

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 (%) = (mass solute/ mass of solution) x 100

2. Mole Fraction X

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

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

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

3. Molality (mol/kg) = m

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

4. Molarity (mol/L) = M

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

5. Normality (equiv/ L) = N

$$\text{equivalents of solute} / \text{liter of solution} = N$$

(Normality used in acid base or redox reactions)

Use of symbols for molar mass

MW molecular weight or MM molar mass or FW formula weight are same
 Example (ex) water MW = MM = FW = 18.0 g/mol

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

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

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

2. Find Mole Fraction of ethanol

= moles of ethanol/ total moles in solution

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

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

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

$$\mathbf{0.904 \text{ H}_2\text{O water}}$$

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

= moles of solute ethanol/ kg of solvent

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

(solution is 5.9 **molal**)

4. Find Molarity (mol/L) of ethanol solution
= moles of solute/ liter of solution

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

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

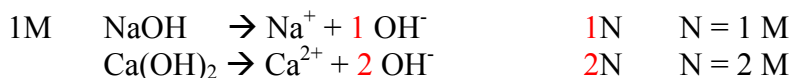
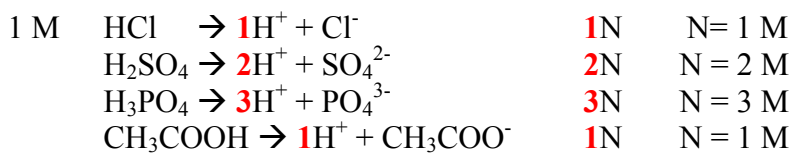
Consider these 1.0 M (molar) solutions and
note the normality may be same or more

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

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

(in other equations n may represent number of moles:

here n 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:

NaOH 40 g/mol (molar mass)
 40g/ equivalent (equivalent mass) since $\text{NaOH} \rightarrow \text{Na}^+ + \underline{1} \text{OH}^-$

H_2SO_4 98 g/mol (molar mass)
 49 g/ equivalent (equivalent mass) since $\text{H}_2\text{SO}_4 \rightarrow \underline{2}\text{H}^+ + \text{SO}_4^{2-}$

2H+

so

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

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

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 H_2O and so

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

To convert molar to molal assume 1.000 L of solution

To convert molal to molar assume 1.000 kg of solvent

Lab Applications

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

1. Make a solution

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

Glucose is $C_6H_{12}O_6$ so

Molar mass (MM) or molar weight (MW) = $6(12) + 12(1) + 6(16) = 180 \text{ g/mol}$

Moles = (concentration) (volume)

Mol = (conc) (vol)

Mol = (mol / L) (L)

notice how units give you equation since molarity $M = \text{mol/L}$

$$\begin{aligned}\text{Moles of solute needed} &= (\text{concentration})(\text{volume}) \\ &= (0.150 \text{ mol/L})(0.200\text{L}) \\ &= 3.00 \times 10^{-2} \text{ mol}\end{aligned}$$

so mass needed is $(3.00 \times 10^{-2} \text{ mol})(180 \text{ g/mol}) = \mathbf{5.40g \text{ glucose}}$

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

2. Do a Dilution

ex: How many mL of 18.0 M sulfuric acid are required to prepare 300 mL of 1.0 M H_2SO_4

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

$$\begin{aligned}(18.0 \text{ mol/L})(V_1) &= (1.0 \text{ mol/L})(0.300\text{L}) \\ V_1 &= 0.0167 \text{ L} \\ V_1 &= 16.7 \text{ ml}\end{aligned}$$

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

$$\begin{aligned}(18.0 \text{ mol/L})(V_1) &= (1.0 \text{ mol/L})(300 \text{ mL}) \\ V_1 &= [(1.0 \text{ mol/L}) / (18.0 \text{ mol/L})] (300 \text{ mL}) \\ V_1 &= \mathbf{16.7 \text{ ml}}\end{aligned}$$

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

$$C_{\text{gas}} = k_{\text{H}} P_{\text{gas}} \quad \text{mol/L} = (\text{mol/L atm}) (\text{atm}) \quad \text{or} \quad \text{g/L} = (\text{g/L atm}) (\text{atm})$$

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 CO_2
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 CO_2 is less soluble and bubbles out of solution.

ex: Consider a carbonated beverage bottled under 5.0 atm of pressure.
What is the concentration of CO_2 when bottled under above pressure
and after opened where pressure of atmospheric CO_2 is 0.00039* atm ?
Henry's law constant **k_{H} (CO_2 in water) is 0.0313 mol/ (L atm)**

Calculate C_{gas} (mol/L) as 0.16 and 1.2×10^{-5} for above pressures using

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

Coke goes flat (loses fizz) after opened because pressure of CO_2 above liquid is
much less than when bottled and sealed.

(*note: atmospheric CO_2 is about 390 ppm parts per million (ppm) and so if
exactly 1 atm pressure then move decimal 6 places to left 0.000390

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

ex: if vapor pressure of pure solvent is 24 torr then if mole fraction is 0.20 what is vapor pressure?

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

$$P_{\text{solution}} = (0.20) (24 \text{ torr})$$

$$P_{\text{solution}} = 4.8 \text{ torr}$$

note that only solvent is considered to have vapor pressure the solute does not go into vapor phase

ex: Water at 100°C has what pressure? and if $X_{\text{solute}} = 0.10$ then what is new vapor pressure of water in this new mixture at 100°C?

$$X_{\text{solvent}} = 1 - X_{\text{solute}}$$

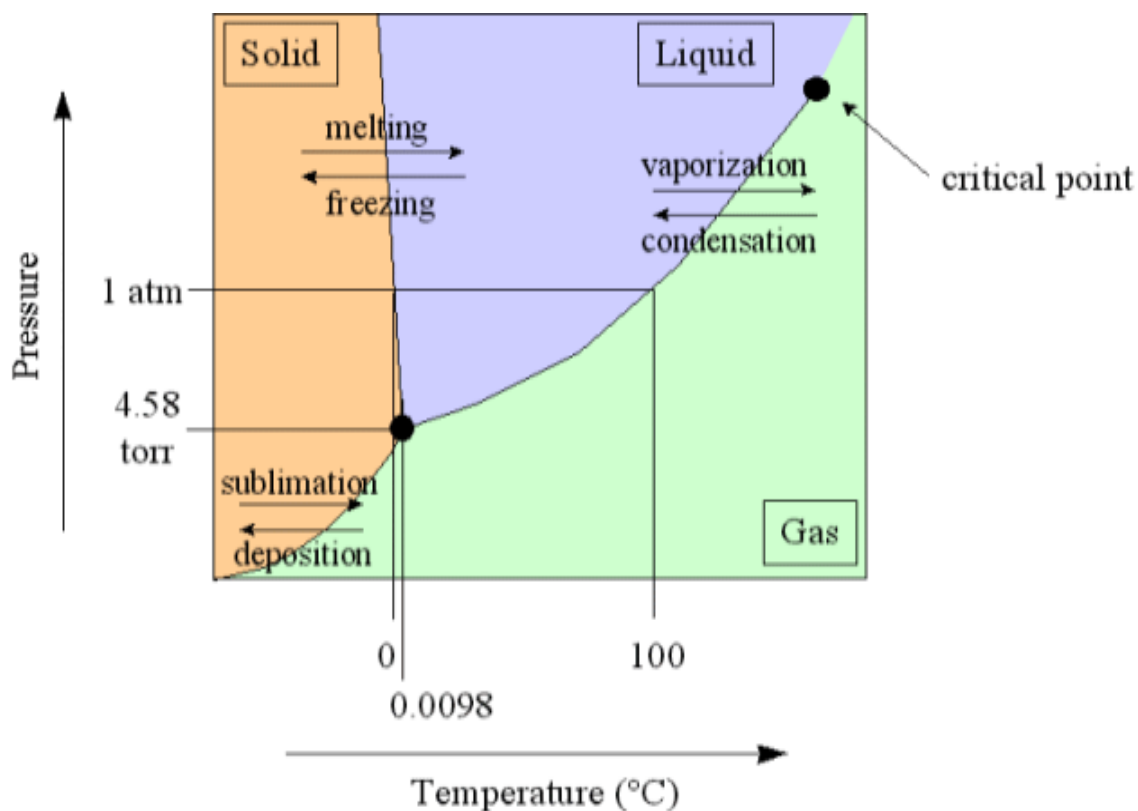
$$0.90$$

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

$$0.90 \text{ atm (or 684 torr)}$$

Freezing point depression and Boiling point elevation

On phase diagram for water below can observe
 the normal freezing point (liquid \rightarrow solid)
 and normal boiling point (liquid \rightarrow 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 Depression and BP Elevation Equations used are:

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

$$\Delta T_b = K_b C_m$$

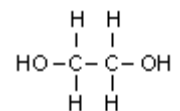
water solvent constants: $K_f = -1.86 \text{ }^\circ\text{C/m}$ (freezing point depression constant)

$K_b = 0.51 \text{ }^\circ\text{C/m}$ (boiling point elevation constant)

Does not matter what solute you use but use **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

ex: 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>)

So 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°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^-)

$$\Delta T_f = i K_f C_m$$

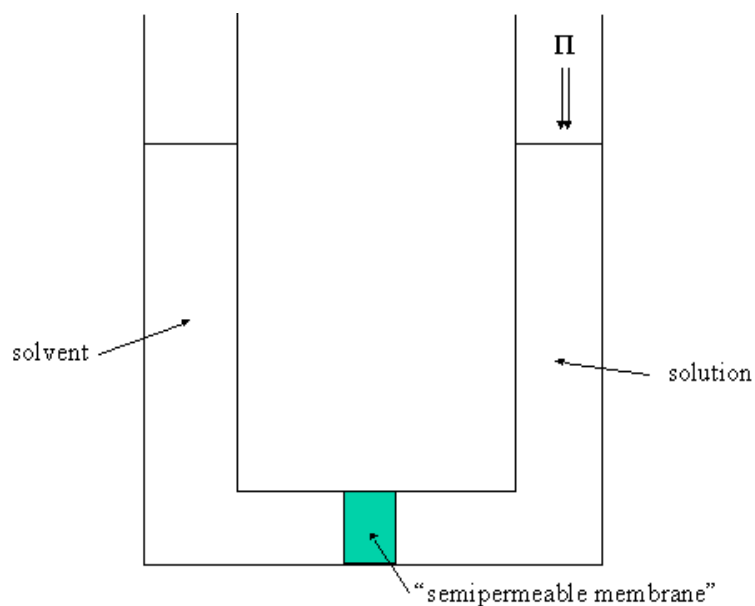
$$\Delta T = (2) (-1.86^\circ\text{C/m}) (5.00\text{m}) = -18.60^\circ\text{C}$$

And for 5.00 CaCl_2 (aq) since Ca^{2+} and Cl^- and Cl^- then $i=3$

$$\Delta T_f = i K_f C_m$$

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

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 or ions cannot go through
but solvent molecules can go through.

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.

Pressure needed to stop flow is: **Osmotic pressure = π**

Osmotic pressure flow direction

Think of solvent (normally water) going from
 where there is more water (solvent side)
 to where there is relatively less water (solution side)

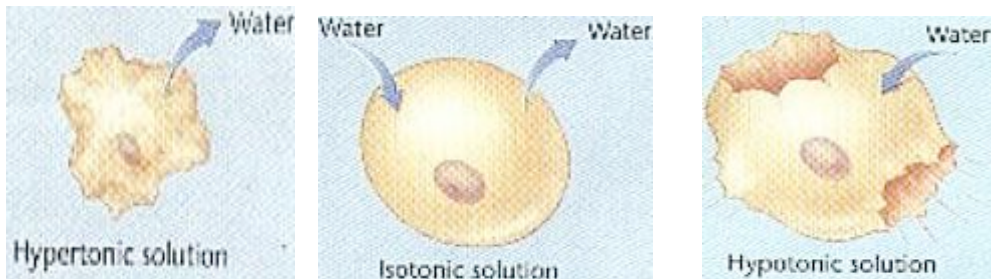
Osmosis is process by which solvent molecules move through membrane from
more solvent (lower concentration)
 into side with **less solvent** (higher concentration)

With the injection of large amounts of fluid such as I.V. fluids
 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>

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

Remember **solvent moves to make two sides less different
 by diluting more concentrated side.**

ex: two sugar solutions of diff conc observe $(1.0M \xrightarrow{\text{water}} \text{water} \rightarrow 5.0M)$

Osmotic pressure calculation

Osmotic pressure $\pi V = n R T$ or $\pi = M R T$

n = moles of solute,

V = volume of solution (L)

R = gas constant (0.08206 L atm / mol K)

T = temperature in (K, Kelvin)

π = osmotic pressure (atm)

$M = n/V$ (mol/L) or molarity

ex: How much glucose needed in 1.00 L solution to make the solution isotonic with blood given that Blood (red blood cells) $\pi = 7.7$ atm and Temp=37°C or $T = (37 + 273) = 310\text{K}$

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

$\pi V = n R T$

$(7.7 \text{ atm})(1.00 \text{ L}) = (n) (0.08206 \text{ L atm/ mol K}) (310 \text{ K})$

$0.303 \text{ mol} = n$

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

ex: San Diego CA <http://www.sdcwa.org/issue-desal>

reverse osmosis info http://en.wikipedia.org/wiki/Reverse_osmosis

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 $C_6H_{12}O_6$ 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

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 expected number of ions.

Ex: approximate as NaCl $i = 2$ $CaCl_2$ $i = 3$

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

Count everything in solution true for osmotic pressure

so expect 1.0 M solution of NaCl would have 2x osmotic pressure
of 1.0 M of $C_6H_{12}O_6$

expect effective conc = 2 mol/L with both Na^+ and Cl^- ions
1 mol/L $C_6H_{12}O_6$ with molecules

Colloids

Particles (collections of molecules) suspended in another medium

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

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 colloid and not solution by Tyndall effect (the scattering of light)

ex: water droplets in air form fog or cloud

because this colloid mixture scatters light

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

Polar and Nonpolar: Like dissolves Like

Substances can be

hydrophobic (water fearing) or **hydrophilic (water loving)**

ex: oil is nonpolar (hydrophobic)

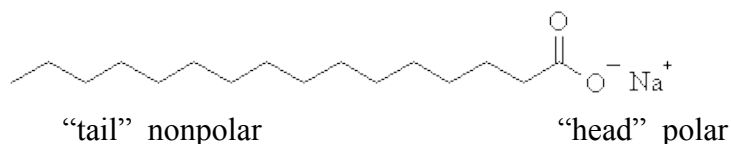
water is polar (hydrophilic)

polar molecule has more negative and more positive side (H₂O HCl)

nonpolar molecule the charges are uniformly distributed (CH₄ C₁₀H₂₂)

larger molecules may have polar and nonpolar regions

soap has a nonpolar portion and polar portion



Like dissolves like means:

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

Small layer of oil in jar of water do not mix

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

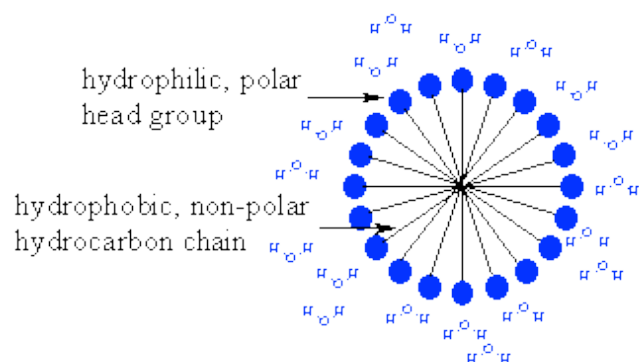
Shake and they still separate into two layers

Add enough soap or detergent and shake and the oil and water will mix together. Soap and detergent molecules have polar portion and nonpolar portion.

More info on soaps and detergents at:

http://jan.ucc.nau.edu/~doetqp-p/courses/env440/env440_2/lectures/lec19/lec19.html

An Association colloid (micelle) is formed with soap or detergent
Soap molecules form a sphere (micelle) around oil with polar portions extended out to dissolve in water. Soap (nonpolar/polar parts) used to remove oil or grease. The hydrophobic part attracts to nonpolar grease or oil and the hydrophilic part is attracted to polar water



For more information see: <http://en.wikipedia.org/wiki/Surfactant>