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Radiochemical Investigations of Nuclear Properties

Patrick J. Daly, Principal Investigator

Progress Report for the period October 1970 to September 1971

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

Department of Chemistry

**Purdue University
Lafayette, Indiana**

September 1971

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I. Research Activities

During this contract period, our research efforts have been devoted almost exclusively to investigations of the structure of nuclei in the transitional region $A = 180-200$. For the first half of 1971 the principal investigator was on sabbatical leave at the Niels Bohr Institute, Copenhagen, where he was involved in several nuclear structure investigations most of which are related to the work of our group at Purdue. An outline of the main results of these studies is included in the following sections.

At the Purdue Tandem Laboratory, our studies of nuclear level structure using $(p, 2n\gamma)$ and $(\alpha, 2n\gamma)$ reaction spectroscopy have continued. Recently, a small scattering chamber, which will enable us to perform on-line γ - γ coincidence measurements has been constructed. Considerable progress has been made in several of our investigations of the radioactive decay of short lived nuclei in the $A = 180-200$ mass range. In some cases the results of separate reaction spectroscopy and decay spectroscopy studies have been combined to yield detailed information about the level structure of the same final nuclei.

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

(Daly, Ahlgren, Hofstetter, Hochel)

This study has been completed and the results have been published (Nucl. Phys. A161 (1971) 177).

1.2 Level structure of odd-A Tungsten nuclei: Coriolis Coupling Effects

(Daly - with Casten, Kleinheinz, Elbek, Bohr Institute)

This study, in which the detailed level structure of the five odd W nuclei, $A = 179-187$ was established and the effects of Coriolis mixing on level energies and transfer cross sections was examined, has also been completed. An analysis and discussion of the Coriolis coupling in these nuclei has been published (Phys. Rev. C 3, (1971) 1271). A much more comprehensive manuscript describing all the important results of this investigation, including the detailed level schemes, has been completed and accepted for publication in Dan. Mat. Fys. Medd.

1.3 The level structure of ^{182}W and ^{184}W

(Daly - with Kleinheinz and Casten)

Although the level structure of the nuclei ^{182}W , ^{184}W has been the subject of very many experimental investigations, our knowledge of these nuclei remains surprisingly scanty. In particular, the 1200-2000 keV range of excitation energy, where several rather pure two quasi-particle excitations can be expected and where many excited states have been located in decay work, is still poorly understood.

We have used the (d,t), (d,p), and ($^3\text{He},\alpha$) transfer reactions to investigate the ^{182}W , ^{184}W level structures. The target nucleus was ^{183}W and the charged reaction products were analyzed using a broad range magnetic spectrometer. Level spectra up to about 2.5 MeV in both nuclei have been obtained and for each level the l-transfer in its population has been inferred from angular distribution measurements. Since ^{183}W has a $\frac{1}{2}^- [510]$ ground state, two neutron states having $\frac{1}{2}^- [510]$ as one component are selectively populated in the neutron transfer reactions.

In ^{182}W , all the observed levels up to ~2000 keV excitation have been satisfactorily explained but only a brief summary of the results and their implications can be given here. Bands based on the $K = 4^-$ and $K = 5^- \frac{1}{2}^- [510] - \frac{9}{2}^+ [624]$ configurations and on the $K = 2^+$ and $K = 1^+ \frac{1}{2}^- [510] - \frac{3}{2}^- [512]$ configurations have been firmly identified. A measure of the $\frac{1}{2}^- [510] - \frac{5}{2}^- [512]$ $K = 2^+$ contribution to the well-known γ -band in ^{182}W has also been obtained from the (d,t) data; the result is in excellent agreement with the microscopic description of Bès.⁽¹⁾ Strongly populated levels in the 2000-2200 keV region probably correspond to the $\frac{1}{2}^- [510] - \frac{1}{2}^- [521]$ $K = 1^+$ and 0^+ configurations; however, since the experimental spectra are extremely complex in this region and the theoretical predictions are fraught with complications, firm assignments of individual levels will probably not be possible.

The analysis of the $^{183}\text{W}(\text{d,p})$ ^{184}W data has also been rather successful. In this case, population of the γ -band proceeds through a large $\frac{1}{2}^- [510] - \frac{3}{2}^- [512]$ $K = 2^+$ two neutron component, again in agreement with the calculations of Bès. Bands based on the $\frac{1}{2}^- [510] - \frac{11}{2}^+ [615]$ $K = 5^-$ and $\frac{1}{2}^- [510] - \frac{7}{2}^- [503]$ $K = 3^+$ configurations have been identified and the remainder of the $\frac{1}{2}^- [510] - \frac{3}{2}^- [512]$ $K = 2^+$ strength has been located (Fig. 1). Several additional but more tentative assignments are currently being considered and Coriolis mixing calculations are being performed. Our study of the $^{184}\text{Ta} \rightarrow ^{184}\text{W}$ decay (described below) may also prove helpful in further interpretation of the transfer data.

This investigation is progressing rapidly and will be completed within the coming year.

$^{183}\text{W}(d,p)^{184}\text{W}$

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

(Yates, Daly)

To complement the results of the (d,p) study described in the previous section, we have recently undertaken a new study of the decay of 8h ^{184}Ta . Earlier attempts^(2,3) to establish an understandable decay scheme for ^{184}Ta have been unsuccessful. It appears that the levels populated in the β -decay all feed a high-lying isomeric state with $t_{1/2} > 1 \mu\text{sec}$. A recent study⁽⁴⁾ of ^{184}Re decay and our (d,p) results into ^{184}W have now identified the isomeric state as the $\frac{1}{2}^- [510] - \frac{11}{2}^+ [615]$ $K = 5^-$ band origin at 1285 keV and it should therefore be possible to obtain a detailed understanding of the ^{184}Ta decay.

Recently we have produced ^{184}Ta activity by the (d, α) reaction on enriched ^{186}W and have performed detailed singles and coincidence γ -ray measurements. Although the results are yet only partially analyzed it is rather clear that the ^{184}Ta ground state $\frac{7}{2}^+ [404] - \frac{3}{2}^- [512]$ $5,5^-$ decays principally to the $\frac{7}{2}^- [503] - \frac{3}{2}^- [512]$ $5,5^+$ state in ^{184}W , which in turn depopulates to $\frac{7}{2}^- [503] - \frac{1}{2}^- [510]$ $K = 3^+$ band members and to the isomeric state. There are additional weak decay branches.

This study is continuing.

1.5 Levels of ^{187}Os from the decay of ^{187}Ir

(Ahlgren, Daly)

Since the last progress report, the experimental work on the ^{187}Ir decay has been completed and a detailed analysis of the results has been performed. The resulting level scheme (K. Ahlgren, Ph.D. thesis, Purdue 1971) accommodates about 98% of the decay intensity and many new

Fig. 2

energy levels of ^{187}Os have been established. Our results support Ewbank's⁽⁵⁾ reinterpretation of the ^{187}Os levels below 300 keV first located by Harmatz et al⁽⁶⁾. At higher energies we identify a $K = 3/2^-$ band based at 501 keV as a $K=2$ γ -vibration built on the $7/2^- [503]$ orbital which also contains as a major component a fraction of the $3/2^- [501]$ single particle strength. Most of the remaining strength of the $3/2^- [501]$ configuration appears in a $K = 3/2^-$ band based at 987 keV. Previous workers^(7,8) have speculated that this Nilsson state might be fractionated in the Hf, W, Os region; this appears to be the first case in which two large fractions have been located in the same nucleus. The $5/2^- 5/2^- [503]$ particle excitation has also been located and, more tentatively, the $1/2^- 1/2^- [501]$ state (or a fraction thereof) (Fig. 2).

On the hole side of the Fermi level, the $9/2^+ [624]$ orbital has been firmly identified and possibly the $1/2^- [521]$ orbital also. Levels at 664 and 725 keV weakly populated in the decay are probably identical with collective states located⁽⁹⁾ at approximately these energies in (d,d') studies of ^{187}Os . They are likely to represent $K=2$ and $K+2$ γ -vibrations built on the ground state.

A more detailed description of the results of this investigation and of the arguments on which the assignments are based is given in Ref⁽¹⁰⁾. A final draft of a manuscript is in preparation and will be submitted for publication shortly.

1.6 Levels in ^{190}Pt , ^{192}Pt by (p,2n γ) and (α ,2n γ) spectroscopy
(Hochel, Yates, Cunnane, Daly)

We have begun a new study of the levels of ^{190}Pt and ^{192}Pt

populated by the $(p,2n\gamma)$ reaction using incident protons of 10-15 MeV from the Purdue Tandem V. D. G. on enriched ^{191}Ir and ^{193}Ir targets. The low lying level structure of ^{192}Pt is already known rather well from numerous studies of the ^{192}Ir decay. {To supplement these data, we have also studied the decay of ^{192}Au in which many more high-lying ^{192}Pt levels are populated than in the ^{192}Ir decay.} In contrast, the level structure of ^{190}Pt is poorly established.

By assuming that analogous states in ^{190}Pt and ^{192}Pt are populated in the $(p,2n)$ reaction with similar excitation functions and absolute cross sections and that the de-exciting γ -rays should display similar angular distribution patterns, the ^{190}Pt and ^{192}Pt level schemes shown in fig 4 have been constructed. Of particular interest is the remarkable resemblance between the well developed quasi γ -vibrational bands and the 3^- octupole states in both nuclei. All the observed γ -rays have not yet been accommodated, but γ - γ coincidence measurements are planned for the near future.

1.7 Levels in ^{184}Os from the decay of ^{184}Ir and from $(p,2n\gamma)$ reaction studies.

(Hochel, Yates, Cunnane, Daly)

The details of this two pronged effort to elucidate the rather complicated level structure of ^{184}Os have been outlined in our previous report.⁽¹¹⁾ Both experimental approaches have been pursued further. In particular, β - γ coincidence measurements and conversion coefficient determinations have settled several key questions in the ^{184}Ir decay and a paper describing our principal findings is in preparation.

Fig 3

1.8 Decay of the 18.7 h isomer of ^{200}Au

Considerable progress has been made in this study. The isomer de-excites to the ^{200}Au ground state in ~18% of the decays and to a level at 2642 in ^{200}Hg in the remainder of the decays. Recently we have determined conversion coefficients and inferred multipolarities for all the strong transitions in the ^{200}Hg decay branch. The proposed decay scheme (Fig 5) is consistent with all our measurements. Since, however, our conclusions conflict with those reported recently by other workers,⁽¹²⁾ we feel that we should repeat some of our coincidence and conversion measurements in order to resolve the disagreement.

1.9 Non-existence of 3h $^{190\text{m}}\text{Re}$

(Yates, Daly)

Some years ago, Baró and Flegenhimer⁽¹³⁾ reported the discovery of a 3h ^{190}Re isomer, which is currently listed in all nuclear data compilations. We planned an investigation of the decay of the isomer partly to determine the nuclear configuration of the isomeric state and partly to investigate the ^{190}Os levels populated in its decay. Enriched ^{192}Os targets were bombarded with 20 MeV deuterons to produce $^{190\text{m}}\text{Re}$ by the (d, α) reaction and rhenium activities were chemically separated from Os and Ir activities by distillation and precipitation techniques. Surprisingly, no trace of a 3h Re activity could be found, although we know from experience that the bombarding conditions were such that μC activities of the isomer should have been produced. A second search for 3h $^{190\text{m}}\text{Re}$ also proved unsuccessful. We tentatively conclude that no such isomer exists and that the activity observed by Baro et al. probably was

Decay of ^{200m}Au

Fig 4

3.1 h ^{190}Ir , which exhibits a γ -ray spectrum similar to that reported for the Re isomer.

Baró et al. also claimed to have produced $^{190\text{m}}\text{Re}$ in fast neutron bombardments of Os metal and this production method will also be tested using 14 MeV neutrons from the Purdue Neutron Generator before we conclude for certain that $^{190\text{m}}\text{Re}$ does not exist.

1.10 Direct determination of Coriolis mixing amplitudes

(Daly - with Herskind, G. Hagemann, K. Hagemann and Johnson,
Bohr Institute)

Several studies (including those described in Section 1.2) have indicated that current models of the nucleus give an inadequate description of the strength of the Coriolis interaction in deformed nuclei. To provide a more rigorous test of this apparent discrepancy, a series of experiments were designed in which the matrix elements could be directly measured by Coulomb excitation of ^{167}Er and ^{161}Dy with ^4He , ^{16}O and ^{32}S projectiles. In these nuclei, the matrix elements between the ground state band and higher-lying bands (which can be populated in Coulomb excitation only as a consequence of Coriolis mixing) have been measured. Preliminary results appear to be promising but further experimental work will be necessary before definite conclusions can be drawn.

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II. Instrumentation

Many improvements in the quality and range of our spectroscopic equipment were made during the past year. Most notable acquisitions were a conversion electron spectrometer incorporating a cooled Si(Li) detector, a new ADC of high digitizing rate which makes possible the accumulation of 4096 channel singles spectra on our Packard analyzer and a new Ge(Li) spectrometer system. In addition several minor electronic components were added.

Very recently the new 8K computer-analyzer system with magnetic tape transport was delivered by Northern Scientific. This will be used for all the nuclear chemistry experiments at the Tandem laboratory and it will provide a major advance in our data acquisition capabilities.

A new 4" scattering chamber, for use in our on-line spectroscopic studies, has been constructed in our workshops. It is located on the same beam as the 18" chamber we have previously used and it will make γ - γ coincidence measurements possible.

III. Personnel

Senior Staff

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

Dr. K. Ahlgren, Instructor and Research Associate

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Jim Cunnane

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IV. Publications

1. The decay of ^{187}Ir , P. J. Daly and Karin Ahlgren, Bull. Am. Phys. Soc., 15 (1970) 1357.
2. The level structure of ^{181}W from the decay of ^{181}Re , P. J. Daly, K. Ahlgren, K. J. Hofstetter and R. Hochel, Nucl. Phys. A161, (1971) 177.
3. Coriolis Coupling in the Odd Tungsten Isotopes, R. F. Casten, P. Kleinheinz, P. J. Daly and B. Elbek, Phys. Rev. C 3 (1971) 1271.
4. Studies of the level structures of ^{181}W , ^{185}Os and ^{187}Os by radioactive decay spectroscopy, K. Ahlgren, Ph.D. thesis, Purdue Univ. (1971).
5. A study of energy levels and Coriolis coupling in odd-mass wolfram nuclei by means of (d,p) (d,t) and ($^3\text{He},\alpha$) reactions, Mat. Fys. Medd. Dan. Vid. Selsk (in press).
6. The level structure of ^{187}Os from the decay of ^{187}Ir , Karin Ahlgren and P. J. Daly, to be submitted to Phys. Rev., October 1971.
7. The level structure of ^{184}Os from ^{184}Ir decay and (p,2n γ) reaction spectroscopy, R. Hochel, J. Cunnane, S. Yates, K. J. Hofstetter, A. LeBoeuf and P. J. Daly (in preparation).