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Letter of Intent to the
ISOLDE and Neutron Time-of-Flight Experiments Committee
for experiments with HIE-ISOLDE

Transfer Reactions and Multiple Coulomb Excitation in the ^{100}Sn region

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Abstract

The ^{100}Sn region of the nuclear chart is a primary testing ground for nuclear models based on microscopically derived interactions. In particular, isotopes close to the N=Z line provide a unique opportunity to study shell-evolution effects far from stability for self-conjugate systems. With this letter we express our intent to continue the research program we have so far carried out at energies up to 3 MeV/u at REX-ISOLDE but now with the HIE-ISOLDE facility at energies 5-10 MeV/u. The new methods that become available, transfer reactions and multiple Coulomb excitation, make it possible to study key excited states dominated by single-particle configurations and to deduce transition probabilities and static moments of a series of $2^{+,}$ 4^+ and 6^+ states below the characteristic isomeric states that exist in several isotopes of different elements in this region.

1. Introduction

In a series of experiments at REX-ISOLDE we have made the first observation of a deviation between predictions made by large-scale shell model calculations, using microscopically derived interactions, based on the CD-Bonn as well as the N3LO potentials, and experimental values for transition probablities in the even-even Sn isotopes [1,2]. In addition we have from studies of the light even-even Cd isotopes concluded that a renormalization of the neutron effective charge may be needed also in the light Cd isotopes in order for theory to reproduce measurements [3]. Furhermore, we have recently used Coulomb excitation with the aim to populate states in the odd Sn isotopes that are dominated by single-particle configurations in order to test single-particle energies [4].

HIE-ISOLDE will provide a unique opportunity to continue this program and to identify single-particle dominated states in this region. It will therefore provide a unique way to measure the evolution of the nuclear shells close to ^{100}Sn. The spin and energy of these states can be determined in transfer reactions. These measurements also make it possible to study changes in the nuclear spin-orbit interaction as a function of neutron number.

The increased energy at HIE-ISOLDE as compared to REX-ISOLDE will enhance the experimental yield in the Coulomb excitation process. It will thus make it possible to address excited states in the lighter radioactive isotopes in the region, whose production yield is limited, and at the same time also allow the population of sets of several states with similar structure in different isotopes. Of particular interest here are low-lying states with a structure dominated by the recoupling of neutron angular momenta.

2. Physics case

The only single particle energy difference that is known in ^{101}Sn to date is the $d_{5/2}$ - $g_{7/2}$ splitting [5,6]. However, even in this case there are conflicting opinions of the level ordering of these two states. Furthermore, the single particle dominated states in the radioactive heavier isotopes in the Sn chain are not known except for some tentative assignments in e.g. ^{109}Sn. Transfer reactions at HIE-ISOLDE will make it possible to populate several of these states in the chain of unstable odd Sn isotopes and to deduce their spectroscopic factors. An issue of related interest that will be addressed simultaneously is the development of the spin-orbit splitting as a function of neutron number. Similar studies have been carried out in the past for the stable Sn isotopes [7]. Reactions that are of interest include the (d,n), (d,p), (a,t) and (a,^{3}He) reactions as well as Coulomb excitation in inverse kinematics using beams of ^{104,106,107,108,109,110}Sn, ^{102,103,104,105,106,107,108}In and $^{98.100,102,103,104,105}$Cd. These reactions can provide different entrance channels to isotopes in the Sn chain itself but also make it possible to map states where the neutrons couple to proton-holes below the Z=50 gap. Furthermore, the higher energy of the HIE-ISOLDE beams will make it possible to use heavier targets in the Coulomb excitation process. This means one can address diagonal matrix elements as well as life times of states above the 2^+ state in the light even-even Sn and Cd isotopes up to the characteristic 6^+ and 8^+ isomers in these nuclei. Here one may even attempt an alternative measurement of the half life of the isomeric states themselves.

We have already developed and used beams of light Sn, Cd and In isotopes for our 3 MeV/u program at REX-ISOLDE that are of such intensity that no further beam development is needed in order to carry out the 5-10 MeV/u program. The development that has been done for the 3 MeV/u program includes new target materials, new laser excitations schemes and a specially made temperature controlled target. Consequently, HIE-ISOLDE provides a unique opportunity for the experiments described here when it comes the facility itself, i.e. the energy upgrade, and the possibility to use newly developed radioactive beams that do not exist elsewhere.

3. Experimental setup

The experimental set up that is needed to start the program, including transfer reactions and Coulomb excitation experiments, is the MINIBALL, or similar, detector system. Transfer reactions would also benefit from the use of either the Lund LuSIA [8] or the corresponding MINIBALL T-REX setup. The use of the neutron wall detector system can also be foreseen at experimental campaigns at HIE-ISOLDE if beneficial [9]. A more advanced experimental setup would include a recoil separator or similar device [10] or possibly a high efficiency scintillator array for gamma-ray detection in order to identify excited states with high efficiency in coincidence with charged particles and their angular distributions. The existing infrastructure for MINIBALL and scattering experiments at REX-ISOLDE suffices to start the program. In addition to Coulomb excitation measurements, life times may also be measured by the differential recoil distance Doppler shift method using a plunger device for Miniball. The design and construction of such a device is currently on going at the university of Cologne.

4. Beam requirements

As indicated above, the isotopes of interest include e.g. ^{104,106,107,108,109,110}Sn, ^{102,103,104,105,106,107,108}In and ^{98,100,102,103,104,105}Cd. Beams of the majority of these isotopes, of sufficient purity to perform the experiments discussed here, have already been produced in the 3 MeV/u program that focussed on single-step Coulomb excitation. Typical minimum intensities that have been useful for experiments in this mass region are 10^4 -10^5 particles/s but intensities several orders of magnitude higher have been measured for some of the beams of interest. Beam energies starting at ~4.5-5 MeV/u will be required for the program. Tests of spectroscopic factors and angular distributions may benefit from increasing the beam energy to 10 MeV/u in a second step but are not crucial for the main aim of the program. Generally a slow extraction system is a positive aspect for further development of the time structure of the beam, particularly for dead time reduction in the detector system. Here one may e.g. investigate different injection/extraction schemes for the EBIS and also see if beam pulse separation of ~100 ns is possible for the LINAC. The beam spot size at the target should preferably be < 5 mm in diameter. A longitudinal beam emittance $\sim 2\pi$ keV/u -ns appears achievable and sufficient for experiments using a recoil spectrometer at a later stage in the program.

5. Safety aspects

There are no special safety aspects for these experiments as compared to the normal ISOLDE program.

6. References

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