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LLNL Nuclear Isomer Group

Group Members

Scientific Staff: John Becker, Gene Henry

Research Associates: M. J. Brinkman, J. R. Hughes, L. P. Farris

Physics being addressed/goals:

Our goal: Understanding the physics of nuclei at the limits of deformation. Superdeformed nuclei (i.e., nuclei with a major-to-minor axis ratio of $\sim 2:1$) provide a unique laboratory for nuclear structure studies at the limits of observable deformation. Islands of superdeformation are predicted and found throughout the table of isotopes. We have focused our attention on the $A = 190$ region, since neutron deficient Hg and Pb nuclei were predicted to support a stable superdeformed minimum at zero angular momentum. We are making major contributions to the development of this region of superdeformation. We find general agreement with fully 3-D Hartree Fock calculations done with a microscopic interaction, including pairing (and recently cranking). Our measurements test predictions in the second well which are based on extrapolation of nuclear theory determined at 'normal' deformation. In addition, unusual phenomena are expected because of the large difference in shape between well I and well II states. Our experiments require the sensitivity and resolution of large scale Ge detector arrays.

Accomplishments/Highlights (1992-94):

We developed the isthmus of superdeformation near $A = 190$ with the following activities:

- Extent of the $A=190$ region — Au, Hg, Tl, and Pb.
  - First evidence of superdeformation in $^{192,193,194}\text{Hg}$, $^{192,194-6,198}\text{Pb}$, $^{194,195}\text{Tl}$, ^{191}Au .
- Demonstrated collectivity with first lifetime measurements of SD cascades in ^{194}Pb , ^{194}Hg .
- Demonstrated stiffness of Well II with first lifetime measurements of an excited SD band (^{194}Hg).
- Assigned level spins to SD band members near $A = 190$.
- Proposed quantized alignment and identical bands in $A=190$ region.
- Made the first observation of oblate bands in $^{196,197,198}\text{Pb}$, $^{193,196}\text{Hg}$.
- Identified candidates for discrete line decay of SD ^{194}Pb . Hence E_x and I^π of SD band members can be deduced.
- Helped install GAMMASPHERE Early Implementation.
- Developed USORTX, an X-Windows based event tape sorting package, and BitStream Merge, a data compression algorithm, to process data streams from large detector arrays.

Funding Support (FY92-FY94):

	FY92	FY93	FY94
Operating Expense	\$0	\$60K	\$60K
Capital Equipment	\$0	\$0	\$0
Total	\$0K	\$60K	\$60K

MASTER

Narrative

Motivation

Nuclear theory predicts well developed secondary minima in the energy surface of nuclei in mass regions throughout the nuclear periodic table. These secondary minima are deep enough to support quasi-stationary states, which have very small overlap with first well states. Related states have been found in heavy nuclei with $A=135$, $A=150$, and most recently, $A=190$, in addition to the fission isomers. Current experimental activity is aimed at gaining understanding of the detailed nuclear structure of these regions. The study of second well states is especially interesting because: (i) Theoretical predictions in the second well are based on extrapolation of nuclear theory determined at 'normal' deformation. However, these states, like the fission isomers, have a shape very different than the nuclear ground state, and the validity of this extrapolation is not clear. (ii) Unusual phenomena are expected because of the large difference in shape between well I and well II states.

The LLNL experimental work emphasizes the $A = 190$ region because microscopic Hartree Fock calculations by the LLNL nuclear theory group and their collaborators predicted deep secondary minima at zero spin for neutron deficient Hg and Os nuclei, and decay by fission for low excitation is forbidden. (^{194}Hg was predicted to have $E_x = 4$ MeV and $E_{\text{depth}} = 2$ MeV, eg.) Experimental studies of these states are very difficult because of the small production cross section and the background of similar signals produced by the first well states and other reaction channels. Our work is done primarily at the 88-Inch Cyclotron Facility. This facility is especially suitable for this investigation, because (i), a wide variety of energetic beams is provided, and (ii), a modern Ge detector array of large granularity is available for spectroscopy, initially HERA and now Gammasphere Early Implementation. The experimental signal sought was the decay of the rotational cascade built on the shape isomer band head, a high multiplicity event.

Our experiments have been done primarily in collaboration with the Nuclear Structure group at LBL, and with our collaborator from Rutgers University, J. Cizewski. Some experiments have been done with the Bonn and recently the ANL groups.

Accomplishments

Figure 1 is a schematic map of superdeformation near $A = 190$. Our collaboration has played a leading role in addressing the physics issues and pioneered development of this map. Our present contributions include:

- Extent of the region. Our collaboration extended superdeformation in Hg, with the 2nd, 3rd and 4th observation of superdeformation in ^{192}Hg , ^{194}Hg , and ^{193}Hg .
- Establishment of the region. We extended superdeformation beyond Hg with the first instance of superdeformation in the Pb isotopes, $^{194,196}\text{Pb}$ [Brinkman, *et al.*, Z. Phys. A 336, 115(1990)], and subsequently in ^{192}Pb (#2), and ^{198}Pb (#1).

This was followed by the initial observation of superdeformation in ^{194}Tl and subsequently, 6 SD bands in that nucleus, (#10) the first observation of SD bands in ^{195}Tl (#10), and the first observation of superdeformation in ^{191}Au . (#13) [Complete references are included in #3.] Observations agree with theory which predicts an extensive region of superdeformation in this mass region. (Krieger, *et al.*, Nucl. Phys A542, 43(1992))

- Well depth. The first instance of multiple bands in this mass region, ^{194}Hg and ^{193}Hg [Henry, *et al.*, Z. Phys. A 336, 115(1990)]. This suggests a potential deep enough to support multiple bands.
- Identical Bands and quantized alignment. The first report of identical band transition energies in this mass region [Henry, *et al.*, Z. Phys. A 336, 115(1990)] and possible pseudo spin interpretation (#8) and the first report of quantized alignment in this mass region. (#9)
- Spin assignments. Spin assignments for SD band members were made based on comparison of transition energies with rotational model predictions. (#3) Level spins are important for interpretation.
- Collectivity and deformation. Measurement of the inband transition rate in ^{194}Pb (#13) and an early unpublished value for ^{194}Hg . The transition quadrupole moment is $\overline{Q}_t = 20 - 22 e b$. Q_t (within errors) is constant within the band, which suggests that the nucleus does not stretch with increasing rotational frequency, $\hbar\omega$. The lifetimes of the SD band levels can be simply related to a quadrupole deformation, modeling the nucleus as a prolate spheroid. The deformation corresponds to a semi-major/minor axis ratio $\approx 1.5/1$. Microscopic mean field calculations suggest that the mean field adjusts itself with increasing rotational frequency so that the deformation remains constant, in agreement with experiment.
- Oblate Bands in Pb and Hg Nuclei. We obtained evidence for regular and irregular $\Delta L = 1$ cascades in $^{194,196-8}\text{Pb}$, and in $^{193,196}\text{Hg}$. [Ref: Brinkman, PhD thesis, #4-6, Roy, *et al.*, Phys. Rev. C R930(1993) and Cederwall, *et al.*, Phys. Rev. C R2443(1993)]. Excitation energies are on the order of $\approx 3 - 5$ MeV, and rough estimate of band head spins are $20\hbar$. The long cascades in Pb are especially interesting because Pb with $Z = 82$ is a closed shell nucleus. Our initial measurements of the large inband M1 strength in ^{198}Pb , ($B(M1) \approx 1 - 2$ Wu, $B(E2) \approx 10$ Wu), (#5) and subsequently in ^{197}Pb , (#12) are seminal to the application of Tilted Axis Cranking to these nuclei, particularly the Pb nuclei.

Recent Contributions

- Excitation of well II. We have identified candidates for discrete transitions connecting the SD band with low lying states in the first well in ^{194}Pb . This very exciting result, if confirmed, establishes the excitation of the SD band in ^{194}Pb , shows that decay by discrete γ -ray emission is important for this SD band (as

opposed to statistical γ -ray emission), confirms the spin assignment we made from comparison with the Bohr formula, (#3) and fixes level parity. The results suggest $E_x = 5.1$ MeV, while HF theory predicts 4.86 MeV.

- Superdeformation in ^{195}Pb . Superdeformation was known only in even-even Pb until we observed 4 SD bands in ^{195}Pb in an Early Implementation experiment.
- Stability of well II. Level lifetimes of the yrast and one excited SD band in ^{194}Hg have been measured. (Hughes, *et al.*, Phys. Rev. Lett. in press.) The excited band twins with ^{192}Hg . The bands can be approximately described by a constant Q_t over a wide rotational frequency. Average transition quadrupole moments are $\overline{Q_t} = 17.6(30)$ and $17.2(20)$ $e b$, respectively. The similar $\overline{Q_t}$ for the two bands suggests that the second well is stable with respect to particle excitations. This measurement is the first for an excited SD band, and together with the accuracy achieved, demonstrates the increased sensitivity and resolving power of Gammasphere compared to earlier arrays.

Near Future Plans

Exciting physics has come from the study of SD nuclei at low spin in the $A = 190$ region. Some of the physics is not yet understood, and some requires refinement of preconceived ideas. Large scale detector arrays offer an unprecedented opportunity to identify the signatures of processes with small cross sections in a background of similar events, as the Gammasphere Early Implementation program has demonstrated. Auxiliary detectors expand the opportunities further. Our work will continue to emphasize SD nuclei with $A = 190$ and heavier, since calculations suggest low spin states can be accessed. Thus the bandhead should be accessible and it may be possible to observe the electromagnetic analog of the fission isomer decay. The main thrust of our work will use heavy-ion accelerators and large scale γ -ray detectors, coupled with auxiliary detectors as they become available. Our plans also include light ion bombardments and decay studies to populate low angular momentum states directly.

Figure 1: Map of the $A=190$ superdeformed region.

LLNL Experimental Group Bibliography (1991–1993)

1. "Superdeformation in $^{198,196}\text{Pb}$," T. F. Wang, *et al.*, Phys. Rev. C **43**, R2465 (1991).
2. "Observation of a Superdeformed Band in ^{192}Pb ," E. A. Henry, *et al.*, Z. Phys. A **338**, 469 (1991).
3. "Level Spin for Superdeformed Nuclei Near $A = 194$," J. A. Becker, *et al.*, Phys. Rev. C **46**, 889(1992).
4. "Oblate Collectivity in ^{197}Pb ," A. Kuhnert, *et al.*, Phys. Rev. C **46**, 133 (1992).
5. "First Lifetime Measurement of Dipole Collective Bands in Neutron Deficient Lead Nuclei," T. F. Wang, *et al.*, Phys. Rev. Lett. **69**, 1737(1992).
6. "Collective Oblate Bands in ^{196}Pb " J. R. Hughes, *et al.*, Phys. Rev. C **47**, R1337(1993).
7. "Collective Band in ^{193}Hg with $E_x \geq 5.7$ MeV" N. Roy, *et al.*, Phys. Rev. C **47**, R930(1993).
8. "Spin Alignment in Superdeformed Hg Nuclei," F. S. Stephens, *et al.*, Phys. Rev. Lett. **64**, 2623 (1990).
9. "Pseudospin Symmetry and Quantized Alignment in Nuclei," F. S. Stephens, *et al.*, Phys. Rev. Lett. **65**, 301 (1990).
10. "Six "Identical" Superdeformed bands in ^{194}Tl ," F. Azaiez, *et al.*, Phys. Rev. Lett. **66**, 1030 (1991); *errata*, Phys. Rev. Lett. **66**, 1030(1991).
11. "Search for the Population of the ^{194}Pb Superdeformed Band using ^{194}Bi β^+ Decay", M. A. Stoyer, *et al.*, Phys. Rev. C **47**, 76 (1993).
12. "Lifetime Measurements in the $\Delta I = 1$ Oblate Band in ^{197}Pb ", J. R. Hughes, *et al.*, Phys. Rev. C **48**, R2135(1993).
13. "Superdeformation in ^{191}Au ", D. T. Vo, *et al.*, Phys. Rev. Lett. **71**, 340(1993)
14. "Transition Quadrupole Moments of Superdeformed States in ^{194}Pb , P. Willsau, *et al.*, Z. Phys. A **344**, 351(1992).
15. "Shape-Coexistence in Pb, Oblate and near Oblate Collectivity," M. J. Brinkman 1992 DNP/APS Meeting, BAPS 37, 1312(1992).
16. "Lifetimes near $A = 194$," J. A. Becker, ACS Symposium on "Nuclear Structure Research with New Arrays and Detectors," Chicago, August 23-26, 1993.
17. "Properties of Collective Oblate Bands in Pb," E. A. Henry, 1993 DNP/APS Workshop BAPS 38, 1792 (1993).
18. Omitted: 14 Publications in refereed journals, 9 Invited Talks, and 53 Contributions to conferences, workshops, and meetings.

Biographical Sketch

J. A. Becker

PhD Physics, 1962, Florida State University

Senior Physicist, N-Division, Lawrence Livermore National Laboratory

Fellow, American Physical Society; Senior Research Fellow, Science Research Council

Experimental nuclear physicist. Activities emphasize gamma-ray, charged-particle, neutron, and fission fragment spectroscopy. Experimental results are interpreted in terms on nuclear models. Technical skills include extensive experience with nuclear counting instrumentation, computer based data acquisition and analysis, and main frame computation.

GAMMASPHERE Executive Users Committee, 1993–

88-Inch Cyclotron Executive Users Committee, 1992–

GAMMASPHERE Software Working Group, Auxiliary Equipment Working Group

E. A. Henry

PhD Physics, 1972, Iowa State University

Senior Chemist, Nuclear Chemistry Division, Lawrence Livermore National Laboratory

Experimental nuclear physicist. Research activities emphasize inbeam gamma-ray and conversion-electron spectroscopy, beta decay, and nuclear structure.

Member, GAMMASPHERE Auxiliary Equipment Working Group, 1992–

DOE GAMMASPHERE Review Committee, 1993

Member, American Physical Society, Nuclear Chemistry and Technology Section of American Chemical Society.

Sixty publications in refereed journals, eleven invited talks.

Students and Former Research Associates

Students	Degree, Year	Thesis Title	Present Position
M. J. Brinkman	PhD 1991	Superdeformation in the A~190 Mass Region and Shape Coexistence in ^{194}Pb	LLNL Postdoctoral

Research Associates	Years	Present Position
N. Roy	3	Unemployed
A. Kuhnert	2.5	Cal Tech Staff
T. F. Wang	1	LLNL Staff
M. Stoyer	2.5	LBL Postdoctoral

END

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