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PROPOSAL TO THE ISOLDE COMMITTEE

Single-particle states in ^{133}Sn.

Strasbourg1) - Studsvik2) - Oslo3) - Göteborg4) - Mainz5) -
Warsaw6) - Lyon7) - Bergen8) - collaboration

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Abstract

It is suggested to investigate the β^--decay of ^{133}In and ^{134}In in order to determine the single-particle states in ^{133}Sn, which are so far unknown and needed for the shell-model description of the region close to ^{132}Sn. Large hyper-pure Ge-detectors will be used for the γ-ray spectroscopy. In the experiments with ^{134}In, delayed neutrons in coincidence with γ-rays from excited states in ^{133}Sn provide the opportunity for a very selective detection of the states in question.

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1. Introduction

Several attempts have been made to determine the energies of the expected pure single-neutron levels in ^{133}Sn, but so far the success has been very limited. Ten years ago, a measurement of delayed neutrons and γ-rays from ^{133}In decay ($T_{1/2}$ = 180 ± 15 ms) was performed at ISOLDE (1), using a 30 % Ge detector and a ^{3}He neutron spectrometer. A fairly good delayed neutron spectrum was obtained, but the γ-ray spectrum was too poor in statistics and difficult to interpret to give any valuable information about the low energy structure of ^{133}Sn.

More recently, an attempt to measure the γ-ray spectrum following the decay of ^{133}In was done at the thermal fission product mass separator OSIRIS at the reactor in Studsvik (2). The separator ion source was run in a surface ionization mode, providing a rather chemically selective ionization of In at mass number 133. The experiment was run for 36 hours at maximum intensity, but no transitions attributable to states in ^{133}Sn were observed. The OSIRIS experiment was run with an 80 % Ge detector.

Although practically no information about the structure of ^{133}Sn could be extracted from these experiments, they revealed the main obstacle for obtaining this information: The delayed neutron branch is as high as 87 ± 9 %. Additionally, a first-forbidden β-transition from the probable $g_{9/2}$ ground state of ^{133}In to the probable $f_{7/2}$ ground state of ^{133}Sn seems to exhaust the part of the β-strength not leading to delayed neutrons (there are no indications for β-decaying isomers in ^{133}In). The total intensity of γ-rays following the ^{133}In decay can be roughly estimated as less than 0.25 % of the total number of decays.

Thus, the experiments up to now have mainly made it clear that the conditions for obtaining detailed experimental information about single-particle states in ^{133}Sn are particularly unfavourable. Nevertheless, the structure of this nucleus is of such importance that a special experimental effort on it can be justified. With a new approach "bypassing" the unfavourable decay properties of ^{133}In, it is therefore suggested that two new series of measurements should be performed at ISOLDE.

2. Scientific motivation

The importance of the single particle levels at the doubly closed shell nucleus ^{132}Sn has been realised for many years. The energies of these levels are essential tests of the shell model at an important closed shell nucleus, as well as crucial parameters in shell-model calculations for $N \geq 82$. The energies of single-neutron levels in odd-mass $N=83$ nuclei have been determined down to ^{135}Te (fig.1), apart from the $i_{13/2}$ states, but the ^{133}Sn states have so far been impossible to determine.

In a recent attempt to construct a shell-model description for $Z \geq 50$, $N \geq 82$ nuclei, Chou and Warburton (3) showed that the lack of information about single-neutron energies at ^{132}Sn was an important obstacle for this type of calculations. Since there was no reliable information from ^{133}Sn, semi-empirical values for the single-neutron energies were chosen to obtain the best possible agreement at other odd-mass $N=83$ isotones, e.g. ^{141}Ce. The general agreement between experimental and theoretical level energies obtained through this procedure was far from satisfactory.

Also for astrophysical considerations, the single-neutron energies in ^{133}Sn are of importance. A general astrophysical background for this type of experiments in the ^{132}Sn region has been given in a recent ISOLDE proposal (4) and will not be repeated here. In r-process calculations, some type of model-dependent extrapolation of the single-particle energies is always necessary. These extrapolations are not always very reliable. For instance, in the case of ^{133}In it has been shown (5) that the commonly used QRPA code (6) leads to a $\nu g_{7/2}$ s.p. energy which is off by several MeV, which in turn gives a theoretical half-life for ^{133}In which is about a factor of 6 too short. Similar large discrepancies may also occur in the estimation of P_n-values, due to the same type of ambiguities. With exact knowledge of the single-neutron energies in ^{133}Sn, the local experimental values can be used directly in the calculations, thus strongly diminishing the uncertainty in the region of interest for the r-process.

It should also be noted that knowledge of single-particle states in ^{133}Sn is a prerequisite to a good shell-model evaluation of the meson-exchange enhancement of the first-forbidden $0^+ \rightarrow 0^-$ β-transitions near ^{132}Sn (7).

A short comparison with ^{135}Sb decay properties (8) is relevant in order to assess the potential of a spectroscopic investigation. In this nucleus, the ground state is $7/2^+$ ($g_{7/2}$). With this spin of the decaying nucleus, the $p_{1/2}$ state in ^{135}Te is very weakly and only indirectly populated and was hard to determine. The almost total absence of γ-transitions from the ^{133}In decay can therefore be considered as an indication for the non-existence of any β-decaying isomer in ^{133}In. A low-spin isomer would have populated the $p_{3/2}$ and $p_{1/2}$ levels and given a transition at the energies of about 600 - 700 keV. The β-decaying ground-state of ^{133}In is therefore likely to be $g_{9/2}$.

This means that a spectroscopic investigation of the ^{133}In decay, even with excellent statistics, probably would only give information about the excitation energy of the $h_{9/2}$ state (the $11/2^-$ state seen in the systematics of fig. 1 is collective and does not exist in ^{133}Sn). It is possible, but not at all sufficiently strongly confirmed, that the weak 1488 keV γ-ray observed in the old ISOLDE experiment (1) was a transition from this level. However, this line was not seen in the OSIRIS experiment (2), and should be more firmly assigned to the ^{133}In decay.

Directly, the $p_{3/2}$ and $p_{1/2}$ states, and possibly also the $f_{5/2}$ state will only be very weakly populated in the $^{133}\text{In} \rightarrow {}^{133}\text{Sn}$ β-decay. Indirect population, which was observed in ^{135}Te, is hardly possible, for the simple reason that no more states able to populate them are expected below approximately 4 MeV in ^{133}Sn. States at 4 MeV will most probably decay exclusively through delayed neutron emission, as the neutron separation energy S_n $\sim$ 2.5 MeV (9).

Therefore, an investigation of the ^{134}In decay seems much more appropriate to obtain information about the structure of ^{133}Sn. The large Q_β-value estimated for ^{134}In (14 MeV) compared to the ^{134}Sn estimated neutron separation energy (4.1 MeV) points to a sizeable delayed neutron branch. Single delayed neutron emission following the decay of ^{134}In will lead to the population of the desired excited states in ^{133}Sn.

The experiment at OSIRIS clearly showed that the yields from thermal fission are not good enough for this experiment. The more broad yields obtained from irradiation with high energy protons are needed.

3. Proposed experiments and experimental method.

^{133}In decay.

Since the measurements of ^{133}In decay at ISOLDE in 1982, the quality of Ge detectors has improved to such an extent that a new effort to investigate this difficult nucleus seems meaningful. It is the intention to make use of the spectroscopic equipment of the Strasbourg group, installed at ISOLDE. The experimental arrangement is illustrated in fig. 2. Four Ge detectors, each with an efficiency around 80 %, will be run simultaneously collecting singles events and in coincidence with each other, in order to make maximum use of the beam time. A thin 4π plastic scintillator allows the identification of β-particles. As explained above, only one single weak γ-ray is expected to follow the decay of ^{133}In.

The production yield of ^{133}In from a uranium carbide target has been measured to 1.1x10^{3} atoms per second and μA. It is asked for 6 shifts for these measurements.

^{134}In decay.

The experimental information on ^{134}In (1) is limited to a half-life measurement (110 ± 30 ms). Some predictions may be outlined from simple shell-model considerations. From the level systematics shown in fig. 1, and the probable $g_{9/2}$ configuration of the ground-state neutron-hole in ^{133}In, it seems very likely that the ground-state configuration of ^{134}In is $(\pi g_{9/2}^{-1}/\nu f_{7/2})$. From this, one can expect either a high-spin (8^-) or a low spin (1^-) ground state in ^{134}In, possibly also an isomer. Unlike ^{133}In, the decay of ^{134}In is not expected to be particularly selective, and a relatively high number of states in ^{134}Sn can be expected to be populated, including states above the neutron binding energy.

The delayed neutron emission from ^{134}Sn populates the desired states in ^{133}Sn. Regardless of the value of the ground-state spin of ^{134}In, it is highly likely that several excited states in ^{133}Sn will be populated through delayed neutron emission.

In view of the "bad prognosis" for the outcome of the ^{133}In decay study, it is therefore suggested to extend the investigation to ^{134}In. The same set-up for γ-ray spectroscopy as outlined in fig. 2 will be used, but with an additional liquid scintillation counter for neutrons (hexagonal cells, active volume per cell 3750 cm^{3}, NE213 scintillator). It is not planned to measure energy spectra of delayed neutrons, because such an effort would seriously decrease the counting efficiency, and energy information is not needed for this experiment.

The production yield of ^{134}In has not been measured. If one assumes it to be 1 order of magnitude less than ^{133}In, and the neutron counting efficiency to be 50 %, one would still get a count-rate of interesting γ-rays which will be roughly the same as from ^{133}In. However, considering the expected less selective decay mode, and the very pure conditions obtained by demanding neutron coincidence, ^{134}In spectroscopy seems to be the most appropriate way to obtain information about the structure of ^{133}Sn.

It is suggested that 8 shifts are allocated for the first test experiments of this important and still almost unknown nucleus.

4. Targets and production techniques.

For both series of experiments, a UC target with a tungsten surface ionizer will be the best production system. Although surface ionization is very favourable for In, the presence of long-lived isobars produced with high yields will represent a problem. At mass number 133, the problematic isobar will be ^{133m}Ba (39 h). The production yield of this nuclide is probably close to 10^{8} at/s at 1 μA proton beam, compared to 1•10^{3} for ^{133}In. Realistically, the disintegration rates of the contaminant can be expected to be of the same order of magnitude as for ^{133}In. However, most of the ^{133m}Ba decays give a γ-transition at 276 keV, which is well below the transitions that can be expected in the ^{133}In decay. We also intend to make use of the bunched beam now available. The sources will only be collected during the first 300 ms after a pulse.

Furthermore, ^{133m}Ba did not hamper the experiments on mass number 133 back in 1982, and there is no reason to assume that the conditions were more favourable then.

At mass number 134, the most problematic disturbing isobar can be expected to be ^{134m}Cs (2.9 h). The yield of the contaminant will be of the order of 10^{10} at/s at 1 μA average intensity, compared to 10^2 which can be expected for ^{134}In. This figure corresponds to a ratio of approximately 2000 between the disintegration rate of the contaminant and the desired nucleus. Although this figure may seem unfavourable, the low energy of the internal transition, 127 keV, allows the setting of a threshold for the Ge detectors well below the transition energies that can be expected in ^{133}Sn. Additionally, the neutron and β coincidence requirements ensures a selective detection of the desired transitions. Also in this case, it is the intention to make use of the bunched proton beam, and collect only for the first 150 ms after a proton pulse.

References:

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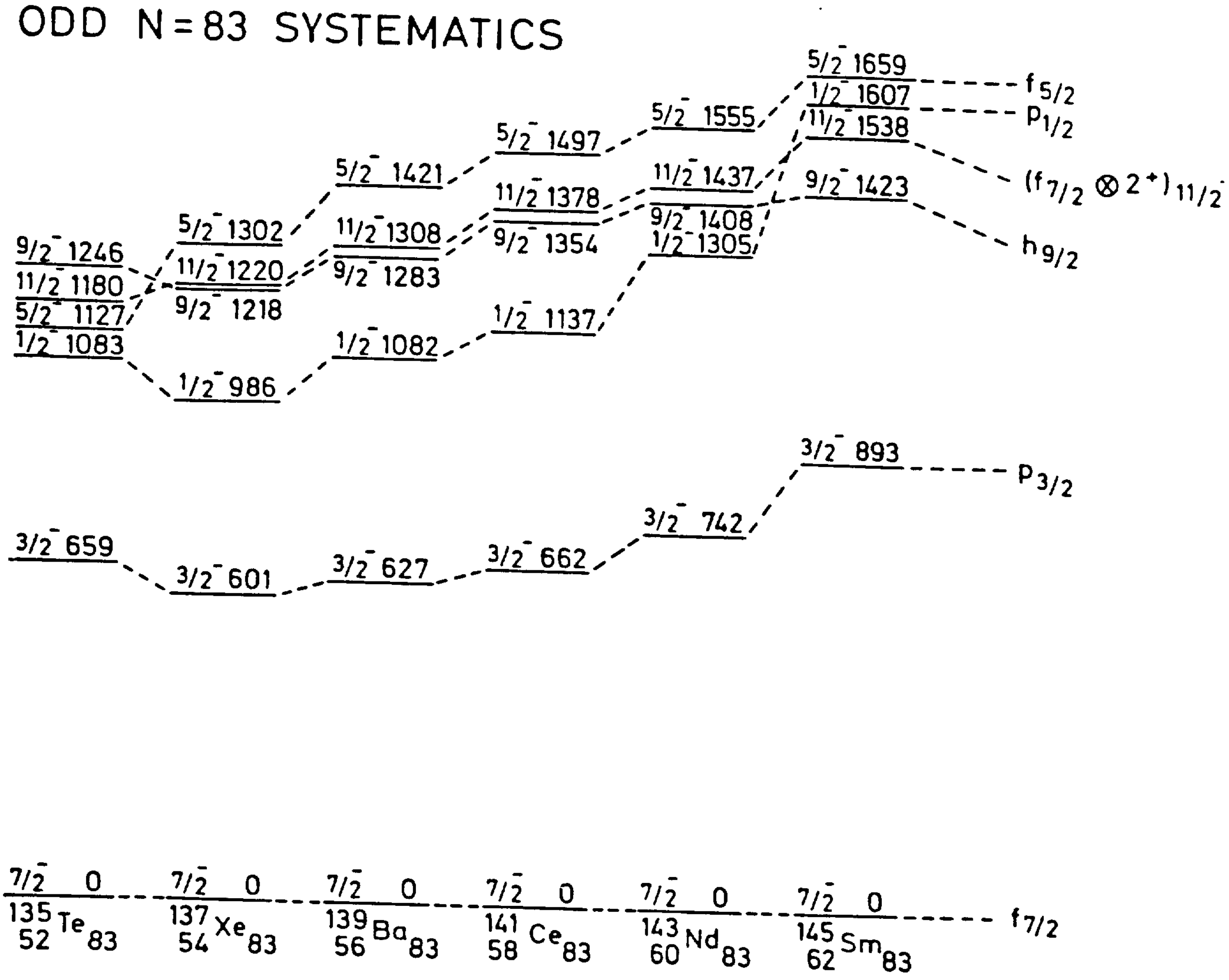

Fig. 1
Level systematics for odd-mass N=83 isotones (from ref. 8)

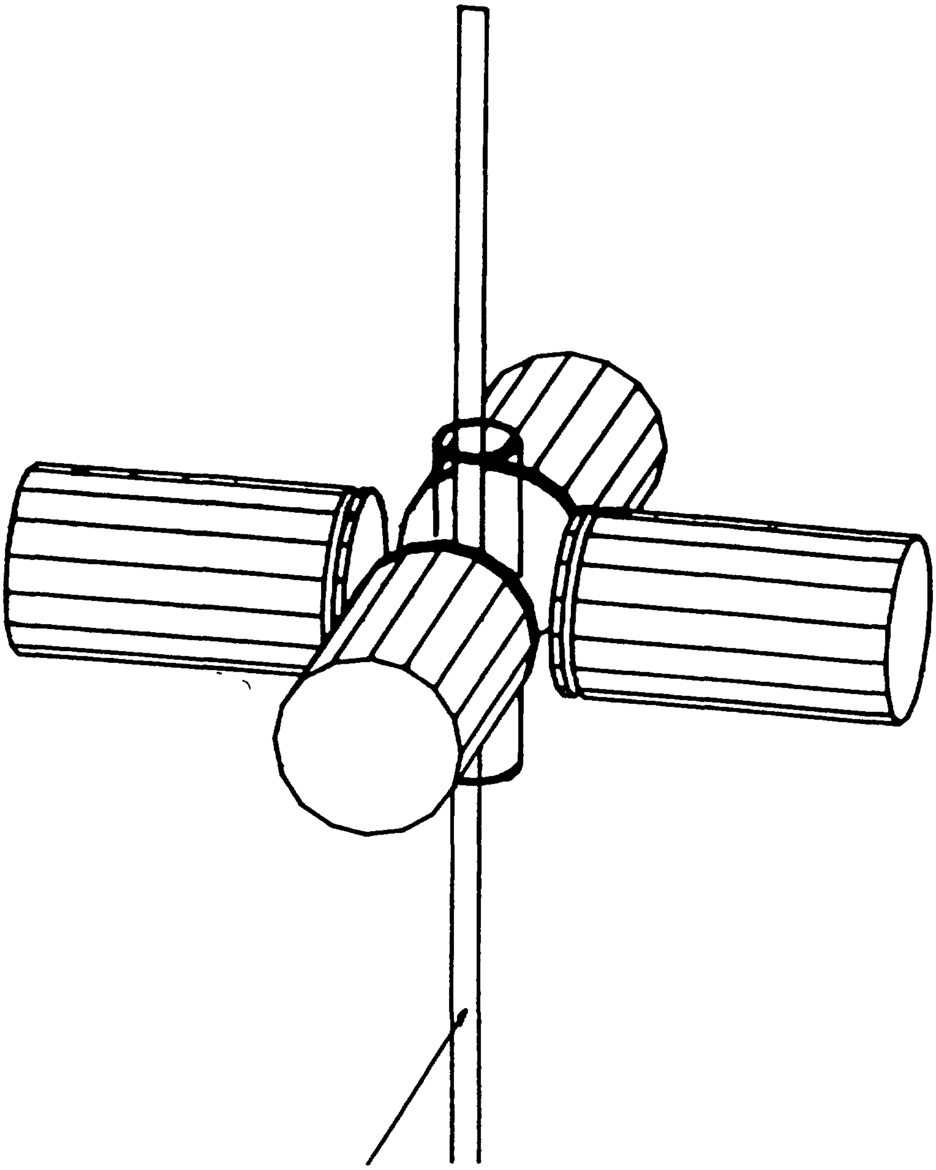

Fig. 2
Schematic view of the experimental arrangement for the ^{133}In experiment, showing the four Ge detectors and the 4π thin plastic scintillator.

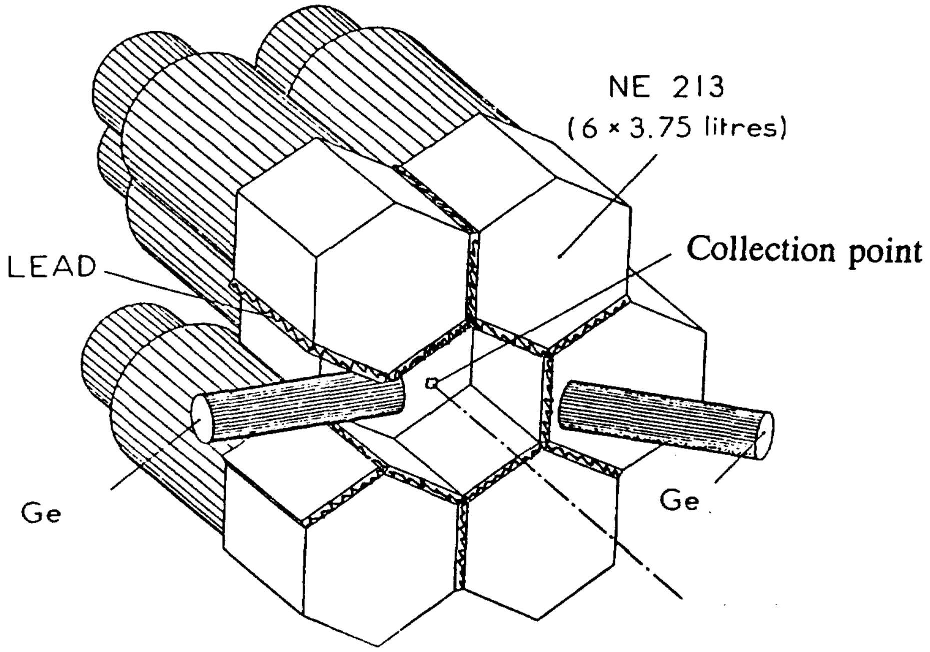

Fig. 3
Schematic view of the experimental arrangement for the ^{134}In experiment, showing the additional liquid scintillation detectors. Two of the Ge detectors and the 4π platic scintillator are not shown on this figure.