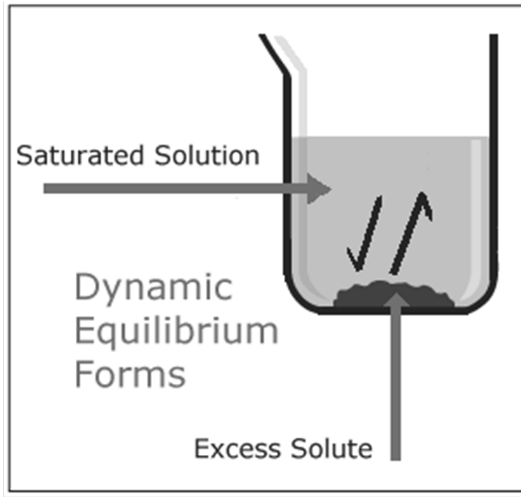
Solutions BASICS

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.

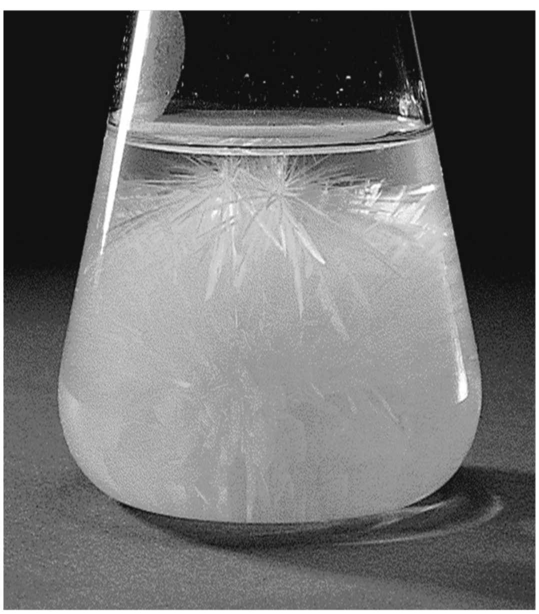
Solutions are homogeneous mixtures consisting of a solute dissolved into a solvent. We most often think of them as "wet", with water as the solvent. Other liquids can be solutes or solvents as well. Gases mix homogeneously which makes a gaseous solution, and we could even melt metals or other solids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



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 does not stop dissolving or precipitating. It's constantly changing and staying the same, the amount of solute and solid remains constant.

An **unsaturated solution** has room to hold more solute. There is a limit to how much solute can fit into any sized solution, and as long as there is LESS THAN that maximum amount, you can add more solute, up to the saturation limit.



A **supersaturated solution** is one that is more highly concentrated than is normally possible under given conditions of temperature and pressure.

If you heat up the solvent, saturate it with solute, usually it holds "more solute" when hotter than when cool.

If you then slowly cool this saturated solution, solute should precipitate out, as cooler solutions usually can hold less solute than warm.

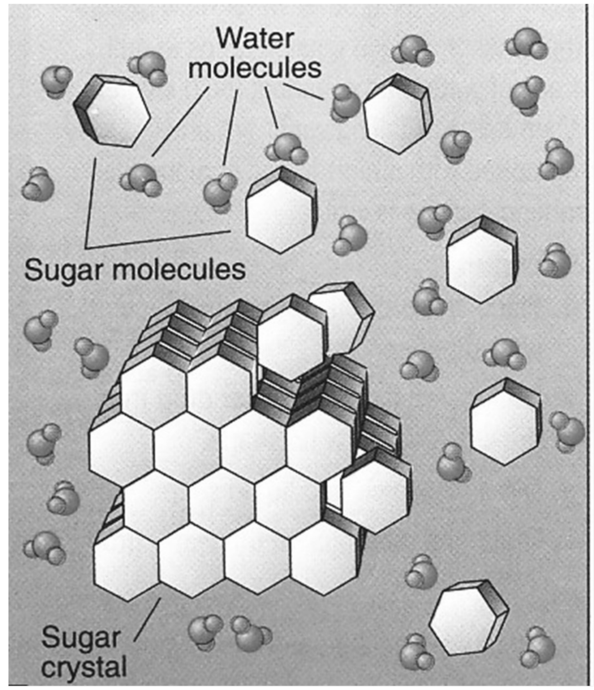
With some solutes (table sugar and sodium acetate) the whole amount of solute remains dissolved. So much solute that you could never dissolve it into that sized solvent when cold, but if you start warm, this solute remains aqueous.

The solution will "hold more solute than possible". At the point you "shock" this physically complex system, the excess solute crashes out of solution and solidifies quickly. This photo shows the crystallization of excess solute after the seeding.

When this happens, remember this important chemistry adage: "When bonds form, energy is released." (any bonds, ionic, covalent, or even hydrogen bonds)

Formation of Solutions…

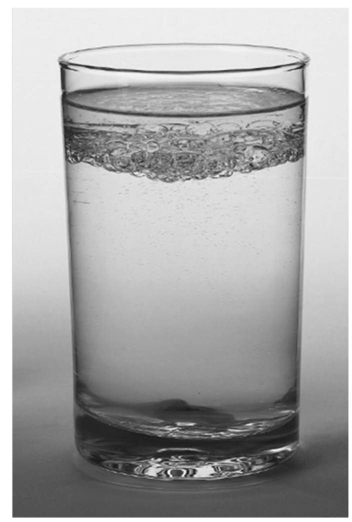
When a crystal of sugar (or other polar compound) is put into the polar solvent water, the crystal is "attacked" by the water molecules. The water molecules surround the sugar molecules, carrying them off molecules of the crystal into solution.



Of course, molecules are too small to see, so the visible crystal is soon invisible to the eye as it's broken into billions of submicroscopic molecules. At some point the solvent cannot hold a single molecule more, so as more sugar dissolves, some other sugar molecules will precipitate out of solution at the same rate.

<u>Like dissolves like</u> is our solution mantra; polar solvents such as water can only dissolve polar molecular compounds, and most ionic compounds (but check table F).

Non-polar compounds can not mix with polar solvents.

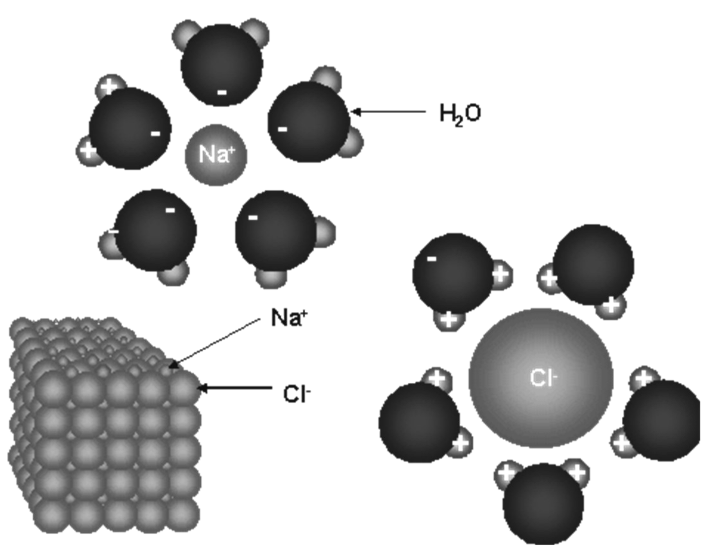


At right is oil sitting atop water. The polar water cannot mix with the nonpolar oil. The oil floats because it's less dense. It doesn't mix because of the fact that <u>Like Dissolves Like</u>. Polar water can't dissolve NONPOLAR oil.

When aqueous ionic compounds are put into a polar solvent like water, they are <u>dissociated</u> or <u>ionized</u> into LOOSE MOBILE IONS. The water molecules surround them as shown below. Ionic solubility exceptions exist LOOK AT table F!

In the picture below, note how the positive hydrogen side of the water molecules surround the negative chloride anions. The oxygen, with their negative charge, surround the positive sodium cations. Water orients itself to polar molecules or ions in aqueous solutions.

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



Remember what an electrolyte is?
It's an aqueous solution that can conduct electricity.

Solutions with AQ ions can conduct electricity, but solutions with AQ molecules (sugar) cannot. The more ions, the better the conduction.

Less ions = the weaker the conduction.

Acids are special chemical compounds in aqueous solutions that are molecular compounds that do form H^{+1} ions in solution, so acids are electrolytes. (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/ liter of solution. The formula is:

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

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 NaCl could be made by putting 1.0 moles NaCl into 1.0 Liters of H_2O.

Or, the same strength or concentration solution could be made with 0.25 moles NaCl and 0.25 L water.

An infinite number of combinations of moles to volume exist to match this concentration.

THINKING PROBLEM:

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…

Always start with a formula!

$$\text{Molarity} = \frac{\text{\#moles KCl}}{\text{liters of solution}}$$

You must first convert the grams into moles.

$$370 \text{ g KCl} \times \frac{1 \text{ mole KCl}}{74 \text{ grams KCl}} = 5.0 \text{ moles KCl}$$

Then put the RIGHT numbers into the formula.

$$M = \frac{5.0 \text{ moles KCl}}{2.5 \text{ Liters}}$$

M = 2.0 molar solution

The molarity formula has 2 uses for you as a chemistry student,
first to quantitatively measure the strength of a solution,
and also to make a solution "from scratch",
meaning you have no solution now,
but wish to make a solution of a specific volume & concentration (molarity).

Making a solution from Scratch

How do you prepare a 1.00 M of $NaCl_{(AQ)}$ solution of 2.00 Liters in volume?

Start with the molarity formula, putting in the data you have, solving for moles of solute (here that's the NaCl).

$$\text{Molarity} = \frac{\#\text{moles solute}}{\text{liters of solution}}$$

$$\frac{1.00\text{ M}}{1} = \frac{\#\text{ moles NaCl}}{2.00\text{ Liters}} = 2.00\text{ moles NaCl}$$

$$\frac{2.00\text{ moles NaCl}}{1} \times \frac{58\text{ grams NaCl}}{1\text{ moles NaCl}} = 116\text{ g NaCl}$$

To make this solution, put 116 grams of NaCl into a VOLUMETRIC FLASK, then fill it up to 2.00 Liters (2000 mL) mark on the neck, to give a TOTAL VOLUME of salt plus water = 2000 mL exactly.

Do not think for one moment that you can put 116 grams of salt into 2000 mL of water!
The dissolved salt has a very small volume, this process would push the total solution volume over 2000 mL !
This is the WRONG way to mix a solution. Always finish a solution by adding water, to the proper volume.

How do you make a 1.75 M $CuCl_{2(AQ)}$ of exactly 250. mL? (start with molarity formula)

$$\text{Molarity} = \frac{\#\text{moles solute}}{\text{liters of solution}}$$

$$\frac{1.75\text{ M}}{1} = \frac{\#\text{ moles }CuCl_2}{0.250\text{ Liters}} = 0.438\text{ moles }CuCl_2$$

$$\frac{0.438\text{ moles }CuCl_2}{1} \times \frac{134\text{ grams }CuCl_2}{1\text{ moles }CuCl_2} = 58.7\text{ grams }CuCl_2$$

To make this solution, put 58.7 grams of copper (II) chloride into a beaker, then fill with water up to the 245 mL mark.
DO NOT PUT 58.7 g $CuCl_2$ into 250. ml Water!

Making Solutions using a solution from the STOCK ROOM

Sometimes a chemist has solutions already mixed in the stock room. Those are called the Stock Solutions. Nothing special about them, except that you have them already mixed up and you know their molarity, you have them "in stock", ready to be used to make more solutions.

You can always make a solution from scratch, using the molarity formula. This next formula is called the Dilution Formula. Write it into your reference table (if you haven't already) next to the molarity formula.

$$M_1V_1 = M_2V_2$$

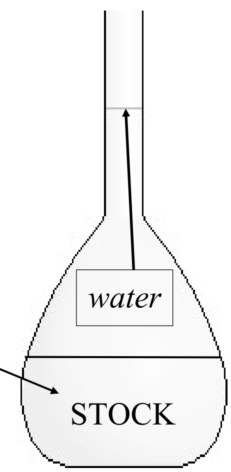
M_1 is the Molarity of the first solution (your stock)
V_1 is the unknown, how much stock will you need to make your new solution? It's the unknown always.
M_2 is the Molarity of the solution you want to make (it must be less than the stock, we're DILUTING here)
V_2 is the total volume of the new solution you want to make.

How would you make 500. mL of a 1.15 M $CuSO_{4(AQ)}$ if you have a stock solution of 2.50 M $CuSO_{4(AQ)}$ as your stock solution? These problems are MATH and telling how to mix this solution up.

Math first $M_1V_1 = M_2V_2$

$$(2.50\ M)\ (V_1) = (1.15\ M)(500.\ mL)$$

$$V_1 = 230.\ mL\ stock$$



Put exactly 230. mL of stock into the volumetric flask, then fill up to the 500. mL mark with water.

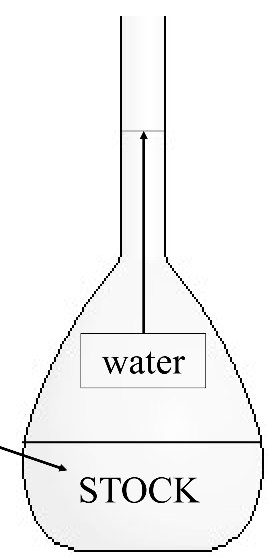
You have a 5.25 M stock NaCl solution. How do you prepare 1000. mL salt water solution of 0.755 M?

Math first $M_1V_1 = M_2V_2$

$$(5.25\ M)\ (V_1) = (0.755\ M)(1000.\ mL)$$

$$V_1 = \frac{(0.755\ M)(1000.\ mL)}{5.25\ M}$$

FIRST: V_1 = 144 mL of stock solution



THEN….

Fill with water up to the
1000. mL mark on the volumetric flask.

Colligative Properties of Solutions

These are physical properties that can change depending upon how much solute is dissolved into a liter of the solution.

We will only cover the colligative properties of water in high school chemistry.

These are boiling point, freezing point, & vapor pressure. These properties change by the amount of solute dissolved into the water (the molarity of the solution). The solute can be molecular or ionic, but it is necessary to calculate the NUMBER OF MOLES OF PARTICLES, be they polar molecules or ions. The more particles in solution, the greater change in these properties.

BOILING POINT ELEVATION

The water boils when it can overcome both the air pressure pressing down on the surface, and the internal hydrogen bonding holding the molecules together. At normal pressure the boiling point of pure water is 373 Kelvin. When polar molecules or ions are dissolved into the water, the water molecules are ALSO attracted to these molecules or ions. This creates MORE INTERNAL ATTRACTION, which means it takes more energy to make the water boil apart into the gas phase.

The boiling point elevation for water is 0.50 K/mole of particles per liter of solution.
For every mole of particles dissolved into a liter of water, the boiling point goes up by 0.50 K.
In high school chemistry all of our solutions will be one liter.

FREEZING POINT DEPRESSION

The freezing point is also impacted by dissolved particles. In order for water to freeze into those neat little 6 molecule rings, the hydrogen bonding between the molecules is stronger than the kinetic energy moving the water molecules around. Polar molecules and ions literally get in the way of these hydrogen bonds, so it will take a lower temperature (lower KE) to freeze them solid. The hydrogen bonds can be though to push these ions or polar molecules out of the way of this ring formation.

The freezing point depression for water is 1.86 K/mole of particles per liter of solution.
For every mole of particles dissolve into a liter of water, the freezing point goes down by 1.86 K.
In high school chemistry all of our solutions will be one liter.

Let us now examine how many moles of polar molecules or ions end up in solutions…		
$C_6H_{12}O_6$	$C_6H_{12}O_{6(S)} \rightarrow C_6H_{12}O_{6(AQ)}$	1 mole $C_6H_{12}O_6 \rightarrow$ 1 mole of molecules
NaCl	$NaCl_{(S)} \rightarrow Na^{+1}{}_{(AQ)} + Cl^{-1}{}_{(AQ)}$	1 mole NaCl $\rightarrow$ 2 moles of ions
$CaCl_2$	$CaCl_2 \rightarrow Ca^{+2}{}_{(AQ)} + Cl^{-1}{}_{(AQ)} + Cl^{-1}{}_{(AQ)}$	1 mole $CaCl_2 \rightarrow$ 3 moles of ions
$AlCl_3$	$AlCl_3 \rightarrow Al^{+3}{}_{(AQ)} + Cl^{-1}{}_{(AQ)} + Cl^{-1}{}_{(AQ)} + Cl^{-1}{}_{(AQ)}$	1 mole $AlCl_3 \rightarrow$ 4 moles of ions
AgCl	AgCl $\rightarrow$ no moles of ions, it's insoluble!	1 mole AgCl = zero particles

First lets examine what happens when substances dissolve into water. Molecular compounds, like sugar, dissolve into water as loose mobile molecules, not ions. When aqueous ionic compounds dissolve into water, they form LOOSE MOBILE IONS. Loose mobile ions makes the solution electrolytic, it can conduct electricity. The more loose mobile ions, the better it conducts. No ions means the solution can't conduct.

The more particles (ions or polar molecules) the greater the change in the colligative properties. How the compounds dissolve (molecularly or ionically) one mole of compound forms a unique number of moles of particles, shown above.

Calculate the boiling point and the freezing point of a 1.0 liter solution of 1.0 M $NaCl_{(AQ)}$.

Start with BP water	ADD elevation	+ BP elevation	= solution boiling point
373 K	+	(2 x 0.50 K) (1.0 K)	= 374 K

In this case, one mole of NaCl forms into 1 mole of Na^{+1} and another mole of Cl^{-1}
Water is attracted to both kinds of ions, the mole of cations increases the BP by 0.50 K,
and the mole of anions does the same. It's a "double" impact.

Next, the freezing point depression

Start with FP water	SUBTRACT depression	— FP depression	= solution boiling point
273 K	—	(2 x 1.86 K) (3.72 K)	= 269.28 K = 269 K (3 SF)

Next, calculate the boiling point and the freezing point of a 1.0 liter solution of 2.25 M $Ca(NO_3)_{2(AQ)}$.

Think: $Ca(NO_3)_2$ forms 3 moles of ions, 1 Ca^{+2} and $2NO_3^{-1}$. This is a 2.25 M solution, so in this case…

2.25 $Ca(NO_3)_2 \rightarrow$ 2.25 moles Ca^{+2} and 2.25 moles NO_3^{-1} + 2.25 moles NO_3^{-1} = 6.75 moles of AQ ions total.

Start with BP water	ADD elevation	+ BP elevation	= solution boiling point
373 K	+	(6.75 x 0.50 K) (3.375 K)	= 376.375 K = 376 K (3 SF)

Next, the freezing point depression

Start with FP water	SUBTRACT depression	— FP depression	= solution boiling point
273 K	—	(6.75 x 1.86 K) (12.555 K)	= 260.455 K = 260. K (3 SF)

Example 1. What is the boiling point of a 2.65 Molar NaCl solution of one liter?		
Start boiling point	Boiling point elevation	New boiling point
373 K	+ (5.30 x 0.50 K) =	373 + 2.65 = 375.65 K = 376 K (3 SF)
The solute will INCREASE THE boiling point, ADD the BP elevation to the normal BP of 373 K.		

Example 2. What is the boiling point of a 4.50 Molar $CaCl_2$ solution of one liter?		
Start boiling point	Boiling point elevation	New boiling point
373 K	+ (13.5 x 0.50 K) =	373 + 6.75 = 379.75 K = 380. K (3 SF)
In this example, this salt has 3 moles of ions per mole. When it does ionize in water, 1 mole → 3 moles ions. 4.50 M means 4.50 X 3 = 13.5 moles of ions in solution.		

Example 3. What is the boiling point of a 2.0 Molar $(NH_4)_3\,PO_{4(AQ)}$ solution of one liter?		
Start boiling point	Boiling point elevation	New boiling point
373 K	+ (8 x 0.50 K) =	373 + 4 = 377 K
$(NH_4)_3\,PO_4$ makes four moles of ions in solution, three ammoniums and one phosphate. This is a 2.0 M solution, so that is 2 X 4 = 8 moles of ions in solution.		

Example 4. What is the freezing point of this 2.0 Molar $(NH_4)_3\,PO_{4(AQ)}$ solution of one liter?		
Start freezing point	Freezing point depression	New freezing point
273 K	— (8 X 1.86 K) =	273 K — 14.88 = 258.12 K = 258 K (3 SF)

Example 5. What is the freezing point of a 4.0 Molar $AlCl_3$ solution of one liter?		
Start freezing point	Freezing point depression	New boiling point
273 K	– (16 x 1.86 K) =	273 – 29.76 = 243.24 K = 243 K (3 SF)
Did you see that? Each mole of aluminum chloride forms 4 moles of ions. Here there are 4 moles, so, 4 x 4 = 16 moles of particles in solution.		

VAPOR PRESSURE ADJUSTMENT

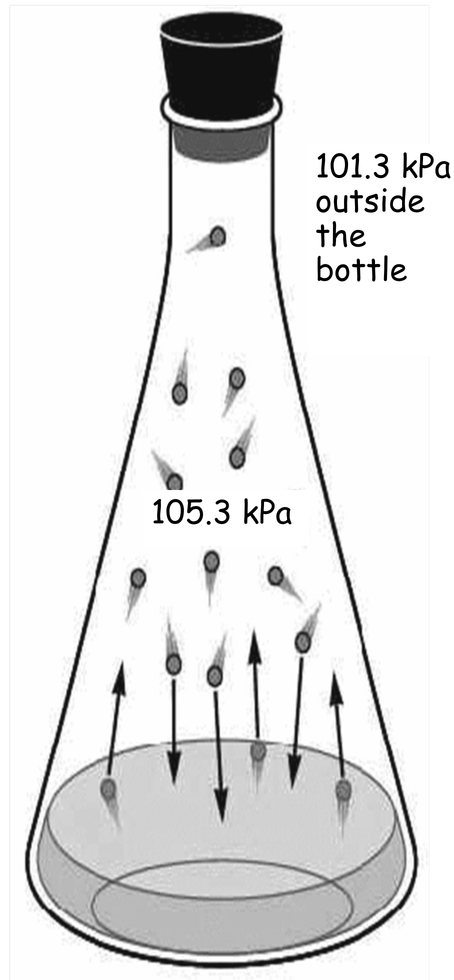
The vapor pressure is shown in table H on the reference tables.
The vapor pressure is THE EXTRA PRESSURE ADDED TO A CLOSED SYSTEM BY THE EVAPORATION OF A LIQUID.

Room temperature water (25°C) has a vapor pressure of about 4 kPa. That means inside that bottle at right, if the starting air pressure inside the bottle was 101.3 kPa (normal), the water evaporating will add to it by about +4 kPa. That makes the pressure in the bottle about 105.3 kPa.

Water doesn't evaporate well because of all the hydrogen bonding it has. That means water has a low vapor pressure. Adding any solute to water only increases the internal attraction, making it harder to evaporate.

In our class we will only know that any solute in water decreases the vapor pressure (makes it evaporate less well).

More concentrated aqueous solutions have lower vapor pressure compared to dilute aqueous solutions.



We'll do NO MATH for the vapor pressure in this part of chem.

We will make generalizations about the relative vapor pressure of solutions in high school chem. We can rank the vapor pressures by knowing how many moles of particles are in solution.

Water has LOW Vapor Pressure.
All solutions have lower vapor pressure, the water is attracted to itself and also to the solute particles. The more solute, the more internal attraction, the less it evaporates, the lower the vapor pressure.

Which of the following aqueous solutions will have the highest and lowest vapor pressures?

A. 3.00 molar $Al(NO_3)_{3(AQ)}$
B. 5.00 molar $NaCl_{(AQ)}$
C. 8.00 molar $C_6H_{12}O_{6(AQ)}$
D. 15.0 molar $SrSO_{4(AQ)}$

THINK

$Al(NO_3)_3 \rightarrow$ 4 moles of particles, 3.00 M solution will form 3.00 X 4 = 12 moles of ions in solution

NaCl $\rightarrow$ 2 moles of particles, 5.00 M solution will form 5.00 X 2 = 10 moles of ions in solution

$C_6H_{12}O_6$ will NOT ionize, it dissolves into 1 mole of particles,
8.00 M solution will form 8.00 X 1 = 8 moles of molecules in solution

$SrSO_4$ will NOT ionize at all, it's insoluble in water according to table F. It makes 0 moles of particles.

Strontium sulfate will have the highest vapor pressure, the same as water's, it will evaporate the best.

Aluminum nitrate will have the lowest VP, it will evaporate the worst because of the strong internal attraction this amount of solute creates.

PARTS PER MILLION

Some solutions are so very dilute that the molarity becomes a super small decimal that our brains can't make easy sense of. If your swimming pool had 58 grams of table salt, or one single mole of salt dissolved into it, technically it would now be $NaCl_{(AQ)}$ The pool is 43,000 liters the molarity is this:

Molarity = $\frac{\text{moles of solute}}{\text{Liters of solution}}$	Molarity = $\frac{\text{0.250 moles NaCl}}{\text{43,000 Liters}}$	M = 0.00000581 M or it's 5.81×10^{-6} Molar NaCl solution this is true but silly

This amount of table salt is not important in real life and the molarity of a solution like this is just dumb. But, if it were mercury, or some other biohazard, a molarity like this could kill people. It has to be measured.

But instead of using such crazy small decimals, we use a different formula, and measure the parts of a solute per million of solution. It makes the numbers more sensible, but the measures are equivalent. The molarity of a small decimal is correct, just less comfortable.

The other measure of this swimming pool sized sodium chloride solution in PPM is this:

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

$$\text{PPM} = \frac{58\text{ g}}{43{,}000{,}000\text{ grams}} \text{ X } 1{,}000{,}000 = \quad 1.35 \text{ parts per million}$$

1.35 PPM = 0.00000581 M.

But 1.35 "makes more sense" to normal people. (you're normal) ☺

If there is 1.25 grams of mercury dissolved into 345 liters of sea water, concentration is parts per million?

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

$$\text{PPM} = \frac{1.25\ \text{g}}{345{,}000\ \text{grams}} \text{X } 1{,}000{,}000 = \quad 3.62 \text{ parts per million}$$

Note: for water 1 Liter = 1000 mL 1 mL = 1 grams 1 Liter = 1000 grams

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An old regents exam had this problem… What is the concentration of a solution in PPM, if 0.02 grams of Na_3PO_4 is dissolved into 1000 grams water?

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

ANSWER

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

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

The regents will sometimes uses just one significant figure in a problem, they are trying to get across the concept, and not the math. You always pick the BEST possible choice. SF count, but the regents breaks that rule often.

End notes

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 it would conduct electricity. Ionic compounds that do not ionize in water are NOT
electrolytes, but they can conduct electricity if they are melted into their LIQUID state.

Electrolytes are solutions with ions in them (soluble ionic compounds), and they can conduct electricity. Electrolytes are always able to conduct electricity dissolved in water. 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 electrolytes only if they can become soluble in water. Electrolytes can be solutions that
conduct, or (strangely enough) solids that *would form* soluble ionic solutions.

Insoluble ionic compounds like AgCl, or molecular compounds are never electrolytes, and
cannot conduct electricity.