

Chapter 9

Acids, Bases, and Solutions

Water is essential to all living things on Earth. Consider your body for example - it is about 65% water by weight. For every hour of vigorous exercise, you may lose as much as a half-gallon of your body's water supply through sweating and exhaling! You also lose small amounts of salts when you sweat. If the lost water and dissolved salts are not replaced, eventually your body will stop functioning. You can replace lost fluid by drinking water. To quickly replace salts, many athletes consume sports drinks. Why is water such an important substance for living creatures?

Sweat and sports drinks are both examples of solutions – they are mostly water with dissolved substances. In this chapter, you will learn about solutions. You will also learn about some special solutions called acids and bases. Among other things, acids create the bitter taste in food and can dissolve some rocks. Bases are slippery, like soap. Both acids and bases play a key role in maintaining your body's internal chemical balance.



Key Questions

1. *What is the difference between 10, 14, and 24-karat gold?*
2. *Why does salt dissolve in water but substances like chalk and sand do not?*
3. *What are acids and bases?*



9.1 Water and solutions

Water is one substance that makes our planet unique. All life on Earth depends on this useful combination of hydrogen and oxygen atoms. In our solar system, only Earth has liquid water in such great abundance. Because we seem to have so much water, it is easy to take it for granted. Think about what you did yesterday. How often did you use water and how much? Now think about how yesterday would have been different if you didn't have fresh water!

Examples of solutions

A solution is homogeneous at the molecular level

A **solution** is a mixture of two or more substances that is uniform at the molecular level. Uniform means there are no clumps bigger than a molecule and the solution has the same ingredients everywhere. Grape soda is a solution you have probably consumed. All the particles in grape soda, from the flavor molecules to the color molecules, are evenly dispersed throughout the bottle (Figure 9.1).

An alloy is a solution of two or more solids

Although we often think of solutions as mixtures of solids in liquids, solutions exist in every phase; solid, liquid, or gas. Solutions of two or more solids are called **alloys**. Steel is an alloy (solution) of iron and carbon. Fourteen-karat gold is an alloy of silver and gold. "Fourteen-karat" means that 14 out of every 24 atoms in the alloy are gold atoms and the rest are silver atoms.



Muddy water is not a solution. Particles of soil are small, but still contain thousands of atoms and molecules. A true solution contains only individual molecules which are not clumped together into larger particles.

VOCABULARY

solution - a mixture of two or more substances that is uniform at the molecular level

alloy - a solution of two or more solids.



Figure 9.1: Examples of solutions.



Solvents and solutes

Solvent and solute A solution contains at least two components: a **solvent**, and a **solute**. The solvent is the part of a mixture that is present in the greatest amount. For example, the solvent in grape soda is water. The remaining parts of a solution (other than the solvent) are called solutes. Sugar, coloring dyes, flavoring chemicals, and carbon dioxide gas are solutes in grape soda.

Dissolving When the solute particles are evenly distributed throughout the solvent, we say that the solute has **dissolved**. The picture shows a sugar and water solution being prepared. The solute (sugar) starts as a solid in the graduated cylinder on the left. Water is added and the mixture is carefully stirred until all the solid sugar has dissolved. Once the sugar has dissolved the solution is clear again.



The molecular explanation for dissolving On the molecular level, dissolving of a solid (like sugar) occurs when molecules of solvent interact with and separate molecules of solute (Figure 9.2). Most of the time, substances dissolve faster at higher temperatures. This is because higher temperature molecules have more energy and are more effective at knocking off molecules of solute. You may have noticed that sugar dissolves much faster in hot water than in cold water.

Why solutes are ground up into powder Dissolving can only occur where the solvent can touch the solute. Most things that are meant to be dissolved, like salt and sugar, are ground up to a powder to increase the surface area. Increased surface area speeds dissolving because more solute is exposed to the solvent.

VOCABULARY

solvent - the component of a solution that is present in the greatest amount

solute - any component of a solution other than the solvent

dissolve - to separate and disperse a solid into individual molecules or ions in the presence of a solvent.

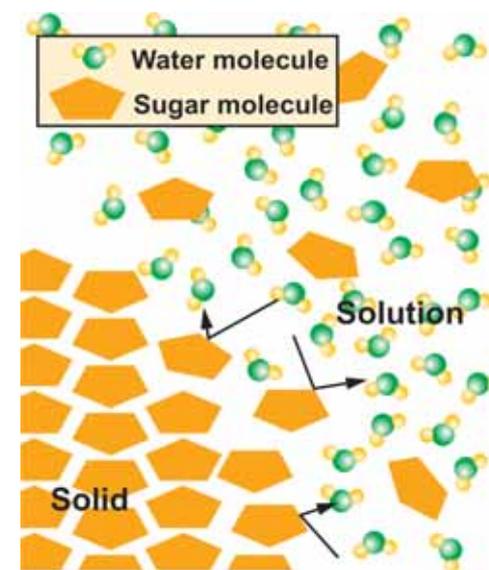


Figure 9.2: *The molecular explanation for a solid dissolving in a liquid. Molecules of solvent interact with and carry away molecules of solute.*

Solubility

What is solubility?

The term **solubility** means the amount of solute (if any) that can be dissolved in a volume of solvent. Solubility is often listed in grams per 100 milliliters of solvent. Solubility is always given at a specific temperature since temperature strongly affects solubility. For example, Table 9.1 tells you that 200 grams of sugar can be dissolved in 100 milliliters of water at 25°C.

Insoluble substances do not dissolve

Notice in Table 9.1 that chalk and talc do not have solubility values. These substances are **insoluble** in water because they do not dissolve in water. You can mix chalk dust and water and stir them all you want but you will still just have a mixture of chalk dust and water. The water will not separate the chalk dust into individual molecules because chalk does not dissolve in water.

Saturation

Suppose you add 300 grams of sugar to 100 milliliters of water at 25°C? What happens? According to Table 9.1, 200 grams will dissolve in the water. *The rest will remain solid.* That means you will be left with 100 grams of solid sugar at the bottom of your solution. Any solute added in excess of the solubility does not dissolve. A solution is **saturated** if it contains as much solute as the solvent can dissolve. Dissolving 200 grams of sugar in 100 milliliters of water creates a saturated solution because no more sugar will dissolve.



How much salt will dissolve in water?

Seawater is a solution of water, salt and other minerals. How much salt can dissolve in 200 milliliters of water at 25°C?

- Looking for: Grams of solute (salt)
- Given: Volume (200 ml) and temperature of solvent
- Relationships: 37.7 grams of salt dissolves in 100 milliliters of water at 25°C (Table 9.1)
- Solution: If 37.7 grams dissolves in 100 milliliters then twice as much, or 75.4 grams will dissolve in 200 milliliters.

VOCABULARY

solubility - the amount of solute that can be dissolved in a specific volume of solvent under certain conditions. For example, 200 grams of sugar can be dissolved in 100 milliliters of water at 25°C.

insoluble - a substance is insoluble in a particular solvent if it does not dissolve in that solvent.

saturated - a solution is saturated if it contains as much solute as the solvent can dissolve.

Table 9.1: Solubility of some materials in water

Common name	Solubility at 25 °C (grams per 100 mL H ₂ O)
table salt (NaCl)	37.7
sugar (C ₁₂ H ₂₂ O ₁₁)	200
baking soda (NaHCO ₃)	approx. 10
chalk (CaCO ₃)	insoluble
talc (Mg silicates)	insoluble



Concentration

How do you express solution concentration?

In chemistry, it is important to know the exact **concentration** of a solution—that is the exact amount of solute dissolved in a given amount of solvent. The mass-percent is an accurate way to describe concentration. The concentration of a solvent in mass-percent is the mass of the solute divided by the total mass of the solution.

$$\text{Concentration} = \frac{\text{mass of solute}}{\text{total mass of solution}} \times 100\%$$

Mass percent example

Suppose you dissolve 10.0 grams of sugar in 90.0 grams of water. What is the mass percent of sugar in the solution (Figure 9.3)?

$$\text{Concentration} = \frac{10\text{g sugar}}{(10\text{g} + 90\text{g}) \text{ solution}} \times (100\%) = 10\%$$

Describing very low concentrations

Parts per million (ppm), parts per billion (ppb), and parts per trillion (ppt) are commonly used to describe very small concentrations of pollutants in the environment. These terms are measures of the ratio (by mass) of one material in a much larger amount of another material. For example, a pinch (gram) of salt in 10 tons of potato chips is about 1 g salt per billion g chips, or a concentration of 1 ppb.



Concentration

How many grams of salt do you need to make 500 grams of a solution with a concentration of 5% salt?

- Looking for: mass of salt (solute)
- Given: concentration (5%) and total mass of solution (500 g)
- Relationships: concentration = mass of solute ÷ total mass of solution
- Solution: $0.05 = \text{mass of salt} \div 500\text{g}$
 $\text{mass of salt} = 0.05 \times 500\text{g} = 25 \text{ grams}$

VOCABULARY

concentration - the ratio of solute to solvent in a solution. For example, a 10% sugar solution contains 10 g of sugar for every 90 g of water.

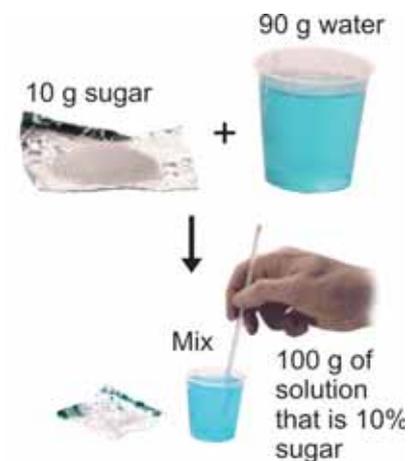


Figure 9.3: Preparing a sugar solution with a concentration of 10%.

CHALLENGE

Lead is toxic to humans and therefore there are limits on the allowable concentration of lead in drinking water. What is the maximum concentration of lead in drinking water allowed by the Environmental Protection Agency (EPA)?

Equilibrium and supersaturation

Dissolving and un-dissolving When a solute like sugar is mixed with a solvent like water, *two* processes are actually going on continuously.

- Molecules of solute dissolve and go into solution
- Molecules of solute come out of solution and become “un-dissolved”

When the concentration is lower than the solubility, the dissolving process puts molecules into solution faster than they come out. The concentration increases and the mass of un-dissolved solute decreases. However, dissolving and un-dissolving are still going on!

Equilibrium concentration The more molecules that are in solution (higher concentration) the faster molecules come out of solution. As the concentration increases, the un-dissolving process also gets faster until the dissolving and un-dissolving rates are exactly equal. When the rate of dissolving equals the rate of coming out of solution, we say **equilibrium** has been reached. At equilibrium, a solution is *saturated* because the concentration is as high as it can go.

Supersaturation According to the solubility table in Figure 9.4, at 80°C, 100 g of water reaches equilibrium with 360 grams of dissolved sugar. At lower temperatures, less sugar can dissolve. What happens if we cool the saturated solution? As the temperature goes down, sugar’s solubility also goes down and the solution becomes **supersaturated**. A supersaturated solution means there is more dissolved solute than the maximum solubility.

Growing crystals



Rock Candy

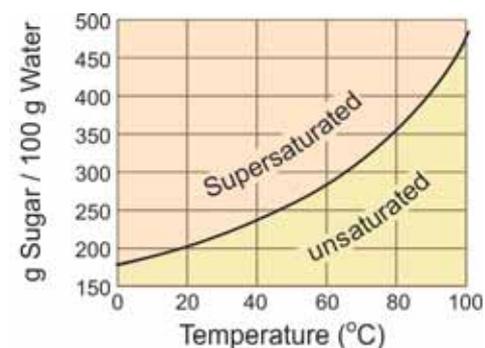
Solid sugar crystals form as the sugar comes out of the supersaturated solution.

A supersaturated solution is unstable. The excess solute comes out of solution and returns to its un-dissolved state. This is how the large sugar crystals of rock candy are made. Sugar is added to boiling water until the solution is saturated. As the solution cools, it becomes supersaturated.

VOCABULARY

equilibrium - occurs when a solution has the maximum concentration of dissolved solute; the dissolving rate equals the rate at which molecules come out of solution (un-dissolve).

supersaturated - a concentration greater than the maximum solubility.



Temp (°C)	g Sugar / 100 g H ₂ O	Temp (°C)	g Sugar / 100 g H ₂ O
0	177	50	259
10	189	60	284
20	204	70	318
30	219	80	360
40	238	90	410

Figure 9.4: The process for making rock candy uses a supersaturated solution of sugar in water.



The solubility of gases and liquids

Gas dissolves in water



Gases can also dissolve in liquids. When you drink carbonated soda, the fizz comes from dissolved carbon dioxide gas (CO_2). Table 9.2 lists the solubility of CO_2 as 1.74 grams per kilogram of water at room temperature and atmospheric pressure (1 atm).

Solubility of gas increases with pressure

The solubility of gases in liquids increases with pressure. Soda is fizzy because the carbon dioxide was dissolved in the liquid at high pressure. When you pop the tab on a can of soda, you release the pressure. The solution immediately becomes supersaturated, causing the CO_2 to bubble out of the water and fizz.

Dissolved oxygen

Table 9.2 also shows that 0.04 grams of oxygen dissolves in a kilogram of water. Dissolved oxygen keeps fish and other underwater animals alive (Figure 9.5). Just like on land, oxygen is produced by underwater plants as a by-product of photosynthesis.

Solubility of gas decreases with temperature

When temperature goes up, the solubility of gases in liquid goes down (Figure 9.6). When the water temperature rises, the amount of dissolved oxygen decreases. Less dissolved oxygen means less oxygen for fish. When the weather is warm, fish stay near the bottom of ponds and rivers where there is cooler, more oxygenated water.

Solubility of liquids



Some liquids, such as alcohol, are soluble in water. Other liquids, such as corn oil, are not soluble in water. Oil and vinegar (water solution) salad dressing separates because oil is not soluble in water. Liquids that are not soluble in water may be soluble in other solvents. For example, vegetable oil is soluble in mineral spirits, a petroleum-based solvent used to thin paints.

Table 9.2: Solubility of gases in water at 21°C and 1 atm.

Gas	Solubility
Oxygen (O_2)	0.04 g/kg water
Nitrogen (N_2)	0.02 g/kg water
Carbon dioxide (CO_2)	1.74 g/kg water



Figure 9.5: Fish and other aquatic life are sustained by dissolved oxygen in water.

Solubility of CO_2 in Water

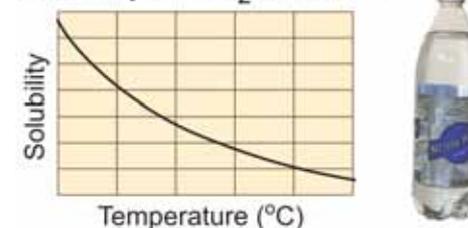


Figure 9.6: The solubility of gases in water decreases as temperature increases.

Water as a solvent

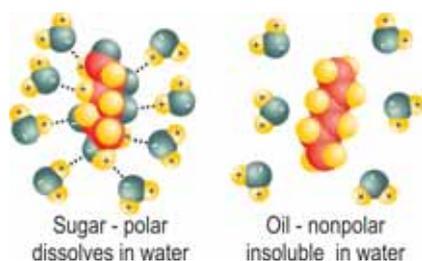
The universal solvent Water is often called the “universal solvent.” While water doesn’t dissolve everything, it does dissolve many different types of substances such as salts and sugars. Water is a good solvent because of the way the H_2O molecule is shaped (Figure 9.7).

Water is a polar molecule A water molecule has a negative end (pole) and a positive end. This is because electrons are shared unequally; pulled toward the oxygen atom and away from the two hydrogen atoms. The oxygen side of the molecule has a partially negative charge and the hydrogen side of the molecule has a partially positive charge. A molecule (like water) with a charge separation is called a **polar** molecule.

How water dissolves salt The polar molecules of water dissolve many ionic compounds. Suppose a sodium chloride (table salt) crystal is mixed with water. The polar water molecules surround the sodium and chlorine atoms in the crystal. This causes the ions in the crystal to separate. Because opposites attract, the negative ends of the water molecules are attracted to the Na^+ ions and the positive ends are attracted to the Cl^- ions. Water molecules surround the Na^+ and Cl^- ions and make a solution (Figure 9.8).

Water dissolves many molecular compounds When sucrose is mixed with water, the individual molecules of sucrose become separated from each other and are attracted to the opposite poles of the water molecules. Because sucrose is a covalent compound, the sucrose molecules do not dissociate into ions but remain as neutral molecules in the solution.

Water does not dissolve oils



Oil does not dissolve in water because water is a polar molecule and oil molecules are nonpolar. In general, like dissolves like: water dissolves polar substances and non-polar solvents (like mineral spirits) dissolve non-polar substances.

VOCABULARY

polar - describes a molecule that has charge separation, like water.

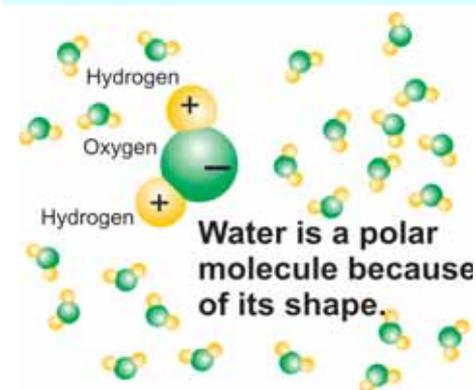


Figure 9.7: Water is a polar molecule because it has a negative pole and a positive pole.

 Sodium ion  Chlorine ion
 Water molecule

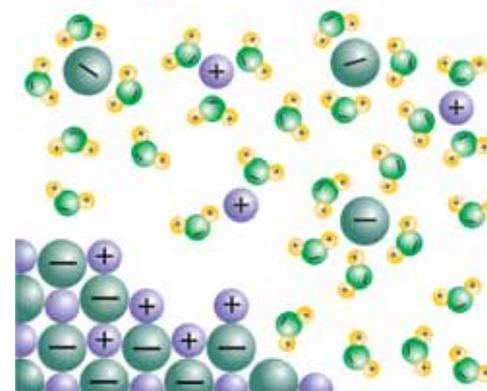


Figure 9.8: Water dissolves sodium chloride to form a solution of sodium (+) and chlorine (-) ions.



9.1 Section Review

1. One of the following is NOT a solution. Choose the one that is *not* a solution and explain why.
 - a. steel
 - b. ocean water
 - c. 24-karat gold
 - d. muddy water
 - e. orange soda
2. For each of the following solutions, name the solvent and the solute.
 - a. saltwater
 - b. seltzer water (hint: what causes the fizz?)
 - c. lemonade made from powdered drink mix
3. Give an example of a solution in which the solute is *not* a solid and the solvent is *not* a liquid.
4. When can you say that a solute has dissolved?
5. Does sugar dissolve faster in cold water or hot water? Explain your answer.
6. Jackie likes to put sugar on her breakfast cereal. When she has eaten all of the cereal, there is some cold milk left in the bottom of the bowl. When she dips her spoon into the milk, she notices a lot of sugar is sitting at the bottom of the bowl. Explain what happened in terms of saturation.
7. Describe exactly how you would make 100 grams of a saltwater solution that is 20% salt. In your description, tell how many grams of salt and how many grams of water you would need.
8. Why is water often called the “universal solvent”?



CHALLENGE

Larry opens a new bottle of soda. He quickly stretches a balloon over the opening of the bottle. As he gently shakes the bottle, the balloon expands! Explain what is happening to cause the balloon to expand. Use at least three vocabulary words from this section. Draw a diagram to illustrate your explanation.

9.2 Acids, Bases, and pH

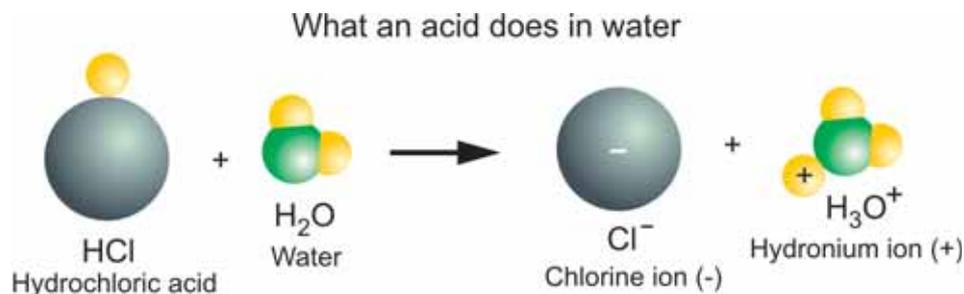
Acids and bases are among the most familiar of all chemical compounds. Some of the acids you may have encountered include acetic acid (found in vinegar), citric acid (found in orange juice), and malic acid (found in apples). You may be familiar with some bases including ammonia in cleaning solutions 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 properties of acids and bases, and how the pH scale works.

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 9.9. Note: you should NEVER taste a laboratory chemical!

- Acids create the sour taste in food, like 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 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.



VOCABULARY

acid - a substance that produces hydronium ions (H_3O^+) when dissolved in water. Acids have a pH less than 7.



Figure 9.9: Some weak acids you may have around your home.



Bases

Properties of bases

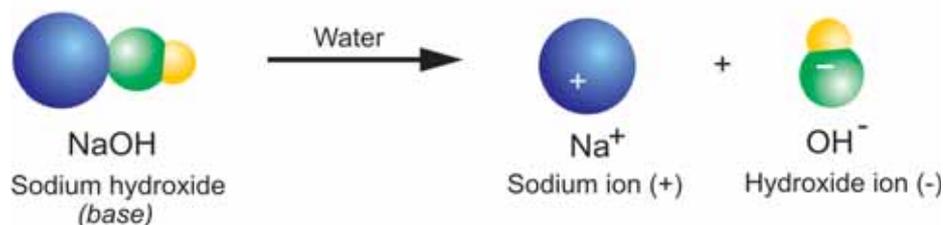
A **base** is a compound that dissolves in water to make a different kind of solution, opposite in some ways to an acid. Some properties of bases are listed below and shown in Figure 9.10.

- 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 ions:

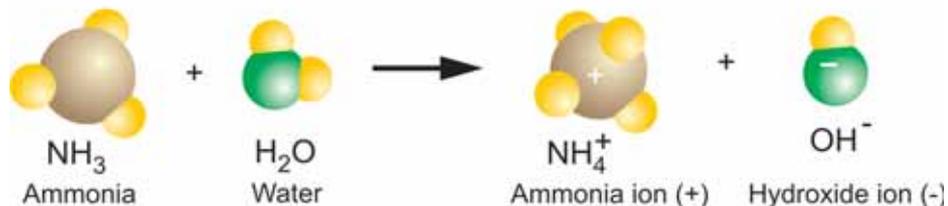
What a base does in water



Ammonia is a base

Ammonia (NH_3), found in cleaning solutions, is a base because it dissociates in water to form hydroxide ions. Notice that a hydroxide ion is formed when ammonia *accepts* H^+ ions from water molecules in solution as shown below. How is this different than NaOH ?

What ammonia (base) does in water



VOCABULARY

base - a substance that produces hydroxide ions (OH^-) when dissolved in water. Bases have a pH greater than 7.



Figure 9.10: Some common bases.

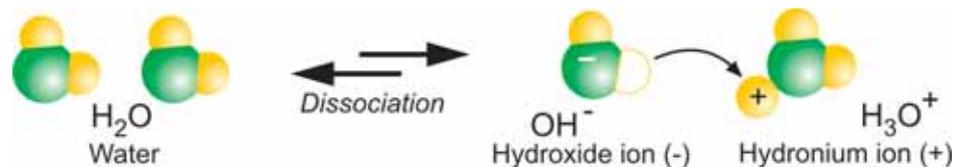
Strength of acids and bases

The strength of acids The strength of an acid depends on the concentration of hydronium ions 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 ($\text{HC}_2\text{H}_3\text{O}_2$), (in vinegar), is an a *weak acid*. When dissolved in water, only a small percentage of acetic acid molecules ionize (break apart) and become H^+ and $\text{C}_2\text{H}_3\text{O}_2^-$ ions. This means that a small number of hydronium ions are produced compared to the number of acetic acid molecules dissolved (Figure 9.11).

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 unit of NaOH that dissolves creates one OH^- ion (Figure 9.12). 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.

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 as 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 equation means that the dissociation of water can occur in *both* directions. This means that water molecules can ionize and ions can also form water molecules. However, water ionizes so slightly that most water molecules exist whole, not as ions.

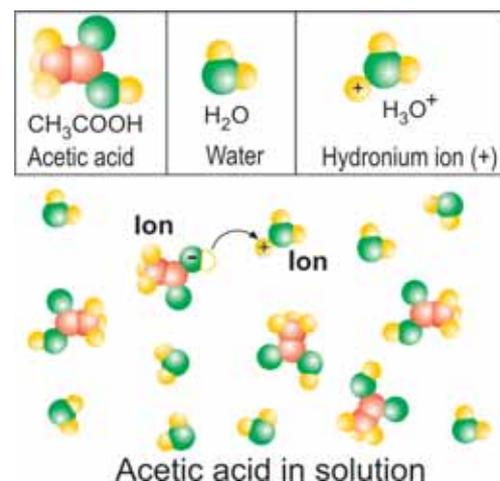


Figure 9.11: Acetic acid dissolves in water, but only a few molecules ionize (break apart) to create hydronium ions.

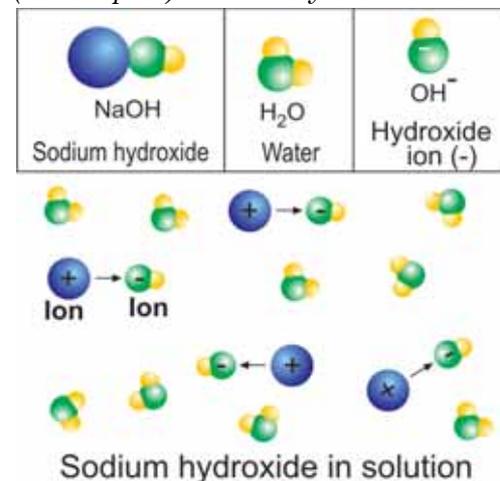


Figure 9.12: Sodium hydroxide (NaOH) is a strong base because every NaOH unit contributes one hydroxide (OH^-) ion.

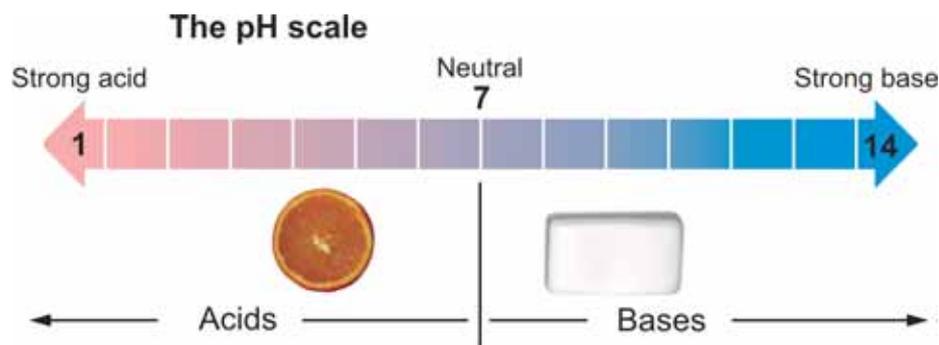


pH and the pH scale

What is pH? The pH scale describes the concentration of hydronium ions in a solution. The **pH scale** ranges from 0 to 14. A pH of 7 is neutral, neither acidic nor basic. Distilled water has a pH of 7.

Acids have a pH less than 7. A concentrated solution of a *strong acid* has the *lowest* pH. Strong hydrochloric acid has a pH of 1. Seltzer water is a weak acid at a pH of 4. Weaker acids have a pH nearer to 7.

A base has a pH greater than 7. A concentrated solution of a *strong base* has the *highest* pH. A strong sodium hydroxide solution can have a pH close to 14. Weak bases such as baking soda have pH closer to 7.



The pH of common substances Table 9.3 lists the pH of some common substances. It turns out that many foods we eat or ingredients we use for cooking are acidic. On the other hand, many of our household cleaning products are bases.

pH indicators Certain chemicals turn different colors at different pH. 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 to yellow at different values of pH. Litmus paper is another pH indicator that changes color (Figure 9.13).

VOCABULARY

pH - pH measures the acidity of a solution

pH scale - the pH scale goes from 1 to 14 with 1 being very acidic and 14 being very basic. Pure water is neutral with a pH of 7.

Table 9.3: The pH of some common chemicals.

Household chemical	Acid or base	pH
lemon juice	acid	2
vinegar	acid	3
soda water	acid	4
baking soda	base	8.5
bar soap	base	10
ammonia	base	11

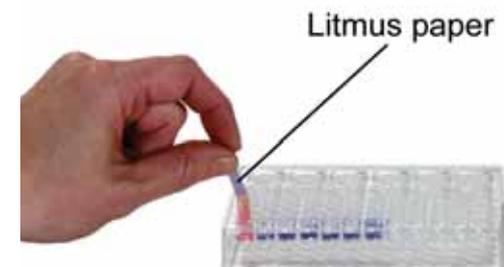


Figure 9.13: Red and blue litmus paper are pH indicators that test for acid or base.

pH in the environment

The best pH for plants

The pH of soil directly affects nutrient availability for plants. Most plants prefer a slightly acidic soil with a pH between 6.5 and 7.0. Azaleas, blueberries, and conifers grow best in more acid soils with a pH of 4.5 to 5.5 (Figure 9.14). Vegetables, grasses and most other shrubs do best in less acidic soils with a pH range of 6.5 to 7.0.

Effects of pH too high or low

In highly acid soils (pH below 4.5) too much aluminum, manganese and other elements may 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 pH values of 6.5 and above, (more basic), iron and manganese become less available.

pH and fish

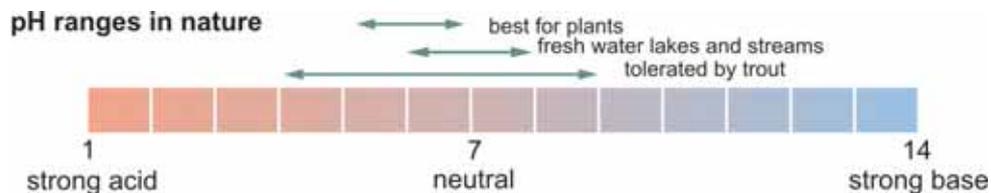


The pH of water directly affects aquatic life. Most freshwater lakes, streams, and ponds have a natural pH in the range of 6 to 8. Most freshwater fish can tolerate pH between 5 and 9 although some negative effects appear below pH of 6. Trout (like the California golden) are among the most pH tolerant 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. The California tree frog, and other frogs prefer pH close to neutral and don't survive below pH of 5.0. Frogs eggs develop and hatch in water with no protection from environmental factors. Research shows that even pH below 6 has a negative effect on frog hatching rates.



CHALLENGE

Test your soil pH

Many garden centers offer soil testing kits. These kits are specially designed to measure the pH of soil. Measure the soil around your house or school. What sorts of plants would thrive in the pH range is that you measure?



Figure 9.14: Blueberries grow best in acid soils that have a pH between 5.0 and 5.5.



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. As you may know, the stomach secretes hydrochloric acid (HCl), a strong acid (pH 1.4). The level of acidity in our stomachs is necessary to break down the protein molecules in food so they can be absorbed. A mucus lining in the stomach protects it from the acid produced (Figure 9.15).

Ulcers and heartburn

Very spicy 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* may occur when the mucus lining of the stomach is damaged. Stomach acid can then attack the more sensitive tissues of the stomach itself. Infections by the bacteria *h. pylori* can also damage the mucus 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 mucus lining of the stomach and is sensitive to acid. Eating very large meals can lead to heartburn because an overflowing stomach pushes acid up into the esophagus.

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 (CO₂) and oxygen. Dissolved CO₂ in blood produces a weak acid. The higher the concentration of dissolved CO₂, the more acidic your blood becomes.

Blood pH is controlled through breathing

Your body regulates the dissolved CO₂ 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 acid. If you hyperventilate, 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 9.16).

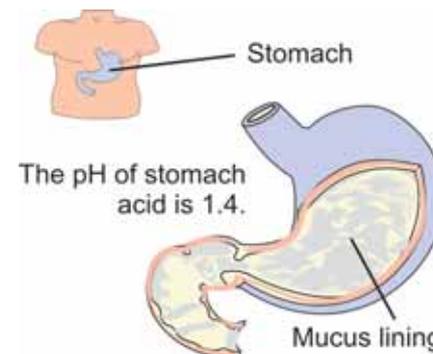


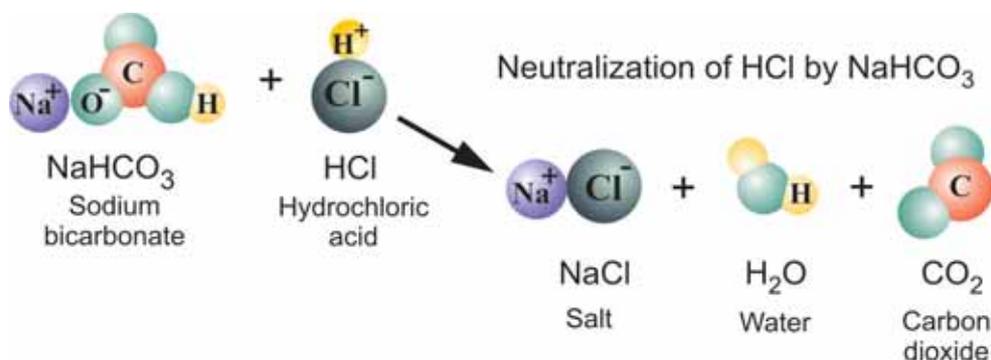
Figure 9.15: The stomach secretes a strong acid (HCl) to aid with food digestion. A mucus lining protects the stomach tissue from the acid.



Figure 9.16: Under normal conditions, your blood pH ranges between 7.35 and 7.45. Holding your breath causes blood pH to drop. High blood pH can be caused by hyperventilating.

Neutralization reactions

Neutralization When an acid and a base are combined, they neutralize each other. Neutralization occurs when the positive ions from the base combine with the negative ions from the acid. This process also goes on in your body. As food and digestive fluids leave the stomach, the pancreas and liver produce bicarbonate (a base) to neutralize the stomach acid. Antacids such as sodium bicarbonate have the same effect.



Adjusting soil pH Neutralization reactions are important in gardening and farming. For example about 1/4 of the yards in the US have soil which is too acidic (pH less than 5.5) to grow grass very well. For this reason, many people add *lime* to their yard every spring. A common form of lime is ground-up calcium carbonate (CaCO₃) made from natural crushed limestone. Lime is a weak base and undergoes a neutralization reaction with acids in the soil to raise the pH.

Neutralization of acid in soil For example, sulfuric acid (H₂S) in soil reacts with the calcium carbonate to form the salt calcium sulfate (CaSO₄) also known as gypsum. Sulfuric acid is in acid rain and is created in the atmosphere from pollutants in the air. Many of the walls of buildings and homes are made with “plaster board” which is a sheet of gypsum (plaster) covered with paper on both sides.

! CHALLENGE



Test your soil

Almost any garden center carries soil test kits. These kits have pH test papers inside and are designed to help gardeners measure the pH of their soil.

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. See if you can answer these questions:

- What kinds of plants thrive in the pH of the soil samples you tested?
- Is the soil the proper pH for the plants you found where you took your soil samples?
- What kinds of treatments are available at your local garden center for correcting soil pH?



9.2 Section Review

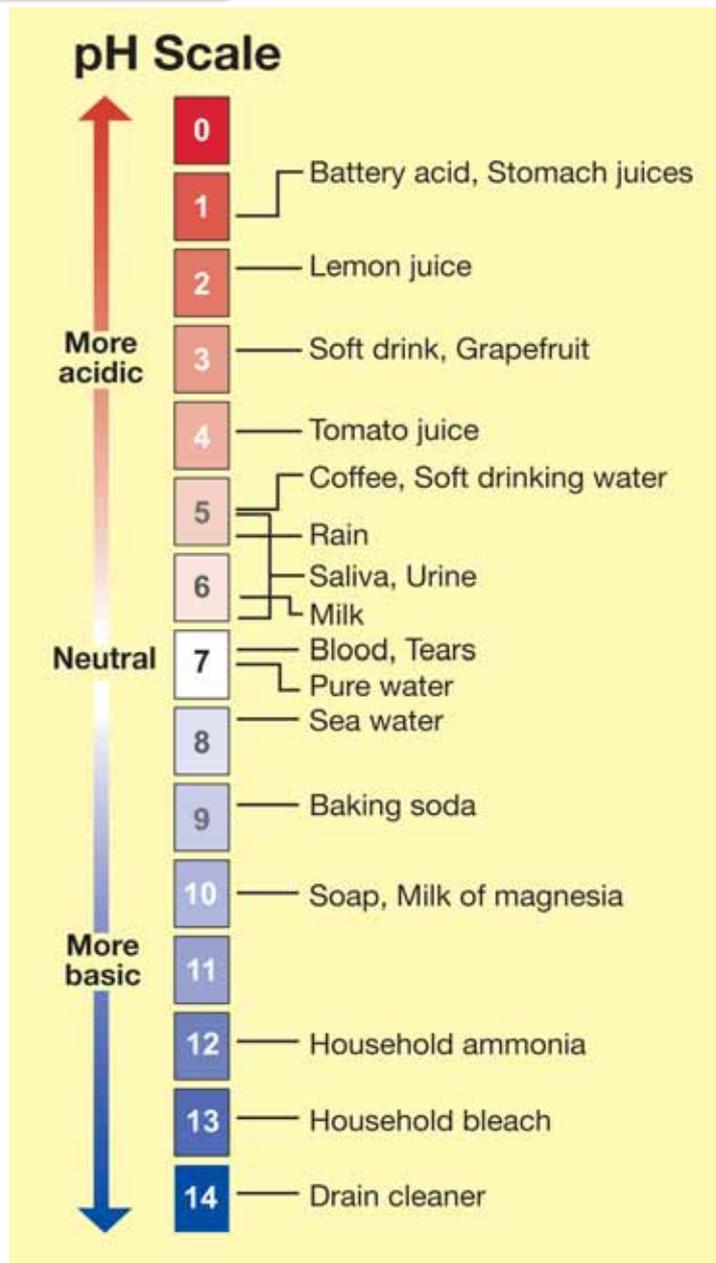
1. List three ways that acids and bases are different.
2. Many foods are acidic. List four examples.
3. Answer these questions about water:
 - a. Is water an acid, a base, neither, or both?
 - b. What is the pH of water?
4. Nadine tests an unknown solution and discovers that it turns blue litmus paper red, and it has a pH of 3.0. Which of the following could be the unknown solution?
 - a. sodium hydroxide
 - b. vinegar
 - c. ammonia
 - d. soap
5. What makes a strong acid strong?
6. What makes a strong base strong?
7. Give two examples of a pH indicator.
8. Describe in your own words how the amount of carbon dioxide dissolved in your blood affects your blood pH.
9. Two years ago, you joined a project to study the water quality of a local pond. During the second spring, you notice that there are not as many tadpoles (first stage in frog development) as there were last year (Figure 9.17). You want to know if the number of tadpoles in the pond is related to the pH of the pond. The records that document the water quality and wildlife started ten years ago. Describe the steps you would take to determine whether a change in the pH of the pond water is affecting the population of frogs and their ability to reproduce.



Figure 9.17: *Because their young develop underwater, outside the female's body, frogs and other amphibians are very sensitive to the pH of their environment.*



Keeping Your (pH) Balance

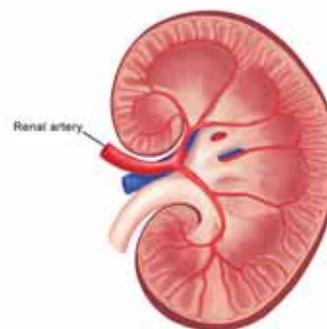


You know that solutions have a pH. A test paper dipped in a solution will show whether it is an acid (acidic) or a base (alkaline). Did you know the same is true of the blood that courses through your body? Our bodies are constantly adjusting to keep our blood pH in a normal range between 7.35 and 7.45. Yes, we are slightly alkaline.

Acids and bases are everywhere. Many of our favorite foods are acidic: Lemons and oranges, for instance, contain citric acid. We depend on gastric acid in our stomachs to digest our food - and if we eat or drink unwisely, we suffer stomach pains caused by that same gastric acid. Then to counter the acid, we have antacids and baking soda.

Imbalances

The human body's many different processes produce a great deal of acid, which then must be removed. For example, our lungs can dispose of excess acid; carbon dioxide can form carbonic acid by causing us to breathe faster. Our kidneys remove excess acid from the blood and dispose of it in urine. But disease or extreme conditions can interfere with the body's self-adjusting system.



There are two types of imbalance. We can have too much acid in our body fluids, or those fluids can be too alkaline. Too much acid is called acidosis and too much alkali is called alkalosis.

These imbalances are either respiratory or metabolic. When the lungs are not functioning properly, the imbalance is respiratory. When the body's physical and chemical processing of substances is not functioning properly, the imbalance is metabolic.

Acidosis and its causes

Respiratory acidosis occurs when the lungs cannot remove all of the carbon dioxide produced by the body. As a result, body fluids become too acidic. This can be caused by almost any lung disease, such as asthma, or by a deadly habit like cigarette smoking.

Treatment may include drugs that expand the air passages in the lungs. Inhaled oxygen may be used to raise the oxygen level in the blood. Stopping smoking is a given among these attempts to restore the body's pH balance.

Metabolic acidosis is a pH imbalance in which the body has too much acid. The body does not have enough bicarbonate needed to neutralize the excess acid. This can be caused by a disease like diabetes, or by severe diarrhea, heart or liver failure, kidney disease, or even prolonged exercise.

A result of prolonged exercise is a buildup of lactic acid, which causes the blood to become acidic. Fluids can restore the body's pH balance, which is why various sports drinks are popular among athletes. Those drinks are formulated to help the body maintain its pH balance under stress.

Alkalosis and its causes

The opposite of acidosis, alkalosis is the result of too much base in the body's fluids. Respiratory alkalosis is caused by hyperventilation, that is, extremely rapid or deep breathing that makes the body lose too much carbon dioxide. It can be provoked by anxiety. In such a case, the person may breathe (or be helped to breathe) into a paper bag. Why? Because the bag retains the exhaled carbon dioxide and it can be taken back in. Altitude or any disease that causes the body to lose carbon dioxide may also cause hyperventilation. Metabolic alkalosis is a result of too much bicarbonate in the blood. Other types of alkalosis are caused by too little chloride or potassium. Alkalosis symptoms include confusion, muscle twitching or spasms, hand tremors, nausea, and lightheadedness.

Balancing act: food, drink, exercise, calm, acid, base ...

By nature our slightly alkaline pH needs to remain balanced there. Yet, what we eat and drink changes our pH. If you eat a lot of meat such as hamburgers, steak, and chicken, your body produces more acid than someone who eats a lot of vegetables and fruits. If we don't balance what we eat, the body has to rely on reserves. For example, if you eat a lot of meat and no vegetables, your pH becomes acidic. Your kidneys can handle only so much acid and, in this case, the reserve the body would use is bicarbonate from your bones to help neutralize the acid level.



This is just one more instance in which the food we eat can affect our bodies in many ways. Maintaining a balanced diet is the first step toward good health—a little on the alkaline side.

Questions:

1. What two organs regulate the acid-base balance?
2. What is a common cause of hyperventilation?
3. How is the alkalosis caused by hyperventilation treated?
4. Name a leading cause of respiratory acidosis.

**CHAPTER
ACTIVITY****Acid Rain and Stone Structures**

Acid rain resulting from air pollution is a growing problem in the industrialized world. It can have devastating effects on the pH of our lakes. Interestingly, while the pH of some lakes has dropped dramatically in recent years, the pH of some nearby lakes during the same time period has changed very little. The type of rock that is found beneath and around the body of water is what makes the difference. Calcium carbonate, which is found in marble and limestone, has the ability to neutralize acid rain while other types of rocks and minerals have no effect. In this activity, we will make solutions of water and soak chips of different types of rock to see their effect on a dilute acid.

We will measure the pH of each solution using an indicator solution. The indicator solution appears red at a pH of 4, orange to yellow at a pH of 6.5, green to blue at a pH of 9, and violet to red-violet at pH of 10.

Materials:

Chalk and/or marble chips, beakers, granite chips, white vinegar, and Universal Indicator solution

What you will do

1. Place a small sample of marble chips in two 50 mL beakers.
2. Place a small sample of granite chips in one other beaker.
3. Be sure to keep some of the original indicator solution as a control.
4. Add 10 mL of vinegar-Universal Indicator solution to each.
5. Record the time and color of each solution according to the data table below.

Applying your knowledge

- a. Compare the pH changes of the solutions containing granite and limestone.
- b. Does the solution become more or less acidic as time passes?
- c. What affect do you think acid rain has on marble statues?
- d. Spelunking (cave exploration) is very popular in Ireland due to the large deposits of limestone. Explain how these caves could have formed.

Time	Color of solution (marble)	Approx. pH (marble)	Color of Solution (granite)	Approx. pH (granite)
0 min.				
5 min.				
10 min.				
20 min.				
30 min.				
40 min.				
overnight				

Chapter 9 Assessment

Vocabulary

Select the correct term to complete the sentences.

solvent	acid	solute
equilibrium	pH	concentration
base	solubility	polar
alloy	solution	supersaturated

Section 9.1

1. The substance that dissolves particles in a solution is called the ____.
2. The substance that is dissolved in a solution is called the ____.
3. A mixture of two or more substances that is uniform at the molecular level is called a(n) ____.
4. A solution of two or more metals is known as a(n) ____.
5. A water molecule is an example of a(n) ____ molecule.
6. When the dissolving rate equals the rate at which molecules come out of solution, the solution is in ____.
7. The exact amount of solute dissolved in a given amount of solvent is the ____ of a solution.
8. A(n) ____ solution has a concentration greater than the maximum solubility.

Section 9.2

9. A substance that produces hydronium ions (H_3O^+) in solution is called a(n) ____.
10. A substance that produces hydroxide ions (OH^-) in solution is called a(n) ____.
11. ____ measures the acidity of a solution.

Concepts

Section 9.1

1. What would happen to the solubility of potassium chloride in water as the water temperature increased from 25°C to 75°C ?
2. What are two ways to increase the dissolving rate of sugar in water?
3. Water is described as a polar molecule because it has:
 - a. a positive and a negative pole.
 - b. two positive poles.
 - c. two negative poles.
 - d. no charge.
4. Water is a solvent in which of the following solutions?
 - a. Air
 - b. Liquid sterling silver
 - c. Saline (salt) solution
5. Very small concentrations are often reported in ppm. What does “ppm” stand for? Give three examples of concentrations that are described in “ppm”.
6. How would the fish in a lake be affected if large amounts of hot water from a power plant or factory were released into the lake?
7. When you open a can of room-temperature soda, why is it more likely to fizz and spill over than a can that has been refrigerated?
8. What happens to a supersaturated solution when more solute is added?

Section 9.2

9. What determines the strength of an acid?

10. What determines the strength of a base?
11. What is the pH of a neutral solution?
12. Indicate whether the following properties belong to an acid (A), a base (B), or both (AB):
 - a. ___ Creates a sour taste in food.
 - b. ___ Creates a bitter taste in food.
 - c. ___ Changes the color of red litmus paper to blue.
 - d. ___ Changes the color of blue litmus paper to red.
 - e. ___ Can be very corrosive.
13. When hydroxide ions are added to a solution, does the pH increase or decrease?
14. Your stomach uses hydrochloric acid to break down the protein molecules in the food you eat. Give two reasons why this acid doesn't destroy your stomach and intestines during digestion.
15. Are hydronium ions contributed to a solution by an acid or a base?
16. If you add water to a strong acid, how will the pH of the diluted acid compare to the pH of the original acid?
 - a. lower
 - b. higher
 - c. the same
17. How can ammonia (NH_3) be a base if it doesn't contain any hydroxide ions?
2. You add 20 grams of baking soda (NaHCO_3) to 100 mL of water at 25°C .
 - a. Approximately how much of the baking soda will dissolve in the water?
 - b. What happens to the rest of the baking soda?
 - c. How could you increase the amount of baking soda that will dissolve in 100 mL of water?
3. How much of the following materials will dissolve in 300 mL of water at 25°C ?
 - a. table salt
 - b. sugar
 - c. chalk
4. How many grams of sugar do you need to make a 20% solution by mass in 500 g of water?

Section 9.2

5. Solution A has a pH of 3 and solution B has a pH of 10.
 - a. Which solution is a base?
 - b. Which solution is an acid?
 - c. What would happen if you combined both solutions?
6. Which of the following pH values is the most acidic?
 - a. 1
 - b. 3
 - c. 7
 - d. 8
7. Luke and Sian want to plant a vegetable garden in their yard. A soil testing kit measures the soil pH at 5.0, but the lettuce they want to plant in their garden does best at a pH of 6.5. Should they add an acid or a base to the soil to make it the optimum pH for growing lettuce?

Problems

Section 9.1

1. What is the mass percent of table salt in a solution of 25 grams of salt dissolved in 75 g of water?