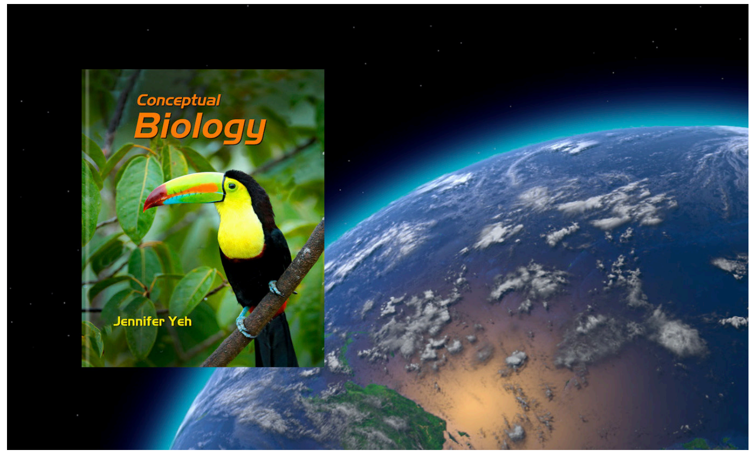
Chapter 2

The Chemistry of Life

Living Earth



An element is defined by the number of protons within the nucleus of each atom. All carbon atoms, by definition, have 6 protons. The number of neutrons within the nucleus, however, can vary. Most carbon atoms have 6 neutrons, but some have 7 neutrons and other have 8 neutrons. Atoms of the same element having a different number of neutrons are called isotopes.

We can identify an isotope by the total number of protons and neutrons, which is the atomic mass number. For example, a carbon atom with 6 neutrons has an atomic mass number of 12, which is the 6 protons plus 6 neutrons, and represented as carbon-12. Similarly, a carbon atom with 7 neutrons is carbon-13. Carbon-12 and carbon-13 are said to be isotopes of each other, as shown in Figure 2.36.

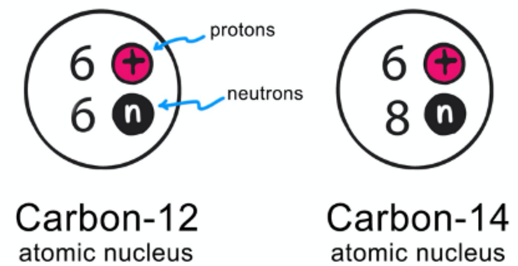


Figure 2.36.
Carbon-12 and carbon-14 are two isotopes of carbon. The carbon-12 atomic nucleus has 6 protons and 6 neutrons while the carbon-14 nucleus has 6 protons and 8 neutrons.

For lighter elements, such as carbon, the nuclei of atoms are most stable when the number of protons and neutrons are equal. While the nucleus of carbon-12 (6 protons and 6 neutrons) is stable, the nucleus of carbon-14 (6 protons and 8 neutrons) is unstable. The instability of carbon-14 results in one of the neutrons transforming into a proton, as shown in Figure 2.37. This produces the stable nitrogen-14 isotope as well as an electron that shoots away from the nucleus at high velocities. That fast-flying electron can be dangerous and is a form of radioactivity called beta radiation. For this reason, we say that carbon-14 is a radioactive isotope.

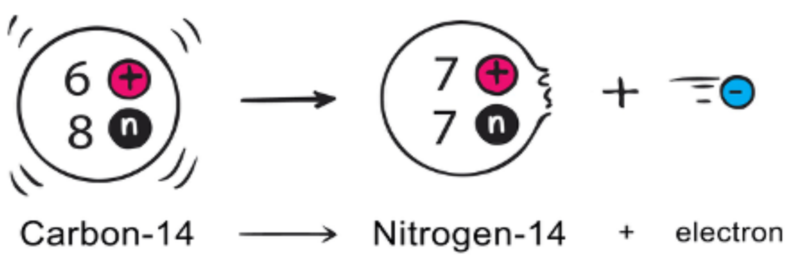


Figure 2.37
The carbon-14 nucleus is unstable and eventually transforms into the nitrogen-14 nucleus while also emitting a fast-flying electron.

There are many other types of isotopes that are radioactive. Examples include hydrogen-3, technicium-99, and uranium-235. An amazing fact about radioactive isotopes is that, when in bulk, the rate at which they release radioactivity is extremely consistent over long time periods. Consider carbon-14. If you had 1 kilogram of carbon-14, given its rate of radioactivity, then after 5730 years you would then have only 0.5 kilograms of carbon-14 remaining. Why? Because half of that carbon-14 has been transformed into nitrogen-14.

The time it takes for half of a radioactive isotope to transform is called the radioactive half-life. Table 2.2 shows some examples.

Table 2.2

Isotope	**Half-Life**
Francium-209	0.05 seconds
Technetium-99m	6 hours
Polonium-210	138 days
Radium-226	1600 years
Carbon-14	5730 years
Uranium-238	4.5 billion years

If an isotope is super radioactive this means that it will quickly disappear. And this means its half-life will be quite short. Thus, the shorter the half-life, the greater the radioactivity. In other words, it would be far safer to be exposed to a kilogram of uranium-235 than a kilogram of francium-209.

Radioactive isotopes have found many uses. Technicium-99m, for example, is used for medical imaging. Within science, isotopes, both radioactive and non-radioactive, are remarkable in helping us to understand the past. Let's look at two examples.

Radiometric Dating

Any living organism is constantly taking in carbon isotopes within its diet. After dying, however, this stops. Over time, the percentage of carbon-14 within the tissues decreases and it does so at a predictable rate based upon carbon-14's half-life. After 5730 years, the radioactivity from carbon-14 will be one half of what it was. Accordingly, any once living material that has half the carbon-14 radiation will have died about 5730 years ago. This relationship between the amount of carbon-14 and age can be used to date once living things back to about 100,000 years ago, as shown in Figure 2.38.

Figure 2.38
The amount of radioactive carbon-14 in the skeleton is reduced by one-half every 5730 years. The result is that the same skeleton today contains only a trace amount of the original carbon-14. The red arrows represent the relative amounts of carbon-14.

Other isotopes can be similarly used to date back to different ages and for different materials. Rocks, for example, can be dated based upon the amount of lead-206, which is a product of the radioactivity of uranium-238.

Isotopic Dating

Hydrogen atoms have 1 proton in the nucleus. Most isotopes of hydrogen, H-1, have zero neutrons. However, about 1 out of every 6400 hydrogen atoms is the deuterium isotope, H-2, which has 1 proton and 1 neutron.

Water molecules that contain H-2 rather than H-1 are a little bit heavier, which makes them a little bit more difficult to evaporate from a liquid to gas. This difference provides us a handle on past climates. When it's warmer, the fraction of "heavy water" that evaporates from the ocean is greater. The resulting precipitation, including snow, is thus also richer in heavy water. Ice caps, such as the one over Greenland, are the result of snow accumulations over millions of years. Studying the ratio of heavy water within ice cores thus provides a way to assess past global temperature changes and hence, past climates (Figure 2.39).

a.

b.

Figure 2.39
a) The subcontinent of Greenland as seen from space is covered with an extensive ice sheet up to three kilometers thick. b) An ice core sample obtained by drilling deep into the Greenland ice sheet contains isotopic evidence from past climates.