Chemistry

Corbin

Weeks 5, 6
Apr 27 – May 8

SECTION 12.3

Concentration of Solutions

Name: ____________

Teacher: CORBIN

The **concentration** of a solution is a measure of the amount of solute in a given amount of solvent or solution. A *dilute* solution is a solution that has a relatively small amount of solute, or a low concentration. A *concentrated* solution is a solution that has a relatively high amount of solute. These terms are not necessarily related to the solubility of a substance. However, a substance with a very low solubility can only form dilute solutions, even if they are saturated.

This section covers two ways of expressing the concentration of a solution. **Molarity** is the number of moles of solute in a liter of solution. **Molality** is the number of moles of solute in a kilogram of solvent. In other words, molarity is a measure of moles per volume, and molality is a measure of moles per mass.

KEY TERMS

concentration
molality
molarity

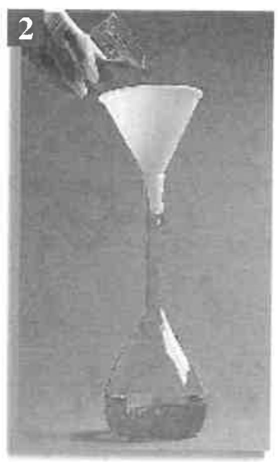
1

Start by calculating the mass of $CuSO_4{\bullet}5H_2O$ needed. Making a liter of this solution requires 0.5000 mol of solute. Convert the moles to mass by multiplying by the molar mass of $CuSO_4{\bullet}5H_2O$. This mass is calculated to be 124.8 g.

Molarity is moles of solute per liter of solution.

Molarity is one way to express the concentration of a solution. The symbol for molarity is M. For example, a 1 M NaOH solution contains one mole of NaOH in every liter of solution. The series of photographs at the right details how to create a 0.5 M solution of $CuSO_4{\bullet}5H_2O$.

2



Add some solvent to the solute to dissolve it, and then pour it into a 1.0 L volumetric flask.

3

Rinse the weighing beaker with more solvent to remove all the solute, and pour the rinse into the flask. Add water until the volume of the solution nears the neck of the flask.

READING CHECK

1. What is the difference between concentration and solubility?

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Calculating Molarity One mole of NaOH has a mass of 40.0 g. If this quantity is dissolved in enough water to make exactly 1.00 L of solution, a 1 M solution results. Dissolving 20.0 g of NaOH, or 0.500 mol, in enough water to make 1.00 L of solution produces a 0.500 M NaOH solution. Likewise, if 80.0 g of NaOH is added to water to make 1.00 L of solution, then a 2 M NaOH solution results.

TIP The word *molar* is often used to describe the molarity of a solution. For example, a one molar solution of NaOH is the same as a 1 M NaOH solution.

Note that the solute is not added to 1.00 L of water to make these solutions. The total volume of the solution should be 1.00 L, so adding solute to a 1.00 L solution will yield a solution that is more than 1.00 L. The proper amount of solute must be dissolved in a smaller quantity of water, and then water added to bring the solution to a 1.00 L volume.

The following equation can be used to compute the molarity of any solution. Note that the amount of solute must be converted from grams to moles if necessary.

$$\text{molarity (M)} = \frac{\text{amount of solute (mol)}}{\text{volume of solution (L)}}$$

READING CHECK

2. Why does 40.0 g NaOH added to 1.00 L of water not make a 1 M NaOH solution?

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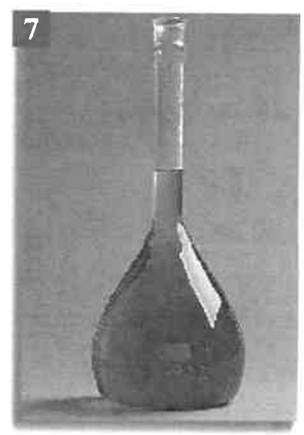
Put the stopper in the flask, and swirl the solution thoroughly.

Carefully fill the flask to the 1.0 L mark with water.

Restopper the flask, and invert it at least 10 times to ensure complete mixing.



The resulting solution has 0.5000 mol of solute dissolved in 1.000 L of solution, which is a 0.5000 M concentration.

SAMPLE PROBLEM

You have 3.50 L of solution that contains 90.0 g of sodium chloride. What is the molarity of the solution?

SOLUTION

1 ANALYZE *Determine the information that is given and unknown.*

Given: solute mass = 90.0 g NaCl
solution volume = 3.50 L

Unknown: molarity of NaCl solution

2 PLAN *Describe how to use the given information to find the unknown.*

Molarity is the number of moles of solute per liter of solution. First, convert the given solute mass into moles of solute.

$$\text{g NaCl} \times \frac{1 \text{ mol NaCl}}{\text{g NaCl}} = \text{mol NaCl}$$

Then use the formula for molarity to calculate the molarity of the solution.

$$\text{molarity of solution (M)} = \frac{\text{amount of solute (mol)}}{\text{volume of solution (L)}}$$

3 SOLVE *Calculate the unknown from the given information.*

First, the molar mass of NaCl must be calculated.

$$\begin{aligned}\text{molar mass of NaCl} &= \text{molar mass of Na} + \text{molar mass of Cl} \\ &= 22.99 \text{ g/mol} + 35.45 \text{ g/mol} \\ &= 58.44 \text{ g/mol}\end{aligned}$$

$$90.0 \text{ g NaCl} = 90.0 \cancel{\text{g NaCl}} \times \frac{1 \text{ mol NaCl}}{58.44 \cancel{\text{g NaCl}}} = 1.54 \text{ mol NaCl}$$

$$\text{molarity of solution} = \frac{1.54 \text{ mol NaCl}}{3.50 \text{ L NaCl}} = 0.440 \text{ M NaCl}$$

4 CHECK YOUR WORK *Check the answer to see if it is reasonable.*

The answer is correctly limited to three significant digits. Because the molar mass of NaCl is about 60 g/mol, 210 g of NaCl would form a 1 M solution in 3.5 L of solvent. The actual solute mass of 90 g is a little less than half that amount, which matches the answer of 0.440 M.

PRACTICE

A. What is the molarity of a solution composed of 5.85 g of potassium iodide, KI, dissolved in enough water to make 1.25 L of solution?

What is the molar mass of KI? ______________________

5.85 g KI = 5.85 g KI × $\frac{\text{1 mol NaCl}}{\text{g KI}}$ = ______________

molarity of solution = $\frac{\text{mol KI}}{\text{1.25 L KI}}$ = ______________

B. You have 0.8 L of a 0.5 M HCl solution. How many moles of HCl does the solution contain?

Rearrange the equation for molarity to solve for the number of moles of solute in the solution.

amount of solute (mol) = ______________________

Substitute the given information into your equation to find the number of moles of HCl.

C. How many moles of H_2SO_4 are present in 0.500 L of a 0.150 L H_2SO_4 solution?

SAMPLE PROBLEM

To produce 40.0 g of silver chromate, Ag_2CrO_4 you will need at least 23.4 g of potassium chromate, K_2CrO_4, in solution as a reactant. All you have on hand is 5 L of a 6.0 M K_2CrO_4 solution. What volume of the solution is needed to give you the 23.4 g K_2CrO_4 needed for the reaction?

SOLUTION

1 ANALYZE *Determine the information that is given and unknown.*

Given: available solution volume = 5 L
concentration of solution = 6.0 M K_2CrO_4 solution
mass of solute = 23.4 g K_2CrO_4
mass of product = 40.0 g Ag_2CrO_4

Unknown: volume of K_2CrO_4 needed in L

2 PLAN *Describe how to use the given information to find the unknown.*

To calculate the volume of solution needed, use the following equation.

$$\text{volume of solution (L)} = \frac{\text{amount of solute (mol)}}{\text{molarity of solution (M)}}$$

The molarity is given. The amount of solute can be calculated by converting the given mass of K_2CrO_4 into moles. The mass of product is not needed for this calculation. The 5 L of solution available sets an upper limit on the answer.

3 SOLVE *Calculate the unknown from the given information.*

molar mass of K_2CrO_4

$$= 2(39.10\text{ g/mol}) + 52.00\text{ g/mol} + 4(16.00\text{ g/mol})$$

$$= 194.20\text{ g/mol}$$

$$23.4\text{ g } K_2CrO_4 = 23.4\,\cancel{\text{g } K_2CrO_4} \times \frac{1\text{ mol } K_2CrO_4}{194.20\,\cancel{\text{g } K_2CrO_4}} = 0.120\text{ mol } K_2CrO_4$$

$$\text{volume of solution} = \frac{0.120\text{ mol } K_2CrO_4}{6.0\text{ M } K_2CrO_4} = 0.020\text{ L}$$

4 CHECK YOUR WORK *Check the answer to see if it is reasonable.*

The answer is below the 5 L amount available. The units cancel correctly, and dividing moles by molarity yields liters.

PRACTICE

D. What volume of 3.00 M NaCl is needed for a reaction that requires 146.3 g of NaCl?

What is the molar mass of NaCl? ____________________

How many moles of NaCl are in 146.3 g of NaCl?

What volume of 3.00 M NaCl solution contains that number of moles?

E. What volume of 1.0 M $AgNO_3$ is needed to provide 169.9 g of pure $AgNO_3$?

What is the molar mass of $AgNO_3$? ____________________

How many moles of $AgNO_3$ are in 169.9 g of $AgNO_3$?

What volume of 1.0 M $AgNO_3$ solution contains that number of moles?

Molality is moles of solute per kilogram of solvent.

While molarity is a measure of solute mass per unit volume of solution, molality is a measure of solute mass per unit mass of solvent. The symbol of molality is m. A 1 m NaOH solution contains one mole of NaOH dissolved in 1 kg of water.

In general, the molality of a solution can be calculated using the following equation.

$$\text{molality } (m) = \frac{\text{amount of solute (mol)}}{\text{mass of solvent(kg)}}$$

Note the similarity between this representation of concentration and molarity. Also note that the mass of the solvent must be expressed in kilograms.

The series of photographs that starts below details how to create a 0.5 M solution of $CuSO_4{\cdot}5H_2O$. Note that the process is simpler because the necessary amount of solvent is defined, whereas with molarity the total volume is defined, not the volume of the solvent.

Molality is commonly used when discussing the properties of solutions related to vapor pressure and temperature changes. This is because the molality of a solution will not change with temperature.

TIP The word *molal* is often used to describe the molality of a solution. For example, a one molal solution of NaOH is the same as a 1 m NaOH solution.

READING CHECK

3. Why is a one molal solution easier to prepare than a one molar solution?

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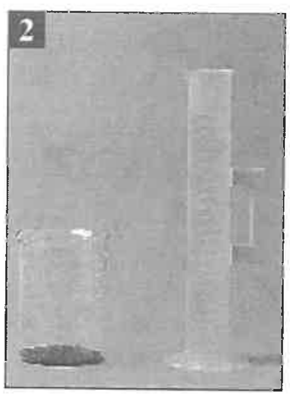
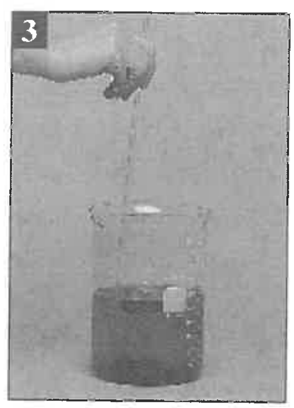
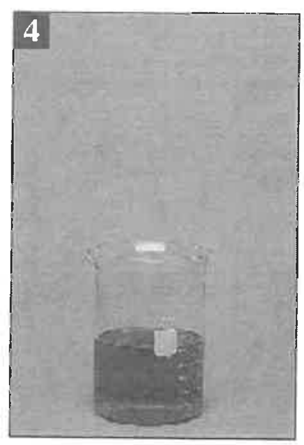
Calculate the mass of $CuSO_4{\cdot}5H_2O$ needed. Making this solution will require 0.5000 mol of $CuSO_4{\cdot}5H_2O$ per kilogram of solvent(1000 g). This mass is calculated to be 124.8 g.



Add 1.000 kg of solvent to the solute in the beaker. Because the solvent is water, 1.000 kg will equal 1000 mL.



Mix thoroughly.



The resulting solution has 0.5000 mol of solute dissolved in 1.000 kg of solvent.

SAMPLE PROBLEM

A solution was prepared by dissolving 17.1 g of sucrose (table sugar, $C_{12}H_{22}O_{11}$) in 125 g of water. Find the molal concentration of this solution.

SOLUTION

1 ANALYZE *Determine the information that is given and unknown.*

Given: solute mass = 17.1 g $C_{12}H_{22}O_{11}$, solvent mass = 125 g H_2O

Unknown: molality of $C_{12}H_{22}O_{11}$ solution

2 PLAN *Describe how to use the given information to find the unknown.*

Molality is the number of moles of solute per kilogram of solvent. First, convert the given solute mass into moles of solute. Then use the formula for molality to calculate the molarity of the solution.

$$\text{molarity } (m) = \frac{\text{amount of solute (mol)}}{\text{mass of solvent (kg)}}$$

3 SOLVE *Calculate the unknown from the given information.*

First, the molar mass of $C_{12}H_{22}O_{11}$ must be calculated.

$$\begin{aligned}&\text{molar mass of } C_{12}H_{22}O_{11}\\&\quad = 12(12.01 \text{ g/mol}) + 22(1.01 \text{ g/mol}) + 11(16.00 \text{ g/mol})\\&\quad = 342.34 \text{ g/mol}\end{aligned}$$

$$17.1 \cancel{\text{g } C_{12}H_{22}O_{11}} \times \frac{1 \text{ mol } C_{12}H_{22}O_{11}}{342.34 \cancel{\text{g } C_{12}H_{22}O_{11}}} = 0.0500 \text{ mol } C_{12}H_{22}O_{11}$$

Convert the mass of the water to kilograms before using it in the equation for molality.

$$\text{molality} = \frac{0.0500 \text{ mol } C_{12}H_{22}O_{11}}{0.125 \text{ kg } C_{12}H_{22}O_{11}} = 0.400\ m\ C_{12}H_{22}O_{11}$$

4 CHECK YOUR WORK *Check the answer to see if it is reasonable.*

The answer is correctly limited to three significant digits. A mass of 125 g is one-eighth of 1 kg. Because the molar mass of $C_{12}H_{22}O_{11}$ is about 340 g/mol, a 1 molal solution of $C_{12}H_{22}O_{11}$ would contain about 340 ÷ 8, or about 40 g. The actual solute mass is 17 g, which is a little less than half of 40 g.

PRACTICE

F. What is the molality of acetone, $(CH_3)_2CO$, in a solution composed of 255 g of acetone dissolved in 200. g of water?

What is the molar mass of acetone? ______________

255 g acetone = 255 g acetone × $\frac{\text{1 mol acetone}}{\text{g acetone}}$ = ________

molality = $\frac{\text{mol acetone}}{\text{1.25 kg acetone}}$ = ______________

G. What quantity, in grams, of methanol, CH_3OH, is required to prepare a 0.244 *m* solution in 400. g of water?

Rearrange the equation for molarity to solve for the number of moles of solute in the solution.

amount of solute (mol) = ______________

Substitute the given information into your equation to find the number of moles of HCl.

What is the molar mass of methanol?

What is the mass, in g, of that number of moles of methanol?

SECTION 12.3 REVIEW

VOCABULARY

1. What quantity represents the ratio of the number of moles of solute for a given volume of solution?

REVIEW

2. You dissolve 5.00 g of sugar, $C_{12}H_{22}O_{11}$, in water to make 1.000 L of solution. What is the concentration of this solution expressed as molarity?

3. A solution is prepared by dissolving 17.1 g of sucrose, $C_{12}H_{22}O_{11}$, in 275 g of H_2O. What is the molality of the solution?

Critical Thinking

4. **ANALYZING DATA** You evaporate all of the water from 100. mL of NaCl solution and obtain 11.3 g of NaCl. What was the molarity of the NaCl solution?

5. **RELATING IDEAS** Suppose you know the molarity of a solution. What additional information would you need to calculate the molality of the solution?

Math Tutor CALCULATING SOLUTION CONCENTRATION

You can use the relationship below to calculate the concentration in molarity of any solution.

$$\text{molarity (M)} = \frac{\text{amount of solute (mol)}}{\text{volume of solution (L)}}$$

Suppose you dissolve 20.00 g of NaOH in some water and dilute the solution to a volume of 250.0 mL (0.2500 L). You do not know the molarity of this solution until you know how many moles of NaOH have been dissolved. You know that the number of moles of a substance can be found by dividing the mass of the substance by the mass of 1 mol of the substance. The molar mass of NaOH is 40.00 g/mol, so the number of moles of NaOH dissolved is

$$40.00 \text{ g NaOH} = 20.00 \cancel{\text{g NaOH}} \times \frac{1 \text{ mol NaOH}}{40.00 \cancel{\text{g NaOH}}} = 0.5000 \text{ mol NaOH}$$

Now you know that the solution has 0.5000 mol NaOH dissolved in 0.2500 L of solution, so you can calculate molarity.

$$\text{molarity of solution} = \frac{\text{moles of NaOH}}{\text{liters of solution}} = \frac{0.5000 \text{ mol NaOH}}{0.2500 \text{ L NaOH}} = 2.000 \text{ M NaOH}$$

Problem-Solving TIPS

- Remember that balances measure mass, not moles, so you often have to convert between mass and moles of solute when making or using solutions.

SAMPLE

A 0.5000 L volume of a solution contains 36.49 g of magnesium chloride, $MgCl_2$. What is the molarity of the solution?

The molar mass of $MgCl_2$ is 24.30 g/mol + 2(35.45 g/mol) = 95.20 g/mol.

The number of moles of $MgCl_2$ can be determined by using the molar mass to convert grams to moles.

$$36.49 \text{ g } MgCl_2 = 36.49 \cancel{\text{g } MgCl_2} \times \frac{1 \text{ mol } MgCl_2}{95.20 \cancel{\text{g } MgCl_2}} = 0.3833 \text{ mol } MgCl_2$$

Molarity can be computed using the equation above.

$$\text{molarity of solution} = \frac{\text{moles of } MgCl_2}{\text{liters of solution}} = \frac{0.3833 \text{ mol } MgCl_2}{0.5000 \text{ L } MgCl_2}$$

$$= 0.7666 \text{ M } MgCl_2$$

Practice Problems: Chapter Review practice problems 13–16

WEEK 6

SECTION 14.1

Properties of Acids and Bases

NAME: ____________________

TEACHER: CORBIN

KEY TERMS

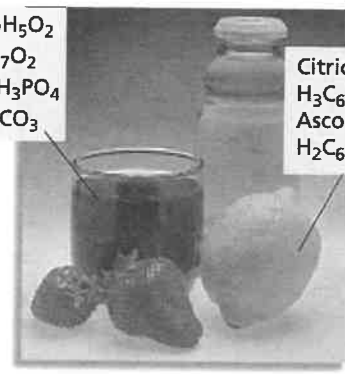
binary acid	Arrhenius base
oxyacid	strong acid
Arrhenius acid	weak acid

Acids and bases are special chemical compounds. You may already be familiar with many acids. Most often when you detect a sour taste in food, it is an acid that you are tasting. Here are some examples of acids in foods.

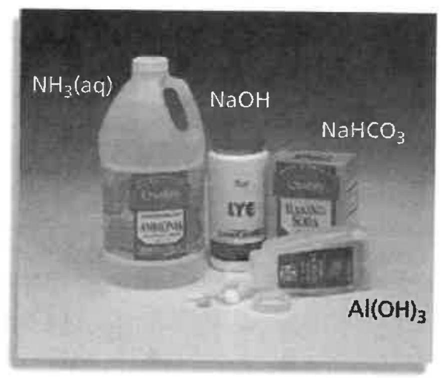
- *Lactic acid* is found in milk.
- *Acetic acid* is found in vinegar and fermented foods.
- *Phosphoric acid* gives a tart flavor to many carbonated beverages.
- *Citric acid* is found in citrus fruits such as lemons, oranges, and grapefruits.
- *Malic acid* is found in apples.
- *Tartaric acid* is found in grape juice.

Bases, another type of chemical compound, have a bitter taste. Bases, such as those listed below, are found in many household products.

- *Ammonia* in solution with water is useful for all types of general cleaning.
- *Lye,* which is the common name of sodium hydroxide, NaOH, is found in some commercial cleaners.
- *Magnesium hydroxide,* $Mg(OH)_2$, is called milk of magnesia when in suspension with water. It is used as an antacid to relieve stomach pain.
- *Aluminum hydroxide,* $Al(OH)_3$, and *sodium hydrogen carbonate,* $NaHCO_3$, are also commonly found in antacids.



(a)



(b)

(a) Fruits, fruit juices, and carbonated beverages all contain acids.
(b) Household cleaners and antacids contain bases.

READING CHECK

1. List three common objects or substances that contain an acid and three that contain a base.

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Acids are identified by their properties.

Acids were first recognized as a distinct class of compounds because of the common properties of their aqueous solutions. Those properties are summarized below.

1. **Aqueous solutions of acids have a sour taste.** Although many fruits contain acids, acids are not always safe to eat. Acids are corrosive, which means they break down body tissue or clothing. Many acids are also poisonous.
2. **Acids change the color of acid-base indicators.** When pH paper is used as an indicator, the paper turns certain colors in acidic solutions, as shown in the photograph.
3. **Some acids react with active metals and release hydrogen gas.** Recall that metals can be ordered in terms of an activity series. Metals above hydrogen in the series undergo single-displacement reactions with certain acids. Hydrogen gas is formed as a product. One example of this type of reaction is shown when barium reacts with sulfuric acid.

   $Ba(s) + H_2SO_4(aq) \longrightarrow BaSO_4(s) + H_2(g)$
4. **Acids react with bases to produce salts and water.** When equal amounts of acids and bases react, the acid is *neutralized.* This means that the properties listed above are no longer present. The products of this neutralization reaction are water and an ionic compound called a salt.
5. **Acids conduct electric current.** All acids are electrolytes because they separate into ions in water. Some acids are strong electrolytes because they completely ionize. Other acids are weak electrolytes.

TIP Taste should NEVER be used as a test to identify or analyze any chemical substance.

A strip of pH paper dipped into vinegar turns red, showing that vinegar is an acid.

READING CHECK

2. Why do all acids conduct electric current?

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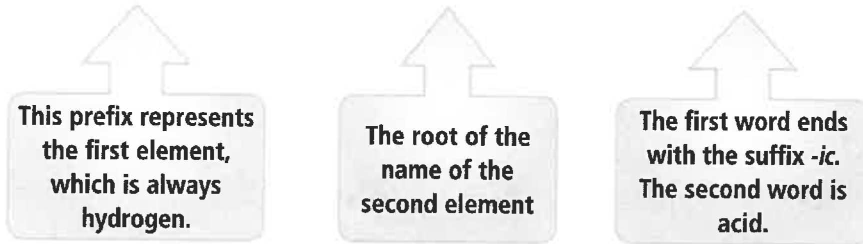
Acid Nomenclature

A **binary acid** is an acid that contains only two different elements: hydrogen and a highly electronegative element. The hydrogen halides are all binary acids. The procedure for naming binary acids is demonstrated at the top of the next page for the acidic compound hydrobromic acid, HBr.

HBr: **hydro-** + **brom** + **-ic acid**



PRACTICE

Name the following binary acids.

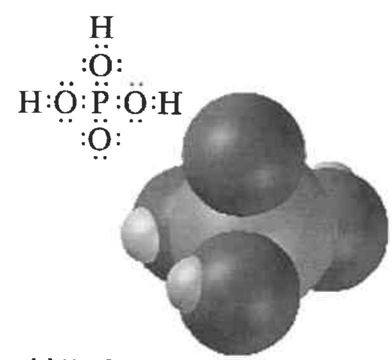
A. HF ____________________ **C.** HI ____________________

B. HCl ____________________ **D.** H_2S ____________________

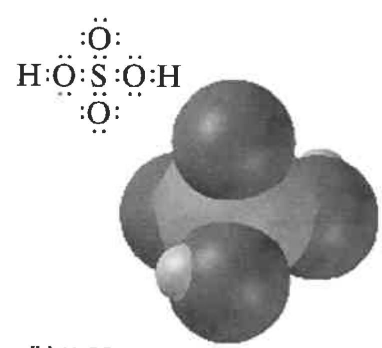
An **oxyacid** is an acid that is composed of hydrogen, oxygen, and a third element, usually a nonmetal. Oxyacids are one type of ternary acid. *Ternary* means composed of three parts, just as the term *binary* means composed of two parts. The table below shows some common oxyacids. The chemical formula usually includes one or more hydrogen atoms and a polyatomic anion. The name of the anion is related to the name of the acid.

Names of Common Oxyacids and Oxyanions

Formula	Acid name	Anion
CH_3COOH	acetic acid	CH_3COO^-, acetate
H_2CO_3	carbonic acid	CO_3^{2-}, carbonate
$HClO$	hypochlorous acid	ClO^-, hypochlorite
$HClO_2$	chlorous acid	ClO_2^-, chlorite
$HClO_3$	chloric acid	ClO_3^-, chlorate
$HClO_4$	perchloric acid	ClO_4^-, perchlorate
HIO_3	iodic acid	IO_3^-, iodate
HNO_2	nitrous acid	NO_2^-, nitrite
HNO_3	nitric acid	NO_3^-, nitrate
H_3PO_3	phosphorous acid	PO_3^{3-}, phosphite
H_3PO_4	phosphoric acid	PO_4^{3-}, phosphate
H_2SO_3	sulfurous acid	SO_3^{2-}, sulfite
H_2SO_4	sulfuric acid	SO_4^{2-}, sulfate



(a) H_3PO_4



(b) H_2SO_4

The structure of (a) phosphoric acid and (b) sulfuric acid is shown. The hydrogen atoms are bonded to the oxygen atoms in oxyacids.

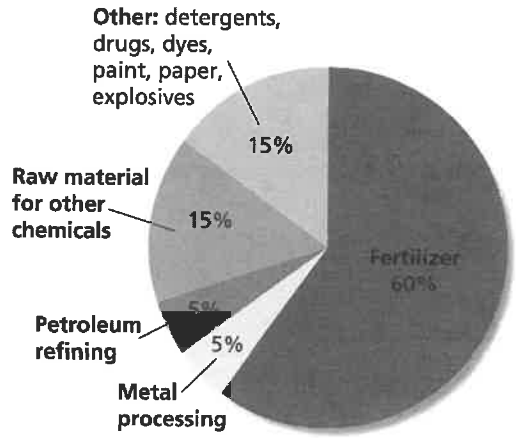
Some acids are useful in industry.

The properties of acids make them important in the laboratory and in industry. Five important acids are discussed below.

Sulfuric Acid

Sulfuric acid, H_2SO_4, is the most commonly produced industrial chemical in the world. More than 37 million metric tons are made each year in the United States alone. Sulfuric acid is used in large quantities in oil refineries and in extracting metals from ores. It is involved in the production of paper, paint, detergents, fertilizers, and automobile batteries.

Because it attracts water, sulfuric acid is often used to dehydrate (remove water from) other compounds. It can dehydrate nonreactive gases, sugar, and some carbon compounds. Because sulfuric acid also attacks the carbon compounds in skin, it can cause serious burns.



The pie chart shows the uses of sulfuric acid in the U.S.

Nitric Acid

Pure nitric acid, HNO_3, is a volatile, unstable liquid. Forming an aqueous solution of nitric acid makes it more stable. These solutions are widely used in industry. The producers of rubber, plastics, dyes, fertilizers, and medical drugs use these solutions.

Nitric acid solutions are initially colorless, but upon standing they turn yellow as a portion of the acid decomposes into NO_2 gas. Nitric acid can stain proteins yellow, as shown below. It has a suffocating odor and can stain and burn skin.

READING CHECK

3. Why are sulfuric acid and nitric acid dangerous?

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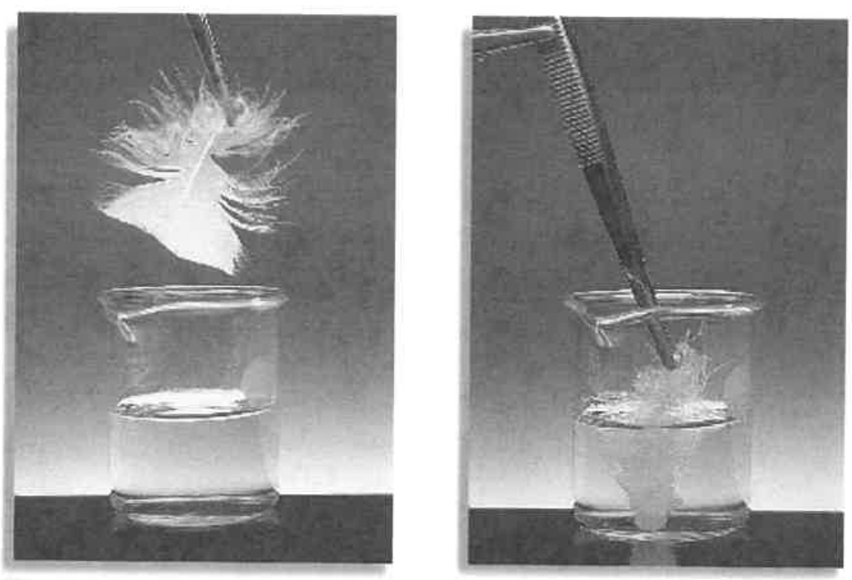


Concentrated nitric acid can stain a feather.

Phosphoric Acid

Phosphorus, along with nitrogen and potassium, is an essential element for plants and animals. The bulk of phosphoric acid, H_3PO_4, produced each year is used directly for making fertilizers and animal feed. Dilute phosphoric acid has a pleasant but sour taste and is not toxic. It is used as a flavoring agent in beverages and as a cleaning agent for dairy equipment. Phosphoric acid is also important in the manufacture of detergents and ceramics.

Top Ten Chemicals Produced in the U.S.

Rank	Chemical	Physical state	Formula
1	sulfuric acid	*l*	H_2SO_4
2	nitrogen	*g*	N_2
3	oxygen	*g*	O_2
4	ethylene	*g*	C_2H_4
5	calcium oxide (lime)	*s*	CaO
6	ammonia	*g*	NH_3
7	phosphoric acid	*l*	H_3PO_4
8	sodium hydroxide	*s*	NaOH
9	propylene	*g*	C_3H_6
10	chlorine	*g*	Cl_2

Hydrochloric Acid

The stomach produces hydrochloric acid, HCl, to aid in digestion. In industry, hydrochloric acid is important for "pickling" iron and steel. Pickling is the immersion of metals in acids to remove surface impurities. This acid is also used as a cleaning agent, in food processing, in getting magnesium from sea water, and in the production of other chemicals.

Concentrated solutions of hydrochloric acid, also known as *muriatic acid,* can be found in hardware stores. It is used to correct acidity in swimming pools and to clean masonry.

Zinc and hydrochloric acid react in a single-replacement reaction and hydrogen gas is released.

Acetic Acid

Pure acetic acid, CH_3COOH, is a clear, colorless, and pungent liquid known as *glacial acetic acid.* This name results from pure acetic acid having a freezing point of 17°C. It can form crystals in a cold room. Fermentation of certain plants produces vinegars containing acetic acid. White vinegar contains 4% to 8% acetic acid.

Acetic acid is important industrially in producing chemicals used in the manufacture of plastics. It is also a raw material in the production of food supplements. For example, it is used to make lysine, an essential amino acid. Acetic acid also helps prevent the growth of molds and other fungi.

READING CHECK

4. Which of these five acids are used in fertilizers?

____

The properties of bases differ from those of acids.

Like acids, bases in the form of an aqueous solution have several common properties. Those properties are summarized below.

1. **Aqueous solutions of bases taste bitter.** You may have noticed the bitterness of a base if you have ever gotten soap in your mouth. Many bases also break down tissues or cause burns.
2. **Bases change the color of acid-base indicators.** When pH paper is used as an indicator, the paper turns certain colors in basic solutions, as shown in the photograph. The color is always different from the color the indicator turns in an acid.
3. **Dilute aqueous solutions of bases feel slippery.** Soap is an example of this property of bases. A wet bar of soap is slippery, and it also slides along your skin easily.
4. **Bases react with acids to produce salts and water.** When equal amounts of acids and bases react, the base is also said to be *neutralized*. The properties listed above are no longer present in the base. The products of this neutralization reaction between an acid and a base are water and a salt.
5. **Bases conduct electric current.** Just like acids, all bases are electrolytes because they separate into ions in water. Some bases are strong electrolytes and others are weak electrolytes.

Remember

Taste should NEVER be used as a test to identify or analyze any chemical substance.

A strip of pH paper dipped into sodium hydroxide turns blue, showing that sodium hydroxide is a base.

Critical Thinking

5. **Compare and Contrast** Use the properties of bases listed above and the properties of acids listed earlier in this chapter to determine how acids and bases are alike and how they are different.

Arrhenius acids and bases produce ions in solution.

Svante Arrhenius was a Swedish chemist who lived from 1859 to 1927. He understood that acids and bases conducted electric current. To explain this property, he theorized that acids and bases formed ions in solution. He defined two types of substances, depending on how they affected solutions in water.

- An **Arrhenius acid** is a chemical compound that increases the concentration of hydrogen ions, H^+, in aqueous solutions. This increase is caused by the ionization of the acid, leading to the formation of H^+ cations.
- An **Arrhenius base** is a chemical compound that increases the concentration of hydroxide ions, OH^-, in aqueous solutions. Some bases dissociate in solution to release hydroxide ions, causing this increase. Other bases react with water molecules to remove a hydrogen ion, resulting in more hydroxide ions in the solution.

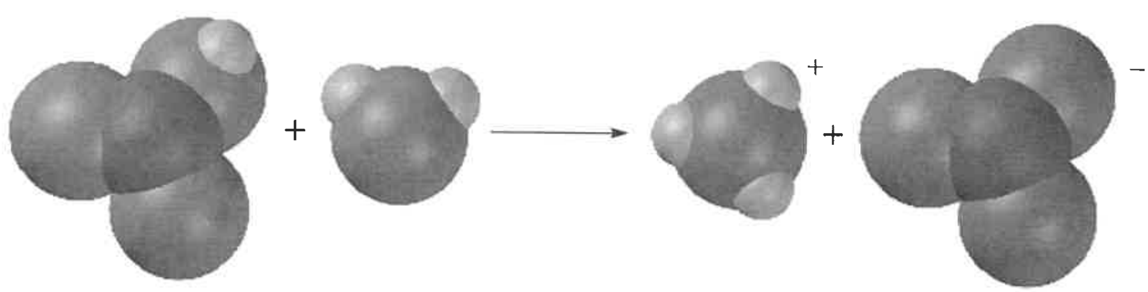
Aqueous Solutions of Acids

Arrhenius acids are molecular compounds with ionizable hydrogen atoms. The solutions of these compounds in water are called *aqueous acids.*

Acid molecules are polar enough to be attracted to the water molecules. This attraction is strong enough to pull the hydrogen ion apart from the acid. Negatively charged anions are left behind. As explained in the chapter "Ions in Aqueous Solutions," the hydrogen ion does not remain in solution by itself. It forms a hydronium ion, H_3O^+, by combining with a water molecule. The ionization of nitric acid, HNO_3, is shown below.

Critical Thinking

6. Apply What are the products of the ionization of hydrochloric acid, HCl, in water?



HNO_3 Nitric acid | H_2O Water | H_3O^+ Hydronium ion | NO_3^- Nitrate ion

Strength of Acids

The strength of an acid depends on the polarity of the bond between hydrogen and the element to which it is bonded. It also depends on how easily that bond can be broken. Acid strength increases with increasing polarity and decreasing bond energy.

A **strong acid** is one that ionizes completely in aqueous solutions. A strong acid is also a strong electrolyte. Three examples of strong acids are perchloric acid, $HClO_4$, hydrochloric acid, HCl, and nitric acid, HNO_3. In all of these acids, 100% of the acid molecules are ionized.

A **weak acid** is an acid that releases few H^+ ions in aqueous solution. The aqueous solution of a weak acid contains hydronium ions, anions, and dissolved acid molecules. Weak acids exist in a state of equilibrium between the processes of ionization and its reverse reaction (de-ionization).

One example of a weak acid is hydrocyanic acid. For every 100 000 molecules in a 1 M HCN solution, 99 998 remain as HCN and 2 molecules ionize. The chemical equation that represents the equilibrium between ionization of HCN and the reverse process is as follows.

$$HCN(aq) + H_2O(l) \rightleftharpoons H_3O^+(aq) + CN^-(aq)$$

Common Aqueous Acids	
Strong acids	
$HI + H_2O$	$\rightarrow H_3O^+ + I^-$
$HClO_4 + H_2O$	$\rightarrow H_3O^+ + ClO_4^-$
$HBr + H_2O$	$\rightarrow H_3O^+ + Br^-$
$HCl + H_2O$	$\rightarrow H_3O^+ +$ Cl^–
$H_2SO_4 + H_2O$	$\rightarrow H_3O^+ + HSO_4^-$
$HClO_3 + H_2O$	$\rightarrow H_3O^+ + ClO_3^-$
Weak acids	
$HSO_4^- + H_2O$	$\rightleftharpoons H_3O^+ + SO_4^{2-}$
$H_3PO_4 + H_2O$	$\rightleftharpoons H_3O^+ + H_2PO_4^-$
$HF + H_2O$	$\rightleftharpoons H_3O^+ + F^-$
$CH_3COOH + H_2O$	$\rightleftharpoons H_3O^+ + CH_3COO^-$
$H_2CO_3 + H_2O$	$\rightleftharpoons H_3O^+ + HCO_3^-$
$H_2S + H_2O$	$\rightleftharpoons H_3O^+ + HS^-$
$HCN + H_2O$	$\rightleftharpoons H_3O^+ + CN^-$
$HCO_3^- + H_2O$	$\rightleftharpoons H_3O^+ + CO_3^{2-}$

LOOKING CLOSER

7. Which would be a better conductor of electricity, a strong acid or a weak acid?

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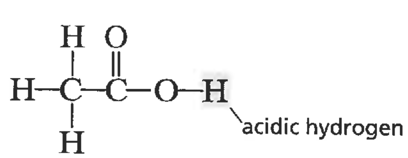
The table above shows some strong acids and weak acids. Note that the number of hydrogen atoms in the chemical formula of the acid does not determine whether or not an acid is strong or weak.

Organic acids contain the carboxyl group —COOH. They are generally weak acids. Acetic acid is one example of an organic acid. Each molecule of acetic acid contains four hydrogen atoms. However, only one of the hydrogen atoms is ionizable, as highlighted in the structural diagram below.



Aqueous Solutions of Bases

Most bases are ionic compounds containing metal cations and the hydroxide anion, OH^-. Because these bases are ionic, they dissociate when dissolved in water. When a base completely dissociates in water to yield aqueous OH^- ions, the solution is referred to as a strong base. Sodium hydroxide, NaOH, is a common strong base used in the laboratory. Its dissociation equation is shown below.

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

You have learned that Group 1 elements are called alkali metals. This group gets its name from the fact that lithium hydroxide, sodium hydroxide, potassium hydroxide, rubidium hydroxide, and cesium hydroxide are all basic solutions. Another word for basic is alkaline.

Not all bases are ionic compounds. Many household cleaners use ammonia, NH_3, which is molecular. Ammonia is a base because it produces hydroxide ions when reacting with water molecules, as shown in the equation below.

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

Remember

Dissociation of ionic compounds is similar to the ionization of molecules but not the same thing. Dissociation involves the splitting of two ions that are bonded. Ionization is the formation of an ion or ions from a neutrally charged particle.

READING CHECK

8. Describe two ways that basic compounds in solutions with water result in an increase in hydroxide ions.

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Common Aqueous Bases

Strong bases	**Weak bases**
$Ca(OH)_2 \rightarrow Ca^{2+} + 2OH^-$	$NH_3 + H_2O \rightleftharpoons NH_4^+ + OH^-$
$Sr(OH)_2 \rightarrow Sr^{2+} + 2OH^-$	$C_6H_5NH_2 + H_2O \rightleftharpoons C_6H_5NH_3^+ + OH^-$
$Ba(OH)_2 \rightarrow Ba^{2+} + 2OH^-$	
$NaOH \rightarrow Na^+ + OH^-$	
$KOH \rightarrow K^+ + OH^-$	
$RbOH \rightarrow Rb^+ + OH^-$	
$CsOH \rightarrow Cs^+ + OH^-$	

Strength of Bases

As with acids, the strength of a base also depends on the extent to which the base dissociates or adds hydroxide ions to the solution. Potassium hydroxide, KOH, is an example of a strong base. Strong bases are strong electrolytes, just as strong acids are strong electrolytes. A strong base completely dissociates into its ions in dilute aqueous solutions.

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

Bases that are not very soluble do not produce a large number of hydroxide ions when added to water. One example is copper hydroxide, $Cu(OH)_2$, as shown in the diagram below. The number of hydroxide ions in an undissolved compound does not affect the strength of the base. Only those hydroxide ions that dissolve and dissociate contribute to the strength of the base.

Bases that are highly soluble can still be weak bases if they form few ions in solution. Ammonia is one example of a weak base that is highly soluble. Many organic compounds that contain nitrogen atoms are also weak bases. For example, the weak base codeine, $C_{18}H_{21}NO_3$, is a pain reliever and cough suppressant found in prescription cough medicine.

CONNECT

Many people are unaware of the level of acidity of the tap water in their homes. Acidic water can cause damage to pipes, increasing the amount of dissolved lead or copper in the water. Lead poisoning is especially dangerous for young children. Some noticeable effects of highly acidic water are blue rings in sinks, water heaters breaking unexpectedly, or tropical fish that die suddenly.

READING CHECK

9. Why is solubility not necessarily related to the strength of a base?

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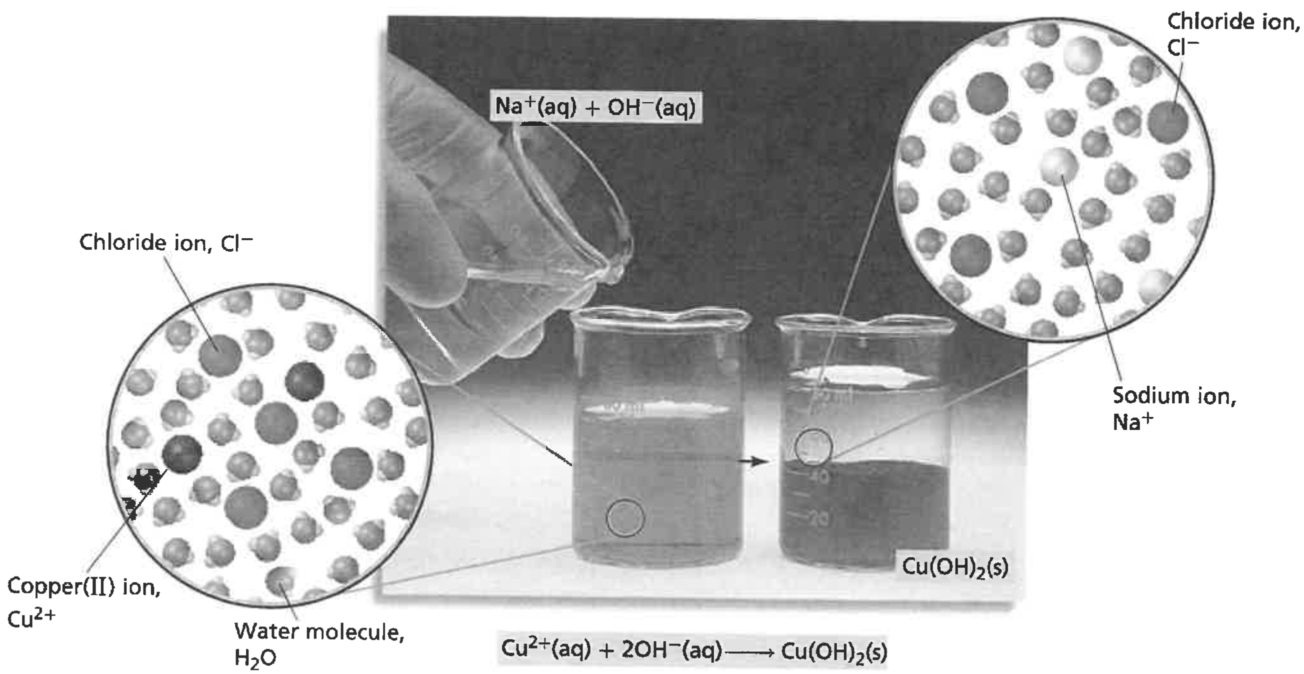

Sodium hydrozide, NaOH, is mixed with a solution of copper chloride, $CaCl_2$. The hydroxides of most *d*-block metals are nearly insoluble in water, as shown by the gelatinous precipitate, copper(II) hydroxide, $Cu(OH)_2$, in the beaker on the right.

SECTION 14.1 REVIEW

VOCABULARY

1. a. Why are strong acids also strong electrolytes?

b. Is every strong electrolyte also a strong acid?

REVIEW

2. Name the following acids.

a. HBrO ______ b. $HBrO_3$ ______

3. What are five general properties of aqueous acids?

4. Name some common acids and common bases.

Critical Thinking

5. **RELATING IDEAS** A classmate states, "All compounds containing H atoms are acids, and all compounds containing OH groups are bases." Do you agree? Give evidence to support your answer.