Heavy Water

Module 13 • i2P • H2O Tour

> "The weight of this sad time we must obey;
> Speak what we feel, not what we ought to say."
>
> - William Shakespeare

CARRY THAT WEIGHT

Have you ever had to carry a bucket of water for any significant distance? Soon your arm becomes tired, and the water starts to slosh over the rim as you struggle down the road. Water is heavy, particularly for the one in six human beings the United Nations estimate have no access to clean water within a kilometer of their home.

The United Nations has set the minimum required domestic water needs of an individual at between 20 and 50 liters a day (see: UN water report 2009). 50 liters of water weighs 50 kilograms (110 lbs). Consider that a family of 6 requires 300 liters of water to survive on a daily basis. This amounts to 300 kilograms of water (660 lbs.), which must be carried home 7 days a week, 365 days a year. On an annual basis this adds up to 109,500 kilograms (240,900 lbs) of water to sustain the family. A quarter of a million lbs. of water is a great deal to carry home each year.

Figure 1: Wikimedia Commons

When Ray and Kevin traveled across Lake Baikal they had all the water they required right at their feet, and with the assistance of their stove were able to melt enough snow and ice for their daily needs. In Tunisia however, where water is scarce, it will need to be carried as the i2P team crosses the desert. Let us assume that the entire water supply for the 10 day expedition must be carried. Given that there will be 12 i2P team members crossing Tunisia, and each will require about 20 liters of water a day, this brings the sum total of water required to 2,400 liters, which weighs 2400 kilograms (5,280 lbs).

Student Exercise

Imagine if you had no running water in your home, and your family had to walk at least a kilometer to find clean water, and carry it home by hand. How would this affect your day to day life? With the other students in your class estimate the following:

1. How much water you use at home each day?
2. How long it would take to carry that water 1 kilometer to your house?
3. Who would carry the water?
4. How this would impact the current activities of your family members (consider work, school and leisure activities)?

The great weight of water impedes its trade from places of plenty like Lake Baikal, to water impoverished locations like Tunisia. If water were light and easy to move, imagine the remarkably profitable trade that would occur with the sale of water from Lake Baikal to water poor nations. Such trade is limited by the great cost associated with transporting such a heavy commodity as water.

All water is not of equal weight. A volume of water can be heavier and lighter depending upon a variety of factors. One factor is the quantity and weight of other substances dissolved in the water. Salt is heavier than water. Consequently water with salt in it will be heavier than water free of salt (see: weight of salt water). Conversely, gases like oxygen can dissolve in water (if oxygen did not dissolve in water, fish and other marine animals could not survive). As gases are lighter than water, the more gas dissolved the lighter the water.

Figure 2: Clouds over Radolne Lake in Poland (Wikimedia)

Student Exercise.

How much does a cloud weigh?

see: cloud weight

Compare the weight of a cloud to the weight of an elephant.

see: elephant clouds

Compare the weight of a cloud to the weight of an airplane.

see: airplane clouds

Pure water which contains nothing but H2O molecules. Such water does not occur naturally in the world, because as we learned in module 2, water is a ‘universal solvent’. This capacity to dissolve just about anything means that water rapidly absorbs materials from its immediate environment, such as minerals and gases. The only way to remove all the ‘impurities’ from water and leave behind only H2O molecules is to distill it. Distilled water is created by boiling regular water and then capturing and condensing the water vapor.

The weight of water also changes with its temperature. Liquid water weighs less as it gets warmer, because as it is heated it expands slightly and is therefore lighter per unit of volume (see: weight of water). Curiously (as explained in module 8) water is one of the few known substances that weigh less in solid form (ice) than is liquid form. This is because in its solid state water molecules form unique bonds that cause liquid water to expand by 9 % when it freezes to ice. Thus ice weighs 9% less than liquid water.

Atoms

Another reason the weight of water may differ is if the molecular composition of the water is changed. There are 94 different elements that occur naturally in the world (see: elements). There are further elements that can be created (95 - 118), but they are unstable in a natural environment, and degenerate quickly. All the elements are represented in the periodic table (see figure 3). The most common element in the universe is hydrogen (oxygen is the third most common).

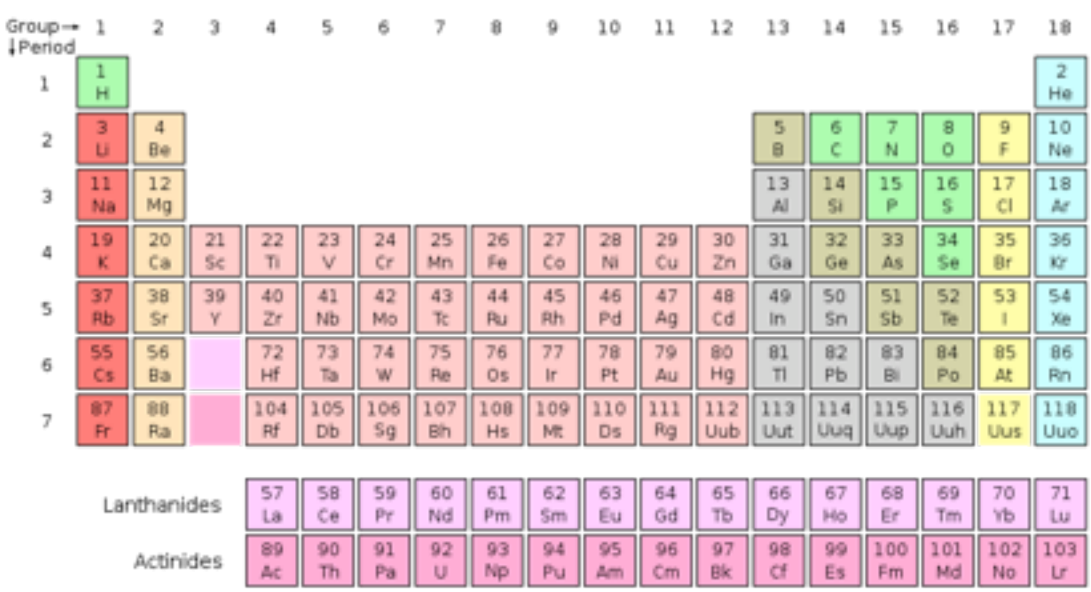

Figure 3: The Periodic Table (Wikimedia Commons)

The atom is the basic building block of all matter in the universe. An atom is the smallest possible unit of a particular element (see: difference between element and atom). All atoms have three constituent parts, electrons, neutrons and protons, with one notable exception: hydrogen, which is made of one proton and one electron, and has no neutron. However sometimes a hydrogen atom can pick up a neutron. When this occurs an isotope (a variation) of the standard hydrogen atom is created. This hydrogen isotope is called deuterium. Deuterium is heavier than a standard hydrogen atom, because neutrons have a defined weight. Hence a hydrogen atom with a neutron added (deuterium) weighs more than a standard hydrogen atom, by the weight of one neutron.

> Definition: Isotope
>
> an atom that has more neutrons in the nucleus than its stable counterpart. For example: Hydrogen has one electron and a nucleus containing one proton, Deuterium (an isotope of hydrogen) has one electron plus a nucleus containing one proton and one neutron (see: isotope)

As we know a water molecule is created by the union of two hydrogen atoms with one oxygen atom: H2O. Just as standard hydrogen atoms combine with oxygen to form water, so can deuterium atoms creating a molecule called D2O. D2O weighs more than standard H2O by the equivalent weight of two neutrons. D2O occurs naturally in nature; for every 6,700 standard hydrogen water molecules (H2O) in a glass of tap water there is on average one deuterium water molecule (D2O) (see: deuterium). Water that contains a higher proportion of D2O molecules than occurs in nature is called *Heavy Water*.

Heavy Water

On a superficial level heavy water (D2O) behaves similarly to normal water. It is a stable molecule that is safe for human's to consume in the quantities that occur in nature. However it differs in significant ways, and these differences influence how it behaves in nature and how in higher concentrations it affects living organisms.

Heavy water lives up to its name in that it is 11% heavier than regular water. This added weight is quite easy to illustrate. Simply freeze some heavy water into a cube of ice and voila, it sinks to the bottom of a glass of

> Student Exercise
>
> Make Ice Cubes that Sink in Water!
>
> 1. Obtain some heavy water - talk to the chemistry teacher - see if it is available in your community.
> 2. Freeze the heavy water in an ice cube tray. Note that heavy water freezes at a higher temperature than regular water.
> 3. Place the heavy water ice cubes in a glass of water and see what happens! (see: heavy ice)
>
> Take a photo of your sinking ice cubes and send it in to us at i2P and we will post it on the website.

Did You Know?

Making Nuclear Bombs

Heavy water is the key to one type of nuclear reactor that can make weapons-grade plutonium from uranium. The first atomic bomb test, detonated on July 16, 1945, near Alamogordo New Mexico used plutonium as its fissile material. An identical design was used in the atomic bomb dropped on Nagasaki, Japan on August 9, 1945, killing 70,000 people and wounding another 100,000.

Figure 4: Atomic bombing of Nagasaki on August 9, 1945 (Wikimedia).

regular water. Recall from module 8 we learned that regular frozen water floats on its liquid counterpart because it expands by roughly 9%, thereby becoming less dense, and lighter in the solid form. Heavy water also expands when it freezes, but the greater weight of the heavy water molecule D2O more than offsets the decreased density of the solid phase, causing an ice cube of heavy water to sink in a glass of regular water.

Heavy Water Production

Heavy water is produced by a number of countries in the world for use in nuclear power plants. Heavy water is used as a moderator to slow down the splitting of atoms (nuclear fission) that releases the energy that nuclear plants are designed to capture. Only certain kinds of nuclear plants rely upon moderators such as heavy water (see: gone fission). The largest heavy water plant in the world is the Bruce Plant in Ontario, Canada.

Did You Know?

Harold Urey, an American chemist, was awarded the Nobel Prize for Chemistry in 1934 for the work that led to his discovery of Heavy Water in 1931 (see: Urey). Urey was born in Walkerton, Indiana, and started his career as a school teacher. Perhaps your school teacher is a future Nobel Laureate.

Heavy Water Toxicity

Although heavy water is completely safe to life forms in the concentrations found in nature, if consumed in higher concentrations, or over prolonged periods of time, it can be very harmful.

In addition to weight, other important properties of heavy water differ from those of regular water, principle among them pH, freezing point, boiling point, surface tension and viscosity. These properties, among others, influence the manner and speed with which heavy water undergoes or supports chemical reactions. Given that water is the 'soup' in which life's chemical reactions occur, if the manner in which these chemical reactions occur is altered this has profound implications for life forms sustained by these chemical reactions.

Student Exercise.

If an ice cube of regular water floats in a glass of regular water, and an ice cube of heavy water sinks in a glass of regular water, what will happen to an ice cube of heavy water in a glass of heavy water?

Laboratory studies demonstrate that as the proportion of heavy water increases in living cells, failures in essential cellular functions like cell division (mitosis) begin to occur (see: heavy water toxicity). Without cell division, living tissue cannot repair itself. Tissue that cannot repair itself will soon die. This is borne out in animals exposed to high levels of heavy water who do not heal normally, thereby undergo a rapid aging process that leads to premature death .