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Tennessee Technological University
Department of Physics

PROGRESS REPORT
ON
RESEARCH IN NUCLEAR PHYSICS

May 1, 1993 - June 30, 1994

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NUCLEAR STRUCTURE MODELS: APPLICATIONS AND DEVELOPMENT

Progress Report

May 1, 1993 - June 30, 1994

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TABLE OF CONTENTS

Preface	1
1. Magnetic Dipole Transitions in Superdeformed Nuclei	2
2. Shape Coexistence in ^{187}Au	4
References	6
Appendix I: Personnel	7
Appendix II: Publications and Reprints	8

PREFACE

This report summarizes the progress made during the period May 1, 1993 through June 30, 1994 on Grant No. DE-FG05-92ER40694.

Our calculations of M1 transition rates within rotational bands of superdeformed nuclei have been extended to 2-quasiparticle states (mainly for odd-odd nuclei) in the $A \approx 190$ region. Several bands are predicted with large $B(M1)$ values and suggest that the M1 properties can give information on details of occupied single particle orbitals, alignment of some high-N particles and the residual two-body interactions at extreme deformation.

Detailed calculations and comparison with UNISOR data for the low energy, low spin structure of ^{187}Au have revealed two coexisting prolate structures built on the $\pi[h_{9/2} + f_{7/2}]$ configuration. This result was completely unexpected and presents strong challenges to our understanding of shape coexistence.

The secretarial and accounting duties for this grant have been performed by Ms. Gloria Julian of the TTU Physics Department, and her efforts are greatly appreciated.

1. Magnetic Dipole Transitions in Superdeformed Nuclei

(with I. Ragnarsson and S. Åberg)

The magnetic properties of superdeformed (SD) states can provide insights into the single-particle structure of these exotic states. Recently, M1 transitions between SD bands in ^{193}Hg were reported [1] and the M1 matrix elements extracted from the data agree well with previous predictions made by us [2]. Encouraged by our success, we have made a theoretical survey of $B(M1)$ values for two-quasiparticle SD rotational bands in the $A \approx 190$ region. This study is motivated in part by the experimental observation of six SD bands in each of the odd-odd nuclei ^{192}Tl [3] and ^{194}Tl [4], demonstrating that some of these states can be observed. The calculations have been performed using the odd-odd particle(s)+rotor model and based on single-particle wave functions obtained from the Woods-Saxon potential that has been widely employed in describing these SD states [5]. The particle(s)+rotor and M1 calculations are standard in the sense that they are a direct application of the methods that have been successful for describing states at normal deformation. The purpose of this investigation is to identify additional configurations that are expected to lie close to the yrast line and show observable M1 strength. No proton-neutron residual interaction has been included as yet.

Table 1 shows the asymptotic ($I \gg K$) $B(M1)$ values estimated from the simple strong coupling limit for some 2-qp configurations of interest. In some cases, very large $B(M1)$ values are obtained and also with a strong dependence on the two possible couplings of the two quasiparticles ($\Omega_p \pm \Omega_n$) in a given configuration. These simple estimates ignore the perturbations induced by the rotational motion, which are sizable for certain configurations. A comparison between the $B(M1)$ values calculated with the particle-rotor model (solid lines) and with the strong coupling limit (dashed lines) is shown for two configurations in ^{194}Tl are shown in fig. 1. The strong coupling estimates are based on the largest component in the particle-rotor wave functions. The $\pi[642]5/2^+ \otimes \nu[624]9/2^+, K^\pi=2^+$ configuration appears to be a good example of two strongly coupled quasiparticles, although some mixing especially with other $N=6$ proton orbitals is present in the calculations. In contrast, for the lowest $\pi[514]9/2^- \otimes \nu j_{15/2}$ configuration, the $j_{15/2}$ neutron shows a gradual alignment and the $B(M1)$ values deviate significantly from the simple strong coupling estimate. (The sharp drop around $I \approx 18$ is due to a crossing in the calculations with the $\pi[514]9/2^- \otimes \nu[512]5/2^-, K^\pi=7^+$ configuration.) In

Table 1 Selected two-quasiparticle configurations for odd-odd SD nuclei around ^{194}Hg . Parallel and antiparallel intrinsic spins are denoted by "p" and "ap".

π -orbital	ν -orbital	K^π	spins	$B(M1), I > K$
[514]9/2 ⁻	[624]9/2 ⁺	9 ⁻	p	0.1
[514]9/2 ⁻	[624]9/2 ⁺	0 ⁻	ap	6.1
[514]9/2 ⁻	[512]5/2 ⁻	7 ⁺	p	0.4
[514]9/2 ⁻	[512]5/2 ⁻	2 ⁺	ap	4.7
[642]5/2 ⁺	[624]9/2 ⁺	7 ⁺	p	< 0.1
[642]5/2 ⁺	[624]9/2 ⁺	2 ⁺	ap	3.9
[642]5/2 ⁺	[512]5/2 ⁻	5 ⁻	p	< 0.1
[642]5/2 ⁺	[512]5/2 ⁻	0 ⁻	ap	2.8

Fig. 1 $B(M1)$ values calculated with the particle-rotor model (solid lines) and the strong coupling limit (dashed lines) for the 2-qp configurations shown.

this case the $B(M1)$ values can serve as a probe of the $j_{15/2}$ neutron alignment.

Of special interest are some cases where the parallel ($K_> = \Omega_p + \Omega_n$) and antiparallel ($K_< = |\Omega_p - \Omega_n|$) coupling schemes of the proton and neutron K quantum numbers gives rise to drastically different $B(M1)$ values. For many configurations expected near the yrast line, the $K_>$ band has parallel intrinsic spins, and consequently has smaller $B(M1)$ values than the $K_<$ band. The $K_>$ band is then favored energetically by the Gallagher-Moszkowski rule [6] as well as by the rotational energy term, $(I(I+1) - K^2)$, as compared to the $K_<$ band. If K partner bands could be identified from their $M1$ properties, then their energy splitting would provide important information on the residual proton-neutron interaction at extreme deformation. Additional information on the residual p-n interaction might be obtained by extracting Newby shifts [7] from the signature splitting in $K=0$ bands. Two such bands, the $\pi[514]9/2^- \otimes \nu[624]9/2^+$ and the $\pi[642]9/2^+ \otimes \nu[512]5/2^-$ $K^\pi=0^-$ bands, should have large $B(M1)$ values, and if the Newby shift is small, then these bands could be identified by a characteristic pattern of interweaving $M1$ transitions with some energy staggering. The Newby shift for the $\pi[514]9/2^- \otimes \nu[624]9/2^+$ $K^\pi=0^-$ configuration has recently been estimated from experimental data in Hf nuclei (at normal deformations) and a value of -2 keV is reported [8]. If this small value is also appropriate for the SD configuration, then the energy staggering in that band would be clearly observable but not so large as to distort the expected pattern of very strong $M1$ transitions interweaving between the signature partners as estimated in table 1.

Thus, $M1$ transitions can give information not only on the magnetic properties (which in principle could be modified by the superdeformation) but also on which single-particle states are occupied, the degree of alignment of some high- N particles, and on the effective two-body residual interactions.

A letter describing these results is nearing completion.

2. Shape Coexistence in ^{187}Au

(with D. Rupnik, E. F. Zganjar, J. L. Wood and W. Nazarewicz)

Prolate-oblate shape coexistence has been known for many years in the region of Pt, Au and Hg nuclei, and particle + triaxial rotor calculations based on the Woods-Saxon potential have been undertaken in order to characterize the underlying nuclear shapes and better quantify

the degree with which shape-fixed models can describe the available low energy, low spin data (including recent UNISOR radioactive decay experiments). These calculations complement the predicted bandhead deformations given in [9] and the potential energy surfaces for the even-even neighbors in [10] since the particle-rotor model can be used to predict additional observable features not available from the bandhead or PES calculations alone and uses the same Woods-Saxon potential. Therefore, this approach aims to test our understanding of shape coexistence and shape polarization induced by an unpaired particle.

Detailed calculations have been made for the low-lying positive parity states (based mainly on the $s_{1/2}$, $d_{3/2}$ and $d_{5/2}$ spherical shell model states), and negative parity states based mainly on the $h_{11/2}$, $h_{9/2}$ and $f_{7/2}$ orbitals. The results for the positive parity states and the $h_{11/2}$ band are qualitatively consistent with the scheme of a proton coupled to the coexisting oblate (or triaxial) and prolate structures in ^{188}Hg (e.g., as in [10]). The bandhead calculations [9] show weakly deformed ($\beta \approx 0.15$) prolate and oblate minima for these states, but were constrained to axial symmetry and the presence or absence of a barrier in the gamma plane was not investigated. Our results find no evidence for a weakly deformed prolate structure, but indicate that a triaxial (or effectively triaxial) description is appropriate.

The bands built on the $h_{9/2}$ and $f_{7/2}$ orbitals are particularly interesting because their deformed orbitals near the Fermi level are strongly downsloping in a Nilsson diagram, and play a key role in stabilizing the prolate configurations. According to [10], the $h_{9/2}$ orbitals are occupied by at least a pair of protons in the prolate configurations of the even-even Hg and Pt isotopes, while the $h_{9/2}$ orbitals are empty for the oblate.

The experimental bands at low energy in ^{187}Au built on these orbitals display a decoupled structure and are rather well described with a near prolate shape, $\beta=0.21$, $\gamma = 20^\circ$ (similar to the prolate "core" for ^{186}Pt). The degree of triaxiality is determined by the signature splitting between the favored sequence of the $h_{9/2}$ band (containing states with $I=9/2 \pm 2n$) and the other sequence of states with $(I=9/2 \pm 2n - 1)$, as well as the $B(E2; 5/2^- \rightarrow 9/2^-)$. The other sequence is not just the unfavored $h_{9/2}$ since it also contains some $f_{7/2}$ character. At this moderate deformation, a second sequence with $I=3/2, 7/2, 11/2$ is expected, and experimentally observed. Additional states, not accounted for by this calculation begin with a $9/2^-$ state 323 keV above the lower $h_{9/2}$ bandhead. Remarkably, these extra states display the same sequence

of spins as the lower $h_{9/2} + f_{7/2}$ bands, and show connecting E0 transitions only between the favored $h_{9/2}$ states, i.e., from the excited $9/2'$, $5/2'$, $1/2'$, $13/2'$, and $17/2'$ but not from the other set of states, with $I=7/2, 3/2, 11/2$. The general pattern of states clearly implies a prolate or near prolate shape, and a somewhat smaller deformation ($\beta \approx 0.17$) is suggested by the smaller moment of inertia exhibited by the excited bands. Thus, the coexisting $h_{9/2}$ structure does not reflect the low-lying oblate states in the ^{186}Pt core, but indicates a second prolate structure! This result was completely unexpected, and is not predicted in [Na90], which shows coexisting prolate and oblate $h_{9/2}$ bands. These results raise a number of intriguing questions: What is the underlying structural difference between these two prolate $h_{9/2}$ bands? Why are the E0 transitions seen only between the favored states in the $h_{9/2}$ band, and not in the unfavored? The usual description of E0 transitions [11] implies strong mixing between coexisting shapes; how can strong shape mixing be reconciled with the apparent success of these shape-fixed particle-rotor calculations?

A short letter describing the $h_{9/2}$ results is near completion and a longer article describing the rest of the ^{187}Au data and theoretical analysis is in preparation.

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APPENDIX I PERSONNEL

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APPENDIX II

PUBLISHED ARTICLES

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PUBLISHED CONFERENCE CONTRIBUTIONS

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