

# Investigation of $^{148,150,152}\text{Ce}$ and $^{113m}\text{Cd}$ using time-correlated gamma ray-coincidence spectroscopy

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## Context and Aims

Nuclear physics is first and foremost the study of nuclei, of which there are hundreds. Among the various experimental and theoretical projects being undertaken in this field, there are researchers performing experiments to try and understand the patterns of nuclear structure that exist across the chart of nuclides. One such phenomenon exhibited by isotopes with neutrons numbers  $N$  around 88 is that of strong octupole collectivity: long-range interactions between nucleons that reside in orbitals separated by three units of both orbital and total angular momentum. Predictions based on models of nuclear structure have been made for the range of nuclides that should exhibit this behaviour, but it has not been experimentally observed for each isotope in this list.

At the same time, a dedicated research campaign is being undertaken to assess the potential of excited states of certain isotopes with relatively long half-lives (known as *nuclear isomers* or metastable states) for storing large amounts of energy in a space-efficient manner over long periods of time.

The first stage of this project will comprise an investigation of yet unanalysed experimental data collected during an experiment with the aim of exploring the structure of isotopes  $^{148,150,152}\text{Ce}$ . These nuclides have  $N = 90, 92$  and  $94$  respectively and are thus expected to exhibit strong octupole collectivity. Following that, should time permit, new measurements will be made to extend knowledge of the structure of the isomer  $^{113m}\text{Cd}$  (the  $m$  denotes the long half-life (14.1 years [1]) of this metastable) and explore its energy storage potential.

## Octupole collectivity

The correlations associated with octupole collectivity are one key factor that governs the level schemes of different nuclides. Most isotopes that exhibit this property have mass numbers  $A$  in the vicinity of either 146 or 222. Nuclei of Ce with  $N \sim 88$  fall into the former category, having traits linked to the presence of significant octupole correlations, rendering them as intriguing cases from which we can learn about nuclear structure.

However, currently only some of the excitation energies and lifetimes of the low lying negative-parity states of  $^{148,150,152}\text{Ce}$  are known. Measuring values of these quantities enables determination of the quadrupole and dipole moments for these nuclides, which in turn allows their quadrupole and octupole collectivity to be assessed. By analysing gamma ray spectra recorded using an array of gamma ray detectors (known as Gammasphere) this project aims

to make measurements of these quantities and thus gauge the afore-mentioned collectivities for these isotopes. Ideally, this will include the first measurement of octupole collectivity in  $^{150}\text{Ce}$ . For the ground state of  $^{152}\text{La}$ , determination of its lifetime and placing bounds on its spin are some additional goals of this part of the project. Doing so will enhance the existing understanding of octupole correlations displayed by the low spin excited states of these cerium nuclei.

## Nuclear isomers

By and large, excited states of atomic nuclei release their excess energy on femtosecond time scales. Yet, there exist long-lived excited nuclear states with half-lives up to 30 orders of magnitude greater than this [1]. The typical energy densities of these isomers are around  $10^9$  J/g, approximately five orders of magnitude higher than the limit placed on chemical means of energy storage (fuels, batteries, food) by the binding energy between particles ( $\lesssim 100$  eV).

For the goal of harnessing this dense energy source, many nuclear isomers with half-lives on the order of years (or greater) have been identified as potentially useful. The question for each such metastable, however, is are there ways by which this energy can be released? Current work in this field is centred around searching for a reaction pathway that will cause the isomer to dispense its energy by moving into a lower energy state.

The leading suggestion for such a reaction pathway is that of isomer depletion. In this process, a sample containing some nuclear isomer is exposed to a beam of high-energy photons. If the isomer absorbs a photon that has the appropriate energy to excite the isomer to a state with a much shorter half-life, then the isomer will decay (via either a single gamma ray transition, or a cascade of multiple gamma ray emissions) to the ground state of that isotope. This process was first reported when a sample of the isomer  $^{180m}\text{Ta}$  was excited to a so-called depletion level (or intermediate state) in 1988, demonstrating that the energy of these isomers can be released on demand [2]. The decay of the metastable state was followed by the decay of the ground state, which resulted in a total of 780 keV being emitted.

However, the energy required to initiate this depletion process was 1000 keV, prompting investigation of other isomers with half-lives in excess of one year, of which ten others have been identified for an ongoing research campaign [1]. With funding provided as part of this campaign, this project aims to experimentally study the isomer  $^{113m}\text{Cd}$  (with energy 263.54 keV above the ground state and a half-life of 14.1 yr) of the isotope  $^{113}\text{Cd}$ , with the primary goal of identifying such an energy-releasing pathway. As part of this overarching aspiration, there are the sub-goals of gaining expertise in gamma ray spectroscopy, nuclear instrumentation and the operation of the 14UD tandem accelerator located at the ANU. In addition, I am to develop my skills in analysing multi-parameter data sets that will be generated as a result of the experimental part of this project. Finally, I aim to meaningfully interpret the results of this analysis under the framework of a range of theoretical models of nuclear structure.

## Background

### Octupole collectivity

### Nuclear isomers

The nucleons contained within nuclei preferentially arrange themselves into the most stable (lowest energy) configuration, which is known as the ground state. Nuclei are split into three



## Project Description

## Project Plan and Feasibility

## References

- [1] E. Shaffer and T. Zheleva, *Innovations in Army Energy and Power Materials Technologies*. Millersville, PA: Materials Research Forum LLC, 2018. OCLC: 1051140034.
- [2] C. B. Collins, C. D. Eberhard, J. W. Glesener, and J. A. Anderson, “Depopulation of the isomeric state Ta m 180 by the reaction Ta m 180 (  $\gamma$  ,  $\gamma'$  ) Ta 180,” *Physical Review C*, vol. 37, pp. 2267–2269, May 1988.
- [3] J. Blachot, Nucl. Data Sheets, 111, 1471 (2010), data extracted from the ENSDF database, revision of June 2010.