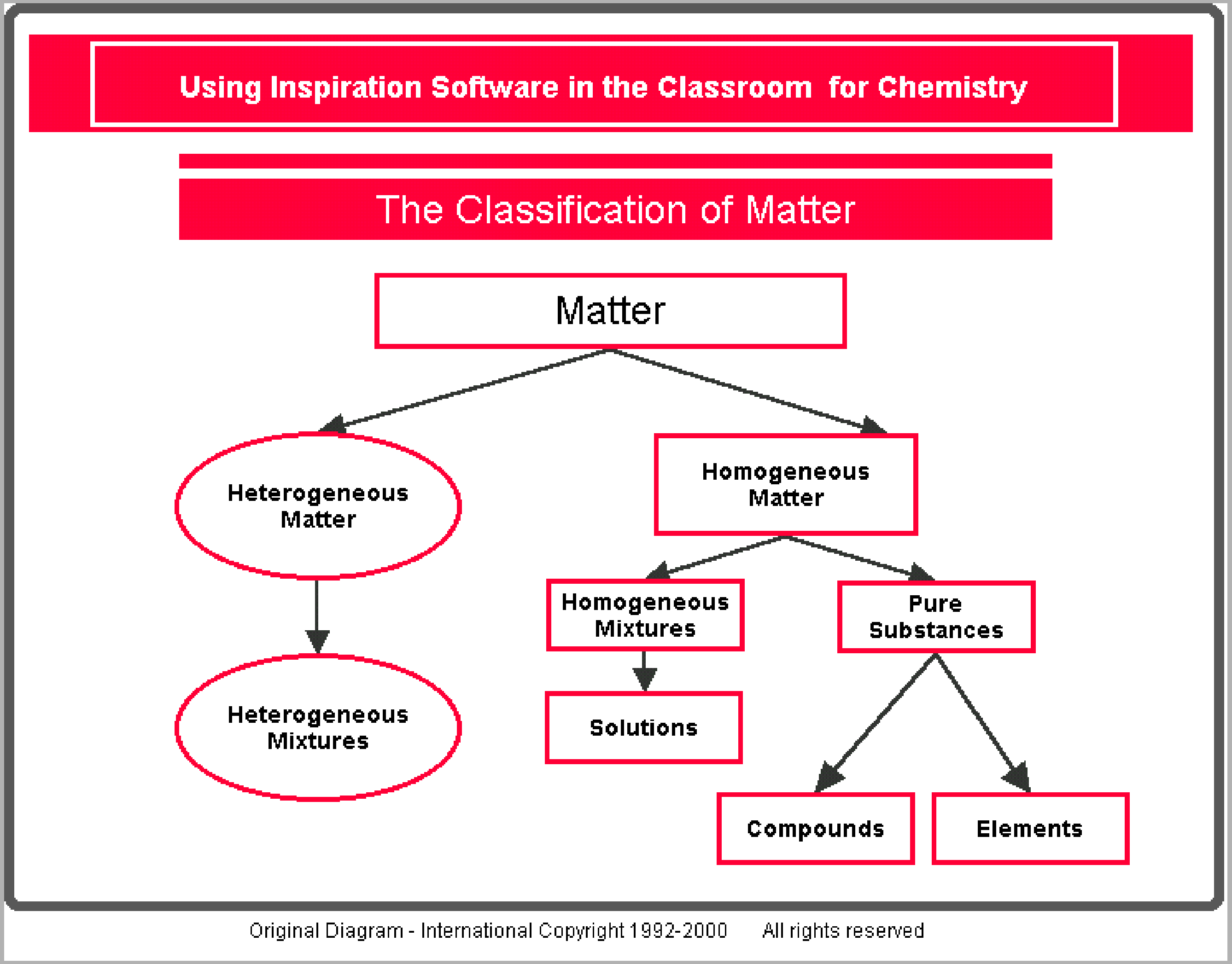
Chapter 11

Properties of solutions

Solutions are Matter



Key Definitions

- Solvent
- Solute

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- Solvent
- Solute
- Examples

Solution Strength

- Molarity
- Normality
- Molality

Solution Strength

- Mass percent (Wt. %)

$$\frac{\textit{Mass of solute}}{\textit{Mass of solution}} \times 100\%$$

Solution Strength

- Mole Fraction

Mole fraction of A:

$$\chi_A = \frac{n_A}{n_A + n_B}$$

$n_A =$ $n_B =$

Heat of solution

- Amount of heat absorbed or release when a solute dissolves in a particular solvent.

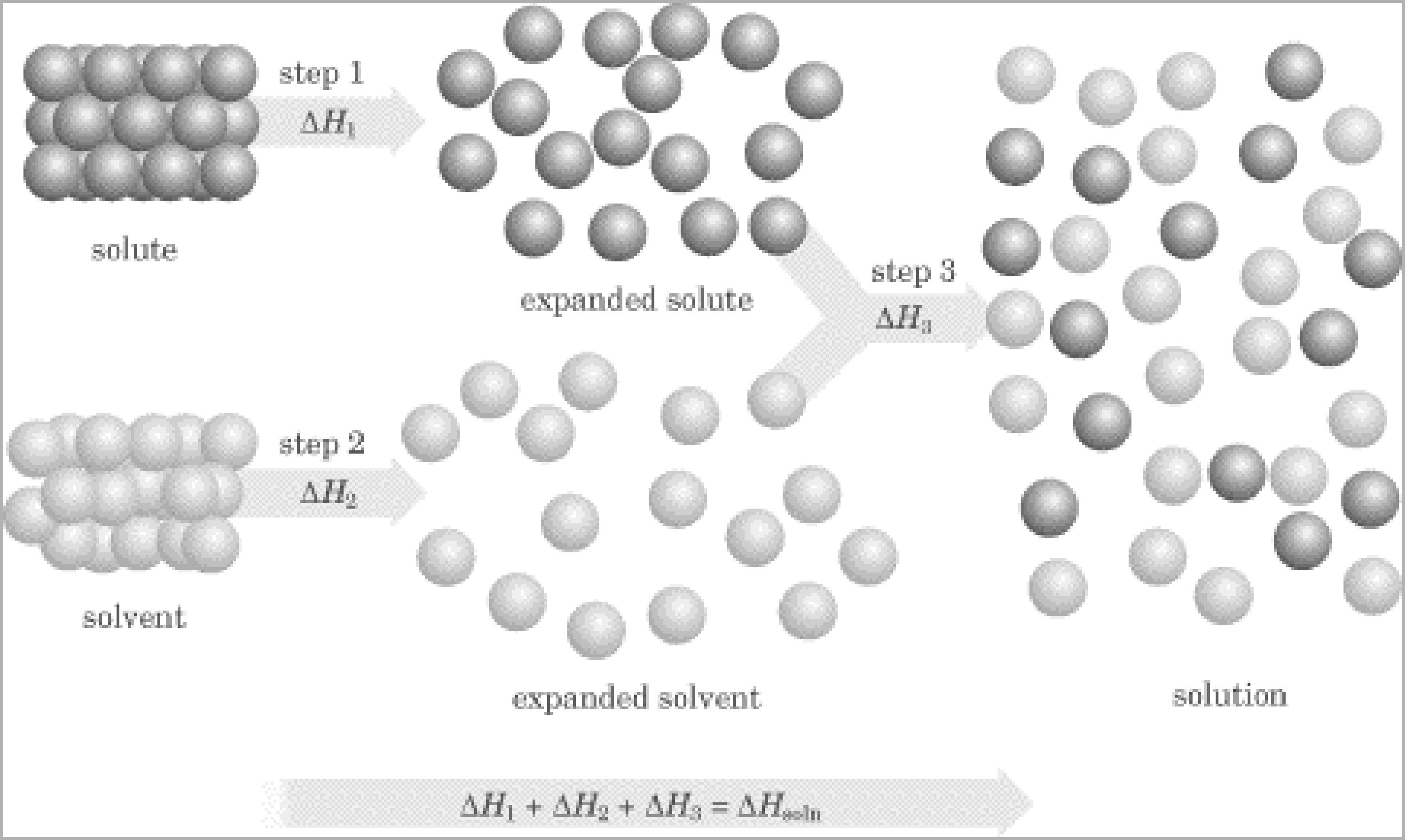
  Exothermic:

  Endothermic:

3 steps to solution

- ΔH_1: energy required to separate the solute or expand it.
- ΔH_2: energy required to separate the solvent.
- ΔH_3: the interaction between solvent and solute.

3 steps to solution



Example

- What is the ΔH_{sol} of NaI given:
- Lattice energy is -686 kcal/mol
- Enthalpy of Hydration -694 kcal/mol
- Is this substance soluble, if so is it endothermic or exothermic.

Example

- We are unmaking a lattice so flip sign on Lattice energy is +686 kcal/mol
- Enthalpy of Hydration -694 kcal/mol
- Sum the energy changes:
- 686 kcal/mol + -694 kcal/mol = -8 kcal/mol.
- ΔH sol is small so… Soluble
- ΔH sol is negative so… exothermic

Predicting Solution Formation

Solvent/ Solute	ΔH_1	ΔH_2	ΔH_3	$\Delta H_{sol'n}$	Outcome
Polar/ Polar	+ large	+ large	- large	+/- small	Solution forms
Polar/ Nonpolar	+ small	+ large	+/- small	+ large	No solution forms
Nonpolar/ Nonpolar	+ small	+ small	+/- small	+/- small	Solution forms
Nonpolar/ polar	+ large	+ small	+/- small	+ large	No solution forms

"Like Dissolves Like"

Nonpolar solutes dissolve best in nonpolar solvents

Fats	Benzene
Steroids	Hexane
Waxes	Toluene

Polar and ionic solutes dissolve best in polar solvents

Inorganic Salts	Water
Sugars	Small alcohols
	Acetic acid

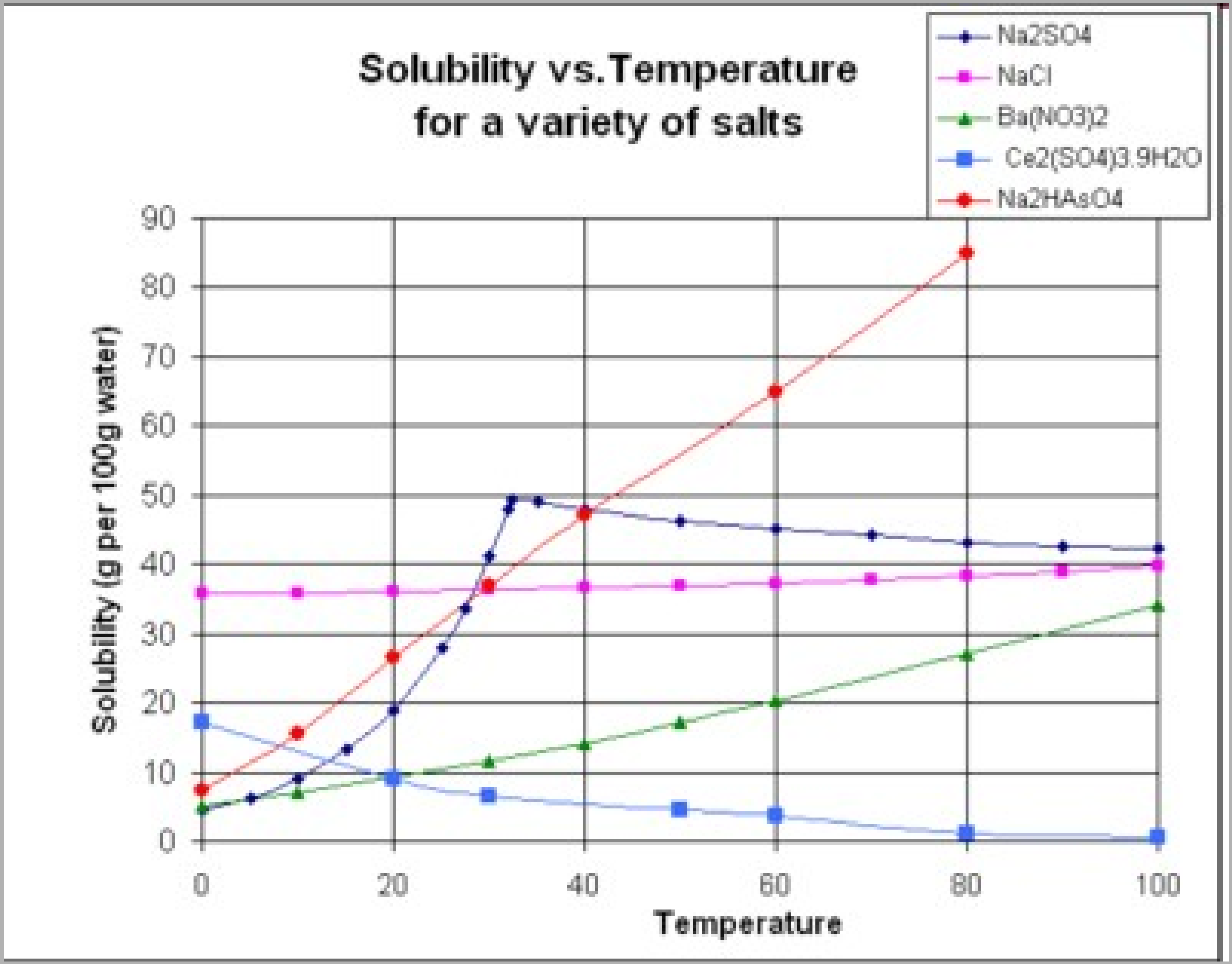
Watch out for this...

- Solubility is a constant for a given solute and solvent at a specified temperature
- But
- The rate of dissolving can be increased by

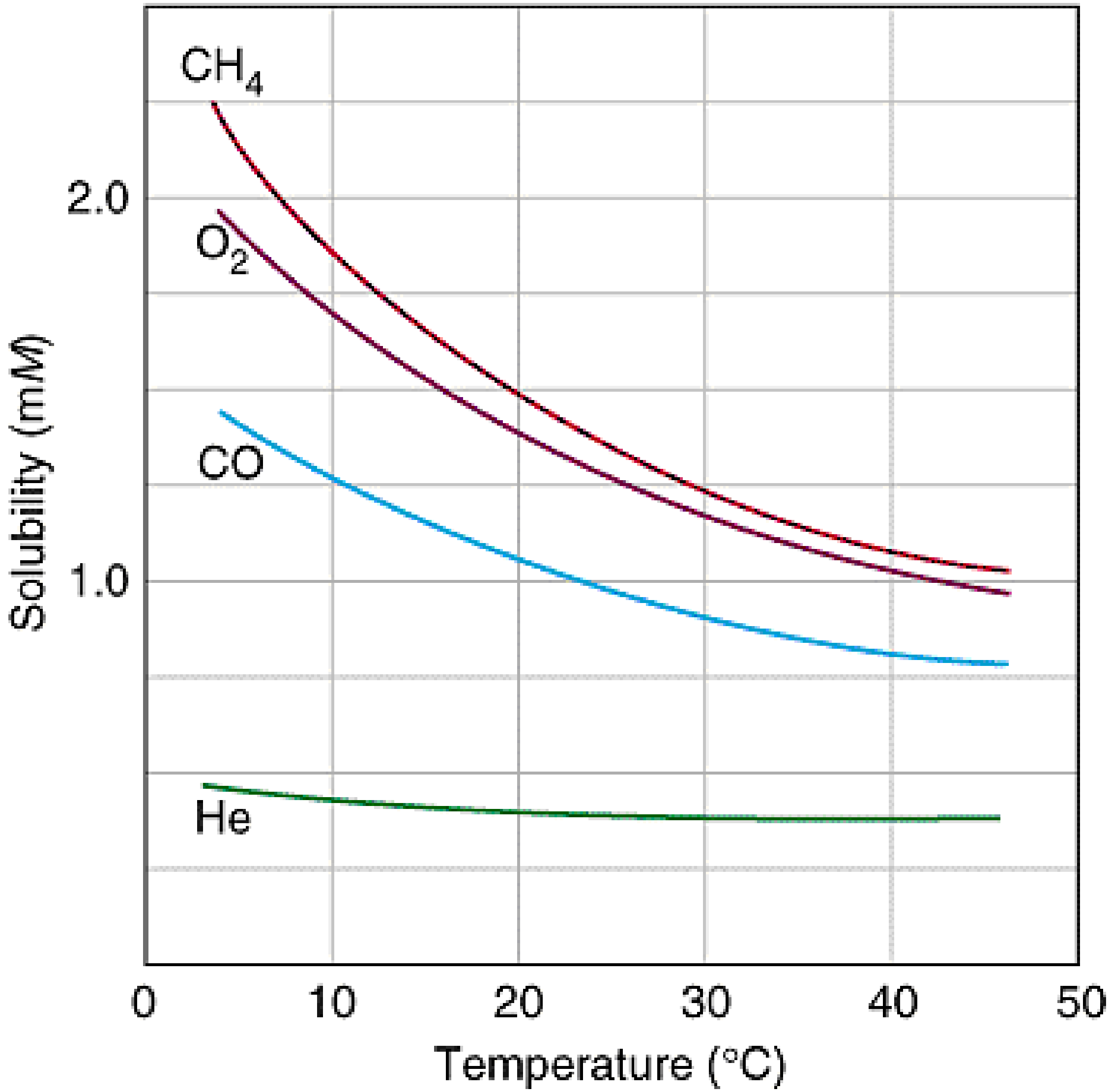
Solubility trends

- Solubility of MOST solids increases with increasing temperature.
- Solubility of gases DECREASES with increasing temperature
- Solubility of gases is directly proportional to the pressure of the gas above the solvent (Henry's Law)

Solubility trends



Solubility trends



Solubility trends

- So in summary
- Solids
  - heating
  - grinding
  - stirring
- Gases
  - cold
  - high pressure

Saturation

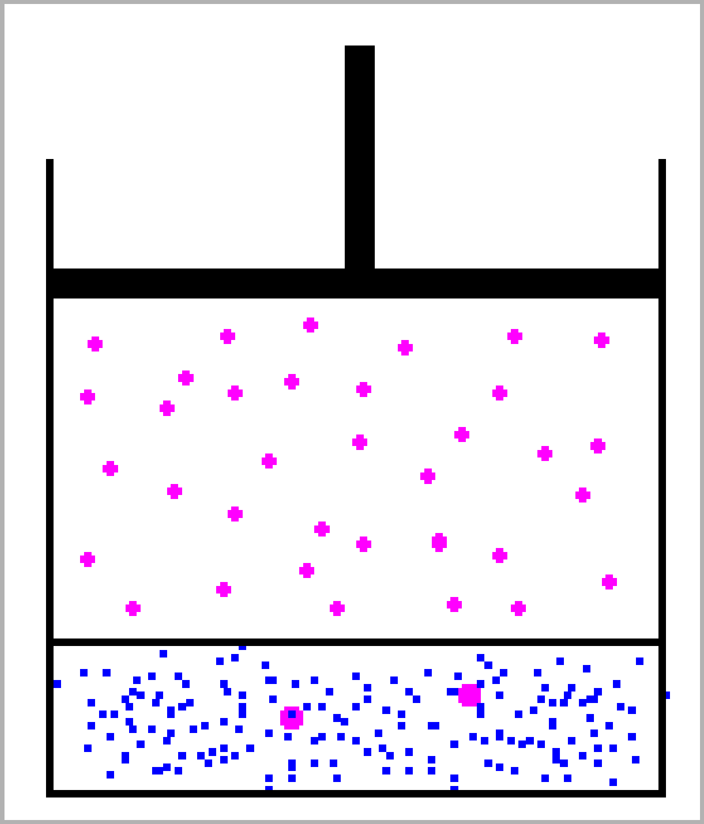
- Saturation
- Under saturation
- Super saturation (metastable)

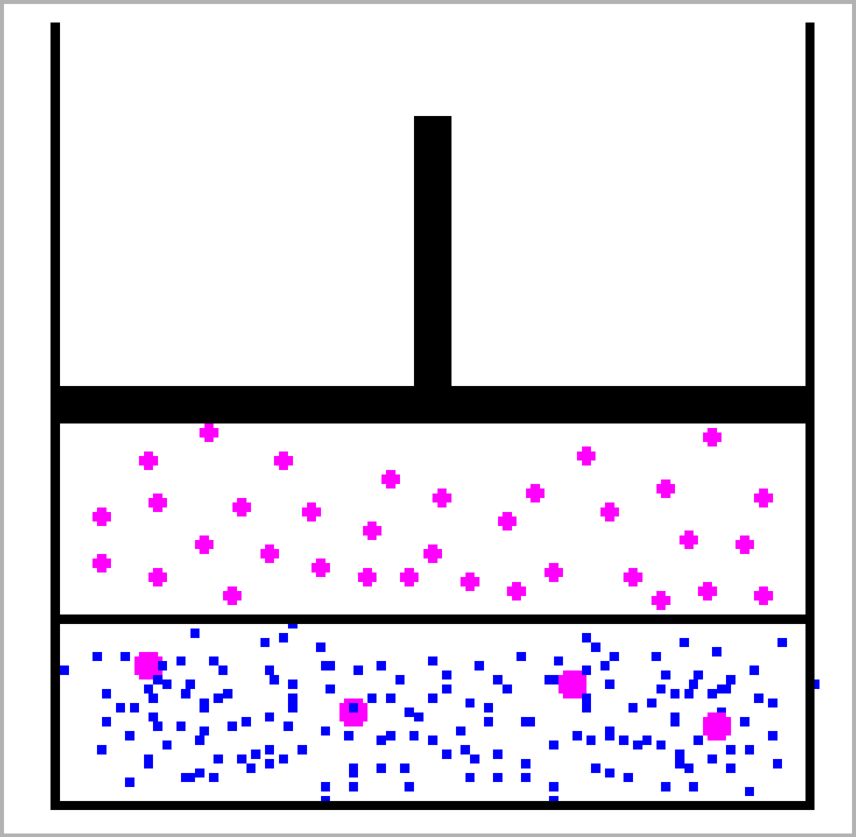
Henry's Law

- Concentration of a gas in a solvent is directly proportional the the pressure of the gas above the solution. Or ...
- $C = kP$ where
- C = concentration
- P = pressure
- k = Henry's constant

Henry's Law

If we double the pressure….



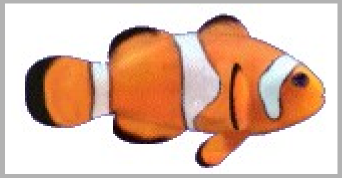


Henry's Law

- Works most accurately for low gas concentrations (dilute solutions)
- Gases that do not react with solvent (dissociate into ions)
- CO_2, N_2 O_2 Yes
- HCl, HI NO!

Henry's Law Example

- What is the amount of O_2 that will dissolve in H_2O at 1 atm pressure and a 25°C? Given Henry's constant is 756.7 L·atm/mol and the mole fraction O_2 in the atmosphere is . 2095 so at 1 atm the partial pressure of O2 is 0.2095 atm.
- $\dfrac{0.2095 \text{ atm} \;|\; 1 \text{ mol}}{|\; 756.7 \text{ atm·L}} = 2.769 \times 10^{-4}$ mol/L



Raoult's Law

Raoult's Law

The presence of a nonvolatile solute lowers the vapor pressure of the solvent.

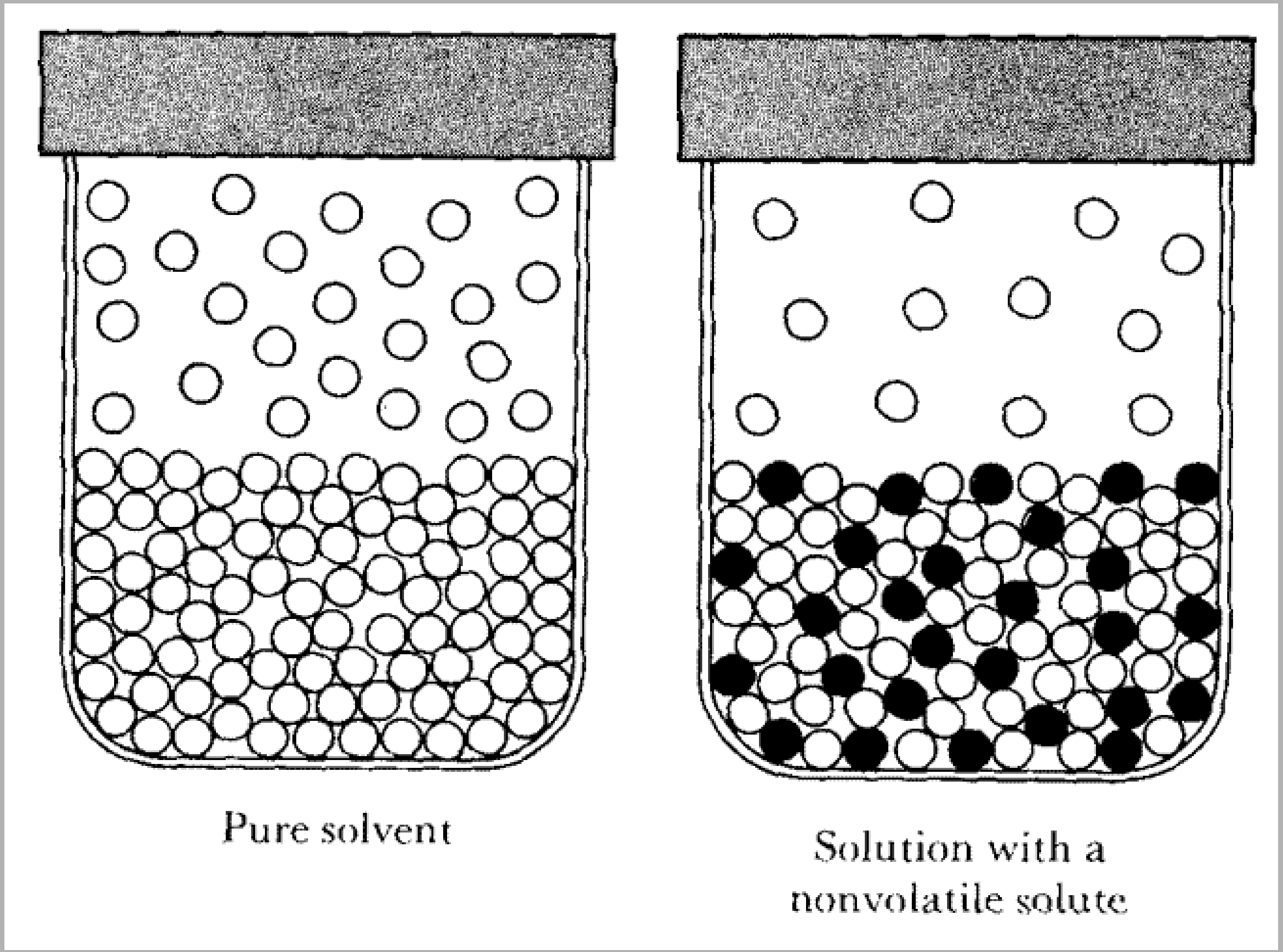
$$P_{solution} = \chi_{solvent} P^0_{solvent}$$

$P_{solution}$ = Observed Vapor pressure of the solution

$\chi_{solvent}$ = Mole fraction of the solvent

$P^0_{solvent}$ = Vapor pressure of the pure solvent

Raoult's Law



Fewer volatile molecules pushing on surface, less pressure

Raoult's Law Example

The vapor pressure of a solution containing 53.6 g glycerin in 133.7 g ethanol is 113 torr at 40C. What is the the vapor pressure of pure ethanol at 40C (Treat gylcerin as nonvolatile and molecular)

$P_{soln} = \chi P^o$ so $P^o = P_{soln} / \chi_{ethanol}$

Raoult's Law Example

- Find χ
- $\chi = n_a/n_a + n_b$
- moles of glycerin ($C_3H_8O_3$)
- moles of ethanol (C_2H_5OH)

Raoult's Law Example

- $P^o = P_{soln} / \chi_{ethanol}$
- $\chi_{\ ethanol} =$
- $P^o = 114\ torr / (2.90mol/3.48mol)$

What happens if

- Both solvent and solute are volatile

- Solvent pushes to the best of its ability
- Solute pushes to the best of its ability
- So we modify Raoult's Law a bit

What happens if

How much there is

$$P_{TOTAL} = P_A + P_B = \chi_A P_A^0 + \chi_B P_B^0$$

How hard it pushes

P^0 is the vapor pressure of the pure solvent

P_A and P_B are the partial pressures

Two Volatiles

- What is the vapor pressure above a mixture made from 0.0300 mol CH_2Cl_2 and 0.0500 mol CH_2Br_2 at 25C
- P^o_{CH2Cl2} = 133 torr
- P^o_{CH2Br2} = 11.4 torr

- Modified Raoults Law

- Steps
  - Find mole fraction of each substance
  - multiply by Po
  - Add the portions up

Two Volatiles

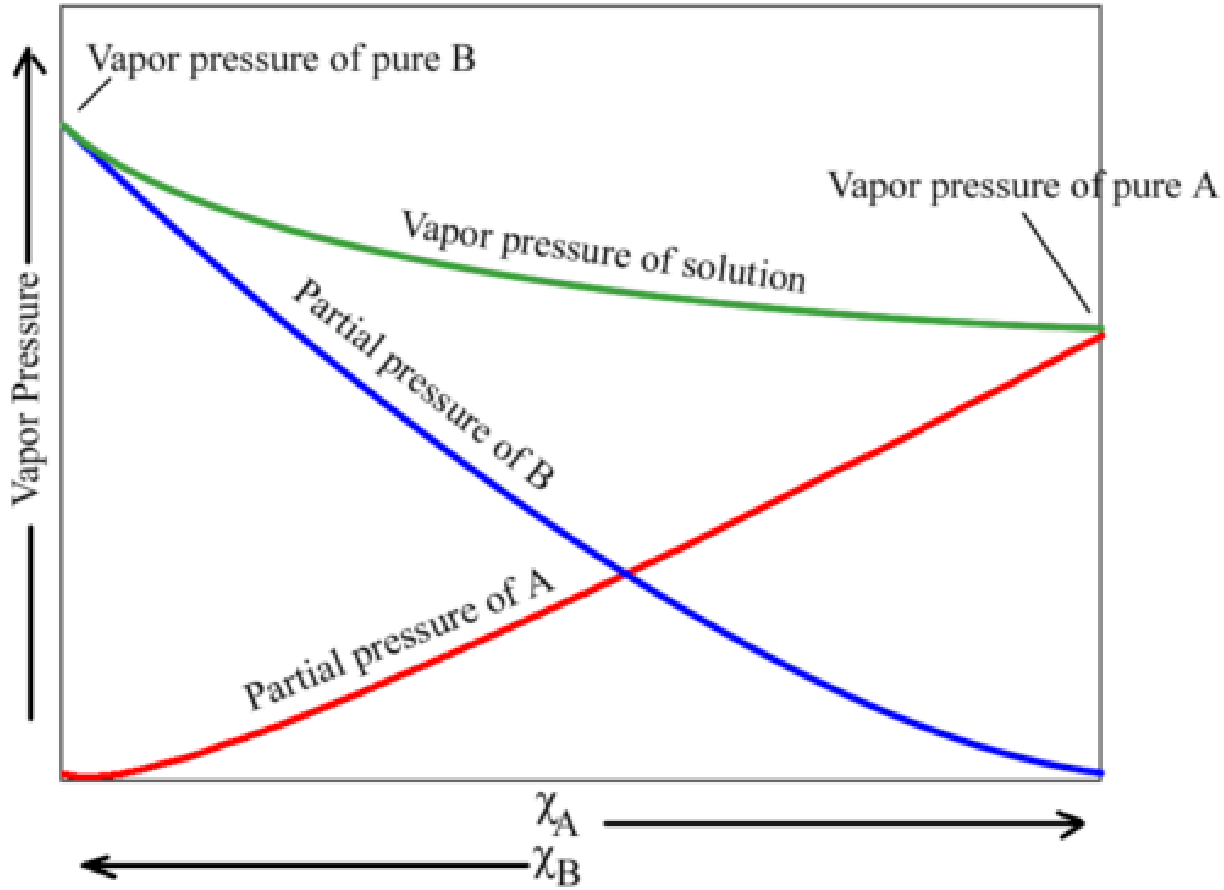
- $P_{total} = PCH_2Cl_2 + P\ CH_2Br_2$
- $P_{total} = \chi P^o CH_2Cl_2 + \chi P^o CH_2Br_2$
- P_{total}= 0.375(133 torr) + 0.625(11.4)

- P_{total}= 57.0 torr.
- Kinda like weighted averages for grades ;)

Negative Deviations from Raoult's Law

Strong solute-solvent interaction results in a vapor pressure lower than predicted

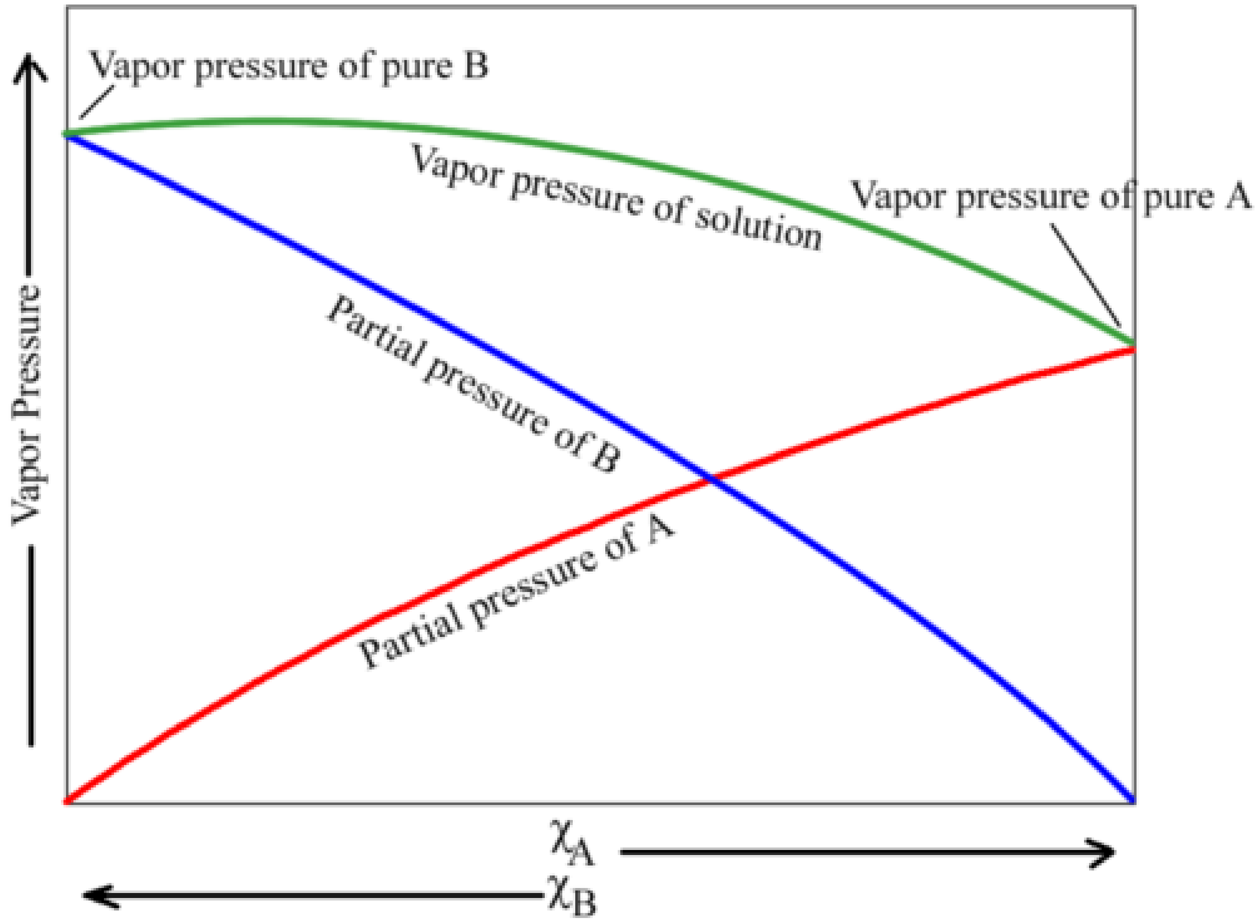
Exothermic mixing = Negative deviation



Positive Deviations from Raoult's Law

Weak solute-solvent interaction results in a vapor pressure higher than predicted

Endothermic mixing = Positive deviation



Electrolytes/Nonelectrolytes

- Aqueous solutions conduct e-
  - Ionically bonded
  - Ionized
- Aqueous solutions do not conduct e-
  - Covalently bonded
  - Molecules stay together

Examples

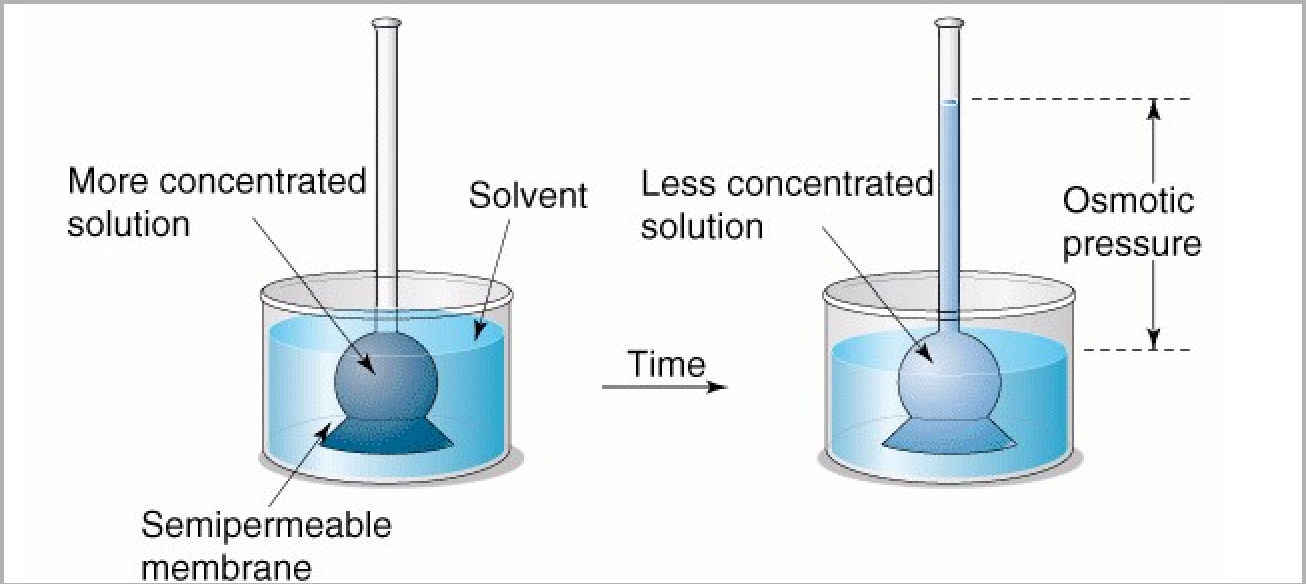
- Pentane
- Solid NaCl
- NaCl solution
- Distilled water
- Tap water
- Ethanol

Colligative Properties

- Depend on the amount of solute
- Does not depend on the identity of solute

- Vapor Pressure (Boiling point)
- Freezing Point
- Osmotic Pressure

Osmotic Pressure



- Water wants to equalize the concentrations
- Flows in until the pressure rises enough to prevent more flow. This is osmotic pressure.

Freezing Point Depression

- No matter what the solute* water's freezing point is lowered by
  - $\Delta T = i \cdot K_f \cdot m_{solute}$
- I is the van't Hoff factor
  - – the effective number of mole of ions supplied
- K_f is 1.86 °C ·kg/mol
- *m* is the molality of the solute

Boiling Point Elevation

- No matter what the solute* water's boiling point is raised by
  - $\Delta T = i \cdot K_b \cdot m_{solute}$
- I is the van't Hoff factor
  - the effective number of moles of ions supplied
- K_b is 0.51 °C ·kg/mol
- *m* is the molality of the solute

Example

- Mr K wants to make sure that his truck is protected this winter. He wants his antifreeze to be good to - 20 C. How much antifreeze should he use? There are 20 L of coolant in the truck. Antifreeze is 1,2-ethanediol.

- $\Delta T = i \cdot K_f \cdot m_{solute}$

Example

- $\Delta T = i \cdot K_f \cdot m_{solute}$
- $-20\ °C = i \cdot 1.86\ °C \cdot kg/mol \cdot m_{solute}$
- $-20\ °C = 1.0 \cdot 1.86\ °C \cdot kg/mol \cdot m_{solute}$
- *10.75 m solute needed or 10.75 mol/kg*
-

10.75 mol	20 kg	62.1 g	1 ml	1L
kg water	1trk	1mol	1.1 g	1000ml

Different van't Hoff factors

Dissociation Equations and the Determination of *i*

$NaCl(s) \rightarrow Na^{+}(aq) + Cl^{-}(aq)$ — $i = 2$

$AgNO_3(s) \rightarrow Ag^{+}(aq) + NO_3^{-}(aq)$ — $i = 2$

$MgCl_2(s) \rightarrow Mg^{2+}(aq) + 2\ Cl^{-}(aq)$ — $i = 3$

$Na_2SO_4(s) \rightarrow 2\ Na^{+}(aq) + SO_4^{2-}(aq)$ — $i = 3$

$AlCl_3(s) \rightarrow Al^{3+}(aq) + 3\ Cl^{-}(aq)$ — $i = 4$

Real world

- Ideal van't Hoff factors only achieved with extremely dilute solutions.

	Molality, *m*					
Solute	**1.0**	**0.10**	**0.010**	**0.0010**	**…**	**Inf dil***
NaCl	1.81	1.87	1.94	1.97	…	2
$MgSO_4$	1.09	1.21	1.53	1.82	…	2
$Pb(NO_3)_2$	1.31	2.13	2.63	2.89	…	3

Osmosis

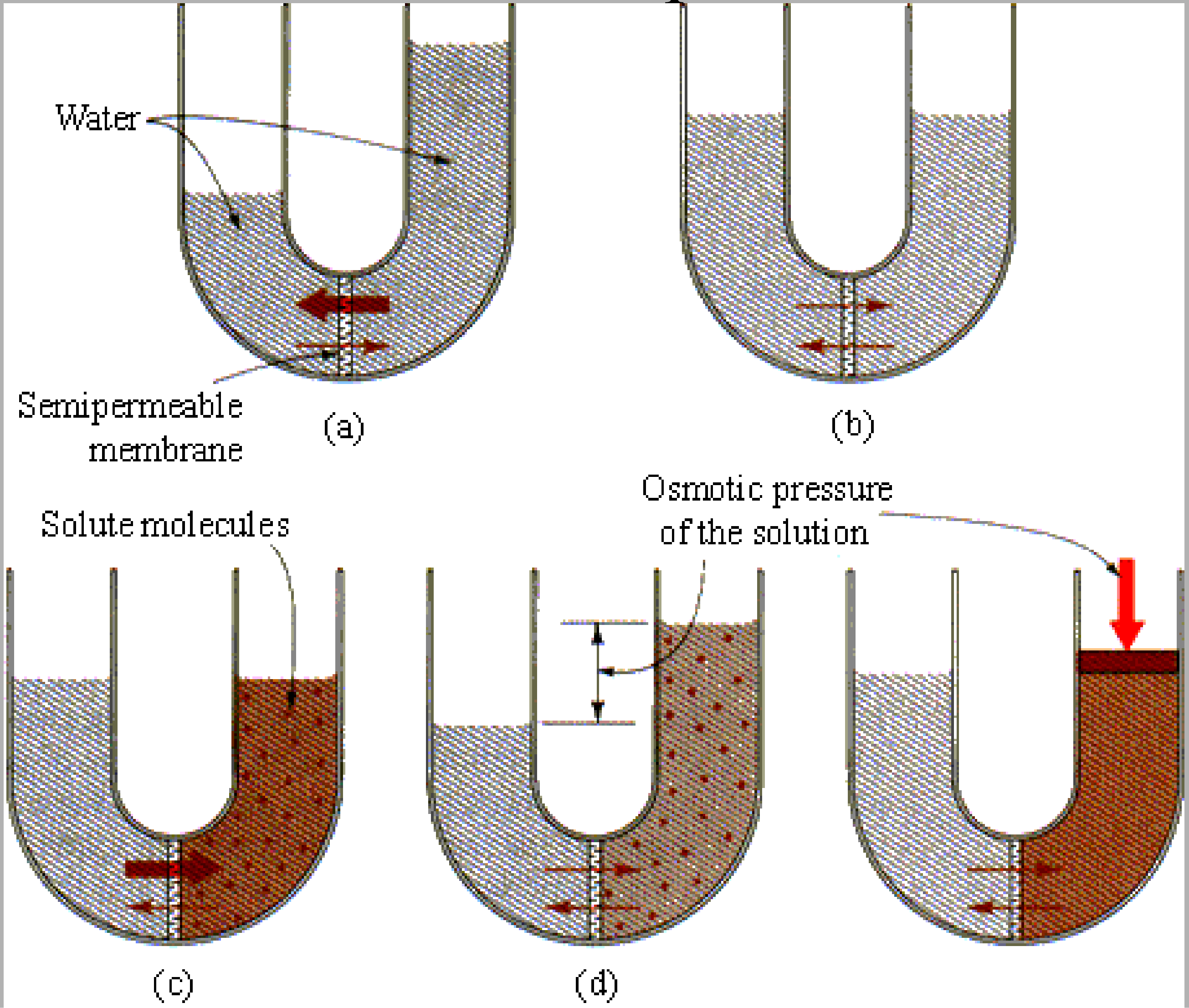
- Diffusion of water across a membrane

Salt Sucks!!

- Water will flood across a membrane to dilute high concentrations of solute.
- It is trying to reach equilibrium

Osmotic Pressure

- Pressure needed to stop osmosis



Osmotic Pressure

Osmotic Pressure Calculations

$$\Pi = iMRT$$

Π = Osmotic pressure

M = Molarity of the solution

R = Gas Constant = 0.08206 L·atm/mol·K

Π = Osmotic pressure

Osmotic Pressure

Osmotic Pressure Calculations

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