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Radiochemical Investigations of Nuclear Properties

Patrick J. Daly, Principal Investigator

Progress Report for the period October 1971 to September 1972

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

Department of Chemistry

Purdue University
Lafayette, Indiana

September 1972

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I Research Activities

During the contract period, further studies of the structure of nuclei in the important transitional region $A = 180-200$ have been conducted using the combined techniques of neutron transfer spectroscopy, radioactive decay spectroscopy and in-beam γ -ray spectroscopy. The principal results obtained are summarised in the following sections.

1.1 Collective and two quasiparticle excitations in ^{182}W and ^{184}W by neutron transfer reactions. (Daly - with Kleinheinz, Casten, Niels Bohr Institute)

A study of the levels of ^{182}W and ^{184}W populated in the (d,p), (d,t) and (t, α) reactions on a ^{183}W target has now been completed. Besides establishing the locations of several previously unknown two quasiparticle states in these nuclei, the transfer reaction results provided important insight into the microscopic structure of the γ -vibrations and higher-lying $K^\pi = 2^+$ excitations and made possible a detailed test of the predictions of microscopic RPA calculations including a residual pairing plus quadrupole force. It was shown that the admixed amplitudes of the $1/2[510] - 3/2[512]$ and $1/2[510] - 5/2[512]$ two-neutron configurations in the $K^\pi = 2^+$ excitations explained not only the neutron transfer data but also the $B(E2)$ values determined in independent (d,d') and Coulomb excitation measurements. A distinct difference in the observed collective character of the higher-lying $K^\pi = 2^+$ excitations in the two nuclei was found to be associated with the $N = 108$ energy gap in the Nilsson level diagram. [Items 4 and 17 in Publication List]

1.2 Levels of ^{184}W from the decay of ^{184}Ta

(Yates, Daly - with Johnson, Aras, ORNL)

This investigation which was undertaken to complement the $^{183}\text{W}(d,p)^{184}\text{W}$

Fig. 1. Levels of ^{184}W from ^{184}Ta decay

study described above has also been completed. The 8 h ^{184}Ta was produced by the $^{186}\text{W}(d,\alpha)^{184}\text{Ta}$ reaction. Radioactivity measurements were performed at two laboratories - high resolution γ -ray singles and γ - γ coincidence measurements at Purdue, β^- endpoint energies and β - γ coincidence determination at Oak Ridge NL. The decay scheme which has been firmly established, and which contains much new information about the ^{184}W levels, is shown in fig. 1. [Publications 3, 16].

1.3 Implications of the allowed unhindered β^- decay of 3 min ^{190}Re .

(Yates, Cunnane, Daly)

The β^- decay of 3 min ^{190}Re was studied using sources produced by the $^{190}\text{Os}(n,p)$ reaction and it was shown that the fast β^- decay ($\log ft = 5.1$) involves the allowed unhindered transition $9/2[505]\nu - 5/2[402]\pi \text{ JK}^\pi = 22^- \rightarrow 11/2[505]\pi - 5/2[402]\pi \text{ JK}^\pi = 33^-$ in accord with a recent microscopic description (Neergaard and Vogel, Nucl. Phys. A145(1970)33) of octupole vibrations in the osmium region. [Publication 5]

1.4 The ^{190}Os level structure from the decay of the ^{190}Re and ^{190}Ir isomers.

(Yates, Cunnane, Daly)

Last year's annual report contained a section in which it was tentatively concluded that the 3 h ^{190}Re isomer probably did not exist. Subsequent work has shown not only that this isomer exists ($t_{1/2} = 3.2$ h) but also that the isomeric state has $\text{JK}^\pi = 66^-$ and arises from either of the configurations $3/2[402]\pi - 9/2[505]\nu$ or $5/2[402]\pi - 7/2[503]\nu$. The decay proceeds partly ($\sim 40\%$) by IT to a 120 keV level in ^{190}Re and partly by β^- decay to high-spin levels in ^{190}Os . To clarify the nature of the higher-lying excitations in ^{190}Os , a reinvestigation of the EC decay of ^{190}Ir has also been undertaken.

Fig. 2. The ^{200m}Au decay scheme

Assignments	π	ν
$h_{11/2}$		$i_{13/2}$
$d_{3/2}$		$i_{13/2}$
$d_{3/2}$		$i_{13/2}$
$d_{3/2}$		$i_{13/2}$
$d_{3/2}$		$f_{5/2}$
$d_{3/2}$		$p_{1/2}$

Fig. 3. Decay schemes of the 12^- isomers in ^{196}Au and ^{198}Au

Additional experimental work on both decays is planned before definite conclusions are drawn.

1.5 Levels in ^{200}Hg from $^{200\text{m}}\text{Au}$ decay and $^{198}\text{Pt}(\alpha, 2n\gamma)$ in-beam spectroscopy.
(Cunnane, Hochel, Yates, Daly)

The decay of the $(h_{11/2}\pi, i_{13/2}^v)12^-$ isomer of ^{200}Au has been studied by γ -ray singles, γ - γ coincidence, conversion electron, β -ray endpoint and β - γ coincidence measurements. To resolve crucial questions about the order of the transitions in ^{200}Hg which follow the β^- decay branch, the reaction $^{198}\text{Pt}(\alpha, 2n\gamma) ^{200}\text{Hg}$ has also been studied by in-beam spectroscopy techniques. The results of this investigation which are illustrated in fig. 2 are particularly striking. The levels in ^{200}Hg populated consist of a $0^+, 2^+, 4^+, 6^+$ ground state band sequence and a $5^-, 7^-, 9^-, 11^-$ level sequence in which the E2 transitions are considerably enhanced implying that the negative parity levels also constitute a rotational band. Moreover, the unambiguous spin-parity assignments in ^{200}Hg and published data from other laboratories lead to the conclusion that the $5^-, 7^-, 9^-, 11^- \dots$ level sequence, connected by fast E2 transitions, will prove to be a recurring feature in even-even nuclei in the $A = 190$ -200 transitional region. It is very probable that these levels constitute a "favored" high-spin band of levels, analogous to the bands built on the $h_{11/2}$ proton state found in odd La nuclei, which Stephens et al (Phys. Rev. Lett. 29(1972)438) have described as decoupled yrast states. This interesting phenomenon is being explored further in our in-beam studies of the Pt and Hg nuclei with the $(p, 2n\gamma)$ and $(\alpha, 2n\gamma)$ reactions. [Publication 14].

1.6 New high-spin isomer 2.3 d $^{198\text{m}}\text{Au}$ and the ^{198}Au level structure.
(Cunnane, Daly)

We have produced a new high-spin isomer 2.27 ± 0.05 d $^{198\text{m}}\text{Au}$ by means of

the reaction $^{200}\text{Hg}(d,\alpha)^{198\text{m}}\text{Au}$. Almost certainly, $^{198\text{m}}\text{Au}$ is analogous to the $(h_{11/2}^{\pi}, i_{13/2}^{\nu})12^{-}$ isomers in ^{196}Au and ^{200}Au . There is no β^{-} branching in the decay of $^{198\text{m}}\text{Au}$. The isomeric transition is followed by a cascade of 204.10 and 180.31 keV γ -rays to a 123ns level at 312.10 keV which de-excites to ground by a sequence of 97.21 (E1) and 214.89 (E2) transitions (fig. 3). An earlier interpretation of the results of (n,γ) and $(d,p\gamma)$ studies of the ^{198}Au level structure must be revised in the light of our findings. In fig. 3 are shown shell model assignments for the levels populated in the isomeric decay, which are consistent also with the (n,γ) and $(d,p\gamma)$ data. The E1 de-excitation of the 123ns isomer probably involves the ℓ -forbidden single-particle transition $(d_{3/2}^{\pi}, i_{13/2}^{\nu})5^{+} \rightarrow (d_{3/2}^{\pi}, f_{5/2}^{\nu})4^{-}$. [Publication 13].

1.7 Levels of ^{187}Os from the decay of ^{187}Ir .

(Ahlgren, Daly)

This investigation has now been concluded and the results have been published recently. [Publication 6].

1.8 A study of the level structure of even-even Osmium nuclei by radioactive decay and in-beam γ -ray spectroscopy.

(Hochel, Cunnane, Yates, Daly)

The levels of ^{184}Os , ^{186}Os and ^{188}Os populated (a) in 3 h ^{184}Ir and 15 h ^{186}Ir decay (b) in the reactions $^{185}\text{Re}(p,2n\gamma)$ and $^{187}\text{Re}(p,2n\gamma)$ and (c) in the reactions $^{182}\text{W}(\alpha,2n\gamma)$, $^{184}\text{W}(\alpha,2n\gamma)$ and $^{186}\text{W}(\alpha,2n\gamma)$ are being intensively studied. The original aim in this work was to elucidate the level structure of ^{184}Os by the complementary techniques of radioactive decay and reaction spectroscopy. An extensive level scheme for this nucleus has been established including well -

developed ground state, γ -vibrational and $K^\pi = 3^-$ octupole bands, which are strongly fed in ^{184}Ir decay and in the $(p,2n)$ and $(\alpha,2n)$ reactions. One of the main difficulties in understanding the ^{184}Ir decay data arises from the observed population of the 4^+ and 6^+ members of the ^{184}Os ground state band directly in the EC decay with $\log ft$ values of about 7. From this, one would infer a high spin and low K-value for the ^{184}Ir ground state. We now believe that the answer to this problem is that the ^{184}Ir ground state configuration is $1/2[541]\pi - 1/2[510]v$ $IK^\pi = 51^+$, and that the very unusual occurrence of a $K^\pi = 1^+$ band with the 5^+ member lying lowest is a consequence of the particularly large decoupling parameter characterizing the $1/2[541]\pi$ orbital. Moreover the high-spin, low K ground state of ^{186}Ir , which has never been satisfactorily accounted for, probably has the same configuration.

This study has now been extended to the nuclei ^{186}Os and ^{188}Os with particular emphasis on locating the octupole excitations corresponding to those found in ^{184}Os and ^{190}Os and the interesting 5^- , 7^- level sequence which we have established in ^{190}Os and in the even-even Pt and Hg nuclei (cf sections 1.5 and 1.9).

1.9 Levels in even-even Pt and Hg nuclei by $(p,2n\gamma)$ and $(\alpha,2n\gamma)$ in-beam spectroscopy.

(Yates, Cunnane, Hochel, Daly)

We are studying the level structure of ^{190}Pt , ^{192}Pt , ^{194}Pt , ^{196}Hg , ^{198}Hg , and ^{200}Hg by $(p,2n\gamma)$ reactions on Ir and Au targets and by $(\alpha,2n\gamma)$ reactions on Os and Pt targets. Both γ -ray singles and γ - γ coincidence measurements are performed and angular distribution measurements are used to distinguish dipole (mostly E1) from quadrupole radiations. Particular attention has been paid to locating low-lying negative parity states, de-exciting predominantly by E1 transitions. The bandhead of the $K^\pi = 3^-$ octupole excitation has been traced across

the Pt nuclei and 5^- , 7^- doublets have been located in all the Pt and Hg nuclei. It is interesting that in each cases where the 5^- level is found below the 6^+ member of the ground state band, the 5^- is very strongly fed in the reactions and the $5^- \rightarrow 4^+$ transition is so strong that in earlier studies it has been mistakenly interpreted as the $6^+ \rightarrow 4^+$ transition in the ground state band.

These studies are continuing.

II Personnel

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III. Publications and Talks

1. "Neutron transfer reactions and the microscopic structure of collective excitations" P. J. Daly, Nuclear Chemistry Seminar, Purdue Univ., Oct. 1971.
2. "Two quasineutron excitations in $^{182,184}\text{W}$ " P. J. Daly, Nuclear Physics Seminar, Purdue Univ., Oct. 1971.
3. "States of ^{184}W populated in ^{184}Ta decay" P. J. Daly and S. W. Yates, Bull. Am. Phys. Soc., 17 (1972)29.
4. "Neutron transfer reaction studies of ^{182}W and ^{184}W " P. J. Daly, P. Kleinheinz, R. F. Casten and B. Elbek, Bull. Am. Phys. Soc., 17(1972)30.
5. "Implications of the allowed unhindered β^- decay of 3 min ^{190}Re " P. J. Daly, S. W. Yates and J. Cunnane, Nucl. Phys. A187(1972)446.
6. "The level structure of ^{187}Os from the decay of ^{187}Ir " Karin Ahlgren and P. J. Daly, Nucl. Phys. A189(1972)368.
7. "Levels in ^{184}Os from ^{184}Ir decay and (p,2n γ) spectroscopy" R. Hochel, S. W. Yates, J. Cunnane and P. J. Daly, Bull. Am. Phys. Soc., 17(1972)487.
8. "Decay of ^{190}Re isomers" S. W. Yates, J. C. Cunnane and P. J. Daly, Bull. Am. Phys. Soc., 17(1972)487.
9. "Levels in ^{190}Pt , ^{192}Pt from (p,2n γ) spectroscopy" J. C. Cunnane, S. W. Yates, R. Hochel and P. J. Daly, Bull. Am. Phys. Soc., 17(1972)606.
10. "A study of energy levels and Coriolis coupling in odd-mass wolfram nuclei by means of (d,p) and (d,t) reactions" R. F. Casten, P. Kleinheinz, P. J. Daly and B. Elbek, Dan. Vid. Selsk. Mat. Fys. Medd., 38(1972) no.13.
11. "Two quasiparticle excitations in ^{184}W and ^{190}Os " S. W. Yates, Nuclear Chemistry Seminar, Purdue Univ., April 1972.
12. "A new high-spin isomer in ^{198}Au and the decay of $^{200\text{m}}\text{Au}$ " James C. Cunnane and Patrick J. Daly, New York ACS meeting August, 1971.
13. "New high-spin isomer 2.3 d $^{198\text{m}}\text{Au}$ and the ^{198}Au level structure" J. C. Cunnane and P. J. Daly, Phys. Rev. C3, 6, no.4 (in press) Oct., 1972.
14. "High-spin negative parity states in ^{200}Hg from $^{200\text{m}}\text{Au}$ decay and $^{198}\text{Pt}(\alpha,2\text{n}\gamma)$ reaction spectroscopy" J. C. Cunnane, R. Hochel, S. W. Yates and P. J. Daly, Nucl. Phys. (accepted for publication Sept. 13, 1972).
15. "Nuclear spectra and nuclear structure" P. J. Daly, Chemistry Colloquium, Indiana State University, Sept., 1972.
16. "The level structure of ^{184}W from the β^- -decay of ^{184}Ta " S. W. Yates, P. J. Daly, N. R. Johnson and N. K. Aras, submitted to Nucl. Phys.

17. "Single neutron transfer studies of collective and two quasiparticle excitations in ^{182}W and ^{184}W ", P. Kleinheinz, P. J. Daly and R. F. Casten, to be submitted to Nucl. Phys.
18. "Properties of nuclear states in ^{182}Re populated in the decay of ^{182}Os ," S. B. Burson, P. J. Daly, P. F. A. Goudsmit and A. A. C. Klaase, to be submitted to Nucl. Phys.