Biochemical importance of water

Water is often referred to as the ' universal solvent' and without there would be no life on this planet. Its involvement is extensive from cellular processes in organism to providing a habitat for life. In this essay I will examine the reason for waters properties and how its properties allow for its vast involvement.

A water molecule is comprised of 2 hydrogen atoms and an oxygen atom. The oxygen forms 4 sp3 hybrid orbital's resulting in a tetrahedral shape. The sp3 hybrid orbital's come about from the overlap of the 2s orbital and the 2px, 2py and 2pz orbital's of the oxygen. Two of these hybrids then overlap with the 1s orbital of the hydrogen's resulting in two covalent bonds. The other orbitals are occupied by the 2 lone pairs on the oxygen.

The VSEPR (valence shell electron pair repulsion) theory states that electrons repel each other and as a result of this the electrons that surround an atom spatially arrange themselves maximising the distance between one another in the effort to reduce this repulsive effect1. However, lone pairs have a greater repulsive effect than valence electrons which results in the distortion of the angle by effecting the positions of the other electrons; this property accounts for water's shape being bent rather than tetrahedral and having a bond angle of 104. 5° rather than a tetrahedral angle of 109. 5°1.

Waters polar nature is contingent upon the difference in the electronegativities of its atoms. Oxygen has a greater electronegativity than hydrogen resulting in oxygen having a bigger pull on the electrons than the hydrogen. The result of this is an inductive effect where the electrons in the covalent bond being drawn closer to the oxygen. As a result of the inductive effect, the oxygen has a partial negative charge (δ-) while the hydrogen's possess a partial positive charge (δ+) producing a polar substance. Waters polar nature allows for the formation of hydrogen bonds between one another. The partially positive hydrogen of one atom forms a hydrogen bond with partially negative oxygen of another water molecule.

The partial charges on the atoms that make up water allow it to act as a solvent for ionic or polar substances. In the case of ions, the water can break bonds between one another to form ion-dipole bonds as well as dipole-dipole bonds5. The charge of the ion attracts the opposite charge on the water and is surrounded by the solvent molecules forming either one or more hydration shells.

Certain biological molecules possess both polar and non polar regions. The polar regions are said to be hydrophilic and will interact with the solvent through hydrogen bonding. The non polar regions are unable to form hydrogen bonds with the water and therefore are unable to interact with it. The water is said to have a hydrophobic effect2 upon these non polar molecules as they interfere with the hydrogen bonding between water molecules. These biological molecules position themselves so that the orientation of the ' hydrophilic head' faces outwards into the solvent while the ' hydrophobic' tail points inwards away from the solvent. Examples of this process would be the micelles, which position themselves so that they form globules and bilayers where they position themselves so that there are two layers of hydrophilic heads pointing outwards into the solvent on either side with the tails conjugating in between.

The bond strength of hydrogen is weak comparatively, it is approximately 20 kJ mol-1 compared to 460 kJ mol-1 for the covalent bond between the oxygen and the hydrogen3. Although hydrogen bonds are weak individually they have a cumulative effect. Due to the vast number of intermolecular hydrogen bonds in water, water has a high specific heat capacity for its molecular weight (4. 18 J K-1 g-1)5 meaning waters able to absorb a substantially high value for heat and as a result the temperature increase is minimal4. This is what makes water an effective temperature buffer. Water spreads the energy from the thermal increase across the entirety of its system; this is the reasoning behind why water is used by organisms to regulate their temperature. Sweat is comprised of water and salt, due to waters high specific heat capacity it requires a lot of energy to evaporate the sweet off the body6. The thermal energy generated by the body is used to evaporate the sweat which in turn cools the body down. This principle also explains why water can exist in liquid forms and allows for the existence of oceans, lakes, etc. Waters existence as a liquid is vital to existence of life.

Osmosis is the movement of water from a region of high concentration to an area of low concentration through a semi permeable membrane. If animal cells were surrounded by an aqueous environment which differs in water potential from their own it could result in cell shrinkage or bursting. In an effort to prevent this, the cells are immersed in an aqueous solution with a similar osmotic potential to that in the cell (isotonic). An example of where osmosis plays a large part in biology is in homeostasis. Water regulation in the body is controlled by the osmoreceptors in the hypothalamus of the brain. The low levels of water in the blood cause these cells to shrink due to osmosis; this causes neurosecretory cells to release the hormone ADH (anti-diuretic hormone)7. Controlling the levels of ADH controls the permeability of the collecting duct, in the liver, to water and thereby controlling the levels of water in the blood and subsequently the body.

Each water molecule forms four hydrogen bonds with 4 other water molecules. Although these water molecules don't stay constantly bonded to each other, reorienting every 10-12 s 3, the extensive network of these bonds results in a large cohesive force holding water together. This is vital for the role water plays for transpiration in plants. When water evaporates and leaves through the stomata a water gradient causes the water to be pulled up the xylem. The water molecules above drag the ones below it due the bonds between them. Waters adhesive properties also play a role in this as it gives water the ability to overcome the gravitational force acting upon it through the adhesion between the water and the cell walls in the xylem.

Water is used inside complex organisms to break down macromolecules into their sub units. One of the hydrogen's of the water is added to one substituent while the hydroxyl group in water is added to the other sub unit. This process is therefore known as hydrolysis. This is important in terms of converting long term storage of carbohydrates, such as glycogen in the body and starch in plants, into short term carbohydrates used in metabolism.

The reverse of this process is known as dehydration. When monomers come together to form polymers, the hydroxyl of one and the hydrogen of the other leave giving rise to a polymer. An example of this would be the reaction between amino acids to form proteins, the hydrogen on the amine group and the hydroxyl group of the carboxyl group on the other.

Water plays a role in respiration; it cleaves a phosphate off ATP, energy currency of cells, to give ADP and energy for respiration.

Waters is produced from the combining of hydrogen ions, electrons and oxygen in oxidative phosphorylation. The significance of this is, the formation of water allows the process to continue7; if water didn't form then cell death would follow. For instance, cyanide inhibits the formation of water from oxidative phosphorylation7.

In photosynthesis, water replenishes the electrons lost by the reaction centre. The hydrogen ions of water pass through the channel in the stalk particle providing the energy for phosphorylation of ADP to ATP. The oxygen that is left combines with another to form O2 and is used in cellular respiration.

Water contributes to buffering changes in pH in organisms. It combines with carbon dioxide to form carbonic acid. The carbonic acid dissociates into hydrogen ions and bicarbonate. All these processes are reversible in both directions. This allows it to act as a buffer. If the pH increases the carbon dioxide and water react to form carbonic acid which, in turn, dissociates to release hydrogen ions, which decrease the pH, and bicarbonate6. The reverse occurs for a decrease in pH.

In conclusion, the significant processes that water is involved in are due to its polarity and its ability to form hydrogen bonds.