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Radiochemical Investigations of Nuclear Properties

Patrick J. Daly, Principal Investigator

Progress Report for the period October 1967 to September 1968

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Department of Chemistry

**Purdue University
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I. RESEARCH ACTIVITIES

The research performed during this contract period follows broadly along the lines set out in our research proposal; a few additional studies have also been undertaken. In both of our major areas of investigation, namely, nuclear reaction mechanisms and nuclear spectroscopy, important and clear-cut results have been obtained and these are described in the following sections. During the summer of 1968, the principal investigator has been engaged in reaction spectroscopy studies at the Bohr Institute in Denmark. As his stay was partly financed from this research contract, preliminary results of the work performed are also described below.

1. Nuclear Reaction Mechanisms

1(a) A Comparison of Reactions Induced by Medium Energy ^3He and ^4He Ions in Heavy Target Nuclei.

(N. E. Scott, P. J. Daly - with J. W. Cobble)

Induced activity methods were used to measure the cross sections of many reactions induced by 10-33 MeV ^3He ions and 10-44 MeV ^4He ions on a number of target nuclei in the mass range $A=180-210$. It was shown that ($^4\text{He}, xn$) reactions account for more than 90% of the optical model total reaction cross section in this mass region (Fig 1) and that these reactions proceed predominantly by compound nuclear mechanisms. On the other hand, ($^3\text{He}, xn$) reactions account for only about half of the ^3He ion total cross section (Fig 2). Using the independence hypothesis, it was shown that at least 40% of all reactions induced by ^3He ions in these nuclei involve charged particle emission and that direct reaction mechanisms are dominant. With the possible exception of

Fig 1. The sum of the experimental cross sections for ^4He ion induced reactions compared with the optical model total reaction cross section

Fig 2. Sums of the experimental cross sections for ^3He ion induced reactions compared with the optical model total reaction cross sections

the ($^3\text{He},n$) reaction, the ($^3\text{He},xn$) results were found to be consistent with compound nuclear reaction mechanisms.

A paper based on this work has been accepted for publication in Nuclear Physics.

1(b) Comparison of the Reactions $^{206}\text{Pb}(\alpha,3n)$ and $^{207}\text{Pb}(^3\text{He},3n)$

(P. Wong, P. J. Daly - with N. T. Porile)

A detailed study of the reactions $^{206}\text{Pb}(\alpha,3n)^{207}\text{Po}$ and $^{207}\text{Pb}(^3\text{He},3n)^{207}\text{Po}$ is in progress. These reactions involve the same compound nucleus ^{210}Po and if they are both purely compound nucleus reactions the results should be strictly comparable, apart from small angular momentum effects.

The first stage of the experiment has involved thick target recoil range measurements. These have been completed and the results show that in both reactions full momentum transfer occurs up to the highest energies of bombardment. A report of this part of the investigation is being prepared for publication.

Measurements of the angular distributions of the recoils using thin enriched ^{206}Pb and ^{207}Pb targets have begun and it is expected to complete the study within half a year.

1(c) Recoil Ranges (N. E. Scott, R. V. Carlson, P. J. Daly)

An attempt was made to establish accurately the nucleon evaporation correction which must be applied to the measured ranges of recoil atoms resulting from (α,xn) reactions. Thick targets of ^{115}In were bombarded with 10-40 MeV α -particles and the recoils ^{113}Sb , ^{118}Sb and ^{117}Sb (resulting from the (α,γ), (α,n) and ($\alpha,2n$) reactions, respectively) were simultaneously

collected, chemically purified and counted. It was found that the recoil species had essentially the same ranges. However, this result had an experimental error of $\pm 11\%$, (arising mainly from the small activities induced in the (α, γ) reaction) and the evaporation correction is already believed⁽¹⁾ to be appreciably smaller than this. As it was not found possible to reduce the experimental uncertainty substantially, this experiment was abandoned.

2. Nuclear Spectroscopy

2(a) Levels of ^{181}Re from the decay of the ^{181}Os isomers.

(K. J. Hofstetter, Daly - with S. B. Burson and P.F.A. Goudsmit, Argonne)

Previously we have reported⁽²⁾ the discovery of 2.8 min and 105 min ^{181}Os isomers. A rather complete study of the decay of the isomers has now been carried out involving γ -ray singles measurements, γ - γ coincidence measurements and conversion electron measurements using a superconducting electron spectrometer. The main results are shown in Table 1 and the proposed decay schemes are illustrated in Fig 3. The 2.8 min ^{181}Os isomer is identified as the $7/2^- [514]$ neutron state which decays by an allowed unhindered β -transition to the $9/2^- [514]$ proton state in ^{181}Re at 263 keV in accord with the observed $\log ft$ of 4.5. The 105 min isomer is identified with the $1/2^- [510]$ neutron orbital, also seen⁽³⁾ as an isomer in the isotone ^{179}W . The state at 827 keV in ^{181}Re de-excites exclusively by pure E2 to the ground state, marking it rather clearly as the K-2 γ -vibration built on the $5/2^+ [402]$ ground state. It is probable that the γ -vibration contains a large component of the $1/2^+ [400]$ Nilsson configuration. Of particular nuclear interest is the strongly disordered $1/2^- [541]$ band originating at 433 keV.

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Table I.

Transitions in ^{181}Re

Energy	ΔE_Y	I_Y	ΔI_Y	I_K	ΔI_K	I_L	ΔI_L	α_K	α_L	Character
75.7	0.6	200	50	8.4**+2				4.2**+0		E2
94.1	1.0	10	5							
99.3	1.0	7	4							
104.6	1.0	10	5							
118.1	0.5	759	80							
144.8	0.5	102	20							
157.7	1.0	6	5							
167.4	0.5	276	40			5.8**+1	1.8		2.1*-1	E2M1
195.2	1.0	5	5							
228.4	0.8	80	25			2.8**+0	0.9		3.5*-2	M1
235.4	0.8	51	30							
238.8	0.5	2580	200	8.6**+1	2.7	1.2**+1	0.5	3.3*-2	4.7*-3	E1
243.2	0.5	378	70	8.5**+1	2.7	1.2**+1	0.5	2.2*-1	3.2*-2	E2M1
267.5	0.8	50	20	7.2**+0	2.2			1.4*-1		E2
311.4	1.0	16	8							
326.4	1.0	43	15							
344.5	0.8	24	10							
356.7	0.6	78	32	9.2*-1	2.8			1.2*-2		E1
393.7	0.8	25	11							
434.0	0.5	112	35	7.2**+0	2.0			6.4*-2		M1E2
532.3	1.3	27	15							
534.0	1.3	18	12							
567.3	1.3	28	20							
569.5	1.3	24	18							
578.5	1.3	27	21							
580.7	1.3	32	26							
675.4	0.6	96	30	1.7**+0	0.6	8.0*-1	3.2	1.8*-2	8.3*-3	E2M1
728.8	0.6	60	23	1.2**+0	0.5			2.0*-2		M1
749.0	1.0	65	35							
751.5	0.8	141	45	2.8**+0	1.4			2.0*-2		M1
759.4	0.6	135	34	1.9**+0	0.8			1.4*-2		M1E2
767.6	0.8	16	8							
787.6	0.6	241	49	2.1**+0	0.7			8.8*-3		
791.0	1.0	31	17							
796.6	0.8	56	21	4.0*-1	1.6			7.2*-3		E2
802.0	1.0	26	14							
827.0	0.6	1000	130	5.0**+0	1.7	1.6**+0	1.2	5.0*-3	1.6*-3	E2
831.6	0.6	402	80	6.0**+0	2.1	2.2**+0	1.6	1.5*-2	5.4*-3	M1
843.0	1.0	24	13							
851.3	1.0	28	15							
868.3	0.6	142	45	1.0**+0	0.4			7.0*-3		E2M1
872.4	0.6	163	48	9.5*-1	4.0			5.8*-3		E2
918.5	0.9	43	21							
921.0	0.9	54	26							

Table I (continued)

Energy	ΔE_Y	I_Y	ΔI_Y	I_K	ΔI_K	I_L	ΔI_L	α_K	α_L	Character
931.4	0.6	70	24	3.4*-1	1.4			4.9*-3		E2
940.5	1.0	40	13							
955.1	0.6	275	48	2.0*+0	0.6			7.4*-3		E2M1
970.0	1.0	86	32	5.0*-1	2.0			5.8*-3		E2M1
981.5	1.0	41	14							
990.5	0.8	103	31	4.3*-1	2.1			4.2*-3		E2
1000.8	1.0	46	17							
1010.1	1.0	62	21							
1030.5	0.8	97	26							
1060.3	0.6	304	61	7.9*-1	3.5			2.6*-3		E2
1086.1	0.8	83	27							
1108.6	1.3	115	36							
1111.8	1.3	99	35							
1131.6	1.0	39	17							
1180.7	1.0	58	24							
1259.4	1.2	24	16							
1304.3	0.8	112	33							
1325.9	1.2	28	16							
1345.6	0.9	63	21							
1385.2	1.0	60	20							
1441.6	1.1	49	18							
1470.0	1.2	17	12							
1493.0	1.0	70	22							
1568.9	1.2	36	15							
1574.1	1.2	53	20							
1590.6	1.0	45	16							
1620.5	1.4	28	15							
1625	1.4	21	11							
1704.9	1.0	21	12							
1740.4	1.0	89	35							
1760.0	1.0	94	36							
1980	1.5	80								

Fig 3. The decay schemes of the ^{181}Os isomers

This band is known to have a large decoupling parameter $a=4.5$ but in this case the band is further disordered by strong Coriolis coupling between the members of the $3/2^-|532|$ band seen at 1008 keV and the $3/2^-$ and $5/2^-$ members of the $1/2^-|541|$ band. We have performed RPC calculations which account satisfactorily for the structure of both bands.

This work was reported in preliminary form at the Washington D. C. and Debrecen meetings and a full report will soon be submitted for publication.

2(b) Levels of ^{182}Re from the decay of ^{182}Os

(Daly - with Burson, Goudsmit)

The decay of ^{182}Os is also being studied using the same techniques and the same sources as in the ^{181}Os experiments. The analysis of the results is in an earlier stage but a complete list of γ -ray energies and intensities has been obtained and conversion coefficients for the strongest transitions have been determined to be: 180 keV, $\alpha_L = 0.010$; 263 keV, $\alpha_K = 0.022$; 510 keV, $\alpha_K = 0.060$, $\alpha_L = 0.011$. It is hoped to complete the analysis of the experimental data within a few months. Table II shows a list of the strongest γ -rays occurring in the decay of ^{182}Os .

2(c) The decay of the ^{183}Os isomers. (K. Blomberg, Daly)

Recently we have begun a re-examination of the decay of ^{183}Os , which has previously been studied by Newton ⁽⁴⁾ using high resolution electron spectrometry. This is a natural extension of our work on the ^{181}Re levels and it is hoped to complete the decay schemes and if possible to locate the $3/2^-|532|$ band which is probably populated in the decay of the $1/2[510]$ isomer. Thus far only γ -ray singles measurements have been performed but

Table II

Transitions in ^{182}Re

E_Y	ΔE_Y	I_Y	ΔI_Y	E_Y	ΔE_Y	I_Y	ΔI_Y
27.6		?		251.4	0.8	3	3
55.6		?		263.3	0.3	153	30
108.6	0.8	21	8	274.4	0.4	28	8
130.1	0.4	109	23	285.4	0.8	2	2
136.3	0.7	19	8	289.1	0.8	1	1
180.2	0.2	986	100	344.5	0.7	4	3
209.1	0.8	1	1	453.8	0.7	5	3
216.6	0.5	20	8	509.9	0.2	1000	70
222.0	0.7	9	5	555	1.0	6	4
235.6	0.7	14	7	570	1.0	10	5
241.1	0.6	21	8	582	1.0	4	3
246.5	0.7	10	5				

many new γ -rays have been identified. This study is continuing.

2(d) Levels of ^{184}Os populated in ^{184}Ir decay (Daly)

Our study of this particularly interesting decay is continuing. To date, over 300 γ -transitions have been identified in the decay of ^{184}Ir and extensive γ - γ coincidence measurements have been carried out. In the coming year, conversion measurements will be performed and it is expected that detailed knowledge of the ^{184}Os level structure will be obtained.

A preliminary report on this work was given at the Washington A.P.S. meeting.

2(e) A new 18.7 h isomer of ^{200}Au (K. Sakai, Daly)

A gold activity with a half-life of about 19 h was observed in α -particle bombardments of enriched ^{196}Pt and ^{198}Pt with 35 MeV α -particles and of enriched ^{202}Hg with 20 MeV deuterons established clearly that the activity occurred in the decay of a previously unknown 18.7 h isomer of ^{200}Au .

Table III shows the energies and intensities of the γ -rays occurring in the decay of $^{200\text{m}}\text{Au}$. By the sum coincidence technique it was shown that the six strongest γ -rays are in prompt coincidence with each other. It is proposed that in the decay of $^{200\text{m}}\text{Au}$ the main β^- decay branch populates a level in ^{200}Hg at 2642 keV which de-excites by a cascade of four γ -rays to the known 4^+ level at 947.3 keV (Fig 4). It is probable that the ^{200}Au isomer is an analogue of the 9.9 h 12^- isomer of ^{196}Au , which is believed ⁽⁵⁾ to arise from the coupling of a $h_{11/2}$ proton with an $i_{13/2}$ neutron.

A paper based on this work has been accepted for publication in Nuclear Physics.

Table III

Energies and relative intensities of γ -rays
occurring in the decay of 18.7 h ^{200}Au

E_{γ} (keV)	Relative [†] Intensity
181.1 ± 0.4	73 $\pm$ 4
255.8 ± 0.2	96 $\pm$ 5
367.8 ± 0.3	100
498.2 ± 0.4	95 $\pm$ 5
579.6 ± 0.3	100 $\pm$ 5
759.6 ± 0.4	90 $\pm$ 5
904.5 ± 0.6	11.0 $\pm$ 1.5
1226.6 ± 1.5	3.5 $\pm$ 1.0

[†]
Relative to an intensity of 100 for the 367.8 keV γ -ray.

Fig 4. The decay of $^{200\text{m}}\text{Au}$

2(f) The 1.7 min isomer of ^{185}W

(Daly - with P. Kleinheinz, R. Casten, B. Elbek, Bohr Institute, Denmark)

Several groups of workers had previously studied the radioactive decay of 1.7 min $^{185\text{m}}\text{W}$ but no clear understanding of the position and nature of the isomeric state or of the low lying level structure of ^{185}W had emerged. The most recent attempt ⁽³⁾ to construct a reasonable level scheme was based on the decay work of Morinaga et al., ⁽⁶⁾ and on the (d,p) studies of Erskine ⁽⁷⁾ and it involved the radical suggestion that the isomer might be an $i_{13/2}$ shell model state - in a deformed nucleus. As we are involved in studying the level structure of odd W isotopes using (d,p) and (d,t) reactions (See 2(g)) it seemed useful to complement these measurements by re-examining the decay of $^{185\text{m}}\text{W}$ using modern detection equipment.

The activity was produced by reactor irradiation of enriched ^{186}W (94%) and high quality sequential γ -spectra were recorded using a 40cc Ge(Li) spectrometer. The energies and relative intensities of the γ -rays assigned to $^{185\text{m}}\text{W}$ are listed in Table IV and the resulting firmly established level scheme is shown in Fig 5. From the intensity of K X-ray, α_K for the 131.6 keV transition was determined to be 1.5 ± 0.3 , establishing the multipolarity as E3. The observed 1.7 min half life is compatible with E3 de-excitation retarded by one degree of K-forbiddenness.

Our (d,p) and (d,t) reaction studies confirm that the low lying levels of ^{185}W occur at 0 ± 2 , 22 ± 2 , 66 ± 2 , 92 ± 2 , 172 ± 2 and 188 ± 2 keV. The $13/2^+$ member of the $11/2[615]$ band has also been identified at an excitation of 380 keV.

A paper based on this work has been submitted for publication in Nuclear Physics.

Fig 5. The Level scheme of ^{185}W

Table IV

γ -rays in the decay of ^{185m}W

E_{γ} (keV)	I_{γ} (Relative)
42.6 ± 0.4	weak
$W . K_d$	99
66.1 ± 0.2	100
94.3 ± 0.4	1.6
107.7 ± 0.2	5.3
122.1 ± 0.3	1.6
131.6 ± 0.3	66
164.5 ± 0.2	9.9
173.8 ± 0.2	58
188.1 ± 0.2	14.5

2(g) Reaction Spectroscopy of odd W isotopes

(Daly - with Kleinheinz, Casten, Elbek)

Single particle states in the odd W isotopes are being investigated using the (d,p) and (d,t) reactions. 12 MeV deuterons from the Bohr Institute Tandem Van De Graaf are used to induce the reactions and the emergent charged particles are analysed with a broad range magnetic spectrometer. The analysis of the results for the nuclei ^{181}W , ^{183}W and ^{185}W is in an advanced stage.

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II PERSONNEL

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