New data on β decay of exotic nuclei close to ^{100}Sn: ^{94}Ag and ^{100}In

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Abstract

The β decay of the proton-rich nuclei ^{94}Ag and ^{100}In was investigated at the GSI on-line mass separator by using modern segmented arrays of Ge and Si detectors, as well as a total absorption spectrometer (TAS). Additional evidence for the spin-gap isomer in ^{94}Ag has been deduced from the observation of high-spin states in ^{93}Rh, which is populated via β-delayed proton emission from the isomer. In the case of ^{100}In, the population of states up to the 8^+ yrast state in ^{100}Cd has been identified from $\beta\gamma\gamma$ coincidences. The experimental β feeding measured in the TAS is compared to predictions of large-scale shell-model calculations, which favour a spin and parity of 6^+ for the ^{100}In ground state.

1 Introduction

Exploring nuclei in the upper proton $g_{9/2}$ shell close to ^{100}Sn gives the opportunity to observe the phenomena generated by the residual hole-hole proton-neutron interaction, resulting in the occurrence of spin-gap isomers (e.g. ^{95}Pd, $J^\pi = 21/2^+$ [1] and tentatively ^{94}Ag, $J^\pi \geq 17^+$ [2]). Another interesting issue is the manifestation of the Gamow-Teller (GT) resonance in β decay of nuclei close to ^{100}Sn. These topics will be illustrated for two examples, recently investigated at the GSI on-line mass-separator: ^{94}Ag and ^{100}In.

2 ^{94}Ag

The ^{58}Ni(^{40}Ca,p3n) reaction was used to produce ^{94}Ag nuclei. The 4.78 MeV/u ^{40}Ca beam was delivered by the UNILAC accelerator of GSI Darmstadt. The reaction recoils were stopped inside a catcher of a FEBIAD-B3C ion source, which possesses excellent release properties for silver while palladium is strongly suppressed by trapping in the two cold pockets [3]. After ionisation, extraction from the ion source and mass separation, the $A = 94$ secondary beam was implanted into a tape. The tape transported the activity every 9.6 s in order to suppress the long-lived isobaric contaminants. The implantation point was surrounded by a triangular-prisma shaped array of Si detectors, each 1 mm thick [4], with a total β efficiency of 65% and by an array of Ge detectors, comprising a Cluster, two Clovers and two single Ge crystals, with a total photopeak efficiency of 3.3% for a γ-ray energy of 1.33 MeV.

The Si detectors could also be used for detecting β-delayed protons which are expected in this case within an energy window of 10 MeV [5]. Thus, the use of this array represents a considerable step forward with respect to the previous experiment [2]. The total measuring time amounted to 80 h. Events with $\beta\gamma$ and $\beta\gamma\gamma$ coincidences were sorted and analysed. The positron energy-loss condition was set in the range of 320 to 800 keV. All the γ rays reported in [2] were observed, including the weak 597 and 1545 keV transitions in ^{94}Pd as seen in Fig. 1(a), which confirms the existence of the tentatively assigned $J \geq 17\ \hbar$ isomer in ^{94}Ag.

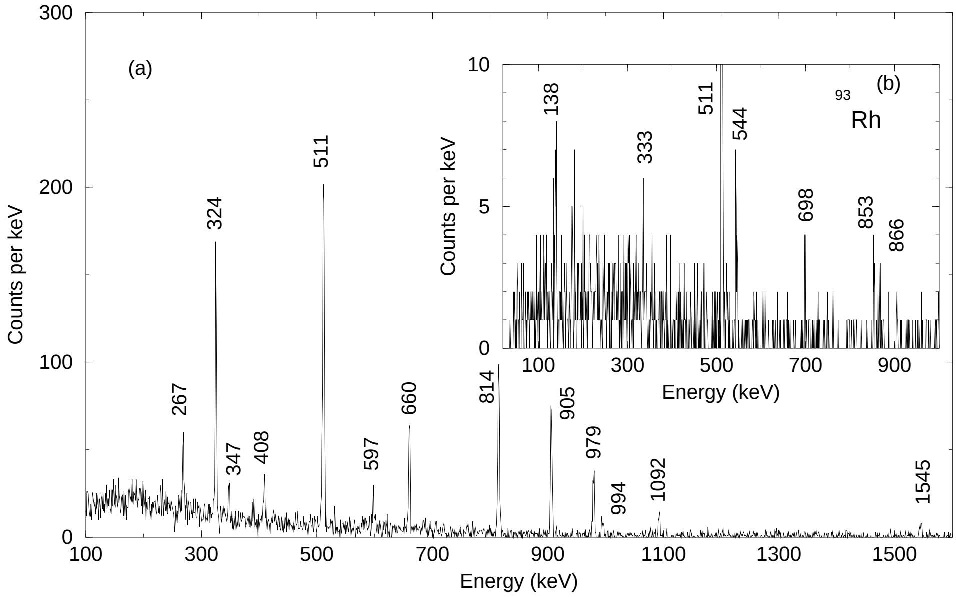

Fig. 1: Spectra resulting from the analysis of $\beta\gamma\gamma$ coincidences of mass separated $A = 94$ sources. The strongest γ rays are marked by their energies in keV. In (a) the sum spectrum obtained by gating on the strongest ^{94}Pd lines 814, 905 and 660 keV, respectively, is shown. In (b) the spectrum represents the sum of 853 and 866 keV individual gates in ^{93}Rh.

Apart from transitions in ^{94}Pd, the β delayed γ rays of ^{94}Ag contain a couple of lines which apparently represent transitions in ^{93}Rh. The strongest γ rays were observed at 853 and 866 keV which have been assigned to ^{93}Rh from a previous in-beam experiment [6]. By setting gates on these low-spin transitions, a part of the known in-beam level scheme of ^{93}Rh was revealed and is depicted in Fig. 1(b). The γ rays presented can clearly be associated with the β-delayed proton decay of ^{94}Ag. Surprisingly, odd-parity states were populated to higher spins than even-parity ones, which requires odd angular momenta of the emitted protons, if the tentative (21^+) assignment [2] for the β-decaying high spin isomer of ^{94}Ag is adopted. The results of proton-γ analysis obtained in [7] are confirmed by the present $\beta\gamma\gamma$ coincidences. The decay pattern into the ^{93}Rh states will be published in detail in [8].

The tentatively assigned maximum observed spin in the odd-parity band in ^{93}Rh is 33/2 $\hbar$ [6]. From this observation we could infer the spin range values of the Gamow-Teller (GT) states in ^{94}Pd as being (15–18) $\hbar$ and hence a spin range of (14 –19) $\hbar$ for the parent ^{94}Ag isomeric state. We can discard the low spin variance in both nuclei by using the following argument. Due to the steepness of the ^{93}Rh yrast line of $\geq$ 0.45 MeV/$\hbar$ based on data presented in [6], the GT resonance states in ^{94}Pd will favour the decay to the lowest possible spin, as the gain in decay energy will outweigh the higher centrifugal barrier. Thus, the lower estimate of the spin limit for the GT states in ^{94}Pd decaying to ^{93}Rh by proton emission is 17 $\hbar$, which leads to a spin value of $J \geq 16\ \hbar$ for the parent ^{94}Ag state.

A first-order lower limit of the energy of the isomeric state (^{94}Ag^m) was obtained from the end-point of the β-delayed proton spectrum and from the mass predictions [5] by using the equation:

$$E_{^{94}Ag^m} \geq E_{pmax} + E_{^{93}Rh}(33/2) - Q_{EC}(^{94}Ag_{g.s.} \rightarrow ^{94}Pd_{g.s.}) + S_p(^{94}Pd), \quad (1)$$

where E_{pmax} is the maximum energy of the proton spectrum obtained experimentally [7], Q_{EC} is the mass difference [5] and S_p is the proton separation energy in ^{94}Pd [5], see Fig. 2 for the details concerning these quantities and the decay scheme of ^{94}Ag. The equation translates into $E_{^{94}Ag^m} \geq$(6.5 + 5.7 - 13 + 4.5) MeV $\geq$ 4 MeV.

Shell-model calculations in the restricted $(1p_{1/2}0g_{9/2})$ model space and using an empirical interaction cannot predict the isomer [2]. It was already observed below ^{56}Ni that the excitation energy of the spin-gap isomers depends to a large extent on the model space [9]. Core-excitations across the $N = Z = 50$ shell gap may be responsible for the isomerism [10].

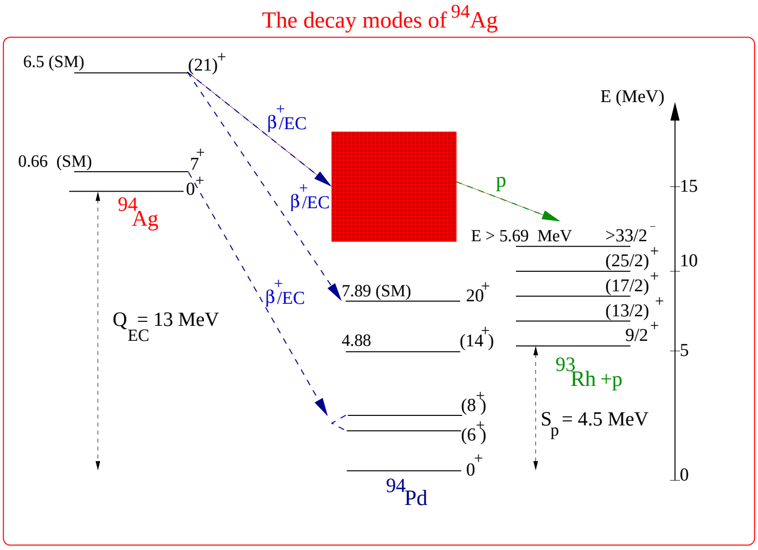

Fig. 2: Illustration of the ^{94}Ag decay scheme.

3 ^{100}In

^{100}In was produced via the ^{50}Cr(^{58}Ni,αp3n) reaction. The reaction recoils were stopped inside a graphite catcher of a thermal ion source which guarantees sufficient selectivity for indium [11]. After ionisation and extraction from the ion source, the beam delivered by the GSI mass separator was directed to the Ge setup (similar to that discussed in the previous section) or to the total-absorption spectrometer (TAS) [12]. The former setup comprised 12 Ge crystals having a photopeak efficiency of 2.7%. The experimental details have been described in [13]. By inspecting the $\beta\gamma\gamma$ data originating from the Ge experiment, we could observe the population of states of 8^+ (E = 2548 keV) and 6^+ (E = 2096 keV, 2458 keV) in the daughter ^{100}Cd nucleus. The issue is how to correlate this information with the spin and parity of the parent state. If the γ-ray balance deduced from the high-resolution experiment were used, the resulting "apparent feeding" would be misleading, since it includes β feeding and unobserved γ feeding as well. A more reliable way to inspect the β feeding is to measure the ^{100}In activity in TAS. The procedure of deriving the β-intensity distribution from the experimental spectra is described in [14]. The β-intensity distribution deduced from TAS is shown in the upper panel of Fig. 3. It is seen from the figure, that for low ^{100}Cd excitation energies, where the Ge setup is sensitive, the TAS spectrum is empty. The main part of the distribution is characterized by a Gamow-Teller resonance occurring at

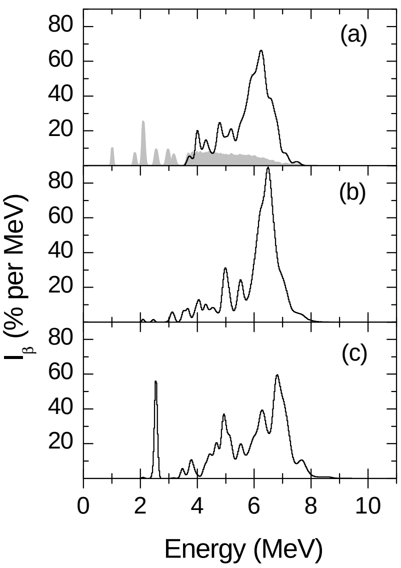

Fig. 3: Beta-intensity distribution deduced from the TAS experiment (a) and from shell-model (SM) predictions, assuming spins and parities of 6^+ (b) and 7^+ (c), respectively, for the ground state of ^{100}In. The experimental uncertainties are indicated as a shadowed area in panel (a).

excitation energies above 4 MeV, peaking at 6.4 MeV and having a full width at half-maximum of 1 MeV. In order to make some predictions with respect to the spin and parity of the ^{100}In ground state, a comparison with theory is needed. Shell-model calculations were performed [13] and the results are presented in the lower panels of Fig. 3. Assuming a spin and parity of 7^+ for the decaying state, a substantial feeding (10 %) of the 2548 keV 8^+ level is obtained, in contradiction with the experimental data, which indicate no direct population of the 8^+ level. A very small feeding of the 6^+ level at 2096 keV is seen in the middle panel of Fig. 3, which might correspond to the same feeding which we observe in the experimental TAS spectrum. Thus, a more likely value for the spin and parity of the ^{100}In ground state is 6^+.

4 Summary

^{94}Ag, a self-conjugate odd-odd nucleus, was produced in fusion-evaporation reaction and studied at GSI ISOL separator. By analysing $\beta\gamma\gamma$ coincidences, its complex decay scheme, including $\beta\gamma$ and β-delayed proton modes was established and the existence of the high-spin isomer was confirmed. In the shell-model frame, the spin-gap isomer cannot be predicted in the restricted $(1p_{1/2}0g_{9/2})$ model space, with the state closest to be isomeric having $J^\pi = 21^+$ at $E \geq 6$ MeV excitation energy [2]. This would imply that both in spin and excitation energy the isomer is unique and unprecedented in the Segré chart. The ^{100}In decay scheme was established and the spin-parity assignment of the ground state was discussed on the basis of the comparison of the experimental β feeding with shell-model calculations.

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