

# LECTURE NOTES FOR GENERAL CHEMISTRY © MM 2001

## CHAPTER 12

### SOLUTIONS

A SOLUTION IS A HOMOGENOUS MIXTURE OF TWO OR MORE SUBSTANCES. THIS IS A VERY BROAD CATEGORY, INCLUDING THE ATMOSPHERE, A SOLUTION OF GASSES, THE OCEANS, A SOLUTION OF SOLIDS IN A LIQUID, AND 14-KARAT GOLD, A SOLUTION OF A SOLID Ag, IN A SOLID, A U.

GENERALLY, THE MAIN COMPONENT OF A SOLUTION IS CALLED THE SOLVENT AND THE MINOR COMPONENTS ARE CALLED THE SOLUTE. THE DISTINCTION MAY LOSE ANY USEFULNESS, FOR EXAMPLE, IN A 50/50 MIXTURE

#### SOLUTION CONCEPTS

MOLARITY  $M$  = MOLES PER LITER

% CONCENTRATION

- THIS UNIT TAKES 3 FORMS, WHICH MUST BE SPECIFIED

EXAMPLE      MASS/MASS      VOLUME/VOLUME      MASS/VOLUME

HOW WOULD YOU PREPARE A  $H_2O$  SOLUTION CONTAINING 2.40% BY MASS OF  $NaCl$ ? THE TOTAL VOLUME NEEDED IS 425g

$$425 \text{ g} \times 0.0240 = 10.2 \text{ g OF } NaCl$$

$$425 - 10.2 = 414.8 \text{ g } H_2O \leftarrow \text{COMBINE THESE 2}$$

TO CONVERT FROM VOL/VOL TO MASS/MASS, USE DENSITY

EXAMPLE

USP ETHANOL CONTAINS 95% ETHANOL, 5%  $H_2O$  BY VOLUME  
WHAT IS THE % BY MASS OF THIS SOLUTION?

THE DENSITY OF USP ETHANOL IS 0.813 g/mL

THE DENSITY OF PURE ETHANOL IS 0.789 g/mL

BASE THE CALCULATION ON 100.0 ML FOR CONVENIENCE

THE MASS OF 100.0 ML USP ETHANOL IS  $100.0 \text{ mL} \times 0.813 \text{ g/mL} = 81.3 \text{ g}$   
IN 100.0 ML USP ETHANOL 95% BY VOLUME IS PURE ETHANOL

$$100.0 \text{ mL} \times 0.95 = 95 \text{ mL}$$

THE MASS OF 95.0 ML PURE ETHANOL IS  $95.0 \text{ mL} \times 0.789 \text{ g/mL} = 75.0 \text{ g}$

THE MASS % ETHANOL OF USP ETHANOL IS  $\frac{75.0 \text{ g ETHANOL}}{81.3 \text{ g SOLUTION}} = 92.3\%$

PARTS PER MILLION, BILLION, TRILLION

A PERCENT IS ONE PART IN ONE HUNDRED

WE ALSO USE PARTS PER THOUSAND = PPT =  $\text{g/L}$

PARTS PER MILLION = PPM =  $\text{mg/L}$

PARTS PER BILLION = PPB =  $\mu\text{g/L}$

PARTS PER TRILLION = PPT =  $\text{ng/L}$

EXAMPLE

WHICH CONCENTRATION IS HIGHER BY MASS %

0.001 M  $\text{MgCl}_2$  OR A  $\text{MgCl}_2$  SOLUTION WITH 105 ppm  $\text{Mg}^{2+}$

0.001 M MEANS .001 MOL/L OR .001 MOL/1000 g

105 ppm MEANS 105 mg/L OR 0.105 g/1000 g

.001 MOL  $\text{MgCl}_2 = .001 \text{ mol} \times 95.2 \text{ g/mol} = 0.095 \text{ g}$

MOLALITY

THE MOLALITY OF A SOLUTION IS THE MOLES OF SOLUTE PER KILOGRAM OF SOLVENT.

FOR EXAMPLE, 0.20 MOL OF ETHYLENE GLYCOL DISSOLVED IN 2 KG OF WATER HAS A MOLALITY OF

$$\frac{0.20 \text{ mol}}{2 \text{ kg}} = 0.10 \text{ m ETHYLENE GLYCO.}$$

## MOLE FRACTION AND MOLE %

$$\text{MOLE FRACTION} = \chi_A = \frac{\text{MOLES OF SUBSTANCE A}}{\text{TOTAL MOLES OF SOLUTION}}$$

EXAMPLE: A N AQUEOUS SOLUTION IS 0.120 M GLUCOSE. WHAT ARE THE MOLE FRACTIONS OF EACH COMPONENT

$$0.120 \text{ m means } \frac{0.120 \text{ MOL}}{1.0 \text{ kg H}_2\text{O}}$$

FIND THE MOLARITY OF H<sub>2</sub>O

$$1 \times 10^3 \text{ g} \times \frac{1 \text{ MOL H}_2\text{O}}{18 \text{ g H}_2\text{O}} = 55.6 \text{ MOL H}_2\text{O}$$

$$\text{MOLE FRACTION GLUCOSE} = \frac{0.120}{55.6 + 0.120} = .00215$$

$$\text{MOLE FRACTION H}_2\text{O} = \frac{55.6}{55.6 + 0.120} = 0.998$$

## ENTHALPY OF SOLUTION

DISSOLVING A SOLUTE MAY BE EXOTHERMIC, ENDOTHERMIC, OR  $\Delta H_{\text{soln}} = 0$

CONSIDER THE INTERMOLECULAR FORCES INVOLVED

FORCES BETWEEN:

- SOLVENT MOLECULES
- SOLUTE MOLECULES
- SOLVENT-SOLUTE FORCES

ENERGY IS CONSUMED SEPARATING THE SOLVENT MOLECULES AND

THE SOLUTE MOLECULES FROM ONE ANOTHER

ENERGY IS PRODUCED WHEN SOLVENT AND SOLUTE MOLECULES MIX

THERE ARE 4 POSSIBILITIES

- 1) ALL INTERMOLECULAR FORCES ARE OF COMPARABLE STRENGTH  
- AN IDEAL SOLUTION  $\Delta H_{\text{soln}} = 0$
- 2) SOLVENT-SOLUTE FORCES ARE STRONGEST  
- A NON IDEAL SOLUTION  
 $\Delta H_{\text{soln}}$  IS NEGATIVE, EXOTHERMIC  
- TOTAL VOLUME WILL BE LESS THAN EXPECTED

3) SOLVENT-SOLUTE FORCES ARE WEAKEST

$\Delta H_{\text{soln}} + \text{ENDOTHERMIC}$

4) SOLVENT-SOLUTE FORCES ARE MUCH WEAKER

- NO SOLUTION WILL FORM OIL AND WATER

### AQUEOUS SOLUTIONS OF IONIC COMPOUNDS

IONIC COMPOUNDS ARE VERY STRONGLY HELD TOGETHER BY ELECTROSTATIC FORCES

IT TAKES LOTS OF ENERGY TO BREAK THESE

ENTHALPY OF FORMATION IS HIGHLY EXOTHERMIC, LATTICE

ENERGIES ARE TYPICALLY 500 TO 1000 KJ/MOL

MELTING POINTS ARE QUITE HIGH 500 - 1000°C

YET MANY IONIC COMPOUNDS DISSOLVE EASILY IN WATER

IONS ARE SURROUNDED BY WATER MOLECULES → "HYDRATED"

IF THE ION-DIPOLE FORCES ARE STRONGER THAN THE

IONIC ATTRACTIVE FORCES, THE SOLID WILL DISSOLVE

MOST IONIC SOLIDS ARE ONLY WATER SOLUBLE UP TO A POINT, THE POINT IS THE SATURATION POINT. AT THIS POINT THERE IS A DYNAMIC EQUILIBRIUM BETWEEN SOLID AND DISSOLVED IONS

### TEMPERATURE

INCREASING T USUALLY MEANS MORE SOLUBILITY

### SOLUBILITY OF GASSES

MOST GASSES BECOME LESS SOLUBLE AS T INCREASES

### THE EFFECT OF PRESSURE

THE SOLUBILITY OF A GASS IS DIRECTLY PROPORTIONAL TO THE PRESSURE OF THE GAS

$$S = kP$$

S = SOLUBILITY  
k = A CONSTANT  
P = PRESSURE

THIS IS HENRY'S LAW

## APPLYING HENRY'S LAW

27 g OF ACETYLENE,  $C_2H_2$  DISSOLVES IN 1 L OF ACETONE AT 1.0 ATM PRESSURE. IF THE PARTIAL PRESSURE OF ACETYLENE IS INCREASED TO 12 ATM, HOW MUCH DISSOLVES IN 1 L

$$\frac{S_2}{S_1} = \frac{P_2}{P_1} \quad \frac{S_2}{27g} = \frac{12 \text{ ATM}}{1 \text{ ATM}} \quad S_2 = 3.2 \times 10^2 g$$

## COLLIGATIVE PROPERTIES

THESE ARE PHYSICAL PROPERTIES THAT DEPEND ON THE NUMBER OF SOLUTE PARTICLES BUT NOT ON THE IDENTITY OF THE SOLUTE

## VAPOR PRESSURE

A NONVOLATILE SOLID, DISSOLVED IN A SOLUTION LOWERS THE VAPOR PRESSURE OF THAT SOLUTION

EXPRESSED AS RAOULTS LAW

- THE VAPOR PRESSURE OF A SOLVENT EQUALS THE VAPOR PRESSURE OF THE PURE SOLVENT TIMES ITS MOLE FRACTION IN THE SOLUTION

$$P_{\text{SOLV}} = X_{\text{SOLV}} \cdot P_{\text{SOLV}}^{\circ}$$

CALCULATE THE VAPOR PRESSURE LOWERING OF WATER WHEN 5.67g OF GLUCOSE IS DISSOLVED IN 25.2 g  $H_2O$  AT  $25^{\circ}C$ . THE VAPOR PRESSURE OF  $H_2O$  IS 23.8 mm Hg.

THIS IS THE GLUCOSE SOLUTION WE PREVIOUSLY FOUND TO BE 0.022 MOLE FRACTION GLUCOSE 0.98 MOLE FRACTION  $H_2O$

$$23.8 \times .98 = 23.3 \text{ mm Hg}$$

THE VAPOR PRESSURE LOWERING IS 0.5 mm

## FREEZING POINT DEPRESSION AND BOILING POINT ELEVATION

ADDITION OF A NONVOLATILE, NONELECTROLYTE SOLUTE LOWERS

A SOLVENT'S FREEZING POINT AND RAISES ITS BOILING POINT

IT'S A COLLIGATIVE PROPERTY - DEPENDS ON THE NUMBER OF SOLUTE PARTICLES

BOILING POINT ELEVATION,  $\Delta T_b$ , DEPENDS ON THE MOLAL CONCENTRATION OF THE SOLUTE  $C_m$

$$\Delta T_b = K_b C_m \quad \text{WHERE } K_b \text{ IS A CONSTANT UNIQUE TO EACH SOLVENT}$$

FOR EXAMPLE  $K_b$  FOR  $H_2O$  IS  $0.512^\circ C/m$

SO AN ANTI FREEZE SOLUTION THAT IS 12 m ETHYLENE GLYCOL

BOILS AT  $12 m \times 0.512^\circ C/m = 6.44^\circ C$  HIGHER THAN PURE  $H_2O$

FREEZING POINT DEPRESSION IS SIMILAR

$$\Delta T_f = K_f \times C_m$$

SO THIS SAME SOLUTION FREEZES AT ( $K_f = 1.86^\circ C/m$ )

$$12 m \times 1.86^\circ C/m = 22.3^\circ C \text{ LOWER THAN } H_2O$$

THIS CAN BE USED TO CALCULATE MOLECULAR WEIGHT

IN 25.4 g  $H_2O$  DISSOLVE 0.131 g SUBSTANCE. BY FREEZING POINT DEPRESSION, THE MOLALITY IS 0.056 m. WHAT IS THE MOLECULAR WEIGHT?

$$\frac{0.056 \text{ mol}}{\text{kg } H_2O} = \frac{x \text{ mol}}{25.4 \times 10^{-3} \text{ kg } H_2O} \quad x = 1.42 \times 10^{-3} \text{ mol}$$

$$\text{MOLECULAR MASS} = \frac{0.131 \text{ g}}{1.42 \times 10^{-3} \text{ mol}} = 92 \text{ g/mol}$$

## OSMOSIS

OSMOSIS IS THE PHENOMENON OF SOLVENT FLOW THROUGH A SEMIPERMEABLE MEMBRANE TO EQUALIZE THE SOLUTE CONCENTRATIONS ON BOTH SIDES OF THE MEMBRANE

THE OSMOTIC PRESSURE,  $\Pi$  IS A COLIGATIVE PROPERTY OF A SOLUTION, EQUAL TO THE PRESSURE THAT, WHEN APPLIED TO THE SOLUTION, IS JUST SUFFICIENT TO STOP OSMOSIS

$$\Pi = MRT$$

M = MOLARITY  
R = GAS CONSTANT  
T = KELVIN TEMPERATURE

### EXAMPLE

0.798 grams OF STARCH, MW = 32,400 IS DISSOLVED IN 100.ML OF H<sub>2</sub>O AT 25° C. WHAT IS THE OSMOTIC PRESSURE?

$$0.798 \text{ g} \times \frac{1 \text{ MOL}}{32,400 \text{ g}} = 2.46 \times 10^{-5} \text{ MOL STARCH}$$

THE MOLARITY OF THE SOLUTION IS

$$\frac{2.46 \times 10^{-5} \text{ MOL}}{0.100 \text{ L}} = 2.46 \times 10^{-4} \text{ M}$$

AND THE OSMOTIC PRESSURE IS

$$\begin{aligned} \Pi &= MRT \\ &= 2.46 \times 10^{-4} \frac{\text{MOL}}{\text{L}} \times 0.0821 \frac{\text{L ATM}}{\text{MOL}^\circ\text{K}} \times 298^\circ\text{K} \\ &= 6.02 \times 10^{-3} \text{ ATM OR } 4.6 \text{ mm Hg} \end{aligned}$$

FOR COMPARISON, CALCULATE THE FREEZING POINT DEPRESSION  
ASSUME  $M = m$  (TRUE ONLY IN VERY DILUTE SOLUTIONS)

$$\Delta T_F = K_F \times c_m = 1.86^\circ\text{C}/m \times 2.46 \times 10^{-4} m = 4.58 \times 10^{-4}^\circ\text{C}$$

THIS IS A BARELY DETECTABLE  $\Delta T$

## PRACTICAL APPLICATIONS OF OSMOSIS

LIVING CELLS ARE SURROUNDED BY A SEMIPERMEABLE MEMBRANE. CELLS PLACED IN PURE WATER BURST DUE TO INFLOW OF  $H_2O$ . PURE WATER IS A HYPOTONIC SOLUTION MEANING IT HAS LOWER AMOUNTS OF DISSOLVED SUBSTANCES IN A CONCENTRATED, HYPERTONIC SALINE SOLUTION, CELLS SUFFER LOSS OF  $H_2O$  AND SHRINK  
AN ISOTONIC SOLUTION HAS THE SAME CONCENTRATION OF DISSOLVED SUBSTANCES AS THE CELL

FRESH WATER IS MADE FROM SEAWATER BY REVERSE OSMOSIS  
SEAWATER ON ONE SIDE OF A SEMIPERMEABLE MEMBRANE IS PLACED UNDER HIGH PRESSURE. PURE WATER IS FORCED THROUGH THE MEMBRANE

WHEN STRONG ELECTROLYTES ARE DISSOLVED EACH ION COUNTS AS 1 PARTICLE. SO, 0.25 M  $NaCl$  IS 0.50 M IN TOTAL PARTICLES  
WEAK ELECTROLYTES ONLY PARTIALLY IONIZE. TO WORK WITH ELECTROLYTES WE INTRODUCE THE VANTHOFF FACTOR  $i$

$$\text{FREEZING POINT DEPRESSION } \Delta T_f = -i K_f m$$

$$\text{BOILING POINT ELEVATION } \Delta T_b = i K_b m$$

$$\text{OSMOTIC PRESSURE } \pi = i M R T$$

FOR NON-ELECTROLYTES,  $i = 1$

FOR DILUTE SOLUTIONS OF STRONG ELECTROLYTES  $i$  APPROACHES INTEGER VALUES 2 FOR  $NaCl$  3 FOR  $MgCl_2$

$NaCl$	$i$
1 M	1.81
0.1 M	1.81
0.01 M	1.94
0.001 M	1.97

FOR WEAK ELECTROLYTES  $i$  DEPENDS ON THE % IONIZATION



## EXAMPLE

CALCULATE THE FREEZING POINT OF A 0.010M AQUEOUS SOLUTION OF ALUMINUM SULFATE  $Al_2(SO_4)_3$   $i = 4.4$

$Al_2(SO_4)_3$  DISSOLVES TO MAKE 5 IONS,  $2Al^{3+} + 3SO_4^{2-}$

$$\Delta T_f = i K_f C_m$$

$$= 4.4 \times 1.86 \text{ } ^\circ\text{C}/m \times 0.01m = 0.086 \text{ } ^\circ\text{C}$$

## COLLOIDS

A COLLOID IS A DISPERSION OF VERY FINE PARTICLES RANGING FROM  $10^3$  pm TO  $2 \times 10^5$  pm IN SIZE. THE PARTICLES (DISPERSED PHASE) ARE DISPERSED IN A "SOLVENT" (CONTINUOUS PHASE)

NAME	CONTINUOUS PHASE	DISPERSED PHASE	EXAMPLE
AEROSOL	GAS	LIQUID	FOG
AEROSOL	GAS	SOLID	SMOKE
FOAM	LIQUID	GAS	WHIPPED CREAM
EMULSION	LIQUID	LIQUID	MILK, MAYONNAIS
SOL	LIQUID	SOLID	PEARL, OPAL, BUTTE
FOAM	SOLID	GAS	PUMICE, STYROFOAM
GEL	SOLID	LIQUID	JELLY
SOLID SOL	SOLID	SOLID	RUBY GLASS GLASS WITH DISPERSED METAL

COLLOIDS SCATTER LIGHT → THE TYNDALL EFFECT

COLLOIDS MAY BE COAGULATED BY THE ADDITION OF ELECTROLYTES  
THE COAGULATION SEPARATES THE DISPERSED PHASE FROM THE CONTINUOUS PHASE

## CHAPTER 12

### SKILLS

### PROBLEMS AND EXAMPLES

WORK WITH SOLUTION CONCENTRATION  
BY MASS %

EX 12.1, 23, 25

WORK WITH CONCENTRATION UNITS  
OF PPM, PPB, PPT

EX 12.3, 33

CALCULATE MOLARITY FROM MOLALITY

38, 39, 35

CALCULATE MASS % FROM VOL %  
USING THE DENSITY

EX 12.2

CALCULATE MOLALITY

35, EX 12.4, 12.5

WORK WITH MOLE FRACTION

EX 12.6, 41, 43

PREDICT WHICH COMPOUND IS  
SOLUBLE IN WHICH SOLVENT

EX 12.8, 47

WORK WITH HENRY'S LAW

EX 12.9, 55, EX 12.10

CALCULATE FREEZING POINT  
DEPRESSION, B.P. ELEVATION

EX 12.14, EX 12.15, 61, 63

CALCULATE OSMOTIC PRESSURE

71, EX 12.16

KNOW THE COLLIGATIVE PROPERTIES  
OF ELECTROLYTES

77, EX 12.17