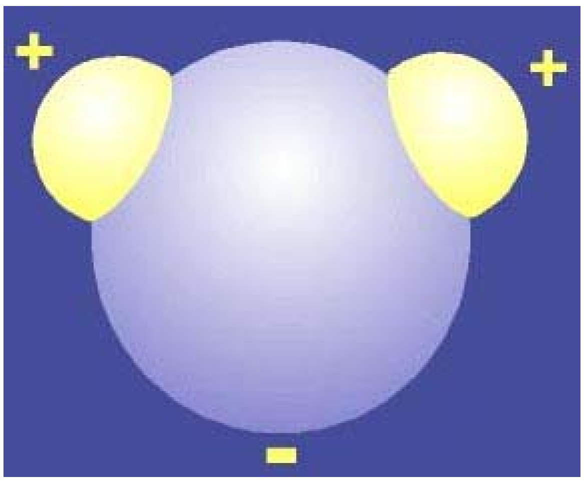
Water Diary

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.

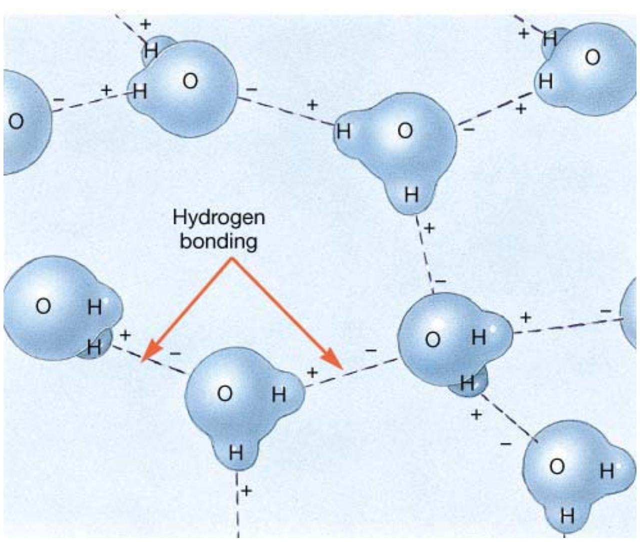


It makes nice pictures, and does cool things, and has physical properties (which are all caused directly or indirectly by the hydrogen bonds between the water molecules).

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 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.



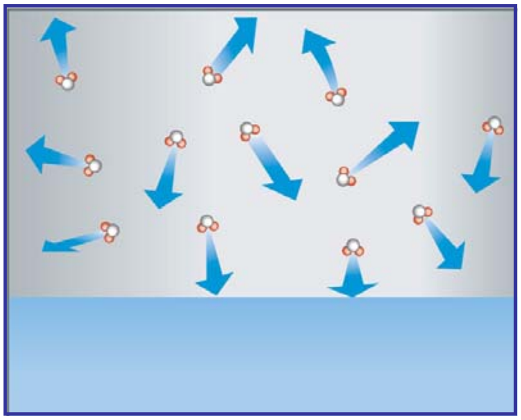
Hydrogen bonds between a group of water molecules is shown at left.

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 when we put sulfur powder (density of more than 2 g/cm^3) onto water, and the sulfur could not get through - 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 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. In order to increase the temperature of water means to make 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

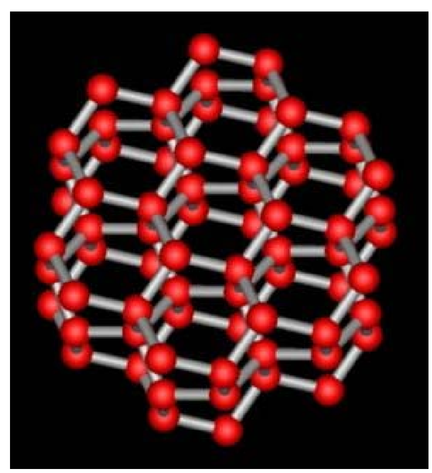
pressure as well as the attractions of the intermolecular hydrogen bonding.

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, for the same reason of hydrogen bonding causing the water to stick together, 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 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 so slowed down 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 $H_2O_{(L)}$

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 due to the hydrogen bonding.

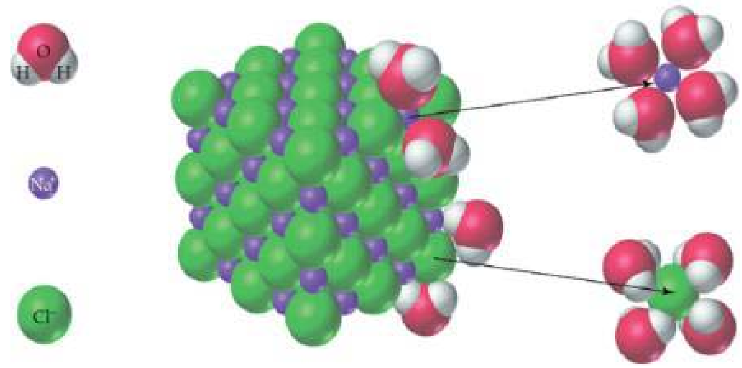


Frozen water molecules arranged in their normal hexagonal shape.
Note the big hole between them, which creates more volume
than these same 6 molecules would have unfrozen.
Liquid water is more dense than solid water.

6. The Solvation process and Electrolyte 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 ($MgSO4{\cdot}7H_2O$). That compound has room for SEVEN molecules of water to be HYDROGEN BONDED onto it.

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 add salt to water, you change all three of these properties. The more salt, 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 lower kinetic energy to solidify. One mole of particles in one liter of solution drops the freezing point by 1.86°C. **Example 1:**

One mole of glucose (189 grams) into one liter of water has a freezing point of −1.86°C. But the addition of one mole (58 grams) of NaCl lowers the freezing point by twice that, because the one mole of NaCl ionizes into one mole of sodium cations AND one mole of chloride anions. Thus, the freezing point for the salty water is −3.2°C.

Example 2: why would people do better with calcium chloride than sodium chloride on their sidewalks in winter? NaCl ionizes into TWO IONS, while the $CaCl_2$ ionoizes into THREE IONS each. More moles of ions means that the sidewalk water would not freeze until 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 H_2O. 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.

End Notes, final vocabulary words, etc.

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.

A dilute solution has a small amount of solute while a concentrated one has a large amount of solute mixed in.

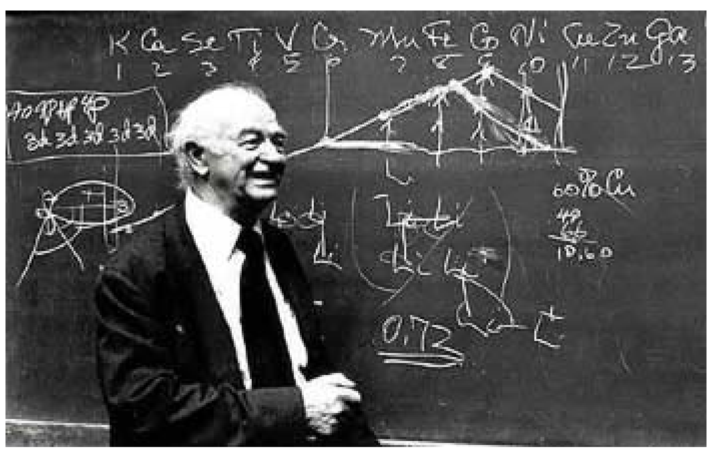
Solutions can be saturated or unsaturated. Strangely they can sometimes be **supersaturated** as well. This is not true for all solutions. When these solutions are physically disrupted, or if more solute is added (seed crystals), they tend to crystallize out, forming solids. The bond formation caused by the liquid becoming solid releases heat. These are usually formed by starting out very warm, with saturated solutions, then cooling the solutions to temperatures that SHOULD NOT hold the amount of solute present. Some solutions do this. Sugar does in water.

If a saturated solution is holding solute and cooled down, the cooler solution will often NOT be able to hold the same amount of solute. The solute tends to fall out of solution, and land in the bottom of the beaker.

Solutions that contain ions become able to conduct electricity. These solutions are electrolytes. Non-electrolytes are solutions with molecular compounds dissolved in them, like sugar water. Junk food companies often call the ions themselves the electrolytes, which is technically incorrect, but common. The solutions are the electrolytes, they contain ions. The presence of ions creates electrolytes, but the ions themselves are not the electrolytes (in chemistry class). Don't be fooled by labels on those large colored beverages.

Linus Pauling is a famous American chemist. He won 2 Nobel Prizes - by himself! Note the elements across the black board above his head. How are they linked together, what is the relationship that they have?

You figure it out!

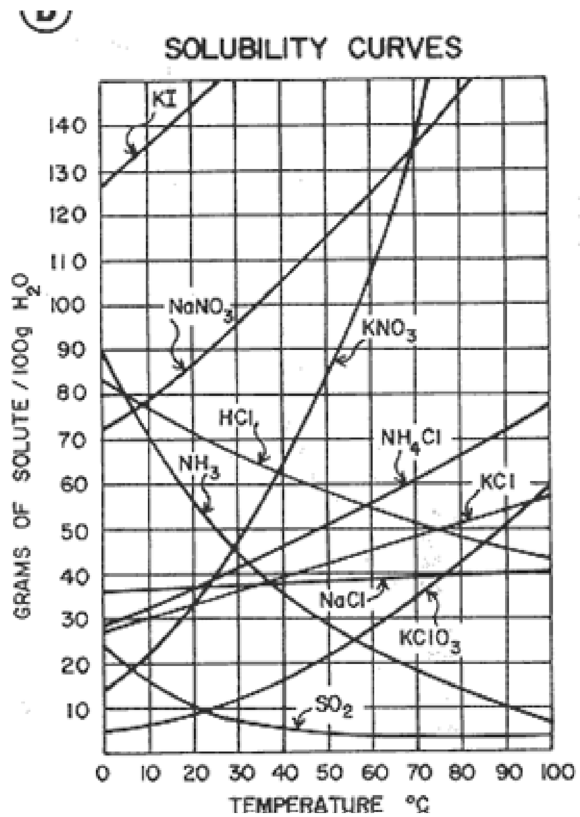


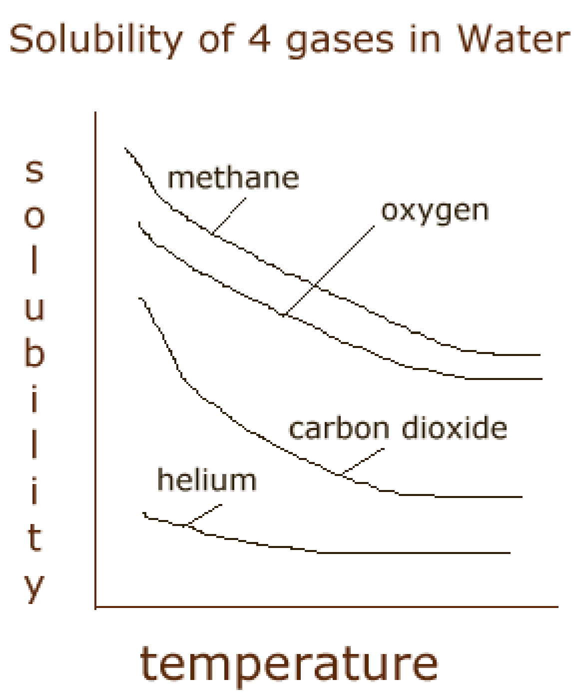
SOLUTIONS
When a solute dissolves into a solvent, a homogenous solution is formed. If the solvent is water, the solution is said to be an AQUEOUS solution. Solutions are homogenous, which means the SAME THROUGHOUT. A given solvent can only hold a certain amount of solute. When it is holding as much as 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. GOOD. Look & learn and THINK.

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.