EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

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

Coulomb excitation and nucleon transfer reactions in the ^{132}Sn region

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Abstract

Aim of this LoI are experiments to investigate nuclei around the doubly-magic ^{132}Sn, a region of great interest for both nuclear structure and nuclear astrophysics, by Coulomb excitation and nucleon transfer reactions.

1. Introduction

Nuclear structure off the valley of stability is one of the major topics in modern nuclear physics. We propose to study the surrounding of the doubly-magic ^{132}Sn. Nuclei around magic shell closures can be addressed by large scale shell model calculations and beyond-mean-field approaches. New experimental data challenge these models and allow for more reliable extrapolations to inaccessible nuclei. This region is also of interest for the nucleosynthesis. The r-process is expected to pass through this region and the underlying nuclear structure is reflected in the abundance pattern.

2. Physics case

Collective properties of nuclei in this region have been already studied at REX-ISOLDE applying "safe" Coulomb excitation (experiment IS411) [1]. However, because of the low beam energies these studies were limited, in most cases, to the first excited 2^+ state. The higher energies at HIE-ISOLDE and the use of heavier targets result in larger cross sections, in particular for states reachable only by multi-step excitation or by a single step, but with a large excitation energy.

For ^{128}Cd a deformed shape is predicted by beyond-mean-field calculations although this isotope is only two neutrons away from N=82 [2]. In contrast, the shell model predicts a spherical shape. This question can be answered by measuring electromagnetic transition probabilities. The experiment approved at REX-ISOLDE (IS477) will determine the B(E2) value to the first 2^+ state (and will give some indication on the quadrupole moment). However, including also higher lying states and covering a wider angular range a clearer conclusion on the rotational or vibrational character of these states can be drawn. Coulomb excitation from the $3/2^+$ g.s. or the isomeric $11/2^-$ state in ^{127}Cd extends the study of collectivity to odd-A Cd isotopes. The latter will allow to investigate the coupling of an intruder neutron (or hole) to an even Cd core, an interesting topic on its own.

The B(E2) value of the first excited 2^+ state in ^{136}Te has caused some discussions in the past, as its value seemed to be lower than predicted by nearly all theories [3]. Now, as this puzzle has been solved by re-analysis of the old data as well as new measurements [4] (IS441 at ISOLDE), new questions arose. E.g. for the second 2^+ state the predictions from the different shell model approaches are again in strong disagreement making a new experiment absolutely necessary [5].

Additionally, shape phase transition phenomena and dynamical symmetries can be studied by multiple Coulomb excitation. Here, the heavy Ba isotopes and ^{124}Ba are promising candidates. For the latter, in particular, the question if the deformed minimum is oblate or prolate is of interest.

A new phenomenon to be studied at HIE-ISOLDE is octupole collectivity in this mass region. Along the Xe isotopic chain such octupole correlations have been studied up to the shell closure at N=82 [6], but beyond no B(E3) values are known. Below N=82 the $\Delta j=\Delta l=3$, $d_{5/2} \otimes h_{11/2}$ correlations are dominant. Above these are blocked for the neutrons as the $\nu h_{11/2}$ orbital is now completely occupied. Other correlations like $f_{7/2} \otimes i_{13/2}$ may become important. HIE-ISOLDE will allow to populate e.g. the first 3^- state in ^{140}Xe with a cross section increased by nearly a factor of 10 compared to the current situation at REX-ISOLDE. For the Ba isotopes, which are more difficult beams, the octupole correlations are expected to be even stronger resulting in larger B(E3) values. The experiments may even enable the investigation of the enhanced F-vector E1 transitions [7] between the octupole vibration and the proton-neutron mixed-symmetric quadrupole vibration.

The determination of the B(E2) and B(E3) values will be done relatively to the B(E2; $0^+ \rightarrow 2^+$) value already known, e.g. from IS411 or IS477. Alternatively, target excitation is needed as reference requiring a target different from ^{208}Pb (e.g. ^{196}Pt) or complementary experiments to measure directly lifetimes with the plunger device which is going to be built already for REX-ISOLDE. This programme is complemented by g-factor measurements addressed by a separate LoI.

The single-particle properties of states are of vital interest as well to understand the nuclear structure in this region. A well-established method for such investigations are nucleon transfer reactions. Because of the low beam energies such studies in the ^{132}Sn region are not possible at REX-ISOLDE. At HIE-ISOLDE, the higher beam energies result in well pronounced angular distributions of the recoiling target-like fragments from which spin assignments can be deduced. Relative spectroscopic factors extracted from the measured cross sections allow a conclusion on the single-particle configurations. Often the energy resolution for the emitted light charged particles is not sufficient to determine the energy of the populated state, therefore a coincidence with de-exciting γ-rays is needed.

In the shell model, the most basic configurations are single particles or holes coupled to the doubly-magic ^{132}Sn core. Single neutron states can populated most easily by (d,p) reactions, e.g. ^{130,132}Sn(d,p)^{131,133}Sn (Q = 3.02 MeV or 0.25 MeV, respectively). In this region most Q values are positive, hence good kinematical matching can be achieved. The strong relation between (d,p)- and (n,γ)-rates makes such studies interesting for nuclear astrophysics. Some capture rates, e.g. ^{130}Sn(n,γ)^{131}Sn, exhibit a strong impact on the r-process abundances in supernova simulations [8].

Single proton configurations (particles or holes) coupled to the Z=50 core are accessible by (^{3}He,d) or (t,α) reactions, e.g. ^{132}Sn(^{3}He,d)^{133}Sb or ^{132}Sn(t,α)^{131}In (Q = 4.18 and 4.11 MeV, respectively). Also isotopes with Z<50 and N>82, a region hardly accessible by other methods, can be reached enabling to map the evolution of single particle states. E.g. for ^{133}In (^{134}Sn(t,α)^{133}In, Q = 3.66 MeV), only a tentative $9/2^+$ spin assignment for the g.s. is known, but not any information on excited states. The analogue (α,t) reactions have usually strong negative Q values. Note that optimal matching conditions for proton transfer depend on the transfer of mass, charge, and angular momentum.

The same reaction types on Cd, Sn, or Te isotopes explore the region further and challenge the predictive power of modern shell calculations. For stable nuclei proton transfer reactions like (^{3}He,d) or (α,t) have been applied to evidence a quenching of the spin-orbit splitting predicted for neutron-rich nuclei, e.g. for the Sb isotopes [9]. It is obvious to continue such studies with RIBs beyond ^{133}Sb. Two-neutron transfer reactions like (t,p) are additionally a tool to study pairing correlations [10].

3. Experimental setup

The experimental set-up will consist of MINIBALL and Si detectors, CD detector or T-REX array, for particle detection. The set-up, so far, will not be much different to experiments at REX-ISOLDE. In the future, this region, in particular the odd-A Cd isotopes, may be investigated also with HELIOS offering a superior energy resolution for the particles. For the transfer reactions, at least, a veto detector to identify products of fusion reactions of the beam with the target carrier material is needed to distinguish light particles evaporated from compound nuclei from direct reactions (elastic scattering, transfer). A separator would be highly advantageous as all beam-like particles are identified event-by-event. For the proton transfer a ^{3}He or ^{4}He target is needed which could be an implanted target or a gas target (as already used at ANL). Both solutions will be investigated.

4. Beam requirements

Typical beam intensities required for the population of higher-lying states (one-step or multi-step Coulomb excitation) as well as for transfer reactions are in the order of 10^5 particles/s. The higher beam intensities at HIE-ISOLDE will enable to extend the studies towards more exotic isotopes compared to REX-ISOLDE. Typical beam times are in the range of 5-10 days per isotope.

The key isotopes for the proposed programme are ^{127,128}Cd, ^{130,132,134}Sn, ^{134,136}Te, ^{124}Ba, Xe and Ba isotopes above N=82. Beam developments are needed for Te (intensity not sufficient) and Ba (beam purity poor, unsuccessful attempt to produce ^{148,150}Ba beams. For ^{127}Cd, the selective laser ionisation of the g.s. or the $11/2^-$ isomer, an unique opportunity available at ISOLDE, is required (used in IS435 for Cu isotopes). One should note that ISOLDE is the only ISOL facility that has Cd beams available.

Beam energies are 5-6 MeV/u for Coulomb excitation ("safe" conditions up to around 60° in the laboratory frame) and preferably 10 MeV/u for transfer reactions. For all experiments a large duty cycle is helpful and an extraction time from the EBIS as long as possible (slow extraction) is mandatory (if the lifetime of the isotope of interest is sufficiently long).

5. Safety aspects

We have demonstrated (IS470) that the radioactive ^{3}H target can be operated without any safety problems. The long half-life of ^{140}Ba ($T_{1/2}$=12 d) has to be considered scheduling the experiments.

6. References

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