Journal_Entry_Two_u1027945.pdf

by Student D6FBD46A29A85

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Journal Entry - Week Three - Entry Two

Caspian Nicholls, u1027945

March 9, 2020

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

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: 749 words.

Context

Internal conversion, whereby an atomic nucleus ejects an electron to release excess energy, is a well-known and experimentally observed phenomenon. However, the inverse process, nuclear excitation by electron capture (NEEC), has been predicted but not yet definitively 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 2430 keV intermediate state will these coincident emissions be observed.

Approach

Jargon

The nuclear reaction ^{7}Li(^{90}Zr, p3n)^{93}Mo was used to produce excited states of ^{93}Mo 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 becoming ionized and electrons being scattered from the target atoms. If the charge state of a ^{93m}Mo ion is such that it has a sufficiently deep atomic orbital at an energy $\sim$5 keV from an atomic state that can be occupied when an electron is captured (matching the energy between the isomer and the intermediate state), 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 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 (which is characteristic of ^{93m}Mo formation). To solidify their conclusion that they had observed NEEC, the authors:

- Repeated the same nuclear reaction they used to observe NEEC, using a 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 $^{90}\mathrm{Zr}(^{7}\mathrm{Li}, p3n)^{93}\mathrm{Mo}$ as causing NEEC.

- 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 crucial γ rays.

- 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 (Pr $\lesssim 10^{-6}$) of the target was too small to account for the experimental probability they measured.

Relevance

We are searching for 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 achievable using a nuclear reaction with heavy projectile nuclei and light target atoms.

Quality

This paper was well-written and made for straightforward reading (unsurprising given it is from *Nature*). 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 enable further investigation of the finer details and potential applications of NEEC, or seeing 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 ANU's 14UD accelerator can not accelerate a ^{110}Pd beam to a high enough energy to make a heavy-projectile-light-target approach worthwhile.

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ORIGINALITY REPORT

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1	Submitted to Australian National University Student Paper	9%
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3	www.nature.com Internet Source	1%

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GRADEMARK REPORT

FINAL GRADE

95/100

GENERAL COMMENTS

Instructor

header	/1	1
context	/3	3
purpose	/2	2
approach	/4	3
contribution	/4	4
relevance	/2	2
quality	/1	1
questions	/1	1
writing	/2	2

Overall, very good - you have done an excellent job of explaining and interpreting their study. Just pay a little bit of attention to your use of jargon.

PAGE 1

Comment 1

good job in this paragraph explaining terms, but you do need to explain what an isomer is. it is a crucial concept for your paper.

Comment 2

this context is very clear.

Comment 3

good.

QM

Jargon

Unexplained jargon or technical language: consider whether this usage is necessary, and if so explain for a general reader.

Comment 4

this is not understandable to a non-nuclear person - use words. If I knew what, e.g. the target was, the whole section would be easier to understand.

Comment 5

This is a very complex sentence, bit too technical and hard to follow. Since it is the key part that explains the method, you want to make it quite clear.

Comment 6

now that you have a few more details, you could explain why this is a signature of NEEC

Comment 7

it is unclear what this is a probability of. This emission vs other decay pathways? Chance of detection in a window?