Water is the most unusual substance in the universe. This sounds like hyperbole, but the reality is, water is unique. For example, you are aquatic creatures. Not in the sense you live in water, but in the sense you carry your water with you. You are 70% water by weight. Individual cells in your body are approximately 90% water by weight. Life as we know it on earth cannot exist without water. You can go 2 or 3 weeks without food, but only 3-4 days without water.

When scientists first explored Mars by spacecraft, they looked for the existence of four elements on Mars: carbon, oxygen, hydrogen and nitrogen. They knew that life, as we know it, cannot exist without those four elements. When the spacecraft landed, a small scoop pulled in some Martian soil and tested for those four elements. They were all present. Another thing checked was the presence of water (hydrogen and oxygen in combination). Today, we know water did exist at one time on Mars. No life was found, but the elements and compounds essential for life are present on Mars.

Since water is so important, this chapter will deal with some of the physical parameters of water.

Physical States of Matter

You've probably heard there are three states of matter. Actually there are four: solids, liquids, gases, and plasmas. Plasmas are streams of electrons and nuclei. This discussion will deal with the first three: solids, liquids and gases. Water exists in all three states. The solid form of water is called ice. The liquid form of water is called – water, and the gaseous form of water is called vapor (not steam).

Solids

Solids are defined as having a definite shape and a definite volume. Think of a desk. It has height, width and depth, therefore its volume may be determined. It has a shape not be confused with something else. Another characteristic of solids is molecular motion is very slow (Brownian motion). It difficult to imagine, but the atoms, ions and molecules in a solid are indeed moving, if no more than vibrating in place. However, compared to other states of matter, molecular motion in solids is very slow.

Liquids

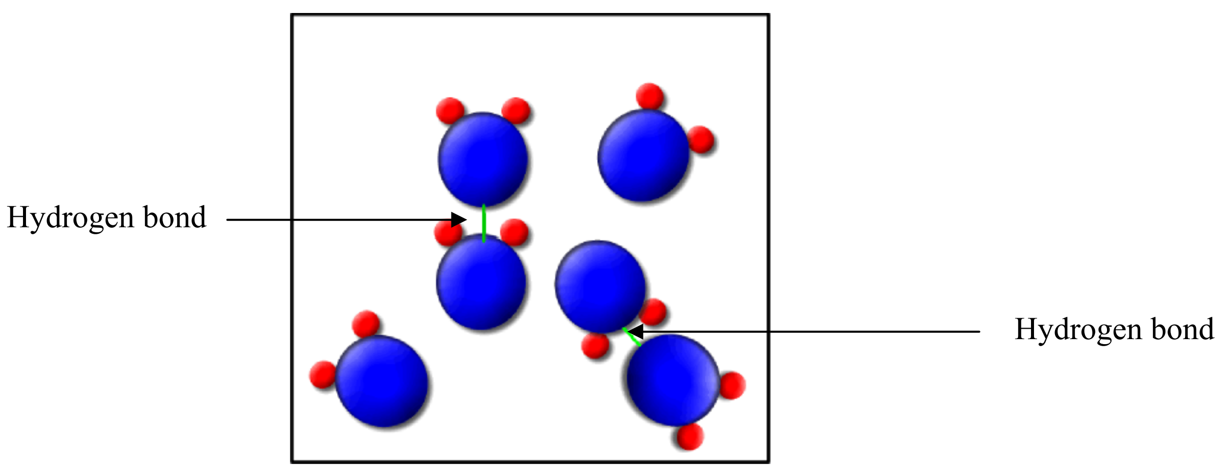
Liquids are defined as having no define shape but a definite volume. Liquids take the shape of their container. If the container is round, the liquid conforms to that shape. If rectangular, then it takes the shape of a rectangle. Regardless of shape, liquids have a definite volume. This is often the method used in dispensing liquids, *i. e.* gallons, liters, etc. Molecular motion is significantly faster than in a solid. The particles that make up a liquid are capable of rapid movement.

Gases
Gases have no definite shape nor definite volume. Gases, like liquids, take the shape of their container. A gas will expand to fill a spherical container (a balloon) or a box. In addition, the gas will expand to fill any volume. A gas may be confined in a large box or a small box. Molecular motion is fastest in gases.

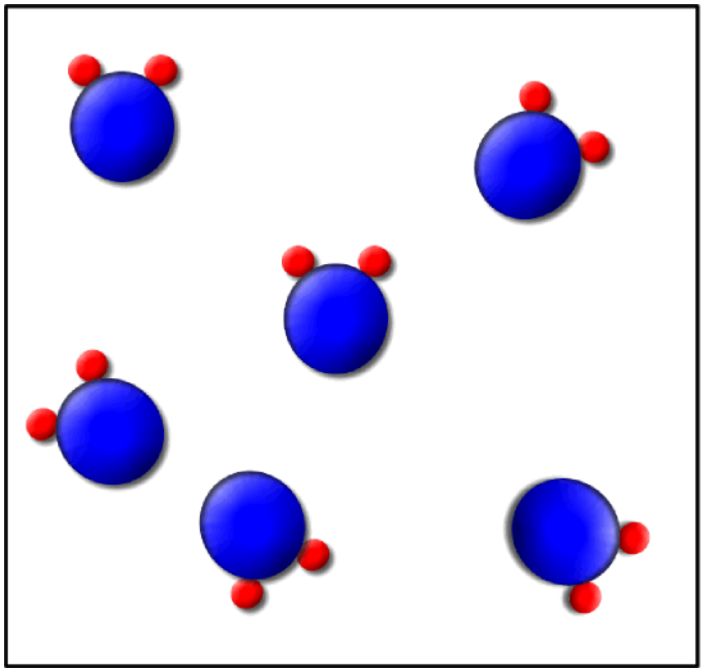
Triple Point of Water
Water can exist in all three states at the same time. This is called the triple point of water. It is often demonstrated in science labs with a vacuum pump and a bell jar. Place a bell jar over a beaker of water on the platform of a vacuum pump. The jar is usually made air tight with a ring of Vaseline around the base so it adheres to the platform. Begin to evacuate the air in the bell jar with the pump. The water soon goes into a rolling boil. The top of the jar begins to form water droplets, a condensation of the water vapor at the top of the jar, and ice crystals form around the mouth of the beaker – all three states at one time!

The Physical States of Water
Water may exist as either a solid (ice), liquid (water) or gas (vapor). To begin, think of 6 water molecules (don't think of the state of matter yet). A single water molecule, composed of two hydrogens and one oxygen has a molecular mass of 18. That's because hydrogen has a mass on 1 (x 2 hydrogen atoms) and oxygen has a mass rounded off to the nearest whole number of 16. Six water molecules would each have a mass of 18 amu's.

Water as A Liquid
Think of the six water molecules mentioned above. What determines the liquid state of water is the amount of hydrogen bonding between water molecules. Water in the liquid state has some water molecules hydrogen bonded together while other water molecules are free and unbonded. Pay particular attention to the amount of space (volume) taken up by the 6 water molecules.



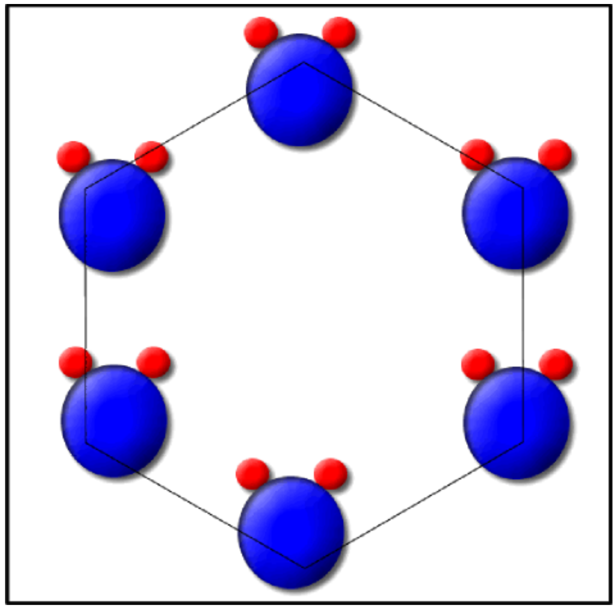
Water as A Gas



Water as a gas or vapor is based again on hydrogen bonding. In this case, there is no hydrogen bonding of water molecules. Again, pay attention to the volume taken up by the gas.

Water as A Solid

Water as a solid is interesting in that the amount of hydrogen bonding is total. All of the molecules are hydrogen bonded. It's no accident that ice crystals and snow flakes are six sided when you look at the arrangement of the water molecules. Again, heed the volume.



Other Physical Parameters of Water
There are other physical parameters of water which make it so unusual. We will look at several: density, specific heat, boiling point, melting point, and specific gravity.

Density
Perhaps you remember everything in the universe has mass and occupies space. The amount of mass per unit of space is called density. In other words, density is equal to the mass divided by the volume:

$$D = m/v.$$

Pure water, and it must be absolutely pure water, has a density of 1.00 g/ml at 4°C. You must stipulate 4°C. The density of ice is different from the density of water vapor, which is different from the density of liquid water. Refer to the diagrams of the three states of water. Compare the volume taken up by each state. You should note that water in the liquid form takes up much less volume than either gaseous or solid. Think of it this way.

A large **MAS S** equals a large **DENSITY**
Divided by a small **volume**

On the other hand,

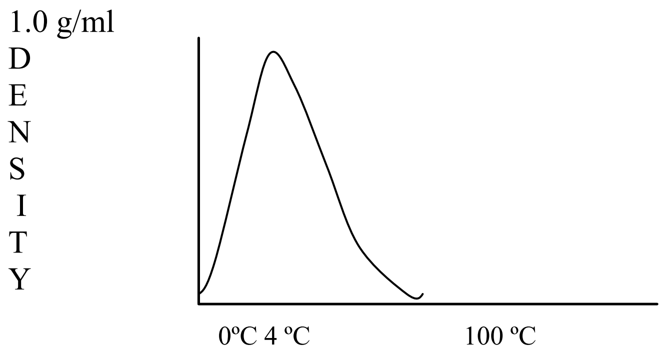
A small **MASS** equals a small **DENSITY**.
Divided by a large VOLUME

Since the 6 water molecules shown in the previous diagrams all have the same masses, the only difference in the three states of water is the amount of volume taken up by each one. Note the volume, in increasing size is:

↓
Water (liquid)
Ice (solid) – remember, water expands upon freezing
Vapor (gas).

This means water has its greatest density (smallest volume) in the liquid state. Anything of a density less than water will float in it and anything with a density greater than liquid water will sink in it. This is why ice floats. Think how this differs from most substances on earth. Generally speaking, the solid form of matter is the one with the greatest density (iron, wood, plastic, etc.).

What about the 4°C thing? Pure water has its greatest density at 4°C. Anything above 4°C, the density gets less. Anything below 4°C, the density gets less.



So What?
OK, so water has its greatest density at 4°C. Big deal. Actually, it is a big deal. Think of the reverse. What if water behaved like most substances on earth and had its greatest density in the solid form? What would happen to a body of water that was exposed to below freezing temperatures? Ice would form at the surface and *sink.* The result would be ponds and lakes would freeze from the bottom up, not from the top down. Again, you think not a big deal. However, if you are a fish, it is a very big deal. You would be exposed to colder and colder environments as the pond froze from the bottom upwards and you would finally be exposed on the surface.

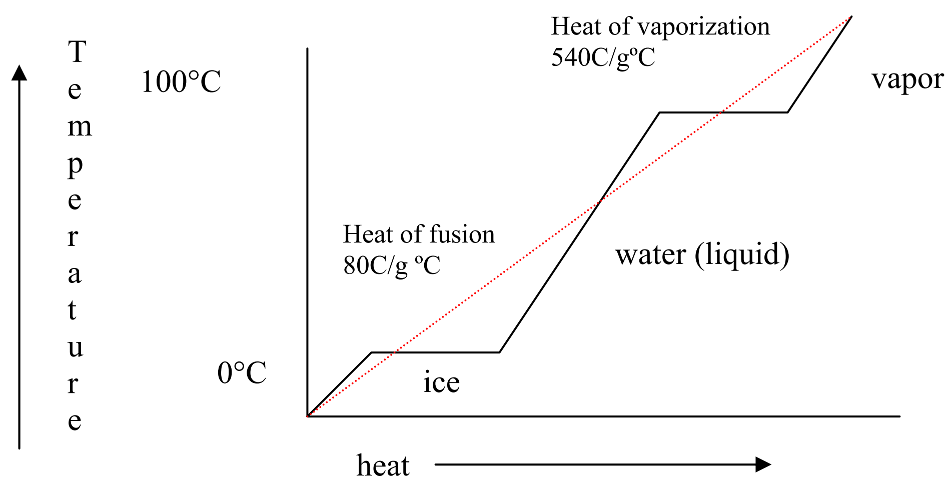
The simple fact that water has its greatest density at 4°C has allowed for life to evolve on this planet.

Freezing Point/Melting Point
At what temperature does liquid water freeze? Most will recognize the freezing point is 0°C. A corollary is "at what temperature does ice melt?" The answer is the same, 0°C. At first, it may be incongruous the freezing point and melting point are the same temperature. However, think of a glass of ice water where both the ice and liquid water are absolutely pure. Insert a thermometer and the temperature should read 0°C (after all, it is ice water). *If* you could design a perfect insulator (and you can't) and insert a glass of ice water in the insulator, you could come back 100 years from now and there would still be ice and water in the glass. The reason: as fast as the ice melts, water freezes. You reach a state of equilibrium. Of course, there is no perfect insulator, therefore, the ice does melt due to the temperature of the surrounding environment.

Boiling Point/Condensation Point
At what temperature does water boil to form a vapor? The answer, as most people know, is 100°C. Then at what temperature does the vapor condense to form liquid? The answer, again, is 100°C. Again, you reach equilibrium where liquid water forms vapor at the same time vapor condenses to form liquid water.

A Word About Boiling, Evaporation, and Condensation
Most people assume boiling is a heating process and condensation is a cooling process. Actually, it's the reverse. Boiling is a cooling process. The most energetic of the water molecules are leaving in the form of vapor. The molecules left behind are the less energetic ones; the cooler ones. Evaporation is also a cooling process since boiling is simply rapid evaporation. Condensation, on the other hand, is a warming process. Condensation pulls water vapor out of the air (a warmer environment) and places the condensed liquid on a cooler surface.

Specific Heat
The specific heat of water is measured as 1.00 Calories/gram °C. In essence, specific heat tells us how many calories of heat energy are necessary to raise the temperature of a gram of water. It can be illustrated in the graph shown.



Heat *versus* Temperature
At first glance, the graph seems nonsensical. Isn't heat and temperature the same thing? If so, you could not plot it on a graph – you must have two variables for a plot. Temperature and heat are not the same.

Temperature
Temperature is the measure of heat loss or heat gain. This measurement is taken with a device called a thermometer. Heat flows in the direction of greater heat to less heat. (Think of a hot cup of coffee placed on a table. Once removed, the table is warm at the location of the coffee cup.)

Heat
Heat is the amount of thermal energy a body possesses. So what is thermal energy?

Thermal Energy
This is the average kinetic energy of a body. What's kinetic energy?

Kinetic Energy
Kinetic energy is the energy of motion. Remember, Robert Brown said all atoms, ions, and molecules are in constant random motion – even those in a solid.

Observe some object in a room, such as a desk. That desk, a solid, is composed of atoms, ions, and molecules in constant random motion, therefore, it has kinetic energy. If we take the average kinetic energy of the desk, it is called thermal energy. The amount of thermal energy a body possesses is called heat. Place a thermometer on the desk and the thermometer will measure any heat loss or heat gain to the thermometer. In essence, heat and temperature are not the same variables, and therefore, may be plotted on a graph.

One would assume, at first thought, as you raise the heat, temperature should increase as a direct proportion – as a straight line (note the dotted line in the graph). In reality, it does not.

Heat of Fusion
When you look at the graph, notice there is a point which plateaus at zero °C.
The graph indicates as you increase heat, the temperature does indeed go up until you reach 0°C. However, at that point, it takes a great deal of heat energy to convert 1 gram of ice into 1 gram of liquid water. The amount of heat energy to change the state of water at 0°C is 80 cal/g, also known as the heat of fusion. At the point you melt the ice, then as you increase heat, temperature increases until you plateau again at 100°C. At that point, a large amount of heat energy must be added to convert liquid to vapor at 100°C. That amount is 540 cal/g, also known as the heat of vaporization.

What's happening? When ice is converted to the liquid state at 0°C, the hydrogen bonds of ice (remember, all the molecules are hydrogen bonded) are broken and only some of the water molecules remain hydrogen bonded. When liquid water is converted to vapor at 100°C, the remaining hydrogen bonds of liquid water are broken.

Calories and calories
A calorie (small letter "c") is defined as the amount of heat energy necessary to raise one gram of pure water, one degree Celsius in temperature. For example, if you have one gram of water at 26°C and raise that 1 gram to 27°C, you have expended 1 calorie.

Additionally, if you have 1 gram of pure water at 26°C and raise it to 36°C, you have used 10 calories. What about 10 grams of pure water raised 1 degree? The answer is still 10 calories. Ten grams raised 10°C would be 100 calories.

The term Calorie (capital "c") is a dietician's calorie. It actually is 1000 small "c" calories, or 1 kilocalorie.

More Specific Heat
What all this means is water has a very high specific heat. Not many substances have a specific heat as high as water. In practical terms, this means it takes a great deal of heat to warm water, but once you have it warm, it stays warm for a long time. Remember the old adage – "a watched pot never boils". This means it takes a long to time boil water, but once it boils it stays hot for a long time. This is the concept behind water "heaters".

In real terms, this means water is a very stable environment. If you were to chose an environment for life to evolve on the planet earth, would you chose an extreme environment (such as a terrestrial one) or one that was very stable with very little temperature extremes?

Physical Parameters Reviewed
Think of some of the physical measurements we've covered and then add one more….

Density of pure water @4°C = 1.00 g/ml
Specific heat of pure water = 1.00 cal/gram°C
Specific gravity of pure water = 1.00 (no units associated with specific gravity).

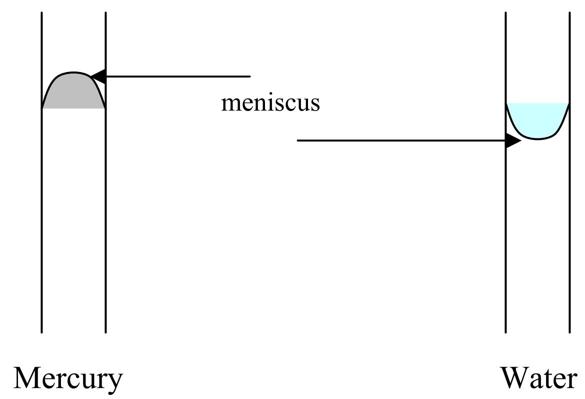
You can see why water is the standard reference for most substances on earth. Look at all those 1.00's.

Other Physical Parameters
Other parameters are the adhesive and cohesive properties of water.

Capillary Action and Adhesion
Water is a polar molecule. This means it is attracted to charged surfaces. One example is a capillary tube. Capillary tubes are narrow diameter tubes which have an overall negative charge associated with them. Water *adheres* to the sides of a charged tube and is pulled up the length of the tube by this adhesion.

Surface Tension and Cohesion
Since water is polar, it not only adheres to charged surfaces, it can also stick to itself. This property of water to be attracted to other molecules of water is called cohesion. The cohesive properties of water work to produce the effect known as surface tension. Surface tension occurs when all the water molecules cohere to others at the interface between the liquid and the air. This "film" of water is quite strong. It allows small insects to be able to be supported by the film.

Meniscus
Water has fairly strong cohesive properties. However, mercury has even greater. When mercury is viewed in a small diameter tube, the cohesive nature of mercury forms a convex surface at the interface. This is important when reading a thermometer or barometer filled with mercury. You have to know where to read the mark. You read the mark at the top of the convex surface. Water has less cohesive properties than mercury and thus forms a concave surface at the interface. You read the bottom of the concave surface for water. Both the convex and concave surfaces are referred to as the meniscus.



Mixtures *versus* Compounds
Why so much detail about water? We are going to make mixtures. Many students confuse the concept of mixtures with compounds. For example, salt water is a mixture whereas salt by itself is a compound and water by itself is a compound. There's a distinct difference. An easy way to distinguish between the two is a comparison.

Characteristics of A Mixture	**Characteristics of A Compound**
1. When formed, mixtures give no evidence of a chemical reaction.	1. When formed, compounds give evidence of a chemical reaction, *i. e.* heat, light, smoke, etc.
2. Components of a mixture are easily separated.	2. Components of a compound are not easily separated.
3. Components of a mixture may be in any proportion.	3. Components of a compound are in *definite* proportions.

Look at comparison # 3. What is the formula for water. Is it HO? What about HO_2? What about H_2O_2? No, the formula for water is H_2O. There *must* be two atoms of hydrogen for every atom of oxygen.

Types of Solutions

Types of Mixtures

There are three basic types of mixtures: solutions, suspensions, and colloids. What distinguishes the three types? One point of difference is whether the mixture looks the same throughout or if there are distinct layers or separations. Mixtures that look the same throughout are referred to as homogeneous (= same kind). Mixtures that have layers or don't look the same throughout are referred to as heterogeneous mixtures.

Solutions – homogeneous mixtures
Suspension – heterogeneous mixture
Colloid – homogeneous mixture

Solutions

A solution is a homogeneous mixture composed of at least two parts: the solute and the solvent. The solute is often described as the substance dissolved. The solvent is often described as the substance which dissolves the solute. An example is salt water. In this case, salt is the solute and water is the solvent.

Type of Solution	**Example**
Solid in a liquid	Salt water
Liquid in a liquid	Bourbon and water (careful on the definition of a solute here)*
Gas in a gas	The atmosphere**
Solid in a solid	Bronze (alloy)
Liquid in a solid	Dental amalgam
Gas in a liquid	Soda pop

In essence, you may have any combination of state of matter forming a solution.

*At bars, bourbon is the solute, water is the solvent. At my house, water is the solute, bourbon is the solvent.

** The atmosphere is 78% N_2, 21% O_2, <1% Ar, CO, CO_2, H_2O vapor, pollution

Suspensions

Suspensions are heterogeneous mixtures that show distinct states or layers of separation. A classical example is sand in water. As long as you stir the mixture, the sand and water look evenly mixed; however, when you stop the agitation, the mixture settles into layers with sand on the bottom. Other examples are vinegar and oil and flour and water. In the case of vinegar and oil, which separates out on top? Hint: which has the less density?

Colloids

Colloids are homogeneous mixtures, like solutions. The difference is that colloids show distinct phases. A favorite colloid is Jello. Jell-O is composed of a protein called gelatin. Gelatin is a charged protein with "+" and "–" charges associated with parts of the protein. When you make Jell-O, the recipe calls to mix the contents of the package of Jell-O with 1 cup boiling water. Boiling water has high heat, thus high thermal energy, thus high kinetic energy, and therefore, the water molecules are moving around a great deal. When you mix the Jell-O and boiling water, it should look the same throughout – homogeneous. Energetic water molecules keep the gelatin evenly distributed throughout the mixture. The recipe then calls for 1 cup cold water and then to place the mixture in the refrigerator. The heat is removed, the thermal energy lessens, and the kinetic energy drops. Water, that had previously kept the gelatin molecules separated, now slow down. The "+" and "-" charges of the protein now take over and the gelatin now orients in the mixture with positive attracted to negative to form a network of gelatin molecules with water trapped in the middle. That's why Jell-O is difficult to eat with a fork – it's like a bunch of springs.

Reversible *versus* Irreversible

In the example of Jell-O, the mixture went from a liquid (sol state – think solvent) to a solid (gel state). If you leave Jell-O out too long on a summer day, it will revert to the sol state. Place it back in the refrigerator, and it will convert once again to the gel state. (Caution! Don't do this. Jell-O is an excellent place to grow bacteria!) Jell-O is an example of a reversible colloid.

Egg white (egg albumen) is a colloid. In the uncooked egg, it is in the sol state. Cook it and it denatures the protein to form a gel state. This colloid is irreversible – once cooked, it stays fixed.

What's the Real Difference in Mixtures?
The real difference among a solution, suspension and colloid is particle size. The particles of the solute are so small that gravity has no effect on them. Instead Brownian movement rules their existence. In a suspension, the particles are so large, that gravity is the over-riding effect. In a colloid, the particles are in between the two other mixtures. The particles are affected by Brownian movement, particularly if you help Brownian movement along, but gravity will have an effect unless it is counterbalanced.

Where Do You Find Mixtures?
Mixtures are all around you. In particular, your cells are composed of solutions, suspensions, and colloids. Surrounding the cells are intercellular fluids composed of solutions, suspension and colloids. Cells may be composed of solutions, suspension, and colloids, but colloids make up the bulk of cellular material.