Journal Entry - Week Three - Entry Two

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Article title: Isomer depletion as experimental evidence of nuclear excitation by electron capture.
Authors: C. J. Chiara, J. J. Carroll, M. P. Carpenter, J. P. Greene, D. J. Hartley, R. V. F. Janssens, G. J. Lane, J. C. Marsh, D. A. Matters, M. Polasik, J. Rzadkiewicz, D. Seweryniak, S. Zhu, S. Bottoni, A. B. Hayes and S. A. Karamian
Reference: Nature, 554, 216-218 (2018).
Link: Article abstract.
Word count: 817 words.

Context

Internal conversion, whereby an atomic nucleus ejects an electron to release excess energy, is a well-known and repeatedly observed event. However, the inverse process, nuclear excitation by electron capture (NEEC), has been predicted but not yet definitely observed. Here, the capture of a free electron into an atomic vacancy excites the nucleus into a higher-energy state. NEEC may result in isomer depletion, whereby an isomer is excited to a higher energy level (*intermediate state*) before emitting successive γ rays to decay toward the ground state. Isomer depletion is being investigated as a way of storing energy at energy densities (per unit mass) many orders of magnitude higher than those of chemical batteries. The observation of NEEC could bring us one step closer to realising the on-demand release of energy from isomeric states.

Purpose

This study searched for evidence of NEEC in ^{93}Mo, from its isomeric state ^{93m}Mo at 2425 keV to a candidate intermediate state at 2430 keV. Based on this isotope's level scheme, the detection of γ rays with energies of 2475, 268, 685 and 1478 keV within a sufficiently narrow time window of each other (so they are emitted in *coincidence*) would provide evidence for NEEC. Both ^{93m}Mo and the 2430 keV states emit a 268-keV γ ray, but only the latter does so at a rate that we can measure. Hence, only if the ^{93m}Mo isomer is excited to the intermediate state will these coincident emissions be observed.

Approach

The nuclear reaction $^{7}\mathrm{Li}(^{90}\mathrm{Zr}, \mathrm{p3n})^{93}\mathrm{Mo}$ was used to produce ^{93}Mo in excited states with energies above that of the isomer, so that they could decay into the isomeric state. Collisions between the emanant ^{93m}Mo nuclei and atoms in the target resulted in the nuclei being ionized and electrons being scattered from the target atoms. If the charge state of a ^{93m}Mo ion is such that it has a deep atomic orbital at an energy $\sim$5 keV (matching the energy between the isomer and the intermediate state) from an atomic state that can be occupied when an electron is captured, then if the kinetic energy of a scattered electron is sufficient to excite the ^{93m}Mo nucleus into this intermediate state, NEEC will occur. The reaction conditions were chosen to ensure that the effective kinetic energy of electron collisions exceeded the predicted amount required to satisfy this energy-matching condition. The chance of recording these events (unobscured by other γ rays) was maximised by setting the detectors within the utilised Gammasphere γ ray spectrometer to only record signals when three or more γ rays were emitted within 2 μs of each other.

Contribution

The expected signature of NEEC (the γ ray emission sequence $2475 \rightarrow 268 \rightarrow 685 \rightarrow 1478$ keV) was observed. The probability of NEEC was calculated as $\geq 0.010(3)$, by analysing the intensity ratio of the 268 keV-peak (unique to NEEC events) to the 2475 keV-peak (characteristic of ^{93m}Mo formation). To solidify their conclusion that they had observed NEEC, the authors then:

- Repeated the same nuclear reaction they used to observe NEEC, but with beam energy below that required to produce ^{93}Mo ions with the necessary energy to facilitate NEEC. The coincident γ rays that indicate NEEC occurred were not observed, ruling out reactions that were not $^{90}\mathrm{Zr}(^{7}\mathrm{Li}, p3n)^{93}\mathrm{Mo}$.
- Fabricated their target in such a way that the other materials (carbon and lead) in their target could not react with the ^{90}Zr beam particles to produce the key γ rays they observed.
- Ran simulations to confirm that the probability of ^{93m}Mo being excited to the 2430 keV intermediate state through inelastic scattering in the lithium, carbon or lead layers ($\mathrm{Pr} \lesssim 10^{-6}$) of the target was too small to account for the experimental probability they measured.

Relevance

We are trying to find a possible isomer depletion pathway through which energy can be released from the isomer ^{113m}Cd. This paper suggests that observing isomer depletion caused by NEEC (and thus identifying potential intermediate states) may be feasible if a nuclear reaction with heavy projectile nuclei and light target atoms is used.

Quality

This paper was well-written and made for straightforward reading. The approach used and the conclusions made were well justified, particularly in the supplementary methods section where additional details to support the decisions they made regarding the experimental design are provided.

Questions/Directions

Looking for other studies that have cited this paper would be a good place to start working towards understanding the finer details and potential applications of NEEC. This could also be a way to see what developments have been made in this area (especially in terms of NEEC-based isomer depletion). For my project, we plan to fire light-ion beams onto a ^{110}Pd target foil, but our 14UD accelerator could not accelerate a ^{110}Pd beam to a high enough energy to initiate a heavy-projectile-light-target approach like these authors used.