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EXPERIMENTAL STUDY OF SUPERNEUTRON-DEFICIENT TIN ISOTOPES

M.Lewitowicz[1], R.Anne[1], G.Auger[1], D.Bazin[1],
M.G.Saint-Laurent[1], R.Grzywacz[2], M.Pfützner[2],
K.Rykaczewski[2], J.Zylicz[2],
S.Lukyanov, A.Fomichov, Yu.Penionzhkevich, O.Tarasov,
V.Borrel[3], D.Guiillemaud-Mueller[3], A.C.Mueller[3],
H.Keller[3], O.Sorlin[3], F.Pougheon[3],
M.Huyse[4], T.Pluym[4], J.Szerypo[4], J.Wauters[4], C.Borcea[5],
K.Schmidt[6], Z.Janas[6]

Fragmentation reactions analyzed by means of the projectile fragment separator LISE3 at GANIL were exploited to enable the nuclei in the closest neighbourhood of ^{100}Sn to be identified and their decay properties studied. Preliminary results of the first experiments performed with the ^{112}Sn beam are presented. The first identification of ^{102}Sn and confirmation of an existence of ^{101}Sn open new possibilties in the study of nuclei close to ^{100}Sn.

The joint investigation has been performed at GANIL by the collaboration LNR — GANIL — Warsaw University.

Эксперименты по синтезу супернейтронодефицитных ионов олова

М.Левитович и др.

Описываются результаты экспериментов по определению стабильности ядер вблизи дважды магического ^{100}Sn. Для этого использовались реакции фрагментации ионов ^{112}Sn, ускоренных на ускорителе ГАНИЛ. Сепарация и идентификация полученных фрагментов осуществлялись на фрагмент-сепараторе LISE3. Впервые идентифицированный изотоп ^{102}Sn и подтверждение существования ^{101}Sn открывают новую возможность в исследовании ядер, близких к ^{100}Sn.

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[1] GANIL, Caen, France
[2] Warsaw University, Poland
[3] IPN, Orsay, France
[4] KU, Leuven, Belgium
[5] IAP, Bucharest, Romania
[6] GSI, Darmstadt, Germany

1. Motivation

Studies of doubly-closed-shell and neighbouring nuclei are obviously important for testing and further development of nuclear models. Such studies of nuclei far from stability [1] have additionally an astrophysical context. Reliable predictions of nuclear structure and disintegration rates, especially for the Gamow — Teller (GT) beta decay, are crucial for understanding the nucleosynthesis scenarios under stellar conditions. In case of neutron-deficient nuclei these scenarios include the rapid proton-capture process.

These remarks may be considred as a general motivation for our interest, and the interest of several other experimental and theory groups, in the ^{100}Sn region. Let us recall that ^{100}Sn is the yet unidentified isotope of tin with a deficit of about 18 neutrons with respect to the line of beta stability. It is the heaviest $Z = N$ doubly magic nuclear system that one may hope to reach in experiment (the next one would be ^{164}Pb, presumably well beyond the proton-drip line). With the shell-model energy gap, that may be here as high as 6.5 MeV, the closed-shell properties of ^{100}Sn are expected to be well pronounced.

The shell model picture of the beta decay in the ^{100}Sn region is extremely simple. This decay is strongly dominated by one channel, the $\pi g_{9/2} \rightarrow \nu g_{7/2}$ GT transformation. Hence, interpretation of experimental data can be particularly unambiguous, a very important feature for testing nuclear models and an insight into the problem of the GT strength quenching.

The large distance of ^{100}Sn from the line of stability is reflected in the decay energy Q_{EC} which is predicted to be 7 to 8 MeV. For some of the neighbouring nuclei, the Q_{EC} values should be even higher. A large fraction of the total GT strength can be observed. Beta-delayed proton emission becomes possible. This proton emission is strongly related to the properties of the GT decay. For odd-A and odd-odd parent nuclei, most of the beta strength is associated with the transformation of a $g_{9/2}$ proton from the even-even core. The relevant GT transitions lead to multiparticle configurations at high excitation energies. This opens a possibility for emission of protons with a detectable yield. In fact, due to law background, measurements of proton spectra can be the best way for an identification and/or GT decay study of nuclei very far from stability.

The decay of nuclei in the ^{100}Sn region has been investigated in several experiments on beta decay using the on-line mass-separators at GSI Darmstadt, ISOLDE CERN and LISOL Leuven. However, ^{100}Sn has not been discovered. Progress towards this nucleus using on-line mass-separator based studies is made very difficult by a drastic decrease of the production cross-section in both spallation and heavy ion fusion-evaporation reactions. The yield is further reduced by the small overall release efficiency caused by the short half-lives of investigated nuclei. Obviously, new production methods and separation techniques have to be tested in order to cross the border line of known nuclei (see the next section).

Therefore we proposed [2] studies of the nuclei in the ^{100}Sn region using the fragmentation reactions and LISE3 projectile fragment separator at the GANIL facility. It was expected that, relative to earlier experiments, production yields of the most neutron-deficient nuclides will be increased, and the limit for detectable half-lives will be essentially improved. These two improvements offer an opportunity to reach ^{100}Sn. The expected increase of the production yields is mainly due to the use of ^{112}Sn as a projectile. This rare primary beam is developed at GANIL in a close and already very fruitful collaboration with the Laboratory of Nuclear Reactions, JINR at Dubna.

2. Border Line of Known Nuclei near ^{100}Sn

A section of the chart of nuclei near ^{100}Sn is displayed in Fig.1. The last decays with unambiguously measured half-life in the vicinity ($Z \leq 50$) of ^{100}Sn are those of ^{103}Sn ($T_{1/2} = 7 \pm 1.5$ s), ^{100}In ($T_{1/2} = 3.5 \pm 0.7$ s) and ^{98}Cd ($T_{1/2} = 9.2 \pm 0.3$ s).

The proton shell closure at $Z = 50$ creates a favorite energy conditions for alpha and proton emission from the ground-state of neutron-deficient tellurium ($Z = 52$) and antimony ($Z = 51$) isotopes, respectively. Indeed, an island of alpha emitters above tin has been found experimentally including the lightest one known so far — ^{106}Te. Recently, the Berkeley group presented an evidence for the ground-state proton decay of ^{105}Sb [4].

3. Experiment

In the experiment performed at GANIL (26 Oct. — 4 Nov., 1993) we used ^{112}Sn^{43+} beam at 58 MeV/nucleon impinging on a 78 mg/cm^2 thick ^{nat}Ni target. The mean intensity of the primary beam was about 130 enA

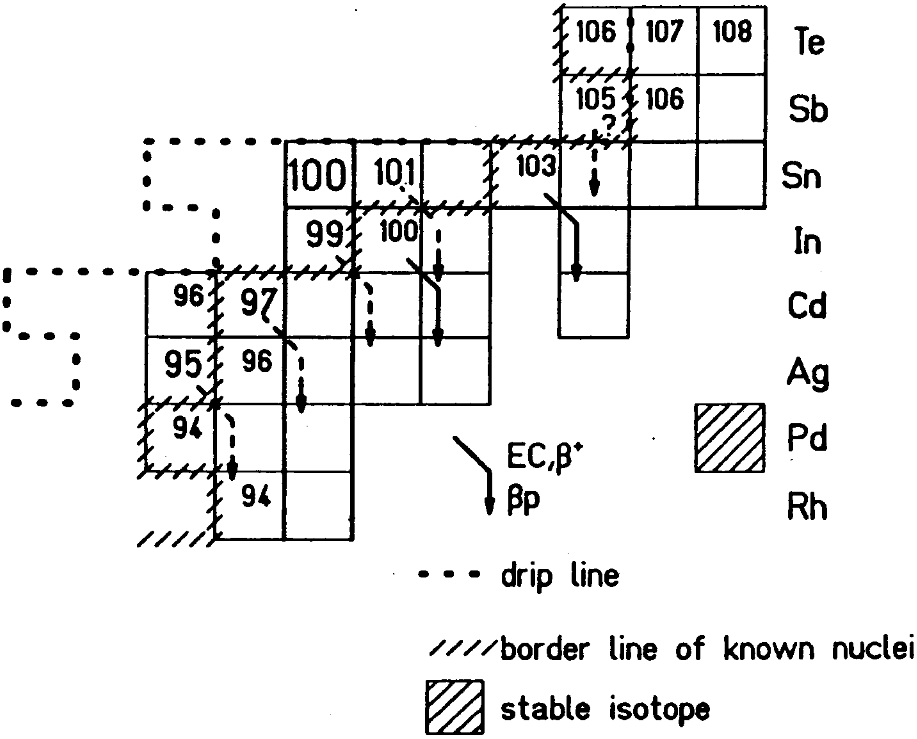

Fig.1. Nuclides near ^{100}Sn known in June 1993 [2]. At present, one has to add ^{94,95}Ag and ^{101}Sn [3], ^{105}Sb [4] and ^{102}Sn — this work

and it was limited by the data acquisition system. The choice of the nickel target enhances a transfer-type reaction. This in particular increases in an important way production of the nuclei with $Z > 50$. A 9.5 mg/cm^2 thick carbon foil placed just behind the target decreased a width of the charge state distribution in this way that about 90% of all tin isotopes were produced in the 48+ and 49+ charge states.

The experimental device used to select the exotic nuclei was the LISE3 spectrometer [5]. Briefly described, LISE3 is a doubly achromatic system providing selection of reaction products following the ratio $Av/Q \sim B\rho$, where A, Q and v are, respectively, the mass, the ionic charge and the velocity of the ions and $B\rho$ is the magnetic rigidity of the spectrometer. The Wien filter placed at the end of the spectrometer allows for an additional velocity selection of the reaction products. In order to have a good velocity determination and to decrease the counting rate we reduced the momuntum acceptance of LISE to ± 0.1%.

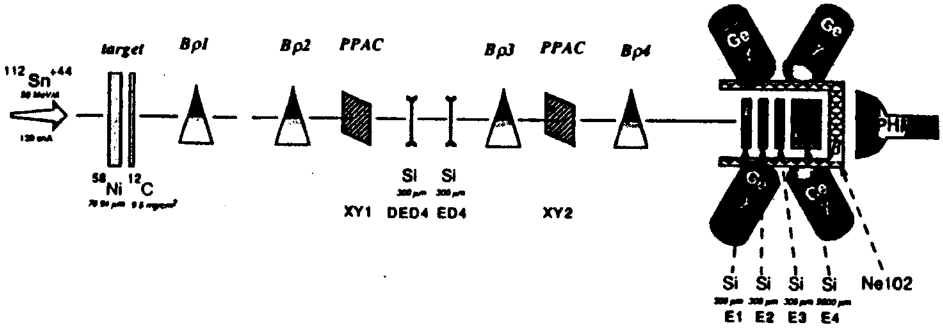

Fig.2. Schematic view of the experimental set-up

A schematic view of the experimental set-up used in the present study is shown in Fig.2. All selected nuclei were stopped at the last image point of the spectrometer in a four-member silicon detector telescope (E1, E2, E3, E4) providing energy-loss (ΔE) and total-kinetic-energy (TKE) measurements. Furthermore, we measured the $B\rho1$ and $B\rho2$ values of the dipoles with a nuclear magnetic resonance probes, and the time-of-flight (TOF) between the target and the telescope, the start signal being given by the first silicon detector E1, and the stop by the radiofrequency of the last GANIL cyclotron. Two removable silicon detectors DED4 and ED4 and two removable position-sensitive avalanche counters XY1 and XY2 were used for a fine tuning of reaction products along the LISE spectrometer. Four big (80—90%) germanium detectors and a NE102 plastic scintillator surrounding the final telescope served for measurements of beta and gamma radiation coming from the nuclei implanted in the silicon detectors.

4. Data Analysis and Results

The analysis of the experimental data aims at a correct identification of all nuclei selected by the spectrometer. The atomic number is determined by a combination of the energy loss ΔE and time-of-flight (TOF) measurements according to the Bethe formula:

$$Z \sim \sqrt{\Delta E / \left(\frac{1}{\beta^2} \ln\left(\frac{5930}{1/\beta^2 - 1}\right) - 1\right)}. \tag{1}$$

The determination of Z used to calibrate this formula is done using the primary beam ($Z = 50$) and by taking into account cross-checks such as the non-existence of ^{8}Be on the $A/Q = 2$ line and other equal-A/Q alignments.

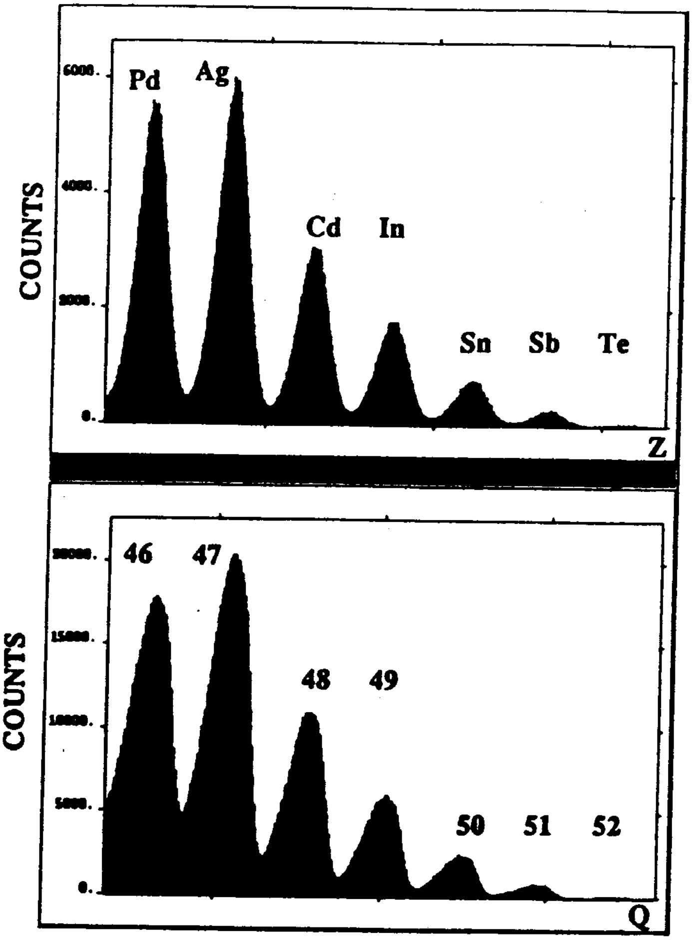

Fig.3. Atomic-number and charge-state distributions obtained from the experimental data at $B\rho$ = 1.98835 Tm with the use of formulae (1) and (2), respectively

The Z spectrum obtained in the experiment for a tin region in presented in an upper part of Fig.3.

The charge state Q of each isotope can be calculted from the relativistic formula:

$$Q = 3.33 \cdot 10^{-3} \frac{\mathrm{TKE}\,\beta\gamma}{B\rho(\gamma - 1)}, \qquad (2)$$

where the TKE has dimensions of MeV.

The TKE is calculated as a sum of energy losses in each silicon detector. A very careful energy calibration of E1, E2, E3 and E4 detectors was done

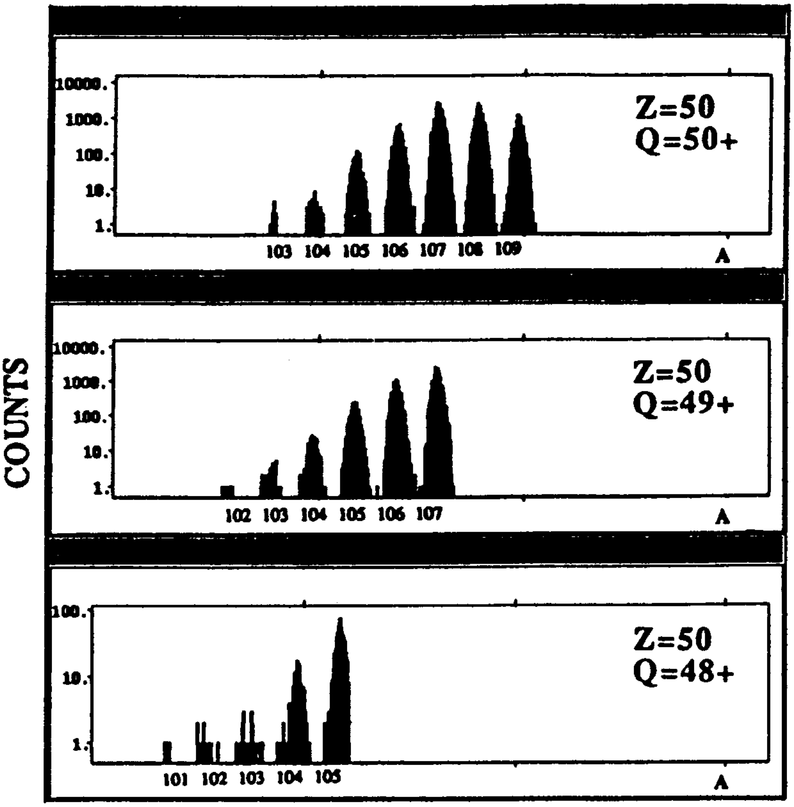

Fig.4. Mass distributions for tin isotopes for selected charge states Q at $B\rho = 1.98835$ Tm

using the primary ^{112}Sn beam of five different energies. This calibration, which is valid in the energy region corresponding to the expected TKE for nuclei around $A = 100$, takes into account nonlinear effects in the electronic chains and the silicon detectors themselves.

Once the charge state has been identified, the mass A of each nucleus expressed in a.m.u. can be extracted from the equation:

$$A = \frac{B\rho Q}{3.105\beta\gamma}. \tag{3}$$

Since the charge resolution was sufficeintly good (see a lower part of Fig.3), it was possible to improve the mass resolution by forcing integer values for Q. These integers were assigned for tin isotopes by putting the $\Delta Q = 0.5$ wide windows on the $Q = 50+$, $49+$ and $48+$ charge states. The resulting mass distributions for selected Q values are shown in Fig.4. In the distributions corresponding to $Q = 49+$ and $Q = 48+$, the events from ^{102}Sn are clearly visible. It is a first observation of this tin isotope. In the second of these distributions, four events due to ^{101}Sn are present.

The above results were obtained at $B\rho$ = 1.98835 Tm which was chosen after test measurements performed at several $B\rho$ values. The above spectra represent statistics obtained after about 30 hours of measurement with a mean intensity of primary beam of about 80 enA.

The complete data evaluation which includes the analysis of beta-gated gamma spectra, is in progress.

5. Conclusions

The first GANIL experiment with the ^{112}Sn beam, aiming at an identification and studies of nuclei near ^{100}Sn, brought promising results and an important experience. With this experience, after an upgrading of the experimental set-up (adding SISSI solenoids right after the CSS2 and a new dipole magnet at the end of LISE3), there will be a good change to identify ^{100}Sn unambiguously and to start the decay spectroscopy in this region of highly neutron-deficient nuclei.

The experience gained during such studies and the detection equipment which will be developed will also be used at the Warsaw Heavy-Ion Cyclotron Laboratory coming into operation in 1994 and also in the future Radioactive Nuclear Beam ISOL-type facility (SPIRAL).

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