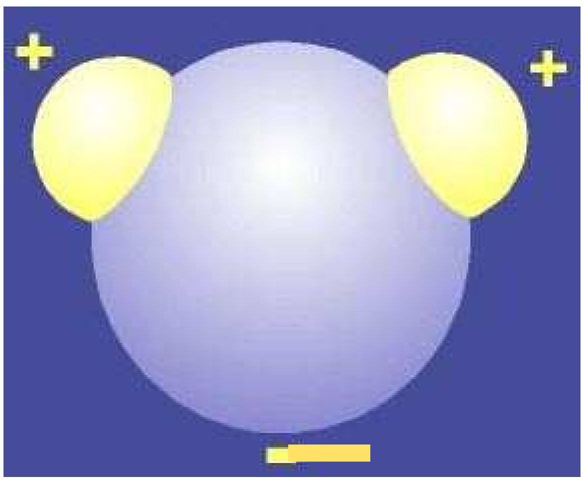
Water Basics

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 his 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 his 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 his driveway, chilling his 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 to learn about. All of these properties are all caused directly or indirectly by the hydrogen bonding between the water molecules.

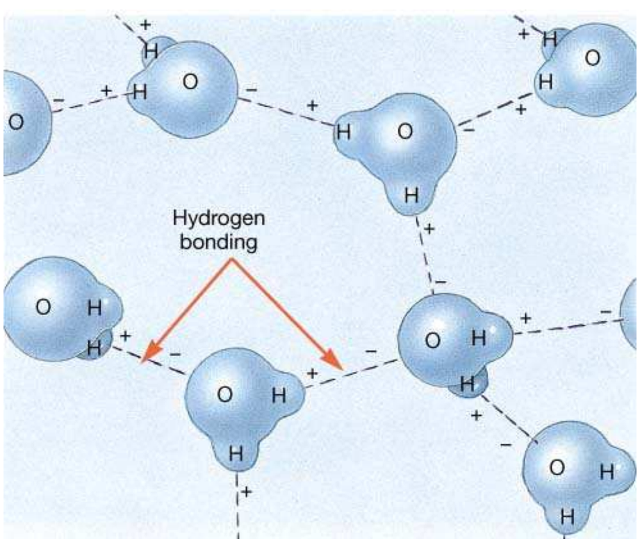


Water is a very polar molecule. It does not have RADIAL SYMMETRY, which would allow its very polar bonds to be “offsetting” to each other. It does have bilateral symmetry, the same type humans have, but that makes it a polar molecule.

The oxygen has an Electronegativity value of 3.4, hydrogen’s is only 2.2, 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 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 pretty strong, and they cause the properties of water below.

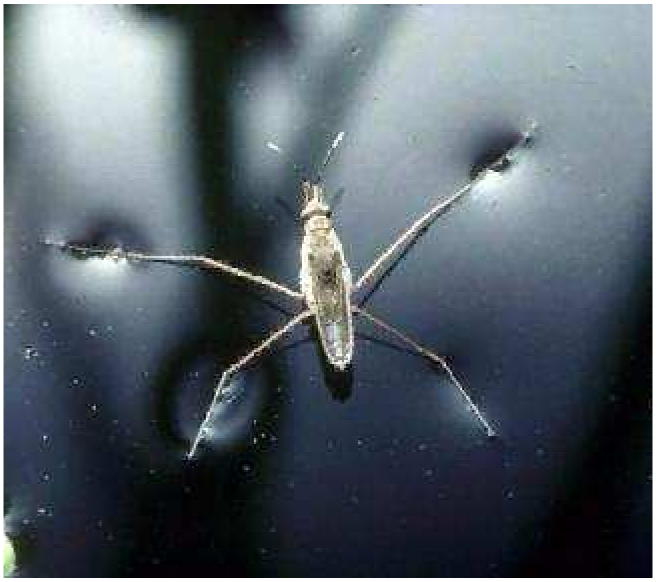


Hydrogen bonds between a group of water molecules is shown at left.

These bonds account for most of the SEVEN MAIN properties of water, such as:

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 saw this in lab when we put sulfur powder (that has a density of 2.00 g/cm^3) onto water; the sulfur could not break through the surface - until we added soap, 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 created an easy way for the sulfur to break through the water surface, and sink.

Surfactant = SURFACE ACTIVE AGENT

2. HIGH SPECIFIC HEAT CAPACITY

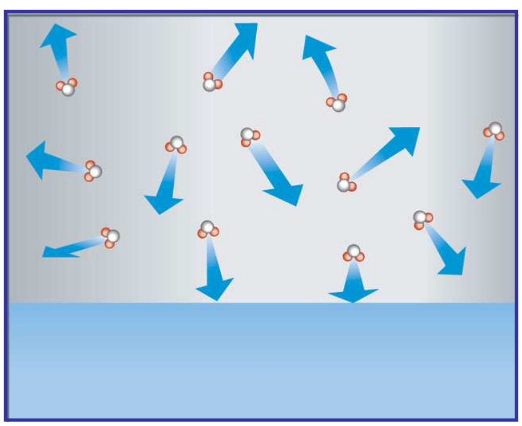
In table B in our reference tables it shows us that the specific heat capacity constant for water is 4.18 J/g·K. This means that in order to raise the temperature of ONE GRAM of water by ONE KELVIN, it will take 4.18 JOULES of energy. Joules are fancy units, but 4.18 Joules = ONE calorie (small "c" calories).

1000 calories = 1 Calorie (capital "C" letter), also known as a food calorie. To increase the temperature of water means to make the water molecules move faster. In order to move faster they must overcome their strong attractions to one another, those being the hydrogen bonds. 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 only 0.46 J/g·K, and for Hg it's only 0.14 J/g·K.

3. LOW VAPOR PRESSURE (low evaporation rate)

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

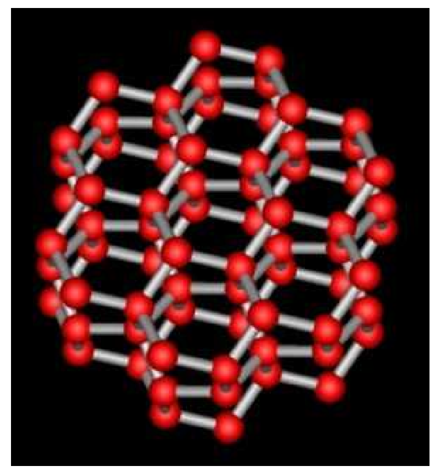
For the same reason of hydrogen bonding causing the water to stick together as a liquid, and to make it evaporate slowly, to make water boil is affected by these hydrogen bonds too. In order to boil, ALL of the molecules must gain enough kinetic energy to break apart from each other.

The water gets heated up to the boiling point first, which takes lots of energy to shake the molecules fast enough. It is difficult because of the hydrogen bonding. To boil it takes 2260 J/g (water's H_V). As water absorbs 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 being 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 slowed down so much that the hydrogen bonds are strong enough to lock them together and force them into a stable complex of six-molecule rings. These rings of water molecules are held together by hydrogen bonds in all three dimensions. Solid ice forms. The six-molecule rings have a small gap - and this gap, which takes up space, creates an unusual situation: the SOLID ice has a LOWER DENISTY than liquid water.



To melt ice, you add 334 J/g (the heat of fusion) which is MUCH less energy than to vaporize it. To melt it you don't have to break every single hydrogen bond, just enough to let the molecules flow over each other. So, it's a much less energetic event to melt one gram of ice than to vaporize it, all this energy is due to the hydrogen bonding.

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.

If you make the classic error and draw a water molecule in a straight line, I tease you and tell you that if that were the case, if water molecules were nonpolar due to their shape, there would be no life on Earth. That's true, and worth explaining one more time.

Water freezes with the gap in the center of every six molecules. Six frozen water molecules take up more space than six liquid water molecules. That extra space allows water to be less dense in the solid phase. The difference is small, but sufficient to make ice float on the surface of water.

If ice sank in water (most solids will sink in their own liquids. Solid copper sinks in liquid copper, solid lead sinks in liquid lead). If solid ice were to sink it liquid water, over a period of years so much ice would sink into the oceans and deep lakes, that all the water on Earth would end up frozen. Except in the summers, when the surface ice could melt, but then refreeze in the winter. This would kill all water life, most importantly the algae, which convert carbon dioxide into oxygen. We'd all suffocate due to a lack of oxygen. Be happy water is bent, and a polar molecule.

6. The Solvation process and Electrolyte Formation

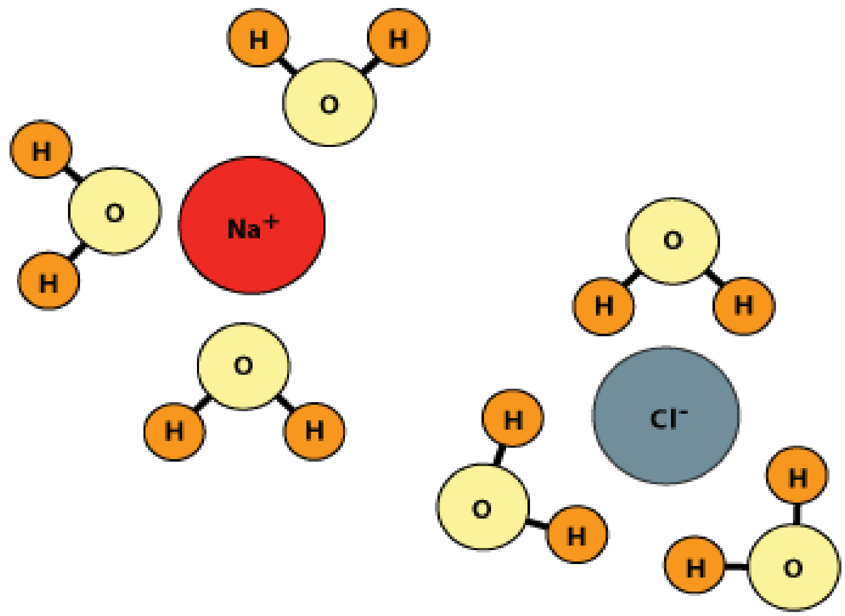
When polar compounds get dissolved into water, the concept of LIKE DISSOVLES LIKE comes to mind. Solvation is the science word for dissolving into solution. Water is a POLAR MOLECULE, which means it has a positive and a negative side (hydrogen side and the oxygen side). The water molecules "gang up" on the ions, or polar molecules, orienting themselves around the charged particles 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 orients itself to the ions of NaCl, and the water is able to "carry" them in solution.

We see the sodium cations surrounded by the oxygen side of water. Below that we see the Cl^{-1} 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 an ionic compound dissolves into water it dissociates into ions. Sometimes it's called ionization. The loose ions in the solution allow it to conduct electricity. The solution is called an ELECTROLYTE.
Electrolytes are ionic aqueous solutions with loose ions that can conduct electricity, or they are just ionic compounds that WOULD form aqueous ionic solutions even though the solids can't conduct electricity as solids. When a solid ionic compound is put into water, it dissolves. This is NOT a chemical reaction, rather it is a phase change from solid to aqueous.

Examples of ionization or dissociation are: $NaOH_{(S)} \rightarrow Na^{+1}_{(AQ)} + OH^{-1}_{(AQ)}$

$NaCl_{(S)} \rightarrow Na^{+1}_{(AQ)} + Cl^{-1}_{(AQ)}$ or $Mg(NO)_{3(S)} \rightarrow Mg^{+2}_{(AQ)} + 2\ NO_3{}^{-1}_{(AQ)}$

When a solution contains loose 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 molecular compound dissolve in water, it is NOT IONIC, it does not form ions, it's not going to be an electrolyte. It can dissolve because the molecules can be polar, like sugar or ethanol alcohol, but the solution is a non-electrolyte - a nonconductor of electricity.

They are SOLUTIONS - but because of a LACK OF IONS, they are NON ELECTROLYTES.
An example of this is sugar dissolving into water $C_{12}H_{22}O_{11(S)} \rightarrow C_{12}H_{22}O_{11(AQ)}$

This is good dissolving, but forms no loose ions, sugar water cannot conduct electricity.

7. Water can form HYDRATED IONIC COMPOUNDS

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 has 5 water molecules hydrogen bonded 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 7 molecules of water to be HYDROGEN BONDED onto it. There are MANY other examples of hydrated ionic compounds as well.

Colligative Properties of Water

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 add salt to water, you change all three of these properties. The more particles dissolved into the water, the greater these properties change.

Salty water also has a lower freezing point than pure water. The ions disrupt the formation of the (neat) six sided rings of solid ice. They quite literally get in the way, and the water molecules can't hydrogen bond together as easily. It takes a COLDER temperatures, or lower kinetic energy for it to solidify.

Salty water will also boil at a higher temperature than pure water. The water boils only when ALL of the molecules can jump from the liquid to gas phase. That happens only when the kinetic energy (heat or motion) exceeds the air pressure pushing down on the surface of the water AND can also overcome all of the hydrogen bonding of the water molecules. When ions are in solution, there is ADDIONAL internal attraction that needs to be overcome, requiring more kinetic energy, or a higher temperature.

Let's imagine an $NaCl_{(AQ)}$ solution. The water molecules have plenty of hydrogen bonds to each other which makes evaporation slow, now they are also attracted to the ions in solution. This makes the evaporation more difficult.

This chart below shows how adding more and more ions per liter of solution changes these colligative properties with the addition of solute. Note, more ions (or polar molecules) has a bigger impact on colligative properties:

When one mole of sugar goes into water, you get one mole of loose polar molecules (there are no ions)

When one mole of NaCl goes into water, 2 moles of ions form: one mole of Na^{+1} and one more mole of Cl^{-1}

When one mole of $CaCl_2$ goes into water, you end up with one mole of Ca^{+2} and TWO moles of Cl^{-1}

When one mole of $Al(NO_3)_3$ goes into water, you end up with one mole of Al^{+3} and THREE moles of NO_3^{-1}

colligative properties (disregarding SF)	pure water	strong $C_6H_{12}O_{6(AQ)}$ (1.0 M)	strong $NaCl_{(AQ)}$ (1.0 M)	strong $CaCl_{2(AQ)}$ (1.0 M)	strong $Al(NO_3)_{3(AQ)}$ (1.0 M)
freezing point	273 K	-271.14 K	- 269.28 K	- 267.42 K	-265.56 K
boiling point	373 K	373.5 K	376.0 K	376.5 K	375.0 K
vapor pressure at 25°C (room temp)	~ 4 kPa	~ 3.5 kPa	~ 3 kPa	~ 2 kPa	~ 1 kPa

Colligative Properties MATH

In our course we will only recognize that any particles dissolved into water will depress vapor pressure (lower the rate of evaporation). The more concentrated an aqueous solution is (the saltier the water) the lower the vapor pressure - the slower or worse it can evaporate.

For <u>boiling point</u> we will need to write down near table A, that the BOILING POINT ELEVATION FOR WATER is 0.50 K/mole of particles per liter of solution. (it's always 1 liter in our class)

Example #1: 1 mole of sugar molecules in 1.0 L H_2O increases the BP this way:
373 Kelvin + [1 mole particles x 0.50 K] = new BP = 373.5 Kelvin (no SF here)

Example # 2: When 3 moles of sugar dissolves into 1.0 L H_2O , the BP changes this way:
373 Kelvin + [3 moles ions x 0.50 K] = 373 + 1.5 = 374.5 Kelvin (no SF here)

It's Tricky Business with ionic compounds though:

When NaCl dissociates into water, one mole NaCl = 2 moles of particles.
$NaCl \rightarrow Na^{+1}$ ions + Cl^{-1} ions.
$CaCl_2$ salt $\rightarrow Ca^{+2}$ plus Cl^{-1} plus another Cl^{-1} (1 mole of this salt $\rightarrow$ 3 moles of ions)

Example #3: 1 mole NaCl dissolves into 1.0 L H_2O increases the BP this way:
373 Kelvin + [2 moles ions x 0.50 K] = new BP = 374 Kelvin (no SF here)

Ex 4: When 1 mole of calcium chloride 1.0 L H_2O , the BP changes this way:
373 Kelvin + [3 moles ions x 0.50 K] = 373 + 1.5 = 374.5 Kelvin (no SF here)

For Freezing Point, the numbers change differently. The Freezing Point Depression for water is 1.86 K/mole of particles per liter of solution (it's always 1 liter in our class)

Example 5: 1 mole of sugar molecules in 1.0 L H_2O decreases the FP this way:
273 Kelvin - [1 mole particles x 1.86 K] = new FP = 271.14 Kelvin (no SF here)

Example 6: When 3 moles of sugar dissolves into 1.0 L H_2O , the FP changes this way:
273 Kelvin - [3 moles ions x 1.86 K] = 273 - 5.58 = 267.42 Kelvin (no SF here)

Example 7: 1 mole NaCl dissolves into 1.0 L H_2O decreases the FP this way:
273 Kelvin - [2 moles ions x 1.86 K] = 273 - 3.72 = 269.28 K (no SF here)

Example 4: When 1 mole of $AlCl_3$ 1.0 L H_2O , the FP changes this way:
273 Kelvin - [4 moles ions x 1.86 K] = 273 - 7.44 = 265.56 K (no SF here)

End Notes, final vocabulary words, etc.

AQUEOUS means dissolved into water, or that the solvent is water.

MISCIBLE is when 2 or more liquids dissolve into each other, for example: water and alcohol.

IMMISCIBLE is when 2 or more liquids DO NOT dissolve into each other, for example: oil and vinegar.

SOLVENT is the stuff that the solute is dissolved into. In salty water, the water is the solvent, salt is the solute

SOLUTE is the stuff dissolved into the solvent. In sugar water, the sugar is the solute, water is the solvent.

LIKE DISSOLVES LIKE means that polar solvents like water only can dissolve polar compounds like sugar or most salts. Some salts will not dissolve in water even though they are polar. Further, nonpolar solvents like gasoline or olive oil can only dissolve nonpolar solutes.

DILUTE solutions have small amounts of solute dissolved into the solvent. CONCENTRATED solutions have lots of solute dissolved into the solvent.

SATURATED solutions contain the normal maximum amount of solute that the solvent can hold based upon volume and temperature. (usually hot solutions hold more solute)

UNSATURATED solutions contain less than the normal maximum amount of solute and can be made more concentrated or stronger by adding more solute.

SUPERSATURATED solutions occur much less often. Most solutions hold certain amounts of solute at certain temperatures. Some compounds can "fool" the solvent into holding more solute than normal. These solutions are unstable, and can "crash" or the solute can precipitate out of solution all at once. Sucrose, or table sugar is a common compound that can supersaturate.

ELECTROLYTIC SOLUTIONS contain loose ions and can conduct electricity. The more loose ions they hold, the better then conduct electricity (the limits being the saturation points).

NONELECTROLYTE SOLUTIONS do not contain loose ions, for example, sugar water has no loose ions even though the sugar dissolves. Molecular compounds like sugar dissolve into invisible small particles called MOLECULES, not ions. Ionic compounds dissolved into water will dissolve into loose ions. Some ionic compounds, like $AgCl$ are INSOLUBLE in water. If you add $AgCl$ to water, you get solid $AgCl$ at the bottom of the beaker, but no loose ions, so no electrical conduction.

COLLIGATIVE PROPERTIES are vapor pressure, boiling point, and freezing point. All are affected by the addition of particles (polar molecules or ions). Vapor pressure depresses (it's harder to evaporate), boiling point increases (it's takes more energy to boil) and freezing point depresses (it's harder to freeze) by the addition of the particles. Usually it's calculated in moles of particles per liter of solution. In AP chem the math is harder as the volumes can be adjusted to any size.

SOLUBLE means able to dissolve. Usually this is into water, but can refer to ANY solvent.

INSOLUBLE means cannot dissolve into a solvent, most often water in our high school chemistry course.

PRECIPITATE means an compound that falls out of solution, due to temperature change, or its formation in a double replacement reaction

SOLUTIONS

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.

This table is nearly identical to our reference table, but it is not quite the same.

To determine the MAXIMUM amount of solute that can fit into 100 mL water at a particular temperature, find the temperature, 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.

For example, how many grams of sodium nitrate fit into 100 mL of aqueous solution at 10°C?

Go to the temperature, and slide your finger up until you hit the $NaNO_3$ line. That happens at exactly 70 grams.

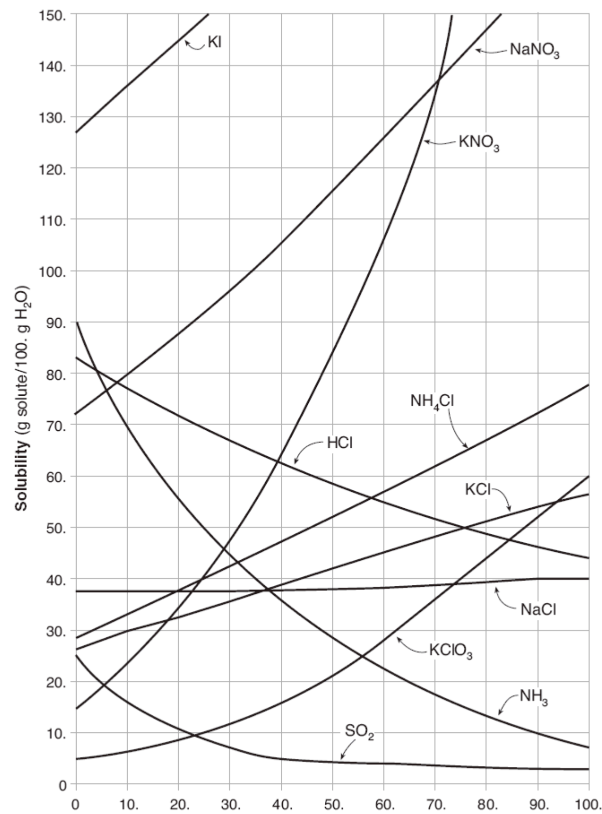
That means, 70 g $NaNO_3$ would saturate 100 mL at 10°C.

How much solute fits into a solution is called the SOLUBILITY. These are the SOLUBILITY CURVES.

Points under the lines means unsaturated, as 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 imagine.

Gas solubility generally drops with increasing temperature. As the temperature of the solution increases, the gas expands, making it even less dense. They bubble out quickly.



Gas solubility does INCREASE with increasing pressure. That's how water is turned into seltzer. This is called becoming carbonated. It can happen only with high pressure. When a can of soda or seltzer is opened the carbon dioxide is released because the pressure holding it in solution is lowered when the can opens to the air. Also because the carbon dioxide is a NONPOLAR molecule that has been jammed into a POLAR solvent.

Since LIKE DISSOLVES LIKE, this carbonation is not chemically normal, and soda gets flat when left open to the air. The CO_2 gas bubbles out of the polar liquid water easily. This is a process though, and depending on the soda's temperature, it can be slow enough that we can enjoy drinking carbonated beverages before they go flat and get boring.