

The Water Cycle, Oxygen-18, and Ice Cores

Adapted from Lesson 1.4: Global or Local of the the BSCS NASA-funded Carbon Connections online curriculum
<http://carbonconnections.bscs.org/>

The Water Cycle and Oxygen Isotopes

The water cycle is a key part of understanding Earth's climate. One process in the water cycle is evaporation.

Evaporation is where molecules of H_2O leave the liquid state becoming molecules of H_2O vapor or gas in the air above. In the gaseous state, H_2O can then move through the atmosphere.

Water, of course, contains both hydrogen and oxygen. *Oxygen is one of the most significant keys to deciphering past climates. Oxygen comes in heavy and light varieties, or isotopes, which are useful for paleoclimate research. Like all elements, oxygen is made up of a nucleus of protons and neutrons, surrounded by a cloud of electrons. All oxygen atoms have 8 protons, but the nucleus might contain 8, 9, or 10 neutrons. "Light" oxygen-16, with 8 protons and 8 neutrons, is the most common isotope found in nature, followed by much lesser amounts of "heavy" oxygen-18 with 8 protons and 10 neutrons.¹* Water, therefore, will contain hydrogen as well as either oxygen-16 or oxygen-18 (shown as H_2^{16}O and H_2^{18}O respectively).

So not all molecules of water are created equal – that's an important point. Some molecules have more mass than others. The following demonstration will illustrate this point. The demonstration simulates evaporation for H_2O molecules with different masses.

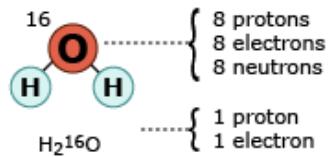
Demonstration

Your teacher has a box fan pointing upward with a clear plexiglass container sitting on top of the fan. Inside the plexiglass container are styrofoam balls which represent molecules of water that contain isotopes of oxygen. Refer to the accompanying worksheet and answer the questions regarding the demonstration.

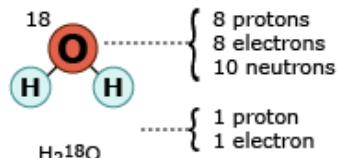
Heavy Water

The demonstration above illustrates the difference in the evaporation of the two types of water molecules (H_2^{16}O and H_2^{18}O) in the water cycle. Transport of these molecules out of the ocean (plexiglass) shows movement in the water cycle. But why were there two types of particles to represent H_2O molecules? You should have seen that they were raised above the fan at different heights (H_2^{16}O higher and H_2^{18}O lower). The diagram to the right shows H_2O molecules A and B. Look at how they differ. The difference isn't big, but it's important in the water cycle.

Water Molecule A



Water Molecule B



¹ http://earthobservatory.nasa.gov/Features/Paleoclimatology_OxygenBalance/

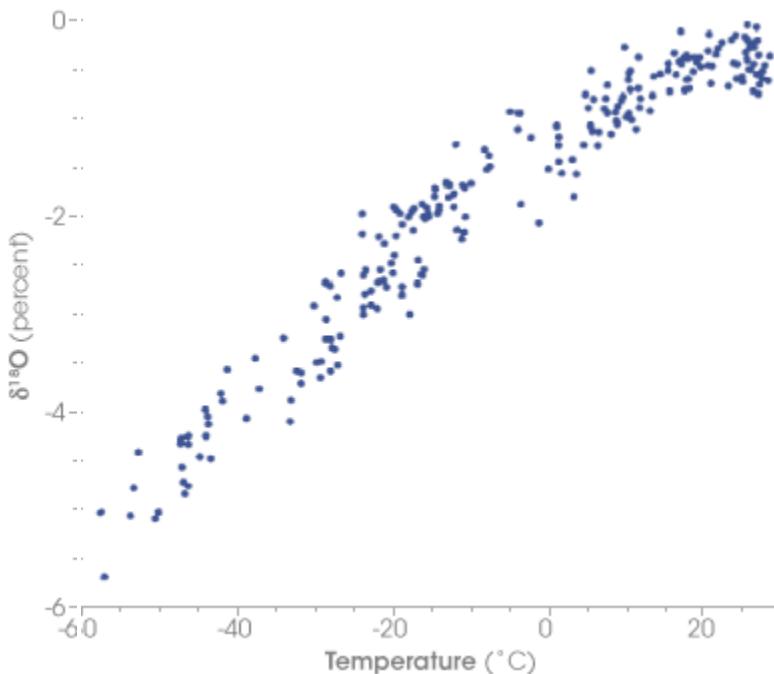
Molecule A has an oxygen with a mass = 16 coming from 8 protons and 8 neutrons. With two hydrogens, the total mass of H_2^{16}O is 18. Molecule B has an oxygen with a mass = 18 from 8 protons and 10 neutrons. Adding two hydrogens, the mass of H_2^{18}O is 20. These two molecules have different masses because ^{16}O and ^{18}O are two **isotopes** of oxygen. (Remember: an isotope is an element that has the same number of protons, but a different number of neutrons). Because of their different masses, H_2^{16}O and H_2^{18}O behave differently in the water cycle.

As water condenses and precipitates out of the atmosphere it can be incorporated into existing ice sheets. Currently, the major ice sheets exist in the polar regions. At times in the past, ice sheets have also existed across the northern hemisphere. They covered much of the United States, all of Canada, and most of northern Europe. Existing ice sheets provide a continuous record of atmospheric conditions dating back as far as 1.5 million years. The water that comprises the frozen ice sheets contains a mixture of light and heavy isotopes. As water evaporates from the oceans, more of this water tends to be the low mass molecule of water (H_2^{16}O). Over time, the precipitation that falls over the poles becomes part of the ice sheets. Thus, the ice sheets will have relatively more H_2^{16}O than H_2^{18}O .

Condensation and Precipitation

As air rises in the atmosphere and cools, the water vapor condenses and falls as precipitation. On a global scale, warm air rises at the equator and circulates towards the poles. Because it is heavier, H_2^{18}O will tend to condense first and the ratio of H_2^{18}O to H_2^{16}O will be greater in rain that falls at lower latitudes. As the moist air mass continues to circulate towards the poles, the precipitation that falls will become increasingly depleted of H_2^{18}O molecules. However, changes in global temperatures impact how far H_2^{18}O can travel from the equator before precipitating out as moisture.

Let's focus for a moment on the precipitation of the different isotopes of water in the atmosphere. During periods of warmer global temperatures there is more heat energy in the atmosphere. This allows heavy water (H_2^{18}O) to stay in the gaseous phase longer and travel farther from the equator before precipitating out. Thus, during times of higher global temperatures, the ratio of heavy water to light water (H_2^{16}O) found in precipitation that falls at the poles changes with a higher percentage of heavy water being present. Scientists have an indicator for the relative amount of H_2^{18}O in water. It is $\delta^{18}\text{O}$, and is pronounced "delta-18-O". The delta, δ , stands for "change," and the ^{18}O represents the oxygen-18 in H_2^{18}O . So, in ice core samples taken at the poles, a higher ratio of heavy water to light water indicates higher average global temperatures. The following figure illustrates this concept:



The concentration of ^{18}O in precipitation decreases with temperature. This graph shows the difference in ^{18}O concentration in annual precipitation compared to the average annual temperature at each site. The coldest sites, in locations such as Antarctica and Greenland, have about 5 percent less ^{18}O than ocean water. (Graph adapted from Jouzel et. al., 1994)

Scientists have performed global atmospheric measurement that allow them to correlate temperature to the ratio of heavy water compared to light water. This laboratory data is then used as a standard to infer past temperatures based on the ratio of isotopes found in ice cores.