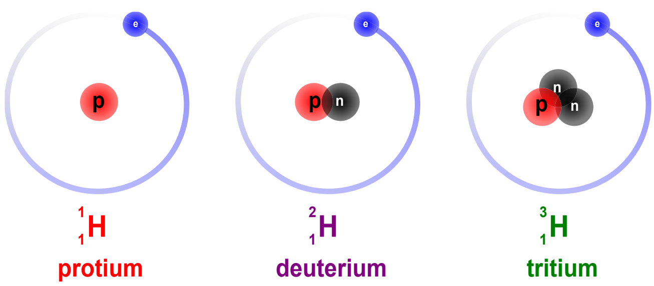
Isotope Geochemistry

By Roger Diamond

■ Isotopes are atoms that belong to the same element, but have different numbers of neutrons. For example, hydrogen can have 0 neutrons (protium) or 1 neutron (deuterium) or 2 neutrons (tritium). The mass changes because of the extra neutrons, so protium hydrogen, with only a proton, has an atomic mass of about 1 amu (atomic mass unit), deuterium hydrogen, with one proton and one neutron, has a mass of about 2 amu and tritium, with one proton and two neutrons, is about 3 amu. Remember – if you change the number of protons, you change the element.

All three isotopes of hydrogen behave in an identical manner chemically. In other words, they are a clear, odourless, flammable gas and will react in the same way to form water, organic molecules and everything else that is familiar about hydrogen. Where the difference lies is that the mass of the isotope will change bond energies and cause small variations in reaction rates. For example, protium evaporates faster than deuterium. A sugar molecule with deuterium and protium in its structure will react in a cell at a different rate to a sugar molecule with only protium hydrogen isotopes. And a water molecule made of $^{1}H^{1}H^{16}O$ will also evaporate faster than a water molecule with $^{1}H^{2}H^{16}O$ or $^{1}H^{1}H^{18}O$.

Some isotopes are stable, meaning they do not change over time, and some are radioactive, decaying into other elements and emitting radiation as they do so. Each radioactive isotope decays at a rate known as its half-life, which is the time taken for half of the original lump of matter to decay into other elements. Of all the isotopes mentioned so far, tritium is radioactive, with a half-life of 12.3 years. There is still tritium around naturally because it keeps being created by solar radiation hitting the upper atmosphere. Other radioactive isotopes are not being made on Earth, such as ^{234}U and ^{238}U, but they are still found here because their half-lives are very long (245 thousand years and 4.5 billion years). They were created in a supernova – or stellar explosion – just before our solar system was formed.



The three isotopes of hydrogen.
Dirk Hünniger, Wikimedia Commons

The isotopes of carbon are ^{12}C, ^{13}C (both stable) and ^{14}C (radioactive), and their variations in reaction rates mean that grasses (including rice, corn and wheat) and marine organisms (fish, shellfish and seaweed) and other plants (nuts, beans, vegetables and fruit) all have different abundances of ^{12}C and ^{13}C. So if we dig up an ancient skeleton, we can tell something about the diet of that person by analysing the carbon isotopes in the bone collagen. The radioactive ^{14}C, with a half-life of 5 730 years, can be used to date organic materials up until about 50 000 years old. In even older materials, there is too little of the ^{14}C left, but other isotopes – such as ^{10}Be, with a half-life of 1.6 million years – can be used instead.

Apart from being essential in archaeology, isotopes provide important information in other fields. The stable isotopes of hydrogen and oxygen can be used to trace the water cycle and understand anything from groundwater recharge and flow to river pollution and evaporation from large dams, helping us to use water more sustainably. Likewise, the isotopes of uranium are essential in dating old rocks, but are also useful for more recent samples such as corals, and for monitoring pollution from mining and ammunitions sites. Isotopes can be used to tell if your fruit juice has had cane sugar added, or if rhino horn comes from the Kruger National Park, where the strontium isotopes have different signatures to areas such as Botswana.

Isotopes are measured in a machine called a mass spectrometer. As the name suggests, the mass of the matter is what is being measured. The sample is turned into an ionised gas and accelerated by electric fields down a flight tube. The flight tube passes through a huge magnet that makes the charged particles curve, but the heavier isotopes will curve less (because they have more momentum) and land in a different spot to the lighter ones. By measuring all of this very accurately, we can determine the isotope composition of substances. Sometimes considerable sample preparation is necessary, such as for organic materials, but with water or gases the sample is quite easily analysed.

Isotope geochemistry is an interesting field of study that can answer all sorts of questions, particularly those related to environmental and water-related issues, which are becoming ever more important.

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