Radiochemical Investigations of Nuclear Properties

Patrick J. Daly, Principal Investigator

Progress Report for the period October 1973 to September 1974

A.E.C. Contract AT(11-1)-1672

Department of Chemistry

**Purdue University
Lafayette, Indiana**

September 1974

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Abstract

The structure of nuclei in the $A = 180-200$ transitional region have been studied. In-beam γ -ray investigations of even- A Hg, Pt, Os using the Purdue tandem accelerator have been completed. The most striking discovery has been the systematic occurrence of a $5^-, 7^-, 9^- \dots$ sequence of levels connected by enhanced E2 transitions; a description of this sequence in terms of the coupling of a rotation-aligned $i_{13/2}$ neutron with a low- j neutron is proposed. More extensive investigations of high-spin phenomena in Pt nuclei are in progress using the Michigan State cyclotron and some preliminary results are reported. Tandem experiments on the structure of $^{191}, ^{193}, ^{195}\text{Au}$ have also been performed and a complementary study of $^{193\text{m}}\text{Hg}$ decay has been completed. An unfruitful search for $(h_{11/2}^{\pi}, i_{13/2}^{\nu}) 12^-$ isomers in ^{192}Au , ^{194}Au and ^{202}Au is described. Studies of the structure of ^{188}Os and ^{190}Os by the combined techniques of radioactive decay and neutron transfer spectroscopy are also briefly described.

I Research Activities

In contrast to 1972-73, when diverse lengthy investigations were brought to a successful conclusion and three Ph.D. projects were completed, this past year has been more transitional in character. New lines of investigation have been opened up with mainly new personnel, and our usage of the Purdue tandem has been reduced in favour of travelling to perform experiments at off-campus accelerators. In particular, an extensive program of experiments on the Michigan State University cyclotron is now in full swing and very interesting results have already been obtained. The dominant theme in our research has been the investigation of high-spin phenomena in the $A = 180-200$ shape transitional region by in-beam γ -ray spectroscopy and related radioactivity studies. Substantial progress has also been made in our collaborative study of the structure of Os nuclei with the Florida State University group.

A. In-beam γ -ray Spectroscopy

Our systematic study of Hg, Pt and Os nuclei, by $(\alpha, 2n\gamma)$ and $(p, 2n\gamma)$ measurements using the Purdue tandem and by complementary radioactivity investigations, has now been completed and the results have been published¹⁾. The most interesting result of this work was the discovery of 5^- , 7^- , 9^- ... sequences of levels, connected by enhanced E2 transitions, in a series of even-even nuclei. Inferences from our radioactivity results led us to propose a description of these sequences in terms of the coupling of a rotation-aligned $i_{13/2}$ neutron with a low- j neutron partner. Recent results from Jülich²⁾ and Berkeley³⁾ have provided strong supporting experimental evidence for this type of description and a theoretical treatment by Vogel⁴⁾ has been rather successful in explaining the existing data.

In an extension of this work, some ten months ago we began an extensive series of experiments in collaboration with Professor Bernthal at Michigan State University. Our purpose is to explore all aspects of the high-spin level structure of the nine nuclei ^{186}Pt - ^{194}Pt by $(\alpha, x\gamma)$ reaction on enriched Os targets. The fact that the series of nuclei studied spans the region in which the change from prolate to oblate nuclear shapes is believed to occur, lends added interest and importance to these investigations.

At this point we have had roughly twenty days of running time on the M.S.U. cyclotron and the experimental work is about two-thirds completed. The measurements have included prompt and delayed γ -ray singles, γ - γ coincidence, angular distribution, excitation function and lifetime determinations. For ^{192}Pt , ^{190}Pt and ^{188}Pt the experimental work has been completed and analyzed, and a wealth of new spectroscopic information has been obtained. In each of these nuclei, the 4^+ member of the ground band is populated by two main de-excitation branches, one involving the 5^- , 7^- , 9^- ... sequence and the other high even spin positive parity states. In ^{192}Pt and ^{190}Pt , we have discovered 10^- isomers ($t_{1/2} = 230$ ns in ^{192}Pt , $t_{1/2} = 47$ ns in ^{190}Pt) which play an important role in the de-excitation cascades. We can make a pretty good case for interpreting these as $9/2[505]\nu 11/2[615]\nu 10^-$ shape isomers; in ^{188}Pt , no such isomer occurs and the negative parity yrast extends more normally to high spin values.

There is a similar sharp transition in the structure of the positive parity yrast sequences between ^{192}Pt , ^{190}Pt and ^{188}Pt . In the two heavier isotopes, isomeric 12^+ states intrude into the positive parity sequences giving rise to highly exaggerated band-bending type structures, whereas in ^{188}Pt the strength of the de-excitation cascade is fragmented between many states above the 10^+ member of the ground band and no 12^+ isomer is observed. These

results are currently being digested and interpreted and the experimental work on the odd-A nuclei (and ^{186}Pt) is continuing.

The quality of the experimental data obtained in this work is shown in figs. 1 and 2 and the ^{192}Pt level scheme displayed in fig. 3 illustrates the rich variety of new information resulting from these studies.

Our proposed studies of the level structure of ^{195}Au , ^{193}Au , ^{191}Au by $(\alpha, 2n\gamma)$ and $(^3\text{He}, 3n\gamma)$ in-beam spectroscopy have been performed on the Purdue tandem. While these experiments were in progress, our enthusiasm was somewhat dampened by the receipt of a Berkeley preprint⁵⁾ reporting on similar studies of these three nuclei. However, on closer examination, it became clear that while the Berkeley study accounted in elegant fashion for the properties of the $h_{11/2}^{\pi}$ bands in these nuclei, several strong transitions observed in our spectra remained unexplained. Therefore, we pursued our studies and complemented them by a thorough investigation of the ^{193}Au levels populated in the radioactive decay of the $1_{13/2}^{\nu} \ ^{193}\text{Hg}$ isomer. Consequently we have been able to locate new families of negative parity levels in all three nuclei which are clearly not related to the $h_{11/2}^{\pi}$ states; instead all the experimental evidence seems to indicate that there are members of bands built on a $h_{9/2}^{\pi}$ intrinsic excitation. This work is continuing. We might comment that we found the $(^3\text{He}, 3n)$ reaction to be rather unpleasant for in beam spectroscopy, since many strong γ -rays arising from ^3He -ion induced reactions involving charged particle emission greatly complicated the γ -ray spectra obtained.

B. Nuclear Structure Studies by other Techniques.

The study of the ^{193m}Hg decay has been briefly mentioned above. Here the activity was produced by chemical separation of mercury from an enriched

^{194}Pt target which had been bombarded with 33 MeV ^3He ions from the Argonne cyclotron. Detailed γ -ray singles and coincidence measurements were performed at Purdue and a decay scheme accommodating many strong γ -rays not previously placed in the ^{193}Au level scheme was established. The results of this study were extremely helpful in clarifying the interpretation of the in-beam γ -ray data.

In recent years we discovered relatively long-lived ($h_{11/2}^{\pi}, i_{13/2}^{\nu}$) 12^{-} isomers in ^{198}Au and ^{200}Au corresponding to the previously known 12^{-} isomer in ^{196}Au . Since the results of our $^{200\text{m}}\text{Au}$ decay study⁶⁾ provided a key to our interpretation of the $5^{-}, 7^{-}, 9^{-}\dots$ level sequences, we have searched for the corresponding isomers in ^{192}Au , ^{196}Au and ^{202}Au . These experiments were performed at the Argonne cyclotron in collaboration with Dr. S. W. Yates. Gold activities were chemically separated following the reactions $^{191}\text{Ir}(\alpha, 3n)$, $^{193}\text{Ir}(\alpha, 3n)$ and $^{204}\text{Hg}(d, \alpha)^{202}\text{Hg}$ but, although the experiments were smoothly performed, no 12^{-} isomers were found. It is possible to place a firm upper limit of 5 min on the half-life of any high-spin isomer in these nuclei.

While the high decay energy may explain the non-observance of the isomer of ^{202}Au , the results for ^{192}Au and ^{194}Au are more surprising. One can only conclude that in these nuclei, a two-quasiparticle state of spin 9, 10 or 11 drops below the 12^{-} state thus providing a less hindered de-excitation pathway. In a subsequent in-beam experiment, Yates⁷⁾ has found a 0.5 s isomer in ^{194}Au .

Our collaborative investigations with Sheline's group at Florida State University of the structure of Os nuclei have continued. The results of the study of ^{190}Os from the decays of ^{190}Ir and $^{190\text{m}}\text{Re}$ and from the $^{189}\text{Os}(d, p)$ reaction, which were summarised in last year's report, have now been published⁸⁾. We have recently completed work on a similar investigation of ^{188}Os in which

F.S.U. $^{189}\text{Os}(d,t)$ data were complemented by a detailed Purdue study of ^{188}Os levels populated in the EC decay of ^{188}Ir . The ^{188}Ir decay scheme is shown in fig. 4. A paper on this work has recently been submitted to Nucl. Phys.⁹⁾

One of the more interesting results of these investigations concerns the interpretation of single neutron transfer cross sections in a case where the target state is not pure in K. The ^{189}Os ground state, for example, has the approximate composition 90% $3/2\ 3/2[512]$, 10% $3/2\ 1/2[510]$. Our analysis indicates that the (d,p) and (d,t) cross sections to the ground and γ -vibrational bands of ^{190}Os and ^{188}Os exhibit dramatic interference effects which can be traced to the admixed character of the target ground state.

The research performed during this past year followed the outline submitted in our last renewal proposal very closely. The principal investigator has devoted approximately 50% of his time and effort to this project during the present contract period and he expects that this will continue for the remainder of the year.

References

1. S. W. Yates et al., Nucl. Phys. A122 (1974) 301
2. H. Beuscher et al., Phys. Rev. Lett. 32 (1974) 843
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4. P. Vogel, Proc. Int. Conf. on Reactions between Complex Nuclei (Nashville, 1974) p. 164
5. P. O. Tjøm et al. LBL-2379 (1974)
6. J. Cunnane et al. Nucl. Phys. A196 (1972) 593
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8. S. W. Yates et al., Nucl. Phys. A122 (1974) 276
9. R. Thompson et al., Nucl. Phys. (in press).

Figure Captions

Fig. 1 The ^{192}Pt γ -ray singles spectrum observed in the $(\alpha, 4n\gamma)$ reaction

Fig. 2 Prompt (top) and delayed (by 300-350 ns) γ -ray spectra illustrating the decay of the new 230 ns 10^{-} isomer in ^{192}Pt

Fig. 3 The ^{192}Pt level scheme

Fig. 4 The level structure of ^{188}Pt from the decay of ^{188}Ir

Fig 1

Fig. 2.

^{192}Pt

Fig 3

Fig 4

II Publication Abstracts

Abstracts are given for articles published or submitted to journals during the period covered by this report.

Levels of ^{190}Os Populated in the Decays of 3.3 h $^{190\text{m}}\text{Re}$ and 12 d ^{190}Ir and in the $^{189}\text{Os}(d,p)^{190}\text{Os}$ Reaction. S. W. Yates, J. C. Cunnane, P. J. Daly, R. Thompson and R. K. Sheline, Nucl. Phys. A222 (1974) 276.

The level structure of ^{190}Os has been investigated by the techniques of radioactive decay and neutron transfer reaction spectroscopy. The existence of 3.3 h $^{190\text{m}}\text{Re}$ has been confirmed; it decays $\approx 49\%$ by isomeric transitions and $\approx 51\%$ by β^- decay to levels in ^{190}Os with spins ≥ 5 . In a re-investigation of the 12 d ^{190}Ir decay, a virtually complete decay scheme has been established and discrepancies between the I^π values assigned to several ^{190}Os levels by earlier workers have been resolved. The reaction $^{189}\text{Os}(d,p)^{190}\text{Os}$ has been studied and information about the locations of two-quasiparticle states involving the $3/2[512]v$ orbital and about the microscopic compositions of collective excitations has been derived. Various aspects of the ^{190}Os level structure are discussed in the light of the combined radioactivity and transfer reaction results.

High-Spin Negative Parity States in Doubly Even Hg, Pt and Os Nuclei.

S. W. Yates, J. C. Cunnane, R. Hochel and P. J. Daly, Nucl. Phys. A222 (1974) 301.

A systematic study of the level structure of ^{200}Hg , ^{198}Hg , ^{196}Hg , ^{194}Pt , ^{190}Pt , ^{188}Os , ^{186}Os and ^{184}Os has been performed by means of $(\alpha, 2n\gamma)$ and $(p, 2n\gamma)$ in-beam γ -ray spectroscopy. Much new information has been obtained about the individual level spectra, and arguments based on level energy and population intensity systematics have been used to trace the behaviour of

interesting spectral features through this series of transitional nuclei. Of particular interest is a $5^-, 7^-, 9^- \dots$ sequence of levels which appears to be a recurring feature in the spectra of the doubly even Pt and Hg nuclei in the mass range $A = 190-200$. These negative parity levels are connected by enhanced E2 transitions and they are very strongly populated in the de-excitation of the residual nuclei formed in $(\alpha, 2n)$ reactions. It is proposed that the $5^-, 7^-, 9^- \dots$ sequences constitute rotation-aligned bands analogous to the decoupled bands identified by Stephens and co-workers in odd-A transitional nuclei. In the doubly even nuclei, the bands may arise from the coupling of an $i_{13/2}$ neutron with a low-j neutron partner (from the $p_{1/2}$, $p_{3/2}$ and $f_{5/2}$ orbitals). Negative parity levels in the Os nuclei are populated much less strongly in the $(\alpha, 2n\gamma)$ reactions. While 5^- levels corresponding to those in the Pt and Hg nuclei appear to be fairly well established in ^{186}Os , ^{188}Os (and ^{190}Os), it is not yet clear whether the $5^-, 7^-, 9^- \dots$ band sequence extends into the Os nuclei.

Levels of ^{188}Os Populated in the $^{189}\text{Os}(d,t)^{188}\text{Os}$ Reaction and in the Decay of $41\text{ h }^{188}\text{Ir}$, Roger Thompson, A. Ikeda, R. K. Sheline, J. C. Cunnane, S. W. Yates and P. J. Daly, Nucl. Phys. (in press).

The level structure of ^{188}Os has been investigated by the $^{189}\text{Os}(d,t)^{188}\text{Os}$ reaction using a broad range magnetic spectrograph, and the properties of the ^{188}Os levels populated in the decay of ^{188}Ir have been re-examined. The (d,t) results yield new information about the location of two-neutron excitations in ^{188}Os involving the $3/2[512]$ orbital. Since the ^{189}Os ground state contains admixtures of both $K=3/2$ and $K=1/2$ character, cross section formulae for single neutron transfer from a target state which is not pure in K are considered, and it is found that rather small $K=1/2$ admixtures in the

^{189}Os ground state give rise to striking interference effects, which are manifested in the experimental (d,t) cross sections into the members of the ^{188}Os ground state band. The consequences of the mixed character of the target state on the (d,t) population of members of the $K^\pi=2^+$ γ -vibration and of higher-lying two-quasiparticle bands are also discussed.

Mixed Odd-A Target State Effects in (d,p) and (d,t) Cross Sections, R. C. Thompson, A. Ikeda, P. Kleinheinz, R. K. Sheline and P. J. Daly, submitted to Phys. Lett.

The effect on (d,p) and (d,t) cross sections of Nilsson orbital admixtures in odd-A target states is considered. Explicit expressions for the population of the even-even ground state band and two-quasiparticle states are presented. A comparison with the results of the $^{189}\text{Os}(d,t)^{188}\text{Os}$ reaction is made.

III Personnel

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IV Publications and Talks

Levels of ^{190}Os Populated in the Decays of $3.3\text{ h }^{190\text{m}}\text{Re}$ and $12\text{ d }^{190}\text{Ir}$ and in the $^{189}\text{Os(d,p)}^{190}\text{Os}$ Reaction, S. W. Yates, J. C. Cunnane, P. J. Daly, R. Thompson and R. K. Sheline, Nucl. Phys. A222 (1974) 276

High-Spin Negative Parity States in Doubly Even Hg, Pt and Os Nuclei, S. W. Yates, J. C. Cunnane, R. Hochel and P. J. Daly, Nucl. Phys. A222 (1974) 301

Levels of ^{188}Os Populated in the $^{189}\text{Os(d,t)}^{188}\text{Os}$ Reaction and in the Decay of $41\text{ h }^{188}\text{Ir}$, R. Thompson, R. K. Sheline, J. C. Cunnane, S. W. Yates and P. J. Daly, Nucl. Phys. A (in press)

Mixed target State Interference Effects in Neutron Transfer Reactions, R. Thompson, A. Ikeda, P. Kleinheinz, R. K. Sheline and P. J. Daly, submitted to Phys. Lett.

Towards a Microscopic Description of Nuclear Structure, Physical Chemistry Seminar, Purdue University, January 1974

"Nuclear Lifetime Measurements by the Doppler Shift Attenuation Technique," Nuclear Chemistry Seminar, Purdue University, March 1974, - given by M. Piiparinen

"High-spin Negative Parity Bands in Transitional Nuclei and the Rotation-Alignment Coupling Scheme," Nuclear Seminar, Argonne National Laboratory,

March 1974, given by P. J. Daly

"High Spin Level Structure in ^{192}Pt ," P. J. Daly, J. C. Cunnane, M. Piiparinen, F. M. Bernthal, C. L. Dors and T. L. Khoo, American Physical Society Meeting, Washington, D. C., April 1974, abstract in Bull. Am. Phys. Soc. 19 (1974) 597