



CHAPTER 5

ACIDS, BASES, AND ACID-BASE REACTIONS

It's test day in chemistry class—they've been learning about acids and bases—and Fran unwisely skips breakfast in order to have time for some last-minute studying. As she reads, she chews on a candy bar and sips a cup of coffee. Fran is well aware that the sugary candy sticking to her molars is providing breakfast for the bacteria in her mouth, which in turn produce an acid that will dissolve some of the enamel on her teeth. Feeling a little guilty about all that sugar from the candy, Fran drinks her coffee black, even though she doesn't like the taste. The caffeine in her coffee is a base, and like all bases, it tastes bitter.

Fran's junk-food breakfast and her worrying about the exam combine to give her an annoying case of acid indigestion, which she calms by drinking some baking soda mixed with water. The baking soda contains a base that "neutralizes" some of her excess stomach acid.

After taking the exam, Fran feels happy and confident. All those hours working problems, reviewing the learning objectives, and participating in class really paid off. Now she's ready for some lunch. Before eating, she washes her hands with soap made from the reaction of a strong base and animal fat. One of the reasons the soap is slippery is because all bases feel slippery on the skin. To compensate for her less-than-healthy breakfast, Fran chooses salad with a piece of lean meat on top for lunch. Like all acids, the vinegar in her salad dressing tastes sour. Her stomach produces just enough additional acid to start the digestion of the protein from the meat.

Read on to learn more about the acids and bases that are important in Fran's life and your own: what they are, how to construct their names and recognize their formulas, and how they react with each other.



The vinegar in salad dressing tastes sour, as do all acids.

5.1	Acids
5.2	Acid Nomenclature
5.3	Summary of Chemical Nomenclature
5.4	Strong and Weak Bases
5.5	pH and Acidic and Basic Solutions
5.6	Arrhenius Acid-Base Reactions
5.7	Brønsted-Lowry Acids and Bases

Review Skills

The presentation of information in this chapter assumes that you can already perform the tasks listed below. You can test your readiness to proceed by answering the Review Questions at the end of the chapter. This might also be a good time to read the Chapter Objectives, which precede the Review Questions.

- Describe the structure of liquid water. (Section 3.3)
- Convert between the names and formulas for common polyatomic ions. (Table 3.5)
- Given a chemical name or formula, decide whether or not it represents an ionic compound. (Section 3.5)
- Convert between names and formulas for ionic compounds. (Section 3.5)
- Write a description of the changes that take place when an ionic compound is dissolved in water. (Section 4.2)
- Predict ionic solubility. (Section 4.2)
- Predict the products of double-displacement reactions. (Section 4.2)

5.1 Acids

Acids have many uses. For example, phosphoric acid is used to make gasoline additives and carbonated beverages. The textile industry uses oxalic acid (found in rhubarb and spinach) to bleach cloth, and glass is etched by hydrofluoric acid. Dyes and many other chemicals are made with sulfuric acid and nitric acid, and corn syrup, which is added to a variety of foods, is processed with hydrochloric acid. The chemical reactions of acids often take place in water solutions, so after discussing what acids are, we will explore a model for visualizing the particle structure of water solutions of acids.



Acids have many uses, including making car batteries, softdrinks, artificial sweeteners, and napkins.

OBJECTIVE 2

They contain citric acid, and old wine that has been exposed to the air tastes sour due to acetic acid. As chemists learned more about these substances, however, they developed more specific definitions that allowed classification without relying on taste. A good thing, too, because many acids and bases should not be tasted—or even touched. They speed the breakdown of some of the substances that form the structure of our bodies or that help regulate the body's chemical changes.

Two different definitions of acid are going to be of use to us. For example, chemists conduct many laboratory experiments using a reagent known as “nitric acid,” a substance that has been classified as an acid according to the Arrhenius definition of acid (named after the Swedish Nobel prize-winning chemist, Svante August Arrhenius). Arrhenius recognized that when ionic compounds dissolve, they form ions in solution. (Thus, when sodium chloride dissolves, it forms sodium ions and chloride ions.) He postulated that acids dissolve in a similar way to form H^+ ions and some kind of anion. For example, he predicted that when HCl is added to water, H^+ ions and Cl^- ions form. We now know that H^+ ions do not persist in water; they combine with water molecules to form hydronium ions, H_3O^+ . Therefore, according to the modern form of the Arrhenius theory, an **acid** is a substance that produces **hydronium ions**, H_3O^+ , when it is added to water. On the basis of this definition, an **acidic solution** is a solution with a significant concentration of H_3O^+ . For reasons that are described in Section 5.7, chemists often find this definition too limiting, so another, broader definition of acids, called the Brønsted-Lowry definition, which we describe later, is commonly used instead.

OBJECTIVE 3

To get an understanding of how hydronium ions are formed when Arrhenius acids are added to water, let's consider the dissolving of gaseous hydrogen chloride, $HCl(g)$, in water. The solution that forms is called hydrochloric acid. When HCl molecules dissolve in water, a chemical change takes place in which water molecules pull hydrogen

Arrhenius Acids

You may have already noticed, in your first few weeks of studying chemistry, that the more you learn about matter, the more ways you have of grouping and classifying the different substances. The most common and familiar way of classifying substances is by their noteworthy properties. For example, people long ago decided that any substance that has a sour taste is an acid. Lemons are sour because

atoms away from HCl molecules. In each case, the hydrogen atom is transferred without its electron, that is, as an H^+ ion, and because most uncharged hydrogen atoms contain only one proton and one electron, most hydrogen atoms without their electrons are just protons. For this reason, the hydrogen ion, H^+ , is often called a proton. We say that the HCl donates a proton, H^+ , to water, forming hydronium ion, H_3O^+ , and chloride ion, Cl^- (Figure 5.1).

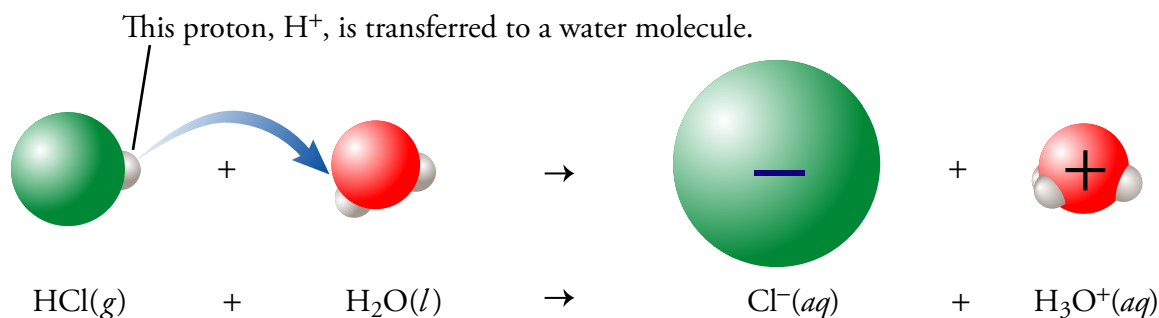


Figure 5.1
HCl Reaction
with Water

Because HCl produces hydronium ions when added to water, it is an acid according to the Arrhenius definition of acids. Once the chloride ion and the hydronium ion are formed, the negatively charged oxygen atoms of the water molecules surround the hydronium ion, and the positively charged hydrogen atoms of the water molecules surround the chloride ion. Figure 5.2 shows how you can picture this solution.

OBJECTIVE 3

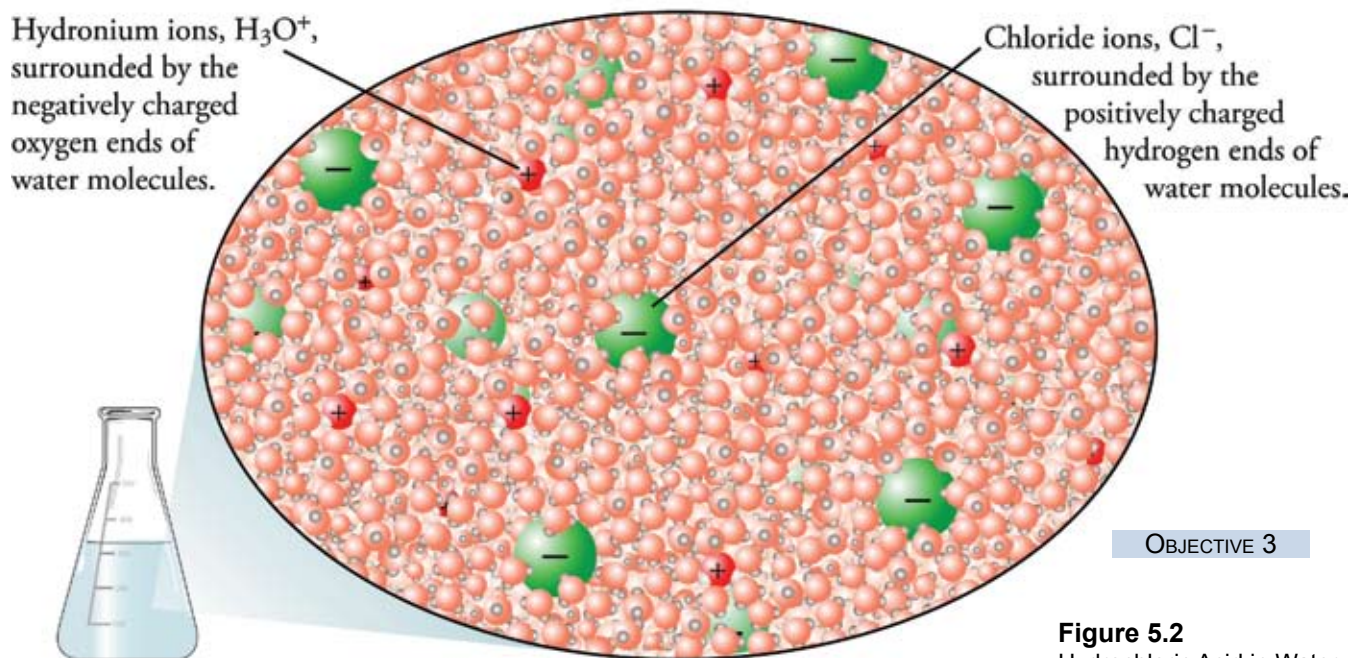


Figure 5.2
Hydrochloric Acid in Water

Hydrochloric acid solutions are used in the chemical industry to remove impurities from metal surfaces (this is called pickling), to process food, to increase the permeability of limestone (an aid in oil drilling), and to make many important chemicals.

Types of Arrhenius Acids

OBJECTIVE 4

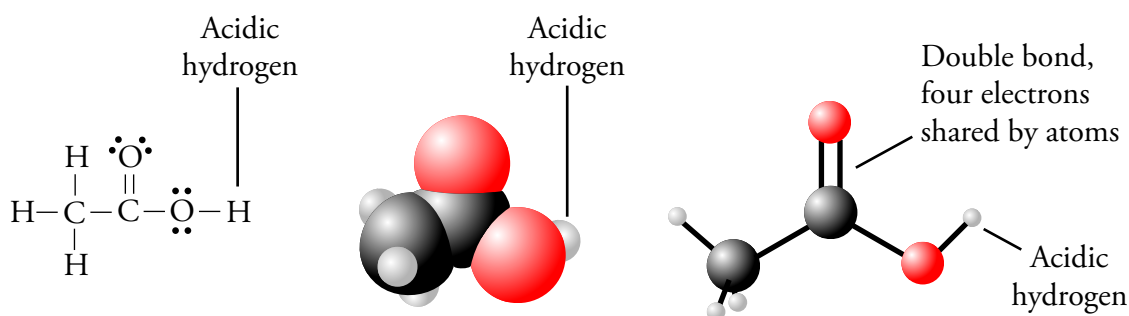
In terms of chemical structure, Arrhenius acids can be divided into several different subcategories. We will look at three of them here: binary acids, oxyacids, and organic acids. The **binary acids** are $\text{HF}(aq)$, $\text{HCl}(aq)$, $\text{HBr}(aq)$, and $\text{HI}(aq)$; all have the general formula of $\text{HX}(aq)$, where X is one of the first four halogens. The formulas for the binary acids will be followed by (aq) in this text to show that they are dissolved in water. The most common binary acid is hydrochloric acid, $\text{HCl}(aq)$.

Oxyacids (often called oxoacids) are molecular substances that have the general formula $\text{H}_a\text{X}_b\text{O}_c$. In other words, they contain hydrogen, oxygen, and one other element represented by X; the a , b , and c represent subscripts. The most common oxyacids in the chemical laboratory are nitric acid, HNO_3 , and sulfuric acid, H_2SO_4 .

OBJECTIVE 5

Acetic acid, the acid responsible for the properties of vinegar, contains hydrogen, oxygen, and carbon and therefore fits the criteria for classification as an oxyacid, but it is more commonly described as an organic (or carbon-based) acid. It can also be called a carboxylic acid. (This type of acid is described in more detail in Section 17.1.) The formula for acetic acid can be written as either $\text{HC}_2\text{H}_3\text{O}_2$, $\text{CH}_3\text{CO}_2\text{H}$, or CH_3COOH . The reason for keeping one H in these formulas separate from the others is that the hydrogen atoms in acetic acid are not all equal. Only one of them can be transferred to a water molecule. That hydrogen atom is known as the acidic hydrogen. We will use the formula $\text{HC}_2\text{H}_3\text{O}_2$ because it is more consistent with the formulas for other acids presented in this chapter. The Lewis structure, space-filling model, and ball-and-stick model for acetic acid (Figure 5.3) show why $\text{CH}_3\text{CO}_2\text{H}$, and CH_3COOH are also common. The acidic hydrogen is the one connected to an oxygen atom.

Figure 5.3
Acetic Acid



Pure acetic acid freezes at $17\text{ }^\circ\text{C}$ ($63\text{ }^\circ\text{F}$). Therefore, it is a liquid at normal room temperature, but if you put it outside on a cold day, it will freeze. The solid has layered crystals that look like tiny glaciers, so pure acetic acid is called glacial acetic acid. The chemical industry uses acetic acid to make several substances necessary for producing latex paints, safety glass layers, photographic film, cigarette filters, magnetic tapes, and clothing. Acetic acid is also used to make esters, which are substances that have very pleasant odors and are added to candy and other foods.

Acids can have more than one acidic hydrogen. If each molecule of an acid can donate one hydrogen ion, the acid is called a **monoprotic acid**. If each molecule can donate two or more hydrogen ions, the acid is a **polyprotic acid**. A **diprotic acid**, such as sulfuric acid, H_2SO_4 , has two acidic hydrogen atoms. Some acids, such as phosphoric

acid, H_3PO_4 , are **triprotic acids**. Most of the phosphoric acid produced by the chemical industry is used to make fertilizers and detergents, but it is also used to make pharmaceuticals, to refine sugar, and in water treatment. The tartness of some foods and beverages comes from acidifying them by adding phosphoric acid. The space-filling model in Figure 5.4 shows the three acidic hydrogen atoms of phosphoric acid.

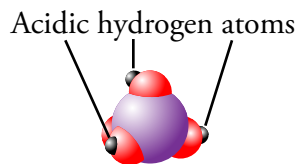


Figure 5.4
The phosphate in this fertilizer was made from phosphoric acid.

Strong and Weak Acids

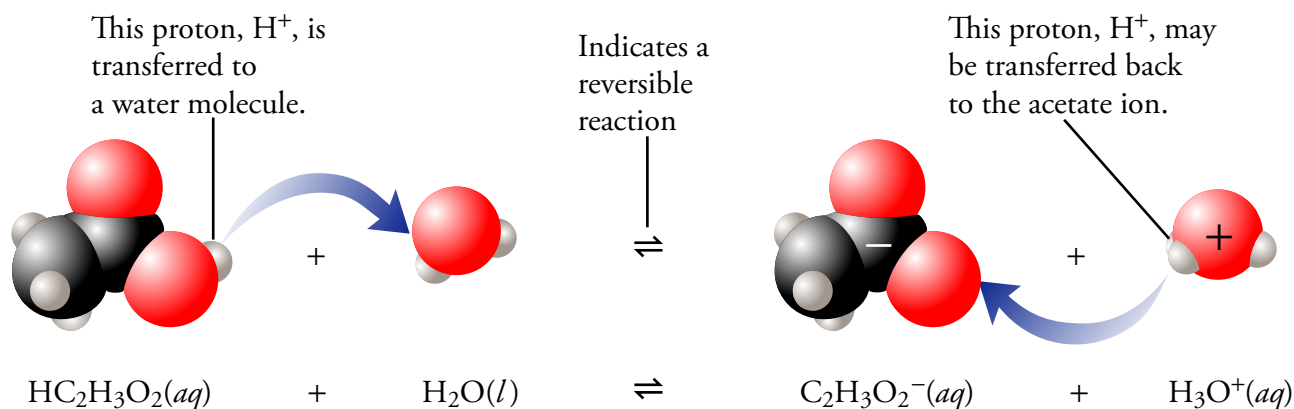
Although hydrochloric acid and acetic acid are both acids according to the Arrhenius definition, the solutions created by dissolving the same numbers of HCl and $\text{HC}_2\text{H}_3\text{O}_2$ molecules in water have very different acid properties. You wouldn't hesitate to put a solution of the weak acid $\text{HC}_2\text{H}_3\text{O}_2$ (vinegar) on your salad, but putting a solution of the strong acid HCl on your salad would have a very different effect on the lettuce. With hydrochloric acid, you are more likely to get a brown, fuming mess rather than a crisp, green salad. **Strong acids** form nearly one H_3O^+ ion in solution for each acid molecule dissolved in water, whereas **weak acids** yield significantly less than one H_3O^+ ion in solution for each acid molecule dissolved in water.

When an acetic acid molecule, $\text{HC}_2\text{H}_3\text{O}_2$, collides with an H_2O molecule, an H^+ can be transferred to the water to form a hydronium ion, H_3O^+ , and an acetate ion, $\text{C}_2\text{H}_3\text{O}_2^-$. The acetate ion, however, is less stable in solution than the chloride ion formed when the strong acid HCl dissolves in water. Because of this instability, the $\text{C}_2\text{H}_3\text{O}_2^-$ reacts with the hydronium ion, pulling the H^+ ion back to reform $\text{HC}_2\text{H}_3\text{O}_2$ and H_2O . A reaction in which the reactants are constantly forming products and, at the same time, the products are re-forming the reactants is called a **reversible reaction**. The chemical equations for reactions that are significantly reversible are written with double arrows as illustrated in Figure 5.5.

OBJECTIVE 6

OBJECTIVE 6

Figure 5.5
Reversible Reaction of Acetic Acid and Water



If you were small enough to be riding on one of the carbon atoms in $\text{HC}_2\text{H}_3\text{O}_2$ or $\text{C}_2\text{H}_3\text{O}_2^-$, you would find that your atom was usually in the $\text{HC}_2\text{H}_3\text{O}_2$ form but often in the $\text{C}_2\text{H}_3\text{O}_2^-$ form and continually changing back and forth. The forward and reverse reactions would be taking place simultaneously all around you. When acetic

OBJECTIVE 6

acid is added to water, the relative amounts of the different products and reactants soon reach levels at which the opposing reactions proceed at equal rates. (We will see why in Chapter 16.) This means that the forward reaction is producing $\text{C}_2\text{H}_3\text{O}_2^-$ as quickly as the reverse reaction is producing $\text{HC}_2\text{H}_3\text{O}_2(aq)$. At this point, there is no more net change in the amounts of $\text{HC}_2\text{H}_3\text{O}_2$, H_2O , $\text{C}_2\text{H}_3\text{O}_2^-$, or H_3O^+ in the solution. For example, for each 1000 molecules of acetic acid added to water, the solution will eventually contain about 996 acetic acid molecules ($\text{HC}_2\text{H}_3\text{O}_2$), four hydronium ions (H_3O^+), and four acetate ions ($\text{C}_2\text{H}_3\text{O}_2^-$). Acetic acid is therefore a **weak acid**, a substance that is incompletely ionized in water because of the reversibility of its reaction with water that forms hydronium ion, H_3O^+ . Figure 5.6 shows a simple model that will help you to picture this solution.

In a typical acetic acid solution, there are about 250 times as many uncharged acetic acid molecules, $\text{HC}_2\text{H}_3\text{O}_2$, as acetate ions, $\text{C}_2\text{H}_3\text{O}_2^-$.

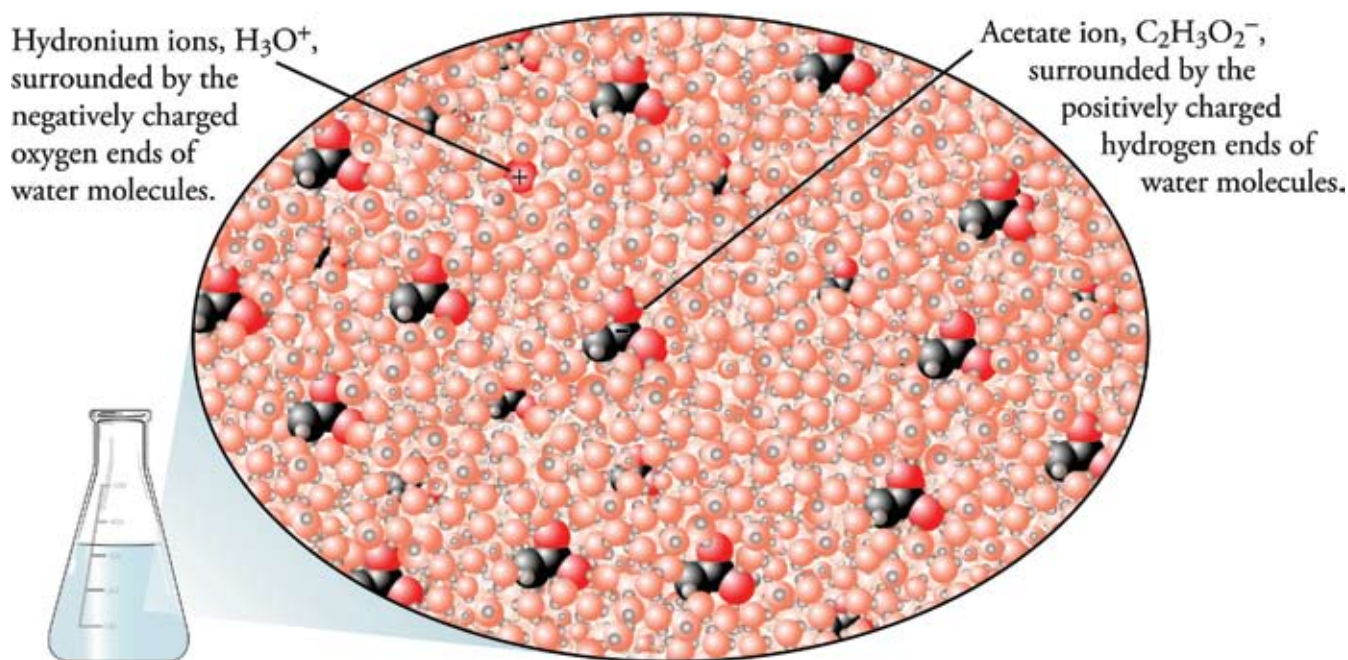
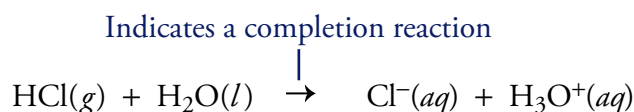


Figure 5.6
Acetic Acid in Water

OBJECTIVE 6

OBJECTIVE 7

The products formed from the reaction of a strong acid and water do not recombine at a significant rate to re-form the uncharged acid molecules and water. For example, when HCl molecules react with water, the H_3O^+ and Cl^- ions that form do not react to a significant degree to reform HCl and H_2O . (Look again at Figure 5.2 to see the behavior of a strong acid in solution.) Reactions like this that are not significantly reversible are often called **completion reactions**. The chemical equations for completion reactions are written with single arrows to indicate that the reaction proceeds to form almost 100% products.



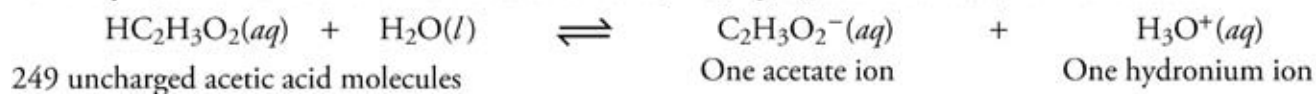
Therefore, a **strong acid** is a substance that undergoes a completion reaction with water such that each acid particle reacts to form a hydronium ion, H_3O^+ . The strong monoprotic acids that you will be expected to recognize are nitric acid, HNO_3 , and hydrochloric acid, $\text{HCl}(aq)$. (There are others that you might be expected to recognize later in your chemical education.) If we were to examine equal volumes of two aqueous solutions, one made with a certain number of molecules of a strong acid and one made with the same number of molecules of a weak acid, we would find fewer hydronium ions in the solution of weak acid than in the solution of strong acid (Figure 5.7).

OBJECTIVE 7

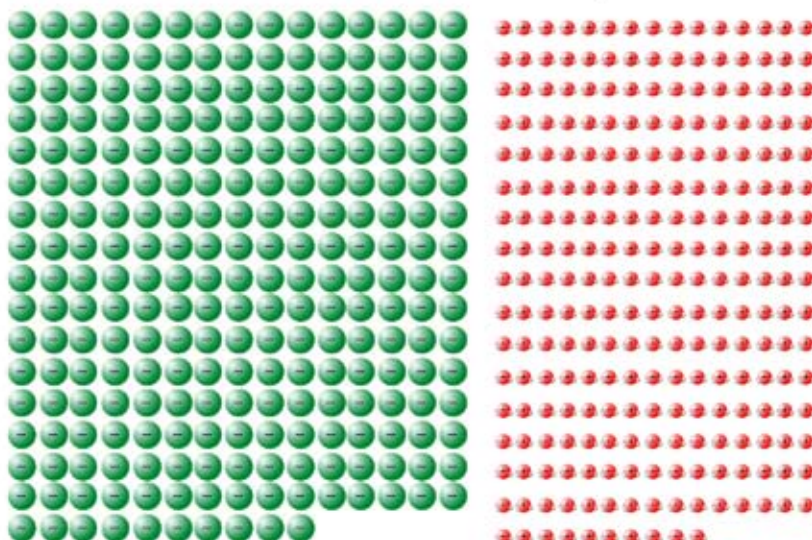
OBJECTIVE 8

Figure 5.7
Weak and Strong Acids

For every 250 molecules of the weak acid acetic acid, $\text{HC}_2\text{H}_3\text{O}_2$, added to water, there are about



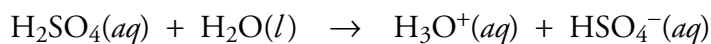
For every 250 molecules of the strong acid hydrochloric acid, HCl , added to water, there are about



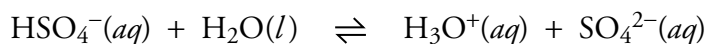
OBJECTIVE 9

OBJECTIVE 10

Sulfuric acid, H_2SO_4 , is a strong diprotic acid. When added to water, each H_2SO_4 molecule loses its first hydrogen ion completely. This is the reason that H_2SO_4 is classified as a strong acid. Notice the single arrow to indicate a completion reaction.



The hydrogen sulfate ion, HSO_4^- , which is a product of this reaction, is a weak acid. It reacts with water in a reversible reaction to form a hydronium ion and a sulfate ion. Notice the double arrow to indicate a reversible reaction.



For each 100 sulfuric acid molecules added to water, the solution will eventually contain about 101 hydronium ions (H_3O^+), 99 hydrogen sulfate ions (HSO_4^-), and 1 sulfate ion (SO_4^{2-}).

Sulfuric acid, H_2SO_4 , is produced by the United States chemical industry in greater mass than any other chemical. Over 40 billion kilograms of H_2SO_4 are produced each year, to make phosphate fertilizers, plastics, and many other substances. Sulfuric acid is also used in ore processing, petroleum refining, pulp and paper-making, and for a variety of other purposes. Most cars are started by lead-acid storage batteries, which contain about 33.5% H_2SO_4 .

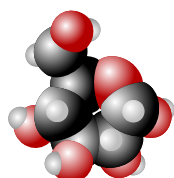
To do the Chapter Problems at the end of this chapter, you will need to identify important acids as being either strong or weak. The strong acids that you will be expected to recognize are hydrochloric acid, $\text{HCl}(aq)$, nitric acid, HNO_3 , and sulfuric acid, H_2SO_4 . An acid is considered weak if it is not on the list of strong acids. Table 5.1 summarizes this information.

OBJECTIVE 11

Table 5.1

Arrhenius Acids

	Strong	Weak
Binary Acids	hydrochloric acid, $\text{HCl}(aq)$	hydrofluoric acid, $\text{HF}(aq)$
Oxyacids	nitric acid, HNO_3 , sulfuric acid, H_2SO_4	other acids with the general formula $\text{H}_a\text{X}_b\text{O}_c$
Organic acids	None	acetic acid, $\text{HC}_2\text{H}_3\text{O}_2$, and others you will see in Section 17.1



Web
Molecules

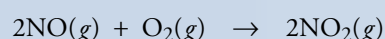
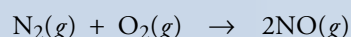
There is an animation that illustrates the differences between strong and weak acids at the textbook's Web site.

Special Topic 5.1 tells how acids are formed in the earth's atmosphere and how these acids can be damaging to our atmosphere.

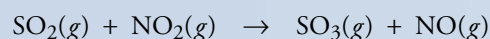
SPECIAL TOPIC 5.1 Acid Rain

Normal rainwater is very slightly acidic due to several reactions between substances dissolved in the water and the water itself. For example, carbon dioxide, nitrogen dioxide, and sulfur trioxide—all of which are natural components of air—react with water to form carbonic acid, nitric acid, and sulfuric acid.

Nitrogen dioxide is produced in nature in many ways, including a reaction between the oxygen and nitrogen in the air during electrical storms.



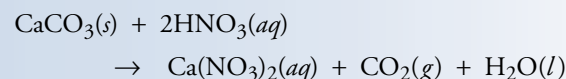
Sulfur dioxide also has natural sources, including the burning of sulfur-containing compounds in volcanic eruptions and forest fires. Sulfur dioxide is converted into sulfur trioxide, SO_3 , by reaction with the nitrogen dioxide in the air, among other mechanisms.



We humans have added considerably to the levels of $\text{NO}_2(g)$ and $\text{SO}_2(g)$ in our air, causing a steady increase in the acidity of rain. Coal, for example, contains a significant amount of sulfur; when coal is burned, the sulfur is

converted into sulfur dioxide, $\text{SO}_2(g)$. The sulfur dioxide is converted into sulfur trioxide, $\text{SO}_3(g)$, in the air, and that compound dissolves in rainwater and becomes sulfuric acid, $\text{H}_2\text{SO}_4(aq)$. As individuals, we also contribute to acid rain every time we drive a car around the block. When air, which contains nitrogen and oxygen, is heated in the cylinders of the car, the two gases combine to yield nitrogen monoxide, $\text{NO}(g)$, which is then converted into nitrogen dioxide, $\text{NO}_2(g)$, in the air. The NO_2 combines with water in rain to form nitric acid, $\text{HNO}_3(aq)$. There are many more H_3O^+ ions in the rain falling in the Northeastern United States than would be expected without human contributions.

The increased acidity of the rain leads to many problems. For example, the acids in acid rain react with the calcium carbonate in marble statues and buildings, causing them to dissolve. (Marble is compressed limestone, which is composed of calcium carbonate, $\text{CaCO}_3(s)$.)



A similar reaction allows a plumber to remove the calcium carbonate scale in your hot water pipes. If the pipes are washed in an acidic solution, the calcium carbonate dissolves.

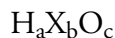
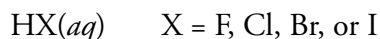


The Renaissance statue on the left was transported by William Randolph Hearst to his home in San Simeon, California. Because it so rarely rains there, and because San Simeon is far from any major sources of pollution, these statues are in much better condition than the similar statues found elsewhere, such as the one on the right, that have been damaged by acid rain.



5.2 Acid Nomenclature

Before exploring how different kinds of acids react with compounds other than water, you need a little more familiarity with their names and formulas. Remember that the names of Arrhenius acids usually end in acid (hydrochloric acid, sulfuric acid, nitric acid) and that their formulas fit one of two general patterns:



For example, $\text{HCl}(aq)$ (hydrochloric acid), H_2SO_4 (sulfuric acid), and HNO_3 (nitric acid) represent acids.

Names and Formulas of Binary Acids

OBJECTIVE 12

Binary acids are named by writing *hydro* followed by the root of the name of the halogen, then *-ic*, and finally *acid* (Table 5.2):

hydro(root)ic acid

The only exception to remember is that the “o” in hydro is left off for $\text{HI}(aq)$, so its name is hydriodic acid (an acid used to make pharmaceuticals).

Most chemists refer to pure HCl gas as hydrogen chloride, but when HCl gas is dissolved in water, $\text{HCl}(aq)$, the solution is called hydrochloric acid. We will follow the same rule in this text, calling HCl or $\text{HCl}(g)$ hydrogen chloride and calling $\text{HCl}(aq)$ hydrochloric acid. The same pattern holds for the other binary acids as well.

You will be expected to be able to write formulas and names for the binary acids found on Table 5.2. Remember that it is a good habit to write *(aq)* after the formula.

OBJECTIVE 12

Table 5.2
Arrhenius Acids

Formula	Named as Binary Covalent Compound	Acid Formula	Named as Binary acid
HF or $\text{HF}(g)$	hydrogen monofluoride or hydrogen fluoride	$\text{HF}(aq)$	hydrofluoric acid
HCl or $\text{HCl}(g)$	hydrogen monochloride or hydrogen chloride	$\text{HCl}(aq)$	hydrochloric acid
HBr or $\text{HBr}(g)$	hydrogen monobromide or hydrogen bromide	$\text{HBr}(aq)$	hydrobromic acid
HI or $\text{HI}(g)$	hydrogen moniodide or hydrogen iodide	$\text{HI}(aq)$	hydriodic acid

Names and Formulas of Oxyacids

To name oxyacids, you must first be able to recognize them by the general formula $H_aX_bO_c$, with X representing an element other than hydrogen or oxygen (Section 5.1). It will also be useful for you to know the names of the polyatomic oxyanions (Table 3.6), because many oxyacid names are derived from them. If enough H^+ ions are added to a (root)ate polyatomic ion to completely neutralize its charge, the (root)ic acid is formed (Table 5.3).

OBJECTIVE 12

- If one H^+ ion is added to nitrate, NO_3^- , nitric acid, HNO_3 , is formed.
- If two H^+ ions are added to sulfate, SO_4^{2-} , sulfuric acid, H_2SO_4 , is formed.
- If three H^+ ions are added to phosphate, PO_4^{3-} , phosphoric acid, H_3PO_4 , is formed.

Note that the whole name for sulfur, not just the root, *sulf-*, is found in the name sulfuric acid. Similarly, although the usual root for phosphorus is *phosph-*, the root *phosphor-* is used for phosphorus-containing oxyacids, as in the name *phosphoric acid*.

Table 5.3

Relationship Between (Root)ate Polyatomic Ions and (Root)ic Acids

OBJECTIVE 12

Oxyanion Formula	Oxyanion Name	Oxyacid Formula	Oxyacid Name
NO_3^-	nitrate	HNO_3	nitric acid
$C_2H_3O_2^-$	acetate	$HC_2H_3O_2$	acetic acid
SO_4^{2-}	sulfate	H_2SO_4	sulfuric acid (Note that the whole name <i>sulfur</i> is used in the oxyacid name.)
CO_3^{2-}	carbonate	H_2CO_3	carbonic acid
PO_4^{3-}	phosphate	H_3PO_4	phosphoric acid (Note that the root of phosphorus in an oxyacid name is <i>phosphor-</i> .)

There is a more complete description of acid nomenclature at the textbook's Web site.

EXAMPLE 5.1 - Formulas for Acids**OBJECTIVE 12**

Write the chemical formulas that correspond to the names (a) hydrobromic acid and (b) sulfuric acid.

Solution

- The name hydrobromic acid has the form of a binary acid, hydro(root)ic acid. Binary acids have the formula $HX(aq)$, so hydrobromic acid is **$HBr(aq)$** . We follow the formula with (aq) to distinguish hydrobromic acid from a pure sample of hydrogen bromide, HBr .
- Sulfuric acid is **H_2SO_4** . Sulfuric acid is a very common acid, one whose formula, H_2SO_4 , you ought to memorize. We recognize sulfuric acid as a name for an oxyacid, because it has the form (root)ic acid. You can also derive its formula from the formula for sulfate, SO_4^{2-} , by adding enough H^+ ions to neutralize the charge. Among the many uses of H_2SO_4 are the manufacture of explosives and the reprocessing of spent nuclear fuel.

EXAMPLE 5.2 - Naming Acids**OBJECTIVE 12**

Write the names that correspond to the chemical formulas (a) HNO_3 and (b) $HF(aq)$.

Solution

- The first step in writing a name from a chemical formula is to decide which type of compound the formula represents. This formula represents an oxyacid. Remember that the (root)ate polyatomic ion leads to the (root)ic acid. The name for NO_3^- is nitrate, so HNO_3 is **nitric acid**.
- The first step in writing a name from a chemical formula is to determine the type of compound the formula represents. This one, $HF(aq)$, has the form of a binary acid, $HX(aq)$, so its name is *hydro-* followed by the root of the name of the halogen, then *-ic* and *acid*: **hydrofluoric acid**. This acid is used to make chlorofluorocarbons, CFCs.

EXERCISE 5.1 - Formulas for Acids**OBJECTIVE 12**

Write the chemical formulas that correspond to the names (a) hydrofluoric acid and (b) phosphoric acid.

EXERCISE 5.2 - Naming Acids**OBJECTIVE 12**

Write the names that correspond to the chemical formulas (a) $HI(aq)$ and (b) $HC_2H_3O_2$.

5.3 Summary of Chemical Nomenclature

Perhaps at this point you are feeling confused by the many different conventions for naming different kinds of chemical compounds. Here is an overview of the guidelines for naming and writing formulas for all of the types of compounds described in this chapter and in Chapter 3.

Some names and formulas for compounds can be constructed from general rules, but others must be memorized. Table 5.4 lists some commonly encountered names and formulas that must be memorized. Check with your instructor to see which of these you need to know. Your instructor might also want to add others to the list.

Table 5.4
Compound Names and Formulas

OBJECTIVE 14

Name	Formula	Name	Formula
water	H ₂ O	ammonia	NH ₃
methane	CH ₄	ethane	C ₂ H ₆
propane	C ₃ H ₈	methanol (methyl alcohol)	CH ₃ OH
ethanol (ethyl alcohol)	C ₂ H ₅ OH	2-propanol (isopropyl alcohol)	C ₃ H ₇ OH

The general procedure for naming other compounds consists of two steps:

OBJECTIVE 14

STEP 1 Decide what type of compound the name or formula represents.

STEP 2 Apply the rules for writing the name or formula for that type of compound.

Table 5.5 on the next page summarizes the distinguishing features of different kinds of formulas and names (Step 1) and lists the sections in this chapter and in Chapter 3 where you can find instructions for converting names to formulas and formulas to names (Step 2).

There is a tutorial on the textbook's Web site that will provide practice identifying types of substances.

Table 5.5

Nomenclature for Some Types of Compounds

OBJECTIVE 13

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Type of Compound	General Formula	Examples	General Name	Examples
Binary covalent (Section 3.4)	A_aB_b	N_2O_5 or CO_2	(prefix unless mono)(name of first element in formula) (prefix)(root of second element)ide	dinitrogen pentoxide or carbon dioxide
Binary ionic (Section 3.5)	M_aA_b	$NaCl$ or $FeCl_3$	(name of metal) (root of nonmetal)ide or (name of metal)(Roman numeral) (root of nonmetal)ide	sodium chloride or iron(III) chloride
Ionic with polyatomic ion(s) (Section 3.5)	M_aX_b or $(NH_4)_aX_b$ X = formula of polyatomic ion	Li_2HPO_4 or $CuSO_4$ or NH_4Cl or $(NH_4)_2SO_4$	(name of metal) (name of polyatomic ion) or (name of metal)(Roman numeral) (name of polyatomic ion) or ammonium (root of nonmetal)ide or ammonium (name of polyatomic ion)	lithium hydrogen phosphate or copper(II) sulfate or ammonium chloride or ammonium sulfate
Binary acid (Section 5.2)	$HX(aq)$	$HCl(aq)$	hydro(root)ic acid	hydrochloric acid
Oxyacid (Section 5.2)	$H_aX_bO_c$	HNO_3 or H_2SO_4 or H_3PO_4	(root)ic acid	nitric acid or sulfuric acid or phosphoric acid

M = symbol of metal

A and B = symbols of nonmetals

X = some element other than H or O

The letters a, b, & c represent subscripts.

EXERCISE 5.3 - Formulas to Names

OBJECTIVE 14

Write the names that correspond to the following chemical formulas.

- | | | |
|--------------|------------------|-------------------|
| a. AlF_3 | d. $CaCO_3$ | g. NH_4F |
| b. PF_3 | e. $Ca(HSO_4)_2$ | h. $HCl(aq)$ |
| c. H_3PO_4 | f. $CuCl_2$ | i. $(NH_4)_3PO_4$ |

There is a tutorial on the textbook's Web site that will provide practice converting between chemical names and formulas.

EXERCISE 5.4 - Names to Formulas

Write the chemical formulas that correspond to the following names. OBJECTIVE 14

- | | |
|---------------------------------|---------------------------|
| a. ammonium nitrate | f. hydrofluoric acid |
| b. acetic acid | g. diphosphorus tetroxide |
| c. sodium hydrogen sulfate | h. aluminum carbonate |
| d. potassium bromide | i. sulfuric acid |
| e. magnesium hydrogen phosphate | |

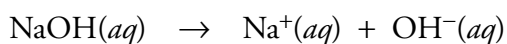
5.4 Strong and Weak Bases

Each year, the US chemical industry produces over 10 billion kilograms of the base sodium hydroxide, NaOH, which is then used for many purposes, including water treatment, vegetable oil refining, the peeling of fruits and vegetables in the food industry, and to make numerous other chemical products, including soaps and detergents. Likewise, over 15 billion kilograms of the base ammonia, NH₃, is produced each year. Although a water solution of ammonia is a common household cleaner, most of the NH₃ produced in the US is used to make fertilizers and explosives. As you read this section, you will learn about the chemical properties of basic compounds that make them so useful to chemists and others.

According to the modern version of the Arrhenius theory of acids and bases, a **base** is a substance that produces hydroxide ions, OH⁻, when it is added to water. A solution that has a significant concentration of hydroxide ions is called a **basic solution**. Sodium hydroxide, NaOH, is the most common laboratory base. It is designated a **strong base** because for every NaOH unit dissolved, one hydroxide ion is formed in solution.



This water treatment plant uses the base sodium hydroxide, NaOH, to remove impurities from the water.



Compounds that contain hydroxide ions are often called **hydroxides**. All water-soluble hydroxides are strong bases. Examples include lithium hydroxide, LiOH, which is used in storage batteries and as a carbon dioxide absorbent in space vehicles, and potassium hydroxide, KOH, which is used to make some soaps, liquid fertilizers, and paint removers.

When ammonia, NH₃, dissolves in water, some hydrogen ions, H⁺, are transferred from water molecules to ammonia molecules, NH₃, producing ammonium ions, NH₄⁺, and hydroxide ions, OH⁻. The reaction is reversible, so when an ammonium ion and a hydroxide ion meet in solution, the H⁺ ion can be passed back to the OH⁻ to reform an NH₃ molecule and a water molecule (Figure 5.8).

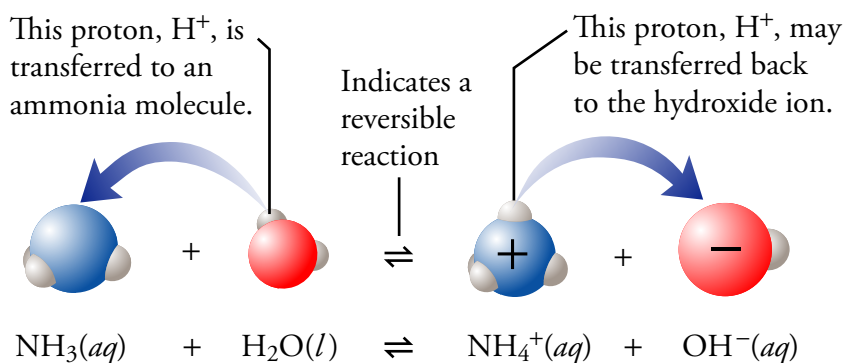


Figure 5.8
The Reversible Reaction
of Ammonia and Water

OBJECTIVE 15

OBJECTIVE 16

OBJECTIVE 16

OBJECTIVE 16

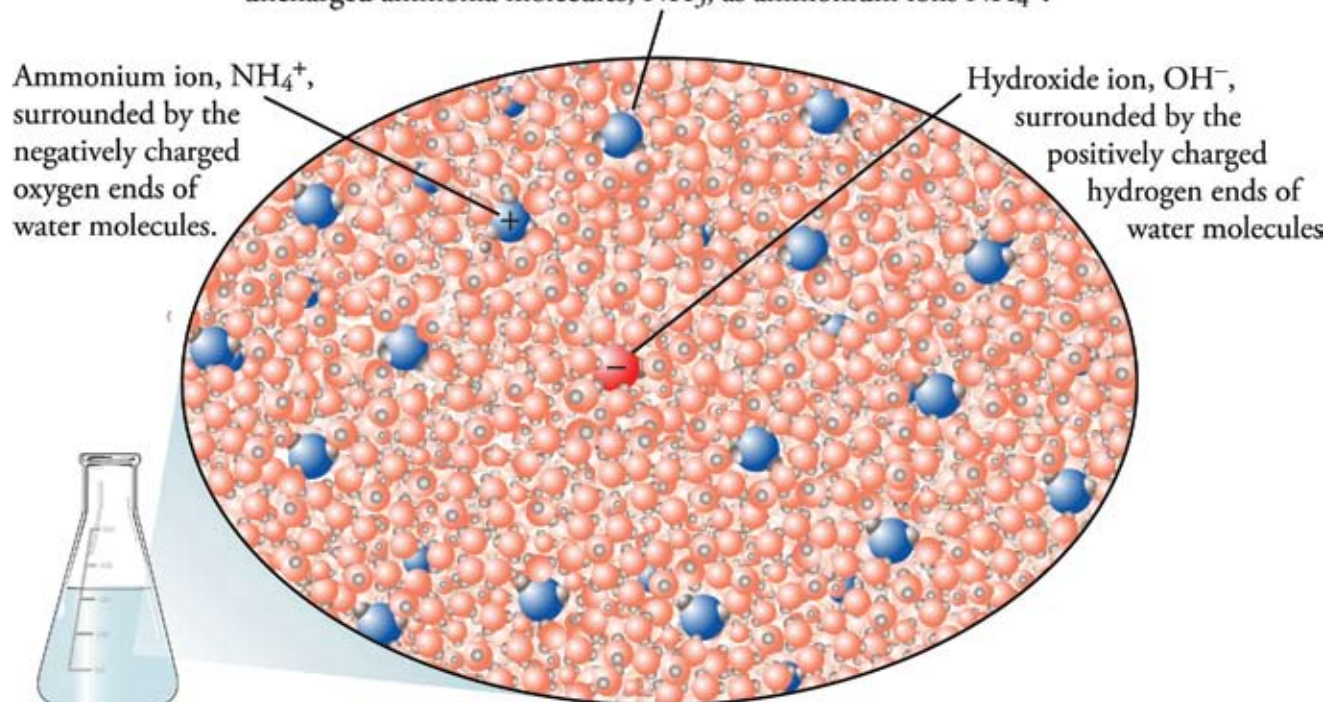
Ammonia is an **Arrhenius base** because it produces OH^- ions when added to water. Because the reaction is reversible, however, only some ammonia molecules have acquired protons (creating OH^-) at any given time, so an ammonia solution contains fewer hydroxide ions than would be found in a solution made using an equivalent amount of a strong base. Therefore, we classify ammonia as a **weak base**, which is a base that produces fewer hydroxide ions in water solution than there are particles of base dissolved.

To visualize the reaction between ammonia and water at the molecular level, imagine that you are taking a ride on a nitrogen atom. Your nitrogen would usually be bonded with three hydrogen atoms in an NH_3 molecule, but occasionally, it would gain an extra H^+ ion from a water molecule to form NH_4^+ for a short time. When your NH_4^+ ion collides with an OH^- ion, an H^+ ion is transferred to the OH^- ion to form H_2O and NH_3 . Ammonia molecules are constantly gaining and losing H^+ ions, but soon after the initial addition of ammonia to water, both changes proceed at an equal rate. At this point, there will be no more net change in the amounts of ammonia, water, hydroxide, and ammonium ion in the solution. When a typical solution of ammonia stops changing, it is likely to contain about 200 NH_3 molecules for each NH_4^+ ion. As you study the ammonia solution depicted in Figure 5.9, try to picture about 200 times as many NH_3 molecules as NH_4^+ or OH^- ions.

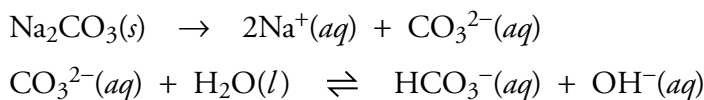
Figure 5.9
Ammonia in Water

OBJECTIVE 16

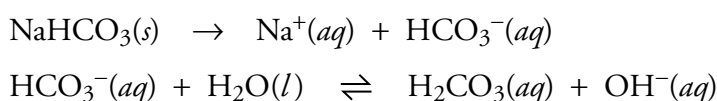
In a typical ammonia solution, there are about 200 times as many uncharged ammonia molecules, NH_3 , as ammonium ions NH_4^+ .



There are many weak Arrhenius bases, but the only ones that you will be expected to recognize are ionic compounds containing carbonate (for example, sodium carbonate, Na_2CO_3) and hydrogen carbonate (for example, sodium hydrogen carbonate, NaHCO_3). When sodium carbonate, which is used to make glass, soaps, and detergents, dissolves in water, the carbonate ions, CO_3^{2-} , react with water in a reversible way to yield hydroxide ions.



In a similar reaction, the hydrogen carbonate ions, HCO_3^- , formed when NaHCO_3 dissolves in water, react to yield hydroxide ions.



Sodium hydrogen carbonate is found in fire extinguishers, baking powders, antacids, and mouthwashes.



These products all contain the weak base sodium hydrogen carbonate.

Table 5.6 summarizes how you can recognize substances as bases and how you can classify them as strong or weak bases. (There are other Arrhenius bases that you may learn about later.)

Table 5.6
Arrhenius Bases

	Strong	Weak
Ionic compounds	Metal hydroxides, such as NaOH	Ionic compounds with CO_3^{2-} and HCO_3^- , such as Na_2CO_3 and NaHCO_3
Certain uncharged molecules	None	NH_3

OBJECTIVE 17

OBJECTIVE 18

You can get more information about strong and weak bases on the textbook's Web site.

The following sample study sheet summarizes the ways you can recognize strong and weak acids and bases.

Sample Study Sheet 5.1

Identification of Strong and Weak Acids and Bases

OBJECTIVE 18

TIP-OFF You are asked to identify a substance as either (1) an Arrhenius strong acid, (2) an Arrhenius weak acid, (3) an Arrhenius strong base, or (4) an Arrhenius weak base.

GENERAL STEPS

STEP 1 Identify the substance as an Arrhenius acid or base using the following criteria.

- The names of the acids end in *acid*. Acid formulas have one of these forms: $\text{HX}(aq)$ or $\text{H}_a\text{X}_b\text{O}_c$.
- Ionic compounds that contain hydroxide, carbonate, or hydrogen carbonate anions are basic. Ammonia, NH_3 , is also a base.

STEP 2 If the substance is an acid or base, determine whether it is strong or weak.

- We will consider all acids except $\text{HCl}(aq)$, HNO_3 , and H_2SO_4 to be weak.
- We will consider all bases except metal hydroxides to be weak.

EXAMPLE See Example 5.3.

EXAMPLE 5.3 - Identification of Acids and Bases

OBJECTIVE 18

Identify (a) H_2SO_4 , (b) oxalic acid, (c) NaHCO_3 , (d) potassium hydroxide, (e) $\text{HCl}(aq)$, and (f) ammonia as either an Arrhenius strong acid, an Arrhenius weak acid, an Arrhenius strong base, or an Arrhenius weak base.

Solution

- a. The H_2SO_4 is an acid because it has the form of an oxyacid, $\text{H}_a\text{X}_b\text{O}_c$. It is on the list of **strong acids**.
- b. Oxalic acid is not on the list of strong acids— $\text{HCl}(aq)$, HNO_3 , and H_2SO_4 —so it is a **weak acid**.
- c. Ionic compounds that contain hydrogen carbonate, such as NaHCO_3 , are **weak bases**.
- d. Ionic compounds that contain hydroxide, such as potassium hydroxide, are **strong bases**.
- e. We know that hydrochloric acid, $\text{HCl}(aq)$, is an acid because its name ends in “acid,” and its formula has the form of a binary acid. It is found on the list of **strong acids**.
- f. Ammonia, NH_3 , is our one example of an uncharged **weak base**.

There is a tutorial on the textbook's Web site that will provide practice identifying acids and bases.

EXERCISE 5.5 - Identification of Acids and Bases

Identify each of the following as either an Arrhenius strong acid, an Arrhenius weak acid, an Arrhenius strong base, or an Arrhenius weak base.

- | | |
|----------------------|----------------------------|
| a. HNO_3 | c. K_2CO_3 |
| b. lithium hydroxide | d. hydrofluoric acid |

OBJECTIVE 18

SPECIAL TOPIC 5.2 Chemistry and Your Sense of Taste

“...[T]hat formed of bodies round and smooth are things which touch the senses sweetly, while those which harsh and bitter do appear, are held together bound with particles more hooked, and for this cause are wont to tear their way into our senses, and on entering in to rend the body.”

Lucretius, a Roman philosopher and poet, about 2000 years ago

Lucretius was mistaken in certain details, but he was correct that the shape of molecules is important in determining whether compounds taste sweet or bitter. Your tongue has about 3000 taste buds, each of which is an onion-shaped collection of 50 to 150 taste cells. Each taste bud is specialized for tasting either sweet, sour, salt, or bitter. It has been suggested that the tongue can also perceive another taste, umami, which is a subtle taste most commonly associated with monosodium glutamate, MSG. At the tips of the bitter and sweet taste cells are receptor molecules shaped to fit parts of certain molecules in our food.

When chocolate, for example, is roasted, caffeine and other compounds are formed that stimulate the bitter taste cells. The molecules of these compounds have a shape that allows them to attach to the taste cell receptors and cause an adjacent nerve cell to fire. This event sends the bitter signal to the brain.

Sugar is added to chocolate to counteract the bitter taste. The arrangement of atoms in sugar molecules allows them to fit into the receptor sites of sweet taste cells. When a sugar molecule like glucose or sucrose attaches to a receptor of a sweet taste cell, the sweet signal is sent to the brain.

The salt taste is thought to have different mechanisms than the sweet and bitter tastes. It is the presence of sodium ions, Na^+ , in the sodium chloride, NaCl , of table salt that causes the taste. The interior of a salt taste cell is negatively

charged. When such a cell is bathed in saliva that contains dissolved sodium ions, the Na^+ ions enter the cell and make its interior less negative. This change triggers the release of chemicals called neurotransmitters into the space between the taste cells and nerve cells. The neurotransmitters cause the nerve cells to fire, sending the salt signal to the brain.



Bases taste bitter.

Acids cause the sour taste in foods. Vinegar is sour because it contains acetic acid, sour milk contains lactic acid, and lemons contain citric acid. What these acids have in common is that they can lose H^+ ions in water solutions such as our saliva. Different animal species have different mechanisms for sending the sour signal. In amphibians the H^+ ions block the normal release of potassium ions from sour taste cells, changing the cells' charge balance and causing them to release neurotransmitters. The neurotransmitters in turn tell the sour nerve cells to fire.

It has been suggested that there are good reasons for the evolution of our sense of taste. The four main tastes either lead us to food we need or warn us away from substances that might be harmful. We need sugar for energy and salt to replace the sodium and potassium ions lost in exercise. On the other hand, spoiled foods produce bitter-tasting substances, and numerous poisons, too, are bitter, while many a bellyache from unripe fruit has been avoided by the warning signal provided by the sour taste.

5.5 pH and Acidic and Basic Solutions



pH-Balanced shampoo

The scientific term **pH** has crept into our everyday language. Advertisements encourage us to choose products that are “pH balanced,” while environmentalists point to the lower pH of rain in certain parts of the country as a cause of ecological damage (Figure 5.10). The term was originated by chemists to describe the acidic and basic strengths of solutions.

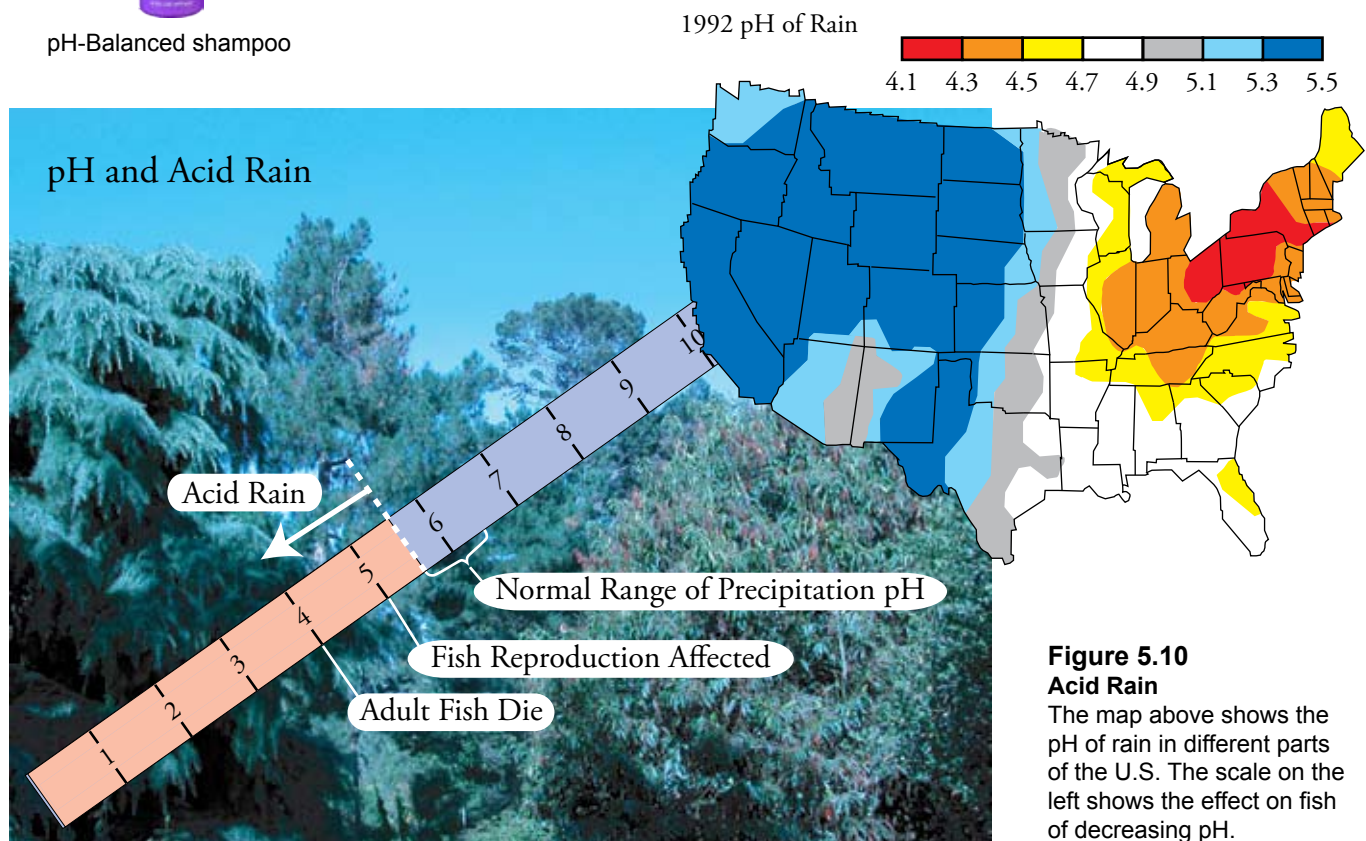


Figure 5.10
Acid Rain

The map above shows the pH of rain in different parts of the U.S. The scale on the left shows the effect on fish of decreasing pH.

We know that an Arrhenius acid donates H^+ ions to water to create H_3O^+ ions. The resulting solution is called an acidic solution. We also know that when you add a certain amount of a strong acid to one sample of water—say the water’s volume is a liter—and add the same amount of a weak acid to another sample of water whose volume is also a liter, the strong acid generates more H_3O^+ ions in solution. Because the concentration of H_3O^+ ions in the strong acid solution is higher (there are more H_3O^+ ions per liter of solution), we say it is more acidic than the weak acid solution. A solution can also be made more acidic by the addition of more acid (while the amount of water remains the same). The pH scale can be used to describe the relative acidity of solutions.

If you take other chemistry courses, you will probably learn how pH is defined and how the pH values of solutions are determined. For now, all you need to remember is that acidic solutions have pH values less than 7, and that the more acidic a solution is, the lower its pH. A change of one pH unit reflects a ten-fold change in H_3O^+ ion concentration. For example, a solution with a pH of 5 has ten times the concentration

OBJECTIVE 19

OBJECTIVE 20

of H_3O^+ ions as a solution with a pH of 6. The pH of some common solutions are listed in Figure 5.11. Note that gastric juice in our stomach has a pH of about 1.4, and orange juice has a pH of about 2.8. Thus gastric juice is more than ten times more concentrated in H_3O^+ ions than orange juice.

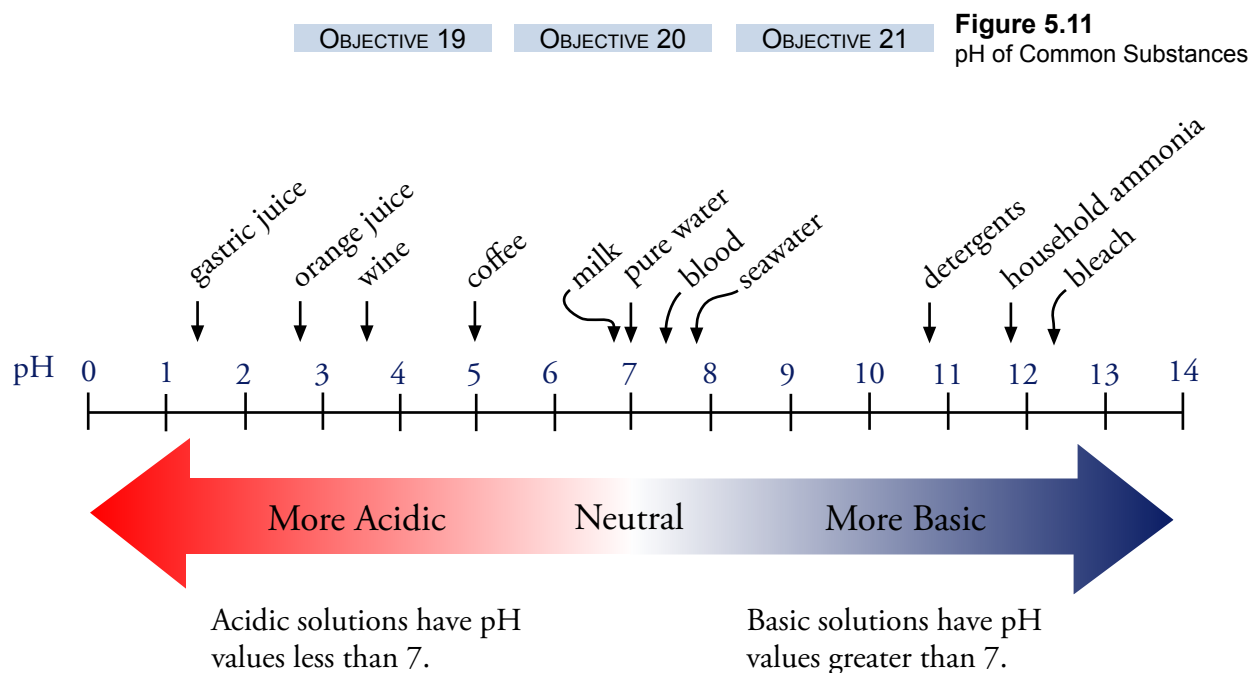
The pH scale is also used to describe basic solutions, which are formed when an Arrhenius base is added to water, generating OH^- ions. When you add a certain amount of a strong base to one sample of water—again, let's say a liter—and add the same amount of a weak base to another sample of water whose volume is the same, the strong base generates more OH^- ions in solution. Because the concentration of OH^- ions in the strong base solution is higher (there are more OH^- ions per liter of solution), we say it is more basic than the weak base solution. A solution can also be made more basic by the addition of more base while the amount of water is held constant.

Basic solutions have pH values greater than 7, and the more basic the solution is, the higher its pH. A change of one pH unit reflects a ten-fold change in OH^- ion concentration. For example, a solution with a pH of 12 has ten times the concentration of OH^- ions as does a solution with a pH of 11. The pH difference of about 4 between household ammonia solutions (pH about 11.9) and seawater (pH about 7.9) shows that household ammonia has about ten thousand (10^4) times the hydroxide ion concentration of seawater.

In nature, water contains dissolved substances that make it slightly acidic, but pure water is neutral and has a pH of 7 (Figure 5.11).

OBJECTIVE 19

OBJECTIVE 21



OBJECTIVE 22

In the laboratory, we can detect acids and bases in solution in several ways. Perhaps the simplest test uses a substance called litmus, a natural dye derived from lichen. It



Litmus, whose natural source is lichen, can be applied to the surface of paper that is then used to identify acidic and basic solutions.

turns red in acidic conditions and blue in basic conditions. Litmus paper is paper that has been coated with litmus. To test if a liquid is acidic, we add a drop of the liquid to blue litmus paper, which is litmus paper that has been made slightly basic and therefore blue. If the paper turns red, the liquid is acidic. To test to see if a liquid is basic, we add a drop of the liquid to red litmus paper, which is litmus paper that has been made slightly acidic and therefore red. If the paper turns blue, the liquid is basic.

5.6 Arrhenius Acid-Base Reactions



This emergency crew is neutralizing an acid spill on the highway by covering it with a basic foam.



Neutralization reactions keep our bodies in balance and also maintain the “health” of the world around us. (Photo by Cliff Reiter)

When an Arrhenius acid is combined with an Arrhenius base, we say that they neutralize each other. By this, we mean that the acid counteracts the properties of the base, and the base counteracts the properties of the acid. For example, a strong acid, such as nitric acid, must be handled with extreme caution, because if it gets on your skin, it could cause severe chemical burns. If you accidentally spilled nitric acid on a laboratory bench, however, you could quickly pour a solution of a weak base, such as sodium hydrogen carbonate, on top of the spill to neutralize the acid and make it safer to wipe. In a similar way, a solution of a weak acid, such as acetic acid, can be poured on a strong base spill to neutralize the base before cleanup. Therefore, reactions between Arrhenius acids and bases are often called **neutralization reactions**.

Neutralization reactions are important in maintaining the necessary balance of chemicals in your body, and they help keep a similar balance in our oceans and lakes. Neutralization reactions are used in industry to make a wide range of products, including pharmaceuticals, food additives, and fertilizers. Let’s look at some of the different forms of Arrhenius acid-base reactions, how they can be visualized, and how to describe them with chemical equations.

Reactions of Aqueous Strong Arrhenius Acids and Aqueous Strong Arrhenius Bases

The reaction between the strong acid nitric acid and the strong base sodium hydroxide is our first example. Figure 5.12 shows the behavior of nitric acid in solution. As a strong acid, virtually every HNO_3 molecule donates an H^+ ion to water to form a hydronium ion, H_3O^+ , and a nitrate ion, NO_3^- . Because the reaction goes essentially to completion, you can picture the solution as containing H_2O , NO_3^- , and H_3O^+ , with no HNO_3 remaining. The negatively charged oxygen ends of the water molecules surround the positive hydronium ions, and the positively charged hydrogen ends of water molecules surround the nitrate ions.

OBJECTIVE 23A

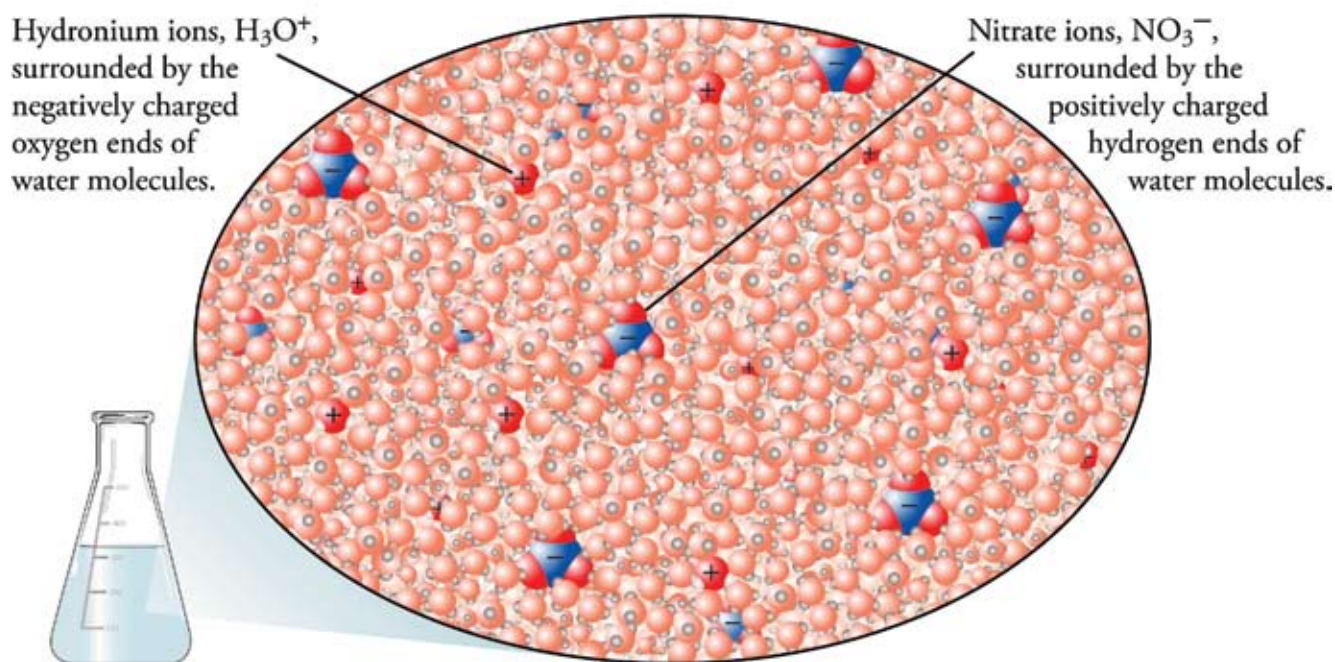


Figure 5.12
Aqueous Nitric Acid

Like a water solution of any ionic compound, a solution of sodium hydroxide (NaOH) consists of ions separated and surrounded by water molecules. At the instant that the solution of sodium hydroxide is added to the aqueous nitric acid, there are four different ions in solution surrounded by water molecules: H_3O^+ , NO_3^- , Na^+ , and OH^- (Figure 5.13 on the next page).

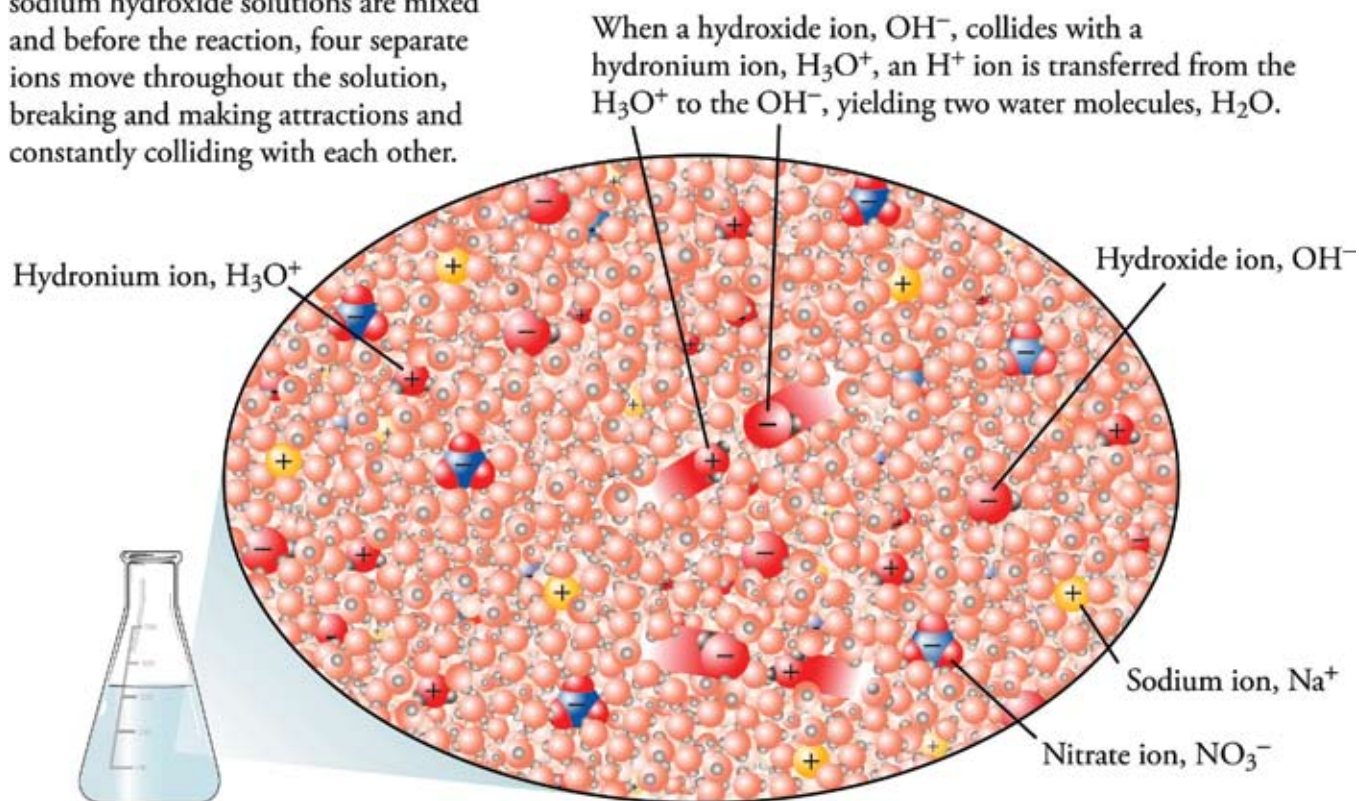
OBJECTIVE 23A

Figure 5.13

Water Solution of Nitric Acid and Sodium Hydroxide before Reaction

OBJECTIVE 23A

At the instant after nitric acid and sodium hydroxide solutions are mixed and before the reaction, four separate ions move throughout the solution, breaking and making attractions and constantly colliding with each other.

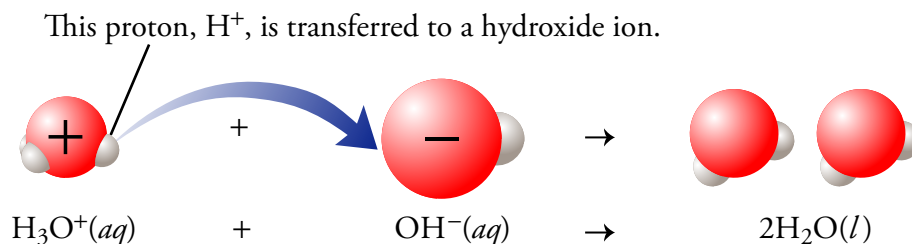


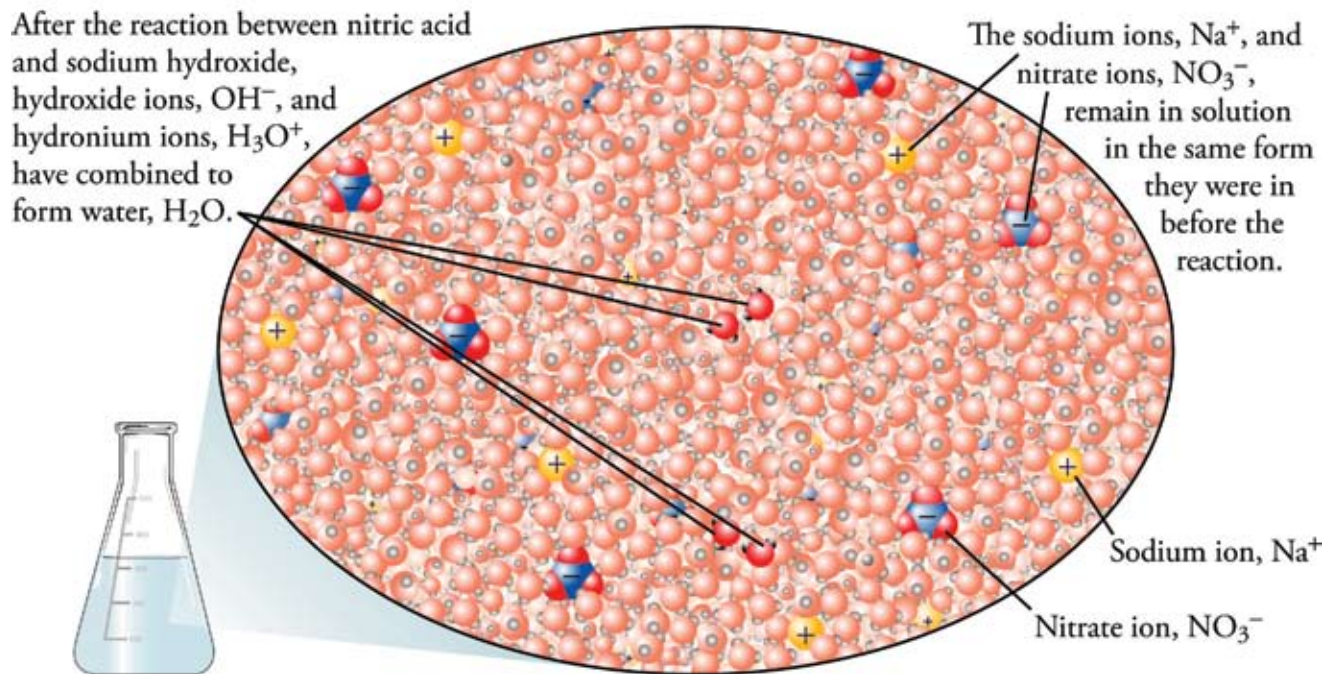
OBJECTIVE 23A

The ions in solution move in a random way, like any particles in a liquid, so they will constantly collide with other ions. When two cations or two anions collide, they repel each other and move apart. When a hydronium ion and a nitrate ion collide, it is possible that the H_3O^+ ion will return an H^+ ion to the NO_3^- ion, but nitrate ions are stable enough in water to make this unlikely. When a sodium ion collides with a hydroxide ion, they may stay together for a short time, but their attraction is too weak and water molecules collide with them and push them apart. When hydronium ions and hydroxide ions collide, however, they react to form water (Figure 5.14), so more water molecules are shown in Figure 5.15 than in Figure 5.13.

Figure 5.14

Reaction Between Hydronium Ion and Hydroxide Ion



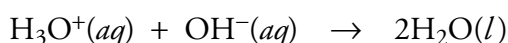


OBJECTIVE 23A

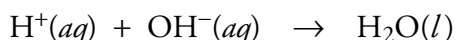
Figure 5.15

After Reaction of Nitric Acid and Sodium Hydroxide

The sodium and nitrate ions are unchanged in the reaction. They were separate and surrounded by water molecules at the beginning of the reaction, and they are still separate and surrounded by water molecules after the reaction. They were important in delivering the hydroxide and hydronium ions to solution, but they did not actively participate in the reaction. In other words, they are spectator ions, so they are left out of the net ionic chemical equation. The net ionic equation for the reaction is therefore



Most chemists are in the habit of describing reactions such as this one in terms of H^+ rather than H_3O^+ , even though hydrogen ions do not exist in a water solution in the same sense that sodium ions do. When an acid loses a hydrogen atom as H^+ , the proton immediately forms a covalent bond to some other atom. In water, it forms a covalent bond to a water molecule to produce the hydronium ion. Although H_3O^+ is a better description of what is found in acid solutions, it is still convenient and conventional to write H^+ in equations instead. You can think of H^+ as a shorthand notation for H_3O^+ . Therefore, the following net ionic equation is a common way to describe the net ionic equation above.



Writing Equations for Reactions Between Acids and Bases

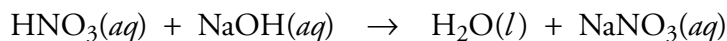
The procedure for writing equations for acid-base reactions is very similar to that used to write equations for precipitation reactions in Section 4.2.

The first step in writing an equation for the reaction between nitric acid, HNO_3 , and the base sodium hydroxide, NaOH , is to predict the formulas for the products by recognizing that most Arrhenius neutralization reactions, like the reaction between

OBJECTIVE 23A

OBJECTIVE 24

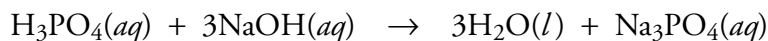
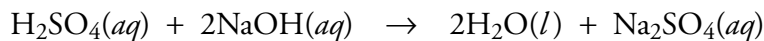
nitric acid and sodium hydroxide, are double-displacement reactions.



OBJECTIVE 24

We consider the positive portion of the acid to be H^+ , so for the reaction above, A is H^+ , B is NO_3^- , C is Na^+ , and D is OH^- . When H^+ ions combine with OH^- ions, they form HOH (that is, water, H_2O). The ion formulas Na^+ and NO_3^- are combined in the complete equation as the CB formula, NaNO_3 .

In picturing reactions of a polyprotic acid with a strong base, we shall assume that enough base is added to react with all of the acidic hydrogen atoms. The following complete equations describe the reactions of the diprotic acid sulfuric acid and the triprotic acid phosphoric acid with sodium hydroxide. Each equation represents the sum of a series of reactions in which the acidic hydrogen atoms are removed one at a time.

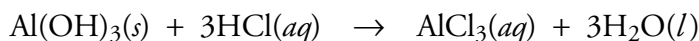


OBJECTIVE 24

The problems at the end of the chapter ask you to write complete equations for reactions like these. Note that these too are double-displacement reactions. In each of these examples, A is H^+ , C is Na^+ , and D is OH^- . In the first reaction, B is SO_4^{2-} , and in the second reaction, B is PO_4^{3-} .

OBJECTIVE 23B

One of the useful properties of acids is that they will react with insoluble ionic compounds that contain basic anions. Because the products of such reactions are soluble, acids can be used to dissolve normally insoluble ionic compounds (See Special Topic 5.3: *Precipitation, Acid-Base Reactions, and Tooth Decay*). For example, water-insoluble aluminum hydroxide dissolves in a hydrochloric acid solution.



EXAMPLE 5.4 - Neutralization Reactions

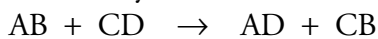
OBJECTIVE 24

Write the complete equations for the neutralization reactions that take place when the following water solutions are mixed. (If an acid has more than one acidic hydrogen, assume that there is enough base to remove all of them. Assume that there is enough acid to neutralize all of the basic hydroxide ions.)

- $\text{HCl}(aq) + \text{KOH}(aq)$
- $\text{H}_2\text{SO}_4(aq) + \text{KOH}(aq)$
- $\text{HNO}_3(aq) + \text{Mn}(\text{OH})_2(s)$

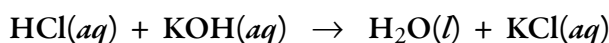
Solution

- Neutralization reactions between strong monoprotic acids, such as $\text{HCl}(aq)$, and ionic compounds, such as KOH , are double-displacement reactions, so they have the form

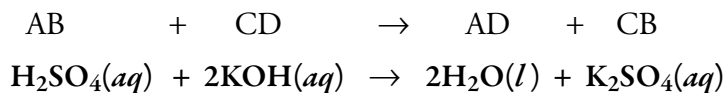


For HCl , A is H^+ , and B is Cl^- . For KOH , C is K^+ , and D is OH^- .

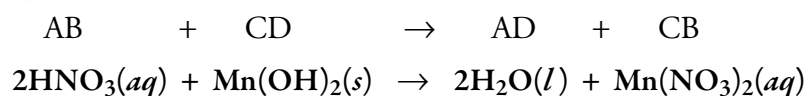
Therefore, AD is HOH or H_2O , which we know is a liquid, and CB is KCl , which is a water-soluble ionic compound and thus aqueous.



- b. For H_2SO_4 in a double-displacement reaction, A is H^+ , and B is SO_4^{2-} . (In neutralization reactions, you can assume that all of the acidic hydrogen atoms are lost to the base. Monoprotic acids lose one H^+ ion, diprotic acids such as H_2SO_4 lose two H^+ ions, and triprotic acids such as H_3PO_4 lose three H^+ ions.) For KOH , C is K^+ , and D is OH^- . Thus AD is H_2O , and CB is K_2SO_4 , a water-soluble ionic compound. The two H^+ ions from the diprotic acid H_2SO_4 react with the two OH^- ions from two units of KOH to form two H_2O molecules.



- c. For HNO_3 in a double-displacement reaction, A is H^+ , and B is NO_3^- . For $\text{Mn}(\text{OH})_2$, C is Mn^{2+} , and D is OH^- . Thus AD is H_2O , and CB is $\text{Mn}(\text{NO}_3)_2$, a water-soluble ionic compound. Two H^+ ions from two nitric acid molecules react with the two OH^- ions from the $\text{Mn}(\text{OH})_2$ to form two H_2O molecules.



EXERCISE 5.6 - Neutralization Reactions

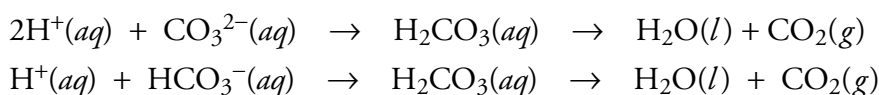
Write the complete equation for the neutralization reactions that take place when the following water solutions are mixed. (If an acid has more than one acidic hydrogen, assume that there is enough base to remove all of them. Assume that there is enough acid to neutralize all of the basic hydroxide ions.)

- $\text{HCl}(\text{aq}) + \text{NaOH}(\text{aq})$
- $\text{HF}(\text{aq}) + \text{LiOH}(\text{aq})$
- $\text{H}_3\text{PO}_4(\text{aq}) + \text{LiOH}(\text{aq})$
- $\text{Fe}(\text{OH})_3(\text{s}) + \text{HNO}_3(\text{aq})$

There is an animation that will help you visualize reactions between acids and bases at the textbook's Web site.

Reactions of Arrhenius Acids and Ionic Compounds Containing Carbonate or Hydrogen Carbonate

The reaction between an acid and an ionic compound containing either carbonate or hydrogen carbonate leads to carbon dioxide and water as products. The addition of H^+ ions to CO_3^{2-} or HCO_3^- forms carbonic acid, H_2CO_3 . Carbonic acid, however, is unstable in water, so when it forms, it decomposes into carbon dioxide, $\text{CO}_2(\text{g})$, and water, $\text{H}_2\text{O}(\text{l})$.



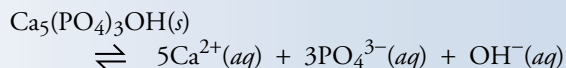
OBJECTIVE 24

OBJECTIVE 23C

OBJECTIVE 25

SPECIAL TOPIC 5.3 Precipitation, Acid-Base Reactions, and Tooth Decay

Teeth have a protective coating of hard enamel that is about 2 mm thick and consists of about 98% hydroxyapatite, $\text{Ca}_5(\text{PO}_4)_3\text{OH}$. Like any ionic solid surrounded by a water solution, the hydroxyapatite is constantly dissolving and reprecipitating.

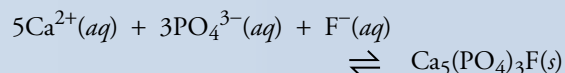


Your saliva provides the calcium ions and the phosphate ions for this process, and as long as your saliva does not get too acidic, it will contain enough hydroxide to keep the rate of solution and the rate of precipitation about equal. Thus there is no net change in the amount of enamel on your teeth.

Unfortunately, certain foods can upset this balance. The bacteria in your mouth break down your food, especially food high in sugar, to form acids such as acetic acid and lactic acid. These acids neutralize the hydroxide in your saliva, slowing the precipitation of enamel. The $\text{Ca}_5(\text{PO}_4)_3\text{OH}$ continues to go into solution, so there is a net loss of the protective coating on the teeth.

Fluoride in our drinking water and our toothpaste can help minimize the damage described above. The fluoride ion takes the place of the hydroxide ion to precipitate fluorapatite, $\text{Ca}_5(\text{PO}_4)_3\text{F}$, a compound very similar to the

original enamel.



Fluorapatite is 100 times less soluble than hydroxyapatite, so it is less likely to be affected by the acid formed by the bacteria.



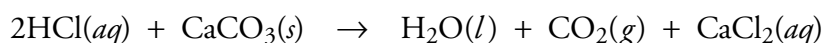
The natural enamel that coats teeth is mostly $\text{Ca}_5(\text{PO}_4)_3\text{OH}$. Fluoride in our water or toothpaste leads to the less soluble $\text{Ca}_5(\text{PO}_4)_3\text{F}$ replacing $\text{Ca}_5(\text{PO}_4)_3\text{OH}$ in tooth enamel, helping to protect our teeth from tooth decay.

OBJECTIVE 24



Acids can be used to make limestone more permeable to oil by converting solid calcium carbonate into water-soluble calcium chloride.

Thus, when H_2CO_3 would be predicted as a product for a double-displacement reaction, write " $\text{H}_2\text{O}(l) + \text{CO}_2(g)$ " instead. Three examples are below.



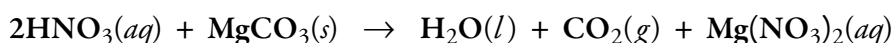
The third equation above describes a reaction that helps the oil industry extract more oil from a well. For oil to be pumped from deep in the earth to the surface, it must first seep through underground rock formations to the base of the oil well's pipes. Limestone, which is composed of CaCO_3 , can be made more permeable to oil by pumping hydrochloric acid down into the limestone formations, converting the insoluble calcium carbonate to soluble calcium chloride.

EXAMPLE 5.5 - Neutralization Reactions with Compounds Containing Carbonate

Write the complete equation for the reaction between $\text{HNO}_3(aq)$ and water-insoluble solid MgCO_3 .

Solution

Translated into the general format of double-displacement reactions, A is H^+ , B is NO_3^- , C is Mg^{2+} , and D is CO_3^{2-} . Compound AD would therefore be H_2CO_3 , but this decomposes to form $\text{H}_2\text{O}(l)$ and $\text{CO}_2(g)$. Compound CB is $\text{Mg}(\text{NO}_3)_2$, which is a water-soluble ionic compound and thus aqueous.



OBJECTIVE 24

EXERCISE 5.6 - Neutralization Reactions with Carbonate Containing Compounds

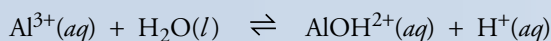
Write the complete equation for the neutralization reaction that takes place when water solutions of sodium carbonate, Na_2CO_3 , and hydrobromic acid, HBr , are mixed.

OBJECTIVE 24

SPECIAL TOPIC 5.4 Saving Valuable Books

Before the 19th century, paper in Europe was made from linen or old rags. Supplies of these materials dwindled as the demand for paper soared, and new manufacturing methods and raw materials were sought. Paper began to be made from wood pulp, but the first such products contained microscopic holes that caused the ink to bleed and blur. To fill these holes, the paper was saturated with "alum," which is aluminum sulfate, $\text{Al}_2(\text{SO}_4)_3$. The new process seemed to make a suitable paper, but as time passed, serious problems emerged.

The aluminum ions in alum, like many metal ions, are acidic in the Arrhenius sense, reacting with moisture from the air to release H^+ ions.

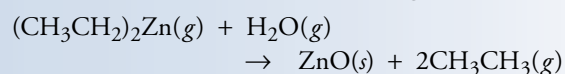
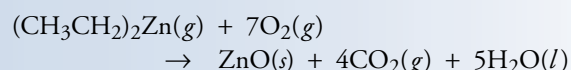


The H^+ ions react in turn with the paper and weaken it. Many valued books are so brittle that they cannot be handled without their pages crumbling.

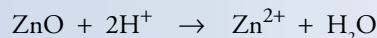
Several techniques are now being developed to neutralize the acid in the paper. As we have seen, most acid-base reactions take place in water, and there are obvious problems with dunking a book in an aqueous solution of base. The challenge, then, has been to develop a technique in which a gas is used to neutralize acid in the paper without causing further damage.

One such technique is called the DEZ treatment. DEZ, or diethyl zinc, $(\text{CH}_3\text{CH}_2)_2\text{Zn}$, can be made gaseous near room temperature. It reacts with either oxygen or water

vapor to form zinc oxide, $\text{ZnO}(s)$, which is deposited evenly on the paper.



The zinc oxide contains the basic anion oxide, O^{2-} , which reacts with H^+ ions to neutralize the acid in the paper.



Damage that has already been done cannot be reversed, so the goal is to save as many books as possible before they deteriorate so much that they cannot be handled.

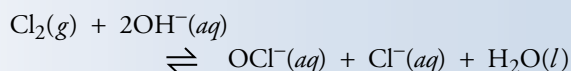


The acid in the paper used to make some books damages the paper and leaves it brittle. The paper in the book above was made with a process that left the paper acidic.

Do you want to know why bleach bottles have a warning label that tells you not to mix the bleach with acidic cleaning agents, such as toilet bowl cleaners? The explanation is in Special Topic 5.5 below.

SPECIAL TOPIC 5.5 Be Careful with Bleach

Common bleach, used for household cleaning and laundering, is a water solution of sodium hypochlorite, $\text{NaClO}(aq)$. The hypochlorite ion is made by reacting chlorine gas with a basic solution.



This reaction is reversible, so the chlorine atoms are constantly switching back and forth from Cl_2 to OCl^- . In a basic solution, the forward reaction is fast enough to ensure that most of the chlorine in the bottle of bleach is in the OCl^- form.

If the bleach is added to an acidic solution, the hydroxide ions in the basic solution of bleach react with the acidic H^+ ions to form water. With fewer hydroxide ions available, the reaction between the OH^- and the Cl_2 slows down, but the reverse reaction continues at the same pace. This creates

potentially dangerous levels of chlorine gas and is the reason that the labels on bleach bottles warn against mixing bleach with other cleaning agents such as toilet bowl cleaners. Toilet bowl cleaners are usually acidic, containing acids such as phosphoric acid, H_3PO_4 , or hydrogen sulfate, HSO_4^- .



Mixing bleach and toilet bowl cleaners can be dangerous.

5.7 Brønsted-Lowry Acids and Bases

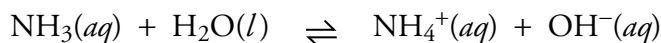
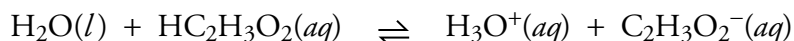
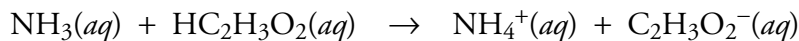
Although the Arrhenius definitions of acid, base, and acid-base reaction are very useful, an alternate set of definitions is also commonly employed. In this system, a **Brønsted-Lowry acid** is a proton (H^+) donor, a **Brønsted-Lowry base** is a proton acceptor, and a **Brønsted-Lowry acid-base reaction** is a proton transfer. Table 5.7 summarizes the definitions of acid and base in the Arrhenius and Brønsted-Lowry systems.

Table 5.7
Definitions of Acid and Base

System	Acid Definition	Base Definition
Arrhenius	Generates H_3O^+ when added to water	Generates OH^- when added to water
Brønsted-Lowry	Proton (H^+) Donor in Reaction	Proton (H^+) Acceptor in Reaction

To better understand the differences and to understand why new definitions were suggested, consider the following reactions.

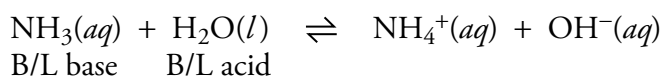
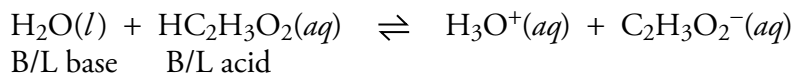
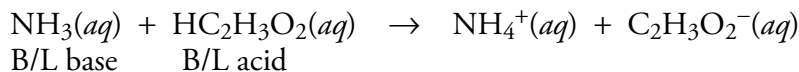
OBJECTIVE 26



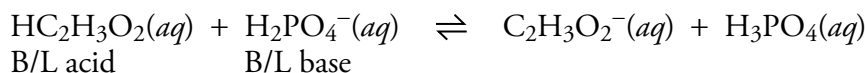
These reactions are very similar, but only the first reaction would be considered an acid-base reaction in the Arrhenius system. In each of the reactions, an H^+ is transferred from one reactant to another, but only the first is a reaction between an Arrhenius acid and an Arrhenius base. In the first reaction, an H^+ is transferred from the Arrhenius weak acid acetic acid, $\text{HC}_2\text{H}_3\text{O}_2(aq)$, to the Arrhenius weak base ammonia, $\text{NH}_3(aq)$. In the second reaction, an H^+ is transferred from the Arrhenius weak acid acetic acid, $\text{HC}_2\text{H}_3\text{O}_2(aq)$, to water, which is not considered an acid or a base in the Arrhenius sense. In the third reaction, an H^+ is transferred from water, which is not considered an acid or base in the Arrhenius sense, to the Arrhenius weak base ammonia, $\text{NH}_3(aq)$.

The Brønsted-Lowry system allows us to describe all of these reactions as acid-base reactions. They are repeated below, with the Brønsted-Lowry acids and bases labeled. Note that in each case, the acid loses an H^+ ion as it reacts, and the base gains an H^+ ion.

OBJECTIVE 26



Acetic acid reacts with the dihydrogen phosphate polyatomic ion, H_2PO_4^- , in a reversible reaction. In the forward reaction, acetic acid acts as the Brønsted-Lowry acid and dihydrogen phosphate acts as the Brønsted-Lowry base



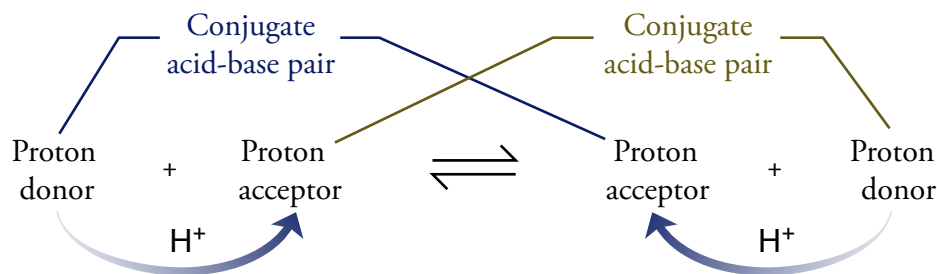
The reverse reaction, too, is a Brønsted-Lowry acid-base reaction. An H^+ ion is transferred from H_3PO_4 (the acid) to a $\text{C}_2\text{H}_3\text{O}_2^-$ ion (the base). The Brønsted-Lowry base for the forward reaction (H_2PO_4^-) gains an H^+ ion to form H_3PO_4 , which then acts as a Brønsted-Lowry acid in the reverse reaction and returns the H^+ ion to $\text{C}_2\text{H}_3\text{O}_2^-$. Chemists say that H_3PO_4 is the conjugate acid of H_2PO_4^- . The **conjugate acid** of a molecule or ion is the molecule or ion that forms when one H^+ ion is added. The formulas H_3PO_4 and H_2PO_4^- represent a **conjugate acid-base pair**, molecules or ions that differ by one H^+ ion.

OBJECTIVE 27

OBJECTIVE 28

Likewise, the Brønsted-Lowry acid for the forward reaction ($\text{HC}_2\text{H}_3\text{O}_2$) loses an H^+ ion to form $\text{C}_2\text{H}_3\text{O}_2^-$, which acts as a Brønsted-Lowry base in the reverse reaction and regains the H^+ ion. Chemists say that $\text{C}_2\text{H}_3\text{O}_2^-$ is the conjugate base of $\text{HC}_2\text{H}_3\text{O}_2$. The **conjugate base** of a molecule or ion is the molecule or ion that forms when one H^+ ion is removed. The formulas $\text{HC}_2\text{H}_3\text{O}_2$ and $\text{C}_2\text{H}_3\text{O}_2^-$ represent a conjugate acid-base pair (Figure 5.16).

Figure 5.16
Conjugate Acid-Base Pairs



EXAMPLE 5.6 - Conjugate Acids

OBJECTIVE 27

Write the formula for the conjugate acid of (a) F^- , (b) NH_3 , (c) HSO_4^- , and (d) CrO_4^{2-} .

Solution

In each case, the formula for the conjugate acid is derived by adding one H^+ ion to the formulas above.

- a. HF b. NH_4^+ c. H_2SO_4 d. HCrO_4^-

EXERCISE 5.8 - Conjugate Acids

OBJECTIVE 27

Write the formula for the conjugate acid of (a) NO_2^- , (b) HCO_3^- , (c) H_2O , and (d) PO_4^{3-} .

EXAMPLE 5.7 - Conjugate Bases

OBJECTIVE 28

Write the formula for the conjugate base of (a) HClO_3 , (b) H_2SO_3 , (c) H_2O , and (d) HCO_3^- .

Solution

In each case, the formula for the conjugate base is derived by removing one H^+ ion from the formulas above.

- a. ClO_3^- b. HSO_3^- c. OH^- d. CO_3^{2-}

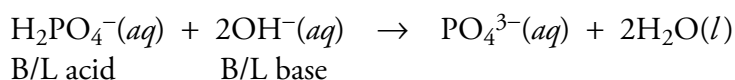
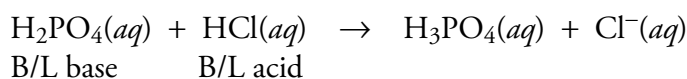
EXERCISE 5.9 - Conjugate Bases

OBJECTIVE 28

Write the formula for the conjugate base of (a) $\text{H}_2\text{C}_2\text{O}_4$, (b) HBrO_4 , (c) NH_3 , and (d) H_2PO_4^- .

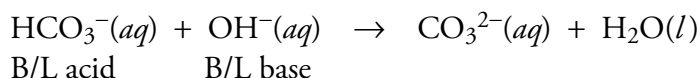
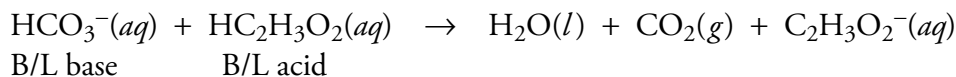
OBJECTIVE 29

Some substances can act as a Brønsted-Lowry acid in one reaction and a Brønsted-Lowry base in another. Consider the following net ionic equations for the reaction of dihydrogen phosphate ion with either the acid hydrochloric acid or the strong base hydroxide.



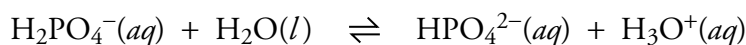
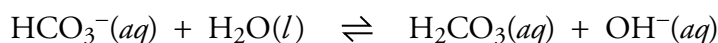
In the first reaction, the dihydrogen phosphate acts as a Brønsted-Lowry base, and in the second reaction, it acts as a Brønsted-Lowry acid. A substance that can act as either a Brønsted-Lowry acid or a Brønsted-Lowry base, depending on the circumstances, is called an **amphoteric** substance.

The hydrogen carbonate ion is another example of an amphoteric substance. In the first reaction below, it acts as a Brønsted-Lowry base, and in the second reaction, it acts as a Brønsted-Lowry acid.



Because both dihydrogen phosphate and hydrogen carbonate (and other substances like them) can be either Brønsted-Lowry acids or bases, they cannot be described as a Brønsted-Lowry acid or base except with reference to a specific acid-base reaction. For this reason, the Arrhenius definitions of acids and bases are the ones used to categorize isolated substances on the stockroom shelf. A substance generates either hydronium ions, hydroxide ions, or neither when added to water, so it is always either an acid, a base, or neutral in the Arrhenius sense. Hydrogen carbonate is an Arrhenius base because it yields hydroxide ions when added to water. Dihydrogen phosphate is an Arrhenius acid because it generates hydronium ions when added to water.

OBJECTIVE 30

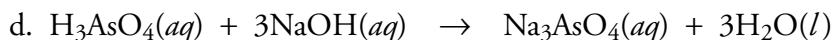
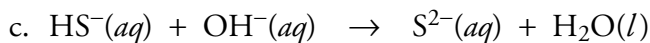
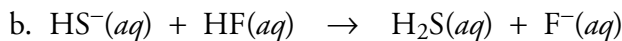
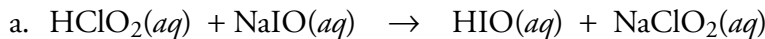


Thus we have two systems for describing acids, bases, and acid-base reactions. The Brønsted-Lowry system is often used to describe specific acid-base reactions, but the Arrhenius system is used to describe whether isolated substances are acids, bases, or neither.

EXAMPLE 5.8 - Brønsted-Lowry Acids and Bases

OBJECTIVE 31

Identify the Brønsted-Lowry acid and base for the forward reaction in each of the following equations..



Solution

a. The HClO_2 loses an H^+ ion, so it is the **Brønsted-Lowry acid**. The IO^- in the NaIO gains the H^+ ion, so the NaIO is the **Brønsted-Lowry base**.

b. The HF loses an H^+ ion, so it is the **Brønsted-Lowry acid**. The HS^- gains the H^+ ion, so it is the **Brønsted-Lowry base**.

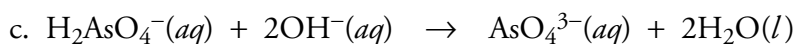
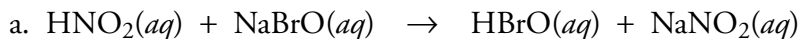
c. The HS^- loses an H^+ ion, so it is the **Brønsted-Lowry acid**. The OH^- gains the H^+ ion, so it is the **Brønsted-Lowry base**.

d. The H_3AsO_4 loses three H^+ ions, so it is the **Brønsted-Lowry acid**. Each OH^- in NaOH gains an H^+ ion, so the NaOH is the **Brønsted-Lowry base**.

EXERCISE 5.10 - Brønsted-Lowry Acids and Bases

OBJECTIVE 31

Identify the Brønsted-Lowry acid and base in each of the following equations..



Chapter Glossary

Hydronium ion H_3O^+

Arrhenius acid According to the Arrhenius theory, any substance that generates hydronium ions, H_3O^+ , when added to water.

Acidic solution A solution with a significant concentration of hydronium ions, H_3O^+ .

Binary acid Substances that have the general formula of $\text{HX}(aq)$, where X is one of the first four halogens: $\text{HF}(aq)$, $\text{HCl}(aq)$, $\text{HBr}(aq)$, and $\text{HI}(aq)$.

Oxyacids (or oxoacids) Molecular substances that have the general formula $\text{H}_a\text{X}_b\text{O}_c$. In other words, they contain hydrogen, oxygen, and one other element represented by X; the a , b , and c represent subscripts.

Monoprotic acid An acid that donates one hydrogen ion per molecule in a reaction.

Polyprotic acid An acid that can donate more than one hydrogen ion per molecule in a reaction.

Diprotic acid An acid that can donate two hydrogen ions per molecule in a reaction.

Triprotic acid An acid that can donate three hydrogen ions per molecule in a reaction.

Strong acid An acid that donates its H^+ ions to water in a reaction that goes completely to products. Such a compound produces close to one H_3O^+ ion in solution for each acid molecule dissolved in water.

Reversible reaction A reaction in which the reactants are constantly forming products and, at the same time, the products are reforming the reactants.

Weak acid A substance that is incompletely ionized in water due to the reversibility of the reaction that forms hydronium ions, H_3O^+ , in water. Weak acids yield significantly less than one H_3O^+ ion in solution for each acid molecule dissolved in water.

Arrhenius base A substance that produces hydroxide ions, OH^- , when added to water.

Basic solution A solution with a significant concentration of hydroxide ions, OH^- .

Strong base A substance that generates at least one hydroxide ion in solution for every unit of substance added to water.

Weak base A substance that produces fewer hydroxide ions in water solution than particles of the substance added.

Neutralization reaction A chemical reaction between an acid and a base.

Brønsted-Lowry acid-base reaction A chemical reaction in which a proton, H^+ , is transferred.

Brønsted-Lowry Acid A substance that donates protons, H^+ , in a Brønsted-Lowry acid-base reaction.

Brønsted-Lowry Base A substance that accepts protons, H^+ , in a Brønsted-Lowry acid-base reaction.

Conjugate acid The molecule or ion that forms when one H^+ ion is added to a molecule or ion.

Conjugate base The molecule or ion that forms when one H^+ ion is removed from a molecule or ion.

Conjugate acid-base pair Two molecules or ions that differ by one H^+ ion.

Amphoteric substance A substance that can act as either a Brønsted-Lowry acid or a Brønsted-Lowry base, depending on the circumstances.

You can test yourself on the glossary terms at the textbook's Web site.

Chapter Objectives

The goal of this chapter is to teach you to do the following.

1. Define all of the terms in the Chapter Glossary.

Section 5.1 Acids

2. Identify acids as substances that taste sour.
3. Describe what occurs when a strong, monoprotic acid, such as HCl, is added to water.
4. Identify the following acids as binary acids: HF(aq), HCl(aq), HBr(aq), and HI(aq).
5. Write or identify three different formulas that can be used to describe acetic acid, and explain why each is used.
6. Describe what occurs when a weak, monoprotic acid, such as acetic acid, is added to water.
7. Explain why weak acids produce fewer H_3O^+ ions in water than strong acids, even when the same numbers of acid molecules are added to equal volumes of water.
8. Identify the following as strong monoprotic acids: HCl and HNO_3 .
9. Identify sulfuric acid as a diprotic strong acid.
10. Describe what occurs when sulfuric acid is added to water.
11. Given a formula or name for any acid, identify it as a strong or weak acid.

Section 5.2 Acid Nomenclature

12. Convert between names and formulas for binary acids and oxyacids.

Section 5.3 Summary of Chemical Nomenclature

13. Given a name or chemical formula, tell whether it represents a binary ionic compound, an ionic compound with polyatomic ion(s), a binary covalent compound, a binary acid, or an oxyacid.
14. Convert between names and chemical formulas for binary ionic compounds, ionic compounds with polyatomic ion(s), binary covalent compounds, binary acids, and oxyacids.

Section 5.4 Strong and Weak Bases

15. Identify ionic compounds containing hydroxide ions as strong bases.
16. Describe the changes that take place when ammonia, NH_3 , is dissolved in water, and use this description to explain why ammonia is a weak Arrhenius base.
17. Describe the changes that take place when an ionic compound containing carbonate or hydrogen carbonate ions is dissolved in water, and use this description to explain why these anions are weak Arrhenius bases.
18. Given a name or formula for a substance, identify it as either (1) an Arrhenius strong acid, (2) an Arrhenius weak acid, (3) an Arrhenius strong base, or (4) an Arrhenius weak base.

Section 5.5 pH and Acidic and Basic Solutions

19. Given the pH of a solution, identify the solution as acidic, basic, or neutral.
20. Given the pH of two acidic solutions, identify which solution is more acidic.
21. Given the pH of two basic solutions, identify which solution is more basic.
22. Describe how litmus paper can be used in the laboratory to identify whether a solution is acidic or basic.

Section 5.6 Arrhenius Acid-Base Reactions

23. Describe the process that takes place at the molecular level for the following reactions. Your description should include mention of the particles in solution before and after the reaction. It should also include a description of the process that leads to the reaction.
 - a. a strong, monoprotic acid, such as HNO_3 , and an aqueous strong base, such as NaOH
 - b. a strong monoprotic acid, such as $\text{HCl}(aq)$, and an insoluble ionic compound, such as $\text{Al}(\text{OH})_3$
 - c. any monoprotic acid and a solution containing carbonate ions or hydrogen carbonate ions
24. Given the names or formulas for a monoprotic or polyprotic acid and an ionic compound containing hydroxide, carbonate, or hydrogen carbonate ions, write the complete balanced equation that describes the neutralization reaction that takes place between them.
25. Identify $\text{H}_2\text{O}(l)$ and $\text{CO}_2(g)$ as the products of the reaction of an acid with carbonate, CO_3^{2-} , or hydrogen carbonate, HCO_3^- .

Section 5.7 Brønsted-Lowry Acids and Bases

26. Explain why the Brønsted-Lowry definitions for *acid* and *base* are often used, instead of the Arrhenius definitions, to describe acid-base reactions.
27. Given a formula for a molecule or ion, write the formula for its conjugate acid.
28. Given a formula for a molecule or ion, write the formula for its conjugate base.
29. Explain why a substance can be a Brønsted-Lowry acid in one reaction and a Brønsted-Lowry base in a different reaction. Give an example to illustrate your explanation.
30. Explain why the Arrhenius definitions for *acid* and *base*, and not the Brønsted-Lowry definitions, are used to describe whether an isolated substance is an acid or base.
31. Given a Brønsted-Lowry acid-base equation, identify the Brønsted-Lowry acid and Brønsted-Lowry base.

Review Questions

- Define the following terms.
 - aqueous
 - spectator ion
 - double-displacement reaction
 - net ionic equation
- Write the name of the polyatomic ions represented by the formulas CO_3^{2-} and HCO_3^- .
- Write the formulas for the polyatomic ions dihydrogen phosphate ion and acetate ion.
- Which of the following formulas represents an ionic compound?
 - MgCl_2
 - PCl_3
 - KHSO_4
 - Na_2SO_4
 - H_2SO_3
- Write the names that correspond to the formulas KBr , $\text{Cu}(\text{NO}_3)_2$, and $(\text{NH}_4)_2\text{HPO}_4$.
- Write the formulas that correspond to the names nickel(II) hydroxide, ammonium chloride, and calcium hydrogen carbonate.
- Predict whether each of the following is soluble or insoluble in water.
 - iron(III) hydroxide
 - barium sulfate
 - aluminum nitrate
 - copper(II) chloride
- Describe the process by which the ionic compound sodium hydroxide dissolves in water.
- Write the complete equation for the precipitation reaction that takes place when water solutions of zinc chloride and sodium phosphate are mixed.

Key Ideas

Complete the following statements by writing one of these words or phrases in each blank.

10-fold	hydro-
acceptor	hydronium ions, H_3O^+ ,
acid	hydroxide ions, OH^- ,
acidic	hydroxides
added	-ic
amphoteric	less than 7
Arrhenius	lower
basic	nearly one
blue	neutralize
Brønsted-Lowry	one hydrogen ion
carbon dioxide, CO_2 ,	red
diprotic	re-forming
donor	removed
double	(root)ate
double-displacement	significantly less than one
fewer	single
forming	sour
greater than 7	strong bases
$\text{H}_a\text{X}_b\text{O}_c$	transfer
halogens	weak
higher	water

10. Any substance that has a(n) _____ taste is an acid.
11. According to the modern form of the Arrhenius theory, an acid is a substance that produces _____ when it is added to water.
12. On the basis of the Arrhenius definitions, a(n) _____ solution is a solution with a significant concentration of H_3O^+ .
13. The binary acids have the general formula of $\text{HX}(aq)$, where X is one of the first four _____.
14. Oxyacids (often called oxoacids) are molecular substances that have the general formula _____.
15. If each molecule of an acid can donate _____, the acid is called a monoprotic acid. A(n) _____ acid, such as sulfuric acid, H_2SO_4 , has two acidic hydrogen atoms.
16. Strong acids form _____ H_3O^+ ion in solution for each acid molecule dissolved in water, whereas weak acids yield _____ H_3O^+ ion in solution for each acid molecule dissolved in water.
17. A reaction in which the reactants are constantly _____ products and, at the same time, the products are _____ the reactants is called a reversible reaction. The chemical equations for reactions that are significantly reversible are written with _____ arrows.
18. A(n) _____ acid is a substance that is incompletely ionized in water because of the reversibility of its reaction with water that forms hydronium ion, H_3O^+ .
19. The chemical equations for completion reactions are written with _____ arrows to indicate that the reaction proceeds to form almost 100% products.
20. Binary acids are named by writing _____ followed by the root of the name of the halogen, then _____, and finally _____.
21. If enough H^+ ions are added to a(n) _____ polyatomic ion to completely neutralize its charge, the (root)ic acid is formed.
22. According to the modern version of the Arrhenius theory of acids and bases, a base is a substance that produces _____ when it is added to water.
23. A solution that has a significant concentration of hydroxide ions is called a(n) _____ solution.
24. Compounds that contain hydroxide ions are often called _____.
25. All water-soluble hydroxides are _____.
26. A weak base is a base that produces _____ hydroxide ions in water solution than there are particles of base dissolved.
27. Acidic solutions have pH values _____, and the more acidic a solution is, the _____ its pH. A change of 1 pH unit reflects a(n) _____ change in H_3O^+ ion concentration.
28. Basic solutions have pH values _____, and the more basic the solution is, the _____ its pH.
29. Litmus, a natural dye, is derived from lichen. It turns _____ in acidic conditions and _____ in basic conditions.
30. When an Arrhenius acid is combined with an Arrhenius base, we say that they _____ each other.

31. When hydronium ions and hydroxide ions collide in solution they react to form _____.
32. Most Arrhenius neutralization reactions, such as the reaction between nitric acid and sodium hydroxide, are _____ reactions.
33. Carbonic acid is unstable in water, so when it forms in aqueous solutions, it decomposes into _____ and water, $\text{H}_2\text{O}(l)$.
34. A Brønsted-Lowry acid is a proton (H^+) _____, a Brønsted-Lowry base is a proton _____, and a Brønsted-Lowry acid-base reaction is a proton _____.
35. The conjugate acid of a molecule or ion is the molecule or ion that forms when one H^+ ion is _____.
36. The conjugate base of a molecule or ion is the molecule or ion that forms when one H^+ ion is _____.
37. A substance that can act as either a Brønsted-Lowry acid or a Brønsted-Lowry base, depending on the circumstances, is called a(n) _____ substance.
38. The _____ system is often used to describe specific acid-base reactions, but the _____ system is used to describe whether isolated substances are acids, bases, or neither.

Chapter Problems

OBJECTIVE 3

- 39.** Describe how the strong monoprotic acid nitric acid, HNO_3 (used in the reprocessing of spent nuclear fuels) acts when it is added to water, including a description of the nature of the particles in solution before and after the reaction with water. If there is a reversible reaction with water, describe the forward and the reverse reactions.

OBJECTIVE 6

40. Describe how the weak monoprotic acid hydrofluoric acid, HF (used in aluminum processing) acts when it is added to water, including a description of the nature of the particles in solution before and after the reaction with water. If there is a reversible reaction with water, describe the forward and the reverse reactions.

OBJECTIVE 10

- 41.** Describe how the strong diprotic acid sulfuric acid, H_2SO_4 (used to make industrial explosives) acts when it is added to water, including a description of the nature of the particles in solution before and after the reaction with water. If there is a reversible reaction with water, describe the forward and the reverse reactions.

OBJECTIVE 5

42. Explain why acetic acid is described with three different formulas: $\text{HC}_2\text{H}_3\text{O}_2$, CH_3COOH , and $\text{CH}_3\text{CO}_2\text{H}$.

OBJECTIVE 7

- 43.** Explain why weak acids produce fewer H_3O^+ ions in water than strong acids, even when the same number of acid molecules are added to equal volumes of water.
44. Classify each of the following acids as monoprotic, diprotic, or triprotic.
- $\text{HCl}(aq)$ (used in food processing)
 - H_2SO_4 (used in petroleum refining)
 - $\text{HC}_2\text{H}_3\text{O}_2$ (solvent in the production of polyesters)
 - H_3PO_4 (catalyst for the production of ethanol)

45. Identify each of the following as strong or weak acids.
- sulfurous acid (for bleaching straw)
 - H_2SO_4 (used to make plastics)
 - oxalic acid (in car radiator cleaners)
46. Identify each of the following as strong or weak acids.
- $\text{HCl}(aq)$ (used to make dyes)
 - nitrous acid (source of nitrogen monoxide, NO , used to bleach rayon)
 - H_2CO_3 (formed when CO_2 dissolves in water)
47. Identify each of the following as strong or weak acids.
- H_3PO_4 (added to animal feeds)
 - hypophosphorous acid (in electroplating baths)
 - $\text{HF}(aq)$ (used to process uranium)
48. Identify each of the following as strong or weak acids.
- benzoic acid (used to make a common food preservative, sodium benzoate)
 - HNO_3 (used to make explosives)
 - hydrocyanic acid (used to make rodenticides and pesticides)
49. For each of the following, write the chemical equation for its reaction with water.
- The monoprotic weak acid nitrous acid, HNO_2
 - The monoprotic strong acid hydrobromic acid, HBr
50. For each of the following, write the chemical equation for its reaction with water.
- The monoprotic weak acid chlorous acid, HClO_2
 - The monoprotic strong acid perchloric acid, HClO_4

OBJECTIVE 11

OBJECTIVE 11

OBJECTIVE 11



OBJECTIVE 11

Sections 5.2 and 5.3 Acid Nomenclature and Summary of Chemical Nomenclature

51. Write the formulas and names of the acids that are derived from adding enough H^+ ions to the following ions to neutralize their charge.
- NO_3^-
 - CO_3^{2-}
 - PO_4^{3-}
52. Write the formulas and names of the acids that are derived from adding enough H^+ ions to the following ions to neutralize their charge.
- SO_4^{2-}
 - $\text{C}_2\text{H}_3\text{O}_2^-$
53. Classify each of the following compounds as either (1) a binary ionic compound, (2) an ionic compound with polyatomic ion(s), (3) a binary covalent compound, (4) a binary acid, or (5) an oxyacid. Write the chemical formula that corresponds to each name.
- phosphoric acid
 - ammonium bromide
 - diphosphorus tetrabromide
 - lithium hydrogen sulfate
 - hydrochloric acid
 - magnesium nitride
 - acetic acid
 - lead(II) hydrogen phosphate

OBJECTIVE 12

OBJECTIVE 13

OBJECTIVE 14

OBJECTIVE 12

54. Classify each of the following compounds as either (1) a binary ionic compound, (2) an ionic compound with polyatomic ion(s), (3) a binary covalent compound, (4) a binary acid, or (5) an oxyacid. Write the chemical formula that corresponds to each name.

OBJECTIVE 13

OBJECTIVE 14

- | | |
|-------------------------|------------------------------|
| a. potassium sulfide | e. copper(I) sulfate |
| b. sulfuric acid | f. hydrofluoric acid |
| c. ammonium nitrate | g. sodium hydrogen carbonate |
| d. iodine pentafluoride | |

OBJECTIVE 12

55. Classify each of the following formulas as either (1) a binary ionic compound, (2) an ionic compound with polyatomic ion(s), (3) a binary covalent compound, (4) a binary acid, or (5) an oxyacid. Write the name that corresponds to each formula.

OBJECTIVE 13

OBJECTIVE 14

- | | |
|---------------------------------|---------------------------------|
| a. $\text{HBr}(aq)$ | e. H_2CO_3 |
| b. ClF_3 | f. $(\text{NH}_4)_2\text{SO}_4$ |
| c. CaBr_2 | g. KHSO_4 |
| d. $\text{Fe}_2(\text{SO}_4)_3$ | |

OBJECTIVE 12

56. Classify each of the following formulas as either (1) a binary ionic compound, (2) an ionic compound with polyatomic ion(s), (3) a binary covalent compound, (4) a binary acid, or (5) an oxyacid. Write the name that corresponds to each formula.

OBJECTIVE 13

OBJECTIVE 14

- | | |
|----------------------------------|--------------------------|
| a. HNO_3 | e. $\text{HI}(aq)$ |
| b. $\text{Ca}(\text{OH})_2$ | f. Li_2O |
| c. $(\text{NH}_4)_2\text{HPO}_4$ | g. Br_2O |
| d. Ni_3P_2 | |

Section 5.4 Arrhenius Bases

OBJECTIVE 16

57. Describe the changes that take place when ammonia, NH_3 , is dissolved in water, and use this description to explain why ammonia is a weak Arrhenius base.

OBJECTIVE 18

58. Classify each of these substances as a weak acid, strong acid, weak base, or strong base in the Arrhenius acid-base sense.

- | | |
|----------------------------|---------------------|
| a. H_2CO_3 | e. NH_3 |
| b. cesium hydroxide | f. chlorous acid |
| c. $\text{HF}(aq)$ | g. $\text{HCl}(aq)$ |
| d. sodium carbonate | h. benzoic acid |

OBJECTIVE 18

59. Classify each of the substances as a weak acid, strong acid, weak base, or strong base in the Arrhenius acid-base sense.

- | | |
|---------------------|----------------------------|
| a. HNO_3 | e. H_2SO_4 |
| b. ammonia | f. nitrous acid |
| c. LiOH | g. NaHCO_3 |
| d. phosphorous acid | |

Section 5.5 pH and Acidic and Basic Solutions

60. Classify each of the following solutions as acidic, basic, or neutral. OBJECTIVE 19
- Tomato juice with a pH of 4.53
 - Milk of magnesia with a pH of 10.4
 - Urine with a pH of 6.8
61. Classify each of the following solutions as acidic, basic, or neutral. OBJECTIVE 19
- Saliva with a pH of 7.0
 - Beer with a pH of 4.712
 - A solution of a drain cleaner with a pH of 14.0
62. Which is more acidic, carbonated water with a pH of 3.95 or milk with a pH of 6.3? OBJECTIVE 20
63. Which is more basic, a soap solution with a pH of 10.0 or human tears with a pH of 7.4? OBJECTIVE 21
64. Identify each of the following characteristics as associated with acids or bases. OBJECTIVE 2
- tastes sour OBJECTIVE 22
 - turns litmus red
 - reacts with HNO_3
65. Identify each of the following properties as characteristic of acids or of bases. OBJECTIVE 22
- turns litmus blue
 - reacts with carbonate to form $\text{CO}_2(g)$

Section 5.6 Arrhenius Acid-Base Reactions

66. Describe the process that takes place between the participants in the neutralization reaction between the strong acid hydrochloric acid, $\text{HCl}(aq)$, and the strong base sodium hydroxide, $\text{NaOH}(aq)$, forming water and sodium chloride, $\text{NaCl}(aq)$. Mention the nature of the particles in the solution before and after the reaction. OBJECTIVE 23A
67. Describe the process that takes place between the participants in the neutralization reaction between the strong acid nitric acid, $\text{HNO}_3(aq)$, and the strong base potassium hydroxide, $\text{KOH}(aq)$, forming water and potassium nitrate, $\text{KNO}_3(aq)$. Mention the nature of the particles in the solution before and after the reaction. OBJECTIVE 23A
68. Describe the process that takes place between the participants in the neutralization reaction between the strong acid nitric acid, $\text{HNO}_3(aq)$, and water insoluble nickel(II) hydroxide, $\text{Ni}(\text{OH})_2(s)$, forming nickel(II) nitrate, $\text{Ni}(\text{NO}_3)_2(aq)$, and water. Mention the nature of the particles in the solution before and after the reaction. OBJECTIVE 23B
69. Describe the process that takes place between the participants in the neutralization reaction between the strong acid hydrochloric acid, $\text{HCl}(aq)$, and water insoluble chromium(III) hydroxide, $\text{Cr}(\text{OH})_3(s)$, forming chromium(III) chloride, $\text{CrCl}_3(aq)$, and water. Mention the nature of the particles in the solution before and after the reaction. OBJECTIVE 23B

OBJECTIVE 23C

70. Describe the process that takes place between the participants in the neutralization reaction between the strong acid hydrochloric acid, $\text{HCl}(aq)$, and the weak base potassium carbonate, $\text{K}_2\text{CO}_3(aq)$, forming water, carbon dioxide, $\text{CO}_2(g)$, and potassium chloride, $\text{KCl}(aq)$. Mention the nature of the particles in the solution before and after the reaction.

OBJECTIVE 23C

71. Describe the process that takes place between the participants in the neutralization reaction between the strong acid nitric acid, $\text{HNO}_3(aq)$, and the weak base lithium hydrogen carbonate, $\text{LiHCO}_3(aq)$, forming water, carbon dioxide, $\text{CO}_2(g)$, and lithium nitrate, $\text{LiNO}_3(aq)$. Mention the nature of the particles in the solution before and after the reaction.

OBJECTIVE 24

72. Write the complete equation for the neutralization reactions that take place when the following water solutions are mixed. (If an acid has more than one acidic hydrogen, assume that there is enough base to remove all of them. Assume that there is enough acid to neutralize all of the basic hydroxide ions.)

- $\text{HCl}(aq) + \text{LiOH}(aq)$
- $\text{H}_2\text{SO}_4(aq) + \text{NaOH}(aq)$
- $\text{KOH}(aq) + \text{HF}(aq)$
- $\text{Cd}(\text{OH})_2(s) + \text{HCl}(aq)$

OBJECTIVE 24

73. Write the complete equation for the neutralization reactions that take place when the following water solutions are mixed. (If an acid has more than one acidic hydrogen, assume that there is enough base to remove all of them. Assume that there is enough acid to neutralize all of the basic hydroxide ions.)

- $\text{LiOH}(aq) + \text{HNO}_2(aq)$
- $\text{Co}(\text{OH})_2(s) + \text{HNO}_3(aq)$
- $\text{H}_3\text{PO}_4(aq) + \text{KOH}(aq)$

OBJECTIVE 24

74. Write the complete equation for the reaction between $\text{HI}(aq)$ and water-insoluble solid CaCO_3 .

OBJECTIVE 25

75. Write the complete equation for the reaction between $\text{HCl}(aq)$ and water-insoluble solid $\text{Al}_2(\text{CO}_3)_3$.

OBJECTIVE 24

OBJECTIVE 25

OBJECTIVE 24

76. Iron(III) sulfate is made in industry by the neutralization reaction between solid iron(III) hydroxide and aqueous sulfuric acid. The iron(III) sulfate is then added with sodium hydroxide to municipal water in water treatment plants. These compounds react to form a precipitate that settles to the bottom of the holding tank, taking impurities with it. Write the complete equations for both the neutralization reaction that forms iron(III) sulfate and the precipitation reaction between water solutions of iron(III) sulfate and sodium hydroxide.

OBJECTIVE 24

77. Industrial chemists make hydrofluoric acid (which is used in aluminum and uranium processing, to etch glass, and to make CFCs) from the reactions of aqueous calcium fluoride and aqueous sulfuric acid. Write the complete equation for this reaction.

78. Complete the following equations by writing the formulas for the acid and base that could form the given products.

- _____ + _____ \rightarrow $\text{H}_2\text{O}(l) + \text{NaCl}(aq)$
- _____ + _____ \rightarrow $2\text{H}_2\text{O}(l) + \text{Li}_2\text{SO}_4(aq)$
- _____ + _____ \rightarrow $\text{H}_2\text{O}(l) + \text{CO}_2(g) + 2\text{KCl}(aq)$



79. Complete the following equations by writing the formulas for the acid and base that could form the given products.

- a. _____ + _____ \rightarrow $\text{H}_2\text{O}(l) + \text{NaC}_2\text{H}_3\text{O}_2(aq)$
 b. _____ + _____ \rightarrow $\text{H}_2\text{O}(l) + \text{CO}_2(g) + \text{LiNO}_3(aq)$
 c. _____ + _____ \rightarrow $\text{H}_2\text{O}(l) + \text{KNO}_3(aq)$

Section 5.7 Brønsted-Lowry Acids and Bases

80. Explain why the Brønsted-Lowry definitions for acid and base are often used instead of the Arrhenius definitions to describe acid-base reactions.

OBJECTIVE 26

81. Write the formula for the conjugate acid of each of the following.

OBJECTIVE 27

- a. IO_3^- b. HSO_3^- c. PO_3^{3-} d. H^-

82. Write the formula for the conjugate acid of each of the following.

OBJECTIVE 27

- a. HC_2O_4^- b. SO_3^{2-} c. BrO^- d. NH_2^-

83. Write the formula for the conjugate base of each of the following.

OBJECTIVE 28

- a. HClO_4 b. HSO_3^- c. H_3O^+ d. H_3PO_2

84. Write the formula for the conjugate base of each of the following.

OBJECTIVE 28

- a. NH_4^+ b. H_2S c. HNO_2 d. HC_2O_4^-

85. Explain why a substance can be a Brønsted-Lowry acid in one reaction and a Brønsted-Lowry base in a different reaction. Give an example to illustrate your explanation.

OBJECTIVE 29

86. Explain why the Arrhenius definitions for acid and base and not the Brønsted-Lowry definitions are used to describe whether an isolated substance is an acid or base.

OBJECTIVE 30

87. For each of the following equations, identify the Brønsted-Lowry acid and base for the forward reaction.

OBJECTIVE 31

- a. $\text{NaCN}(aq) + \text{HC}_2\text{H}_3\text{O}_2(aq) \rightarrow \text{NaC}_2\text{H}_3\text{O}_2(aq) + \text{HCN}(aq)$
 b. $\text{H}_2\text{PO}_3^-(aq) + \text{HF}(aq) \rightleftharpoons \text{H}_3\text{PO}_3(aq) + \text{F}^-(aq)$
 c. $\text{H}_2\text{PO}_3^-(aq) + 2\text{OH}^-(aq) \rightarrow \text{PO}_3^{3-}(aq) + 2\text{H}_2\text{O}(l)$
 d. $3\text{NaOH}(aq) + \text{H}_3\text{PO}_3(aq) \rightarrow 3\text{H}_2\text{O}(l) + \text{Na}_3\text{PO}_3(aq)$

88. For each of the following equations, identify the Brønsted-Lowry acid and base for the forward reaction.

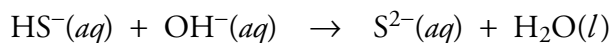
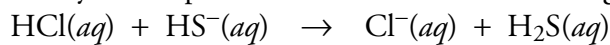
OBJECTIVE 31

- a. $3\text{NaOH}(aq) + \text{H}_3\text{PO}_4(aq) \rightarrow 3\text{H}_2\text{O}(l) + \text{Na}_3\text{PO}_4(aq)$
 b. $\text{HS}^-(aq) + \text{HIO}_3(aq) \rightarrow \text{H}_2\text{S}(aq) + \text{IO}_3^-(aq)$
 c. $\text{HS}^-(aq) + \text{OH}^-(aq) \rightarrow \text{S}^{2-}(aq) + \text{H}_2\text{O}(l)$

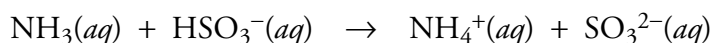
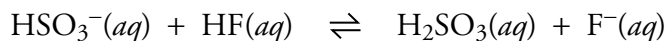
89. Butanoic acid, $\text{CH}_3\text{CH}_2\text{CH}_2\text{CO}_2\text{H}$, is a monoprotic weak acid that is responsible for the smell of rancid butter. Write the formula for the conjugate base of this acid. Write the equation for the reaction between this acid and water, and indicate the Brønsted-Lowry acid and base for the forward reaction. (The acidic hydrogen atom is on the right side of the formula.)

90. One of the substances that give wet goats and dirty gym socks their characteristic odors is hexanoic acid, $\text{CH}_3\text{CH}_2\text{CH}_2\text{CH}_2\text{CH}_2\text{CO}_2\text{H}$, which is a monoprotic weak acid. Write the formula for the conjugate base of this acid. Write the equation for the reaction between this acid and water, and indicate the Brønsted-Lowry acid and base for the forward reaction. (The acidic hydrogen atom is on the right side of the formula.)

91. Identify the amphoteric substance in the following equations.

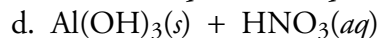
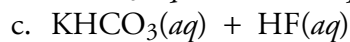
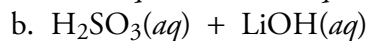
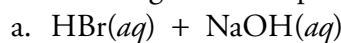


92. Identify the amphoteric substance in the following equations.

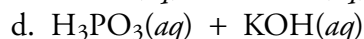
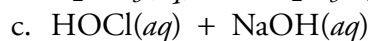
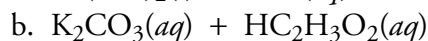
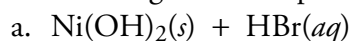


Additional Problems

93. For each of the following pairs of compounds, write the complete equation for the neutralization reaction that takes place when the substances are mixed. (You can assume that there is enough base to remove all of the acidic hydrogen atoms, that there is enough acid to neutralize all of the basic hydroxide ions, and that each reaction goes to completion.)



94. For each of the following pairs of compounds, write the complete equation for the neutralization reaction that takes place when the substances are mixed. (You can assume that there is enough base to remove all of the acidic hydrogen atoms, that there is enough acid to neutralize all of the basic hydroxide ions, and that each reaction goes to completion.)



95. Classify each of the following substances as acidic, basic, or neutral.

a. An apple with a pH of 2.9

b. Milk of Magnesia with a pH of 10.4

c. Fresh egg white with a pH of 7.6

96. Classify each of the following substances as acidic, basic, or neutral.

a. A liquid detergent with a pH of 10.1

b. Maple syrup with a pH of 7.0

c. Wine with a pH of 3.2

97. The pH of processed cheese is kept at about 5.7 to prevent it from spoiling. Is this acidic, basic, or neutral?

98. Is it possible for a weak acid solution to have a lower pH than a strong acid solution? If so, how?

99. The walls of limestone caverns are composed of solid calcium carbonate. The ground water that makes its way down from the surface into these caverns is often acidic. The calcium carbonate and the H^{+} ions from the acidic water react to dissolve the limestone. If this happens to the ceiling of the cavern, the ceiling can collapse, leading to what is called a sinkhole. Write the net ionic equation for the reaction between the solid calcium carbonate and the aqueous H^{+} ions.

100. Magnesium sulfate, a substance used for fireproofing and paper sizing, is made in industry from the reaction of aqueous sulfuric acid and solid magnesium hydroxide. Write the complete equation for this reaction.
101. Manganese(II) phosphate is used to coat steel, aluminum, and other metals to prevent corrosion. It is produced in the reaction between solid manganese(II) hydroxide and aqueous phosphoric acid. Write the complete equation for this reaction.
102. The smell of Swiss cheese is, in part, due to the monoprotic weak acid propanoic acid, $\text{CH}_3\text{CH}_2\text{CO}_2\text{H}$. Write the equation for the complete reaction between this acid and sodium hydroxide. (The acidic hydrogen atom is on the right.)
103. Lactic acid, $\text{CH}_3\text{CH}(\text{OH})\text{CO}_2\text{H}$, is used in cosmetic lotions, some of which claim to remove wrinkles. The lactic acid is thought to speed the removal of dead skin cells. Write the equation for the complete reaction between this acid and potassium hydroxide. (The acidic hydrogen atom is on the right.)
104. Malic acid, $\text{HO}_2\text{CCH}_2\text{CH}(\text{OH})\text{CO}_2\text{H}$, is a diprotic weak acid found in apples and watermelon. Write the equation for the complete reaction between this acid and sodium hydroxide. (The acidic hydrogen atoms are on each end of the formula.)
105. One of the substances used to make nylon is hexanedioic acid, $\text{HO}_2\text{CCH}_2\text{CH}_2\text{CH}_2\text{CH}_2\text{CO}_2\text{H}$. This diprotic weak acid is also called adipic acid. Write the equation for the complete reaction between this acid and sodium hydroxide. (The acidic hydrogen atoms are on each end of the formula.)
106. For the following equation, identify the Brønsted-Lowry acid and base for the forward reaction, and write the formulas for the conjugate acid-base pairs.
$$\text{NaHS}(aq) + \text{NaHSO}_4(aq) \rightarrow \text{H}_2\text{S}(g) + \text{Na}_2\text{SO}_4(aq)$$
107. For the following equation, identify the Brønsted-Lowry acid and base for the forward reaction, and write the formulas for the conjugate acid-base pairs.
$$\text{HF}(aq) + \text{NaHSO}_3(aq) \rightleftharpoons \text{NaF}(aq) + \text{H}_2\text{SO}_3(aq)$$

Discussion Problems

108. Assume you are given a water solution and told that it contains either hydrochloric acid or sodium chloride. Describe how you could determine which of these is present.
109. Assume that you are given a water solution that contains either sodium hydroxide or sodium chloride. Describe how you could determine which is in solution.
110. Assume that you are given a water solution that contains either sodium carbonate or sodium hydroxide. Describe how you could determine which is in solution.