or neutral.

The pH within your body fluids is critical to good health. For example, your body works hard to maintain a very stable blood pH of about 7.40. Anything significantly different from that would be lethal. How so? The answer is because of acid-base reactions. Notice the role of the nitrogen atom back in Figure 2.20.

When exposed to an acid, it accepts the hydrogen ion to become ionized. As we'll be exploring, the biomolecules within your body abound with nitrogen atoms and other atoms that are susceptible to becoming ionized. In some cases, it's good that they are ionized. In other cases, it's important that they remain not ionized. A reason for this is because it impacts the shape of the overall larger biomolecule within which that atom is found. If there's one major take-away from the study of biochemistry, it would be that the shape of a biomolecule is everything. This includes biomolecules that act as enzymes, biomolecules that act as our genetic carriers, biomolecules that transport oxygen within our blood, and many other examples.

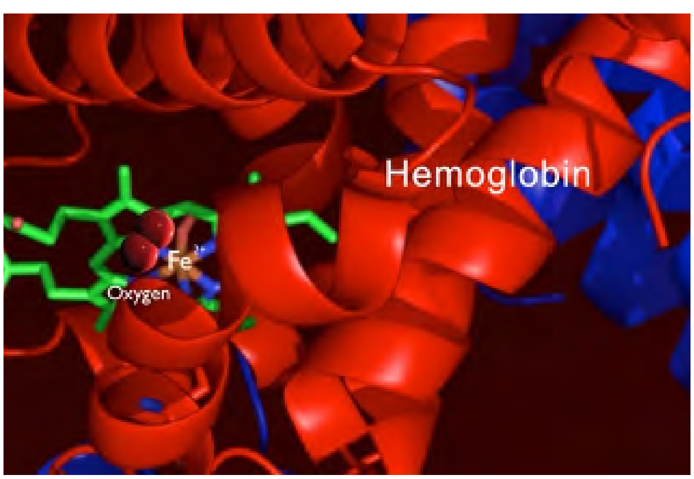



**Figure 2.28**

The hemoglobin biomolecule is able to bind the oxygen molecule only within a very narrow pH range. Where there is much muscle activity, the pH tends to drop. This causes hemoglobin molecules within that vicinity to release their oxygen molecules, which helps to support the continued muscle activity. The role of the pH of body fluids is very important.

Of course, there are many other examples in biology where understanding the concept of pH is key. Perhaps most significant, as we discuss in Chapter 17, is how increasing levels of atmospheric carbon dioxide are leading to a decrease in the pH of the oceans. This, in turn, results in the destruction of calcium carbonate-based shells of marine organisms, such as phytoplankton, which are part of the foundation of marine food chains.

### READING CHECK

**How does adding ammonia, $NH_3$, to water make a basic solution?**

### CHECK YOUR ANSWER

Ammonia increases the hydroxide ion concentration by reacting with water:

$NH_3 + H_2O \rightarrow NH_4^+ + OH^-$

This reaction raises the hydroxide ion concentration, which has the effect of lowering the hydronium ion concentration. With the hydroxide ion concentration now higher than the hydronium ion concentration, the solution is basic.

## Oxidations and Reductions

**Oxidation** is the process whereby a chemical loses one or more electrons. **Reduction** is the opposite process, whereby it 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. How so? The electrons lost by one chemical in an oxidation reaction don't simply disappear; they are gained by another chemical in a reduction reaction.

Different atoms have different tendencies of whether to gain or lose electrons. This is neatly spelled out by the periodic table, as shown in Figure 2.29. Briefly, atoms of elements toward the upper right side of the table tend to have the best ability to gain electrons. Conversely, atoms of elements toward the lower left side tend to have the best ability to lose electrons. Thus, you can gauge the tendency of any atom to gain or lose electrons simply by finding its relative position within the periodic table.

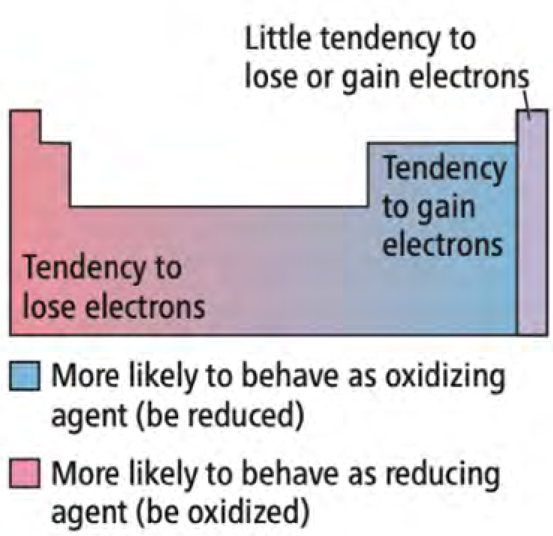



**Figure 2.29**

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

An atom most notorious for tending to grab electrons is the oxygen atom. You'll note that oxygen is positioned in the far upper right side of the periodic table. In fact, this is where the term "oxidation" comes from. Most any atom that gets close to an oxygen atom will get robbed of its electrons by that oxygen atom. We say that that atom has become *oxidized* (it has lost electrons). The oxygen atom, in turn, becomes "reduced", which means it has gained a negative charge. Wait a second. Gaining is a reduction? Think of it this way: What happens to your bank account when you add a *negative* amount of money? Answer: your bank account is "reduced".

The burning of a campfire is an example of an oxidation-reduction reaction, as is cellular respiration, a biological process that provides us bodily energy. In both cases oxygen will be found grabbing electrons from some source. For the campfire, it's grabbing electrons from the burning wood. For cellular respiration, it's grabbing electrons from food molecules. These particular chemical reactions happen to be exothermic. The release of energy results as the electrons jump over to the oxygen atoms where they'll find themselves a bit closer to an atomic nucleus. This explains why the campfire is warm. It also explains how we get energy from the food we eat.

**Figure 2.30**

The oxygen, $O_2$, found in our atmosphere is vital for the burning of a campfire and the continued production of bodily energy within us.

**READING CHECK**

**Oxygen, $O_2$, is a good oxidizer, but so is chlorine, $Cl_2$. What does this indicate about their relative positions in the periodic table?**

**CHECK YOUR ANSWER**

Chlorine and oxygen must lie in the same area of the periodic table. Both are strong oxidizers, which means they're good at pulling electrons away from other atoms.