Age Determination

Radiometric Dating
Halflives of Radio-Isotopes for Dating

\[ \frac{1}{2} \text{ years} \quad \text{Age of Earth} \quad \text{Nucl. Synth.} \]

\begin{align*}
10^3 & \quad 10^4 & \quad 10^5 & \quad 10^6 & \quad 10^7 & \quad 10^8 & \quad 10^9 & \quad 10^{10} & \quad 10^{11} \\
10^3 & \quad 5.73 & \quad 3.25 & \quad 7.5 & \quad 2.47 & \quad 1.6 & \quad 1.7 & \quad 8.2 & \quad 7.0 & \quad 1.25 & \quad 4.7 & \quad 1.40 & \quad 4.9 \\
\end{align*}

\[
\begin{array}{ccccccccccccccc}
^14\text{C} & ^{23}\text{Na} & ^{235}\text{U} & ^{238}\text{U} & ^{230}\text{Th} & ^{234}\text{Th} & ^{230}\text{Pa} & ^{231}\text{Pa} & ^{10}\text{Be} & ^{24}\text{Mg} & ^{244}\text{Pu} & ^{235}\text{U} & ^{238}\text{U} & ^{232}\text{Th} & ^{87}\text{Rb} \\
\downarrow\beta^- & \downarrow\alpha & \downarrow\alpha & \downarrow\alpha & \downarrow\beta^- & \downarrow\alpha & \downarrow\beta^- & \downarrow\beta^- & \downarrow\beta^- & \downarrow\beta & \downarrow\beta & \downarrow\beta & \downarrow\beta & \downarrow\beta & \\
\end{array}
\]

\(\alpha, \beta, \beta^-: \) particles measured to identify abundance of radioactive isotope,

K: K electron capture

R: measure series of several decay products
Carbon Dating of Fossil Objects

\[ \lambda = \frac{0.6931}{t_{1/2}} = \frac{0.6931}{5730 \text{a}} = 1.21 \times 10^{-4} \text{a}^{-1} \]

\[ N_{12C}(t) = N_{12C}(t = 0) \]
\[ N_{14C}(t) = N_{14C}(t = 0) \cdot e^{-\lambda t} \]
\[ R(t) = \frac{N_{14C}(t)}{N_{12C}(t)} = R(t = 0) \cdot e^{-\lambda t} \approx 1.3 \cdot 10^{-12} \]

"age" = \[ t = \frac{1}{\lambda} \ln \left( \frac{R(0)}{R(t)} \right) \]

Now:
\[ \dot{N}(^{14}\text{C}) \approx 2.5 \text{ cm}^{-2} \text{s}^{-1} \]
\[ ^{14}\text{C}/^{12}\text{C} = 1.3 \cdot 10^{-12} \]
\[ t_{1/2} = 5730 \text{a} \]

Direct \(^{14}\text{C}\) counting method: Accelerator Mass Spectroscopy \(\rightarrow R \geq 10^{-16} \quad (10^5 \text{a})\)

Measure \(R\) of \(^{14}\text{C}/^{12}\text{C}\) ratio of sample at \(t\)

Calibrate \(R\) of sample at \(t\)

Conventional method: \(\beta\) counting
Calibration of $^{14}$C Dating Methods

Variation in $^{14}$C Production

**Cosmic rays:** $t$-dependent flux (solar cycles) → $t$-dependent $^{14}$C production and intake

**Calibration:**

$^{14}$C-analyze yearly rings in trees of different ages (number and widths of rings), connect to fossils

**Errors** in dating very old samples: $^{14}$C abundance larger than assumed → **underestimation** of age ($\sim$ few hundred years).

(a) CE →
Rb/Sr Dating of Rocks/Age of the Earth

All rocky objects (planets, asteroids, meteorites) of solar system crystallized ≈ simultaneously \((t=0)\) out of interstellar dust/nebula (supernova remnants).

Parent \(P = {}^{87}\text{Rb},\) daughter \(D = {}^{87}\text{Sr}\)

Reference stable \(R = {}^{86}\text{Sr}\)

\((\text{stable} : N_R(t) = N_R(0))\)

At time of mixing \((t = 0)\)

\(N_P(0) + N_D(0) = N_P(t) + N_D(t)\) unknown!

\(N_P(t) = N_P(0) \cdot e^{-\lambda t}\)

\(N_D(t) = N_P(0) - N_P(t) + N_D(0)\)

\(N_D(t) = N_P(t) \cdot [e^{+\lambda t} - 1] + N_D(0)\)

\[
\frac{N_D(t)}{N_R(t)} = \frac{N_P(t)}{N_R(t)} \cdot \left[ e^{+\lambda t} - 1 \right] + \frac{N_D(0)}{N_R(0)}
\]

\[
y = y_0 + m(t) \cdot x
\]

\[
t = \frac{1}{\lambda} \cdot \ln[m + 1]
\]

Age of rock (since formation)

W. Udo Schröder, 2007
Age of the Earth

Age of Earth = $4.5 \cdot 10^9$ a

Moon has similar age

Terrestrial volcanic activity dated:

Whole-rock rubidium-strontium isochron for a set of samples of a Precambrian granite body exposed near Sudbury, Ontario.

Produces younger rocks