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

Studies of collectivity and single-particle behaviour in Te nuclei above the the *N*=50 shell gap

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Abstract

We propose to study the evolution of collectivity of low-energy excitations and their underlying single-particle properties in neutron-deficient Te nuclei. We aim to measure transition probabilities between the low-spin states and occupancies of single-particle orbitals by means of Coulomb excitation and transfer reactions at HIE-ISOLDE. The proposed study aims to study the structures of the light Te nuclei, which lie in the region of the nuclear chart where a departure from the expected energy level systematics has been observed. The proposed study will shed light on the ordering of single-particle orbitals, residual proton-neutron interactions and the role of the tensor force in the development of collectivity when approaching the *N*=*Z*=50 region.

1. Introduction

Nuclei near closed proton or neutron shells exhibit a rich variety of phenomena. In such regions of the nuclear chart, a small change in the number of constituent nucleons can introduce dramatic changes in the structures of observed states. Significant effort has been invested in the study of $N \approx Z$ nuclei residing just above the *Z*=50 shell gap. For example, recent gamma spectroscopy studies of neutron-deficient Te [1], I [2] and Xe [3] nuclei have provided evidence of enhanced collectivity when approaching the *N*=50 shell gap. However, while quantities such as level energies yield invaluable information about the structure of a nucleus, knowledge of transition probabilities and the single-particle structure of the states is required to acquire precise information about the nuclear wave functions and their degree of collectivity. Therefore we intend to initiate a programme of Coulomb excitation and particle transfer reaction studies of neutron-deficient Te nuclei at HIE-ISOLDE.

2. Physics case

The experimental level-energy systematics of the 2^+ and 4^+ states in neutron-deficient Te nuclei (shown in Fig. 1) suggest that there is an enhancement in collectivity which begins around ^{112}Te and persists as the N=50 shell closure is approached. The decreasing trend of the energy of the 2^+, 4^+ state energies from ^{114}Te is observed down to ^{108}Te, before increasing again slightly at ^{106}Te. It is interesting to note that a similar phenomenon has also been observed in neutron-deficient I and Xe nuclei and the origins are probably related to those in the Te nuclei. Such an unusual effect has been previously been suggested to arise from increased octupole correlations [4] or from isoscalar proton-neutron interactions as N approaches Z [3].

Shell model calculations, using a model space of $0g_{7/2}$, $1d_{5/2}$, $1d_{3/2}$ and $2s_{1/2}$ orbitals and the realistic CD-Bonn nucleon-nucleon potential without any empirical adjustment, have been carried out by members of the collaboration. Although the present calculations do not get the absolute energies of the states correct (see fig. 1), they do reproduce the general trend of the observed level energies, which minimises around the neutron mid shell at $N \sim 66$, and then increases up to ^{114}Te before starting to decrease again at ^{112}Te down to ^{108}Te, in nice agreement with experiment. The anticipated onset of collectivity is also supported by the enhanced transition probabilities that are predicted from the shell model calculations as the N=50 shell closure is approached. At the present time, however, there is no experimental information of the transition probabilities for even mass Te isotopes with A<114, which in part is due to the experimental difficulties of using fusion-evaporation reactions for these studies.

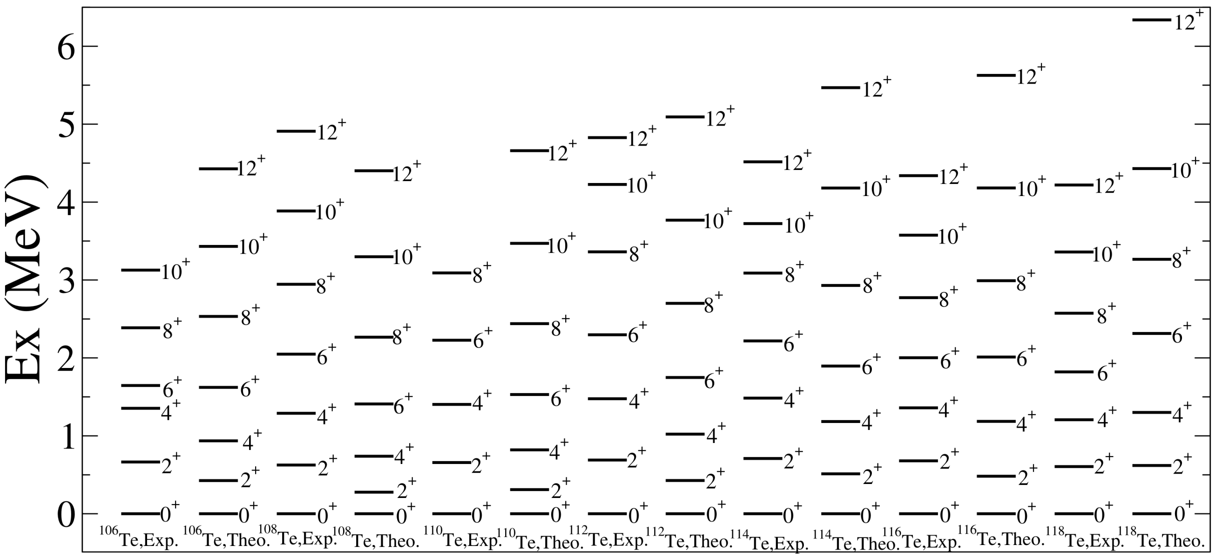

Figure 1. Experimental and theoretical level energies of neutron-deficient even-mass Te nuclei.

The low lying states with spin $I \leq 10$ are dominated by the coupling of neutrons and protons in $0g_{7/2}$-$1d_{5/2}$ shell. Calculated $E2$ strengths indicate their sensitivity to the occupancy of $0g_{7/2}$ and $1d_{5/2}$ orbitals. In the neutron-deficient Te isotopes the proton-neutron interaction results in the $1d_{5/2}$ orbital being the lowest, and thus the proton pair mostly occupy the $1d_{5/2}$ orbital for the low-spin states. However, the tensor force between the proton $0g_{7/2}$ and neutron $1d_{5/2}$ orbitals should be strong. The enhanced collectivity in the light Te isotopes may arise as a result of the configuration mixing effect between the proton $d_{5/2}$ and $g_{7/2}$ orbitals. Indeed the occupancy of the orbitals is found to be particularly sensitive to the n-p monopole terms involving the $g_{7/2}$ and $d_{5/2}$ orbitals with isospin T=0 and 1, but other monopole terms involving the $g_{7/2}$-$g_{7/2}$, $d_{5/2}$-$d_{5/2}$ and $d_{3/2}$-$d_{3/2}$ may also be important. The calculations also suggest that the development of the collectivity is strongly linked to the occupancy of the key orbitals. The data obtained in the proposed experiments will help determine the importance of these monopole terms and improve our understanding of the nature and origin of the enhanced collectivity that is predicted to exist. The calculations are sensitive to the proton-neutron interaction and therefore knowledge of transition probabilities and diagonal matrix elements are critical in helping to provide a description of the structure properties of these nuclei. In addition, single-particle properties are also vital for the understanding the nuclear structure near N=Z=50. This is crucial especially as the evolution of the quadrupole degrees of freedom are going to be driven by the underlying single particle structure.

We propose to measure transition probabilities and diagonal matrix elements $\langle 2^+||\mathcal{O}(E2)||2^+\rangle$ in the even-mass $^{108\text{-}114}$Te nuclei and probe the occupancies of the single-particle orbitals of adjacent odd-mass (proton and neutron) isotopes of $^{108\text{-}118}$Te at HIE-ISOLDE. This will be possible through the anticipated order of magnitude improvement in the primary yield, thus allowing us to extend the Coulomb excitation and particle transfer measurements towards the N=Z=50 shell closure. Furthermore, multi-step Coulomb excitation measurements will be possible in favourable cases where the transition energies are not overlapping. The cross section for the multi-step Coulomb excitation process will be enhanced by the increased energy (5.5 MeV/u) of the HIE-ISOLDE facility. Inverse neutron and proton transfer reactions will be performed on the Te nuclei to probe the single-particle occupancies of the states, which can then be compared with shell model calculations.

3. Experimental setup

The experimental setup will require a Ge-detector detector array with high efficiency (MINIBALL) and a Si detector/detector array (MINIBALL CD or T-REX) for the event-by-event detection of the scattered beam- and target particles following Coulomb excitation events. For the inverse particle transfer reactions, the use of the T-REX Si detector array to measure the angular distributions and energies of the outgoing light particle is required. For the proton transfer experiments a ^{3}He target is needed. The use of a detector set-up or a separator to veto out fusion events when utilising transfer reactions is foreseen.

4. Beam requirements

As noted in Ref. [5] radioactive Te beams could be produced through impurities in the fibrous ZrO_2 primary target and with the hot plasma ion source. However, as that is not an optimal method to produce such beams, target development is required to reach the Te isotopes down to A=108. It was recommended that HfO_2 or CeO_2 would be suitable target materials for the production of neutron-deficient Te beams [5].

The isotopes of interest will be accelerated up to 5.5 MeV/u in Coulomb excitation studies. For the particle transfer studies good particle angular distribution information can already be obtained with energies of around 5.5 MeV/u, however, an improvement is expected with beam energies of around 10 MeV/u. The required beam current delivered to the Coulomb excitation target is on the order of 10^4 pps, for transfer studies on the order of 10^5 pps. Beam purity should be greater than 50%. However, the use of event-by-event identification of the Coulomb excitation events could relax this condition. Furthermore, RILIS may be used in order to improve the beam purity. Typical beam times of an experiment within the present Letter of Intent are up to 21 shifts per nucleus, i.e. very similar to current experiments at MINIBALL.

5. Safety aspects

No safety concerns are envisaged.

6. References

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