13.5: The Structure and Properties of Water

With 70% of our earth being ocean water and 65% of our bodies being water, it is hard to not be aware of how important it is in our lives. There are 3 different forms of water, or H_2O: **solid** (ice), **liquid** (water), and **gas** (steam). Because water seems so ubiquitous, many people are unaware of the unusual and unique properties of water, including:

- Boiling Point and Freezing Point
- Surface Tension, Heat of Vaporization, and Vapor Pressure
- Viscosity and Cohesion
- Solid State
- Liquid State
- Gas State

Boiling Point and Freezing Point

If you look at the periodic table and locate tellurium (atomic number: 52), you find that the boiling points of hydrides decrease as molecule size decreases. So the hydride for tellurium: **H_2Te (hydrogen telluride)** has a boiling point of **-4°C**. Moving up, the next hydride would be **H_2Se (hydrogen selenide)** with a boiling point of **-42°C**. One more up and you find that **H_2S (hydrogen sulfide)** has a boiling point at **-62°C**. The next hydride would be **H_2O (WATER!)**. And we all know that the boiling point of water is **100°C**. So despite its *small* molecular weight, water has an incredibly *big* boiling point. This is because water requires more energy to break its hydrogen bonds before it can then begin to boil. The same concept is applied to freezing point as well, as seen in the table below. The boiling and freezing points of water enable the molecules to be very slow to boil or freeze, this is important to the ecosystems living in water. If water was very easy to freeze or boil, drastic changes in the environment and so in oceans or lakes would cause all the organisms living in water to die. This is also why sweat is able to cool our bodies.

COMPOUND	BOILING POINT	FREEZING POINT
Hydrogen Telluride	-4°C	-49°C
Hydrogen Selenide	-42°C	-64°C
Hydrogen Sulfide	-62°C	-84°C
Water	100°C	0 °C

Surface Tension, Heat of Vaporization, and Vapor Pressure

Besides mercury, water has the highest **surface tension** for all liquids. Water's high surface tension is due to the hydrogen bonding in water molecules. Water also has an exceptionally high **heat of vaporization**. Vaporization occurs when a liquid changes to a gas, which makes it an endothermic reaction. Water's heat of vaporization is 41 kJ/mol. **Vapor pressure** is inversely related to intermolecular forces, so those with stronger intermolecular forces have a lower vapor pressure. Water has very strong intermolecular forces, hence the low vapor pressure, but it's even lower compared to larger molecules with low vapor pressures.

- Viscosity is the property of fluid having high resistance to flow. We normally think of liquids like honey or motor oil being viscous, but when compared to other substances with like structures, water is viscous. Liquids with stronger intermolecular interactions are usually more viscous than liquids with weak intermolecular interactions.
- Cohesion is intermolecular forces between like molecules; this is why water molecules are able to hold themselves together in a drop. Water molecules are very cohesive because of the molecule's polarity. This is why you can fill a glass of water just barely above the rim without it spilling.

Solid State (Ice)

All substances, including water, become less dense when they are heated and more dense when they are cooled. So if water is cooled, it becomes more dense and forms ice. Water is one of the few substances whose solid state can float on its liquid state! Why? Water continues to become more dense until it reaches 4°C. After it reaches 4°C, it becomes *LESS* dense. When freezing, molecules within water begin to move around more slowly, making it easier for them to form hydrogen bonds and eventually arrange themselves into an open crystalline, hexagonal structure. Because of this open structure as the water molecules are being held further apart, the volume of water *increases* about 9%. So molecules are more tightly packed in water's liquid state than its solid state. This is why a can of soda can explode in the freezer.

Liquid State (Liquid Water)

It is very rare to find a compound that lacks carbon to be a liquid at standard temperatures and pressures. So it is unusual for water to be a liquid at room temperature! Water is liquid at room temperature so it's able to move around quicker than it is as solid, enabling the molecules to form fewer hydrogen bonds resulting in the molecules being packed more closely together. Each water molecule links to four others creating a tetrahedral arrangement, however they are able to move freely and slide past each other, while ice forms a solid, larger hexagonal structure.

Gas State (Steam)

As water boils, its hydrogen bonds are broken. Steam particles move very far apart and fast, so barely any hydrogen bonds have the time to form. So, less and less hydrogen bonds are present as the particles reach the critical point above steam. The lack of hydrogen bonds explains why steam causes much worse burns that water. Steam contains all the energy used to break the hydrogen bonds in water, so when steam hits your face you first absorb the energy the steam has taken up from breaking the hydrogen bonds it its liquid state. Then, in an exothermic reaction, steam is converted into liquid water and heat is released. This heat adds to the heat of boiling water as the steam condenses on your skin.

Water as the "Universal Solvent"

Because of water's polarity, it is able to dissolve or dissociate many particles. Oxygen has a slightly negative charge, while the two hydrogens have a slightly positive charge. The slightly negative particles of a compound will be attracted to water's hydrogen atoms, while the slightly positive particles will be attracted to water's oxygen molecule; this causes the compound to dissociate. Besides the explanations above, we can look to some attributes of a water molecule to provide some more reasons of water's uniqueness:

- Forgetting fluorine, oxygen is the most electronegative non-noble gas element, so while forming a bond, the electrons are pulled towards the oxygen atom rather than the hydrogen. This creates 2 polar bonds, which make the water molecule more polar than the bonds in the other hydrides in the group.
- A 104.5° bond angle creates a very strong dipole.
- Water has hydrogen bonding which probably is a vital aspect in waters strong intermolecular interaction

Why is this important for the real world?

The properties of water make it suitable for organisms to survive in during differing weather conditions. Ice freezes as it expands, which explains why ice is able to float on liquid water. During the winter when lakes begin to freeze, the surface of the water freezes and then moves down toward deeper water; this explains why people can ice skate on or fall through a frozen lake. If ice was not able to float, the lake would freeze from the bottom up killing all ecosystems living in the lake. However ice floats, so the fish are able to survive under the surface of the ice during the winter. The surface of ice above a lake also shields lakes from the cold temperature outside and insulates the water beneath it, allowing the lake under the frozen ice to stay liquid and maintain a temperature adequate for the ecosystems living in the lake to survive.

Resources

1. Cracolice, Mark S. and Edward Peters I. *Basics of Introductory Chemistry*. Thompson, Brooks/Cole Publishing Company. 2006
2. Petrucci, et al. General Chemistry: Principles & Modern Applications: AIE (Hardcover). Upper Saddle River: Pearson/Prentice Hall, 2007.

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