21.3 Acids, Bases, and pH

Acids and bases are among the most familiar of all chemical compounds. Some of the acids you might have encountered include acetic acid (found in vinegar), citric acid (found in orange juice), and malic acid (found in apples). You might also be familiar with some bases, including ammonia in cleaning solutions and magnesium hydroxide found in some antacids. The pH scale is used to describe whether a substance is an acid or a base. This section is about the properties of acids and bases, and the pH scale.

VOCABULARY

acid - a substance that produces hydronium ions (H_3O^+) when dissolved in water.

What are acids?

Properties of acids

An **acid** is a compound that dissolves in water to make a particular kind of solution. Some properties of acids are listed below and some common acids are shown in Figure 21.21. Notes: You should NEVER taste a laboratory chemical. Be sure to wear goggles to protect your eyes when you use chemicals.

- Acids create the sour taste in foods such as lemons.
- Acids react with metals to produce hydrogen gas (H_2).
- Acids change the color of blue litmus paper to red.
- Acids can be very corrosive, destroying metals and burning skin through chemical action.
- Acids can react with carbonate minerals to produce CO_2 gas.

Acids make hydronium ions

Chemically, an acid is any substance that produces hydronium ions (H_3O^+) when dissolved in water. When hydrochloric acid (HCl) dissolves in water, it ionizes, splitting up into hydrogen (H^+) and chlorine (Cl^-) ions. Hydrogen ions (H^+) are attracted to the negative oxygen end of a water molecule, combining to form hydronium ions.

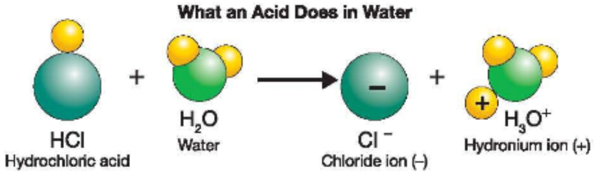


Figure 21.21: *Some weak acids you might have around your home.*

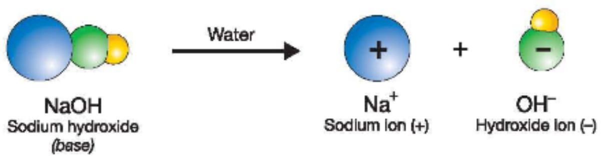
Bases

Properties of bases A **base** is a compound that dissolves in water to make a different kind of solution, opposite in some ways to an acid. Some properties of bases are listed below and some common bases are shown in Figure 21.22.

- Bases create a bitter taste.
- Bases have a slippery feel, like soap.
- Bases change the color of red litmus paper to blue.
- Bases can be very corrosive, destroying metals and burning skin through chemical action.

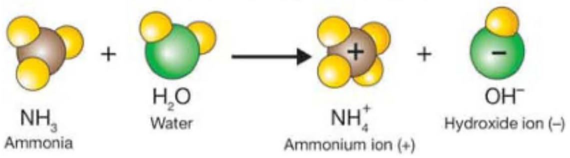
Bases produce hydroxide ions A base is any substance that dissolves in water and produces hydroxide ions (OH^-). A good example of a base is sodium hydroxide (NaOH), found in many commercial drain cleaners. This compound dissociates in water to form sodium (Na^+) and hydroxide (OH^-) ions.

What a Base Does in Water



Ammonia is a base Ammonia (NH_3), found in some cleaning solutions, is a base because it increases the pH of water. It also is a base because it accepts a proton (H^+). This is another definition for a base—a proton acceptor. Notice that a hydroxide ion, from water, is formed in this reaction (below).

What Ammonia (Base) Does in Water



VOCABULARY

base - a substance that produces hydroxide ions (OH^-) when dissolved in water; a base is also known as a proton (H^+) acceptor.

Some Common Bases

Figure 21.22: *Common bases include ammonia, baking soda, soap, and drain cleaner.*

Strength of acids and bases

The strength of acids The strength of an acid depends on the concentration of the hydronium ions (H_3O^+) the acid produces when dissolved in water. Hydrochloric acid (HCl) is a strong acid because HCl completely dissolves into H^+ and Cl^- ions in water. This means that every molecule of HCl that dissolves produces one hydronium ion.

Acetic acid is a weak acid Acetic acid ($HC_2H_3O_2$), in vinegar, is a weak acid. When dissolved in water, only a small percentage of acetic acid molecules ionize (break apart) and become H^+ and $C_2H_3O_2^-$ ions. This means that only a small number of hydronium ions are produced compared to the number of acetic acid molecules dissolved (Figure 21.23).

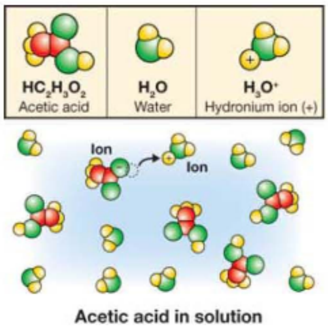


Figure 21.23: *Acetic acid dissolves in water, but only a few molecules ionize (break apart) to create hydronium ions.*

The strength of bases The strength of a base depends on the relative amount of hydroxide ions (OH^-) produced when the base is mixed with water. Sodium hydroxide (NaOH) is considered a strong base because it dissociates completely in water to form Na^+ and OH^- ions. Every molecule of NaOH that dissolves creates one OH^- ion (Figure 21.24). Ammonia (NH_3), on the other hand, is a weak base because only a few molecules react with water to form NH_4^+ and OH^- ions.

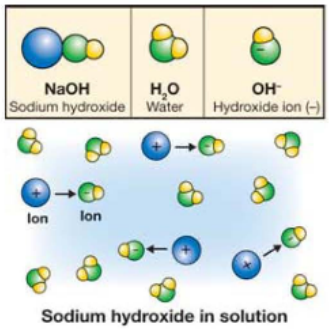
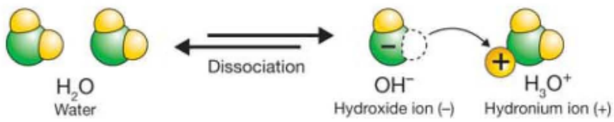


Figure 21.24: *Sodium hydroxide (NaOH) is a strong base because every NaOH molecule contributes one hydroxide (OH^-) ion.*

Water can be a weak acid or a weak base One of the most important properties of water is its ability to act as both an acid and a base. In the presence of an acid, water acts as a base. In the presence of a base, water acts as an acid. In pure water, the H_2O molecule ionizes to produce both hydronium and hydroxide ions. This reaction is called the *dissociation of water.*

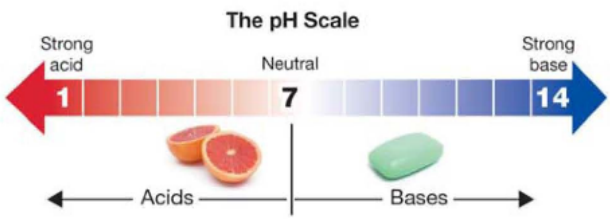


What does the double arrow mean? The double arrow in the illustration means that the dissociation of water reaction can occur in *both* directions. This means that water molecules can ionize and ions can form water molecules. However, water ionizes so slightly that most water molecules exist whole, not as ions.

The pH scale and pH

What is pH? The **pH scale** is a range of values from 0 to 14 that describe a solution, with 0 being very acidic, 7 being neutral, and 14 being basic or very low acidity. The term **pH** is an abbreviation for "the power of hydrogen" and is a measure of the concentration of hydronium ions (H_3O^+) in a solution.

The numbers on the scale A pH of 7 is *neutral*, neither acidic nor basic. Distilled water has a pH of 7. Acidic solutions have a pH less than 7. A concentrated solution of hydrochloric acid, a strong acid, has a pH of 1. Seltzer water is a weak acid at a pH of 4. Many foods we eat and many ingredients we use for cooking are acidic. Basic or alkaline solutions have a pH greater than 7. A concentrated solution of a *strong base* has the *highest* pH. For example, a strong sodium hydroxide solution can have a pH close to 14. Weak bases, such as baking soda, and weak acids have pH values that are close to 7. Many household cleaning products are basic (Figure 21.25).



pH indicators Certain chemicals turn different colors when pH changes. These chemicals are called pH indicators and they are used to determine pH. The juice of boiled red cabbage is a pH indicator that is easy to prepare. Red cabbage juice is deep purple and turns various shades ranging from purple to yellow at different values of pH. Litmus paper is another pH indicator that changes color. Red and blue litmus paper strips are pH indicators that test for acids or bases.

VOCABULARY

pH scale - the pH scale goes from 0 to 14 with 1 being very acidic and 14 being very basic.

pH - a measure of the concentration of hydronium ions in a solution.

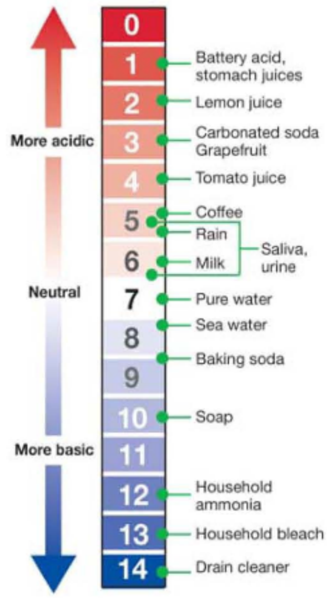


Figure 21.25: *The pH scale showing common substances.*

pH in the environment

The best pH for plants The pH of soil directly affects nutrient availability for plants. Most plants, such as vegetables, grasses, and most shrubs, prefer a slightly acidic soil with a pH between 6.5 and 7.0. Azaleas, blueberries, and conifers grow best in more acidic soils with a pH of 4.5 to 5.5 (Figure 21.26).

Effects of pH too high or low In highly acid soils (pH below 4.5), too much aluminum, manganese, and other elements might leach out of soil minerals and reach concentrations that are toxic to plants. Also, at these low pH values, calcium, phosphorus, and magnesium are less available to plant roots. At more basic pH values (above 6.5), iron and manganese become less available.

pH and fish

The pH of water directly affects aquatic life. Most freshwater lakes, streams, and ponds have a natural pH in the range of 6 to 8. Most freshwater fish can tolerate a pH between 5 and 9, although some negative effects appear below a pH of 6. Trout (such as the California Golden shown above) are among the most pH-tolerant fish and can live in water with a pH from 4 to 9.5.

pH and amphibians

Frogs and other amphibians are even more sensitive to pH than fish. This California tree frog and other frogs prefer a pH close to neutral and don't survive below a pH of 5. Frog eggs develop and hatch in water with no protection from environmental factors. Research shows that pH values below 6 have a negative effect on frog hatching rates.

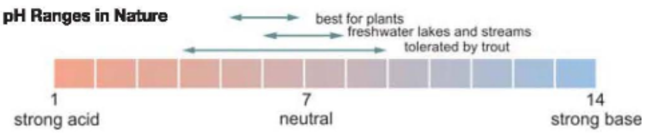


Figure 21.26: *Blueberries grow best in soils with a pH between 4.5 and 5.5.*

CHALLENGE

Acid Rain

Many environmental scientists are concerned about acid rain. Do research to answer the following questions.

1. What kinds of acids are in acid rain?
2. What is the typical pH of acid rain?
3. What is the cause of acid rain?
4. What are some environmental impacts of acid rain?
5. What can be done to reduce acid rain?

Acids and bases in your body

Acids and bases play a role in digestion Many reactions, such as the ones that occur in your body, work best at specific pH values. For example, acids and bases are very important in the reactions involved in digesting food. The stomach secretes hydrochloric acid (HCl), a strong acid (pH 1.4). The level of acidity in your stomach is necessary to break down the protein molecules in food so they can be absorbed. A mucous lining in the stomach protects it from the acid it produces (Figure 21.27).

Ulcers and heartburn Deep-fried foods, stress, or poor diet can cause the stomach to produce too much acid, or allow stomach acid to escape from the stomach. An ulcer might occur when the mucous lining of the stomach is damaged. Stomach acid can then attack the more sensitive tissues of the stomach itself. Infections by the bacteria *Helicobacter pylori* can also damage the mucous lining of the stomach, leading to ulcers. The uncomfortable condition called heartburn is caused by excessive stomach acid backing up into the esophagus. The *esophagus* is the tube that carries food from your mouth to your stomach. The esophagus lacks the mucous lining of the stomach and is sensitive to acid.

pH and your blood Under normal conditions, the pH of your blood is within the range of 7.3–7.5, close to neutral but slightly basic. Blood is a watery solution that contains many solutes, including the dissolved gases carbon dioxide (CO_2) and oxygen (O_2). Dissolved CO_2 in blood produces a weak acid. The higher the concentration of dissolved CO_2, the more acidic your blood becomes.

Blood pH is controlled through breathing Your body regulates the dissolved CO_2 level by breathing. For example, if you hold your breath, more carbon dioxide enters your blood and the pH falls as your blood becomes more acidic. If you hyperventilate (breathe more quickly than usual), less carbon dioxide enters your blood and the opposite happens—blood pH starts to rise, becoming more basic. Your breathing rate regulates blood pH through these chemical reactions (Figure 21.28).

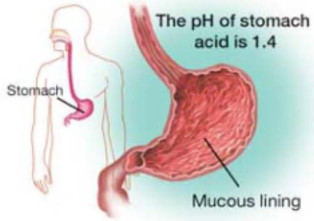
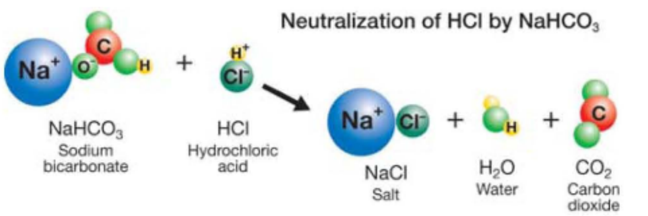


Figure 21.27: *The stomach secretes a strong acid (HCl) to aid with food digestion. A mucous lining protects the stomach tissue from the acid.*

Figure 21.28: *Under normal conditions, your blood pH ranges between 7.3 and 7.5. Holding your breath causes blood pH to drop. High blood pH can be caused by hyperventilating.*

Neutralization reactions

Mixing acid and base solutions When acid and base solutions are mixed in the right proportions, their characteristic properties disappear. The positive ions from the base combine with the negative ions from the acid and a new ionic compound forms. Water is also a product of this type of reaction, called **neutralization**. The graphic below shows what happens when the base, sodium bicarbonate (baking soda), is mixed with hydrochloric acid.



Neutralization in your body Neutralization goes on in your body every day. As food and digestive fluids leave the stomach where the pH is very low, the pancreas and liver produce bicarbonate (a base) to neutralize the stomach acid. Antacids, many of which are composed of sodium bicarbonate, have the same effect. The graphic above also illustrates what happens in your digestive system when you take an antacid. The antacid mixes with excess stomach acid to produce salt, water, and carbon dioxide.

Adjusting soil pH Neutralization reactions are important in gardening and farming. For example, having soil that is too acidic (pH less than 5.5) is a common problem in the U.S. Grass does not grow well in acidic soil. For this reason, many people add lime to their yard. A common form of lime is ground-up calcium carbonate ($CaCO_3$) made from natural crushed limestone. Lime is a weak base and undergoes a neutralization reaction with acids in the soil to raise the pH.

VOCABULARY

neutralization - the reaction of an acid and a base to produce a salt and water.

CHALLENGE

Test Your Soil

Most garden centers carry soil test kits. These kits have pH test papers inside and are designed to help gardeners measure soil pH.

Get a soil test kit and test samples of soil from around your home or school. Repeat the test, taking new soil samples after a rainfall to see if the pH changes.

Answer the following questions.

1. What kinds of plants thrive in the pH of the soil samples you tested?
2. What kinds of treatments are available at your local garden center for changing soil pH?

Section 21.3 Review

1. What is a hydronium ion?
2. In this section, you learned about the properties of acids and bases. Make a table that organizes this information.
3. Both strong acids and strong bases are corrosive. Come up with a hypothesis for why this is so.
4. Answer the following questions about water.
   a. Why is water considered to be a weak acid or a weak base?
   b. What is the pH of pure water?
   c. What does the double arrow mean in this reaction?

$$2\,H_2O \rightleftarrows OH^- + H_3O^+$$

5. Nadine tests an unknown solution and discovers that it turns blue litmus paper red, and it has a pH of 3.0. Which of the following could be the unknown solution? Explain your choice.
   a. a solution of sodium hydroxide
   b. vinegar
   c. ammonia
   d. soap
   e. pure water
6. Is the solution in question 5 acidic or basic?
7. Is tomato juice acidic or basic? Justify your answer.
8. Give two examples of a pH indicator.
9. Plants and animals live in environments that have conditions for which they are adapted. Is pH an important environmental factor for plants and animals? Why or why not?
10. Describe in your own words how the amount of carbon dioxide dissolved in your blood affects your blood pH.
11. What are the main reactants and products in a neutralization reaction?
12. Neutralization is an important part of digestion. Why?

BIOGRAPHY

Current Solutions

Svante August Arrhenius of Sweden was noted for his mathematical skills at an early age. In 1884, he submitted his dissertation, which included the idea that ions in solution conduct electrical current (rather than pure water or salt). Although his professors rejected this idea and barely passed him, other key scientists were supportive. In fact, Arrhenius's work was so important that he was awarded the Nobel Prize in 1903!

Chemicals that dissociate into ions in water are called *electrolytes*. Solutions with electrolytes can conduct current. All acids and bases and some salts are electrolytes.

Find out more about how Arrhenius contributed to our understanding of acids, bases, and electrolytes.