Silicon Cascade Probabilities

S. Brown, A. N. Villano

Department of Physics, Metropolitan State University of Denver

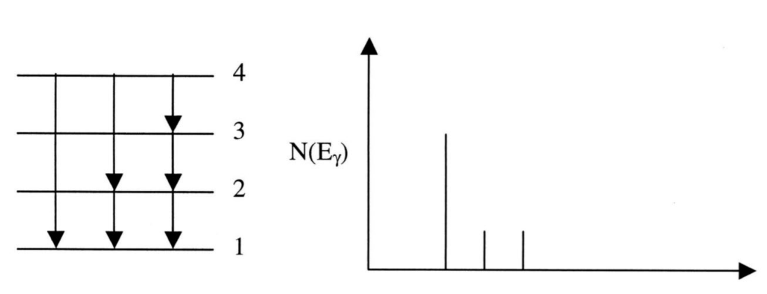
Department of Physics, University of Colorado Denver

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.

Gamma ray decay
Oregonstate.edu
Lesson 10



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.

Si28	92.23%
Si29	4.67%
Si30	3.10%

Periodictable.com

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_γ) 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.

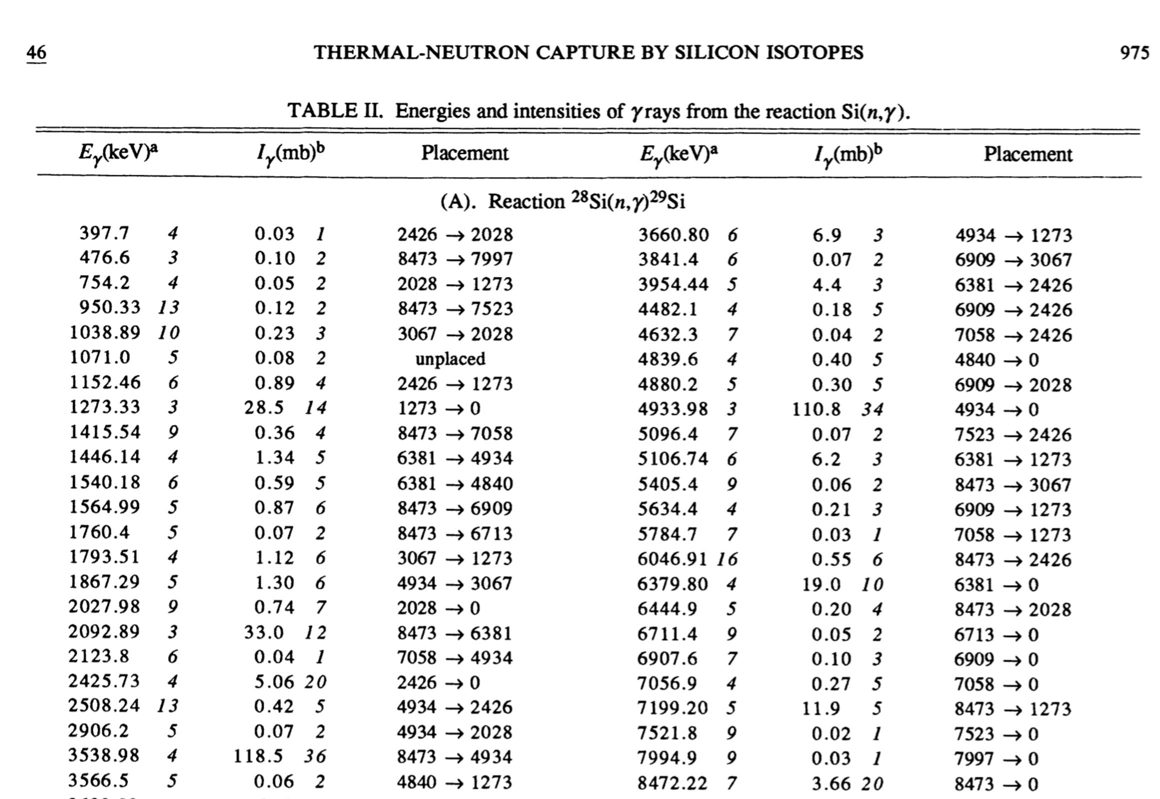


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TABLE II. Energies and intensities of γ rays from the reaction Si(n,γ).

E_γ(keV)[a]	I_γ(mb)[b]	Placement	E_γ(keV)[a]	I_γ(mb)[b]	Placement
(A). Reaction ^{28}Si(n,γ)^{29}Si					
397.7 4	0.03 1	2426 → 2028	3660.80 6	6.9 3	4934 → 1273
476.6 3	0.10 2	8473 → 7997	3841.4 6	0.07 2	6909 → 3067
754.2 4	0.05 2	2028 → 1273	3954.44 5	4.4 3	6381 → 2426
950.33 13	0.12 2	8473 → 7523	4482.1 4	0.18 5	6909 → 2426
1038.89 10	0.23 3	3067 → 2028	4632.3 7	0.04 2	7058 → 2426
1071.0 5	0.08 2	unplaced	4839.6 4	0.40 5	4840 → 0
1152.46 6	0.89 4	2426 → 1273	4880.2 5	0.30 5	6909 → 2028
1273.33 3	28.5 14	1273 → 0	4933.98 3	110.8 34	4934 → 0
1415.54 9	0.36 4	8473 → 7058	5096.4 7	0.07 2	7523 → 2426
1446.14 4	1.34 5	6381 → 4934	5106.74 6	6.2 3	6381 → 1273
1540.18 6	0.59 5	6381 → 4840	5405.4 9	0.06 2	8473 → 3067
1564.99 5	0.87 6	8473 → 6909	5634.4 4	0.21 3	6909 → 1273
1760.4 5	0.07 2	8473 → 6713	5784.7 7	0.03 1	7058 → 1273
1793.51 4	1.12 6	3067 → 1273	6046.91 16	0.55 6	8473 → 2426
1867.29 5	1.30 6	4934 → 3067	6379.80 4	19.0 10	6381 → 0
2027.98 9	0.74 7	2028 → 0	6444.9 5	0.20 4	8473 → 2028
2092.89 3	33.0 12	8473 → 6381	6711.4 9	0.05 2	6713 → 0
2123.8 6	0.04 1	7058 → 4934	6907.6 7	0.10 3	6909 → 0
2425.73 4	5.06 20	2426 → 0	7056.9 4	0.27 5	7058 → 0
2508.24 13	0.42 5	4934 → 2426	7199.20 5	11.9 5	8473 → 1273
2906.2 5	0.07 2	4934 → 2028	7521.8 9	0.02 1	7523 → 0
3538.98 4	118.5 36	8473 → 4934	7994.9 9	0.03 1	7997 → 0
3566.5 5	0.06 2	4840 → 1273	8472.22 7	3.66 20	8473 → 0
3633.0?	< 0.12	8473 → 4840			

Published in: E.T. Journey, J.W. Starner, J.E. Lynn, *Physical Review C,* Vol 46 No 3 (Sept 1992) (Si 28 only)

Examples

Energy Level Transition	Cross section in mb (from experimental data)	Total cross section for transitions from higher level (mb)	Probability of this transition occurring in a Si28n,ySi29 capture
8473-2426	.55	169.5 (from 8473)	.003245
2426-1273	.89	5.9 (from 2426)	.148829
1273-0	28.5	28.5 (from 1273)	1

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.

Probability	Cascade	Lifetimes
0.0004129549879063182	[8473 6712.9 0]	[0.1 1000000000000000.0]
0.0411262710723437	[8473 6380.58 0]	[0.36 1000000000000000.0]
0.6482331337006535	[8473 4934.39 0]	[0.84 1000000000000000.0]
0.0006155850751398532	[8473 4840.34 0]	[3.5 1000000000000000.0]
0.0004828988690399971	[8473 2425.86 1273.37 0]	[18.1 291.0 1000000000000000.0]
7.80196036154674e-07	[8473 4934.39 2425.86 2028.05 1273.37 0][8473 4934.39 2425.86 2028.05 1273.37 0]	[0.84 18.1 396.0 291.0 1000000000000000.0]

Weisskopf estimate formula
Published: oregonstate.edu, Lesson 10, Gamma Ray Decay

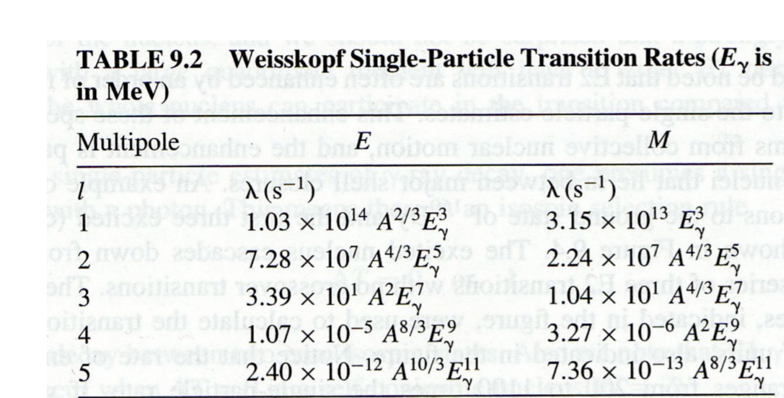

TABLE 9.2 Weisskopf Single-Particle Transition Rates (E_γ is in MeV)

Multipole	E	M
l	λ (s^{-1})	λ (s^{-1})
1	$1.03 \times 10^{14}\ A^{2/3}E_\gamma^3$	$3.15 \times 10^{13}\ E_\gamma^3$
2	$7.28 \times 10^{7}\ A^{4/3}E_\gamma^5$	$2.24 \times 10^{7}\ A^{4/3}E_\gamma^5$
3	$3.39 \times 10^{1}\ A^{2}E_\gamma^7$	$1.04 \times 10^{1}\ A^{4/3}E_\gamma^7$
4	$1.07 \times 10^{-5}\ A^{8/3}E_\gamma^9$	$3.27 \times 10^{-6}\ A^{2}E_\gamma^9$
5	$2.40 \times 10^{-12}\ A^{10/3}E_\gamma^{11}$	$7.36 \times 10^{-13}\ A^{8/3}E_\gamma^{11}$