# INVESTIGATIONS OF NEUTRON DEFICIENT NUCLEI CLOSE TO $^{100}$Sn WITH EUROBALL*

M. Palacz[a], C. Fahlander[b], D. Sohler[c], D. Rudolph[b]
J. Blomqvist[d], J. Kownacki[a], K. Lagergren[d], L.O. Norlin[d]
J. Nyberg[e], A. Algora[f], C. Andreoiu[b], G. de Angelis[f], A. Ataç[e]
D. Bazzacco[g], L. Berglund[b], T. Bäck[d], J. Cederkäll[d]
B. Cederwall[d], Zs. Dombradi[c], B. Fant[h], E. Farnea[i], A. Gadea[f,j]
M. Górska[k], H. Grawe[k], N. Hashimoto-Saitoh[l], A. Johnson[d]
A. Kerek[d], W. Klamra[d], S.M. Lenzi[f], A. Likar[m]
M. Lipoglavšek[m], M. Moszyński[n], D. Napoli[f], C. Rossi-Alvarez[g]
H. Roth[o], T. Saitoh[l], D. Seweryniak[p], Ö. Skeppstedt[o]
M. Weiszflog[e] and M. Wolińska[a]

[a]Heavy Ion Laboratory, University of Warsaw, Warsaw, Poland
[b]Department of Physics, Lund University, Lund, Sweden
[c]Institute for Nuclear Research, Debrecen, Hungary
[d]Royal Institute of Technology, Stockholm, Sweden
[e]Department of Neutron Research, Uppsala University, Sweden
[f]Laboratori Nazionali di Legnaro, Padova, Italy
[g]Dipartimento di Fisica and INFN, Sezione di Padova, Padova, Italy
[h]Department of Physics, Helsinki University, Helsinki, Finland
[i]University of Valencia, Valencia, Spain
[j]Instituto de Fisica Corpuscular, Valencia, Spain
[k]GSI, Darmstadt, Germany
[l]Niels Bohr Intitute, University of Copenhagen, Denmark
[m]J. Stefan Institute, Ljubljana, Slovenia
[n]Sołtan Institute for Nuclear Studies, Świerk, Poland
[o]Chalmers University of Technology, Gothenburg, Sweden
[p]Argonne National Laboratory, Chicago, USA

*(Received December 1, 2000)*

Excited states of nuclei in the vicinity of $^{100}$Sn have been studied using the EUROBALL detector array. Gamma-ray lines from $^{103}$Sn have been identified for the first time, and a level scheme of low-lying excited states of $^{103}$Sn has been established. New constraints on energies of single particle orbitals with respect to the $^{100}$Sn core are obtained.

PACS numbers: 21.60.Cs, 23.20.Lv, 27.60.+j

* Presented at the XXXV Zakopane School of Physics “Trends in Nuclear Physics”, Zakopane, Poland, September 5–13, 2000.

## 1. Introduction

The $^{100}$Sn nucleus, the heaviest doubly magic nucleus with equal number of protons and neutrons, provides a unique testing ground for the nuclear shell model. This extremely neutron deficient nucleus, and its closest neighbours in the chart of nuclides, are however not accessible today for in-beam studies. Information about the Single Particle Energies (SPE) and Two-Body Matrix Elements (TBME) with respect to $^{100}$Sn has thus to be deduced indirectly, by studying excited states in more distant neighbours of $^{100}$Sn. An experimental challenge at present is to study excited states of nuclei with a few valence particles outside the doubly-magic core, approaching $^{100}$Sn as close as possible.

## 2. Experiment

Excited states in close neighbours of $^{100}$Sn have been studied in an experiment performed at Laboratori Nazionali di Legnaro in Italy using the EUROBALL [1] detector array in a configuration consisting of 15 Clover [2] and 26 Cluster [3] composite Compton suppressed Ge detectors, 40 silicon $\Delta E/E$ telescopes [4] for the detection and identification of light charged particles, and a Neutron Wall [5] of 50 liquid scintillator detectors situated in the forward $1\pi$ section of the setup. Fusion-evaporation reactions were induced by a $^{58}$Ni beam with an energy of 240 MeV and an average intensity of 2 pnA, bombarding a 1.4 mg/cm$^2$ thick $^{54}$Fe target on a gold backing. Events were registered if (a) at least one Compton unsuppressed $\gamma$-ray was detected in the Ge detectors together with one hardware pre-discriminated neutron in the neutron detectors, or (b) at least 7 Compton unsuppressed $\gamma$ rays were detected in the Ge detectors. About $2 \times 10^9$ events collected during the 76 hours of the effective beam time made possible identification of gamma ray-lines from 24 different neighbours of $^{100}$Sn [6].

## 3. Results and discussion

In the present experiment $\gamma$-ray lines from the $^{103}$Sn nucleus have been identified for the first time and a level scheme of low lying excited states has been established. The identification of the $^{103}$Sn $\gamma$-ray lines has been done by a comparative analysis of two $\gamma$-ray spectra, gated by the requirement that (a) two $\alpha$ particles and one neutron, and (b) two $\alpha$ particles one neutron and one proton are detected. Lines from nuclei produced via the emission of exactly two $\alpha$ particles and one neutron should be present in spectrum (a) but not in spectrum (b), which contained lines from nuclei associated with the emission of additional protons, like $^{102}$In $(2\alpha\, n\, p)$ and $^{101}$Cd $(2\alpha\, n\, 2p)$.

The $^{103}$Sn nucleus was produced with a cross section of $5 \pm 3\mu$b. Note that only an upper limit for this cross section was given in our previous reports [6,7]. The uncertainties in the determination of the cross section are due to the difficulties in estimating the influence of: (a) the above mentioned trigger condition which strongly enhanced neutron evaporation channels, (b) differences in mean $\gamma$-ray multiplicity for various evaporation residua which affects the registration probability. Details of the experimental procedure leading to the identification of $^{103}$Sn $\gamma$-ray lines have been described elsewhere [6,7], as well as the discussion of the observed $\gamma$-ray coincidences. The level scheme of $^{103}$Sn is presented in Fig. 1.

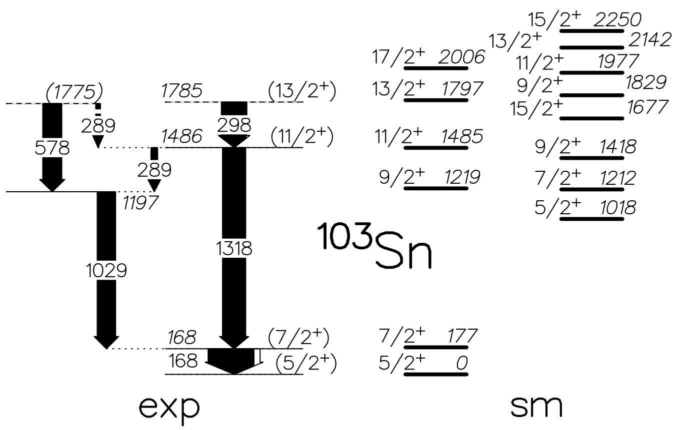


Fig. 1. Level scheme of $^{103}$Sn established in the present work (exp) and results of the shell model calculations (sm). Widths of the arrows indicate transition intensities as seen in the $^{58}$Ni (240 MeV) $+^{54}$Fe $\rightarrow^{103}$Sn $+2\alpha n$ reaction.

The $^{103}$Sn nucleus may provide the best possible verification of neutron single-particle energies with respect to $^{100}$Sn as long as studies of excited states of $^{101}$Sn are not feasible. Prior to the work described here, there was no experimental information on excited states in the $^{103}$Sn nucleus. Conclusions regarding single particle-energies with respect to $^{100}$Sn based on excited states in $^{103}$Sn are, however, affected by assumptions about the residual interactions among the three valence neutrons.

Interaction which can be calculated from the bare nucleon–nucleon potential, including also effects of the nuclear medium, is known in other regions to be burdened by significant errors and this limits the exploitation of the powerful shell model technique. Alternatively, one can try to determine the interactions from experimental data. Such an approach is very successful for other doubly magic nuclei, in particular $^{208}$Pb, where the experimental levels in close neighbours of the doubly magic core can be reproduced with the precision of the order of 10 keV. In the region of $^{100}$Sn the main difficulty is that only 3 excited states are known in $^{102}$Sn [8], in contrast to an almost complete set of about 40 excited states in $^{206}$Pb. It is thus necessary to extend the calculations to less neutron deficient tin isotopes. Results of such calculations are shown in Fig. 1. The SPE and TBME derived from the Bonn A potential [9] were varied in the shell model code to obtain a good fit to the experimental data on nuclei from $^{102,103}$Sn up to $^{113,114}$Sn. A truncated single particle basis including the $1g_{7/2}$, $2d_{5/2}$, $2d_{3/2}$, $3s_{1/2}$ and $1h_{11/2}$ neutron orbitals was used.

The calculations lead to the conclusion that the spacing of the two most important neutron orbitals for $N>50$, $g_{7/2}$ and $d_{5/2}$, is equal to $110 \pm 40$ keV. The error bar represents the uncertainty related to variations of the effective interactions. Further discussion of the single particle constraints obtained in this work is presented in Ref. [7].

The $7/2^+$ (168 keV), $11/2^+$ (1486 keV) and $13/2^+$ (1785 keV) states are very well reproduced by the calculations. The state at 1197 keV almost certainly corresponds to the first $9/2^+$ shell model state. The interpretation of the 1775 keV state is less straightforward. We would tend to interpret this state as the second $13/2^+$ state, but the calculations do not predict such two close lying $13/2^+$ states. The same kind of deficiency shows up however in $^{105}$Sn, were two $13/2^+$ states were reported [10] with the relative spacing of 66 keV, but the calculations predict a much larger distance between these states (219 keV). The $^{105}$Sn nucleus is relatively strongly populated in the present experiment — about 5% of the trigger preselected yield [6]. The analysis of the level scheme of $^{105}$Sn is currently in progress, and we can already confirm that the two close lying $13/2^+$ states in $^{105}$Sn do exist. Alternatively the 1775 keV level can possibly be the third excited $9/2^+$ state, in agreement with the calculations. An open question is, of course, why such non yrast state should be strongly populated in a heavy ion reaction.

In summary, based on the observation of excited states in $^{103}$Sn, the most accurate estimate to date for the relative spacing of the $1g_{7/2}$ and $2d_{5/2}$ neutron single particle orbitals was obtained. A wealth of information on other nuclei in the region has also been collected, and analysis of the data is in progress.

## REFERENCES


[1] EUROBALL III, A European $\gamma$-ray facility, Eds. J. Gerl and R.M. Lieder, GSI 1992.

[2] P. M. Jones *et al.*, *Nucl. Instrum. Methods Phys. Res.* **A357**, 458 (1995).

[3] J. Eberth *et al.*, *Nucl. Instrum. Methods Phys. Res.* **A369**, 135 (1996).

[4] E. Farnea *et al.*, *Nucl. Instrum. Methods Phys. Res.* **A400**, 87 (1997).

[5] Ö. Skeppstedt *et al.*, *Nucl. Instrum. Methods Phys. Res.* **A421**, 531 (1999).

[6] M. Palacz *et al.*, Proc. Int. Symposium Shell Model 2000, RIKEN, Japan, March 2000; *Nucl. Phys.* **A**, in print.

[7] C. Fahlander *et al.*, *Phys. Rev.* **C**, in print.

[8] M. Lipoglavšek *et al.*, *Phys. Lett.* **B440**, 246 (1998).

[9] M. Hjorth-Jensen *et al.*, *Phys. Rep.* **261**, 125 (1995).

[10] A. Gadea *et al.*, *Phys. Rev.* **C55**, 55 (1997).