Solutions

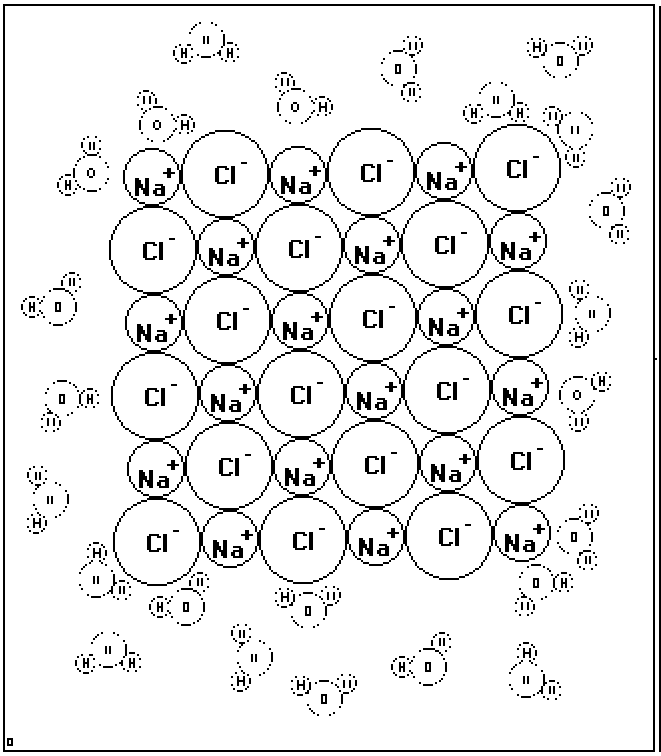
Word	**Definition**
Aqueous	A solution in which the solvent is water.
Colligative property	A property of a solution that is dependent on concentration. Examples include boiling point, freezing point and vapor pressure.
Molality	The concentration of a solution measured in moles of solute per kilogram of solvent.
Molarity	The concentration of a solution measured in moles of solute per liter of solution.
Parts per million	The concentration of a solution measured in mass of solute per mass of solution multiplied by one million.
Percent by mass	The concentration of a solution measured in mass of solute per mass of solution multiplied by one hundred.
Percent by volume	The concentration of a solution measured in volume of solute per volume of solution multiplied by one hundred.
Saturated	A solution that has the maximum concentration of solute possible in a given quantity of solvent at a given temperature, a solution at equilibrium.
Solubility	The maximum quantity of solute that can be dissolved in a given quantity of solvent at a given temperature to make a saturated solution.
Solute	A substance that is torn apart and kept separate by solvent particles.
Solution	A homogeneous mixture formed from a solute dissolved into a solvent.
Solvent	A substance that attaches to solute particles, tears them apart from each other and keeps them apart.
Supersaturated	A solution in which there is an excess of solute beyond the solubility point for a given temperature. Either the excess will precipitate or it will remain precariously dissolved until the solution is agitated, whereupon the excess will precipitate out.
Unsaturated	A solution in which there are still solvent particles free to attach to and dissolve more solute particles.

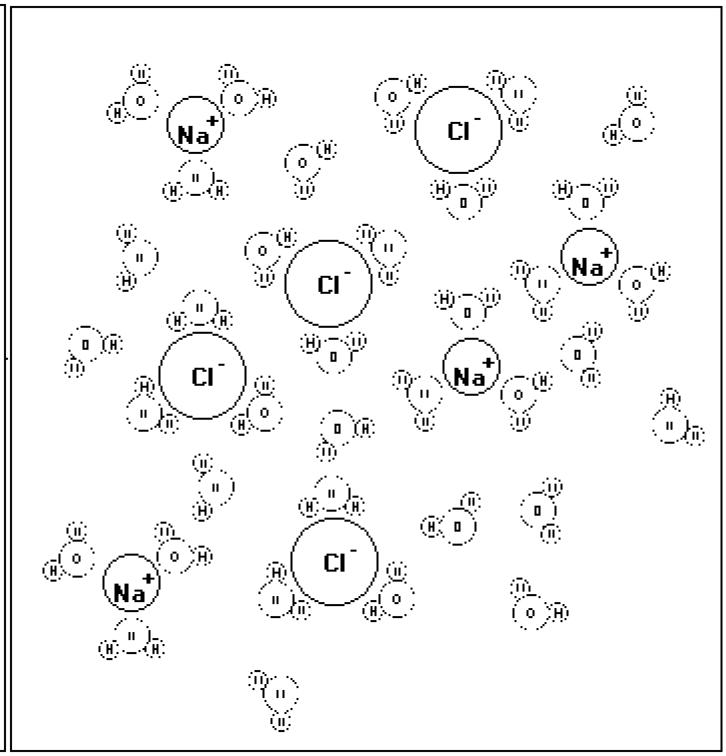
Topic 1) Solutions and Solubility (HW: p. 13, 14)

Essential Questions: Why doesn't oil mix with water? Why does sugar dissolve better in hot water than cold? Why do you have to be careful of the temperature you keep your fish tank at?

Mixtures: made from physically mixing two or more substances together without a chemical reaction occurring.

Mixing ionic compounds with water forms aqueous solutions of dissolved ions. The polar water molecules attract to the ions, tearing them apart from other ions and holding them away from other ions. This is called **molecule-ion attraction.**





A crystal of NaCl is dropped into a beaker of water. Immediately the polar water molecules attract to the charged ions. The partially positive ends of the water molecules (hydrogen) attracts to the negatively charged chloride ions. The partially negative ends of the water molecules (oxygen) attracts to the postively charged sodium ions. When enough water molecules attach to an ion, the natural motion of the water molecules will allow them to tear the ions apart from each other. This is the MOLECULE-ION ATTRACTION.

The hydrated ions are kept apart from each other by the water molecules that are attached to them. In this example, three water molecules around each ion are enough to keep the ions apart from each other. There are still free water molecules roaming around, these are free to pull apart any other sodium chloride crystals that might be put into the water. This solution can hold more ions, so it is an UNSATURATED solution. If more sodium chloride were added until all of the water molecules were bound to ions, the solution would bcome SATURATED. At that point, any additional sodium chloide crystal added to the solution would simply sink to the bottom of the beaker as a PRECIPITATE, since no more water molecules would be available to dissolve them. The number of water molecules it takes to keep ions apart depends on the temperature. The higher the temperature, the faster the molecules move, so it would take fewer molecules.

SOLUBILITY: The quantity of solute that can be added to a quantity of solvent to make a saturated solution at a given temperature and pressure.

Saturated: The solution holds as many dissolved particles as it can possibly hold (100-seat restaurant that has 100 people in it). In a saturated solution, all the solvent (water) molecules are occupied with keeping ions apart, so no more are available to do any more dissolving. Any further added solute will sink to the bottom of the container as a precipitate.

Unsaturated: The solution holds fewer solute particles than can theoretically be dissolved (100 seat restaurant with 40 people in it), can add more solute. There are still free solvent molecules available to dissolve more added solute.

Supersaturated: A very rare situation where the solution holds more solute than is theoretically possible, unstable situation where the excess will precipitate if the solution is agitated (100-seat restaurant with 120 people, when the manager comes in, he throws the extra 20 people out).

FACTORS AFFECTING SOLUBILITY:

1) **Temperature**
   a) For solid and liquid solutes, solubility in water increases as temp increases

Effect of temperature on solubility of a solid solute in water: An example of this is the sugar water needed to make rock candy. A saturated solution is formed at high temperature. As the temperature cools, the sugar becomes less soluble, so water molecules holding some sugar molecules apart from each other have to jump off to assist other water molecules in keeping sugar molecules apart. The released sugar molecules re-form a crystal structure, a solid precipitate that grows slowly, that forms the rock candy crystal that is so yummy.

   b) For gaseous solutes, solubility in water decreases as temp increases

Effect of temperature on solubility of a gas solute in water: An example of this is dissolved oxygen in a fishtank. Fish need dissolved oxygen to breathe, so it is bubbled into the tank. Gases hate being dissolved in water, because this forces their entropy to decrease, which is unfavored by nature. Increasing the temperature makes the entropy increase, which makes the gas even less likely to dissolve. At high temperatures, very little oxygen can dissolve. Tropical fish either have to have large gills to extract the small amount of dissolved oxygen from the water or have evolved to require less oxygen to survive. Cold-water fish don't need gills that are as large, because oxygen is more soluble in colder water.

2) **Pressure**
   a) For gaseous solutes, solubility increases as pressure increases

In soda machines, water traveling through a tube gets flavored syrup added to it as well as carbon dioxide. Since gases hate being dissolved in water, it requires a great deal of pressure to get the carbon dioxide into the water. When a soda bottle is opened, the pressure decreases, releasing the carbon dioxide gas. If the soda bottle is left open, virtually all of the gas will escape, leaving the soda flat. CO_2 gas is soluble at high pressures and nearly insoluble at low temperatures.

   b) Pressure does not affect solid or liquid solutes.

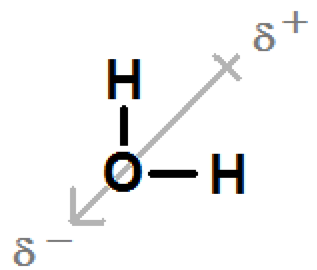
3) **Nature of Solute and Solvent (Like Dissolves Like)**
   a) Polar solutes dissolve in polar solvents

Water, being polar, has partially charged ends that can attract polar or ionic solutes. This is why ionic solutes like salt and polar molecular solutes like sugar can be dissolved in water.

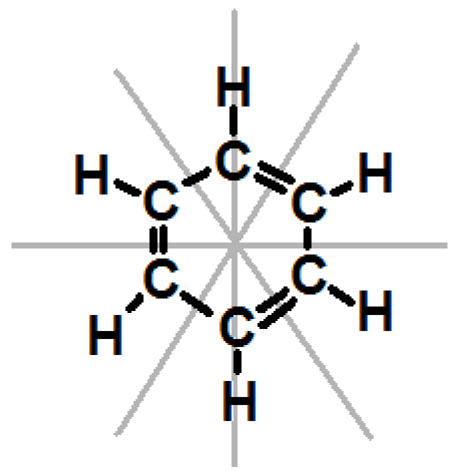
Water, being polar, has no attraction for nonpolar molecular solutes like oil. The oil will simply float on top of the water. This is why water should never be used to put out a grease or oil fire, the oil will simply float on top of the water and continue to burn, and the risk is great that the fire will spread. This is another reason why gases such as CO_2 and O_2 are not very soluble in water, since these gases are nonpolar!

b) Nonpolar solutes dissolve in nonpolar solvents

While oil will not dissolve in water, it will dissolve very nicely in a nonpolar organic solvent called benzene. Benzene, C_6H_6, is as good dissolving nonpolar solutes as water is at dissolving polar solutes. The enamel in nail polish is also nonpolar, and can be nicely dissolved with another nonpolar solvent, acetone. Nail polish remover is made of acetone and nail polish itself is a solution made of enamel dissolved in acetone. When the nail polish is painted on the fingernail, the acetone evaporates, leaving the enamel behind on the nail as a precipitate. There are non-acetone nail polish removers available, they are just other nonpolar solvents.



Water has ONE line of symmetry, making it a POLAR solvent, able to dissolve POLAR or IONIC solutes.

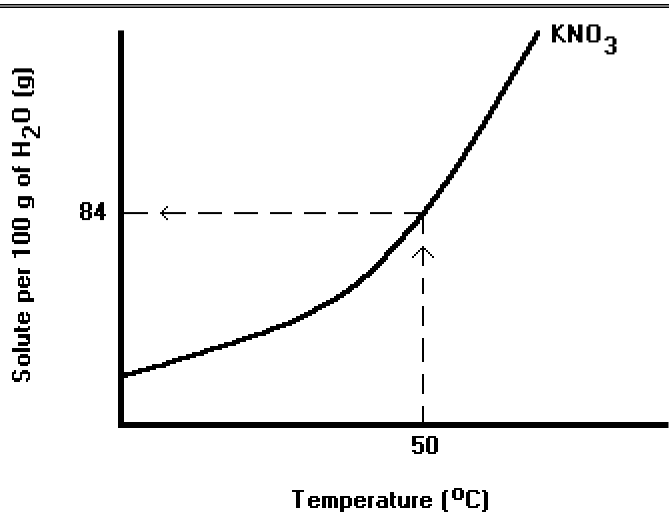


Benzene has SIX lines of symmetry, making it a NONPOLAR solvent, able to dissolve NONPOLAR solutes (like plastic!) that water cannot dissolve.

<u>USING REFERENCE TABLE G (up curves represent SALTS, down curves represent GASES)</u>

Reference Table G: Solubility Curves can be used to determine the following:

a) Solubility of a solute in 100 grams of water at various temperatures
Each line on this table represents a saturated solution of a solute at different temperatures. The higher a line is at a given temperature, the more soluble it is. The data given tells us how many grams of solute can be dissolved in 100 grams of water at a particular temperature. If you want to know how many grams of solute can dissolve in any amount other than 100 grams of water, find out how much can dissolve in 100 grams of water first, and then set up a proportion.



WHAT IS THE SOLUBILITY OF KNO_3 IN 100 G OF WATER AT 50°C?

Start at 50 C, go straight up until you hit the line for KNO_3. Then, go across until you hit the Y axis. The mass it shows is 84 grams.

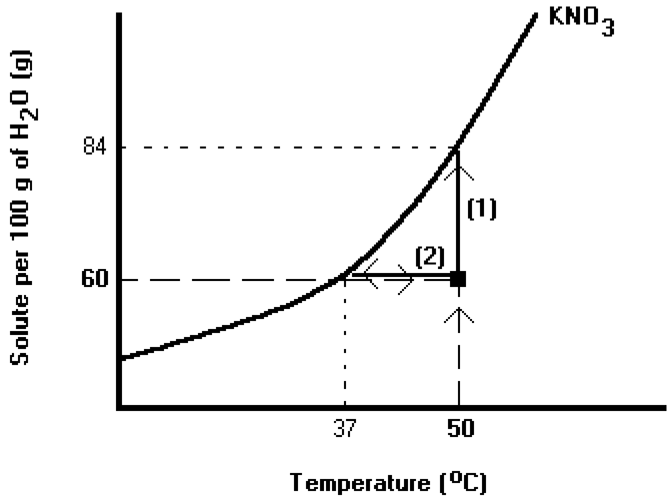
Therefore, 84 grams of KNO_3 can be dissolved in 100 g of water at 50°C.

If we wanted to know the solubility of KNO_3 in 50 g of water, set up the proportion:

$$\frac{84}{100} = \frac{X}{50} \qquad X = 42 \text{ grams.}$$

Therefore, 42 grams of KNO_3 can be dissolved in 50 grams of water at 50°C.

b) Degree of saturation (unsaturated, saturated or supersaturated)



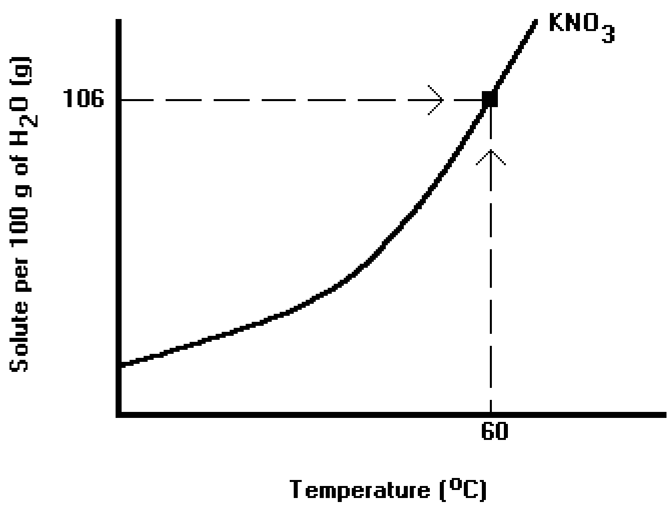
IF 60 GRAMS OF KNO_3 ARE ADDED TO 100 GRAMS OF WATER AT 50°C, WHAT KIND OF SOLUTION IS FORMED?

See where the two lines cross over. As you can see from the diagram on the left, the cross underneath the KNO_3 line. This means the solution is UNSATURATED.

This solution can be made saturated in the following ways:

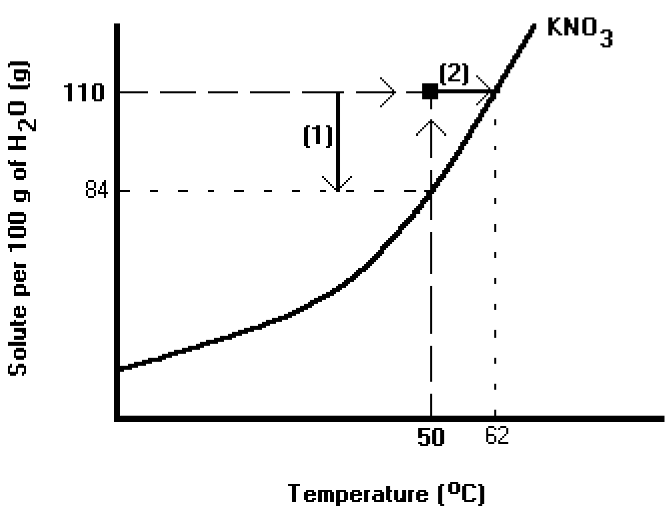
1) Add more KNO_3 (line 1): Since a saturated solution of KNO_3 at 50 °C can hold 84 grams, the difference (84-60) = 24 grams of KNO_3, is what can be added to make the solution saturated.

2) Lower the temperature (line 2): Since 60 grams of KNO_3 in 100 grams of water is saturated at 37°C, the temperature can be lowered by the difference (60-37) = 23°C.



IF 106 GRAMS OF KNO_3 ARE ADDED TO 100 GRAMS OF WATER AT 60°C, WHAT KIND OF SOLUTION IS FORMED?

Cross over the two lines. Hey! They converge right on the KNO_3 line. Since the line represents a saturated solution, the solution is saturated!



IF 110 GRAMS OF KNO_3 ARE ADDED TO 100 GRAMS OF WATER AT 50°C, WHAT KIND OF SOLUTION IS FORMED?

Cross over the lines and find that they converge above the line for KNO_3 at that temperature. This means that the solution is SUPERSATURATED.

This solution can be made saturated in two ways:

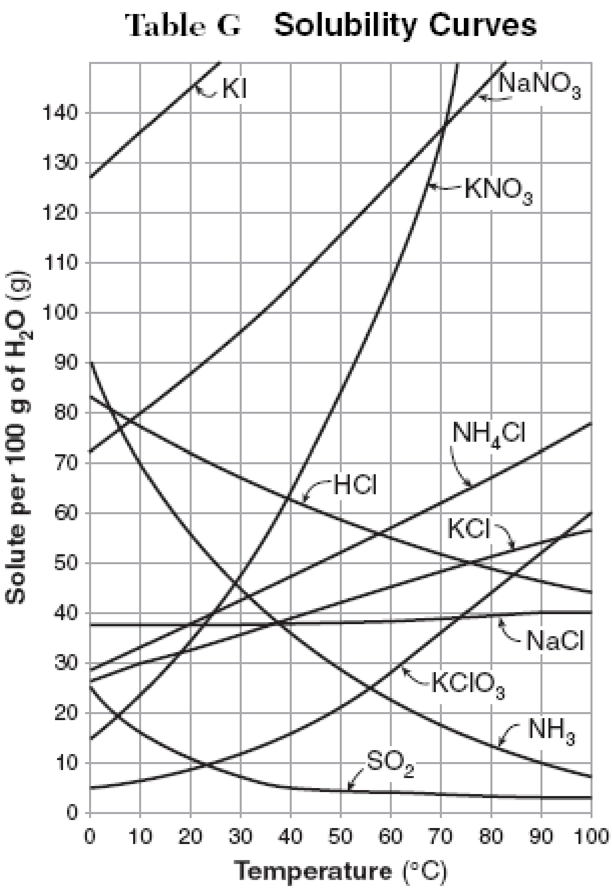
1) The excess precipitates (line 1). How many grams of precipitate will form? The solubility of KNO_3 in 100 grams of water at 50°C is 84 grams. The difference (110 - 84 = 26) is how much precipitate forms. Therefore, 26 grams of KNO_3 will precipitate.

2) Raise the temperature (line 2). Since 110 grams of KNO_3 will dissolve in 100 grams of water at 62°C, the difference (62-50 = 12) is the number of degrees that the temperature must be raised to make the solution saturated. Raising the temperature by 12°C will make this solution saturated.

What if you have an amount of water that is different from the 100g on the Reference Table?

Reference Table G shows solubility data assuming that a 100-gram sample of water is used to dissolve the solute. Because of the miracles of proportionality, one does not need a separate reference table for every possible amount of water used! For example, if the solute is dissolved in 50 g of water, that is half as much solvent, so half as much solute can be dissolved!

1) Figure out your amount of grams of solute per 100 grams of water.
2) Use a proportion to determine the grams of solute per how ever much water you have!
3) This gives you the grams of solute for any amount of water you might have!



How many grams of $NaNO_3$ are required to make a saturated solution in 100 g of water at 30^{o}C?

Start at 30^{o}C, move up to the $NaNO_3$ line. Scoot across to Solute (g). **<u>96 grams</u> can be dissolved in 100 g of water at 30^{o}C.**

How many grams of $NaNO_3$ are required to make a saturated solution in 50 g of water at 30^{o}C?

Since in the last question, it was determined that 96 grams of $NaNO_3$ can be dissolved in 100 g H_2O, since 50 g is half as much water, only half as much $NaNO_3$ can be dissolved. Therefore, 96/2 = **<u>48 g of $NaNO_3$</u> can be dissolved in 50 g H_2O.**

How many grams of $NaNO_3$ are required to make a saturated solution in 200 g of water at 30^{o}C?

Since in the first question, it was determined that 96 grams of $NaNO_3$ can be dissolved in 100 g H_2O, since 200 g is twice as much water, twice as much $NaNO_3$ can be dissolved. Therefore, 96 X 2 = **<u>192 g of $NaNO_3$</u> can be dissolved in 200 g H_2O.**

What is the solubility of HCl in 100 g of water at 70^{o}C?

Start at 70^{o}C, up to HCl and across: **<u>52 g HCl</u> in 100 g H_2O @ 70^{o}C**

What kind of solution do you have if 80 grams of $KClO_3$ are dissolved in 100 g of water at 40^{o}C?

Start at 80 grams, and 40^{o}C. See where the lines intersect with respect to the $KClO_3$ line. They intersect far above the $KClO_3$ line. At 40^{o}C, the solubility of $KClO_3$ is only 16 grams in 100 g of water. This solution is **supersaturated**.

For the above solution, what can you do with temperature and amount of $KClO_3$ to make the solution saturated?

If you want to dissolve 80 g of KClO3 in 100 grams of water, the table says you need to **heat the solution to 75^{o}C** (adding an additional 35^{o}C to the current temperature of 40^{o}C).

Since $KClO_3$ has a solubility of only 16 grams in 100 g of water, and the solution contains 80 grams, the excess precipitates out. 80 g – 16 g = 64 **grams of precipitate will fall out of the solution**, leaving a saturated solution behind.

At what temperature do HCl and NH_4Cl have the same solubility? Their solubility lines intersect at **57^{o}C**.

Topic 2) Concentration (HW: p. 15, 16)

Essential Question: How do EPA standards keep our drinking water safe?

CONCENTRATION - a measure of the amount of substance per unit volume.

For solutions, there are several expressions of concentration:

1) Grams of solute/100 mL of solvent (Ref. Table D)

This is what you did yesterday when determining the solubility of a solute in water.

2) Molarity (M) = moles of solute/L of solution

This is the most commonly used unit of concentration in the laboratory.

A) To experimentally determine the molarity of a solution,

1) Determine the volume of solution you have

2) Determine how many moles of solute are dissolved in the solution by
   - a) Evaporating off the solvent
   - b) Weighing the solute
   - c) Dividing the mass of the solute by the formula mass of the solute

3) Molarity (M) = moles of solute/L of solution.

What is the molarity of a solution if it contains 2.0 moles of KNO_3 in 4.0 L of solution?

M = moles of solute/L of solution = 2.0 moles / 4.0 L = **0.50 M**, which can also be written **0.50 moles/L**.

What is the molarity of a solution if it contains 2.0 moles of NaCl in 250. mL of solution?

1) First, 250. mL must be converted to L: (250.) mL / (1000 mL/L) = 0.250 L

2) M = moles of solute/L of solution = (2.0 moles) / (0.250 L) = **8.0 M**, which can also be written **8.0 moles/L**.

What is the molarity of a solution if it contains 20. grams of NaOH in 2.0 L of solution?

1) First, 20. grams of NaOH must be converted to moles: (20. g) / (40.0 g/mole) = 0.50 moles

2) M = moles of solute/L of solution = (0.50 moles) / (2.0 L) = **0.25 M**, which can also be written **0.25 moles/L**.

What is the molarity of a solution if it contains 60. grams of NaOH in 400. mL of solution?

1) First, 60. grams of NaOH must be converted to moles: (60. g) / (40.0 g/mole) = 1.5 moles

2) Then, 400. mL must be converted to L: (400.) mL / (1000 mL/L) = 0.400 L

3) M = moles of solute/L of solution = (1.5 moles) / (0.400 L) = **3.8 M**, which can also be written **3.8 moles/L**.

B) To make a specific volume of solution with a desired molarity,

The equation M = moles/L can be rearranged to solve for moles: **moles = M X L**

1) Determine the desired concentration (what is the molarity of the solution you are trying to make?)

2) Determine how much solution you want to make (how many L of solution do you need to make?)

3) Multiply the two. This will give you moles. (M X L = moles. If you are given mL, convert to L first)

4) Determine the formula mass of the solute. (FM = sum of atomic masses of all atoms in the compound, to the tenths place)

5) Multiply the number of moles of solute calculated in step 3 by the formula mass of the solute. This will tell you how many grams of solute are needed. (moles X formula mass = grams)

6) Mix with enough solvent to make the desired volume of solution. This is usually carried out in a volumetric flask.

Who needs to do this? I, your chemistry teacher, needs to do this, every time I make a solution for you to use in lab. Anyone who works with chemicals needs to do this…medical, biological, geological…any profession that uses solutions will involve using this calculation. It is actually one of the most practical calculations you are learning in this course!

How many grams of NaOH are needed to make 4.0 L of a 0.50 M solution of NaOH?

First, determine how many moles are needed: Moles = M X L = (0.50 moles/L) X (4.0 L) = 2.0 moles of NaOH
Then, convert moles to grams: (2.0 moles) X (40.0 g/mole) = **80. grams of NaOH are needed.**

So, now you can weigh out 80. grams of NaOH on a triple-beam or digital balance and put it into a 4.0 L volumetric flask and fill it to the top line with distilled water.

How many grams of KCl are needed to make 500. mL of a 0.100 M solution of KCl?

First, convert the 500. mL to L: (500. mL) / (1000 mL/L) = 0.500 L
Second, determine how many moles are needed: Moles = M X L = (0.100 moles/L) X (0.500 L) = 0.0500 mol of NaOH
Then, convert moles to grams: (0.0500 moles) X (74.6 g/mole) = **3.73 grams of KCl are needed.**

So, now you can weigh out 3.73 grams of KCl on a triple-beam or digital balance and put it into a 500. mL volumetric flask and fill it to the top line with distilled water.

3) Parts Per Million (ppm) = (grams of solute/grams of solution) X 1 000 000

Used to determine trace amounts of dissolved ions in drinking water. Established toxic threshold levels are reported in ppm or sometimes ppb (parts per billion) if it is a particularly nasty toxin. It is also used to measure the concentration of particulates in the air. Air pollution is measured in parts per million, as is dust in a clean room at an electronics manufacturing plant.

What is the concentration, in ppm, of lead ions in 100. g of tap water with 0.0000450 g of lead ions dissolved in it?

ppm = (g of solute / grams of solution) X 1 000 000 = {(0.0000450 g) / (100. g)] X 1 000 000 = **0.45 ppm**

A well is drilled on some property nearby a landfill to determine its suitability for supplying water for proposed new homes. When tested, it is found that a 1.000 kg (1000. gram) sample of water taken from this well contains 0.00330 grams of cadmium. Cadmium is a toxic heavy metal leached out of rechargeable batteries that people often throw out with the trash instead of recycling.

What is the concentration, in ppm, of cadmium ions in this tap water?

First, ppm is measured in GRAMS, so convert 1.00 kg to g: (1.000 kg) X (1000 g/kg) = 1000. g

Then, ppm = (g of solute / grams of solution) X 1 000 000 = {(0.00330 g) / (1000. g)] X 1 000 000 = **3.30 ppm**

The Environmental Protection Agency has set a legal limit of 0.005 ppm for cadmium ion concentration for drinking water. 3.30 ppm far exceeds this limit, therefore, any well tapping into this water supply cannot be used, and a house that gets its water supply from this

What is the concentration, in ppm, of a solution containing 5.0 grams of solute dissolved into 250. grams of water?

This situation is slightly different. Here, you are not told the total mass of the solution, but the mass of each of its parts. To get the total mass of the solution, you must add the mass of the solute (2.0 grams) and the mass of the solvent (250. grams) together. The mass of the solution is 255 grams.

ppm = (g of solute / grams of solution) X 1 000 000 = {(5.0 g) / (250. g)] X 1 000 000 = **20 000 ppm**

A 50.0 gram sample of solution is evaporated to dryness. If the concentration of solute in the original solution was 25.0 ppm, what is the mass of solute that is left after the solvent has been evaporated away?

OK, now you need some algebra. You know the concentration in ppm, you know the mass of the solution. Rearrange to find the mass of the solute:

ppm = (g of solute / grams of solution) X 1 000 000 → **g of solute = (ppm X grams of solution) / 1 000 000**

g solute = (25.0 ppm X 50.0 g) / 1 000 000 = **0.00125 grams of solute** in the original solution

4) Percent by Mass = (grams of solute/grams of solution) X 100

A 25.0 gram sample of an aqueous NaCl solution is evaporated and found to contain 2.0 grams of NaCl. What is the percent by mass of NaCl in this solution?

% by mass = (grams of solute/grams of solution) X 100 = [(2.0 g) / (25.0 g)] X 100 = **8.0% NaCl by mass**

5) Percent by Volume = (mL of solute/mL of solution) X 100

Percent by volume is often used to describe the concentration of alcohol in alcoholic beverages or in medications containing alcohol. Wine is often 14% alcohol by volume, and 50% or greater alcohol by volume (100 proof) is actually flammable. This is where the term *proof* comes from…back in the old days, a bartender might water down the whiskey to save money. Whiskey was supposed to be at least 50% alcohol by volume. If a patron demanded proof that the whiskey wasn't watered down, a sample had to be touched with a flame. If it wouldn't burn, the bartender might be shot! Or just run out of business.

A 50.0 mL sample of an aqueous ethanol solution is distilled to yield 33.2 mL of ethanol. What is the percent by volume of ethanol in this solution?

% by volume = (mL of solute / mL of solution) X 100 = [(33.2 mL) / (50.0 mL)] X 100 = **66.4% ethanol by volume**

Topic 3) Colligative Properties (HW: p. 17, 18)

Essential Questions: How does antifreeze work? Why do we put salt on the roads and sidewalks in the winter? What is the difference between salt crystals and those white pellets that they use to melt ice?

Antifreeze. It isn't just for breakfast anymore. Actually, it never was, as it is a deadly poison. As it metabolizes, it forms razor-sharp crystals in the kidneys, liquefying them and leading to an excruciatingly painful death. Keep it away from children and pets. There is an antidote that prevents the crystals from forming, but it has to be administered before it metabolizes to that point.

It might not be good to drink, but it is excellent at preventing the water coolant in your car's engine from boiling or freezing. In hot weather, going up a steep hill, your car's engine produces a lot of heat. Water flowing through pipes in the engine carries heat out of the engine, where it passes through the radiator and cooled before being sent back to the engine. The temperature might reach 100^oC, the boiling point of water. If the water is allowed to boil, the pressure of the steam that is produced might cause the engine to crack. In addition, steam is only half as efficient per gram as liquid water at carrying heat away from the engine.

This water coolant is still in your engine when the weather is cold. If the car is parked outside in sub-freezing temperatures, the water in the engine's coolant pipes might freeze. Water expands when it freezes, and this would cause the pipes to burst, causing expensive repairs and towing costs.

Adding a solute like antifreeze helps tremendously, because the solute makes it a lot harder for the water to boil or freeze. Remember, when solutes dissolve, water molecules hold on to the solute particles to keep them apart. To boil, the water has to be detached from the solute particles, which requires adding more energy than usual. **When dissolving solutes in water, the boiling point increases. The more solute that is dissolved, the higher the boiling point will go.**

When a liquid like water freezes, it does so by forming a crystal lattice. The solute particles interfere with this process, meaning that the solution has to be cooled down to a lower temperature than the normal freezing point for it to freeze. **The more solute that is added, the lower the freezing point will drop.** This is why salt is dumped on the roadways during the winter! The road has snow packed on it. A truck comes along and dumps salt on the snow. When cars drive over the salted snow, the pressure and friction from the tires causes the snow to melt. The salt dissolves in the freshly melted snow, and prevents it from refreezing. The salt that is the least expensive to use is crushed halite salt (NaCl). More and more communities are using a different salt, calcium chloride ($CaCl_2$). This forms round pellets; you may have seen them on the road or on a walkway. $CaCl_2$ is more effective than halite salt at preventing the water from refreezing. NaCl breaks up into two ions (Na^{+1} and Cl^{-1}) when dissolved. Calcium chloride breaks up into THREE ions when dissolved (one Ca^{+2} ion and two Cl^{-1} ions). The more ions that are dissolved in the water, the more they will interfere with water freezing, and the freezing point of water will drop even further…or the less salt you will need!

Electrolytes vs. Nonelectrolytes

1) Electrolytes

Most ionic compounds and many acids dissolve well in water. These are called **electrolytes**, because they cause the solution to conduct electricity due to the free-moving ions. They ionize 100% in water to yield ions in a reaction that resembles a decomposition reaction. The reaction is called **dissociation**, and it is a physical change, not a chemical change. **The more ions a solute breaks up into, the higher the boiling point and the lower the freezing point of the solution will be.**

NaCl (s) → Na^{+1} (aq) + Cl^{-1} (aq)

One mole of sodium chloride dissolves to form one mole of sodium ions and one mole of chloride ions **(2 moles of dissolved ions total)**.

$CaBr_2$ (s) → Ca^{+2} (aq) + 2 Br^{-1} (aq)

One mole of calcium bromide dissolves to form one mole of calcium ions and two moles of bromide ions **(3 moles of dissolved ions total)**

$Al(NO_3)_3$ (s) → Al^{+3} (aq) + 3 NO_3^{-1} (aq)

One mole of aluminum fluoride dissolves to form one mole of aluminum ions and three moles of nitrate ions **(4 moles of dissolved ions total)**

2) Nonelectrolytes

Substances formed from covalent bonding do not dissolve into ions upon entering the water. These include polar molecules that dissolve, but do not ionize. These include sugar ($C_6H_{12}O_6$, $C_{12}H_{22}O_{11}$), antifreeze (CH_2OHCH_2OH) and alcohol (C_2H_5OH). These have less impact on the melting and boiling point of a solution than ionic compounds do, because they do not break up any further.

$C_{12}H_{22}O_{11}$ (s) → $C_{12}H_{22}O_{11}$ (aq)

One mole of sucrose dissolves to form one mole of dissolved sucrose. No ions are formed, so no electricity can be conducted.

CH_2OHCH_2OH (l) → CH_2OHCH_2OH (aq)

One mole of ethylene glycol dissolves to form one mole of dissolved ethylene glycol. No ions are formed, so no electricity can be conducted.

COLLIGATIVE PROPERTIES OF SOLUTIONS - physical properties of solutions that depend on the concentration of solute in a given amount of solvent.

1) Freezing Point Depression: The freezing point of water **decreases** as solute is added to it.

2) Boiling Point Elevation: The boiling point of water **increases** as solute is added to it.

Example Problem-Solving:

1) The higher the concentration of solute is, the higher the boiling point and the lower the freezing point will be.

Which of the following solutions will boil at the highest temperature?

a) 100 g NaCl in 1000 g of water
b) 100 g NaCl in 500 g water
c) 100 g NaCl in 250 g of water
d) 100 g NaCl in 125 g of water

The answer is D because it has the highest concentration:

Concentration = mass of solute/mass of solvent. The less solvent there is, the higher the concentration of the solution there will be. **As the concentration of solution increases, the boiling point increases.**

Which of the following solutions will boil at the lowest temperature?

a) 100 g NaCl in 1000 g of water
b) 100 g NaCl in 500 g water
c) 100 g NaCl in 250 g of water
d) 100 g NaCl in 125 g of water

The answer is A because it has the lowest concentration:

Concentration = mass of solute/mass of solvent. The more solvent there is, the lower the concentration of the solution there will be. **As the concentration of the solution decreases, the boiling point decreases.**

Which of the following solutions will freeze at the lowest temperature?

a) 100 g NaCl in 1000 g of water
b) 100 g NaCl in 500 g water
c) 100 g NaCl in 250 g of water
d) 100 g NaCl in 125 g of water

The answer is D because it has the highest concentration:

Concentration = mass of solute/mass of solvent. The less solvent there is, the higher the concentration of the solution there will be. **As the concentration of the solution increases, the freezing point decreases.**

Which of the following solutions will freeze at the highest temperature?

a) 100 g NaCl in 1000 g of water
b) 100 g NaCl in 500 g water
c) 100 g NaCl in 250 g of water
d) 100 g NaCl in 125 g of water

The answer is A because it has the lowest concentration:

Concentration = mass of solute/mass of solvent. The more solvent there is, the lower the concentration of the solution there will be. **As the concentration of the solution decreases, the freezing point increases.**

2) The more particles that a solute ionizes into, the higher the boiling point and the lower the freezing point will be.

Which of the following solutions will boil at the highest temperature?

a) 1 mole $C_6H_{12}O_6$ in 500 g of water
b) 1 mole KBr in 500 g of water
c) 1 mole MgF_2 in 500 g of water
d) 1 mole $AlCl_3$ in 500 g of water

The answer is D because $AlCl_3$ breaks into 4 particles, the most of any of the choices. The more particles that a solute ionizes into, the higher the boiling point will be.

Which of the following solutions will boil at the lowest temperature?

a) 1 mole $C_6H_{12}O_6$ in 500 g of water
b) 1 mole KBr in 500 g of water
c) 1 mole MgF_2 in 500 g of water
d) 1 mole $AlCl_3$ in 500 g of water

The answer is A because $C_6H_{12}O_6$ breaks into 1 particles, the least of any of the choices. The fewer particles that a solute ionizes into, the lower the boiling point will be.

Which of the following solutions will freeze at the lowest temperature?

a) 1 mole $C_6H_{12}O_6$ in 500 g of water
b) 1 mole KBr in 500 g of water
c) 1 mole MgF_2 in 500 g of water
d) 1 mole $AlCl_3$ in 500 g of water

The answer is D because $AlCl_3$ breaks into 4 particles, the most of any of the choices. The more particles that a solute ionizes into, the lower the freezing point will be.

Which of the following solutions will freeze at the highest temperature?

a) 1 mole $C_6H_{12}O_6$ in 500 g of water
b) 1 mole KBr in 500 g of water
c) 1 mole MgF_2 in 500 g of water
d) 1 mole $AlCl_3$ in 500 g of water

The answer is A because $C_6H_{12}O_6$ breaks into 1 particle, the least of any of the choices. The fewer particles that a solute ionizes into, the higher the freezing point will be.

Student Name:________________________________ Grades: _____, _____, _____
Solubility Conc Collig P

1) Solutions and Solubility Homework

A) Complete the following chart:

For the solutes below, dissolved in water:	If temperature is increased, the solubility of this solute will:	If temperature is decreased, the solubility of this solute will:	If surface area is increased, the solubility of this solute will:
NH_3 (g)			
KCl (s)			

B) Complete the following chart:

Draw the structures of the compounds If they are molecular.	Is the solute polar or nonpolar or ionic?	Will this solute dissolve in water or benzene?
CH_4		
KBr		
H_2S		

C) Explain, in terms of *molecular polarity* of both substances, why oil does not dissolve in water.

D) Hydrochloric acid is actually hydrogen chloride gas dissolved in water. The solubility of hydrogen chloride in water at 298 K and 1 atm is 12.1 moles (442 grams) per liter of solution. In what two ways can the solubility of hydrogen chloride in water be increased to make the solution more concentrated?

a)____

b)____

E) Use Reference Table G to answer the following:

______________________ 1) As the temperature decreases, the solubility of gases

______________________ 2) As the temperature decreases, the solubility of solids in liquids

______________________ 3) Which of the **salts** on Table G is the *least* soluble at 90^{o}C

______________________ 4) Which **gas** on Table G is *most* soluble at 60^{o}C?

______________________ 5) Which **salt** on Table G shows the *least* change in solubility between 30^{o}C and 70^{o}C?

For # 6-8, determine whether the following solutions are <u>unsaturated</u>, <u>saturated</u> or <u>supersaturated</u>:

______________________ 6) 108 g of KNO_3 at 60^{o}C

______________________ 7) 20 g of NH_4Cl at 30^{o}C

______________________ 8) 50 g af KCl at 60^{o}C

______________________ 9) What is the **solubility** of $NaNO_3$ in 100 grams of water at 40^{o}C?

______________________10) How many **grams** of $KClO_3$ can be dissolved in 1000 g of water at 30^{o}C?

______________________11) What is the **solubility** of NaCl in 50 grams of water at 70^{o}C?

______________________12) How many **grams** of solute must be added to a solution containing 30 g of NH_4Cl at 90^{o}C in order to make it a saturated solution?

______________________13) A solution contains 80 g of KNO_3 at 80^{o}C. **To what temperature** must the solution be lowered in order to make it a saturated solution?

______________________14) Consider a saturated solution of $NaNO_3$ at 70^{o}C. If the solution is cooled to 20^{o}C, how many **grams** of solute will precipitate?

______________________15) How many **grams** of solute will precipitate if a saturated solution of $NaNO_3$ in 50. g of water at 30^{o}C is evaporated to dryness?

______________________16) **At what temperature** do KCl and HCl have the same solubility?

2) Concentration Homework

All work must be shown, including numerical setup. units and answers must be properly rounded.

A) Calculate the molarities of the following solutions:

1) 2 moles of NaCl in 4 L of solution

2) 34 grams of $CaSO_4$ in 2 L of solution

3) 28 grams of KOH in 100. mL of solution

4) 3.65 g HCl dissolved in 0.500 L of solution

B) Calculate the number of grams of each solute necessary to make the following solutions:

1) 1.0 L of a 2.0 M NaOH solution

2) 500. mL of a 10.0 M HCl solution

3) 1.0 L of 5.0 M $Ba(NO_3)_2$ solution

4) 2.0 L of 5.0 M LiOH solution

C) 50.0 mL of a NaOH solution is evaporated to dryness and the resulting residue is massed at 2.5 grams. What was the molarity of the solution?

D) Parts Per Million

1) A sample of tap water is analyzed and shown to contain 0.015 grams of lead ions per 10 grams of solution. Calculate the concentration, in ppm, of this solution.

2) Lead is a heavy metal that is found in car batteries. If they are disposed of in the dump, they can leach the lead out and contaminate the ground water. The EPA has been called in to test the water around one particular dump and found that every 1000. g of groundwater tested contains 0.00027 grams of lead. The EPA's legal limit on lead concentration is 0.015 ppm. Does the dump site break the legal limit? Show your work.

3) 3.0 grams of salt are mixed in with 450.0 grams of water. What is the concentration of salt in the solution, in parts per million?

4) A 100.0 –mL sample of solution is labeled as being 8.50 ppm. How many grams of solute should be left over if all of the solvent is evaporated away?

5) A clean room where microchip parts are being manufactured contains a total mass of air of 450 000 grams. If the maximum allowable amount of particulates (dust, etc) in the air is 0.100 ppm in that room, how many grams of particulates does that come out to?

E) Percent

1) Calculate the percent by mass of a solution that contains 35.8 grams of Na_2SO_4 in 136.3 grams of solution.

2) Calculate the percent by volume of a solution that contains 4.55 mL of ethylene glycol in 7.83 mL of solution.

3) Colligative Properties Homework

A) Ionic compounds are broken apart by water molecules into their individual ions. Only ionic bonds can be broken by dissolving, the covalent bonds that make up a polyatomic ion will remain unbroken. For the following ionic compounds, determine which ions make up the compound and how many ions total go into making the compound.

Ionic Compound	# of and identity of CATION	# of and identity of ANION	Total # of Ions
$KHCO_3$			
$Fe(C_2H_3O_2)_2$			
$Mg(OH)_2$			
$CaBr_2$			

B Ionic compounds (which contain metals and nonmetals) break up into ions when dissolved into water, as seen in A), above. These ions can carry electrical charge and so ionic solutions are called "electrolytes". Molecular compounds (nonmetals only) have covalent bonds, which water cannot break. Therefore, no ions will form and a solution with a molecular solute is called a "nonelectrolyte". The more particles there are in the solution, the greater the impact on the boiling and freezing point.

Compound	**Ionic Or Molecular?**	**Electrolyte or Nonelectrolyte?**	**How many particles the compound breaks up into**	**Rank in order of which one affects the boiling and freezing points the least to most 1 = affects them least 4 = affects them most**
$BaBr_2$				
LiF				
C_2H_6O				
$Fe(NO_3)_3$				

C) Multiple Choice Questions: Place your answer in the space in front of each question.

______1) Which of the following 1 molal aqueous solutions will have the highest boiling point?
a) NaCl (aq) b) $C_6H_{12}O_6$ c) K_3PO_4 d) $Cu(NO_3)_2$

Explain why:____

______2) Which of the following 1 molal aqueous solutions will have the lowest boiling point?
a) NaCl (aq) b) $C_6H_{12}O_6$ c) K_3PO_4 d) $Cu(NO_3)_2$

Explain why:____

______3) **Which of the following 1 molal aqueous solutions will have the highest freezing point?**

a) NaCl (aq) b) $C_6H_{12}O_6$ c) K_3PO_4 d) $Cu(NO_3)_2$

Explain why:____

______4) **Which of the following 1 molal aqueous solutions will have the lowest freezing point?**

a) NaCl (aq) b) $C_6H_{12}O_6$ c) K_3PO_4 d) $Cu(NO_3)_2$

Explain why:____

______5) **Which of the following aqueous solutions will have the highest boiling point?**

a) 500 g solute in 1000 g solvent b) 500 g solute in 500 g solvent
c) 1000 g solute in 500 g solvent d) 1000 g solute in 1000 g solvent

Explain why:____

______6) **Which of the following aqueous solutions will have the lowest boiling point?**

a) 500 g solute in 1000 g solvent b) 500 g solute in 500 g solvent
c) 1000 g solute in 500 g solvent d) 1000 g solute in 1000 g solvent

Explain why:____

______7) **Which of the following aqueous solutions will have the highest freezing point?**

a) 500 g solute in 1000 g solvent b) 500 g solute in 500 g solvent
c) 1000 g solute in 500 g solvent d) 1000 g solute in 1000 g solvent

Explain why:____

______8) **Which of the following aqueous solutions will have the lowest freezing point?**

a) 500 g solute in 1000 g solvent b) 500 g solute in 500 g solvent
c) 1000 g solute in 500 g solvent d) 1000 g solute in 1000 g solvent

Explain why:____

PEAK® ANTIFREEZE & COOLANT MEANS MAXIMUM SEVERE CONDITIONS PROTECTION

Cooling System Capacity in Quarts	Quarts of Antifreeze Required for Protection to Temperatures (°F) Shown								
	3	4	5	6	7	8	9	10	11
8	-7	-34	-69						
9	0	-21	-50	-70					
10	4	-12	-34	-62					
11	8	-6	-23	-47	-65				
12	10	0	-15	-34	-57				
13		3	-9	-25	-45	-64			
14		6	-5	-18	-34	-54	-68		
15		8	0	-12	-26	-43	-62		
16		10	2	-8	-19	-34	-52	-64	
17			5	-4	-14	-27	-42	-58	-69
18			7	0	-10	-21	-34	-50	-62
19			9	2	-7	-16	-28	-42	-56
20			10	4	-3	-12	-22	-34	-48

For best overall protection, solution strengths within the yellow color band are recommended.

FREEZE/BOIL PROTECTION CHART	% of Cooling System Capacity	PROTECTS FROM Freezing Down to	PROTECTS FROM Boiling Up to*
	50	-34°F	265°F
	60	-62°F	270°F
	70	-84°F	276°F

*Using a 15 PSI Pressure Cap

D) Based on this chart, to the right:

1) If your cooling system has a capacity of 14 quarts, how many quarts of antifreeze will be needed to protect your car's engine down to -28°F?

2) Based on the bottom chart, does dissolving a solute in water provide a greater protection against freezing or against boiling? Explain, using the information on the chart.

Solutions Review

1) What is a solution?

2) How does a solution form?

3) What is solubility?

4) Fill in the chart below with either increases, decreases, or remains the same for changing the following factors on the SOLUBILITY of the solute in water:

Solute	Increasing Temperature	Decreasing Temperature	Increasing Pressure	Decreasing Pressure
CO_2 (g)				
NaCl (s)				

5) Using Reference Table G, determine the solubility of:

a) $NaNO_3$ in 100 g of water at 30°C		c) KNO_3 in 100 g of water at 40°C	
b) $NaNO_3$ in 200 g of water at 30°C		d) KNO_3 in 50 g of water at 40°C	

6) Using Reference Table G, determine if the following solutions are saturated, unsaturated or supersaturated. If they are anything but saturated, list two things you can do to make them saturated (include numbers).

Solution (in 100g H_2O)	Sat, Unsat, Supersat	+/- how many °C to make saturated?	+/- how many g to make saturated?
40 g of $KClO_3$ at 50°C			
110 g $NaNO_3$ at 45°C			
70 g KNO_3 at 60°C			
70 g NH_4Cl at 70°C			

7) Calculate the molarities of the following solutions:

a) 120 g NaOH in 500. mL of solution

b) 3.0 moles NaCl in 750. mL of solution

c) 50.0 g of $NaNO_3$ in 2.5 L of solution

8) Calculate the number of grams of solute needed to make the following solutions:

a) 2.00 L of 0.50 M NaBr (aq)

b) 250. mL of 3.0 M KNO_3 (aq)

c) 350. mL of 0.10 M HCl

9) Calculate the following concentrations:

a) In ppm, of 0.044 grams of mercury ions in 200. g of solution

b) In % by mass, 3.88 grams of NaCl in 10.0 g of solution

c) In % by volume, 5.63 mL of ethyl acetate in 7.89 mL of solution