Sub-barrier Coulomb excitation of ^{107}Sn

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Abstract. A Coulomb excitation experiment in inverse kinematics has been carried out at the REX-ISOLDE facility in order to study the properties of low-lying excited states in ^{107}Sn. The measured γ-ray spectrum has been compared to predicted γ-ray spectra from a combined shell-model and GOSIA analysis. In this approach, a set of matrix elements, generated within the shell-model framework, based on a realistic nucleon-nucleon interaction and a set of single-particle energies in ^{101}Sn, is used as input. Comparison between the calculated and predicted spectra can be used to help identify the placement of the single-neutron states in ^{101}Sn. In particular, the results can potentially provide clues on the ordering of the two lowest-lying orbits; the $g_{7/2}$ and $d_{5/2}$ states.

1. Introduction

Over the last several years, experimental studies have been approaching the doubly magic nucleus ^{100}Sn. Nuclei in the vicinity of the shell closure provide valuable information for calibrating theoretical models and for predicting the structure of nuclei in the $N = 50$ to $N = 82$ shell. The single-neutron states relative to the closed shell, for example, are one of the main input parameters for shell-model calculations. Identification of the energy of these states can therefore provide important constraints for these calculations. Experimental studies in the vicinity of ^{100}Sn are however hampered by low production cross-sections and thus little information is currently known about the single-neutron states relative to ^{100}Sn. These states, relevant for the shell model, include the $d_{5/2}$, $g_{7/2}$, $d_{3/2}$, $s_{1/2}$, and $h_{11/2}$ orbits. To this date, the only conclusive information regarding these orbits is the energy splitting between the two lowest-lying $d_{5/2}$ and $g_{7/2}$ neutron states, measured to be 172 keV in the β-decay of ^{101}Sn [1] and later confirmed in a study involving the α-decay chain ^{109}Xe$\rightarrow$^{105}Te$\rightarrow$^{101}Sn [2]. The two studies however arrived at different conclusions regarding the spin ordering of the two orbits. In the current work, we have carried out Coulomb excitation measurements on the nucleus ^{107}Sn. We have compared the collected γ-ray spectra to predicted γ-ray spectra calculated from a shell-model and GOSIA [3] analysis. The input for these calculations includes an effective nucleon-nucleon interaction and a set of single-neutron states relative to ^{100}Sn. We find that the calculated γ-ray spectra are dependent on the ordering of the two lowest-lying orbits. The method can therefore be potentially used to help identify the ordering of the orbits. It is also interesting to note that the ordering may be important for describing the measured enhanced transition probabilities, with respect to shell-model calculations, in the light even-even Sn nuclei [4, 5, 6, 7].

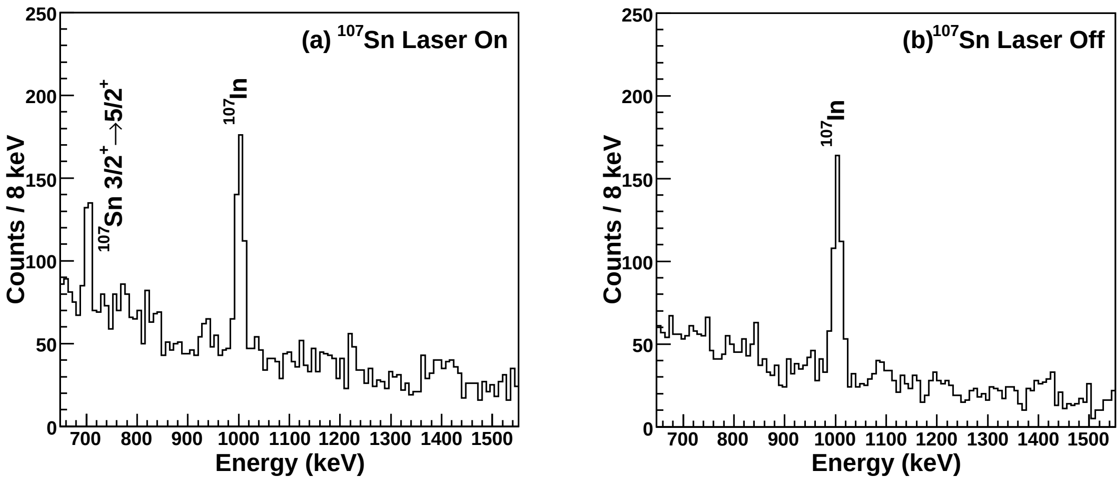

Figure 1. Collected γ-ray spectra for ^{107}Sn with (a) the laser ionization flag switched on and (b) the laser ionization flag switched off in the analysis. The ^{107}In peak most likely arises from the Coulomb excitation of the ^{107}In contamination.

2. Experimental Methods

The Coulomb excitation experiment was carried out at the REX-ISOLDE facility at CERN and a detailed description of the experimental results and procedures will be the subject of a future publication [8]. The methods of the production of the ^{107}Sn beam and the methods used during the analysis of the data are similar to a number of previous reported measurements, e.g. see Refs. [5, 7, 9, 10] and will only be covered briefly here. The ^{107}Sn beam was produced by bombarding a LaC_x target with a 1.4 GeV proton beam delivered by the CERN PS booster. After diffusing out of the target, the Sn atoms were singly ionized using a three-step laser ionization scheme and separated in the general purpose separator. The low-energy beam was then accelerated in the REX linear accelerator to a final energy of 2.866 MeV/u before hitting a 1.95 mg/cm^2 ^{58}Ni target placed in the center of the MINIBALL γ-ray detector array. At this beam energy, the interaction is completely electromagnetic, as the projectile and target nucleus do no penetrate their mutual Coulomb barrier. The scattered beam and target nuclei were detected with a doubled sided silicon strip detector (DSSSD) located downstream of the target. The inverse kinematics of the reaction made it possible to uniquely identify the scattered Ni and Sn nuclei and their angles and energies were used for Doppler correction of the collected γ-rays. The collected Doppler corrected γ-ray spectra for the experiment with the Laser ionization flag switched on and off in the analysis is shown in Fig. 1. The ^{107}In contamination is present when the laser ionization flag is switched off, indicating that the peak does not originate from the Coulomb excitation of ^{107}Sn. The γ-ray at 704 keV can be assigned to the nucleus ^{107}Sn and has been observed previously [11].

3. Shell model based GOSIA calculations

The measured γ-ray spectrum has been compared to calculated γ-ray spectra based on a combined Shell model and GOSIA approach. The method has been previously used to investigate excited states in the nuclei ^{106,108}In [10]. Here, the method has been used to explore the sensitivity of the calculated spectra to the ordering of the lowest-lying single-neutron states. The

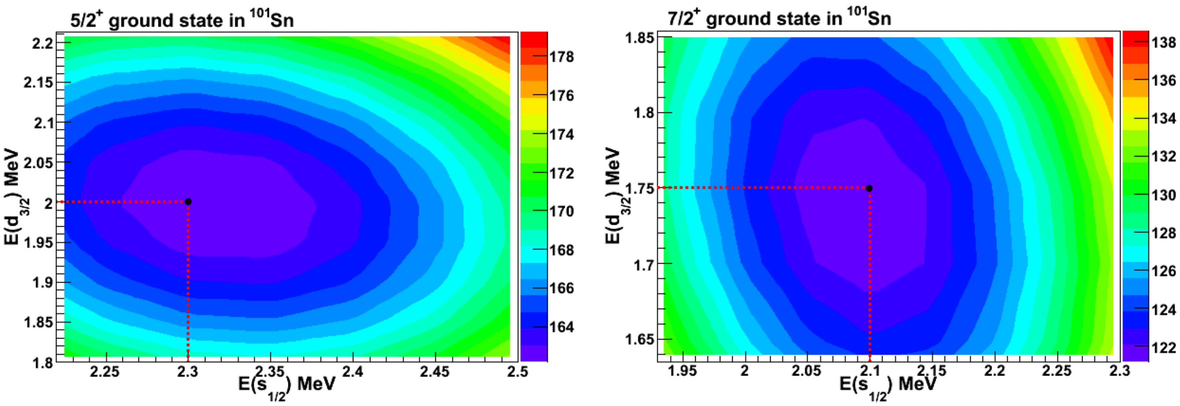

Figure 2. The rms deviation (keV) between the calculated and measured energy levels for ^{109}Sn plotted as a function of the energy of the $d_{3/2}$ and $s_{1/2}$ orbits for either a $5/2^+$ or $7/2^+$ ground state in ^{101}Sn. The • marks the minimum found during the adjustment of the single-particle states.

input to the calculations includes effective two-body matrix elements and a set of single-neutron states relative to ^{100}Sn. The effective interaction used in this work was derived from a G-matrix renormalized CD-Bonn potential and the single-neutron states were determined based on fitting to the energy levels below 1 MeV in ^{109}Sn [11, 12]. These input parameters are used to create both the level scheme and transition matrix elements between the energy levels in ^{107}Sn. The $E2$ matrix elements have been generated with the neutron effective charge set to $e_\nu = 1.0e$ and the $M1$ matrix elements with the neutron g-factors set to $g_l = 0$ and g_s=-3.82. Our calculations in the nearby nucleus ^{109}Sn however suggest that the shell model, with these g-factors, may be over-estimating the strength of the $M1$ components. If pure $E2$ transitions are instead assumed, the main conclusions drawn below still hold. The calculated level scheme and transition matrix elements are used as input to the semi-classical Coulomb excitation code GOSIA. The input to GOSIA also includes the experimental setup of the particle and γ-ray detectors, the efficiency curves of the γ-ray detectors, conversion coefficients, beam energy and target thickness. The final result is a set of calculated γ-ray yields. The counts in the observed 704 keV peak were used to normalize the calculations to the experiment. The yields were then broadened to meet the experimentally measured full width at half maximum (FWHM) and added to the experimentally determined background spectrum for visual comparison to the measured spectrum.

In the method described above, the first problem encountered is the fact that little information is known about the single-neutron states relative to ^{100}Sn. The only firm experimental evidence is the energy splitting between the $d_{5/2}$ and $g_{7/2}$ orbits. The lightest Sn nucleus in which a predominately single-neutron state has been suggested for each of the five orbits is ^{109}Sn [11]. In our calculations, we have adjusted the positions of the $d_{3/2}$ and $s_{1/2}$ orbits in order reproduce the low-lying excited-states in ^{109}Sn while fixing the energy of the $h_{11/2}$ at 3.0 MeV [13]. The procedure was carried out for both choices of ground states in ^{101}Sn and the quality of the fits are shown in Fig. 2 where the rms deviation between the calculated and measured energy levels is plotted as a function of the energy of the $d_{3/2}$ and $s_{1/2}$ orbits. Both fits well reproduce the energy of the excited states in ^{109}Sn with the fit including the $g_{7/2}$ orbit as the lowest-lying orbit resulting in a slightly better rms deviation of 121 keV compared to 162 keV for the fit with the $d_{5/2}$ state as the lowest-lying orbit. Based on these calculations only,

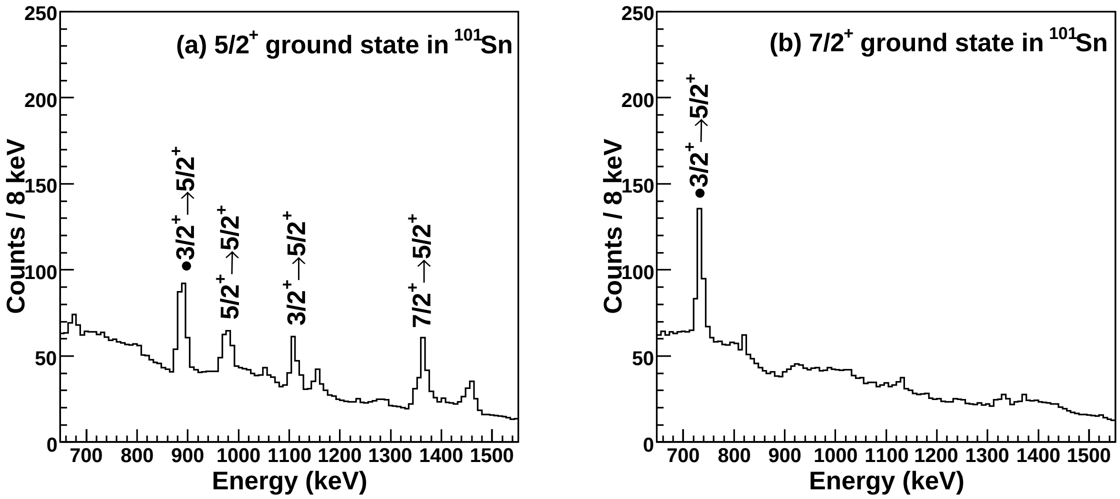

Figure 3. Calculated spectra using the GOSIA and shell model approach described in the text for the choices of a (a) $5/2^+$ ground state in ^{101}Sn or (b) $7/2^+$ ground state in ^{101}Sn. The peaks marked with • were used to normalize the calculations to the experimental results shown in Fig. 1.

it is difficult to choose which set of single-neutron states is preferred. The $h_{11/2}$ orbit may also be important for the energy levels, however it was not varied in the current work. A detailed investigation of the effect of the $h_{11/2}$ orbit is currently in progress.

As described above, the calculated transition matrix elements were used as input to the code GOSIA and the calculated γ-ray spectra for both choices of ground states in ^{101}Sn are shown in Fig. 3. In the case of the $5/2^+$ ground state, several other peaks would have been observed in the experiment. For example, with 140 counts in the $3/2^+ \rightarrow 5/2^+$ peak, the peaks corresponding to the $7/2^+ \rightarrow 5/2^+$, $3/2^+ \rightarrow 5/2^+$, and $5/2^+ \rightarrow 5/2^+$ transitions would contain around 90, 60, and 60 counts, respectively. If instead a $7/2^+$ ground state is used in the calculations, the calculations predict that only the $3/2^+ \rightarrow 5/2^+$ would have been observed, which is supported by the experimental results shown in Fig. 1. The differences in the two calculated spectra originate from the calculated transition probabilities for the $3/2^+ \rightarrow 5/2^+$ transition. This $B(2)$ value for the $7/2^+$ground state choice is about 2.5× larger than the value calculated with the $5/2^+$ ground state choice. The changes in the transition probabilities for the remaining states is less important for the calculated spectra as they are not effected to the same extent. Further analysis has indicated that the position of the $h_{11/2}$ orbit may be partially responsible for the differences in the calculated patterns. As the energy of the orbit is reduced, the calculated pattern with the $5/2^+$ state as the ground state in ^{101}Sn approaches the pattern calculated with the $7/2^+$ state as the ground state. The lowering of the orbit however results in a lower $11/2^-$ level in ^{107}Sn. In the current calculations, the energy of the this level for the $5/2^+$ and $7/2^+$ ground state choices is 1.557 MeV and 1.400 MeV, respectively. The measured energy has been reported to be 1.667 MeV [14]. It is not clear yet how low the orbit must be decreased in order to reproduce the measured γ-ray spectrum. This will be the subject of an upcoming publication [8].

4. Summary and outlook

In this work, we present results from the Coulomb excitation of ^{107}Sn carried out at REX-ISOLDE. We have compared the measured spectrum to calculated spectra based on a GOSIA and shell model approach. The calculated spectra are sensitive to the ordering of the single-neutron states relative to ^{100}Sn. The method can potentially be used to help identify the recently debated ground state in ^{101}Sn [1, 2]. The preliminary analysis shows that the experimentally measured spectrum is better reproduced with the choice of the $g_{7/2}$ orbit as the lowest lying single-neutron state relative to ^{100}Sn. Lowering of the $h_{11/2}$ orbit may however be important for the calculated spectra. Our calculations suggest that if the $d_{5/2}$ state is the lowest orbit relative to ^{100}Sn, the position of the $h_{11/2}$ orbit would be at a lower energy than if the $g_{7/2}$ orbit was the lowest lying orbit. In addition, we have carried out a Coulomb excitation experiment on ^{109}Sn. A similar analysis of the data, as presented in this work, is currently in progress.

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