Radiochemical Investigations of Nuclear Properties

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**RADIOCHEMICAL INVESTIGATIONS OF
NUCLEAR PROPERTIES**

Progress Report

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Abstract

Investigations of the structure of transitional nuclei in the region below ^{208}Pb have been continued, and considerable progress has been made in establishing and characterizing the principal high-spin excitation modes in these nuclei. Most of the experiments were performed by in-beam γ -ray spectroscopy using beams of ^3He and ^4He ions from the Michigan State University cyclotron. The main results of $(\alpha, x\text{n}\gamma)$ studies of nine Pt nuclei ($A=186-194$) are briefly summarised. The most fruitful new study undertaken has been the first investigation of the semi-magic nuclei ^{203}Pb , ^{201}Pb , ^{199}Pb , ^{197}Pb and ^{195}Pb . Strong yrast cascades terminating in $\nu i_{13/2}^{-1}$ isomeric states have been observed in all five nuclei, many high-spin multiple neutron hole isomers have been identified, and the isomeric decay schemes have been established. A new study of ^{200}Hg has located the predicted even-spin members of the known 5^- semidecoupled band; on the other hand, a perplexing problem in interpreting the positive parity level structure of the same nucleus has been encountered. Results of a study of the N-83 nucleus ^{149}Dy , already published, are also very briefly outlined.

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I. Research Activities

During the past year, our program of investigations of the structure of heavy nuclei has been vigorously pursued, and considerable progress has been made in establishing and characterizing the principal high-spin excitation modes in these nuclei. Most of the experiments were performed at the Michigan State University cyclotron laboratory in collaboration with F. M. Bernthal and T. L. Khoo. In the following sections, a summary of the main results obtained is given, with the emphasis on the more significant newer findings which have not already been written up in final manuscript form.

High-spin Level Structure of Pt Nuclei

In last year's annual report¹⁾, we reviewed the results of extensive investigations of the nine Pt nuclei ($A=186-194$) by both $(\alpha, x\gamma)$ and radioactive decay spectroscopy. The most noteworthy findings were 1) the observation of extremely acute backbending-type behavior in the ground bands of the even- A nuclei, which we attributed to intersection with rotation-aligned structures of both $(\nu i_{13/2}^{-2})$ and $(\pi h_{11/2}^{-2})$ character. 2) persuasive evidence for rather stable triaxial nuclear shapes in this region, obtained in analyses of extensive $(\nu i_{13/2}^{-1})$ level families in the odd- A nuclei.

Final analyses of the data performed during this contract year tended to strengthen these conclusions and a series of papers setting out the detailed results and implications have been prepared and submitted for publication. At the time of writing, four papers have appeared in print and a fifth is in press. During the coming year, attempts will be made to solve a few remaining puzzles in interpreting the spectra of the more neutron deficient Pt nuclei.

Multiple Neutron Hole Excitations in Light Odd-A Pb Nuclei

The most fruitful new study undertaken during the year has been the first investigation of the high-spin level spectra of the semi-magic nuclei ^{203}Pb , ^{201}Pb , ^{199}Pb , ^{197}Pb and ^{195}Pb . These experiments were performed at the M.S.U. cyclotron laboratory by means of $(\alpha, xn\gamma)$ and $(^3\text{He}, xn\gamma)$ reactions on isotopically enriched Hg targets.

Strong yrast cascades terminating in $\nu i_{13/2}^{-1}$ isomeric states have been observed in all five nuclei. Isotopic identifications have been based on excitation function measurements and on the requirement of intensity balance, at all bombarding energies, between the transitions populating and depopulating the well-established $13/2^{+}$ isomers. The experiments have included γ -ray singles and comprehensive $(\gamma\gamma t)$ coincidence measurements, γ -ray angular distributions and lifetime determinations spanning the range from 2 ns to many seconds. In all of the odd-A Pb nuclei, several new isomers have been located and characterized.

In general, a very close correspondence has been found between the levels built on the $\nu i_{13/2}$ isomer in each of the odd-A nuclei and the high-spin neutron hole excitations previously identified^{2,3)} in the adjacent even-A Pb core nucleus.

The nucleus ^{203}Pb : A pulsed beam $^{202}\text{Hg}(\alpha, 3n\gamma)$ experiment revealed a new ^{203}Pb isomer with $t_{1/2} = 0.48 \pm 0.04$ sec, which de-excites through high-spin positive parity levels to the known 6.2-sec $13/2^{+}$ isomer at 825 keV. From γ - γ coincidence data and transition multipolarities based on intensity balance requirements and on prompt angular distribution measurements, the complete isomeric decay scheme shown in Figure 1 has been firmly established. The 0.5-sec isomeric state is assigned $J^{\pi} = 29/2^{-}$, and since this state can be attributed to the coupling of the ^{204}Pb 9^{-} state (Fig. 1) with the additional $\nu i_{13/2}$ hole,

the dominant neutron hole configuration $(p_{1/2}^{-2})_0^+$, $f_{5/2}^{-1}$, $i_{13/2}^{-2}$ is confidently proposed. For the lower-lying even parity states, a weak coupling interpretation is strongly indicated.

The nuclei ^{201}Pb and ^{199}Pb : These nuclei have been investigated by $(\alpha, 3n\gamma)$ reactions on ^{200}Hg and ^{198}Hg targets. Three new isomers have been identified in each nucleus, as is shown in simplified level schemes of Fig. 2. The closely lying $17/2^+$, $15/2^+$ and $19/2^+$, $21/2^+$ doublets are almost certainly components of weak coupling multiplets associated with the 2_1^+ and 4_1^+ collective states of the ^{202}Pb and ^{200}Pb core nuclei. It is evident from the structure of the yrast cascades, that the missing members of the weak coupling multiplets in ^{199}Pb , ^{201}Pb (and in ^{203}Pb) would scarcely be observable by these experimental methods.

The systematics of the negative parity states also manifest the intrinsic relationship between the prominent high-spin features of the odd-A and even-A level spectra. The change in the negative parity level ordering of both odd-A and even-A nuclei below ^{204}Pb , ^{203}Pb can readily be correlated with the location of the Fermi surface (closer to the $p_{3/2}$ subshell than the $f_{5/2}$) in the lighter nuclei, since the dominant active components in the intrinsic structures are almost certainly

$$\begin{aligned} 21/2^-: & \quad \nu i_{13/2}^{-2}, \nu p_{3/2}^{-1} + \dots \\ 25/2^-: & \quad \nu i_{13/2}^{-2}, \nu p_{1/2}^{-1} + \nu i_{13/2}^{-2}, \nu p_{3/2}^{-1} + \dots \\ \text{and } 29/2^-: & \quad \nu i_{13/2}^{-2}, \nu f_{5/2}^{-1} + \dots \end{aligned}$$

The nuclei ^{197}Pb and ^{195}Pb : These nuclei have been studied by $(^3\text{He}, 4n\gamma)$ and $(^3\text{He}, 6n\gamma)$ reactions on a ^{198}Hg target. In ^{197}Hg , the $21/2^-$ level occurs at such a low energy that it is a rather long-lived isomer ($t_{1/2} = 1.5 \pm 0.1 \mu\text{s}$) and the $17/2^+$, $15/2^+$ and $19/2^+$, $21/2^+$ weak coupling doublets have again been

observed here (Fig. 2). At the time Fig. 2 was prepared, our investigation of the ^{195}Pb level structure had not yet been completed, but we have now established quite definitely that the 10- μs isomer previously attributed³⁾ to ^{194}Pb should be reassigned to ^{195}Pb . (Here again, the μs lifetime is associated with the de-excitation of the $21/2^-$ state.)

The analysis and contemplation of these results is continuing with particular emphasis on the comparison between modes of excitation and reduced transition probabilities in the odd-A and even-A Pb nuclei, and on the weak coupling aspects of the level spectra.

The Strange Case of ^{200}Hg

The high-spin spectra of Hg nuclei, both even- and odd-A, have been intensively studied^{4,5)} in recent years. Systematic irregularities in the even-parity level structures of the even-A nuclei, characterized by a low-lying 8^+ , 10^+ doublet in each nucleus, have generally been attributed to intersection of the ground-bands by $\pi h_{11/2}^{-2}$ rotation-aligned bands. We have studied the reaction $^{198}\text{Pt}(\alpha, 2n\gamma) ^{200}\text{Hg}$ using in-beam techniques and established a detailed ^{200}Hg level scheme, the principal features of which are shown in Fig. 3.

The sequence of 5^- , 7^- , 9^- , 11^- levels, connected by enhanced E2 transitions, was first observed in an earlier radioactivity study in this laboratory⁶⁾, and subsequent work established similar 5^- bands in other even-A Hg, Pt and Os nuclei. Calculations by Neergard et al.⁷⁾ indicate that these bands can be understood as semidecoupled bands involving dominant two-quasi-particle components of the type $(\nu i_{13/2}^{-1}, \nu j^{-1})$. These calculations also predicted a somewhat higher energy sequence consisting of even-spin odd-parity levels starting with 6^- . The present experiment has located exactly such a

sequence of levels in ^{200}Hg , with level energies and reduced transition probabilities in remarkably good agreement with the theoretical predictions, thus lending forceful support to the semidecoupled band description.

However, the most intriguing feature of the results concerns the positive parity levels. Even though the coincidence data were of exceptionally high quality, no transition which could reasonably be interpreted as $8^+ \rightarrow 6^+$ was observed. If an 8^+ , 10^+ doublet exists in ^{200}Hg at about the same energy as in other even-A Hg nuclei, the population of these levels in the $(\alpha, 2n)$ reaction is less than 0.2% of the total ^{200}Hg formation cross-section. One is forced to speculate that either

- 1) there are no 8^+ and 10^+ levels at about 2600 keV in ^{200}Hg . If this is true, a radical reappraisal of currently accepted ideas on the nature of high-spin excitations in the $A=190-200$ transitional region would seem to be called for
- 2) there are 8^+ and 10^+ levels with the expected properties in ^{200}Hg , but they are negligibly populated in the $(\alpha, 2n)$ reaction because of some little known feature of the reaction mechanism

These two alternative conclusions seem equally difficult to accept. It is most interesting to note that the lowest even-parity level identified above the 6^+ is the 12^+ at 3215 keV, which is very close to the energy of the 12^+ state of $(\nu 1_{13/2}^{-2})$ character in the isotone ^{202}Pb . We plan further experiments aimed at resolving the perplexing problems posed by the even-parity level structure of ^{200}Hg .

The N=83 Nucleus ^{149}Dy

In last year's annual report¹⁾, brief mention was made of the principal investigator's participation in $(\alpha, 7n\gamma)$ and $(\alpha, 8n\gamma)$ experiments at the Jülich cyclotron in late summer, 1975. Since then, the final analysis of the data

has been completed and a paper describing the first results for the N=83 nucleus ^{149}Dy has been published⁸⁾. The principal findings are illustrated in Fig. 4; of particular interest here is the $27/2^-$ 0.5 sec isomer, which is interpreted as the $(\pi h_{11/2})^2_{10^+} (\nu f_{7/2})$ three-particle configuration on the doubly closed shell nucleus ^{146}Gd .

Summary.

The research performed during the contract year followed the outline submitted in our renewal proposal fairly closely, but in one respect we were forced to alter plans. We had hoped to start the proposed studies of very neutron deficient Pt nuclei using high-energy α -particle beams from the Indiana University Cyclotron (IUCF) many months ago. However there was a policy switch at IUCF which resulted in the postponement of α -beam development in favor of more exotic (but to us less useful) beams. Although beam-time has been allotted to our experiments, it is still unclear when we can get on the air at IUCF. On the other hand our Pb investigations at M.S.U. have extended far beyond the program proposed, and five nuclei, rather than two, have been rather thoroughly explored.

The principal investigator has devoted approximately 50% of his time and effort to this project during the contract period and he expects that this will continue for the remainder of the year.

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Figure Captions

- Fig. 1. The new 0.5 sec $29/2^-$ E3 isomer in ^{203}Pb and its decay scheme.
- Fig. 2. High-spin level systematics in the semi-magic Pb nuclei. Data for the even-A nuclei are from the literature and for the odd-A nuclei from the present work.
- Fig. 3. Main features of the ^{200}Hg high-spin level spectrum.
- Fig. 4. Partial level scheme of ^{149}Dy .

12^+ --- 158ns
 10^+ 304

12^+ --- 221ns
 10^+ ---

12^+ --- 295ns
 10^+ 2644

9^- 2307 51ns
 7^- 2169 < 5ns

(25/2⁺) 1981

5^- 1797 130ns
 4^+ 1738

(21/2⁺) 1556 10.0 μ s
(19/2⁺) 1551

(21/2⁺) 1594 1.5 μ s
 $21/2^+$ 1562
 $19/2^+$ 1537

(17/2⁺) 970

2^+ 1049

$15/2^+$ 1082
 $17/2^+$ 1005

2^+ 1063

$15/2^+$ 1012
 $17/2^+$ 977

2^+ 1026

$15/2^+$ 917
 $17/2^+$ 913

2^+ 961

$17/2^+$ 839

2^+ 899

9^- --- 3.7 μ s
 7^- 2140 < 5ns
 $29/2^-$ --- 10.6 μ s
 $25/2^-$ 2075 33ns

5^- 1822 49ns

4^+ 1625

$21/2^-$ 1702 3.6ns

(19/2⁺) 1547

$21/2^+$ 1417
 $19/2^+$ 1401

9^- 2237 480ns
 7^- 2153 44ns

5^- 1908 1.3ns

4^+ 1762

4^+ 1488 0.33ns

$29/2^-$ --- 540ns
 $25/2^-$ 2089 55ns

$21/2^-$ 1867

$21/2^+$ 1273
 $19/2^+$ 1267 3.2ns

(7⁻) 2208 42ns
 9^- 2170 3.6h

5^- 2040

4^+ 1623

4^+ 1383 2ns

$29/2^-$ 2124 0.48s

$23/2^+$ 1971

(21/2⁺) 1336
(19/2⁺) 1293

$19/2^+$ 1119
 $21/2^+$ 1097 42ns

5^- 2258
 9^- 2185 67min
 5^+ 2065

(4)⁺ 1817

4^+ 1563

4^+ 1274 260ns

$13/2^+$ 0
 195 Pb

0^+ 0
 196 Pb

$13/2^+$ 0
 197 Pb

0^+ 0
 198 Pb

$13/2^+$ 0
 199 Pb

0^+ 0
 200 Pb

$13/2^+$ 0
 201 Pb

0^+ 0
 202 Pb

$13/2^+$ 0
 203 Pb

0^+ 0
 204 Pb

^{200}Hg