Eur. Phys. J. A **15**, 49–51 (2002)
DOI 10.1140/epja/i2001-10225-9

THE EUROPEAN PHYSICAL JOURNAL A

Charge radius change in the heavy tin isotopes until A = 132 from laser spectroscopy

F. Le Blanc[1,a], L. Cabaret[2], J.E. Crawford[3], S. Essabaa[1], V. Fedoseyev[4], W. Geithner[5], J. Genevey[6], M. Girod[7], R. Horn[5], G. Huber[5], S. Kappertz[5], J. Lassen[5], J.K.P. Lee[3], G. Le Scornet[8], V. Mishin[4], R. Neugart[5], J. Obert[1], J. Oms[1], A. Ouchrif[1], S. Peru[7], J. Pinard[2], H. Ravn[8], B. Roussière[1], J. Sauvage[1], D. Verney[1], and the Isolde Collaboration[8]

[1] Institut de Physique Nucléaire, IN2P3-CNRS, 91406 Orsay cedex, France
[2] Laboratoire Aimé Cotton, 91405 Orsay cedex, France
[3] Physics Department, Mc Gill University, H3A2T8 Montréal, Canada
[4] Institute for Spectroscopy, Troisk, Russia
[5] Institut für Physik der Universität Mainz, 55099 Mainz, Germany
[6] Institut des Sciences Nucléaires, Université Joseph Fourier, 38026 Grenoble cedex, France
[7] Service de Physique et Techniques Nucléaires, CEA, BP 12, 91680 Bruyères-le-Châtel, France
[8] CERN, 1211 Genève 23, Switzerland

Received: 21 March 2002 /
Published online: 31 October 2002 –

Abstract. Laser spectroscopy measurements have been carried out on the very neutron-rich tin isotopes with the COMPLIS experimental setup. Using the $5s^25p^2\ {}^3P_0 \rightarrow 5s^25p6s\ {}^3P_1$ optical transition, hyperfine spectra of $^{126\text{-}132}$Sn and $^{125\text{m},127\text{m},129\text{m-}131\text{m}}$Sn where recorded for the first time. The variation of the mean-square charge radius ($\delta\langle r^2\rangle$) between these nuclei and nuclear moments of the isomers and the odd isotopes were thus measured. An odd-even staggering which inverts at $A = 130$ is clearly observed. This indicates a small appearance of a plateau on the $\delta\langle r^2\rangle$ which has to be confirmed by measuring the isotope shift beyond $A = 132$.

PACS. 21.10.Ft Charge distribution – 21.10.Ky Electromagnetic moments – 31.30.Gs Hyperfine interactions and isotope effects, Jahn-Teller effect

1 Introduction

The doubly magic nuclei are of great interest in nuclear physics because their properties (binding energy, radius...) are the basis of the parametrization of the effective interactions used for mean-field calculations [1,2]. For the last two decades, these calculations successfully described the global properties of the nuclear ground states [3–6]. In the same time, the relativistic mean-field theory [7] was also getting success to describe these properties [6,8, 9]. In parallel, numerous new and accurate results were obtained making systematic data available along isotopic series from light to heavy nuclei. This motivated many theoretical works in particular to improve the parameters of the effective interactions currently used. The goal of these theoretical studies is to define an effective interaction valid not only along the stability but also for exotic nuclei. We have thus studied the effect of the shell closure at $N = 82$ on the mean-square charge radius variation ($\delta\langle r^2\rangle$) far from stability. The most important question is: will the $\delta\langle r^2\rangle$ exhibit a slope change at ^{132}Sn as it does for ^{208}Pb? Moreover, $\delta\langle r^2\rangle$ curves have been calculated for neutron-rich tin [10,11] and the predictions depend on the type of calculations.

The measurement of isotope shift gives a direct acces to the $\delta\langle r^2\rangle$ along isotopes series. To perform such measurements on tin isotopes, we have successfully used a technique of ion-beam implantation followed by Resonant Ionisation Spectroscopy (RIS) studies of the laser desorbed radioactive element. Such a system (COMPLIS) is installed at the ISOLDE-Booster facility. Accumulated products from the implanted ISOLDE beams are prepared as pulsed mass-separated ion beams by laser desorption and selective ionization.

In this contribution, we report on recent laser spectroscopy measurements performed on these heavy tin isotopes up to $A = 132$. From the $5s^25p^2\ {}^3P_0 \rightarrow 5s^25p6s\ {}^3P_1$ optical transition, the hyperfine spectra of $^{126\text{-}132}$Sn as well as these of $^{125\text{m},127\text{m},129\text{m-}131\text{m}}$Sn were recorded for the first time. The variation of the mean-square charge

[a] e-mail: leblanc@ipno.in2p3.fr

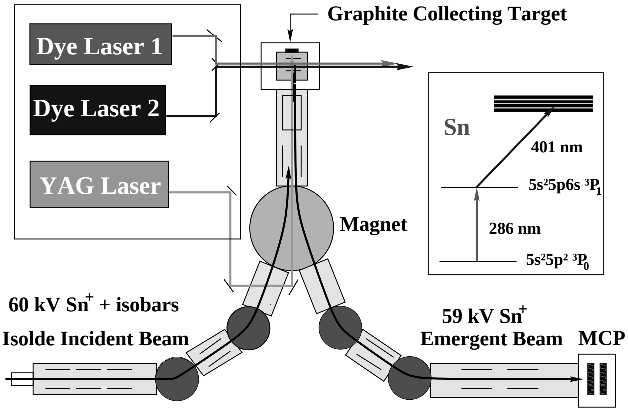

Fig. 1. The COMPLIS experimental scheme used for tin.

radius $\delta\langle r^2\rangle$ between these nuclei and the nuclear moments of the isomers and the odd isotopes were thus measured. These results are discussed and compared with different theoretical predictions.

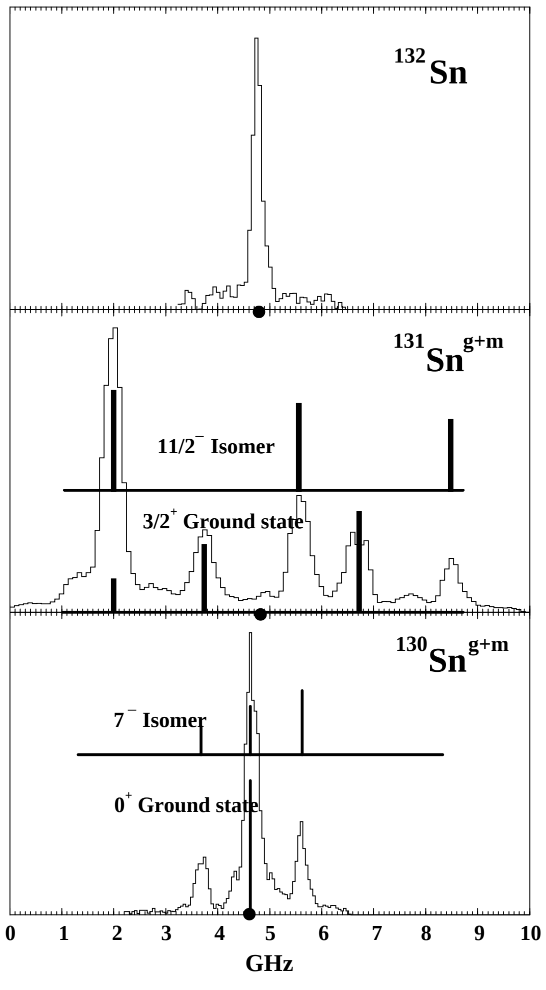

Fig. 2. Hyperfine spectra of $^{130}\mathrm{Sn}^{\mathrm{g+m}}$, $^{131}\mathrm{Sn}^{\mathrm{g+m}}$ and $^{131}\mathrm{Sn}^{\mathrm{g+m}}$. For $^{130}\mathrm{Sn}$ and $^{131}\mathrm{Sn}$ one line of the isomer is blended with one of the ground state.

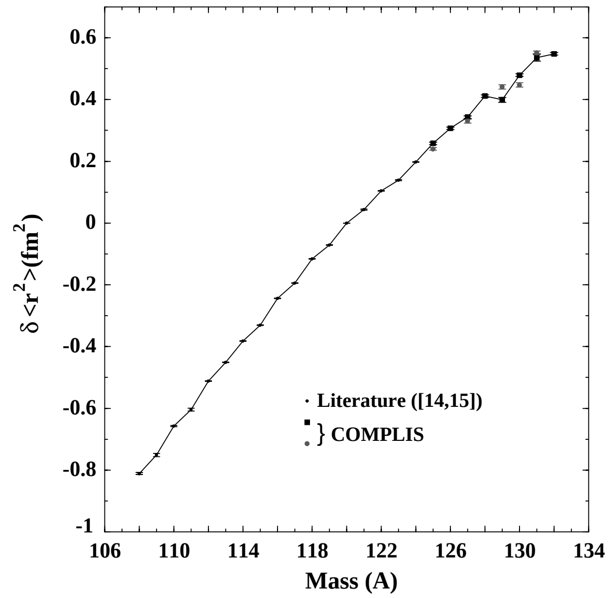

Fig. 3. Charge radius change in the tin isotopes. The line relies all the ground-states nuclei.

2 Experimental method

The COMPLIS experimental setup has already been described in ref. [12]. For the tin studies, the experiment is performed as follows. The radioactive tin isotopes are produced via fission reactions in the ISOLDE UC_2 target with the 1 GeV CERN PS-Booster proton beam. The ions are extracted at 60 kV and mass separated by the Ground Purpose Separator (GPS) of ISOLDE. It is worth noting that, with the hot-plasma source we used, many other elements like In, Cd, Sb, Te, I and Cs are ionized and, for example, at mass unit 132, tin represents only 0.24% of the produced nuclei. The ions enter the COMPLIS beam line, are slowed to 1 kV and are thus deposited on the first atomic layers of a rotating graphite substrate. Once the amount of the collected atoms is optimum (the collection time depending on the half-life of the isotope to be studied) they are desorbed by a Nd:YAG laser and selectively ionized by a set of two pulsed, tunable dye lasers where the first-excitation step at 286.3 nm ($5s^25p^2\ ^3P_0 \rightarrow 5s^25p6s\ ^3P_1$) is obtained from frequency doubling. The ions are finally detected with time-of-flight identification using a microchannel plate detector. This experimental setup is shown in fig. 1. The frequency scan over the hyperfine structure of a given isotope (and eventually isomer) is made as follows: after a sufficient collection time, the desorption of the tin atoms is made over the entire collection spot on the slowly rotating target at a given frequency step. After the desorption is complete, a new cycle of implantation desorption is run at an advanced frequency step. Whenever the laser frequency corresponds to a hyperfine transition, the desorbed atoms are excited and ionized by the other fixed laser frequency. The number of counted ions at the detector is directly proportional to the intensity of the hyperfine transition. With

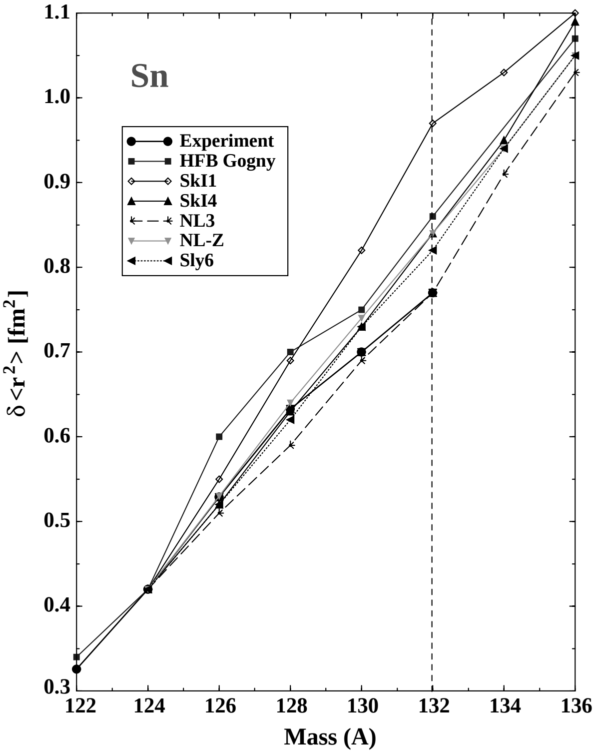

Fig. 4. Comparison of the even isotopes experimental $\delta\langle r_c^2\rangle$ with some theoretical predictions.

this apparatus, the efficiency we measured is of about 10^{-6} with a resolution of 170 MHz.

For the first experiment on tin, we measured all the isotopes and isomers from $A = 125$ to $A = 132$. The measured hyperfine spectra of ^{132}Sn, ^{131}Sn^{g+m} and ^{130}Sn^{g+m} are shown as examples in fig. 2. From the displacement of the centers of gravity of the hyperfine spectra, we were able to extract the isotope shift. From the relative position of the three lines of each isomer and odd isotope we can extract the magnetic and quadrupole moments.

3 Experimental results

The experimental isotope shift consists of a mass shift $\delta\nu_{\rm MS}$ and a field shift $\delta\nu_{\rm FS}$; it is from this last contribution that $\delta\langle r_c^2\rangle$ beween two nuclei A and A' can be extracted: $\delta\nu_{\rm FS}^{A,A'} = K \cdot F_\lambda \cdot \delta\langle r_c^2\rangle^{A,A'}$ [13], where $K = 0.975$ [13] and $F_\lambda = 3.35(20)$ GHz/fm^2 [14]. Using formula (2) in [15] but with the correct values of F_λ and $\delta\langle r_c^2\rangle^{124,116} = 0.442(5)$ [14], one avoids to introduce the specific mass shift which is very difficult to estimate. The updated $\delta\langle r_c^2\rangle$ curve is presented in fig. 3. The main remarkable thing that we can observe is the appearance of a plateau at mass 131. This suggests the emergence of a neutron skin at $A = 130$ and beyond but experimental data are now needed to confirm this hypothesis. The $\delta\langle r_c^2\rangle$ of the even isotopes can however be compared with existing mean-field calculations: some including relativistic effect (NL3, NL-Z) [10], some using Skyrme forces (SkI1, SkI4, Sly6) [10] and one using the Gogny force [11] (see fig. 4). Most of them are not as far from the experimental values but the appearance of the plateau is not predicted. Once more, experimental data on ^{134}Sn are necessary to definitely constrain the models.

A second phenomenon that we can observe is a larger odd-even staggering than for the lighter masses which is moreover, inverted. Theoretical data are waited on the odd isotopes to try to explain this unexpected phenomenon.

Moreover, from the A and B hyperfine constants of the excited atomic state, one can extract the magnetic and quadrupole moments of each isomer and odd isotope. The data are under analysis and the extracted experimental values will be compared with calculations assuming a given nuclear orbital.

References

1. D. Vautherin, D.M. Brink, Phys. Rev. C **5**, 626 (1972).
2. J. Dechargé, D. Gogny, Phys. Rev. C **21**, 1568 (1980).
3. P. Quentin, H. Flocard, Annu. Rev. Nucl. Sci. **28**, 523 (1978).
4. M. Girod, B. Grammaticos, Phys. Rev. C **27**, 2317 (1983).
5. M. Girod *et al.*, Phys. Rev. Lett. **62**, 2452 (1989).
6. Z. Patyk *et al.*, Phys. Rev. C **59**, 704 (1999).
7. J.D. Walecka, Ann. Phys. (N.Y.) **83**, 491 (1974).
8. P.G. Reinhard, Rep. Prog. Phys. **52**, 439 (1989).
9. V. Blum *et al.*, Phys. Rev. B **323**, 262 (1994).
10. P.G. Reinard, private communication (1997).
11. M. Girod, private communication (1998).
12. J. Sauvage *et al.*, Hyperfine Interact. **129**, 303 (2000).
13. G. Torbohm *et al.*, Phys. Rev. A **31**, 2038 (1985).
14. C. Piller *et al.*, Phys. Rev. C **42**, 182 (1990).
15. M. Anselment *et al.*, Nucl. Phys. A **451**, 471 (1986).