

Precision Half-life Measurements of Excited States in $^{146}_{62}\text{Sm}$

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Abstract

We propose to measure the decay probabilities from the 6_1^+ and other populated states in ^{146}Sm . Excited states in ^{146}Sm will be populated via the $^{139}\text{La}(^{11}\text{B},4n)$ fusion-evaporation reaction, at a beam energy of 52 MeV. De-exciting γ -rays will be detected in ROSPHERE; a mixed fast-timing array of cerium-doped lanthanum bromide ($\text{LaBr}_3(\text{Ce})$) and high-purity germanium (HPGe) detectors. Measuring the half-lives and thus the transition probabilities from isomeric states in ^{146}Sm and its neighbouring nuclei, will allow us to investigate the systematics of nuclei around the proton ($Z=64$) sub-shell and $N=82$ shell closures, providing a test for shell model calculations.

1 Motivation

The nuclei in the $A \sim 150$ region have been the subject of considerable investigation. In particular, the samarium isotopes have been extensively studied since these accessible nuclei span the transitional region from below the $N=82$ closed shell (^{144}Sm) to strongly deformed nuclei with $N \approx 92$.

The level structure of the ^{146}Sm nucleus (with 62 protons and 84 neutrons) cannot be interpreted in terms of simple collective models as it shows neither clear vibrational nor rotational structure. It is also only a few nucleons removed from ^{146}Gd which has 64 protons and 82 neutrons and exhibits doubly magic shell structure effects, the 3^- octupole state is the lowest-lying excitation, only 1579 keV above the g.s. compared with 2615 keV in ^{208}P [1]. The ^{146}Sm and ^{144}Nd nuclei present a low-lying 3^- level, at energy close to that of the corresponding level of ^{148}Gd . Some states of these nuclei can be interpreted as a result of an octupole excitation built on low lying positive-parity states, such as the weak-coupling multiplet ($2^+ \otimes 3^-$) [2].

One of the common features of the $N=84$ isotones (^{148}Gd , ^{146}Sm and ^{144}Nd) (See Fig. 1) is the existence of a negative parity level sequence converging on to the $I^\pi=9^-$ isomeric level [4]. There is a difference observed in the de-excitation modes of the 9^- state in the various $N=84$ isotones. In ^{148}Gd the 9^- level is observed to be isomeric with a half-life of $T_{1/2}=17.5$ ns. The $I^\pi=9^-$ level de-excites through $E3$, ($9^- \rightarrow 6^+$) and $E2$, ($9^- \rightarrow 7^-$) transitions. Two transitions very close in energy, 883.5 keV ($8^+ \rightarrow 6^+$) and 883.8 keV ($9^- \rightarrow 6^+$), have also been observed to populate the $I^\pi=6^+$ state in ^{148}Gd . This situation is not observed in ^{146}Sm and ^{144}Nd , where the 9^- state is de-excited by means of an $E2$, ($9^- \rightarrow 7^-$) transition and an $E1$, ($9^- \rightarrow 8^+$) transition.

In ^{146}Sm , the half-life of the $I^\pi=6^+$ yrast state of 0.09 ns is limited to a 1982 report with an uncertainty approaching 110% [3]. The aim of the current proposal is to use the gamma-ray fast-timing coincidence timing method to establish accurate values for the transition rates from the $I^\pi=6^+$ and other excited states in ^{146}Sm .

A successful experiment performed in Bucharest last year measured the half-lives of the 6^+ , 5^- , 11^+ and 14^+ states in ^{138}Ce , (eight valence protons outside the $Z=50$ closed shell and two neutron holes with respect to $N=82$) [5]. Figure 2 shows the fitted exponential decay of the yrast 6_1^+ state in ^{138}Ce , resulting from the time difference observed between the 815-keV "Start" and 467-keV "Stop" γ -ray transitions above and below this state, detected with the $\text{LaBr}_3(\text{Ce})$ detectors. These gated energies were then used to increment a $E_{\gamma_1}-E_{\gamma_2}-\Delta t$ cube, with "anticipated" gates in the HPGe detectors[7]. This time-difference spectrum was fitted with an exponential decay, convoluted with a Gaussian time resolution, giving $T_{1/2}=880(19)$ ps [5] for the 6_1^+ .

2 Experimental Overview

The $I^\pi=6_1^+$ and other excited levels in ^{146}Sm will be populated using $^{139}\text{La}(^{11}\text{B},4n)$ fusion-evaporation reaction at a beam energy of 54 MeV. The Coulomb barrier of this reaction ($^{139}\text{La}+^{11}\text{B}$), is expected to be ~ 39 MeV. The cross-section was calculated using PACE4 [8] and was found to

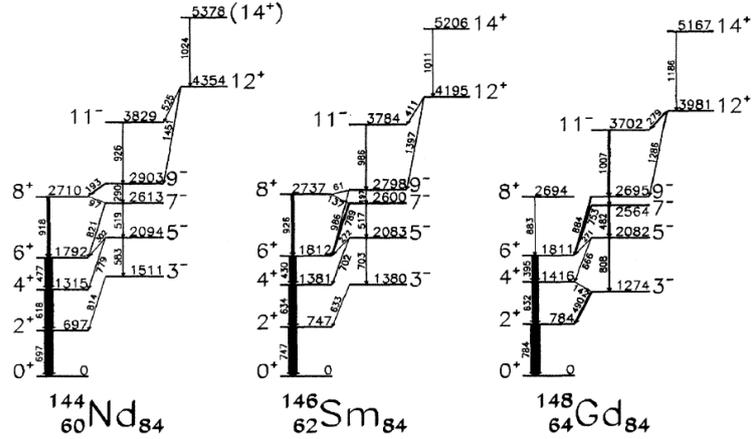


Figure 1: Partial energy level scheme of the $N=84$ isotones ^{148}Gd , ^{146}Sm and ^{144}Nd [1].

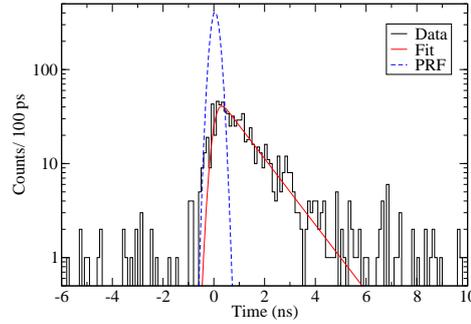


Figure 2: Time spectra of the 6_1^+ , showing the time difference between the 467- and 815-keV transitions in ^{138}Ce . The continuous line is the Gaussian exponential convolution fit to the spectra [5].

be ~ 700 mb at 52 MeV corresponding to approximately 83% of the total fusion cross-section. The γ -rays produced in this reaction will be detected using the mixed ROSPHERE array of $\text{LaBr}_3(\text{Ce})$ and HPGe detectors [7]. The HPGe detectors will be used to gate on the transitions of interest to produce relatively clean $\text{LaBr}_3(\text{Ce})$ - $\text{LaBr}_3(\text{Ce})$ spectra, which will be used to create the E_{γ_1} - E_{γ_2} - Δt cube. Analysis using the centroid shift method with the $\text{LaBr}_3(\text{Ce})$ detectors will allow us to make half-life measurements down to around ~ 30 ps [7, 6].

We aim to measure the half-lives and branching ratios of excited states in ^{146}Sm by taking the time difference between the feeding and de-exciting transitions as described in Ref. [7]. It is envisaged that with the ROSPHERE array at Bucharest, we can improve on the tentative half-life of 0.09^{+10}_{-5} ns that has been assigned to the $I^\pi=6^+$ yrast state [9].

3 Beam-Time Request

The cross-section for this reaction is estimated to be ~ 700 mb. A minimum beam current of ~ 10 pA will be used with a 1 mg/cm^2 ^{139}La target to create 19×10^4 ^{146}Sm ions/s. Using an estimated 10% population of the 6_1^+ state, 2% HPGe efficiency and an average $\text{LaBr}_3(\text{Ce})$ efficiency of 0.5%, we can expect 34 useful $\text{Ge-LaBr}_3(\text{Ce})\text{-LaBr}_3(\text{Ce})$ coincidences per hour or roughly 800 coincidences a day. Therefore, with 5 days of beam time, it is estimated that we will obtain enough statistics to perform accurate centroid shift measurements of the half-lives we hope to measure.

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