AlAYEN IRAQI UNIVERSITY
Health and Medical Technologies
Anesthesia Department

General Chemistry

Solutions

Lec 5

Objectives

1- Solutions

2- Electrolytes and Non-electrolytes

3- Solubility

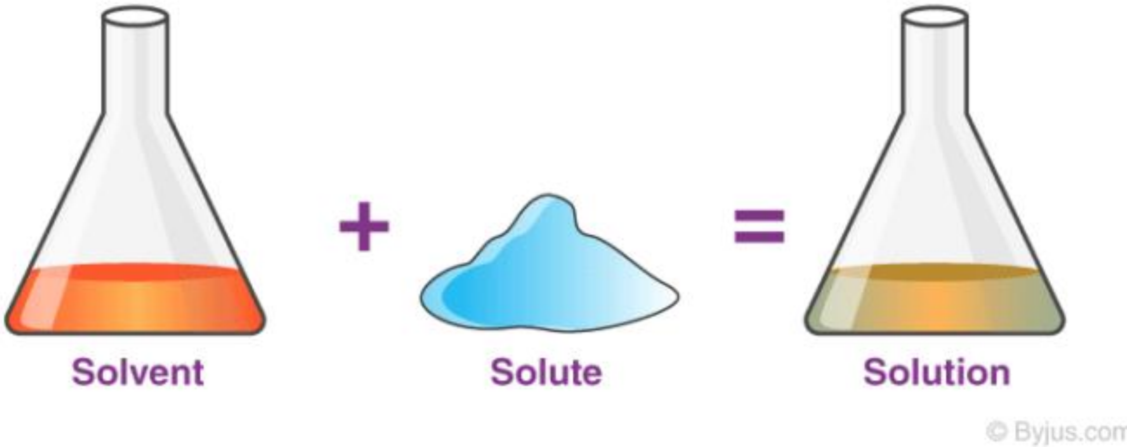
4- Concentration of a Solution

5- Dilution of Solutions

6- Properties of Solutions


Examples of Solutions

Important Definitions



Solvent: The component of a solution that is the "dissolving" medium. The solvent determines the physical state of the solution (solid, liquid, or gas).

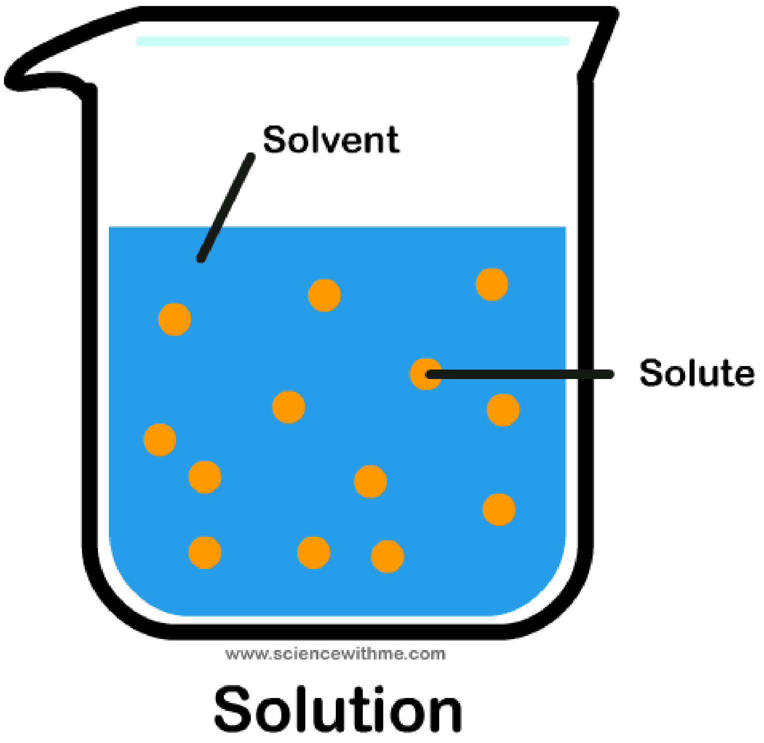
Solute: The components of a solution that are "dissolved" by the medium.

Solution: A homogeneous mixture consisting of one or more substances uniformly dispersed as separate atoms, molecules, or ions in another substance.

Solutions

Usually, the solute is the substance present in the smaller amount, whereas the solvent is present in the larger amount.

In a solution, the particles of the solute are evenly dispersed among the molecules within the solvent



Aqueous Solution: A solution wherein water is the solvent.

When the solute and solvent are both in the same physical state, the one in the largest quantity is the solvent.

Solutions

CONCEPT CHECK 7.1

Identifying a Solute and a Solvent

Identify the solute and the solvent in each of the following solutions:

a. 15 g of sugar dissolved in 100 mL of water
b. 75 mL of water mixed with 25 mL of isopropyl alcohol
c. a tincture of iodine prepared with 0.10 g of I_2 and 10.0 mL of ethanol

ANSWER

a. Sugar, the smaller quantity, is the solute; water is the solvent.
b. Isopropyl alcohol, which has the smaller volume, is the solute; water is the solvent.
c. Iodine, the smaller quantity, is the solute; ethanol is the solvent.

Types of Solutes and Solvents

The solution that forms has the same physical state as the solvent.

Phase of solution	Solute	Solvent	Example
Gas	gas	gas	air
Liquid	gas	liquid	soft drinks
Liquid	liquid	liquid	antifreeze
Liquid	solid	liquid	salt water
Solid	gas	solid	H_2 in Pt
Solid	solid	solid	brass

Brass

H_2 in platinum

Formation of Solutions

like dissolves like

TABLE 7.3 Possible Combinations of Solutes and Solvents

Solutions Will Form		Solutions Will Not Form	
Solute	**Solvent**	**Solute**	**Solvent**
Polar/ionic	Polar	Polar/ionic	Nonpolar
Nonpolar	Nonpolar	Nonpolar	Polar

$$NaCl(s) \xrightarrow{H_2O} Na^{+}(aq) + Cl^{-}(aq)$$

$$\underset{\text{Sucrose}}{C_{12}H_{22}O_{11}(s)} \xrightarrow{H_2O} \underset{\text{Solution of sucrose molecules}}{C_{12}H_{22}O_{11}(aq)}$$

Formation of Solutions

CONCEPT CHECK 7.2

Polar and Nonpolar Solutes

Indicate whether each of the following substances will dissolve in water. Explain.

a. KCl

b. octane, C_8H_{18}, a compound in gasoline

ANSWER

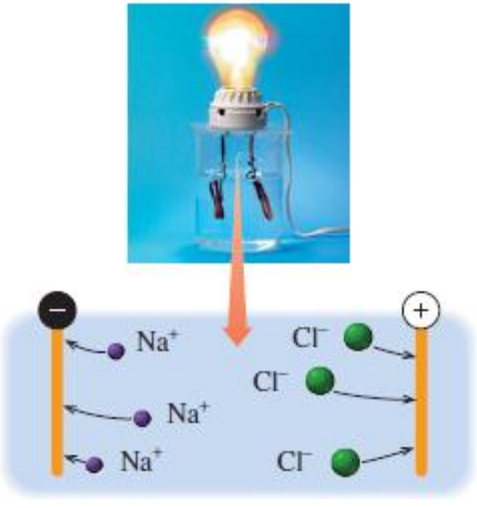
a. Yes. KCl is an ionic compound. The solute–solvent attractions between the ions K^+ and Cl^- and polar water molecules provide the energy to break solute–solute and solvent–solvent bonds. Thus, a KCl solution will form.

b. No. Octane is a nonpolar compound of carbon and hydrogen, which means it does not form a solution with the polar water molecules. There are no nonpolar–polar solvent attractions, and no solution forms.

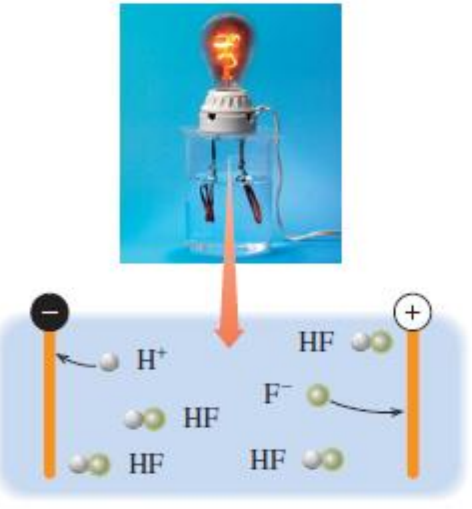
Electrolytes and Nonelectrolytes

TABLE 7.4 Classification of Solutes in Aqueous Solutions

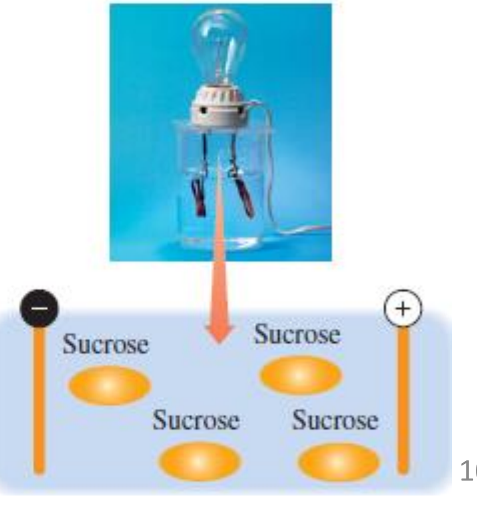
Type of Solute	Dissociates	Type(s) of Particles in Solution	Conducts Electricity?	Examples
Strong electrolyte	Completely	Ions only	Yes	Ionic compounds such as NaCl, KBr, $MgCl_2$, $NaNO_3$; bases such as NaOH, KOH; acids such as HCl, HBr, HI, HNO_3, $HClO_4$, H_2SO_4
Weak electrolyte	Partially	Mostly molecules and a few ions	Weakly	HF, H_2O, NH_3, $HC_2H_3O_2$ (acetic acid)
Nonelectrolyte	None	Molecules only	No	Carbon compounds such as CH_3OH (methanol), C_2H_5OH (ethanol), $C_{12}H_{22}O_{11}$ (sucrose), CH_4N_2O (urea)



Strong electrolyte

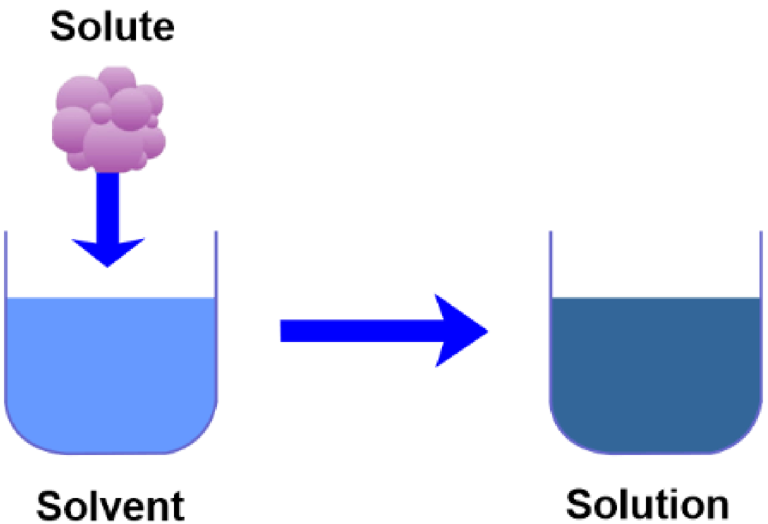


Weak electrolyte

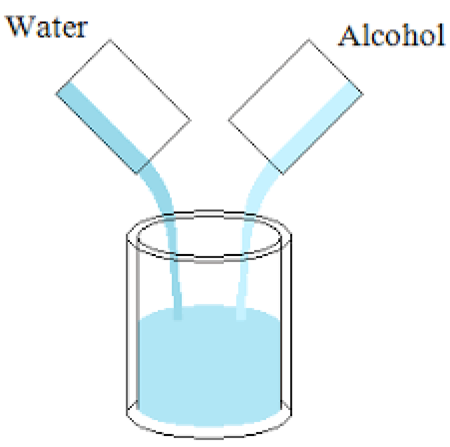


Solubility

Solubility is the amount of a solute that can dissolve in a given amount of solvent under given conditions (T and P).

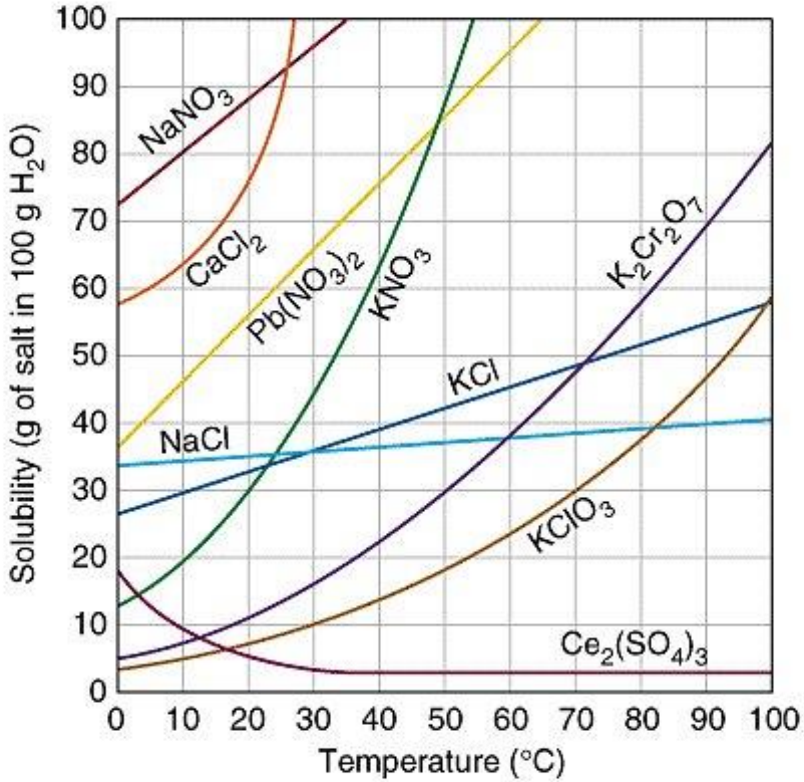


Liquids can also be classified as miscible (soluble in each other) or immiscible (not soluble in each other).



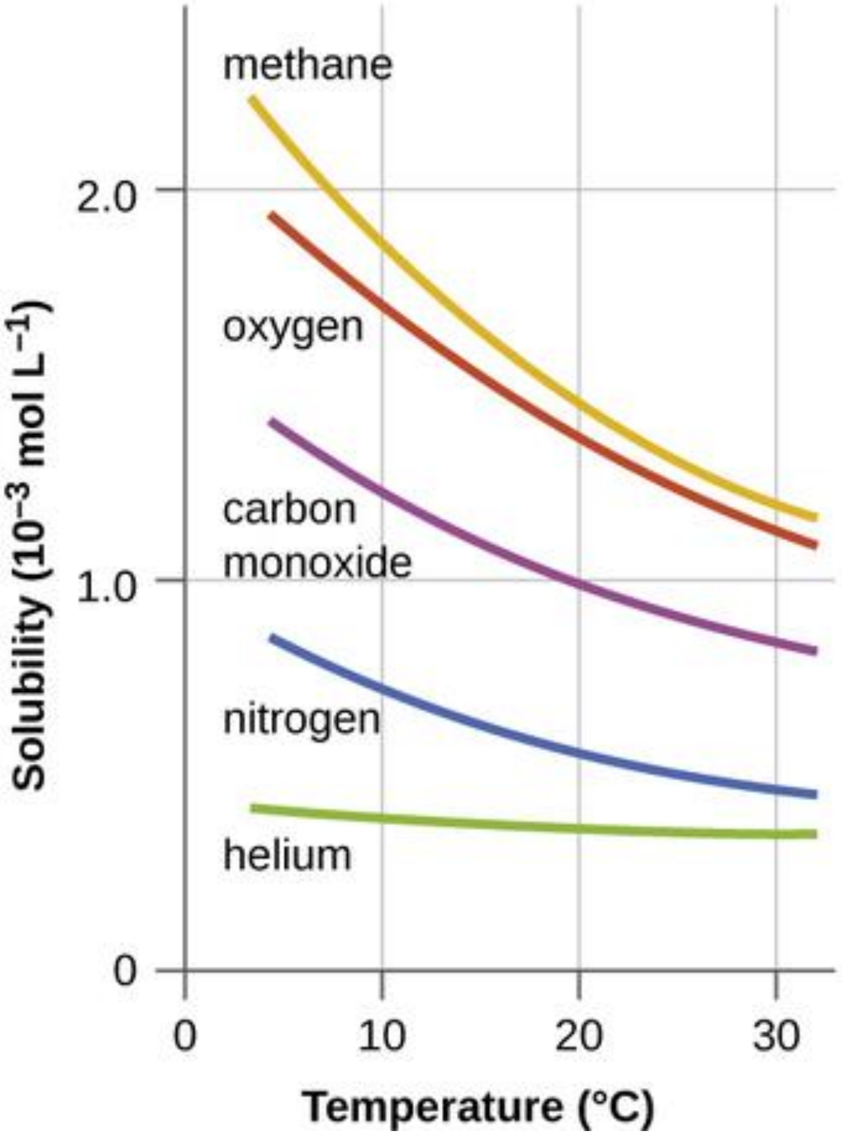
Factors Related to Solubility
Temperature

As temperature increases, the Solubility of a solid in a liquid tends to increase.



Factors Related to Solubility
Temperature

As temperature increases, the Solubility of a gas in a liquid tends to decrease.

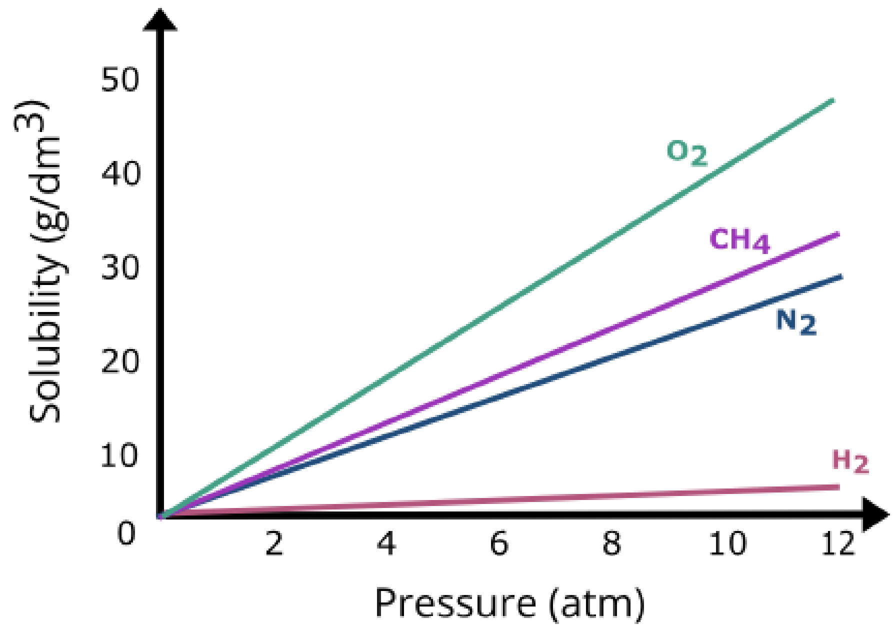


Factors Related to Solubility
Pressure

As pressure increases:

- Solubility of a solid in a liquid remains constant.

- Solubility of a gas in a liquid tends to increase.



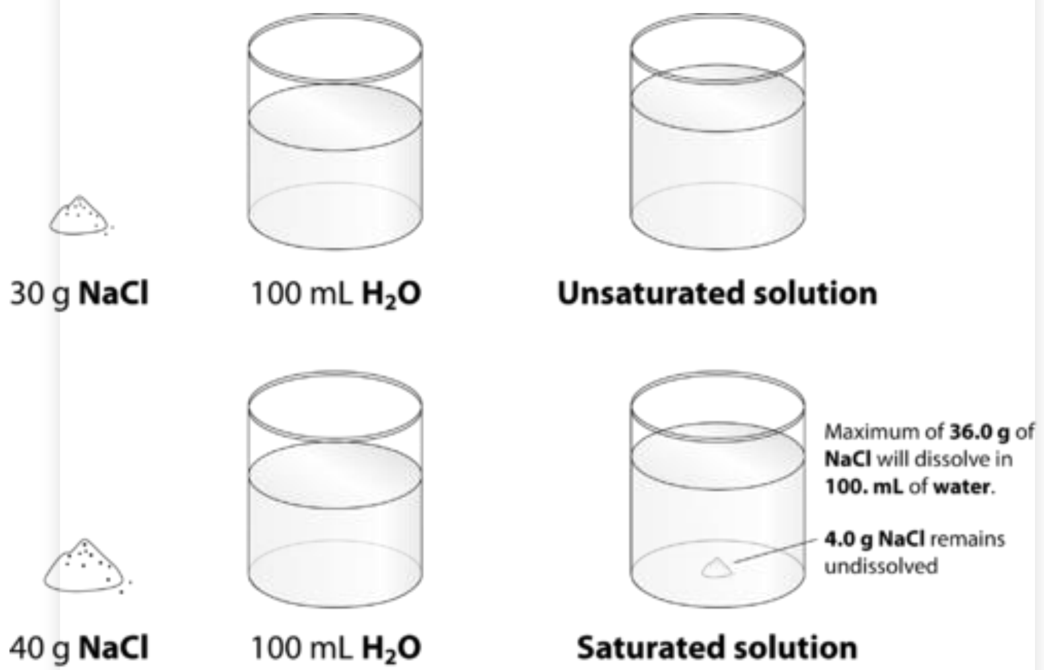
Effect of Pressure on Solubility of Gases

Factors Related to Solubility

- At a specific temperature, the amount of solute that can dissolve in a solvent has a limit:

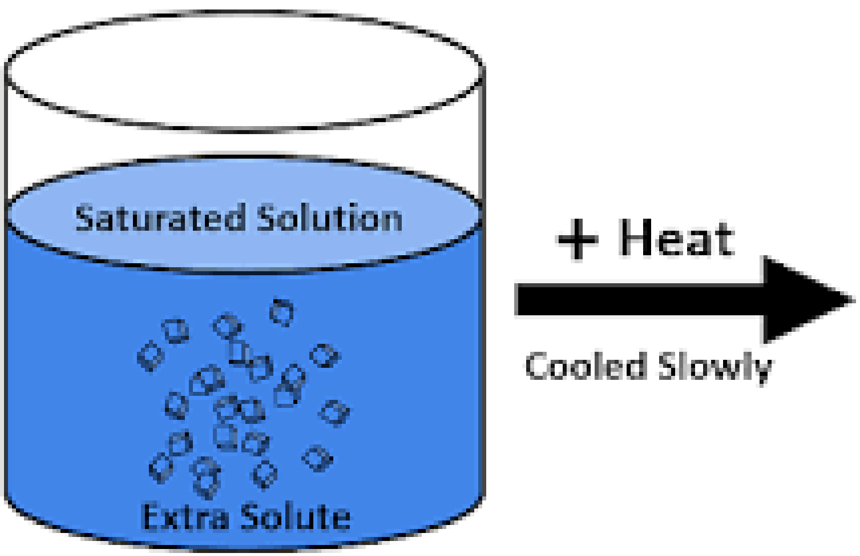
- Unsaturated solutions contain less solute than the limit.

- Saturated solutions contain dissolved solute at the limit.



Factors Related to Solubility

- Supersaturated solutions contain more solute than the limit and are therefore unstable. If disturbed, the excess solute will precipitate out of solution.



Factors Related to Solubility

SAMPLE PROBLEM 7.3

Saturated Solutions

At 20 °C, the solubility of KCl is 34 g/100 g of water. In the laboratory, a student mixes 75 g of KCl with 200. g of water at a temperature of 20 °C.

a. How much of the KCl will dissolve?
b. Is the solution saturated or unsaturated?
c. What is the mass, in grams, of any solid KCl on the bottom of the container?

SOLUTION

a. KCl has a solubility of 34 g of KCl in 100 g of water. Using the solubility as a conversion factor, we can calculate the maximum amount of KCl that can dissolve in 200. g of water as follows:

$$200.\ \cancel{\text{g } H_2O} \times \frac{34\text{ g KCl}}{100\ \cancel{\text{g } H_2O}} = 68\text{ g of KCl}$$

b. Because 75 g of KCl exceeds the amount (68 g) that can dissolve in 200. g of water, the KCl solution is saturated.

c. If we add 75 g of KCl to 200. g of water and only 68 g of KCl can dissolve, there is 7 g (75 g − 68 g) of solid (undissolved) KCl on the bottom of the container.

Factors Related to Solubility

CONCEPT CHECK 7.3

Factors Affecting Solubility

Indicate whether there is an increase or decrease in each of the following:

a. the solubility of sugar in water at 45 °C compared to its solubility in water at 25 °C

b. the solubility of O_2 in a lake as the water warms

ANSWER

a. A decrease in the temperature from 45 °C to 25 °C decreases the solubility of the sugar.

b. An increase in the temperature decreases the solubility of O_2 gas.

Solubility Rules

TABLE 7.8 Solubility Rules for Ionic Solids in Water

Soluble If Salt Contains		Insoluble If Salt Contains
NH_4^+, Li^+, Na^+, K^+, NO_3^-, $C_2H_3O_2^-$ (acetate)	← but are soluble with	CO_3^{2-}, S^{2-}, PO_4^{3-}, OH^-
Cl^-, Br^-, I^-	but are not soluble with →	Ag^+, Pb^{2+}, Hg_2^{2+}
SO_4^{2-}	but are not soluble with →	Ba^{2+}, Pb^{2+}, Ca^{2+}, Sr^{2+}

TABLE 7.9 Using Solubility Rules

Ionic Compound	Solubility in Water	Reasoning
K_2S	Soluble	Contains K^+
$Ca(NO_3)_2$	Soluble	Contains NO_3^-
$PbCl_2$	Insoluble	Is an insoluble chloride
$NaOH$	Soluble	Contains Na^+
$AlPO_4$	Insoluble	Contains no soluble ions

Solubility Rules

CONCEPT CHECK 7.4

Soluble and Insoluble Salts

Predict whether each of the following salts is soluble in water and explain why:

a. Na_3PO_4 b. $CaCO_3$

ANSWER

a. The salt Na_3PO_4 is soluble in water because any compound that contains Na^+ is soluble.

b. The salt $CaCO_3$ is not soluble. The compound does not contain a soluble positive ion, which means that a calcium salt containing CO_3^{2-} is not soluble.

Concentration of a Solution

Mass percent	% m/m	$\frac{\text{mass solute}}{\text{mass solution}} \times 100$
Parts per million	ppm	$\frac{\text{mass solute}}{\text{mass solution}} \times 1{,}000{,}000$
Mass/volume	% m/v	$\frac{\text{mass solute}}{\text{mL solution}} \times 100$ percent
Volume percent	% v/v	$\frac{\text{mL solute}}{\text{mL solution}} \times 100$
Molarity	M	$\frac{\text{moles solute}}{\text{L solution}}$
Molality	m	$\frac{\text{moles solute}}{\text{kg solvent}}$

Concentration of a Solution

CONCEPT CHECK 7.5

Mass Percent (m/m) Concentration

A NaBr solution is prepared by dissolving 4.0 g of NaBr in 50.0 g of H_2O.

a. What is the mass of the solution?

b. Is the final concentration of the NaBr solution equal to 7.4% (m/m), 8.0% (m/m) or 80.% (m/m)?

ANSWER

a. The mass of the NaBr solution is the sum of 4.0 g of NaBr and the mass of the H_2O solvent, which is 54.0 g (4.0 g of NaBr + 50.0 g of H_2O).

b. The mass percent of the NaBr is equal to 7.4% (m/m).

$$\frac{4.0 \text{ g NaBr}}{54.0 \text{ g solution}} \times 100\% = 7.4\% \text{ (m/m) NaBr solution}$$

Concentration of a Solution

SAMPLE PROBLEM 7.4

Calculating Mass Percent (m/m) Concentration

What is the mass percent of a solution prepared by dissolving 30.0 g of NaOH in 120.0 g of H_2O?

$$\text{Mass percent (m/m)} = \frac{\text{grams of solute}}{\text{grams of solution}} \times 100\%$$

$$\text{Mass percent (m/m)} = \frac{30.0 \text{ g NaOH}}{150.0 \text{ g solution}} \times 100\%$$

$$= 20.0\% \text{ (m/m) NaOH solution}$$

Concentration of a Solution

SAMPLE PROBLEM 7.5

Calculating Volume Percent (v/v) Concentration

A student prepared a solution by adding water to 18 mL of ethanol (C_2H_5OH) to give a final solution volume of 150 mL. What is the volume percent (v/v) of the ethanol solution?

$$\text{Volume percent (v/v)} = \frac{\text{volume of solute}}{\text{volume of solution}} \times 100\%$$

$$\text{Volume percent (v/v)} = \frac{18 \text{ mL } C_2H_5OH}{150 \text{ mL solution}} \times 100\%$$

$$= 12\% \text{ (v/v) } C_2H_5OH \text{ solution}$$

SAMPLE PROBLEM 7.6

Calculating Mass/Volume Percent (m/v) Concentration

A student prepared a solution by dissolving 5.0 g of KI in enough water to give a final volume of 250 mL. What is the mass/volume percent of the KI solution?

$$\text{Mass/volume percent (m/v)} = \frac{\text{mass of solute}}{\text{volume of solution}} \times 100\%$$

$$\text{Mass/volume percent (m/v)} = \frac{5.0 \text{ g KI}}{250 \text{ mL solution}} \times 100\%$$

$$= 2.0\% \text{ (m/v) KI solution}$$

Concentration of a Solution

SAMPLE PROBLEM 7.7

Calculating Molarity

What is the molarity (M) of 60.0 g of NaOH in 0.250 L of solution?

$$\text{Molarity (M)} = \frac{\text{moles of solute}}{\text{liters of solution}}$$

$$\text{Moles of NaOH} = 60.0\ \cancel{\text{g NaOH}} \times \frac{1\ \text{mole NaOH}}{40.0\ \cancel{\text{g NaOH}}} = 1.50\ \text{moles of NaOH}$$

$$\text{M} = \frac{1.50\ \text{moles NaOH}}{0.250\ \text{L solution}} = \frac{6.00\ \text{moles NaOH}}{1\ \text{L solution}} = 6.00\ \text{M NaOH solution}$$

Concentration of a Solution

TABLE 7.11 Conversion Factors from Concentrations

Percent Concentration	Meaning	Conversion Factors		
10% (m/m) KCl solution	10 g of KCl in 100 g of KCl solution	$\frac{10\text{ g KCl}}{100\text{ g solution}}$	and	$\frac{100\text{ g solution}}{10\text{ g KCl}}$
12% (v/v) ethanol solution	12 mL of ethanol in 100 mL of ethanol solution	$\frac{12\text{ mL ethanol}}{100\text{ mL solution}}$	and	$\frac{100\text{ mL solution}}{12\text{ mL ethanol}}$
5% (m/v) glucose solution	5 g of glucose in 100 mL of glucose solution	$\frac{5\text{ g glucose}}{100\text{ mL solution}}$	and	$\frac{100\text{ mL solution}}{5\text{ g glucose}}$
Molarity				
6.0 M HCl solution	6.0 moles of HCl in 1 liter of HCl solution	$\frac{6.0\text{ moles HCl}}{1\text{ L solution}}$	and	$\frac{1\text{ L solution}}{6.0\text{ moles HCl}}$

SAMPLE PROBLEM 7.8

Using Mass/Volume Percent to Find Mass of Solute

A topical antibiotic is 1.0% (m/v) Clindamycin. How many grams of Clindamycin are in 60. mL of the 1.0% (m/v) solution?

$$100\text{ mL of solution} = 1.0\text{ g of Clindamycin}$$

$$\frac{1.0\text{ g Clindamycin}}{100\text{ mL solution}} \quad \text{and} \quad \frac{100\text{ mL solution}}{1.0\text{ g Clindamycin}}$$

$$60.\ \cancel{\text{mL solution}} \times \frac{1.0\text{ g Clindamycin}}{100\ \cancel{\text{mL solution}}} = 0.60\text{ g of Clindamycin}$$

Concentration of a Solution

SAMPLE PROBLEM 7.9

Using Molarity to Calculate Volume of Solution

How many liters of a 2.00 M NaCl solution are needed to provide 67.3 g of NaCl?

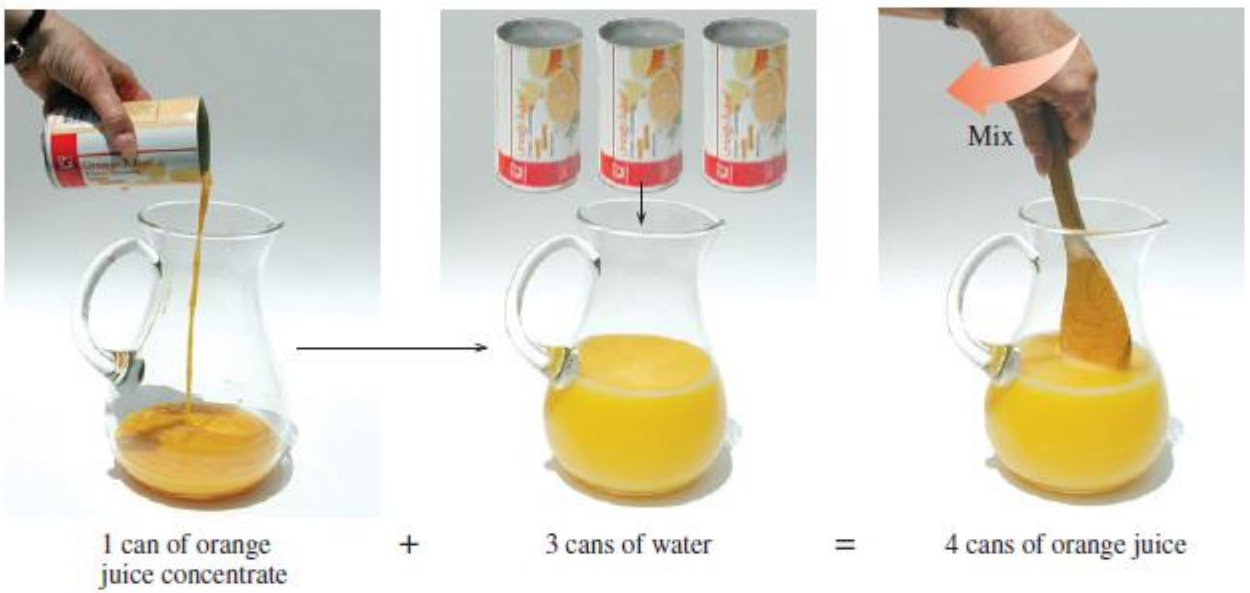
M = n/ v => n = M x V

=> m/m. wt = M x V

=> V = m / (m.wt x M) = (63.7 g) / (58.5 g/mol x 2 mol/lit) = 0.575 L

Dilution of Solutions

In a process called **dilution, a solvent, usually water, is added to a solution,** which increases the volume. As a result, the concentration of the solution decreases.



Amount of solute in the concentrated solution	=	amount of solute in the diluted solution
Grams or moles of solute	=	grams or moles of solute
Concentrated solution		Diluted solution

$$C_1V_1 = C_2V_2$$

Concentrated solution = Diluted solution

Dilution of Solutions

CONCEPT CHECK 7.6

Volume of a Diluted Solution

A 50.0-mL sample of a 20.0% (m/v) $SrCl_2$ solution is diluted with water to give a 5.00% (m/v) $SrCl_2$ solution. Use this data to complete the table with the given concentrations and volumes of the solutions. Indicate what we know (increases or decreases), and predict the change in the unknown (increases or decreases).

Concentrated Solution	Diluted Solution	Know	Predict
$C_1 =$	$C_2 =$		
$V_1 =$	$V_2 = ?$ mL		

ANSWER

Concentrated Solution	Diluted Solution	Know	Predict
$C_1 = 20.0\%$ (m/v)	$C_2 = 5.00\%$ (m/v)	C decreases	
$V_1 = 50.0$ mL	$V_2 = ?$ mL		V increases

Dilution of Solutions

SAMPLE PROBLEM 7.10

Volume of a Diluted Solution

What volume (mL) of a 2.5% (m/v) KOH solution can be prepared by diluting 50.0 mL of a 12% (m/v) KOH solution?

$$C_1V_1 = C_2V_2$$

$$\frac{C_1V_1}{C_2} = \frac{\cancel{C_2}V_2}{\cancel{C_2}}$$

$$V_2 = V_1 \times \frac{C_1}{C_2}$$

$$V_2 = 50.0\ \text{mL} \times \frac{12.0\cancel{\%}}{2.50\cancel{\%}} = 240\ \text{mL of diluted KOH solution}$$

SAMPLE PROBLEM 7.11

Molarity of a Diluted Solution

What is the molarity of a solution prepared when 75.0 mL of a 4.00 M KCl solution is diluted to a volume of 500. mL?

$$M_1V_1 = M_2V_2$$

$$\frac{M_1V_1}{V_2} = \frac{M_2\cancel{V_2}}{\cancel{V_2}}$$

$$M_2 = M_1 \times \frac{V_1}{V_2}$$

$$M_2 = 4.00\ \text{M} \times \frac{75.0\ \cancel{\text{mL}}}{500.\ \cancel{\text{mL}}} = 0.600\ \text{M (diluted KCl solution)}$$

Colligative Properties of Solutions

Properties of a solution that depend only on the number of solute particles in solution are called colligative properties.

Freezing point depression and boiling point elevation

Solution containing 1 mol (60.06 g) of urea in 1 kg of water has a freezing point of 1.68 °C not 0°C as for pure water.

Both the freezing point depression and the boiling point elevation are directly proportional to the number of moles of solute per kilogram of solvent.

$$\Delta t_f = mK_f$$

$$\Delta t_b = mK_b$$

$$m = \frac{\text{mol solute}}{\text{kg solvent}}$$

m = molality; mol solute/kg solvent
Δt_f = freezing point depression; °C
Δt_b = boiling point elevation; °C
K_f = freezing point depression constant; °C kg solvent/mol solute
K_b = boiling point elevation constant; °C kg solvent/mol solute

Solvent	Freezing point depression constant, K_f $\left(\frac{°\text{C kg solvent}}{\text{mol solute}}\right)$
Water	1.86
Acetic acid	3.90
Benzene	5.1
Camphor	40

Colligative Properties of Solutions

Example 14.14

What is the molality (m) of a solution prepared by dissolving 2.70 g CH_3OH in 25.0 g H_2O?

$$m = \frac{\text{mol solute}}{\text{kg solvent}}$$

n = m/m.wt = 2.7 g / 32 g/mol = 0.084 mol

m = 0.084 mol / 25 x 0.001 Kg = 3.37 molal (m)

Colligative Properties of Solutions

Example 14.15

A solution is made by dissolving 100. g of ethylene glycol ($C_2H_6O_2$) in 200. g of water. What is the freezing point of this solution?

K_f (for water): $\frac{1.86°C \text{ kg solvent}}{\text{mol solute}}$

$$\Delta t_f = mK_f = \frac{\text{mol solute}}{\text{kg solvent}} \times K_f$$

n= mass/m.wt = 100 g / (62.07 g/mol) = 1.61 mol

m = mol solute / Kg solvent = 1.61 mol / (200 x 0.001 Kg) = 8.05 mol/Kg

ΔT_f = mK_f = 8.05 mol/Kg x 1.68 ^{o}C Kg /mol = 15.0 ^{o}C

ΔT_f = T_f(solvent) – T_f(solution) => T solution = T(solvent) - ΔT_f = 0 – 15 = -15 ^{o}C

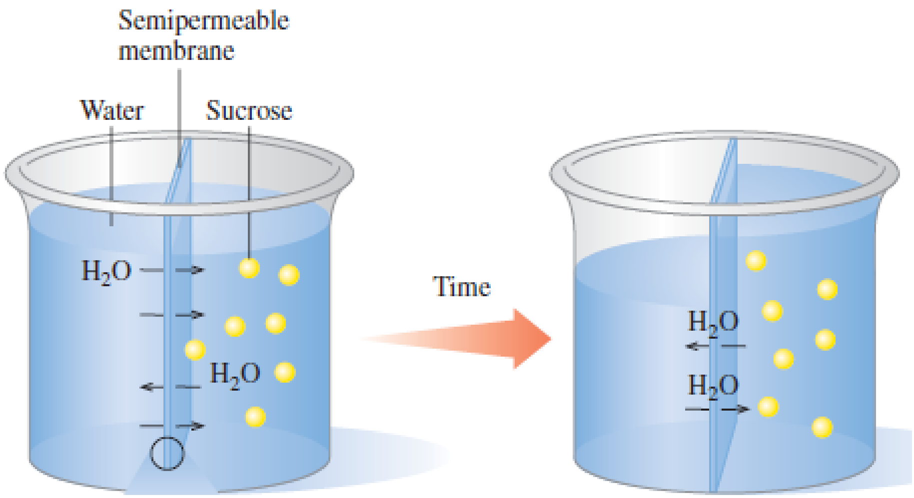
Colligative Properties of Solutions

Example 14.16

A solution made by dissolving 4.71 g of a compound of unknown molar mass in 100.0 g of water has a freezing point of −1.46°C. What is the molar mass of the compound?

Colligative Properties of Solutions

Osmosis, water molecules move through a semipermeable membrane from the solution with the lower concentration of solute into a solution with the higher solute concentration.



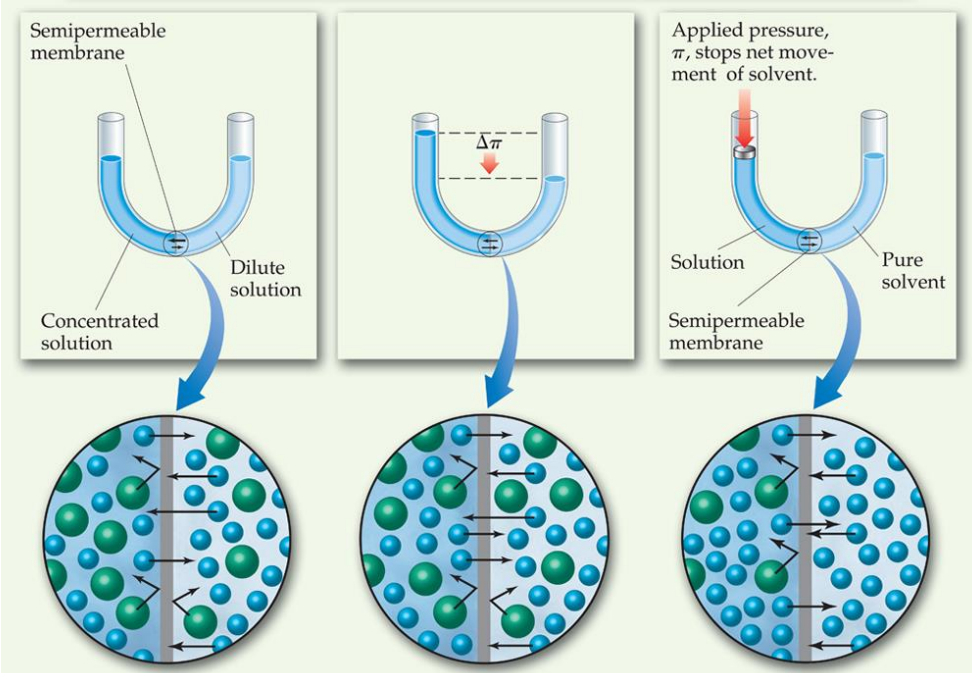
Eventually the height of the sucrose solution creates sufficient pressure to equalize the flow of water between the two compartments. This pressure, called **osmotic pressure**, prevents the flow of additional water into the more concentrated solution.

Osmosis

Some substances form semipermeable membranes, allowing some smaller particles to pass through, but blocking other larger particles.

In biological systems, most semipermeable membranes allow water to pass through, but solutes are not free to do so.

Osmosis



In osmosis, there is net movement of solvent from the area of **higher solvent concentration** (*lower solute concentration*) to the are of **lower solvent concentration** (*higher solute concentration*).

Osmotic Pressure

The pressure required to stop osmosis, known as osmotic pressure, π, is

$$\pi = \left(\frac{n}{V}\right)RT = MRT$$

where M is the molarity of the solution

If the osmotic pressure is the same on both sides of a membrane (i.e., the concentrations are the same), the solutions are isotonic.