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Regular Article – Nuclear Structure and Reactions

Beta decay of ^{101}Sn

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Abstract. The β decay of the very neutron-deficient isotope ^{101}Sn was studied at the GSI on-line mass separator using silicon detectors for recording charged particles and germanium detectors for γ-ray spectroscopy. Based on the β-delayed proton data the production cross-section of ^{101}Sn in the ^{50}Cr + ^{58}Ni fusion-evaporation reaction was determined to be about 60 nb. The half-life of ^{101}Sn was measured to be 1.9(3) s. For the first time β-delayed γ-rays of ^{101}Sn were tentatively identified, yielding weak evidence for a cascade of 352 and 1065 keV transitions in ^{101}In. The results for the ^{101}Sn decay as well as those from previous work on the ^{103}Sn decay are discussed by comparing them to predictions obtained from shell model calculations employing a new interaction in the ^{88}Sr to ^{132}Sn model space.

PACS. 27.60.+j $90 \le A \le 149$ – 21.10.-k Properties of nuclei; nuclear energy levels – 23.40.-s β decay; double β decay; electron and muon capture – 21.10.Tg Lifetimes

1 Introduction

Measuring properties of doubly magic nuclei and their closest neighbours is of great interest as it provides information on the underlying shell structure. Concerning the closest neighbours of the heaviest particle-stable self-conjugated nucleus $^{100}_{50}$Sn, *i.e.* $^{99}_{49}$In, $^{99}_{50}$Sn, $^{101}_{50}$Sn and $^{101}_{51}$Sb, only one of them is known so far, namely ^{101}Sn. The scarce experimental information available on this nucleus stems from studies of its β^+/EC decay [1,2] or from investigating the α-decay chains ^{105}Te $\rightarrow$ ^{101}Sn [3] and ^{109}Xe $\rightarrow$ ^{105}Te $\rightarrow$ ^{101}Sn [4]. In order to approach experimentally these nuclei, heavy-ion–induced fusion-evaporation reactions have been found to be a suitable production mechanism, as can be seen, *e.g.*, from the studies of the β decay of ^{102}Sn, ^{103}Sn and ^{104}Sn [5–8]. However, far away from β stability the production cross-section and, correspondingly, the number of atoms available for investigations become very low, causing a problem for the detailed spectroscopy necessary to gain information on nuclear-structure properties. In this context, experimental data on production cross-sections of exotic nuclei are important. This paper reports on such a measurement for ^{101}Sn and on an attempt to improve the data on the β-delayed proton (βp) and γ ($\beta\gamma$) decay of this nucleus.

The β^+/EC decay of nuclei "southeast" of ^{100}Sn is dominated by the Gamow-Teller (GT) transformation of a $g_{9/2}$ proton into a $g_{7/2}$ neutron. Based on shell model

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considerations [9] and experimental systematics of the ground-state spin and parity of odd-A tin isotopes and $N = 51$ isotones, one expects a $5/2^+$ assignment for the ground state of ^{101}Sn. Hence for the decay $^{101}\text{Sn} \to {}^{101}\text{In}$, the GT transition can be expressed as $5/2^+\{0^+(\text{core}) \otimes 5/2^+\nu d_{5/2}\} \to \{1^+(\pi g_{9/2}^{-1}, \nu g_{7/2}) \otimes \nu d_{5/2}\}$. Such one proton-hole, two neutron-particle states in ^{101}In were predicted [10] to be populated in GT decay of ^{101}Sn in a resonance-like fashion. The centroid of the broad predicted resonance lies at an excitation energy of about 4 MeV with respect to the $9/2^+\{9/2^+\pi g_{9/2}^{-1} \otimes 0^+\nu d_{5/2}^2\}$ ^{101}In ground state. This excitation energy is larger than the proton separation energy S_p in ^{101}In which is estimated by extrapolating systematic trends to be 1650(310) keV [11]. Since the corresponding estimates yield a decay energy (Q_{EC}) of 9050(420) keV [11] for ^{101}Sn, the energy window for the βp decay ($Q_{EC} - S_p$) of this nucleus is large, namely $\approx$ 7400 keV, and the probability for its βp decay is thus expected to be high. As the $Q_{EC} - S_p$ value of ^{101}In is only 2200 keV and those of lower-Z isobars are also low or even negative [11], a βp measurement of ^{101}Sn offers Z selectivity. In addition, the detection of protons does not suffer from the laboratory background that represents a major problem for the $\beta\gamma$ spectroscopy of weak activities.

Shell model calculations for the GT decay of heavier odd-A tin isotopes ^{103,105}Sn show a high sensitivity of position and width of the GT resonance on the interaction employed [6,7]. Keypoints are the near degeneracy of the $d_{5/2}$ and $g_{7/2}$ in ^{101}Sn [9] causing mixture and redistribution of the GT strength and the $\pi g_{9/2}\nu g_{7/2}$ interaction [7,12]. On the other hand in-beam experiments have identified a wealth of high-spin states in ^{101,103}In [13,14]. Therefore these nuclei provide a unique test ground for the determination of a shell model interaction that describes the yrast line and highly non-yrast low-spin states which are fed in β decay.

The decay of ^{101}Sn was studied employing two different detector setups that aimed at βp and $\beta\gamma$ spectroscopy, respectively, and are introduced in sect. 2. The results of the βp and $\beta\gamma$ measurements, presented in sects. 3.1 and 3.2, respectively, are discussed in sect. 4 and summarised in sect. 5.

2 Experimental techniques

^{101}Sn was produced at the GSI on-line mass separator [15] by using the $^{50}\text{Cr}(^{58}\text{Ni}, \alpha 3\text{n})^{101}\text{Sn}$ fusion-evaporation reaction. A ^{58}Ni beam from the linear accelerator UNILAC impinged on an enriched ^{50}Cr target (3 mg/cm^2, enrichment 97%). The intensity and specific energy of the ^{58}Ni beam amounted to 36 particle-nA, 4.9 MeV/u for the βp experiment and 34 particle-nA, 5.2 MeV/u for the $\beta\gamma$ measurement. FEBIAD-B2C ion sources were used which contained niobium, graphite and ZrO_2-felt catchers, respectively. Most of the data were collected with the latter catcher which yielded the highest separation efficiency. High chemical selectivity for tin was achieved by adding CS_2 vapour to the ion source. Using this technique about 60% of the tin ion-output is shifted to the SnS^+ molecular side-band, thus strongly suppressing the isobaric contaminants of indium, cadmium, silver and palladium isotopes [16]. The suppression factors are, *e.g.*, of the order of $5 \cdot 10^4$ for silver and $5 \cdot 10^5$ for indium isotopes [16]. After ionisation, acceleration to 55 keV and mass separation in a magnetic sector field, the ions with $A = 101 + 32$ were implanted either into thin carbon foils in front of a βp setup or into a tape positioned in the centre of an array of silicon and germanium detectors (Si-Ge array) for $\beta\gamma$ spectroscopy.

In the βp experiment the mass-separated beam was periodically switched between two carbon foils in consecutive grow-in (12 s) and decay (12 s) intervals, the collected βp activity being recorded by two identical ΔE-E Si-detector telescopes. Each ΔE detector had an area of 450 mm^2 and a thickness of 20 μm, while the corresponding dimensions of the E detector were 2000 mm^2 and 500 μm, respectively. The solid angle covered by each of the telescopes amounted to 34(3)% of 4π. The ΔE singles and ΔE-E coincidence events were tagged by the time elapsed since the start of each 24 s cycle. The resulting time profiles were used to determine the half-life of ^{101}Sn.

In the $\beta\gamma$ experiment, two 30 mm $\times$ 30 mm Si detectors and one 14 mm $\times$ 14 mm one were placed in a cube-like geometry inside of a small vacuum chamber. The other three sides of the cube, which remained open, were used to let the beam pass onto a tape in the centre of the cube and to guide the tape to the implantation position and away from it. The solid angle covered by the Si detectors amounted to about 40%. Around this setup two GSI VEGA-SuperClover detectors [17] and a small Clover detector were mounted. The photopeak efficiency of the 12 Ge crystals was 7.5% at 1.3 MeV. The measurement was performed in grow-in mode, *i.e.* during the time when the $A = 101 + 32$ beam was continuously implanted into the tape at rest. After a pre-selected time of 8 s the implanted activity was removed from the implantation position.

3 Experimental results

3.1 Beta-delayed proton emission

Data on the βp decay of ^{101}Sn were collected by using ZrO_2 and graphite catchers (see sect. 2) during 10364 24 s cycles (12 s irradiation and 12 s decay), which correspond to a total measurement time of 69 h. The time profile was analysed for energy loss events observed in the ΔE detectors within the range from 400 to 2500 keV. This leads to 137 events in the grow-in and 39 events in the decay parts of the time profile. From the ratio of 3.5(6) between these numbers, the half-life of ^{101}Sn was determined to be 1.9(3) s. This result is in good agreement with but considerably more accurate than the previously obtained values of 3(1) s [1] and 1.5(6) s [2].

On the basis of the 138 βp events obtained in 5843 cycles with the ZrO_2 catcher (see sect. 2) and registered

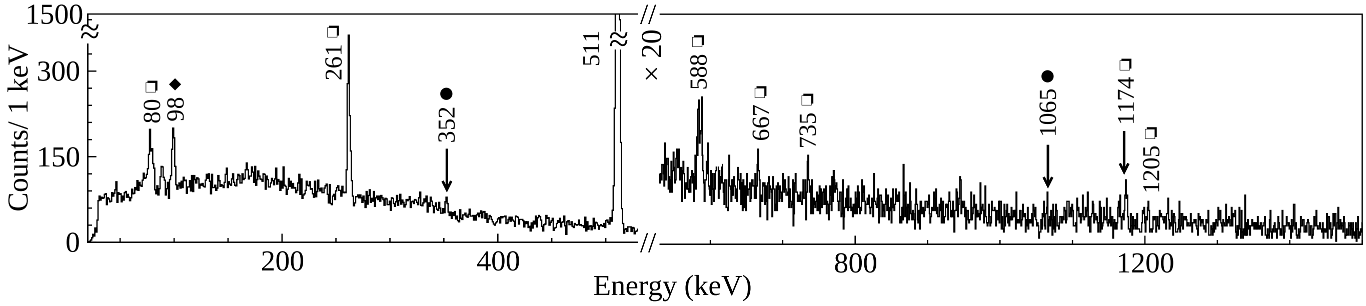

Fig. 1. Gamma-ray spectrum obtained in coincidence with positrons. Gamma rays known to belong to the decay of ^{101}Ag and ^{101}Cd [19] are marked by open squares and diamond, respectively. Gamma rays marked by filled circles indicate evidence for β-delayed γ-rays of ^{101}Sn. The γ-ray lines of interest are labelled by their energies in keV. The spectrum is scaled by a factor of 20 above 530 keV.

in the ΔE detectors of the telescopes, the ^{101}Sn beam intensity was found to be about 150 atoms/h at an average ^{58}Ni beam intensity of 34 particle-nA. This estimate is based on a branching ratio for βp decay ($b_{\beta p}$) of $0.14^{+0.10}_{-0.06}$ for ^{101}Sn [2] as well as the detector efficiency and cycle time as given in sect. 2. Assuming a separation efficiency of 7.5% for ^{101}Sn^{32}S^{+} ions [16,18] and the ^{50}Cr target as specified in sect. 2, the production cross-section of ^{101}Sn in the fusion-evaporation reaction ^{50}Cr(^{58}Ni, α3n) was determined to be about 60 nb. This value corresponds to an average over the target thickness.

3.2 Beta-delayed γ rays

The ^{101}Sn beam intensity, determined in sect. 3.1, allowed for the feasibility estimation of a $\beta\gamma$ measurement of ^{101}Sn. Considering the implantation cycle and the efficiency of the Si-Ge array as described in sect. 2, and a $\beta\gamma$ branching ratio of 86% [2], a few events/h are expected to occur in the photopeak of a β-coincident γ spectrum, assuming a 1 MeV γ-ray to follow the β decay of ^{101}Sn. This rate is low indeed but not out of reach for an experiment based on the high chemical selectivity of the FEBIAD-B2C ion source (see sect. 2).

For the $\beta\gamma$ measurement performed at mass $A = 101 + 32$, 37216 collection-counting cycles were accumulated corresponding to a total measurement time of 82 h. Figure 1 presents part of the resulting γ-ray data. Most of the γ-ray lines identified in this spectrum belong to the decay of ^{101}Ag and ^{101}Cd [19]. The latter activities were observed in spite of their strong suppression by the sulphurisation technique and by choosing an 8 s cycle for the tape collector (see sect. 2). In contrast to the occurrence of the $\beta\gamma$ activity of ^{101}Ag and ^{101}Cd, the non-observation of $\beta\gamma$-rays of ^{101}In apparently means that this isotope does not form a sizeable part of the $A = 101 + 32$ beam but is dominantly produced as a daughter activity of ^{101}Sn on the tape during the implantation period.

Figure 1 also shows weak evidence for the occurrence of β-delayed γ-rays at 352 and 1065 keV. The assignment to $\beta\gamma$-rays of ^{101}Sn is tentative as their low intensity did not allow for half-life analysis. The number of counts observed for these transitions corresponds to the expectations based on the experimental production cross-section (see sect. 3.1), taking into account γ-γ coincidence efficiency and using normalisation to the ^{103}Sn level scheme [6,7].

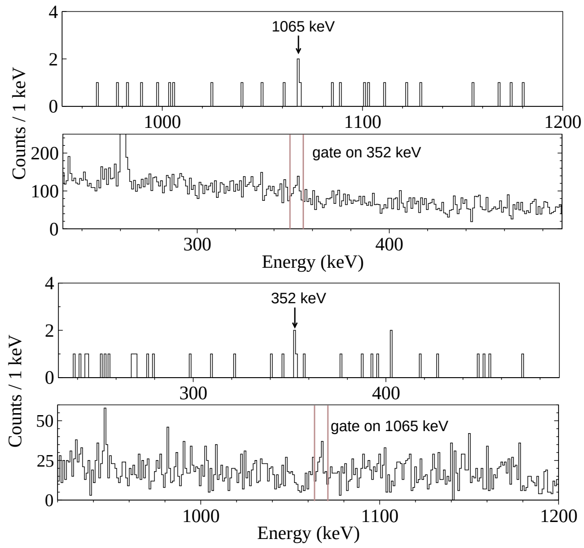

Fig. 2. Background-subtracted β-γ-γ coincidence spectrum gated on the 352 keV (first panel) and the 1065 keV line (third panel). The gates conditions for these two lines are indicated in the spectra obtained in coincidence with all γ-rays (second and fourth panels, respectively).

The γ-γ coincidence data shown in fig. 2 yielded evidence for mutual coincidence between the 352 and 1065 keV transitions. The three coincidence events observed for these lines at almost zero background indicate that these γ-rays belong to the same cascade, corresponding to ^{101}In level energies of 1065 and 1417 keV. The tentative assignment of the 352 and 1065 keV transitions to the ^{101}Sn decay is supported by the following arguments: mass determination and non-observation of these γ-rays in previous works on the decay of ^{101}In, ^{101}Cd and ^{101}Ag [19].

4 Discussion

4.1 Production cross-section

The production cross-section for the ^{50}Cr(^{58}Ni, α3n)^{101}Sn reaction was estimated for the first time by Janas *et al.* [1]

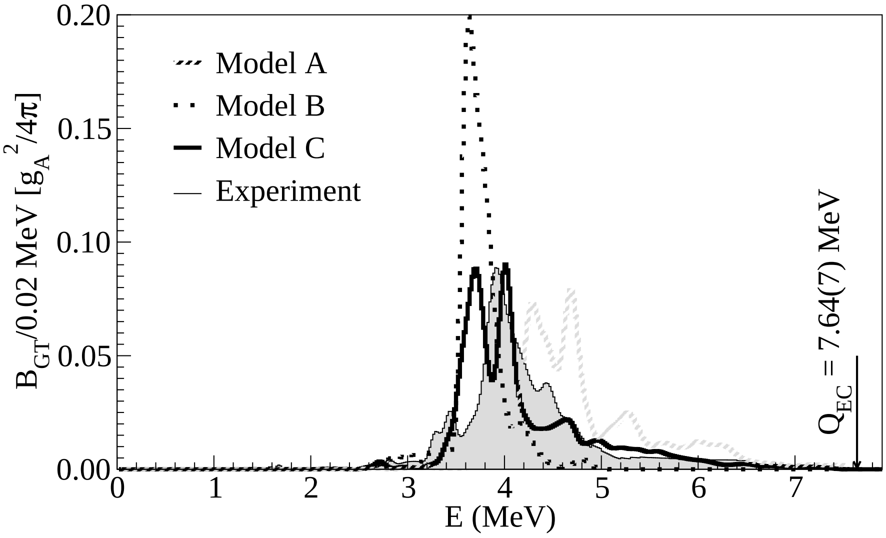

Fig. 3. Gamow-Teller strength distributions for the ^{103}Sn decay, obtained from experiment (shaded-area histogram) and resulting from shell model calculations based on the Models A (grey-line histogram), B (dotted histogram) and C (black-line histogram).

to be 10 nb. These authors used a ^{58}Ni beam current of 40 particle-nA and determined the ^{101}Sn beam intensity to be 40 atoms/h. This rate estimate is based on a theoretically predicted $b_{\beta p}$ value of 40% [10] for ^{101}Sn. A re-evaluation of the βp rate measured by Janas *et al.* assuming a $b_{\beta p}$ value of about 14% [2] yields a ^{101}Sn rate of 110 atoms/h. A normalisation of this result to the ^{58}Ni beam intensity of 34 particle-nA, used in our work, yields an intensity of 95 atoms/h. This has to be compared to the value of 150 atoms/h derived in sect. 3.1. However, in this context we note that the separation efficiency given in the present work takes losses between target and catcher into account which makes it about two times lower compared to the value given in ref. [1]. All in all, the re-evaluation of the results presented by Janas *et al.* [1] yields a ^{101}Sn production cross-section of about 50 nb which is in agreement with the value of 60 nb obtained in this work, taking the uncertainties of such estimates into account. A compilation of ^{50}Cr(^{58}Ni, 2pxn) cross-section for the production of light tin isotopes, including the extrapolation to ^{100}Sn, has recently been given by Karny *et al.* [5].

4.2 Shell model calculations

Several shell model calculations with different interactions have been performed for $N \geq 50$ palladium-to-tin isotopes in the proton $\pi(p_{1/2}, g_{9/2})$ $\nu(d_{5/2}, g_{7/2}, d_{3/2}, s_{1/2}, h_{11/2},)$ model space, using ^{88}Sr as an inert core [10,20,12,13]. In the present work a newly developed interaction was used [21] that started from a G-matrix, based on the CD-Bonn potential [22] and determined by the method outlined in refs. [23,24], and experimental single-particle energies inferred from the ^{88}Sr one-proton and one-neutron neighbours. By application of monopole corrections the standard ^{100}Sn single-neutron particle and single-proton hole energies [9] and the evolution of the $\pi(p_{1/2}, g_{9/2})$ hole states in the indium isotopes were reproduced. Furthermore, the overall agreement with experiment was optimised by tuning the $\pi\pi$ interaction for the $N = 50$ isotones by multiplying all two-body matrix elements by a factor of 0.9, while the $\nu\nu$ pairing was reduced by $\Delta\langle j_1^2|V|j_2^2\rangle_{J=0} = \Delta G/2 \cdot \sqrt{(2j_1+1)(2j_2+1)}$, $\Delta G = 25\,\text{keV}$ for the tin isotopes. Thus a good agreement with experiment was warranted for single-particle states, high-spin yrast and the highly non-yrast states in the GT resonance populated in the decay of tin isotopes, *i.e.* in $N = 50, 51$ and isotones of $Z = 50$ (tin) and $Z = 49$ (indium) nuclei. Calculations were performed with the shell model code OXBASH [25]. Further details will be given in a forthcoming paper [21]. We shall characterise the predictions obtained by using the new interaction by "Model C" in order to distinguish them from those derived from the Models A and B introduced in ref. [7].

In fig. 3 the experimental GT distribution for the well-studied ^{103}Sn decay [6,7] is compared to shell model results obtained by using the present interaction (Model C) and the ones characterised as Models A and B in ref. [7] (see also refs. [10,12]). It is interesting to note that, without the optimisation described above, the present interaction would correspond to that characterised as Model A in [7], yielding a too narrow and too low-lying GT resonance compared to the experiment. The improvement of the new interaction in reproducing centroid, width and the high-energy tail of the GT resonance is clearly evident. It should be noted that inclusion of ^{100}Sn core excitations will cause a moderate redistribution of the GT strength around the resonance. This may reduce the splitting of the double peak which is due to the concentration of the $I^\pi = 3/2^+, 5/2^+$ final-state feeding in the lower and the $I^\pi = 7/2^+$ strength in the upper peak.

For calculating GT strength distributions for the ^{101}Sn decay, we assumed a $5/2^+$ or $7/2^+$ spin-parity assignment for the ^{101}Sn ground-state corresponding to the two lowest-lying, almost degenerate neutron orbitals above the $N = 50$ gap near ^{100}Sn. The resulting distributions predicted by Model C are characterised by a resonance that is narrower and peaks at higher energy than for the ^{103}Sn decay, with negligible strength at low energies which excludes direct feeding to states below 2 MeV. The predicted GT strength distribution has a centroid at a ^{101}In excitation energy of about 4.1 MeV in the $5/2^+$ case while in the $7/2^+$ case it is double-humped with peaks at about 4.0 and 4.5 MeV, the latter being dominated by contributions from $9/2^+$ states in ^{101}In [21]. The β-intensity distributions, deduced from these GT strength predictions by assuming a Q_{EC} value of 9050 keV based on systematics [11], are narrow and peak at ^{101}In excitation energies of about 4.2 MeV (see fig. 4) for both spin-parity assignments. In the $7/2^+$ case the β-intensity distribution has a somewhat more extended high-energy tail without showing a separate high-energy peak. For the β decay of both ^{101}Sn and ^{103}Sn the GT resonance lies well above the proton separation energy in ^{101}In and ^{103}In, namely 1650(310) keV [11] and 3550(320) keV [7]. However, as the βp spectra peak at 3.0 and 2.5 MeV for ^{101}Sn (see fig. 4) and ^{103}Sn [7], respectively, it is obvious that this decay mode probes mainly the high-energy tail of the GT resonance. This explains the sizeable $b_{\beta p}$ values of $0.14^{+0.10}_{-0.06}$ for ^{101}Sn [2] and 0.012(1) for ^{103}Sn [7]. More details on the βp decay of ^{101}Sn will be discussed in the following section.

4.3 Beta-delayed proton emission

Figure 4 shows the βp energy spectrum obtained from the ΔE-E coincidence events in one of the telescopes and results of Model C calculations described in sect. 4.2. The experimental βp spectrum represents an improvement over that reported previously [1], due to the lower degree of contamination achieved by using the tin-selective ion source (see sect. 2). The calculated proton spectra, shown in fig. 4, were obtained by using an S_p value of ^{101}In of 1650 keV according to systematics [11] and a barrier transmission calculation based on a statistical model [26, 27], with the optical model parameters being derived from the back-shifted Fermi gas level density [28]. The proton energy scale of the β-intensity distributions displayed in fig. 4 was shifted by again using the S_p value of 1650 keV. Moreover, its intensity relative to that of the βp energy spectrum correspond to the $b_{\beta p}$ values of 0.26 and 0.14, found for the $5/2^+$ and $7/2^+$ assumption, respectively, by using Model C. The latter results are both in agreement with the experimental value of $0.14^{+0.10}_{-0.06}$ [2].

It is interesting to note that the theoretical βp spectrum for the $7/2^+$ case shown in fig. 4 is double-humped. This means that the broad single peak predicted for the β-intensity distribution (see sect. 4.2) splits, due to its spin-energy structure, into two components of the related proton energy spectrum (see fig. 4). In order to further study this effect as well as the possibility of using proton spectra for spin and parity assignment of the β-decaying state, we performed additional calculations of proton spectra by

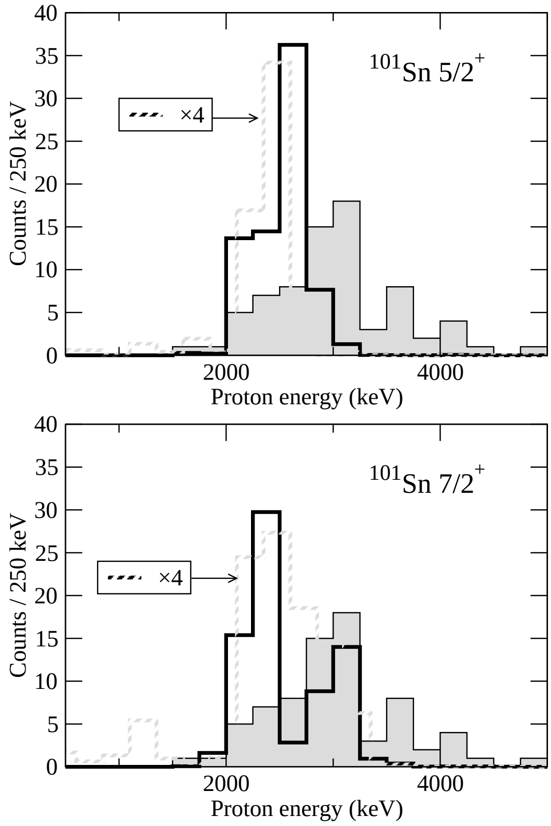

Fig. 4. Energy spectrum of β-delayed protons from the ^{101}Sn decay, measured at mass $A = 101+32$ (shaded-area histogram) and predicted on the basis of Model C (solid-line histogram). The theoretical proton spectra were obtained by assuming a $5/2^+$ (upper panel) or $7/2^+$ (lower panel) spin-parity assignment for the ^{101}Sn ground state. Theoretical and experimental proton spectra are normalised to equal integral number of counts. Moreover, the theoretical β-intensity distributions (dashed-line histogram) are displayed as resulting from the $5/2^+$ and $7/2^+$ assumption. The proton energy scale of the theoretical proton spectra and β-intensity distributions were deduced by assuming an S_p value of ^{101}In of 1650 keV (see text for details).

varying the S_p value of ^{101}In within the 1-σ limits of the result of 1650(310) keV from systematics [11]. For an S_p value of 1300 keV the predicted proton spectra are in reasonably good agreement with the measured ones, whereas the calculated $b_{\beta p}$ values of 0.48 and 0.38 for the $5/2^+$ and $7/2^+$ assumption, respectively, disagree with experiment. On the other hand, an S_p value of 2000 keV yields proton spectra whose centroids occur at considerably lower energies than the experimental ones. The $b_{\beta p}$ values calculated for this case are considerably smaller, namely 0.08 and 0.02, respectively, but still in fair agreement with experiment. The spectra resulting for the $7/2^+$ case and S_p values of 2000 and 1600 keV are double-humped and even triple-humped, respectively.

From the data displayed in fig. 4 and the above-mentioned additional calculations based on variations of the S_p value of ^{101}In we conclude that the *shape* of the experimental energy spectrum of β-delayed protons tends to agree with the prediction for the $5/2^+$ case rather than with that for the or $7/2^+$ case. Conclusions based on considering the discrepancy between the *centroids* of the experimental and theoretical distributions are less firm. This is due to the fact that the proton energy scale of the theoretical proton spectra (and β-intensity) distributions was deduced by using the estimated S_p value of ^{101}In which has a large uncertainty and is not a truly experimental result.

The tentative $5/2^+$ assignment for the ground state of ^{101}Sn confirms an earlier proposal [9] that the $\nu 2d_{5/2}$ orbital is the lowest-lying one above the $N = 50$ shell closure near ^{100}Sn. The assignment $5/2^+$ has been tentatively confirmed by experimental data on the β^+p decay of ^{101}Sn that were published earlier [1], and also in a report on preliminary results from the present work [29]. Moreover, the latter reference was used for the $5/2^+$ assignment to the members of the α-decay chain $^{109}\mathrm{Xe} \to {}^{105}\mathrm{Te} \to {}^{101}\mathrm{Sn}$ [4].

Generally speaking, the ambiguity of this interpretation is related to the numerous assumptions made in the statistical-model calculation, which cannot be checked against experiment and contain, in particular, the experimentally unknown Q_{EC} and S_p values. The large uncertainty of 420 and 310 keV, respectively, obtained for the latter quantities by extrapolating systematic trends [11] prevent us from drawing a quantitative conclusion from the βp data of ^{101}Sn shown in fig. 4. The same ambiguity has to be stated with respect to the $b_{\beta p}$ value of $0.14^{+0.10}_{-0.06}$ for ^{101}Sn [2] which has to be compared to predictions of 0.26 and 0.14 for the $5/2^+$ and $7/2^+$ case, respectively. Such βp predictions depend not only on the assumptions made on Q_{EC} and S_p but also on those concerning the (statistical) γ de-excitation of the ^{101}In levels populated in β decay. Another uncertainty is due to the splitting respective spreading of the GT resonance which is interaction dependent (see fig. 3 for the ^{103}Sn decay). Therefore the spin determination for the ^{101}Sn ground state, discussed in this paper, is indeed model dependent.

On the basis of the estimated S_p value of ^{101}In [11], the peak of the βp energy spectrum of about 3 MeV corresponds to an excitation energy of 4.7 MeV in this nucleus. Qualitatively speaking, βp emission thus probes the (high-energy part of the) GT resonance which is predicted to be centered around 4 MeV (see also next section and ref. [10]). This is expected to be a characteristic feature of the βp decay of very proton-rich nuclei near ^{100}Sn due to their large Q_{EC}, small S_p values and dominance of the $g_{9/2} \to g_{7/2}$ GT resonance.

4.4 Beta-delayed γ-ray emission

A cascade of 352 and 1065 keV transitions was tentatively assigned as β-delayed γ-rays of ^{101}Sn, identifying ^{101}In levels at 1065 and 1417 keV. The existence of a 352 keV level is excluded, since there are no excited states predicted in the odd light-indium isotopes, according to the experimental systematics [19] and shell model calculations (see sect. 4.2 and refs. [23,9]). The level energies found in

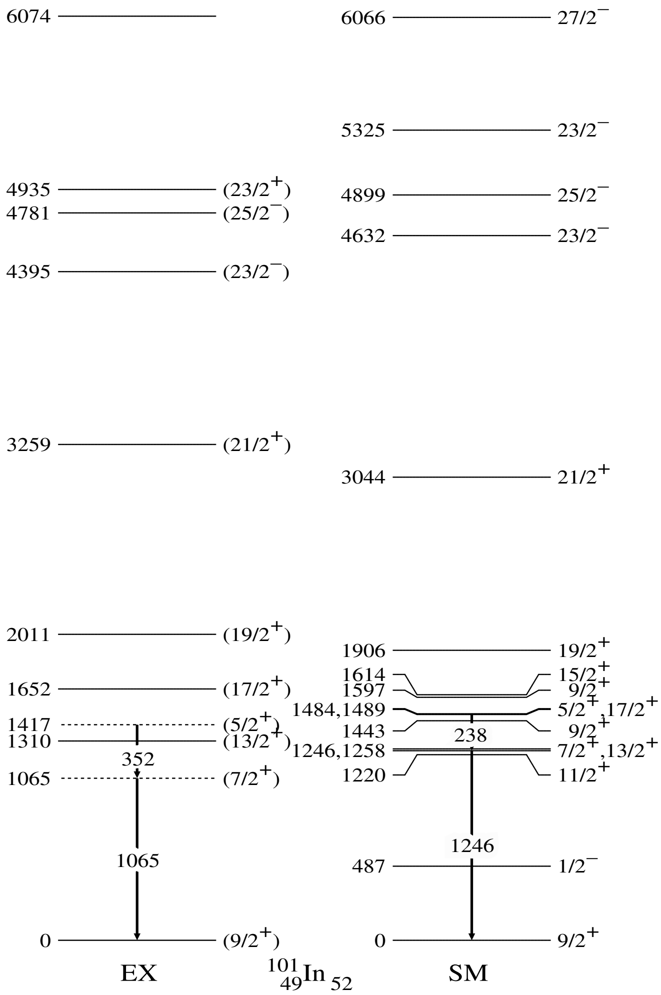

Fig. 5. Experimental and shell model high-spin yrast and low-energy low-spin states in ^{101}In. The new tentatively assigned γ-ray cascade observed in the present work and the possible shell model predictions are shown, too.

this work differ from those known from in-beam work [13], where 1310 and 342 keV γ-rays were found to represent de-excitations of tentatively assigned levels $(17/2^+)$ to $(13/2^+)$ and of $(13/2^+)$ to the ground state, respectively. $13/2^+$ levels in ^{101}In are not populated by the GT decay of the $5/2^+$ ground state of ^{101}Sn. However, it is not excluded that they are fed by γ-ray de-excitation paths of increasing spin, for example those starting from primarily populated $7/2^+$ states. Such a phenomenon has been observed, *e.g.*, for the β decay of the $7/2^+$ ground state of ^{97}Ag, with a $(11/2^+) \to (13/2^+) \to (15/2^+) \to 17/2^+$ cascade occurring in the daughter nucleus [12]. However, as the γ-ray intensities within this cascade are weak this argument cannot be used for assigning spin and parity to the newly observed ^{101}In states. The Model C calculations predict between 1.0 and 1.6 MeV besides the known $I^\pi = (13/2^+)$ state 5 levels with spin and parity $I^\pi = 5/2^+$–$11/2^+$, that may be populated by β decay directly or a $\beta\gamma$ cascade (see fig. 5). Among them the four lowest states belong to the $I^\pi = 5/2^+$–$13/2^+$,

$\{^{102}\mathrm{Sn}, 2^+ \otimes \pi g_{9/2}^{-1}\}$ quintuplet. The shell model β intensity distribution (see sect. 4.2) excludes direct population of states in this energy region. We have therefore modelled the γ decay of the most strongly fed primary β daughter states in the GT resonance region to the states in question and cascades from these states towards the ground state allowing for $M1$ and $E2$ multipolarity. Only 3 of the candidates favour a cascade over the direct decay to the ground state, namely the $I^\pi = 5/2_1^+, 9/2_{2,3}^+$ states. The results for the γ decay from the GT resonance to these states show a clear preference for a $5/2^+$-$7/2^+$-$9/2^+$ cascade taking about 60% of the feeding intensity while the alternatives $9/2_{2,3}^+$-$(7/2^+, 11/2^+)$-$9/2^+$ take only 16% and 24%, respectively, which is less than the present detection limit. The experimentally observed states at 1065 and 1417 keV have therefore likely $I^\pi = 7/2^+$ and $5/2^+$, respectively. The tentative levels and their assignments are indicated in fig. 5. This is in striking agreement with the strongest 314 keV-1356 keV cascade in the ^{103}Sn decay, which may have a similar assignment.

5 Summary

The development of SnS$^+$ beams at the GSI on-line mass separator allowed us to obtain improved data on the β decay of ^{101}Sn, the closest neighbour of the doubly magic nucleus ^{100}Sn. By comparing the experimental energy spectrum of β-delayed protons to a theoretical prediction, the $5/2^+$ spin and parity assignment for the ^{101}Sn ground state was confirmed. The βp data allowed us to redetermine with improved accuracy the half-life of this nucleus to be 1.9(3) s and its production cross-section in the ^{50}Cr(^{58}Ni, α3n) fusion-evaporation reaction to be about 60 nb. Moreover, for the first time weak evidence has been obtained for the observation of β-delayed γ-rays of ^{101}Sn which apparently form a cascade of 352 and 1065 keV transitions in ^{101}In.

Shell model predictions employing a new interaction tuned to high-spin yrast, low-spin and single-particle states in the $N = 50, 51$ to the $Z = 49, 50$ region account well for the experimental observations as tested for the case of ^{103}Sn. For the ^{101}Sn decay, the shell model predictions were used to assign the tentatively assigned cascade of β-delayed γ-rays, whereas an attempt to quantitatively interpret the βp data remained somewhat inconclusive. Firm conclusions beyond these tentative ones would require improved decay data, including in particular high-resolution and total-absorption γ-ray spectroscopy as well as the determination of the Q_{EC} value of ^{101}Sn and the S_p value in ^{101}In.

The new $\beta\gamma$ results for ^{101}Sn together with the non-observation of such data for ^{100}Sn [5] show that 60 nb is the present sensitivity level when using fusion-evaporation reactions for studies of β-delayed γ-rays of nuclei near the doubly-magic ^{100}Sn. Considerably higher sensitivities can be reached for fusion-evaporation reaction if decay modes involving protons or α particles are considered. For example, the recent discovery of the direct two-proton radioactivity of (21^+) ^{94m}Ag [30] was achieved at a partial production cross-section of only 350 pb.

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