

Solutions

Concentration

Solution concentration = how much solute dissolved in solvent

Coffee crystal = solute

Water = solvent

Liquid Coffee = solution

so a solute is dissolved in solvent to make a solution

Sodium chloride in makes salt water

Sucrose (common table sugar) in water makes sugar water

Lemon juice and sucrose sugar in water make lemonade

Ways to Express Concentration

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

2. Mole Fraction X

$X_A = n_A / n_{\text{total}}$ = moles of some solute A / total moles in solution

And if mixture of multiple components A, B, C, ... then

$$1 = X_A + X_B + X_C + \dots$$

3. Molality (mol/kg) = m

moles of solute / kg of solvent = m

4. Molarity (mol/L) = M

moles of solute / liter of solution = M

5. Normality (equiv/ L) = N

equivalents of solute / liter of solution = N

(Normality used in acid base or redox reactions)

Concentration Examples

1. Percent by weight (mass)
2. Mole fraction
3. Molality
4. Molarity

Given the mixture below:

23.0g Ethanol M.W. = 46.0g/mol solute $\text{CH}_3\text{CH}_2\text{OH}$

85.0g Water M.W. = 18.0 g/mol solvent H_2O

and a total of 100 ml of ethanol/water solution or ethanol(aq)
aq means aqueous (in water)

1. Find Percent by mass (%) ethanol

$$= [\text{mass ethanol solute} / (\text{mass of solute} + \text{mass solvent})] \times 100$$

$$= (23 / (85 + 23)) \times 100 = \mathbf{21.3\% \text{ ethanol}} \quad \text{and } 78.7\% \text{ water by weight}$$

2. Find Mole Fraction of ethanol

$$= \text{moles of ethanol} / \text{total moles in solution}$$

$$(23.0\text{g ethanol}) (\text{mol}/46.0\text{g}) = 0.500 \text{ mol ethanol}$$

$$(85.0\text{g water}) (\text{mol}/18.0\text{g}) = 4.72 \text{ mol water}$$

$$\text{Mole fraction} = 0.500 / (4.72 + .50) = 0.500 / 5.22 = \mathbf{0.096 \text{ C}_2\text{H}_6\text{O ethanol}}$$
$$0.904 \text{ H}_2\text{O water}$$

3. Find Molality (mol/kg) of ethanol solution

$$= \text{moles of solute ethanol} / \text{kg of solvent}$$

$$= 0.50 \text{ mol ethanol} / 0.085 \text{ kg water} = 5.9 (\text{mol}/\text{kg}) = \mathbf{5.9 \text{ m}} \text{ (molal solution)}$$

4. Find Molarity (mol/L) of ethanol solution

$$= \text{moles of solute} / \text{liter of solution}$$

$$= 0.50 \text{ mol} / 0.100 \text{ L solution} = 5.0 (\text{mol}/\text{L}) = \mathbf{5.0 \text{ M}} \text{ (molar solution)}$$

Note: In very dilute aqueous solution the molarity \sim molality (approximately equal)
because 1 L water = 1 kg water
that is density of water is 1 kg/L so if very dilute solution 1.0 kg \sim 1.0 L

Normality

Normality = equivalents of solute/ L of solution

Acid-base reactions relates to changes in H^+ or OH^-

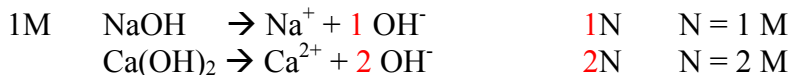
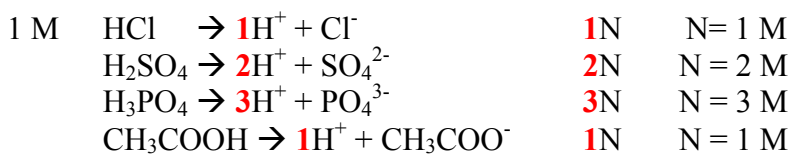
Redox reaction relates to loss or gain (transfer) of electrons

Consider these 1.0 M (molar) solutions and note how the normality may be same or more

N is equal to molarity or small multiple of molarity $N = n M$ where $n = \text{integer}$

so for examples below M multiplied by integer based on H^+ , OH^- , or e^-

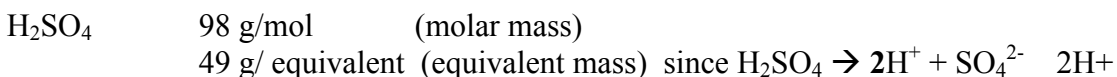
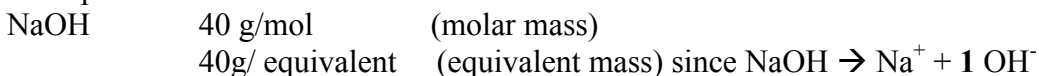
(in other equations n may represent number of moles: here it is just an integer 1, 2, 3...)



1 Normal solution (1N) contains one equivalent

N is equivalent of solute/ L of solution = (g solute/(g/equivalent))/ L of solution

Example:



so

$$(98g/(49g/equiv))/ (1L) = 2N \text{ (equivalent/liter)}$$

$$(98g/ (98g/mol))/ (1L) = 1M \text{ (mole/liter)}$$

Equivalent weights (masses) are weights (masses) of substances that are equivalent in chemical reaction

for example: 49g of H_2SO_4 will neutralize 40g of NaOH so these are equivalent weights

Conversion between molarity and molality

To convert from molarity to molality directly, must know density.

Ex: What is molality of 2.00M NaCl(aq) solution with a density of 1.08 g/mL?

Assume you have 1.000L (can assume convenient amount even if not given)

then 2.00 mol of NaCl is 2.00 mol (58.5 g/mol) = 117 g NaCl

If density is 1.08 g/mL then 1.000 L = 1000 mL (1.08 g/mL) = 1080 g total mass

Water portion is 1080 g total – 117 g NaCl = 963 g H₂O and so

$m = \text{mol solute} / \text{kg solvent} = 2.00 \text{ mol} / 0.963 \text{ kg} = 2.08 \text{ m NaCl(aq)}$

Lab Applications

Below are examples of very useful solution calculations for lab and lecture work

1. Make a solution

Example: How much glucose is required to prepare 200 mL of 0.150 M of glucose?

Glucose is C₆H₁₂O₆ so

Molar mass (MM) or molar weight (MW) = 6(12) + 12(1) + 6(16) = 180 g/mol

Moles = (concentration) (volume)

Mol = (conc) (vol)

Mol = (mol / L) (L)

notice how units give you equation since molarity M = mol/L

Moles of solute needed = (concentration)(volume)
= (0.150 mol/L)(0.200L)
= 3.00 x 10⁻² mol

so mass needed is (3.00 x 10⁻² mol)(180 g/mol) = 5.40g glucose

Procedure is to measure out amount needed then add to volumetric flask and add water to dilute to mark

2. Do a Dilution

How many mL of 18.0 M sulfuric acid are required
to prepare 300 mL of 1.0 M H₂SO₄

$M_1V_1 = M_2V_2$ note: moles constant since (M)(V) = mol
Before After

$$(18.0 \text{ mol/L})(V_1) = (1.0 \text{ mol/L})(0.300\text{L})$$

$$V_1 = 0.0167 \text{ L}$$

$$V_1 = 16.7 \text{ ml}$$

So add 16.7 mL of 18.0M sulfuric acid to enough water to make 300mL solution

Notice that in the above problem

can use L on both sides or mL because concentration units cancel out

$$(18.0 \text{ mol/L})(V_1) = (1.0 \text{ mol/L})(300 \text{ mL})$$

$$V_1 = [(1.0 \text{ mol/L}) / (18.0 \text{ mol/L})] (300 \text{ mL})$$

$$V_1 = 16.7 \text{ ml}$$

REMEMBER to THINK UNITS and THINK EQUATIONS

in all problem based work

Henry's Law

Concentration of gas dissolved in solution is greater if pressure of gas above liquid is greater

$$C_{\text{gas}} = k_{\text{H}} P_{\text{gas}}$$

where C_{gas} is concentration of gas dissolved in liquid (mol/L)

P_{gas} is the pressure of gas above liquid (atm)

k_{H} is the Henry's law constant that connects these two values (mol/L)/atm

(determine k_{H} experimentally or look up available values in tables)

A carbonated beverage is sealed under high pressure of CO₂

and this causes more carbon dioxide to dissolve in water.

and so when opened with lower pressure in the air around us than in the can,

the CO₂ is less soluble and bubbles out of solution.

Colligative Properties

Colligative properties depend only on concentration of solute rather than the specific type of solute and include:

Vapor pressure lowering
Freezing point depression
Boiling point elevation
Osmotic pressure

Vapor pressure lowering

Raoult's Law says
adding nonvolatile solute to solvent causes the vapor pressure of the solution to be lower.
or Raoult's Law equation is

$$P_{\text{solution}} = X_{\text{solvent}} P^{\circ}_{\text{solvent}}$$

P_{solution} = vapor pressure of solution

X_{solvent} = mole fraction of solvent in solution

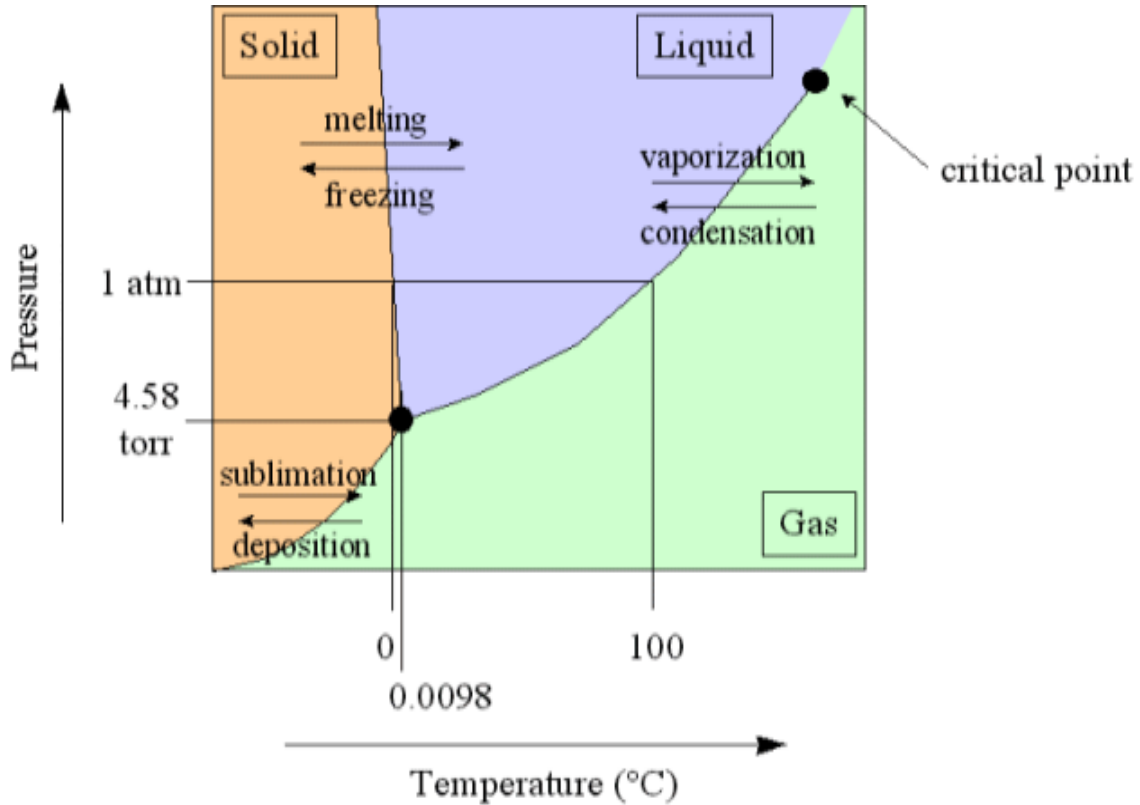
$P^{\circ}_{\text{solvent}}$ = vapor pressure of pure solvent

Since mole fraction ($0 < X < 1$) is more than 0 and less than 1 for a solution
then $P_{\text{solution}} < P^{\circ}_{\text{solvent}}$

Example: if vapor pressure of pure solvent is 24 torr then if mole fraction is 0.2

Freezing point depression and Boiling point elevation

On phase diagram for water below can observe
the normal freezing point (liquid → solid)
and normal boiling point (liquid → gas) that occurs at 1.00 atm pressure



<http://www.naturalsci.gardner-webb.edu/Faculty/vtotten/PChem/h2ophase.gif>

In a solution (mixture):
the freezing point is lower than pure solvent
the boiling point is higher than pure solvent

ΔT_f freezing point depression

ΔT_b boiling point elevation

FP and BP Equations used are:

$$\Delta T_f = K_f C_m \quad C_m = \text{concentration in molality (m = mol solute/kg solvent)}$$

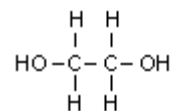
$$\Delta T_b = K_b C_m$$

water solvent constants: $K_f = -1.86 \text{ }^\circ\text{C/m}$ (freezing point depression constant)
 $K_b = 0.51 \text{ }^\circ\text{C/m}$ (boiling point elevation constant)

Does not matter what solute you use but have to have K_f and K_b values for solvent
Those would be given on exam and may need to be looked up in textbook for homework

For example: in car radiators we add ethylene glycol to raise boiling point for summer driving and lower freezing point in winter driving.

Ethylene glycol (antifreeze)



<http://www.inchem.org/documents/pims/chemical/pim227.htm>

Example:

What is the freezing point of 621 g of ethylene glycol in 2000g of water?

$$\text{MW} = 62.1 \text{ g/mol}$$

$$621\text{g} = 10.0 \text{ mol}$$

2000g of water in radiator (2.00 kg)

$$C_m = 10.0 \text{ mol} / 2.00 \text{ kg} = 5.00 \text{ m}$$

$$\Delta T = (-1.86 \text{ }^\circ\text{C/m})(5.00\text{m}) = -9.30 \text{ }^\circ\text{C}$$

Note if K_f given as positive (as it is in some tables of data)

Then have to change to negative since fp is always decreased

and since water freezes at $0.00 \text{ }^\circ\text{C}$ then this would be lower by

$$T_{\text{solution}} = T_{\text{solvent}} + \Delta T = 0.00 + (- 9.30) = - 9.30 \text{ }^\circ\text{C}$$

And solution would freeze at $- 9.30^\circ\text{C}$

If instead of molecular solid an ionic solid is dissolved then the effect may be larger since we must count all the things dissolved in solution

And we use equations:

$$\Delta T_f = i K_f C_m$$

$$\Delta T_b = i K_b C_m \quad \text{where } i \text{ is number of actual of effective different ions dissolved}$$

Consider a 5.00 m solution of NaCl(aq) then 5.00 m in Na⁺ and 5.00 m in Cl⁻
so a 5.00 m solution of NaCl(aq) would have $i = 2$ (1 Na⁺ and 1 Cl⁻)

$$\Delta T_f = i K_f C_m$$

$$\Delta T = (2) (-1.86 \text{ }^\circ\text{C/m}) (5.00\text{m}) = -18.60 \text{ }^\circ\text{C}$$

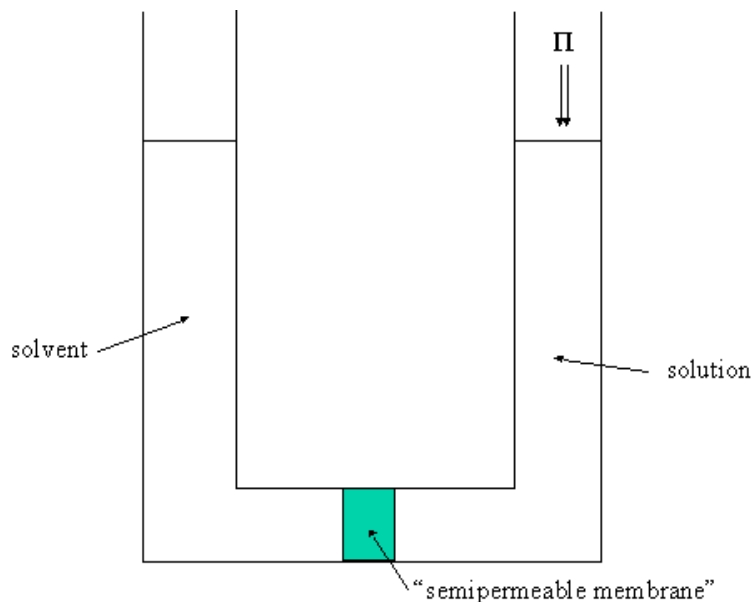
And for 5.00 CaCl₂ (aq) since Ca²⁺ and Cl⁻ and Cl⁻ then $i=3$

$$\Delta T_f = i K_f C_m$$

$$\Delta T = (3) (-1.86 \text{ }^\circ\text{C/m}) (5.00\text{m}) = -27.90 \text{ }^\circ\text{C}$$

In some problems value of i maybe given and not be an integer because there is some clustering of ions and i is less then you would expect to calculate. If this is the case just use the given value of i given, otherwise calculate based on number of ions.

Osmotic Pressure



(<http://www.chem.arizona.edu/~salzmanr/480a/480ants/colprop/colprop.html>)

Semipermeable membrane means solute molecules cannot go through but solvent can. Solvent molecules such as water will go through membrane to dilute solution unless a pressure equal to the osmotic pressure is applied to stop the flow.

Osmotic pressure = π

Osmosis is process by which solvent molecules move through membrane into more concentrated solution

Osmotic pressure $\pi V = nRT$ or $\pi = MRT$

since n = moles of solute, V is volume of solution and $M = n/V$ (mol/L) or molarity

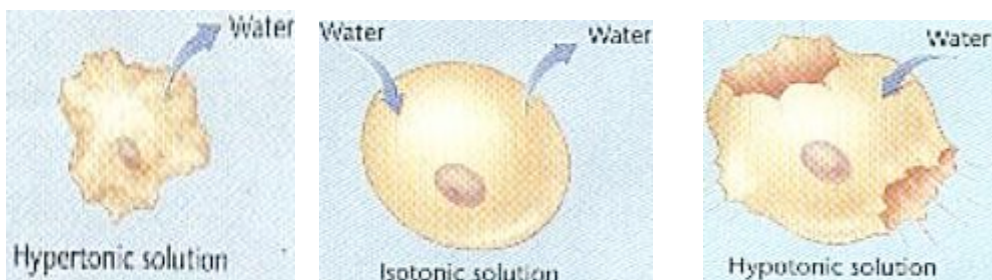
R is gas constant and T is temperature in Kelvin

With the injection of large amounts of fluid such as I.V. must use isotonic solutions

Hypertonic → greater concentration than cell fluid

Isotonic → same concentration as cell fluid

Hypotonic → lower concentration than cell fluid



<http://www.sirinet.net/~jgjohnso/homeostasis.html>

Example Contact lens solution is made to be isotonic with corneal cells in eye

Example: How much glucose needed in 1.00 L solution to make an isotonic with blood
Given that

Blood (red blood cells) $\pi = 7.7 \text{ atm}$ and Temp = 37°C or 310K

(for glucose MM = MW = 180g/mol where MM = molar mass and MW = molar weight)

$$\pi V = nRT$$

$$(7.7 \text{ atm})(1.00\text{L}) = (n)(.08206 \text{ L atm/ mol K})(310 \text{ K})$$

$$0.303 \text{ mol} = n$$

$$\text{or } (.303 \text{ mol})(180 \text{ g/mol}) = 54\text{g} \quad 54\text{g of glucose}$$

Application of Reverse osmosis is to Purify salt water (desalination)

Force water through membrane by applying pressure above osmotic pressure

Salt will not go through membrane but only water

Persian Gulf War in 1990s– Saudi desalination plants shut down so oil dumped into water by Iraq would not destroy filters in reverse osmosis facilities. Reverse osmosis is used to get pure water from ocean water and requires special filters.

Colligative Properties of Electrolyte Solution (ions in solution)

Presence of ions applies in all cases of colligative properties

ΔT_f in solutions of

-1.86	1m glucose $C_6H_{12}O_6$	\rightarrow	1m $C_6H_{12}O_6$	so expected amount for 1m
-3.72	1m NaCl	\rightarrow	1m Na^+ 1m Cl^-	so 2x as much lowering
-5.58	1m $CaCl_2$	\rightarrow	1m Ca^{2+} 2m Cl^-	so 3x as much lowering

Colligative properties depend on amount of solute molecules or ions added to solvent

And this count of everything in solution is also true for osmotic pressure

1.0 M solution of NaCl would have 2x the effect of 1.0 M of $C_6H_{12}O_6$

Effective conc = 2 mol/L or 1 mol/L for above

Colloids

Particles (collections of molecules) suspended in another medium

1 phase (s,l,g) suspended in another

example	phases	general name for
smoke	solids in gas	aerosol
milk	butterfat liquid in water liquid	emulsion
marshmallow	NO_2 in solid	foam
fog	water in air	aerosol

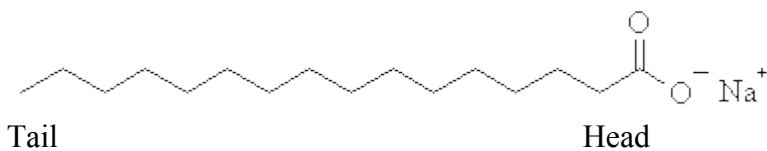
Can show it is not solution by Tyndall effect, the scattering of light

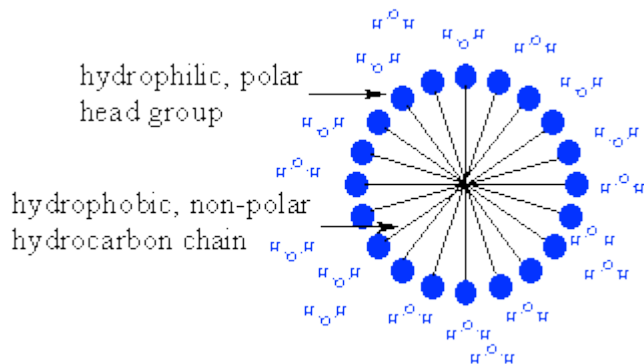
Ex. water droplets in air forms a white cloud because this colloid mixture scatters light

In water a substance can be hydrophobic (water fearing) or hydrophilic (water loving)

An Association colloid (micelle)

is made of molecules that have both a hydrophobic and hydrophilic end





(<http://www.chem.ucalgary.ca/courses/351/Carey5th/Ch26/ch26-1-2.html>)

Examples include soap and surfactants used for cleaning. The hydrophobic part attracts to nonpolar grease and the hydrophilic part is attracted to polar water

Like dissolves like

In water a substance can be hydrophobic (water fearing) or hydrophilic (water loving)

polar solutes dissolve in polar solvents

nonpolar solutes dissolve in nonpolar solvents

1) Example

Given that:

purple iodine I_2 is nonpolar

blue food coloring dye is polar

yellow cooking oil is nonpolar

colorless water is polar

We observe the following

I_2 in water	NOT dissolve	water remains colorless
I_2 in oil	dissolves	forms red solution
blue dye in water	dissolves	forms blue solution
blue dye in oil	NOT dissolve	oil remains yellow

2) Example

Oil and water pour together do not mix

Layer of yellow oil stays on top of colorless layer of water

Shake and they still separate into two layers

Add enough soap or detergent and shake and the oil and water will mix together