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

Shape changes and proton-neutron pairing around the N=Z line

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Abstract

We propose to continue our studies of the evolution of nuclear shape in nuclei between A=60 and 90, close to the line of N=Z. This enhanced programme will make full use of the potential for multi-step Coulomb excitation at HIE-ISOLDE as well as foreseeing the opportunity for a more detailed understanding of the shape coexistence phenomenon through single particle- and pair-transfer reactions.

1. Introduction

A remarkable feature of atomic nuclei is their ability to adopt different mean field shapes for a small cost in energy compared to their total binding energy. The nuclei close to the N=Z line between mass 60 and 90 are predicted to lie in a region of rapidly evolving nuclear shape. Macroscopic-microsopic models suggest a transition from gamma-soft shapes at ^{64}Ge, through oblate-prolate shape-coexistence in ^{68}Se and ^{72}Kr to some of the most prolate deformed nuclei at ^{76}Sr and ^{80}Zr. The shape coexistence in N=Z nuclei, in particular, may be enhanced by the occupation of the same orbitals for protons and neutrons. The N=Z nuclei are also an excellent laboratory for investigating effects like np-pairing.

A key tool for identifying the sign of the nuclear deformation is the reorientation effect in low-energy Coulomb excitation. We have begun to carry out such measurements on nuclei of interest at REX-ISOLDE. Given the existing beam energy, however, it was only possible to excite essentially the first

2^+ states in these nuclei. An example is ^{70}Se where the nucleus of interest was produced as an isobarically pure beam through extracting it from ISOLDE as an SeCO$^+$ molecule and breaking this molecule in the EBIS. In conjunction with new data on lifetimes of low-lying states in ^{70}Se, it was possible to show that the 2^+ state in ^{70}Se was associated with an oblate shape [1,2]. A similar experiment for the N=Z nucleus ^{72}Kr is scheduled for July 2010 (IS478).

2. Physics case

HIE-ISOLDE promises a step-change in what is presently achievable in terms of studying shape evolution close to the line of N=Z. Performing Coulomb excitation at 5 MeV/u will allow the extraction of transition and diagonal matrix elements between a number of low-lying states, not just the first 2^+ state. The importance of being able to extract a range of matrix elements has been clearly demonstrated in the case of ^{74}Kr and ^{76}Kr studied using SPIRAL beams at GANIL [2]. In this case, the high quality data allowed discrimination between different nuclear models. Furthermore, using the rotational-invariant technique prescription, the centroids and fluctuation widths of the intrinsic E2 moment for certain states can be determined in a model independent way, provided the relative signs and magnitudes of the connecting E2 matrix elements are measured [3,4]. It would be extremely important to our understanding of the shape coexistence phenomenon to extend this methodology to the N=Z nuclei such as ^{68}Se and ^{72}Kr.

These collective aspects, such as the evolution of quadrupole degrees of freedom, are driven by the underlying single-particle structure – in particular the filling of the $g_{9/2}$ orbital, which strongly influences the proton-neutron interaction, and drives these effects. The occupation of these orbitals can be probed, for example, using (d,p) reactions in inverse kinematics. Exploring how the occupation evolves from A=60 to A=80 will provide a quantitative basis for understanding collective motions and shape coexistence phenomenon.

Another important way in which the shape changes could be explored and the different configurations connected is to use transfer reactions which add or remove correlated pairs of protons of neutrons e.g. (t,p) and (p,t) reactions. This was, and remains, an important technique for probing such phenomena, and exploring nuclear symmetries. For Q-value reasons, only (t,p) transfer reactions can be done at energies lower than 10 MeV/nucleon in the region of light Se and Kr isotopes. The identification and measurement of low-lying 0^+ excited states ptovides evidence for shape coexistence and gives unique information on the energy difference of competing configurations. The angular distribution of the light recoiling particle in (t,p) reactions unambiguously identifies L=0 transfer. In the last 20 years, such states have been searched for in this mass region. Low-lying 0^+ states are predicted by several shell-model calculations and have been observed in light Krypton isotopes from ^{76}Kr to ^{72}Kr. In case of Selenium isotopes several low-lying 0^+ states are also predicted but not experimentally observed. These measurements represent a necessary key for understanding the shape coexistence phenomenon in this mass region. The chief challenges here are choosing an appropriate spectrometer and the availability of suitable targets such as a radioactive tritiated target.

It is still an open question as to what role neutron-proton pairing plays in nuclei. In particular, since np pairs do not have to obey the exclusion principle, it is possible to have both T=0 and T=1 np-pairs. It is not clear which pairing mode is the more important. Chasman [5] has emphasized odd-odd N=Z nuclei as being the most favourable testing ground for the role of np-pairing. A specific prediction is that T=1, S=0 and T=0, S=1 states should form a degenerate ground state in odd-odd N=Z nuclei if T=0 and T=1 pairing are on an equal footing. This situation does not appear to be realized but transfer reactions may help in identifying underlying parentage of states. Some years ago, Macchiavelli [6] suggested that pn pair transfer could be an important way of probing np-pairing in N=Z nuclei. Practically speaking, this corresponds to (^{3}He,p) reactions on even-even N=Z nuclei. HIE-ISOLDE would open up such possibilities experimentally, perhaps uniquely worldwide.

3. Experimental setup

Coulomb excitation would be carried out with the MINIBALL array and an annular CD silicon detector. Transfer reactions could be carried out with a silicon barrel like T-REX or with a helical-orbit spectrometer such as HELIOS.

4. Beam requirements

We would like to obtain beams of proton-rich Se, Kr and Sr including the N=Z nucleus in each case. Such beams may all be produced in an isobarically pure form: Se and Sr through molecular extraction and Kr since it is a noble gas. Unfortunately, Zr and Mo are not possible as they are refractory elements. For Coulomb excitation, we require beams of around 5 MeV/u. For transfer reactions such as (d,p), we require up to 10 MeV/u, in principle, but in many cases satisfactory measurements can be made with beam energies as low as 6 MeV/u.

For pn pair transfer studies, we would need beams of, for example, ^{56}Ni, ^{60}Zn, and ^{64}Ge.

5. Safety aspects

No particular hazards. The long half-life (5 days) of ^{56}Ni might impose scheduling issues.

6. References

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