Radioactivity

In the environment in which we live, there are many chemical processes going on. Thousands of chemical processes occur inside our bodies to keep them functioning. Atoms change configurations forming different molecules. But the nuclei of all these atoms don’t change at all. They sit at the centers of the atoms, providing the atoms’ masses and the electrostatic attractive force that holds onto the electrons.

But in a nuclear process, a change occurs inside a nucleus. Protons can turn into neutrons, or neutrons into proton, or nucleons can enter or leave the nucleus.

Because atomic nuclei are about 100,000 times smaller in diameter than the whole atom, the nucleons are much closer to each other than they are to the electrons, and so the forces between them are much stronger than the forces between protons and electrons. For this reason, the amount of energy released in a nuclear process can be millions of times greater than those released in a chemical process.

Nuclear weapons are so much more powerful than conventional explosives because the reaction that releases energy is a nuclear process.

Radioisotopes

The most common type of nuclear process on Earth is the decay of the nucleus of a radioisotope. An example of a radioisotope is carbon 14 (symbol is $^{14}C$), a rare isotope of carbon. Carbon 14 is unstable, meaning it doesn’t last forever. At some point, one of the neutrons in the nucleus switches into a proton, and it becomes nitrogen 14 (symbol $^{14}N$). This conversion of neutron to proton (or proton to neutron) is caused by the Weak Nuclear Force, the last of the four known forces.

An isotope is one version of an element. Three isotopes of carbon exist on Earth: $^{12}C$, $^{13}C$, & $^{14}C$. The only difference between them is the number of neutrons in the nuclei: $^{12}C$ has 6, $^{13}C$ has 7, and $^{14}C$ has 8. The first two are stable: no one has ever seen one of them undergo a nuclear process by itself. But $^{14}C$ is unstable; it’s a radioisotope.

Most of the atoms that exist on Earth are of stable isotopes. There are known radioisotopes of all of the elements, but they’re rare on Earth because they’ve mostly decayed since the Earth formed (in this context the word decay means “change into another isotope,” not vanish)

Halflife of a Radioisotope

Some isotopes are more unstable than others. If you had an ounce of oxygen 19 and an ounce of carbon 14, the oxygen 19 would be gone in less than an hour, while the carbon 14 would take tens of thousands of years. We express the rate at which an isotope decays by its halflife, the amount of time it takes for half of a sample to decay. The halflife of $^{14}C$ is 5700 years. If a pound of $^{14}C$ was put in a safe place and it was recovered 5700 years later, one half pound would be left. If it was put back and someone else recovered it after an additional 5700 years, one quarter pound would be left. No matter how much there is, half of it will be gone after one halflife.

The figure below plots the percent of the pound of $^{14}C$ that’s left as a function of time. The amount drops off smoothly, and the red lines
mark each passing half-life, at multiples of 5700 years. Each red line is half the height of the previous one.

Below is the same curve plotted with two other curves with different half-lives. The lower curve represents a half-life of 1200 years and the upper curve 60000. The shapes are the same but their horizontal scales are different.

**Chart of the Nuclides**

The Periodic Table contains information about the elements. But since each element can have more than one isotope, it would be useful to have some kind of chart to depict them all. Nuclear physicists have one that they call the Chart of the Nuclides (nuclide is a synonym for isotope). In this chart each isotope is represented by one square. The horizontal position of the square reflects the number of neutrons in the isotope’s nucleus and the vertical position reflects the number of protons. A section of this chart is seen below. You can see that for example, the row with a vertical position of Z=6 contains the symbols for the carbon isotopes. $^{12}\text{C}$ is the square that is at vertical position 6 (6 protons) and horizontal position 6 (6 neutrons).

The black squares are the stable isotopes. Notice that carbon has two black squares, $^{12}\text{C}$ and $^{13}\text{C}$, and that the $^{14}\text{C}$ is not black because this is a radioisotope. Very few of the radioisotopes in this diagram actually exist on Earth, but physicists know that they can all exist, even if for a short time.

The figure above shows the whole nuclide chart, of which the first chart is the lower left hand corner. The black square, the stable isotopes, snake their way to the upper right,
and the last black square is Bismuth 209 (symbol $^{209}\text{Bi}$). There are no elements heavier than Bismuth that have any stable isotope.

The colors in this chart indicate how unstable the radioisotopes are. The pink ones are very unstable (they have extremely short halflives) and the dark blue ones have the longest halflives. Some of the dark blue squares are isotopes whose halflives are so long that they do exist on Earth even though Earth is very old.