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Radiochemical Investigations of Nuclear Properties

Patrick J. Daly, Principal Investigator

Progress Report for the period October 1969 to September 1970

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

Department of Chemistry

Purdue University
Lafayette, Indiana

September 1970

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I. Research Activities

During the contract period, our program of nuclear structure investigation in the transitional region $A = 180-200$, using both reaction and decay spectroscopy, has been continued and expanded. Several studies involving the radioactive decay of rather short lived species have been substantially advanced. During the year, considerable effort was devoted to the installation at the Purdue Tandem Laboratory of experimental facilities for nuclear chemistry research, including an 18 inch scattering chamber. These were subsequently used to initiate studies of (1) charged particle evaporation spectra; (2) nuclear structure using $(p, 2n\gamma)$ reaction spectroscopy.

1.1 ^{181}W level structure from ^{181}Re decay

(Daly, Ahlgren, Hofstetter, Hochel)

The preliminary results of this investigation were reported in our last progress report.⁽¹⁾ The work has now been completed and a detailed picture of the ^{181}W level structure (Fig 1), accommodating more than 99% of the ^{181}Re decay intensity, has been established. All the observed ^{181}W states below 1200 KeV excitation have been interpreted with some confidence in terms of the Nilsson Model. This study was particularly important in that it complemented a concurrent investigation of the ^{181}W level structure using neutron transfer reactions (see below) and the radioactivity work located a number of crucial states which were negligibly populated in the transfer reaction. In

particular, the location in the decay work of the $1/2^-$ [510] band provided the key to the understanding of the Coriolis mixing in this nucleus.

A paper based on this study will soon appear in Nuclear Physics.

1.2 Level structure of odd-A Tungsten Nuclei; Coriolis Coupling Effects (Daly - with Casten, Kleinheinz, Elbek, Niels Bohr Institute)

These experiments, in which neutron transfer reactions were used to study the level structure of five odd-A tungsten nuclei, were described in our last progress report. Interpretation of the results has been recently completed. In brief, the level structure of each nucleus up to about 1100 keV excitation can be satisfactorily explained and 5-10 intrinsic states were identified in each nucleus. It was found that many gross discrepancies between the experimental cross-sections and those calculated using the Nilsson model and the DWBA could be eliminated or reduced by inclusion in the cross-section calculations of the Coriolis interaction with coupling matrix elements reduced according to a specific energy dependent prescription. In particular, the highly distinctive systematics of the cross-sections could be reproduced.

A manuscript describing the success of the Coriolis reduction procedure has recently been submitted to Phys. Rev. Letters, and a longer, more comprehensive report is in the final stages of preparation for Dan. Mat. Fys. Medd.

1.3 Levels in ^{185}Os , ^{187}Os from the decays of ^{185}Ir , ^{187}Ir (Ahlgren, Daly)

These studies of the nuclei ^{185}Os , ^{187}Os represent a natural extension of our previous work on the odd W nuclei and these $N = 109, 111$ nuclei would be expected to exhibit low energy excitation modes rather similar to those of their isotones ^{183}W , ^{185}W . However, the Os nuclei are considerably less deformed and sharp deviations from Nilsson model behavior may be observable [The question of whether the well low-lying level structure of ^{189}Os should be interpreted as rotational bands is currently the subject of some controversy⁽²⁾].

The decays of ^{185}Ir and ^{187}Ir have previously been studied by high resolution conversion electron spectrometry and partial decay schemes have been proposed. In our studies the Ir activities are chemically isolated following ^3He and ^4He bombardments of enriched ^{185}Re target and the decays are studied by γ -ray singles and coincidence spectrometry. The investigations are proceeding in parallel and are both nearing completion. In each decay, we have identified approximately three times as many transitions as were observed in the conversion electron studies and our coincidence measurements have revealed that many earlier transition placements, based on energy sum relationships, are in error. Table 1 gives the results of the singles and coincidence results for the ^{187}Ir decay and the level scheme established is illustrated in Fig 2. Currently we are working on interpreting the level structure of both ^{185}Os and ^{187}Os in terms of nuclear models.

1.4 Levels in ^{184}Os from the decay of ^{184}Ir (Hochel, Daly)

Studies of the 3h decay of ^{184}Ir have established a complicated ^{184}Os level scheme extending up to 3 MeV. The ground state band and the γ -vibrational band are clearly identifiable but thus far other ob-

served excited states cannot be unambiguously interpreted. By complementing the decay results with those of (p,2n γ) reactions (Section 1.6), it is hoped that a clear understanding of the principal excitation modes in this important nucleus can be achieved.

1.5 Levels in ^{200}Hg and ^{200}Au from the decay of $^{200\text{m}}\text{Au}$ (Cunnane, Daly)

A detailed study is in progress of the decay of the 18.7h isomer of ^{200}Au which was recently discovered⁽³⁾ in our laboratory. We suspect that this is a $J^\pi = 12^-$ isomer arising from the coupling of a $h_{11/2}$ proton with an $i_{13/2}$ neutron, and that the β -decay branch populates, in ^{200}Hg , a sequence of high spin states, which are of much interest from the nuclear structure viewpoint. The activity is produced by the reaction $^{202}\text{Hg}(d,\alpha)^{200\text{m}}\text{Au}$ and careful chemistry is performed to separate the relatively weak $^{200\text{m}}\text{Au}$ activity from other intense activities, principally those of Tl isotopes. Extensive singles and coincidence γ -ray measurements have been performed and the results (Table 2) establish that $\sim 85\%$ of the $^{200\text{m}}\text{Au}$ nuclei formed undergo β -decay to a 2643 KeV level in ^{200}Hg , which subsequently de-excites to ground by γ -ray emission; the remaining 15% of the decays involve isomeric transitions followed by γ -ray de-excitation to the 48 min ground state of ^{200}Au . Table 2 indicates the particular decay mode to which each of the observed γ -rays has been assigned. To determine transition multipolarities, to identify the isomeric transition and to clarify the overall energy balance in this decay system, further investigations are planned in which conversion electron and β -ray spectra will be measured.

Table 1. The ^{187}Ir decay data. The results of conversion electron measurements (Harmatz et al⁽⁶⁾) and of the present γ -ray measurements (Ahlgren) are listed together as well as assigned multipolarities and transition assignments.

E_{ce}	Harmatz $I_{ce, K}$	$E \gamma$	Ahlgren I_{γ}	α_K	Harmatz Transit.	Exper. Trans.
9.8	>1.3(N)					9.8 $\rightarrow$ 0
25.5	2.7(L)				M1	100.5 $\rightarrow$ 9.8
64.6	1.4(L)				M1	74.4 $\rightarrow$ 9.8
65.3	5.3(L ₃)				E2	75.1 $\rightarrow$ 9.8
74.4	2.0(L ₁)				M1	74.4 $\rightarrow$ 0
75.1	2.2(L ₃)				E2	75.1 $\rightarrow$ 0
84.9	>0.07	84.9	.10	> .70		E2/M1 586.5 $\rightarrow$ 501.4 (c 400)
87.1	$\approx$ 0.07(L ₁)					187.5 100.5
90.7	0.01(L ₃)					100 $\rightarrow$ 9.8
112.4	$\approx$ 0.03(L ₃)	97.7 μsec				(173 $\rightarrow$ 75)
113.2	0.21	{113.0}	{.20}	(>1.1)	E2	prob E2 187.5 $\rightarrow$ 75.1 $\rightarrow$ 74.4
115.7	0.05					
		117.7	.018			
137.9	(Emery)					
150.5	$\approx$.005(L ₃)				E1, E2	501.4 $\rightarrow$ 351
156.6	0.17	Masked by Ir188 155.0 kev				
162.8	0.08	162.8	.10	.80	M1, E2	E2/M1 (73 $\rightarrow$ 9.8), (LL4 $\rightarrow$ 501)
163.5	0.05					(351.1 $\rightarrow$ 187.5)
		169.1	.014			
170.4	$\approx$ 0.002(L ₃)					
177.7	1.28	177.6	1.6	.82	M1/E2	M1/E2 187.5 $\rightarrow$ 9.8
180.9	0.03	{180.7}	{.15}	($\sim$.21)	E2	prob E2
181.9	0.01					
187.5	0.22 0.22	187.3	1.1	Theor.20	E2	187.5 $\rightarrow$ 0.0
189.2	0.004					
198.7	$\approx$ 0.03	198.5	.059	$\approx$.51		M1/E2
206.9	0.004	207.3	.018	.22		E2/(M1)
		220.6	.0065			
224.4	$\approx$ 0.02	224.2	.047	$\approx$.43		M1/E2 1090.2 $\rightarrow$ 967
						725.0 $\rightarrow$ 501.4

Harmatz		Ahlgren		Harmatz	Expt'l
E_{ce}	I_{ceK}	E_{λ}	I_{λ}	Trans.	Trans.

252.9	0.016	252.5	.030	.54		M1	949 → 617
258.5	< .09	258.8	.19	< .47		prob M1	
261.5	0.044	261.7	.12	.37		M1	987 → 725
263.4	0.004						
266.3	0.007	265.7	.059	.12		E2/M1	617.2 → 351.1
276.0	0.007	{ 276.9 }	{ .080 }	(> .09)		prob M1, E2	(351 → 75.1) (987.3 → 711.9)
276.6	w					prob M1, E2	(351 → 74.4)
		284.4	.021				
299.5	0.034	299.4	.17	.21	M1, E2	M1	
314.0	0.14	314.0	.67	.21	M1	M1	501.4 → 187.5 (1770314)
		323	.15				987 → 664
		336.0	.017				
		339.5	.016				
344.6	0.006	344.7	.048	.13		M1	
348.2	0.007	348.9	.033	.21		M1	935.0 → 586
		354.9	.035				
		361.4	.025				
370.1	0.008	370.3	.071	.11		M1	987 → 517
		374.9	.016				725.9 → 351.1
		378.2	.026				1090 → 711
		384.5	.21				
395.6	0.010	395.8	.11	.090		M1/E2	
398.7	0.026	398.4	.15	.17		M1	586.3 → 501.4 617
doublet 400.7	0.09	400.8	2.9	.032	E2	(E2)	{ 501.4 → 100.5 } { 987. → 586 }
		412.5	.15				
		422.3	.049				
426.4		{ 427.0 }	{ 3.0 }	(> .08)		prob M1	501.4 → 75.1 (1070 → 664)
427.1	≈ 0.24						501.4 → 74.4
		439.7	.051				
447.6	0.007	448.2	.10	.070		M1	1111.9 → 664

Harmatz		Ahlgren		Harmatz	Expt'l
E_{ce}	I_{ce_K}	E_γ	I_γ	Trans.	Trans.
		461.2	.014		
		477			664 → 187.5 (177)
486.1	0.012	485.8	.53	F2	(586.3 → 100.5) (997 → 501) ^{d.s.}
491.7	0.045	491.6	.90	M1/(E2)	501.4 → 9.8
501.4	0.053	501.5	1.0	M1	501.4 → 9.8
515.5	0.014	511			586.3 → 71.4 or 75.1
515.5	0.014	515.6	.27	M1	1102.0 → 586.3
522.0	0.010	522.1	.20	M1	
		564.8	.025		
		567.6	.020		
576.7	≈ 0.02	576.6	.57	M1	586.3 → 9.8
586.7	0.006	586.5	.20	M1/(E2)	586.3 → 0.0
588.9	0.005	589.4	.23	M1/E2	664.2 → 75.1, 1070 → 501.4
		607.5	.10		647 → 9.8
610.9	0.08	610.9	3.3	M1	711.4 → 100.5
636.8	< 0.007	Hidden in Ir 188 633, 634			(711.4 → 74.4) (967 - 351)
651.5	0.005	651.4	.29	M1/E2	725.8 → 74.4
654.4	0.005	654.3	.29	M1/E2	664.2 → 7.9
		663.8	.10		664.0 → 0
		667.1	.042		
		683.5	.016		
		696.2	.041		
		699.2	.033		
		701.2	.045		711.4 → 9.8
		709.0	.016		
		711.3	.028		711.4 → 0.0
715.9	< 0.004	715.3	.18	prob M1	725.8 → 9.8
		721.9	.054		
doub 725.6	0.004	725.0	.33	M1/E2	725.8 → 0.0
			.012		1232 → 501

Harmatz E _{ce}	Harmatz I _{ceK}	Ahlgren E _g	Ahlgren I _Δ	Δ _K	Harmatz Trans.	Expt'l Trans.
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		735.4	.027	
		740.9	.041	
747.4	0.004	747.5	.20	.020
757.1	0.003	756.5	.16	.20
760.3	≈ 0.001			
		788.4	.066	
800.2	0.009	800.0	.63	.014
		813.7	.064	
		840.8	.20	
		860.6	.066	
		866.7	.024	
886.9	w	Masked by Ir 188		
		899.7	.13	
903.1	0.003	903.2	.22	.013
912.8	^A 0.031	913.0	3.8	.081
may be Ir -lived		922.4	.036	
		933.0	.034	
		⁵ 936.2	.060	
978.0	0.014	977.6	2.2	.0064
987.9	0.015	987.2	2.1	.0071
		1012.6	.038	
		~ 1015.6	.064	
		~ 1027.6	.038	
		1037.4	.20	
1038.1		1080.1	.078	
		^{0.4} 1091.2	.014	
1102.8	w	1102.1	.11	($< .010$)
1112.1	0.002	1111.8	.35	.0058
		1126.1	.021	
		1230.0	.0078	

M1	935 → 187.5
M1	1111.8 → 351
M1	987 → 157
	935. → 74.4
	987 → 104.5
M1	1090 → 187
M1	987 → 74.4
M1/E2	935 → 0.0
M1	987 → 9.7
M1	987 → 0
M1/E2	1090 → 74.75
	1102.3 → 74.4
	1111.8 → 74.4
	1090 → 9.8
	1090 → 0
prob M1	1102 → 0.1
M1/E2	1111.8 → 0

doubl

Table 2

The decay of $^{200\text{m}}\text{Au}$: γ -ray singles and coincidence results

	E_{γ} (KeV)	I_{γ}	Assignments
1	105.2	0.8	^{200}Au
2	111.3	2.3	^{200}Hg
3	120.4	1.3	^{200}Au
4	133.4	4.6	^{200}Au
5	146.1	4.9	^{200}Au
6	181.1	71.0	^{200}Hg
7	218.1	2.5	^{200}Au
8	255.9	92.0	^{200}Hg
9	332.7	16.0	^{200}Au
10	368.2	100.0	} ^{200}Hg
11	498.1	96.0	
12	579.6	94.0	
13	648.3	0.2	
14	760.0	88.0	
15	904.7	10.0	
16	1226.0	2.8	^{200}Hg via 48 min $^{200\text{g}}\text{Au}$
17	1263.2	0.8	^{200}Hg via 48 min $^{200\text{g}}\text{Au}$

Table 2 (cont)

Coincidence Results

Gating γ -Ray	Observed Coincidences
K X-ray	$\gamma_3, \gamma_4, \gamma_5, \gamma_7, \gamma_9$
181 KeV	$\gamma_2, \gamma_8, \gamma_{10}, \gamma_{11}, \gamma_{12}, \gamma_{14}, \gamma_{15}$
256 KeV	$\gamma_6, \gamma_{10}, \gamma_{11}, \gamma_{12}, \gamma_{13}, \gamma_{14}$
332 KeV	$\gamma_3, \gamma_4, \gamma_5, \gamma_7$
368 KeV	$\gamma_2, \gamma_6, \gamma_8, \gamma_{11}, \gamma_{12}, \gamma_{13}, \gamma_{14}, \gamma_{15}$
498 KeV	$\gamma_2, \gamma_6, \gamma_8, \gamma_{10}, \gamma_{12}, \gamma_{13}, \gamma_{14}, \gamma_{15}$
580 KeV	$\gamma_2, \gamma_6, \gamma_8, \gamma_{10}, \gamma_{11}, \gamma_{14}, \gamma_{15}$
760 KeV	$\gamma_6, \gamma_8, \gamma_{10}, \gamma_{11}, \gamma_{12}, \gamma_{13}$
904 KeV	$\gamma_2, \gamma_6, \gamma_8, \gamma_{10}, \gamma_{11}, \gamma_{12}$

1.6 Reaction spectroscopy using (p,2n γ) reactions

(Hochel, Yates, Cunnane, Daly)

A program of studies in which measurements of γ -rays accompanying (p,2n) reactions will be used to investigate the level structure of deformed and transitional neutron deficient nuclei is underway. In the initial experiment, a tantalum foil target was used to study the $^{181}\text{Ta}(p,2n\gamma)$ reaction because (1) this reaction had previously been investigated using conversion electron spectrometry; (2) the level structure of ^{180}W had previously been studied in this laboratory in the radioactive decay of ^{180}Re .⁽⁴⁾

During this exploratory phase of the work the emphasis was on the determination of optimum experimental conditions; the effects of varying such experimental parameters as the size and collimation of the beam and the positioning and shielding (from fast neutrons and background γ -radiation) of the Ge(Li) detector were investigated. The final adopted configuration yields γ -spectra of a quality comparable with those obtained using radioactive sources. In the $^{181}\text{Ta}(p,2n\gamma)^{180}\text{W}$ reaction, γ -ray peaks corresponding to virtually all the transitions observed in the conversion electron study were clearly seen together with many additional weak γ -rays.

We are now carrying out an intensive study of the level structure of ^{184}Os and ^{186}Os by inducing the (p,2n) reaction in ^{185}Re and ^{187}Re . Earlier radioactivity studies⁽⁵⁾ have yielded a detailed knowledge and a fair understanding of the ^{186}Os low-lying levels whereas published data on the ^{184}Os level structure is meager and contradictory. In our laboratory investigations of the ^{184}Os structure are proceeding on two fronts: (1) detailed measurements of the radioactive decay of 3h ^{184}Ir ;

(2) by (p,2n γ) reaction studies using ^{185}Re targets.

The (p,2n γ) experiments are based on the following rationale: ^{184}Os and ^{186}Os are expected to exhibit similar excitation modes - whether they be collective or quasi-particle in nature; since the target nuclei ^{185}Re and ^{187}Re have almost identical properties, the (p,2n) reaction in either target should populate analogous states of excitation with excitation functions closely similar in shape and in magnitude; furthermore, the angular distributions of γ -rays depopulating analogous states should be similar. Thus, it is hoped to use ^{186}Os as a stepping stone to an understanding of the ^{184}Os nucleus.

Thin ($\sim 5 \text{ mg/cm}^2$) self-supporting electroplated targets of ^{185}Re and ^{187}Re have been bombarded with 9-14 MeV protons and γ -spectra have been recorded using our 30cc Ge(Li) detector. The γ -rays accompanying the (p,2n) reaction on the Re isotopes are readily distinguished by their characteristic intensity variations with bombarding energy. It is immediately clear that 70-80% of the γ -rays observed in our ^{184}Ir decay studies are also excited strongly in the $^{185}\text{Re}(p,2n)$ process. (Fig 3) Detailed analyses of the spectra and construction of excitation functions for the individual product γ -rays are now in progress.

Further experiments are planned in which the γ -ray angular distributions with respect to the beam direction will be measured at a single bombarding energy.

1.7 Spectra of charged particles evaporated from compound nuclei

One of us (PJD) has joined the research group of N. T. Porile in a study of nuclear shell effects on proton and α -particle evaporation

from compound nuclei. These experiments are carried out using 12-14 MeV incident protons from the Tandem accelerator and particle identification is achieved using a conventional $\Delta E-E$ detector telescope. Preliminary results were recently reported in C00-1505-42.

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II. Instrumentation

During the contract period, the research facilities for nuclear chemistry research at the Purdue Tandem Laboratory were considerably expanded. In the target area, one beam line is presently assigned to the nuclear chemistry experiments of Dr. N. T. Porile and ourselves. On this line an 18 inch scattering chamber with its ancillary pumping equipment has been permanently installed and aligned. The chamber is equipped with beam collimators, target holders, Faraday cup, detector holders, etc., and it is suitable for diverse types of nuclear experimentation.

Signals from the target area are fed through to a data room where a Packard 45 analyzer (incorporating a digital gate facility) is currently used for data acquisition. This analyzer is used in our radioactive decay studies as well as in all the nuclear chemistry experiments on the Tandem; its low digitizing rate (4 Mc) and inflexible data acquisition modes imposes real restrictions on the types of experiments which can be undertaken. It is hoped that a more powerful data acquisition system, incorporating a medium sized computer, can be acquired in this coming year.

Additional equipment purchased with contract funds include a fast oscilloscope, which is used in all the nuclear chemistry experiments and a cooled Si(Li) spectrometer which will be used for conversion electron measurements.

III. Personnel

Senior Staff

Dr. P. J. Daly, Associate Professor of Chemistry, Principal Investigator

Graduate Research Assistants

Karin Blomberg
James Cunnane
Robert Hochel
Steven Yates

Service Staff

E. Schmidlin, Electronics Engineer
J. Clark, Electronics Technician
L. Eckstein, Draftsman

IV. Publications

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Fig 2. The level structure of ^{187}Os from the decay of ^{187}Ir

Fig 3. ^{184}Os γ -spectra from ^{184}Os decay and from the $(p, 2n\gamma)$ reaction on ^{185}Re