P-503 Shape coexistence and N=50 gap: coulex reactions on ground and isomeric states in N=49 ^{79}Zn, ^{81}Ge isotones *(Requested shifts: 21)*

This proposal addresses the role of collectivity in the structure of nuclei close to the doubly magic ^{78}Ni. It was shown in the proposal that even-even nuclei appear to have a low-lying intruder 0^+ state that represents collective effects including cross-shell excitations. A relatively low-lying $1/2^+$ state in ^{79}Zn that had tentatively been identified in a transfer experiment at ISOLDE was the subject of special interest. This state was discussed in quite a speculative way, and it was not entirely clear whether this state should correctly be associated with a particle coupled to the deformed or the spherical shape in the core ^{78}Zn. This case needs to be made clearer, regarding the impact that would be achieved by a measurement of any collective transition strengths observed in ^{79}Zn, with regard to the theoretical interpretation of the structure. The committee was unable to come to any definite conclusions regarding this impact, and hence was unable to approve the proposal or to consider it in detail. As a consequence of the uncertainty in the physics motivation, the requested development of the ^{81}Ge was also not approved. A letter of clarification will be required before this proposal can be more clearly evaluated.

CLARIFICATION LETTER for P-503

A. Gottardo[1,2], M. Zielinska[3], D. Verney[1], T. Cocolios[4], I. Matea[1], F. Ibrahim[1], F. Flavigny[1], G. de Angelis[5], D. Bazzacco[6], G. Benzoni[7], M. Babo[4], A. Boso[6], A. Bracco[7], F. Camera[7], E. Clement[8], F. Crespi[7], , C. Delafosse[1], M.C. Delattre[1], I. Deloncle[9], D. Doherty[10], P. Van Duppen[4], W. Korten[3], Th. Kroll[11], M. Komorowska[3,13], D. T. Yordanov[1], S. Franchoo[1], L. Gaffney[12], C. Gaulard[9], G. Georgiev[9], A. Giaz[7], A. Goasduff[5], F. Gramegna[5], K. Hadynska-Klek[5], C. Henrich[11], M. Huyse[4], J. Jaworski[5], P.R. John[11], A. Illana Sison[4], S. Lenzi[6], S. Leoni[7], J. Ljungvall[9], S. Lunardi[6], T. Marchi[4], M. Matejska-Minda[13], B. Melon[14], D.Mengoni[6], A. Nannini[14], P. Napiorkowski[13], D. Napoli[5], L. Olivier[1], R. Orlandi[15], Zs. Podolyak[10], E. Rapisarda[16], M. Rocchini[14], B. Roussière[1], F. Recchia[6], P. Reiter[17], S. Roccia[9], G. Simpson[2], J. Srebrny[13], I. Stefan[1], D. Testov[5], J.J. Valiente-Dobón[5], N. Warr[17], O. Wieland[7], K. Wrzosek-Lipska[13], S. Ceruti[4], S. Peru-Desenfants[18], M. L. Cortes[19], D. Cox[20], J. Pakarinen[20], N. Patronis[21], G. Duchene[22], F. Didierjean[22]

[1]*Institut de Physique Nucléaire d'Orsay, F-91406 Orsay, France*
[2] *LPSC, Université Joseph Fourier Grenoble 1, CNRS/IN2P3, Institut National Polytechnique de Grenoble, F-38026 Grenoble Cedex, France*
[3] *Irfu, CEA, Université Paris-Saclay, F-91191 Gif-sur-Yvette, France*
[4]*Instituut voor Kern-en Stralingsfysica, KU Leuven, University of Leuven, B-3001 Leuven, Belgium*
[5]*Laboratori Nazionali di Legnaro, I-35020 Legnaro, Italy*
[6]*Istituto Nazionale di Fisica Nucleare, Sezione di Padova, I-35100 Padova, Italy*
[7]*Dipartimento di Fisica, Università di Milano e Istituto Nazionale di Fisica Nucleare, Sezione di Milano, I20100 Milano, Italy*
[8] *GANIL, CEA/DRF-CNRS/IN2P3, F-14076 Caen Cedex 05, France*
[9]*CSNSM, UMR 8609, IN2P3-CNRS, Université Paris-Sud 11, F-91405 Orsay Cedex, France*
[10] *University of Surrey, Guildford, UK*
[11] *Institut für Kernphysik, TU Darmstadt, Schlossgartenstrasse 9 64289 Darmstadt, Germany*
[12] *CERN, Geneva, Switzerland*
[13] *Heavy Ion Laboratory, University of Warsaw, 02-093 Warsaw, Poland*
[14] *Istituto Nazionale di Fisica Nucleare, Sezione di Firenze, Firenze, Italy*
[15]*Advanced Science Research Center, Japan Atomic Energy Agency Tokai, Ibaraki, 319-1111, Japan*

^{16} *PSI Viligen, Switzerland*
^{17} *Institut für Kernphysik, Universität zu Köln, D-50937 Köln, Germany*
^{18}*CEA/DAM-Ile de France, Service de Physique Nucléaire, Bruyères-le-Châtel, F-91297 Arpajon Cedex, France*
^{19} *RIKEN Nishina Center, 2-1 Hirosawa, Wako, Saitama 351-0198, Japan*
^{20} *Department of Physics, University of Jyväskylä, P.O. Box 35, FIN-40014, Finland*
^{21} *Department of Physics, University of Ioannina, 45110 Ioannina, Greece*
22 Université de Strasbourg, IPHC, F-67037 Strasbourg, France and CNRS, F-67037 Strasbourg, France

Spokesperson(s): A. Gottardo (gottardo@ipno.in2p3.fr), M. Zielinska (magda@slcj.uw.edu.pl)
Local contact: L. Gaffney, liam.gaffney@cern.ch

Abstract

Recent measurements have unambiguously pointed out the occurrence of shape coexistence close to ^{78}Ni. The nature of the 1/2$^+$ isomer in N=49 ^{79}Zn has been established as that of an intruder s$_{1/2}$ state by g-factor measurements. Its large isomeric ratio points either to a large quadrupole deformation or to an increased orbital radius. We propose to study the properties of the 1/2$^+$ intruder states in ^{79}Zn, ^{81}Ge by Coulomb excitation on reaccelerated, laser-ionized (isomeric and ground state) beams. We will take advantage of the fact that a 10% fraction of the ^{79}Zn and ^{81}Ge beams is produced on the 1/2$^+$ isomeric state.

Requested shifts: 21 shifts
Beamline: MINIBALL + CD-only

Physics Motivation - clarification

Shape coexistence in the ^{78}Ni region has been reported in Refs. [Gottardo, Yang] in ^{80}Ge and ^{79}Zn. The shape-coexisting 1/2$^+$ state in ^{79}Zn has also the peculiarity of being a long-lived isomer (seconds). The wave function of this isomeric level has been investigated through g-factor measurement with LASER spectroscopy. It is an N=50 intruder level with a $\nu g_{9/2}^{-2} \nu s_{1/2}^{1}$ configuration. Contamination of the wave function from the other known intruder $\nu g_{9/2}^{-2} \nu d_{5/2}^{1}$ state is possible, though limited [Yang]. The same state was previously observed in a ^{78}Zn(d,p)^{79}Zn transfer measurement at ISOLDE [Orlandi], and indeed the transferred angular momentum was compatible with an s wave. The measurement in Ref. [Yang] not only determines the intruder $\nu g_{9/2}^{-2} \nu s_{1/2}^{1}$ nature of the state, but also shows a large isomer shift of the 1/2$^+$ isomer with respect to the 9/2$^+$ ground state. In their paper, Yang et al. suggest this is due to a large quadrupole deformation with β=0.22, against the β≈0.14 value of the ground state [Yang]. This result was obtained by assuming an axial deformation and that the mean radius of the wave function of this intruder state follows the standard 1.2·A$^{1/3}$ fm rule (5.1 fm for ^{79}Zn). However, since the g factor clearly points out a major s$_{1/2}$ component in the wave function, the <r^2> of the 1/2+ isomer may actually be 10-15% larger [Bonnard2], justifying the measured isomeric shift even with an almost spherical shape.

In [Bonnard1, Bonnard2] it is shown how the s-wave function radius may be even larger than what was previously thought, having implication in shell formation. Indeed, the rapid decrease of the s$_{1/2}$ energy in N=51 isotones leading to a possible 1/2$^+$ ground state in ^{79}Ni, has been shown to be due to the coupling to the continuum of the s$_{1/2}$ shell [Hagen, Nowacki].

The understanding of how the $s_{1/2}$ determine shape coexistence can thus help to infer important information on the neutron shell structure at N=50. On the other hand, ^{79}Zn may represent a very particular case of coexistence between the slightly deformed ground state shape and a similarly spherical intruder shape but with a large radius.

In order to support our proposal we performed new complete core-coupling calculations following the prescriptions of Ref. [Heyde]. This code takes as input the configurations of the N=48 and N=50 cores, deduced from the spectroscopy in the region. It then calculates the energies of the intruder and normal configurations and their coupling to the N=48 and N=50 cores, respectively, in N=49 isotones. Normal configurations in the N=49 isotones come as a neutron hole coupling to the N=50 core (^{80}Zn), while intruder configurations as 1p-2h states coupled to the N=48 core (^{78}Zn). The nuclear force employed in the calculation is a "pairing+quadrupole" model. These calculations are thus particularly adapted to describe the coexistence of configurations from different cores in this region.

Our calculations can reproduce the low-lying spectroscopy of N=49 isotones from ^{87}Sr down to ^{79}Zn [Matea]. In particular, they reproduce the spectroscopic factors of the intruder $1/2^+$ states along the isotonic chain, showing the gradual purification of its wave function. In ^{89}Sr the $1/2^+$ configuration is mainly $\nu g_{9/2}^{-2} \nu d_{5/2}^{1}$ coupled to the 2^+ core N=48, while in ^{79}Zn the $s_{1/2}$ intruder $\nu g_{9/2}^{-2} \nu s_{1/2}^{1}$ configuration accounts for around 60% of the wave function (which allows us to reproduce the measured g-factor for the ^{79}Zn isomer with a 10% precision). This is the result of the lowering in energy of the $s_{1/2}$ shell beyond N=50 when going towards ^{78}Ni, likely due to its coupling to the continuum and thus its increasing radius [Hagen, Bonnard].

Figure 1 shows what should be the result of a coulomb excitation on the intruder isomer in ^{79}Zn, using known and calculated E2 excited levels over the ground state and the $1/2^+$ isomer. See also Fig. 2.
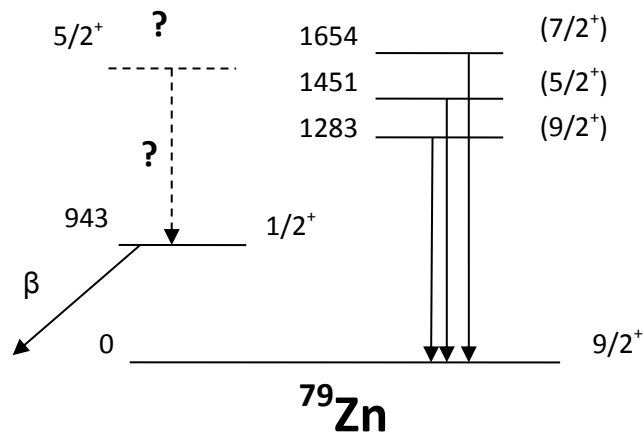

Fig. 1: Partial level scheme of ^{79}Zn from Ref. [Delattre]. We also

indicated in dashed line state we expect to see from the Coulomb excitation

of the $1/2^+$ isomer.

The proposed Coulomb excitation measurement will help to understand the nature of the shape coexistence of the intruder $1/2^+$ isomer: a (almost) spherical larger $s_{1/2}$ intruder state as suggested by recent calculations on s shell in this region, or a more deformed configuration (likely involving at least some d5/2 components) as suggested in Ref. [Yang]. The measured energies and transitional quadrupole moments will help, also in comparison with theoretical calculations, to verify if the large measured isomer shift is due to a large radius or to a large deformation. A schematic comparison is shown in Fig. 1. The band built on a (more deformed) $1/2^+$ isomer with a strong $d_{5/2}$ component is different (larger level density) from the one (suggested by g-factor measurements) with a predominant $s_{1/2}$ component. The levels populated by the coulex reaction will thus already be indicative of the wave function we want to probe. Another important observable we will get from coulomb excitation are B(E2) values from $3/2^+$ and $5/2^+$ states coming from the coupling of the intruder states with the 2^+ of the ^{78}Zn core. The B(E2) value of the 2^+ of the ^{78}Zn core is 8 Wu$\downarrow$. In the case of an almost spherical, s-wave state, we will observe slightly larger (5-10%) reduced E2 matrix elements in the band built on the intruder-state, due to the isomer shift of the $1/2^+$ state (since B(E2) $\propto \langle r^2 \rangle^2$). On the contrary, if the deformation is the large one claimed in Ref. [Yang], β=0.22, B(E2) values will be much larger, several times the 8 Wu$\downarrow$ value of the ^{78}Zn core. The combination of the energy and B(E2) measurements with the coulex reaction will thus provide an unambiguous characterization of the shape coexistence in this region, also helping to understand the role played by the $s_{1/2}$ in the N=50 gap stability and size going towards ^{78}Ni.
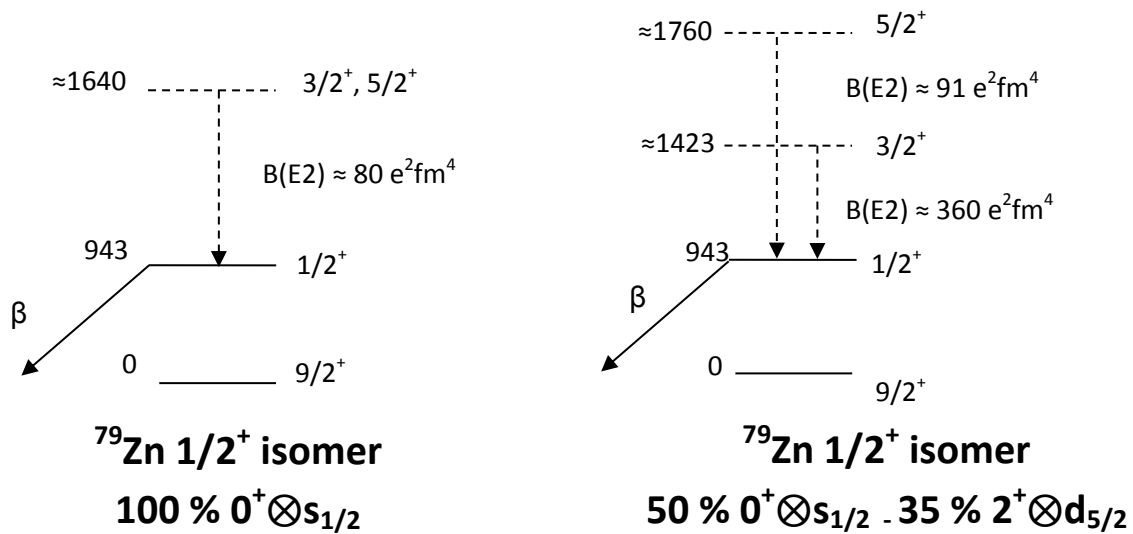

Fig. 2: Unified core-coupled model calculations for the bands built on the $1/2^+$ isomer in ^{79}Zn. The cases of dominant $s_{1/2}$ (spherical shape with a large radius) or more fragmented wave function (larger deformation) are presented schematically for a comparison.

Proposed Measurement(s)

Coulex on ^{79}Zn (proposal), ^{81}Ge (LOI)

The ISOL beam will be produced by laser ionization for both ^{81}Ge and ^{79}Zn. Post-acceleration up to the energy of 3.4 MeV/u is envisaged. This value will guarantee a larger range of safe scattering angles, corresponding to the detection of scattered projectiles and target recoils between 16 and 60 degrees in the LAB frame and will maximise the final counting rate, according to GOSIA calculations. Gamma rays will be detected by the MINIBALL array, while recoils with the Si CD detector. The target will be ^{196}Pt, 4 mg/cm^2. The frequency width of the RILIS source will guarantee ionization of both isomers in ^{79}Zn: the beam intensity on the Miniball target will be around $5*10^3$ pps. The states we expect to populate will come from the coupling to the 2$^+$ state of ^{78}Zn with the neutron in the s$_{1/2}$ shell. A large deformation was deduced from the isomer shift of the 1/2$^+$ isomer, but we conservatively take a 10 W.u. value for the B(E2↑) from the 1/2$^+$ to the 3/2$^+$, 5/2$^+$ states. A 700 keV excitation energy was also hypothesized, following the energy of the 2$^+$ state of ^{78}Zn. The result, taking into account Miniball efficiency and the available angular range from the Si CD detector, is of 250 counts per shift if the entire beam were in the isomeric state. From Ref. [Yang, Bissell2] we could infer a 10% 1/2$^+$-isomer fraction of the laser-ionized ^{79}Zn beam. The result is that we require 7 days of beam time to have about 150-200 counts in the first-excited state above the 1/2$^+$ isomer. This figure also takes into account that, due to contamination from surface-ionized ^{79}Ga, we will need to switch off the laser for certain periods (30 % time) for background (Ga) subtraction. The background from Rb contamination can also be reduced by the use of a quartz line.

The production of a ^{81}Ge beam is more complicated and demands Ge beam development, as detailed in the proposal [Bissel]. Rates will be similar or higher than in the case of ^{79}Zn. We leave this second measurement as a LOI and we join the proposal [Bissel] in asking for further investigation into the production of Ge beams. At the moment, we are aware an ionisation scheme has been developed by RILIS with a 2% offline efficiency, but only offline [Day Goodacre]. It would be important to implement the suggested improvements and measure the yields towards the neutron-rich isotopes. GeS beams have been produced on the neutron-deficient side [Delonca] but have yet to be studied on the neutron-rich side. It would be interesting to compare them to the RILIS yields and to ensure that molecules are broken down efficiently in EBIS to avoid contamination or decay losses in the process.

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