# SOLUTIONS

- a SOLUTION is a HOMOGENEOUS MIXTURE.

Uniform properties throughout!

- parts of a solution:

(1) SOLUTE(S)

- component(s) of a solution present in small amounts.

(2) SOLVENT

- the component of a solution present in the GREATEST amount

- in solutions involving a solid or gas mixed with a LIQUID, the liquid is typically considered the solvent.

- solutions are usually the same phase as the pure solvent. For example, at room temperature salt water is a liquid similar to pure water.

# SOLVENTS

- We traditionally think of solutions as involving gases or solids dissolved in liquid solvents. But ANY of the three phases may act as a solvent!

## (1) GAS SOLVENTS

- Gases are MISCIBLE, meaning that they will mix together in any proportion.
- This makes sense, since under moderate conditions the molecules of a gas don't interact wth each other.
- Gas solvents will only dissolve other gases.

## (2) LIQUID SOLVENTS

- Can dissolve solutes that are in any phase: gas, liquid, or solid.
- Whether a potential solute will dissolve in a liquid depends on how compatible the forces are between the liquid solvent and the solute.

## (3) SOLID SOLVENTS

- Solids can dissolve other solids, and occasionally - liquids.
- Solid-solid solutions are called ALLOYS. Brass (15% zinc dissolved in copper) is a good example.
- AMALGAM is a solution resulting from dissolving mercury into another metal.

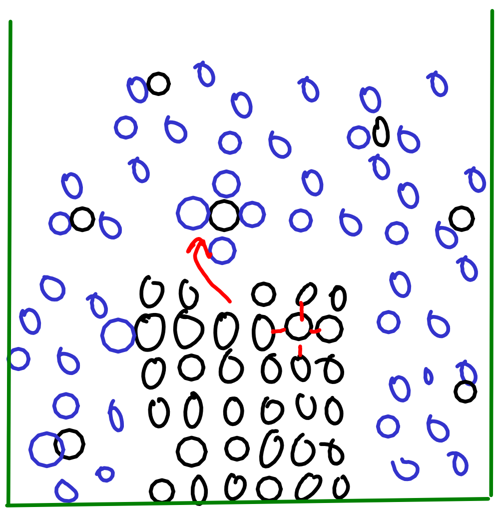
# HOW THINGS DISSOLVE

- Let's look at how things dissolve into water, since aqueous solutions are quite common.

sucrose (table sugar)

$$C_{12}H_{22}O_{11}(s) \underset{}{\overset{H_2O}{\rightleftharpoons}} C_{12}H_{22}O_{11}(aq)$$

... what happens?



- Water molecules pull the sugar molecules out of the sugar crystal and into solution.

- Attractions between sugar molecules and water allow this to happen.

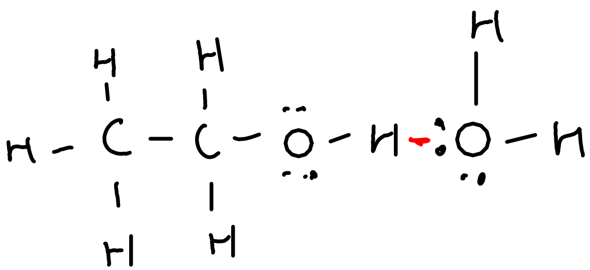
- The solubility of the sugar depends on how well water and sugar interact (HYDRATION) versus how well the sugar molecules are held in the crystal (LATTICE ENERGY)

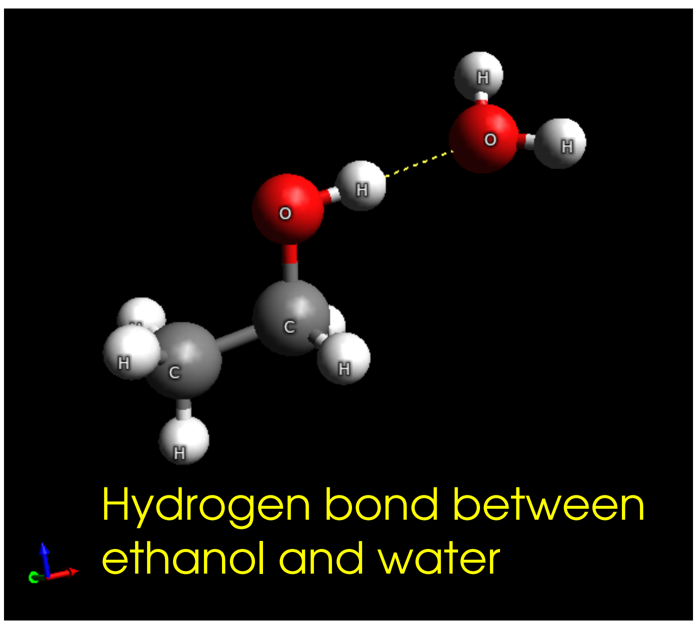
- "like dissolves like": Substances held together by similar (or at least compatible) kinds of attractive forces can dissolve in each other. Substances that are held together by very different kinds of attractive forces will not dissolve in one another!

# Consider WATER:

## HYDROGEN BONDS

Water mixes well with other substances that can hydrogen bond, like ETHANOL!




Hydrogen bond between ethanol and water

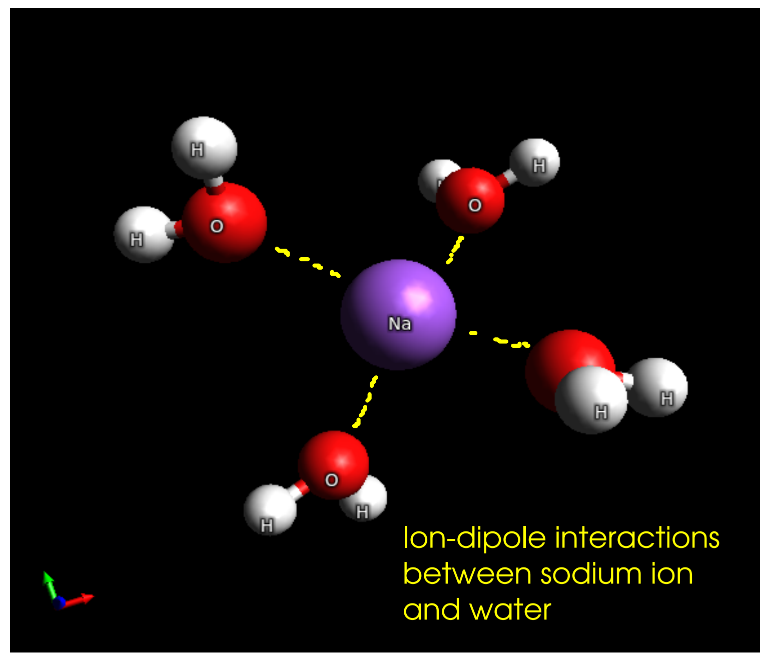
## POLAR

Water can dissolve polar substances!

(SUCROSE is polar!)

Since IONIC BONDS are also interactions between opposite charges (You can think of an ionic bond here as an extreme case of dipole-dipole interaction), many IONIC SUBSTANCES will also dissolve in water!

$Na^+ - Cl^-$




Ion-dipole interactions between sodium ion and water

## SMALL (little London force)

large and/or nonpolar solutes do not dissolve well in water!

(example: OILS and WAXES)

# MOLECULAR AND IONIC SOLUTIONS

- MOLECULAR solutions:

Contain MOLECULES dissolved in one another.

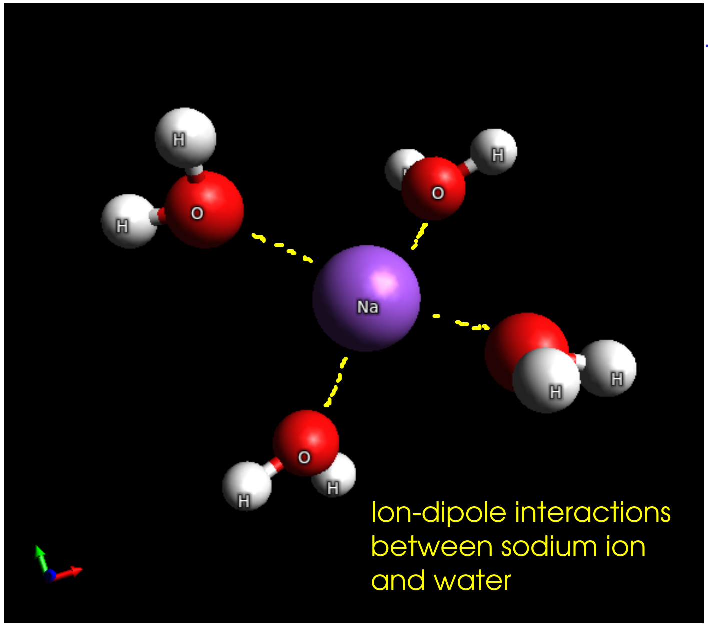
1. - Any mixture of GASES
   - all gases mix with one another, since gas molecules (effectively) do not interact with one another.

2. - Liquids
   - Liquids dissolve well in one another only if they are held together by similar kinds of forces

3. - Solids and liquids
   - MOLECULAR SOLIDS will dissolve well in liquids if they are held together by similar forces.
   - IONIC SOLIDS will sometimes dissolve in POLAR liquids, but not in nonpolar liquids
   - COVALENT NETWORK solids don't generally dissolve well in other substances

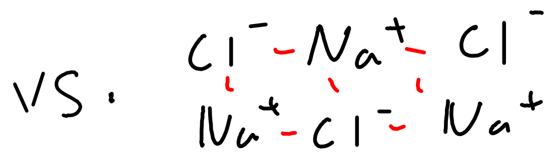
# IONIC solutions

- form when ions from IONIC SUBSTANCES interact with POLAR solvents - often WATER.



Ion-dipole interactions between sodium ion and water

The charged ends of the water molecule HYDRATE the ions.




- The solubility of an ionic compound depends on whether HYDRATION (attraction of water molecules for an ion) is greater than LATTICE ENERGY - the attrraction of ions in a crystal lattice for one another..

- SMALLER IONS are usually easier to enclose in water than larger ones, and ions with larger charges are attracted to water molecules.

- But solubility is also determined by LATTICE ENERGY - which holds the solid ionic compound together. Ions with high charges tend to be strongly attracted to other ions in a crystal, meaning lattice energy is high. Smaller ions also tend to have higher lattice energies. Lattice energy and hydration are competing trends!

## EXTERNAL FACTORS AFFECTING SOLUBILITY

- There are a few external factors that affect the solubility. (By external, we mean other than the chemical identity of the solute and solvent).

### (1) TEMPERATURE

-For gases dissolved in liquids, the solubility DECREASES as the temperature INCREASES

- This is why THERMAL POLLUTION is bad! Hot water holds less oxygen than cooler water.

- For solids dissolved in liquids, solubility USUALLY increases with temperature. This is not true for ALL solid/liquid solutions.

### (2) PRESSURE

- For gases dissolved in liquids, solubility INCREASES when the partial pressure of the solute gas over the solution INCREASES.

- Consider soft drinks. They go flat after opening because the pressure of carbon dioxide over the liquid goes down.

- No significant pressure effects for solid/liquid solutions.

# CONCENTRATION

- When you discuss a solution, you need to be aware of:
  - what materials are in the solution
  - how much of each material is in the solution

- CONCENTRATION is the amount of one substance compared to the others in a solution. This sounds vague, but that's because there are many different ways to specify concentration!

- We will discuss four different concentration units in CHM 111:

(1) MASS PERCENTAGE

$$= \frac{\text{mass solute}}{\text{mass solution}} \times 100\% \qquad \%\ ,\ \%\ w/w$$

(2) MOLARITY

$$= \frac{\text{moles solute}}{\text{L solution}} \qquad M \text{ or } \underline{M}$$

(3) MOLALITY

$$= \frac{\text{moles solute}}{\text{kg solvent}} \qquad m$$

(4) MOLE FRACTION

$$= \frac{\text{moles component A}}{\text{moles solution}} \qquad X_A$$

How would you prepare 455 grams of an aqueous solution that is 6.50% sodium sulfate by mass?

$$\frac{\text{mass sodium sulfate}}{\text{mass solution}} \times 100$$

mass percent (definition)

Write the defintion of the unit we're working with. Then, fill in as much as we know.

(from problem statement)

$$\frac{\text{mass sodium sulfate}}{455\text{ g}} \times 100 = 6.50$$

(from problem statement)

Since the mass of sodium sulfate is the only unknown here, we can solve for it.

Divide both sides by 100, then multiply both sides by 455 g:

$$\text{mass sodium sulfate} = 29.6\text{ g } Na_2SO_4$$

Since we are making 455 g of solution, subtract out the mass of sodium sulfate to give us the mass of solvent (water) we need to use.

$$455\text{ g} - 29.6\text{ g} = 425.4\text{ g } H_2O$$

To make this solution, weight out 29.6 grams of sodium sulfate, then add 425.4 grams of water.

# What's the MOLALITY and MOLE FRACTION OF SOLUTE of the previous solution?

29.6 g $Na_2SO_4$, 425.4 g water ← previous solution

Let's find MOLALITY first. Like before, write down the defintion and see what it tells us!

$$\frac{\text{moles } Na_2SO_4 \text{ (1)}}{\text{kg } H_2O \text{ (2)}}$$

molality (defintion)

To find molality, we need to calculate two things: (1) moles of sodium sulfate and (2) the mass of water used, in kilograms.

(1) Find moles of sodium sulfate. Convert 29.6 grams sodium sulfate to moles. Use FORMULA WEIGHT.

$Na_2SO_4$: Na: 2 x 22.99
S: 1 x 32.07
O: 4 x 16.00
142.05 g $Na_2SO_4$ = mol $Na_2SO_4$

$$29.6 \text{ g } Na_2SO_4 \times \frac{\text{mol } Na_2SO_4}{142.05 \text{ g } Na_2SO_4} = 0.2083773319 \text{ mol } Na_2SO_4$$

(2) Find mass of water. We already know the mass in grams; just convert to kilograms.

$kg = 10^3 g$

$$425.4 \text{ g } H_2O \times \frac{kg}{10^3 g} = 0.4254 \text{ kg } H_2O$$

$$\frac{0.2083773319 \text{ mol } Na_2SO_4}{0.4254 \text{ kg } H_2O} = 0.490 \text{ m } Na_2SO_4$$

29.6 g $Na_2SO_4$, 425.4 g water ← previous solution

Now, we can calculate mole fraction. As before, write out the defintion of the unit.

$$\frac{\text{moles } Na_2SO_4 \;①}{\text{total moles} \;②}$$

We need to calculate these two things!

mole fraction (definition)

① Find moles of sodium sulfate by converting 29.6 grams sodium sulfate to moles. We've already done that to get molality, so we'll just use that number.

0.2083773319 mol $Na_2SO_4$

② Find the total moles of solution. Since there are two things in the solution and we already know the moles of sodium sulfate, we just need to calculate the moles of water. Convert 425.4 grams of water to moles. Use FORMULA WEIGHT.

$H_2O$: H - 2 x 1.008
O - 1 x 16.00

18.016 g $H_2O$ = mol $H_2O$

$$425.4\text{ g } H_2O \times \frac{\text{mol } H_2O}{18.016\text{ g } H_2O} = 23.6123445 8\text{ mol } H_2O$$

$$\text{total moles} = 0.2083773319 \text{ mol } Na_2SO_4 + 23.61234458 \text{ mol } H_2O$$
$$= 23.82072191 \text{ mol}$$

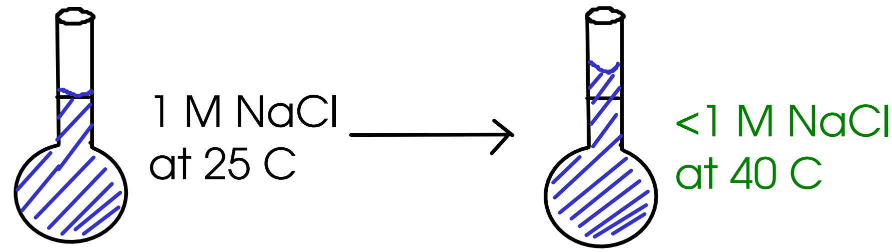
$$X_{Na_2SO_4} = \frac{0.2083773319 \text{ mol } Na_2SO_4}{23.82072191 \text{ mol}} = \boxed{0.00875}$$

# MOLARITY

- In the previous example, we converted between three of the four units that we discussed: mass percent, molality, and mole fraction.

- We didn't do MOLARITY, because the information given in the previous problem was not sufficient to determine molarity!

$$M = \frac{\text{moles solute}}{\text{L solution}}$$




Molarity is based on VOLUME, while the other three units are based on MASS. (moles and mass can be directly converted)

Volume depends on TEMPERATURE!

- If you HEAT a solution, what happens to CONCENTRATION?

ex: 5.00 mol $Na_2SO_4$ in 1L solution

5.00 mol $Na_2SO_4$ — constant when heated

1L solution — increases. (thermal expansion)

... the MOLAR CONCENTRATION decreases. (But the concentration in the other three units we discussed stays the same.)

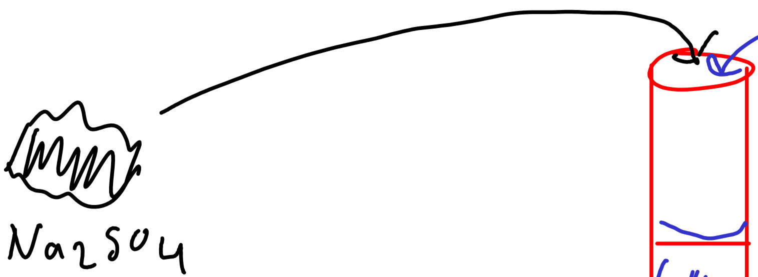
- If you COOL a solution, the MOLAR CONCENTRATION increases. (The other three units stay the same!)

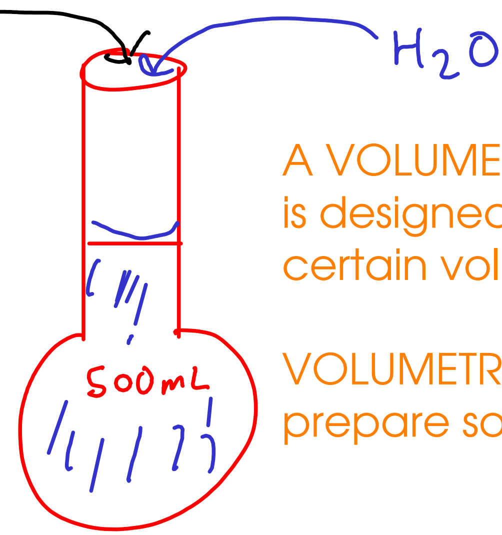
... we use MOLARITY so much because it's easy to work with. It is easier to measure the VOLUME of a liquid solution than it is to measure mass.

$Na_2SO_4$: (142.05 g/mol)

Example: How would we prepare 500. mL of 0.500 M sodium sulfate in water?

Dissolve the appropriate amount of sodium sulfate into enough water to make 500. mL of solution.




volumetric flask

A VOLUMETRIC FLASK is a flask that is designed to precisely contain a certain volume of liquid.

VOLUMETRIC FLASKS are used to prepare solutions.

$*500 mL = 0.500 L$

$$\underset{(0.500\,M)}{M} = \frac{\text{mol } Na_2SO_4}{\underset{(0.500\,L)}{\text{L solution}}}$$

molarity (defintion)

Write down the defintion of molarity and fill in the things we know (concentration ... 0.500 M, and volume ... 500. mL or 0.500 L)

$$0.500\,M = \frac{\text{mol } Na_2SO_4}{0.500\,L} \ ; \ \text{mol } Na_2SO_4 = 0.250 \text{ mol } Na_2SO_4 \text{ required}$$

We found that we need 0.250 moles sodium sulfate. Convert to mass for weighing.

$142.05\,g\ Na_2SO_4 = \text{mol } Na_2SO_4$

$$0.250 \text{ mol } Na_2SO_4 \times \frac{142.05\,g\ Na_2SO_4}{\text{mol } Na_2SO_4} = 35.5\,g\ Na_2SO_4$$

Weigh 35.5 grams of sodium sulfate into a 500 mL volumetric flask, then add water to the mark.