11.5: Radioactive Half-Life

Elements such as $^{238}_{92}U$ that emit radioactive particles do so at rates that are *constant* and *unique* for each element. The rate at which an radioactive element decays is measured by its **half-life**; the time it takes for one half of the radioactive atoms to decay, emitting a particle and forming a new element. Half-lives for elements vary widely, from billions of years to a few microseconds. On a simple, intuitive level, if you begin with 1.00 gram of a radioactive element, after one half-life there will be 0.500 grams remaining; after two half-lives, half of this has decayed, leaving 0.250 grams of the original element; after three half-lives, 0.125 grams would remain, etc. For those that prefer equations, the amount remaining after *n* half-lives can be calculated as follows:

$$R = I\left(\frac{1}{2}\right)^n$$

where ***I*** represents the initial mass of the element and ***R*** represents the mass remaining.

Example 11.5.1:

The half-life of Actinium-225 is 10.0 days. If you have a 1.00 gram sample of Actinium-225, how much is remaining after 60.0 days?

Solution

The number of half-lives is 6.00 (that is *n*) and I = 1.00 gram. Substituting:

$$R = (1.00\ gram)\left(\frac{1}{2}\right)^{6.00} = (1.00\ gram)(0.0156) = 0.0156\ gram$$

Exercise 11.5.1

The half-life of Antimony-124 is 60.20 days. If you have a 5.00 gram sample of Actinium, how much is remaining after 5.0 half-lives?

One of the interesting uses for half-life calculations involves radiocarbon dating, where the content of carbon-14 in organic (formally living matter) is used to calculate the age of a sample. The process begins in the upper atmosphere, where nitrogen is bombarded constantly by high-energy neutrons from the sun. Occasionally, one of these neutrons collides with a nitrogen nucleus and the isotope that is formed undergoes the following nuclear equation:

$$^{1}_{0}n + ^{14}_{7}N \rightarrow ^{1}_{1}\rho + ^{14}_{6}C$$

Plants take up atmospheric carbon dioxide by photosynthesis, and are ingested by animals, so every living thing is constantly exchanging carbon-14 with its environment as long as it lives. Once it dies, however, this exchange stops, and the amount of carbon-14 gradually decreases through radioactive decay with a half-life of about 5,730 years, following the nuclear equation shown below:

$$^{14}_{6}C \rightarrow ^{0}_{-1}\beta + ^{14}_{7}N$$

Thus, by measuring the carbon-14/carbon-12 ratio in a sample and comparing it to the ratio observed in living things, the number of half-lives that have passed since new carbon-14 was absorbed by the object can be calculated.