Isotopes

Same Z, different A (variable # of neutrons)

General notation for a nuclide: $^{14}_6\text{C}$
Isotopes

Same Z, different A (variable # of neutrons)
General notation for a nuclide: \(^{14}_6\)C

As n varies \(\rightarrow\) different isotopes of an element

\(^{12}\)C  \(^{13}\)C  \(^{14}\)C
Radioactive (Radiogenic) Isotopes

- Unstable isotopes decay to other nuclides
- The rate of decay is constant, and not affected by P, T, X…
- *Parent* nuclide = radioactive nuclide that decays
- *Daughter* nuclide(s) are the radiogenic atomic products
Isotopic variations between rocks, etc. due to:

1. *Mass fractionation* (as for stable isotopes)
   Only effective for light isotopes: H  He  C  O  S
Isotopic variations between rocks, etc. due to:

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2. Daughters produced in varying proportions resulting from previous event of chemical fractionation
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1. Mass fractionation (as for stable isotopes)
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3. Time
Radioactive Decay

The Law of Radioactive Decay

eq. 9.11 \[ -\frac{dN}{dt} \propto N \quad \text{or} \quad -\frac{dN}{dt} = \lambda N \]
\[ D = N e^{\lambda t} - N = N(e^{\lambda t} - 1) \quad \text{eq 9.15} \]

→ age of a sample \((t)\) if we know:

- \(D\) the amount of the daughter nuclide produced
- \(N\) the amount of the original parent nuclide remaining
- \(\lambda\) the decay constant for the system in question
Isotopic composition of Sr has changed continuously since nucleosynthesis because of radioactive $\beta^-$ decay of $^{87}\text{Rb}$ to $^{87}\text{Sr}$.

\[ ^{87}_{37}\text{Rb} \rightarrow ^{87}_{38}\text{Sr} + \beta^- + \nu + E \]

Decay of $^{87}\text{Rb}$:

\[ \lambda = 1.42 \times 10^{-11} \text{ y}^{-1} \]
\[ T_{1/2} = 48.8 \times 10^9 \text{ y} \]

Growth of radiogenic $^{87}\text{Sr}$:

\[ ^{87}\text{Sr} = ^{87}\text{Sr}_i + ^{87}\text{Rb}(e^{\lambda t}-1) \]

$^{87}\text{Sr}$ = total No. of atoms at present time.
$^{87}\text{Sr}_i$ = initial No. of atoms.
$^{87}\text{Rb}$ = No. of atoms at present time.
**Rb-Sr Systematics**

**Chemical Properties**

**Rb**  
Alkali metal  
Ionic radius = 1.48 Å  
Similar to K (1.33 Å) = substitution.

**Sr**  
Alkaline earths  
Ionic radius = 1.13 Å  
Similar to Ca (0.99 Å) = substitution.  
But restricted, Sr$^{2+}$ favors 8 fold coordinated sites, whereas Ca$^{2+}$ can be in 6 & 8 fold sites.
Rb-Sr System

- Rb behaves like K → micas and alkali feldspar
- Sr behaves like Ca → plagioclase and apatite (but not clinopyroxene)
- $^{88}\text{Sr} : ^{87}\text{Sr} : ^{86}\text{Sr} : ^{84}\text{Sr}$ ave. sample = 10 : 0.7 : 1 : 0.07
- $^{86}\text{Sr}$ is a stable isotope, and not created by breakdown of any other parent
Table 5.1. Average Concentrations (ppm) of Rb, K, Sr, and Ca in Igneous and Sedimentary Rocks

<table>
<thead>
<tr>
<th>Rock Type</th>
<th>Rb</th>
<th>K</th>
<th>Sr</th>
<th>Ca</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ultramafic</td>
<td>0.2</td>
<td>40</td>
<td>1</td>
<td>25,000</td>
</tr>
<tr>
<td>Basaltic</td>
<td>30</td>
<td>8,300</td>
<td>465</td>
<td>76,000</td>
</tr>
<tr>
<td>High-Ca granitic</td>
<td>110</td>
<td>25,200</td>
<td>440</td>
<td>25,300</td>
</tr>
<tr>
<td>Low-Ca granitic</td>
<td>170</td>
<td>42,000</td>
<td>100</td>
<td>5,100</td>
</tr>
<tr>
<td>Syenite</td>
<td>110</td>
<td>48,000</td>
<td>200</td>
<td>18,000</td>
</tr>
<tr>
<td>Shale</td>
<td>140</td>
<td>26,600</td>
<td>300</td>
<td>22,100</td>
</tr>
<tr>
<td>Sandstone</td>
<td>60</td>
<td>10,700</td>
<td>20</td>
<td>39,100</td>
</tr>
<tr>
<td>Carbonate</td>
<td>3</td>
<td>2,700</td>
<td>610</td>
<td>302,300</td>
</tr>
<tr>
<td>Deep-sea carbonate</td>
<td>10</td>
<td>2,900</td>
<td>2000</td>
<td>312,400</td>
</tr>
<tr>
<td>Deep-sea clay</td>
<td>110</td>
<td>25,000</td>
<td>180</td>
<td>29,000</td>
</tr>
</tbody>
</table>

Rb-Sr Systematics

Easier to measure ratios, divide by $^{86}\text{Sr}$ which is stable:

$$\frac{^{87}\text{Sr}}{^{86}\text{Sr}} = \left(\frac{^{87}\text{Sr}}{^{86}\text{Sr}}\right)_i + \frac{^{87}\text{Rb}}{^{86}\text{Sr}} (e^{\lambda t} - 1)$$

Isotopic Abundances:

$^{88}\text{Sr} = 82.53\%$

$^{87}\text{Sr} = 7.04\%$

$^{86}\text{Sr} = 9.87\%$

$^{84}\text{Sr} = 0.56\%$

$^{37}\text{Rb} = 72.1654\%$

$^{37}\text{Rb} = 27.8346\%$
Isochronon Technique

Requires 3 or more cogenetic samples with a range of Rb/Sr

Could be:

- 3 cogenetic rocks derived from a single source by partial melting, FX, etc.

Figure 9.3. Change in the concentration of Rb and Sr in the melt derived by progressive batch melting of a basaltic rock consisting of plagioclase, augite, and olivine. From Winter (2001) An Introduction to Igneous and Metamorphic Petrology. Prentice Hall.
Isochronon Technique

Requires 3 or more cogenetic samples with a range of Rb/Sr

Could be:

- 3 cogenetic rocks derived from a single source by partial melting, FX, etc.
- 3 coexisting minerals with different K/Ca ratios in a single rock
Recast age equation by dividing through by stable $^{86}\text{Sr}$

$$
\frac{^{87}\text{Sr}}{^{86}\text{Sr}} = \left(\frac{^{87}\text{Sr}}{^{86}\text{Sr}}\right)_o + \left(\frac{^{87}\text{Rb}}{^{86}\text{Sr}}\right)\left(e^{\lambda t} - 1\right) \quad \text{eq 9.17}
$$

$$
\lambda = 1.4 \times 10^{-11} \text{ a}^{-1}
$$

For values of $\lambda t$ less than 0.1: $e^{\lambda t} - 1 \cong \lambda t$

Thus eq. 9.15 for $t < 70 \text{ Ga (!!)}$ reduces to:

**eq 9.18**

$$
\frac{^{87}\text{Sr}}{^{86}\text{Sr}} = \left(\frac{^{87}\text{Sr}}{^{86}\text{Sr}}\right)_o + \left(\frac{^{87}\text{Rb}}{^{86}\text{Sr}}\right)\lambda t
$$

$$
y = b + x m
$$

= equation for a line in $\frac{^{87}\text{Sr}}{^{86}\text{Sr}}$ vs. $\frac{^{87}\text{Rb}}{^{86}\text{Sr}}$ plot
**Rb-Sr Isochrons**

Age determination for suite of cogenetic samples.

Plot of N versus D yields straight line = *isochron*.

\[ y = mx + b \]

Age is calculated from slope:

\[ m = \left( e^{\lambda t} - 1 \right) \]

\[ t = \frac{1}{\lambda} \ln (m+1) \]
Begin with 3 rocks plotting at a b c at time $t_o$
After some time increment ($t_0 \rightarrow t_1$) each sample loses some $^{87}$Rb and gains an equivalent amount of $^{87}$Sr.
At time $t_2$ each rock system has evolved → new line
Again still linear and steeper line
Internal Rb-Sr Isochrons

Dickin, Radiogenic Isotope Geology, 2005
Isochron technique produces 2 valuable things:

1. The age of the rocks (from the slope $= \lambda t$)

2. $\left(\frac{^{87}\text{Sr}}{^{86}\text{Sr}}\right)_0 = \text{the initial value of } \frac{^{87}\text{Sr}}{^{86}\text{Sr}}$

Figure 9.12. Rb-Sr isochron for the Eagle Peak Pluton, central Sierra Nevada Batholith, California, USA. Filled circles are whole-rock analyses, open circles are hornblende separates. The regression equation for the data is also given. After Hill et al. (1988). Amer. J. Sci., 288-A, 213-241.