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In-beam γ-ray spectroscopy of nuclei in the ^{132}Sn region performed at RIKEN

V. Vaquero([1])(*), A. Jungclaus([1]), P. Doornenbal([2]), K. Wimmer([3])
and the NP1306-RIBF98R1 Collaboration

([1]) *Instituto de Estructura de la Materia, CSIC - E-28006 Madrid, Spain*
([2]) *RIKEN Nishina Center - 2-1 Hirosawa, Wako, Saitama 351-0198, Japan*
([3]) *Department of Physics, University of Tokyo, 7-3-1 Hongo, Bunkyo, Tokyo 113-0033, Japan*

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Summary. — The nucleus ^{133}Sn$_{83}$, with one single neutron outside doubly-magic ^{132}Sn, was studied at the Radioactive Isotope Beam Factory at RIKEN. The excited states of ^{133}Sn were populated via one-neutron knockout from a ^{134}Sn beam on a carbon target at relativistic energies. Besides the γ rays emitted following the decay of known neutron single-particle states, additional γ strength above the neutron separation energy was observed for the first time. It has been interpreted as evidence for a competition between γ-ray and neutron emission in the decay of neutron-unbound states in ^{133}Sn.

1. – Introduction

The region around the doubly-magic nucleus ^{132}Sn (Z=50 and N=82) is of particular interest for nuclear structure investigations. Nuclei with a few nucleons outside this closed-shell core provide direct information about the evolution of nucleon-nucleon correlations, quadrupole collectivity and single-particle energies. In this context, the low-lying states in the neutron-rich nucleus ^{133}Sn, which consists of a single neutron coupled to the doubly-magic nucleus ^{132}Sn, provide information with respect to the position of the neutron single-particle orbitals belonging to the N=82-126 major shell. Neutron single-particle energies of 854, 1367, 1561, and 2002 keV for the $2p_{3/2}$, $2p_{1/2}$, $0h_{9/2}$ and $1f_{5/2}$ orbitals, respectively, relative to the $1f_{7/2}$ orbital, have been established combining the information from both β decay and neutron-transfer experiments [1-4]. The neutron single-hole states in ^{133}Sn (corresponding to particle-hole excitations across the N=82 gap) are expected to have excitation energies significantly above S_n=2.402(4) MeV and thus to decay via neutron emission mediated by the strong interaction. Here, we present

(*) e-mail: victor.vaquero@csic.es

first experimental evidence that electromagnetic decay is competing in the decay of unbound neutron-holes states in ^{133}Sn. Note that more details of this work have recently been reported in Ref. [5].

2. – Experiment

The experiment was performed in April 2015 at the Radioactive Isotope Beam Factory (RIBF) at RIKEN. The exotic nuclei to be investigated were produced by the in-flight fission of a 345 MeV/u ^{238}U primary beam with an average intensity of 15 pnA impinging on a 4-mm-thick Be target. The first stage of the BigRIPS separator was used to select the nuclei of interest while the second part was used to identify the secondary beam [6]. This identification was performed event-by-event using the TOF-Bρ-ΔE method [7], in which the time of flight (TOF), magnetic rigidity (Bρ) and energy loss (ΔE) were measured using the focal-plane detectors on the beam line. After the selection and identification, the secondary beam was delivered to the focal plane F8, where it impinged on a 3-mm-thick C target. The energy of the ^{134}Sn ions in front of the C target was 165 MeV/u. The reaction products were delivered to the ZeroDegree spectrometer, where they were identified using the same method as in BigRIPS [6]. Figure 1 shows the ZeroDegree particle identification following the interaction of ^{134}Sn ions with the C target, showing that the ions are detected in different charge states. For γ-ray detection the DALI2 spectrometer was mounted surrounding the C target. DALI2 consists of 186 NaI(Tl) detectors covering polar angles from 20° to 150° and is characterized by a high photo-peak efficiency and a moderate energy resolution [8]. Figure 2 shows the Doppler-corrected γ-ray spectrum measured in coincidence with ^{134}Sn ions detected in BigRIPS and ^{133}Sn nuclei detected in the ZeroDegree spectrometer. Besides the known γ rays emitted in the decay of the single-particle states (transitions at 513, 854, 1561, and 2002 keV), clearly additional γ strength is observed above the neutron separation energy up to about 5.5 MeV with a line at 3570(50) keV being the strongest component.

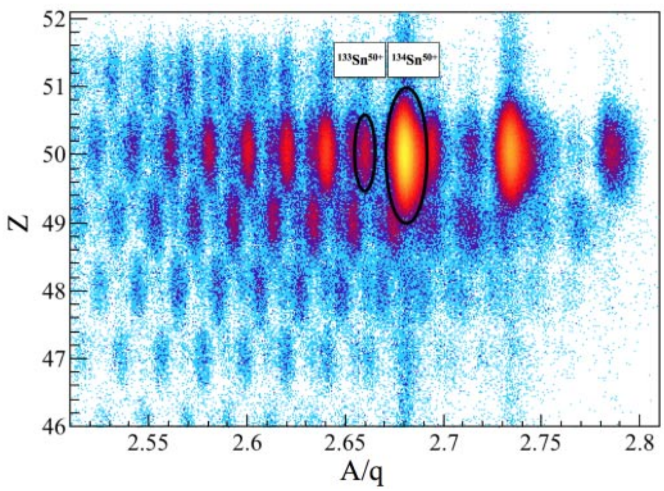

Fig. 1. – Particle identification plot from the ZeroDegree spectrometer requiring the identification of ^{134}Sn ions in BigRIPS. Note that the ions are observed in different charge states in ZeroDegree.

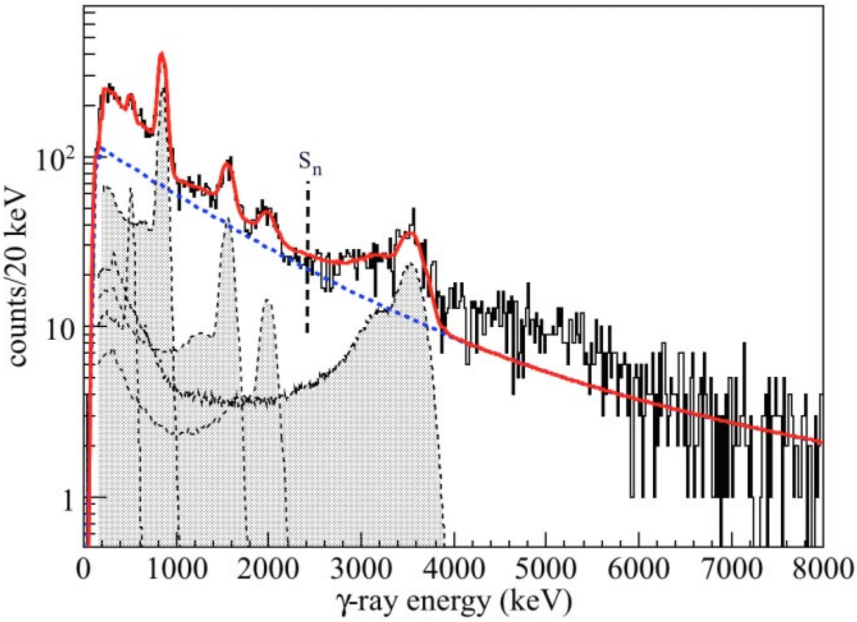

Fig. 2. – Doppler-corrected γ-ray spectrum (for γ-ray multiplicity M_γ=1 and applying add-back) of ^{133}Sn populated via one-neutron knockout from ^{134}Sn. The fit of the DALI2 response function to the experimental spectrum is shown by the thick red line while the individual components are shown as black and the background as blue dashed lines.

3. – Discussion

The excited states above S_n, whose decay is observed in Fig. 2, are interpreted as neutron-hole states that are populated following the knockout of a neutron from the closed N=50-82 shell of the ^{134}Sn projectile. The transition observed at 3570(50) keV most probably corresponds to the γ decay of the $0h_{11/2}$ neutron-hole state. Since this orbital is situated close to the Fermi level and occupied by as many as twelve neutrons, it is expected to have the highest cross section. In fact, in Ref. [1] a line at 1.26 MeV has been observed in the β-delayed neutron spectrum of ^{134}In and it was concluded that this neutron transition corresponds to the decay of the $0h_{11/2}$ neutron-hole state, positioning this state at an energy of around 3.66 MeV, i.e. close to the energy of the γ ray observed in the present work. The remaining γ-ray strength observed in the range 4-6 MeV could be caused by neutron removal from the other, in particular the $1d_{5/2}$ and $0g_{7/2}$, orbitals of the N=50-82 shell. All these neutron-hole states are situated at least 1.2 MeV above the neutron separation energy and therefore are expected to decay exclusively via neutron emission. However, the ability of γ-ray emission to compete with neutron decay can be understood taking into account the structure of the initial and final states and the resultant wave-function overlap. Once the neutron is removed from the closed N=50-82 shell of ^{134}Sn, the ^{133}Sn nucleus is populated with a neutron hole in this shell. Since the excitation energy of the first excited state 2^+ state of ^{132}Sn is 4.041 MeV, neutron emission from unbound states in the excitation energy range 2.4-6.4 MeV can only proceed to the ground state of ^{132}Sn. Therefore, following neutron emission, ^{132}Sn would remain in a configuration comprising two neutron holes below and two neutrons above the N=82 gap. However, the ground state of ^{132}Sn is not expected to contain large contributions of such two-particle-two-hole configurations and therefore the overlap between the wave functions of the parent and daughter states is rather small. As a consequence, neutron emission is retarded allowing γ decay to compete in the decay of unbound neutron-hole states in ^{133}Sn [5]. Similar nuclear structure arguments were already put forward in the past to explain the observed electromagnetic decay of unbound states positioned at energies up to more than 2 MeV above the neutron-separation energy in other regions of the nuclear chart [9-12].

4. – Conclusion

To conclude, we presented experimental evidence for the γ decay of unbound neutron-holes states of ^{133}Sn which are situated at excitation energies up to more than 3 MeV above S_n. The ability of electromagnetic decay to compete with neutron emission is traced back to particular nuclear structure effects. Our study raises the question whether γ decay above the neutron threshold may play a much more important role than generally assumed in the decay of highly excited states populated following β decay in the region southeast of ^{132}Sn.

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REFERENCES

[1] P. Hoff et al., Phys. Rev. Lett. **77**, 1020 (1996).
[2] K.L. Jones et al., Nature **465**, 454 (2010); Phys. Rev. C **84**, 034601 (2011).
[3] K. L. Jones et al., Phys. Rev. C **84**, 034601 (2011).
[4] J.M. Allmond et al., Phys. Rev. Lett. **112**, 172701 (2014).
[5] V. Vaquero et al., Phys. Rev. Lett. **118**, 202502 (2017).
[6] T. Kubo et al., Prog. Theor. Exp. Phys. 2012, 03C003 (2012).
[7] N. Fukuda, T. Kubo, T. Ohnishi, N. Inabe, H. Takeda, D. Kameda, and H. Suzuki, Nucl. Instr. Meth. B **317**, 323 (2013).
[8] S. Takeuchi, T. Motobayashi, Y. Togano, M. Matsushita, N. Aoi, K. Demichi, H. Hasegawa, and H.Murakami, Nucl. Instr. Meth. A **763**, 596 (2014).
[9] S. R. Stroberg et al., Phys. Rev. C **90**, 034301 (2014).
[10] J. L. Tain et al., Phys. Rev. Lett. **115**, 062502 (2015).
[11] R. Dungan et al., Phys. Rev. C **93**, 021302(R) (2016).
[12] A. Spyrou et al., Phys. Rev. Lett. **117**, 142701 (2016).