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Nuclear Structure Research

Annual Progress Report

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1. Introductory Overview

The most significant development this year has been the outcome of a survey of E0 transition strength, ρ^2(E0), in heavy nuclei. The systematics of ρ^2(E0) reveals that the strongest E0's are between pairs of excited states with the same spin and parity. This is observed in the regions Z,N = 38,60; 48,66; 64,88; and 80,106. Unlike other multipoles it is rare that nuclear ground states are strongly connected to excited states by monopole transitions. An invited paper on E0 transitions was presented in Antibes, France.

Another significant finding is in the results of the experimental study of levels in ^{187}Au. Two bands of states are observed with identical spin sequences, very similar excitation energies, and E0 transitions between the "favored" band members but not between the "unfavored" band members. This is interpreted in terms of nearly identical diabatic structures. A short "letter" has been submitted.

Experimental data sets for the radioactive decays of ^{183}Pt and ^{186}Au to ^{183}Ir and ^{186}Pt, respectively, have been under analysis. These decay schemes constitute parts of student Ph.D. theses. The studies are aimed at elucidating shape coexistence and triaxiality in the A = 185 region.

An extensive program of systematics for nuclei at and near N = Z has been continued in preparation for the planned nuclear structure research program using the Holifield Radioactive Ion Beam Facility (HRIBF) at Oak Ridge. An invited paper on multiparticle-multihole states near N = Z was presented in Stockholm, Sweden.

A considerable effort has been devoted to HRIBF target development. This is a critical component of the HRIBF project. Exhaustive literature searches for targets suitable for producing beams of Cl and Ga have been made. Melting point and vapor pressure measurements have been carried out.

Theoretical investigations have continued in collaboration with Prof. K. Heyde (Institute of Nuclear Physics, Gent, Belgium), Prof. D. J. Rowe (Univ. of Toronto), and Prof. P. B. Semmes (Tenn. Tech. Univ.). A paper on particle-hole intruder multiplets near Z = 82 has been published in Physical Review C.

This year the contract has supported, besides the principal investigator (two months, full time), three graduate students (two for twelve months), half time; and one for eight months, half time).

2.0 Experiment

Experimental research has involved data analysis, level scheme construction, and comparison of level schemes with theory. All or part of two students' theses depend on this. There are on-going collaborations with Prof. E. F. Zganjar (LSU), Prof. K. S. Krane (Oregon State Univ.), Dr. B. E. Gnade (Texas Instr. Corp., Dallas), and Dr. R. A. Braga (Sch. of Chemistry, Georgia Tech). The data sets relate to two areas of nuclear structure: the onset of deformation in the extremely neutron-deficient Pr, Nd, Pm, and Sm isotopes; and shape coexistence in the neutron-deficient Ir, Pt, Au, and Hg isotopes. (The 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

Decay schemes for $^{133}Pm \rightarrow {}^{133}Nd$ and for $^{133}Nd \rightarrow {}^{133}Pr$ have been completed. Manuscripts have been prepared. Finalization of the work awaits results of particle-core coupling calculations which are being made by P. B. Semmes. Analysis of data on $^{135}Sm \rightarrow {}^{135}Pm \rightarrow {}^{135}Nd$ and $^{137}Eu \rightarrow {}^{137}Sm \rightarrow {}^{137}Pm$ is in progress in collaboration with R. A. Braga.

The major finding of our work is that, contrary to the prediction of a sudden onset of deformation in this region, a gradual onset of deformation occurs.

2.2 Shape Coexistence in the Neutron-Deficient Ir, Pt, Au, and Hg Isotopes

Decay schemes for $^{181}Pt \rightarrow {}^{181}Ir$, $^{187}Hg \rightarrow {}^{187}Au$, $^{189}Hg \rightarrow {}^{189}Au$, and $^{189}Tl \rightarrow {}^{189}Hg$ are completed. A letter entitled "Coexistence Effects in ^{187}Au: Evidence for Nearly Identical Diabatic Intruder Structures" has been submitted to Physical Review Letters. Manuscripts for ^{187}Au, ^{189}Au, and ^{187}Hg are nearing completion. Analysis of data on $^{183}Pt \rightarrow {}^{183}Ir$, $^{184}Au \rightarrow {}^{184}Pt$, and

$^{186}Au \rightarrow {}^{186}Pt$ is in progress. The $^{181,183}Pt \rightarrow {}^{181,183}Ir$ decay schemes constitute part of the thesis work of K. Jentoft-Nilsen (Georgia Tech). The $^{186}Au \rightarrow {}^{186}Pt$ decay scheme constitutes part of the thesis work of J. McEver (Georgia Tech). The other studies are in collaboration with E. F. Zganjar, B. E. Gnade (^{189}Hg), and K. S. Krane (^{184}Pt).

These studies are part of a very large program investigating the detailed structure of nuclei in the region around $Z \sim 80$, $N \sim 104$. A major outcome of the program in the past year has been the identification of evidence for nearly identical diabatic intruder structures, as noted above, in ^{187}Au. This region is the best anywhere on the mass surface for exploring the many facets of shape coexistence and coexisting intrinsic structures in nuclei. Further, it is evident from the work on $^{184,186}Pt$ that these nuclei are probably among the best examples anywhere of triaxial rotors.

Contributed papers on the ^{183}Ir scheme and triaxiality in ^{186}Pt were presented at the Williamsburg APS Meeting by K. Jentoft-Nilsen adn J. McEver, respectively.

3.0 Planning of Experiments for HRIBF

A considerable effort has been devoted to planning the nuclear structure physics that will be pursued at HRIBF. A number of criteria are considered to be important guides to these plans and are outlined below.

The main theme of the experimental program at HRIBF should be to obtain nuclear structure information that cannot be obtained using any other facility or techniques. Thus, a strong case can be made for studying heavy ($40 < A < 100$) nuclei at and near the $N = Z$ line: the information on nuclei with $N \simeq Z$ could be roughly doubled. Nuclear structure at and near the $N \simeq Z$ line is characterized by isobaric symmetry. This region also has a number of closed shells which gives rise to simple spherical shell model configurations and exotic multi-particle - multi-hole configurations.

Among the directions chosen for HRIBF research are identification of J_{max} states in the $f_{7/2}$ shell and 4p - 4h and 8p - 8h states in ^{56}Ni (similar to the deformed coexisting states in ^{40}Ca, cf. J. L. Wood et al., Phys. Repts. 215, 101 (1992) -- see Figure 3.2). (A number of excited 0^+ states are known in ^{56}Ni from a (p,t) study (H. Nann and W. Benenson, Phys. Rev. C10, 1880 (1974)), but nothing is known of their structure.) The J_{max} states are very simple (they are "stretched" shell model states) and are sensitive to the residual force acting between nucleons (cf. A Poves and A. Zucker, Phys. Repts. 70, 235 (1981)). However, the goal is to take the program into a potentially new area of nuclear structure: the collectivity of multi-particle-multihole structures with low isospin. A theoretical initiative is underway on this topic in collaboration with K. Heyde (see Section 5.1). One of the issues is whether or not particle-hole excitations break isobaric symmetry: protons, being further apart in a particle-hole excitation should Coulombically repel less strongly.

An invited paper entitled "Experimental Perspectives on Multi-Particle Multi-Hole Collective States at Closed Shells" was given at the international symposium "New Nuclear Structure Phenomena in the Vicinity of Closed Shells" held in Stockholm, Aug. 30 - Sept. 3, 1994.

4.0 HRIBF Development Work

The program of target development for HRIBF has been continued and expanded. In order to be a good target, a material must be stable within the ion source environment, maximize production of the desired radionuclide while minimizing production of undesirable species, and optimize extraction of the nuclide complex from the target material. A data base has been created to organize the properties of all target material candidates in such a way as to ultimately allow the selection of the target that will contribute the highest efficiency to the production of a specific radioactive ion beam. An extensive and ongoing literature search has provided the groundwork for this data base. However, since the properties of many materials of interest have not been throughly studied, a materials testing program is also being developed.

One focus of the search for target candidates has been the thermophysical properties that will allow the material to remain stable within the ion source. Since liquid targets will not be supported at least in the first ion sources, the material must have a high melting point, above 1600 degrees Celsius. The material must also have a low vapor pressure for the proper operation of the ion source. The maximum vapor pressure that will not interfere with the ion source is around 0.1 mTorr. This value however is dependent on the type of ion source. Melting points of 50 candidate materials have been collected into the data base. However, vapor pressure information is known for only 29 of these materials, and often this information consists of a single data point. Vapor pressure over a range of temperatures is desirable.

For many materials, adequate data is not available. An existing vacuum bell jar system is being used to determine the stability of these materials in an environment similar to that of an ion source. Melting points are being measured with an optical pyrometer. A quartz crystal microbalance is being used to determine information about vapor pressures and evaporation rates. Concurrently, estimates of the reactivity between the material and the target holder are being made. A new materials test stand has been designed specifically for such tests. This stand will also be used for outgassing of ion sources and targets before use online.

Particular effort has been made to find an appropriate sulfur target for the production of a radioactive chlorine beam. A systematic review of the melting points of all known sulfur compounds containing only one other element other than the sulfur has been completed. However, vapor pressure information is limited.

This work has been carried out by K. Jentoft-Nilsen and J. McEver. An invited talk entitled "Vapor Pressure Measurements Using a Quartz Crystal Microbalance" was given by K. Jentoft-Nilsen at the "North American Conference on Radioactivity, Ion Sources and Targets (NACRIST)" held in Vancouver, Aug. 10-12, 1994. Kristi Jentoft-Nilsen spent ten weeks at the Holifield Lab this summer, making these measurements.

5.0 Theory

Theory has involved development of two themes: modelling of intruder states and a description of coexisting collective structures; modelling of collective structures in heavy even- and odd-mass nuclei based on an SU(3) core description.

5.1 Intruder States and Coexisting Collective Structures

Work has continued on the concept of intruder analog states (K. Heyde et al., Phys. Rev. C46, 541 (1992)) with an application to collective bands in the very neutron-deficient Pb isotopes. A paper has been published in Physical Review C, entitled "Possible Evidence for Particle-Hole Intruder Analog Multiplets in the Pb Region". Applications to light N = Z region nuclei and Z = 50 region nuclei are now underway. In light N = Z region nuclei an exploration of intruder spin 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 (with whom the P. I. holds a NATO Travel Grant) and Dr. P. Van Isacker (Ganil, Caen, France).

A broad and thorough survey of E0 transitions in nuclei has been initiated. An early surprise in this work is the revelation that the strongest E0 transitions in heavy nuclei are between pairs of excited states, i.e., not to the ground state. An invited paper entitled "Shape Coexistence and Electric Monopole Transitions" was given at the international workshop "Nuclear Shapes and Nuclear Structure at Low Excitation Energies" held in Antibes (France), June 20-25, 1994.

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

5.2 Description of Collective Bands in Heavy Even- and Odd-Mass Nuclei Based on an SU(3) Core Description

It has long been known that light nuclei can be described by an SU(3) coupling scheme. In heavier nuclei, however, it is expected that strong mixing of irreps will occur due to interactions such as spin-orbit coupling. Nevertheless, we believe that SU(3) models can still provide a context for understanding rotational behavior in heavy deformed nuclei.
Calculations for even-even nuclei are rather straightforward. Using the Coupled Rotor-Vibrator Model, we have found (M. Jarrio, J. L. Wood, and D. J. Rowe, Nucl. Phys. A528, 409 (1991)) that there is, indeed, considerable mixing of SU(3) irreps. However, we find that these mixtures remain rather constant within each particular rotational band. It is thus possible to picture an intrinsic state experiencing adiabatic rotations, and we can describe these nuclei in terms of a "soft" SU(3) structure.

We are currently working towards a similar description of odd-mass nuclei. With the inclusion of an unpaired nucleon, it becomes necessary to investigate the effects of particle-core coupling. We expect a strongly coupled basis to be most appropriate for heavy deformed nuclei, and this has led us to investigate the nature of strongly coupled SU(3) states. Unlike standard rotor models, however, SU(3) does not admit spinor irreps. Hence, due to the odd nucleon's spin, it is not possible in the strongly-coupled system to build true SU(3) representations. Our immediate goal has thus been to obtain an approximate picture in which an SU(3) core, a spinless particle, and a spinor are coupled. With this intent, we have been investigating the structure of Nilsson Model states in the absence of spin. Such states will not possess pure SU(3) symmetry, as the L-squared ("well-flattening") term will split the degeneracy of states within a given irrep. Nevertheless, we find that SU(3) does provide a dynamical symmetry, and hence there will be no mixing of SU(3) irreps. Thus we can strongly couple the spinless particle and the core in a rather straightforward manner.

The long-term goal of this research is to provide a comprehensive description of heavy deformed nuclei in an SU(3) context. Toward this aim, we hope to build an SU(3) picture of particle-core coupling including spin degrees of freedom, in order to establish a solid description of odd-mass nuclei. With such a model in hand, it will be possible to begin making comparisions with experimental data. These comparisons will enable us to infer details about the mixtures of SU(3) states which make the intrinsic states of rotational bands.

This work constitutes part of the thesis work of M. Jarrio (Georgia Tech).

This work is in collaboration with D. J. Rowe.

6.0 Overseas Trips

Invited talks were given by the P.I. at the international symposium "New Nuclear Structure Phenomena in the Vicinity of Closed Shells" held in Stockholm, Aug. 30 - Sept. 3, 1994 and the international workshop "Nuclear Shapes and Nuclear Structure at Low Excitation Energies", held in Antibes (France), June 20-25, 1994. Travel to these two meetings was partially supported by DOE.

7. Personnel

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, 12 months.

Ms. Kristi Jentoft-Nilsen, Ph.D. thesis work. Half-time, 12 months.

Mr. Jimmie McEver, Ph.D. thesis work. Half-time, 8 months.

8.0 Summary of Publications, Preprints, Abstracts, and Invited Talks, 94

1. "Possible Evidence for Particle-Hole Intruder Analog Multiplets in the Pb Region", K. Heyde, P. Van Isacl and J. L. Wood, Phys. Rev. C49, 559 (1994).

2. "Shape Coexistence and Electric Monopole Transitions", J. L. Wood [preprint].

3. "Coexistence Effects in ^{187}Au: Evidence for Nearly Identical Diabatic Intruder Structures", D. Rupnik, E. F. Zganjar, J. L. Wood, P. B. Semmes, and W. Nazarewicz [preprint].

4. "The Decay of Mass-Separated ^{183}Pt to ^{183}Ir and Systematics of the Odd-Mass Ir Isotopes", K. Jentoft-Nilsen, J. L. Wood, and J. Schwarzenberg, Bull. Am. Phys. Soc. 39, 1419, DD6 (1994).

5. "Energy Level Structure of Platinum 186", J. McEver, J. L. Wood, M. Jarrio, and J. Schwarzenberg, Bull. Am. Phys. Soc. 39, 1419, DD7 (1994).

6. "Some New Perspectives on the Spectroscopy of Electric Monopole Transitions", J. L. Wood, Bull. Am. Phys. Soc. 39, 1418, DD1 (1994).

7. "Coexisting Near-Prolate Triaxial Structures in ^{187}Au", D. Rupnik, E. F. Zganjar, J. L. Wood, P. B. Semmes, and W. Nazarewicz, Bull. Am. Phys. Soc. 39, 1419, DD8 (1994).

8. "Experimental Perspectives on Multi-Particle Multi-Hole Collective States at Closed Shells", J. L. Wood, invited talk, International Symposium: "New Nuclear Structure Phenomena in the Vicinity of Closed Shells", Stockholm, Aug. 30 - Sept. 3, 1994.

9. "Shape Coexistence and Electric Monopole Transitions", J. L. Wood, invited talk, International Workshop: "Nuclear Shapes and Nuclear Structure at Low Excitation Energies", Antibes (France), June 20-25, (1994).

10. "Vapor Pressure Measurements Using a Quartz Crystal Microbalance", K. Jentoft-Nilsen, invited talk, North American Conference on Radioactivity, Ion Sources and Targets (NACRIST), Vancouver, Aug. 10-12, 1994.