Lecture 2—Properties of Water

Water is the third most common molecule in the universe (after H_2 and CO), but it turns out that water is some funny stuff. In fact, there are at least 37 documented “anomalies” in water’s physical properties when compared with similar molecules. For example:

- Water has an unusually high melting point. (0°C, compared to -63°C for $CHCl_3$).

  This is important because it allows for a phase change within temperatures normally found on Earth.

- Water has an unusually high boiling point. (100°C, compared to 61°C for $CHCl_3$).

  This is also important because it allows for liquid water over most temperatures found on Earth.

- Water has unusually high viscosity. (0.89 cP, compared to 0.22 cP for pentane, at 25°C).

  This will become important to us when we deal with solids moving in water.

- Water has an unusually high heat of vaporization. (40.7 kJ/mol, compared to 18.7 kJ/mol for H_2S)

  This is really important for thermoregulation of living organisms, but it says a lot about cloud formation, too.

- Water shrinks on melting, and solid has lower density than liquid.

  This is vital in explaining why freeze-thaw is such a good erosional agent. It also explains why pipes burst in winter.

- Water is unusually dense, and reaches a maximum density at 4°C.

  This explains why streams freeze from the top down, thus insulating against further freezing. It also explains why lakes can have seasonal overturning.

- Pressure reduces its melting point.

  This is why there's liquid water under glaciers.

- Water shows an unusually large viscosity increase as the temperature is lowered.

  This will explain why we need to worry so much about the temperature of water when dealing with sediment transport.

- Water has unusually low compressibility.

  Not only does this provide for hydraulics, but the *slight* compressibility depresses sea level by 40 m.

- The specific heat capacity (C_P and C_V) is unusually high. (4.18 J/gK, compared to 1.66 J/gK for pentane at 25°C)

  This allows oceans to act as large heat reservoirs (land temperatures vary three times as much as sea temperatures), moderating global temperature.

- Liquid water has over twice the specific heat capacity of ice or steam.

  This explains why the oceans are so much better at moderating temperature than are, say, glaciers.

Suffice it to say that the world as we know it (and life as we know it) exists because of the unusual properties of water. SO, why *is* water so unusual? Turns out it all hinges on the molecular structure of water.

A molecule of water consists of an atom of oxygen with two hydrogens bound to it. The hydrogens are effectively protons, and thus they are, at the same time, trying to get at the electrons now circling the molecule, and trying to stay away from each other (and the oxygen nucleus). As a result, they reach a rather malleable equilibrium at an angle of 104.45° (this angle will change, obviously, if there are other water molecules in the area). The net result is a molecule looking sort of like Mickey Mouse—two positively charged "ears" on one end, and a negatively charged "chin" on the other. This makes water a *polar* molecule, and makes it especially good at dissolving solids.

This *also* allows for an unusual form of bonding, where two oxygens can share a proton (this is *sort* of like the bonding in SiO_2). In fact, water molecules share hydrogens in a very fluid process that amounts to forming a weird metastructure in liquid water. This is the water icosahedron.

The bonding, called *hydrogen bonding*, accounts for many of the odd properties of water. First, it increases the boiling and melting points because you have to break all those hydrogen bonds to get the stuff to vaporize. Next, it increases the viscosity because of the 3D "structure" of liquid water. This oddness accounts for the heat of vaporization and heat capacities, too. The icosahedral structure explains the change in density and the lack of compressibility.