EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

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

Shape coexistence in the neutron-deficient region around Z=82 studied via Coulomb excitation and few-nucleon transfer reactions

D. Voulot, F.Wenander, J. Pakarinen, Y. Blumenfeld (CERN-ISOLDE, Switzerland)
T. Davinson, P. Woods (University of Edinburgh, U.K.)
P.T. Greenlees, P. Jones, R. Julin, S. Juutinen, T. Grahn, P. Rahkila (University of Jyväskylä, Finland)
M Huyse, H. De Witte, R. Raabe, P. Van Duppen (K.U.Leuven, Belgium)
P.A. Butler, R.-D. Herzberg, D.T Joss, R.D. Page and M. Scheck (University of Liverpool, U.K.)
J. Cederkäll, D. Di Julio C. Fahlander (University of Lund, Sweden)
V. Bildstein, R. Gernhäuser, R. Krücken, K. Nowak, K. Wimmer, D. Mücher(TU-München, Germany)
Th. Kröll, N. Pietralla, G. Rainovski (TU-Darmstadt, Germany)
A. Goergen, W. Korten(CEA-Saclay, France)
M. Zielinska, P. Napiorkowski, J. Srebrny (HIL University of Warsaw, Poland)
D.G. Jenkins, B.S Nara Singh, R. Wadsworth (University of York, U.K.)
A. Blazhev, J. Jolie, N. Warr, P. Reiter (University of Köln, Germany)
S. Freeman (University of Manchester, U.K.)
E. Clément, B. Bastin (GANIL, France)
A.N. Andreyev (University of Paisley, U.K.)
S. Harissopulos, A. Lagoyannis, M. Axiotis, T. J. Mertzimekis (NCSR-Demokritos, Greece)
A. Pakou, N. Patronis (UOI-Greece)
J. Wood (Atlanta, U.S.A.)
K. Heyde (U.Gent, Belgium)
M. Carpenter, R.V.F. Janssens, F.G. Kondev, S. Zhu (ANL, U.S.A.)

Spokespersons:
P. Van Duppen (Leuven), D. Joss (Liverpool), D. Jenkins (York), J. Pakarinen (CERN)

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Abstract

We propose to study the interplay between individual nucleon behavior and collective degrees of freedom, as manifested in shape coexistence, in the neutron deficient lead region. Radioactive beams from HIE-ISOLDE will be used to perform Coulomb excitation experiments and one- and two nucleon transfer reactions using the MINIBALL and T-REX set-up. The use of a recoil separator is envisaged.

1. Introduction

Shape coexistence whereby two or more shapes coexist at low excitation energy in the atomic nucleus is an intriguing phenomenon [1,2]. Its manifestation in the neutron-deficient nuclei in the Z=82 region has been first observed through optical spectroscopy measurements whereby a sharp transition in the mean-square-charge-radii was discovered between ^{187}Hg and ^{185}Hg [3] and since then a wide spectrum of experimental tools has been used to understand shape coexistence in this mass region (decay studies, laser spectroscopy and in-beam spectroscopy studies, and more recently Coulomb excitation experiments using post-accelerated beams from REX-ISOLDE). This resulted, amongst others, in the discovery of triple shape coexistence in ^{186}Pb [4]. Understanding the evolution and microscopic origin of quadrupole collectivity and shape coexistence is important as it highlights the subtle interplay between the individual nucleon behavior sharpened by the strong Z=82 shell closure and collective degrees of freedom in the atomic nucleus. These experimental observations, therefore, form ideal testing grounds of different theories and several contemporary theoretical models have been applied to describe the structure of the nuclei around Z=82, such as phenomenological shape mixing calculations, shell model calculations, symmetry guided models like e.g. the interacting boson model truncations, and beyond mean-field approaches. These models do reproduce the global trends in the experimental findings however important elements on the subtle mixing of the different configurations, even on the mere existence of the intruder states, together with other open questions remain.

ISOLDE is the place to provide intense and pure, pencil-like beams ideal suited for decay spectroscopy, laser spectroscopy, mass measurements and for reaction studies in the lead region. The successful Coulomb excitation experiments to study some selected neutron-deficient, even-even mass isotopes of mercury, polonium and radon have shown the potential to perform such experiments using post-accelerated REX-ISOLDE beams and to obtain important information (transitional and diagonal matrix elements, mixing amplitudes and the population of yrast and non-yrast states) [5]. With the low-energy of the current REX accelerator, however, the population of the excited states is mainly limited to the first 0^+, 2^+ and 4^+ states. Higher beam energies and intensities, and improved purity and phase space conditions, will allow extracting precise matrix elements for several excited states (including non-yrast states) where currently little information is known. 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 [6,7].

Furthermore Coulomb excitation on odd-mass isotopes will characterize the nature of the shape coexisting isomers observed and few nucleon transfer reactions will shed light on the underlying single particle nature of these states. This efforts, combined with new decay spectroscopy, mass measurements and laser spectroscopy profiting from the intensity increase, and life time measurements can result in important breakthroughs in the understanding shape coexistence in atomic nuclei.

2. Physics case

With this LOI we wish to prepare for a number of experimental campaigns focused around the study of shape-coexistence in the neutron-deficient lead region. All these experiments need the improvements and the new possibilities offered by the HIE-ISOLDE project: a higher beam energy, higher intensity and better purity and phase space definition of the beam. Below we list possible physics cases.

a. Coulomb excitation on even-even and odd-mass neutron-deficient isotopes in the mercury ($^{180-188}$Hg), lead ($^{186-192}$Pb), polonium ($^{196-202}$Po) and radon ($^{200-204}$Rn) isotopes:

With the higher beam energy the multiple Coulex cross section will be enhanced and the higher beam intensity and purity will bring us further out from stability towards the N=104 region where the shape coexisting states become lowest in energy (this is especially needed for the lead, polonium and radon isotopes). The better phase space definition of the beam will give a better definition of the scattering angle; this will allow improved Doppler correction (better peak-to-background ratio) and to obtain better quality data of the excitation cross section as a function of scattering angle. The latter is essential to obtain reliable diagonal matrix elements. The Coulomb excitation on selected isomers from the odd mass isotopes (e.g. on the 13/2+ and 1/2- isomers in the Hg isotopes) will allow a study of the collective properties of these isotopes and of the bands built on top of them.

b. Life time measurements of excited states in the Pb and Po isotopes after Coulomb excitation
The sign and magnitude of the diagonal matrix element of the excited states can be deduced by combining results from life time measurements with results from Coulomb excitation cross sections fix [8]. A plunger device, as the one under development by the Athens-Köln-München collaboration for the MINIBALL set-up, is ideally suited to perform life time measurements [9]. However, for certain lead (A>188) and polonium (A>196) isotopes long lived isomers prevent from applying this technique using heavy ion fusion evaporation reactions [9]. We should suffer from this problem using Coulomb excitation to populate the relevant states and propose to apply life time measurements using the new plunger device at HIE-ISOLDE after Coulomb excitation. Also electron spectroscopy to determine conversion coefficients especially for the $\Delta I=0$ intra-band transitions is important. A separate LOI concerning the latter aspect will be submitted.

c. One- and two-neutron transfer reactions:
One neutron transfer reactions (stripping or pick-up) from the even mass mercury isotopes will populate states that are connected to the low-spin (1/2-) shape isomer or the high-spin (13/2+) ground state of the mercury isotopes (e.g. ^{184}Hg(d,p), see also Fig. 2). The relative population of these states can supply information on the different components in the ground state of the even-mass nuclei. Starting from e.g. the 1/2- shape isomers in the odd-mass Hg isotopes (using an isomeric beam produced by RILIS), the one-neutron transfer reaction can populate low-spin (0+, 2+, 4+) states in the even-mass Hg and, assuming that the neutron acts as a spectator, the relative cross section contains information on the ‘intruder’ contribution to these states. Essential for these studies are the higher beam energy as a better sensitivity to the angular momentum transfer can be obtained.

d. Two-proton transfer reactions
It has been suggested that the driving mechanism behind shape-coexistence are the proton-pair excitation across the Z=82 proton shell closure. However, so far, this has not been proven experimentally. Two-proton transfer reactions (pick-up and stripping reactions) might be a way to obtain this crucial information. We propose to investigate two-proton transfer reactions (e.g. ^{184}Hg(^{3}He,n)^{186}Pb, ^{184}Hg(^{16}O,^{14}C)^{186}Pb and ^{196}Po(^{6}Li,^{8}B)^{194}Pb or other reactions) to study the character of the excited 0^+ states involved from the relative population of these states. For these experiments the highest beam energies, purity and intensities are essential.

Note that the quantitative interpretation of the results from the transfer reactions will require a substantial theoretical effort which will be worked on within the collaboration.

The HIE-ISOLDE beams (intensity, purity, energy, phase space characteristics, wide spectrum of different beams - including the isomeric beams from RILIS) offer worldwide unique opportunities. The combination with the MINIBALL and T-REX and a recoil separator for reaction products identification and primary beam suppression will make these campaigns very rewarding to tackle this physics question.

3. Experimental setup

These experiments will be performed with the MINIBALL germanium detector array and the T-REX transfer set-up. The use of a recoil separator for reaction products identification and primary beam suppression is under study [10].

4. Beam requirements

- isotopes: $^{180\text{-}188}$Hg, $^{188\text{-}192}$Pb, $^{196\text{-}202}$Po and $^{200\text{-}204}$Rn, including isomeric beam (e.g. $1/2^-$ and $13/2^+$ isomer in ^{185}Hg)

- 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
- beam energy: 4 to 5 MeV/u for the Coulomb excitation measurements, 10 MeV/u (the highest energy) for the transfer reactions.
- 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
- purity: as high as possible but at least >50%, ways to measure the purity will be developed.
- isomeric beams: are essential for this program (e.g.1/2- isomer in ^{185}Hg)
- time profile: the beam pulse from the EBIS should be 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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