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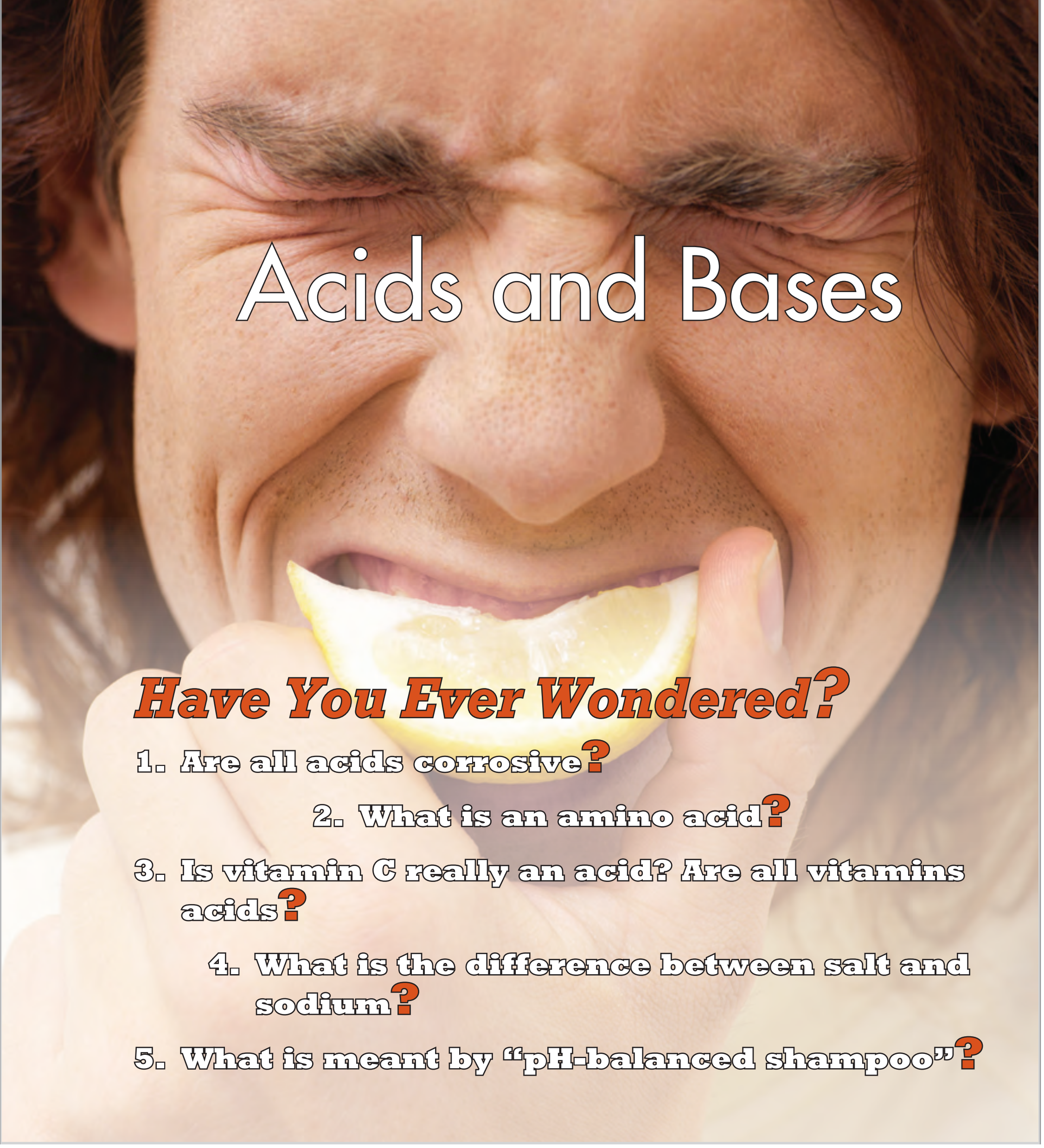


Acids and Bases

Have You Ever Wondered?

1. Are all acids corrosive?
2. What is an amino acid?
3. Is vitamin C really an acid? Are all vitamins acids?
4. What is the difference between salt and sodium?
5. What is meant by "pH-balanced shampoo"?

Learning Objectives

- Distinguish between acids and bases using their chemical and physical properties. (7.1)
- Explain how an acid–base indicator works. (7.1)
- Identify Arrhenius and Brønsted–Lowry acids and bases. (7.2)
- Write a balanced equation for a neutralization or an ionization. (7.2)
- Identify acidic and basic anhydrides, and write equations showing their reactions with water. (7.3)
- Define and identify strong and weak acids and bases. (7.4)
- Identify the reactants and predict the products in a neutralization reaction. (7.5)
- Describe the relationship between the pH of a solution and its acidity or basicity. (7.6)
- Find the molar concentration of hydrogen ion, $[H^+]$, from a pH value or the pH value from $[H^+]$. (7.6)
- Write the formula for the conjugate base of an acid or for the conjugate acid of a base. (7.7)
- Describe the action of a buffer. (7.7)
- Describe everyday uses of acids and bases and how they affect daily life. (7.8)
- Write equations for the production of soap and of biofuel.
- Describe ways by which acids and bases can contribute to greener production of consumer products.

Please pass the protons Have you ever tasted a lemon or a grapefruit? Or felt a burning sensation on your arm after using a cleaning solution containing ammonia? These are but two examples of acids (citric acid in lemons and grapefruit) and bases (ammonia in cleaning solutions) we encounter in our daily lives. Other familiar acids are vinegar (acetic acid), vitamin C (ascorbic acid), and battery acid (sulfuric acid). Some familiar bases are drain cleaner (sodium hydroxide), baking soda (sodium bicarbonate), and antacids.

From "acid indigestion" to "acid rain," the word *acid* appears frequently in the news and in advertisements. Air and water pollution often involve acids

The chemical substances we call acids and bases are all around us. Acids are used in steel production and metal plating, as well as in chemical analysis. Acids are even found in the food we eat. Pancakes and muffins rise because of acids and bases in the ingredients, and the tart taste of fruit comes from the different acids in its flesh. Although the items described and shown here are dramatically different, the acids in them have something in common. All of them can provide hydrogen (hydronium) ions.

and bases. Acid rain, for example, is a serious environmental problem. In arid areas, alkaline (basic) water is sometimes undrinkable.

Did you know that our senses recognize four tastes related to acid–base chemistry? Acids taste sour, bases taste bitter, and the compounds formed when acids react with bases (salts) taste salty. The sweet taste is more complicated. To taste sweet, a compound must have both an acidic part and a basic part, plus just the right geometry to fit the sweet-taste receptors of our taste buds.

In this chapter, we discuss some of the chemistry of acids and bases. You use them every day. Your body processes them continuously. You will probably hear and read about them as long as you live. What you learn here can help you gain a better understanding of these important classes of compounds.

⚠ **SAFETY ALERT:** Although all acids taste sour and all bases taste bitter, a taste test is not the best general-purpose way to determine whether a substance is an acid or a base. Some acids and bases are poisonous, and some are quite corrosive unless greatly diluted. NEVER TASTE LABORATORY CHEMICALS. Too many of them are toxic, and others might be contaminated.

▲ Many skin-peel preparations used by cosmetologists contain alpha-hydroxy acids such as glycolic acid or lactic acid.

7.1 Acids and Bases: Experimental Definitions

Learning Objectives › Distinguish between acids and bases using their chemical and physical properties. › Explain how an acid–base indicator works.

Acids and bases are chemical opposites, and so their properties are quite different—often opposite. Let's begin by listing a few of these properties.
An *acid* is a compound that

- tastes sour.
- causes litmus indicator dye to turn red.
- dissolves active metals such as zinc and iron, producing hydrogen gas.
- reacts with bases to form water and ionic compounds called *salts*.

A *base* is a compound that

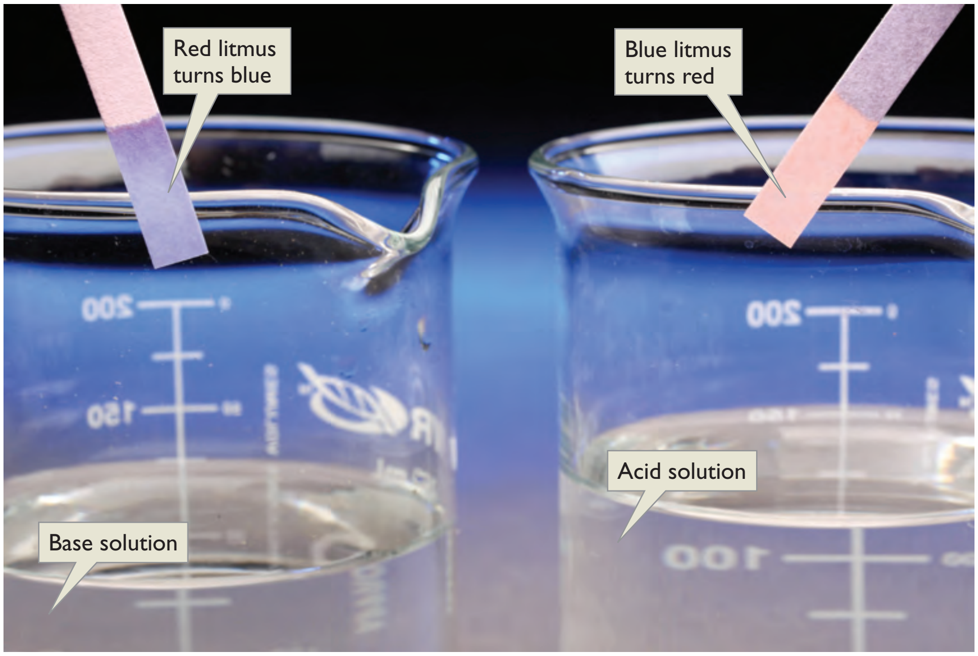
- tastes bitter.
- causes litmus indicator dye to turn blue.
- feels slippery on the skin.
- reacts with acids to form water and salts.

1. Are all acids corrosive? It is clear from Table 7.1 that *acid* does not necessarily mean "corrosive." Many acids are harmless enough to be included in foods we eat, and some are necessary to life.

We can identify foods that are acidic by their sour taste. Vinegar and lemon juice are examples. Vinegar is a solution of acetic acid (about 5%) in water. Lemons, limes, and other citrus fruits contain citric acid. Lactic acid gives yogurt its tart taste, and phosphoric acid is often added to carbonated drinks to impart tartness. The bitter taste of tonic water, on the other hand, comes in part from quinine, a base. Figure 7.1 shows some common acids and bases.

▶ **Figure 7.1** Some common acids (left), bases (center), and salts (right). Acids, bases, and salts are components of many familiar consumer products.

Q: *How would each of the three classes of compounds affect the indicator dye litmus? (See Figure 7.2.)*



▲ **Figure 7.2** Strips of paper impregnated with litmus dye (extracted from a fungus) are often used to distinguish between acids and bases. The sample on the left turns litmus blue and is therefore basic. The sample on the right turns litmus red and is acidic.

▲ **It DOES Matter!**

Hydrangea is one of many types of flowers that may show different colors depending on the acidity of the soil in which it is grown. Some varieties are blue (top) when planted in slightly acidic soil and pink (bottom) when planted in more basic soil.

A litmus test is a common way to identify a substance as an acid or a base. Litmus (Figure 7.2) is an **acid–base indicator**, one of many such compounds. If you dip a strip of neutral (violet-colored) litmus paper into an unknown solution and the strip turns pink, the solution is acidic. If it turns blue, the solution is basic. If the strip does not turn pink or blue, the solution is neither acidic nor basic. Many substances, such as those that give the colors to grape juice, red cabbage, blueberries, and many flower petals, are acid–base indicators.

▲ You can make your own indicator dye. Chop about 2 cups of red cabbage. Cover with boiling water. Stir. After about 10 min, filter out the solids with a coffee filter. Use about 50 mL of the liquid to test various household chemicals (vinegar, baking soda, ammonia, and so on) for pH. The indicator changes from red at about pH 2 to purple at pH 4, violet at pH 6, blue at pH 8, blue-green at pH 10, and greenish-yellow at pH 12. Other plant materials that contain indicators include blackberries, black raspberries, red radish peels, red rose petals, and turmeric.

Self-Assessment Questions

1. Which of the following is *not* a property of acids?
   a. feel slippery on the skin
   b. react with Zn to form hydrogen gas
   c. taste sour
   d. turn litmus red
2. Which of the following is *not* a property of bases?
   a. feel slippery on the skin
   b. react with salts to form acids
   c. taste bitter
   d. turn litmus blue
3. In general, when an acid and a base are mixed,
   a. a new acid and a salt are formed
   b. a new base and a salt are formed
   c. no reaction occurs
   d. a salt and water are formed
4. A common substance that contains lactic acid is
   a. salad oil
   b. soap
   c. vinegar
   d. yogurt
5. The sour taste of grapefruit is due to
   a. acetic acid
   b. ammonia
   c. carbonic acid
   d. citric acid

Answers: 1, a; 2, b; 3, d; 4, d; 5, d

▲ Swedish chemist Svante Arrhenius (1859–1927) proposed the theory that acids, bases, and salts in water are composed of ions. He also was the first to relate carbon dioxide in the atmosphere to the greenhouse effect (Chapter 13).

7.2 Acids, Bases, and Salts

Learning Objectives › Identify Arrhenius and Brønsted–Lowry acids and bases.
› Write a balanced equation for a neutralization or an ionization.

Acids and bases have certain characteristic properties. But why do they have these properties? We use several different theories to explain these properties.

The Arrhenius Theory

Svante Arrhenius developed the first successful theory of acids and bases in 1887. According to Arrhenius's concept, an **acid** is a molecular substance that breaks up in aqueous solution into hydrogen ions (H^+) and anions. (Because a hydrogen ion is a hydrogen atom from which the sole electron has been removed, H^+ ions are also called *protons*.) The acid is said to *ionize*. For example, nitric acid ionizes in water.

$$HNO_3(aq) \longrightarrow H^+(aq) + NO_3^-(aq)$$

In water, then, the properties of acids are those of the H^+ ion. It is the hydrogen ion that turns litmus red, tastes sour, and reacts with active metals and bases. Table 7.1 lists some common acids. Notice that each formula contains one or more hydrogen atoms. Chemists often indicate an acid by writing the formula with the H atom(s) first. HCl, H_2SO_4, and HNO_3 are acids; NH_3 and CH_4 are not. The formula $HC_2H_3O_2$ (acetic acid) indicates that one H atom ionizes when this compound is in aqueous solution, and three do not.

Ionizable (acidic) H atoms   Nonionizable (nonacidic) H atoms

H_2SO_4 HNO_3 $HC_2H_3O_2$ NH_3 CH_4

An Arrhenius **base** is defined as a substance that releases hydroxide ions (OH^-) in aqueous solution. Some bases are ionic solids that contain OH^-, such as sodium hydroxide (NaOH) and calcium hydroxide [$Ca(OH)_2$]. These compounds simply release hydroxide ions into the solution when the solid is dissolved in water:

$$NaOH(s) \xrightarrow{H_2O} Na^+(aq) + OH^-(aq)$$

We write H_2O over the arrow to indicate that it is a solvent, not a reactant.

Other bases are molecular substances such as ammonia that ionize to produce OH^- when placed in water (see page 181).

Experimental evidence indicates that the properties of bases in water are due to OH^-. Table 7.2 lists some common bases. Most of these are ionic compounds containing positively changed metal ions, such as Na^+ or Ca^{2+}, and negatively charged hydroxide ions. When these compounds dissolve in water, they all provide OH^- ions, and thus they are all bases. The properties of bases are those of hydroxide ions, just as the properties of acids are those of hydrogen ions.

Table 7.1 Some Common Acids

Name	Formula	Acid Strength	Common Uses/Notes
Sulfuric acid	H_2SO_4	Strong	Battery acid; ore processing, fertilizer manufacturing, oil refining
Hydrochloric acid	HCl	Strong	Cleaning of metals and bricks, removing scale from boilers
Phosphoric acid	H_3PO_4	Moderate	Used in colas and rust removers
Lactic acid	$CH_3CHOHCOOH$	Weak	Yogurt; acidulant (food additive to increase tartness), lotion additive
Acetic acid	CH_3COOH	Weak	Vinegar; acidulant
Boric acid	H_3BO_3	Very weak	Antiseptic eyewash, roach poison
Hydrocyanic acid	HCN	Very weak	Plastics manufacture; extremely toxic

Table 7.2 Some Common Bases

Name	Formula	Classification	Common Uses/Notes
Sodium hydroxide	$NaOH$	Strong	Acid neutralization; soap making
Potassium hydroxide	KOH	Strong	Making liquid soaps and biodiesel fuels
Lithium hydroxide	$LiOH$	Strong	Alkaline storage batteries
Calcium hydroxide	$Ca(OH)_2$	Strong[a]	Plaster, cement; soil neutralizer
Magnesium hydroxide	$Mg(OH)_2$	Strong[a]	Antacid, laxative
Ammonia	NH_3	Weak	Fertilizer, household cleansers

[a]Although these bases are classified as strong, they are not very soluble in water. Calcium hydroxide is only slightly soluble, and magnesium hydroxide is practically insoluble.

Arrhenius further proposed that the essential reaction between an acid and a base, **neutralization**, is the combination of H^+ and OH^- to form water. The cation that was originally associated with the OH^- combines with the anion that was associated with the H^+ to form an ionic compound, a **salt**.

$$\text{An acid} + \text{a base} \longrightarrow \text{a salt} + \text{water}$$

CONCEPTUAL Example 7.1 Ionization of Acids and Bases

Write equations showing **(a)** the ionization of nitric acid (HNO_3) in water and **(b)** the ionization of solid potassium hydroxide (KOH) in water.

Solution

a. An HNO_3 molecule ionizes to form a hydrogen ion and a nitrate ion. Because this reaction occurs in water, we can use the label "(aq)" to indicate that the substances involved are in aqueous solution.

$$HNO_3(aq) \longrightarrow H^+(aq) + NO_3^-(aq)$$

b. Potassium hydroxide (KOH), an ionic solid, simply dissolves in the water, forming separate $K^+(aq)$ and $OH^-(aq)$ ions.

$$KOH(s) \xrightarrow{H_2O} K^+(aq) + OH^-(aq)$$

■ EXERCISE 7.1A

Write equations showing **(a)** the ionization of HBr (hydrobromic acid) in water and **(b)** the ionization of solid calcium hydroxide in water.

■ EXERCISE 7.1B

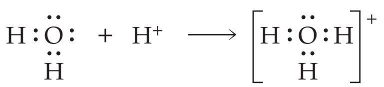
Historically, formulas for carboxylic acids (compounds containing a —COOH group; see Chapter 9) are often written with the ionizable hydrogen *last*. For example, instead of writing the formula for acetic acid as $HC_2H_3O_2$, it can be written as CH_3COOH. Write an equation showing the ionization of CH_3COOH in water.

2. What is an amino acid? An amino acid is a molecule that contains both −COOH, which is acidic, and —NH_2 (an *amino group*; see Sections 9.8 and 9.9), which is basic. Amino acids undergo acid-base reactions with one another and link together to form the proteins in living tissue.

Limitations of the Arrhenius Theory

The Arrhenius theory is limited in several ways.

- A simple free proton does not exist in water solution. The H^+ ion has such a high positive charge density that it is immediately attracted to a lone pair of electrons on an O atom of an H_2O molecule, forming a *hydronium ion*, H_3O^+.



Water Hydronium ion

- It does not explain the basicity of ammonia and related compounds. Ammonia seems out of place in Table 7.2 because it contains no hydroxide ions.
- It applies only to reactions in aqueous solution.

As with many scientific theories, a better one based on newer data has supplanted Arrhenius's theory.

The Brønsted–Lowry Acid–Base Theory

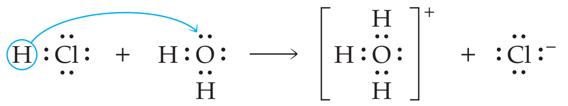
The shortcomings of the Arrhenius theory were largely overcome by a theory proposed in 1923, by J. N. Brønsted in Denmark and T. M. Lowry in Great Britain, who were working independently. In the Brønsted–Lowry theory,

- an acid is a *proton donor*, and
- a base is a *proton acceptor*.

The theory portrays the ionization of hydrogen chloride in this way:

$$HCl(aq) + H_2O \longrightarrow H_3O^+(aq) + Cl^-(aq)$$

Here, water is a reactant. The acid molecules donate hydrogen ions (protons) to the water molecules, so the acid (HCl) acts as a proton donor.



Acid (proton donor) — Hydrochloric acid

In water, an H^+ ion is associated with several H_2O molecules—for example, four H_2O molecules in the ion $H(H_2O)_4^+$, or $H_9O_4^+$. For most purposes, we simply use H^+ and ignore the associated water molecules. However, keep in mind that the notation H^+ is a simplification of the real situation: Protons in water actually exist associated with water molecules.

The HCl molecule donates a proton to a water molecule, producing a hydronium ion and a chloride ion and forming a solution called *hydrochloric acid*. Other acids react similarly; they donate hydrogen ions to water molecules to produce hydronium ions. If we let HA represent any acid, the reaction is written as

$$HA(aq) + H_2O \longrightarrow H_3O^+(aq) + A^-(aq)$$

Even when the solvent is something other than water, the acid acts as a proton donor, transferring H^+ ions to the solvent molecules.

CONCEPTUAL **Example 7.2** Brønsted–Lowry Acids

Write an equation showing the reaction with water of HNO_3 as a Brønsted–Lowry acid. What is the role of water in the reaction?

Solution

As a Brønsted–Lowry acid, HNO_3 donates a proton to a water molecule, forming a hydronium ion and a nitrate ion.

$$HNO_3(aq) + H_2O \longrightarrow H_3O^+(aq) + NO_3^-(aq)$$

The water molecule accepts a proton from HNO_3. Water is a Brønsted–Lowry base in this reaction.

■ EXERCISE 7.2A

Write an equation showing the reaction with water of HBr as a Brønsted–Lowry acid.

■ EXERCISE 7.2B

Write an equation showing the reaction of methanol (CH_3OH) with $HClO_4$ as a Brønsted–Lowry acid.

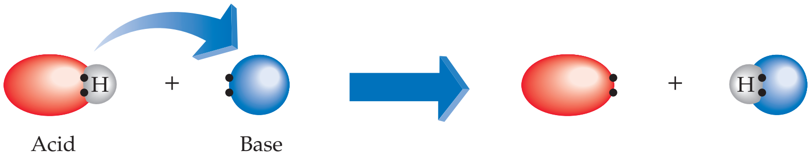
Where does the OH^- come from when bases such as ammonia (NH_3) are dissolved in water? The Arrhenius theory proved inadequate in answering this question, but the Brønsted–Lowry theory explains how ammonia acts as a base in water.

Ammonia is a gas at room temperature. When it is dissolved in water, some of the ammonia molecules react as shown by the following equation.

$$NH_3(aq) + H_2O \longrightarrow NH_4^+(aq) + OH^-(aq)$$

An ammonia molecule accepts a proton from a water molecule; NH_3 acts as a Brønsted–Lowry base. (Recall that the N atom of ammonia has a lone pair of electrons, which it can share with a proton.) The water molecule acts as a proton donor—an acid. The ammonia molecule accepts the proton and becomes an ammonium ion. When a proton leaves a water molecule, it leaves behind the electron pair that it shared with the O atom. The water molecule becomes a negatively charged hydroxide ion.

In general, then, *a base is a proton acceptor* (Figure 7.3). This definition includes not only hydroxide ions but also neutral molecules such as ammonia and *amines* (organic compounds such as CH_3NH_2 that are derived from ammonia). It also includes other negative ions such as the oxide (O^{2-}), carbonate (CO_3^{2-}), and bicarbonate (HCO_3^-) ions. The idea of an acid as a proton donor and a base as a proton acceptor greatly expands our concept of acids and bases.



◀ **Figure 7.3** A Brønsted–Lowry acid is a proton donor. A base is a proton acceptor.

Q: *Can you write an equation in which the acid is represented as HA and the base as :B⁻?*

Salts

Salts, formed from the neutralization reactions of acids and bases, are ionic compounds composed of cations and anions. These ions can be simple ions, such as sodium ion (Na^+) and chloride ion (Cl^-), or polyatomic ions, such as ammonium ion (NH_4^+), sulfate ion (SO_4^{2-}), and acetate ion (CH_3COO^-). Sodium chloride, ordinary table salt, is probably the most familiar salt.

Salts that conduct electricity when dissolved in water are called *electrolytes*. Various electrolytes, in certain amounts, are critical for many bodily functions including nerve conduction, heartbeat, and fluid balance. Medical blood tests often check levels of Na^+, K^+, Cl^-, HCO_3^-, and other electrolyte ions (Chapter 19).

There are many common salts with familiar uses. Sodium chloride and calcium chloride are used to melt ice on roads and sidewalks in winter. Copper(II) sulfate is used to kill tree roots in sewage lines. We will encounter many other examples in later chapters as dietary minerals (Chapter 17), fertilizers (Chapter 20), and more. Table 7.3 lists some salts used in medicine.

Table 7.3 Some Salts with Present or Past Uses in Medicine

Name	Formula	Uses
Silver nitrate	$AgNO_3$	Germicide and antiseptic
Stannous fluoride [tin(II) fluoride]	SnF_2	Toothpaste additive to prevent dental cavities
Calcium sulfate (plaster of Paris)	$(CaSO_4)_2 \cdot H_2O$[a]	Plaster casts
Magnesium sulfate (Epsom salts)	$MgSO_4 \cdot 7H_2O$[a]	Laxative, foot baths
Potassium permanganate	$KMnO_4$	Cauterizing agent, antiseptic
Ferrous sulfate [iron(II) sulfate]	$FeSO_4$	Prescribed for iron deficiency (anemia)
Zinc sulfate	$ZnSO_4$	Skin treatment (eczema)
Barium sulfate	$BaSO_4$	Provides the contrast material in "barium cocktail" given for gastrointestinal X-rays
Mercurous chloride [mercury(I) chloride; calomel]	Hg_2Cl_2	Laxative; no longer used

[a] These compounds are hydrates, substances containing water molecules combined in a definite ratio as an integral part of the compound.

GREEN CHEMISTRY

Principles 1, 4, 7, 9, 10

Irv Levy, *Gordon College*

Sustainability: It's Basic (and Acidic)

Green chemistry is a part of sustainable chemistry. Sustainability, often defined as "meeting the needs of the present generation without compromising the ability of future generations to meet their needs," is much in the news these days. Green chemistry is one of the critical means of attaining sustainability. Understanding of acids and bases has led to greener, more sustainable methods for producing consumer products. Two important examples are soap and renewable biofuels.

Soap traditionally has been made from fats left from cooking meats and from vegetable oils. Fats and oils contain substances composed of three long chains of carbon atoms connected to a central set of three carbon atoms, an arrangement called a *triglyceride* (Chapter 16). To make soap, the fats are heated and mixed with lye solution (aqueous sodium hydroxide—a base). Each mole of triglyceride reacts with three moles of base to produce three moles of soap and one mole of the byproduct glycerol (also called glycerin). Soaps are salts (Section 7.2) of carboxylic acids that usually have a long chain of carbon atoms. An example of a typical soap is sodium palmitate. Its chemical formula is shown here.

$$CH_3(CH_2)_{14}COO^-Na^+$$

The byproduct glycerol has a number of uses, including as a moisturizing ingredient in soap. Chemists at Gordon College (Wenham, MA) found that adding glycerol to the fats and oils traditionally used in soap-making decreased the quantity of starting materials required for soap production. Much more glycerol byproduct is produced industrially than can be used by the soap industry, however, so the search continues for other green uses for glycerol.

The chemistry of biodiesel fuel production (also see Chapter 15) is much like that of soap-making. In both processes, bases are used and glycerol is formed. With the use of methanol (CH_3OH) in place of water and a catalytic amount of base, though, the triglycerides are converted to compounds called *esters* (Section 9.7). An example of a typical biodiesel molecule is shown here.

$$CH_3(CH_2)_{14}COOCH_3$$

Although the long chains of carbon atoms in biodiesel often are the same as in soap molecules, biodiesel molecules have a different group on one end of the chain. Compare these compounds to a typical diesel molecule from petroleum that does not contain any atoms other than carbon and hydrogen.

$$CH_3(CH_2)_{14}CH_3$$

What do soap, biodiesel, and glycerol have to do with sustainability and green chemistry? The first principle of green chemistry encourages the prevention of waste. Sometimes wastes also are harmful to the environment. Wouldn't it be better to redirect apparently useless materials into something useful?

Consider this: Each year billions of gallons of fats and oils are used to fry foods. Fryer oils degrade fairly quickly in commercial kitchens. For many years the used oils were carted off by disposal companies as waste. Today, much of that used oil is converted into biodiesel fuel, providing an alternative fuel that doesn't deplete fossil petroleum reserves. This approach satisfies the green chemistry principle of using renewable resources while providing new use for what was once considered waste. And it gets better! Petroleum diesel fuel is hazardous to humans and toxic to the environment. Biodiesel is much safer.

Acids also are involved in green processes such as cleaning. For example, polylactic acid (PLA) is a type of biodegradable and renewable plastic made from chemicals derived from corn (see green chemistry essay, Chapter 10). PLA plastic, made by companies such as NatureWorks, is found in many consumer materials, such as plastic cups. Research at Simmons College in Boston has led to a new way to convert used PLA cups into an antimicrobial cleaning solution containing lactic acid ($CH_3CHOHCOOH$). The shredded plastic is mixed with alcohol and base to break down the polymer to sodium lactate ($CH_3CHOHCOONa$). The basic sodium lactate solution is neutralized with acid to form the lactic acid cleaner, which is useful for wiping away soap scum.

In the quest for sustaisnability, acids and bases are an essential part of the toolbox that will continue to be used as chemists search for better ways to prevent waste and use renewable starting materials. You might argue that sustainability is basic—not to mention acidic.

▲ Biodiesel is made from waste fats and oils used in cooking. In the past, those wastes would require disposal; now, they are useful. Biodiesel is an excellent example of sustainable chemistry.

Self-Assessment Questions

For Questions 1–5, match each formula with the compound's application.

1. CH_3COOH	(a) battery acid
2. H_3BO_3	(b) soap making
3. HCl	(c) antiseptic eyewash
4. H_2SO_4	(d) remove boiler scale
5. NaOH	(e) vinegar

6. Which of the following equations best represents what happens when hydrogen bromide dissolves in water?

a. $2\ HBr \xrightarrow{H_2O} Br_2 + H_2$ **b.** $HBr(g) \xrightarrow{H_2O} H(aq) + Br(aq)$

c. $HBr \longrightarrow H^+(aq) + Br^-(aq)$ **d.** $HBr(g) + H_2O \longrightarrow Br^-(aq) + H_3O^+(aq)$

For Questions 7–10, match each term with the correct definition.

7. Arrhenius acid	(a) proton acceptor
8. Arrhenius base	(b) proton donor
9. Brønsted acid	(c) produces H^+ in water
10. Brønsted base	(d) produces OH^- in water

Answers: 1, e; 2, c; 3, d; 4, a; 5, b; 6, d; 7, c; 8, d; 9, b; 10, a

7.3 Acidic and Basic Anhydrides

Learning Objective › Identify acidic anhydrides and basic anhydrides, and write equations showing their reactions with water.

Certain metal and nonmetal oxides are well known for their ability to produce or to neutralize acids or bases. For example, nitrogen dioxide (NO_2) and sulfur dioxide (SO_2) are notorious for producing acid rain. Calcium oxide (quicklime, CaO) is widely used to neutralize acidic soils. In the Brønsted–Lowry view, many metal oxides act directly as bases because the oxide ion can accept a proton. These metal oxides also react with water to form metal hydroxides, compounds that are bases in the Arrhenius sense. And many nonmetal oxides react with water to form acids.

Nonmetal Oxides: Acidic Anhydrides

Many acids are made by reacting nonmetal oxides with water. For example, sulfur trioxide reacts with water to form sulfuric acid.

$$SO_3 + H_2O \longrightarrow H_2SO_4$$

Similarly, carbon dioxide reacts with water to form carbonic acid.

$$CO_2 + H_2O \longrightarrow H_2CO_3$$

In general, nonmetal oxides react with water to form acids.

$$\text{Nonmetal oxide} + H_2O \longrightarrow \text{acid}$$

Nonmetal oxides that act in this way are called **acidic anhydrides**. *Anhydride* means "without water." These reactions explain why rainwater is acidic (Section 7.8).

CONCEPTUAL Example 7.3 Acidic Anhydrides

Give the formula for the acid formed when sulfur dioxide reacts with water.

Solution

The formula for the acid, H_2SO_3, is obtained by adding the two H atoms and one O atom of water to SO_2. The equation for the reaction is simply

$$SO_2 + H_2O \longrightarrow H_2SO_3$$

▲ **It DOES Matter!**
Slaked lime is inexpensive, easily made from cheap raw materials, and low in toxicity. These properties make it the most widely used base for neutralizing acids. It is an ingredient in such diverse materials as bricklayer's mortar, plaster, glues, and even pickles and corn tortillas. The whitewash made famous in Mark Twain's *Adventures of Tom Sawyer* was a simple mixture of slaked lime and water.

■ EXERCISE 7.3A
Give the formula for the acid formed when selenium dioxide (SeO_2) reacts with water.

■ EXERCISE 7.3B
Give the formula for the acid formed when dinitrogen pentoxide (N_2O_5) reacts with water. (*Hint:* Two molecules of acid are formed.)

Metal Oxides: Basic Anhydrides

Just as acids can be made from nonmetal oxides, many common hydroxide bases can be made from metal oxides. For example, calcium oxide reacts with water to form calcium hydroxide ("slaked lime").

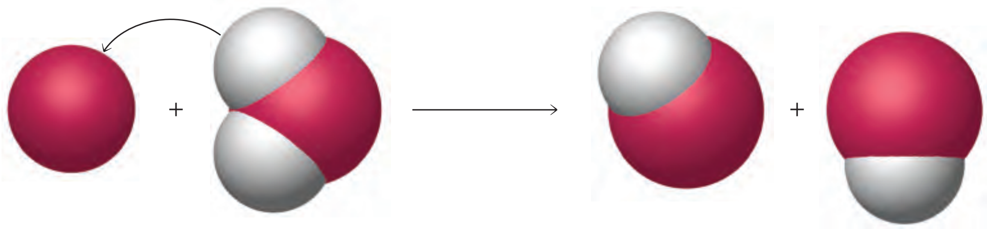
$$CaO + H_2O \longrightarrow Ca(OH)_2$$

Another example is the reaction of lithium oxide with water to form lithium hydroxide.

$$Li_2O + H_2O \longrightarrow 2\,LiOH$$

In general, metal oxides react with water to form bases (Figure 7.4). These metal oxides are called **basic anhydrides**.

$$\text{Metal oxide} + H_2O \longrightarrow \text{base}$$



▲ **Figure 7.4** Metal oxides are basic because the oxide ion reacts with water to form two hydroxide ions.

Q: *Can you write an equation that shows how solid sodium oxide (Na_2O) reacts with water to form sodium hydroxide?*

CONCEPTUAL Example 7.4 Basic Anhydrides

Give the formula for the base formed by the addition of water to barium oxide (BaO).

Solution
Again, we add the atoms of a water molecule to BaO. Because a barium ion has a 2+ charge, the formula for the base has *two* hydroxide (1–) ions.

$$BaO + H_2O \longrightarrow Ba(OH)_2$$

■ EXERCISE 7.4A
Give the formula for the base formed by the addition of water to strontium oxide (SrO).

■ EXERCISE 7.4B
What base is formed by the addition of water to potassium oxide (K_2O)? (*Hint:* Two moles of base are formed for each mole of potassium oxide.)

Self-Assessment Questions

1. Selenic acid (H_2SeO_4) is an extremely corrosive acid that when heated is capable of dissolving gold. It is quite soluble in water. The anhydride of selenic acid is
   a. SeO **b.** SeO_2
   c. SeO_3 **d.** SeO_4
2. Zinc hydroxide [$Zn(OH)_2$] is used as an absorbent in surgical dressings. The anhydride of zinc hydroxide is
   a. ZnO **b.** ZnOH
   c. ZnO_2 **d.** Zn_2O_3

Answers: 1, c; 2, a

7.4 Strong and Weak Acids and Bases

Learning Objective › Define and identify strong and weak acids and bases.

When gaseous hydrogen chloride (HCl) reacts with water, it reacts completely to form hydronium ions and chloride ions.

$$HCl + H_2O \longrightarrow H_3O^+ + Cl^-$$

For many purposes, we simply write this reaction as the ionization of HCl and use (aq) to indicate a solution in water.

$$HCl(aq) \longrightarrow H^+(aq) + Cl^-(aq)$$

Most acids do not ionize completely, however. The poisonous gas hydrogen cyanide (HCN) also ionizes in water to produce hydrogen ions and cyanide ions. But HCN ionizes only to a slight extent. In a solution that has 1 mol of HCN in 1 L of water, only one HCN molecule in 40,000 ionizes to produce a hydrogen ion.

$$HCN(aq) \rightleftharpoons H^+(aq) + CN^-(aq)$$

We represent this slight ionization by using a double arrow. The opposite-pointing arrows indicate that the reaction is reversible; the ions can also combine to form HCN molecules. A short arrow points to the right and a longer arrow points to the left to indicate that most of the HCN remains intact as HCN molecules.

Clearly, acids can be classified according to their extent of ionication.

- An acid such as HCl that ionizes completely in (reacts completely with) water is called a **strong acid**.
- An acid such as HCN that ionizes only slightly in water is a **weak acid**.

The word *strong* does not refer to the *amount* of acid or base in a solution. As mentioned in Section 5.5, a solution that contains a relatively large amount of an acid or a base, whether strong or weak, as the solute in a given volume of solution is called a *concentrated* solution. A solution with only a little solute in that same volume of solution is a *dilute* solution.

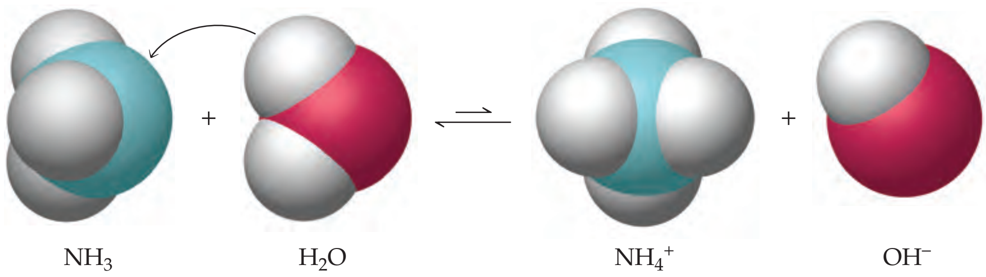
There are only a few strong acids. The first two acids listed in Table 7.1 (sulfuric and hydrochloric) are the common ones. The other strong acids are nitric acid (HNO_3), hydrobromic acid (HBr), hydroiodic acid (HI), and perchloric acid ($HClO_4$). Most acids are weak acids.

Bases are also classified as strong or weak.

- A **strong base** is completely ionized in water.
- A **weak base** is only slightly ionized in water.

Perhaps the most familiar strong base is sodium hydroxide (NaOH), commonly called *lye*. It exists as sodium ions and hydroxide ions even in the solid state. Other strong bases include potassium hydroxide (KOH) and the hydroxides of all the other group 1A metals. Except for $Be(OH)_2$, the hydroxides of group 2A metals are also strong bases. However, $Ca(OH)_2$ is only slightly soluble in water, and $Mg(OH)_2$ is nearly insoluble. The concentration of hydroxide ions in a solution of $Ca(OH)_2$ or $Mg(OH)_2$ is, therefore, not very high.

3. Is vitamin C really an acid? Are all vitamins acids?
Yes, vitamin C is a complex organic compound known as *ascorbic acid.* Some, but not all, vitamins are acids (including folic acid and niacin). Like most acids, these vitamins are weak acids. Not only are they not corrosive but they are necessary to health.



▲ **Figure 7.5** Ammonia is a base because it accepts a proton from water. A solution of ammonia in water contains ammonium ions and hydroxide ions. Only a small fraction of the ammonia molecules react, however; most remain unchanged. Ammonia is therefore a *weak* base.

Q: *Amines are related to ammonia; in an amine, one or more of the H atoms of NH_3 is replaced by a carbon-containing group. Amines react in the same way as ammonia does. Can you write an equation that shows how the amine CH_3NH_2 reacts with water? One product is hydroxide ion.*

The most familiar weak base is ammonia (NH_3). It reacts with water to a slight extent to produce ammonium ions (NH_4^+) and hydroxide ions (Figure 7.5).

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

In its reaction with HCl (page 180), water acts as a base (proton acceptor). In its reaction with NH_3, water acts as an acid (proton donor). A substance such as water that can either donate a proton or accept a proton is said to be *amphiprotic* (see also Additional Problem 65).

Self-Assessment Questions

For Questions 1–7, select the correct classification (more than one substance may fit into a given classification).

1. $Ca(OH)_2$ — (a) strong acid
2. HCN — (b) strong base
3. HF — (c) weak acid
4. HNO_3 — (d) weak base
5. H_3PO_4
6. KOH
7. NH_3

8. Acetic acid reacts with water to form
a. $CH_3COO^+ + H_2O$ **b.** $CH_3COOH + OH^-$
c. $CH_3COO^- + H_3O^-$ **d.** $CH_3COO^+ + OH^-$

9. Ammonia reacts with water to form
a. $NH_3 + H_2O$ **b.** $NH_4^+ + OH^-$
c. $NH_2^- + H_3O^+$ **d.** $NH_3 + OH^-$

Answers: 1, b; 2, c; 3, c; 4, a; 5, c; 6, b; 7, d; 8, c; 9, b

7.5 Neutralization

Learning Objective › Identify the reactants and predict the products in a neutralization reaction.

When an acid reacts with a base, the products are water and a salt. If a solution containing hydrogen ions (an acid) is mixed with another solution containing exactly the same amount of hydroxide ions (a base), the resulting solution does not change the color of litmus, dissolve zinc or iron, or feel slippery on the skin. It is no longer either acidic or basic. It is neutral. As was mentioned earlier, the reaction of an acid with a base is called *neutralization* (Figure 7.6).

$$H^+ + OH^- \longrightarrow H_2O$$

(a) (b) (c)

◀ **Figure 7.6** The amount of acid (or base) in a solution is determined by careful neutralization. Here a 5.00-mL sample of vinegar, some water, and a few drops of phenolphthalein (an acid–base indicator) are placed in a flask (a). A solution of 0.1000 M NaOH is added to the flask slowly from a buret (a device for precise measurement of volumes of solutions) (b). As long as the acid is in excess, the solution is colorless. When the acid has been neutralized and a tiny excess of base is present, the phenolphthalein indicator turns pink (c).

Q: *Can you write an equation for the reaction of acetic acid (CH_3COOH), the acid in vinegar, with aqueous NaOH?*

If sodium hydroxide is neutralized by hydrochloric acid, the products are water and sodium chloride (ordinary table salt)

$$\overset{\text{A base}}{\mathrm{NaOH(aq)}} + \overset{\text{An acid}}{\mathrm{HCl(aq)}} \longrightarrow \overset{\text{A salt}}{\mathrm{NaCl(aq)}} + \overset{\text{Water}}{\mathrm{H_2O}}.$$

Example 7.5 Neutralization Reactions

Potassium nitrate, a component of black powder gunpowder and some fertilizers, was obtained from the late Middle Ages through the nineteenth century by precipitation from urine. Commonly called *saltpeter*, it can be prepared by the reaction of nitric acid with potassium hydroxide. Write the equation for this neutralization reaction.

Solution

The OH^- from the base and the H^+ from the acid combine to form water. The cation of the base (K^+) and the anion of the acid (NO_3^-) form a solution of the salt (potassium nitrate, KNO_3).

$$\mathrm{KOH(aq) + HNO_3(aq) \longrightarrow KNO_3(aq) + H_2O(l)}$$

■ EXERCISE 7.5A

Countertop spills of lye solutions (aqueous sodium hydroxide) can be neutralized with vinegar (aqueous acetic acid; see Table 7.1). Write the equation for the neutralization reaction.

■ EXERCISE 7.5B

A toilet-bowl cleaner contains hydrochloric acid. An emergency first-aid treatment for accidental ingestion is a teaspoon of milk of magnesia (magnesium hydroxide). Write the equation for the neutralization reaction between magnesium hydroxide and hydrochloric acid. (*Hint:* Be sure to write the correct formulas for the reactants and the salt before attempting to balance the equation.)

4. What is the difference between salt and sodium? A salt is any ionic compound formed by reacting an acid and a base. In everyday life, *salt* usually means table salt—sodium chloride (NaCl). Sodium is a highly reactive metal element. Sodium ions are essential for life, but you wouldn't want to eat pure sodium. It reacts violently with water.

Self-Assessment Questions

1. When equal amounts of acids and bases are mixed,
   - **a.** the acid becomes stronger
   - **b.** the base becomes stronger
   - **c.** no reaction occurs
   - **d.** they neutralize each other
2. What amount in moles of hydrochloric acid is needed to neutralize 1.5 mol of sodium hydroxide?
   - **a.** 1 mol
   - **b.** 1.5 mol
   - **c.** 3.0 mol
   - **c.** 4.5 mol

3. What amount in moles of hydrochloric acid is needed to neutralize 2.4 mol of calcium hydroxide?
   a. 1.2 mol **b.** 2.4 mol
   c. 3.0 mol **d.** 4.8 mol

4. What amount in moles of sodium hydroxide is needed to neutralize 1.5 mol of phosphoric acid?
   a. 0.5 mol **b.** 3.0 mol
   c. 4.5 mol **d.** 6.0 mol

Answers: 1, d; 2, b; 3, d; 4, c

7.6 The pH Scale

Learning Objectives › Describe the relationship between the pH of a solution and its acidity or basicity. › Find the molar concentration of hydrogen ion, $[H^+]$, from a pH value or the pH value from $[H^+]$.

Table 7.4 Relationship between pH and Concentration of H^+ Ion

Concentration of H^+(mol/L)	pH
1×10^{-0}	0
1×10^{-1}	1
1×10^{-2}	2
1×10^{-3}	3
1×10^{-4}	4
1×10^{-5}	5
1×10^{-6}	6
1×10^{-7}	7
1×10^{-8}	8
1×10^{-9}	9
1×10^{-10}	10
1×10^{-11}	11
1×10^{-12}	12
1×10^{-13}	13
1×10^{-14}	14

The relationship between pH and $[H^+]$ is perhaps easier to see when the equation is written in the following form. $[H^+] = 10^{-pH}$

In solutions, the concentrations of ions are expressed in moles per liter (molarity; see Section 5.5). Because hydrogen chloride is completely ionized in water, a 1 molar solution of hydrochloric acid (1 M HCl), for example, contains 1 mol H^+ ions per liter of solution. Likewise, 1 L of 3 M HCl contains 3 mol H^+ ions, and 0.500 L of 0.00100 M HCl contains 0.500 L $\times$ 0.00100 mol/L = 0.000500 mol H^+ ions.

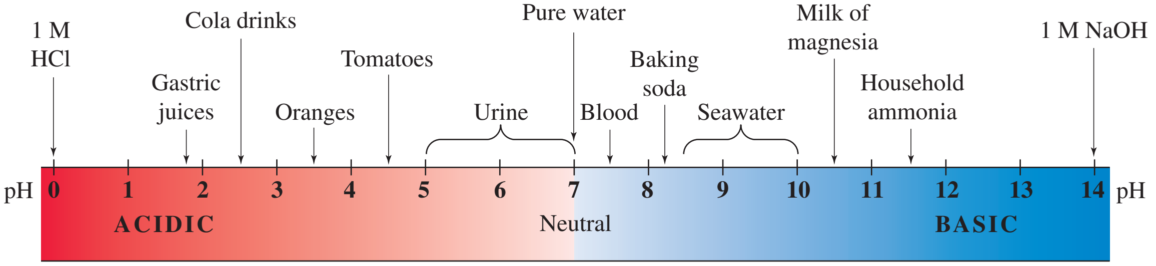
We can describe the acidity of a particular solution in moles per liter: The hydrogen ion concentration of a 0.00100 M HCl solution is 1×10^{-3} mol/L. However, exponential notation isn't very convenient. More often, the acidity of this solution is reported simply as pH 3.

We usually use the **pH** scale, first proposed in 1909 by the Danish biochemist S. P. L. Sørensen, to describe the degree of acidity or basicity. Most solutions have a pH that lies in the range from 0 to 14. The neutral point on the scale is 7, with values below 7 indicating increasing acidity and those above 7 increasing basicity. Thus, pH 6 is slightly acidic, whereas pH 12 is strongly basic (Figure 7.7).

The numbers on the pH scale are directly related to the hydrogen ion concentration. We might expect pure water to be completely in the form of H_2O molecules, but it turns out that about 1 out of every 500 million water molecules splits into H^+ and OH^- ions. This gives a concentration of hydrogen ion and of hydroxide ion in pure water of 0.0000001 mol/L, or 1×10^{-7} M. Can you see why 7 is the pH of pure water? It is simply the power of 10 for the molar concentration of H^+, with the negative sign removed. (The H in pH stands for "hydrogen," and the p for "power.") Thus, pH is defined as the negative logarithm of the molar concentration of hydrogen ion (refer to Table 7.4):

$$pH = -\log[H^+]$$

The brackets around H^+ mean "molar concentration."



▲ **Figure 7.7** The pH scale. A change in pH of one unit means a tenfold change in the hydrogen ion concentration.

Q: *Are tomatoes more acidic or less acidic than oranges? About how many times more (or less) acidic?*

Table 7.5 Approximate pH Values of Some Common Solutions

Solution	pH
Hydrochloric acid (4%)	0
Gastric juice	1.6–1.8
Soft drink	2.0–4.0
Lemon juice	2.1
Vinegar (4%)	2.5
Urine	5.5–7.0
Rainwater[a]	5.6
Saliva	6.2–7.4
Milk	6.3–6.6
Pure water	7.0
Blood	7.4
Fresh egg white	7.6–8.0
Bile	7.8–8.6
Milk of magnesia	10.5
Washing soda	12.0
Sodium hydroxide (4%)	13.0

[a] Saturated with carbon dioxide from the atmosphere but unpolluted.

▲ A pH meter is a device for determining pH quickly and accurately.

Q: *Is the solution in the beaker more basic or less basic than household ammonia? (Refer to Figure 7.7.)*

Although pH is an acidity scale, note that its value goes down when acidity goes up. Not only is the relationship an inverse one, but it is also logarithmic. A decrease of 1 pH unit represents a tenfold increase in acidity, and when pH goes down by 2 units, acidity increases by a factor of 100. This relationship may seem strange at first, but once you understand the pH scale, you will appreciate its convenience.

Table 7.4 summarizes the relationship between hydrogen ion concentration and pH. A pH of 4 means a hydrogen ion concentration of 1×10^{-4} mol/L, or 0.0001 M. If the concentration of hydrogen ions is 0.01 M, or 1×10^{-2} M, the pH is 2. Typical pH values for various common solutions are listed in Table 7.5.

5. What is meant by "pH-balanced shampoo"? Shampoo on either end of the pH scale would damage hair (and probably skin as well!). Most shampoos are formulated to be neutral (pH 7) or slightly basic.

Example 7.6 pH from Hydrogen Ion Concentration

What is the pH of a solution that has a hydrogen ion concentration of 1×10^{-5} M?

Solution

The hydrogen ion concentration is 1×10^{-5} M. The exponent is -5; the pH is, therefore, the negative of this exponent: $-(-5)$ or 5.

■ EXERCISE 7.6A

What is the pH of a solution that has a hydrogen ion concentration of 1×10^{-9} M?

■ EXERCISE 7.6B

What is the pH of a solution that is 0.010 M HCl? (*Hint:* HCl is a strong acid.)

Example 7.7 Finding Hydrogen Ion Concentration from pH

What is the hydrogen ion concentration of a solution that has a pH of 4?

Solution

A pH value of 4 means that the exponent of 10 is -4. The hydrogen ion concentration is, therefore, 1×10^{-4} M.

■ EXERCISE 7.7A

What is the hydrogen ion concentration of a solution that has a pH of 2?

■ EXERCISE 7.7B

What is the hydrogen ion concentration of a HI solution that has a pH of 3? (*Hint:* HI is a strong acid.)

CONCEPTUAL Example 7.8 Estimating pH from Hydrogen Ion Concentration

Which of the following is a reasonable pH for a solution that is 8×10^{-4} M in H^+?

a. 2.9 **b.** 3.1 **c.** 4.2 **d.** 4.8

Solution

The $[H^+]$ is greater than 1×10^{-4} M, and so the pH must be less than 4. That rules out answers (c) and (d). The $[H^+]$ is less than 10×10^{-4} (or 1×10^{-3} M), and so the pH must be greater than 3. That rules out answer (a). The only reasonable answer is (b), a value between 3 and 4.

(With a scientific calculator, you can calculate the actual pH, usually with the following keystrokes: 8 exp 4 ± log This gives a value of −3.1 for the log of 8×10^{-4}. Because pH is the *negative* log of the H^+ concentration, the pH value is 3.1.)

■ EXERCISE 7.8

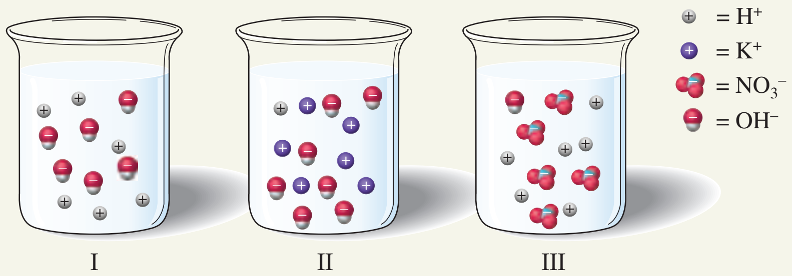
Which of the following is a reasonable pH for a solution that is 2×10^{-10} M in H^+?

a. 2.0 **b.** 8.7 **c.** 9.7 **d.** 10.2

It's not obvious right away, but every aqueous solution contains *both* hydrogen ions and hydroxide ions. An acidic solution contains more H^+ ions than OH^- ions. For example, a solution with a pH of 4 is 1×10^{-4} M in H^+ ions but only 1×10^{-10} M in OH^- ions. On the other hand, a basic solution contains more OH^- ions than H^+ ions. A solution with a pH of 12 is 1×10^{-12} M in H^+ ions and 1×10^{-2} M in OH^- ions. And a neutral solution contains equal concentrations of H^+ ions and OH^- ions; both are 1×10^{-7} M.

CONCEPTUAL Example 7.9 Hydrogen and Hydroxide Ions in Acids and Bases

Classify the three aqueous solutions shown below as acidic, basic, or neutral. (Water molecules are not shown.)



Solution

Beaker I contains equal numbers of OH^- ions and H^+ ions—six of each—so that solution is neutral. Beaker II contains more OH^- ions (seven) than H^+ ions (one), so its solution is basic. Beaker III contains six H^+ ions and one OH^- ion; the solution is acidic.

■ EXERCISE 7.9

What is the formula of the compound that was dissolved in Beaker III of Example 7.9? What is the formula of the compound that was dissolved in Beaker II?

Self-Assessment Questions

1. The hydrogen ion concentration, $[H^+]$, of a 0.0010 M HNO_3 solution is
   a. 1.0×10^{-4} M **b.** 1.0×10^{-3} M
   c. 1.0×10^{-2} M **d.** 10 M
2. What is the pH of a solution that has a hydrogen ion concentration of 1.0×10^{-11} M?
   a. 1.0 **b.** 3 **c.** 10 **d.** 11
3. Swimming pool water with a pH of 8 has a hydrogen ion concentration of
   a. 8.0 M **b.** 8.0×10^{-8} M
   c. 1.0×10^{-8} M **d.** 1.0×10^{8} M
4. The pH of pure water is
   a. 0 **b.** 1 **c.** 7 **d.** 10 **e.** 14
5. Which of the following is a reasonable pH for 0.15 M HCl?
   a. 0.15 **b.** 0.82 **c.** 8.24 **d.** 13.18
6. Which of the following is a reasonable pH for 0.15 M NaOH?
   a. 0.15 **b.** 0.82 **c.** 8.24 **d.** 13.18
7. Physiological pH (7.4) is the average pH of blood. Which of the following is a reasonable hydrogen ion concentration of a solution at physiological pH?
   a. −7.4 M **b.** 0.6 M **c.** 6×10^{-7} M
   d. 1×10^{-8} M **e.** 4×10^{-8}

Answers: 1, b; 2, d; 3, c; 4, c; 5, b; 6, d; 7, e

7.7 Buffers and Conjugate Acid–Base Pairs

Learning Objectives › Write the formula for the conjugate base of an acid or for the conjugate acid of a base. › Describe the action of a buffer.

In the Brønsted–Lowry theory, a pair of compounds or ions that differ by one proton (H^+) is called a **conjugate acid–base pair**. HF and F^- are a conjugate acid-base pair, as are NH_3 and NH_4^+. When a base (for example, NH_3) accepts a proton, it becomes an acid because it now has a proton that it can donate. NH_4^+ is an acid; it can donate its "extra" proton. Similarly, when an acid (for example, HF) donates a proton, it becomes a base, because it can now accept a proton. F^- is a base; it can accept a proton.

CONCEPTUAL Example 7.10 Conjugate Acid–Base Pairs

What is the conjugate base **(a)** of HBr and **(b)** of HNO_3? What is the conjugate acid **(c)** of OH^- and **(d)** of HSO_4^-?

Solution

a. Removing a proton from HBr leaves Br^-; the conjugate base of HBr is Br^-.
b. Removing a proton from HNO_3 leaves NO_3^-; the conjugate base of HNO_3 is NO_3^-.
c. Adding a proton to OH^- gives H_2O; the conjugate acid of OH^- is H_2O.
d. Adding a proton to HSO_4^- gives H_2SO_4; the conjugate acid of HSO_4^- is H_2SO_4.

■ EXERCISE 7.10

What is the conjugate base **(a)** of HCN and **(b)** of H_3O^+? What is the conjugate acid **(c)** of SO_4^{2-} and **(d)** of HCO_3^-?

Buffer Solutions

A **buffer solution** maintains an almost constant pH when small amounts of a strong acid or a strong base are added to it. Buffer solutions have many important applications in industry, in the laboratory, and in living organisms because some chemical reactions consume acids, others produce acids, and many are catalyzed by acids[1]. A buffer solution consists of a weak acid and its conjugate base (for example, $HC_2H_3O_2$ and $C_2H_3O_2^-$) or a weak base and its conjugate acid (for example, NH_3 and NH_4^+).

Consider the equation for the ionization of acetic acid, in which the double arrow indicates the slight extent to which the acid ionizes.

$$HC_2H_3O_2(aq) \rightleftharpoons H^+(aq) + C_2H_3O_2^-(aq)$$

If we add sodium acetate to a solution of acetic acid, we are adding the conjugate base of acetic acid—that is, acetate ion—thus forming a buffer solution. If we add a little strong base to this solution, it will react with the weak acid.

$$OH^- + HC_2H_3O_2 \longrightarrow H_2O + C_2H_3O_2^-$$

Do you see that the solution no longer contains the strong base? Instead, it has a little more weak base and a little less weak acid than it did before the strong base was added. The pH remains very nearly constant. Likewise, if a little strong acid is added, it will react with the weak base.

$$H^+ + C_2H_3O_2^- \longrightarrow HC_2H_3O_2$$

The strong acid is consumed, a weak acid is formed, and the solution pH increases slightly. This behavior of buffered solutions contrasts sharply with that of unbuffered solutions, in which any added strong acid or base changes the pH greatly.

A dramatic and essential example of the action of buffers is found in our blood. Blood must maintain a pH very close to 7.4 or it cannot carry oxygen from the lungs to cells. The most important buffer for maintaining acid–base balance in the blood is the carbonic acid–bicarbonate ion (H_2CO_3/HCO_3^-) buffer.

Self-Assessment Questions

1. Which of the following pairs is a conjugate acid–base pair?
   a. CH_3COOH and OH^- **b.** HCN and CN^-
   c. HCN and OH^- **d.** HCl and OH^-
2. Which of the following is *not* a conjugate acid–base pair?
   a. CH_3COO^- and CH_3COOH **b.** F^- and HF
   c. H_2O and H_3O^+ **d.** NH_3 and H_3O^+
3. A buffer solution is made from formic acid (HCOOH) and sodium formate (HCOONa). Added acid will react with
   a. $HCOO^-$ **b.** HCOOH
   c. Na^+ **d.** OH^-
4. Which of the following pairs could form a buffer?
   a. C_6H_5COOH and C_6H_5COONa **b.** HCl and NaCl
   c. HCl and NaOH **d.** NH_3 and NO_3^-

Answers: 1, b; 2, d; 3, a; 4, a

7.8 Acids and Bases in Industry and in Daily Life

Learning Objective › Describe everyday uses of acids and bases and how they affect daily life.

Acids and bases play an important role in our bodies, in medicine, in our homes, and in industry, they are useful products in many ways, As industrial by-products, they can damage the environment. Their use requires caution, and their misuse can be dangerous to human health.

[1]A *catalyst* is a substance or mixture that speeds up a reaction. Unlike a reactant, a catalyst can be recovered unchanged after the reaction is complete, and ordinarily it can be reused. For example, the breakdown of some flavoring components of fruits is catalyzed by acid, and the formation of biodiesel fuel from waste oil is catalyzed by a strong base such as sodium hydroxide.

Acid Rain

Carbon dioxide is the anhydride of carbonic acid (Section 7.3). Raindrops falling through the air absorb CO_2, which is converted to H_2CO_3 in the drops. Rainwater is thus a dilute solution of carbonic acid, a weak acid. Rain saturated with carbon dioxide has a pH of 5.6. In many areas of the world, particularly those downwind from industrial centers, rainwater is much more acidic, with a pH as low as 3 or less. Rain with a pH below 5.6 is called **acid rain**.

Acid rain is due to acidic pollutants in the air. As we shall see in Chapter 13, several air pollutants are acid anhydrides. These include sulfur dioxide (SO_2), mainly from the burning of high-sulfur coal in power plants and metal smelters, and nitrogen dioxide (NO_2) and nitric oxide (NO), from automobile exhaust fumes.

Some acid rain is due to natural pollutants, such as those resulting from volcanic eruptions and lightning. Volcanoes give off sulfur oxides and sulfuric acid, and lightning produces nitrogen oxides and nitric acid from nitrogen, oxygen, and water in the air.

Acid rain is an important environmental problem that involves both air pollution (Chapter 13) and water pollution (Chapter 14). It can have serious effects on plant and animal life.

Antacids: A Basic Remedy

The stomach secretes hydrochloric acid to aid in the digestion of food. Sometimes overindulgence or emotional stress leads to *hyperacidity* (too much acid is secreted). Hundreds of brands of antacids (Figure 7.8) are sold in the United States to treat this condition. Despite the many brand names, there are only a few different antacid ingredients, all of which are bases. Common ingredients are sodium bicarbonate, calcium carbonate, aluminum hydroxide, magnesium carbonate, and magnesium hydroxide. Even a single brand name often encompasses a variety of products. For example, there are more than a dozen varieties of Alka-Seltzer®.

Sodium bicarbonate ($NaHCO_3$), commonly called *baking soda*, was one of the first antacids and is still used occasionally. It is the principal antacid in most forms of Alka-Seltzer for heartburn relief. The bicarbonate ions react with the acid in the stomach to form carbonic acid, which then breaks down to carbon dioxide and water.

$$HCO_3^-(aq) + H^+(aq) \longrightarrow H_2CO_3(aq)$$

$$H_2CO_3(aq) \longrightarrow CO_2(g) + H_2O(l)$$

The $CO_2(g)$ is largely responsible for the burps that bicarbonate-containing antacids produce. Overuse of sodium bicarbonate can make the blood too alkaline,

You can make your own aspirin-free "Alka-Seltzer." Simply place half a teaspoon of baking soda in a glass of orange juice. (What is the acid and what is the base in this reaction?)

◀ **Figure 7.8** Claims that antacids are "fast acting" are almost meaningless because most common acid–base reactions are almost instantaneous. Some tablets may dissolve a little more slowly than others. You can speed their action by chewing them.

Why Doesn't Stomach Acid Dissolve the Stomach?

We know that strong acids are corrosive to skin. Look back at Table 7.1 and you will see that the gastric juice in your stomach is extremely acidic. Gastric juice is a solution containing about 0.5% hydrochloric acid. Why doesn't the acid in your stomach destroy your stomach lining? The cells that line the stomach are protected by a layer of mucus, a viscous solution of a sugar–protein complex called *mucin* and other substances in water. The mucus serves as a physical barrier, but its role is broader than that. The mucin acts like a sponge that soaks up bicarbonate ions from the cells lining the stomach and hydrochloric acid from within the stomach. The bicarbonate ions neutralize the acid within the mucus.

It used to be thought that stomach acid was the cause of ulcers, but it is now known that the acid plays only a minor role in ulcer formation. Research has shown that most ulcers develop as a result of infection with a bacterium called *Helicobacter pylori* (*H. pylori*) that damages the mucus, exposing cells in the stomach lining to the harsh stomach acid. Other agents, such as aspirin and alcohol, may be contributing factors to the development of ulcers. Treatment usually involves antibiotics that kill *H. pylori.*

▲ Drugs such as ranitidine (Zantac™), famotidine (Pepcid AC™), cimetidine (Tagamet HB™), and omeprazole (Prilosec) are not antacids. Rather than neutralizing stomach acid, these drugs act on cells in the lining of the stomach, reducing the amount of acid that is produced.

a condition called **alkalosis**. Also, antacids that contain sodium ion are not recommended for people with hypertension (high blood pressure).

Calcium carbonate ($CaCO_3$) is safe in small amounts, but regular use can cause constipation. Also, taking large amounts of calcium carbonate can actually result in increased acid secretion after a few hours. Tums® and many store brands of antacids have calcium carbonate as the only active ingredient.

Aluminum hydroxide $[Al(OH)_3]$, like calcium carbonate, can cause constipation. There is also some concern that antacids containing aluminum ions can deplete the body of essential phosphate ions. Aluminum hydroxide is the active ingredient in Amphojel®.

A suspension of magnesium hydroxide $[Mg(OH)_2]$ in water is sold as *milk of magnesia*. Magnesium carbonate ($MgCO_3$) is also used as an antacid. These magnesium compounds act as antacids in small doses, but as laxatives in large doses.

Many antacid products have a mixture of antacids. Rolaids® and Mylanta® contain calcium carbonate and magnesium hydroxide. Maalox® liquid has aluminum hydroxide and magnesium hydroxide. These products balance the tendency of magnesium compounds to cause diarrhea with that of aluminum and calcium compounds to cause constipation.

Although antacids are generally safe for occasional use, they can interact with other medications. Anyone who has severe or repeated attacks of indigestion should consult a physician. Self-medication can sometimes be dangerous.

Acids and Bases in Industry and at Home

Sulfuric acid is by far the leading chemical product in both the United States (average production of about 40 billion kg each year) and the world (over 200 billion kg annually). Most of it is used for making fertilizers and other industrial chemicals. Around the home, we use sulfuric acid in automobile batteries and in some special kinds of drain cleaners.

Hydrochloric acid is used in industry to remove rust from metal, in construction to remove excess mortar from bricks and etch concrete for painting, and in the home to remove lime deposits from fixtures and toilet bowls. The product used in the home is often called *muriatic acid*, an old name for hydrochloric acid. Concentrated solutions (about 38% HCl) cause severe burns, but dilute solutions can be used safely in the home if handled carefully. Yearly production of hydrochloric acid is more than 4 billion kg in the United States and about 20 billion kg worldwide.

Lime (CaO) is the cheapest and most widely used commercial base. It is made by heating limestone ($CaCO_3$) to drive off CO_2.

$$CaCO_3(s) + \text{heat} \longrightarrow CaO(s) + CO_2(g)$$

Yearly production of calcium oxide is about 22 billion kg in the United States and about 280 billion kg worldwide. Adding water to lime forms calcium hydroxide $[Ca(OH)_2]$, or slaked lime, which is generally safer to handle. Slaked lime is used in agriculture and to make mortar and cement.

Sodium hydroxide (NaOH, lye) is the strong base most often used in the home. It is employed in products such as Easy Off® for cleaning ovens, in products such as Drano® for unclogging drains, and to make both commercial and homemade soaps. Yearly U.S. production of sodium hydroxide is about 9 billion kg.

Ammonia (NH_3) is produced in huge volume, mainly for use as fertilizer. Yearly U.S. production is nearly 11 billion kg. Ammonia is used around the home in a variety of cleaning products (Chapter 21).

▲ It DOES Matter!
The proper pH is as important for plant growth as fertilizer is. Soil that is "sour," or too acidic, is "sweetened" by adding slaked lime (calcium hydroxide). A few plants, such as blueberries and citrus fruit, require acidic soil, and an acid such as vinegar may have to be periodically added to the soil they grow in.

Acids and Bases in Health and Disease

When they are misused, acids and bases can be damaging to human health. Concentrated strong acids and bases are corrosive poisons (Chapter 22) that can cause serious chemical burns. Once the chemical agents are removed, these injuries resemble burns caused by heat and are often treated in the same way. Besides being a strong acid, sulfuric acid is also a powerful dehydrating agent that can react with water in the cells.

Strong acids and bases, even in dilute solutions, break down, or *denature*, the protein molecules in living cells, much as cooking does. Generally, the fragments are not able to carry out the functions of the original proteins. If exposure to the acid or base is sustained, this fragmentation continues until the tissue has been completely destroyed.

Acids and bases affect human health in more subtle ways. A delicate balance between acids and bases must be maintained in the blood, other body fluids, and cells. If the acidity of the blood changes too much, the blood loses its capacity to carry oxygen. In living cells, proteins function properly only at an optimal pH. If the pH changes too much in either direction, the proteins can't carry out their functions. Fortunately, the body has a complex but efficient mechanism for maintaining a proper acid–base balance.

▲ Safety Alert
Concentrated acids and bases can cause severe burns and are especially damaging to the eyes. Use great care in working with them. Always follow directions carefully. Wear chemical-splash safety goggles to protect your eyes and clothing that will protect your skin and clothes.

Self-Assessment Questions

1. Which of the following is a common ingredient in antacids?
- **a.** $CaCO_3$
- **b.** $Ca(OH)_2$
- **c.** HCl
- **d.** KOH

2. When a person with excess stomach acid takes an antacid, the pH of the person's stomach changes
- **a.** from a low value to a value nearer 7
- **b.** from 7 to a much higher value
- **c.** from a low value to an even lower value
- **d.** from a high value to a lower value

3. The leading chemical product of U.S. industry is
- **a.** ammonia
- **b.** lime
- **c.** pesticides
- **d.** sulfuric acid

4. The acid used in automobile batteries is
- **a.** citric acid
- **b.** hydrochloric acid
- **c.** nitric acid
- **d.** sulfuric acid

5. The base often used in soap making is
- **a.** $Ca(OH)_2$
- **b.** $Mg(OH)_2$
- **c.** NaOH
- **d.** NH_3

Answers: 1, a; 2, a; 3, d; 4, d; 5, c

CRITICAL THINKING EXERCISES

Apply knowledge that you have gained in this chapter and one or more of the FLaReS principles (Chapter 1) to evaluate the following statements or claims.

7.1 A television advertisement claimed that the antacid Maalox neutralizes stomach acid faster and, therefore, relieves heartburn faster than Pepcid AC®, a drug that inhibits the release of stomach acid. To illustrate this claim, two flasks of acid were shown. In one, Maalox rapidly neutralized the acid. In the other, Pepcid AC did not neutralize the acid.

7.2 Some people claim that putting salt on grapefruit takes away a little of the acidity.

7.3 Testifying in a court case, a witness makes the following statement: "Although runoff from our plant did appear to contaminate a stream, the pH of the stream before the contamination was 6.4, and after contamination it was 5.4. So the stream is now only slightly more acidic than before."

7.4 A Jamaican fish recipe calls for adding the juice of several limes to the fish, but no heat is used to cook the fish. The directions state that the lime juice in effect "cooks" the fish.

7.5 An advertisement claims that vinegar in a glass-cleaning product will remove the spots left on glasses by tap water. The spots are largely calcium carbonate deposits.

SUMMARY

Section 7.1—Acids taste sour, turn litmus red, and react with active metals to form hydrogen. Bases taste bitter, turn litmus blue, and feel slippery to the skin. Acids and bases react to form salts and water. An **acid–base indicator** such as litmus has different colors in acid and in base and is used to determine whether solutions are acidic or basic.

Section 7.2—According to Arrhenius's definition, an *acid* produces hydrogen ions (H^+, also called protons) in aqueous solution, and a *base* produces hydroxide ions (OH^-). **Neutralization** is the combination of H^+ and OH^- to form water. The anion and cation that were associated with H^+ and OH^- ions combine to form an ionic **salt**. In the more general Brønsted–Lowry acid–base theory, an **acid** is a proton donor and a **base** is a proton acceptor. When a Brønsted–Lowry acid dissolves in water, the H_2O molecules pick up H^+ to form hydronium ions (H_3O^+). A Brønsted–Lowry base in water accepts a proton from a water molecule, forming OH^-.

Section 7.3—Some nonmetal oxides (such as CO_2 and SO_3) are **acidic anhydrides** in that they react with water to form acids. Some metal oxides (such as Li_2O and CaO) are **basic anhydrides**; they react with water to form bases.

Section 7.4—A **strong acid** is one that ionizes completely in water to form H^+ ions and anions. A **weak acid** ionizes only slightly in water; most of the acid exists as intact molecules. Common strong acids are sulfuric, hydrochloric, and nitric acids. Likewise, a **strong base** is completely ionized in water, and a **weak base** is only slightly ionized. Sodium hydroxide and potassium hydroxide are common strong bases.

Section 7.5—The reaction between an acid and a base is called *neutralization*. In aqueous solution, it is the combination of H^+ and OH^- that forms water. The other anions and cations form an ionic salt.

Section 7.6—The **pH** scale indicates the degree of acidity or basicity; pH is defined as $pH = -\log[H^+]$, where $[H^+]$ is the molar concentration of hydrogen ion. A pH of 7 ($[H^+] = 1 \times 10^{-7}$ M) is neutral; pH values lower than 7 represent increasing acidity, and pH values greater than 7 represent increasing basicity. A change in pH of one unit represents a tenfold change in $[H^+]$.

Section 7.7—A pair of compounds or ions that differ by one proton (H^+) is called a **conjugate acid–base pair**. A **buffer solution** is a mixture of a weak acid and its conjugate base or a weak base and its conjugate acid. A buffer maintains a nearly constant pH when a small amount of a strong acid or a strong base is added.

Section 7.8—An antacid is a base such as sodium bicarbonate, magnesium hydroxide, aluminum hydroxide, or calcium carbonate that is taken to relieve hyperacidity. Overuse of some antacids can make the blood too alkaline (basic), a condition called **alkalosis**. **Acid rain** is rain with a pH less than 5.6. The acidity is due to sulfur oxides and nitrogen oxides from natural sources as well as industrial air pollution and automobile exhaust fumes. Acid rain can have serious effects on plant and animal life. Sulfuric acid is the number one chemical produced in the United States and is used for making fertilizers and other industrial chemicals. Hydrochloric acid is used for rust removal and etching mortar and concrete. Lime (calcium oxide) is made from limestone and is the cheapest and most widely used base. It is an ingredient in plaster and cement and is used in agriculture. Sodium hydroxide is used to make many industrial products, as well as soap. Amm onia is a weak base produced mostly for use as fertilizer. Concentrated strong acids and bases are corrosive poisons that can cause serious burns. Living cells have an optimal pH that is necessary for the proper functioning of proteins.

Green chemistry Base is used to convert renewable fats and oils into products such as soaps and biofuels. Treatment with acid can decompose special plastics (such as polylactic acid, PLA) into a useful antimicrobial cleaner. Application of the Twelve Principles of Green Chemistry can guide us to find practical uses for materials that were once considered waste.

Learning Objectives

› Distinguish between acids and bases using their chemical and physical properties. (7.1)	Problems 1, 26, 27
› Explain how an acid–base indicator works. (7.1)	Problem 2
› Identify Arrhenius and Brønsted–Lowry acids and bases. (7.2)	Problems 4, 12–22, 59
› Write a balanced equation for a neutralization or an ionization. (7.2)	Problems 8, 39–46, 60, 67
› Identify acidic and basic anhydrides, and write equations showing their reactions with water. (7.3)	Problems 7, 29, 30
› Define and identify strong and weak acids and bases. (7.4)	Problems 5, 9, 10, 31–38, 61
› Identify the reactants and predict the products in a neutralization reaction. (7.5)	Problems 43–46
› Describe the relationship between the pH of a solution and its acidity or basicity. (7.6)	Problems 47–54
› Find the molar concentration of hydrogen ion, $[H^+]$, from a pH value or the pH value from $[H^+]$. (7.6)	Problems 49–54
› Write the formula for the conjugate base of an acid or for the conjugate acid of a base. (7.7)	Problems 55, 56
› Describe the action of a buffer. (7.7)	Problem 65
› Describe everyday uses of acids and bases and how they affect daily life. (7.8)	Problems 11, 57, 58
› Write equations for the production of soap and of biofuel.	Problem 73
› Describe ways by which acids and bases can contribute to greener production of consumer products.	Problems 71, 72, 74

REVIEW QUESTIONS

1. Define the following terms, and give an example of each.
   a. acid **b.** base **c.** salt
2. Describe the effect on litmus and the action on iron or zinc of a solution that has been neutralized.
3. List four general properties **(a)** of acidic solutions and **(b)** of basic solutions.
4. Can a substance be a Brønsted–Lowry acid if it does not contain H atoms? Are there any characteristic atoms that must be present in a Brønsted–Lowry base?
5. Both strong bases and weak bases have properties characteristic of hydroxide ions. How do strong bases and weak bases differ?
6. What is meant by a proton in acid–base chemistry? How does it differ from a nuclear proton (Chapter 3)?
7. What is an acidic anhydride? A basic anhydride?
8. Describe the neutralization of an acid or a base.
9. Magnesium hydroxide is completely ionic, even in the solid state, yet it can be taken internally as an antacid. Explain why taking it does not cause injury although taking sodium hydroxide would.
10. What are the effects of strong acids and strong bases on the skin?
11. What is alkalosis? What antacid ingredient might cause alkalosis if taken in excess?
12. According to the Arrhenius theory, all acids have one element in common. What is that element? Are all compounds containing that element acids? Explain.

PROBLEMS

Acids and Bases: The Arrhenius Theory

13. Write an equation that represents how perchloric acid ($HClO_4$) behaves as an Arrhenius acid.
14. Write an equation that represents how dihydrogen phosphate ion ($H_2PO_4^-$) behaves as an Arrhenius acid. (Be sure to include the correct charges for ions.)
15. Write an equation showing that rubidium hydroxide (RbOH) acts as an Arrhenius base in water.
16. Write an equation showing that calcium hydroxide acts as an Arrhenius base in water.

Acids and Bases: The Brønsted–Lowry Acid–Base Theory

17. Use the Brønsted–Lowry definitions to identify the first compound in each equation as an acid or a base. (*Hint:* What is produced by the reaction?)
    a. $(CH_3)_2NH + H_2O \longrightarrow (CH_3)_2NH_2^+ + OH^-$
    b. $C_6H_5NH_2 + H_2O \longrightarrow C_6H_5NH_3^+ + OH^-$
    c. $C_6H_5CH_2NH_2 + H_2O \longrightarrow C_6H_5CH_2NH_3^+ + OH^-$
18. Use the Brønsted–Lowry definitions to identify the first compound in each equation as an acid or a base.
    a. $CH_3NH_2 + H_2O \longrightarrow CH_3NH_3^+ + OH^-$
    b. $H_2O_2 + H_2O \longrightarrow H_3O^+ + HO_2^-$
    c. $NH_2Cl + H_2O \longrightarrow NH_3Cl^+ + OH^-$

19. Write the equation that shows hydrogen chloride gas reacting as a Brønsted–Lowry acid in water. What is the name of the acid formed?

20. Write the equation that shows hydrogen iodide gas reacting as a Brønsted–Lowry acid in water. Based on the answer to Problem 19, suggest a name for the acid formed.

21. Write the equation that shows how ammonia acts as a Brønsted–Lowry base in water.

22. Hydroxylamine ($HONH_2$) is not an Arrhenius base, even though it contains OH, but it *is* a Brønsted–Lowry base. Write an equation that shows how hydroxylamine acts as a Brønsted–Lowry base in water.

Acids and Bases: Names and Formulas

23. For the following acids and bases, supply a formula to match the name or a name to match the formula.
a. HCl **b.** strontium hydroxide
c. KOH **d.** boric acid

24. For the following acids and bases, supply a formula to match the name or a name to match the formula.
a. rubidium hydroxide **b.** $Al(OH)_3$
c. hydrocyanic acid **d.** HNO_3

25. Name the following, and classify each as an acid or a base.
a. H_3PO_4 **b.** CsOH **c.** H_2CO_3

26. Name the following, and classify each as an acid or a base.
a. $Mg(OH)_2$ **b.** NH_3 **c.** CH_3COOH

27. When an acid name ends in *-ic acid*, there is often a related acid whose name ends in *-ous acid*. The formula of the *-ous* acid has one less oxygen atom than that of the *-ic* acid. With this information, write formulas for **(a)** nitrous acid and **(b)** phosphorous acid.

28. Refer to Problem 27 and Table 7.1. Tellurium is chemically similar to sulfur. Use this information to write the formulas for **(a)** telluric acid and **(b)** tellurous acid.

Acidic and Basic Anhydrides

29. Give the formula for the compound formed when **(a)** sulfur trioxide reacts with water and **(b)** magnesium oxide reacts with water. In each case, is the product an acid or a base?

30. Give the formula for the compound formed when **(a)** potassium oxide reacts with water and **(b)** carbon dioxide reacts with water. In each case, is the product an acid or a base?

Strong and Weak Acids and Bases

31. When 1.0 mol of hydrogen iodide (HI) gas is dissolved in a liter of water, the resulting solution contains 1.0 mol of hydronium ions and 1.0 mol of iodide ions. Classify HI as a strong acid, a weak acid, a weak base, or a strong base.

32. Thallium hydroxide (TlOH) is a water-soluble ionic compound. Classify TlOH as a strong acid, a weak acid, a weak base, or a strong base.

33. Methylamine (CH_3NH_2) gas reacts slightly with water to form relatively few hydroxide ions and methylammonium ions ($CH_3NH_3^+$). Classify CH_3NH_2 as a strong acid, a weak acid, a weak base, or a strong base.

34. When 1 mol of hydrogen sulfide (H_2S) gas is dissolved in a liter of water, the resulting solution contains about 0.0004 mol of H^+ ions and about 3×10^{-11} mol of OH^- ions. Classify H_2S as a strong acid, a weak acid, a weak base, or a strong base.

35. Identify each of the following substances as a strong acid, a weak acid, a strong base, a weak base, or a salt.
a. LiOH **b.** HBr **c.** HNO_2 **d.** $CuSO_4$

36. Identify each of the following substances as a strong acid, a weak acid, a strong base, a weak base, or a salt.
a. K_3PO_4 **b.** $CaBr_2$
c. $Mg(OH)_2$ **d.** $BaCO_3$

37. Which of the following aqueous solutions has the highest concentration of H^+ ions? Which has the lowest?
a. 0.10 M HNO_3 **b.** 0.10 M NH_3
c. 0.10 M CH_3COOH

38. Consider 0.10 M solutions of acetic acid, ammonia, hydrochloric acid, and sodium hydroxide. Rank these solutions in order of increasing pH.

Ionization of Acids and Bases

39. Write equations showing the ionization of the following as Arrhenius acids or bases.
a. HNO_2
b. $Ba(OH)_2$
c. HBr

40. Write equations showing the ionization of the following as Arrhenius acids or bases.
a. HI **b.** LiOH **c.** $HClO_2$

41. Write equations showing the ionization of the following as Brønsted–Lowry acids in water.
a. HClO **b.** HNO_2 **c.** H_2S

42. Write equations showing the ionization of the following as Brønsted–Lowry acids in water.
a. HI **b.** $HClO_3$
c. $CFH_2CHOHCOOH$

Neutralization

43. Write equations for the reaction **(a)** of potassium hydroxide with hydrochloric acid and **(b)** of lithium hydroxide with nitric acid.

44. Write equations for the reaction **(a)** of 1 mol of calcium hydroxide with 2 mol of hydrochloric acid and **(b)** of 1 mol of sulfuric acid with 2 mol of potassium hydroxide.

45. Write the equation for the reaction of 1 mol of sulfurous acid (H_2SO_3) with 1 mol of magnesium hydroxide.

46. Write the equation for the reaction of 1 mol of phosphoric acid with 1 mol of aluminum hydroxide.

The pH Scale

47. Indicate whether each of the following pH values represents an acidic, basic, or neutral solution.
a. 4 **b.** 7 **c.** 3.5 **d.** 9

48. Lime juice is quite sour. Which of the following is a reasonable pH for lime juice?
a. 2 **b.** 6 **c.** 7.8 **d.** 12

49. What is the pH of a solution that has a hydrogen ion concentration of 1.0×10^{-5} M?

50. What is the pH of a solution that has a hydrogen ion concentration of 1.0×10^{-9} M?

51. What is the hydrogen ion concentration of a solution that has a pH of 3?

52. What is the hydrogen ion concentration of a solution that has a pH of 11?

53. Milk of magnesia has a hydrogen ion concentration between 1.0×10^{-10} M and 1.0×10^{-11} M. What two whole-number values is the pH of milk of magnesia between?

54. Oven cleaner has a pH between 13 and 14. What two whole-number values of x should be used in 1.0×10^{-x} M to express the range of hydrogen ion concentration?

Conjugate Acid–Base Pairs

55. In the following reaction in aqueous solution, identify **(a)** which of the reactants is the acid and which is the base, **(b)** the conjugate base of the acid, and **(c)** the conjugate acid of the base.

$$HNO_3\,(aq) + NH_3(aq) \longrightarrow NO_3^{-}\,(aq) + NH_4^{+}\,(aq)$$

56. In the following reaction in aqueous solution, identify **(a)** which of the reactants is the acid and which is the base, **(b)** the conjugate base of the acid, and **(c)** the conjugate acid of the base.

$$CH_3CH_2COOH + H_2O \longrightarrow CH_3CH_2COO^{-} + H_3O^{+}$$

Antacids

57. Mylanta liquid has 200 mg of $Al(OH)_3$ and 200 mg of $Mg(OH)_2$ per teaspoonful. Write the equation for the neutralization of stomach acid [represented as HCl(aq)] by each of these substances.

58. What is the Brønsted–Lowry base in each of the following compounds, which are ingredients in antacids?
   a. $NaHCO_3$
   b. $Mg(OH)_2$
   c. $MgCO_3$
   d. $CaCO_3$

ADDITIONAL PROBLEMS

59. According to the Arrhenius theory, is every compound that contains OH a base? Explain.

60. Lime deposits on brass faucets are mostly $CaCO_3$. The deposits can be removed by soaking the faucets in hydrochloric acid. Write an equation for the reaction that occurs.

61. The conjugate base of a very weak acid is a strong base, and the conjugate base of a strong acid is a weak base. **(a)** Is Cl^{-} ion a strong base or a weak base? **(b)** Is CN^{-} a strong base or a weak base?

62. Strontium iodide can be made by the reaction of solid strontium carbonate ($SrCO_3$) with an acid. Identify the acid, and write the balanced equation for the reaction.

63. The *pOH* is related to $[OH^{-}]$ just as pH is related to $[H^{+}]$. What is the pOH **(a)** of a solution that has a hydroxide ion concentration of 1.0×10^{-3} M? **(b)** Of a 0.01 M KOH solution?

64. Rank 0.1 M solutions of **(a)** acetic acid ($HC_2H_3O_2$), **(b)** ammonia (NH_3), **(c)** nitric acid (HNO_3), **(d)** sodium chloride (NaCl), and **(e)** sodium hydroxide (NaOH) from the highest pH to the lowest pH.

65. Human blood contains buffers that minimize changes in pH. One blood buffer is the hydrogen phosphate ion (HPO_4^{2-}). Like water, HPO_4^{2-} is amphiprotic. That is, it can act either as a Brønsted–Lowry acid or as a Brønsted–Lowry base. Write equations that illustrate the reaction with water of HPO_4^{2-} as an acid and as a base.

66. Three varieties of Tums have calcium carbonate as the only active ingredient: Regular Tums tablets have 500 mg; Tums E-X, 750 mg; and Tums ULTRA, 1000 mg. How many regular Tums would you have to take to get the same quantity of calcium carbonate as you would get with two Tums E-X? With two Tums ULTRA tablets?

67. The active ingredient in the antacid Basaljel is a gel of solid aluminum carbonate. Write the equation for the neutralization of aluminum carbonate by stomach acid (aqueous HCl).

68. Milk of magnesia has 400 mg of $Mg(OH)_2$ per teaspoon. Calculate the mass of stomach acid that can be neutralized by 1.00 teaspoon of milk of magnesia, assuming that the stomach acid is 0.50% HCl by mass.

69. When a well is drilled into rock that contains sulfide minerals, some of the minerals may dissolve in the well water, yielding "sulfur water" that smells like rotten eggs. The water from these wells feels slightly slippery, contains HS^{-} ions, and turns litmus paper blue. From this information, write an equation representing the reaction of HS^{-} ions with water.

70. Sulfuric acid is produced from elemental sulfur by a three-step process: (1) Sulfur is burned to produce sulfur dioxide. (2) Sulfur dioxide is oxidized to sulfur trioxide using oxygen and a vanadium (V) oxide catalyst. (3) Finally, the sulfur trioxide is reacted with water to produce 98% sulfuric acid. Write equations for the three reactions.

71. The pH of soap is sometimes adjusted by adding citric acid before the raw soap is formed into bars. Would citric acid increase or decrease the pH of the finished soap?

72. Write an equation to show soap [as $CH_3(CH_2)_{14}COO^{-}Na^{+}$] acting as a base with sulfuric acid.

73. Write an equation for the neutralization reaction of a fatty acid ($HC_{16}H_{31}O_2$) with potassium hydroxide (KOH) in water. Is the product of this reaction a fuel or a soap?

74. Most soaps have a bitter taste and a slippery feel. What does this hint indicate about the pH of most soaps?

COLLABORATIVE GROUP PROJECTS

Prepare a PowerPoint, poster, or other presentation (as directed by your instructor) to share with the class.

1. Prepare a brief report on one of the following acids or bases. List sources (including local sources for the acid or base, if available) and commercial uses.
   a. ammonia **b.** hydrochloric acid
   c. phosphoric acid **d.** nitric acid
   e. sodium hydroxide **f.** sulfuric acid
2. Examine the labels of at least five antacid preparations. Make a list of the ingredients in each. Look up the properties (medical use, side effects, toxicity, and so on) of each ingredient on the Web or in a reference book such as *The Merck Index*.
3. Examine the labels of at least five toilet-bowl cleaners and five drain cleaners. Make a list of the ingredients in each. Look up the formulas and properties of each ingredient on the Web or in a reference book such as *The Merck Index*. Which ingredients are acids? Which are bases?
4. A web page on making biodiesel claims that any water in the waste oil must be removed before starting the reaction.