Assessing collective properties in transitional nuclei

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The Nuclear Spectroscopy with Light Ions Group has developed a line of research to explore the coulomb-nuclear interference (CNI) in the inelastic scattering of isoscalarly interacting projectiles following the evolution of the collective behavior through isotope chains¹⁺⁻⁶. The adopted procedure applies the deformed optical potential model (DOMP) with global optical parameters as the nuclear transition potential in the analysis of the inelastic scattering. It is to be noted that for the first quadrupole excitation the majority of the calculated microscopic form factors do not differ substantially from the macroscopic ones in the important asymptotic region. Through this macroscopic CNI analysis in the DWBA approach, the square of mass deformation length, $(\delta^M_L)^2$, is extracted as a scale factor from the fit of the predicted cross sections to the experimental data of the inelastic scattering reaction and, analyzing the characteristic changes in the angular distribution shape, the value of the ratio between charge $\delta^C_L$ and mass $\delta^N_L$ deformation lengths, C, is also obtained. The squares these last two quantities can be put in correspondence respectively with the value of the reduced isoscalar transition probability $B(ISL)$ and of the ratio $B(EL)/B(ISL)$, for which, therefore, a scale uncertainty cancellation occurs, favoring more accurate results. The previous CNI work using the S. Paulo Pelletron-Enge-Spectrograph facility, in the A ~ 70 transitional mass region, considering the germanium isotopic chain demonstrate an abrupt change in the $B(E2)/B(IS2)$ ratio for $^{74}$Ge. Although for $^{70,72}$Ge the C values obtained were of the order of 1.0 or slightly higher, the extracted value is 0.775 (8) for $^{74}$Ge. However, the CNI study of 28 MeV inelastic scattering on $^{76}$Ge recently measured in S. Paulo revealed $C=1.101(20)$, an almost homogeneous excitation also for this nucleus. The $^{74}$Ge isotope is thus one of the few nuclei that, so far, have been shown to present clear mixed symmetry components in their ground-state band not only related to the neutron degree of freedom. One

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possibility could be that $^{76}\text{Ge}$ has an isomeric state configuration of an alpha plus $^{70}\text{Zn}$ ($Z=30, \ N=40$) leading to a sub-shell closure.

The Pelletron-Enge-split-pole-spectrograph facility is extremely well suited for CNI studies, due to good energy resolution and detection at rather forward angles. The $^6\text{Li}$ beam, with isoscalar character, has been employed in the study of the Ge chain$^{1,6}$, where a survey of collective characteristics of the first $2^+$ state of the transitional $^{70,72,74,76}\text{Ge}$ nuclei was measured. The beam energy of 28 MeV was chosen, since the predicted DWBA-DOMP angular distribution is well structured and measurements near the interference minimum, at approximately $\theta_{\text{CM}} = 12.5^\circ$, were still accessible with the spectrograph. The detection was performed with position sensitive surface barrier detector on the focal plane of the spectrograph and the digital pulse processing was implemented in the acquisition system for the recent $^{76}\text{Ge}$ CNI study.

To continue the study of the evolution of the nuclear structure characteristics in this same interesting $A\sim70$ transitional region, the next focus of interest will be the study of the CNI of the first quadrupole excitation in the stable selenium ($Z=34$) isotopes ($A = 74, 76, 78, 80, 82$), from the subshell closure at $N=40$ to $N=48$.

Starting on $^{74}\text{Se}$ and $^{76}\text{Se}$ nuclei, it will be particularly interesting to investigate in this chain the existence of the equivalent abrupt transition at $N=42$ as was revealed in the Ge isotopes. In fact, this study can also produce additional information for the $^{76}\text{Ge}$-$^{76}\text{Se}$ system that will be investigated in the NUMEN project (NUclear Matrix Elements of Neutrinoless double beta decay), which aims at the determination of systematic information on the nuclear matrix elements of interest for $0\nu\beta\beta$ by heavy-ion double charge exchange reactions$^{7}$. 

During the first year, at a terminal potential of 7 MV, a total of ten days ($5+5$) is required for the CNI work, employing $^6\text{Li}$ projectiles. The requested machine time was estimated considering a beam intensity of 100 nA, targets of Se with 50 $\mu$g/cm$^2$ thickness, a solid angle of 1.237 msr, 3000 counts in one peak, a cross section of about 30 mb/sr and a downward variation of the cross section of about one order of magnitude into account. Detailed experimental inelastic angular distributions, with at least thirty points each, are required for the analysis. It is also to be remembered that, besides the inelastic angular distribution, an elastic one is usually taken, under the same conditions, to provide a good absolute scale reference for the cross sections.
References

## Previous Information on Project

<table>
<thead>
<tr>
<th>Proposal approved</th>
<th>N E97</th>
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<tbody>
<tr>
<td>Period of beam time (date)</td>
<td>April 2014 – 6 days</td>
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### Results or problems:

The last proposal approved considered the CNI measurement for $^{76}$Ge and a preliminary survey on $^{64,66,68}$Zn. The CNI work on $^{76}$Ge was completed resulting in a Master program concluded last year and the implementation of the new acquisition system with the digital pulse processing. Due to a long strike in the university and problems with the ion source on 2014 and problems with the vacuum system of the spectrograph on 2015, the preliminary survey on $^{64,66,68}$Zn was not performed. A new turbo pump was installed on the system. There remains a vacuum leak in a dynamic bellows. Repair of this vacuum leak is in progress.
Technical information

<table>
<thead>
<tr>
<th>Ion source</th>
<th>Accelerator</th>
<th>Experimental Area</th>
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<tbody>
<tr>
<td>Beam</td>
<td>Cathode</td>
<td>Bunched beam?</td>
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<tr>
<td>$^6$Li</td>
<td>100 nA</td>
<td>7.0 MV</td>
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Other relevant/needed information: