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Experiment IS418

Coulomb excitation of neutron deficient Sn-isotopes using REX-ISOLDE
The case of even Cd isotopes and odd Sn isotopes

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ABSTRACT

In our proposal to the INTC in 2003 and our addendum submitted in 2005 we discussed the case for measuring the reduced transition probabilities, B(E2; 2+ → 0+), for neutron deficient Sn isotopes. The physics case is a general shell evolution study for a double shell closure far from stability. Measurements on the even Sn isotopes have been successfully carried out late September 2006 with the Coulomb excitation of the first 2^+ state in ^{108}Sn and ^{106}Sn by the proponents. Near-online analysis indicates approximately 2000 photo-peak events in the Doppler corrected spectrum for ^{108}Sn and ~300 photo peak events for ^{106}Sn. In 2004 we collected ~800 events in the corresponding spectrum for ^{110}Sn, a result which has allowed us to determine the B(E2) for the excitation of the first 2^+ state in that nucleus to a precision of ~10%. This addendum addresses the continuation of the measurement series to the even neutron-deficient Cadmium isotopes mentioned in the original proposal. We also reiterate our interest to measure similar properties using Coulomb excitation, and in the longer term transfer reactions, of the odd Sn isotopes.

1. Background

As mentioned in the original proposal [1] the experiment IS418 is directed towards a general shell evolution study of the double shell closure at ^{100}Sn. The general approach using Coulomb excitation in this kind of work is to measure the reduced transition probability of the first, and sometimes the first few, excited states above the ground state in few-particle/hole isotopes in the vicinity of a shell closure. Studying the isotopic chain of the shell closure element itself gives information on the neutron states and thus the effective charge in the corresponding orbit. The study can then be completed by visiting the proton states. In the case of the Sn double-shell closure this amounts to studying proton-hole states in e.g. In and Cd isotopes. This addendum primarily addresses Coulomb excitation of the first 2^+ state in the $\pi^{-2} \otimes \upsilon^{6,4,2}$ nuclei ^{104,102,100}Cd and the odd Sn isotopes. The study is mirrored in two similar studies carried out at REX-ISOLDE and MINIBALL i.e. the investigations of the ^{132}Sn and ^{78}Ni shell closures with the addition that the ^{100}Sn closure is self-conjugate and thus is a testing ground for isospin symmetric residual interactions or so-called neutron-proton pairing.

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 accelerated beams that cannot be found at any other laboratory. This is also the case for the study discussed in this addendum.

2. The Physics Cases Revisited

As discussed earlier there are significantly fewer cases of neutron-deficient than neutron-rich isotopes where the reduced transition probability of the first 2^+ state is not known. The reason for this is that it is only in certain cases the life-time of an excited state cannot be measured for a residue in a fusion evaporation reaction. The proponents have previously carried out measurements of this kind to establish excited states and the de-excitation patterns in isotopes close to ^{100}Sn, including e.g. ^{102}Sn [2] and ^{98}Cd [3]. However, in the case of the even Sn isotopes we have mentioned that a set of isomeric 6^+ states at approximately 2 MeV will influence the life-time measured for any lower lying state including the first 2^+ state and for this reason it is preferred to address the life-time of these states using Coulomb excitation. The 6^+ states in turn have a general character of coupling two neutrons in the configuration $(\upsilon g_{7/2})^2$or $(\upsilon g_{7/2})(\upsilon d_{5/2})$ to a maximally aligned spin state of 6^+. These states therefore tend to be rather pure and can be used to extract the corresponding effective charges. However, one tend to find inconsistent results when comparing calculations that try to reproduce the life-time measured for the 6^+ state and the 2^+ state in the same stable nucleus [4,5]. It is thus of general interest to study the configurations of the states in several of the unstable isotopes closer to ^{100}Sn in order to understand the microscopic description of the states in this region. This is consequently the goal of this study.

The isomerism in the light Sn isotopic chain arises from the relative closeness in energy between the 6^+ and 4^+ states. The case is rather similar for the Cd isotopic chain. Here the 2 proton-hole nucleus ^{98}Cd has a sequence of states spanning up to 8^+ that is built on the $(\pi g_{9/2})^{-2}$ configuration [3]. The Cd isotopes that, due to intensity limitations, are of interest for this addendum are ^{104,102,100}Cd. Comparing calculations for ^{100}Cd and ^{98}Cd gives that the 8^+,6_2^+ and 4_2^+ states in ^{100}Cd are built on the $(\pi g_{9/2})^{-2}$ configuration to a purity between 80 and 90% [6]. The first 6^+ and 4^+ states are according to ref. [6] mainly neutron configurations and the 2^+ state is highly mixed while, as mentioned, the states up to 8^+ in ^{98}Cd are generally considered pure proton states. By combining our study of the 2^+ states in the even Sn isotopes, which are typically of neutron character, with the results for the mixed 2^+ states in the Cd chain one can thus extract information on the evolution of both the neutron and proton shells when approaching ^{100}Sn from life-time measurements. Such an approach is generally more sensitive to the components of the wave function than the energy of the state. Furthermore, the 8^+ states in the Cd isotopes are known and their half-lives measured. The ^{104,106,108}Cd isotopes are e.g. the topic of ref. [7]. The comparison of the 6^+ and 2^+ states in the Sn isotopes can be extended to a similar a comparison between 8^+ and 2^+ states in the Cd isotopes. It should be mentioned in this context that the energy of the 2^+ states in ^{104,102,100}Cd are 658, 777 and 1004 keV respectively and therefore easier to excite than the 2^+ states in the even Sn isotopes.

The second case concerns the position of the $s_{1/2}$ orbit in the odd Sn isotopes. The lightest stable odd Sn isotope, ^{115}Sn, has $1/2^+$ ground state generally 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. [8]. 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. However, it was also possible to observe the decay of the excited states via an isomeric $7/2^+$ excited state to the ground 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 [9]. 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 ^{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 [8]. The lowest suggested $7/2^+$ state is at 1079 keV. The $d_{3/2}$ state is suggested at 926 keV. 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 [9]. In ^{107}Sn a set of states have been assigned, some tentatively to $3/2^+$ [10]. In line with the discussion above it is important for the microscopic description of shell model states to determine the single particle energies. Tracing the energy of an orbit over a shell provides information that can be used to this end. We thus propose to search for the energy of states built on single-particle orbits, in particular the $s_{1/2}$ orbit, in ^{109,107,105}Sn by Coulomb exciting the $5/2^+$ ground states of these nuclei.

Furthermore, pending the outcome of tests with g-factor measurements in the ^{132}Sn region and transfer reactions for lighter elements we are considering to submit a final addendum to this proposal addressing those questions within the coming two years. The decision on a continuation of the program beyond this addendum depends critically on the energy upgrades of the post-accelerator.

Finally, we remind that the kinematics for the even Cd and odd Sn cases are very similar to what we have presented in the original proposal [1] and the first addendum for the even Sn isotopes. The cross sectional calculation is also almost identical for the Cd case after taking into account the lower excitation energies. The odd Sn case is somewhat more complicated if one wants to extract the reduced transition probabilities (which is not our primary goal). Using the experience we have gained by observing the excitations in the Sn and In isotopes in the previous runs we prefer to base the beam time request on this experience instead of a calculation using estimated B(E2) values. In particular experience tells that the time necessary for setting up the post-accelerated beam and changing masses is reasonable only for an experiment that runs for at least 5 shifts.

3. Targetry

Neutron deficient Cadmium isotopes have been produced in a recent target test (2003) at ISOLDE from an LaC_x target used together with the RILIS, as well as from molten Sn targets [11]. It should be mentioned that neutron deficient Cadmium isotopes were extracted already in 1969 at ISOLDE [12]. The half-lives of the Cd isotopes of interest for this addendum, ^{104,102,100}Cd, are 57.7 min, 5.5 min and 49 s, respectively. It is thus expected that the rather slow release time of molten targets, which can be in the region of minutes [13], leads to decay losses for the isotopes below ^{102}Cd and that these losses can be overcome using the LaC_x target together with the RILIS for the lighter isotopes. The measured yields of ref. [11] point to an in-target production rate in the region between $10^8 – 10^7$ atoms/μC for ^{104}Cd, $10^7 – 10^6$ atoms/μC for ^{102}Cd and $10^6 – 10^5$ atoms/μC for ^{100}Cd. The yield situation is thus very similar to the cases we have recently measured (^{110,108,106}Sn). As we indicated in our previous addendum the estimates of the production rate for the Sn isotopes were rather conservative and were surpassed by an order of magnitude in the experiment. We note that the recent test means that there exists a laser ionization scheme for the Cd isotopes that can be used together with the two LaCx targets already employed for light Sn production. The typical ionization efficiency for the Cd isotopes is given as 10% in ref.[11]. This leads to a yield for ^{100}Cd between 10^4 and 10^5 atoms/μC which corresponds to the pre-experiment estimate of the yield of ^{106}Sn. It is likely that neither the ^{104,102}Cd cases will require full proton intensity (~ 2 μA). A possible target development that could be beneficial for the measurement is the inclusion of a quartz transfer line in order to suppress e.g. In isobars and to run with a hot cavity [11]. However, at the estimated production rates for ^{104,102}Cd it is very likely that a delayed opening of the beam gate, similar to that for the Sn beams, will be sufficient. We have also developed simple methods to monitor the purity of the beam at the experimental set-up making it possible to run with less isobarically clean beams. The proponents can contribute manpower to target tests or to other target development related activities if needed. Further studies to reach e.g. ^{98}Cd or ^{104}Sn, in the latter case using molecular beams, could also be assisted by the proponents in view of a final addendum. Extending the measurements to these isotopes is a natural continuation of our previous study reported in ref. [14].

4. 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 ~ 10^6 pps on target. The main limitation in beam current is the scattering rate into the solid state detector of the MINIBALL set-up, as the detector deteriorates with increased heavy-ion bombardment, and the gamma-ray background from radioactivity deposited in and around the target chamber and beam dump. The ~2000 events mentioned above for the ^{108}Sn case were collected over ~9 shifts and the 300 events for ^{106}Sn were collected over a similar time span. Taking this into account together with the lower excitation energy of the 2^+ states in the Cd isotopes we estimate that we would reach sufficient statistics in 5 shifts each for $^{104,\ 106}$Cd and 10 shifts for ^{100}Cd. We also ask for 2 shifts for set-up and changing of masses for the post-accelerator. 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 will be in the high background accumulated around the set-up and the maximum current of ~3-4 pA should be attainable for these isotopes. As a starting point we also request the same number of shifts for ^{105}Sn as for ^{100}Cd. The total request is given in Table 1. The experiments could preferable be divided into two parts, one for the even Cd isotopes and one for the odd Sn isotopes that could run over two running periods (two years).

100Cd	102Cd	104Cd	REX set-up
10	5	5	2
105Sn	107Sn	109Sn	
10	5	5	2

Table 1: Suggested shift distribution for IS418. The continued use of the existing LaC_x target(s) with the RILIS is assumed.

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