EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

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

Nuclear-structure evolution from ^{68}Ni towards ^{78}Ni studied with multiple Coulomb excitation

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Abstract

We propose to study the evolution of the nuclear structure along the nickel isotopic chain towards the doubly magic nucleus ^{78}Ni. The structure is determined by the importance of the N=40 and 50, and Z=28 shell gaps where the specific role of the neutron $g_{9/2}$ orbital is essential. Radioactive beams from HIE-ISOLDE at 5 MeV/u will be used to study excited states in a selected set of iron, nickel and zinc isotopes using multi-step Coulomb excitation.

1. Introduction

Studying the region around the doubly magic nucleus 78Ni with the Z=28 and N=50 shell closures is particularly interesting for testing the validity of the contemporary nuclear models and for unraveling new aspects of the interactions used in these models (see e.g. [1,2,3]). Especially the evolution of single-particle and collective phenomena between the harmonic oscillator shell closure at N=40 and the shell closure at N=50 challenges our understanding of the nuclear structure. In this region the transition from harmonic oscillator to spin-orbit type shell closure is manifested and the neutron g9/2 neutron orbital plays an important role in this process [1-4]. In recent years, intense experimental and theoretical work has resulted in a substantial progress in our understanding of the nuclear structure in this region, but still several questions remain.

Coulomb excitation experiments [5,6,7,8] and decay experiments around ^{68}Ni [9,10] exemplify on the one hand the importance of neutron pair scattering across N=40 and proton excitation across Z=28 while on the other hand, the neighbors of ^{68}Ni can be well described as proton/neutron particles and holes coupled to a rigid core. Furthermore, recent work indicates the presence of proton 2p-2h states at low excitation energy in ^{68}Ni [11].

Studies in the copper isotopes (Z=29) using co-linear laser spectroscopy [12], Coulomb excitation [13], isomer decay [3] and beta decay studies [14] indicate a significant variation in the excitation energy of the proton single-particle states in the odd-*A* Cu isotopes beyond N=40 and the presence of collective structures that coexist at low excitation energy. Recent shell-model calculations predict that these collective phenomena will disappear when approaching the N=50 shell closure [1,3] but the picture is far form complete as certain experimental observables (like e.g. magnetic moments) can only be explained when invoking excitations across the N=50 into the d5/2 neutron orbital. It is suggested that this orbital plays a significant role in the region between N=40 and 50 [4].

Coulomb excitation studies in the neutron-rich Zn isotopes up to the N=50 ^{80}Zn nucleus, revealed the energy of the first 2^+ state and the 2^+-0^+ transition matrix element. Both observables indicate a significant N=50 shell closure [15], but essential information on the other excited states in ^{80}Zn is lacking. Recent shell model calculations do not fully reproduce the experimental findings and new data are essential to obtain a more sensitive comparison between theory and experiment [1]

Finally, below Z=28 a surprisingly swift onset of deformation has been observed experimentally from beta-decay, in-beam studies and proton-knock out reactions [16,17,18,19]. Further study of these phenomena is essential.

2. Physics case

To shed more light onto the issues mentioned above, we propose to perform multiple Coulomb excitation measurements using the higher beam energy and intensity from HIE-ISOLDE. The higher beam energy, the better beam purity and the better phase space definition will allow the identification and study of higher-lying collective (sometimes non-yrast) states by determining their excitation energy, spin and parity as well as quadrupole transition matrix elements between certain states. Furthermore, using the rotational-invariant technique prescription, the centroids and fluctuation widths of the intrinsic E2 moment for certain states can be determined in model independent way, provided the relative signs and magnitudes of the connecting E2 matrix elements are measured [20,21]. It should be noted that multi-step Coulomb excitation cannot be studied in intermediate or relativistic energy Coulomb excitation as mainly one-step Coulomb excitation is observed at these energies.

a. Coulomb excitation of ^{68,70}Ni

The higher beam energy will enhance the cross section for the populations of the excited states in ^{68}Ni (the 2^+ state lies at 2033 keV) substantially. Furthermore the transition matrix elements can be directly compared to the recent shell model calculations and will give information to unravel especially the structure of the proton and/or neutron intruder 0^+_2 and 2^+_2states.

b. Coulomb excitation of $^{69-75}$Cu

The work on Coulomb excitation of the odd-mass copper isotopes has revealed the presence of a collective low-lying $1/2^-$ state next to core coupled 7/2- states and 5/2- states of single particle nature in $^{69-73}$Cu [7]. Candidates for the single hole $7/2^-$ have been suggested from beta-decay studies [14] and a proposal for the low-lying structure in ^{75}Cu was recently given in [3,12]. The higher beam energy from HIE ISOLDE allows Coulomb excitation studies towards these $7/2^-$ states revealing there nature and a Coulex study of ^{75}Cu would result in more detailed information that can be compared to large-scale shell model calculations [1-3]

c. Coulomb excitation of ^{76,78,80}Zn

So far good quality data have been obtained for the transition matrix element of the 2^+-0^+ transition in the even Zn isotopes close to N=50. The higher beam energy will allow obtaining information on the higher lying states e.g. the 4^+, eventually 6^+ and other 2^+ states in ^{80}Zn. Static quadrupole moments can also be obtained, in particular if the Coulomb excitation data are combined with life time measurements, e.g. after multi-nuclei transfer reactions.

d. Coulomb excitation of ^{62,63,64,65}Fe

HIE-ISOLDE has a unique capability to produce post-accelerated pencil like beams of neutron rich iron isotopes using in-trap/in-EBIS decay of the intense, short-lived and laser ionized neutron rich manganese beams [22]. Multiple Coulex will allow to obtain information on the collectivity of higher lying states above the 2^+ state in ^{62,64}Fe. Coulomb excitation of the odd-mass ^{63,65}Fe will allow to study inconsistencies in the current level schemes and clarify issues related to isomerism in this region. Recently, life-time measurements on the even mass iron isotopes ($^{62\text{-}66}$Fe) have been performed at GANIL and MSU. These values combined with the Coulex results will constraint values on the spectroscopy quadrupole moments.

3. Experimental setup

These experiments will be performed with the MINIBALL germanium detector array and the T-REX Si detector array.

4. Beam requirements

Beam development to increase the intensity and purity of the ^{68,70}Ni, ^{78,80}Zn and ^{62,64}Mn/^{62,64}Fe is essential for this proposal. The use of RILIS is essential for all beams proposed. The nickel and zinc beams will also be used for transfer reaction studies that are subject of another LOI.

- isotopes: $^{68\text{-}70}$Ni, $^{78\text{-}80}$Zn, $^{62\text{-}65}$Fe
- intensity: 10^4 pps is the minimal beam intensity for the multiple Coulomb excitation experiments
- beam energy: 4 to 5 MeV/u for the Coulomb excitation measurements
- beam time: typical beam times are 5 to 10 days per isotope under study.
- spatial properties of the beam: 3 mm diameter beam spot size at the target position
- in-trap or in-EBIS decay: Fe beams have to be produced after the beta decay of Mn beams inside the REX-trap or EBIS
- purity: as high as possible but at least >50%, ways to measure the purity will be developed.
- time profile: the beam pulse from the EBIS should as long and as homogeneous as possible (a flat profile >400 microsecond long would be ideal).

5. Safety aspects

The same as for the current experiments at REX-ISOLDE

6. References

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