Shell model based Coulomb excitation γ-ray intensity calculations in ^{107}Sn

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Abstract. In this work we present recent shell model calculations, based on a realistic nucleon-nucleon interaction, in the light ^{107,109}Sn nuclei. By combining the calculations with the semi-classical Coulomb excitation code GOSIA, a set of γ-ray intensities has been generated. The calculated intensities are compared with data from recent Coulomb excitation studies in inverse kinematics at the REX-ISOLDE facility with the nucleus ^{107}Sn. The results are discussed in the context of the ordering of the single-particle orbits relative to ^{100}Sn.

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1. Introduction

The single neutron states relative to the closed shell nucleus ^{100}Sn are key ingredients for understanding the nuclear properties of nuclei in the $N = 50$ shell to the $N = 82$ shell. These states, along with the residual interaction between valence neutrons, are the basic input for shell model calculations in the light Sn isotopes. The five lowest-lying relevant neutron single particle energies (SPEs) these for calculations consist of the $d_{5/2}, g_{7/2}, d_{3/2}, s_{1/2}$, and $h_{11/2}$ levels. The orbits can in principle be inferred by studying the excited states in ^{101}Sn. However, these measurements have been hampered by difficulties in producing the extremely neutron deficient isotope ^{101}Sn. The current experimental data is limited to the energy splitting between the ground-state and the first excited state, which was measured to be 172 keV in the β-decay of ^{101}Sn [1] and later confirmed in an experimental study of the $\alpha-$decay chain ^{109}Xe$\rightarrow$^{105}Te$\rightarrow$^{101}Sn [2]. In the former experiment, the 172 keV γ-ray was attributed to the transition of a single neutron from the $g_{7/2}$ orbit to a lower-lying $d_{5/2}$ orbit. In the α-decay study, the authors however suggest a $7/2^+$ ground-state followed by a $5/2^+$ first excited state. In both studies, experimental energies in the light odd-Sn isotopes were compared with shell model calculated energies to help identify the ordering of the single-particle states in ^{101}Sn. In addition, it is reasonable to expect that the transition probabilities between the various states would also be affected by the ordering of the single-particle orbits. The ordering may also be important for explaining the measured increase of the $E2$-strengths in the light even-even Sn nuclei [3, 4, 5, 6].

In this work, we have carried out shell model calculations for the nuclei ^{107,109}Sn. The calculations are combined with the semi-classical Coulomb excitation code GOSIA [7] to produce γ-ray intensities which are directly compared with experimental data. A similar approach has been previously used to investigate the low-lying states in the odd-odd isotopes ^{106,108}In [8]. Here, the method is tested against recent results from Coulomb excitation measurements with the nucleus ^{107}Sn at REX-ISOLDE. These measurements will be the subject of a future publication [9]. The results are analyzed in the context of the ordering of the single-particle orbits relative to ^{100}Sn.

2. Shell model calculations

In the following, we discuss shell model calculations for the nuclei ^{107,109}Sn, starting from a realistic nucleon-nucleon interaction derived from a G-matrix renormalized CD-Bonn potential. The basic approach has been outlined in Ref [10] and the interaction/renormalization scheme has been frequently applied to the light even-even Sn nuclei; for example see Refs. [4, 6].

In addition to the effective interaction, the remaining input for the shell model calculations comprise of a set of single-particle energies relative to ^{100}Sn. As the experimental evidence for these levels in ^{101}Sn is limited at this time, the orbits can instead be determined by fitting the energies levels of the light odd-Sn nuclei. In this study the experimentally determined level scheme of ^{109}Sn is used for this purpose [11, 12]. The function to be minimized is of the standard chi-square type, where the ground-state and excited states are given equal weight. In the fit, some constraints are placed on the single particle orbits. Namely, the energy splitting between the $d_{5/2}$ and $g_{7/2}$ is fixed to be the experimentally determined value of 172 keV and the $h_{11/2}$ orbit is set to 3.0 MeV, as given in Ref [10]. The $d_{3/2}$ and $s_{1/2}$ orbits and the ordering of the $d_{5/2}$ and $g_{7/2}$ states then define the free parameters to be determined. The best sets of single-particle orbits from the two separate fits are shown in Fig. 1.

The calculated excited states for ^{107}Sn and ^{109}Sn, using the single-particle orbits given in Fig. 1, are compared with the experimental energy levels in Fig. 2. Interestingly, regardless of the choice of the lowest-lying single particle orbit relative to ^{100}Sn, the ground state of ^{107}Sn and ^{109}Sn comes out to be $5/2^+$, in agreement with the experimentally observed spin. In addition, the experimentally measured excited states are well reproduced for both cases, thus making it difficult to draw conclusions regarding the ordering of the first two single-particle orbits from the energy levels alone.

3. GOSIA intensity calculations

The shell model calculations, described in the previous section, can be combined with the semi-classical code GOSIA to calculate γ-ray spectra, which can be directly compared to experiment. The two-body matrix elements and energy levels, resulting from the shell model calculations are used to create a set of $E2$ and $M1$ transition

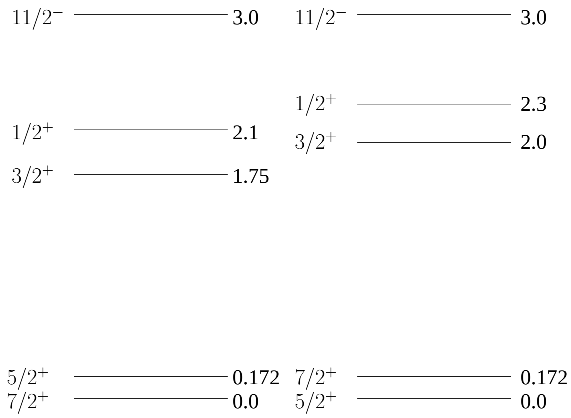

Figure 1. Best fits of single-particle energies (MeV) relative to ^{100}Sn with (right) $5/2^+$ ground-state and (left) $7/2^+$ ground-state used in the present work. See text for details.

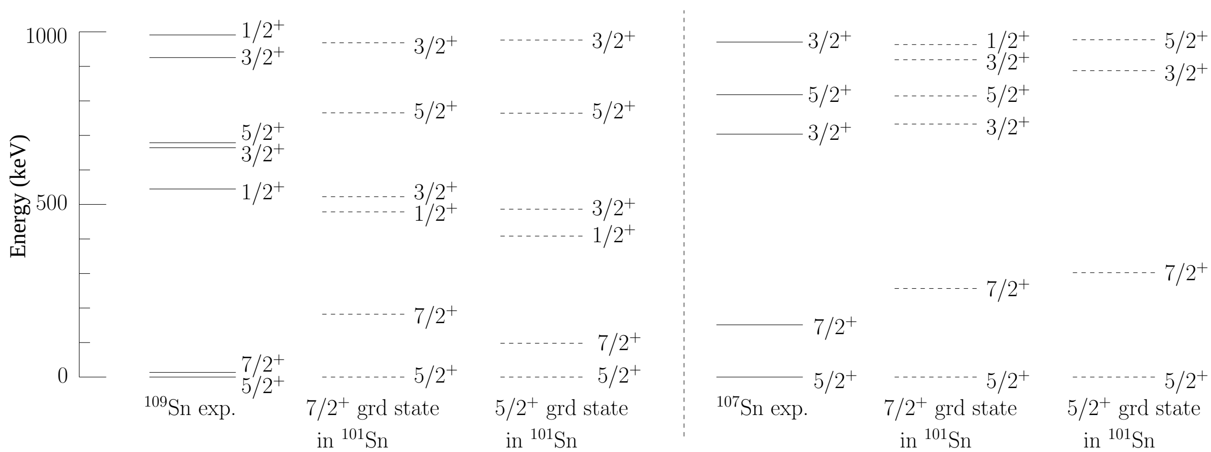

Figure 2. Comparison of experimentally determined energy levels (solid lines) in ^{109}Sn [11, 12] and ^{107}Sn [11, 13] with shell model calculated energy levels (dashed lines) using the sets of single-particle energies in Fig. 1.

matrix elements which serve as input for the code GOSIA. The matrix elements were generated with the neutron effective charge set to $e_\nu = 1.0e$ and the neutron g-factors set to g_l=0 and g_s=-3.82. In addition, the relevant parameters which define the experimental setup, i.e., the particle and γ-ray detector geometries, efficiency curves, target thickness, conversion coefficients, and beam energy, are provided as input to the code. The result of the calculation is a set of theoretically calculated relative γ-ray intensities. Comparison with experiment is carried out by normalizing one of the calculated intensities to the intensity of an experimentally observed transition. The intensities are subsequently Doppler broadened to meet the experimentally measured FWHM as a function of energy and added to the experimentally determined γ-ray

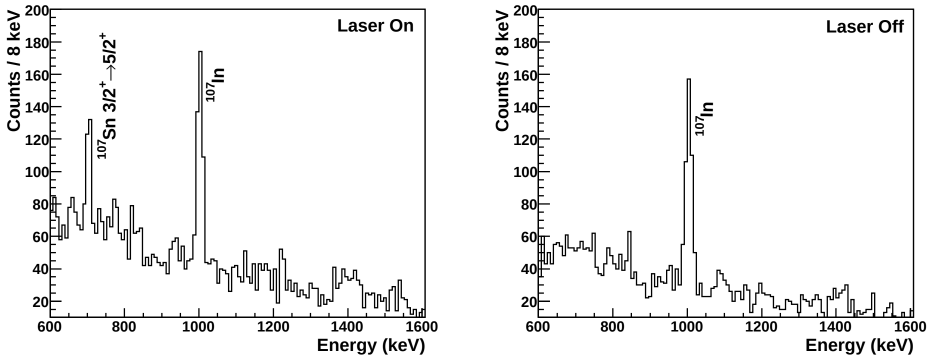

Figure 3. Preliminary experimental results from the Coulomb excitation of ^{107}Sn at REX-ISOLDE with the laser ionization turn on (left panel). The strong ^{107}In line is still present when the laser ionization is switched off (right panel) indicating that it does not originate from the Coulomb excitation of ^{107}Sn.

background spectrum.

The theoretically calculated spectra are compared with recent results from a Coulomb excitation experiment on ^{107}Sn. The data were collected at the REX-ISOLDE facility utilizing the MINIBALL γ-ray array combined with a double-sided silicon strip detector (DSSSD) placed downstream of the ^{58}Ni target. The methods of production of the ^{107}Sn beam, post-acceleration, data collection, and data analysis are very similar to a number of previous measurements [4, 6, 8, 14]. We present preliminary results, which are shown in the left panel of Fig. 3, for comparison with our shell model calculations. The observed γ-ray at 704 keV arises from the $3/2^+ \rightarrow 5/2^+$ dexcitation in ^{107}Sn. The strong line around 1000 keV originates from either the Coulomb excitation of the beam contaminant, ^{107}In, or from the decay chain ^{107}Sn$\rightarrow$^{107}In$\rightarrow$^{107}Cd$\rightarrow$^{107}Ag. The contaminant structure is present when the laser ionization flag is turned off during the analysis, as shown in the right panel of Fig. 3, thereby confirming that it does not originate from the Coulomb excitation of ^{107}Sn. It should be noted that the $3/2^+$ assignment for the 704 keV level in ^{107}Sn is based on the β-decay studies performed in Ref. [11].

The calculated spectra, based on the combined shell model and GOSIA approach, are shown in Fig. 4 for both choices of the single-particle ordering relative to ^{100}Sn. The lowest lying $3/2^+ \rightarrow 5/2^+$ transition was used as normalization to the experimental data. The experimentally measured spectrum in Fig. 3 is well reproduced with the choice of a $7/2^+$ as the lowest-lying neutron single-particle orbit. In this case, the strongest predicted γ-ray to be observed is from the $3/2^+ \rightarrow 5/2^+$ transition. Interestingly, assigning the lowest lying orbit a $5/2^+$ spin results in a complex decay pattern which is not supported by the experimental data. The calculations predict, assuming that 150 counts are collected in the 888 keV $3/2^+ \rightarrow 5/2^+$ peak, that several higher energy lines should have been observed above the background. For example, the 1364 keV $7/2^+ \rightarrow 5/2^+$ peak would have about 90 counts and the 1108 keV $3/2^+ \rightarrow 5/2^+$ and 977 keV $5/2^+ \rightarrow 5/2^+$ transitions would have about 70 and 60 counts, respectively.

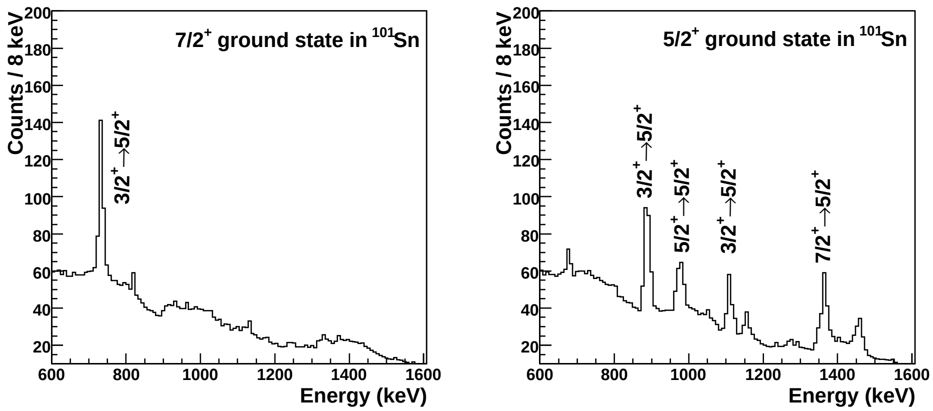

Figure 4. Calculated γ-ray spectra using the combined GOSIA and shell model approach for a (left) $7/2^+$ and (right) $5/2^+$ ground-state in ^{101}Sn with the single particle energies from Fig. 1. See text for details on the generation of the spectra.

4. Summary

In conclusion, we present preliminary shell model calculations combined with the semi-classical Coulomb excitation code GOSIA to calculate a set of γ-ray yields. The method is tested against data from the Coulomb excitation of ^{107}Sn at REX-ISOLDE. The initial results indicate that the experimentally observed decay patterns are best represented with the choice of a $7/2^+$ as the lowest-lying neutron single-particle orbit relative to ^{100}Sn. Continuation of the work will be carried out by comparing results of the shell model and GOSIA approach with recent data from the Coulomb excitation of ^{109}Sn, which will be the subject of a future publication [9].

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