Centroid Determination of ^{35}Cl(n,γ) and ^{56}Co Lines

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1 Introduction

At a basic level, the most distinguishing characteristic between a proton and neutron is the difference that they have in charge. In a world without the electromagnetic interaction, the difference between these two particles is minute. There are many other types of particles which are very similar when the Coulomb force is removed, and to keep a distinction between these types of particles, the idea of isospin has been introduced. For example, we can treat the proton and neutron as different states of the same particle, the nucleon, by assigning them isospin ↑ and isospin ↓ respectively. Isospin can be treated formally in the same way as spin in an electron, and mathematically they are identical.

The existence of isobaric multiplets in nature becomes intuitive when we think of a world without the Coulomb force. Clearly, elements with the same number of nucleons will have a similar structure. This effect can be observed by comparing the different excited states of elements with the same atomic mass, and looking at the associated energies and observables of each level. By correcting the energies for the electromagnetic effect, it can be seen that the states are almost identical.

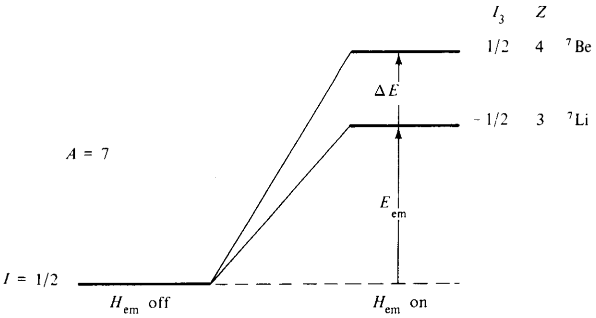

Figure 1: The world of isospin without and with the electromagnetic interaction for A = 7 [1]. The degeneracy is broken when the electromagnetic force is turned back on to form an isobaric multiplet.

The Isobaric Multiplet Mass Equation,

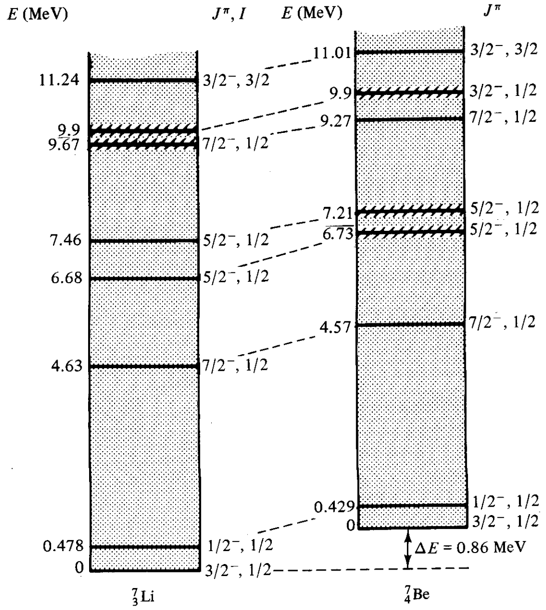

Figure 2: Level structure in two isobars ^{7}Li and ^{7}Be [1]. Notice the similarities between the associated energy levels.

(IMME) first proposed by Wigner in 1957 [2], relates the mass of a state to the z component of its isobaric spin, T_z. T_z is determined by the difference in number of protons and neutrons in an element, i.e. $T_z = \frac{1}{2}(Z-N)$. The IMME is as follows:

$$M(T_z) = a + bT_z + c{T_z}^2 \tag{1}$$

The IMME has been shown to work well for 21 of the 22 examined quartets, with the only deviation in the A = 9 quartet, which is currently the most accurately known [2]. To perform a more stringent test of the IMME for the lowest T = 2 quintuplet, an accurate measurement of the mass of ^{32}S in its lowest T = 2 state is needed, as the masses of the other members are well known [3]. Once completed, we will have performed the most rigorous test of the IMME to date.

To achieve the desired precision, several calibration reactions are required including ^{35}Cl(n,γ). To assure that we achieve the desired accuracy, we must take into account all possible sources of uncertainties which may distort the energy-channel relationship in our detectors. Possible sources of uncertainties are ADC nonlinearities, Doppler shifts, recoil effects, gain shifts from the electronics, and peak position variation from the geometry of our Ge detectors. The effects of recoil and Doppler shifts can be corrected for using Monte Carlo simulations, but corrections for the gain shifts, ADC nonlinearities, and geometry in the Ge detectors must be extrapolated from the actual data.

Gain shifts are caused by fluctuations in temperature that affect the electronics. Its characteristic trademark is evident in seeing the centroids of the measured gamma ray peak energies shift their energies in the same direction with respect to time. ADC nonlinearities are most prevalent at lower energies. Fortunately, we are interested in peaks of higher energies in which the effect is negligible. Peak position variations caused by the geometry of a Ge detector could possibly have a major effect on the accuracy of our calibration because of differences in the detector orientation during the ^{35}Cl(n,γ) calibration reaction and the ^{32}S measurement. Due to the detector bias voltage, it may be possible for the secondary electrons (resulting from the gamma ray) produced at places with different electric potentials to be accelerated, resulting in peak shifts [4].

2 Experiment

Our first experiment was to place a ^{56}Co source at 0° and 90° with respect to the detector. The Ge detector was biased at $\approx$ 4 kV and with a goal of resolving the peak centroid to within 100 eV. The raw data was then sorted and corrected for gain shifts (occuring with a characteristic time of $\approx$ 1 hour) with a linear regression program.

Before the data was corrected, prominent peaks were fitted with Gaussians and the χ^2 values recorded, as shown in the following table. Poor fits to the Gaussian distribution were believed to be an artifact of the gain shifts, but after performing the correction the fits still gave unacceptable χ^2 values. It is now our hypothesis that the aberrant shape of the peaks is mainly an effect of the response function of the detector that we were using, or effects from Compton scattering.

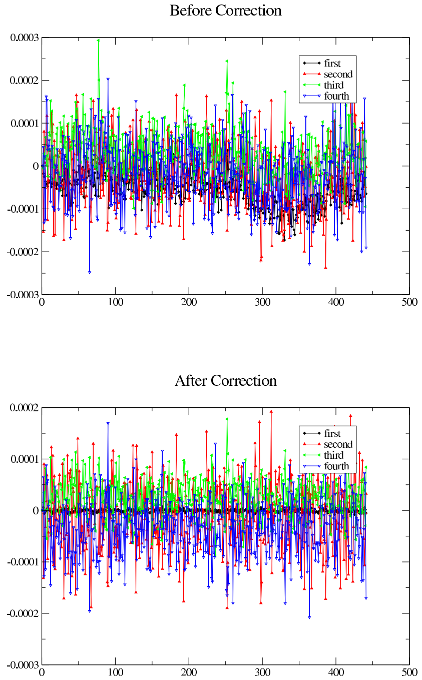

Figure 3: Linear regression corrections done to ^{56}Co data.

To check for possible peak shifts in our ^{35}Cl(n,γ) calibration reaction, neutrons are produced via ^{7}Li(p,n) with $E_p = 1912$ keV, where the protons are incident upon a thick Li$_2$O target evaporated upon a Ta backing. The resulting cone of neutrons with energies ranging up to $\approx$ 110 keV is moderated by a 4 cm thick slab of paraffin before absorbing in $\approx$ 8 x 10^3 cm^3 volume of NaCl. The resulting spectrum was measured at a back, 90^o, and forward angle with respect to the NaCl in order to see any effects that orientation might have upon our data. A ^{56}Co source

χ^2 values before and after correction

Centroid Energy	χ^2 Before	χ^2 After
846.771	157.44	153.76
977.330	1.29	1.29
1037.840	10.24	10.82
1175.102	1.95	2.13
1238.282	118.88	116.13
1360.215	46.24	44.70
1460.830	4.17	4.30
1771.351	16.66	15.19
1810.772	1.41	1.42
1963.714	1.24	1.25
2015.181	2.48	2.71
2034.755	9.72	9.17
2276.360	1.17	1.10
2598.495	24.33	23.38
3009.596	1.48	1.43
3201.962	4.47	4.37
3253.416	11.88	10.77
3272.990	2.61	2.97
3451.152	1.19	1.10

was present, with its location static with respect to the detector for comparison of the Cl peak shifts.

Currently, analysis of this data is being performed. Time permitting, conclusions should be realized allowing for us to gain an extremely accurate measurement of the mass of ^{32}S.

3 Conclusion

With continued work on isolating and correcting for the errors in our measurement, we should soon be able to achieve an accurate calibration with our $^{35}\mathrm{Cl}(n,\gamma)$ source with determinations of the centroids to within 100 eV, which will lead us to our ultimate goal of testing the IMME. However, further work is needed to ensure that all the known errors are accounted for.

4 Thanks

I'd like to thank the National Science Foundation, University of Washington, and Center for Experimental Nuclear Physics and Astrophysics for letting me participate in this year's REU program. I'd also like to thank my advisor Dr. Alejandro Garcia and Smarajit Triambak for answering my endless questions, introducing me to nuclear physics, and helping to solve the many problems I managed to create.

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