The Sm-Nd System

- Both Sm and Nd are LREE
  - Incompatible elements fractionate → melts
  - Nd has lower Z → larger → liquids > does Sm

<table>
<thead>
<tr>
<th>Ac-Lr</th>
<th>Actinide series</th>
<th>Eu²⁺ is LIL</th>
<th>Eu³⁺ is HFS</th>
</tr>
</thead>
<tbody>
<tr>
<td>La³⁺ 1.25</td>
<td>Lanthanum</td>
<td>Pr³⁺ 1.22</td>
<td>Eu²⁺ 1.15</td>
</tr>
<tr>
<td>Ce³⁺ 1.22</td>
<td>Cerium</td>
<td>Nd³⁺ 1.20</td>
<td>Eu³⁺ 1.14</td>
</tr>
<tr>
<td>Pr³⁺ 1.22</td>
<td>Praseodymium</td>
<td>Sm³⁺ 1.17</td>
<td>Gd³⁺ 1.14</td>
</tr>
<tr>
<td>Nd³⁺ 1.20</td>
<td>Neodymium</td>
<td>Eu³⁺ 1.15</td>
<td>Tb³⁺ 1.12</td>
</tr>
<tr>
<td>Sm³⁺ 1.17</td>
<td>Samarium</td>
<td>Gd³⁺ 1.14</td>
<td>Dy³⁺ 1.11</td>
</tr>
<tr>
<td>Eu³⁺ 1.15</td>
<td>Europium</td>
<td>Tb³⁺ 1.12</td>
<td>Ho³⁺ 1.10</td>
</tr>
<tr>
<td>Gd³⁺ 1.14</td>
<td>Gadolinium</td>
<td>Dy³⁺ 1.11</td>
<td>Er³⁺ 1.08</td>
</tr>
<tr>
<td>Tb³⁺ 1.12</td>
<td>Terbium</td>
<td>Ho³⁺ 1.10</td>
<td>Erbium</td>
</tr>
<tr>
<td>Dy³⁺ 1.11</td>
<td>Dysprosium</td>
<td>Er³⁺ 1.08</td>
<td>Thulium</td>
</tr>
<tr>
<td>Ho³⁺ 1.10</td>
<td>Holmium</td>
<td>Yb³⁺ 1.08</td>
<td>Lutetium</td>
</tr>
<tr>
<td>Er³⁺ 1.08</td>
<td>Erbium</td>
<td>Lu³⁺ 1.05</td>
<td></td>
</tr>
</tbody>
</table>
$^{147}\text{Sm} \rightarrow ^{143}\text{Nd}$ by alpha decay

$\lambda = 6.54 \times 10^{-13} \text{ a}^{-1}$ (half life 106 Ga)

- Decay equation derived by reference to the non-radiogenic $^{144}\text{Nd}$

$$\frac{^{143}\text{Nd}}{^{144}\text{Nd}} = \left(\frac{^{143}\text{Nd}}{^{144}\text{Nd}}\right)_0 + \left(\frac{^{147}\text{Sm}}{^{144}\text{Nd}}\right)(e^{\lambda t} - 1)$$
Evolution curve is opposite to Rb - Sr

The U-Pb-Th System

A little more complex system……..

- 3 radioactive isotopes of U: $^{234}$U, $^{235}$U, $^{238}$U
- 3 radiogenic isotopes of Pb: $^{206}$Pb, $^{207}$Pb, and $^{208}$Pb
  - Only $^{204}$Pb is strictly non-radiogenic

- U, Th, and Pb are incompatible elements, & concentrate in early melts

- Isotopic composition of Pb in rocks = function of
  
  - $^{238}$U $\rightarrow$ $^{234}$U $\rightarrow$ $^{206}$Pb ($\lambda = 1.5512 \times 10^{-10}$ a$^{-1}$)
  - $^{235}$U $\rightarrow$ $^{207}$Pb ($\lambda = 9.8485 \times 10^{-10}$ a$^{-1}$)
  - $^{232}$Th $\rightarrow$ $^{208}$Pb ($\lambda = 4.9475 \times 10^{-11}$ a$^{-1}$)
The U-Pb-Th System

**Concordia** = Simultaneous co-evolution of $^{206}\text{Pb}$ and $^{207}\text{Pb}$ via:

\[ ^{238}\text{U} \rightarrow ^{234}\text{U} \rightarrow ^{206}\text{Pb} \]
\[ ^{235}\text{U} \rightarrow ^{207}\text{Pb} \]

The U-Pb-Th System

**Discordia** = loss of both $^{206}\text{Pb}$ and $^{207}\text{Pb}$

The U-Pb-Th System

Concordia diagram after 3.5 Ga total evolution

Figure 9.17. Concordia diagram for three discordant zircons separated from an Archean gneiss at Morton and Granite Falls, Minnesota. The discordia intersects the concordia at 3.55 Ga, yielding the U-Pb age of the gneiss, and at 1.85 Ga, yielding the U-Pb age of the depletion event. From Faure (1986). Copyright © reprinted by permission of John Wiley & Sons, Inc.
Stable Isotopes

- **Stable**: last ~ forever
- **Chemical** fractionation is impossible
- **Mass** fractionation is the only type possible
### Example: Oxygen Isotopes

<table>
<thead>
<tr>
<th>Isotope</th>
<th>Concentration</th>
</tr>
</thead>
<tbody>
<tr>
<td>$^{16}\text{O}$</td>
<td>99.756% of natural oxygen</td>
</tr>
<tr>
<td>$^{17}\text{O}$</td>
<td>0.039%</td>
</tr>
<tr>
<td>$^{18}\text{O}$</td>
<td>0.205%</td>
</tr>
</tbody>
</table>

Concentrations expressed by reference to a standard International standard for O isotopes = standard mean ocean water (SMOW)
$^{18}\text{O}$ and $^{16}\text{O}$ are the commonly used isotopes and their ratio is expressed as $\delta$:

$$\delta \left( ^{18}\text{O}/^{16}\text{O} \right) = \frac{\left( ^{18}\text{O}/^{16}\text{O} \right)_{\text{sample}} - \left( ^{18}\text{O}/^{16}\text{O} \right)_{\text{SMOW}}}{\left( ^{18}\text{O}/^{16}\text{O} \right)_{\text{SMOW}}} \times 1000$$

result expressed in per mil (‰)

What is $\delta$ of SMOW??

What is $\delta$ for meteoric water?
What is $\delta$ for meteoric water?

Evaporation seawater $\rightarrow$ water vapor (clouds)

- Light isotope enriched in vapor $>$ liquid
- Pretty efficient, since $\Delta$ mass $= 1/8$ total mass
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Evaporation seawater $\rightarrow$ water vapor (clouds)

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$$\delta = \frac{(^{18}\text{O}/^{16}\text{O})_{\text{vapor}} - (^{18}\text{O}/^{16}\text{O})_{\text{SMOW}}}{(^{18}\text{O}/^{16}\text{O})_{\text{SMOW}}} \times 1000$$

therefore $$(^{18}\text{O}/^{16}\text{O})_{\text{vapor}} < (^{18}\text{O}/^{16}\text{O})_{\text{SMOW}}$$

thus $\delta_{\text{clouds}}$ is (-)
Figure 9.9. Relationship between $\delta^{18}O/^{16}O$ and mean annual temperature for meteoric precipitation, after Dansgaard (1964). *Tellus*, 16, 436-468.
Stable isotopes useful in assessing relative contribution of various reservoirs, each with a distinctive isotopic signature

- O and H isotopes - juvenile vs. meteoric vs. brine water
- $\delta^{18}O$ for mantle rocks ≠ surface-reworked sediments: evaluate contamination of mantle-derived magmas by crustal sediments