Chapter 13

Solutions

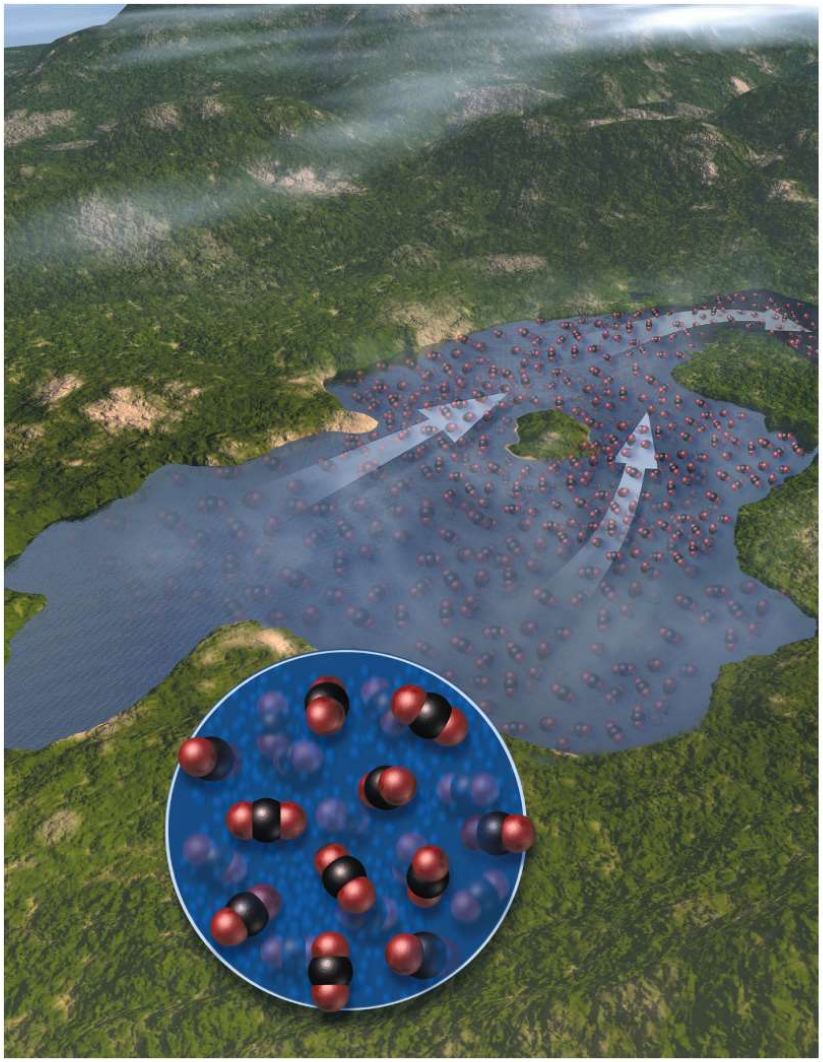
Based on slides provided with Introductory Chemistry, Fifth Edition
Nivaldo J. Tro

By Dr. Sylvia Esjornson
Southwestern Oklahoma State University
Weatherford, OK

With some modifications and additions by
Dr. Deniz Cizmeciyan-Papazyan
and
Dr. Arno Papazyan

Tragedy in Lake Nyos, Cameroon, West Africa

- Late in the summer of 1986, carbon dioxide bubbled out of Lake Nyos and flowed into the adjacent valley.
- The carbon dioxide came from the bottom of the lake, where it was held in ***solution*** by the pressure of the water above it.
- When the layers in the lake were disturbed, the carbon dioxide came out of solution due to the decrease in pressure—with lethal consequences.



Tragedy in Lake Nyos, Cameroon, West Africa

- Lake Nyos is a water-filled volcanic crater.
- Molten volcanic rock beneath the lake produces carbon dioxide gas that seeps into the lake through the volcano's plumbing system.
- The ***concentration*** of carbon dioxide that can build up in water increases with increasing pressure.
- The great pressure at the bottom of the deep lake allows the concentration of carbon dioxide to become very high.
- Over time, the carbon dioxide and water mixture at the bottom of the lake became so concentrated that some gaseous carbon dioxide escaped.
- The rising bubbles disrupted the stratified layers of lake water, causing the highly concentrated carbon dioxide and water mixture at the bottom of the lake to rise, thereby lowering the pressure on it.
- The drop in pressure on the mixture released more carbon dioxide bubbles.
- Since carbon dioxide is heavier than air, once freed from the lake, it traveled down the sides of the volcano and into the nearby valley, displacing air and killing more than 1700 people.

Tragedy in Lake Nyos, Cameroon, West Africa

- In an effort to prevent these events from occurring again, scientists built a piping system to slowly vent carbon dioxide from the lake bottom.
- Since 2001, this system has gradually been releasing the carbon dioxide into the atmosphere, preventing a repeat of the tragedy.
- Engineers watch as the carbon dioxide vented from the bottom of Lake Nyos creates a geyser.
- The controlled release of carbon dioxide from the lake bed is designed to prevent future catastrophes.

Solutions: Homogeneous Mixtures

- The carbon dioxide and water mixture at the bottom of Lake Nyos is an example of a **solution,** a homogeneous mixture of two or more substances.
- Solutions are common—most of the liquids and gases that we encounter every day are actually solutions.
- The ocean is a solution of salt and other solids dissolved in water.
- Blood plasma (blood that has had blood cells removed from it) is a solution of several solids (as well as some gases) dissolved in water.
- A solution may be composed of a gas and a liquid (like the carbon dioxide and water of Lake Nyos), a liquid and another liquid, a solid and a gas, or other combinations.

Common Types of Solutions

TABLE 13.1 Common Types of Solutions

Solution Phase	Solute Phase	Solvent Phase	Example
gaseous solutions	gas	gas	air (mainly oxygen and nitrogen)
liquid solutions	gas	liquid	soda water (CO_2 and water)
	liquid	liquid	vodka (ethanol and water)
	solid	liquid	seawater (salt and water)
solid solutions	solid	solid	brass (copper and zinc) and other alloys

Solutions: Homogeneous Mixtures

- A solution has at least two components. The majority component is usually called the **solvent,** and the minority component is called the **solute.**
- In a solid/liquid solution, the liquid is usually considered the solvent, regardless of the relative proportions of the components.
- Because water is so abundant on Earth, it is a common solvent that forms ***aqueous*** solutions.
- Other solvents are used in the laboratory, in industry, and in the home, especially to form solutions with nonpolar solutes.

Choosing Solvents

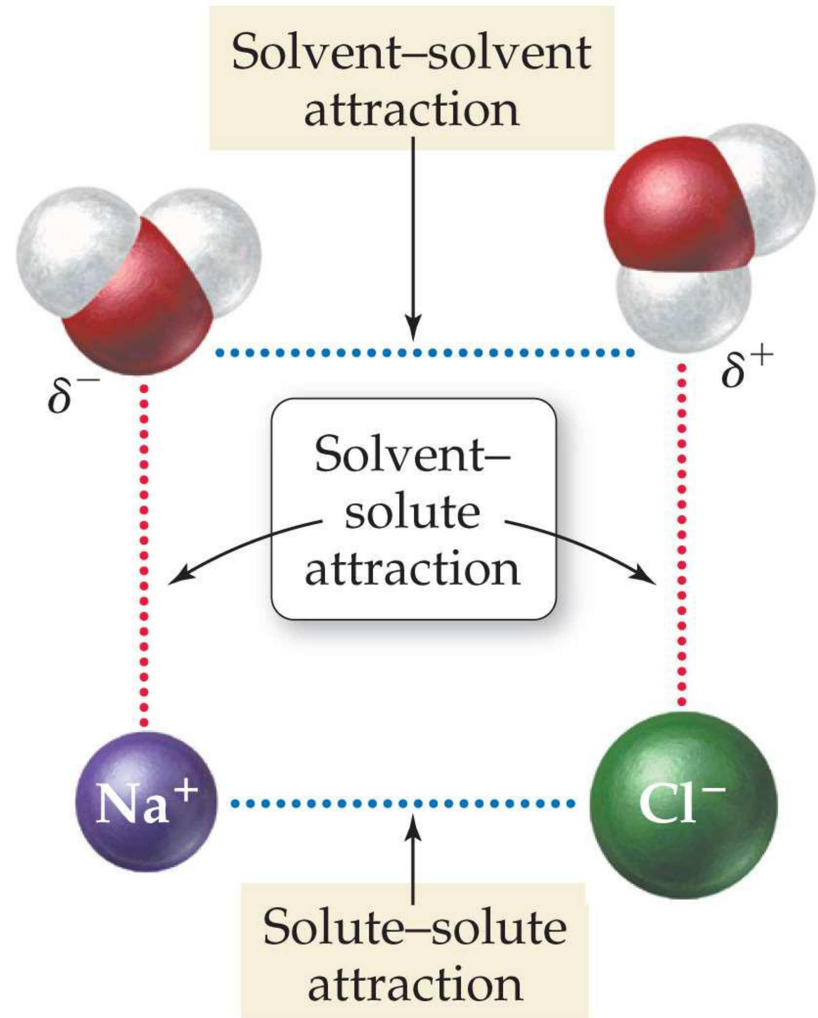
TABLE 13.2 Common Laboratory Solvents

Common Polar Solvents	Common Nonpolar Solvents
water (H_2O)	hexane (C_6H_{14})
acetone (CH_3COCH_3)	diethyl ether ($CH_3CH_2OCH_2CH_3$)
methyl alcohol (CH_3OH)	toluene (C_7H_8)

Like dissolves like—polar solvents dissolve polar solutes, and nonpolar solvents dissolve nonpolar solutes.

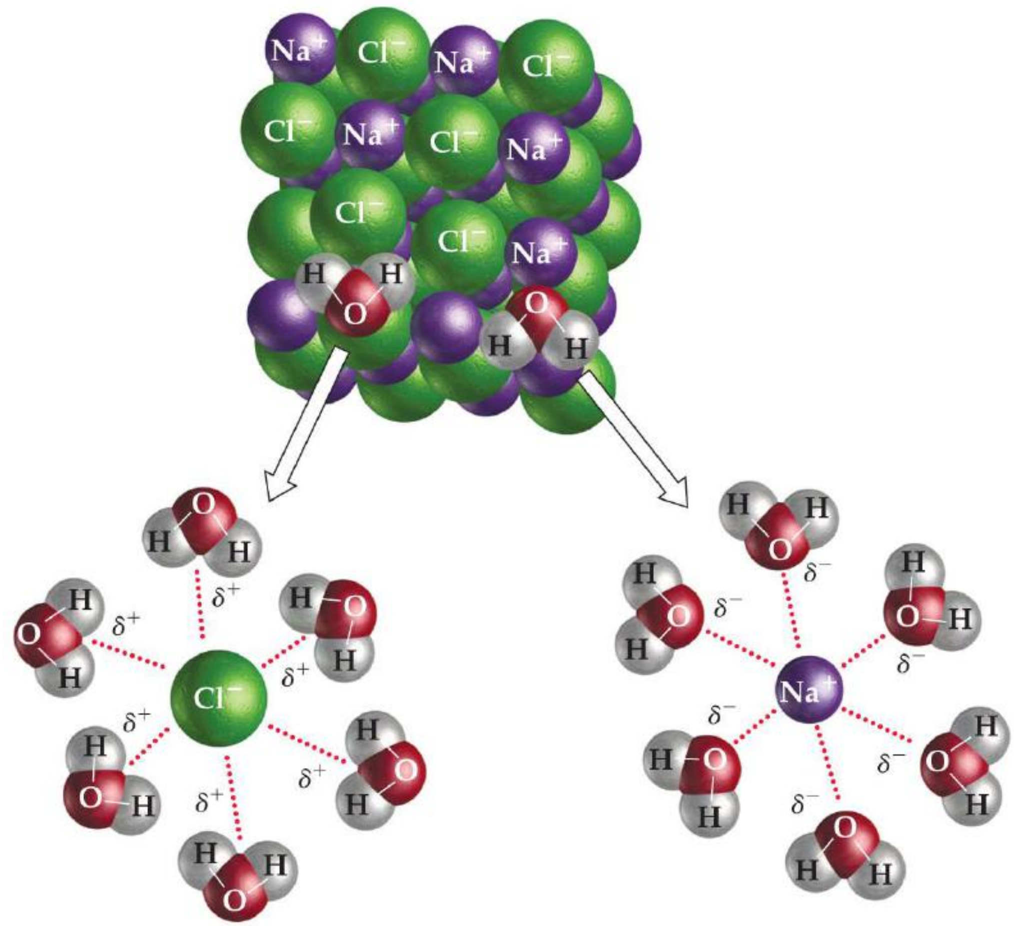
Formation of Solutions of Solids Dissolved in Water

The solvent–solute attractions overcome the solute–solute and solvent–solvent attractions.

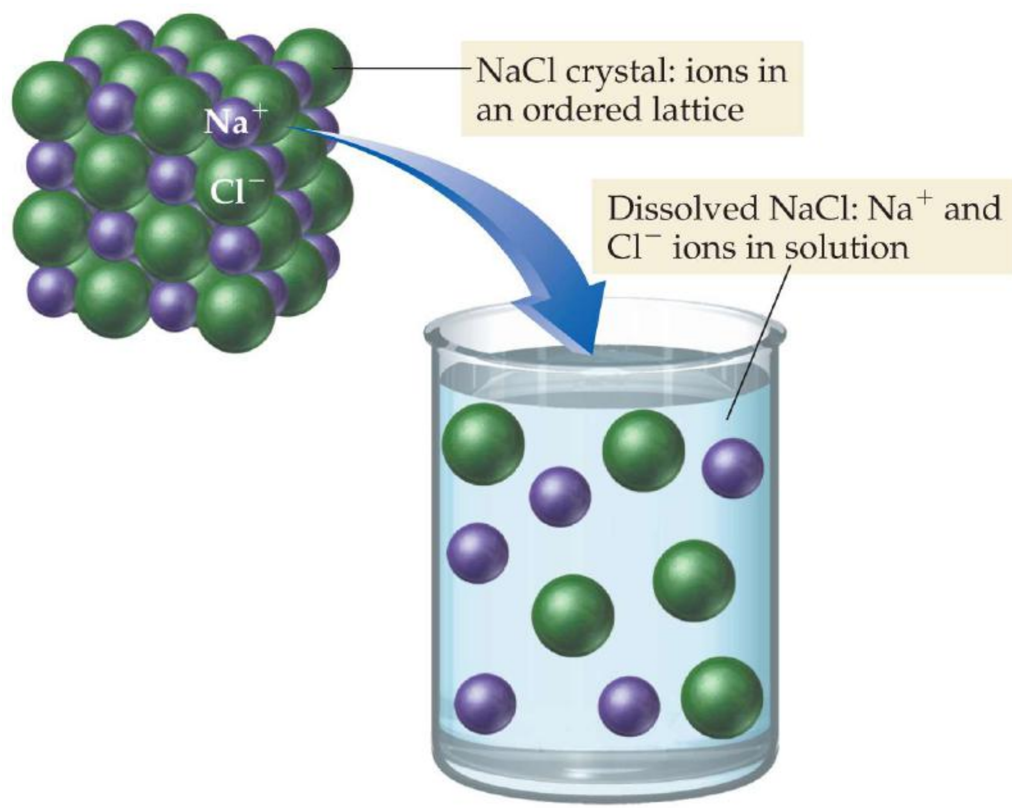


How a Solid Dissolves in Water

The positive ends of the water dipoles are attracted to the negatively charged ions, and the negative ends of the water dipoles are attracted to the positively charged ions.



- In a solution of NaCl, the Na^+ and Cl^- ions are dispersed in the water. The water molecules surround the ions of NaCl and disperse them in the solution.



Solubility and Saturation

- The **solubility** of a compound is defined as the amount of the compound, usually in grams, that dissolves in a certain amount of liquid.
- The solubility of sodium chloride at 25 °C is 36 g NaCl per 100 g water. A solution that contains 36 g of NaCl per 100 g water is a *saturated* sodium chloride solution.
- A **saturated solution** holds the maximum amount of solute under the solution conditions. If additional solute is added to a saturated solution, it will not dissolve.
- An **unsaturated solution** is holding less than the maximum amount of solute. If additional solute is added to an unsaturated solution, it will dissolve.
- A **supersaturated solution** is one holding more than the normal maximum amount of solute. The solute will normally *precipitate* from (or come out of) a supersaturated solution.

Solubility and Saturation

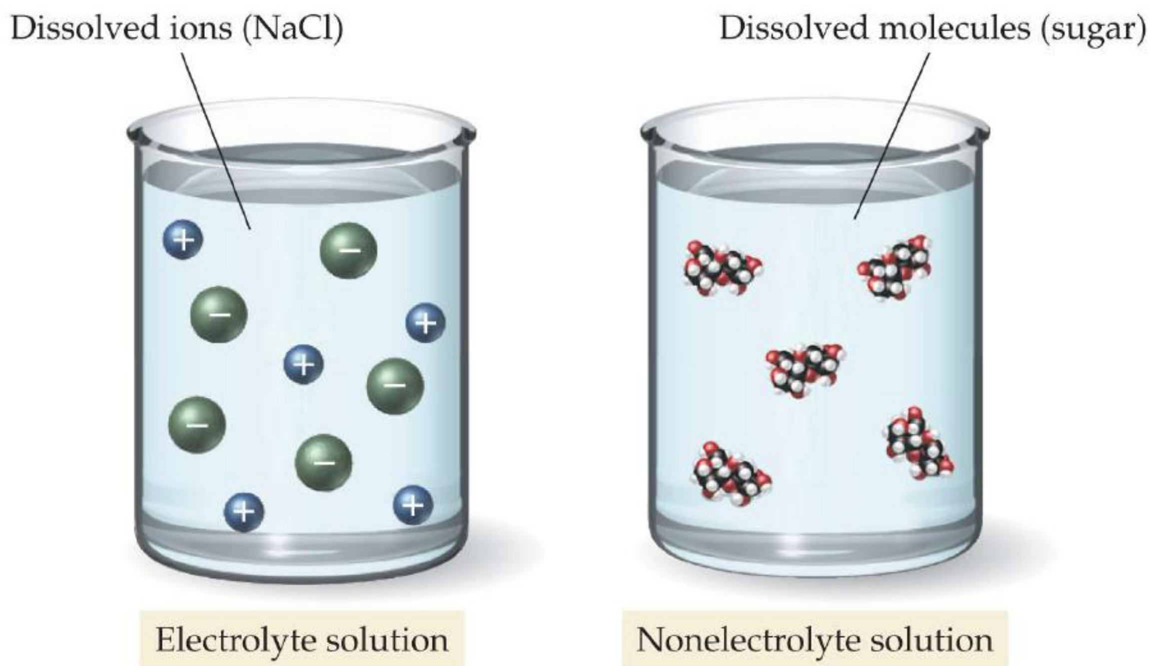
- Supersaturated solutions can form under special circumstances, such as the sudden release in pressure that occurs in a soda can when it is opened.
- A supersaturated solution holds more than the normal maximum amount of solute.
- As the carbon dioxide and water solution rose from the bottom of Lake Nyos, for example, it became supersaturated because of the drop in pressure. The excess gas came out of the solution and rose to the surface of the lake, where it was emitted into the surrounding air.

Solubility

- The solubility rules give us a qualitative description of the solubility of ionic solids.
- In the case of calcium carbonate, an insoluble compound, the attraction between Ca^{2+} ions and CO_3^{2-} ions is greater than the solvent–solute attraction, and calcium carbonate does not dissolve in water. The solubility of calcium carbonate is close to zero grams per 100 g water.
- Molecular solids may also be soluble in water depending on whether the solid is polar.
- Table sugar ($C_{12}H_{22}O_{11}$), for example, is polar and soluble in water.
- Nonpolar solids, such as lard and vegetable shortening, are usually insoluble in water.

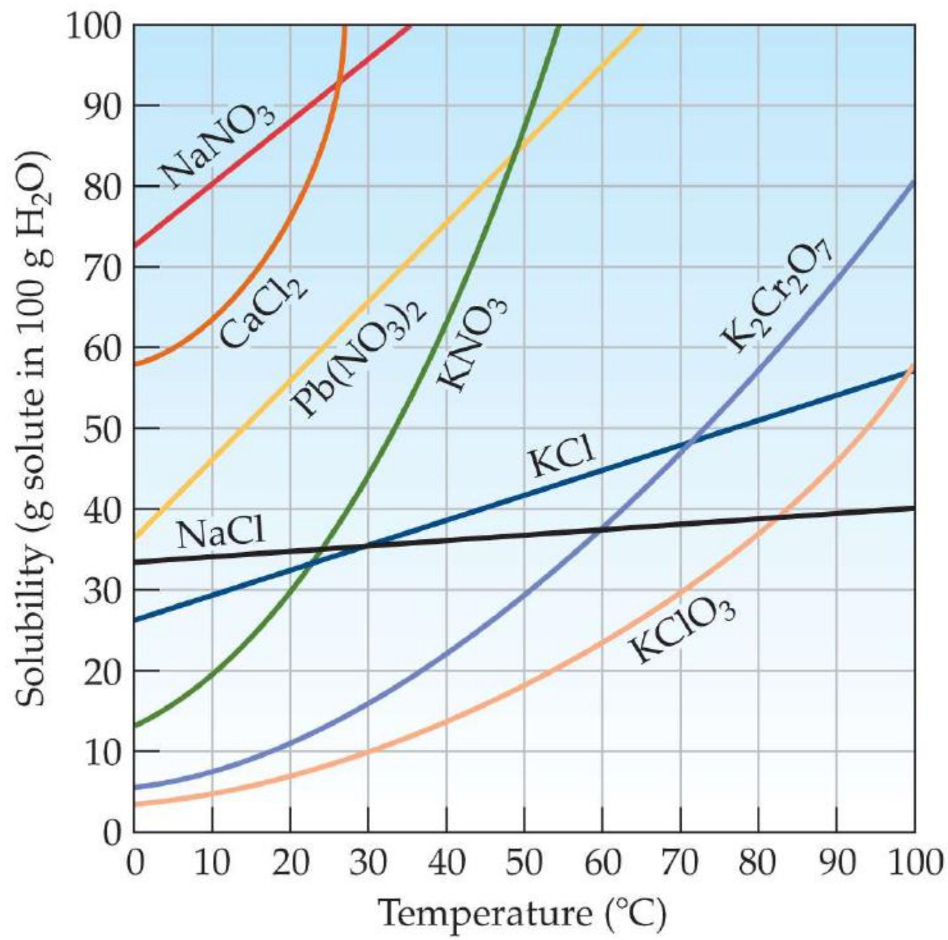
Electrolyte and Nonelectrolyte Solutions

Electrolyte solutions contain dissolved ions (charged particles) and therefore conduct electricity.
Nonelectrolyte solutions contain dissolved molecules (neutral particles) and therefore do not conduct electricity.



How Solubility Varies with Temperature

In general, the solubility of *solids* in water *increases* with *increasing* temperature.



Using Temperature Dependence of Solubility to Purify Compounds

- A common way to purify a solid is a technique called **recrystallization.**
- Recrystallization involves putting the solid into water (or some other solvent) at an elevated temperature.
- Enough solid is added to the solvent to create a saturated solution at the elevated temperature.
- As the solution cools, the solubility decreases, causing some of the solid to precipitate from solution.
- If the solution cools slowly, the solid will form crystals as it comes out. The crystalline structure tends to reject impurities, resulting in a purer solid.

How to Make Rock Candy

- Recrystallization can be used to make rock candy.
- Prepare a saturated sucrose (table sugar) solution at an elevated temperature.
- Dangle a string in the solution, and leave it to cool and stand for several days.
- As the solution cools, it becomes supersaturated and sugar crystals grow on the string.
- After several days, beautiful and sweet crystals, or “rocks,” of sugar cover the string, ready to be admired and eaten.

Solutions of Gases in Water: How Soda Pop Gets Its Fizz

- The water at the bottom of Lake Nyos and a can of soda pop are both examples of solutions in which a gas (carbon dioxide) is dissolved in a liquid (water).
- Most liquids exposed to air contain some dissolved gases.
- Lake water and seawater contain dissolved oxygen necessary for the survival of fish.
- Our blood contains dissolved nitrogen, oxygen, and carbon dioxide.
- Even tap water contains dissolved atmospheric gases.

The Solubility of *Gases* in Water *Decreases* with *Increasing* Temperature

- You can see the dissolved gases in ordinary tap water by heating it on a stove.
- Before the water reaches its boiling point, you will see small bubbles develop in the water.
- These small bubbles are dissolved air (mostly nitrogen and oxygen) coming out of solution.
- As the temperature of the water rises, the solubility of the dissolved nitrogen and oxygen decreases and these gases come out of solution, forming small bubbles around the bottom of the pot.
- Once the water boils, the bubbling becomes more vigorous —these larger bubbles are composed of water vapor, not dissolved air.

Solubility of CO_2 Changes with Temperature

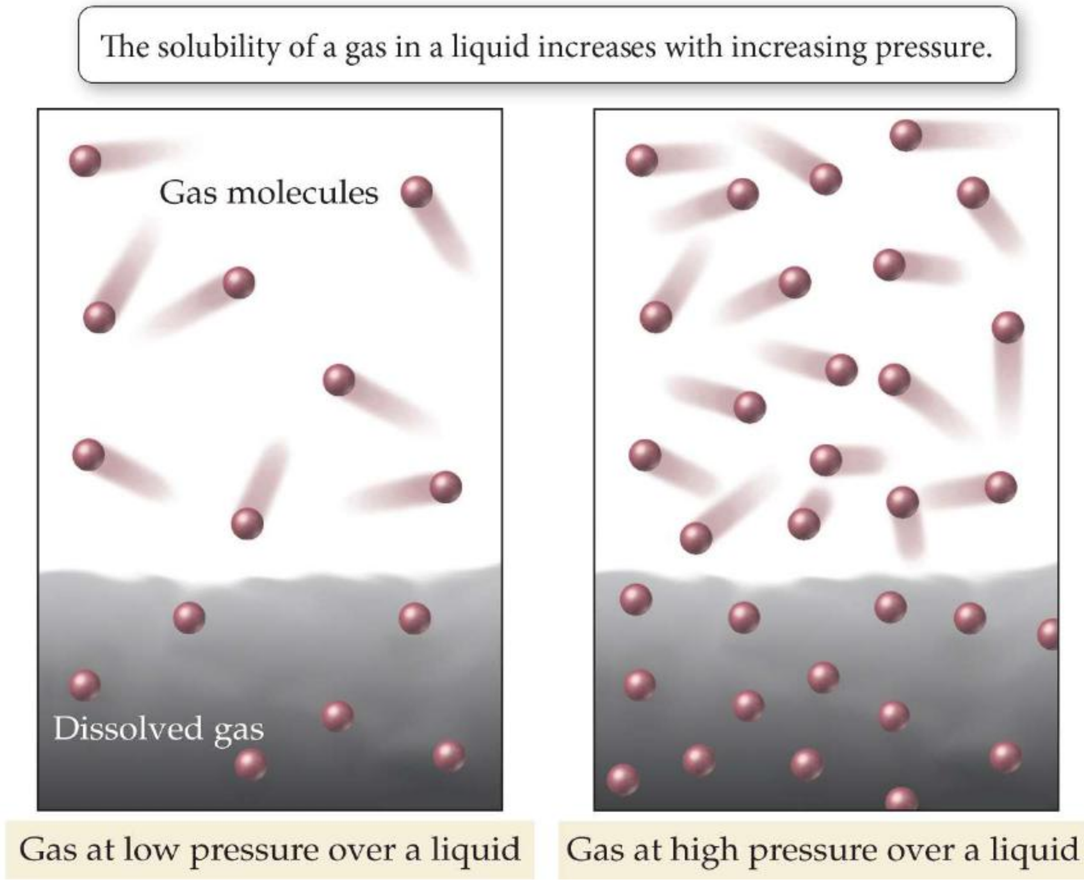
Warm soda pop fizzes more than cold soda pop because the solubility of the dissolved carbon dioxide gas decreases with increasing temperature.

Cold soda pop: carbon dioxide more likely to stay in solution

Warm soda pop: carbon dioxide more likely to bubble out of solution

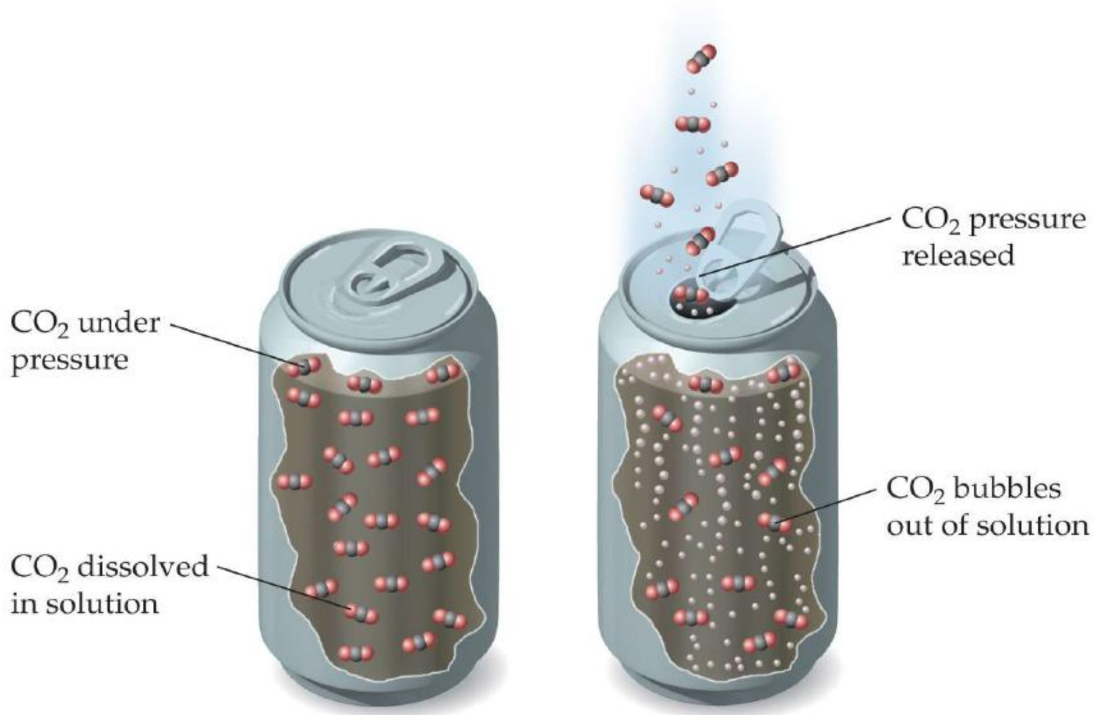
Henry's Law

The higher the pressure of a gas above a liquid, the more soluble the gas is in the liquid.



Pop! Fizz! A Can of Soda Pop is Pressurized with Carbon Dioxide

When the can is opened, the pressure is released, lowering the solubility of carbon dioxide in the solution.



Specifying Solution Concentration: Mass Percent

- **Mass percent** is the number of grams of solute per 100 g of solution.
- A solution with a concentration of 14% by mass contains 14 g of solute per 100 g of solution.
- To calculate mass percent, divide the mass of the solute by the mass of the solution (solute *and* solvent) and multiply by 100%.

Mass Percent

$$\text{Mass percent} = \frac{\text{Mass solute}}{\text{Mass solute} + \text{Mass solvent}} \times 100\%$$

- Note that the denominator is the mass of *solution*, not the mass of solvent.
- In addition to parts per hundred (%), also in common use are *parts per million* (ppm), the number of grams of solute per 1 million g of solution, and *parts per billion* (ppb), the number of grams of solute per 1 billion g of solution.

Using Mass Percent in Calculations

- We can use the mass percent of a solution as a conversion factor between mass of the solute and mass of the solution.
- The key to using mass percent as a conversion factor is to write it as a fraction.

$$\text{Mass percent} = \frac{\text{g solute}}{100\text{ g solution}}$$

A Water Sample from the Bottom of Lake Nyos **contains 8.5% carbon dioxide by mass. Determine how much carbon dioxide, in grams, is contained in 28.6 L of the water solution.**

GIVEN:

- 8.5% CO_2 by mass
- 28.6 L solution
- density = 1.03 g/mL

RECALL:

- 1000 mL = 1 L

FIND:

- g CO_2

A Water Sample from the Bottom of Lake Nyos

SOLUTION MAP:

$$\text{L solution} \xrightarrow{\frac{1\ \text{mL}}{10^{-3}\ \text{L}}} \text{mL solution} \xrightarrow{\frac{1.03\ \text{g}}{\text{mL}}} \text{g solution} \xrightarrow{\frac{8.5\ \text{g } CO_2}{100\ \text{g solution}}} \text{g } CO_2$$

SOLUTION:

$$28.6\ \cancel{\text{L solution}} \times \frac{1\ \cancel{\text{mL}}}{10^{-3}\ \cancel{\text{L}}} \times \frac{1.03\ \cancel{\text{g}}}{\cancel{\text{mL}}} \times \frac{8.5\ \text{g } CO_2}{100\ \cancel{\text{g solution}}} = 2.5 \times 10^{3}\ \text{g } CO_2$$

Practice: Check your answer on the next slide

What volume of 10.5% by mass soda contains 78.5 g of sugar?

Practice: What volume of 10.5% by mass soda contains 78.5 g of sugar?

Given: **Find:**	78.5 g sugar volume, mL
Conceptual Plan:	g solute $\xrightarrow{\frac{100\text{ g sol'n}}{10.5\text{ g sugar}}}$ g sol'n $\xrightarrow{\frac{1\text{ mL sol'n}}{1.04\text{ g sol'n}}}$ mL sol'n
Relationships:	100 g sol'n = 10.5 g sugar, 1 mL sol'n = 1.04 g
Solve:	$78.5\ \cancel{\text{g sugar}} \times \frac{100\ \cancel{\text{g}}}{10.5\ \cancel{\text{g sugar}}} \times \frac{1\text{ mL}}{1.04\ \cancel{\text{g}}} = 719\text{ mL}$
Check:	the unit is correct, the magnitude seems reasonable as the mass of sugar $\approx$ 10% the volume of solution

Chemistry in the Environment:
Fat-Soluble Persistent Organic Pollutants (POPs)

- A number of potentially harmful chemicals can make their way into our water sources from industrial dumping, atmospheric emissions, agriculture, and household dumping.
- Since crops, livestock, and fish all rely on water, they too can accumulate these chemicals from water.
- Human consumption of food or water contaminated with these chemicals leads to a number of diseases and adverse health effects such as increased cancer risk, liver damage, or central nervous system damage.
- Governments around the world have joined forces to ban a number of these chemicals—called persistent organic pollutants, or POPs—from production.
- The original treaty targeted 12 such substances called the dirty dozen.

Chemistry in the Environment:
Fat-Soluble Persistent Organic Pollutants (POPs)

- Once they get into the environment, POPs stay there for a long time.
- A second problematic characteristic is POPs' tendency to undergo *bioamplification.*
- Because these chemicals are nonpolar, they are stored and concentrated in the fatty tissues of the organisms that consume them.
- As larger organisms eat smaller ones who have consumed the chemical, the larger organisms consume even more of the stored chemicals.
- The result is an increase in the concentrations of these chemicals as they move up the food chain.

In the United States, the presence of these contaminants in water supplies is monitored under supervision of the Environmental Protection Agency (EPA). The EPA has set limits, called maximum contaminant levels (MCLs), for each of the dirty dozen in food and drinking water.

TABLE 13.3 The Dirty Dozen

1. aldrin (insecticide)
2. chlordane (insecticide by-product)
3. DDT (insecticide)
4. dieldrin (insecticide)
5. dioxin (industrial by-product)
6. eldrin (insecticide)
7. furan (industrial by-product)
8. heptachlor (insecticide)
9. hexachlorobenzene (fungicide, industrial by-product)
10. mirex (insecticide, fire retardant)
11. polychlorinated biphenyls (PCBs) (electrical insulators)
12. toxaphene (insecticide)

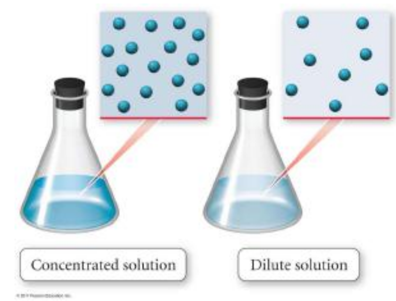
TABLE 13.4 EPA Maximum Contaminant Level (MCL) for Several "Dirty Dozen" Chemicals

chlordane	0.002 mg/L
dioxin	0.00000003 mg/L
heptachlor	0.0004 mg/L
hexachlorobenzene	0.001 mg/L

Specifying Solution Concentration: Molarity

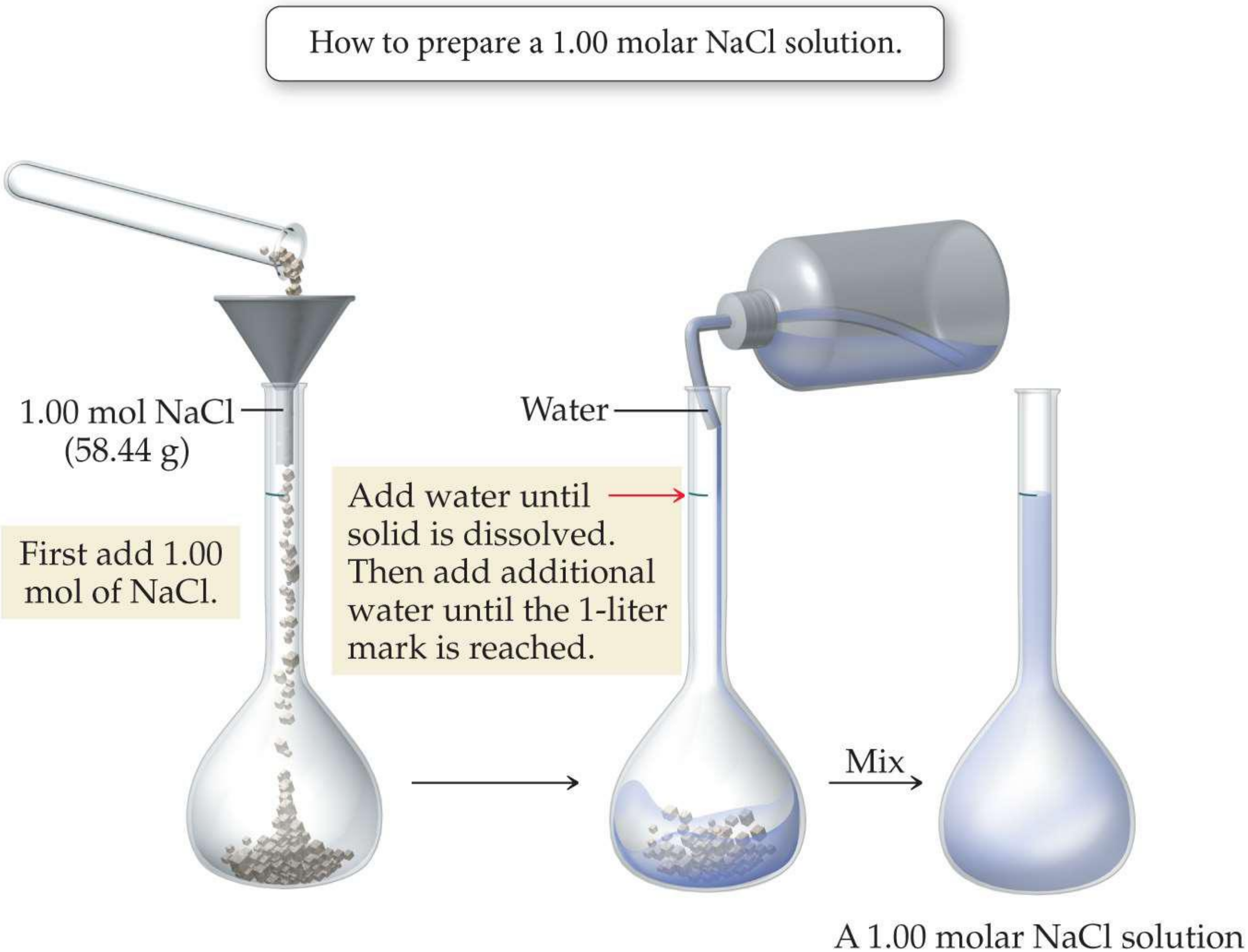
- **Molarity** (M) is defined as the number of moles of solute per liter of solution.

$$\text{Molarity (M)} = \frac{\text{Moles solute}}{\text{Liters solution}}$$



- Note that molarity is moles of solute per liter of *solution,* not per liter of solvent.
- To make a solution of a specified molarity, you usually put the solute into a flask and then add water to the desired volume of solution.

Making a Solution of Specific Molarity



Calculate the molarity of a solution made by putting 15.5 g NaCl into a beaker and adding water to make 1.50 L of NaCl solution.
GIVEN: 15.5 g NaCl, 1.50 L solution. FIND: molarity

SOLUTION:

$$\text{mol NaCl} = 15.5\ \cancel{\text{g NaCl}} \times \frac{1\ \text{mol NaCl}}{58.44\ \cancel{\text{g NaCl}}} = 0.26\underline{5}2\ \text{mol NaCl}$$

$$\begin{aligned}\text{Molarity (M)} &= \frac{\text{Moles solute}}{\text{Liters solution}} \\ &= \frac{0.26\underline{5}2\ \text{mol NaCl}}{1.50\ \text{L solution}} \\ &= 0.177\ \text{M}\end{aligned}$$

Determine how many grams of sucrose ($C_{12}H_{22}O_{11}$) are contained in 1.72 L of 0.758 M sucrose solution.

SOLUTION MAP:

$$\text{L solution} \xrightarrow{\frac{0.758\ \text{mol}\ C_{12}H_{22}O_{11}}{\text{L solution}}} \text{mol}\ C_{12}H_{22}O_{11} \xrightarrow{\frac{342.34\ \text{g}}{\text{mol}}} \text{g}\ C_{12}H_{22}O_{11}$$

RELATIONSHIPS USED:

$\dfrac{0.758\ \text{mol}\ C_{12}H_{22}O_{11}}{\text{L solution}}$ (given molarity of solution, written out as a fraction)

$1\ \text{mol}\ C_{12}H_{22}O_{11} = 342.34\ \text{g}$ (molar mass of sucrose)

Determine how many grams of sucrose ($C_{12}H_{22}O_{11}$) are contained in 1.72 L of 0.758 M sucrose solution.

SOLUTION:

$$1.72\ \cancel{\text{L solution}} \times \frac{0.758\ \cancel{\text{mol } C_{12}H_{22}O_{11}}}{\cancel{\text{L solution}}} \times \frac{342.34\ \text{g } C_{12}H_{22}O_{11}}{\cancel{\text{mol } C_{12}H_{22}O_{11}}} = 446\ \text{g } C_{12}H_{22}O_{11}$$

Practice
Check your answer on next slide

Find the molarity of a solution that has 25.5 g KBr dissolved in 1.75 L of solution

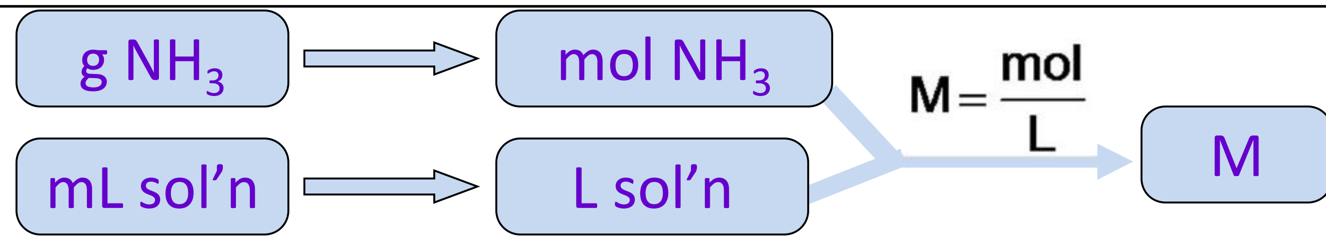
Practice: Find the molarity of a solution that has 25.5 g KBr dissolved in 1.75 L of solution

Given: **Find:**	25.5 g KBr, 1.75 L solution molarity, M
Conceptual Plan: **Relationships:**	g KBr $\xrightarrow{\frac{1\,\text{mol}}{119.00\,\text{g}}}$ mol KBr, L sol'n $\xrightarrow{M = \frac{\text{mol}}{\text{L}}}$ M 1 mol KBr = 119.00 g, M = moles/L
Solution:	$25.5\ \cancel{\text{g KBr}} \times \frac{1\,\text{mol KBr}}{119.00\ \cancel{\text{g KBr}}} = 0.21\underline{4}29\ \text{mol KBr}$ $\text{molarity, M} = \frac{\text{moles KBr}}{\text{L solution}} = \frac{0.21\underline{4}29\ \text{mol KBr}}{1.75\ \text{L}} = 0.122\ \text{M}$
Check:	because most solutions are between 0 and 18 M, the answer makes sense

Practice:
Check your answer on next slide

What Is the molarity of a solution containing 3.4 g of NH_3 (MM 17.03) in 200.0 mL of solution?

Practice — What Is the molarity of a solution containing 3.4 g of NH_3 (m.m. 17.03 g/mol) in 200.0 mL of solution?

Given:	3.4 g NH_3, 200.0 mL solution
Find:	M
Conceptual Plan:	
Relationships:	M = mol/L, 1 mol NH_3 = 17.03 g, 1 mL = 0.001 L
Solve:	$3.4\,\cancel{g\,NH_3} \times \frac{1\,mol\,NH_3}{17.03\,\cancel{g\,NH_3}} = 0.20\,mol$ $200.0\,\cancel{mL} \times \frac{0.001 L}{1\,\cancel{mL}} = 0.2000\,L$ $M = \frac{0.20\,mol\,NH_3}{0.2000\,L}$ $M = 1.0\,M$

Ion Concentrations

- The reported concentration of a solution containing a *molecular* compound usually reflects the concentration of the solute as it actually exists in solution (unless the molecules dissociate into ions, like acids).
- A 1.0 M glucose ($C_6H_{12}O_6$) solution contains 1.0 mol of $C_6H_{12}O_6$ per liter of solution.
- The reported concentration of a solution containing an *ionic* compound reflects the concentration of the solute *before it is dissolved in solution*.
  - Concentration of "formulas" (pretend molecules) of the compound (e.g. $CaCl_2$)
  - Not the concentration of the ions (Ca^{2+} ions and Cl^- ions)
- A 1.0 M $CaCl_2$ solution contains 1.0 mol of Ca^{2+} per liter and 2.0 mol of Cl^- per liter.

Example: Determine the molar concentrations of Na^+ and PO_4^{3-} in a 1.50 M Na_3PO_4 solution.

GIVEN: 1.50 M Na_3PO_4

FIND: molarity (M) Na^+ and PO_4^{3-}

SOLUTION:

Molarity of Na^+ = 3(1.50 M) = 4.50 M

Molarity of PO_4^{3-} = 1.50 M

Number of moles from molarity and volume

$$\mathbf{n = M\ V}$$

Moles of solute = Moles of solute per liter x No. of liters

Practice
Check your answer on the next slide

- How many liters of 0.125 M NaOH contain 0.255 mol NaOH?

Practice: How many liters of 0.125 M NaOH contain 0.255 mol NaOH?

Given:	0.125 M NaOH, 0.255 mol NaOH
Find:	liters, L
Conceptual Plan:	$\text{mol NaOH} \xrightarrow[\ \ \frac{1\,\text{L solution}}{0.125\,\text{mol NaOH}}\ \ ]{} \text{L sol'n}$
Relationships:	0.125 mol NaOH = 1 L solution

Solution:

$$0.255\,\cancel{\text{mol NaOH}} \times \frac{1\,\text{L solution}}{0.125\,\cancel{\text{mol NaOH}}} = 2.04\,\text{L solution}$$

Check:	because each L has only 0.125 mol NaOH, it makes sense that 0.255 mol should require a little more than 2 L

Practice
Check your solution on the next slide

Determine the mass of $CaCl_2$
(MM = 110.98) in 1.75 L of 1.50 M solution

Practice Determine the mass of $CaCl_2$ (MM = 110.98) in 1.75 L of 1.50 M solution

Given: **Find:**	1.50 M $CaCl_2$, 1.75 L mass $CaCl_2$, g
Conceptual Plan:	L sol'n $\xrightarrow{\frac{1.50\ \text{mol}\ CaCl_2}{1\ \text{L solution}}}$ mol $CaCl_2$ $\xrightarrow{\frac{110.98\ \text{g}}{1\ \text{mol}\ CaCl_2}}$ g $CaCl_2$
Relationships:	1.50 mol $CaCl_2$ = 1 L solution; 110.98 g $CaCl_2$ = 1 mol

Solution:

$$1.75\ \cancel{\text{L solution}} \times \frac{1.50\ \cancel{\text{mol}}\ CaCl_2}{1\ \cancel{\text{L}}} \times \frac{110.98\ \text{g}}{1\ \cancel{\text{mol}\ CaCl_2}} = 291\ \text{g}\ CaCl_2$$

Check: because each L has 1.50 mol $CaCl_2$, it makes sense that 1.75 L should have almost 3 moles

Practice :
Check your solution on the next slide

How would you prepare 250.0 mL of 0.150 M $CaCl_2$ (MM = 110.98)?

Practice : How would you prepare 250.0 mL of 0.150 M $CaCl_2$?

Given:	250.0 mL solution
Find:	mass $CaCl_2$, g
Conceptual Plan:	mL sol'n → L sol'n → mol $CaCl_2$ → g $CaCl_2$ $\frac{0.001\,L}{1\,mL}$ $\frac{0.150\,mol}{1\,L\,sol'n}$ $\frac{110.98\,g}{1\,mol}$
Relationships:	1.00 L sol'n = 0.150 mol; 1 mL = 0.001L; 1 mol = 110.98 g

Solution:

$$250.0\,\cancel{mL} \times \frac{0.001\,\cancel{L}}{1\,\cancel{mL}} \times \frac{0.150\,\cancel{mol\,CaCl_2}}{1\,\cancel{L}} \times \frac{110.98\,g}{1\,\cancel{mol\,CaCl_2}} = 4.16\,g\,CaCl_2$$

Dissolve 4.16 g of $CaCl_2$ in enough water to total 250.0 mL

Check:	the unit is correct, the magnitude seems reasonable as the volume is ¼ of a liter

Solution Dilution

- If we dilute a solution by adding more solvent, we don’t change the number of moles of solute
- Increasing V simply leads do reduced concentration (M)

Solution Dilution

- Solutions are often stored in concentrated forms called **stock solutions.**
- Many lab procedures call for less concentrated solutions, so chemists must dilute the stock solution to the required concentration.
- This is done by combining a certain amount of the stock solution with water.
- To determine how much of the stock solution to use, use the dilution equation:

$$M_1V_1 = M_2V_2$$

where M_1 and V_1 are the molarity and volume of the initial concentrated solution and M_2 and V_2 are the molarity and volume of the final diluted solution.

$$M_1V_1 = M_2V_2$$

- This equation works because the molarity multiplied by the volume gives the number of moles of solute ($M \times V$ = mol), which is the same in both solutions.

- **The equation $M_1V_1 = M_2V_2$ applies only to solution dilution, NOT to stoichiometry.**

Laboratory Safety Note

- When diluting acids, always add the concentrated acid to the water.
- *Never add water to concentrated acid solutions.*

Prepare 5.00 L of a 1.50 M KCl solution from a 12.0 M stock solution.

GIVEN:

M_1 = 12.0 M

M_2 = 1.50 M

V_2 = 5.00 L

FIND:

V_1

SOLUTION:

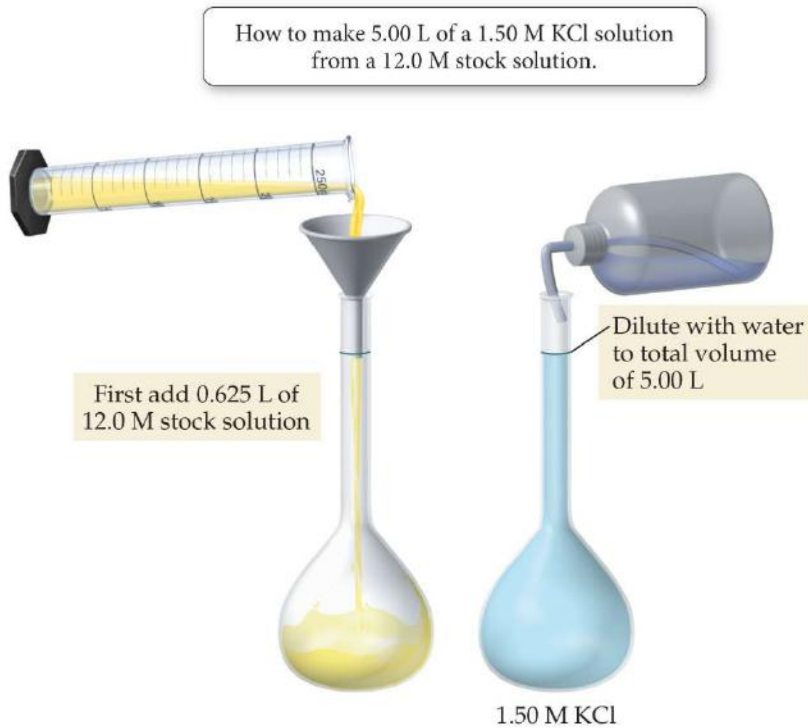
$$M_1V_1 = M_2V_2$$

$$V_1 = \frac{M_2V_2}{M_1}$$

$$= \frac{1.50\frac{\cancel{\text{mol}}}{\cancel{\text{L}}} \times 5.00\text{ L}}{12.0\frac{\cancel{\text{mol}}}{\cancel{\text{L}}}}$$

$$= 0.625\text{ L}$$

Prepare 5.00 L of a 1.50 M KCl solution from a 12.0 M stock solution.



$$M_1V_1 = M_2V_2$$

$$\frac{12.0\ \text{mol}}{\cancel{\text{L}}} \times 0.625\ \cancel{\text{L}} = \frac{1.50\ \text{mol}}{\cancel{\text{L}}} \times 5.00\ \cancel{\text{L}}$$

$$7.50\ \text{mol} = 7.50\ \text{mol}$$

Practice
Check your solution on the next slide

To what volume should you dilute 0.200 L of 15.0 M NaOH to make 3.00 M NaOH?

Practice : To what volume should you dilute 0.200 L of 15.0 M NaOH to make 3.00 M NaOH?

Given: **Find:**	$V_1 = 0.200\text{L}$, $M_1 = 15.0\text{ M}$, $M_2 = 3.00\text{ M}$ V_2, L
Conceptual Plan: **Relationships:**	$V_1, M_1, M_2 \xrightarrow{\frac{M_1 V_1}{M_2} = V_2} V_2$ $M_1V_1 = M_2V_2$
Solution:	$$\frac{\left(15.0\,\frac{\text{mol}}{\text{L}}\right)(0.200\text{ L})}{\left(3.00\,\frac{\text{mol}}{\text{L}}\right)} = 1.00\text{ L}$$
Check:	because the solution is diluted by a factor of 5, the volume should increase by a factor of 5, and it does

Practice
Check your answer on the next slide

What is the concentration of a solution prepared by diluting 45.0 mL of 8.25 M HNO_3 to 135.0 mL?

Practice – What is the concentration of a solution prepared by diluting 45.0 mL of 8.25 M HNO_3 to 135.0 mL?

Given: **Find:**	V_1 = 45.0 mL, M_1 = 8.25 M, V_2 = 135.0 mL M_2, L
Conceptual Plan: **Relationships:**	$V_1, M_1, V_2 \xrightarrow[\frac{M_1 \bullet V_1}{V_2} = M_2]{} M_2$ $M_1V_1 = M_2V_2$
Solution:	$\dfrac{\left(8.25 \frac{\text{mol}}{\text{L}}\right) \bullet \left(45.0\ \cancel{\text{mL}}\right)}{\left(135.0\ \cancel{\text{mL}}\right)} = 2.75 \frac{\text{mol}}{\text{L}} = 2.75\,\text{M}$
Check:	because the solution is diluted by a factor of 3, the molarity should decrease by a factor of 3, and it does

Practice
Check your answer on the next slide

How would you prepare 200.0 mL of 0.25 M NaCl solution from a 2.0 M solution?

Practice – How would you prepare 200.0 mL of 0.25 M NaCl solution from a 2.0 M solution?

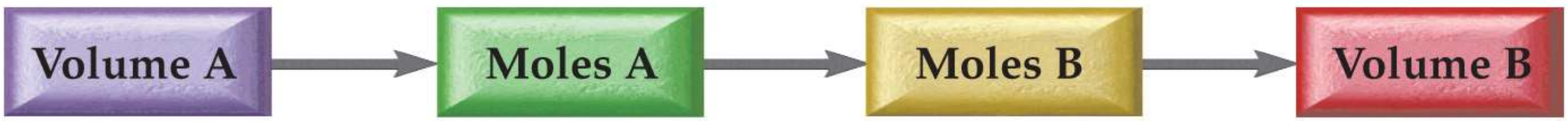
Given:	$M_1 = 2.0\ M$, $M_2 = 0.25\ M$, $V_2 = 200.0\ mL$
Find:	V_1, L
Conceptual Plan:	$M_1, M_2, V_2 \rightarrow V_1$ $V_1 = \frac{M_2 \bullet V_2}{M_1}$
Relationships:	$M_1V_1 = M_2V_2$
Solution:	$$\frac{\left(0.25\ \frac{\cancel{mol}}{L}\right)\bullet(200.0\ mL)}{\left(2.0\ \frac{\cancel{mol}}{L}\right)} = 25\ mL$$ Dilute 25 mL of 2.0 M solution up to 200.0 mL
Check:	because the solution is diluted by a factor of 8, the volume should increase by a factor of 8, and it does

Solution Stoichiometry

- In reactions involving aqueous reactant and products, it is often convenient to specify the amount of reactants or products in terms of their volume and concentration.
- We can use the volume and concentration to calculate the number of moles of reactants or products, and then use the stoichiometric coefficients to convert to other quantities in the reaction.

Solution Stoichiometry

The general solution map for these kinds of calculations is as follows:



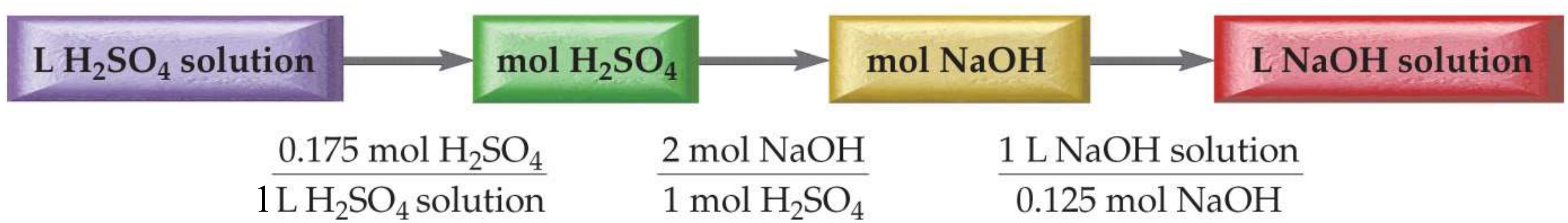
where A and B are two different substances involved in the reaction, and the conversion factor between them comes from the stoichiometric coefficients in the balanced chemical equation.

$H_2SO_4(aq) + 2\ NaOH(aq) \rightarrow Na_2SO_4(aq) + 2\ H_2O(l)$

How much 0.125 M NaOH solution do we need to completely neutralize 0.225 L of 0.175 M H_2SO_4 solution?

SOLUTION MAP:

0.225L H_2SO_4 ???L NaOH



$H_2SO_4(aq) + 2\ NaOH(aq) \rightarrow Na_2SO_4(aq) + 2\ H_2O(l)$

How much 0.125 M NaOH solution do we need to completely neutralize 0.225 L of 0.175 M H_2SO_4 solution?

SOLUTION:

$$0.225\ \text{L}\ \cancel{\text{H}_2\text{SO}_4\ \text{solution}} \times \frac{0.175\ \cancel{\text{mol H}_2\text{SO}_4}}{\cancel{\text{L H}_2\text{SO}_4\ \text{solution}}} \times \frac{2\ \cancel{\text{mol NaOH}}}{1\ \cancel{\text{mol H}_2\text{SO}_4}} \times \frac{1\ \text{L NaOH solution}}{0.125\ \cancel{\text{mol NaOH}}} = 0.630\ \text{L NaOH solution}$$

Practice
Check your answer on the next slide

What volume of 0.150 M KCl is required to completely react with 0.150 L of 0.175 M $Pb(NO_3)_2$ in the reaction

$$2\ KCl(aq) + Pb(NO_3)_2(aq) \rightarrow PbCl_2(s) + 2\ KNO_3(aq)$$

Practice: What volume of 0.150 M KCl is required to completely react with 0.150 L of 0.175 M $Pb(NO_3)_2$ in the reaction 2 KCl(*aq*) + $Pb(NO_3)_2$(*aq*) → $PbCl_2$(*s*) + 2 KNO_3(*aq*)?

Given: 0.150 M KCl, 0.150 L of 0.175 M $Pb(NO_3)_2$

Find: L KCl

Conceptual Plan:

$$\text{L } Pb(NO_3)_2 \xrightarrow{\frac{0.175\text{ mol}}{1\text{ L } Pb(NO_3)_2}} \text{mol } Pb(NO_3)_2 \xrightarrow{\frac{2\text{ mol KCl}}{1\text{ mol } Pb(NO_3)_2}} \text{mol KCl} \xrightarrow{\frac{1\text{ L KCl}}{0.150\text{ mol}}} \text{L KCl}$$

Relationships: 1 L $Pb(NO_3)_2$ = 0.175 mol, 1 L KCl = 0.150 mol, 1 mol $Pb(NO_3)_2$: 2 mol KCl

Solution:

$$0.150\,\cancel{\text{L}\,Pb(NO_3)_2} \times \frac{0.175\,\cancel{\text{mol}}}{1\,\cancel{\text{L}\,Pb(NO_3)_2}} \times \frac{2\,\cancel{\text{mol}}\text{ KCl}}{1\,\cancel{\text{mol}\,Pb(NO_3)_2}} \times \frac{1\text{ L KCl}}{0.150\,\cancel{\text{mol}}}$$

$$= 0.350\text{ L KCl}$$

Check: because you need 2x moles of KCl as $Pb(NO_3)_2$, and the molarity of $Pb(NO_3)_2$ > KCl, the volume of KCl should be more than 2x the volume of $Pb(NO_3)_2$

Practice
Check your answer on the next slide

43.8 mL of 0.107 M HCl is needed to neutralize 37.6 mL of $Ba(OH)_2$ solution.
What is the molarity of the base?

Practice – 43.8 mL of 0.107 M HCl is needed to neutralize 37.6 mL of $Ba(OH)_2$ solution. What is the molarity of the base? $2\ HCl(aq) + Ba(OH)_2(aq) \rightarrow BaCl_2(aq) + 2\ H_2O(aq)$

Given: 43.8 mL of 0.107 M HCl, 37.6 mL $Ba(OH)_2$

Find: M $Ba(OH)_2$

Conceptual Plan:

L HCl → mol HCl → mol $Ba(OH)_2$

mol $Ba(OH)_2$, L $Ba(OH)_2$ → M $Ba(OH)_2$

$$M = \frac{mol}{L}$$

Relationships: 1 mL= 0.001 L, 1 L HCl = 0.107 mol, 1 mol $Ba(OH)_2$: 2 mol HCl

Solution:

$$43.8\ \cancel{mL} \times \frac{0.001\ L}{1\ \cancel{mL}} = 0.0438\ L$$

$$37.6\ \cancel{mL} \times \frac{0.001\ L}{1\ \cancel{mL}} = 0.0376\ L$$

$$0.0438\ \cancel{L\ HCl} \times \frac{0.107\ \cancel{mol\ HCl}}{1\ \cancel{L\ HCl}} \times \frac{1\ mol\ Ba(OH)_2}{2\ \cancel{mol\ HCl}} = 0.00234\ mol\ Ba(OH)_2$$

$$\frac{0.00234\ mol\ Ba(OH)_2}{0.0376\ L\ Ba(OH)_2} = 0.0623\ M\ Ba(OH)_2$$

Colligative Properties:
Freezing Point Depression and Boiling Point Elevation

- Adding a nonvolatile solute—one that does not readily evaporate—to a liquid extends the temperature range over which the liquid remains a liquid.
- The solution has a lower melting point and a higher boiling point than the pure liquid; these effects are called **freezing point depression** and **boiling point elevation.**
- Freezing point depression and boiling point elevation depend only on the number of solute particles in solution, not on the type of solute particles.
- Properties such as these—which depend on the number of dissolved solute particles and not on the type of solute particles—are called **colligative properties.**

Freezing Point Depression

The freezing point of a solution containing a nonvolatile solute is lower than the freezing point of the pure solvent.

Intuitively, we can interpret this as the disruption of the forming of crystals by the presence of impurities. Colder temperatures are required to compensate for the disruption and form crystals.

Boiling Point Elevation

The boiling point of a solution containing a nonvolatile solute is higher than the boiling point of the pure solvent.

Intuitively, this happens because the solute molecules still attract the solvent molecules (reducing vapor pressure) but they do not contribute to the vapor pressure by evaporating.

In automobiles, antifreeze not only prevents the freezing of coolant within engine blocks in cold climates, but also prevents the boiling of engine coolant in hot climates.

- In calculations of freezing point depression and boiling point elevation, the concentration of the solution is usually expressed in **molality (*m*),** the number of moles of solute per kilogram of solvent.
- Notice that molality is defined with respect to kilograms of *solvent,* not kilograms of solution (or liters of solution.)

The freezing point depression of a nonelectrolyte solution is quantified as

$$\Delta T_{\mathrm{f}} = m \cdot K_{\mathrm{f}}$$

where

- ΔT_{f} is the change in temperature of the freezing point in °C (from the freezing point of the pure solvent).
  $\Delta T_{\mathrm{f}} = T_{\mathrm{f,solvent}} - T_{\mathrm{f,solution}}$
- m is the molality of the solution in (mol solute/kg solvent).
- K_{f} is the freezing point depression constant for the solvent.

Different solvents have different values of K_{f}.

For water:

$$K_f = 1.86°\mathrm{C}\,\frac{\text{kg solvent}}{\text{mol solute}}$$

Calculate the molality of a solution containing 17.2 g of ethylene glycol $C_2H_6O_2$ dissolved in 0.500 kg of water.

GIVEN: 17.2 g $C_2H_6O_2$, 0.500 kg H_2O

FIND: molality (m)

SOLUTION:

$$\text{mol } C_2H_6O_2 = 17.2\ \cancel{\text{g } C_2H_6O_2} \times \frac{1 \text{ mol } C_2H_6O_2}{62.08\ \cancel{\text{g } C_2H_6O_2}}$$

$$= 0.27\underline{7}1 \text{ mol } C_2H_6O_2$$

$$\text{Molality } (m) = \frac{\text{Moles solute}}{\text{Kilograms solvent}}$$

$$= \frac{0.2771 \text{ mol } C_2H_6O_2}{0.500 \text{ kg } H_2O}$$

$$= 0.554\ m$$

Calculate the freezing point of a 1.7 *m* ethylene glycol (automotive antifreeze) aqueous solution.

SOLUTION:

$$\Delta T_f = m \times K_f$$

$$= 1.7\,\frac{\text{mol } \cancel{\text{solute}}}{\cancel{\text{kg solvent}}} \times 1.86\,\frac{{}^\circ\text{C}\ \cancel{\text{kg solvent}}}{\cancel{\text{mol solute}}}$$

$$= 3.2\ {}^\circ\text{C}$$

$$\text{Freezing point} = 0.00\ {}^\circ\text{C} - 3.2\ {}^\circ\text{C}$$

$$= -3.2\ {}^\circ\text{C}$$

The boiling point elevation of a nonelectrolyte solution is quantified as

$$\Delta T_b = m \cdot K_b$$

where

- ΔT_b is the change in temperature of the boiling point in °C (from the boiling point of the pure solvent).
  $\Delta T_b = T_{b,solution} - T_{b,solvent}$
- m is the molality of the solution in (mol solute/kg solvent).
- K_b is the boiling point elevation constant for the solvent.

Different solvents have different values of K_b.

For water: $K_b = 0.512 \dfrac{°C \text{ kg solvent}}{\text{mol solute}}$

Calculate the boiling point of a 1.7 *m* ethylene glycol (automotive antifreeze) solution.

SOLUTION:

$$\Delta T_b = m \times K_b$$

$$= 1.7\,\frac{\cancel{\text{mol solute}}}{\cancel{\text{kg solvent}}} \times 0.512\,\frac{°\text{C}\;\cancel{\text{kg solvent}}}{\cancel{\text{mol solute}}}$$

$$= 0.87\ °\text{C}$$

$$\text{Boiling point} = 100.00\ °\text{C} + 0.87\ °\text{C}$$

$$= 100.87\ °\text{C}$$

Colligative properties can be used to estimate the molar mass of the solute.

- Dissolve a known mass of solute in a solvent with a known colligative coefficient
- Measure the change in freezing point or boiling point
- Calculate the molality of the solute from that measurement and the colligative coefficient
- Calculate the moles of solute from the mass (in kilograms) of the solvent and the solute molality
- Molar mass = mass / moles

Everyday Chemistry: Antifreeze in Frogs

- In the frozen state, the frog has no heartbeat, no blood circulation, no breathing, and no brain activity. Within 1 to 2 hours of thawing, however, these vital functions return, and the frog hops off to find food. How is this possible?
- The fluids in frog cells are protected by a high concentration of glucose that acts as antifreeze, lowering their freezing point so the intercellular fluids remain liquid to temperatures as low as −8.0 °C.

Wood frogs survive cold winters in a remarkable way—they partially freeze.

Osmosis

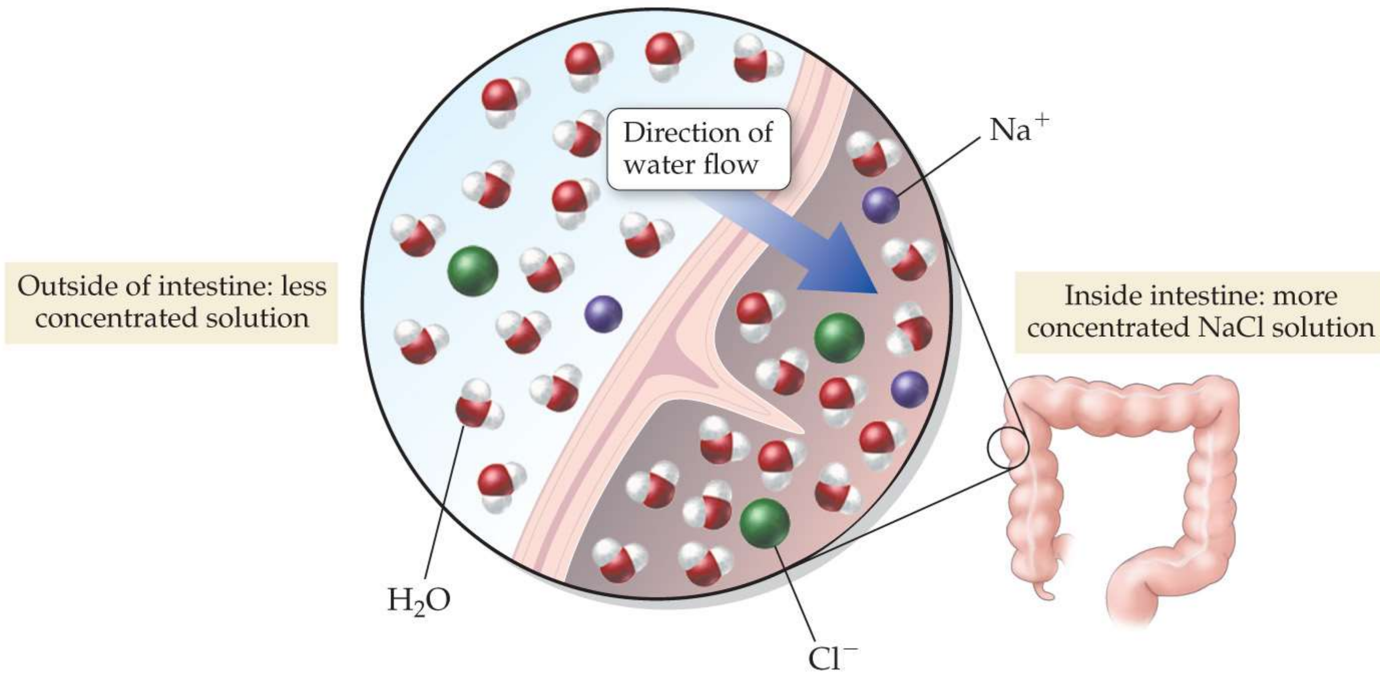
Why Drinking Salt Water Causes Dehydration

Osmosis

- The flow of **solvent** from a less concentrated solution to a more concentrated solution.
- It occurs when solutions containing a high concentration of solute draw solvent from solutions containing a lower concentration of solute.

Osmosis

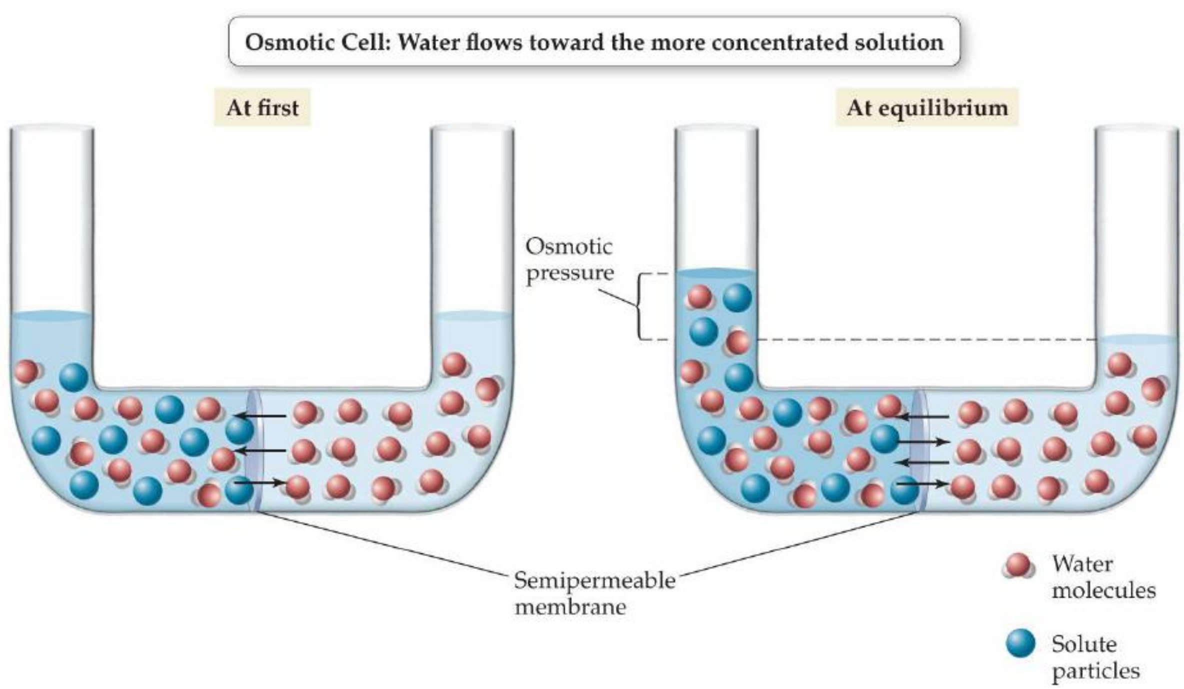
- **Seawater is a *thirsty* solution.**
  As it flows through the stomach and intestine, seawater draws water *out of* bodily tissues, promoting dehydration.



In an osmosis cell, water flows through a semipermeable membrane from a less concentrated solution into a more concentrated solution.

As a result, fluid rises in one side of the tube until the weight of the excess fluid creates enough pressure to stop the flow.

This pressure is the osmotic pressure of the solution.



Osmotic Pressure

- Osmotic pressure—like freezing point depression and boiling point elevation—is a colligative property; it depends only on the concentration of the solute particles, not on the type of solute.
- The more concentrated the solution, the greater its osmotic pressure.
- The membranes of living cells act as semipermeable membranes.
- If you put a living cell into seawater, it loses water through osmosis and becomes dehydrated.

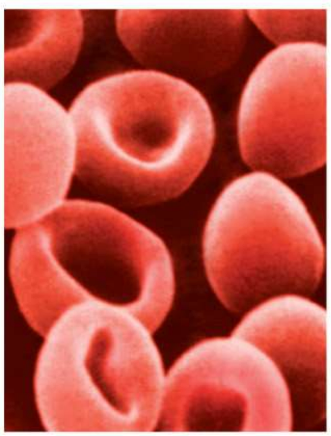
Red Blood Cells in Solutions of Different Concentration

(a) The solute concentration of the surrounding fluid is equal to that within the cell, so there is no net osmotic flow, and the red blood cell exhibits its typical shape.

(b) A cell is placed in pure water and osmotic flow of water into the cell causes it to swell up. Eventually, it may burst.

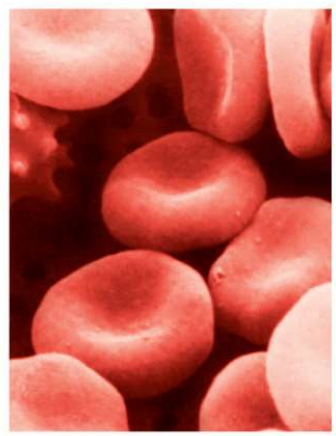
(c) A cell is placed in a concentrated solution and osmosis draws water out of the cell, distorting its normal shape.

Normal red blood cell



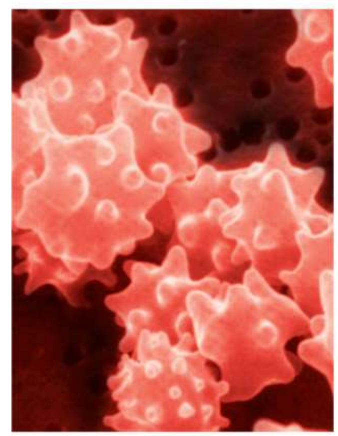
(a)

Red blood cell in pure water: water flows into cell



(b)

Red blood cell in concentrated solution: water flows out of cell



(c)

Chemistry and Health: Solutions in Medicine

- Solutions having osmotic pressures less than that of bodily fluids are called *hypoosmotic*. These solutions tend to pump water into cells.
- Solutions having osmotic pressures greater than that of bodily fluids are called *hyperosmotic*. These solutions tend to take water out of cells and tissues.
- Intravenous solutions must have osmotic pressure equal to that of bodily fluids. These solutions are called *isoosmotic*.
- When a patient is given an IV in a hospital, the majority of the fluid is usually an isoosmotic saline solution—a solution containing 0.9 g NaCl per 100 mL of solution.

Chapter 13 in Review

- **Solutions:** A solution is a homogeneous mixture with two or more components. The solvent is the majority component, and the solute is the minority component. Water is the solvent in aqueous solutions.
- **Solid-and-Liquid Solutions:** The solubility of solids in liquids increases with increasing temperature.
- **Gas-and-Liquid Solutions:** The solubility of gases in liquids decreases with increasing temperature but increases with increasing pressure.

Chapter 13 in Review

- **Solution Concentration:** Three common ways to express solution concentration are mass percent, molarity, and molality.
- **Solution Dilution:** These problems are most conveniently solved using the following equation: $\boldsymbol{M_1V_1 = M_2V_2}$**.**
- **Freezing Point Depression and Boiling Point Elevation:** A nonvolatile solute will extend the liquid temperature range of a solution relative to the pure solvent.

Chapter 13 in Review

- **Osmosis:** Osmosis is the flow of water from a low-concentration solution to a high-concentration solution through a semipermeable membrane.

Chemical Skills Learning Objectives

1. LO: Calculate mass percent.
2. LO: Use mass percent in calculations.
3. LO: Calculate molarity.
4. LO: Use molarity in calculations.
5. LO: Calculate solution dilution.
6. LO: Use solution stoichiometry.
7. LO: Calculate molality.
8. LO: Calculate freezing point depression and boiling point elevation.