V. Radiometric age dating

5.1 Isotope explanation and example of Carbon isotopes

Radiometric age dating is based on the fact that certain elements spontaneously decay into others. Example: Consider three carbons:

1. $^{12}C_6$ is the common one,
2. $^{13}C_6$ is rare.
Both (1) and (2) are stable.
3. $^{14}C_6$ is unstable—it decays (it is produced in the upper atmosphere by cosmic radiation reacting with $^{14}N$). This occurs when a neutron $\rightarrow$ electron + proton (Beta-decay). The resulting ion now has 7 protons (atomic number 7) so it’s nitrogen-14 $\rightarrow ^{14}N_7$. This is often written $^{14}C_6 \rightarrow ^{14}N_7 + e^-$. Weight stays same, atomic number changes, $e^-$ sometimes written $\beta$. A $\beta$ particle is an electron.

The important thing is that the decay rate is proportional to the amount of $^{14}C_6$ present.

5.2 General Theory

Let’s write this in general: The decay rate of a parent isotope is

$$\frac{dP}{dt} = - \lambda P_t$$

$\lambda$ decay constant. So, the amount (number of atoms) of P present at time t is
\[ P_t = P_0 e^{-\lambda t} \]

If we start off with \( P_0 \) atoms, half or \( \frac{P_0}{2} \), will be left when

\[ \frac{1}{2} = e^{-\lambda t_{1/2}} \text{ or } \ln 2 = \lambda t_{1/2} \]

\[ t_{1/2} = \frac{\ln 2}{\lambda} = \frac{693}{\lambda} \]

Often, its more useful to write things in terms of the result of the decay-the daughter element. To do this, we assume that the only way the daughter is produced is by this reaction:

\[ (D_t - D_0) = P_0 - P_t \]

\((D_t - D_0)\) change in \( D \) from time zero, \( (P_0 - P_t) \) amount of \( P \) that decayed

"AGE EQUATION" (derivation not important)

\[ D_t - D_0 = P_t(e^{\lambda t} - 1) \]

\[ t = \frac{\ln[\frac{D_t - D_0}{P_t} + 1]}{\lambda} \]

To use this for dating we
- measure \( P_t, D_t \)
- assume \( \lambda, D_0 \)
- assume \( D_t \) is produced only by this decay
Naturally, to date things we need to have a reasonable amount of the parent left. This means we’d better not try for more than a few half-lives. Fortunately, there are a variety of these decay schemes

### 5.3 Decay schemes

1) Carbon-Carbon

\[ ^{14}C_6 \rightarrow ^{14}N_7 + e^-, \text{ half-life 5750 years} \]

(not useful much beyond 70,000 years-limited value for geology but very valuable for archeology)

2) Rubidium-Strontium

\[ ^{87}Rb_{37} \rightarrow ^{87}Sr_{38} + e^-, \text{ half-life } 4.7 \times 10^{10} \text{ yr, 47 billion years!} \]

This is more like it!

3) URANIUM-LEAD-THORIUM

\[ ^{238}U_{92} \rightarrow ^{206}Pb_{82} + 8\alpha + 6e^-, \text{ half-life 4.5 billion years} \]

(\(\alpha\) paricle-helium nucleus-2 neutrons, 2 protons)

\[ ^{235}U_{92} \rightarrow ^{207}Pb_{82} + 7\alpha + 4e^-, \text{ halflife 713 my} \]

\[ ^{232}Th_{90} \rightarrow ^{208}Pb_{82} + 6\alpha + 4e^-, \text{ halflife 13.9 billion years} \]

4) POTASSIUM-ARGON

\[ ^{40}K_{19} \rightarrow ^{40}Ca_{20} + e^-, \text{ halflife 1.47 billion yrs} \]

\[ ^{40}K_{19} + e^- (\text{electron capture}) \rightarrow ^{40}Ar_{18}, \text{ halflife 11.9 billion years} \]

The \(^{40}Ca\) isn’t useful since there’s lots of natural \(^{40}Ca\), but the \(^{40}Ar\) is useful.

We don’t want to become emeshed in the details of age dating, but lets look at one method (Rubidium-Strontium) in a bit more detail.

### 5.4 Rubidium-Strontium method

\[ ^{87}Rb_{37} \rightarrow ^{87}Sr_{38} + e^- \]

using the age equation

\[ ^{87}Sr_t = ^{87}Sr_o + ^{87}Rb_t(e^{\lambda t} - 1) \]

There are other naturally occurring Sr isotopes, which are not produced by radioactive decay, one is \(^{86}Sr\).

For instrumental reasons (discuss later) isotope ratios are best measured, so divide by \(^{86}Sr\):

\[ \frac{^{87}Sr_t}{^{86}Sr} = \frac{^{87}Sr_o}{^{86}Sr} + \frac{^{87}Rb_t}{^{86}Sr}(e^{\lambda t} - 1) \]

The above equation has the form:

\[ y = b + x m \]

The initial strontium ratio must be known to use the age equation for dating

How-within one rock has two minerals formed at the same time with different \(^{87}Rb\) content.
At time $t = 0 \rightarrow$ all the $^{87}\text{Sr}$ is the initial strontium.

But, as time increases ($e^{2t} - 1$) increases. This is the slope of the line - the intercept stays at the initial strontium point.

slope $= (e^{2t} - 1)$, so age (t) can be found (actually - little trick - since $\Delta t$ is small, from Taylor series: $e^{2t} \approx 1 + \Delta t \rightarrow e^{2t} - 1 = \Delta t$)

This age is called a "whole rock" age-it measures the time since the rock became a "closed system"-cooled to some temperature below which $^{87}\text{Sr}$ can’t get out (200° - 500° C). Later reheating (metamorphism) can "overprint".
Ages from meteorites: 4.6 billion years, presumably age of solar system

Oldest rocks ≈ 3.9 by (Canada)