Method 2

A TSP solution that is 1.7% (m/v) contains 1.7 g of solute dissolved in 100 mL of solution.

$$\frac{1.7\text{ g}}{100\text{ mL}} = \frac{x}{2000\text{ mL}}$$

$$0.017\text{ g/mL} = \frac{x}{2000\text{ mL}}$$

$$x = 0.017\text{ g/}\cancel{\text{mL}} \times 2000\ \cancel{\text{mL}}$$

$$= 34\text{ g}$$

Therefore, 34 g of TSP are needed to make 2.0 L of cleaning solution.

Check Your Solution

The units are appropriate for the problem. The answer appears to be reasonable.

Practice Problems

1. What is the concentration in percent (m/v) of each solution?
   - **(a)** 14.2 g of potassium chloride, KCl (used as a salt substitute), dissolved in 450 mL of solution
   - **(b)** 31.5 g of calcium nitrate, $Ca(NO_3)_2$ (used to make explosives), dissolved in 1.80 L of solution
   - **(c)** 1.72 g of potassium permanganate, $KMnO_4$ (used to bleach stone-washed blue jeans), dissolved in 60 mL of solution
2. A solution of hydrochloric acid was formed by dissolving 1.52 g of hydrogen chloride gas in enough water to make 24.1 mL of solution. What is the concentration in percent (m/v) of the solution?
3. At 25°C, a saturated solution of carbon dioxide gas in water has a concentration of 0.145% (m/v). What mass of carbon dioxide is present in 250 mL of the solution?
4. Ringer's solution contains three dissolved salts in the same proportions as they are found in blood. The salts and their concentrations (m/v) are as follows: 0.86% NaCl, 0.03% KCl, and 0.033% $CaCl_2$. Suppose that a patient needs to receive 350 mL of Ringer's solution by an intravenous drip. What mass of each salt does the pharmacist need to make the solution?

Concentration as a Mass/Mass Percent

The concentration of a solution that contains a solid solute dissolved in a liquid solvent can also be expressed as a mass of solute dissolved in a mass of solution. This is usually expressed as a percent relationship. A **mass/mass percent** gives the mass of a solute divided by the mass of solution, expressed as a percent. The mass/mass percent is also referred to as the *percent (m/m)*, or the *mass percent*. It is often inaccurately referred to as a weight (w/w) percent, as well. Look at your tube of toothpaste, at home.

Act on Your Strategy

Method 1

$$\text{Mass/mass percent} = \frac{4.58\ \cancel{g}}{23.47\ \cancel{g}} \times 100\%$$
$$= 19.5\%$$

Method 2

$$\frac{x\ \text{g}}{100\ \text{g}} = \frac{4.58\ \text{g}}{23.47\ \text{g}}$$
$$\frac{x\ \cancel{g}}{100\ \cancel{g}} = 0.195$$
$$x = 19.5\%$$

The mass/mass percent was 19.5% (m/m). 19.5 g of calcium chloride was dissolved in 100 g of solution.

Check Your Solution

The mass units divide out properly. The final answer has the correct number of significant digits. It appears to be reasonable.

Practice Problems

5. Calculate the mass/mass percent of solute for each solution.
   - **(a)** 17 g of sulfuric acid in 65 g of solution
   - **(b)** 18.37 g of sodium chloride dissolved in 92.2 g of water
     Hint: Remember that a solution consists of both solute and solvent.
   - **(c)** 12.9 g of carbon tetrachloride dissolved in 72.5 g of benzene
6. If 55 g of potassium hydroxide is dissolved in 100 g of water, what is the concentration of the solution expressed as a mass/mass percent?
7. Steel is an alloy of iron and about 1.7% carbon. It also contains small amounts of other materials, such as manganese and phosphorus. What mass of carbon is needed to make a 5.0 kg sample of steel?
8. Stainless steel is a variety of steel that resists corrosion. Your cutlery at home may be made of this material. Stainless steel must contain at least 10.5% chromium. What mass of chromium is needed to make a stainless steel fork with a mass of 60.5 g?
9. 18-carat white gold is an alloy. It contains 75% gold, 12.5% silver, and 12.5% copper. A piece of jewellery, made of 18-carat white gold, has a mass of 20 g. How much pure gold does it contain?

Concentration as a Volume/Volume Percent

When mixing two liquids to form a solution, it is easier to measure their volumes than their masses. A **volume/volume percent** gives the volume of solute divided by the volume of solution, expressed as a percent. The volume/volume percent is also referred to as the *volume percent concentration*, *volume percent*, *percent* (*v*/*v*), or the percent by volume. You can see this type of concentration on a bottle of rubbing alcohol from a drugstore. (See Figure 7.17.)

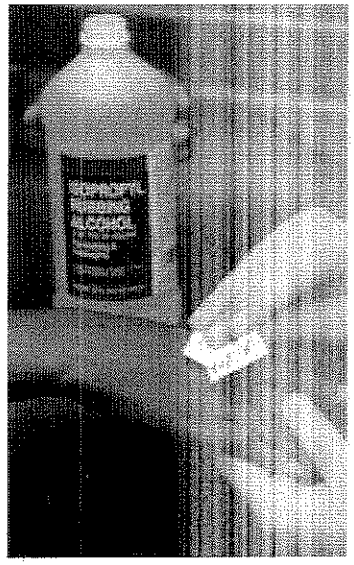


Figure 7.17 The concentration of this solution of isopropyl alcohol in water is expressed as a volume/volume percent.

Practice Problems

10. 60 mL of ethanol is diluted with water to a final volume of 400 mL. What is the percent by volume of ethanol in the solution?

11. Milk fat is present in milk. Whole milk usually contains about 5.0% milk fat by volume. If you drink a glass of milk with a volume of 250 mL, what volume of milk fat have you consumed?

12. Both antifreeze (shown in Figure 7.18) and engine coolant contain ethylene glycol. A manufacturer sells a concentrated solution that contains 75% (v/v) ethylene glycol in water. According to the label, a 1:1 mixture of the concentrate with water will provide protection against freezing down to a temperature of −37°C. A motorist adds 1 L of diluted solution to a car radiator. What is the percent (v/v) of ethylene glycol in the diluted solution?

13. The average adult human body contains about 5 L of blood. Of this volume, only about 0.72% consists of leukocytes (white blood cells). These essential blood cells fight infection in the body. What volume of pure leukocyte cells is present in the body of a small child, with only 2.5 L of blood?

14. Vinegar is sold as a 5% (v/v) solution of acetic acid in water. How much water should be added to 15 mL of pure acetic acid (a liquid at room temperature) to make a 5% (v/v) solution of acetic acid? **Note:** Assume that when water and acetic acid are mixed, the total volume of the solution is the sum of the volumes of each.

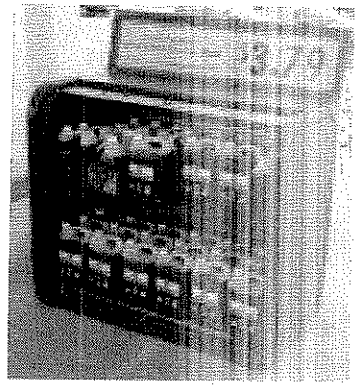


Figure 7.18 **Antifreeze is a solution of ethylene glycol and water.**

Concentration in Parts per Million and Parts per Billion

The concentration of a very small quantity of a substance in the human body, or in the environment, can be expressed in **parts per million (ppm)** and **parts per billion (ppb)**. Both parts per million and parts per billion are usually mass/mass relationships. They describe the amount of solute that is present in a solution. Notice that parts per million does not refer to the number of particles, but to the *mass* of the solute compared with the *mass* of the solution.

$$\text{ppm} = \frac{\text{Mass of solute}}{\text{Mass of solution}} \times 10^6$$

or

$$\frac{\text{Mass of solute}}{\text{Mass of solution}} = \frac{x\ \text{g}}{10^6\ \text{g of solution}}$$

$$\text{ppb} = \frac{\text{Mass of solute}}{\text{Mass of solution}} \times 10^9$$

or

$$\frac{\text{Mass of solute}}{\text{Mass of solution}} = \frac{x\ \text{g}}{10^9\ \text{g of solution}}$$

Math Link

One part per million is equal to 1¢ in $10 000. One part per billion is equal to 1 s in almost 32 years.

What distance (in km) would you travel if 1 cm represented 1 ppm of your journey?

A swimming pool has the dimensions 10 m × 5 m × 2 m. If the pool is full of water, what volume of water (in cm^3) would represent 1 ppb of the water in the pool?

Practice Problems

15. Symptoms of mercury poisoning become apparent after a person has accumulated more than 20 mg of mercury in the body.

(a) Express this amount as parts per million for a 60 kg person.

(b) Express this amount as parts per billion.

(c) Express this amount as a (m/m) percent.

16. The use of the pesticide DDT has been banned in Canada since 1969 because of its damaging effect on wildlife. In 1967, the concentration of DDT in an average lake trout, taken from Lake Simcoe in Ontario, was 16 ppm. Today it is less than 1 ppm. What mass of DDT would have been present in a 2.5 kg trout with DDT present at 16 ppm?

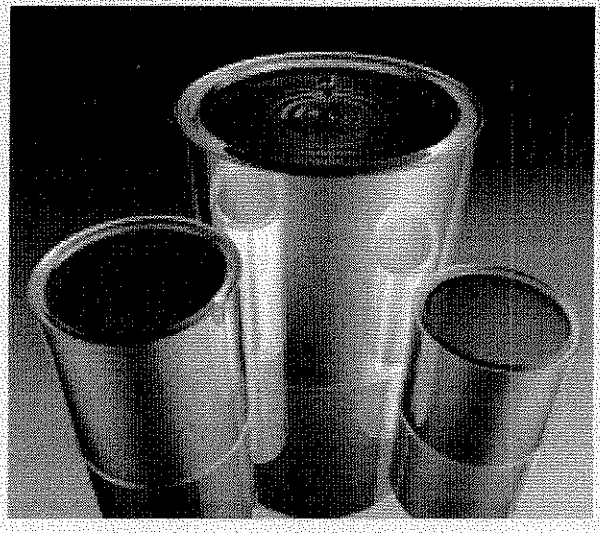
17. The concentration of chlorine in a swimming pool is generally kept in the range of 1.4 to 4.0 mg/L. The water in a certain pool has 3.0 mg/L of chlorine. Express this value as parts per million. (**Hint:** 1 L of water has a mass of 1000 g.)

18. Water supplies with dissolved calcium carbonate greater than 500 mg/L are considered unacceptable for most domestic purposes. Express this concentration in parts per million.

Careers in Chemistry

Product Development Chemist

A solvent keeps paint liquefied so that it can be applied to a surface easily. After the paint has been exposed to the air, the solvent evaporates and the paint dries. Product development chemists develop and improve products such as paints. To work in product development, they require at least one university chemistry degree.



Chemists who work with paints must examine the properties of many different solvents. They must choose solvents that dissolve paint pigments well, but evaporate quickly and pose a low safety hazard.

Product development chemists must consider human health and environmental impact when choosing between solvents. Many solvents that have been used in the past, such as benzene and carbon tetrachloride, are now known to be harmful to health and/or the environment. A powerful new solvent called *d-limonene* has been developed from the peel of oranges and lemons. This solvent is less harmful than many older solvents. It has been used successfully in domestic and industrial cleaning products and as a pesticide. Chemists are now studying new applications for d-limonene.

Make Career Connections

1. Use reference books or the Internet to find the chemical structure of d-limonene. What else can you discover about d-limonene?
2. To learn more about careers involving work with solvents, contact the Canadian Chemical Producers Association (CCPA).

Continued

$\therefore$ Amount of solute = Molar concentration $\times$ Volume of solution

$$= 0.0153 \text{ mol/}\cancel{\text{L}} \times 0.065\cancel{\text{L}}$$

$$= 9.94 \times 10^{-4} \text{ mol}$$

Step 3 Determine the molar mass. Then find the mass in grams.

Molar mass of $CaSO_4 = 40.08 + 32.07 + (4 \times 16.00)$

$$= 136.15 \text{ g/mol}$$

Mass (in g) of $CaSO_4 = 9.94 \times 10^{-4} \cancel{\text{mol}} \times 136 \text{ g/}\cancel{\text{mol}}$

$$= 0.135 \text{ g}$$

Therefore, 0.14 g of calcium sulfate are left in the evaporating dish.

Check Your Solution

The answer has the correct units and the correct number of significant figures.

Practice Problems

19. What is the molar concentration of each solution?

(a) 0.50 mol of NaCl dissolved in 0.30 L of solution

(b) 0.289 mol of iron(III) chloride, $FeCl_3$, dissolved in 120.0 mL of solution

(c) 0.0877 mol of copper(II) sulfate, $CuSO_4$, dissolved in 0.07 L of solution

(d) 4.63 g of sugar, $C_{12}H_{22}O_{11}$, dissolved in 16.8 mL of solution

(e) 1.2 g of $NaNO_3$ dissolved in 80 mL of solution

20. What mass of solute is present in each aqueous solution?

(a) 1.00 L of 0.045 mol/L calcium hydroxide, $Ca(OH)_2$, solution

(b) 500.0 mL of 0.100 mol/L silver nitrate, $AgNO_3$, solution

(c) 2.5 L of 1.00 mol/L potassium chromate, K_2CrO_4, solution

(d) 0.040 L of 6.0 mol/L sulfuric acid, H_2SO_4, solution

(e) 4.24 L of 0.775 mol/L ammonium nitrate, NH_4NO_3, solution

21. A student dissolves 30.46 g of silver nitrate, $AgNO_3$, in water to make 500.0 mL of solution. What is the molar concentration of the solution?

22. What volume of 0.25 mol/L solution can be made using 14 g of sodium hydroxide, NaOH?

23. A 100.0 mL bottle of skin lotion contains a number of solutes. One of these solutes is zinc oxide, ZnO. The concentration of zinc oxide in the skin lotion is 0.915 mol/L. What mass of zinc oxide is present in the bottle?

24. Formalin is an aqueous solution of formaldehyde, HCHO, used to preserve biological specimens. What mass of formaldehyde is needed to prepare 1.5 L of formalin with a concentration of 10.0 mol/L?

You have done many calculations for the concentration of various solutions. Now you are in a position to do some hands-on work with solution concentration. In the following investigation, you will use what you have learned to design your own experiment to determine the concentration of a solution.

$$\text{Molar concentration (in mol/L)} = \frac{\text{Amount of solute (in mol)}}{\text{Volume of solution (in L)}}$$

$\therefore$ Amount of solute = Molar concentration $\times$ Volume of solution

For the final dilute solution,

Amount of solute = 0.10 mol/~~L~~ $\times$ 2.0 ~~L~~
= 0.20 mol

Step 2 Calculate the volume of the original concentrated solution that is needed.

Rearrange and use the molar concentration equation. Substitute in the amount of solute you calculated in step 1.

$$\text{Volume of solution (in L)} = \frac{\text{Amount of solute (in mol)}}{\text{Molar concentration (in mol/L)}}$$
$$= \frac{0.20 \text{ ~~mol~~}}{18 \text{ ~~mol~~/L}}$$
$$= 0.011 \text{ L}$$

Therefore, 0.011 L, or 11 mL, of the concentrated 18 mol/L solution should be used to make 2.0 L of 0.10 mol/L sulfuric acid.

Check Your Solution

The units are correct. The final solution must be much less concentrated. Thus, it is reasonable that only a small volume of concentrated solution is needed.

Practice Problems

25. Suppose that you are given a solution of 1.25 mol/L sodium chloride in water, $NaCl_{(aq)}$. What volume must you dilute to prepare the following solutions?

(a) 50.0 mL of 1.00 mol/L $NaCl_{(aq)}$

(b) 200.0 mL of 0.800 mol/L $NaCl_{(aq)}$

(c) 250.0 mL of 0.300 mol/L $NaCl_{(aq)}$

26. What concentration of solution is obtained by diluting 50.0 mL of 0.720 mol/L aqueous sodium nitrate, $NaNO_{3(aq)}$, to each volume?

(a) 120.0 mL **(b)** 400.0 mL **(c)** 5.00 L

27. A solution is prepared by adding 600.0 mL of distilled water to 100.0 mL of 0.15 mol/L ammonium nitrate. Calculate the molar concentration of the solution. Assume that the volume quantities can be added together.

Now that you understand how to calculate standard solutions and dilution, it is time for you to try it out for yourself. In the following investigation, you will prepare and dilute standard solutions.

CHAPTER 7 Review

Reflecting on Chapter 7

Summarize this chapter in the format of your choice. Here are a few ideas to use as guidelines:

- Describe the difference between a saturated and an unsaturated solution.
- What factors affect the rate of dissolving?
- What factors affect solubility?
- How does temperature affect the solubility of a solid, a liquid, and a gas?
- Describe how particle attractions affect solubility.
- Explain how to plot a solubility curve.
- Write the formulas for (m/v) percent, (m/m) percent, (v/v) percent, ppm, ppb, and molar concentration.
- Explain how you would prepare a standard solution using a volumetric flask.

Reviewing Key Terms

For each of the following terms, write a sentence that shows your understanding of its meaning.

solution
solvent
solutes
variable composition
dilute
aqueous solution
miscible
immiscible
alloys
solubility
saturated solution
unsaturated solution
rate of dissolving
dipole
dipole-dipole attraction
hydrogen bonding
ion-dipole attractions
hydrated
electrolyte
non-electrolytes
concentration
mass/volume percent
mass/mass percent
volume/volume percent
parts per million
parts per billion
molar concentration
standard solution
volumetric flask

Knowledge/Understanding

1. Identify at least two solutions in your home that are
   (a) beverages
   (b) found in the bathroom or medicine cabinet
   (c) solids
2. How is a solution different from a pure compound? Give specific examples.
3. Mixing 2 mL of linseed oil and 4 mL of turpentine makes a binder for oil paint. What term is used to describe liquids that dissolve in each other? Which liquid is the solvent?
4. How does the bonding in water molecules account for the fact that water is an exellent solvent?
5. Why does an aqueous solution of an electrolyte conduct electricity, but an aqueous solution of a non-electrolyte does not?
6. Use the concept of forces between particles to explain why oil and water are immiscible.
7. Explain the expression "like dissolves like" in terms of intermolecular forces.
8. What factors affect the rate of dissolving of a solid in a liquid?
9. Which of the following substances would you predict to be soluble in water? Briefly explain each answer.
   (a) potassium chloride, KCl
   (b) carbon tetrachloride, CCl_4
   (c) sodium sulfate, Na_2SO_4
   (d) butane, C_4H_{10}
10. Benzene, C_6H_6, is a liquid at room temperature. It is sometimes used as a solvent. Which of the following compounds is more soluble in benzene: naphthalene, $C_{10}H_8$, or sodium fluoride, NaF? Would you expect ethanol, CH_3CH_2OH, to be soluble in benzene? Explain your answers.

Inquiry

11. Boric acid solution is used as an eyewash. What mass of boric acid is present in 250.0 g of solution that is 2.25% (m/m) acid in water?
12. 10% (m/m) sodium hydroxide solution, $NaOH_{(aq)}$, is used to break down wood fibre to make paper.
    (a) What mass of solute is needed to make 250.0 mL of 10% (m/m) solution?
    (b) What mass of solvent is needed?
    (c) What is the molar concentration of the solution?
13. What volume of pure ethanol is needed to make 800.0 mL of a solution of ethanol in water that is 12% (v/v)?
14. Some municipalities add sodium fluoride, NaF, to drinking water to help protect the teeth of children. The concentration of sodium fluoride is maintained at 2.9×10^{-5} mol/L. What mass (in mg) of sodium fluoride is dissolved in 1.00 L of water? Express this concentration in ppm.

Answers to questions highlighted in red type are provided in Appendix A.

15. A saturated solution of sodium acetate, $NaCH_3COO$, can be prepared by dissolving 4.65 g in 10.0 mL of water at 20°C. What is the molar concentration of the solution?

16. What is the molar concentration of each of the following solutions?
   (a) 7.25 g of silver nitrate, $AgNO_3$, dissolved in 100.0 mL of solution
   (b) 80 g of glucose, $C_6H_{12}O_6$, dissolved in 70.0 mL of solution

17. Calculate the mass of solute that is needed to prepare each solution below.
   (a) 250 mL of 0.250 mol/L calcium acetate, $Ca(CH_3COO)_2$
   (b) 1.8 L of 0.35 mol/L ammonium sulfate, $(NH_4)_2SO_4$

18. Calculate the molar concentration of each solution formed after dilution.
   (a) 20 mL of 6.0 mol/L hydrochloric acid, $HCl_{(aq)}$, diluted to 70 mL
   (b) 300.0 mL of 12.0 mol/L ammonia, $NH_{3(aq)}$, diluted to 2.50 L

19. Calculate the molar concentration of each solution. Assume that the volumes can be added.
   (a) 85.0 mL of 1.50 mol/L ammonium chloride, $NH_4Cl_{(aq)}$, added to 250 mL of water
   (b) a 1:3 dilution of 1.0 mol/L calcium phosphate (that is, one part stock solution mixed with three parts water)

20. A standard solution of 0.250 mol/L calcium ion is prepared by dissolving solid calcium carbonate in an acid. What mass of calcium carbonate is needed to prepare 1.00 L of the solution?

21. Suppose that your teacher gives you three test tubes. Each test tube contains a clear, colourless liquid. One liquid is an aqueous solution of an electrolyte. Another liquid is an aqueous solution of a non-electrolyte. The third liquid is distilled water. Outline the procedure for an experiment to identify which liquid is which.

22. Fertilizers for home gardeners may be sold as aqueous solutions. Suppose that you want to begin a company that sells an aqueous solution of potassium nitrate, KNO_3, fertilizer. You need a solubility curve (a graph of solubility versus temperature) to help you decide what concentration to use for your solution. Describe an experiment that you might perform to develop a solubility curve for potassium nitrate. State which variables are controlled, which are varied, and which must be measured.

23. Potassium alum, $KAl(SO_4)_2 \cdot 12H_2O$, is used to stop bleeding from small cuts. The solubility of potassium alum, at various temperatures, is given in the following table.

Solubility of Potassium Alum

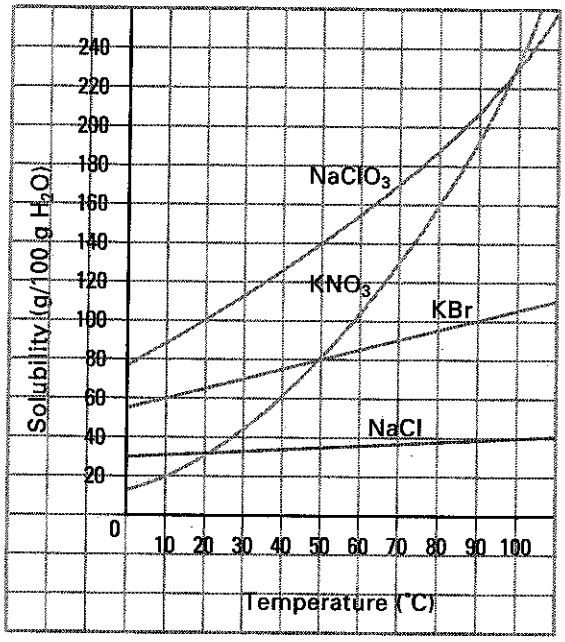
Solubility (g/100 g water)	Temperature (°C)
4	0
10	10
15	20
23	30
31	40
49	50
67	60
101	70
135	80

   (a) Plot a graph of solubility against temperature.
   (b) From your graph, interpolate the solubility of potassium alum at 67°C.
   (c) By extrapolation, estimate the solubility of potassium alum at 82°C.
   (d) Look at your graph. At what temperature will 120 g of potassium alum form a saturated solution in 100 g of water?

24. Use the graph on the next page to answer questions 24 and 25. At 80°C, what mass of sodium chloride dissolves in 1.0 L of water?

25. What minimum temperature is required to dissolve 24 g of potassium nitrate in 40 g of water?

26. A teacher wants to dilute 200.0 mL of 12 mol/L hydrochloric acid to make a 1 mol/L solution. What safety precautions should the teacher take?



This graph shows the solubility of four salts at various temperatures. Use it to answer questions 24 and 25.

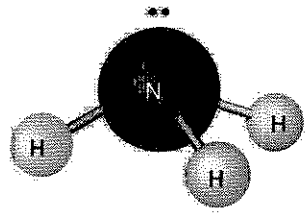
Communication

27. Suppose that you make a pot of hot tea. Later, you put a glass of the tea in the refrigerator to save it for a cool drink. When you take it out of the refrigerator some hours later, you notice that it is cloudy. How could you explain this to a younger brother or sister?

28. Define each concentration term.
    (a) percent (m/v)
    (b) percent (m/m)
    (c) percent (v/v)
    (d) parts per million, ppm
    (e) parts per billion, ppb

29. The concentration of iron in the water that is supplied to a town is 0.25 mg/L. Express this in ppm and ppb.

30. Ammonia is a gas at room temperature and pressure, but it can be liquefied easily. Liquid ammonia is probably present on some planets. Scientists speculate that it might be a good solvent. Explain why, based on the structure of the ammonia molecule shown above.



31. At 20°C, the solubility of oxygen in water is more than twice that of nitrogen. A student analyzed the concentration of dissolved gases in an unpolluted pond. She found that the concentration of nitrogen gas was greater than the concentration of oxygen. Prepare an explanation for the student to give to her class.

32. What is the concentration of pure water?

Making Connections

33. A bright red mineral called cinnabar has the chemical formula HgS. It can be used to make an artist's pigment, but it is a very insoluble compound. A saturated solution at 25°C has a concentration of 2×10^{-27} mol/L. In the past, why was heavy metal poisoning common in painters? Why did painters invariably waste more cinnabar than they used?

34. Vitamin A is a compound that is soluble in fats but not in water. It is found in certain foods, including yellow fruit and green vegetables. In parts of central Africa, children frequently show signs of vitamin A deficiency, although their diet contains a good supply of the necessary fruits and vegetables. Why?

Answers to Practice Problems and Short Answers to Section Review Questions:
Practice Problems: **1.(a)** 3.16% **(b)** 1.75% **(c)** 2.9% **2.** 6.31% **3.** 0.362 g **4.** 3.0 g, 0.1 g, 0.12 g **5.(a)** 26% **(b)** 16.61% **(c)** 15.1% **6.** 35% **7.** 85 g **8.** 6.35 g **9.** 15 g **10.** 15% **11.** 12 mL **12.** 38% **13.** 18 mL **14.** 285 mL **15.(a)** 0.33 ppm **(b)** 3.3×10^2 ppb **(c)** 0.000033% **16.** 0.040 g **17.** 3.0 ppm **18.** 500 ppm **19.(a)** 1.7 mol/L **(b)** 2.41 mol/L **(c)** 1.2 mol/L **(d)** 0.804 mol/L **(e)** 0.18 mol/L **20.(a)** 3.3 g **(b)** 8.49 g **(c)** 4.9×10^2 g **(d)** 24 g **(e)** 263 g **21.** 0.3589 mol/L **22.** 1.4 L **23.** 7.45 g **24.** 4.5×10^2 g **25.(a)** 40 mL **(b)** 128 mL **(c)** 60.0 mL **26.(a)** 0.300 mol/L **(b)** 9.00×10^{-2} mol/L **(c)** 7.20×10^{-3} mol/L **27.** 2.1×10^{-2} mol/L
Section Review: **7.1:** **1.** solute, solvent **7.** polar, ionic **7.2:** **3.(a)** increases **(b)** decreases **6.(a)** $Ce_2(SO_4)_3$ **(b)** $Ce_2(SO_4)_3$, $NaNO_3$ **(c)** NaCl **(d)** 84°C **(e)** 10 g **7.3:** **1.** 33.3 **2.** 23.8% **3.** 8.67 mol/L **7.4:** **1.** 3.73 g **2.** 0.25 mol/L **4.** 601 mL **5.** 175 mL, 525 mL