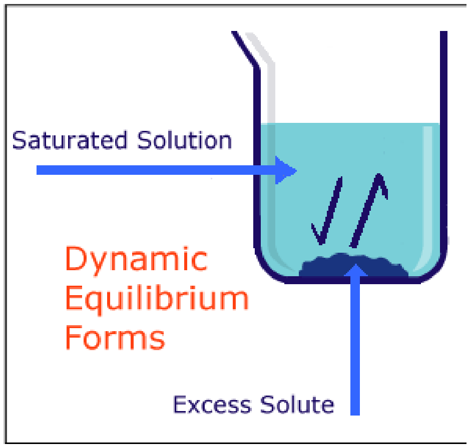
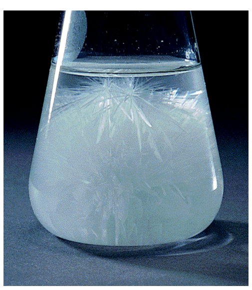
Chapter 13 Solutions Diary

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.

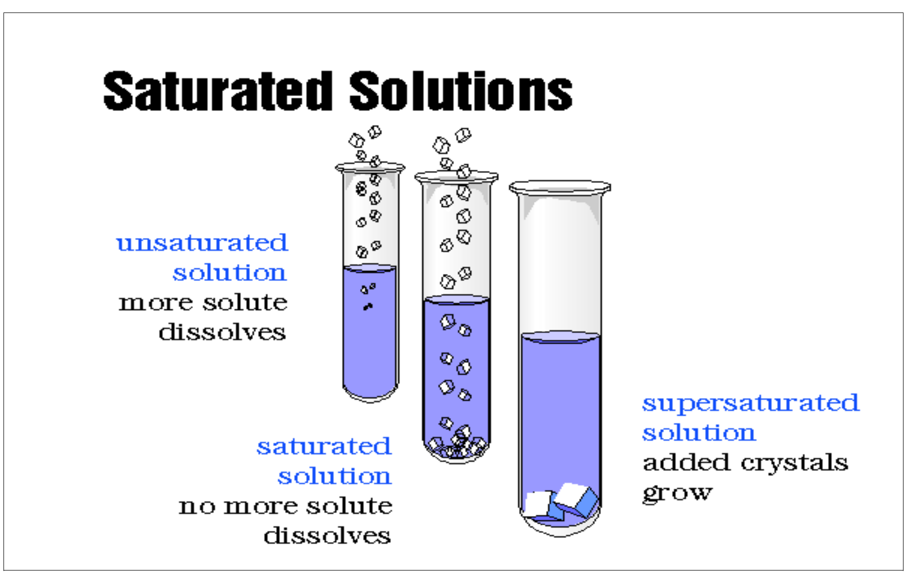


Solutions can be ***saturated***, holding as much solute in a given volume of solvent as possible. At some point there is just no more room in the solvent and added solute cannot be held, so it falls to the bottom of the container. Although a saturated solution is "maxed out", excess solute continues 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.

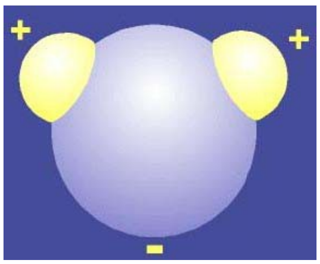


A ***supersaturated solution*** is one that is more highly concentrated than is normally possible under given conditions of temperature and pressure. Usually you heat up the solvent, saturate it with solute, then cool it to a lower temperature which would not normally be able to contain that amount of 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.

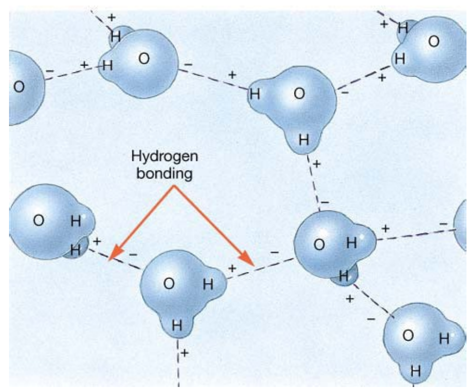


The Magic of Water

One of the very best molecules in chemistry class is dihydrogen monoxide. Your teacher admits to drinking it often, swimming in it a lot, splashing it in her face, cooking food in it, spraying it on his grass, doing dishes in it, washing clothes in it, bathing in it, skating on it, throwing it at her kids, molding it into somewhat rounded but human like forms and sticking a carrot where the nose belongs, shoveling it, cursing it when it falls too deeply in her driveway, chilling her beverages with it, and on and on. Water is pretty cool stuff, even when hot. It makes nice pictures, and does cool things, and has physical properties (which are all caused directly or indirectly by the hydrogen bonds between the water molecules).



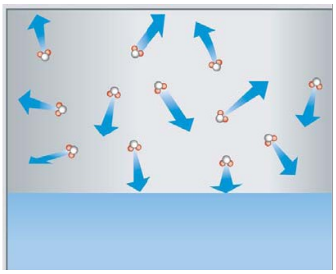
Water is a very polar molecule. It does not have RADIAL SYMMETRY, which would allow its very polar bonds to be "offsetting" to each other. It does have bilateral symmetry, the same type humans have, but that makes it a polar molecule. The oxygen has an Electronegativity value of 3.5, hydrogen's is only 2.1, which means that the oxygen "gets" the electrons from hydrogen most of the time, leaving the molecule charged as shown here (oxygen negative, hydrogen's are more positive). This opposite charged set up makes water a polar molecule. Being a polar molecule, and having hydrogen bonded to such a strongly electronegative atom, gives rise to "hydrogen bonds". Hydrogen bonds are the intermolecular attractions between positive hydrogen's of one molecule and the negative oxygen's of nearby molecules. These dipoles of the molecules make the molecules attracted to each other. The strength of these hydrogen bonds is fair, and causes the properties of water below. Hydrogen bonds between a group of water molecules is shown at right.



1. STRONG SURFACE TENSION: the molecules bond tightly to each other, but not to the air. These bonds create a tightness on the surface, that actually has the strength to hold denser particles from breaching the edge. We see this when we put sulfur powder (density of more than 2 g/cm3) onto water, and the sulfur could not get through - until soap is added, which is a **surfactant**.
Surfactants interfere with hydrogen bonds as their molecules get between the water molecules, creating millions of tiny holes in the surface. Soap creates an easy way for the sulfur to break through the water surface, and sink.
Surfactant = SURFACE ACTIVE AGENT

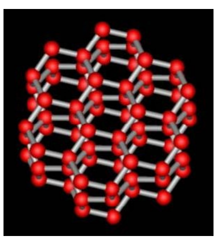
2. HIGH SPECIFIC HEAT CAPACIY: In table B in our reference tables it shows that the specific heat capacity constant for water is 4.18 J/g·°C. This means that in order to raise the temperature of ONE GRAM of water by ONE DEGREE centigrade, it will take 4.18 JOULES of energy. Joules are fancy units, but 4.18 Joules is also the same amount of energy as ONE calorie (small letter). 1000 calories = 1 Calorie (capital letter), also known as a food calorie.

Increasing the temperature of water means making the water molecules move faster. In order to move faster they must overcome their attraction to one another. These hydrogen bonds are strong enough to make water require much more energy to increase in temperature than most other substances. (the specific heat of Fe is 0.46 J/g·°C , and for Hg it's only 0.14 J/g·°C.



3. LOW EVAPORATION RATE (low vapor pressure). When a liquid is in a SEALED container, some of the liquid will evaporate. The pressure created by the evaporated liquid exerts a pressure, called the vapor pressure. Water has a low vapor pressure, because of its hydrogen bonds, the water does not want to let go of itself, and so most stays in the liquid phase. To evaporate, each molecule must gain enough kinetic energy to overcome the air pressure as well as the attractions of the intermolecular hydrogen bonding. In the open air, water will evaporate of course, but it evaporates much slower than other liquids without hydrogen bonds. Rubbing alcohol or gasoline, for examples, evaporate much more quickly, and cools your skin faster, because they have very little hydrogen bonding.

4. HIGH BOILING POINT. Again, this occurs for the same reasons listed above. Hydrogen bonding causes the water to stick together. In order to boil water ALL of the molecules must gain enough kinetic energy to break apart from each other. This takes 2260 J/g (the heat of vaporization). As the water gains this energy, it boils. The bubbles in boiling water are water vapor, H_2O gas, water molecules that have gained so much energy that they rush apart, from liquid to gas phase, and are LESS DENSE, so they appear as bubbles which we see.



5. The Density OF ICE IS LOWER than the DENSITY of LIQUID WATER. When the kinetic energy of water gets lower and lower, the temperature drops and the water feels colder. At a certain point (0° C at normal pressure of 101.3 kPa) the water will turn to solid ice. The water molecules are so slowed down so that the hydrogen bonds are strong enough to overcome them and force them into the most stable complexes of six molecule rings. These rings of water molecules are held together by hydrogen bonds in 3 directions, and ice forms. The molecules have a small gap and this gap, which takes up space, creates a strange situation: the SOLID ice has a LOWER DENISTY than H2O(L)

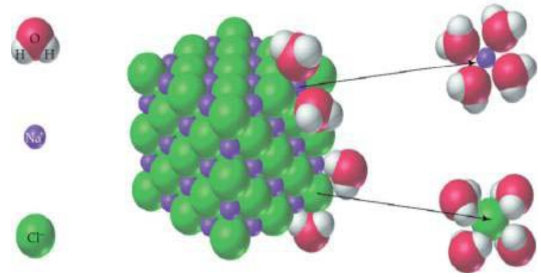
Frozen water molecules arranged in their normal hexagonal shape. Note the big hole between them, which creates more volume than these same 6 molecules would have unfrozen. Liquid water is more dense than solid water.

6. SOLVATION AND ELETROLYTE FORMATION. When polar or ionic compounds get dissolved into water, the concept of LIKE DISSOVLES LIKE comes to mind. Solvation is the science word for dissolving into solution. Water is a POLAR MOLECULE, which has a positive and a negative side (hydrogen side and the oxygen side).

The water molecules “gang up” on the polar molecules, arranging themselves around the polar molecules according to opposite charges. For ionic compounds, the formula units are broken up into cations and anions, again the water arranges itself around each ion, depending upon the charge of the ion, and the particular side of the water molecule.

In this picture…

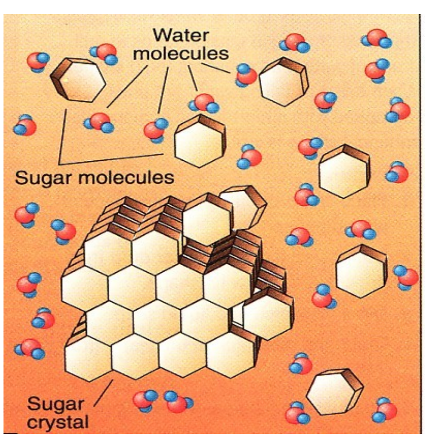
Water: OXYGEN is RED, HYDROGEN IS WHITE.
Sodium chloride: PURPLE SODIUM CATIONS, and **GREEN CHLORIDE ANIONS**.



Above we see the sodium cations surrounded by the oxygen side of water. Below that we see the chloride anions surrounded by the positive charged side of water, hydrogen. The water “attacks” the ionic compound and pulls the ions off of the solid. At some point the water molecules are all “BUSY” surrounding the cations and anions. At that point the water is SATURATED with salt. If more salt is added, it cannot stay in solution because ALL the water is busy.
When a solution contains ions, when an IONIC COMPOUND is dissolved into it, the solution is an ELECTROLYTE. That is, it can conduct electricity. The more ions, the better the conductor. The less ions, the worse conductor. Aqueous sodium chloride solution conducts electricity very well. When a molecule dissolve in water, but is NOT IONIC, like sugar, or alcohol, the solution is a non-electrolyte, a non-conductor of electricity. They are SOLUTIONS but because of a LACK OF IONS, they are NON ELECTROLYTES.

7. WATER OF HYDRATION. Water can be hydrogen bonded to a variety of ionic compounds. The water is “loosely” bonded to the ionic compound, but it is attached. Certain hydrates (as they are called) exist and we are familiar with several. Copper (II) sulfate pentahydrate connects five water molecules to the $CuSO_4$ compound. Another compound we used in lab is known commonly as EPSOM SALT, or magnesium sulfate heptahydrate ($MgSO_4 \cdot 7H_2O$). That compound has room for SEVEN molecules of water to be HYDROGEN BONDED onto it.

Formation of Solutions

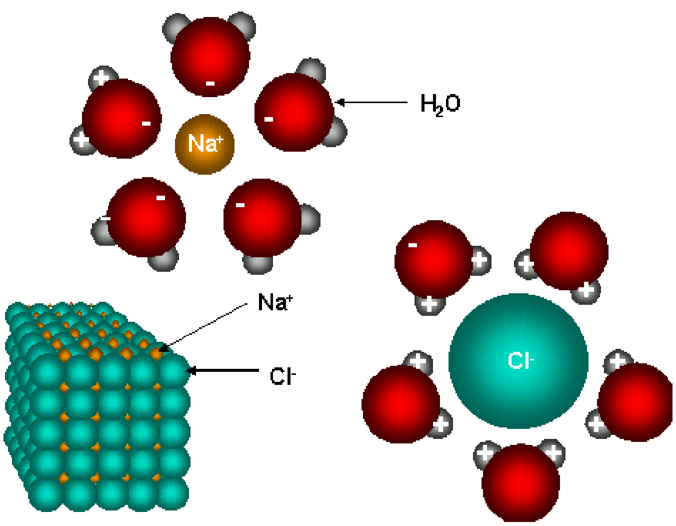


When a crystal of sugar (or other polar compound) is put into the polar solvent water, the crystal is “attacked” by the water molecules. The water molecules surround the molecules, carrying they off the crystal and into solution. Of course, molecules are too small to see, so the macroscopic crystal is 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.

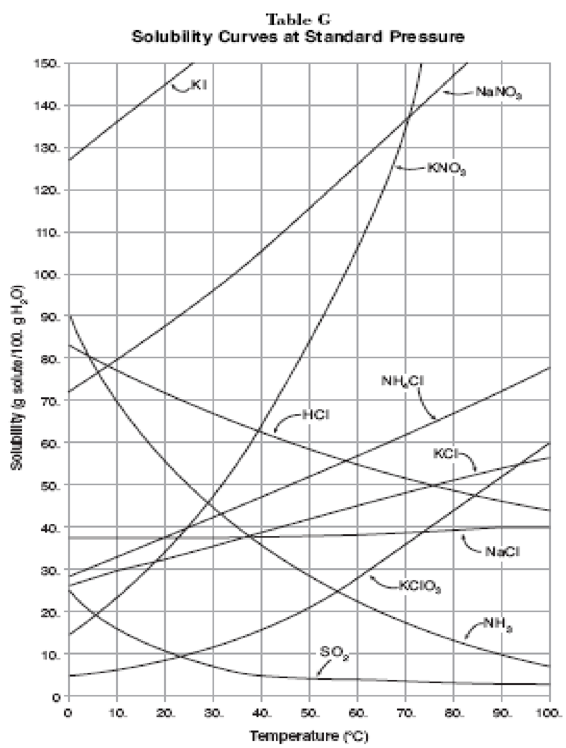
Acids are special chemical compounds in aqueous solutions that appear to be molecular compounds like sugar (no metals), which they are, but they do form ions (we'll learn about acids and bases soon enough).

Again, remember that ***Aqueous solutions*** means that the solvent is water.

When 2 or more liquids dissolve into each other, say, water and alcohol. Like dissolves like, so, since water is polar, alcohol must be too (it is). Two liquids that dissolve into each other are said to be MISCIBLE. If the 2 liquids DO NOT mix, they are called IMMISCIBLE.

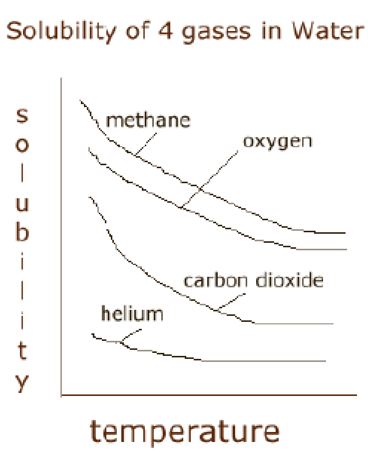
Solutions and Reference Table G

When a solute dissolves into a solvent, a homogenous solution is formed. If the solvent is water, the solution is said to be an AQUEOUS solution. Solutions are homogenous, which means the SAME THROUGHOUT. A given solvent can only hold a certain amount of solute. When it is holding as much as possible, the solution is said to be SATURATED. When the solution has some solute, but not the maximum amount that can fit in, the solution is UNSATURATED. We can see the amounts of ten different solutes that fit into 100 mL of water at ANY TEMPERATURE by looking at our TABLE G in the reference tables.



To determine the MAXIMUM amount of solute that can fit into 100 mL water at a particular temperature, find the temp, slide your finger up to the PROPER CURVE. Where they cross is the SATURATION POINT for that temperature. Slide to the left, and READ how
many grams of solute will fit into the 100mL of water at that temperature. How much solute fits is called the compound's SOLUBILITY. These are the SOLUBILITY CURVES. Under the lines is unsaturated, the lines represent the MAXIMUM amount of solute, or the saturation level.

NOT all compounds are listed on Table G, gases have solubility curves that you should be able to interpret. Clearly, gas solubility generally drops with increasing temperature. Gas solubility does INCREASE with increasing pressure. That's how water is carbonated, under high pressure. When the soda water is opened to the air, the carbon dioxide is released.



Based on the graph representing solubility of 4 gases in water, which compounds are gases in table G?

Answer: SO2, NH3, HCl

Concentration

MOLARITY is 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:

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

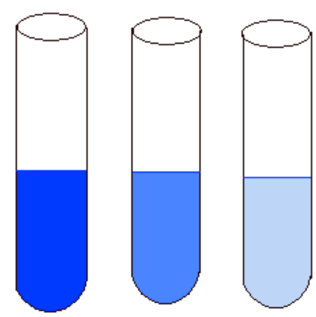
The formula is set up as moles divided by LITERS of solution but any volume of a solution can be made, and its CONCENTRATION will be measured by this formula.

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.

Example 1:

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…

$\text{Molarity} = \frac{\text{\#moles KCl}}{\text{liters of solution}}$	$370\text{ g KCl} \times \frac{1\text{ mole KCl}}{2.74\text{ grams KCl}} = 5.0\text{ moles KCl}$	$M = \frac{5.0\text{ moles KCl}}{2.5\text{ Liters}}$ 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.

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?
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

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

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

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?

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.

The Molar Dilution formula is…

$$M_1V_1 = M_2V_2$$

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,

$$M_1V_1 = M_2V_2$$

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

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

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 : Now we'll do a second dilution, to make an even weaker solution from the first, say 0.4 M.

How do you dilute our 2.0 M stock $CuSO_4$ solution to form a 0.4 M solution of 500 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.

we'll use the same formula…

$$M_1V_1 = M_2V_2$$

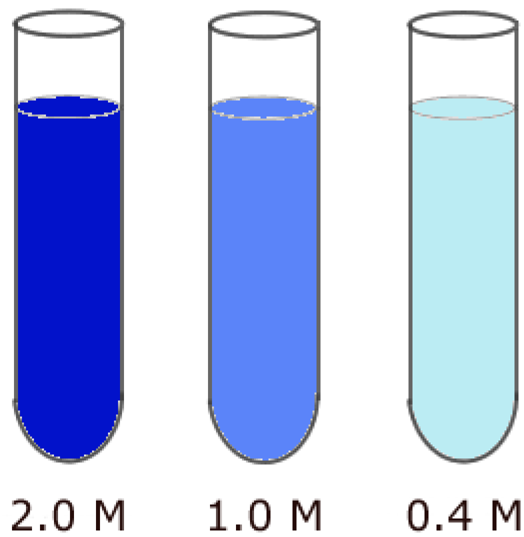
$$(2.0\ M)\ (X\ mL) = (0.4\ M)(500\ mL)$$

$$X = 150\ mL$$

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.



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

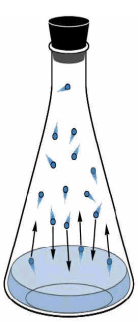
Solutions have physical properties (boiling point, freezing point, & vapor pressure) that are different from the properties of the pure solvent that made the solutions. If you dissolve particles (ions or polar molecules) into water, you change all three of these properties. The more particles in solution, 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°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°C = -1.86°C
NaCl	2 moles of ions	2 X −1.86°C = -3.72°C
$CaCl_2$	3 moles of ions	3 X −1.86°C = -5.58°C

Why do people use calcium chloride rather than sodium chloride on their sidewalks in winter? NaCl ionizes into TWO IONS, while the CaCl2 ionizes into THREE IONS each. More moles of ions means that the sidewalk water would not freeze until nearly −5°C with the calcium chloride [3 ion] treatment. A mole of particles also RAISES the BOILING POINT, each mole of particles raises the boiling point by 0.5°C.

One mole of sodium chloride ionizes into 2 moles of ions, and when added to ONE liter of water, the BOILING POINT is now 101°C. This occurs for the same reason, the water sticks together well due to 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 and into the gas phase. ICE MELTS, when each gram of water gains 334 Joules, the heat of fusion energy for H2O. By adding an ionic compound, the temperature required for freezing decreases by 1.86°C with each mole of particles added, per liter of water.



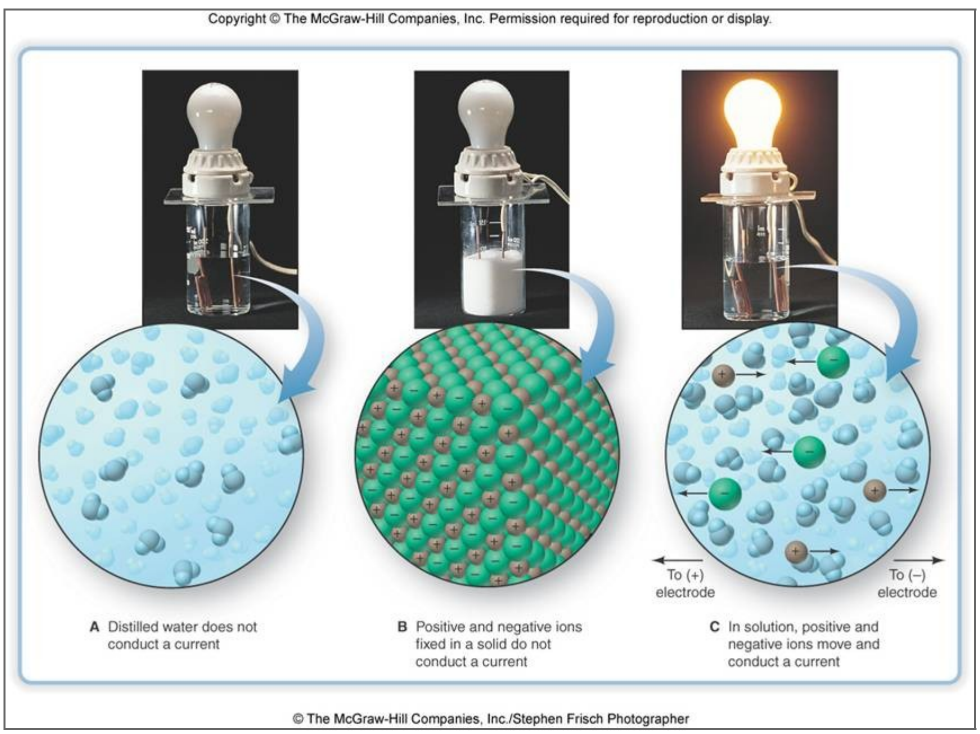
Vapor Pressure is the pressure exerted by the gas phase of a liquid above the surface of this liquid, in a sealed system, such as this sealed jar at right.

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.

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 a solid ionic compound ($NaCl_{(s)}$) 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.