A solution is a homogenous mixture of two or more substances. This is a very broad category, including the atmosphere, a solution of gases, the oceans, a solution of solids in a liquid, and 14-karat gold, a solution of a solid Ag, in a solid, Au.

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

Mass/mass    volume/volume   mass/volume

Example

How would you prepare a H₂O solution containing 2.40% by mass of NaCl? The total volume needed is 425g

\[ 425 \text{g} \times 0.0240 = 10.2 \text{g of NaCl} \]
\[ 425 - 10.2 = 414.8 \text{g H₂O} \]

Combine these 2

To convert from vol/vol to mass/mass, use density

Example

USP ethanol contains 95% ethanol, 5% H₂O 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 mL \times 0.813 g/mL = 81.3 g

IN 100.0 mL USP ETHANOL 95% BY VOLUME IS PURE ETHANOL

100.0 mL \times 0.95 = 95 mL

THE MASS OF 95.0 mL PURE ETHANOL IS 95.0 mL \times 0.789 g/mL = 75.0 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 = \frac{g}{L}

PARTS PER MILLION = PPM = \frac{mg}{L}

PARTS PER BILLION = PPB = \frac{ug}{L}

PARTS PER TRILLION = PPT = \frac{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 0.001 \text{ mol/L} OR 0.001 \text{ mol/1000 g}

105 ppm MEANS 105 \text{ mg/L} OR 0.105 \text{ g/1000 g}

0.001 \text{ mol MgCl}_2 = 0.001 \text{ mol \times 95.2 g/mol} = 0.095 g

MOLALITY

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

FOR EXAMPLE, 0.20 \text{ 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 glycol}
Mole Fraction and Mole %

Mole Fraction: \( \chi_A = \frac{\text{moles of substance A}}{\text{total moles of solution}} \)

Example: An aqueous solution is 0.120 M glucose. What are the mole fractions of each component

0.120 M means \( \frac{0.120 \text{ mol}}{1.0 \text{ kg H}_2\text{O}} \)

Find the molarity of \( \text{H}_2\text{O} \)

\( 1 \times 10^3 \text{ g} \times \frac{1 \text{ mol H}_2\text{O}}{18 \text{ g H}_2\text{O}} = 55.6 \text{ mol H}_2\text{O} \)

Mole Fraction Glucose: \( \frac{0.120}{55.6 + 0.120} = 0.00215 \)

Mole Fraction \( \text{H}_2\text{O} = \frac{55.6}{55.6 + 0.120} = 0.998 \)

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
   \( \Delta H_{soln} \) + ENDOOTHERMIC

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 KS/mol
MELTING POINTS ARE QUITE HIGH 500 - 1000°C
YET MANY IONIC COMPOUNDS DISSOLVE EASILY IN WATER
IONS ARE SURROUNDED BY WATER MOLECULES \( \rightarrow \) “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 THE 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

2.7 g of acetylene, C₂H₂ 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

\[
\frac{S_2}{S_1} = \frac{P_2}{P_1}
\]

\[
\frac{S_2}{27\text{ g}} = \frac{12\text{ atm}}{1\text{ atm}}
\]

\[
S_2 = 3.2 \times 10^2\text{ g}
\]

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 Raoult's Law

- The vapor pressure of a solvent equals the vapor pressure of the pure solvent times its mole fraction in the solution

\[
P_{\text{solv}} = x_{\text{solv}} \cdot P^0_{\text{solv}}
\]

Calculate the vapor pressure lowering of water when 5.67 g of glucose is dissolved in 25.2 g H₂O at 25°C. The vapor pressure of H₂O is 23.8 mm Hg.

This is the glucose solution we previously found to be 0.022 mole fraction glucose 0.98 mole fraction H₂O

23.8 \times 0.98 = 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 IS A COLLIGATIVE PROPERTY THAT DEPENDS ON THE NUMBER OF SOLUTE PARTICLES.

BOILING POINT ELEVATION, \( \Delta T_b \), DEPENDS ON THE MOLAL CONCENTRATION OF THE SOLUTE \( C_m \):

\[
\Delta T_b = K_b C_m
\]

WHERE \( K_b \) IS A CONSTANT UNIQUE TO EACH SOLVENT.

FOR EXAMPLE, \( K_b \) FOR H\(_2\)O IS 0.512 \(^\circ\)C/m.

SO AN ANTI-FREEZE SOLUTION THAT IS 12 m ETHYLENE GLYCOL BOILS AT 12 m x 0.512 \(^\circ\)C/m = 6.14 \(^\circ\)C HIGHER THAN PURE H\(_2\)O.

FREEZING POINT DEPRESSION IS SIMILAR:

\[
\Delta T_f = K_f C_m
\]

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

\[
12 \, m \times 1.86 \, ^\circ C/m = 22.3 \, ^\circ C \text{ LOWER THAN H}_2\text{O.}
\]

THIS CAN BE USED TO CALCULATE MOLECULAR WEIGHT.

IN 25.4 g H\(_2\)O DISSOLVE 0.131 g SUBSTANCE. BY FREEZING POINT DEPRESSION, THE MOALITY IS 0.056 m. WHAT IS THE MOLECULAR WEIGHT?

\[
0.056 \, \text{mol/KCH}_2\text{O} \quad \frac{x \, \text{mol}}{25.4 \times 10^{-3} \, \text{kg H}_2\text{O}} \quad x = 1.42 \times 10^{-3} \, \text{mol}
\]

MOLAR MASS = \[
\frac{0.131 \, g}{1.42 \times 10^{-3} \, \text{mol}} = 92 \, \text{g/mol}
\]
Osmosis is the phenomenon of solvent flow through a semi-permeable membrane to equalize the solute concentrations on both sides of the membrane. The osmotic pressure, \( \Pi \), is a colligative 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 \( H_2O \) at \( 25^\circ C \). What is the osmotic pressure?

\[
0.798 g \times \frac{1 \text{ mol}}{32,400 g} = 2.46 \times 10^{-5} \text{ mol starch}
\]

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

\[
\Pi = MRT
\]

\[
= 2.46 \times 10^{-4} \text{ M} \times 0.0821 \text{ L atm} / \text{ mol} \cdot \text{ K} \times 298 \text{ K}
\]

\[
= 6.02 \times 10^{-3} \text{ atm} \text{ or } 4.6 \text{ mm Hg}
\]

For comparison, calculate the freezing point depression. Assume \( M = m \) (true only in very dilute solutions)

\[
\Delta T_F = K_f \times c_m = 1.86 \times 10^{-2} \times 2.46 \times 10^{-4} = 4.58 \times 10^{-4} ^\circ C
\]

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 flow of H₂O. Pure water is a hypotonic solution meaning it has lower amounts of dissolved substances in a concentrated, hypertonic saline solution, cells suffer loss of H₂O 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 van't Hoff factor i:

\[ \Delta T_f = -i \cdot K_f \cdot m \]
\[ \Delta T_b = i \cdot K_b \cdot m \]
\[ \Pi = i \cdot M \cdot R \cdot T \]

For nonelectrolytes, \( i = 1 \)

For dilute solutions of strong electrolytes \( i \) approaches integer values 2 for NaCl, 3 for MgCl₂

<table>
<thead>
<tr>
<th>Concentration (M)</th>
<th>( i )</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 M</td>
<td>1.81</td>
</tr>
<tr>
<td>0.1 M</td>
<td>1.81</td>
</tr>
<tr>
<td>0.01 M</td>
<td>1.94</td>
</tr>
<tr>
<td>0.001 M</td>
<td>1.97</td>
</tr>
</tbody>
</table>

For weak electrolytes \( i \) depends on the % ionization
EXAMPLE
CALCULATE THE FREEZING POINT OF A 0.010 M AQUEOUS SOLUTION OF ALUMINUM SULFATE Al₂(SO₄)₃ \( i = 4.4 \)
\( \text{Al}_2(\text{SO}_4)_3 \) DISSOLVES TO MAKE 5 IONS, \( 2\text{Al}^{3+} + 3\text{SO}_4^{2-} \)

\[ \Delta T_f = i \Delta K_f C_m \]
\[ = 4.4 \times 1.86^\circ \text{C/mol} \times 0.01 \text{m} = 0.086^\circ \text{C} \]

COLLOID

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

<table>
<thead>
<tr>
<th>NAME</th>
<th>CONTINUOUS PHASE</th>
<th>DISPERSED PHASE</th>
<th>EXAMPLE</th>
</tr>
</thead>
<tbody>
<tr>
<td>AEROSOL</td>
<td>GAS</td>
<td>LIQUID</td>
<td>FOG</td>
</tr>
<tr>
<td>AEROSOL</td>
<td>GAS</td>
<td>SOLID</td>
<td>SMOKE</td>
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<tr>
<td>FOAM</td>
<td>LIQUID</td>
<td>GAS</td>
<td>WHIPPED CREAM</td>
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<td>EMULSION</td>
<td>LIQUID</td>
<td>LIQUID</td>
<td>MILK, MAYONNAISES</td>
</tr>
<tr>
<td>SOL</td>
<td>LIQUID</td>
<td>SOLID</td>
<td>PEARL, OPAL, BUTTE</td>
</tr>
<tr>
<td>FOAM</td>
<td>SOLID</td>
<td>GAS</td>
<td>PUMICE, STYROFOAM</td>
</tr>
<tr>
<td>GEL</td>
<td>SOLID</td>
<td>LIQUID</td>
<td>JELLY</td>
</tr>
<tr>
<td>SOLID SOL</td>
<td>SOLID</td>
<td>SOLID</td>
<td>RUBY GLASS</td>
</tr>
</tbody>
</table>

COLLOID SCATTER LIGHT - THE TYNODALL EFFECT

COLLOIDS MAY BE COAGULATED BY THE ADDITION OF ELECTROLYTES

THE COAGULATION SEPARATES THE DISPERSED PHASE FROM THE CONTINUOUS PHASE
CHAPTER 12

SKILLS

WORK WITH SOLUTION CONCENTRATION BY MASS %

WORK WITH CONCENTRATION UNITS OF PPM, PPB, PPT

CALCULATE MOLARITY FROM MORALITY

CALCULATE MASS % FROM VOL % USING THE DENSITY

CALCULATE MOALITY

WORK WITH MOLE FRACTION

PREDICT WHICH COMPOUND IS SOLUBLE IN WHICH SOLVENT

WORK WITH HENRY'S LAW

CALCULATE FREEZING POINT DEPRESSION, B.P. ELEVATION

CALCULATE OSMOTIC PRESSURE

KNOW THE COLLECTIVE PROPERTIES OF ELECTROLYTES

PROBLEMS AND EXAMPLES

Ex 12.1, 23, 25

Ex 12.3, 33

38, 39, 35

Ex 12.2

35, Ex 12.4, 12.5

Ex 12.6, 41, 43

Ex 12.8, 47

Ex 12.9, 55, Ex 12.10

Ex 12.14, Ex 12.15, 61, 63

71, Ex 12.16

77, Ex 12.17