

# Chapter 13

## Properties of Solutions

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### Chapter 13 suggested problems

10th Ed.: 13, 23, 25, 27, 37, 45a, 47a, 55

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## Class Notes

### I. The solution process

#### A. Solutions, colloids, and suspensions

1. Solution: homogeneous mixture, equally dispersed at the molecular level, uniform throughout in its physical and chemical properties
2. Colloid: a state of matter intermediate between a solution and a suspension, in which solute particles are large enough to scatter light but too small to be affected by gravity - solutes are aggregations of particles forming larger particles
3. Suspension: molecular-level aggregations of particles physically suspended in liquid, sometimes so small that gravity has no effect on the particles
4. Types of solutions
  - a. Gas in gas: air
  - b. Gas in liquid: air dissolved in water, carbonated water
  - c. Liquid in liquid: ethanol in water
  - d. Liquid in solid: mercury in silver in dental amalgam
  - e. Solid in liquid: any salt in water
  - f. Solid in solid: brass, bronze, and all alloys

#### B. Terminology

1. Solvent: does the dissolving, present in greater abundance (except when gases or solids are dissolved in a liquid)
  2. Solute: gets dissolved, present in lesser abundance
  3. Assumption: chemical reactions do not occur between solvent and solutes while in solution
  4. Solubility: the maximum amount of a substance that will dissolve in a specific amount of solvent to give a thermodynamically stable solution, usually expressed in grams and at specific temperature and pressure conditions
    - a. NaCl: 35.7 g per 100 cc of water at 0°C
    - b. CO<sub>2</sub>: 171.3 g per 100 cc of water at 0°C
    - c. Barium sulfate: 0.000222 g per 100 cc of water at 18°C
  5. Molar solubility: solubility expressed in moles rather than in grams per specific amount of solvent or solution
  6. Saturated solution: a solution in which as much solute as is physically possible has been dissolved in the solvent, with some solute remaining undissolved
  7. Unsaturated solutions and supersaturated solutions
  8. Miscible: two (or more) substances that can form solutions in all proportions
- C. General solvation theory at a molecular level
1. Solvation: the molecular process by which solutes are dissolved by solvents
  2. Hydration: the molecular process by which solutes are dissolved by water
  3. "Like attracts like" governs solvent-solute interactions and dissolution, or the lack of reaction between a solvent and solute
- D. Temperature and pressure may both affect solubility
- E. Enthalpy and entropy of solution
1. If a solute is more soluble at a warmer temperature than at a cooler temperature, solvation is endothermic
  2. If a solute is more soluble at a cooler temperature than at a warmer temperature, solvation is exothermic
  3. Dissolving solutes in solvents make the system more chaotic (less ordered), which also encourages spontaneity as the entropy of the system increases (i.e., + S)

## II. Ways of expressing concentration

- A. Concentration: a measure of the amount of solute dissolved in either a specific amount of solvent or solution
- B. Percent composition: in general, the ratio of amount of solute to amount of solution multiplied by 100
1. Weight/weight (w/w):  $(\text{grams solute} / \text{grams solution}) \times 100$
  2. Weight/volume (w/v):  $(\text{grams solute} / \text{volume solution}) \times 100$
  3. Volume/volume (v/v):  $(\text{volume solute} / \text{volume solution}) \times 100$
  4. Examples
    - a. What is the (w/w) concentration of 100 g of solution containing 1.22 g of sodium chloride? 1.22% w/w
    - b. What is the (w/v) concentration of 50.0 mL of solution containing 1.22 g of sodium chloride? 2.44% w/v
    - c. What is the (v/v) concentration of a solution containing 100 mL of isopropyl alcohol that is diluted with water to 150 mL? 66.7% v/v
- C. Concentrations of dilute solutions
1. mg %:  $(\text{mg solute} / 100 \text{ mL solution}) \times 100$
  2. ppm: parts per million,  $(\text{mg solute} / \text{L solution})$
  3. ppb: parts per billion,  $(\text{ug solute} / \text{L solution})$
- D. Molality: (m), molal concentration, moles solute / kg solvent
1. What is the molal concentration of 125 grams of glucose that is dissolved in 750 grams of water?
  2.  $(125 \text{ g glucose}) \times (\text{mole glucose} / 180.2 \text{ g glucose}) \times (1 / 750 \text{ g water}) \times (1000 \text{ g water} / 1 \text{ kg water}) = 0.925 \text{ m}$
- E. Molarity: (M), molar concentration, moles solute / L solution
1. What is the molar concentration of 125 grams of glucose that is dissolved in 750 grams of water?
  2.  $(125 \text{ g glucose}) \times (\text{mole glucose} / 180.2 \text{ g glucose}) \times (1 / 0.750 \text{ L solution}) = 0.925 \text{ M}$
  3. Molar and molal concentrations will not always be the same

## 4. Calculating molarity

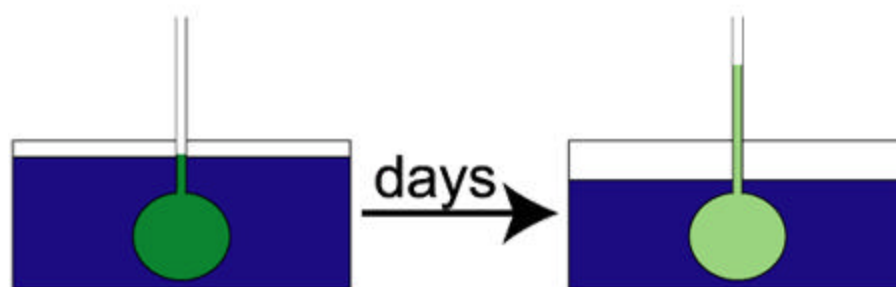
- a. If 0.100 moles of  $\text{H}_2\text{SO}_4$  is dissolved in 450 mL of water, what is the molarity of the resulting solution? (0.222 M)
- b. If 37.6 grams of copper (II) nitrate is dissolved in 500 mL of water, what is the molarity of the resulting concentration? ( $M_M = 187.56$  g/mol; 0.334 M)
- c. How many moles of copper (II) nitrate are contained in 25.0 mL of 2.5 M solution? (0.0625 moles copper (II) nitrate)
- d. How many grams of ammonium hydroxide are contained in 75 mL of concentrated (15M) solution? ( $M_M = 35.05$  g/mol; 39.43 g)

## III. Colligative properties - solution properties which depend on the number of particles rather than on the chemical nature of the particles

## A. Vaporization and vapor pressure lowering

1. An important difference between molecules in the liquid and gas phases is the KE of the particles
2. If we examine the KE of all of the particles in any phase we find not a single KE but a Gaussian distribution of energies - i.e., there are many molecules with very high energies and many with very low energies as well
3. Molecules in the liquid phase with high KE and near the l-g phase boundary can actually have enough KE to "escape" from the liquid and join the gas phase
4. This is why heating a liquid facilitates the l-g transition
5. Molecules in the vapor phase collide with the liquid surface during their random travels
  - a. High KE - bounce off surface
  - b. Low KE - "stick" and become part of liquid phase
  - c. By cooling a vapor we lower the average KE of the molecules in the gas phase and make it easier for them to "stick" to the liquid surface if they collide with it
6. At any given temperature an equilibrium exists between the rates of  $l \rightarrow g$  and  $g \rightarrow l$
7. The pressure exerted by the vapor when this equilibrium exists is called the vapor pressure

8. Boiling point: when the vapor pressure of a liquid is equal to atmospheric pressure
  9. Normal boiling point: when the vapor pressure of a liquid is equal to exactly 1 atm
  10. Vapor pressure is like BP in that it gives a general relative sense of the strengths of intermolecular forces
    - a. Propane - 8.6 atm, acetone - 266 T, i-PrOH - 33 T
    - b. Hexane - 124 T, 2-hexanone - 3 T
  11. Vapor pressure lowering: if a nonvolatile solute is dissolved in a volatile solvent the vapor pressure of the resulting solution is less than that of the pure solvent.
- B. Diffusion: molecules tend to move from areas of high to low concentration until uniformly distributed
1. This randomizing effect will occur independent of any external forces (e.g. mixing) and is due to random collisions between molecules (Brownian motion; see **Einstein's Explanation of Brownian Motion**)
  2. The rate of diffusion depends on several factors including temperature, viscosity and pressure, the molecular weight of the solute, and solute concentration
  3. This is how a solute achieves uniform distribution throughout a solvent in the process of forming a solution - g/g, g/l, l/l, l/s
- A. Osmosis
1. Definitions
    - a. Membrane: a sheet-like structure, often porous, that can regulate the passage of substances from one side of the membrane to the other based on molecular size or charge
    - b. Membranes that allow some substances to pass but not others are called semi-permeable
    - c. Osmosis: the flow of water through a semi-permeable membrane from areas of low to high solute concentration



Sugar water solution enclosed in a semi-permeable membrane and placed in a water bath. An open glass tube sticks out of the end of the semi-permeable membrane. Over a period of days water will diffuse into the sugar water solution, forcing the solution up the glass tube, diluting the solution, and lowering the water level in the bath.

- d. Osmotic pressure: a force is generated by osmosis. The pressure that would be required to stop the net flow of water (i.e., the force required to stop osmosis) is the osmotic pressure
  - a. Reverse osmosis: forcing water across a semi-permeable membrane from areas of high to low solute concentration
  - b. Used to desalinate sea water for drinking
- e. Osmolarity: the behavior of dilute solutions is similar to the behavior of gases in some respects, to the extent that the behavior of dilute solutions can be approximated using the Ideal Gas Law
  - i.  $\pi = i n R T / V = i M R T$
  - ii.  $i = \#$  of particles per solute molecule,  $i = 1$  for nonelectrolytes,  $i = 2$  or greater for all electrolytes
  - iii.  $n = \#$  moles of solute
  - iv.  $M =$  solute molarity

## 2. Examples

- a. What is the osmotic pressure ( $\pi$ ) of a 0.0020 M solution of sucrose ( $C_{12}H_{22}O_{11}$ ) at 20°C? (0.048 atm = 37 T)
- b. The average osmotic pressure of blood is 7.7 atm at 25°C. What concentration of glucose will be isotonic with blood? (0.315 M)
  - i. Isotonic: two solutions with equal osmotic pressures
  - ii. Hypotonic: one solution has a lower osmotic pressure than the

other

iii. Hypertonic: one solution has a higher osmotic pressure than the other

c. Finding the  $M_M$  of an unknown substance via osmotic pressure

i. since  $n = g / M_M$  then  $\pi = nRT/V = igRT/(M_M V) \Rightarrow M_M = igRT/(\pi \times v)$

ii. The osmotic pressure of an aqueous solution of an unknown protein was found to be 1.54 T at 20°C. The solution contained 3.50 mg of the protein, which had been dissolved in 5.00 mL of water. Find the molar mass of the protein (assume  $i = 1$  for proteins). ( $M_M = 8451$  g/mol)

B. Boiling point elevation:  $T_b = iK_b c_m$

C. Freezing point depression:  $T_f = iK_f c_m$

D. Vapor pressure depression:  $P_a = X_a P_a^\circ$

E. Osmotic pressure elevation:  $\pi = iMRT$

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***[Chemistry 1210 Index Page]***

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Last Modified 11/24/2006 20:27:31

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