Acids, Bases, and Salts

## How Scientists Study Acids, Bases, and Salts

?

What makes an acid strong or weak?

?

Why is HCl a strong acid and CH₃COOH a weak acid? Does it need more time at the gym to build molecules?

Quite the opposite. HCl has learned to relax and completely ionize its molecules into hydrogen and chloride ions. Acetic acid has many molecules and only a few ions. It's the number of hydrogen ions that determines if an acid is strong or weak.
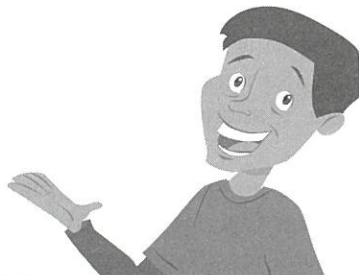
10 Acids, Bases, and Salts

Vocabulary

acidity	electrolyte	neutralization
alkalinity	hydrogen ion	pH scale
Arrhenius acid	hydronium ion	salt
Arrhenius base	indicator	titration

Topic Overview

Ⓡ Common Acids and Common Bases in the *Reference Tables for Physical Setting/Chemistry* list a few of the most common acids and bases. But what exactly are acids and bases? Acids and bases are classes of compounds that can be recognized by their easily observed properties. In this topic you will learn about these properties, the definitions that are used to explain these properties, and the important reactions that occur between acids and bases.

Properties of Acids and Bases

Certain observable properties can be used to identify both acids and bases. Although these properties can indicate whether or not a substance is an acid or a base, they do not explain why acids and bases behave the way they do.

Characteristic Properties of Acids

- *Dilute solutions of acids have a sour taste.* It would be foolish to taste a substance to see if it is an acid. However, there are acids in many of the foods that we eat. You have probably noticed the sour taste of lemons; the sour taste is due to the presence of citric acid. Vinegar contains acetic acid, and carbonated drinks have carbonic acid as one of the ingredients.

- *Aqueous solutions of acids conduct an electric current.* Substances that conduct an electric current are called **electrolytes.** The ability of a solution to conduct an electric current is dependent on the concentration (number) of ions in solution. That is, the greater the concentration of ions in solution, the greater the electrical conductivity. If a solution of an acid is a good conductor of electricity, it is called a strong acid. If such a solution is a poor conductor, it is termed a weak acid.

- *Acids react with bases to form water and a salt.* This type of reaction is called a **neutralization** reaction. Neutralization reactions are in fact a type of double replacement reaction. The **salt** that is formed as a product of a neutralization reaction is an ionic substance composed of a positively charged metallic or polyatomic ion and a negative ion other than the hydroxide ion.

- *Acids react with certain metals to produce hydrogen gas.* The metals listed in Table J of the *Reference Tables for Physical Setting/Chemistry* that are ⓡ above hydrogen (H_2) will react with acids to produce hydrogen gas and a salt. Thus, magnesium will react with hydrochloric acid, whereas copper will not.
- *Acids cause acid-base indicators to change color.* Indicators are substances that have different colors when mixed in acidic and basic solutions. Table M of the *Reference Tables for Physical Setting/Chemistry* lists several ⓡ common indicators and the color changes that they undergo.

Characteristic Properties of Bases

- *Bases have a bitter taste.*
- *Bases have a slippery or soapy feeling.*
- *Bases conduct an electric current.* Note that the terminology used to describe the strength of a base is the same as that used for acids. Thus, a solution of a base with a high concentration of ions that conducts electricity is called a strong base. Weak bases are poor conductors of electricity and are not highly ionized.
- *Bases react with acids to produce water and a salt.*
- *Bases cause acid-base indicators to change color.*

Arrhenius Theory

There have been several attempts to develop explanations for the observable properties of acids and bases. Svante Arrhenius, a Swedish chemist, proposed a commonality of all acids to explain their similar properties. An **Arrhenius acid** is defined as a substance whose water solution contains the hydrogen ion as the only positive ion. For example, hydrochloric acid ionizes in water to form hydrogen and chloride ions.

$$HCl \rightarrow H^+ + Cl^-$$

Not all substances that contain hydrogen are acids. Methane (CH_4) is an organic compound containing hydrogen, yet it is not an acid. The hydrogen atoms in methane are bonded to the carbon by covalent bonds. These hydrogen atoms do not ionize in solution: rather, they remain attached to the molecule. Because the hydrogen atoms do not form ions, methane is neither an electrolyte nor an acid.

The Nature of the Hydrogen Ion

A hydrogen atom consists of a single electron orbiting a nucleus that contains a single proton. As shown in Figure 10-1, when the hydrogen atom becomes a positive ion, the electron is lost, leaving behind the proton. Thus, a positive **hydrogen ion** is a proton.

Chemists believe that this proton cannot exist in a water solution as an isolated proton. The positively charged proton is attracted to an unshared pair of electrons in the water molecule. See Figure 10-2. The proton covalently bonds with
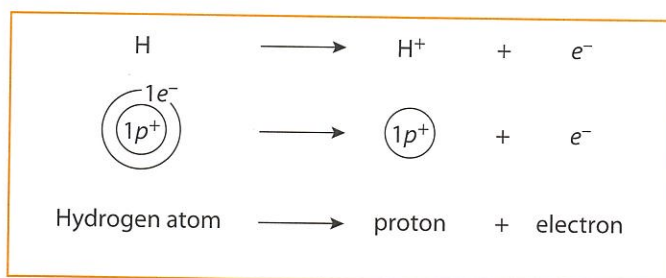

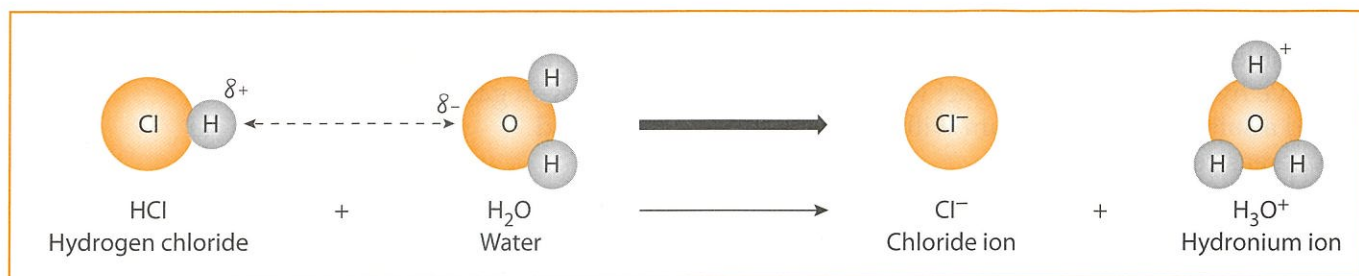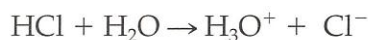**Figure 10-1.** An H^+ ion is a proton.

Figure 10-2. Acids react with water to produce the hydronium ion.

the water forming H_3O^+, the **hydronium ion.** Acids dissolve in water and react to produce hydronium and negative ions.

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

$$H^+ + H_2O \rightarrow H_3O^+$$

According to the Arrhenius theory, the properties of acids are properties of the hydrogen (hydronium) ion.

As shown in the first equation above, each molecule of hydrochloric acid (HCl) that ionizes in water produces a single hydrogen ion. Hydrochloric acid and other acids that produce a single hydrogen ion are called monoprotic acids. Sulfuric acid (H_2SO_4), however, ionizes in two steps.

$$H_2SO_4 \rightarrow H^+ + HSO_4^-$$

$$HSO_4^- \rightarrow H^+ + SO_4^{2-}$$

Each molecule of H_2SO_4 that ionizes produces two hydrogen ions. Sulfuric acid and other acids that produce two hydrogen ions are called diprotic acids. Similarly, an H_3PO_4 molecule ionizes to yield three hydrogen ions and is called a triprotic acid.

The Nature of the Hydroxide Ion

In a parallel manner to acids, the properties of bases are explained as properties of the hydroxide ion (OH^-) in solution. Each **Arrhenius base** produces hydroxide ions when dissolved in water. The presence of the hydroxide ion makes the base an electrolyte. It is also the presence of the hydroxide ion that produces the slippery feel and bitter taste common to Arrhenius bases.

Ammonia (NH_3) and organic compounds called amines are bases, though at first glance their chemical formulas do not show the presence of hydroxide ions. However, ammonia reacts with water to form the ammonium and hydroxide ions.

$$NH_3 + H_2O \rightarrow NH_4^+ + OH^-$$
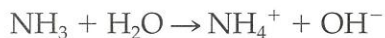
Amines are compounds containing carbon and nitrogen that are related to ammonia. Amines also react with water to produce hydroxide ions.

$$CH_3NH_2 + H_2O \rightarrow CH_3NH_3^+ + OH^-$$
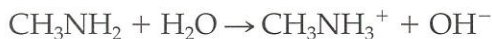
There are also other compounds whose formulas do contain an −OH group but which are not bases. The hydroxyl group is composed of an oxygen atom and a hydrogen atom covalently bonded to a carbon chain. This group of organic compounds, called alcohols, are not bases as they do not

ionize in water. Thus, they are nonelectrolytes and do not have the characteristics of bases. CH_3OH and CH_3CH_2OH are examples of alcohols, and they do not ionize to produce the hydroxide ion.

Strength of Acids and Bases

Hydrochloric acid is a dangerous acid that can cause severe injury to your skin. Citric acid is present in citrus and other fruits that we commonly eat. Even more surprising, boric acid is used as an eye-washing solution. How can we explain that these substances are all acids, yet have such different effects? The answer involves the strength of each acid.

When one hundred molecules of hydrochloric acid dissolve in water, all one hundred molecules ionize and form ions. When an acid completely ionizes, it is called a strong acid. Other acids ionize to a much smaller degree. Perhaps only one molecule out of one hundred ionizes. Acids that ionize only slightly are called weak acids.

The degree of ionization is a function of the number of ions that are produced. Highly ionized (strong) acids and bases produce large numbers of ions. These strong acids and bases are strong electrolytes, and hence good conductors of electricity.

Naming Acids and Bases

Binary acids are composed of hydrogen and one other element. Hydrogen chloride (HCl) is a molecular gas, but becomes an Arrhenius acid when it reacts with water to produce hydrogen ions. The names of binary acids begin with *hydro-* followed by the name of the other element modified to end with −*ic*. Thus, hydrogen chloride gas becomes hydrochloric acid when dissolved in water. Other binary acids are named in the same fashion.

Table 10-1. Names of Several Acids and Their Ions		
Acid Name	**Formula of Acid**	**Anion Name**
Hydrochloric	HCl	chloride
Sulfuric	H_2SO_4	sulfate
Sulfurous	H_2SO_3	sulfite
Nitric	HNO_3	nitrate
Nitrous	HNO_2	nitrite

Ternary acids are also molecular substances that produce hydrogen ions when dissolved in water. They consist of a polyatomic ion containing oxygen such as nitrate (NO_3^-) or sulfate (SO_4^{2-}). To name a ternary acid, the anion suffixes −*ate* and −*ite* usually are replaced by the suffixes −*ic* and −*ous* respectively. For example, HNO_3 is nitric acid. Sometimes the names are modified slightly, as in H_2SO_4, sulfuric acid. Table 10-1 lists the names of several common acids.

Bases are quite simple to name. The name of the positive ion is not modified, and the name of the base ends with hydroxide. For example, $Ca(OH)_2$ is named calcium hydroxide.

Review Questions   Set 10.1

1. According to the Arrhenius theory, when an acidic substance is dissolved in water it will produce a solution containing only one kind of positive ion. To which ion does the theory refer?

   (1) acetate   (3) chloride
   (2) hydrogen   (4) sodium

2. When an Arrhenius base is dissolved in H_2O, the only negative ion present in the solution is

   (1) OH^- (3) H^-
   (2) H_3O^- (4) O^{2-}

3. According to the Arrhenius theory of acids, citric acid in oranges and acetic acid in vinegar are classified as acids because their aqueous solutions contain

(1) hydrogen ions   (3) hydroxide ions
(2) hydrogen atoms   (4) hydroxide atoms

4. In an aqueous solution, which substance yields hydrogen ions as the only positive ion?

(1) C_2H_5OH (3) KH
(2) CH_3COOH (4) KOH

5. Which compound is an electrolyte?

(1) $C_6H_{12}O_6$ (3) CH_3CH_2OH
(2) $C_{12}H_{22}O_{11}$ (4) CH_3COOH

6. If 1 mol of each of the following substances were dissolved in 1 L of water, which solution would contain the highest concentration of OH^- ions?

(1) H_2SO_4 (2) NH_4Cl (3) KNO_3 (4) NaOH

7. If 1 mol of each of the following substances were dissolved in 1 L of water, which solution would contain the highest concentration of H_3O^+ ions?

(1) CH_3COOH (3) KBr
(2) NaCl   (4) $Ba(OH)_2$

8. Which compound is an electrolyte?

(1) CH_4 (3) $Ca(OH)_2$
(2) CH_3OH (4) $C_6H_{12}O_6$

9. Which species is classified as an Arrhenius base?

(1) CH_3OH (2) LiOH   (3) PO_4^{3-} (4) CO_3^{2-}

10. As 1 g of sodium hydroxide dissolves in 100 g of water, the conductivity of the water

(1) decreases   (3) remains the same
(2) increases

11. A solution of a base differs from a solution of an acid in that the solution of a base

(1) is able to conduct electricity
(2) is able to cause an indicator color change
(3) has a greater $[H_3O^+]$
(4) has a greater $[OH^-]$

12. A solution of hydrochloric acid is a stronger acid than a solution of acetic acid of the same concentration because

(1) it has more hydrogen ions in solution
(2) it has more hydroxide ions in solution
(3) it has fewer hydrogen ions in solution
(4) it has fewer hydroxide ions in solution.

13. When an Arrhenius acid is dissolved in water, it produces

(1) H^+ as the only positive ion in solution
(2) NH_3^+ as the only positive ion in solution
(3) OH^- as the only negative ion in solution
(4) HCO_3^- as the only negative ion in solution

14. Potassium hydroxide is classified as an Arrhenius base because KOH contains

(1) OH^- ions.   (3) K^+ ions.
(2) O^{2-} ions.   (4) H^+ ions.

15. Name the following acids and bases.

(a) H_2S (c) LiOH
(b) HBr   (d) $Mg(OH)_2$

16. A student tests the conductivity of an unknown substance and determines it to be a good conductor of electricity. Based on this he decides that it is an acid. Criticize the student's conclusion. Is there enough evidence to warrant the conclusion? What additional test or tests could be performed to confirm the conclusion? For each test, indicate the result that would verify the substance to be an acid.

## Reactions Involving Acids and Bases

Chemical reactions involving acids and bases are common in industrial and consumer applications, natural processes, and in classroom experiments. Acids and bases undergo many reactions because they are able to react with each other as well as with other compounds and elements.

Reactions of Acids with Metals

You may recall that any element in the Activity Series of the *Reference*
Ⓡ *Tables for Physical Setting/Chemistry* will react with the ion of any element

below it. Note that hydrogen (H_2) is found near the bottom of the table. Thus, any metal above hydrogen in the table will react with the hydrogen ions in acids to produce H_2 and a salt. The reaction between zinc and hydrochloric acid is an example.

$$Zn(s) + 2HCl(aq) \rightarrow H_2(g) + ZnCl_2(aq)$$
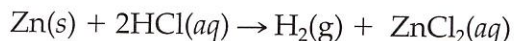
Copper, which is below hydrogen in the table, will not react with hydrogen ions in acids.

Neutralization Reactions

In a neutralization reaction, an Arrhenius acid reacts with an Arrhenius base to produce water and a salt. There are several ways that these reactions can be expressed. For example, consider the neutralization reaction between hydrochloric acid (HCl) and sodium hydroxide (NaOH).
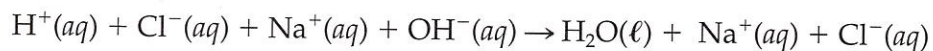
This reaction can be expressed as a word equation:

Hydrochloric acid + Sodium hydroxide $\rightarrow$ Water + Sodium chloride
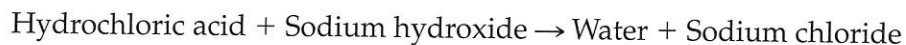
Substituting the chemical formulas for words yields the formula equation:

$$HCl(aq) + NaOH(aq) \rightarrow H_2O(\ell) + NaCl(aq)$$
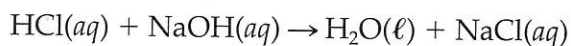
Writing the equation to take the ions in solution into account yields the ionic equation:

$$H^+(aq) + Cl^-(aq) + Na^+(aq) + OH^-(aq) \rightarrow H_2O(\ell) + Na^+(aq) + Cl^-(aq)$$

Note that the sodium and chloride ions are present on both sides of the reaction arrow. Because they have not taken part in the reaction, they are called spectator ions and can be omitted.

$$H^+(aq) + \cancel{Cl^-(aq)} + \cancel{Na^+(aq)} + OH^-(aq) \rightarrow H_2O(\ell) + \cancel{Na^+(aq)} + \cancel{Cl^-(aq)}$$
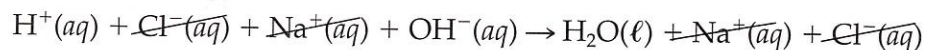
Omitting the spectator ions yields the net ionic equation:

$$H^+(aq) + OH^-(aq) \rightarrow H_2O(\ell)$$
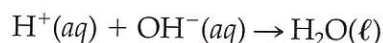
Because hydrogen ions exist in solution as hydronium ions (H_3O^+), this equation can also be written as the reaction between hydronium and hydroxide ions.

$$H_3O^+(aq) + OH^-(aq) \rightarrow 2H_2O(\ell)$$

All neutralization reactions have the same net equation. The Arrhenius definition is able to explain the process of neutralization as a reaction between hydrogen (hydronium) ions and hydroxide ions to form water with the spectator ions forming a salt.

Writing Neutralization Reactions Writing neutralization reactions is not a difficult task, as shown in the following Sample Problem.
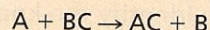
SAMPLE PROBLEM

Write the equation for the neutralization reaction between dilute nitric acid and potassium hydroxide.

SOLUTION: Identify the known and unknown values.

Known
reactant 1 = nitric acid (HNO_3)

reactant 2 = potassium
             hydroxide (KOH)

Unknown
neutralization
equation = ?

1. Write a simple word equation for the neutralization reaction.

   acid + base → water + salt

2. Substitute the known compounds into the general word equation.

   HNO_3 + KOH → water + salt

3. Picture a box enclosing the hydroxide (OH^-) of the base and the hydrogen (H^+) of the acid. These particles combine to form water (H_2O).

   HNO_3 + KOH → H_2O + salt

The remaining K^+ and NO_3^- ions combine to form the salt KNO_3.

HNO_3 + KOH → H_2O + KNO_3

4. Now check to see that the equation is balanced. Because the hydroxide and hydrogen ions combine in a 1:1 ratio to form water molecules, they must be present in equal numbers. If needed, the coefficients of the acid and the base are adjusted to balance these ions. In this example, there is one hydroxide ion and one hydrogen ion, so the coefficients are both 1. A coefficient of 1 is not written; the above equation is balanced. Note that the spectator ions form the salt.

Digging Deeper

Because salts are produced by neutralization, it would seem logical that a salt would be neutral, that is, neither acidic nor basic. There are, however, acidic, basic, and neutral salts. Salts that were formed from a strong acid and a strong base are neutral salts. If the salt was formed by the reaction of a strong acid and a weak base, it will be acidic. If the opposite is the case, that is, a salt formed from a strong base and a weak acid, the salt will be basic. The acidity or basicity of a salt formed from a weak acid and a weak base must be evaluated on a case-by-case basis.

When a diprotic acid reacts with a dihydroxy base, there are two hydrogen ions and two hydroxide ions. These will combine to form two molecules of water. The remaining ions will form the salt.

$$Ca(OH)_2 + H_2SO_4 \rightarrow 2H_2O + CaSO_4$$
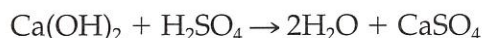
Combinations of acids and bases that do not have an equal number of hydroxide and hydrogen ions are also easy to balance. Consider the following unbalanced equation:

$$Mg(OH)_2 + HCl \rightarrow H_2O + MgCl_2$$
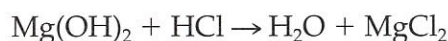
Note that there are two hydroxide ions but only one hydrogen ion. Placing a 2 in front of the HCl balances the hydroxide and hydrogen ions that form two molecules of water. The 2 coefficient also supplies the two chloride ions needed to form the salt. The equation is now balanced:

$$Mg(OH)_2 + 2HCl \rightarrow 2H_2O + MgCl_2$$
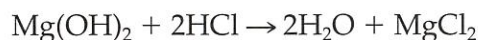
Salts

As you learned earlier, when a metal reacts with an acid, hydrogen gas and a salt are formed. In a neutralization reaction, an acid and a base react to form water and a salt. The salts in these reactions are ionic substances composed of positively charged metallic or polyatomic ions, and negative ions other than hydroxide ions. Sodium chloride (NaCl) and ammonium phosphate (($NH_4)_3PO_4$) are examples of salts. Salts are named by using the name of the positive ion of the base, and the negative ion of the acid.

17. According to the *Reference Tables for Physical Setting/Chemistry,* which metal would react spontaneously with hydrochloric acid?

(1) gold   (2) silver   (3) copper   (4) zinc

18. According to the *Reference Tables for Physical Setting/Chemistry,* which of the following metals will react most readily with HCl to release hydrogen gas?

(1) aluminum   (3) silver
(2) copper   (4) gold

19. Which solution reacts with LiOH(*aq*) to produce a salt and water?

(1) KCl(*aq*)   (3) NaOH(*aq*)
(2) H_2SO_4(*aq*)   (4) CaO(*aq*)

20. The reaction between one mole of hydrogen ions and one mole of hydroxide ions is called

(1) oxidation   (3) hydrolysis
(2) reduction   (4) neutralization

21. Which type of reaction occurs when equal volumes of 0.1M HCl and 0.1M NaOH are mixed?

(1) neutralization   (3) electrolysis
(2) ionization   (4) hydrolysis

22. Which type of reaction occurs when 50-mL quantities of 1 M $Ba(OH)_2$(*aq*) and H_2SO_4(*aq*) are combined?

(1) hydrolysis   (3) hydrogenation
(2) ionization   (4) neutralization

23. Which compound reacts with an acid to produce water and a salt?

(1) CH_3Cl (3) KCl
(2) CH_3COOH (4) KOH

24. How much water is formed when 1.0 mol of HCl reacts completely with 1.0 mol of NaOH?

(1) 1.0 mol   (3) 0.50 mol
(2) 2.0 mol   (4) 0.25 mol

25. A water solution contains 0.50 mol of HCl. How much NaOH should be added to the HCl solution to exactly neutralize it?

(1) 1.0 mol   (3) 0.25 mol
(2) 2.0 mol   (4) 0.50 mol

26. Which is the net ionic equation for a neutralization?

(1) $H^+ + H_2O \rightarrow H_3O^+$
(2) $H^+ + NH_3 \rightarrow NH_4^+$
(3) $2H^+ + 2O^{2-} \rightarrow 2OH^-$
(4) $H^+ + OH^- \rightarrow H_2O$

27. Which substance is always produced by a neutralization reaction?

(1) water
(2) acid
(3) ester
(4) base

28. Which products are formed when an acid reacts with a base?

(1) an alcohol and carbon dioxide
(2) an ester and water
(3) a soap and glycerin
(4) a salt and water

29. Which compound is a salt?

(1) Na_3PO_4
(2) H_3PO_4
(3) CH_3COOH
(4) $Ca(OH)_2$

30. Which compound is classified as a salt?

(1) CH_3COOH
(2) C_2H_5OH
(3) NaOH
(4) $NaC_2H_3O_2$

31. Which formula represents a salt?

(1) KOH
(2) KCl
(3) CH_3OH
(4) CH_3COOH

32. The diagram below shows an acid being added to a base.

A
50 mL of I M HCl

B
50 mL of I M NaOH
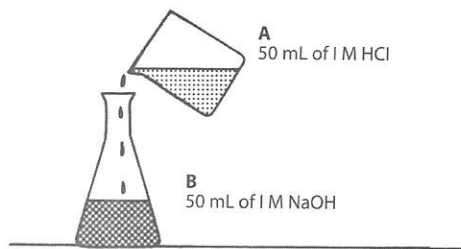
As the acid in beaker A is added to the base in flask B, the number of OH^- ions in flask B

(1) decreases and the number of Na^+ ions decreases
(2) increases and the number of Na^+ ions decreases
(3) decreases and the number of Na^+ ions remains the same
(4) increases and the number of Na^+ ions remains the same

33. The diagram below illustrates an apparatus used to test the conductivity of various solutions.
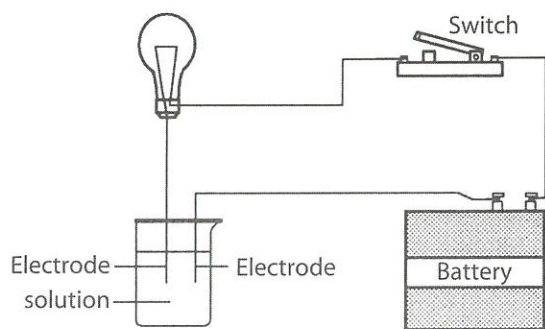
When the switch is closed, which of the following 1-molar solutions would cause the bulb to glow most brightly?

(1) ammonia
(2) acetic acid
(3) carbonic acid
(4) sulfuric acid

34. Which salt is formed when hydrochloric acid is neutralized by a potassium hydroxide solution?

(1) potassium chloride
(2) potassium chlorate
(3) potassium chlorite
(4) potassium perchlorate

35. In the neutralization reaction between hydrochloric acid and sodium hydroxide, the spectator ions are

(1) H^+ and OH^-
(2) Cl^- and OH^-
(3) Na^+ and H^+
(4) Na^+ and Cl^-

36. When NaOH(*aq*) reacts completely with HCl(*aq*) and the resulting solution is evaporated to dryness, the solid remaining is

(1) an ester
(2) an alcohol
(3) a salt
(4) a metal

37. Name each of the following.

(a) HF
(b) H_2Se
(c) HI

38. Consult the Activity Series in the *Reference Tables for Physical Setting/Chemistry* to determine if the following reactions actually occur. If a reaction does occur, write the correctly balanced equation. If the reaction does not occur, write "No reaction."

(a) calcium and hydrochloric acid
(b) zinc and dilute nitric acid
(c) lead and carbonic acid
(d) aluminum and acetic acid
(e) copper and phosphoric acid

39. Write the balanced equation for each of the following neutralization reactions, and write the name of the salt formed.

(a) nitric acid and sodium hydroxide
(b) nitric acid and magnesium hydroxide
(c) sulfuric acid and magnesium hydroxide
(d) sulfuric acid and potassium hydroxide
(e) phosphoric acid and lithium hydroxide
(f) phosphoric acid and calcium hydroxide

Acid–Base Titration

Titration is the process of adding measured volumes of an acid or a base of known concentration to an acid or a base of unknown concentration until neutralization occurs. The solution of known concentration is called the standard solution. Knowing the volumes of acid and base used in the titration, together with the known concentration of the standard solution, it is possible to calculate the concentration of the unknown solution.

In all neutralization reactions there must be a 1:1 ratio between the moles of hydrogen ions (H^+) and the moles of hydroxide ions (OH^-). The equation for concentration shows the relationship among number of moles, volume in liters, and molarity.

$$molarity = \frac{moles}{volume}$$

or

$$moles = molarity \times volume$$

Since the number of moles of H^+ ions must equal the number of moles of OH^- ions, equating mol H^+ and mol OH^- yields the following equation.

$$\text{molarity } H^+ \times \text{volume}_{acid} = \text{molarity } OH^- \times \text{volume}_{base}$$

or

$$M_A \times V_A = M_B \times V_B$$

In the above equation, M_A = molarity of H^+, V_A = volume of acid in milliliters, M_B = molarity of OH^-, and V_B = volume of base in milliliters.

To solve any titration problem, the molarity of the acid and base must be expressed as the molarity of the hydrogen ion (H^+) and the molarity of the hydroxide ion (OH^-), respectively. In the case of monoprotic acids such as HCl, the molarity of the H^+ is the same as the molarity of the acid. Thus, a 2.0 M HCl solution has a 2.0 M H^+ concentration. The same applies to monohydroxy bases. That is, a 2.5 M NaOH solution has a 2.5 M OH^- concentration.

The case is different for diprotic and triprotic acids. Consider the complete ionization of a 1.0 M solution of sulfuric acid (H_2SO_4).

$$H_2SO_4(aq) \rightarrow 2H^+(aq) + SO_4^{2-}(aq)$$

One liter of 1.0 M solution of H_2SO_4 yields 2 mol of H^+ ions. The molarity of the H^+ ions will be twice the molarity of the acid solution. Similarly, a triprotic acid produces an H^+ ion molarity three times that of the molarity of the acid solution.

The following examples summarize the relationships between the concentration of an acid or base and the resulting concentration of hydrogen ions (H^+) or hydroxide ions (OH^-) in solution for mono-, di-, and triprotic acids and mono- and dihydroxy bases.

Monoprotic Acids The H^+ molarity equals the molarity of the acid solution. Hydrochloric acid is an example.

$$2.5 \text{ M HCl} = 2.5 \text{ M } H^+$$
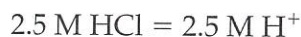
Diprotic Acids The H^+ molarity is twice the molarity of the acid solution. Sulfuric acid is an example.

$$2.5 \text{ M } H_2SO_4 = 5.0 \text{ M } H^+$$
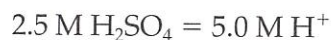
Triprotic Acids The H^+ molarity is three times the molarity of the acid solution. Phosphoric acid is an example.

$$2.0 \text{ M } H_3PO_4 = 6.0 \text{ M } H^+$$
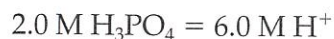
Monohydroxy Bases The OH^- molarity equals the molarity of the base solution. Sodium hydroxide is an example.

$$3.0 \text{ M NaOH} = 3.0 \text{ M } OH^-$$
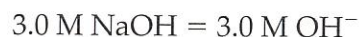
Dihydroxy Bases The OH^- molarity is twice the molarity of the base solution. Barium hydroxide is an example.

$$0.5 \text{ M Ba(OH)}_2 = 1.0 \text{ M } OH^-$$
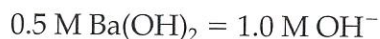
SAMPLE PROBLEM

What is the concentration of a hydrochloric acid solution if 50.0 mL of a 0.250 M KOH are needed to neutralize 20.0 mL of the HCl solution of unknown concentration?

SOLUTION: Identify the known and unknown values.

Known
molarity of KOH = 0.250 M
V_B = volume of KOH = 50.0 mL
V_A = volume of HCl = 20.0 mL

Unknown
M_A = molarity
of HCl = ? M

1. Write the balanced equation for the neutralization reaction
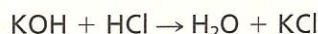
$KOH + HCl \rightarrow H_2O + KCl$

2. Determine the molarity of the hydroxide ion. Because KOH is a monohydroxy base, the molarity of the hydroxide ion is the same as the molarity of the base solution.

M_B = molarity KOH = 0.250 M

3. Solve the neutralization reaction equation for M_A, substitute the known values, and solve.

$$M_A \times V_A = M_B \times V_B$$

$$M_A = (M_B \times V_B)/ V_A$$

$$M_A = \frac{(0.250 \text{ M})(50.0 \text{ mL})}{20.0 \text{ mL}}$$

$$M_A = 0.625 \text{ M}$$

The molarity of the hydrogen ion is 0.625 M. Because HCl is a monprotic acid, the molarity of the acid is also 0.625 M.

SAMPLE PROBLEM

What is the concentration of a sulfuric acid solution if 50. mL of a 0.25 M KOH are needed to neutralize 20. mL of the H_2SO_4 solution of unknown concentration?

SOLUTION: Identify the known and unknown values.

Known
molarity of KOH = 0.25 M
V_B = volume of KOH = 50. mL
V_A = volume of H_2SO_4 = 20. mL

Unknown
M_A = molarity of
H_2SO_4 = ? M

1. Write the balanced equation for the neutralization reaction.
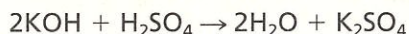
$2KOH + H_2SO_4 \rightarrow 2H_2O + K_2SO_4$

2. Determine the molarity of the hydroxide ion. Because KOH is a monohydroxy base, the molarity of the hydroxide ion is the same as the molarity of base solution.

M_B = molarity KOH = 0.25 M

3. Solve the neutralization reaction equation for M_A, substitute the known values, and solve.

$$M_A \times V_A = M_B \times V_B$$

$$M_A = (M_B \times V_B)/ V_A$$

$$M_A = \frac{(0.250 \text{ M})(50.0 \text{ mL})}{20.0 \text{ mL}}$$

$$M_A = 0.625 \text{ M}$$

4. To determine the molarity of the H_2SO_4, adjust for the fact that the acid is diprotic. That is, the molarity of the acid is only half that of the hydrogen ion.

$$\text{molarity } H_2SO_4 = \frac{[H^+]}{2} = \frac{0.625 \text{ M}}{2} = 0.31 \text{ M}$$

40. Which compound reacts with an acid to form a salt and water?

(1) CH_3F (3) LiCl
(2) C_2H_5COOH (4) LiOH

41. To neutralize 1 mol of sulfuric acid, 2 mol of sodium hydroxide are required. How many liters of 1 M NaOH are needed to exactly neutralize 1 L of 1 M H_2SO_4?

(1) 1   (2) 2   (3) 0.5   (4) 4

42. How many moles of sodium hydroxide (NaOH) are required to completely neutralize 2 mol of nitric acid (HNO_3)?

(1) 1   (2) 2   (3) 40   (4) 60

43. During an acid-base neutralization, how many moles of hydroxide ions will react with one mole of hydrogen ions?

(1) 1.0 mol   (3) 17.0 mol
(2) 0.5 mol   (4) 22.4 mol

44. How many moles of KOH are needed to exactly neutralize 500. mL of 1.0 M HCl?

(1) 1.0 mol   (3) 0.25 mol
(2) 2.0 mol   (4) 0.50 mol

45. One liter of 1 M NaOH will completely neutralize one liter of

(1) 1 M H_2SO_4 (3) 2 M H_2SO_4
(2) 0.5 M H_2SO_4 (4) 1.5 M H_2SO_4

For questions 46–54, show all of your work.

46. Consider the following reaction.

$$KOH + HCl \rightarrow H_2O + HOH$$

How many milliliters of 2.0 M KOH are necessary to neutralize 50. mL of 1.0 M HCl?

47. How many milliliters of 2.5 M HCl are required to exactly neutralize 1.5 L of 5.0 M NaOH?

48. How many milliliters of 0.20 M H_2SO_4 are required to completely neutralize 40. mL of 0.10 M $Ca(OH)_2$?

49. How many milliliters of 0.200 M NaOH are needed to neutralize 100. mL of 0.100 M HCl?

50. A 2.0-mL sample of NaOH solution is exactly neutralized by 4.0 mL of 3.0 M HCl solution. What is the concentration of the NaOH solution?

51. A 10.-mL sample of hydrochloric acid neutralizes 15 mL of a 0.40 M solution of NaOH. What is the molarity of the hydrochloric acid?

52. How many mL of 0.20 M hydrochloric acid is required to neutralize 100. mL of 0.80 M potassium hydroxide?

53. A 3.0-mL sample of HNO_3 solution is exactly neutralized by 6.0 mL of 0.50 M KOH. What is the molarity of the HNO_3 solution?

54. What is the molarity of hydrogen ions in a 2.7 M solution of the strong acid HCl?

55. Write the electron dot diagram of a hydrogen chloride molecule.

56. Write the electron dot diagram for the hydronium ion (H_3O^+).

57. Write the electron dot diagram for the hydroxide ion (OH^-).

58. Write the word equation form of the net ionic equation for all neutralization equations.

59. Write the electron dot diagram for the net ionic equation for a neutralization reaction. Be sure to include the charge on any ionic substance.

60. Phosphoric acid is neutralized by a solution of sodium hydroxide. What is the name of the salt formed from the neutralization?

Acidity and Alkalinity of Solutions

Although water is a covalently bonded substance, it does ionize to a very small extent as shown by the equation below.

$$HOH \leftrightarrow H^+ + OH^-$$

It can be seen that in pure water $[H^+] = [OH^-]$. Le Châtelier's principle tells us that if one of these factors increases, the other decreases. When HCl is added to pure water, the concentration of the hydrogen ion increases, and the concentration of the hydroxide ion decreases. When $[H^+] > [OH^-]$, the solution is acidic. If the reverse is true, and the concentration of OH^- is

greater than the concentration of the H^+, the solution is alkaline, or basic. The terms **acidity** and **alkalinity** (or basicity) refer to the relative strength of the acid or base in terms of their H^+ and OH^- concentrations.

pH Scale

A scale, called the **pH scale,** has been developed to express $[H^+]$ as a number from 0 to 14. A pH of 0 is strongly acidic, a pH of 7 is neutral, and a pH of 14 is strongly basic. The pH scale is logarithmic. Each change of a single pH unit signifies a tenfold change in the concentration of the hydrogen ion. Thus the $[H^+]$ is ten times greater in a solution with a pH of 5 as in a solution with a pH of 6.

Because $[H^+]$ and $[OH^-]$ are directly related, a pH change of one unit represents a tenfold increase or decrease of both the hydrogen ion and hydroxide ion concentration. As the concentration of the hydrogen ion increases, the concentration of the hydroxide ion decreases.

$$\text{HIn} \longrightarrow H^+ + In^-$$
$$\text{(colorless)} \qquad \text{(pink)}$$

Figure 10-3. Color change in phenolphthalein: Indicators are weak acids that have different colors depending on the presence or absence of hydrogen. In the diagram above, HIn represents the indicator phenolphthalein.

Acid-Base Indicators

An **indicator** is a substance that changes its color when it gains or loses a proton. Phenolphthalein is a common indicator that is colorless when it is protonated, that is, when it contains a hydrogen atom. When a base is gradually added to an acid containing phenolphthalein, the solution is initially colorless. Once the acid has been neutralized by the addition of the base, the base then reacts with the hydrogen atom of the indicator. As the phenolphthalein loses its hydrogen (proton), it turns pink. This color change is why phenolphthalein is an indicator; the color change in the phenolphthalein shows (indicates) when a titration has reached an end point.

Other indicators react in a similar way to phenolphthalein, but each has a unique color change that occurs over a specific pH range. Common Ⓡ Acid-Base Indicators in the *Reference Tables for Physical Setting/Chemistry* lists several common indicators, the color changes they undergo, and the pH range over which the color change occurs.

Another example of an indicator is methyl orange. An acid solution with a pH of 2.0 containing methyl orange is red in color. As a base is added to the acid solution, the pH slowly increases. Between pH 3.2 and 4.4, the solution contains both the red and the yellow forms of the indicator, resulting in an orange color. When a pH of 4.4 is achieved, there is no longer an appreciable number of red molecules present, and the solution appears yellow. This same process occurs in other indicators as well. That is, indicators tend to have a distinct color at each end of their useful pH range and pass through an intermediate color region that is a mixture of these two colors.

61. Which pH value indicates the most basic solution?

(1) 7   (2) 8   (3) 3   (4) 11

62. Which pH value represents a solution with the lowest OH^- ion concentration?

(1) 1   (2) 7   (3) 10   (4) 14

63. When tested, a solution turns red litmus to blue. This indicates that the solution contains more

(1) H^+ ions than OH^- ions
(2) H_3O^+ ions than OH^- ions
(3) OH^- ions than H_3O^+ ions
(4) H^+ and OH^- ions than H_2O molecules

64. Pure water at 25°C has a pH of

(1) 1   (2) 5   (3) 7   (4) 14

65. If an aqueous solution turns blue litmus red, which relationship exists between the hydronium ion and hydroxide ion?

(1) $[H_3O^+] < [OH^-]$
(2) $[H_3O^+] = [OH^-]$
(3) $[H_3O^+] > [OH^-]$
(4) neither ion is present

66. The pH of a 0.1 M CH_3COOH solution is

(1) less than 1
(2) greater than 1, but less than 7
(3) equal to 7
(4) greater than 7 but less than 14

67. As 0.1 M HCl is added to 0.1 M KOH, the pH of the basic solution

(1) decreases and the basicity decreases
(2) decreases and the acidity decreases
(3) increases and the basicity decreases
(4) increases and the acidity decreases

68. As a strong acid is added to a beaker containing NaOH, the number of OH^- ions in the beaker

(1) decreases and the number of Na^+ ions decreases
(2) decreases and the number of Na^+ ions remains the same
(3) increases and the number of Na^+ ions decreases
(4) increases and the number of Na^+ ions remains the same

69. A water solution is tested with phenolphthalein and reveals a pink color. Which is a possible pH of this solution?

(1) 1   (2) 4   (3) 7   (4) 10

70. As the H_3O^+ ion concentration of a solution increases, the pH of a solution

(1) increases
(2) decreases
(3) remains the same

Answer questions 71–72 using complete sentences.

71. A blue solution containing an acid-base indicator was tested with a pH meter and found to have a pH of 5.5. Which of the indicators on Common Acid-Base Indicators in the *Reference Tables for Physical Setting/Chemistry* could be this indicator?

72. A solution was yellow in bromthymol blue and blue in bromcresol green. According to Common Acid-Base Indicators in the *Reference Tables for Physical Setting/Chemistry,* what could be the pH of the solution?

Brønsted-Lowry Acids and Bases

There are other acid-base definitions that expand upon the Arrhenius definition of acids and bases. One of these, the Brønsted-Lowry theory, defines an acid as any substance that donates a hydrogen ion (H^+). As you know, a hydrogen ion is a hydrogen atom without an electron, that is, it is simply a proton. Thus, a Brønsted-Lowry acid is defined as a proton donor. All Arrhenius acids are also Brønsted-Lowry acids. Brønsted-Lowry theory expands upon the Arrhenius concept by including proton donors that are not in aqueous solution.
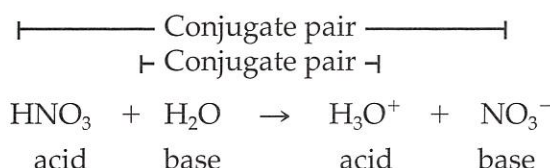
The Brønsted-Lowry theory defines a base as any substance that accepts a proton (H^+). Like the Arrhenius definition, the Brønsted-Lowry definition treats the hydroxide ion (OH^-) as a base. Compared with the Arrhenius definition, however, the Brønsted-Lowry definition greatly expands the number of substances that are considered bases.

Conjugate Acid-Base Pairs When an acid loses a proton, the remaining portion of the acid has an unshared pair of electrons that can act as a base. Consider the following reaction.

$$HNO_3 + H_2O \rightarrow H_3O^+ + NO_3^-$$

The HNO_3 acts as an acid, donating its proton to the water (which acts as a base) producing the hydronium and nitrate ions. If the reaction is reversed, the hydronium ion acts as an acid, donating its proton to the nitrate ion (which acts as a base) to produce nitric acid and water. Note that HNO_3 and NO_3^- differ only by a hydrogen ion (H^+). A pair of chemical formulas that differ only by the presence of a hydrogen ion are known as a conjugate acid-base pair. HNO_3 cannot donate a proton unless there is a proton acceptor (base) available to accept that proton. In this reaction, water serves the role of a base. As you can see, H_2O and H_3O^+ differ only by a hydrogen ion as well. The water and hydronium ion are also a conjugate acid-base pair in this reaction.

The reaction between HNO_3 and water illustrates the reaction between a Brønsted acid and a Brønsted base.
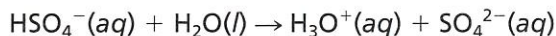
$$
\begin{array}{ccccccc}
\overbrace{}^{\text{Conjugate pair}} \\
HNO_3 & + & H_2O & \rightarrow & H_3O^+ & + & NO_3^- \\
\text{acid} & & \text{base} & & \text{acid} & & \text{base}
\end{array}
$$

Review Questions   Set 10.5

73. According to one acid-base theory, a base is an
   (1) H^+ acceptor   (3) Na^+ acceptor
   (2) H^+ donor   (4) Na^+ donor

74. Given the balanced equation representing a reaction:

   $$HSO_4^-(aq) + H_2O(l) \rightarrow H_3O^+(aq) + SO_4^{2-}(aq)$$

   According to one acid-base theory, the $H_2O(l)$ molecules act as

   (1) a base because they accept H^+ ions
   (2) a base because they donate H^+ ions
   (3) an acid because they accept H^+ ions
   (4) an acid because they donate H^+ ions

75. Given the balanced equation representing a reaction:

   $$H_2PO_4^-(aq) + H_2O(l) \rightarrow H_3PO_4(aq) + OH^-(aq)$$

   According to one acid-base theory, the $H_2O(l)$ molecules act as

   (1) a base because it accepts an H^+
   (2) a base because it donates an H^+
   (3) an acid because it accepts an H^+
   (4) an acid because it donates an H^+

76. Which of the following pairs of substances could be a conjugate acid-base pair in a reaction?

   (1) HCl and OH^-
   (2) $H_2PO_4^-$ and Na_3PO_4
   (3) NH_3 and NH_4^+
   (4) $NaOH$ and Na^+

Directions

Review the Test–Taking Strategies section of this book. Then answer the following questions. Read each question carefully and answer with a correct choice or response.

Part A

1 According to the Arrhenius theory, the only negative ions in an aqueous solution of a base are
(1) OH^- ions
(2) HS^- ions
(3) H^- ions
(4) HCO_3^- ions

2 Which statement best describes the solution produced when an Arrhenius acid is dissolved in water?
(1) The only negative ion in solution is OH^-.
(2) The only negative ion in solution is HCO_3^-.
(3) The only positive ion in solution is H^+.
(4) The only positive ion in solution is NH_4^+.

3 Which substance can act as an Arrhenius acid in aqueous solution?
(1) NaI
(2) HI
(3) LiH
(4) NH_3

4 Unlike an acid, an aqueous solution of a base
(1) causes some indicators to change color
(2) conducts electricity
(3) contains more H^+ than OH^-
(4) contains more OH^- than H^+

5 According to the Arrhenius theory, when a base is dissolved in water it will produce a solution containing only one kind of negative ion. To which ion does the theory refer?
(1) hydride
(2) hydroxide
(3) hydrogen
(4) hydronium

6 Which compounds yield hydrogen ions as the only positive ions in an aqueous solution?
(1) NH_3 and $HC_2H_3O_2$
(2) H_2CO_3 and $NaHCO_3$
(3) H_2CO_3 and $HC_2H_3O_2$
(4) NH_3 and $NaHCO_3$

7 What are the relative ion concentrations in an acid solution?
(1) more H^+ ions than OH^- ions
(2) fewer H^+ ions than OH^- ions
(3) an equal number of H^+ ions and OH^- ions
(4) H^+ ions, but no OH^- ions

8 What color is phenolphthalein in a basic solution?
(1) blue
(2) pink
(3) yellow
(4) colorless

9 Which substance is always produced by a neutralization reaction?
(1) water
(2) acid
(3) ester
(4) base

10 According to one acid-base theory, an acid is an
(1) OH^- acceptor.
(2) OH^- donor.
(3) H^+ acceptor.
(4) H^+ donor.

11 Pure water has a pH of
(1) 1   (3) 10
(2) 7   (4) 4

Part B–1

12 Which substance is classified as a salt?
(1) $Ca(OH)_2$
(2) C_2H_4OH
(3) CCl_4
(4) $CaCl_2$

13 Consider this neutralization reaction.
$$H_2SO_4 + 2KOH \rightarrow K_2SO_4 + 2HOH$$

Which compound is the salt produced in this reaction?
(1) KOH
(2) H_2SO4
(3) K_2SO_4
(4) HOH

14 An aqueous solution turns litmus red. The pH of the solution could be
(1) 14
(2) 11
(3) 8
(4) 4

15 If equal volumes of 0.1 M NaOH and 0.1 M HCl are mixed, the resulting solution will contain a salt and
(1) HCl
(2) NaOH
(3) H_2O
(4) NaCl

16 If equal volumes of 0.1 M NaOH and 0.1 M H_2SO_4 are mixed, the resulting solution will contain water,
(1) H_2SO_4 and Na_2SO_4
(2) H_2SO_4 and NaOH
(3) NaOH and Na_2SO_4
(4) and Na_2SO_4

17 A sample of a solution with a pH of 10 is tested separately with litmus and phenolphthalein. The colors of the indicators are as follows:
(1) litmus is blue; phenolphthalein is pink
(2) litmus is red; phenolphthalein is pink
(3) litmus is blue; phenolphthalein is colorless
(4) litmus is red; phenolphthalein is colorless

18 A student observes that an unknown solution conducts electricity and turns blue litmus red. The student should be able to conclude that the unknown solution is most likely
(1) an acid
(2) a base
(3) an ester
(4) an alcohol

19 An aqueous solution of an ionic compound turns red litmus blue, conducts electricity, and reacts with an acid to form a salt and water. This compound could be
(1) HCl
(2) NaI
(3) KNO_3
(4) LiOH

20 What will be the concentration of 150. mL of a 2.4 M NaOH solution if it is diluted to form 200. mL of solution?
(1) 1.6 M
(2) 1.8 M
(3) 2.0 M
(4) 3.2 M

21 Both HNO_3 and CH_3COOH can be classified as
(1) Arrhenius acids that turn blue litmus red
(2) Arrhenius bases that turn blue litmus red
(3) Arrhenius acids that turn red litmus blue
(4) Arrhenius bases that turn red litmus blue

22 When the pH value of a solution is changed from 2 to 1, the concentration of the hydronium ions
(1) decreases by a factor of 2.
(2) increases by a factor of 2.
(3) increases by a factor of 10.
(4) decreases by a factor of 10.

23 Given the equation representing a reversible reaction:

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

According to one acid-base theory, the reactant that donates an H^+ ion in the forward reaction is
(1) $H_2O(\ell)$
(2) $NH_3(g)$
(3) $NH_4^+(aq)$
(4) $OH^-(aq)$

24 Which volume of 2.0 M NaOH(aq) is needed to completely neutralize 24 milliliters of 1.0 M HCl(aq)?
(1) 6.0 mL
(2) 12 mL
(3) 24 mL
(4) 48 mL

25 Sulfuric acid, H_2SO_4(aq) can be used to neutralize barium hydroxide, $Ba(OH)_2$(aq). What is the formula of the salt produced by this neutralization?
(1) BaS
(2) $BaSO_2$
(3) $BaSO_3$
(4) $BaSO_4$

Parts B–2 and C

Use the following information to answer questions 26 through 30.

(A) KCl (B) CH₃OH (C) Ba(OH)₂ (D) CH₃COOH
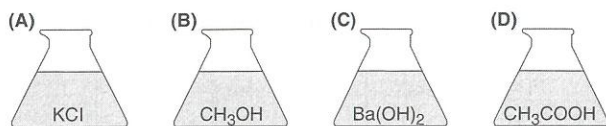
Four flasks each contain 100 milliliters of aqueous solutions of equal concentrations at 25°C and 1 atm.

26 Which solutions contain electrolytes?

27 Which solution has the lowest pH?

28 Which solution has a solute that is classified as a salt?

29 Which solution is most likely to react with an acid to form salt and water?

30 Which solution has the lowest freezing point?

Base your answers to questions 31 through 33 on the information below.

Some carbonated beverages are made by forcing carbon dioxide gas into a beverage solution. When a bottle of one kind of carbonated beverage is first opened, the beverage has a pH value of 3.

31 State, in terms of the pH scale, why this beverage is classified as acidic.

32 Using Table M, identify *one* indicator that is yellow in a solution that has the same pH value as this beverage.

33 After the beverage bottle is left open for several hours, the hydronium ion concentration in the beverage solution decreases to 1/1000 of the original concentration. Determine the new pH of the beverage solution.

Use the following information to answer questions 34 and 35.

A student titrates 60.0 mL of $HNO_3(aq)$ with 0.30 M NaOH. Phenolphthalein is used as the indicator. After adding 42.2 mL of $NaOH(aq)$ a color change remains for 25 seconds, and the student stops the titration.

34 What color change does the phenolphthalein undergo during this titration?

35 What is the molarity of the HNO_3?

Base your answers to questions 36 and 37 on the information below.

In a titration experiment, a student use a 1.4 M $HBr(aq)$ solution and the indicator phenolphthalein to determine the concentration of a $KOH(aq)$ solution. The data for trial 1 is recorded in the table below.

Trial 1 Data		
Buret readings	HBr(*aq*)	KOH(*aq*)
Initial volume (mL)	7.50	11.00
Final volume (mL)	22.90	33.10
Volume used (mL)	15.40	22.10

36 Calculate the molarity of the KOH.

37 Why is it better to use several trials of a titration rather than one trial to determine the concentration of a solution of unknown concentration?

Use the information below to answer questions 38 and 39.

Using burets, a student titrated a sodium hydroxide solution of unknown concentration with a standard solution of 0.10 M hydrochloric acid. The data are recorded in the table below.

Titration Data		
Solution	HCl(*aq*)	NaOH(*aq*)
Initial buret reading (mL)	15.50	5.00
Final buret reading (mL)	25.00	8.80

38 Determine both the total volume of $HCl(aq)$ and the total volume of $NaOH(aq)$.

39 What is the molarity of the NaOH solution?

Base your answers to questions 40–42 on the following information.

Two samples of the same rainwater are tested using two indicators at an environmental lab. The first indicator, Methyl Orange, reveals a distinct yellow color when added to the sample. The second indicator, Litmus, turns red when placed in contact with the water sample.

40 Identify a possible pH value for the rainwater.

41 Explain, in terms of hydronium ions and hydroxide ion concentrations, the pH value of the rainwater.

42 If the rainwater were tested with Bromthymol Blue, what color would be observed?

Base your answers to questions 43 through 45 on the following information.

In a titration, a few drops of an indicator are added to a flask containing 35.0 milliliters of $HNO_3(aq)$ of unknown concentration. After 30.0 milliliters of 0.15 M NaOH(aq) solution is slowly added to the flask, the indicator changes color, showing the acid is neutralized.

43 The volume of the NaOH(aq) solution is expressed to what number of significant figures?

44 Complete the equation for this neutralization reaction by writing the formula of *each* product in the spaces below.

   $$HNO_3(aq) + NaOH(aq) \rightarrow \underline{\hspace{1cm}} + \underline{\hspace{1cm}}$$

45 Show a correct numerical setup for calculating the concentration of the $HNO_3(aq)$ solution.

Base your answers to questions 46 through 49 on the information below.

In one trial of an investigation, 50.0 milliliters of HCl(aq) of an unknown concentration is titrated with 0.10 M NaOH(aq). During the titration, the total volume of NaOH(aq) added and the corresponding pH value of the reaction mixture are measured and recorded in the table below.

Titration Data

Total Volume of NaOH(aq) Added (mL)	pH Value of Reaction Mixture
10.0	1.6
20.0	2.2
24.0	2.9
24.9	3.9
25.1	10.1
26.0	11.1
30.0	11.8

46 On the grid below, plot the data from the table. Circle and connect the points.

pH Value of Reaction Mixture Versus Total Volume of NaOH(aq) Added
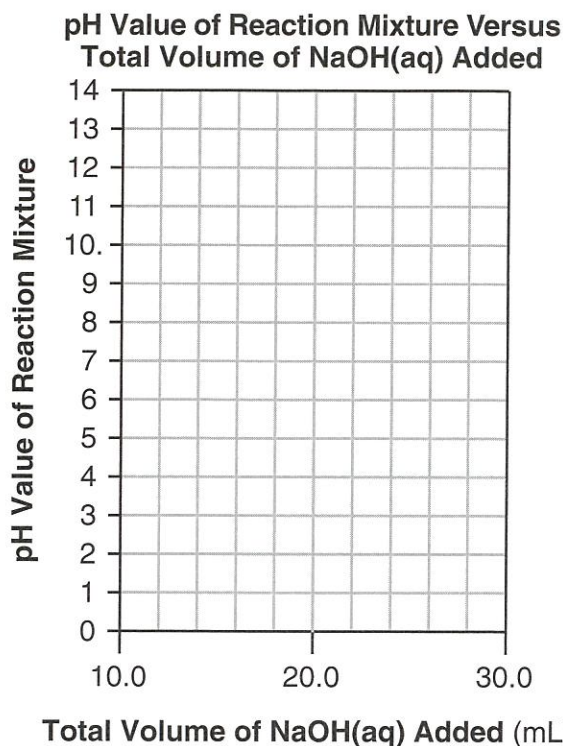
47 Determine the total volume of NaOH(aq) added when the reaction mixture has a pH value of 7.0.

48 Write a balanced equation that represents this neutralization reaction.

49 In another trial, 40.0 milliliters of HCl(aq) is completely neutralized by 20.0 milliliters of this 0.10 M NaOH(aq). Calculate the molarity of the titrated acid in this trial.