DOE/ER /40330-96

Nuclear Structure Research

Annual Progress Report

U. S. Department of Energy

Grant DE-FG05-87ER40330

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October 31, 1996

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1.0 Introductory Overview

The most significant development this year has been the realization that EO transition strength is a fundamental manifestation of nuclear mean-square charge radius differences. Thus, EO transitions provide a fundamental signature for shape coexistence in nuclei. In this sense, EO transitions are second only to E2 transitions for signalling (quadrupole) shapes in nuclei and do so when shape differences occur.

A major effort has been devoted to the review of EO transitions in nuclei. This is being carried out in collaboration with Prof. K. Heyde (Rijksuniversiteit, Gent, Belgium), and Prof. E. F. Zganjar (LSU). Besides the above general conclusion, detailed studies of EO transitions in sd-shell nuclei, singly-closed shell heavy nuclei, deformed nuclei, and collective non-deformed nuclei have been/are being made. A letter on the sd-shell nuclei is nearing completion.

Experiments have been carried out or are scheduled at: ATLAS/FMA (α decay of very neutron-deficient Bi isotopes); MSU/NSCL (β decay of ^{56}Cu); and HRIBF/RMS (commissioning of tape collector, internal conversion/internal-pair spectrometer; β decay of ^{58}Cu).

One graduate student spent the summer at Oak Ridge working on target/radioactive beam development. Data analysis proceeded on β decay schemes of the very neutron-deficient Pr, Nd, Pm, Sm, and Eu isotopes and Ir, Pt, Au, Hg, and Tl isotopes.

A considerable effort has been devoted to planning the nuclear structure physics that will be pursued using HRIBF.

Theoretical investigations have continued in collaboration with Prof. K. Heyde (Rijksuniversiteit, Gent, Belgium), Prof. D. J. Rowe (Univ. of Toronto), Prof. J. O. Rasmussen (Lawrence Berkeley National Laboratory), and Prof. P. B. Semmes (Tenn. Tech. Univ.). These studies focus on shape coexistence and particle-core coupling.

This year the grant has supported the principal investigator (two months, full time), and three graduate students (twelve months, half time).

Two Ph.D.'s were awarded to students (supported on this grant) by the Georgia Tech School of Physics.

2.0 Experiment

Experimental research has involved: runs (planned/scheduled at ATLAS/FMA, MSU/NSCL, and HRIBF/RMS); data analysis, level scheme construction and comparisons of level schemes with theory; and planning for experiments with radioactive beams at HRIBF. All or part of four students' theses depend(ed) on this. There are on-going collaborations with Prof. E. F. Zganjar (LSU), Prof. K. S. Krane (Oregon State Univ.), Prof. C. R. Bingham (Univ. of Tennessee), Dr. B. E. Gnade (Texas Instr. Corp, Dallas/DARPA, Washington, D. C.), and Dr. R. A. Braga (Sch. of Chemistry, Georgia Tech).

The data sets relate to three areas of nuclear structure: the onset of deformation in the extremely neutron-deficient Pr, Nd, Pm, and Sm isotopes; shape coexistence in the neutron-deficient Ir, Pt, Au, Hg, Tl, Pb, and Bi isotopes; and deformation and shape coexistence in heavy N~Z line nuclei. (Some data sets were obtained during the last years of operation of UNISOR.)

2.1 Onset of Deformation in the Extremely Neutron-Deficient Pr, Nd, Pm, and Sm Isotopes.

A paper on the decay scheme for $^{133}\text{Pm} \rightarrow ^{133}\text{Nd}$ and detailed particle-core coupling calculations for ^{133}Nd has been published: J.B. Breitenbach et al., Nuclear Physics A, Vol. 592, pp. 194-210 (1995).

A paper on the decay schemes for $^{133\text{m.g}}\text{Nd} \rightarrow ^{133}\text{Pr}$ and detailed particle-core coupling calculations for ^{133}Pr has been published: J. Brietenbach et al., Nuclear Physics A, Vol. 595, pp. 481- 498 (1995).

Analysis of data on $^{135}\text{Sm} \rightarrow ^{135}\text{Pm} \rightarrow ^{135}\text{Nd} \rightarrow ^{135}\text{Pr}$ and $^{137}\text{Eu} \rightarrow ^{137}\text{Sm} \rightarrow ^{137}\text{Pm}$ is essentially completed. This work is in collaboration with R. A. Braga.

The major finding of this work is that systematic identification of Nilsson configurations and associated rotational bands is possible and that the onset of deformation is gradual.

2.2 Shape Coexistence in the Neutron-Deficient Ir, Pt, Au, Hg, Tl, Pb, and Bi Isotopes.

The region of very neutron-deficient nuclei near Z~ 80, N~104 exhibits the best example of shape coexistence anywhere on the mass surface. A wide variety of studies are in progress, aimed at various aspects of shape coexistence in this region.

A paper on the decay scheme for $^{189m,g}\text{Hg} \rightarrow ^{189}\text{Au}$ and detailed particle-core coupling calculations for ^{189}Au has been published: J. L. Wood et al, Nuclear Physics A, Vol. 600, pp. 283-334 (1996).

An extensive study of ^{187}Au has been completed. A paper describing the work is in preparation. This work is in collaboration with E.F. Zganjar and P.B. Semmes.

A study of the systematic features of the very neutron-deficient odd-mass Ir isotopes has been completed. A paper describing the work is in preparation. This constituted part of the thesis work of K. Jentoft-Nilsen.

A study of the $^{184m,g}\text{Au} \rightarrow ^{184}\text{Pt}$ decay schemes has been completed. Three papers describing the work are in preparation. The first discusses the half lives of ^{184m}Au and ^{184g}Au . The second describes the discovery of high-energy EO transitions in ^{184}Pt . The third presents the detailed $^{189m,g}\text{Au} \rightarrow ^{184}\text{Pt}$ decay schemes. This work is in collaboration with K. S. Krane and E. F. Zganjar.

A study of the $^{186}\text{Au} \rightarrow ^{186}\text{Pt}$ decay schemes is in progress. A short note on EO transitions in ^{186}Pt is in preparation. This is part of the thesis work of J. McEver.

A study of the $^{190m,g}\text{Tl} \rightarrow ^{190}\text{Hg}$ decay schemes is in progress. A contributed talk at the APS Division of Nuclear Physics Meeting in Cambridge, Ma. was given on this work. This is part of the thesis work of M. DeShon.

A study of the $^{192m,g}\text{Tl} \rightarrow ^{192}\text{Hg}$ decay schemes is in progress.. This is part of the thesis work on B. MacDonald.

A study of the intruder states in the very neutron-deficient Bi and Tl isotopes using α decay has been carried out at ATLAS using the FMA. The data are now being analyzed. This work is in collaboration with E. F. Zganjar and C. R. Bingham.

A study of the decay scheme $^{189m}\text{Tl} \rightarrow ^{189}\text{Hg}$ has been completed. Completion of a paper awaits particle-core coupling calculations for ^{189}Hg . This work is in collaboration with B.E. Gnade, E.F. Zganjar, and P.B. Semmes.

2.3 Deformation and Shape Coexistence in Heavy N~ Z Line Nuclei.

This area of investigation will be a major focus of the program at HRIBF. Two experiments are approved for beam time : a study of $^{56}\text{Cu} \rightarrow ^{56}\text{Ni}$ at MSU/NSCL and a study of $^{58}\text{Cu} \rightarrow ^{58}\text{Ni}$ at HRIBF. The HRIBF experiment is scheduled for next month and will be a commissioning run for the tape transport system on the back end of the RMS and will use a stable beam. These studies are aimed at determining whether $^{56,58}\text{Ni}$ exhibit shape coexistence similar to $^{40,42}\text{Ca}$ (see e.g., J. L. Wood et al., Physics Report 215, 101 (1992)). This work is in collaboration with E.F. Zganjar and Prof. Paul Mantica (MSU).

3.0 Planning of Experiments for HRIBF

A considerable effort has been applied to planning the nuclear structure physics that will be pursued at HRIBF. A proposal entitled "Search for Maximally Deformed Nuclei in the $Z > 50, N < 82$ Region" has been approved for beam time and will use the radioactive ^{69}As beam. This work will be carried out in collaboration with UNIRIB consortium members.

4.0 HRIBF Development Work

Some details of the activities of K. Jentoft-Nilsen, who received her Ph.D. from Georgia Tech earlier this year, are contained in a brief report entitled "Target Selection for the HRIBF Project", which has been published: J. Dellwo et al., Nuclear Instruments and Methods B, Vol. 99, pp. 335-337 (1995).

During the Summer, Brian MacDonald (a graduate student who started his thesis research at Georgia Tech earlier this year) worked at Oak Ridge on the development of arsenic beams at HRIBF. The focus was on optimizing transport to the tandem ion source of (radioactive) arsenic from the primary target.

5.0 Theory and Systematics

Theory has pursued three themes. The first is detailed particle-core coupling calculations to complement the experimental studies in the very neutron-deficient Ir-Tl isotopes. The second is the modelling of shape coexistence and intruder state structures. The third is the modelling of particle-core coupling in heavy nuclei using an SU(3) core description. Systematics has involved a thorough review of EO transitions and their association with shape coexistence.

5.1 Particle-Core Coupling Calculations in the Very Neutron-Deficient Ir-Tl Isotopes

Detailed particle-core coupling calculations have been carried out in the very neutron-deficient Ir-Tl isotopes. These calculations employ the particle-plus-triaxial-rotor model (PTRM) with a Woods-Saxon potential (S.E. Larsson et al., Nucl. Phys. **A307**, 189 (1978)). The PTRM can be applied over nearly the whole mass surface with a minimum of free parameters.

Currently, calculations are being completed for ^{187}Au (cf. Section 2.2). This work is in collaboration with P.B. Semmes.

5.2 Intruder States and Coexisting Structures

Work has continued on the concept of intruder analog states with applications in the $Z=50$ and 82 closed shell regions and in light nuclei. This program is aimed at classifying shape coexistence in terms of multi-particle-multi-hole excitations using simple boson algebraic concepts.

A paper entitled, "Particle-Hole Excitations in the Interacting Boson Model. (I) General Structure and Symmetries" has been published: C. De Coster et al., Nuclear Physics A, Vol. 600, pp. 251-271 (1996). A second paper entitled, "Particle-Hole Excitations in the Interacting Boson Model: The $O(6)$ -SU(3) coupling" is nearly completed.

The program is continuing with applications to light $N=Z$ region nuclei. In light $N=Z$ region nuclei an exploration of intruder spin (K. Heyde et al., Phys. Rev. C **46**, 541 (1992)) combined with isospin is being explored as the basis of an algebraic description of coexisting collective structures in, e.g., ^{56}Ni . (This program is, in part, targeted at potential experiments at HRIBF.)

This work is in collaboration with K. Heyde and Dr. P. Van Isacker (GANIL, Caen, France).

5.3 Modelling of Particle-Core Coupling in Heavy Nuclei Using an SU (3) Description.

This program has been completed. Details appear in the doctoral dissertation of M. Jarrio which is entitled: "A Microscopic Study of Nuclear Deformed States".

5.4 Electric Monopole Transitions

The survey continues with data compilation and evaluation and comparison with theory. A clearly emerging picture is the association of all known strong EO transitions in nuclei with shape coexisting configurations which are mixed. A strong case can be made for the association of strong EO transitions with the decay of superdeformed bands. A short note entitled: "The Strength of Electric Monopole Transitions and the Decay Out of Superdeformed Bands" has been published: J. L. Wood, E. F. Zganjar and K. Heyde, Zeitschrift für Physik A, Vol. 353, pp. 355-356 (1996).

A study of EO transitions in sd shell nuclei is nearing completion.

A study of EO transitions in deformed nuclei is in progress. (This is in collaboration also with J.O. Rasmussen.)

This program is in collaboration with K. Heyde and E. F. Zganjar.

6.0 Overseas Trips

A trip to Gent, Belgium is to be made in December to work on the review of EO transitions, being carried out in collaboration with K. Heyde

7.0 Personal

Senior Staff

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

Graduate Students

Mr. Martin Jarrio, Ph.D. thesis work. Half-time, 5 months

Ms. Kristi-Jentoft Nilsen, Ph.D. thesis work. Half-time, 4 months

Mr. Jimmie McEver, Ph.D. thesis work, Half-time, 12 months

Mr. Markus DeShon, Ph.D. thesis work, Half-time, 9 months

Mr. Brian MacDonald, Ph.D. thesis work, Half-time, 6 months

8.0 Summary of Publications, Preprints, Abstracts, and Theses, 1996

1. "The Decay of ^{133}Pm and the Structure of ^{133}Nd ," J. B. Breitenbach, J. L. Wood, M. Jarrio, R. A. Braga, J. Kormicki, and P. B. Semmes, Nucl. Phys. A592, 194 (1995).
2. "The Decays of Mass-Separated $^{133\text{m,g}}\text{Nd}$ to ^{133}Pr ", J.B. Breitenbach, J.L. Wood, M. Jarrio, R.A. Braga, H. K. Carter, J. Kormicki, and P. B. Semmes Nucl. Phys. A595, 481 (1995).
3. "Comments on Shape and Superdeformed Structure in Hg Isotopes in Relativistic Mean Field Models and Structure of Neutron-Deficient Pt, Hg, and Pb Isotopes", K. Heyde, C. De Coster, P. Van Duppen, M. Huyse, J. L. Wood, and W. Nazarewicz, Phys. Rev. C53, 1035 (1996).
4. "Particle-Hole Excitations in the Interacting Boson Model. (I) General Structure and Symmetries", C. De Coster, K. Heyde, B. Decroix, P. Van Isacker, J. Jolie, H. Lehmann, and J. L. Wood, Nucl. Phys. A600, 251 (1996).
5. "Decay of Mass-Separated $^{189\text{m}}\text{Hg}$ (8.7 min) and $^{189\text{g}}\text{Hg}$ (7.7 min) to ^{189}Au ", J. L. Wood, M.O. Kortelahti, E.F. Zganjar, and P. B. Semmes, Nucl. Phys. A600, 283 (1996).
6. "The Strength of Electric Monopole Transitions and the Decay Out of Superdeformed Bands", J. L. Wood, E. F. Zganjar, and K. Heyde, Z. Phys. A353, 355 (1996).
7. "Target Selection for the HRIBF Project". J. Dellwo, G.D. Alton, J.C. Batchelder, J. Breitenbach, H.K. Carter, J. A. Chediak, G. D. Bartolo, S. Ichikawa, K. Jentoft-Nilsen, and J. Kormicki, Nucl. Instr. and Meth. B99, 335 (1995).
8. "Electric Monopole Transitions: What They Can Tell Us About Nuclear Structure", E. F. Zganjar and J. L. Wood, in Proceedings of the International Conference on Exotic Nuclei and Atomic Masses, Arles, France, June 19-23, 1995, ed. M. deSaint Simon and O. Sorlin (Editions Frontiers, Gif-sur-Yvette, 1995), p. 437.
9. "The Diffusion Properties of Ion Implanted Species in Selected Target Materials", G. D. Alton J. Dellwo, H. K. Carter, J. Kormicki, G. diBartolo, J. C. Batchelder, J. Breitenbach, J. A. Chediak, K. Jentoft-Nilsen, and S. Ichikawa, (in press, Proc. of Conf. on Applications in Nuclear Technology, Heraklion, Crete, Greece).
10. "Nuclear Monopole Properties: EO Transitions and Radii as a Measure of Shape Mixing", K. Heyde, C. De Coster, B. Decroix, J. Wood, and E.F. Zganjar, (in press, Proc. Conf. On Capture Gamma-Ray Spectroscopy, Budapest, October 1996).

11. "Nuclear Orientation and Spectroscopic Studies of the Decay on ^{187}Pt to ^{187}Ir ", M. A. Gummin, K. S. Krane, Y. Xu, T. Lam, E. F. Zganjar, J. B. Breitenbach, B.E. Zimmermann, H.K. Carter, and P.F. Mantica, Jr., Nucl. Phys. A. (in press).
12. "Verification of Isomerism and Direct Measurement of Halfives in ^{184}Au ", K. Zaerpoor, Y. Xu, M.Gummin, K. S. Krane, J. L. Wood, N.J. Stone, and J. Rikvoska, submitted.
13. "Energy Level Structure of Mercury 190", M. DeShon, J. L. Wood, P. Joshi, and E. Zganjar, Bull. Am. Phys. Soc.____, (1996).
14. "Deformation and the Search for Shape Coexistence in Odd-Mass Neutron-Deficient Iridium Isotopes: Studies of the β +/EC Decay of ^{183}Pt and ^{181}Pt ", K. Jentoft-Nilsen, Ph.D. Thesis, Georgia Tech, May 1996.
15. "A Microscopic Study of Nuclear Deformed States", M. M. Jarrio, Ph.D. Thesis, Georgia Tech, June 1996.

MASTER RECORD REPORT

PAGE: 1

DUPCHECK-ID-NUMBER: 97001798430

PERMANENT-DOCUMENT-NUMBER: M97006647 000

<013>	DATE-COMPLETED	970721
<014>	DATE-OF-RECORD-ENTRY	970624
<015>	DATE-RECEIVED	970624
<016>	COPIES-RECEIVED	2
<020>	DOCUMENT-TYPE	R
<022>	MEDIUM-CODE	H
<030>	CLASSIFICATION-CODE	Uncl
<040>	LITERARY-INDICATOR	Y
<050>	GPO-SUPERINTENDENT-OF-DOCUMENTS	Y
<072>	PERSONAL-AUTHOR-AND-AFFILIATION	Wood, J.L.
<080>	SPONSORING-ORGANIZATION-CODE	DOE/ER
<110>	TITLE-ENGLISH	
	Nuclear structure research. Annual progress report	
<150>	PRIMARY-REPORT-NUMBER	DOE/ER/40330--96
<240>	CONTRACT-NUMBER-DOE	FG05-87ER40330
<241>	ABBREV-CONTRACT-NUMBER-DOE	ER40330
<242>	AWARDING-OFFICE-CODE	05
<245>	LEGIBILITY-CODE	0
<246>	DOE-INITIATING-OFFICE-CODE	ER
<247>	MICROFICHE-DISTRIBUTION-CODE	4
<248>	VENDOR-ID-CODE	097540-0101-4
<249>	VENDOR-NAME	GEORGIA TECH RESEARCH CORP
<276>	DUPCHECK-BYPASS-FLAG	N
<291>	PACKED-PRIMARY-REPORT-NUMBER	DOEER4033096
<293>	PREFIX	DE
<295>	INDEX-DOCUMENT-NUMBER	M97006647
<370>	PUBLICATION-DATE	31 Dec 1996
<376>	REPORT-TYPE-CODE-AND-FREQUENCY	A/00/96
<390>	PAGES-BIBLIOGRAPHIC	14
<400>	REPORT-DISTRIBUTION-CODE	A
<421>	LANGUAGE-CODE	EN
<425>	AUDIENCE-CODE	01
<426>	LIMITATION-CODE	UNL
<510>	DISTRIBUTION-CATEGORY	M -413
<520>	PROJECT-STATUS	P
<530>	ANNOUNCEMENT-CODE	EDB;ETD;INS;NTS
<540>	EDB-SUBJECT-CATEGORIES	663100
<550>	SOURCE-OF-BIBLIOGRAPHIC-INPUT	IMS
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<570>	COUNTRY-OF-PUBLICATION	US
<600>	INIS-TYPE	R
<610>	INIS-CATEGORIES	G3100
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<700>	CORPORATE-CODE	2769000
<748>	TAPE-VOL-ISSUE	97R14
<749>	TAPE-INCOMING-SERIAL-NUMBER	AHC29714%%108
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	PROGRESS REPORT;RESEARCH PROGRAMS;NUCLEAR STRUCTURE:T;E0-TRANSITIONS;	
	NUCLEAR RADII;NUCLEAR DECAY;EXPERIMENT PLANNING;SHAPE	
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	E0-TRANSITIONS;EXPERIMENT PLANNING;NUCLEAR DECAY;NUCLEAR RADII;NUCLEAR	
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<931>	AVAILABILITY-CODE	OS;NT;IN

DUPCHECK-ID-NUMBER: 97001798430

PERMANENT-DOCUMENT-NUMBER: M97006647 000

<950> ABSTRACT

The most significant development this year has been the realization that E0 transition strength is a fundamental manifestation of nuclear mean-square charge radius differences. Thus, E0 transitions provide a fundamental signature for shape coexistence in nuclei. In this sense, E0 transitions are second only to E2 transitions for signaling (quadrupole) shapes in nuclei and do so when shape differences occur. A major effort has been devoted to the review of E0 transitions in nuclei. Experiments have been carried out or are scheduled at: ATLAS/FMA (α decay of very neutron-deficient Bi isotopes); MSU/NSCL (β decay of ^{56}Cu); and HRIBF/RMS (commissioning of tape collector, internal conversion/internal-pair spectrometer; β decay of ^{58}Cu). A considerable effort has been devoted to planning the nuclear structure physics that will be pursued using HRIBF. Theoretical investigations have continued in collaboration with Prof. K. Heyde, Prof. D.J. Rowe, Prof. J.O. Rasmussen, and Prof. P.B. Semmes. These studies focus on shape coexistence and particle-core coupling.