Radioactive Decay Worksheet

**Alpha decay**: nucleus spontaneously emits an alpha particle (symbol: α particle), which is 2 p+ and 2 n (or also the same as a Helium (He) atom).
  - Result: atomic number decreases by 2 (lost 2 p+)
  - Result: atomic mass decreases by 4 (lost 2 p+ and 2n = 4 amu)

**Beta decay**: neutron in nucleus spontaneously emits a beta particle (symbol: β particle), which is essentially an electron trapped in a neutron. The neutron, therefore, turns itself into a proton.
  - Result: atomic number increases by 1 (gained 1 p+)
  - Result: atomic mass stays same (no mass lost or gained: β particle or electrons have no mass)

**Beta or electron capture**: proton in nucleus captures a beta particle (symbol: β particle), which is essentially an electron that can become part of a neutron. The proton, therefore, turns itself into a neutron.
  - Result: atomic number decreases by 1 (lost 1 p+)
  - Result: atomic mass stays same (no mass lost or gained: β particle or electrons have no mass)

**Example**

<table>
<thead>
<tr>
<th>Original</th>
<th>alpha decay</th>
<th>beta decay</th>
<th>alpha decay</th>
<th>beta capture</th>
<th>beta decay</th>
<th>alpha decay</th>
</tr>
</thead>
<tbody>
<tr>
<td>85</td>
<td>83</td>
<td>84</td>
<td>82</td>
<td>81</td>
<td>82</td>
<td>80</td>
</tr>
<tr>
<td>At</td>
<td>Bi</td>
<td>Po</td>
<td>Pb</td>
<td>Tl</td>
<td>Pb</td>
<td>Hg</td>
</tr>
<tr>
<td>Astatine</td>
<td>Bismuth</td>
<td>Polonium</td>
<td>Lead</td>
<td>Thallium</td>
<td>Lead</td>
<td>Mercury</td>
</tr>
<tr>
<td>210</td>
<td>206</td>
<td>206</td>
<td>202</td>
<td>202</td>
<td>202</td>
<td>198</td>
</tr>
</tbody>
</table>

**Complete this table**

<table>
<thead>
<tr>
<th>Original</th>
<th>beta decay</th>
<th>alpha decay</th>
<th>beta capture</th>
<th>alpha decay</th>
<th>alpha decay</th>
<th>beta decay</th>
</tr>
</thead>
<tbody>
<tr>
<td>90</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Th</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Thorium</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>232</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Complete this table**

<table>
<thead>
<tr>
<th>Original</th>
<th>beta capture</th>
<th>alpha decay</th>
<th>alpha decay</th>
<th>beta capture</th>
<th>alpha decay</th>
<th>beta decay</th>
</tr>
</thead>
<tbody>
<tr>
<td>92</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>U</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Uranium</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>238</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Radiometric Dating Worksheet

When radioactive isotopes (parent – P) decay, they produce daughter products (D) at a constant rate, called the half-life (T). Example: if we start with 100 atoms of the parent, after one half-life, there will be 50 parent atoms remaining and 50 daughter atoms newly made. After another half-life (two half-lives), there will be 25 parent atoms remaining and now 75 daughter atoms. Each parent-daughter isotope pair has its own half-life. To achieve the above example with U-238 takes 9 billion years (two half-lives). To achieve the above example with C-14 takes 11400 years (two half-lives). In the geologic environment, we use a mass spectrometer to count the number of Parent and Daughter atoms in a closed-system (like minerals crystallizing from magmas), and use the relative proportions to find out how old the closed-system is.

1. Assuming we start with only parent isotopes (no daughter), after one half-life has passed, there should be ½ parent remaining and ½ daughter newly formed. The ratio of P:D is ½ : ½ or 1:1. Complete the rest of this table, as in the first example:

<table>
<thead>
<tr>
<th># Halflives</th>
<th>Fraction of original Parent remaining</th>
<th>Fraction of original parent turned into daughter</th>
<th>Parent:Daughter ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>½</td>
<td>½</td>
<td>1:1</td>
</tr>
<tr>
<td>2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Not all rocks can be dated radiometrically. Some because they cannot maintain closed systems (like metamorphic rocks); others because they do not contain radioactive isotopes (like quartz sandstones); and finally some because the radioactive isotopes that they do contain have half-lives that are either too long or too short to be measured for a rock of a certain age (like trying to date a 1 m.y.-old rock by using C-14 decay – which would have been completely decayed after about 150,000 years).

<table>
<thead>
<tr>
<th>Parent (P)</th>
<th>Daughter (D)</th>
<th>Half-lives ($T_{1/2}$)</th>
<th>Materials dated</th>
</tr>
</thead>
<tbody>
<tr>
<td>U-238</td>
<td>Pb-206</td>
<td>$4.5 \times 10^9$ yr</td>
<td>Zircon (igneous rocks – source; and sedimentary rocks as grains)</td>
</tr>
<tr>
<td>U-235</td>
<td>Pb-207</td>
<td>$0.7 \times 10^9$ yr</td>
<td>Zircon (igneous rocks – source; and sedimentary rocks as grains)</td>
</tr>
<tr>
<td>K-40</td>
<td>Ar-40</td>
<td>$1.4 \times 10^9$ yr</td>
<td>Micas, volcanic rock (igneous rocks)</td>
</tr>
<tr>
<td>C-14</td>
<td>N-14</td>
<td>5700 yr</td>
<td>Shells, limestone, organic materials</td>
</tr>
</tbody>
</table>

2. To date the age of a shell found in an old Indian fishing village, which isotope pair would you measure? Why?

3. If you want to date a meteorite, which isotope pair would you measure? Why?

4. If you want to date lava flows on an old lava flow on Kauai (probably about 8 m.y.), which isotope pair would you measure? Why?

5. If you want to date zircon crystals in ancient sandstones in Australia, which isotope pair would you measure? Why?
6. If the C-14:N-14 ratio in a shell in a sandstone was found to be 1:3, how old is the shell?

7. If the U-235:Pb-207 ratio in a zircon in a sandstone was found to be 1:3, how old is the zircon?

8. If the K-40:Ar-40 ratio in a zircon in a granite was found to be 1:1, how old is the sample?

9. If the U-238:Pb-206 ratio in a zircon in a lava flow was found to be 3:1, how old is the flow?

<table>
<thead>
<tr>
<th>T (# of) Halflives</th>
<th>Fraction Parent</th>
<th>Daughter</th>
<th>Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1</td>
<td>0</td>
<td>infinity:1</td>
</tr>
<tr>
<td>0.0227</td>
<td>63/64</td>
<td>1/64</td>
<td>63:1</td>
</tr>
<tr>
<td>0.0458</td>
<td>31/32</td>
<td>1/32</td>
<td>31:1</td>
</tr>
<tr>
<td>0.0931</td>
<td>15/16</td>
<td>1/16</td>
<td>15:1</td>
</tr>
<tr>
<td>0.1927</td>
<td>7/8</td>
<td>1/8</td>
<td>7:1</td>
</tr>
<tr>
<td>0.4151</td>
<td>3/4</td>
<td>1/4</td>
<td>3:1</td>
</tr>
<tr>
<td>1.0000</td>
<td>1/2</td>
<td>1/2</td>
<td>1:1</td>
</tr>
<tr>
<td>2.0000</td>
<td>1/4</td>
<td>3/4</td>
<td>1:3</td>
</tr>
<tr>
<td>3.0000</td>
<td>1/8</td>
<td>7/8</td>
<td>1:7</td>
</tr>
<tr>
<td>4.0000</td>
<td>1/16</td>
<td>15/16</td>
<td>1:15</td>
</tr>
<tr>
<td>5.0000</td>
<td>1/32</td>
<td>31/32</td>
<td>1:31</td>
</tr>
<tr>
<td>6.0000</td>
<td>1/64</td>
<td>63/64</td>
<td>1:63</td>
</tr>
</tbody>
</table>

CURVE EQUATION: $T = -1.443\ln(f)$  \( f = \text{fraction of parent left}; T = \# \text{of half lives that have passed} \)