Clark University
Department of Chemistry

Annual Progress Report
January 1, 1973 - November 30, 1973

Nuclear Spectroscopy

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Daeg S. Brenner
Principal Investigator

MASTER

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I. General

A. Introduction

The nuclear chemistry research program at Clark University is concerned with experimental determination of the energy level structure of nuclei with permanently deformed ground-state configurations. These ends are accomplished by measurement of the radioactive decay of sources prepared at various nuclear facilities. In recent years our work has been oriented toward use of the Yale University Heavy-Ion Accelerator. During the latter months of the period covered by this report the principal investigator has been on sabbatical leave at the Lawrence Livermore Laboratory and a portion of this report deals with work done in conjunction with colleagues at Livermore, using facilities at Livermore and the Lawrence Berkeley Laboratory.

During this year another member of our group completed the requirements for the doctoral degree and left us to accept a teaching position at the level of assistant professor. We continue to be pleased to note that our graduates successfully enter and remain employed in positions where they make use of their training in nuclear science.

A year ago a significant improvement in the computer facilities at Clark University was implemented. The installation of an IBM 1130 computer linked to a remote CDC 6600 system has vastly improved our capability to digest spectral data. With this system we are now routinely using large data reduction programs such as SAMPO and have increased the productivity of our group significantly as a result.

For the immediate future we expect to continue our efforts in nuclear spectroscopy at the Yale HIA. In addition, we hope to initiate an ongoing series of cooperative projects with Dr. Richard A. Meyer and colleagues

at Livermore in continuation of several interesting projects begun during the sabbatical leave of the principal investigator. Also, with the start-up of the Bates Linac, we look with interest toward a joint effort in nuclear spectroscopy with Dr. Meyer, using this new facility. Funds for both of these projects will be requested for the coming year.

This report is concerned with research done during the 11-month period, January 1, 1973 - November 30, 1973. The reporting period has been shortened this year because of logistical problems in preparing the necessary documents while the principal investigator is on leave from Clark University.

B. Personnel

Dr. Daeg S. Brenner, Associate Professor, Chemistry Department

Mr. David L. Anderson, Graduate Student

Mr. Thomas J. Ruth, Graduate Student (terminated)

Mr. Norman A. Bouffard, Part-time Technician

Mr. Anderson and Mr. Ruth completed the requirements for the masters degree and their degrees were conferred in June, 1973. Subsequently, Mr. Ruth also completed the requirements for the Ph.D. He has joined the staff of Sacred Heart University, Bridgeport, Connecticut as an Assistant Professor of Chemistry. Mr. Anderson is engaged in research on a full-time basis and was awarded an NSF Traineeship this year.

C. Publication and Other Activities

1. Articles

"Levels in ^{186}Os as Populated from Decay of $15.8\text{-h }^{186}\text{Ir}$," K. J. Hofstetter, T. T. Sugihara and D. S. Brenner, to be published in Phys. Rev. C3, December, 1973.

"The Decay of ^{158}Er to Levels in ^{158}Ho ," T. J. Ruth and D. S. Brenner, to be submitted to Nucl. Phys.

"Levels in ^{158}Dy from Decay of ^{158}Ho ," T. J. Ruth and D. S. Brenner, to be submitted to Nucl. Phys.

2. Talks

"The Decay Chain, ^{158}Er to ^{158}Dy , Inclusive," 166th ACS National Meeting, Chicago, August, 1973, T. J. Ruth.

"The Structure of Even-A Deformed Nuclei in the Rare-Earth Region," Sacred Heart University, Bridgeport, Conn., March, 1973, T. J. Ruth.

"Nuclear Decay Scheme Studies of ^{186}Ir and ^{158}Er ," Lawrence Livermore Laboratory, December, 1973, D. S. Brenner.

3. Professional Activities

Daeg S. Brenner:

Member: American Chemical Society, American Physical Society, Sigma Xi, Phi Lambda Upsilon, Yale HIA User's Group, Berkeley Super Hilac User's Group.

Research Collaborator - Brookhaven National Laboratory

Participating Guest - Lawrence Livermore Laboratory

Associate Chairman - Chemistry Department, Clark University,
until 6/1/73.

II. Completed Work

A. Nuclear Spectroscopy

Levels in ^{186}Os as Populated from Decay of 15.8-h ^{186}Ir . Hofstetter (Kentucky), Sugihara (Texas A&M) and Brenner

The level scheme of ^{186}Os as populated by the decay of 15.8-h ^{186}Ir has been studied using Ge(Li) detectors in singles and coincidence spectrometers. The coincidence data confirm essentially all of the previously known intraband and interband transitions assigned to the ground-state band (to the 6^+ level), the γ -band (to the 7^+ level), and to the $I = 4, 5$ and 6 members of the two-phonon $K=4$ band. Coincidence data also establish levels in keV at 1194.45, (4^+); 1461.09, 4^+ ; 1480.3, 4^+ ; 1628.3, 5^- ; 1775.8, 6^+ ; 1812.5, 5^+ ; 1875.40, 4^+ ; 2056.38, (5^+ , 6^+); 2081.21, 4^+ ; 2377.3, (5^+ , 6^+); and 2771.7, 4^+ . The I^π assignments are based on multipolarities determined from internal conversion coefficients. Additional levels based on energy sums are tentatively proposed at 1582.3, 2661.2, 3041.3, 3151.7, 3268.8 and 3413.6 keV (see Fig. 1). The 15.8-h ^{186}Ir state is believed to have $I^\pi = 5^+$ and an argument is presented based on the β -decay pattern that $K=1$.

III. Work in Progress

A. Nuclear Spectroscopy

1. The Decay Chain ^{158}Er to ^{158}Dy , Inclusive. Ruth and Brenner

The decay of 2.3-h ^{158}Er and $^{158\text{m}}, ^{158}\text{Ho}$ produced by (heavy ion, xn) reactions on isotopically enriched rare-earth targets has been studied by γ -ray singles and coincidence spectroscopy using Ge(Li) detectors. Results were extracted from the experimental data by the computer code SAMPO. The conversion electron results of Harmatz and Handley (^{158}Ho)¹ and Abdurzakov et al., (^{158}Dy)² were combined with the γ -ray results of the present study to calculate conversion coefficients and deduce multipolarities. Nearly 150 γ -transitions have been assigned to the $A=158$ decay chain among levels in ^{158}Ho and ^{158}Dy (Figs. 2 and 3).

Combining the results of Harmatz and Handley with the results of this study confirmed levels with keV, I^π ; 67.3(2^-), 118.0(2^+), 139.3(1^-), 182.7(2^-), 315.9(1^+), 378.1(1^-), 408.8(2^+), 425.5(1^-), 454.2(1^-), 478.7 and 655.5(1^-). New levels were assigned at 710.6, 1070.7, 1335.5, 1340.8 and 1597.4 keV. Using the Gallagher-Moskowsky coupling rules for odd-odd nuclei and the energy level systematics of adjacent odd-A nuclei, Nilsson-state configurations were suggested for levels with a known spin. The half-life for β -decay of ^{158}Er was determined to be 2.27 ± 0.18 h.

The results of the study of $^{158\text{m},158}\text{Ho}$ decay confirmed the existence of previously proposed levels in ^{158}Dy : the ground-state rotational band $I^\pi K$ (keV); 2^+0 (98.9), 4^+0 (317.1) and 6^+0 (637.6); a γ -vibrational band, 2^+2 (946.2), 3^+2 (1044.7), 4^+2 (1163.7) and 5^+2 (1314.7); and a β -vibrational band, 0^+0 (991.1), and 2^+0 (1085.4). New results include the 8^+0 (1043.6) member of the ground-state rotational band; the 6^+2 (1486.1) and 7^+2 (1676.6) γ -vibrational band members; and the 4^+0 (1280.0) and 6^+0 (1551.1) β -vibrational band members. A two-quasineutron rotational band is proposed with configuration $\nu \frac{5^-}{2} [523] + \nu \frac{3^-}{2} [521]$; 4^+4 (1895.0), 5^+4 (2021.9) and 6^+4 (2153.5). Other new results from this study include the location of several negative parity bands in the region of 1300-1500 keV and a number of energy levels above 2 MeV in excitation.

Further analysis of the results is in progress with effort directed toward a better understanding of the octupole vibrational states. Manuscripts are being prepared for the publication of this work.

1. B. Harmatz and T. H. Handley, Nucl. Phys. A191 (1972) 497.
2. A. A. Abdurazakov et al., Soviet J. Nucl. Phys. 8 (1969) 367.

2. The Decay Chain $^{157}\text{Er} \rightarrow ^{157}\text{Ho} \rightarrow ^{157}\text{Dy}$. Anderson and Brenner

Experiments were begun this summer to help elucidate the energy structure of ^{157}Ho and ^{157}Dy . Rather thorough work on the $^{157}\text{Ho} \rightarrow ^{157}\text{Dy}$ decay has been reported by Torres, et al,¹ but little is known about the odd-proton energy states in ^{157}Ho , with only limited NaI(Tl) data having been published.²

Targets of $20 \text{ mg/cm}^2 \text{ Sm}_2\text{O}_3$, enriched to 97.7% ^{149}Sm , were used for the reaction $^{149}\text{Sm}(^{12}\text{C}, 4n)^{157}\text{Er}$. The bombardments at the Yale Heavy Ion Accelerator produced, in addition to the $(^{12}\text{C}, 4n)$ reaction, substantial amounts of activity due to the $(^{12}\text{C}, 3n)$, $(^{12}\text{C}, 5n)$, and $(^{12}\text{C}, 6n)$ reactions. Thus, complex spectra were obtained, containing up to 250 resolvable photopeaks, many in the form of multiplets. Initially, a singles spectrum of the 24-min ^{157}Er decay was taken. Then, an experiment was devoted to determining photopeak half-lives, and, most recently, low-energy transitions were examined with a low-energy γ -ray detector. Both this and the 4.5% Ge(Li) detector also used were available at the Yale HIA. All bombardments were of one-hour duration, as were the counting times for each target. All counting was done with the PDP-8I computer at Yale. Yet to be done are high-energy singles and low-energy half-life experiments.

Analysis of the data has begun with the help of the computer program SAMPO,³ stored on the CDC-6600 computer at Waltham, Massachusetts and called at the terminal at Clark University. So far, nearly 100 transitions in ^{157}Dy , as reported by Torres, et al,¹ and over 50 additional rapidly decaying photopeaks below 2.5 MeV has been seen. Most of these decay with the 24-min half-life characteristic of ^{157}Er . More than ten photopeaks are seen having shorter half-lives and may be part of either the ^{155}Er or ^{156}Er decay schemes. Further computer analysis and experimentation are expected to clarify the situation.

1. J. P. Torres, et al., Nuclear Phys. A185 (1972) 574.
2. P. Lagarde, et al., Le Journal de Physique 27 (1966) 116.
3. J. T. Routti, UCRL-19452 (1969).

3. The Decay of ^{173}Hf to Levels in ^{173}Lu . Brenner and Meyer (Livermore)

A reinvestigation of ^{173}Hf decay was begun this year at Livermore in order to supplement data obtained in earlier work by our group at Clark. Sources of ^{173}Hf were produced by the $(\alpha, 2n)$ reaction on enriched $^{171}\text{Yb}_2\text{O}_3$ at the Berkeley 88" cyclotron. The ^{173}Hf was chemically separated from the rare-earth elements by a simple procedure. Sources prepared in this manner were counted on a variety of Ge(Li) detectors including a Compton-suppression spectrometer and a low-energy photon spectrometer. The results of these experiments have led to the assignment of approximately 80 lines to ^{173}Hf decay, roughly twice the number previously reported. Work is continuing on the ^{173}Lu level scheme and experiments to measure the γ -ray coincidence spectrum with Ge(Li) detectors are planned for the near future. It is expected that work on this project will be completed during the coming year.

4. The Decay Scheme of ^{153}Tb . Brenner and Meyer (Livermore)

The decay of 56-h ^{153}Tb produced by the $(\alpha, 2n)$ reaction on enriched $^{151}\text{Eu}_2\text{O}_3$ has been studied with a Compton-suppression Ge(Li) γ -ray spectrometer and a variety of other Ge(Li) and Si(Li) detectors. The level scheme of the daughter nucleus, ^{153}Gd , is of particular interest although complex since it occurs in the transitional mass region between vibrational and rotational nuclei. Some of the sources used in the γ -ray experiments and all the conversion electron data were obtained with sources which had

undergone mass separation. Over 200 γ -transitions have been associated with ^{153}Tb decay.

This project which is being done using the facilities at Livermore and Berkeley will be continued next year. Coincidence experiments are expected to provide adequate data for construction of a detailed level scheme for ^{153}Gd .

5. The Decay Schemes of ^{81}Se and ^{83}Se . Brenner and Meyer (Livermore)

Experiments have begun on the decay schemes of ^{81}Se and ^{83}Se using facilities at Livermore. Both activities are produced by the (n,γ) reaction on isotopically enriched targets in the Livermore Pool-Type Reactor (LPTR). A rapid chemical separation is performed and the Se fraction is counted on various Ge(Li) γ -ray spectrometers. The experiments on ^{83}Se decay are particularly difficult to perform because the half-lives of the isomers of ^{83}Se are 70 sec and 22 sec, respectively. The fast irradiation and chemical separation system now operating at the LPTR is designed to facilitate the study of radionuclides with half-lives in this range. Cooperative projects involving the study of other short-lived nuclides are planned for the future.

IV. Figure Captions

Fig. 1. Level scheme of ^{186}Os from decay of 15.8-h ^{186}Ir . Levels drawn with heavy lines are members of the ground-state band, the $K=2$ γ -vibrational band, and a proposed $K=4$ two-phonon band. Transitions between the ground-state and γ -vibrational bands are not shown and dashed levels are based on energy sums. A circle indicates a transition is confirmed by coincidence measurements.

Fig. 2. The level scheme of ^{158}Ho from decay of 2.3-h ^{158}Er . Dashed transitions are seen in the conversion electron measurements of Harmatz and Handley but not in our γ -ray experiments.

Fig. 3. The level scheme of ^{158}Dy from decay of $^{158\text{m}},^{158}\text{Ho}$ in transient equilibrium with ^{158}Er .

Fig. 2

Fig. 3