CERN-INTC-2007-028+INTC-I-073
11 October 2007

LETTER OF INTENT

Study the effect of shell stabilization of the collective isovector valence-shell excitations along the N=80 isotonic chain

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Physics case

Of particular importance for understanding the dynamics of the nuclear many-body system are those phenomena which reflect the mutual balance and interplay between nuclear collectivity, the nuclear shell structure, and the isospin degree of freedom. The quadrupole-collective isovector valence-shell excitations, so-called proton-neutron *mixed-symmetry states (MSSs)* [1,2], are the best studied examples of this class of phenomena. A special type of MSS, the 1^+ scissors mode, was first discovered in nuclei [4] and subsequently found or suggested to exist in Bose-Einstein condensates [5] and metallic clusters [6]. In this respect, the impact of a deeper understanding of the structure of these states extends even beyond the field of nuclear structure physics. The fundamental MSS in weakly collective vibrational nuclei, is the one-quadrupole phonon $2^+_{1,ms}$ state [1] which is the lowest-energy isovector quadrupole excitation in the valence shell. The MSSs can be identified experimentally by their unique decay to the low-lying fully symmetric states (FSS) [1,7]. This comprises a major experimental challenge because it requires full spectroscopic information, i.e. the spin-parities of these highly excited non-yrast states, the branching and multipole mixing ratios of their γ-decay, and their lifetimes have to be determined. For more detailed insight in the structure of these states information about their magnetic moments and the magnetic moments of the FS 2^+_1 state is also necessary. Until recently obtaining all this information was possible for several stable nuclei only. The best examples of MSSs in stable nuclei are found in the mass $A \approx 90$ region [7–13]. Among them the clearest case of multi-phonon MS structure has been found in ^{94}Mo [7,11–13]. *No MSSs have ever been identified in unstable nuclei on the solid basis of large absolute M1 strengths.*

There are only few MSSs identified in the mass A≈130 region [14–16]. The main reason for this comes from the fact that the stable open-shell nuclei in this region have relatively low abundance. Recently, we have shown that Coulomb excitation reactions in inverse kinematics can serve as a powerful tool to study MSSs [17]. Using the Gammasphere array at Argonne National Laboratory we have started an experimental program using ion beams of various Xe, Ba, and Ce isotopes in projectile Coulomb excitation, an experimental technique which can straightforwardly be applied to radioactive ion beams (RIBs). The data yield the E2 and M1 strength distributions between low spin states which reveals the $2^+_{1;ms}$ state from absolute M1 data. Recent examples are given by our data on the N=80 isotones ^{138}Ce [17] and ^{134}Xe [18]. In contrast to the isotone ^{136}Ba, the $2^+_{1;ms}$ state in ^{138}Ce is strongly mixed with a nearby 2^+ fully symmetric state with a mixing matrix element of V_{mix} = 44(3) keV first measured directly from the properties of a state with dominant mixed-symmetry character.

The results for the ^{138}Ce [17] demonstrate that the microscopic structure can have a dramatic influence on the properties of MSSs. In fact, for the low-collective vibrational nuclei the single-particle structure of the wave function can be the most important factor for preserving or fragmenting the MSSs. The observed mixing in ^{138}Ce is attributed to the lack of *shell stabilization* at the proton $g_{7/2}$ subshell closure which reflects the fact that at Z=58 the $g_{7/2}$ orbital is completely filled. As a consequence, the proton part of 2^+ one-phonon states (both FS and the MS) are dominated by seniority-two excitations in the $d_{5/2}$ orbital. The higher-seniority 2^+ states are then also formed within the same proton space as the one-phonon states. Consequently, the proton configuration of the $2_{1;ms}$ state does not differ substantially from that of the nearby 2^+ states at 2 MeV. Residual proton-neutron interactions, such as the quadrupole-quadrupole interaction, easily lead to an enhanced mixing which concurs with our measurement of $V_{F\text{-}mix}$(^{138}Ce)=44(3) keV. This scenario also implies an increased neutron character for the symmetric 2^+_1 state at Z=58 since the excitations within the $\nu h_{11/2}$ orbital are energetically favorable over promotion of protons to higher orbitals. The situation in ^{136}Ba is just the opposite – there are two holes in the $g_{7/2}$ subshell, which are enough for forming the dominant seniority two components of the one-phonon states. As a result the wave function of the one-phonon MSS is simpler than the wave functions of its higher-seniority neighbors. Therefore, the mixing between the MSS and the FSS in ^{136}Ba is strongly suppressed and the one-phonon states have more balanced proton-neutron character.

The evolution of the MSSs from ^{136}Ba to ^{138}Ce was used for the first time to quantify how the strength concentration of collective-isovector excitations in the valence shell reflects the underlying single-particle structure. The preliminary results for ^{134}Xe indicate a well pronounced MSSs that concur with the proposed mechanism. At the same time this mechanism predicts increased shell stabilization for the one-phonon MSS in the Z=60 Neodymium isotopes, just above the Z=58 sub-shell closure. To verify this prediction, the MSSs of the N=80 nuclei above ^{138}Ce must be studied. The natural step in this direction is to study the ^{140}Nd and the ^{142}Sm nuclei. The proton structure of these nuclei is dominated by the $d_{5/2}$ orbital. If the mechanism of the shell stabilization is correct, we can expect well pronounced MSSs in these nuclei. It is a purpose of this letter to express our intentions to begin an experimental program at REX-ISOLDE which is concentrated on the investigation of the MSSs in the heavy N= 80 isotones. For these nuclei the first 2^+ state typically lies at about 800 keV with ground state transition strength of 50-80 W.u. while the MSSs are expected to appear at about 2 MeV with an excitation strength of a few W.u.. As a first step we are planning to submit a proposal to measure the transition strengths and the magnetic moments of the first excited 2^+ (FSS) in the ^{140}Nd and the ^{142}Sm nuclei. Having this information will allow for the actual search for the MSSs in the ^{140}Nd and the ^{142}Sm nuclei by performing relative Coulomb excitation measurements. This step is foreseen for the time when the upgrade of REX-ISOLDE, the HIE-ISOLDE, becomes operational. We stress that the future HIE-ISOLDE upgrade is an absolute condition for the search for MSSs in radioactive nuclei. With this letter of intent we also express our readiness to contribute to the activities related to the ISOLDE upgrade.

Experimental requirements

The Nd and Sm nuclei of interest can potentially be produced at ISOLDE with sufficiently high primary intensity (> 5 x 10^6 ions/s) which can provide at least of about 10^5 ions/s on target for γ-ray yield measurements using MINIBALL. A beam of ^{140}Nd has not been produced before but some lighter and heavier Nd isotopes have been produced by using the Ta target. A beam of ^{142}Sm has been produced by using the GdLa target. At present, both nuclei of interest can be made out of a Ta target [19]. However, it is necessary to demonstrate that the beams can be produced with the expected rate. The breeding time in the EBIS, necessary to achieve ionization states which allow a post-acceleration up to 3 MeV/u also needs to be determined. Finally, it has to be demonstrated that a reasonable (few %) efficiency for REX-EBIS can be achieved.

Both, ^{140}Nd and ^{142}Sm, have stable isobars - ^{140}Ce and ^{142}Nd, respectively. It might be expected that these isobars will constitute major contaminations in the beams of interest. To avoid this problem we intent to use selective laser ionization. The ionization schemes for the Nd and the Sm elements exist but have never been tested at RILIS [20]. It is necessary to check the applicability of the ionization schemes and to determine the suppression factor for the stable contaminants.

Summary

In this letter of intent we ask for developing radioactive beams of ^{140}Nd and ^{142}Sm and for testing the RILIS schemes for these elements. If the expected parameters can be achieved, the next step will be to submit a full proposal for measuring the transition strengths $B(E2;2^+_1 \rightarrow 0^+_1)$ and the magnetic moments of the first excited 2^+ states in the radioactive nuclei ^{140}Nd and ^{142}Sm. This proposal is meant as the starting point of our program to study MSSs of heavy radioactive nuclei at HIE-ISOLDE.

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