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Nuclear Structure from Radioactive Decay

Annual Progress Report

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1.0 Introductory Overview

The most exciting development this year was the discovery that an approximate SU(3) fermion structure, the so-called soft SU(3) model (J. Carvalho et al., Nucl. Phys. A452, 240 (1986)), can accurately describe heavy deformed nuclei. A paper has been submitted to Nuclear Physics A.

Our experimental program continues to focus on shape coexistence and electric monopole (EO) transitions in nuclei. We have found a band of states in ^{195}Pb which all de-excite by EO transitions and reveal, via the spin sequence of the band members, that the deformed structures in the neutron-deficient lead isotopes are triaxial. This is a straightforward and simple method (that is the use of EO transitions and odd-A band structure) to elucidate shapes of coexisting collective core structures.

The program to systematically study the structure of the very neutron-deficient nuclei in and near the region of deformation with $Z > 50$, $N < 82$ is ready for detailed experiments: A new high-temperature "thermal" ion source has been successfully constructed and tested. The refractory nature of the elements with $Z > 50$ has been a major block to radioactive decay studies in this region. This thermal ion source will permit detailed studies of low-spin states in nuclei far from stability in this region. Until now, essentially nothing is known about low-spin states in nuclei with $Z > 56$, $N < 78$.

Experimental research at UNISOR has been the principal focus of the program this year. All the students are involved in development of equipment, experimental runs, and/or data reduction connected with UNISOR. In particular a number of successful runs with the $^3\text{He}/^4\text{He}$ dilution refrigerator have been made.

A new review of shape coexistence (following on from K. Heyde et al., Phys. Repts. 102, 291 (1983)) is being written at the invitation of Physics Reports. This is in collaboration with Prof. K. Heyde, Institute for Nuclear

Physics, Gent, Belgium, and others. A NATO travel grant partially supports this work.

A number of theoretical and experimental collaborations continue with other groups both in the USA and overseas. The overseas work has not been conducted at DOE expense.

This year the contract has supported, besides the principal investigator (two months, full time), a research scientist (twelve months, one-twelfth time), and three graduate students (nine months, half time), all of whom are pursuing Ph.D. degrees. A fourth Ph.D. student has worked on topics in this program with full support from the Georgia Tech School of Physics.

2.0 Experimental Program in the $Z = 82$ Region

A major area of activity is the study of neutron-deficient nuclei around the $Z = 82$ shell closure, with special emphasis on the levels of the odd-mass Ir, Pt, Au, Hg, Tl, and Pb isotopes. A crucial ingredient of this work is the systematic investigation of low-energy structural features of sequences of isotopes (and isotones) over many adjacent mass numbers. This has a two-fold purpose. First, it enables us to build up a very complete picture of the nuclear structure that connects the regions of stable nuclei (where, e.g., transfer reactions and Coulomb excitation permit the measurement of detailed spectroscopic properties) with regions far from stability, where detailed spectroscopic information is very limited. Second, it provides a map of the excitation degrees of freedom as a function of the changing proton and neutron number over broad mass regions. The mass region under study possesses the richest variety of nuclear excitations observed anywhere on the mass surface. It includes the $Z = 82$ shell closure, and is bounded by the strongly deformed nuclei with $Z \leq 76$ and the $N = 126$ shell closure. Between $Z = 76$ and $Z = 82$ there is a shape transition from strongly deformed prolate axial symmetry through oblate axial asymmetry to spherical symmetry. This transition has alternatively been described in terms of the interacting boson approximation (IBA) as a transition from the $SU(3)$ through the $O(6)$ limiting algebraic symmetries of the IBA Hamiltonian. Finally, and most dramatically of all, an island of ground-state deformation has been established adjacent to the $Z = 82$ closed shell for the very neutron-deficient isotopes of Hg, Au, and Pt. This deformation is now understood in terms of proton intruder orbitals which give rise to the large deformation ($\beta \sim 0.27$) through an increased proton valence space and the proton-neutron residual interaction. The experiments described have all (except part of one) been done at UNISOR.

2.1 Neutron-Deficient Iridium Isotopes

Two experiments have been conducted on the iridium isotopes this year. The $^{181}\text{Pt} \rightarrow ^{181}\text{Ir}$ decay was studied by γ - γ and e - γ coincidence spectroscopy. The $^{185}\text{Pt} \rightarrow ^{185}\text{Ir}$ decay scheme was studied by γ -ray spectroscopy of low-temperature oriented ^{185}Pt . The $A = 181$ data together with previously obtained γ - γ and e - γ coincidence data for $A = 183, 185$ are being analyzed. The $A = 185$ orientation study is in collaboration with Prof. K. Krane, Oregon State University. The iridium isotopes border the region of shape coexistence defined by $78 \leq Z \leq 83$. So far, shape coexistence has not been found in the iridium isotopes. It is being looked for in this work through the EO transition "fingerprint". Beam time is approved for a study of $^{179}\text{Pt} \rightarrow ^{179}\text{Ir}$ later this year. This work constitutes part of the Ph.D. thesis of Ms. K. Jentoft-Nilsen (Ga. Tech, School of Physics).

2.2 Neutron-Deficient Platinum Isotopes

Two experiments have been conducted on the platinum isotopes this year. The $^{181}\text{Au} \rightarrow ^{181}\text{Pt}$ decay was studied by γ - γ and e - γ coincidence spectroscopy. The $^{185}\text{Au} \rightarrow ^{185}\text{Pt}$ decay scheme was studied by γ -ray spectroscopy of low-temperature oriented ^{185}Au (this was in collaboration with K. Krane). The extensive γ - γ and e - γ coincidence data previously obtained for $A = 183, A = 184$ and $A = 185$ together with these new data are being analyzed. Some details of the large number of EO transitions seen in $^{183, 184, 185}\text{Pt}$ are being prepared for publication. These studies are aimed at elucidating the shape coexisting structures in the neutron-deficient Pt isotopes. Beam time is approved for a study of $^{179}\text{Au} \rightarrow ^{179}\text{Pt}$ later this year. This work is in collaboration with Prof. E. F. Zganjar, Louisiana State University and constitutes part of the Ph.D. thesis of Mr. J. Schwarzenberg (Ga. Tech, School of Chemistry).

2.3 Neutron-Deficient Gold Isotopes

One experiment has been conducted on the gold isotopes this year. The $^{187}\text{Hg} \rightarrow ^{187}\text{Au}$ decay scheme was studied by γ -ray spectroscopy of low-temperature oriented ^{187}Hg . The extensive γ - γ and e - γ coincidence data previously obtained for $A = 187$ and $A = 191$ together with these new data are being analyzed. A study of the $^{189m}\text{Hg} \rightarrow ^{189}\text{Au}$ and $^{189g}\text{Hg} \rightarrow ^{189}\text{Au}$ decay scheme is being prepared for publication. These studies have three goals: mapping the shape coexisting structures in the neutron-deficient Au isotopes; establishing detailed systematics for these isotopes; and testing particle-core coupling models for these nuclei. This work is in collaboration with E. F. Zganjar.

2.4 Neutron-Deficient Mercury Isotopes

One experiment has been conducted on the mercury isotopes this year. The $^{192m}\text{Tl} \rightarrow ^{192}\text{Hg}$ decay was studied by γ - γ and e - γ coincidence spectroscopy to search for superdeformed bands in ^{192}Hg . These data are being analyzed. A study of the $^{190}\text{Tl} \rightarrow ^{190}\text{Hg}$ decay scheme has been prepared for publication. This paper reports the discovery of shape coexistence in ^{190}Hg . A study of the $^{189m}\text{Tl} \rightarrow ^{189}\text{Hg}$ decay scheme is being prepared for publication. Coincidence data obtained for the $^{191m}\text{Tl} \rightarrow ^{191}\text{Hg}$ decay scheme in an earlier experiment are being analyzed. The goal of these studies is the characterization of shape coexistence and systematics in the Hg isotopes. The search for superdeformation in ^{192}Hg is aimed at connecting the superdeformed band, observed by in-beam γ -ray spectroscopy, with low-lying low-spin states. This work is in collaboration with E. F. Zganjar.

2.5 Neutron-Deficient Thallium Isotopes

A study of the $^{195m}\text{Pb} \rightarrow ^{195}\text{Tl}$ and $^{195g}\text{Pb} \rightarrow ^{195}\text{Tl}$ decay schemes has been prepared for publication. Details of the $^{193}\text{Pb} \rightarrow ^{193}\text{Tl}$ decay scheme are being prepared for publication. The thallium isotopes are being studied to find shape coexistence resulting from the odd-proton coupling to the neighboring Pb cores (which exhibit shape coexistence). Particle-core coupling is also being studied because the thallium isotopes are a rare example of ground-state oblate deformation. This work is in collaboration with Prof. C. R. Bingham, University of Tennessee and E. F. Zganjar.

2.6 Neutron-Deficient Lead Isotopes

A study of the $^{195}\text{Bi} \rightarrow ^{195}\text{Pb}$ decay scheme has been prepared for publication. Part of this study was done at the LISOL isotope separator in Louvain-la-Neuve, Belgium. The study also includes the first systematics of low-spin states in the neutron-deficient lead isotopes. Further, as noted in the Introduction, a coexisting band is established in ^{195}Pb with de-exciting EO transitions. This is the first such band identified in an odd-mass closed shell nucleus. This work is in collaboration with C. R. Bingham and Dr. Marc Huyse (LISOL).

3.0 Experimental Program in the $Z > 50$, $N < 82$ Region

A systematic study of low-spin states in nuclei in and bordering the deformed region with $Z > 50$, $N < 82$ has been initiated. This is a new region of deformation and almost nothing is known about low-spin states in this region. Extensive in-beam studies have begun recently in these nuclei, but such studies see mainly high-spin states. Radioactive decay is unique in its ability to strongly populate low-spin states. This has been a difficult region for decay scheme studies in the past because the elements involved are relatively refractory and, thus, not easily released from an ion source, hence precluding isotope separation. This is now changing with new ion-source techniques.

Two approaches have been taken with the UNISOR ion-source technology. The first approach uses small amounts of carbon tetrachloride injected into the UNISOR FEBIAD ion source. This enhances the volatility and subsequently the ionization of samarium and europium isotopes. The second approach uses a new ion source design provided by Dr. R. Kirchner of GSI, Darmstadt, West Germany. This can operate at temperatures up to 2500°C . Our prototype version has been successfully tested. The ion-source development is part of the Ph.D. thesis of Mr. J. Breitenbach (Ga. Tech, School of Physics).

3.1 Neutron-Deficient Promethium Isotopes

Preliminary γ - γ and e - γ coincidence data have been obtained for the $^{137}\text{Sm} \rightarrow ^{137}\text{Pm}$ decay scheme. A partial level scheme for ^{137}Pm has been constructed. More experiments are planned. A γ - γ and e - γ coincidence study of the $^{139\text{m,g}}\text{Sm} \rightarrow ^{139}\text{Pm}$ decay scheme is scheduled for later this contract year. This is part of the Ph.D. thesis of J. Breitenbach. These studies will allow the beginnings of a systematic map of trends in excited states of the odd-mass Pm isotopes. A clear systematic picture is essential for under-

standing excited states of nuclei far from stability. (This has been demonstrated clearly in our on-going study of the $Z \sim 82$ region.)

3.2 Neutron-Deficient Samarium Isotopes

Preliminary γ - γ and e - γ coincidence data have been obtained for the $^{137}\text{Eu} \rightarrow ^{137}\text{Sm}$ decay scheme. These data were taken using CCP_4 injection into a FEBIAD ion source. Production rates of $\geq 10^3$ atoms/sec were achieved for ^{137}Eu ($T_{1/2} = 6$ s). Further studies of the $^{137}\text{Eu} \rightarrow ^{137}\text{Sm}$ and the $^{139}\text{Eu} \rightarrow ^{139}\text{Sm}$ decay schemes are scheduled for later this year.

4.0 Nuclear Systematics and Models

A study of the mixing of spherical and deformed states in the even-mass Pb isotopes has been published. This work was done in collaboration with M. Huyse and P. van Duppen, Katholieke Universiteit, Leuven, Belgium.

A simple model of prolate and oblate band mixing, developed to describe the structure of ^{75}Kr , has been published. This work was in collaboration with Prof. Jürgen Eberth, Universität zu Köln, Germany.

A study of the SU(3) structure of rotational states in heavy deformed nuclei has been undertaken. A major goal of this work is to explore SU(3) fermion structures as a means of describing shape coexistence and super-deformation in heavy nuclei. Preliminary details have been prepared for publication. This work constitutes part of the Ph.D. thesis of Mr. M. Jarrico (Ga. Tech, School of Physics) and is in collaboration with Prof. D. J. Rowe, University of Toronto.

A study of intruder states, shape coexistence and deformed ground states in closed-shell nuclei with $N = 20$ has been completed. The results have been prepared for publication. This work was in collaboration with K. Heyde, Institute for Nuclear Physics, Gent, Belgium.

A systematic study of the proton-neutron interacting boson model parameters is being pursued. This is aimed at describing coexisting states in nuclei near to closed shells, especially the Pt isotopes, using the extension of the interacting boson model introduced by Duval and Barrett. A detailed study of ^{194}Pt has been completed and prepared for publication. This work is in collaboration with Dr. B. E. Gnade, Texas Instruments Corp., Dallas and Prof. D. Cline, University of Rochester.

A major review of shape coexistence in even-mass nuclei is in progress, at the invitation of Physics Reports. This is being done in collaboration with K. Heyde (Gent), Prof. W. Nazarewicz (University of Warsaw), and M. Huyse and P. van Duppen (Leuven).

5.0 Overseas Trips

No overseas trips were made at DOE expense or on DOE supported time this year.

6.0 Personnel

Senior Staff

Dr. J. L. Wood, Associate Professor, Principal Investigator, Full time,
2 months.

Dr. R. A. Braga, Research Scientist, One-twelfth time, 12 months.

Graduate Students

Mr. Johannes Schwarzenberg, Ph.D. thesis work. Half-time, 9 months.

Mr. Martin Jarrio, Ph.D. thesis work. Half-time, 9 months.

Mr. Jürgen Breitenbach, Ph.D. thesis work. Half-time, 9 months.

Ms. Kristi Jentoft-Nilsen, Ph.D. thesis work. Not supported by DOE.

7.0 Summary of Publications, Preprints, Abstracts, and Presentations at Conferences, and Symposia 1989

1. "Anomalous Behavior of Transition Probabilities in ^{75}Kr ", S. Skoda, J. L. Wood, J. Eberth, J. Busch, M. Liebchen, T. Mylaeus, N. Schmal, R. Sefzig, W. Teichert, and W. Wiosna, Z. Phys. A336, 391 (1990).
2. "Mixing of Intruder and Normal States in Pb Nuclei", P. van Duppen, M. Huyse, and J. L. Wood, J. Phys. G16, 441 (1990).
3. "The SU(3) Structure of Rotational States in Heavy Deformed Nuclei", M. Jarrio, J. L. Wood, and D. J. Rowe, preprint.
4. "Shape Coexistence in ^{190}Hg ", M. O. Kortelahti, E. F. Zganjar, J. L. Wood, C. R. Bingham, H. K. Carter, K. S. Toth, J. H. Hamilton, J. Kormicki, L. Chaturvedi, and W. B. Newbolt, preprint.
5. "Interacting Boson Model Description of Electric Quadrupole Matrix Elements in ^{194}Pt ", B. E. Gnade, J. L. Wood, D. Cline, and C. Y. Wu, preprint.
6. "Intruder States and Shape Coexistence in the Region $N \sim 20$, $Z \sim 12$ ", K. Heyde, and J. L. Wood, preprint.
7. "Shape Coexistence in ^{195}Pb ", J. C. Griffin, R. A. Braga, R. W. Fink, J. L. Wood, H. K. Carter, R. L. Mlekodaj, C. R. Bingham, E. Coener, M. Huyse, and P. van Duppen, preprint.
8. "Studies of the $Z = 81$ Transitional Nucleus ^{195}Tl ", C. R. Bingham, H. V. Carmichael, L. L. Collins, V. P. Jansen, L. L. Riedinger, G. D. O'Kelley, P. B. Semmes, R. A. Braga, J. L. Wood, R. W. Fink, M. Kortelahti, E. F. Zganjar, I. C. Girit, H. K. Carter, and R. L. Mlekodaj, preprint.
9. "Spectroscopic Techniques in the Study of Radioactive Nuclei Far From Stability: Results for the $Z = 82$ Region", E. F. Zganjar, J. L. Wood, and J. Schwarzenberg, preprint (invited paper, Symposium on

Exotic Nuclear Spectroscopy, American Chemical Society, Miami Beach, Florida, Sept. 1989).

10. "Electric Monopole Transitions and Shape Coexistence in Nuclei", E. F. Zganjar and J. L. Wood, preprint (invited paper, Conference on Nuclear Structure in the Nineties, Oak Ridge, Tennessee, April 1990).
11. "On-Line Nuclear Orientation of ^{184}Au ", Y.-S. Xu, K. S. Krane, M. A. Gummin, J. T. Elliott, H. K. Carter, I. C. Girit, D. Rupnik, E. F. Zganjar, J. L. Wood, P. F. Mantica, and B. E. Zimmerman, Bull. Am. Phys. Soc. 35, 1657, BC7 (1990).
12. "Electric Monopole Transitions and Shape Coexistence in Nuclei", E. F. Zganjar and J. L. Wood, invited talk, Conference on Nuclear Structure in the Nineties, Oak Ridge, Tennessee, April 1990.

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