Silicon Cascade Probabilities

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**Abstract**

Determining Cascade Probabilities for Thermal Neutron Calibration of Dark Matter Detectors

One aspect of thermal neutron calibration of CMDS (Cryogenic Dark Matter Search) detectors is modeling thermal neutron capture. When a thermal neutron is captured by a nucleus, it is initially captured by some energy level of that isotope which is lower than the separation energy for that isotope. It will then quickly cascade back down to ground level. Each transition from one energy level to another releases a photon with energy equal to the difference in energy levels minus the recoil energy of the nucleus. Part of the calibration involves knowing the probability of various cascades and their expected lifetimes. Using experimental data on the various commonly used isotopes of Silicon(Si) and Germanium(Ge), the probability of all possible cascades was determined. These were then weighted by the percentage of each isotope present in a naturally occurring sample. Using the spin and parity of each energy level and the Weisskopf estimates, the lifetime in femtoseconds of each transition was estimated.

**Methodology**

In this project, I created an algorithm that (using the raw data in the following table) would:

- Determine the transition for each gamma ($E_\gamma$) listed
- Calculate the relative probability of each transition for an isotope
- Output the probability of all possible cascades for that isotope
- Include the lifetimes of each transition in the output.
- Weigh this by the percentage of that isotope in the sample.

### Examples

<table>
<thead>
<tr>
<th>Energy Level Transition</th>
<th>Cross section in mb (from experimental data)</th>
<th>Total cross section for transitions from higher level (mb)</th>
<th>Probability of this transition occurring in a Si28 neutron capture</th>
</tr>
</thead>
<tbody>
<tr>
<td>8473-2426</td>
<td>.55</td>
<td>160.5 (from 8473)</td>
<td>0.0003245</td>
</tr>
<tr>
<td>2426-1273</td>
<td>.89</td>
<td>5.9 (from 2426)</td>
<td>.000282</td>
</tr>
<tr>
<td>1273-0</td>
<td>28.5</td>
<td>168.3 (from 1273)</td>
<td>1</td>
</tr>
</tbody>
</table>

According to the example above, by multiplying the probabilities of each transition, we see that the cascade [8473,2426,1273,0] has a probability of 0.000483. Multiplying this by the amount of Si28 in a naturally occurring sample gives a final probability of 0.000445.

An excerpt from the table of results for Si28 includes the lifetime of each transition level. If the lifetime is unknown, the Weisskopf estimate is used. The lifetime of ground level is considered to be indefinite.

<table>
<thead>
<tr>
<th>Probability Cascade Lifetimes</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.00041295498706318</td>
</tr>
<tr>
<td>0.041126271073437</td>
</tr>
<tr>
<td>0.648233133706535</td>
</tr>
<tr>
<td>0.006155850751398352</td>
</tr>
<tr>
<td>0.00048288869039971</td>
</tr>
</tbody>
</table>

Weisskopf estimate formula


**Next Steps**

Our goal is to build a model that includes neutron capture, as well as electron recoil and neutron recoil, and then use it to calibrate the detector. We will also want to account for what happens when a nucleus decays in flight and how the transition lifetimes affect the model.

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