Research Proposal

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Context and Aims

- field: fundamental nuclear physics and energy storage
- problem we are trying to solve: looking for evidence of isomer depletion in ^{113}Cd and trying to find an intermediate state that is part of a depletion pathway. If we find such an intermediate state, or observe isomer depletion, this will be a significant step towards realising the use of nuclear isomers for long-lived, high (spatial) density energy storage.
- Motivation: finding a way to release the energy stored in nuclear isomers to allow us to realise energy storage at high energy density with a long "half-life" (14.1 years in the case of ^{113m}Cd [1])
- Motivation #2: refining/developing the level scheme of ^{113}Cd ('investigating the nuclear levels of ^{113}Cd"), in particular by looking for candidate intermediate states/depletion levels.
- Motivation #3: measuring reaction cross sections for the reactions $^{7}\text{Li}(^{110}\text{Pd}, p3n)^{113}\text{Cd}$ and $^{9}\text{Be}(^{110}\text{Pd}, 2p4n)^{113}\text{Cd}$ (or$^{7}\text{Li}(^{110}\text{Pd}, tn)$ and $^{9}\text{Be}(^{110}\text{Pd}, \alpha 2n)^{113}\text{Cd}$).
- Motivation #4: investigating breakup of the compound nuclei ^{7}Li ($\alpha + t$) and ^{9}Be ($2\alpha + n$) [2–6]
- Tentative motivation #5: observing NEEC (may have been observed in 2016, but the jury is out on that one).

Outline of how this section might flow:

- There is a chemical limit on the intrinsic energy density of chemical fuels and batteries of around 10^5 J/g [1].
- As the demand for energy and power continues to grow around the world, and the space available to us remains constant, finding ways to generate more energy in the same amount of space is becoming progressively more crucial.
- Radioisotopes are one medium that can store energy at a greater mass density than chemicals, with energy densities on the order of 10^9 J/g [1].
- Aside: these materials can also have long half-lives (on the order of years or greater), enabling means of storing energy that can potentially be useful over extended periods of time.

- However, some radioisotopes also have excited states which also have long half-lives. These *metastable* states, known as *nuclear isomers*, could potentially allow for even greater energy densities to be achieved than would be possible with only the ground state forms of radioisotopes.
- Around eleven long-lived isomers with half-lives in excess of one year are known (their half-lives range over 16 orders of magnitude (in years)).
- Yet it is not known if there is a means of releasing the energy from these isomers on demand.
- The isomer ^{113m}Cd, with a half-life of 14.1 years [1], is one such example of a metastable form that does not have a known pathway along which the energy can be released. The half-life of this isomer is such that it is fit for relatively long-term energy storage applications, should such a pathway be discovered.
- Research campaigns are already being undertaken into some other long-lived isomers as part of a collaboration between the ANU and the US Army. As yet, an exploration into the potential of ^{113m}Cd has not been conducted [1]. My project aims to fill this void by conducting experiments to investigate the nuclear levels of ^{113}Cd and search for a pathway within the energy level structure of this isotope via which the energy of the isomer can be harnessed.

Aims

- Investigate the nuclear levels of 113Cd by reconstructing pathways through which nuclear excited states decay by the emission of gamma rays (using gamma spectroscopy). Ideally, find a suitable candidate depletion level that is known to decay into the isomeric state, or at least add new levels to the known scheme of this isotope.
- Gain expertise in gamma ray spectroscopy.
- Gain expertise in using nuclear instrumentation and operating the 14UD tandem accelerator.
- Develop my skills in analysing multi-parameter data sets using a new digital data acquisition system.
- Interpret my results within a range of theoretical nuclear-structure models (shell model, ...)
- Secondary goals:
  - Measure cross sections for certain nuclear reactions
  - Utilise and test charged particle detectors (GAGG)
  - Record and quantify/qualify evidence of breakup in nuclear reactions

Background

"Background information necessary to understand my particular project".

- Why do nuclear isomers exist? Vibrations, rotations, collective motion. Selection rules and forbidden photon transitions. From physics of matter (lecture 26 Greg), nuclear isomers exist because the decay of the isomeric state is inhibited, generally from a combination of the following factors:

- The state can only decay (by spontaneous emission) via a high multipolarity gamma-ray transition, which are known to be relatively slow (compared to lower multipolarity transitions). It could be this for 113Cd, as the spin-parity of the isomer is $11/2^-$ whilst the ground has $J^\pi = 1/2^+$ (E5 or M6 transition since there is a change in parity).
- The most probable decay path is a very low energy transition - the Weisskopf estimates show that low energy transitions are strongly inhibited.
- The wavefunction overlap between the parent and daughter wavefunction is very small, inhibiting the decay.

- Energy level scheme for cadmium 113.
- The process of isomer depletion. What is an intermediate state/depletion level?
- Breakup phenomenon. Why breakup occurs (because of the cluster structures of 7Li and 9Be).
- What is a cross section?

Project Description

Project Plan and Feasibility

References

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[3] W. von Oertzen, "Two-center molecular states in9B,9Be,10Be, and10B," *Zeitschrift für Physik A Hadrons and Nuclei*, vol. 354, pp. 37–43, Dec. 1996.

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