Radioactive Decay

Radioactive materials are radioactive because they are unstable. Specifically, the nuclei of their atoms are unstable and would be more stable if they had some different number of neutrons and protons. The nuclei change to a more stable state by emitting (or possibly absorbing) a beta particle (an electron moving at high speed) or an alpha particle (essentially a helium nucleus: two protons and two neutrons). These types of particle radiation aren't horribly dangerous; a sheet of paper can stop alpha particles while beta particles will be stopped by thick aluminum foil. The rate of decay of atoms in a block of material can be determined very accurately and is quantified in units of the *half-life*—the amount of time required for half of the atoms in a sample to decay.

For biological samples, scientists generally use *radiocarbon dating* looking at the ratio between a radioactive isotope of carbon, ^{14}C, and the normal stable form, ^{12}C. The ^{14}C beta decays with a half-life of 5730 years. You're exposed to a significant amount of radiation in normal life—rocks around us are naturally radioactive and we're also bombarded by high-energy cosmic rays from space. Of this background radiation, the naturally occurring ^{14}C in your body is responsible for about a quarter of your annual radiation exposure.

1. If you're given an object to radiocarbon date and you find that it's 17190 years old, what fraction of its original ^{14}C does it still contain?

2. How much of its original ^{14}C would the sample have if it were 28528 years old?

3. There's a critical uncertainty with radiocarbon dating. Hint: look up information about the age of seals in the arctic. What information needs to be known to accurately date an object?

4. In astronomy, we need to determine the ages of things that may be billions of years old. Why can't we use ^{14}C to do this?

It’s much easier to use Potassium-40, ^{40}K, to date astronomical objects. ^{40}K radioactively decays to argon-40, ^{40}Ar, through beta decay. Your body naturally contains a significant amount of ^{40}K and it results in a radiation dose slightly larger than the one associated with ^{14}C. Since ^{40}K is a metal and ^{40}Ar is a gas, we typically assume that a given meteorite contained no ^{40}Ar at formation and that all of the ^{40}Ar trapped in the material came from radioactive decay.

Imagine that you have a small piece of meteorite, which you can heat to extract the ^{40}Ar and analyze chemically. You determine that the ratio of potassium-40 to argon-40 present in the sample is approximately 0.85 potassium-40 atoms for every 9.15 argon-40 atoms.

5. What does the “40” mean? How many protons and neutrons do the ^{40}K and ^{40}Ar atoms contain?

6. What is the half-life of potassium-40?

7. Given the half-life of ^{40}K, use Excel or its equivalent to plot the decrease in the numbers of ^{40}K atoms and the related increase in the numbers of ^{40}Ar atoms. On the vertical axis, put the fraction of the original isotope. ^{40}K will start at 1 and decrease; ^{40}Ar will start at 0 and increase. Put the time in billions of years or in half-lives on the horizontal axis.

8. Use your plot to figure out how long ago the meteorite must have solidified. Check your result using the following formula $(N_{current} / N_{original}) = (0.5)^{-t/half\text{-}life}$.