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 chains[(1-6)]. 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,$(\delta_L^N)^2$, 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 δ_L^C and mass δ_L^N 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}Ge has an isomeric state configuration of an alpha plus ^{70}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}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 $^{70,72,74,76}Ge$ 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 $\theta_{CM} = 12.5°$, 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}Ge CNI study.

To continue the study of the evolution of the nuclear structure characteristics in this same interesting A~70 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}Se and ^{76}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}Ge-^{76}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}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

[1] M. D. L. Barbosa, T. Borello Lewin, L. B. Horodynski-Matsushigue, J. L. M. Duarte, C. L. Rodrigues, M. R. D. Rodrigues, G. M. Ukita, "Coulomb-nuclear interference with Li: isospin character of the 2_1^+ excitation in $^{70,72,74}Ge$", *Phys. Rev. C* **71**, 024303 :1-13 (2005).

[2] G. M. Ukita, T. Borello-Lewin, L. B. Horodynski-Matsushigue, J. L. M. Duarte, and L. C. Gomes, "Coulomb-nuclear interference with deuterons: Isospin character of the 2_1^+ and 3_1^- excitations in $^{94,98}Mo$", *Phys. Rev. C* **64**, 014316:1-10 (2001).

[3] J. L. M. Duarte, G. M. Ukita, T. Borello-Lewin, L. B. Horodynski-Matsushigue, and L. C. Gomes, "Inelastic deuteron scattering in the Coulomb-nuclear interference region: Procedures for estimating the statistical uncertainty of the extracted B(E2) and B(IS2) values", *Phys. Rev. C* **56**, 1855-1865 (1997).

[4] M. R. D. Rodrigues, C. L. Rodrigues, T. Borello-Lewin, L. B. Horodynski-Matsushigue, J. L. M. Duarte and G. M. Ukita, "Coulomb Nuclear Interference with deuterons in even Palladium Isotopes", *Brazilian Journal of Physics* **34 n3A**, 777-780 (2004).

[5] C. L. Rodrigues, M. R. D. Rodrigues, T. Borello-Lewin, L. B. Horodynski-Matsushigue, J. L. M. Duarte, G. M. Ukita and G. N. Hanninger, "Coulomb-Nuclear Interference (CNI) Results of the Collective Quadrupolar Excitations in Odd and Even Ru isotopes", *Brazilian Journal of Physics* **34 n3A**, 760-762 (2004).

[6] T. Borello-Lewin, M. R. D. Rodrigues, X. X. Zhang, C, L, Rodrigues, G. M. Ukita, J. L. M. Duarte and L. B. Horodynski-Matsushigue, "Coulomb-nuclear interference in the inelastic scattering of 6Li to the first quadrupole state in the Ge isotopic chain",CERN-Proceedings-2015-001,14th International Conference on Nuclear Reaction Mechanisms, Villa Monastero, Varenna, Italy. Editors: Ceruti, F; Chadwick, M; Ferrari, A; Kawano,T; Schoofs, P. Geneva CERN,2015 pg 137-140.

[7] F.Cappuzzello, C.Agodi, M.Bondi, D.Carbone, M.Cavallaro, A.Foti, "The role of nuclear reactions in the problem of 0νββ decay and the NUMEN project at INFN-LNS", XXXVII Brazilian Meeting on Nuclear Physics, Maresias, Sao Paulo, Brazil, 8-12 Sept. 2014, J.Phys.:Conf. Ser. **630**, 012018 (2015).

Previous Information on Project

Proposal approved	N **E97**
Period of beam time (date)	April 2014 – 6 days

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.

LABORATÓRIO ABERTO DE FÍSICA NUCLEAR

PAC 2016

Proposal	N° **E97**
Title: Assessing collective properties in transitional nuclei	
Responsable: Márcia Regina Dias Rodrigues	e-mail: marciadr@if.usp.br
Participants Márcia Regina Dias Rodrigues, Thereza Borello-Lewin, Hideaki Miyake, Lighia Brigitta Horodynski-Matsushigue, José Luciano Miranda Duarte, Gilberto Mitsuo Ukita, Cleber Lima Rodrigues, Francesco Cappuzzello, Clementina Agodi, Antonino Foti, Manuela Cavallaro, Diana Carbone.	
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Number of days for experiment:	5 + 5
Period planned for the experiment (are the setup ready for beam time?): August-September 2016. The targets still need to be produced.	

Technical information

Ion source			Accelerator			Experimental Area	
Beam	Cathode	$I_{mínima}$	V_{min}	V_{max}	Bunched beam?	Beam line	Target
^{6}Li		100 nA	7,0 MV	8,0 MV	No	15° A	$^{74,76}Se$

Other relevant/needed information: