CHAPTER 22
Acids, Bases, and Salts

Launch Lab
The Effects of Acid Rain

Water mixes with rain and carbon dioxide in the atmosphere to create acid which can damage buildings and statues. Observe this reaction using soda water to represent acid rain and chalk to represent calcium carbonate, such as limestone and marble.

For a lab worksheet, use your StudentWorks™ Plus Online.

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Video
Audio
Review
Inquiry

WebQuest
Assessment
Concepts in Motion
Multilingual eGlossary

Make a three-tab book. Label it as shown. Use it to compare and contrast your notes on acids, bases, and salts.

Foldables®
Acids
Salts
Bases
THEME FOCUS Structure and Properties of Matter
You can observe the properties of acids and bases in many everyday substances—from the sour taste of grapefruit juice to the slippery feel of soap.

**BIG IDEA** Acids and bases can be defined in terms of hydrogen ions and hydroxide ions.

**Section 1** • Acids and Bases

**Section 2** • Strength of Acids and Bases

**Section 3** • Salts
Acids and Bases

**Main Idea**
Acids produce hydronium ions ($\text{H}_3\text{O}^+$) in water, and bases produce hydroxide ions ($\text{OH}^-$) in water.

**Real-World Reading Link**
You might have had orange juice this morning at breakfast. Then, you might have used dish soap to clean your glass. Orange juice and dish soap are just a few of the many everyday mixtures that can be classified as acids or bases.

**Acids**

What comes to mind when you hear the word *acid*? Do you think of a substance that can burn your skin or burn a hole through a piece of metal? Do you think about sour foods like those shown in **Figure 1**? Although some acids can burn and are dangerous to handle, the acids in foods are safe to eat.

**Properties of acids**
An acid is a substance that produces hydrogen ions ($\text{H}^+$) in a water solution. The ability to produce these ions gives acids their characteristic properties. As acids dissolve in water, $\text{H}^+$ ions interact with water molecules to produce **hydronium ions** ($\text{H}_3\text{O}^+$) (hi DROH nee um • I ahnz).

Acids have several common properties. The sour taste of many foods is due to the presence of acids. However, taste should never be used to test for the presence of acids. Some acids can damage tissue by producing painful burns. Acids are corrosive. Some acids react strongly with certain metals, which seem to eat away the metals as metallic compounds and hydrogen gas form. An example of this type of reaction is zinc reacting with hydrochloric acid to produce zinc chloride and hydrogen gas. Acids also react with indicators to produce predictable changes in color. An **indicator** is an organic compound that changes color in the presence of acids and bases. For example, blue litmus paper is an indicator that turns red in acid.

**Figure 1** The acids in these common foods give them their distinctive sour tastes.
### Table 1  Common Acids and Their Uses

<table>
<thead>
<tr>
<th>Name, Formula</th>
<th>Use</th>
<th>Other Information</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acetic acid (CH₃COOH)</td>
<td>food preservation, commercial organic syntheses</td>
<td>vinegar (about 5% acetic acid)</td>
</tr>
<tr>
<td>Acetylsalicylic acid (HOOC–C₆H₄–OOCCH₃)</td>
<td>pain relief, fever relief; to reduce inflammation</td>
<td>main component of aspirin</td>
</tr>
<tr>
<td>Ascorbic acid (H₂C₆H₈O₆)</td>
<td>antioxidant, vitamin</td>
<td>Vitamin C occurs naturally in some foods and is added to others.</td>
</tr>
<tr>
<td>Carbonic acid (H₂CO₃)</td>
<td>carbonated drinks</td>
<td>involved in cave formation and acid rain</td>
</tr>
<tr>
<td>Hydrochloric acid (HCl)</td>
<td>cleans steel in a process called pickling</td>
<td>Gastric juice in the stomach is a solution of HCl and water.</td>
</tr>
<tr>
<td>Nitric acid (HNO₃)</td>
<td>to make fertilizers</td>
<td>colorless, yet yellows when it is exposed to light</td>
</tr>
<tr>
<td>Phosphoric acid (H₃PO₄)</td>
<td>to make soft drinks, fertilizers, and detergents</td>
<td>Slightly sour but pleasant taste; detergents containing phosphates cause water pollution.</td>
</tr>
<tr>
<td>Sulfuric acid (H₂SO₄)</td>
<td>car batteries; to manufacture fertilizers and other chemicals</td>
<td>dehydrating agent that extracts water from air</td>
</tr>
</tbody>
</table>

**Common acids**  Many foods contain acids. In addition to citric acid in citrus fruits, another example is lactic acid found in yogurt and buttermilk. It is also produced in your muscles during high levels of exercise when your muscles need oxygen. Any pickled food contains vinegar, also known as acetic acid. Your stomach uses hydrochloric acid to help digest your food. At least four acids (sulfuric, phosphoric, nitric, and hydrochloric) play vital roles in industrial applications. All four of these acids are used in wastewater and water treatment. Sulfuric, phosphoric, and nitric acids are used in the production of fertilizers. Most of the nitric acid and sulfuric acid and approximately 90 percent of phosphoric acid produced are used for this purpose. Sulfuric acid is used to process pulp and make paper. Phosphoric acid is used in odor control. Nitric acid is involved in the production of nylon. Hydrochloric acid is part of the production of asphalt.

**Reading Check**  Name four acids that are important for industry.

**Table 1**  shows the names and formulas of a few acids, their uses, and some of their properties. Many acids can cause a chemical burn. For example, sulfuric acid reacts with skin cells and removes water as easily as it takes water from sugar, as shown in Figure 2.

**Figure 2**  When sulfuric acid in the graduated cylinder is added to sugar in the beaker, a reaction occurs that produces black solid carbon and water.
Observe Acid Relief

**WARNING:** Do not eat antacid tablets.

**Procedure**

1. Read the procedure and safety information, and complete the lab form.
2. Add 150 mL of water to a 250-mL beaker.
3. Add three drops of 1M HCl and 12 drops of universal indicator.
4. Observe the color of the solution.
5. Add an antacid tablet and observe for 15 minutes.

**Analysis**

1. Describe any changes that took place in the solution.
2. Based on the color of the mixture, how would you classify the HCl solution in step 3? How would you classify the solution at the end of step 5?
3. Conclude why the tablet is used to treat acid indigestion.

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**Bases**

Most bases contain an OH⁻, called a hydroxide ion, in their chemical formula. A base is a substance that produces hydroxide ions when it is dissolved in water. In addition, a base is any substance that accepts H⁺ from acids. The definitions are related because the OH⁻ ions produced by some bases accept H⁺ ions produced by some acids. Acids can be defined using this framework as well. An acid is any substance that donates H⁺ to a base. In this definition, acids and bases are complements of one another—the base accepts the ion donated by the acid.

You might not be as familiar with bases as you are with acids. Although you can eat some foods that contain acids, you do not consume many bases. Some foods, such as egg whites, are slightly basic. Other examples of basic materials are baking powder and amines, organic compounds with a –NH₂ group, found in some foods. Some medicines, such as milk of magnesia and antacids, are also basic. Still, you come in contact with many bases every day. For example, each time you wash your hands using soap, you are using a base. Bases remove dirt and grime.

Bases also are important in many types of cleaning products, such as those shown in Figure 3. Bases are important in industry. For example, sodium hydroxide is used in the paper industry to separate fibers of cellulose from wood pulp. These fibers are made into paper.

**Properties of bases** Although acids and bases share some properties in common, bases have their own characteristic properties. In the pure, undissolved state, many bases are crystalline solids. In solution, bases feel slippery and have a bitter taste. Like strong acids, strong bases are corrosive and contact with skin can result in severe chemical burns. Therefore, taste and touch should never be used to test for the presence of a base. Finally, like acids, bases react with indicators to produce changes in color. Red litmus paper turns blue in bases.

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**SC.912.P.8.11:** Relate acidity and basicity to hydronium and hydroxyl ion concentration and pH.

**Foldables**

Incorporate information from this section into your Foldable.

**Figure 3** Bases are found in many cleaning products used in the home. For example, many glass cleaners contain ammonia (NH₃). Identify the property of bases that is evident in soaps.
**Common bases** You are probably familiar with the bases in common cleaning products, but the uses of other bases, such as NaOH and Al(OH)$_3$, as shown in Figure 4, might be unfamiliar to you. Table 2 includes some bases that have household and industrial uses and some additional information about them.

<table>
<thead>
<tr>
<th>Name, Formula</th>
<th>Use</th>
<th>Other Information</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aluminum hydroxide (Al(OH)$_3$)</td>
<td>color-fast fabrics, antacid, water purification</td>
<td>sticky gel that collects suspended clay and dirt particles on its surface</td>
</tr>
<tr>
<td>Calcium hydroxide (Ca(OH)$_2$)</td>
<td>leather-making, mortar and plaster; lessen acidity of soil</td>
<td>slaked lime</td>
</tr>
<tr>
<td>Magnesium hydroxide (Mg(OH)$_2$)</td>
<td>laxative, antacid</td>
<td>called milk of magnesia when it is mixed with water</td>
</tr>
<tr>
<td>Sodium hydroxide (NaOH)</td>
<td>to make soap, oven cleaner, drain cleaner, textiles, and paper</td>
<td>called lye and caustic soda; generates heat when it is combined with water; reacts with metals to form hydrogen (exothermic reaction)</td>
</tr>
<tr>
<td>Ammonia (NH$_3$)</td>
<td>cleaners, fertilizer; to make rayon and nylon</td>
<td>irritating odor that is damaging to nasal passages and lungs</td>
</tr>
</tbody>
</table>
Solutions of Acids and Bases

Most of the products that rely on the chemistry of acids and bases are solutions, such as the cleaning products and food products mentioned previously. Because of its polarity, water is the main solvent in these products. Solutions of acids and bases produce ions that are capable of conducting an electric current. Thus, they are said to be electrolytes.

Ionization of acids

You have learned that substances such as HCl, HNO$_3$, and H$_2$SO$_4$ are acids because of their abilities to produce hydrogen ions (H$^+$) in water. When an acid dissolves in water, the water molecules surround the neutral molecules of the acid, pulling them apart into ions. The positive hydrogen ions are attracted to the negative ends of the water molecules to form hydronium ions (H$_3$O$^+$). Therefore, an acid can be described more accurately as a compound that produces hydronium ions when dissolved in water. This process is shown in Figure 5.

Dissociation of bases

Many bases are ionic compounds, formed from a positive metal ion and a negative hydroxide ion (OH$^-$). If you look at Table 2, you will find that most of the substances listed contain the letters OH in their chemical formulas. When bases that contain the letters OH dissolve in water, the negative areas of nearby water molecules attract the positive ion in the base. The positive areas of nearby water molecules attract the OH$^-$ of the base. The base dissociates into a positive metal ion and a negative hydroxide ion (OH$^-$). This process is also shown in Figure 5. Unlike acid ionization, water molecules do not combine with the ions formed from the base.

$$\text{NaOH(s)} \rightarrow \text{Na}^+(aq) + \text{OH}^-(aq)$$
Ionization of bases  Recall that a base is also any substance that accepts an $H^+$ from acids. Ammonia ($NH_3$) is a base, even though it does not contain the letters OH in its chemical formula. Ammonia is a base because it accepts a hydrogen ion ($H^+$) from water. In a water solution, ionization takes place when the ammonia molecule attracts a hydrogen ion from a water molecule, forming an ammonium ion ($NH_4^+$). This produces a hydroxide ion ($OH^-$), as shown in Figure 6.

**Reading Check** Explain how ammonia reacts in a water solution.

Ammonia is a common household cleaner. However, products containing ammonia should never be mixed with other chlorine-based cleaners (sodium hypochlorite), such as some bathroom bowl cleaners and bleach. A reaction between sodium hypochlorite and ammonia produces the toxic gases hydrazine and chloramine. Breathing these gases can severely damage lung tissues and cause death.

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**Section 1 Review**

**Section Summary**

- Acids are sour tasting and corrosive, and they make blue litmus turn red.
- Bases exist as crystals in the solid state, are slippery, have a bitter taste, are corrosive, and make red litmus turn blue.
- The polar nature of water allows acids and bases to dissolve in water and form ions.

1. **Main Idea** Describe how an acidic solution forms when HCl is mixed in water and how a basic solution forms when NaOH is mixed in water.

2. **Explain** what an indicator is.

3. **Write** the formulas of three important acids and three important bases and describe their uses.

4. **Compare and contrast** how $NH_3$ and Ca(OH)$_2$ form $OH^-$ ions in water.

5. **Think Critically** A friend asks you to get his favorite item from the kitchen, but he uses chemical formulas to ask for it. He asks for a drink which does not contain $H_2CO_3$, but does have $H_C6H_6O_6$. What might he be asking for?

6. **Calculate** the molecular mass of acetylsalicylic acid ($HOOC-C_9H_7-OOCCH_3$).

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**Figure 6** Ammonia reacts with water to produce hydroxide ions in solution; therefore, it is a base.
Strength of Acids and Bases

**Main Idea** Strength describes the degree to which an acid or base ionizes or dissociates in water; concentration describes the amount of acid or base dissolved in a certain volume of water.

**Real-World Reading Link** During a basketball game, there are times when all ten players are concentrated in half the court. At other times, the players are spread out over the whole court. Similarly, an acid or a base would be considered dilute if a small amount were added to a large amount of water. Also, an acid or a base would be considered concentrated if that same amount were added to a small amount of water.

**Strong and Weak Acids and Bases**

Some acids must be handled with great care. For example, the sulfuric acid found in car batteries can burn your skin. Yet you drink acids, such as citric acid in orange juice and carbonic acid in soft drinks. Obviously, some acids are stronger than others.

The strength of an acid or a base depends on the degree to which acid or base particles form into ions in water. In a **strong acid**, all the acid ionizes upon dissolving in water. Hydrochloric acid, nitric acid, and sulfuric acid are examples of strong acids. In a **weak acid**, only a small fraction of the molecules ionize upon dissolving in water. Acetic acid and carbonic acid are examples of weak acids.

Ions in solution can conduct an electric current. The more ions that a solution contains, the more current it can conduct. The ability of a solution to conduct a current can be demonstrated by using a lightbulb connected to a battery with leads placed in the solution, as shown in Figure 7. The strong acid solution conducts more current, and the lightbulb burns brightly. The weak acid solution does not conduct as much current as a strong acid solution, and the bulb burns less brightly.
**Acid strength** In strong acids, such as hydrochloric acid (HCl), nearly all the acid ionizes to form hydronium ions (H$_3$O$^+$) and chloride ions (Cl$^-$) and leaves almost no HCl molecules present. This is shown by writing the equation using a single arrow pointing toward the ions that are formed.

$$\text{HCl(g)} + \text{H}_2\text{O(l)} \rightarrow \text{H}_3\text{O}^+(aq) + \text{Cl}^-(aq)$$

Equations describing the ionization of weak acids, such as acetic acid (CH$_3$COOH), are written using double arrows pointing in opposite directions. This means that the reaction does not go to completion.

$$\text{CH}_3\text{COOH(l)} + \text{H}_2\text{O(l)} \rightleftharpoons \text{H}_3\text{O}^+(aq) + \text{CH}_3\text{COO}^-(aq)$$

An acetic acid solution is mostly made of CH$_3$COOH molecules. Only a relatively few hydronium ions (H$_3$O$^+$) and acetate ions (CH$_3$COO$^-$) are in solution.

**Base strength** Many bases are ionic compounds that dissociate to produce ions when they dissolve. A **strong base** dissociates completely upon dissolving in water. The dissociation of sodium hydroxide (NaOH) to form sodium ions (Na$^+$) and hydroxide ions (OH$^-$) is shown below.

$$\text{NaOH(s)} \rightarrow \text{Na}^+(aq) + \text{OH}^-(aq)$$

When ammonia (NH$_3$) is dissolved in water, an ammonia ion (NH$_4^+$) and a hydroxide ion (OH$^-$) form. This is shown using double arrows to indicate that not all of the molecules ionize. A **weak base** is one that does not ionize completely. Ammonia produces only a few ions in water, and most of the ammonia remains in the form of NH$_3$.

$$\text{NH}_3(aq) + \text{H}_2\text{O(l)} \rightleftharpoons \text{NH}_4^+(aq) + \text{OH}^-(aq)$$

**Strength and concentration** The terms **strength** and **concentration** can be confused when describing acids and bases. The terms **strong** and **weak** refer to the degree to which an acid or base ionizes or dissociates in solution. **Strong** acids ionize completely, and **strong** bases dissociate completely. **Weak** acids and bases ionize only partially. In contrast, the terms **dilute** and **concentrated** indicate the concentration of a solution, which is the amount of acid or base dissolved in the solution. It is possible to have dilute solutions of strong acids and bases and concentrated solutions of weak acids and bases, as shown in **Figure 8**.
**Figure 9** The pH scale helps classify solutions as acidic or basic. Each number on the pH scale represents a change in the H⁺ concentration of ten times. For example, a solution of pH = 3 has an H⁺ concentration that is ten times greater than a solution of pH = 4.

**Concepts in Motion**

**Animation**

**Figure 10** The pH of a sample can be measured in several ways, two of which (indicator paper or a pH meter) are shown below.

**Determine which method provides a more accurate reading.**

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**pH of a Solution**

If you have a swimming pool or a tropical fish aquarium, you know that the pH of the water must be controlled. Also, many products, such as shampoos, claim to control pH so it suits your type of hair. **pH** is a measure of the concentration of H⁺ (H₃O⁺) ions in solution. The pH measures how acidic or basic a solution is. The greater the (H₃O⁺) concentration is, the lower the pH and the more acidic the solution. A scale to indicate pH has been devised, as shown in **Figure 9**.

As the scale shows, solutions with pHs lower than 7 are described as acidic. The lower the value, the more acidic the solution. Solutions with pHs greater than 7 are basic. The higher the pH is, the more basic the solution. A solution that has a pH of exactly 7 has equal concentrations of (H₃O⁺) ions and OH⁻ ions. These solutions are considered to be neutral.

Pure water at 25°C has a pH of 7.

One way to determine pH is by using universal indicator paper. This paper undergoes color changes in the presence of H₃O⁺ ions and OH⁻ ions in solution. The final color of the pH paper is matched with colors in a chart to find the pH, as shown in **Figure 10**.

An instrument called a pH meter is another tool to determine the pH of a solution. This meter is operated by immersing the electrodes in the test solution and reading the display. Small, battery-operated pH meters that have digital readouts are precise and convenient for use outside the laboratory when testing the pH of soils and streams, as shown in **Figure 10**.

**Blood pH** Your blood circulates throughout your body carrying oxygen, removing carbon dioxide, and absorbing nutrients from food that you have eaten. For blood to carry out its many functions properly, the pH of blood must remain between 7.0 and 7.8. The main reason for this is that enzymes, which are the protein molecules that act as catalysts for many reactions in the body, cannot work outside this pH range. Yet, you can eat foods that are acidic without changing the pH of your blood. How can this be? The answer is that your blood contains solutions called buffers that resist pH changes when small amounts of acids or bases are added.
Buffers are solutions containing ions that react with acids or bases to minimize their effects on pH. One buffer system in blood involves a solution of carbonic acid ($H_2CO_3$) and bicarbonate ions ($HCO_3^-$). Because of these buffer systems, even small amounts of concentrated acids will not change the pH of blood much, as shown in Figure 11. Buffers help keep your blood close to a nearly constant pH of 7.4. If the pH of 7.4 is not maintained, a medical condition called acidosis can occur. This can occur during severe dehydration when excessive levels of acids build up in body fluids.

Reading Check Explain what buffers are and how are they important for health.

Section Review

Section Summary

- Strength refers to the degree to which an acid or base forms ions in water. Concentration refers to how much acid or base is present in solution.
- Acids and bases can conduct electricity in solution.
- Acids and bases are classified based on pH.
- Buffers are solutions that minimize the effects of the addition of an acid or a base on pH.

7. MAIN Idea Compare and contrast a dilute solution of a strong acid and a concentrated solution of a weak acid.

8. Describe two techniques used to measure the pH of a solution.

9. Explain how electricity can be conducted by acids and bases.

10. Classify pH values of 9.1, 1.2, and 5.7 as basic, acidic, or very acidic.

11. Think Critically The proper pH range for a swimming pool is between 7.2 and 7.8. Most pools use two substances, Na$_2$CO$_3$ and HCl, to maintain this range. How would you adjust the pH if you found it was 8.2? 6.9?

Apply Math

12. Use Equations To determine the difference in pH strength, calculate $10^n$, where $n$ is the difference between pHs. How much more acidic is a solution of pH 2.4 than a solution of pH 4.4?
**Objectives**

- **Determine** the relative concentrations of common acidic substances.

**Background:** The science of acids and bases is not investigated only in a high-tech laboratory by degreed scientists. You can investigate the acidic concentrations of things in your home using a simple homemade indicator solution.

**Question:** How can you determine the relative concentration of the $H^+$ ions in several acidic solutions?

**Preparation**

**Materials**
- homemade cabbage indicator (indicates acids and bases)
- coffee filter
- waxed paper
- grease pencil or masking tape
- teaspoons (3)
- alum
- cream of tartar
- fruit preservative

**Safety Precautions**

| ☢ | ☢ | ☢ |

**Procedure**

1. Read the procedure and safety information, and complete the lab form.
2. Use the grease pencil or masking tape and a pencil to label three areas on the waxed paper: **alum**, **cream of tartar**, and **fruit preservative**. These areas should be about 8 cm apart.
3. Place approximately $\frac{1}{2}$ teaspoon of each of the three powders on the waxed paper where labeled. Use a separate teaspoon for each substance.
4. Cut three strips from the coffee filter, about 1 cm wide by 8 cm long.
5. Dip the end of one of the strips into the cabbage indicator solution, and then lay the wet end on top of the alum.
6. Wet a second strip and lay it in on top of the cream of tartar.
7. Wet the third strip and lay it on top of the fruit preservative.
8. Wait 5 minutes and then check the indicator strips. Record your observations.

**Conclude and Apply**

1. **Determine** if all three substances were acids. Did the indicator strips turn a similar color? Explain why each substance produced a different color.
2. **Propose** a possible rank of the $H^+$ ion concentrations. Explain your reasoning.
3. **Predict** what you would have observed if you used sodium hydroxide instead of alum.

**Communicate Your Data**

Compare your answer to question 3 above with other groups in the class. Come to an agreement on your prediction. As a group, design a procedure to test your prediction.
Salts

An acid and a base react to form a salt and water.

Real-World Reading Link The human body uses ions from salts to carry out many important functions, including prevention of muscle cramps, stabilization of irregular heartbeats, and sleep regulation.

Neutralization

Normally, stomach acid contains a dilute solution of hydrochloric acid and water. Too much acid can cause indigestion. Antacids contain bases or other compounds of sodium, potassium, calcium, magnesium, or aluminum that react with stomach acid to lower acid concentration. Figure 12 shows antacid tablets reacting in a solution that is similar to stomach acid. The equation for this reaction is:

\[ \text{HCl(aq)} + \text{NaHCO}_3(s) \rightarrow \text{NaCl(aq)} + \text{CO}_2(g) + \text{H}_2\text{O(l)} \]

Neutralization is a chemical reaction between an acid and a base that forms a salt and water. In the above equation, HCl is neutralized by NaHCO₃.

Salt formation Hydrochloric acid can be neutralized by sodium hydroxide in another common neutralization reaction.

\[ \text{HCl(aq)} + \text{NaOH(aq)} \rightarrow \text{NaCl(aq)} + \text{H}_2\text{O(l)} \]

In the equation above, the hydrogen and hydroxide ion form water. Remaining ions form the salt sodium chloride (NaCl). A salt is a compound formed when negative ions from an acid combine with positive ions from a base.
Table 3

<table>
<thead>
<tr>
<th>Name, Formula</th>
<th>Common Name</th>
<th>Uses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sodium chloride (NaCl)</td>
<td>salt</td>
<td>food, manufacture of chemicals</td>
</tr>
<tr>
<td>Sodium hydrogen carbonate (NaHCO₃)</td>
<td>sodium bicarbonate, baking soda</td>
<td>food, antacids</td>
</tr>
<tr>
<td>Calcium carbonate (CaCO₃)</td>
<td>calcite, chalk</td>
<td>manufacture of paint and rubber tires</td>
</tr>
<tr>
<td>Potassium nitrate (KNO₃)</td>
<td>saltpeter</td>
<td>fertilizers</td>
</tr>
<tr>
<td>Potassium carbonate (K₂CO₃)</td>
<td>potash</td>
<td>manufacture of soap and glass</td>
</tr>
<tr>
<td>Sodium phosphate (Na₃PO₄)</td>
<td>TSP</td>
<td>detergents</td>
</tr>
<tr>
<td>Ammonium chloride (NH₄Cl)</td>
<td>sal ammoniac</td>
<td>dry-cell batteries</td>
</tr>
</tbody>
</table>

**Acid-base general equation** The following general equation represents acid-base reactions in water.

\[
\text{acid + base} \rightarrow \text{salt} + \text{water}
\]

Another example of a neutralization reaction occurs between HCl, an acid, and Ca(OH)₂, a base. This reaction produces the salt CaCl₂ and water.

\[
2\text{HCl(aq)} + \text{Ca(OH)₂(aq)} \rightarrow \text{CaCl₂(aq)} + 2\text{H₂O(l)}
\]

**Salts**

There are many salts, a few of which are shown in Table 3. Most salts are composed of a positive metal ion and an ion with a negative charge, such as Cl⁻ or CO₃²⁻. Ammonium salts contain the ammonium ion (NH₄⁺), rather than a metal.

Salts are essential for many animals, large and small. Some domestic animals are supplied salts, as shown in Figure 13. Some animals find it at natural deposits. At these natural deposits, animals obtain ions, such as sodium ions (Na⁺) and calcium ions (Ca²⁺), that are important for health. Even insects, such as butterflies, need salts and are often found clustered on moist ground. You also need salts, especially because you lose them through perspiration. How humans obtain one salt, sodium chloride, is shown in Figure 14.
Table salt (NaCl) is used for a variety of purposes: seasoning and preservation of food, deicing roadways, feeding animals and plants, and softening water. Salt is extracted from land and water. Three different technologies are commonly used.

**Visualizing Salt Production**

Table salt (NaCl) is used for a variety of purposes: seasoning and preservation of food, deicing roadways, feeding animals and plants, and softening water. Salt is extracted from land and water. Three different technologies are commonly used.

**Evaporation Salt** Shallow ponds are filled with brine (salt water). The brine is moved from pond to pond to remove impurities and to concentrate it through evaporation. When the desired salt concentration has been reached, it is then pumped from evaporation ponds into crystallizing ponds. After the salt crystallizes, the remaining water is drained off. The crystals are washed, crushed, and dried.

**Rock Salt** Salt deposits exist due to the gradual evaporation of bodies of localized salt water. Salt can be found in deposits that have layers of sedimentary rocks, such as anhydrite, which is a calcium sulfate mineral. Salt deposits are found at relatively shallow depths, averaging 150 m to 600 m below Earth’s surface. Salt is mined from these deposits by drilling and blasting.

**Solution Mining** Solution mining is another technology used to obtain the table salt that we sprinkle on our food. A well pumps water into an underground salt deposit to dissolve the salt and to form a saturated solution called a brine. The brine is heated, and the salt crystallizes after the water boils away.
Sometimes you need to know the amount of acid or base in a solution, for example, to determine the purity of a commercial product. This can be done using titration (ti TRAY shun). Titration is the process in which a solution of known concentration is used to determine the concentration of another solution. Figure 15 shows a titration procedure.

Titration involves a solution of known concentration called the standard solution. The standard solution is slowly added to a solution of unknown concentration, which contains an acid/base indicator. If the solution of unknown concentration is a base, a standard acid solution is used. If the solution of unknown concentration is an acid, a standard base solution is used.

The endpoint has a color change

The titration shown in Figure 15 shows how to determine the concentration of an acid solution. First, add a few drops of an indicator, such as phenolphthalein (fee nul THAY leen), to a carefully measured volume of the acidic solution of unknown concentration. Phenolphthalein is colorless in an acid, but it turns bright pink in the presence of a base.

Then, slowly and carefully add a basic solution of known concentration to this acid/indicator mixture. Toward the end of the titration, add the base drop by drop until one last drop of the base turns the solution pink and the color persists. The point at which the color persists is known as the endpoint, the point at which the acid is completely neutralized by the base. When the volume of base used is known, use that value, the known concentration of the base, and the volume of the acid to calculate the concentration of the acid solution.
Many natural substances are acid-base indicators. In fact, the indicator litmus comes from a lichen, a combination of a fungus and an algae or a cyanobacterium. Flowers that are indicators include hydrangeas, which produce blue blossoms when the pH of the soil is acidic and pink blossoms when the soil is basic. The hydrangeas’ color change is just the opposite of litmus.

Other natural indicators possess a range of colors. For example, the color of red cabbage varies from deep red at pH 1 to lavender at pH 7 and yellowish green at pH 10. Figure 16 shows common substances that can be used as natural indicators. Grape juice is also an indicator, as you can learn by doing the MiniLab.

Figure 16 Natural indicators include red cabbage, radishes, and roses.

**MiniLab**

**Test a Grape Juice Indicator**

**Procedure**
1. Read the procedure and safety information, and complete the lab form.
2. Add one-half cup of water to each of two small glasses.
3. Add 1 tablespoon of purple grape juice to each glass.
4. To one glass, add 1 teaspoon of baking soda. Stir.
5. To the other glass, add 1 teaspoon of white vinegar.
6. Note the color after each addition in steps 3, 4, and 5.

**Analysis**
1. Describe What happened when baking soda was added?
2. Explain Did the color change when you added vinegar? Why or why not?

**How can you handle an upsetting situation?**

At some time, most of us have experienced an upset stomach. Often, the cause is the excess acid within our stomachs. For digestive purposes, our stomachs contain dilute hydrochloric acid with a pH between 1.6 and 3.0. A doctor might recommend an antacid treatment for an upset stomach. What type of compound is “anti acid”?

**Identify the Problem**

You have learned that neutralization reactions of acids and bases form salts. Antacids typically contain small amounts of Ca(OH)$_2$, Al(OH)$_3$, or NaHCO$_3$, which are bases.

Whereas having an excess of acid lowers the pH of your stomach contents, antacid compounds raise the pH of your stomach contents. How does an antacid change pH to make you feel better?

**Solve the Problem**

1. Write the chemical equation for the reaction of HCl and Mg(OH)$_2$. Use it to explain why an antacid helps excess stomach acid.
2. Why is it important to have some acid in your stomach?
3. Design an experiment that compares how well antacid products neutralize acid.
Soaps and Detergents

The next time that you are in a supermarket, go to the aisle with soaps and detergents. You will see all kinds of products—solid soaps, liquid soaps, and detergents for washing clothes and dishes. What are all these products? Do they differ from one another? Yes, they differ slightly in how they are made and in the ingredients included for color and aroma. Still, all these products are classified into two types—soaps and detergents.

Soaps  The reason why soaps clean so well is explained by polar and nonpolar molecules. Soaps are salts. As shown in Figure 17, they have a nonpolar chain of carbon atoms on one end and a sodium or potassium salt of a carboxylic acid (kar bahk SIH lihk) group (–COOH) at the other end. The nonpolar, hydrocarbon end interacts with nonpolar oils and dirt so they can be removed readily, and the polar, ionic end (–CO O Na+ or –CO O K+) helps them dissolve in polar water.

To make an effective soap, the acid must contain 12 to 18 carbon atoms. If it contains fewer than 12 atoms, it will not be able to mix well to clean oily dirt. If it has too many carbon atoms, the salt will not be soluble in water. Figure 18 shows how soap interacts with dirt particles to clean your hands.

Reading Check  Explain why soaps must have polar and nonpolar ends.
Commercial soaps One problem with all soaps is that the sodium ions and potassium ions can be replaced by ions of calcium, magnesium, and iron found in some water known as hard water. When this happens, the salts formed are insoluble and precipitate out of solution in the form of soap scum. Detergents were developed to avoid this problem.

Reading Check Explain What is soap scum?

Detergents Similar to soaps, detergents have long hydrocarbon chains. But instead of a salt of a carboxylic acid group at the end, they may contain a salt of a sulfonic acid group. These acids form more soluble salts with the ions in hard water, lessening the problem of soap scum. Detergents can also be used in cold water. Most contain additional ingredients called builders and surfactants to enhance the ability to clean and to produce suds.

Despite solving the problem of cleaning in hard water, detergents are not the complete solution to our needs. Some detergents contained phosphates but are no longer produced because they cause water pollution. Certain sulfonic acid detergents also present problems in the form of excess foaming in water treatment plants and streams, as shown in Figure 19. These detergents do not break down easily and remain in the environment for long periods of time.

Section 3 Review

Section Summary

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

Salt is a dietary essential.

Titration is a method used to determine the concentration of an acidic or a basic solution.

Molecules of soaps and detergents have polar and nonpolar ends.

Apply Math

17. Calculate Ratios In the following reaction, how many molecules of HCl are needed to produce four molecules of H_2O?

\[ 2\text{HCl(aq)} + \text{Ca(OH)}_2\text{(aq)} \rightarrow \text{CaCl}_2\text{(aq)} + 2\text{H}_2\text{O(l)} \]
LAB
Be a Soda Scientist

DESIGN YOUR OWN

Objectives
- Observe evidence of a neutralization reaction using an indicator.
- Compare the acidity levels in soft drinks.
- Design an experiment that uses the independent variable of acid content of soft drinks and the dependent variable of amount of base added to determine the relative acidity of the drinks.

Background: The next time that you drink a soft drink, take a look at the ingredients label. Carbonated soft drinks contain carbonic acid and sometimes contain phosphoric acid.

Question: Using a proper indicator and a base solution, how can you compare the acidity levels in soft drinks?

Preparation

Possible Materials
different colorless soft drinks (3)
test tubes (3)
test-tube holder
25-mL graduated cylinder
droppers (2)
1% phenolphthalein
dilute NaOH solution (0.1M)

Safety Precautions

WARNING: Sodium hydroxide is a caustic, flammable solution. Wear chemical splash goggles, gloves, and an apron and avoid any skin contact. Flush thoroughly under a stream of tepid water for a minimum of 15 minutes if any of the NaOH touches your skin. Keep your hands away from your face.

Form a Hypothesis

Based on your knowledge of acids and bases, develop a hypothesis about how neutralization can be used to rank the acidities of soft drinks.
Calculate Compile the data from your class groups in a table or spreadsheet and calculate the class average for each soft drink. Discuss reasons data from different groups might differ from the class average.

Follow Your Plan
1. Make sure your teacher approves your plan before you begin.
2. Observe the color change of phenolphthalein at the endpoint of each titration.
3. While you are doing the experiment, record your observations and complete the data table.

Analyze Your Data
1. \textbf{Classify} the soft drinks that you tested based on their acidities. Rank them in the order of most acidic to least acidic.
2. \textbf{Explain} how you determined the ranking.

Conclude and Apply
1. \textbf{Evaluate} the results. Do they support your hypothesis? Explain why or why not.
2. \textbf{Predict} At warmer temperatures, less gas dissolves in a liquid. How would this affect the results of an experiment comparing two sodas stored at different temperatures?
Fish, shellfish, and insects die. The leaves and needles of trees are damaged. Some trees die. Other animals, such as frogs and birds, grow sick and die. In a nearby city, something is slowly damaging the edges of buildings and statues, as shown in Figure 1. What has caused this devastation? Acid precipitation is the culprit.

**What is acid precipitation?** Acid precipitation forms when sulfur dioxide ($\text{SO}_2$) and nitrogen oxides ($\text{NO}_x$) in the atmosphere combine with oxygen, other chemicals, and precipitation, such as rain and snow, to form acids. These substances cause the precipitation’s pH to fall from its normal pH of approximately 5.6 to between 5.0 and 5.5. In some parts of the United States, the pH of acid precipitation is as low as 4.3.

**Reduction and prevention** What is being done to reduce or prevent acid precipitation? The U.S. government requires power plants that burn fossil fuels, especially coal, to keep their emissions of these gases below certain levels. Power plants do this by installing scrubbers in the plants’ smokestacks, which remove $\text{SO}_2$ from smoke. Power plants have also started burning coal that contains less sulfur.

For the last 20 years, automobiles made in the United States have been required to contain catalytic converters, which reduce the emission of $\text{NO}_x$ from cars. Many people and some local governments and businesses are using alternative energy sources, such as solar, wind, and water power, as shown in Figure 2, which do not release $\text{SO}_2$ and $\text{NO}_x$ into the atmosphere.

Acid precipitation can be further reduced by simple actions, such as turning off lights and appliances when they are not in use and by not overheating or overcooling homes. New appliances are now more energy efficient. To reduce pollution from automobiles, people can carpool, use public transportation, ride bicycles, walk, or drive vehicles that run on alternative fuels, which emit no or low amounts of harmful gases.

**WebQuest** How is acid precipitation affecting your community? Work with a partner to locate information and evidence of the effects of acid precipitation. Explain how scientific knowledge informed decisions made by your local government. What actions resulted from this knowledge, such as legislation, studies, or activities?
### Theme Focus: Structure and Properties of Matter

Observable properties of common acids and bases include the sour taste of acidic foods and the slippery feel of soaps. Acids and bases can be described by pH, whether they are strong or weak, and by concentration.

**BIG Idea** Acids and bases can be defined in terms of hydrogen ions and hydroxide ions.

### Section 1 Acids and Bases

<table>
<thead>
<tr>
<th>Term</th>
<th>p.</th>
</tr>
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<tbody>
<tr>
<td>acid</td>
<td>678</td>
</tr>
<tr>
<td>base</td>
<td>680</td>
</tr>
<tr>
<td>hydronium ion</td>
<td>678</td>
</tr>
<tr>
<td>hydroxide ion</td>
<td>680</td>
</tr>
<tr>
<td>indicator</td>
<td>678</td>
</tr>
</tbody>
</table>

**MAIN Idea** Acids produce hydronium ions ($H_3O^+$) in water, and bases produce hydroxide ions ($OH^-$) in water.

- Acids are sour tasting and corrosive, and they turn blue litmus red.
- Bases exist as crystals in the solid state, are slippery, have a bitter taste, are corrosive, and turn red litmus blue.
- The polar nature of water allows acids and bases to dissolve in water and form ions.

### Section 2 Strength of Acids and Bases

<table>
<thead>
<tr>
<th>Term</th>
<th>p.</th>
</tr>
</thead>
<tbody>
<tr>
<td>buffer</td>
<td>687</td>
</tr>
<tr>
<td>pH</td>
<td>686</td>
</tr>
<tr>
<td>strong acid</td>
<td>684</td>
</tr>
<tr>
<td>strong base</td>
<td>685</td>
</tr>
<tr>
<td>weak acid</td>
<td>684</td>
</tr>
<tr>
<td>weak base</td>
<td>685</td>
</tr>
</tbody>
</table>

**MAIN Idea** Strength describes the degree to which an acid or base ionizes in water; concentration describes the amount of acid or base that is dissolved in a certain volume of water.

- Strength refers to the degree to which an acid or base forms ions in water. Concentration refers to how much acid or base is present in solution.
- Acids and bases can conduct electricity in solution.
- Acids and bases are classified based on pH.
- Buffers are solutions that minimize the effects of the addition of an acid or base on pH.

### Section 3 Salts

<table>
<thead>
<tr>
<th>Term</th>
<th>p.</th>
</tr>
</thead>
<tbody>
<tr>
<td>neutralization</td>
<td>689</td>
</tr>
<tr>
<td>salt</td>
<td>689</td>
</tr>
<tr>
<td>soap</td>
<td>694</td>
</tr>
<tr>
<td>titration</td>
<td>692</td>
</tr>
</tbody>
</table>

**MAIN Idea** An acid and a base react to form a salt and water.

- Neutralization is a chemical reaction between an acid and a base.
- Salt is a dietary essential.
- Titration is a method used to determine the concentration of an acidic or a basic solution.
- Molecules of soaps and detergents have polar and nonpolar ends.
Use Vocabulary

Compare and contrast the following pairs of terms.

18. acid—base
19. acid—salt
20. salt—soap
21. base—soap
22. neutralization—salt
23. strong acid—pH
24. hydronium ion—acid
25. indicator—titration
26. pH—buffer
27. weak base—strong base

Check Concepts

28. Which phrase best describes solutions of equal concentrations of HCl and CH₃COOH?
   A) do not have the same pH
   B) will react the same with metals
   C) will make the same salts
   D) have the same amount of ionization

29. Which item is a solution of hydrochloric acid and water?
   A) battery acid
   B) vitamin C
   C) stomach acid
   D) vinegar

30. Which acid ionizes only partially in water?
   A) HCl
   B) H₂SO₄
   C) HNO₃
   D) HC₂H₃O₂

31. Carrots have a pH of 5.0; how would you describe them?
   A) acidic
   B) basic
   C) neutral
   D) an indicator

32. What is the pH of pure water at 25°C?
   A) 0
   B) 5.2
   C) 7
   D) 14

33. A change of what property permits certain materials to act as indicators?
   A) acidity
   B) color
   C) concentration
   D) taste

34. Which substance might you use to titrate an oxalic acid solution?
   A) HBr
   B) Ca(NO₃)₂
   C) NaOH
   D) NH₄Cl

Interpret Graphics

Use the table below to answer question 35.

<table>
<thead>
<tr>
<th>pH Readings</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Substance</strong></td>
</tr>
<tr>
<td>Battery acid</td>
</tr>
<tr>
<td>Lemon juice</td>
</tr>
<tr>
<td>Apple</td>
</tr>
<tr>
<td>Milk</td>
</tr>
<tr>
<td>Seawater</td>
</tr>
<tr>
<td>Ammonia</td>
</tr>
</tbody>
</table>

35. Which of the substances shown in the table would be most effective for neutralizing battery acid?
36. Compare the pH test strips for Sample A and Sample B, and determine the approximate pH of both samples. Which sample is the acid?

37. Describe What happens to hydrogen chloride (HCl) when it is dissolved in water to form hydrochloric acid?

38. Summarize the process for titrating an unknown basic solution with an acidic solution of known concentration.

39. BIG Idea Explain Why is ammonia considered a base, even though it contains no hydroxide ions? Is it a strong or weak base?

40. THEME FOCUS Compare and Contrast How would the pH of a dilute solution of HCl compare with the pH of a concentrated solution of the same acid?

41. Hypothesize Ramón often saw his mother cleaning white deposits from inside her teakettle using vinegar. After she added vinegar, bubbles formed. When she finished, all the white deposits were gone. What do you think these white deposits might be? Do you think dish detergent would have worked as well?

42. Conclude You have equal amounts of three colorless liquids: A, B, and C. You add several drops of phenolphthalein to each liquid. A and B remain colorless, but C turns pink. Next, you add some C to A, and the pink color disappears. Then, you add the rest of C to B, and the mixture becomes pink. What can you infer about each of these liquids?

43. Infer Why do solutions of the substances CH₄ and SiO₂ not conduct electricity?

44. Calculate If an acid is added to a solution that has a pH of 10 and the solution changes 4 pH units, what is the new pH?

45. Calculate To make an indicator solution, a student mixes 3 mL of a concentrated solution with water to create a 100-mL sample. How much concentrate is needed to make 3 L of the indicator?

46. Interpret The graph illustrates two acid-base neutralization reactions. Which line (red or blue) represents a base that is being neutralized by an acid?

47. Interpret How much acid must be added to the base to neutralize it?
Multiple Choice

Record your answers on the answer sheet provided by your teacher or on a sheet of paper.

Use the figures below to answer questions 1 and 2.

<table>
<thead>
<tr>
<th>Acid Solution Data</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solution</td>
</tr>
<tr>
<td>W</td>
</tr>
<tr>
<td>X</td>
</tr>
<tr>
<td>Y</td>
</tr>
<tr>
<td>Z</td>
</tr>
</tbody>
</table>

1. Which solution has the lowest concentration of hydrogen ions?
   A. solution W     C. solution Y
   B. solution X     D. solution Z

2. Which solution contains a strong acid?
   A. solution W     C. solution Y
   B. solution X     D. solution Z

3. Hard water often contains various amounts of metallic substances. Which of the following ions does NOT contribute to hard water?
   A. calcium        C. magnesium
   B. iron           D. sodium

4. An unknown substance in solution is slippery to the touch, dissolves easily in water, and makes litmus paper turn blue. The substance is most likely
   A. an acid.      C. a salt.
   B. a base.       D. an indicator.

5. Which chemical formula below describes a hydronium ion?
   A. H₃O⁺            C. −COOH
   B. OH⁻             D. H₂O

Use the graph below to answer questions 6–8.

6. The titration curve above indicates the changes that happened to a solution of a strong acid as drops of a strong base were added. Before any drops were added, what was the pH of the solution?
   A. 1           C. 9
   B. 3           D. 13

7. At which drop count are the acid and base exactly neutralized?
   A. 0           B. 25
   C. 50          D. 75

8. At the instant of neutralization, what is in the beaker besides water?
   A. acid only    C. salt only
   B. base only    D. equal amounts of acid and base

9. The chemical equation for a reaction is
   \[2\text{HCl} + \text{Ca(OH)}₂ \rightarrow \text{CaCl}_₂ + 2\text{H}_₂\text{O}\]. How many water molecules are formed as \(x\) molecules of CaCl₂ form?
   A. 2
   B. twice as many, \(2x\)
   C. half as many, \(\frac{x}{2}\)
   D. an equal number, \(x\)
10. What is the chemical formula for this substance?
11. How many hydronium ions can it form in water?
12. Write the chemical equation for the ionization reaction of hydrogen sulfide in water.
13. A conductivity apparatus is inserted into a beaker of water, but the lightbulb does not glow. Describe what will happen if NaCl crystals are added to the beaker and stirred.
14. At pH = 3.0, the hydronium ion concentration of a solution is 0.0010 M. When the pH of the solution drops to 1.0, the hydronium ion concentration increases by a factor of 100. What is the H_3O^+ concentration at pH = 1.0?
15. Compare and contrast the terms strength and concentration as they apply to acids and bases in solution.
16. Name the salt that is produced by each of the following acid-base pairs: HCl + NaOH, HCl + Mg(OH)_2, and HBr + KOH.

17. One of the solutions has a pH of 10, and the other has a pH of 12. Explain why the lightbulbs glow with different intensities. Use the words strong and weak in your answer.
18. Describe how dishwashing liquid cleans dirty plates.
19. Na_2SO_4 is a soluble salt. Write the chemical equation describing its dissociation in water.
20. Identify the acid and base that form the salt Na_2SO_4 in a titration reaction.
21. Suppose you have an HCl solution of an unknown concentration. If 25.0 mL of this solution requires 50.0 mL of a known concentration of a NaOH solution to neutralize it, then how much more concentrated is the HCl solution than the NaOH solution?