E1-Resonances in Neutron-Rich Nuclei

N. Dinh Dang[1,2], V. Kim Au[1*], Toshio Suzuki[3], A. Arima[1,4]
[1] *RI-beam factory project office, RIKEN, Hirosawa 2-1, Wako, Saitama 351-0198, Japan*
[2] *Institute for Nuclear Science and Technique, Hanoi - Vietnam*
[3] *Department of Physics, College of Humanities and Sciences, Nihon University, Sakurajosui 3-25-40, Setagaya-ku, Tokyo 156-8550*
[4] *House of Councilors, 2-1-1 Nagata-cho, Chiyoda-ku, Tokyo 100-8962*

The photoabsorption and electromagnetic (EM) E1 differential cross sections of for oxygen and calcium isotopes are calculated within the phonon damping model (PDM) [1] including the superfluid pairing correlations. Clear pygmy dipole resonances (PDR) are seen in the EM cross sections in ^{18,20,22,24}O and some very neutron-rich calciums (^{50,52}Ca). The present work demonstrates that the EM differential cross section is a better probe for the PDR as compared to the photoabsorption cross section because, in the former, the low-energy tail of giant dipole resonance (GDR) is enhanced. It also shows that, using low-energy beams at around 50 – 60 MeV/n, one can separate PDR peaks out of admixture with the GDR in the EM differential cross sections. An example for the energy-weighted sums (EWS) of pygmy dipole resonance's (PDR) strength is shown in Fig. 1 for oxygen isotopes, where the results of calculations within PDM are compared with the preliminary experimental systematic [2] and the prediction by the cluster model sum rule (CRS).

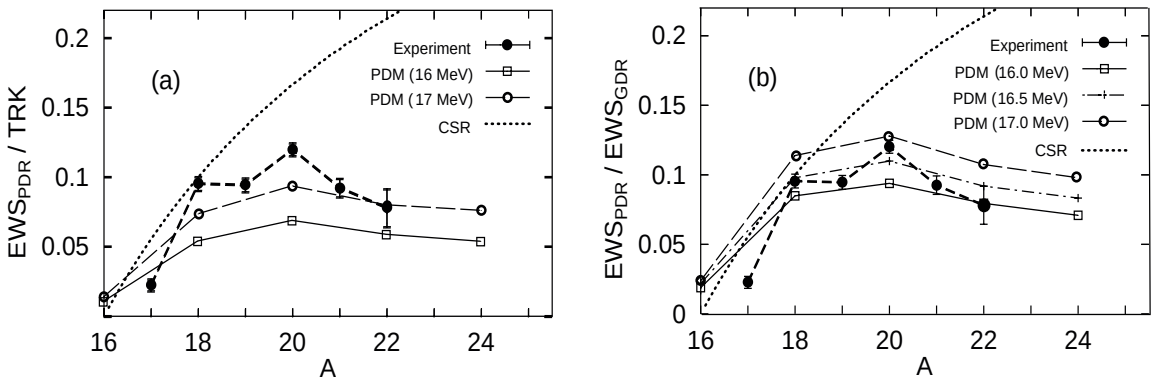

FIG. 1. EWS of PDR strength up to excitation energy $E_{\max}$ for oxygens. Results obtained within PDM with $E_{\max}$ = 16, 16.5, and 17 MeV are displayed as open boxes connected with solid line, crosses connected with dash-dotted line, and open circles connected with thin dashed line, respectively. The PDM results are shown in units of Thomas-Reich-Kuhn sum rule (TRK) in (a), and in units of the total GDR strength integrated up to 30 MeV in (b). Experimental data (in units of TRK), obtained with $E_{\max}$ = 15 MeV, are shown by full circles connected with thick dashed line. The dotted line is the prediction by CSR (in units of TRK).

[1] N. Dinh Dang and A. Arima, Phys. Rev. Lett. **80** (1998) 4145, Nucl. Phys. **A 636** (1998) 427.
[2] T. Aumann et al., GSI scientific report 1999 (GSI 2000-1, March 2000) 27.

*address after January 1, 2001: Cyclotron Institute, Texas A&M University

High-Spin Spectroscopy Near ^{56}Ni*

W. Reviol[1], D.G. Sarantites[1], R.J. Charity[1], V. Tomov[1], D. Rudolph[2], R.M. Clark[3], P. Fallon[3], A.O. Macchiavelli[3], M. Cromaz[3], M.P. Carpenter[4], D. Seweryniak[4], and J. Dobaczewski[5]

[1]*Department of Chemistry, Washington University, St. Louis, MO 63132, USA*
[2] *Department of Physics, Lund University, S-22100 Lund, Sweden*
[3] *Nuclear Science Division, Lawrence Berkeley National Lab., Berkeley, CA 94720, USA*
[4] *Physics Division, Argonne National Laboratory, Argonne, IL 60439, USA*
[5] *Institute of Theoretical Physics, Warsaw University, PL-00681, Warsaw, Poland*

High-spin studies in the nuclear region around ^{56}Ni haven been topical for several years now. Benefiting from powerful detection devices, impressive results have been obtained such as the observation of highly and superdeformed rotational bands in second (or third) minima of Ni, Cu and Zn nuclei [1-3]. In a recent 2-day experiment using Gammasphere, the Microball, and the new Neutron Shell (30 liquid scintillator counters) [4], we have studied the evaporation residues in the $^{32}S + ^{28}Si \rightarrow ^{60}Zn^*$ reaction at 130 MeV. Some highlights of our findings are summarized below.

In ^{57}Ni (2pn channel) and ^{57}Co (3p), highly deformed rotational bands are newly observed [5]. The bands in ^{57}Co, which are signature partner bands, are particularly interesting. Their observation extends the mass 60 region of large deformation below Z = 28 and provides an important test for the picture of particle-hole excitations across this shell gap. Their magnetic properties (B(M1) values for the interband transitions) are discussed in the context of possible configuration assignments. The features of the new bands are theoretically described by Skyrme Hartree-Fock calculations.

The level schemes for the N = Z nucleus ^{54}Co (αpn) and its neighboring isotope ^{56}Co (3pn) have also been extended significantly towards higher spin. The newly observed states are exclusively located in the first, spherical minimum. Calculations to obtain a shell model description for these states are under way.

A follow-up experiment will enable us to study the products from the $^{60}Zn^*$ compound system with higher statistical accuracy. First results from this experiment should be available by the time of this conference.

[1] C.E. Svensson et al., Phys. Rev. Lett. **79**, 2104 (1997).
[2] D. Rudolph et al., Phys. Rev. Lett. **80**, 2104 (1998).
[3] D. Rudolph et al., Phys. Rev. Lett. **82**, 2104 (1998).
[4] http://wunmr.wustl.edu/~dgs/NeutronShell.
[5] W. Reviol et al., Nucl. Phys. A, in press.

---

*This work was supported by the U.S. Department of Energy under grant no. DE-FG02-88ER-40406.

Gamma ray spectroscopy using radioactive beams at Notre Dame

S.M. Vincent[1], A.A. Aprahamian[2], F.D. Becchetti[3], J.A. Brown[4], T.W. O'Donnell[3], V. Guimaraes[2], R.C. de Haan[2], J.J. Kolata[2], M. Lee[3], D. Peterson[2], D. Robertson[3], P. Santi[2], R. White Stevens[2], A. Teymurazyan[2], J. Zimmerman[3].

[1] *University of Surrey, Department of Physics, Guildford, Surrey, GU2 7XH, UK.*
[2] *Physics Department, University of Notre Dame, Notre Dame, In 46556, USA.*
[3] *University of Michigan, Department of Physics, Randall Lab, Ann Arbour, Mi 48109, USA*
[4] *Millikin University, Decatur, Mi USA*

Gamma ray spectroscopy has been performed from fusion evaporation reactions produced by a radioactive beam of ^{6}He on a Copper target. Only one other radioactive beam spectroscopy experiment has been published to date [1] making this a state of the art apparatus. There are consequently many experimental difficulties to overcome in the design of any such facility, and these will be discussed.

The radioactive beam facility at the University of Notre Dame nuclear structure laboratory [2-4] was used to produce a beam of ^{6}He at an energy of 28 MeV and with an intensity of 5×10^5 pps. This radioactive beam was produced by 1 proton transfer from a ^{7}Li primary beam on a gas cooled ^{9}Be target. The secondary beam was separated from non-reacting primary beam using the 'Twinsol' dual superconducting magnet apparatus, and was then incident on a target of natural (63% ^{63}Cu) copper. Two large volume HPGe detectors were used to detect gamma rays from excited states in the secondary fusion evaporation reaction fragments, and coincidence spectra will be presented.

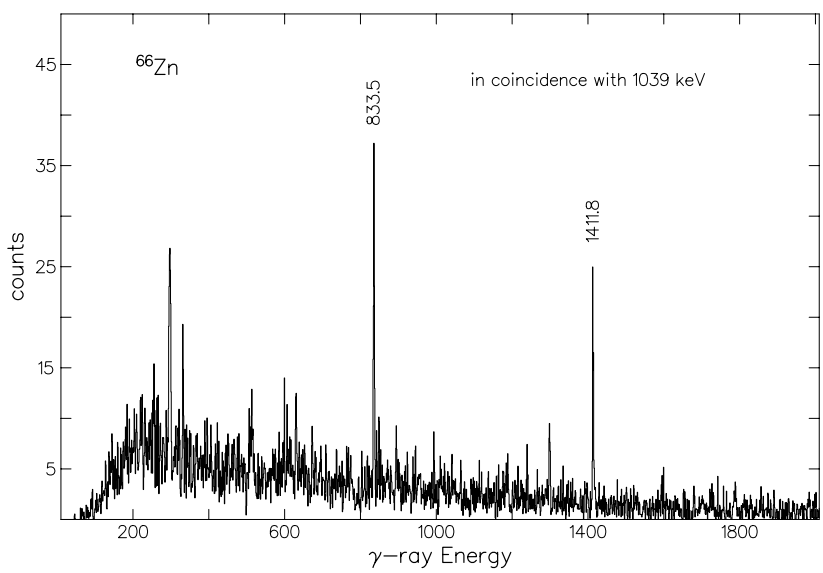

FIG. 1. Coincidence spectrum from reaction of radioactive ^{6}He on ^{63}Cu, gated by $2^+ \rightarrow 0^+$ in ^{66}Zn.

[1] W. Catford *et al.*, Nucl. Instr. Meth **A371** (1996) 449

[2] J.J. Kolata, A. Morsad, X.J. Kong, R.E. Warner, F.D. Becchetti, W.Z. Liu, D.A. Roberts, J.W. Jänecke, *Nucl. Instr. Meth. Phys. Rev. Sect.* **B40/41**, 503 (1989).

[3] F.D. Becchetti and J.J. Kolata, *Application of Accelerators in Research and Industry*, edited by J.L. Duggan and I.L. Morgan, AIP Conf. Proc. No. 392 (AIP Press, New York, 1997), 369-375.

New Transitions Found in ^{27}Na Using a ^{14}C Beam on a ^{14}C Target *

M.W. Cooper[1], D.B. Campbell[1], C. Chandler[1], K.W. Kemper[1], A. Pipidis[1], I. Ragnarsson[2], M.A. Riley[1], M. Wiedeking[1], and S.L. Tabor[1]

[1] *Department of Physics, Florida State University, Tallahassee, Florida 32306 USA, USA*

[2] *Department of Mathematical Physics, Lund Institute of Technology, S-21100 Lund, Sweden*

Until recently it has been difficult to study nuclei that do not lie near the line of stability. Due to the recent developments in radioactive beams, it has become increasingly important to study the structure of nuclei in *s-d* shell region. At present, very little is known about the structure of the neutron rich *s-d* shell nuclei. The study of nuclei in this region would prove invaluable in comparing microscopic and macroscopic nuclear models.

Previous studies of the *s-d* shell nuclei have resulted in observation of several transitions in ^{25}Na [1], but very little in the other Na nuclei further from the line of stability. However, advances in radioactive beams and detectors make it important to re-examine the nuclear structure of these Na nuclei and other nearby nuclei, which may also help in the study of more neutron rich nuclei.

Several new transitions in ^{27}Na were found using the ^{14}C(^{14}C,p) reaction at E_{lab} = 22 MeV. The ^{14}C target was 0.28 mg/cm^2 thick and the beam was stopped in a 33.8 mg/cm^2 Au foil. γ-γ, particle-γ, and particle-γ-γ coincidences were measured using 2 four-crystal Eurogam type "clover" detectors, 7 Compton suppressed HPGe detectors, and a particle E-ΔE telescope at 0°. The 67, 1660, 1756, 1823, and 2219 keV transitions, which are in coincidence with the high energy protons, have been identified as transitions in ^{27}Na, as shown in Fig. 1.

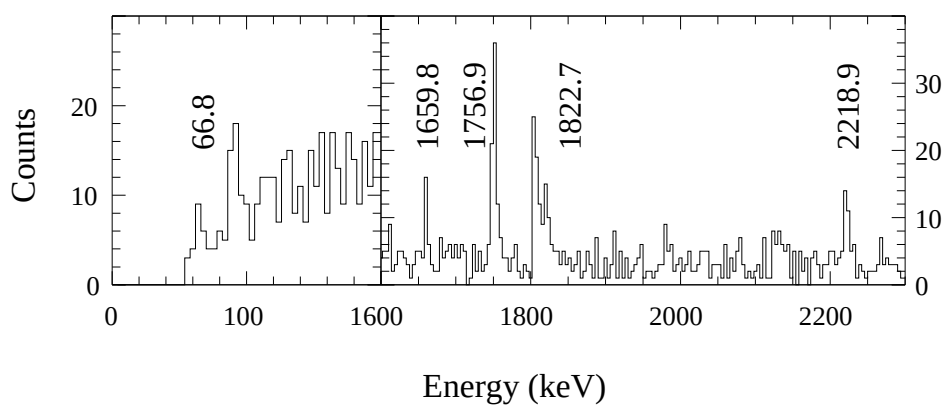

FIG. 1. γ spectrum in coincidence with high energy protons (x-axis in keV).

[1] P.M. Endt and C. Van der Leun, Nucl. Phys. **A521**, 1 (1990).
[2] L.K. Fifield *et al.*, Nucl. Phys. **A437**, 141 (1985).

*This work was supported in part by the National Science Foundation.

Physics with Heavy Neutron−Rich RIBs at the HRIBF*

D.C. Radford[1], C. Baktash[1], A. Galindo−Uribarri[1], C.J. Gross[1,2], T.A. Lewis[1], P.E. Mueller[1], D. Shapira[1], D.W. Stracener[1], C.−H. Yu[1], D.J. Hartley[3] and L.L. Riedinger[3]

[1] *Physics Division, Oak Ridge National Laboratory, Oak Ridge, TN 37831, USA*
[2] *Oak Ridge Institute for Science and Education, Oak Ridge, TN 37831, USA*
[3] *Department of Physics and Astronomy, University of Tennessee, Knoxville, TN 37996, USA*

We have performed an experiment using neutron−rich radioactive ion beams from the HRIBF facility, together with the CLARION Ge detector array and the HyBall CsI charged−particle detector array. A foil−plus−multichannel−plate detector was also placed at the achromatic focus of the Recoil Mass Spectrometer [1] and used to detect recoiling reaction products.

A beam of ^{118}Ag ($T_{1/2}$ ~2 s for ^{118m}Ag, $T_{1/2}$ ~4 s for ^{118g}Ag) was produced by proton−induced fission of ^{238}U, and accelerated to 455 and 500 MeV in the tandem accelerator. These energies required the use of the second stripping foil in the high−energy beam tube, but beam intensities on target of approximately10^6 ^{118}Ag ions per second were obtained. The data collected consisted of γ−HyBall coincidences, together with γ−γ−recoil coincidences where the recoil was detected in the multichannel−plate detector. The overall efficiency for detecting such products was about 40%.

Two different reactions were used. Firstly, a target of 0.6 mg/cm^2 ^{12}C was bombarded at 500 MeV. Fusion−evaporation reactions leading to the known nuclides ^{125,126}I [1] (5n and 4n evaporation) and ^{126}Te (p3n) were observed, together with α3n evaporation to previously unobserved states in ^{123}Sb. Also observed were inelastic scattering events, where a scattered ^{12}C from the target was detected with HyBall in coincidence with a γ ray detected in CLARION. Inelastic excitation of the first 2^+ state of ^{118}Sn, from a weak (approx. 5%) isobaric contamination of the beam can be clearly identified in the carbon−gated spectrum, suggesting an excellent means of performing Coulomb−excitation B(E2) measurements of RIBs in future experiments. In the γ−γ−recoil events, levels up to the known [2] $31/2^-$ state of ^{125}I were observed.

Secondly, a target of 1.25 mg/cm^2 ^{9}Be was bombarded at a beam energy of 455 MeV in an attempt to observe new levels in the 4n−evaporation product, ^{123}Sb. The γ−γ spectrum observed in coincidence with recoils was virtually identical to the α−gated γ−ray spectrum from the C target, confirming the assignment of the peaks to ^{123}Sb. With the Be target, a large number of α particles from incomplete fusion were also observed in the HyBall array.

Results from this test experiment, and plans for future measurements with Sn and Te neutron−rich radioactive beams, will be presented.

[1] C.J. Gross *et al.,* Nuclear Instrum. and Methods, **A450** (2000) 12.
[2] D.J. Hartley *et al.*, private communication.

---

*This work was supported by the U.S. Department of Energy under contracts DE−AC05−76OR00033 and DE−AC05−96OR22464.

Triaxiality in Neutron Deficient Odd-Ta Nuclei?

M.S. Fetea and R.F. Fetea
Physics Department, University of Richmond, VA 23173, USA

The high-spin $h_{11/2}$ and $i_{13/2}$ orbitals in odd-proton nuclei are convenient objects for studying the effects of nuclear shape changes. For such intruder orbitals there is less ambiguity about the nature of the wave functions than in the case of other orbitals.

Deviation from axial symmetry is generally expected for high-spin states. Although the signature splitting of the excitation energies offers a clue for possible γ - deformation, it appears even in the presence of only β - deformation. Therefore, in order to gain insight into the shape of the nucleus, the electromagnetic transition strengths must be investigated.

We report on odd- A neutron deficient Ta isotopes. Recently, data on ^{165}Ta [1], the most neutron deficient Ta isotope became available. Although data on some other Ta nuclei have already been analyzed by using the cranking shell model or projected shell model, no attempt has been made to obtain a systematic trend from the experimental data. For $^{165\text{-}179}$Ta isotopes, the shape favored by neutrons differs from the one preferred by the protons. One might therefore expect shape coexisting states and nuclear potentials that are very soft in the γ - degree of freedom. This was indeed obtained in the total routhian surface calculations [2].

The properties of the negative-parity $[514]9/2$ bands of $^{165\text{-}179}$Ta are used to study the relation between the signature splitting of the energies and the signature dependence of the $M1$ transition elements in connection with the deviation of nuclear shape from axial symmetry. The rapid increase of signature splitting with decreasing neutron number in the bands associated with the same quasiproton configuration strongly suggests that the observed trend is due to the properties of the even-even core and will reflect the nuclear shape. According to the cranking shell model calculations even a 50% change in the pairing gap barely affects the signature splitting. Also a variation of quadrupole deformation β_2 within the interval $0.16-0.29$ leads to small, almost constant signature splitting of the $\pi h_{11/2}$ orbitals. It seems that for the light odd-mass Ta isotopes only non-axially symmetric shapes can cause such an effect.

The analysis of the available experimental data on Ta isotopes indicates that lighter Ta nuclei exhibit an appreciable amount of deviation from axially symmetric shape (up to $\gamma = -18^o$ for ^{165}Ta).

[1] D. G. Roux et al., Phys. Rev. C **63**, 024303 (2001).
[2] W. Nazarewicz et al., Nucl. Phys. A **467**, 437 (1987).
[3] W. F. Mueller et al., Phys. Rev. C **50**, 1901 (1994).
[4] W. Nazarewicz et al., Nucl. Phys. A **512**, 61 (1990).