Journal Entry - Week Two - Entry One

Caspian Nicholls, u1027945

March 2, 2020

I give permission for portions of this work to be used as examples in future science communication course notes.

Article title: Measurement of the isomer production ratio for the $^{112}\mathrm{Cd}(n,\gamma)^{113}\mathrm{Cd}$ reaction using neutron beams at J-PARC.
Authors: T. Hayakawa, Y. Toh, M. Huang, T. Shizuma, A. Kimura, S. Nakamura, H. Harada, N. Iwamoto, S. Chiba, and T. Kajino
Reference: PHYSICAL REVIEW C 94, 055803 (2016).
Link: Article abstract.
Word count: 738 words.

Context

Astrophysically, neutron-deficient isotopes are generally formed in stars via the slow (s-) or rapid (r-) neutron-capture processes. Yet, the solar abundances (indicative of their broader Universal abundances) of $^{112}\mathrm{Sn}$ and $^{114}\mathrm{Sn}$ are predominantly explained by the γ-process. However, none of these processes have been able to explain the solar abundance of $^{115}\mathrm{Sn}$, so the search for its astrophysical origin continues.

Purpose

This study aimed to estimate the magnitude of the contribution of the slow neutron-capture process that results in nucleosynthesis of $^{115}\mathrm{Sn}$ from $^{113m}\mathrm{Cd}$, to try and pin down its astrophysical origin. A previous work by these authors [1] had found through statistical modelling that the ratio of the reaction cross-section for the process $^{112}\mathrm{Cd}(n,\gamma)^{113m}\mathrm{Cd}$ to the cross-section for the process $^{112}\mathrm{Cd}(n,\gamma)^{113\mathrm{gs}}\mathrm{Cd}$ (gs: ground state) is related to the abundance of $^{115}\mathrm{Sn}$ for incident neutron energies between 1 and 50 keV. Through measuring this ratio, they hoped to establish whether or not this s-process could be the primary contributor to the astrophysical formation of $^{115}\mathrm{Sn}$.

Approach

A high energy pulsed proton beam was fired onto a mercury target to initiate spallation reactions and generate a high flux beam of pulsed neutrons. This neutron beam was fired onto a $^{112}\mathrm{Cd}$ foil, with two cluster high-purity germanium (HPGe) and bismuth germanate (BGO) Compton-suppression detectors used to record the γ-rays that were emitted from the neutron-capture reactions. The neutron energies were recorded using a time-of-flight (TOF) method, by measuring the time when the detectors measured the γ-rays from the target. The energies of the recorded neutrons could be reconstructed as when a γ-ray hit any one of the fourteen crystals in their set up, the energies of all γ-rays detected by the other crystals in coincidence were also recorded in a joint list.

Contribution

The following conclusions were made as a result of this study:

- The astrophysical origin of Sn-115 remains a mystery. While its s-process abundance does depend on the isomer production ratio in the ^{112}Cd$(n,\gamma)^{113}$Cd reaction, this process' contribution is minor.
- A spin-parity of $J^{\pi} = 3/2^{-}$ was assigned to the neutron-capture (on ^{112}Cd) resonance at 737 eV. This state was reasoned to be populated by the capture of a p-wave neutron, supported by the results of calculating these branching ratios using a Hauser-Feshbach statistical model.
- Measuring isomer production ratios using an HPGe array and a TOF method was found to be an effective way of making spin-parity assignments for neutron-capture resonances.

Relevance

This paper is strongly centered around ^{113m}Cd—the isomer that I seek to study as part of my Honours project. Part of my introductory work is a summary of the nuclear physical studies that have been done on this isomer before to provide context for the work I am doing. This paper has also helped inform my ideas for which reaction processes I will use to produce this isomer using the 14UD pelletron accelerator.

Quality

The results presented were typically clearly written and well structured. Typically the approach and conclusions that were used seem reasonable and well justified. A sufficient amount of detail to solidly support the conclusions made in this study or modelling results was included. However, the explanation of the details of the implementation of the Hauser-Feshbach code within the CCONE code they used to model the neutron-capture of ^{112}Cd was not as clear as the rest of this work, because it relied quite heavily on other works through the frequent references to other articles made within that section. Overall, the level of explanation that they provided did give some sense that their model was reasonable but it was not wholly reassuring. In general, sections where they included references to other papers for further details seemed less clearly written than the rest of the paper.

Questions/Directions

I wonder if any further spin-parity assignment work using this combined TOF and HPGe detector method has been done, particularly for phenomena other than neutron-capture resonances. Given more time to explore other directions than that planned for my thesis, exploring neutron-capture resonances further would be worthwhile. This could be achieved by looking for subsequent studies by these authors or looking through the papers that have cited this article.

The only approach used in this study that I might be able to use advantageously is the time-of-flight method, given we are also going to be using HPGe and BGO detectors to measure the emitted γ-rays from the reactions we will be facilitating with the 14UD accelerator. However, given this accelerator produces beams with quite precisely-known energies, this method would probably not add any extra information to our results and thus would probably not be worthwhile.

References

[1] T. Hayakawa, T. Shizuma, S. Chiba, T. Kajino, Y. Hatsukawa, N. Iwamoto, N. Shinohara, and H. Harada, "NEUTRON CAPTURE CROSS SECTION TO ^{113}Cd ISOMER AND s-PROCESS CONTRIBUTION TO RARE p-NUCLIDE ^{115}Sn," *The Astrophysical Journal*, vol. 707, pp. 859–865, Dec. 2009.