SECTION 10.1

Arrhenius Acids and Bases

Key Terms

- Arrhenius theory of acids and bases
- ionization
- dissociation
- acid-base indicator
- universal indicator
- pH scale
- strong acid
- weak acid
- strong base
- weak base

Every day, you use, see, and even eat many acids and bases. Citrus fruits, such as oranges and lemons, contain citric acid. Household cleaners, such as soap and ammonia, contain bases. There are even acids and bases inside the human body. These acids and bases are important for normal body functions. **Figure 10.1** shows a variety of common items that have acidic or basic properties.

Figure 10.1 Many foods and household items contain acids or bases.

Identify *What properties do lemons and grapes have in common?*

Acid-base Theories

Arrhenius theory of acids and bases an acid-base theory stating that acids ionize to produce hydrogen ions in solution and bases dissociate to produce hydroxide ions in solution

Compounds and solutions can be categorized as acidic, basic, or neutral. What determines whether a substance is acidic or basic? Scientists have developed a few different theories to explain acids and bases. Each of these theories is useful in different situations, but none of them completely explains every acid-base interaction.

An early acid-base theory was developed by a Swedish chemist and physicist named Svanté Arrhenius, shown in **Figure 10.2**. Arrhenius's theory was part of his doctoral thesis in 1884. His examiners found his theory hard to accept, and Arrhenius was just barely awarded his degree. However, he received a Nobel Prize for this theory in 1903, and today his theory is recognized as a fundamental concept in chemistry. You will learn about other acid-base theories in higher-level chemistry classes, In this chapter, however, the focus will be on the **Arrhenius theory of acids and bases**.

Figure 10.2 Svanté Arrhenius (1859–1927) was only 25 years old when he proposed his theory of acids and bases. Scientists still use his theory today.

The Arrhenius Theory of Acids and Bases

The Arrhenius theory of acids and bases uses the concept of ions in solution to explain the nature of acids and bases. According to Arrhenius, an acid must contain a hydrogen atom that can become a hydrogen ion, $H^+(aq)$, in solution. For example, hydrogen chloride, $HCl(g)$, is a molecular substance that forms ions when dissolved in water:

$$HCl(g) \xrightarrow{\text{in water}} H^+(aq) + Cl^-(aq)$$

Similarly, a base must contain a hydroxyl group, $-OH$, which is a source of hydroxide ions, $OH^-(aq)$, in an aqueous solution. For example, sodium hydroxide, $NaOH(s)$, is an ionic substance that breaks apart into ions when dissolved in water:

$$NaOH(s) \xrightarrow{\text{in water}} Na^+(aq) + OH^-(aq)$$

Arrhenius Acids and Bases

- An acid is a substance that ionizes in water to produce one or more hydrogen ions, $H^+(aq)$.
- A base is a substance that dissociates in water to form one or more hydroxide ions, $OH^-(aq)$.

ionization the process of forming ions

dissociation the process in which ions break apart when dissolved in solution

Acids are molecular compounds that are held together by covalent bonds. When acids dissolve in water, they *form* ions and therefore undergo **ionization**. Conversely, most bases are made up of ions because they are ionic compounds. When a base is dissolved in water, the ions in the base break apart, or dissociate. Therefore, the base undergoes **dissociation**.

The Arrhenius theory explains the properties of acids and bases. Acids have characteristic properties because acids form hydrogen ions in solution. For example, the reaction between an acid and zinc and the sour taste of an acid are both due to the presence of hydrogen ions. Bases have characteristic properties because most bases dissociate to form hydroxide ions in solution.

The Arrhenius theory also explains neutralization reactions. Consider the reaction between hydrochloric acid and sodium hydroxide:

$$HCl(aq) + NaOH(aq) \rightarrow NaCl(aq) + H_2O(\ell)$$

In this reaction, and in all reactions between Arrhenius acids and bases, the hydrogen ions from the acid combine with the hydroxide ions from the base to form water. Thus, a base and an acid can neutralize each other.

Properties of Acids and Bases

Acids and bases are substances that have been used for thousands of years for a wide variety of applications. The extensive use of acids and bases is in large part due to the characteristic physical and chemical properties that each of these substances has. **Table 10.1** summarizes some important properties of acids and bases, and provides some common examples of substances that are acidic or basic. When reading through **Table 10.1**, make note of the differences between acids and bases. One important difference, which is commonly used to identify a substance as being acidic or basic, is the substance's pH, which can be estimated with pH indicators.

Table 10.1 Properties of Acids and Bases

Property	Acids	Bases
Taste*	Sour	Bitter
Texture*	No characteristic texture	Slippery to the touch
Electrical conductivity in aqueous solution	Conduct electricity	Conduct electricity
pH	Less than 7	Greater than 7
Indicator colours • Litmus • Phenolphthalein	 Red Colourless	 Blue Pink
Corrosion	Corrode tissues and metals	Corrode tissues but not metals
Reactions • With metals • With carbonates	 React with active metals to produce hydrogen gas React with carbonates to produce carbon dioxide gas	 No reaction No reaction
Common examples	Citrus fruits, vinegar, carbonated drinks, vitamin C	Soap, baking soda, oven cleaner, household ammonia

*Never taste any chemical in the laboratory and do not touch chemicals without wearing protective gloves.

The pH Scale

Advertisements for soaps, shampoos, and skin creams often use the terms "pH balanced" and "pH controlled." Gardeners and farmers monitor the pH of the soil, because it can affect plant growth. Some plants, such as the hydrangeas shown in **Figure 10.3**, respond visibly to the acidity or basicity—also known as alkalinity—of the soil in which they are planted. If the pH of your blood becomes too high or too low, your blood will lose its ability to transport oxygen and you will become very sick. Clearly, pH values can be important, but what does the term "pH" actually mean?

The **pH scale** is used to describe the acidity or basicity of a solution based on the concentration of hydrogen ions in solution. Acids produce hydrogen ions in solution. Therefore, an acidic solution has a hydrogen ion concentration that is greater than its hydroxide ion concentration and has a pH that is less than 7. Bases produce hydroxide ions in solution. Thus, a basic solution has a hydroxide ion concentration that is greater than its hydrogen ion concentration and has a pH that is greater than 7. Neutral solutions, such as pure water, have equal concentrations of hydrogen ions and hydroxide ions. The pH of a neutral solution is 7. **Figure 10.4** shows the pH values of various common substances.

pH scale a scale used to describe the acidity or basicity of a solution

acid-base indicator a substance that changes colour beyond a threshold pH level

universal indicator a chemical mixture that changes colour throughout the range of pH values from 0 to 14

*Go to **Logarithms and Calculating pH** in **Appendix A** for information about calculating the pH of a solution.*

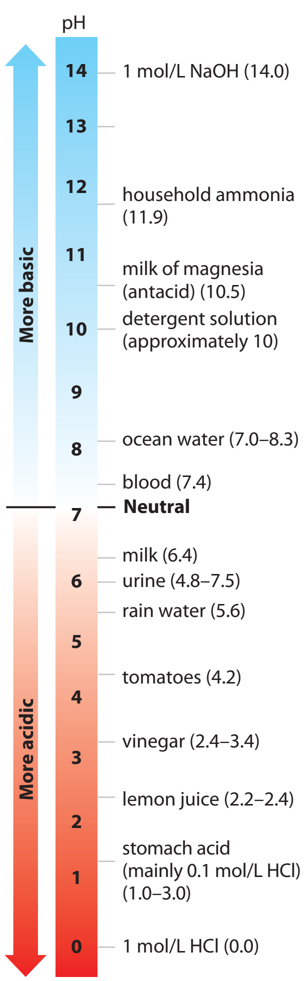


Figure 10.4 The pH scale has values between 0 and 14. The higher the pH of a substance, the more basic the substance is.

Acid-base Indicators and pH

Acids and bases react differently with **acid-base indicators**, such as litmus and bromocresol green. This property is exploited when using acid-base indicators to determine if a substance is acidic or basic. How acid-base indicators work is based on a characteristic colour they have at certain pH values. An acid-base indicator has one colour in a solution when the pH is below a certain level and a noticeably different colour when the pH is above this level.

Some acid-base indicators, such as litmus, can be used to distinguish between acids and bases because they change colour around pH 7. Other indicators can be used to measure pH values that are greater or lower than 7, depending on the pH at which they change colour. **Table 10.2** lists some common indicators and the pH ranges they can measure. Often, something called a **universal indicator** is used. This type of acid-base indicator contains a mixture of chemicals that changes colour throughout the range of pH values from 1 to 14.

Figure 10.3 The blue flowers on a hydrangea plant indicate that the soil is acidic. When the soil is more basic, the flowers are pink.

Table 10.2 Common Indicators

Indicator	pH Range	Colour Change as pH Increases
methyl violet	0.0 to 1.6	yellow to blue
orange IV	1.4 to 2.8	red to yellow
methyl orange	3.2 to 4.4	red to yellow
bromocresol green	3.8 to 5.4	yellow to blue
methyl red	4.8 to 6.0	red to yellow
bromothymol blue	6.0 to 7.6	yellow to green to blue
phenol red	6.6 to 8.0	yellow to red
phenolphthalein	8.2 to 10.0	colourless to pink
indigo carmine	11.4 to 13.0	blue to yellow

Suggested Investigation

Inquiry Investigation 10-A, Physical and Chemical Properties of Acids and Bases

Learning Check

1. According to the Arrhenius theory of acids and bases, what characterizes an acid? What characterizes a base?
2. Acids and bases are commonly found in the home. They can be identified by their properties.
   a. Name two foods that contain acidic substances.
   b. Name two household items that contain basic substances.
3. Use **Table 10.1** to create a graphic organizer, such as a Venn diagram, that compares the properties of acids and bases.
4. Identify each substance as an acid or an base.
   a. $HBr(aq)$ **d.** $HClO_4(aq)$ **g.** $Sr(OH)_2(aq)$
   b. $KOH(aq)$ **e.** $Ca(OH)_2(aq)$ **h.** $CsOH(aq)$
   c. $H_3PO_4(aq)$ **f.** $HNO_3(aq)$
5. When one drop of phenolphthalein is added to a clear colourless solution, the solution becomes pink. If another sample of the solution is tested with a piece of blue litmus paper, what observation would you expect? Explain your answer.
6. For each of the following, identify whether the hydrogen ion concentration is higher or lower than the hydroxide ion concentration.
   a. a solution with a pH of 4
   b. lemon juice
   c. a solution of sodium hydroxide

Activity 10.1 Determining the pH of an Unknown Solution with Indicators

The pH values of solutions can be determined in different ways. One way to determine a pH value is to use an indicator.

Safety Precautions

- Wear safety eyewear throughout this activity.
- Wear gloves and a lab coat or apron throughout this activity.
- Solutions of acids and bases can be toxic and corrosive or caustic. Flush any spills on skin or clothing with plenty of cool water. Inform your teacher immediately.
- If any solutions get into your eyes, flush your eyes at an eye-wash station for 15 min and inform your teacher.

Materials

- 4 indicator solutions: methyl orange, methyl red, bromothymol blue, and phenolphthalein in dropper bottles
- 4 solutions of unknown pH in dropper bottles
- spot plate or 4 small test tubes

Procedure

1. Place two drops of methyl orange indicator in four wells on the spot plate (or in four small test tubes).
2. Add five drops of each unknown solution to the indicator.
3. Record the colours.
4. Repeat steps 1 to 3 with the other three indicators.

Questions

1. Using **Table 10.2**, estimate the pH of each of the four solutions.
2. Your teacher will use a pH meter to determine the pH of the solutions. How do the results you obtained using indicators compare with the results your teacher obtained using a pH meter?
3. With the permission of your teacher, repeat this activity using a universal indicator, such as pH paper. Which method, a combination of indicators or a universal indicator, is more accurate? Explain your answer.

Strong and Weak Acids

Go to **scienceontario** to find out more

Household vinegar contains approximately 1.0 mol/L acetic acid, $CH_3COOH(aq)$. The pH of household vinegar is about 2.4 and can be eaten and handled without causing harm. In comparison, 1.0 mol/L hydrochloric acid, HCl(aq), has a pH of 0. Hydrochloric acid is corrosive and must be handled with caution. The difference is based on the strengths of the acids.

Strong Acids

A solution that contains a high concentration of ions conducts electric current better than a solution that contains a low concentration of ions, as shown in **Figure 10.5**. Any solution of hydrochloric acid contains many more hydrogen ions than a solution with the same concentration of acetic acid. In fact, *all* the molecules of hydrochloric acid ionize in water, whereas relatively few molecules of acetic acid ionize.

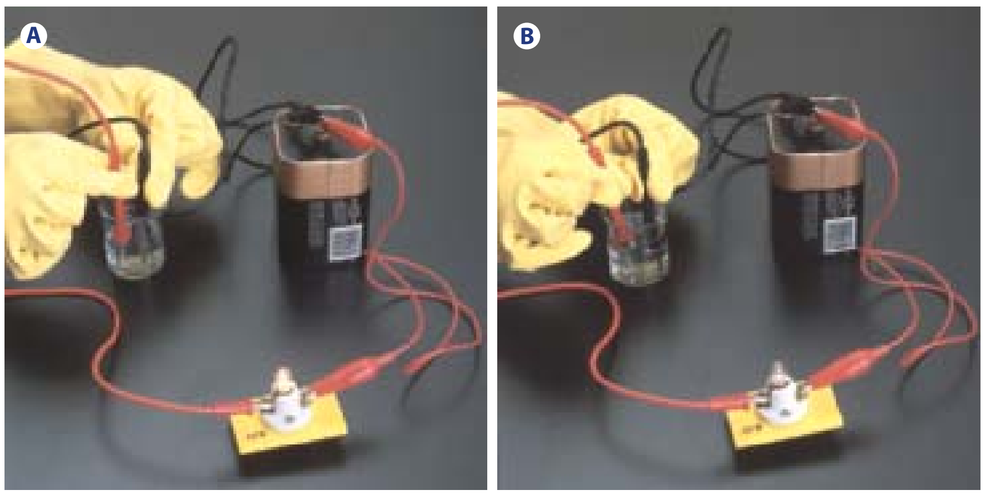


Figure 10.5 The brightness of a conductivity tester is a clue to the concentration of ions in a solution. **(A)** A solution of 1 mol/L hydrochloric acid, HCl(aq), contains many ions and conducts electricity very well. **(B)** A solution of 1 mol/L acetic acid, $CH_3COOH(aq)$, contains relatively few ions and is a poor conductor of electricity.

strong acid an acid that ionizes completely in water

An acid that ionizes completely in water is called a **strong acid**. For example, hydrochloric acid, HCl(aq), is a strong acid. When hydrochloric acid is dissolved in water, all the molecules ionize to form hydrogen ions, $H^+(aq)$, and chloride ions, $Cl^-(aq)$. In fact, the concentration of hydrogen ions in a dilute solution of a strong acid is equal to the concentration of the acid. There are very few strong acids. The most common strong acids are listed in **Table 10.3**.

Acid rain, which affects salamanders and other living things in the environment, is harmful because it contains strong acids. The acids in acid rain are sulfuric acid, $H_2SO_4(aq)$, and nitric acid, $HNO_3(aq)$. These acids form when sulfur dioxide, $SO_2(g)$, and nitrogen dioxide, $NO_2(g)$, react with water and oxygen in the atmosphere. The primary sources of these gases are power plants and factories that burn fossil fuels. To reduce acid rain, many factories employ different methods to remove the sulfur compounds from the gases that are emitted into the atmosphere.

Table 10.3 The Most Common Strong Acids

Name	Formula
hydrochloric acid	HCl(aq)
hydrobromic acid	HBr(aq)
hydroiodic acid	HI(aq)
perchloric acid	$HClO_4(aq)$
nitric acid	$HNO_3(aq)$
sulfuric acid	$H_2SO_4(aq)$

Weak Acids

Most acids are weak. A **weak acid** is an acid that does not ionize completely in water. When dissolved in water, most of the molecules in a weak acid remain intact. In an aqueous solution of a weak acid, the number of acid molecules that ionize depends on the concentration and the temperature of the solution. In most weak acids, only a small number of acid molecules ionize. For example, only about 1 in 100 acetic acid molecules ionize in a 0.1 mol/L solution at room temperature. Thus, the concentration of hydrogen ions in a solution of a weak acid is always less than the concentration of the dissolved acid. **Figure 10.6** shows how the ionization of a strong acid differs from the ionization of a weak acid. Four examples of weak acids are acetic acid, $CH_3COOH(aq)$, hydrocyanic acid, $HCN(aq)$, hydrofluoric acid, $HF(aq)$, and phosphoric acid, H_3PO_4.

weak acid an acid that ionizes very slightly in a water solution

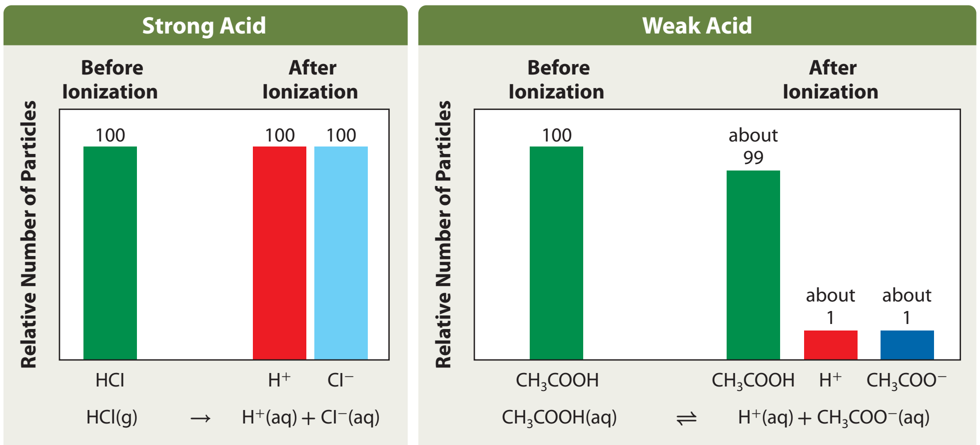


Figure 10.6 Hydrochloric acid, HCl(aq), ionizes completely in water, whereas only about 1 percent of acetic acid molecules ionize in water.

The Strong Binary Acids

Hydrochloric acid, $HCl(aq)$, hydrobromic acid, $HBr(aq)$, and hydroiodic acid, $HI(aq)$, are strong binary acids. Recall that binary acids are acids composed of hydrogen and a non-metal. As shown in **Figure 10.7**, the electronegative chlorine atom in hydrochloric acid draws electrons away from the hydrogen atom, making the hydrogen atom relatively positive. The slightly negative pole of a water molecule is strongly attracted to the hydrogen atom on the acid molecule and is able to tear it away from the chlorine atom. Hydrobromic acid and hydroiodic acid ionize completely in water in the same way.

Binary acids that contain an atom from the halogen family are all strong, with the exception of the binary acid that contains fluorine. The fluorine atom is very electronegative and has a small radius. These properties make the H-F bond so strong that hydrofluoric acid, $HF(aq)$, does not ionize completely. Although hydrofluoric acid is a weak acid, it is extremely corrosive. It can etch glass, and it is quite dangerous if spilled on the skin.

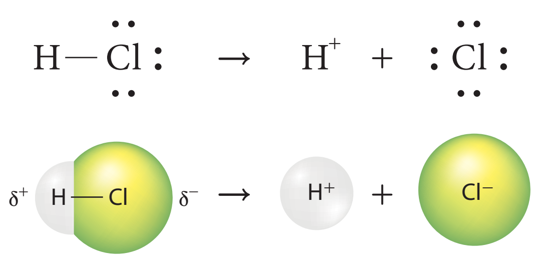


Figure 10.7 The highly polar bond in hydrochloric acid molecules causes hydrochloric acid to ionize completely in aqueous solution.

The Strong Oxoacids

Recall from Chapter 2 that oxoacids are composed of hydrogen, oxygen, and another element. The strong oxoacids are nitric acid, $HNO_3(aq)$, perchloric acid, $HClO_4(aq)$, and sulfuric acid, $H_2SO_4(aq)$. In oxoacids, the hydrogen atom that ionizes is *always* attached to an oxygen atom. The oxygen atom is electronegative and draws electrons away from the hydrogen atom. Water molecules are attracted to the resulting positive charge on the hydrogen atom. The more oxygen atoms there are in an acid molecule, the greater the polarity of the bond between the hydrogen atom that ionizes and the oxygen atom that it is attached to. Thus, you can predict that perchloric acid, $HClO_4(aq)$, is a stronger acid than chloric acid, $HClO_3(aq)$.

Acids with two hydrogen atoms that can ionize are called *diprotic acids*. (Acids with three hydrogen atoms that can ionize are called *triprotic acids*.) Sulfuric acid is the only strong diprotic acid. The high electronegativity of oxygen atoms makes each oxygen-hydrogen bond polar. As shown in **Figure 10.8**, sulfuric acid in an aqueous solution ionizes completely into hydrogen ions and hydrogen sulfate ions, $HSO_4^-(aq)$. The hydrogen sulfate ion can also act as an acid. However, the negative charge on the ion makes the hydrogen-oxygen bond much less polar, so the hydrogen is less likely to ionize to form another hydrogen ion. Thus, the hydrogen sulfate ion is a weak acid.

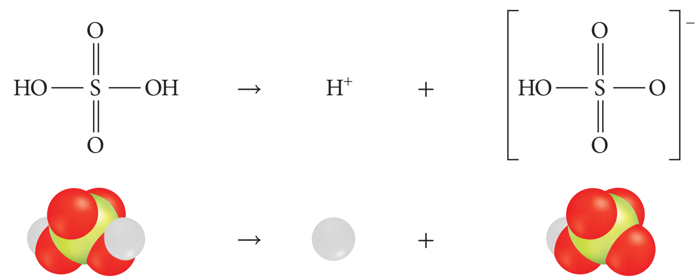


Figure 10.8 The oxygen atoms increase the polarity of both of the oxygen-hydrogen bonds in sulfuric acid. At least one hydrogen ion ionizes from each sulfuric acid molecule in water.

Strong and Weak Bases

Bases also can be classified as being strong or weak, based on their degree of dissociation in water. The characteristics of strong bases are similar to the characteristics of strong acids and the characteristics of weak bases are similar to the characteristics of weak acids.

Strong Bases

strong base a base that dissociates completely in water

A **strong base** dissociates completely in water. For example, sodium hydroxide, $NaOH(s)$, is a strong base. When sodium hydroxide is dissolved in water, it completely dissociates to form sodium ions, $Na^+(aq)$, and hydroxide ions, $OH^-(aq)$. The concentration of hydroxide ions in a dilute solution of a strong base is equal to the concentration of the base.

All hydroxides of the alkali metals (Group 1 elements) are strong bases. The alkaline earth metal (Group 2) hydroxides below beryllium in the periodic table are also strong bases. Beryllium is the exception because it is a relatively small atom and its bond with oxygen is strong. **Table 10.4** lists the strong bases that you are most likely to use in activities and investigations.

Go to **scienceontario** to find out more

Table 10.4 Some Common Strong Bases

Name	Formula
lithium hydroxide	$LiOH(aq)$
sodium hydroxide	$NaOH(aq)$
potassium hydroxide	$KOH(aq)$
calcium hydroxide	$Ca(OH)_2(aq)$
barium hydroxide	$Ba(OH)_2(aq)$

Weak Bases

Most bases are weak. A **weak base** is a base that produces relatively few hydroxide ions in water. Like a weak acid, only a small number of the particles in a weak Arrhenius base dissociate in water.

weak base a base that produces relatively few hydroxide ions in water

The most common weak base is ammonia, $NH_3(aq)$. However, the Arrhenius theory cannot explain why ammonia is a base since ammonia does not contain hydroxide ions. To understand why ammonia is a base, you must look at the reaction between ammonia and water. In this reaction, ammonia removes a hydrogen ion, H^+, from water, producing an ammonium ion, $NH_4^+(aq)$, and a hydroxide ion, $OH^-(aq)$:

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

Strong and Weak versus Concentrated and Dilute

When discussing acids and bases, people often confuse the terms *strong* and *concentrated* and the terms *weak* and *dilute*. The terms *strong* and *weak* refer to the ionization or dissociation of particles in water. On the other hand, the terms *concentrated* and *dilute* refer to the amount of solute in a solvent. A concentrated solution is a solution that has a high concentration of solute. A dilute solution is a solution that has a low concentration of solute.

An example of a concentrated acid is 12.0 mol/L hydrochloric acid. An example of a dilute acid is 0.1 mol/L hydrochloric acid. Notice that both are solutions of the same acid, and this acid is a strong acid. Thus, you can have a concentrated solution of a strong acid and a dilute solution of a strong acid. You can also have a concentrated solution of a strong base and a dilute solution of a strong base.

Weak acids and weak bases can also be made into concentrated and dilute solutions. A concentrated base is a 5.0 mol/L solution of ammonia, $NH_3(aq)$. A dilute base is a 0.2 mol/L solution of ammonia. Ammonia is a weak base, so these solutions are examples of a concentrated weak base and a dilute weak base.

Figure 10.9 illustrates the differences between strong and concentrated acids and between weak and dilute acids. Similar diagrams could be drawn for bases.

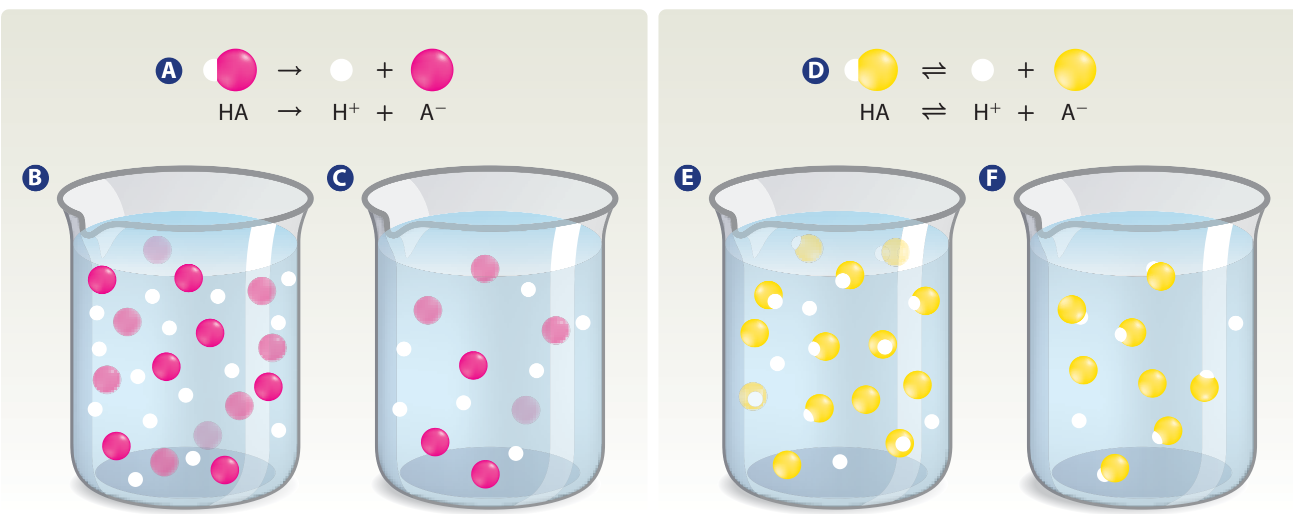


Figure 10.9 **(A)** When a strong acid is dissolved in water, all of its molecules ionize to form hydrogen ions and acid anions. **(B)** In a *concentrated* solution of a *strong* acid, there are many hydrogen ions and acid anions. **(C)** In a *dilute* solution of a *strong* acid, there are a few hydrogen ions and acid anions.

(D) When a weak acid is dissolved in water, only a few of its molecules ionize to form hydrogen ions and acid anions. **(E)** In a *concentrated* solution of a *weak* acid, there are many acid molecules and some hydrogen ions and acid anions. **(F)** In a *dilute* solution of a *weak* acid, there are a few acid molecules and even fewer hydrogen ions and acid anions.

Learning Check

7. Summarize the difference between "strong" and "concentrated" when describing a solution of an acid. Give examples to illustrate this difference.

8. The terms "concentrated" and "dilute" can be used to describe acids and bases.
   a. Give an example of a dilute solution of a strong base.
   b. Give an example of a concentrated solution of a weak acid.

9. The pH of one type of soft drink is 3.0. The soft drink contains carbonic acid, $H_2CO_3(aq)$, and phosphoric acid, $H_3PO_4(aq)$. Are these acids strong or weak? Give reasons for your answer.

10. Predict the relative strengths of the following acids: hypochlorous acid, $HClO(aq)$; chlorous acid, $HClO_2(aq)$; chloric acid, $HClO_3(aq)$; perchloric acid, $HClO_4(aq)$. Explain your reasoning.

11. Draw diagrams that show the difference between strong and weak versus concentrated and dilute bases.

12. Why are the safety warnings for investigations that use strong acids or bases much more strict than those that use weak acids or bases?

Activity 10.2 Differentiating between Weak and Strong Acids and Bases

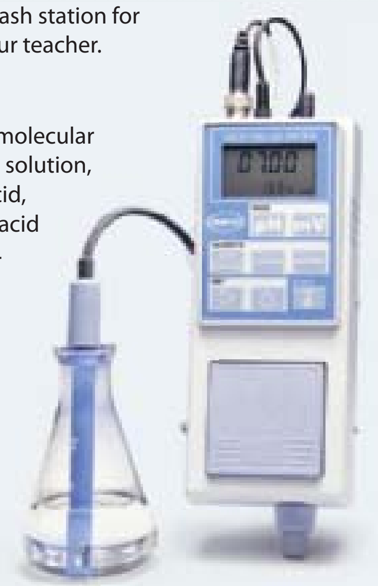
In this activity, you will be given six unknown solutions of equal concentration. You will identify each solution as a strong acid, a strong base, a weak acid, a weak base, a neutral ionic solution, or a molecular solution.

Safety Precautions

- Wear safety eyewear throughout this activity.
- Wear gloves and a lab coat or apron throughout this activity.
- Acids and bases are often both toxic and corrosive. Wash any spills on skin or clothing with plenty of cool water, and inform your teacher immediately.
- When you have completed this activity, wash your hands.
- If any solutions get into your eyes, flush your eyes at an eye-wash station for 15 min and inform your teacher.

Materials

- unknown 0.10 mol/L molecular solution, neutral ionic solution, strong base, strong acid, weak base, and weak acid
- pH paper or pH meter
- 0.5 cm strips of magnesium, Mg(s), ribbon
- 6 beakers (50 mL)
- conductivity tester
- 6 test tubes



Procedure

1. Read steps 2 to 5 in this Procedure, and create an appropriate table to record your results.
2. Place 25 mL of each solution in a 50 mL beaker. Determine the pH of each solution, using either pH paper or a pH meter. Record your observations.
3. Determine the conductivity of each solution using the conductivity tester. Record your observations.
4. Determine the reactivity of each solution with magnesium by placing 5 mL of the solution in a test tube and adding a piece of magnesium ribbon. Record your observations. Note whether some solutions reacted more vigorously with magnesium than others.
5. Dispose of all the materials as directed by your teacher.

Questions

1. Using your data, classify each of the six unknown solutions.
2. How did you distinguish the neutral solutions from the acids and bases?
3. How did you determine which solution was the molecular solution and which solution was the neutral ionic solution?
4. How did you distinguish between the strong base and the weak base and between the strong acid and the weak acid?

Section 10.1 REVIEW

Section Summary

- According to the Arrhenius theory, an acid is a substance that ionizes in water to produce one or more hydrogen ions, $H^+(aq)$, and a base is a substance that dissociates in water to produce one or more hydroxide ions, $OH^-(aq)$.
- Aqueous solutions of acids and aqueous solutions of bases both conduct electricity. However, the other properties of acids and bases, such as reactions with indicators and metals, are different.
- The pH scale describes the concentration of hydrogen ions in solution. Acids have pH values that are less than 7, and bases have pH values that are greater than 7.
- A strong acid or strong base ionizes or dissociates completely into ions in aqueous solution.
- Most acids and bases are weak.

Review Questions

1. K/U The Arrhenius theory of acids and bases describes acids and bases in terms of the ions formed when the compounds are dissolved in water.
   a. According to the Arrhenius theory, can a substance that does not contain hydrogen atoms be an acid? Explain your answer.
   b. Is every substance that contains hydrogen atoms an acid? Explain your answer.
2. K/U How can the properties of an acid be explained? Why does glucose, $C_6H_{12}O_6(aq)$, not have acidic properties even though 1 mol of glucose contains six times as many hydrogen atoms as 1 mol of sulfuric acid, $H_2SO_4(aq)$?
3. C Draw diagrams to show the difference between ionization and dissociation.
4. K/U What is a universal indicator? How is it useful in a laboratory?
5. T/I Describe two different tests you could perform in a laboratory to determine if an unknown compound is an acid.
6. T/I Three aqueous solutions were tested using litmus paper. The results of these tests are given in the table below. Identify each solution as neutral, acidic, or basic.

Reactions with Litmus Paper

Litmus Paper	Solution A	Solution B	Solution C
Red	Paper turns blue.	Paper stays red.	Paper stays red.
Blue	Paper stays blue.	Paper stays blue.	Paper turns red.

7. A A solution of household vinegar and water is sometimes used to clean glass. Marble is made up primarily of calcium carbonate, $CaCO_3(s)$. Why should vinegar never be used to clean marble tiles?
8. K/U The pH scale measures the acidity and basicity of solutions.
   a. What pH values correspond to acidic solutions?
   b. What pH values correspond to basic solutions?
9. A The pH of some common beverages are as follows: buttermilk, pH 4.5; coconut milk, pH 6.5; cranberry juice, pH 2.4; lime juice, pH 2.2; orange juice, pH 4.0.
   a. Arrange the beverages in order of increasing acidity.
   b. Predict how the taste of these beverages would compare, based on your arrangement.
10. T/I Explain why there are no molecules of hydrogen chloride in a 1 mol/L solution of hydrochloric acid, HCl(aq). What is present in the solution?
11. K/U Consider the following substances: $H_2SO_4(aq)$, $NaHCO_3(s)$, KOH(aq), HCl(aq), oxalic acid, aqueous ammonia.
    a. Which (if any) is a strong acid?
    b. Which (if any) is a weak base?
12. K/U What does it mean when an aqueous solution of an acid is described as "weak"?
13. T/I Consider 0.1 mol/L solutions of hydrochloric acid, HCl(aq); acetic acid, $CH_3COOH(aq)$; and ammonia, $NH_3(aq)$. List these solutions in order of increasing hydrogen ion concentration. Explain your reasoning.
14. T/I What piece of laboratory equipment could you use to distinguish between a strong base and a weak base? Describe how you would do this.
15. A Citric acid and most of the other acids found in nature are weak acids. Explain why this is a good thing for humans.
16. C Is it possible to have a concentrated solution of a weak acid? Explain your answer in a way that a student in ninth grade could understand you.