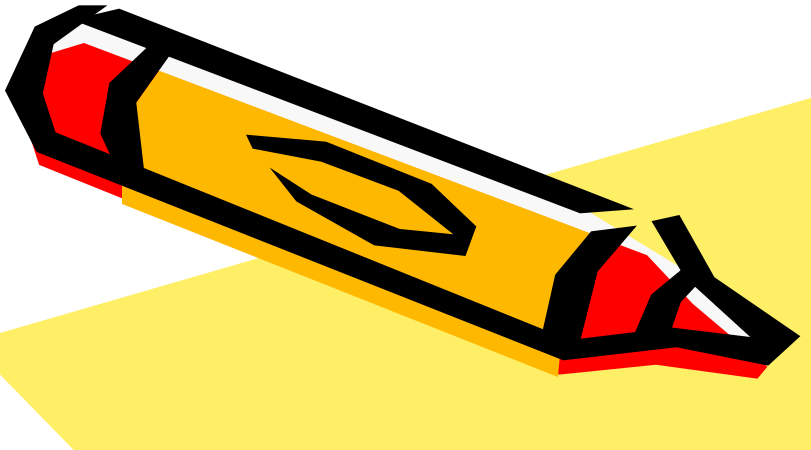
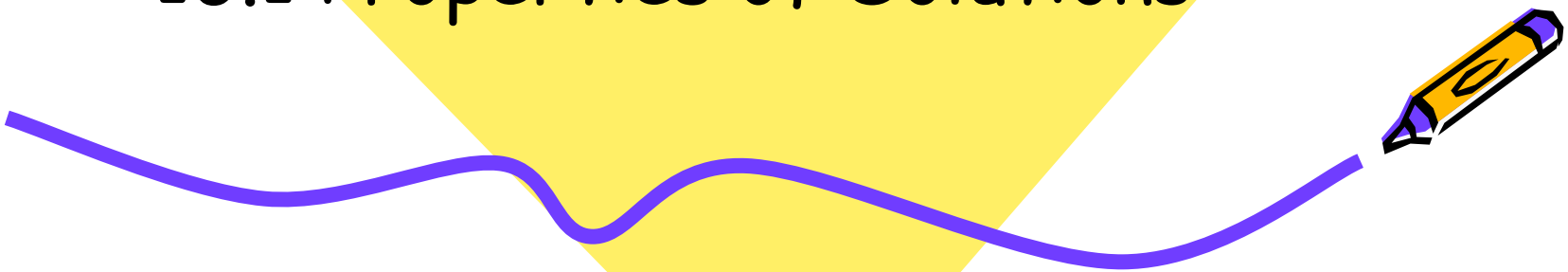


Chapter 16: Solutions

16.1 Properties of Solutions



Solution Formation

- The compositions of the solvent and the solute determine whether a substance will dissolve. The factors that determine how fast a substance dissolves are
  - stirring (agitation)
  - temperature
  - the surface area of the dissolving particles

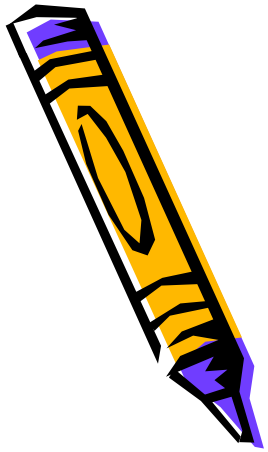
Solution Formation

- Stirring and Solution Formation
  - Stirring speeds up the dissolving process because fresh solvent (the water in tea) is continually brought into contact with the surface of the solute (sugar).

Solution Formation

- Temperature and Solution Formation
  - At higher temperatures, the kinetic energy of water molecules is greater than at lower temperatures, so they move faster. As a result, the solvent molecules collide with the surface of the sugar crystals more frequently and with more force.

Solution Formation



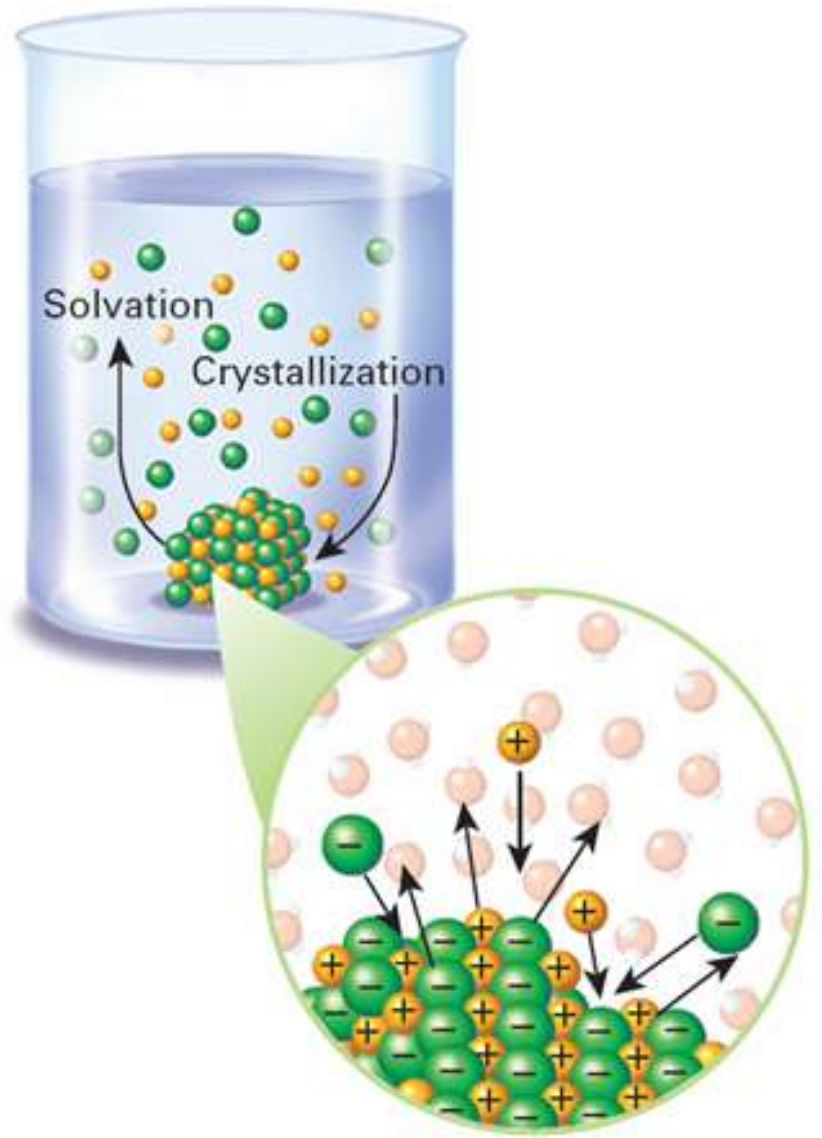
- Particle Size and Solution Formation
  - A spoonful of granulated sugar dissolves more quickly than a sugar cube because the smaller particles in granulated sugar expose a much greater surface area to the colliding water molecules.

Solubility

- A **saturated solution** contains the maximum amount of solute for a given quantity of solvent at a given temperature and pressure.
- An **unsaturated solution** contains less solute than a saturated solution at a given temperature and pressure.

Solubility

- In a saturated solution, the rate of dissolving equals the rate of crystallization, so the total amount of dissolved solute remains constant.



Solubility

- The **solubility** of a substance is the amount of solute that dissolves in a given quantity of a solvent at a specified temperature and pressure to produce a saturated solution.
  - Solubility is often expressed in grams of solute per 100 g of solvent.

Solubility

- Some liquids combine in all proportions, while others don't mix at all.
  - Two liquids are **miscible** if they dissolve in each other in all proportions.
  - Two liquids are **immiscible** if they are insoluble in each other.

Factors Affecting Solubility

- Temperature affects the solubility of solid, liquid, and gaseous solutes in a solvent; both temperature and pressure affect the solubility of gaseous solutes.

Factors Affecting Solubility

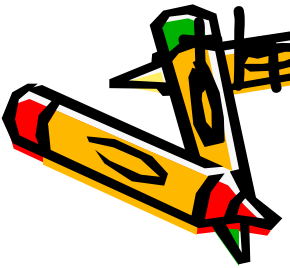
- Temperature
  - The solubility of most solid substances increases as the temperature of the solvent increases.
  - The solubilities of most gases are greater in cold water than in hot.

Factors Affecting Solubility

- A **supersaturated solution** contains more solute than it can theoretically hold at a given temperature.
- The crystallization can be initiated if a very small crystal, called a seed crystal, is added.

Factors Affecting Solubility

- Pressure
  - Changes in pressure have little effect on the solubility of solids and liquids, but pressure strongly influences the solubility of gases.
  - Gas solubility increases as the partial pressure of the gas above the solution increases.

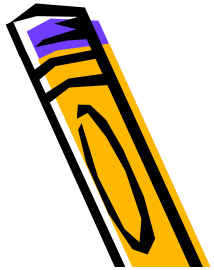


Factors Affecting Solubility

- **Henry's law** states that at a given temperature, the solubility (S) of a gas in a liquid is directly proportional to the pressure (P) of the gas above the liquid.

$$\frac{S_1}{P_1} = \frac{S_2}{P_2}$$

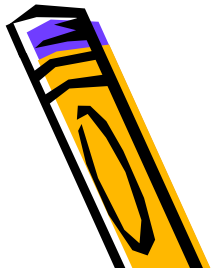
Sample Problem 16.1



Calculating the Solubility of a Gas

If the solubility of a gas in water is 0.77 g/L at 3.5 atm of pressure, what is its solubility (in g/L) at 1.0 atm of pressure? (The temperature is held constant at 25°C.)

for Sample Problem 16.1



2. A gas has a solubility in water at 0°C of 3.6 g/L at a pressure of 1.0 atm. What pressure is needed to produce an aqueous solution containing 9.5 g/L of the same gas at 0°C?

16.1 Section Quiz.

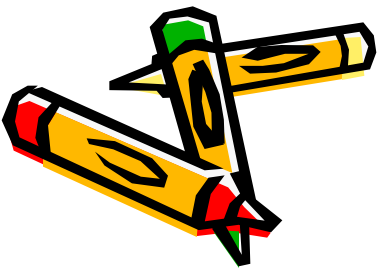
– 1. For a given substance, which of the following will NOT influence how fast it dissolves?

- a) temperature
- b) amount of agitation
- c) molar mass
- d) size of the crystals

16.1 Section Quiz.

–2. The solubility of a substance is often expressed as the number of grams of solute per

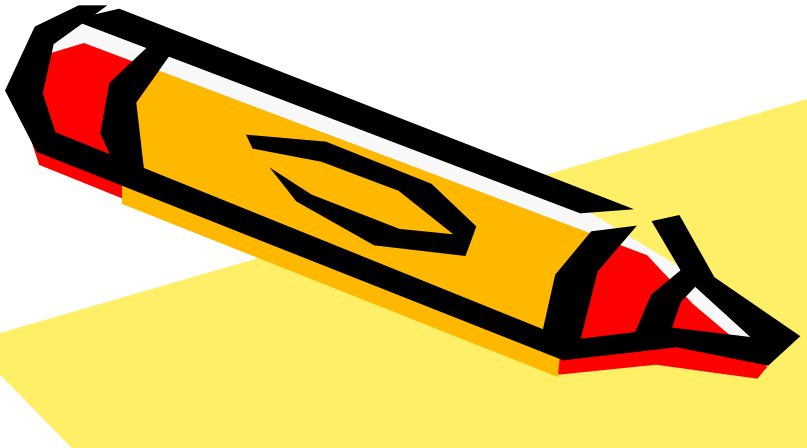
- a) 100 liters of solvent.
- b) 1 cm^3 of solvent.
- c) 100 grams of solution.
- d) 100 grams of solvent.



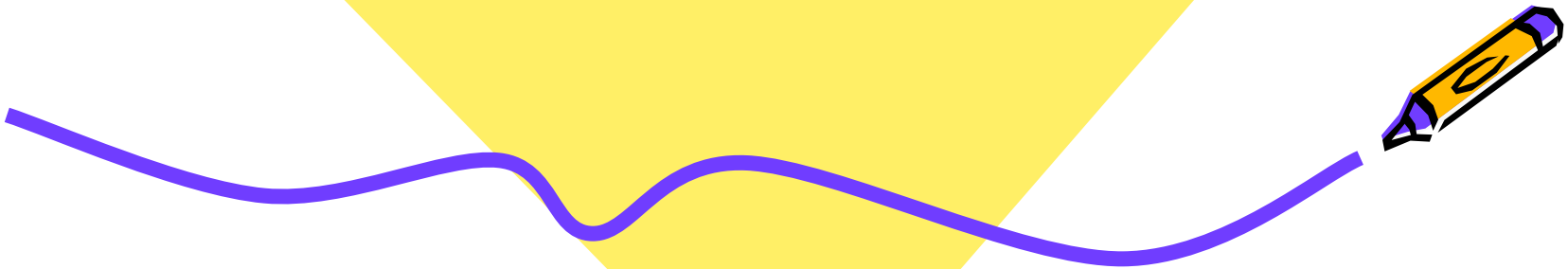
16.1 Section Quiz.

–3. The solubility of a gas in a solvent is affected by

- a) both temperature and pressure.
- b) only pressure.
- c) only temperature.
- d) both pressure and agitation.



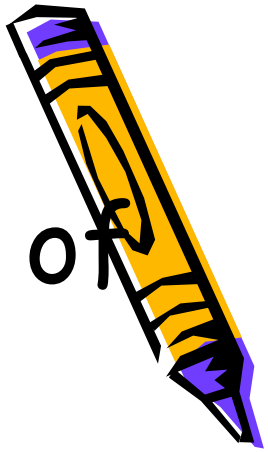
16.2 Concentrations of Solutions



Molarity

- The **concentration** of a solution is a measure of the amount of solute that is dissolved in a given quantity of solvent.
  - A **dilute solution** is one that contains a small amount of solute.
  - A **concentrated solution** contains a large amount of solute.

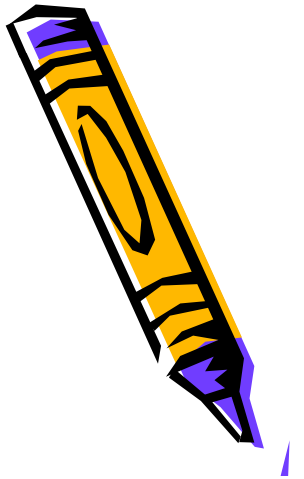
Molarity



- **Molarity** (*M*) is the number of moles of solute dissolved in one liter of solution.
- **To calculate the molarity of a solution, divide the moles of solute by the volume of the solution.**

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

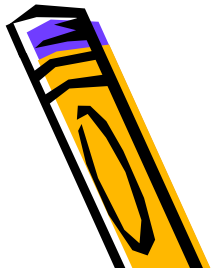
Sample Problem 16.2



Calculating the Molarity of a Solution

Intravenous (IV) saline solutions are often administered to patients in the hospital. One saline solution contains 0.90 g NaCl in exactly 100 mL of solution. What is the molarity of the solution?

for Sample Problem 16.2



8. A solution has a volume of 2.0 L and contains 36.0 g of glucose ($C_6H_{12}O_6$). If the molar mass of glucose is 180 g/mol, what is the molarity of the solution?

Practice

- 1) Calculate the molarity of 15.6 g KBr dissolved in water to make 1.25 L of solution
- 2) Calculate the molarity of 250.0 g $Ca(NO_3)_2$ to make 2.50 L of solution

Practice

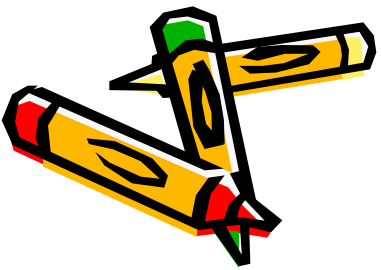
- 3) Calculate molarity of 1.56 g HCl to make 26.8 mL solution
- 4) Calculate molarity of 2.30 g NaCl to make 135 mL solution

Molarity of Ionic Compounds

- Ionic compounds separate into ions when dissolved in water
- Ex: 0.5 M $Co(NO_3)_2$
  - 0.5 M Co
  - 2 x 0.5 = 1.0 M $(NO_3)_2$

Explain in terms of ions:

- 1) 1 M $FeCl_3$
- 2) 0.1 M Na_2CO_3
- 3) 0.010 M $Al_2(SO_4)_3$
- 4) 1.20 M Na_2SO_4
- 5) 0.75 M K_2CrO_4

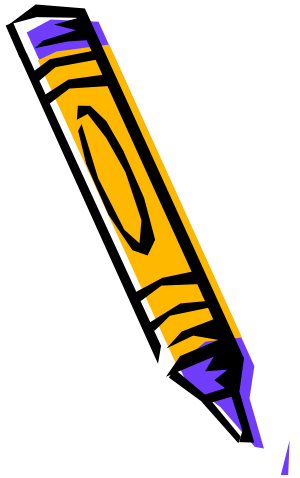


Calculating moles of solute

- M = $\frac{\text{mol solute}}{\text{L solution}}$

Mol solute = M x Liters

Sample Problem 16.3



Finding the Moles of Solute in a Solution

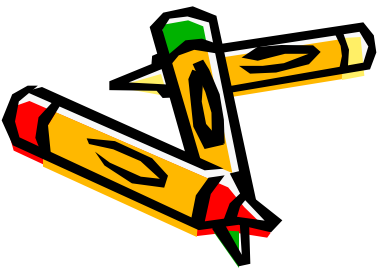
Household laundry bleach is a dilute aqueous solution of sodium hypochlorite (NaClO). How many moles of solute are present in 1.5 L of 0.70*M* NaClO?

for Sample Problem 16.3

11. How many moles of solute are in 250 mL of 2.0*M* $CaCl_2$? How many grams of $CaCl_2$ is this?

Practice

- 1) What mass of $(NH_4)_2SO_4$ is required to make 1.25 L of a 0.250 M solution?
- 2) How many grams of formaldehyde (HCHO) is used to prepared 2.5 L of a 12.3 M solution?



Making Dilutions

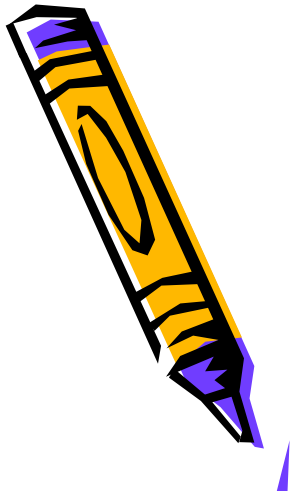
- Diluting a solution reduces the number of moles of solute per unit volume, but the total number of moles of solute in solution does not change.

Making Dilutions

- The total number of moles of solute remains unchanged upon dilution, so you can write this equation.

$$\text{Moles of solute} = M_1 \times V_1 = M_2 \times V_2$$

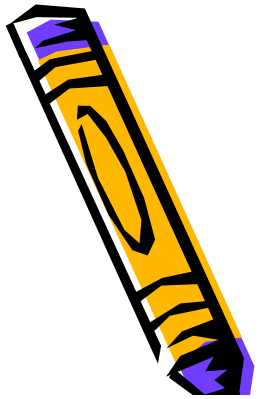
Sample Problem 16.4



Preparing a Dilute Solution

How many milliliters of aqueous 2.00*M* $MgSO_4$ solution must be diluted with water to prepare 100.0 mL of aqueous 0.400*M* $MgSO_4$?

for Sample Problem 16.4



12. How many milliliters of a solution of 4.00*M* KI are needed to prepare 250.0 mL of 0.760*M* KI?

Practice

- 1) What volume of 19 M NaOH must be used to prepare 1.0 L of a 0.15 M solution?
- 2) What volume of 12 M HCl must be taken to prepare 0.75 L of 0.25 M HCl?

Percent Solutions

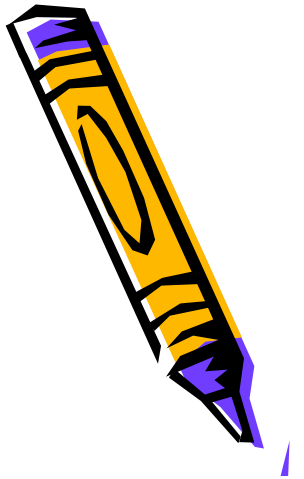
- The concentration of a solution in percent can be expressed in two ways: as the ratio of the volume of the solute to the volume of the solution or as the ratio of the mass of the solute to the mass of the solution.

Percent Solutions

- Concentration in Percent (Volume/Volume)

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

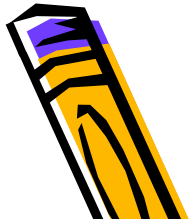
Sample Problem 16.5



Calculating Percent (Volume/Volume)

What is the percent by volume of ethanol (C_2H_6O, or ethyl alcohol) in the final solution when 85 mL of ethanol is diluted to a volume of 250 mL with water?

for Sample Problem 16.5



15. A bottle of the antiseptic hydrogen peroxide (H_2O_2) is labeled 3.0% (v/v). How many mL H_2O_2 are in a 400.0-mL bottle of this solution?

Percent Solutions

- Concentration in Percent (Mass/Mass)

$$\text{Percent by mass (\% (m/m))} = \frac{\text{mass of solute}}{\text{mass of solution}} \times 100\%$$

Practice

- 1) 2.5 g $CaCl_2$ is mixed with 50 g water. Calculate mass %
- 2) A 75 g sample of solution contains 23.8 g glucose. Calculate mass %

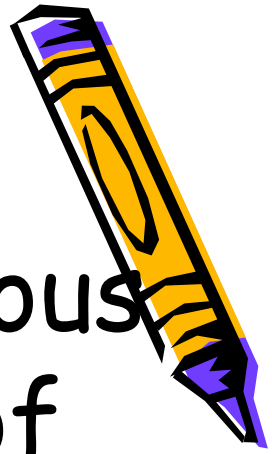
Practice

- 3) Concentrated HCl is 37.2% by mass. What mass of HCl is in 35.5 g concentrated HCl?
- 4) Cow's milk is 4.5% by mass of lactose. Calculate the mass of lactose present in 175 g of milk.

Practice

- 5) What volume of ethanol (C_2H_5OH) is in 100.0 mL of 0.15 M solution? The density of ethanol is 0.7893 g/mL.

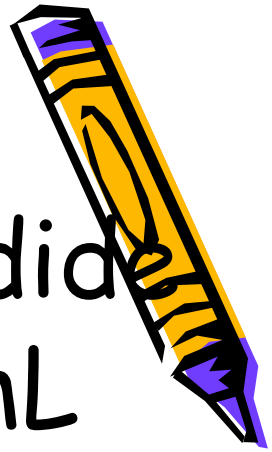
16.2 Section Quiz.



– 1. To make a 1.00*M* aqueous solution of NaCl, 58.4 g of NaCl are dissolved in

- a) 1.00 liter of water.
- b) enough water to make 1.00 liter of solution
- c) 1.00 kg of water.
- d) 100 mL of water.

16.2 Section Quiz.



– 2. What mass of sodium iodide (NaI) is contained in 250 mL of a 0.500*M* solution?

- a) 150 g
- b) 75.0 g
- c) 18.7 g
- d) 0.50 g

16.2 Section Quiz.

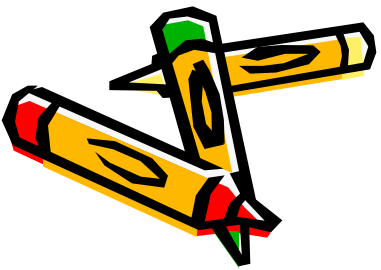
– 3. Diluting a solution does NOT change which of the following?

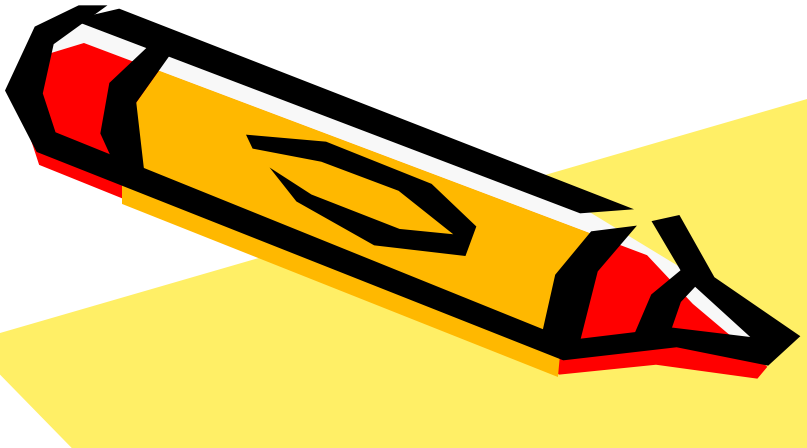
- a) concentration
- b) volume
- c) milliliters of solvent
- d) moles of solute

16.2 Section Quiz.

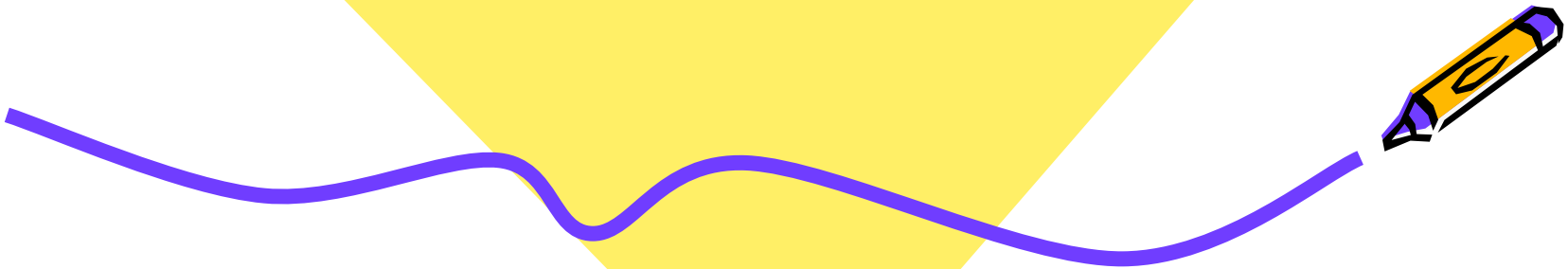
–4. In a 2000 g solution of glucose that is labeled 5.0% (m/m), the mass of water is

- a) 2000 g.
- b) 100 g.
- c) 1995 g.
- d) 1900 g.





16.3 Colligative Properties of Solutions



Colligative Property

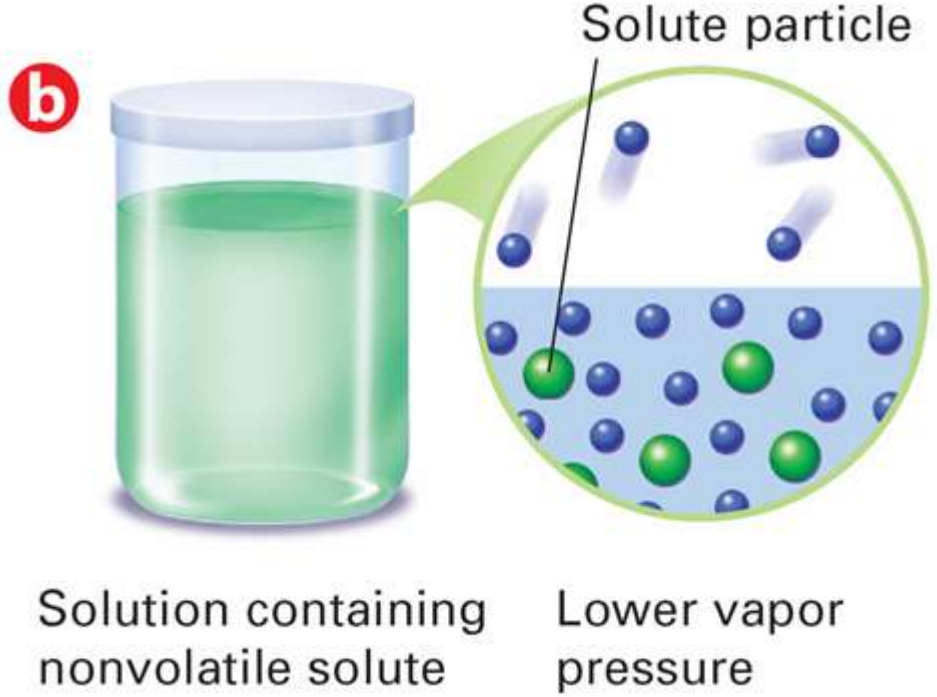
- A property that depends only upon the number of solute particles, and not upon their identity, is called a **colligative property**.

Colligative Properties

- Three important colligative properties of solutions are
  - **vapor-pressure lowering**
  - **boiling-point elevation**
  - **freezing-point depression**

Vapor-Pressure Lowering

- In a solution, solute particles reduce the number of free solvent particles able to escape the liquid. Equilibrium is established at a lower vapor pressure.



Vapor-Pressure Lowering

- The decrease in a solution's vapor pressure is proportional to the number of particles the solute makes in solution.

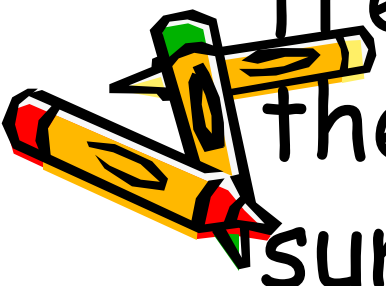
Freezing-Point Depression

- The difference in temperature between the freezing point of a solution and the freezing point of the pure solvent is the **freezing-point depression**.

Freezing-Point Depression

- The magnitude of the freezing-point depression is proportional to the number of solute particles dissolved in the solvent and does not depend upon their identity.

- Boiling-Point Elevation
  - The difference in temperature between the boiling point of a solution and the boiling point of the pure solvent is the **boiling-point elevation**.
    - The same antifreeze added to automobile engines to prevent freeze-ups in winter, protects the engine from boiling over in summer.



Boiling-Point Elevation

- The magnitude of the boiling-point elevation is proportional to the number of solute particles dissolved in the solvent.
  - The boiling point of water increases by 0.512°C for every mole of particles that the solute forms when dissolved in 1000 g of water.

16.3 Section Quiz.

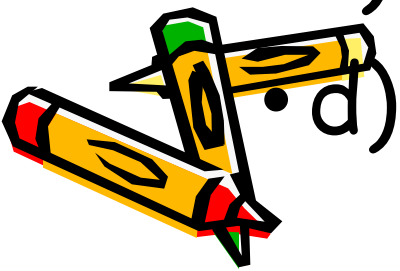
–1. Which of the following is NOT a colligative property of

- a) vapor-pressure lowering
- b) freezing-point depression
- c) boiling-point elevation
- d) solubility elevation

16.3 Section Quiz.

– 2. Choose the correct word for the space: The magnitude of each colligative property of solutions is proportional to the _____ solute dissolved in the solution.

- a) type of
- b) number of particles of
- c) molar volume of
- d) particle size of the



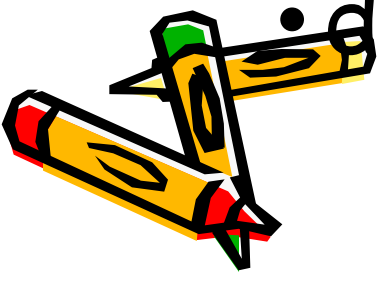
16.3 Section Quiz.

– 3. The decrease in vapor pressure when a solute is added to a liquid is due to

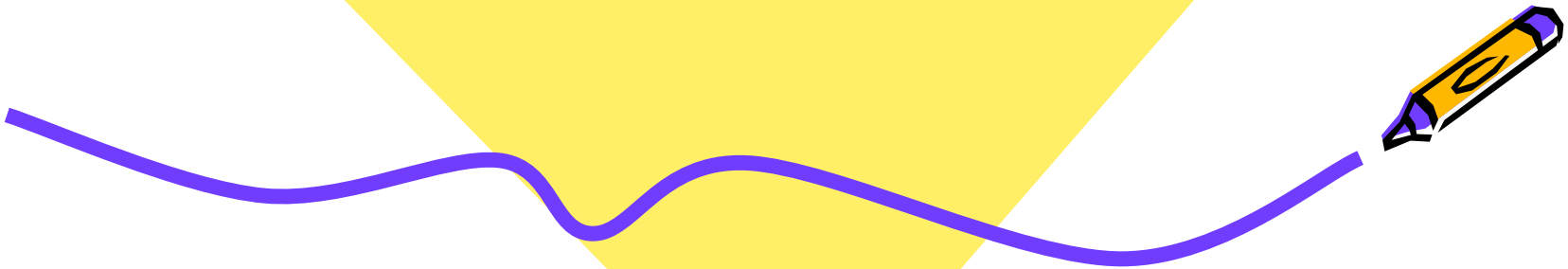
- a) attractive forces between solvent particles.
- b) repulsion of the solute particles by the solvent particles.
- c) dissociation of the solvent particles.
- d) attractive forces between solvent and solute particles.

16.3 Section Quiz.

- 4. You have 500 mL of 1*M* solutions of NaCl, Na_2SO_4, Na_3PO_4, and $Al_2(SO_4)_3$. Which solution will have the highest boiling point?
  - a) NaCl(*aq*)
  - b) Na_2SO_4(*aq*)
  - c) Na_3PO_4(*aq*)
  - d) $Al_2(SO_4)_3$(*aq*)



16.4 Calculations Involving Colligative Properties



Molality and Mole Fraction

- The unit molality and mole fractions are two additional ways in which chemists express the concentration of a solution.

Molality

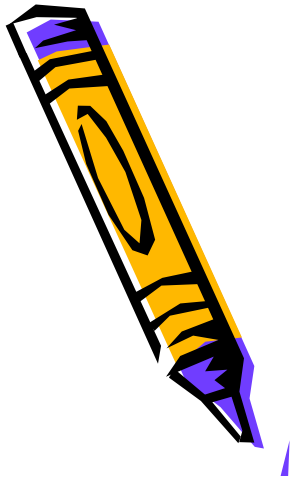
- The **unit molality (*m*)** is the number of moles of solute dissolved in 1 kilogram (1000 g) of solvent. Molality is also known as molal concentration.

$$\text{Molality} = \frac{\text{moles of solute}}{\text{kilogram of solvent}}$$

Molality Practice

- 1. What is the molality of a solution containing 10.0 g Na_2SO_4 dissolved in 1000.0 g of water?
- 2.What is the molality of a solution containing 30.0 g napthalene ($C_{10}H_8$) dissolved in 500.0 g toluene?

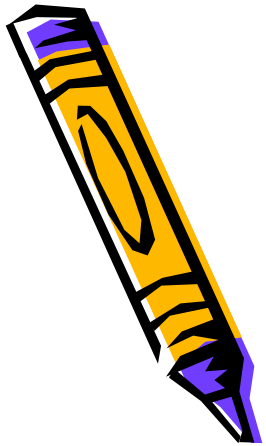
Sample Problem 16.6



Using Solution Molality

How many grams of potassium iodide must be dissolved in 500.0 g of water to produce a 0.060 molal KI solution?

for Sample Problem 16.6



29. How many grams of sodium fluoride are needed to prepare a 0.400*m* NaF solution that contains 750 g of water?

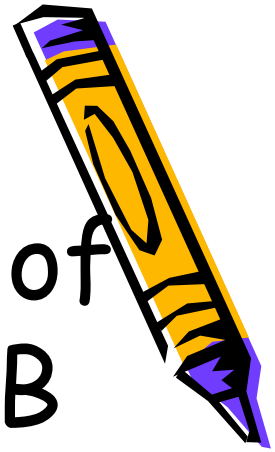
Practice

- How many grams of barium hydroxide are needed to make a 1.00 *m* aqueous solution?

Mole Fraction

- The **mole fraction** of a solute in a solution is the ratio of the moles of that solute to the total number of moles of solvent and solute.

Mole Fraction



- In a solution containing n_A mol of solute A and n_B mol of solvent B (X_B), the mole fraction of solute A (X_A) and the mole fraction of solvent B (X_B) can be expressed as follows.

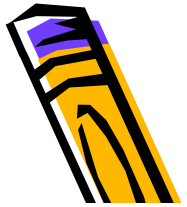
$$X_A = \frac{n_A}{n_A + n_B} \qquad X_B = \frac{n_B}{n_A + n_B}$$

Sample Problem 16.7

Calculating Mole Fractions

Ethylene glycol ($C_2H_6O_2$) is added to automobile cooling systems to protect against cold weather. What is the mole fraction of each component in a solution containing 1.25 mol of ethylene glycol (EG) and 4.00 mol of water?

for Practice Problem 16.7



32. A solution contains 50.0 g of carbon tetrachloride (CCl_4) and 50.0 g of chloroform ($CHCl_3$). Calculate the mole fraction of each component in the solution.

Practice

- What is the mole fraction of NaOH in an aqueous solution that contains 22.8% NaOH by mass?
- If the mole fraction of sulfuric acid (H_2SO_4) in an aqueous solution is 0.325, how much water in grams is in 100 mL of the solution?

Freezing-Point Depression and Boiling-Point Elevation

- The magnitudes of the freezing-point depression (ΔT_f) and the boiling-point elevation (ΔT_b) of a solution are directly proportional to the molal concentration (m), when the solute is molecular, not ionic.

Freezing-Point Depression

- The constant, K_f, is the **molal freezing-point depression constant**, which is equal to the change in freezing point for a 1-molal solution of a nonvolatile molecular solute.

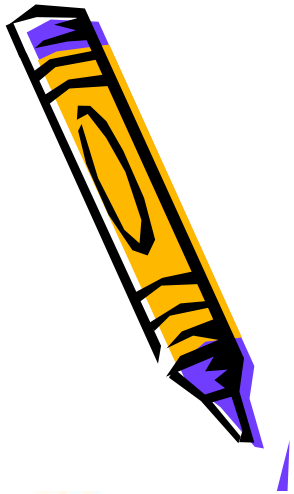
$$\Delta T_f = K_f \times m$$

Boiling-Point Elevation

- The constant, K_b, is the **molal boiling-point elevation constant**, which is equal to the change in boiling point for a 1-molal solution of a nonvolatile molecular solute.

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

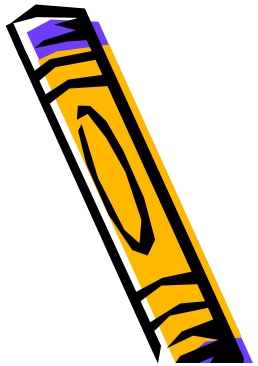
Sample Problem 16.8



Calculating the Freezing-Point Depression of a Solution

Antifreeze protects a car from freezing. It also protects it from overheating. Calculate the freezing-point depression and the freezing point of a solution containing 100 g of ethylene glycol ($C_2H_6O_2$) antifreeze in 0.500 kg of water.

for Sample Problem 16.8



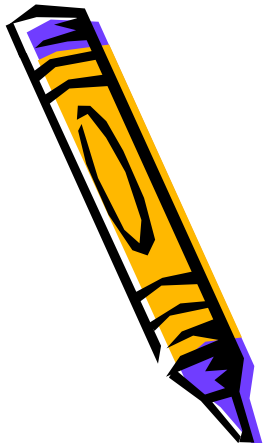
33. What is the freezing point depression of an aqueous solution of 10.0 g of glucose ($C_6H_{12}O_6$) in 50.0 g H_2O?

Sample Problem 16.9

Calculating the Boiling Point of a Solution

What is the boiling point of a 1.50m NaCl solution?

for Sample Problem 16.9



36. What mass of NaCl would have to be dissolved in 1.000 kg of water to raise the boiling point by 2.00°C?

Practice

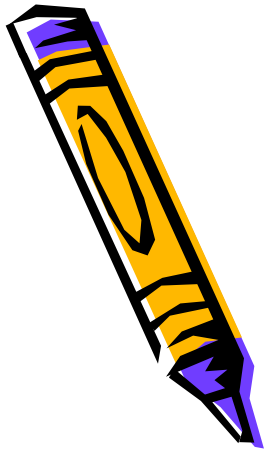
- What are the boiling point and freezing point of a 0.40 *m* solution of sucrose in ethanol?
- *A* 0.045*m* solution (consisting of a nonvolatile nonelectrolyte) is found to have a freezing point depression of 0.08°C. What is the freezing point depression constant (K_f)? Which is most likely the solvent: water, ethanol or chloroform?

16.4 Section Quiz.

–1. What is the mole fraction of He in a gaseous solution containing 4.0 g of He, 6.5 g of Ar, and 10.0 g of Ne?

- 0.60
- 1.5
- 0.20
- 0.11

16.4 Section Quiz.



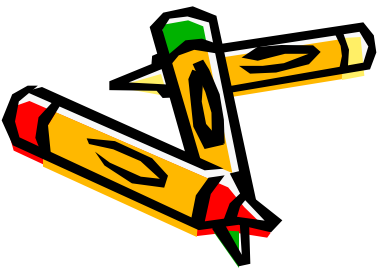
– 2. The freezing point depression caused by a given concentration of a nonvolatile molecular solute

- depends on the solute.
- depends on the solvent.
- is always the same.
- cannot be determined.

16.4 Section Quiz.

–3. What are the freezing and boiling points of a 0.1m solution of $CaCl_2$ in water?

- -0.2°C, 100.1°C
- -0.6°C, 100.1°C
- -0.6°C, 100.2°C
- -0.6°C, 99.8°C



16.4 Section Quiz.

- 4. Compared to the freezing point depression by ethylene glycol ($C_2H_6O_2$,) for a given solvent, the freezing point depression caused by the same molal concentration of $CaCl_2$ would be
  - exactly the same.
  - twice as large.
  - three times as large.
  - four times as large