Solutions Diary

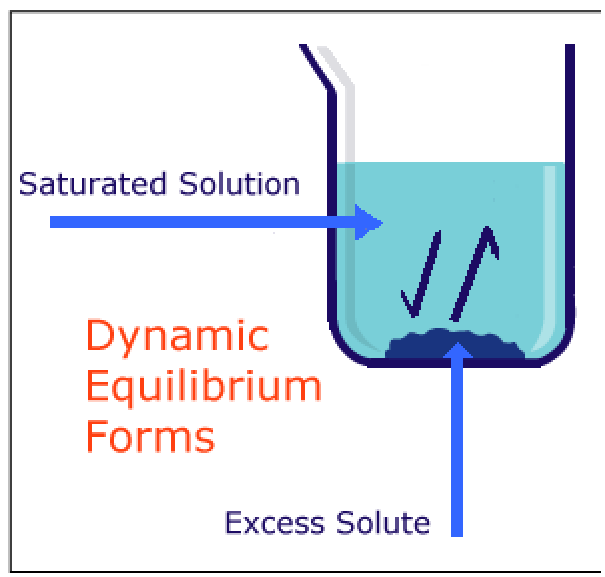
In this section of chemistry we'll be examining solutions, how they form, how to measure their strength, their properties, and how to dilute them exactly to get new solutions of lesser concentration and volume. Then we'll study about changing Colligative properties of water with dissolving particles into it. We'll examine the concept of parts per million for very un-concentrated solutions, finally, we'll do the math with this.

This part of the course uses the text a lot, chapter 17 starting at page 501! Welcome to chem proper, the fun's about to begin.

Solutions are homogeneous mixtures containing a solute in a solvent. We most often think of them as wet, with water as the solvent. Other liquids can be solutes as well. Gases can mix homogeneously which makes a gaseous solution, and we could even melt metals or other solids and stir them together. When they cool, technically speaking they are solid solutions (like steel). For now we'll stick to the "wet" solutions.

Solutions can be **saturated**, holding as much solute in a given volume of solvent as possible. At some point there is just no more room in the solvent and added solute cannot be held, so it falls to the bottom of the container. Although a saturated solution is "maxed out", excess solute continues to dissolve into solution while solute falls out of solution– **a dynamic equilibrium is formed**. The rate of dissolving is equal to the rate of precipitation. It's a "full" solution, but it's not stuck, rather it's constantly changing while the amount of solute is constant.

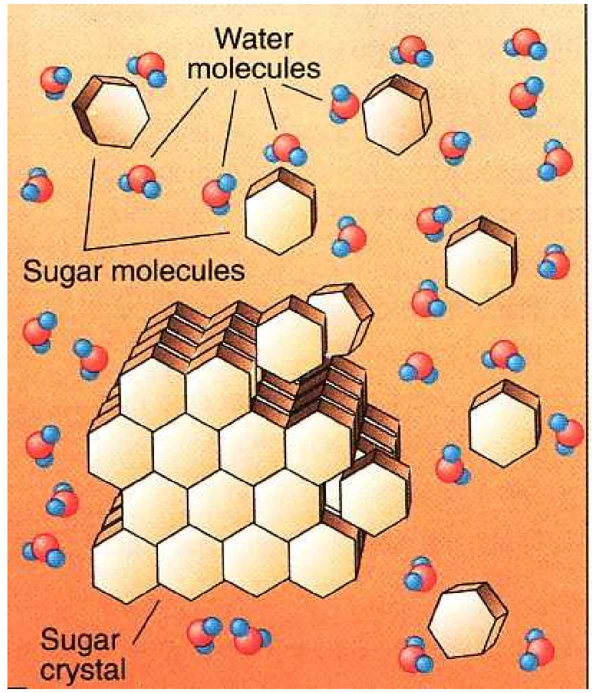
An **unsaturated solution** has room to hold more solute. You can add as much solute as you want, and the solution will allow it to dissolve until it reaches the saturation level.



A supersaturated solution is one that is more highly concentrated than is normally possible under given conditions of temperature and pressure. Usually you heat up the solvent, saturate it with solute, then cool it to a lower temperature which would not normally be able to contain that amount of solute. If you add some "seed" crystals of solute to this super saturated solution, the excess will collapse out onto these seeds, forming larger crystals. This photo at left shows the crystallization of excess solute after the seeding of a supersaturated solution.

Formation of Solutions…

When a crystal of sugar (or other polar compound) is put into the polar solvent water, the crystal is "attacked" by the water molecules. The water molecules surround the molecules, carrying they off the crystal and into solution. Of course, molecules are too small to see, so the macroscopic crystal is soon invisible to the eye as it's broken into billions of molecules that you can't see anymore. At some point the solvent cannot hold a single molecule more, so as more sugar dissolves, sugar precipitates out of solution at the same rate.



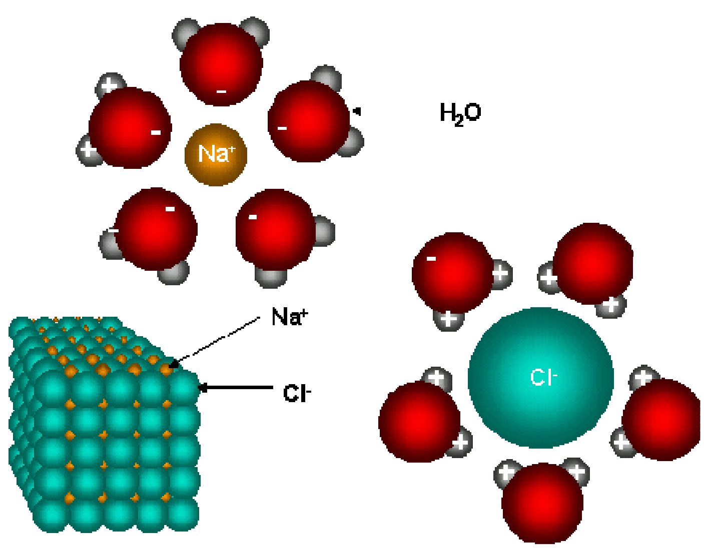
Like dissolves like is our solution mantra; polar solvents like water can only dissolve polar molecular compounds, or ionic compounds. Non-polar compounds can not mix with polar solvents.

At right is oil sitting atop water. The polar water cannot allow the nonpolar oil to mix. The oil floats because it's less dense. It doesn't mix because: Like Dissolves Like is true.

When ionic compounds are put into a polar solvent like water, they too are broken down, but into ions, and the water molecules surround them as well.

In the picture below, note how the + side of the water molecules (hydrogen) surround the negative chloride anions. The oxygen, with their — charges, surround the positive sodium cations.

The solvent will dissolve solute until saturated, then the dynamic equilibrium will form.



Remember what an electrolyte is? It's a solution that can conduct electricity. Solutions with ions dissolved can conduct electricity, but solutions with dissolved molecules like sugar cannot conduct. The more ions, the better the conduction. The less ions, the weaker the conduction.

Acids are special chemical compounds in aqueous solutions that appear to be molecular compounds like sugar (no metals), which they are, but they do form ions (we'll learn about acids and bases soon enough).

The CONCENTRATION of solutions.

One of the coolest concepts in chemistry is MOLARITY, the measure of how concentrated a solution is. Molarity can best be described as the molar concentration of a solution, expressed as the number of moles of solute per liter of solution. The formula is:

$$\text{Molarity} = \frac{\text{number of moles of solute}}{\text{Liters of solution}}$$

The formula is set up as moles divided by LITERS of solution but any volume of a solution can be made, and its CONCENTRATION will be measured by this formula.

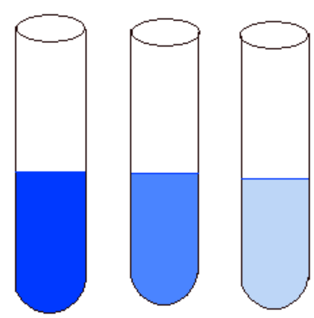
For example…

A 1.0 Molar aqueous solution of HCl could be made by putting 1.0 moles HCl into 1.0 Liters of H_2O.

Or, the same strength or concentration solution could be made with 0.25 moles HCl and 250 mL water.

In fact, an infinite number of combinations of moles to volume exist to make the same concentration of HCl solution.

These three tubes represent 3 different solutions of the SAME compound, but at different concentrations. The darkest one, on the left, would have the HIGHEST MOLARITY or greatest concentration. The one on the far right the LOWEST MOLARITY or least concentration.



A problem may look like this:

What is the concentration of an aqueous solution of KCl containing 370 grams KCl dissolved into 2.5 liters water?

Using the formula above for molarity, we figure this way…

$\text{Molarity} = \frac{\text{\#moles KCl}}{\text{liters of solution}}$	$370 \text{ g KCl} \times \frac{1 \text{ mole KCl}}{74 \text{ grams KCl}} = 5.0 \text{ moles KCl}$	$M = \frac{5.0 \text{ moles KCl}}{2.5 \text{ Liters}}$ M = 2.0 molar solution

Of course we could solve for concentration or molarity, or the number of moles in a solution of certain volume and strength, or volume of solution if we know the molarity and number of moles. Grams to moles conversions are necessary often as well.

The Molar Dilution Formula

Another formula that we can use is called the dilution formula. We can start out with a concentrated stock solution of known volume and molarity, and use it to make a new solution with a new volume and concentration.

How much of the strong solution is needed to create a new solution as stated?

The Molar Dilution formula is…

$$M_1V_1 = M_2V_2$$

To do a problem like this we substitute in what we know, and calculate our answer. So... For example, assume you have a lot of a concentrated $CuSO_{4(AQ)}$, of 2.0 Molar strength. How would you dilute this to create a 500. mL $CuSO_4$ solution of only 1.0 Molarity? How much of the strong solution is needed? We'll look at the formula, then we'll do the math.

$$M_1V_1 = M_2V_2$$

$$(2.0\text{ M})\ (X\text{ mL}) = (1.0\text{ M})(500.\text{ mL})$$

$$X = 250\text{ mL}$$

This means you will need to add 250 mL of the stronger, original solution into a flask, and add enough pure water to dilute it to make a 500. mL solution. So,

250 mL 2.0 M $CuSO_4$ + 250 mL H_2O = 500. mL 1.0 M $CuSO_4$ solution.

The original solution, the concentrated one, is called a STOCK SOLUTION.

Example 2: Now we'll do a second dilution, to make an even weaker solution from the first, say 0.40 M.

How do you dilute our 2.0 M stock $CuSO_4$ solution to form a 0.40 M solution of 500. mL?

we'll use the same formula…

$$M_1V_1 = M_2V_2$$

$$(2.0\ M)\ (X\ mL) = (0.40\ M)(500.\ mL)$$

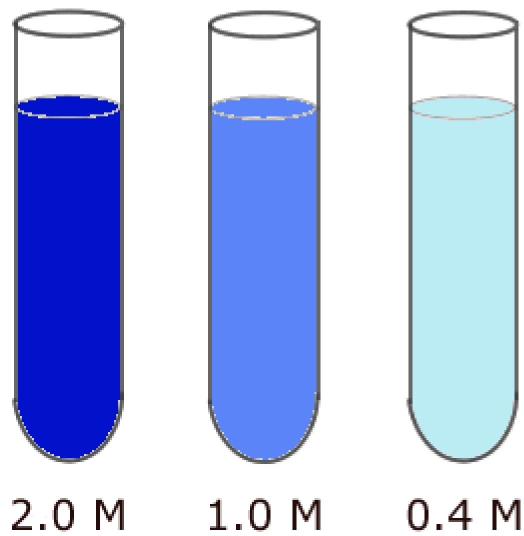
$$X = 150\ mL$$

Which means, we need to take 150 mL of the strong $CuSO_4$, put it into a flask, and add enough pure water to dilute it to get a solution of 500 mL.

150 mL of 2.0 M $CuSO_{4(AQ)}$ + 350 mL H_2O = 500 mL of 0.4 M $CuSO_{4(AQ)}$

These three tubes represent the 2.0 M stock solution, the 1.0 M diluted solution we made first, and the final weakest aqueous solution of 0.4 M $CuSO_4$. All made of the same $CuSO_4$, but of different concentrations or strengths.

Aqueous solutions of $CuSO_4$ would be shades of blue, the darkness of solution would depend upon the concentration or molarity of the solutions.



Another example:

You have a 5.0 M stock NaCl solution. You want to prepare a 500. mL salt water solution of 0.75 M concentration. Put into the formula what that you know, then solve for the VOLUME of stock solution.

$$M_1V_1 = M_2V_2$$

$$(5.0\ M)\ (X\ mL) = (0.75\ M)(500.\ mL)$$

$$X = 75\ mL$$

That means, you need 75 mL of the concentrated stock salt water solution and you need to dilute it then with 425 mL of pure water, to make a total of 500 mL of the 0.75 Molar salt water solution you wish to create.

Colligative Properties of Solutions

Solutions have physical properties (boiling point, freezing point, & vapor pressure) that are different from the properties of the pure solvent that made the solutions. If you dissolve particles (ions or polar molecules) into water, you change all three of these properties. The more particles in solution, the greater the properties change.

Let's imagine a salt water solution. The salt ions are now present, and although the water molecules have plenty of hydrogen bonds to each other, they also have attraction to these ions. This makes evaporation more difficult or slower.

The salt water also has a lower freezing point, as the ions disrupt the formation of the (neat) six sided rings of solid ice. It takes COLDER temperatures, or a lower kinetic energy to solidify into ice. One mole of particles in one liter of solution drops the freezing point by 1.86 Kelvin or 1.86°C.

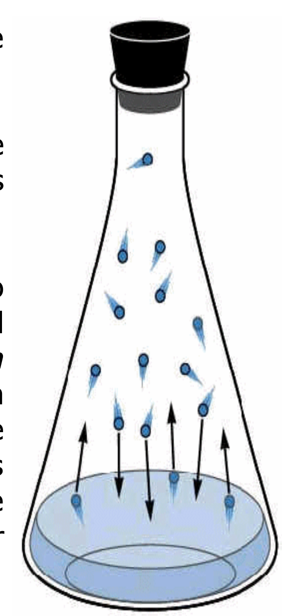
Dissolve one mole of...	into 1.0 L water, forms	new freezing point
$C_6H_{12}O_6$ - glucose	1 mole of molecules	1 X −1.86 K = -1.86 K
NaCl	2 moles of ions	2 X −1.86 K = -3.72 KC
$CaCl_2$	3 moles of ions	3 X −1.86 K = -5.58 K

Example 2: Why would people do better with calcium chloride than sodium chloride on their sidewalks in winter? NaCl ionizes into TWO IONS, while the $CaCl_2$ ionoizes into THREE IONS each. More moles of ions means that the sidewalk water would not freeze until about 6K less than 273K. (3 x −1.86 K = -5.58 K) with the calcium chloride salt treatment.

Moles of particles also RAISES the BOILING POINT, each mole of particles raises the boiling point by 0.50 Kelvin or 0.50°C. One mole of sugar molecules raises the boiling point of one liter of water to 373.5 K. One mole of sodium chloride ionizes into 2 moles of ions, and when added to ONE liter of water, the BOILING POINT is now 374 K.

One mole of $CaCl_2$ dissolved into one liter of water makes the boiling point now 374.5 K. This occurs for the same reason as the change in freezing point — the water sticks together well due to the many hydrogen bonds. With the addition of extra particles, there are further attractions that have to be over come to shake all those water molecules apart into the gas phase.

Example 3: Vapor Pressure is the pressure exerted by the gas phase of a liquid above the surface of this liquid, in a sealed system, such as this sealed jar at right.



Vapor pressure is also affected by particles in solution, but we won't do any math with this. In a sealed system, molecules of the liquid will evaporate into the space above the surface of the liquid. ***How much*** evaporation is determined by the attractiveness of the particles to each other which keeps them liquid, also by the temperature (the more Kinetic Energy means more evaporating), and also how many particles are dissolved into the liquid. The more particles that are dissolved, the more attractive the liquid is to itself; the less evaporation means lower vapor pressure.

Parts Per Million

Another way to measure concentration is called PPM or parts per million. Some concentrations are so small that molarity is too small to grasp easily, so another expression is used. For example, if there is 0.12 grams of mercury dissolved into 100. liters of sea water, what is the molarity?

Molarity = $\frac{\text{moles of solute}}{\text{Liters of solution}}$	Molarity = $\frac{0.00060 \text{moles Hg}}{100. \text{ Liters}}$	M = 0.0000060 M which is silly small

The formula for PPM is on the back of your reference table. It is

$$PPM = \frac{\text{grams of solute}}{\text{grams of solution}} \times 1{,}000{,}000$$

$$PPM = \frac{0.12 \text{ g Hg}}{100{,}000 \text{ g water}} \times 1{,}000{,}000 = 1.2 \text{ parts per million}$$

This means: 1.2 parts Hg per million parts water

From an old regents exam was this problem…

What is the concentration of a solution in parts per million if 0.02 grams Na_3PO_4 is dissolved into 1000 grams water?

A. 20 PPM B. 2 PPM C. 0.2 PPM D. 0.02 PPM

$$PPM = \frac{\text{grams of solute}}{\text{grams of solution}} \times 1{,}000{,}000$$

$$PPM = \frac{0.02 \text{ g } Na_3PO_4}{1000 \text{ g water}} \times 1{,}000{,}000 =$$ 20 parts per million choice A

The end of solutions, but still important.

To make a proper solution, of perfect volume, there is only one way to proceed. First get a special flask with a line that shows exactly a particular volume (often 1.00 L). Put the solute in first. Then fill with pure water up to the line. This is the ONLY WAY to make a perfect solution. You can't just add solute into the solvent, it will affect the volume (in a small but measurable way).

When an ionic compound (NaCl, KCl, MgO, etc.) is dissolved into water it forms an ionic solution. It has free ions floating in the water. This solution is a mixture. The more ions in solution, the better electrical conduction that occurs. Fewer ions means a lesser electrical conduction.

If you melt an ionic compound like $NaCl_{(L)}$ or $CuBr_{(L)}$ it will be super duper hot. It will also be able to conduct electricity because the ions are loose, almost like in an aqueous solution. This is weird, it would be way too hot to handle in most colleges and impossible in high school, but true nonetheless.

Electrolytes are solutions with ions in them (soluble ionic compounds), and they conduct electricity. Electrolytes are always able to conduct electricity. The more ions in solution, the better the electricity flows.

Ionic compounds in the solid form CANNOT conduct electricity because there are no loose ions, and no loose electrons (as with metals and metallic bonds). Solid ionic compounds are called electrolytes if they are soluble in water. Electrolytes can be solutions that conduct, or (strangely enough) solids that would form soluble ionic solutions.