What properties of water make it so important in biology?

**Water, a great solvent**

A solution is produced when a substance (the solute) is dissolved in a liquid (the solvent). When the solvent is water (by the way, water is an excellent solvent) it is known as an aqueous solution. Many of the important molecules in biological systems are polar and therefore soluble in water. Ionic substances are soluble (they dissolve) in water because the poles of the polar water molecules interact with the ionic substances and separate them into ions. The slight negative charge of the oxygen end of a water molecule are attracted to cations (like the sodium of common table salt) and the hydrogen regions are positively charged and are attracted to the anions (like the chloride of table salt). The result is a solution of two solutes, sodium cations and chloride anions mixed homogeneously with water. Substances with polar covalent bonds are similarly soluble because of the interaction of their poles with those of water. Substances that dissolve in water are called hydrophilic (“water loving”). A compound does not need to be ionic to dissolve in water (think sugar). Because they lack charged poles, non-polar covalent substances do not dissolve in water and are called hydrophobic (“water fearing”). Long hydrocarbon chains (like oil) are non-polar and therefore hydrophobic. Any polar molecule, or polar group of atoms like the hydroxyl group, is hydrophilic. When a substance ionizes in water, it dissolves, and is therefore hydrophilic as well. It is important to consider concentrations when thinking of solutions. Quantitative analysis does not yield direct counts of molecules; instead a chemist would use a constant that relates the weight of any substance to the number of molecules of that substance. This constant is called Avogadro’s number, which is 6.02x10^{23} molecules per mole. A mole of one substance has exactly the same amount of molecules as a mole of another substance. Keep in mind that one molar solution of any substance is rarely found inside organisms. More often, solutions are a tenth or a mole, or even one hundredth of a mole as is the case of hormones.

**Water has a high heat capacity**

Heat capacity is the degree to which a substance changes temperature in response to a gain or loss of heat. Water has a high heat capacity, changing temperature very slowly with changes in its heat content. Thus, the temperatures of large bodies of water are very stable in response to the temperature changes of the surrounding air. You must add a relatively large amount of energy to warm (and boil) water or remove a relatively large amount of energy to cool and freeze water. The high amount of energy required to vaporize water ranges in its effect from moderating the Earth's climate, stability of lake temperature, cooling of plants and even cooling of you. Water also has a high heat of vaporization, which means that a lot of heat is required to change water from its liquid to its gaseous state (evaporation). Again, heat energy is used to break hydrogen bonds. This heat is absorbed by the environment. As the liquid evaporates, the remaining water cools down and thus you have evaporative cooling. When sweat evaporates from your skin, a large amount of heat is taken with it and you are cooled.

**Increased density in water has rare property of expansion**

Put simply, ice floats. Unlike most substances that contract and become denser when they freeze, water expands as it freezes, becomes less dense than its liquid form and as a result floats in liquid water. Hydrogen bonds are typically weak, constantly breaking and reforming, allowing molecules to periodically approach one another. In the solid state of water, the weak hydrogen bonds between water molecules become rigid and form a crystal that keeps the molecules separated and less dense than its liquid form. If ice did not float, it would sink and remain frozen due to the insulating protection of the overlying water. There are many biological consequences is ice did not float. Not only does it float, keeping bodies of water from freezing from the bottom up, but the ice acts as a layer of insulation for the rest of the water. This property is a particularly important water property for ocean and fresh water organisms.
**Water cohesion, adhesion and surface tension**

Water has strong cohesion and high surface tension. Cohesion, or the attraction between like substances, occurs in water because of the hydrogen bonding between water molecules. The cohesion of water molecules refers to their capacity to resist coming apart from one another. The strong cohesion between water molecules produces a high surface tension, creating a water surface that is firm enough to allow many insects to walk upon it without sinking.

Cohesion due to hydrogen bonding contributes to the transport of water and dissolved nutrients against gravity in plants. Water is able to travel from the root system up the network of water-conducting cells to the leaves. As water evaporates, the hydrogen bonds holding the molecules together pull more water up the system. Water has strong adhesion. Adhesion is the attraction of unlike substances. If you wet your finger you can easily pick up a straight pin by touching it because the water on your finger adheres to both your skin and the pin. Similarly, some people wet their fingers to help them turn pages. When water adheres to the walls of narrow tubing or to absorbent solids like paper, it demonstrates capillary action by rising up the tubing or creeping through the paper.

Water adhesion compliments water cohesion in that it helps water ‘stick’ to the cell walls of plants.

**Water spontaneously ionizes**

Water spontaneously ionizes, forming hydrogen ions (H+) and hydroxide ions (OH-). This ionization is the result of one hydrogen atom nucleus (a proton) dissociating from the rest of the water molecule, leaving behind its electron. An acid is any substance that dissociates to form h+ ions when it is dissolved in water. A base is any substance that combines with H+ ions, as OH- ions do. The pH scale indicates the concentration of H+ ions in solution. The potential for hydrogen scale (pH) is a scale ranging from 0-14, with 7 being neutral. A 7 really means that there is 0.0000001 fraction of ionized molecules at any one time, or 10^-7. Each level of the pH scale is 10 times more concentrated than the level above or below it. For example, a pH of 5 has 10 times more H+ ions than a pH of 6. A pH of 11 had 10 times less H+ ions than a pH of 12. The ionization of water is critical to life processes because many reactions that take place in living systems involve the transfer of a proton from an acid to a base.

**Life’s chemistry began in water**

The presence of water on a planet- Mars, Earth or any other- is a necessary prerequisite for life as we know it. Astronomers believe our solar system began forming about 4.6 billion years ago, when a star exploded and collapsed to form the sun and 500 or so celestial bodies called planetesimals. These planetesimals collided with one another to form the inner planets, including Earth and Mars. The first chemical signatures indicating the presence of life on Earth now appear to be about 4 billion years old. So it took 600 million years, during a geological time frame called the Hadean, for the chemical conditions on Earth to become just right for life including the presence of water.

Ancient Earth probably had a lot of water high in the atmosphere. But the new planet was hot, and this water evaporated into space. As Earth cooled, it became possible for water to remain on its surface, but where did that water come from? One current view is that comets—loose agglomerations of dust and ice that have orbited the sun since the planets formed—struck Earth and Mars repeatedly and brought not only water but other chemical components of life, such as nitrogen. As the planets cooled, chemicals from their crusts dissolved in the water, and simply chemical reactions then take place. Some reactions may have led to life, but impacts by large comets and rocky meteorites would have released enough energy to heat to nearly boil the developing oceans, thus destroying any early life. On Earth, these large impacts eventually subsided, and life gained a foothold about 3.8 to 4 billion years ago. The prebiotic Hadean was over. The Archean had begun, and there has been life on Earth ever since.

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WATER

Biologic importance:

Example

Complete the cluster map while you read.

Interesting facts!
Answer the following questions to check your understanding.

1. Many mammals control their body temperature by sweating. Which property of water is most directly responsible for the ability of sweat to lower body temperature?
   a. Water’s change in density when it condenses
   b. Water’s ability to dissolve molecules in the air
   c. The release of heat by the formation of hydrogen bonds
   d. The absorption of heat by the breaking of hydrogen bonds
   e. Water’s high surface tension

2. The bonds that are broken when water vaporizes are
   a. Ionic bonds.
   b. Hydrogen bonds between water molecules.
   c. Covalent bonds between atoms within water molecules.
   d. Polar covalent bonds.
   e. Nonpolar covalent bonds.

3. Draw three water molecules and label the atoms. Draw solid lines to indicate covalent bonds and dotted lines for hydrogen bonds. Add partial-charge labels where appropriate.

4. Oil and water don’t mix because
   a. The surface tension of the oil is not great enough.
   b. Oil molecules are too cohesive.
   c. Hydrogen bonds will not allow the interaction.
   d. Water does not dissolve nonpolar substances.

5. What term describes any substance that dissociates to form H+ ions when it is dissolved in water?
   a. Acid
   b. Base
   c. Isotope
   d. Molecule

Unpolluted rainwater has a pH of about 5. Acid precipitation has a pH of about 4. About how much more acidic is acid precipitation than unpolluted rainwater? Suggest one reason why a fish biologist might be concerned about acid precipitation.