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:

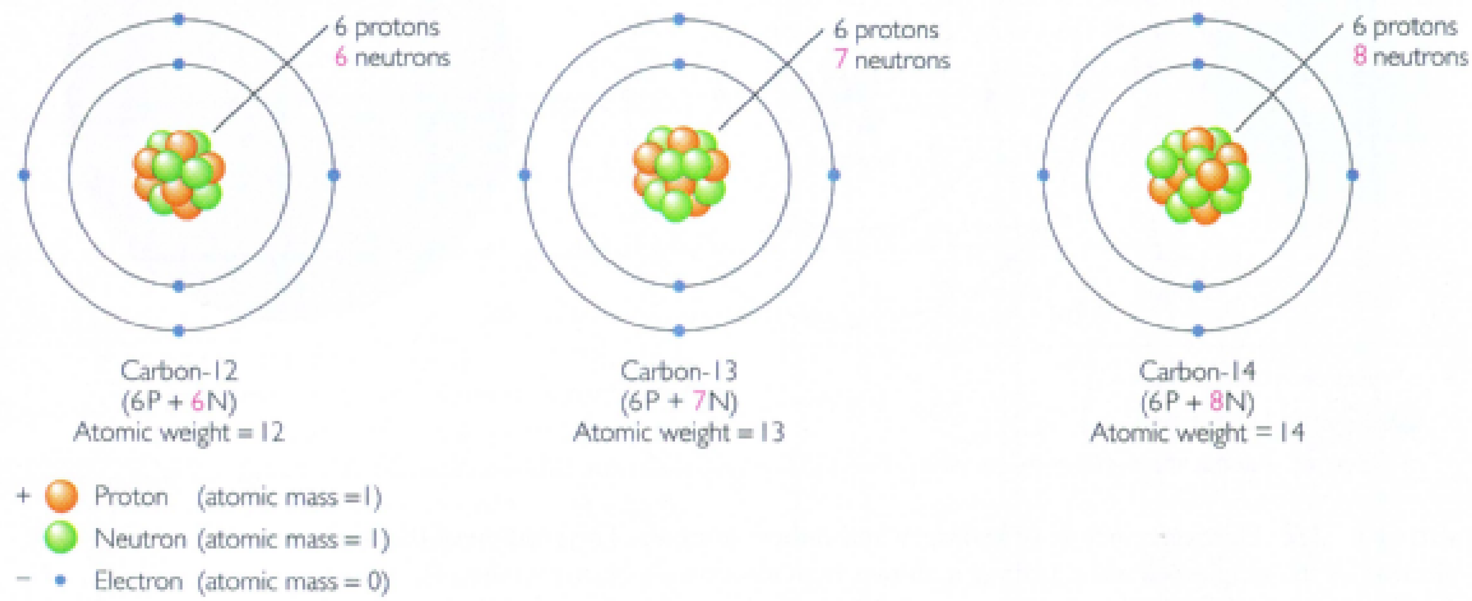


FIGURE 2.3 These three carbon isotopes all have the same number of protons and thus the same atomic number, 6. Their atomic masses differ, however, because they have slightly different numbers of neutrons. The atomic mass of any element is the average of the weighted sum of the atomic masses of its various isotopes. One isotope of an element—for example, carbon-12—is far more abundant than the others because natural processes favor that particular isotope.

(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 $\longrightarrow$ electron + proton (Beta-decay). The resulting ion now has 7 protons (atomic number 7) so it's nitrogren-14 $\longrightarrow$ $^{14}N_7$. This is often written $^{14}C_6 \longrightarrow {}^{14}N_7 + e^-$. Weight stays same, atomic number changes, e^- sometimes written β. A β 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

Lets write this in general: The decay rate of a *parent* isotope is

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

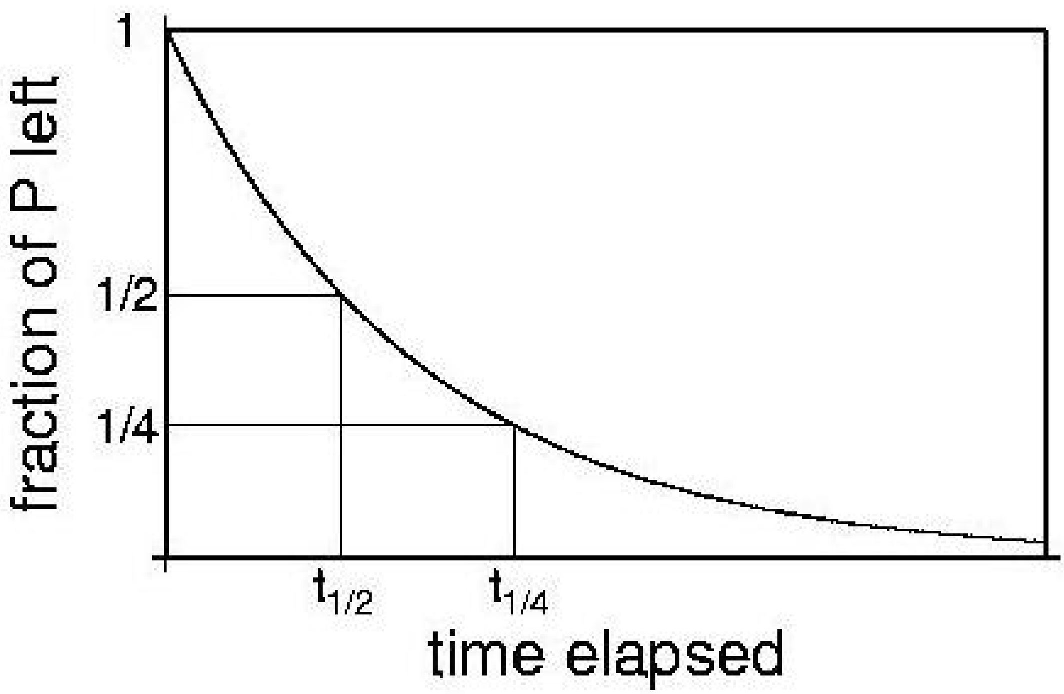
λ decay constant. So, the amount (number of atoms) of P present at time t is

$P_t = P_o e^{-\lambda t}$

If we start off with P_o atoms, half or $\frac{P_o}{2}$, will be left when

$1/2 = e^{-\lambda t_{1/2}}$ or $\ln 2 = \lambda t_{1/2}$

$t_{1/2} = \frac{\ln 2}{\lambda} = \cdot \frac{693}{\lambda}$



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:

$D_t - D_o = P_o - P_t$

$(D_t - D_{o)}$ change in D from time zero, $(P_o - P_{t)}$ amount of P that decayed

"AGE EQUATION" (derivation not important)

$D_t - D_o = P_t(e^{\lambda t} - 1)$

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

To use this for dating we
-measure P_t, D_t
-assume λ, D_o
-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

$^{14}C_6 \rightarrow {}^{14}N_7 + e^-$, halflife 5750 years

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

2) Rubidium-Strontium

$^{87}Rb_{37} \rightarrow {}^{87}Sr_{38} + e^-$, halflife $\approx 4.7 \times 10^{10}$ yr, 47 billion years!

This is more like it!

3) URANIUM-LEAD-THORIUM

$^{238}U_{92} \rightarrow {}^{206}Pb_{82} + 8\alpha + 6e^-$, halflife 4.5 billion years

(α paricle-helium nucleus-2 neutrons, 2 protons)

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

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

4) POTASSIUM-ARGON

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

$^{40}K_{19} + e^-$ (electron capture) $\rightarrow {}^{40}Ar_{18}$, 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 occuring 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:

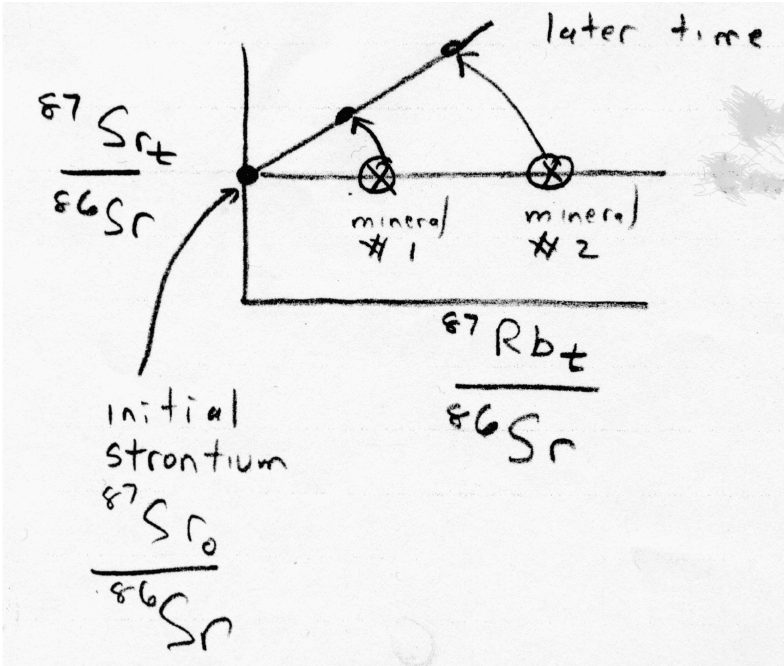
$$\frac{^{87}Sr_t}{^{86}Sr} = \frac{^{87}Sr_o}{^{86}Sr} + \frac{^{87}Rb_t}{^{86}Sr}(e^{\lambda t} - 1)$$

The above equation has the form:

$$y \quad = \quad b \quad + \quad x \quad m$$

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

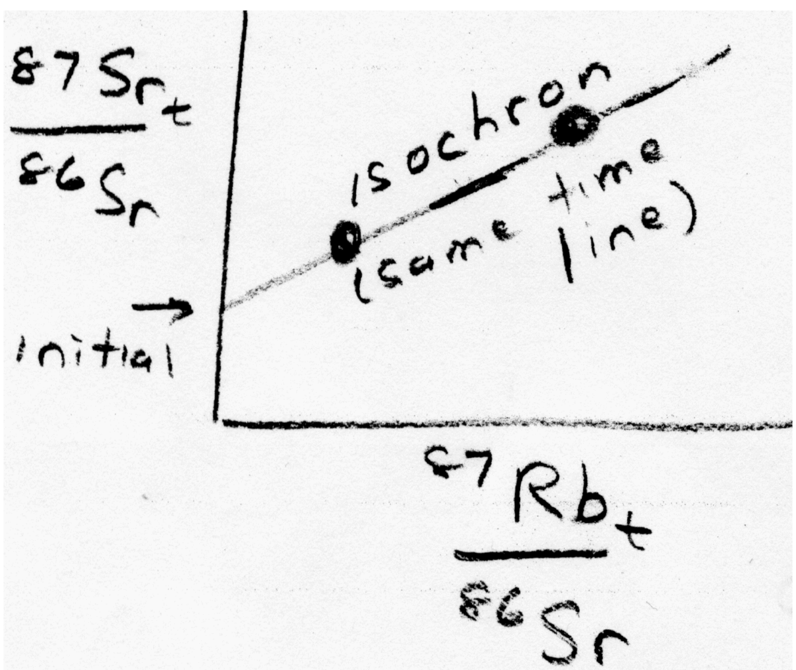
How-within one rock has two minerals formed at the same time with different ^{87}Rb content.



At time t = 0 $\longrightarrow$ all the ^{87}Sr is the initial strontium.

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

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



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}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)