EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

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

Shape studies in the neutron rich N ~ 60 region

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Abstract

We aim to investigate the onset of deformation and shape coexistence in the region around N=60 using Coulomb excitation and transfer reactions with MINIBALL at HIE-ISOLDE.

1. Introduction

One of the primary goals of modern nuclear physics is an understanding of the interplay between single-particle and collective modes of excitation. Of particular interest are the onset of deformation and the phenomenon of shape coexistence, where structures built on the ground state coexist with higher-lying ones with a different deformation. In such regions, the strong dependence of the observed spectroscopic properties on proton or neutron number makes the theoretical interpretation particularly challenging. Well defined rotational bands have been found in ^{97}Sr and ^{99}Zr [1] and studies of microsecond isomers in ^{98}Zr have given evidence for shape coexistence [2], indicating an onset of quadrupole deformation around N = 60. This can be interpreted in terms of the competition between the spherical sub-shell closure at N = 56 and the deformed ones at N = 60, 62, 64, where the downsloping $\nu_{3/2}$[541] orbital drives the deformation [3]. In the Sr and Zr isotopic chains, this transition from spherical to deformed occurs between N = 58 and N = 60. On the other hand, recent shell-model calculations [4], that don't include the $\nu h_{11/2}$ orbital, seem to imply the interaction between the spin-orbit partner $\pi g_{9/2}$ and $\upsilon g_{7/2}$ orbits as the main deformation-driving mechanism.

A recent paper by Möller *et al*. [5] has presented calculations of potential energy surfaces (see Fig. 1) using the finite-range liquid drop model for over 7000 nuclei and has highlighted regions where such shape coexistence effects are expected to be observed. Several of the regions highlighted by this work promise interesting physics and are the subjects of letters of intent for HIE-ISOLDE. In this letter we will focus on the neutron-rich region around N = 60 and Z = 34-40.

2. Physics case

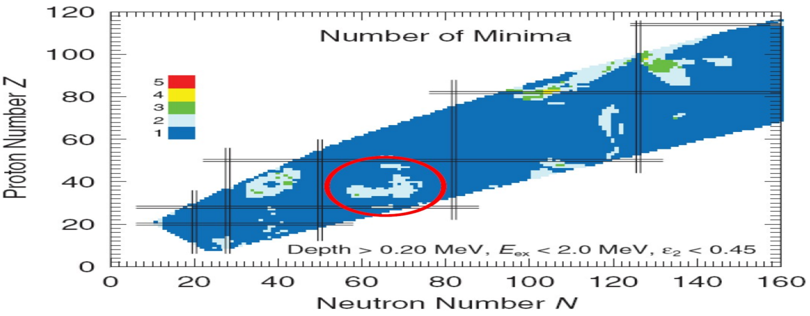

Fig 1: Number of minima in the nuclear potential calculated with the macro-scopic-microscopic finite-range liquid-drop model from [5]. The circle indicates the region of interest for this letter of intent.

From the mean field point of view, around N=60 different shapes are expected to coexist in a narrow energy range. Potential energy curves present an oblate absolute minimum in ^{96}Sr and a strongly deformed prolate minimum about 1 MeV above. Oblate and prolate minima are almost degenerate in ^{98}Sr. This scenario is supported by the observation of excited 0^+ states at 1229 and 1465 keV in ^{96}Sr and at only 215 keV in ^{98}Sr. In ^{96}Sr, the two low-lying 0^+ states are interpreted as candidates for a deformed band head. An extremely strong electric monopole transition of $\rho^2(E0)=0.18$ was observed between the 0^+_3 and 0^+_2 states [6,7], indicating the presence of a sizeable deformation and strong mixing of the configurations. The experimental description of the low-lying 0^+ states and their associated structure will bring clues to the microscopic understanding of the collapse of the Z=40 sub-shell closure when the $\nu g_{7/2}$ orbital is filled as well as the shape coexistence scenario suggested by the mean field approach. The complete description in terms of electromagnetic matrix elements will allow us to understand the mechanism of shape transition in this mass region.

In ^{96}Sr the IS451 collaboration measured a rather large $B(E2;0^+\rightarrow 2^+)$ and a small quadrupole moment in the 2^+ state, suggesting a quasi vibrator character of the ground-state band structure and excluding a pure quadrupole degree of freedom. The highly deformed ground-state band structure of ^{98}Sr will be investigated in an addendum of the experiment in 2011/2. With the present beam energy, of up to 3 MeV/A, spectroscopic information can only be obtained on the 2^+ state in ^{96}Sr as states above remain inaccessible. In ^{98}Sr, only the ground-state band can be investigated. A 4.7 MeV/A beam impinging on a Pb target would increase significantly the Coulomb excitation cross section for higher-lying states and allow studies beyond the first excited state.

The rubidium isotopes are particularly attractive candidates (IS493) to investigate the rapid spherical-to-deformed shape change when increasing the number of neutrons from 58 to 60, due to their rapid release times and high extraction efficiency from thick UC_X targets. The observation of three different shapes in odd-neutron nuclei, such as ^{99}Zr [8] has underlined the deformation-driving role of intruder orbits and spherical-favoring extruder orbits. It would therefore be interesting to investigate the deformation of states containing different proton configurations and their role in the deformation-driving mechanism across the N=59 shape change ($^{93-99}$Rb).

The neutron-rich krypton isotopes ^{94,96}Kr were studied by IS485, yielding important information about the collectivity of the first 2^+ state. However, a complete understanding of these nuclei can only be obtained by studying both the spherical and deformed configurations when they are off-yrast, which can be performed using Coulomb excitation around 5 MeV/u. The evolution of these states further from stability is also an important topic but the short lifetimes and low yields make such studies difficult. The increased intensity available with HIE-ISOLDE will, however, open up the possibility of studying ^{98}Kr. An understanding of the single-particle states can be obtained by performing transfer reactions such as (d,p) into the odd-A krypton isotopes. For the even-even isotopes, transfer experiments provide information on spins. The excited 0^+ states are crucial to understanding shape coexistence and these may be populated by (t,p) reactions using a ^{3}H target.

The selenium isotopes would also be of interest as they lie well within the region of predicted shape coexistence. However, the lifetimes are not known experimentally, so preliminary investigations would be required to determine if they are long-lived enough to be post-accelerated.

For the Coulomb excitation experiments, only the lowest lying states are populated at the present REX-ISOLDE energy of just under 3 MeV/u. However, the study of higher-lying states is crucial to the understanding of the evolution of nuclear states and shape coexistence. Such states will only be populated at HIE-ISOLDE with energies around 4 to 5 MeV/u. For transfer reactions, even higher energies such as the 10 MeV/u expected in the second phase of HIE-ISOLDE are desirable. For both kinds of experiment, the increase in beam intensity is needed for nuclei further from stability, particularly when the lifetimes are of the same order of magnitude as the flight time from the primary target to MINIBALL. The improved spatial properties of the beam are needed to minimize losses in the accelerator, not just to increase the yield at MINIBALL, but to reduce the accumulation of radiation along the beam line which has often imposed a limit on experiments.

3. Experimental setup

The experiments will be performed using the existing MINIBALL germanium array setup with its ancillary particle detectors (the CD detector or C-REX setup for Coulomb excitation experiments and the T-REX setup for transfer experiments). In addition to Coulomb excitation, lifetimes may be measured directly by the differential recoil distance Doppler shift method and a plunger device for such measurements is being constructed in Cologne. The existing ionization chamber has proved crucial in determining beam composition in this mass region and will continue to be available. The inclusion of a recoil separator after MINIBALL would be particularly useful for the transfer experiments, where it would make it possible to distinguish between the direct beam and the transfer products on an event-by-event basis. Such a device is the subject of a separate letter of intent [9]. These experiments would all benefit from in-beam electron measurements, which would provide information on the E0 transitions between the 0^+ states which are the band-heads for each deformed structure. A separate letter of intent [10] addresses the construction of the relevant instrumentation.

4. Beam requirements

- isotopes of interest: ^{96,98}Sr, ^{93,95,97,99}Rb, ^{94,96,98}Kr, Se isotopes if lifetime long enough to post-accelerate.
- beam purity: as high as possible but at least >50%. For Sr it should be investigated whether SrF molecule extraction or in-trap decay of Rb is better.
- beam intensity: 10^4 pps is the minimal beam intensity for the Coulomb excitation experiments, 10^5 pps is the minimal beam intensity for the transfer experiments. Between five and ten days beam time are needed per isotope, depending on the yield.
- beam energy: 4 to 5 MeV/u for the Coulex, 10 MeV/u (the highest energy) for the transfer reactions.
- spatial properties of the beam: 3 mm diameter beam spot size at the target position.
- time structure of the beam: in order to minimize the dead time of the acquisition system, the beam pulse from the EBIS should be as long and flat (slow extraction) as possible (ideally > 400 μs).

5. Safety aspects

The same as for current REX-ISOLDE experiments. Tritiated targets have already been used (IS470).

6. References

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