EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

Proposal to the ISOLDE-Neutron-Time-of-flight-Committee (INTC)

Further Studies of neutron-deficient Sn-isotopes using REX-ISOLDE

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ABSTRACT

Encouraged by the committee to submit the latter part of our latest addendum to experiment IS418 under a new heading this proposal focuses on the second physics case mentioned there. We propose to use Coulomb excitation of odd mass neutron-deficient Sn isotopes to study some dominantly “one quasi-particle” states in these nuclei. Due to spin selection rules these states are difficult to populate following either beta-decay or in a cascade after a fusion-evaporation reactions, whereas the excitation from the ground-state is of E2 character for some of the most interesting cases.

1. Background

As discussed in the original proposal and addenda to experiment IS418 [1] this experimental program is directed towards a general shell evolution study of the double shell closure at ^{100}Sn. The physics we aim to study include the evolution of collectivity and the single particle properties in this region. Much of the most crucial structure information remains unknown in this region. Several methods need to be employed to carry out these measurements. In addition to what is discussed in this proposal they include Coulomb excitation of some specific 2^+ states, population of single-particle states using transfer reactions and the measurements of magnetic moments of the 2+ states in e.g. the even-even Sn isotopes. When the development work towards these experiments started eight years ago none of the prerequisites for the experiments existed but we have gradually developed them over time. The first results from the two successful runs of IS418 in 2004 and 2006 have now been accepted for publication [2]. The core participants of this proposal have a long standing engagement in studies in this field. The current Lund group has been a driving force behind numerous experiments in the ^{100}Sn region starting with two experiments using the former NORDBALL array at NBITAL (see e.g. ref. [3-6]). The collaboration was later joined by colleagues from HMI for the so-called pre-EUROBALL (PEX) experiments also NBITAL[7-8]. The series of experiments continued with successful runs using the EUROBALL spectrometer [9] as well as at the experimental facilities at INFN-LNL and ANL [10]. However, with the accumulation of new data it has became clear that further progress in the field requires the development of radioactive ion beams. It is in this light that the current series of experiments should be seen. We thus reiterate that REX-ISOLDE continues to be a world unique facility for this kind of experiments. In particular the combination of the ISOLDE RILIS and the REX post-accelerator provides a wide range of post-accelerated beams that cannot be found at any other laboratory.

2. General Introduction to the Physics Case

The single-particle energies (SPE) and the two-body matrix elements (TBME) are the two most important quantities that enter into a shell-model description of the nucleus. As long as the interaction is of two-body nature all interactions between nucleons can be reduced to depend on these using the coefficients of fractional parentage [11]. Furthermore, the truncation of the model space into a core and a few valance particles makes it possible to express the total interaction by a residual interaction combined with an overall mean field. An interesting aspect is that this process makes it possible to relate effective interactions derived from the nucleon-nucleon potential to actual data [12]. It is thus one way to study in-medium effects of the nuclear interaction. There are two aspects to this problem. The SPE and TBME can be extracted from measurement in one and two-particle nuclei. When this can be realized experimentally these quantities can in turn be used to predict the properties of nuclei in the corresponding region. At the same time these states, that give the SPE and the TBME, can be compared to predictions using effective interactions derived from the NN-potential. However, in many cases the corresponding one or two particle nucleus is particle unbound or very difficult to produce. In these cases one can determine the single-particle energies from a set of states that are predominately of “one-quasi particle” nature by employing a fitting procedure. One such case is e.g. discussed in ref. [13].

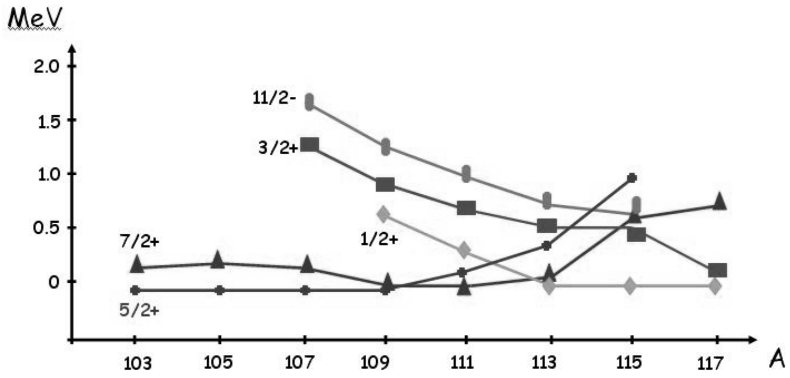

Fig. 1 The systematics of the predominately "single-particle" neutron states in the light Sn isotopes. From ref. [17].

The single-particle neutron states in ^{101}Sn are currently not known in the literature although experiments are ongoing to identify the first excited state in this nucleus [14]. As an example of the importance of knowing the single-particle energies in general we mentioned in ref. [1] that there is a set of isomeric 6^+ states in the light Sn isotopes. These have been used in the past to determine the effective neutron charge in this region by measurements in ^{102}Sn. Similarly states in ^{98}Cd have been used to determine the effective proton charge from the corresponding 8^+ states in that nucleus. The isomeric 6^+ states in the light Sn isotopes are considered to be dominantly composed of particles in the $d_{5/2}$ and $g_{7/2}$ orbits, with increasing purity as the two-particle nucleus ^{102}Sn is approached. One can note that the seniority-zero overlap has been calculated to be approximately 90% for the two lowest states in the Sn chain. It is in the same range for the first 6^+ state but the situation is more complex for other states with spin 4^+ and 6^+ [15]. Estimates of the energy of the $s_{1/2}$ orbit in ^{101}Sn put it at ~2.45 MeV [15]. Similarly the energies of the $d_{3/2}$ and $h_{11/2}$ neutron states in this shell are unknown and are estimated to be ~2.54 MeV and ~3.0 MeV above the $d_{5/2}$ orbit, respectively. The current knowledge of the dominantly single-particle states in the neutron deficient odd Sn isotopes is given in Fig. 1. Looking at the systematics, the lightest stable odd Sn isotope, ^{115}Sn, has $1/2^+$ ground state built on the $s_{1/2}$ orbit. The Coulomb excitation of that state into excited $3/2^+$ and $5/2^+$ states built on the $d_{3/2}$ and $d_{5/2}$ single particle orbits, respectively has been observed in ref. [16]. A $3/2^+$ and $5/2^+$ state mainly built on the coupling of the ground state to a quadrupole phonon was also observed in that study. The excitation patterns for ^{115,117,119}Sn are given in Fig, 2. In that study it was also possible to observe the decay of the excited states via an isomeric $7/2^+$ excited state and thus to indirectly observe the energy of this state which would be impossible to excite directly. The next odd Sn isotope, ^{113}Sn, has a half life of 115 days and also a $1/2^+$ ground state [17]. The isomeric $7/2^+$ state is known in this isotope from decay studies (which is also true in ^{115}Sn) as well as from heavy ion reactions. In ^{111}Sn the situation is reversed and the $7/2^+$ state is now the ground state and the $1/2^+$ state forms an isomeric state 255 keV above the ground state with a half-life of 12.5 μs. Moving to the unstable isotopes partial level schemes for ^{105,107,109}Sn can be found in Fig. 3. In ^{109}Sn the ground state has spin $5/2^+$. A state with spin and parity $1/2^+$ has been tentatively observed at 544.89 keV [17,18]. The lowest suggested $7/2^+$ state is at 1079 keV. The $d_{3/2}$ state is suggested at 926 keV [18]. The situation is similar in ^{107}Sn and ^{105}Sn. For the ^{105}Sn isotope no $1/2^+$ or $3/2^+$ states are known above the assumed $5/2^+$ ground state [17]. A first $3/2^+$ state is calculated to be at ~800 keV and the first $s_{1/2}$ at ~1400 keV [15]. With the arguments above we thus propose to determine the energy of states dominantly built on one single-particle orbit, in particular the $s_{1/2}$ orbit, in ^{109,107}Sn by Coulomb

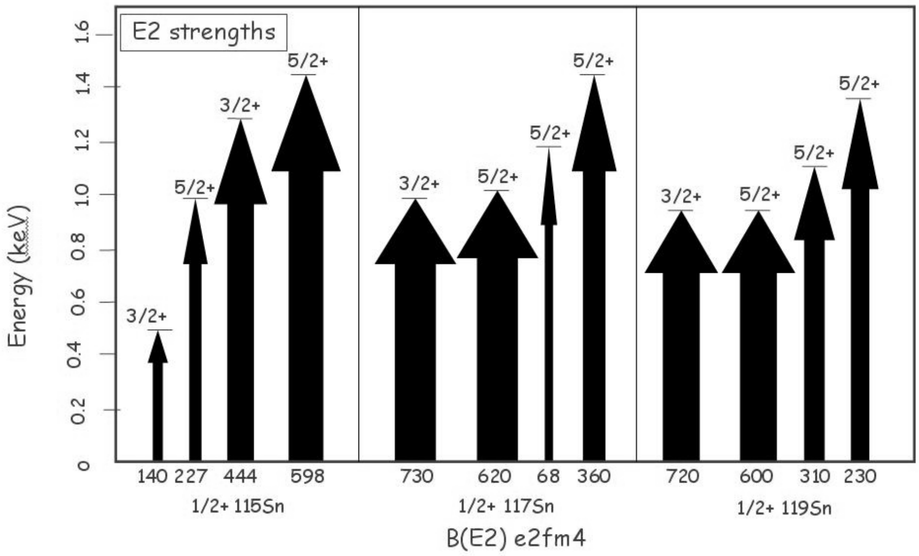

Fig 2. E2 strengths in Coulomb excitation of ^{115,117,119}Sn from ref[16].

exciting the 5/2$^+$ ground states of these nuclei. For the case of ^{105}Sn Coulomb excitation the case is more general. The method suggested here would give a unique window to low lying states with spin close to the ground state as the beta-decay to this nucleus is currently not known. We thus plan to focus on the predominantly "single-particle" states for ^{107,109}Sn and on the identification of new low spin states in ^{105}Sn. We also find it is of interest to mention that ^{105}Sb has been suggested to be a proton emitter [19]. This observation was however not confirmed when that decay mode was revisited (see e.g. ref. [20]). Here one can note that new results concerning the alpha-decay of ^{109}I to ^{105}Sb have recently been accepted for publication [21].

4. Experimental Details

The kinematics for the odd Sn cases is very similar to what we presented in the original proposal [1] for the even Sn isotopes. One expects to detect a significant ratio of triple-coincidences (target particle, beam-particle and gamma-ray coincidences) due the kinematics of the particles involved in the collision. We refer to ref. [2] for the details of this discussion and the method employed in the analysis. As mentioned above the main aim of the experiment is to determine the energy of the states. For this it is sufficient to detect the corresponding gamma-ray above background. In our previous measurement on ^{110}Sn we detected the 2$^+$ excitation at ~1200 keV with a peak-to-background of ~17. Using this as guidance we note that 50 counts, detected from the corresponding excitation of a single-particle like state in ^{107}Sn, would rest on a background of ~3 counts. One can also note that as a secondary effect it may be possible to extract the excitation strength for the states. We also note that recent results from Coulomb excitation of the even Zn isotopes confirm that a detection limit of ~50 counts is more than adequate [22].

The setup planned to be used for the experiment is the MINIBALL Ge detector array including the DSSSD CD-detector and beam monitoring equipment (PPAC and Bragg chamber). The details of

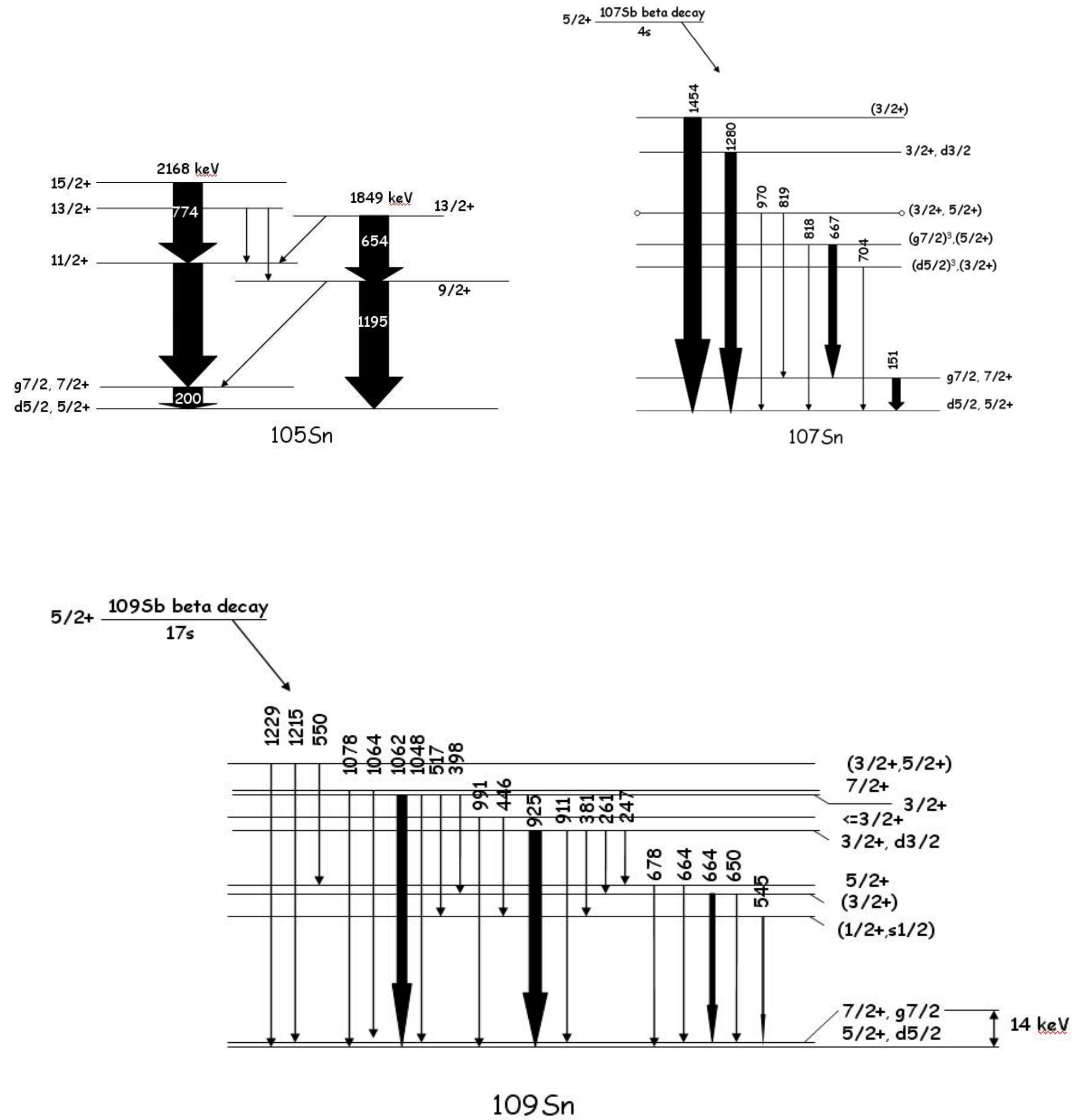

Fig. 3. Partial level schemes for the isotopes $^{105,107,109}Sn$ [17,18]. The $s_{1/2}$ state in ^{109}Sn is assigned from a weak branch following beta-decay. Due to its low energy this state should be relatively easy to populate using Coulomb excitation from the $5/2^+$ ground state. Beta-decay measurements have also been carried out to populate the corresponding state in ^{107}Sn. These measurements have not been successful. The $s_{1/2}$ state is predicted around 1.3 MeV in this nucleus. Gamma-emission following beta-decay of ^{105}Sb to ^{105}Sn remains unknown. One can note that proton decay from ^{105}Sb has been reported[19] but that this decay mode was not been observed when the experiment was revisited by another group[20].

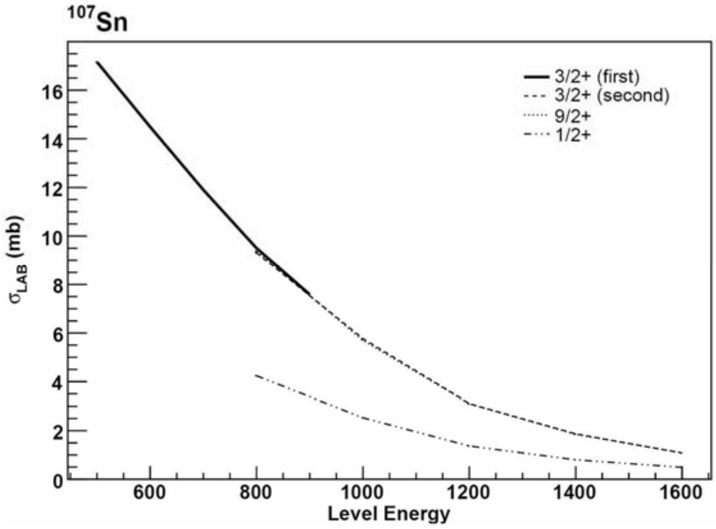

Fig. 4. The Coulomb excitation cross-section for the indicated levels in ^{107}Sn as a function of the level energy The figure shows the case for the $s_{1/2}$ state and for states of spin 3/2 and 9/2 using the reduced transition probabilities mentioned in the text.

this setup have been described in detail in the past. We thus refer to the corresponding references in e.g. [1].

5. Cross sections

We have carried out cross sectional calculations for a number of scenarios using the Coulomb excitation code GOSIA. The results from some of these calculations are summarized in Table 1 in the beam request section. In particular we have used the reduced transition probability for the single particle transition s1/2 → d5/2 from ref [23] adjusted for the spin factors when calculating the 5/2+ →1/2+ excitation probability. Ref. [23] also gives the corresponding values for the s1/2 → d3/2 single particle transition. For the more collective states we have used the experimental results in the neighboring stable odd Sn istopes as guidance when estimating the B(E2). Typically we have used a B(E2) of 100 e^2fm^4 for the more collective transitions starting at the $5/2^+$ ground state. With these values as input the GOSIA cross sections were integrated over the angular interval covered by the charged-particle detector. We have also calculated the cross sections as a function of the unknown level energy. An example of this is given in Fig. 4. The level energies at which we give the cross section in Table 1 correspond to the region they are expected in according to shell-model calculations. A ^{58}Ni target is assumed in all cases.

6. Targetry

We note that two LaCx targets have already employed for light Sn production. As indicated before the estimates of the production rate for the Sn isotopes in previous runs were rather conservative and were surpassed by an order of magnitude in the experiment. We have also developed straightforward methods to monitor the purity of the beam at the experimental set-up. This makes it possible to run with less isobarically clean beams. We thus request the use of a LaCx target for this experiment that is identical to either of the two targets used previously for light Sn production.

7. Beam time request

Experience from our previous experiments with REX and MINIBALL tells that the maximum beam current that is feasible to run is 3-4 pA for an A~100 beam on a A~58 target. In order to fulfill the A/q requirement for the post-accelerator an A~100 beam is typically charge-bred to Z~25. With these numbers 4 pA corresponds to ~ 10E6 pps on target. The main limitation in beam current is the scattering rate into the solid state detector of the MINIBALL set-up and the gamma-ray background from radioactivity deposited in and around the target chamber and beam dump. Approximately 2000 events were collected for the 2+ excitation of ^{108}Sn (~1200 keV) over ~9 shifts in 2006 and ~300 corresponding events for ^{106}Sn over a similar time span. For the case of the odd Sn isotopes the yield situation is rather similar to the even isotopes. For the isotopes down to ^{105}Sn the limitation is likely to be in the high background accumulated around the set-up and the maximum current of ~3-4 pA should be attainable for these isotopes. We have based our request on the actual number of photo peak events obtained in the recent ^{108,110}Sn runs by scaling the cross sections calculated for those cases to the cross sections calculated for the cases of interest here (as described above). We request 10 shifts each for ^{105,107,109}Sn. The total request is given in Table 1. In view of our recently approved addendum for IS418 the preferable running period for the experiment of this proposal would be 2008.

	B(E2) (e2fm4)	Energy (keV)	Cross section (mb)	Counts	Shifts
109Sn					10
5/2+ -> 1/2+	45	545	6.5	~200	
107Sn					10
5/2+ -> 3/2+	100	800	11.9	~300	
5/2+ -> 1/2+	45	1200	1.3	~30	
5/2+ -> 3/2+	100	1200	3.0	~80	
105Sn					10
5/2+ ->3/2+	100	700	10	~25.0	
5/2+ ->3/2+	15	1300	0.5	~1	
5/2+ ->1/2+	45	1400	1.0	~3	
5/2+ ->1/2+	45	1800	0.4	~1	

Table 1:Cross sections and suggested shift distribution. The continued use of the existing LaC_x target(s) with the RILIS is assumed. Note that shell-model calculations predict the 545 keV state in ^{109}Sn at somewhat higher energy. A drop in intensity of a factor of 10 is assumed from ^{107}Sn to ^{105}Sn, i.e. a current of approx 0.3-0.4 pA. Different alternatives for the B(E2) and energy of the states of interest are indicated and the cross sections are calculated for these.

8. Summary

We are proposing to use Coulomb excitation as a means to populate excited states in the neutron deficient odd Sn isotopes. The states of interest have so far not been possible to populate using either beta-decay or fusion-evaporation reactions. The states of primary interest have spin and parity 1/2+ and 3/2+, respectively. For some of the states the wave function is dominated by single particle configurations involving the s1/2.

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