MASTER

COO-1672-74

RADIOCHEMICAL INVESTIGATIONS OF NUCLEAR PROPERTIES

Progress Report

for Period October 1, 1977 to December 31, 1978

Patrick J. Daly
Principal Investigator

Purdue University, West Lafayette, Indiana 47907

January 1979

Prepared For

THE U.S. DEPARTMENT OF ENERGY
UNDER CONTRACT NO. EY-76-S-02-1672

Abstract

Results of $(\alpha,xn\gamma)$ and (Heavy Ion, $xn\gamma$) investigations of high-spin excitations in spherical and transitional heavy nuclei are summarised. Considerable progress has been made in studies of the level structures of $^{187,188,189}Pt$ and of $^{200,201,202}Pb$. Investigations of the structure of the Z = 64, N = 82 nucleus ^{146}Gd and of other nuclei consisting of the ^{146}Gd core plus one, two or three valence nucleons are also briefly described.

I. Research Activities

The research activities of our group during the contract period can be divided naturally into two categories. On the one hand, we have pursued our investigations at the Michigan State Cyclotron Laboratory of the high-spin excitations of the transitional nuclei $^{187,188,189}Pt$ and of the spherical nuclei $^{200,201,202}Pb$. Several additional measurements were performed aimed at completing these particular studies before the impending shutdown of the MSU machine for the installation of the 500 MeV superconducting cyclotron. The other line of research has concerned the structure of Gd, Tb and Dy nuclei in the neighborhood of the N=82 closed shell. These are collaborative studies which the principal investigator was involved in during a sabbatical year 1977-78 at the Institut für Kernphysik, KFA Jülich; some of the results have already been published and others are being worked up towards publication at Jülich and at Purdue. Progress in the various projects is summarised in the following sections.

The Light Pt Nuclei $^{187,188,189}Pt$

We have expended considerable effort on unravelling the extremely complex level structures of these three Pt nuclei by $(p,xn\gamma)$, $(\alpha,xn\gamma)$ and $(^{12}C,xn\gamma)$ reaction spectroscopy and by radioactive decay spectroscopy. The breakthrough in understanding the ^{188}Pt high-spin level spectrum was described in our last annual report[1)], and the full level scheme is shown in Fig. 1. It is, as far as we know, the only nucleus in which rotation-aligned states of $\nu i^{-2}_{13/2}$ or $\pi h^{-2}_{11/2}$ character are observed to de-excite predominantly to the γ-vibrational band. These ^{188}Pt results were reported at the Dresden High-Spin Conference and at the 1978 Washington APS meeting: they are currently being written up for publication.

Work on the level structures of the two odd-A nuclei is also nearing completion and the resulting level schemes are shown in Fig. 2. The ^{189}Pt level structure is particularly intricate with well developed odd-parity bands as well as an extensive $\nu i_{13/2}$ family of levels. In the case of ^{187}Pt, three weaker γ-ray cascades, which are probably counterparts of the odd-parity bands in ^{189}Pt, were observed, but since we have been unable to fit them together with the $\nu i_{13/2}$ levels, they are omitted from Fig. 2. These results have been interpreted in terms of the triaxial rotor model[2); they illustrate rather nicely the gradual shape change from prolate to oblate that occurs across the Pt isotopes. A paper on the ^{187,189}Pt level structure is also in preparation.

<u>High-Spin Excitation Modes in Light Pb Nuclei</u>

Earlier[3) we explored the high-spin level spectra, up to $I^{\pi}=29/2^{-}$, of the five odd-A Pb nuclei in the A=195-203 mass range; the results formed S. K. Saha's Ph.D. thesis, completed in January 1978. We have gone on to investigate the high-spin excitations of the nuclei ^{200}Pb, ^{201}Pb and ^{202}Pb above the known 9^{-} isomers in the even-A nuclei and the $29/2^{-}$ isomer in ^{201}Pb.

Extensive γ-γ-t coincidence and $t_{\gamma\text{-}RF}$ timing measurements using (α,xn) reactions on enriched Hg targets have yielded new and detailed high-spin level schemes in all three nuclei. In contrast to ^{204}Pb, which has no known high-spin isomers[4), several isomers with half-lives in the range 20 to 180 ns have been located in each of the even-A nuclei. The previously reported[5)] 200 ns 12^+ isomer at 3103 keV in ^{202}Pb could not be confirmed; instead, we identify a 21 ns isomer at 3238 keV as the 12^+ state of $\nu i^{-2}_{13/2}$ character in this nucleus. The corresponding state in ^{200}Pb is found at a slightly lower energy.

There are still definite problems in interpreting the established level schemes and, particularly, in deciding the configurations of the several isomers located above the 12^+ states in ^{200}Pb and ^{202}Pb. The main difficulty is that the usual method of inferring transition multipolarities from γ-ray angular distributions has proved to be of limited usefulness in nuclei containing so many rather long lived isomers. In an attempt to solve some of the problems, we performed in-beam conversion electron measurements in our most recent run, but the results have not yet been analyzed.

Excitation Modes in $^{146}_{64}Gd_{82}$ and Neighboring Nuclei

While the principal investigator was on sabbatical leave at KFA Jülich, Germany, he collaborated in an interesting series of experiments involving nuclei in the neighborhood of the N=82 closed shell. On the basis of γ-ray angular distribution results, Kleinheinz et al.[6)] had interpreted the 1579 keV first excited level in ^{146}Gd as the 3^- octupole state, and not a 2^+ state as had been previously claimed. It was desirable to test this conclusion using more widely accepted experimental methods. Accordingly, in the first experiments the K-conversion coefficient of the 1579 keV transition was determined accurately by e^- and γ-ray measurements, and the half-life of the 1579 keV level was determined as $T_{1/2}$ = 1.06±0.12 ns. The results showed that the 1579 keV transition indeed had pure E3 character, and that the B(E3) value was 37±4 Weisskopf units, comparable to the large values found for enhanced $3^- \rightarrow 0^+$ transitions in the Pb region. These were rather significant results establishing ^{146}Gd, with Z=64, N=82, as the only nucleus besides ^{208}Pb with a 3^- first excited state.

It then seemed important to determine the true location of the lowest 2^+ state in ^{146}Gd. In a specially designed experiment involving careful ^{144}Sm(α,2nγ) threshold measurements, that 2^+ state was identified at 1971 keV - more than 300 keV higher than in any other N=82 isotone. This result provided a strong indication that the energy gap in the single particle level spectrum at Z=64 is unusually large, perhaps as large as the gaps observed at the magic numbers.

Subsequently, a more comprehensive study of the high-spin level structure of ^{146}Gd and ^{147}Gd by in-beam γ-ray and electron spectroscopy established detailed level schemes for the two nuclei to above 4 MeV excitation energy. An analysis using empirical single particle energies and two nucleon interactions characterized all the observed energy levels as parcle-hole excitations (Fig. 3). Most importantly, the observed energies of pure 1 particle-1 hole states of the types $\pi h_{11/2} d^{-1}_{5/2}$ and $\pi h_{11/2} g^{-1}_{7/2}$ in ^{146}Gd showed that the Z-64 energy gap is approximately 3.4 MeV, which is nearly as large as the well established N=82 gap. The inferred proton and neutron single particle level schemes for the Z=64, N=82 region are displayed in Fig. 3.

The above studies showed that ^{146}Gd can be viewed as a doubly closed shell nucleus and that the shell model might be as successful in describing the excitation modes of nuclei consisting of the ^{146}Gd core plus a few nucleons as it has been in the neighborhood of ^{208}Pb. Accordingly, investigations of the previously unknown level spectra of the one-proton nucleus ^{147}Tb, the one-proton one-neutron nucleus ^{148}Tb, and the two-proton nucleus ^{148}Dy were undertaken. The analyses and interpretation of the data for the Tb nuclei are still in progress but it is already clear that the results will be interesting and unusual. The ^{148}Dy study is further advanced, and a preliminary report on the findings has already been published[7)]. In this nucleus, a complete j^2-spectrum of $\pi h^2_{11/2}$ 0^+, 2^+,---10^+ levels was observed and an effective $\pi h_{11/2}$ charge of 1.53e was extracted from the measured $10^+ \rightarrow 8^+$ E2 transition probability. The results also provided a valuable extension of the 2^+ and 3^- energy systematics for the N=82 isotones.

Apart from the intrinsic interest of the spectroscopy of these nuclei, the establishment of accurate single particle level spectra for both proton and neutrons around Z=64, N=82 was important because it is this region that a much discussed Copenhagen-Darmstadt experiment[8)] located an island of high spin isomers. Many workers seem inclined to identify these isomers as the yrast traps first suggested by Bohr and Mottelson[9)]. In a separate investigation, we found that α-particle induced reactions on Sm targets populate high-lying isomers in ^{146}Gd and ^{147}Gd, which are clearly identical to the two best established isomers reported by the Copenhagen-Darmstadt team. Moreover, we were able to show that these isomers have rather modest spin-values ($\sim 20\ \hbar$). Therefore, these two isomers cannot be the very high-spin yrast traps theoretically predicted for this region. Since the levels observed in these nuclei below 4 MeV are convincingly explained in terms of shell model configurations of seniorities one, two and three, it seems much more natural to interpret these isomers as as spherical shell model states of higher seniority.

It remains to be seen whether the other members of the reported island of isomers could be the predicted yrast traps in deformed nuclei rotating around a symmetry axis. Studies of the detailed spectroscopy of the nuclei above the Z=64, N=82 shells should provide answers to this topical question.

Summary

The research performed during the contract period followed closely the outline submitted in our renewal proposal. The principal investigator devoted approximately 40% of his time and effort to this project during the period.

References

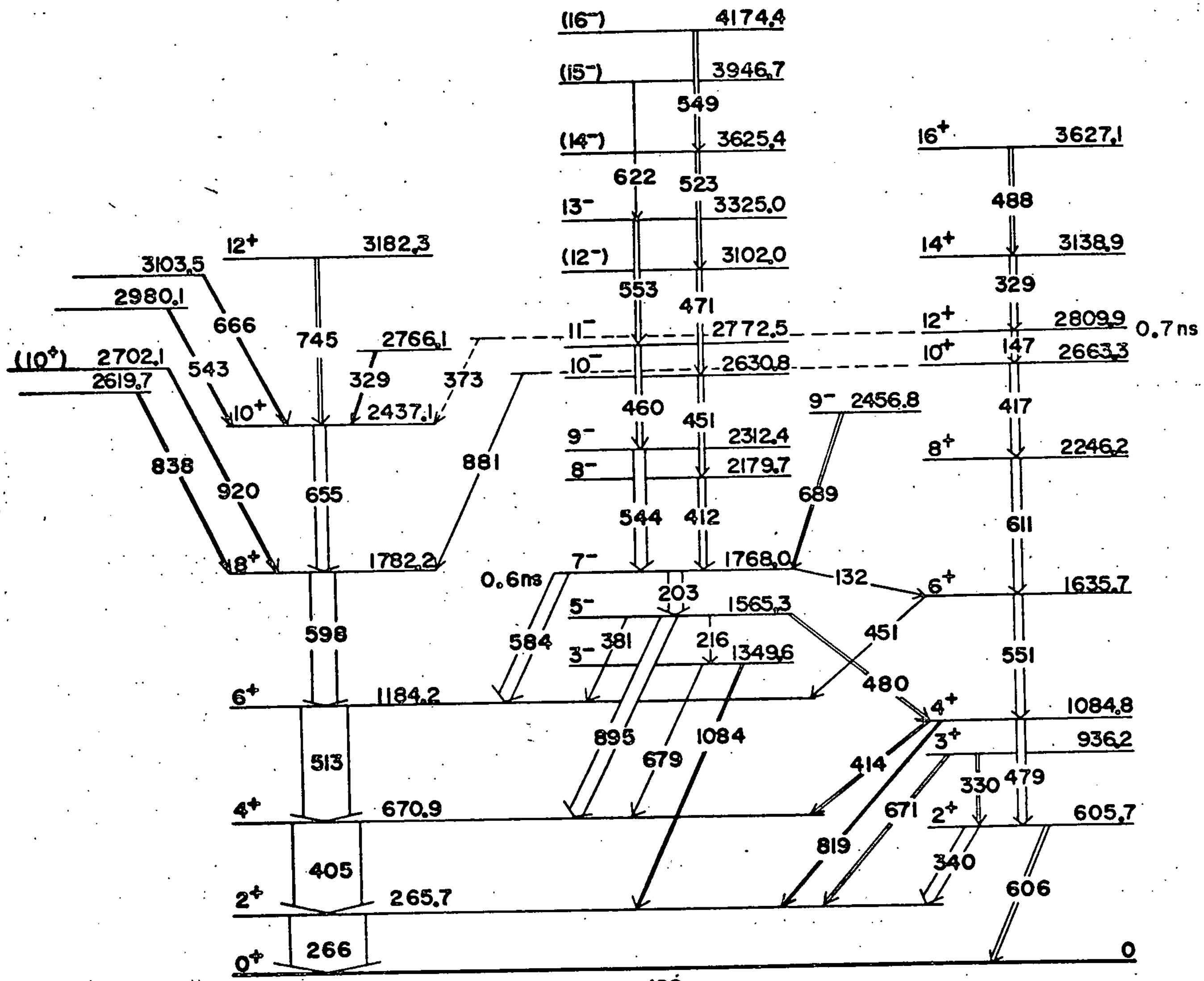
1. P. J. Daly, ERDA Report COO-1672-73 (1977)
2. J. Meyer-ter-vehn, Nucl. Phys. A249 (1975) 111 and 141
3. H. Helppi et al., Phys. Lett. 67B (1977) 279
4. C. G. Linden et al., Z. Physik A284 (1978) 217
5. Nucl. Data Sheets 25 (1978) 705
6. P. Kleinheinz et al., Z. Physik A284 (1978) 351
7. P. J. Daly et al., Z Physik A288 (1978) 103
8. J. Pedersen et al., Phys. Rev. Lett. 39 (1977) 990
9. A. Bohr and B. R. Mottelson, Phys. Scr. 10A (1974) 13

Figure Captions

Fig. 1 The ^{188}Pt level scheme

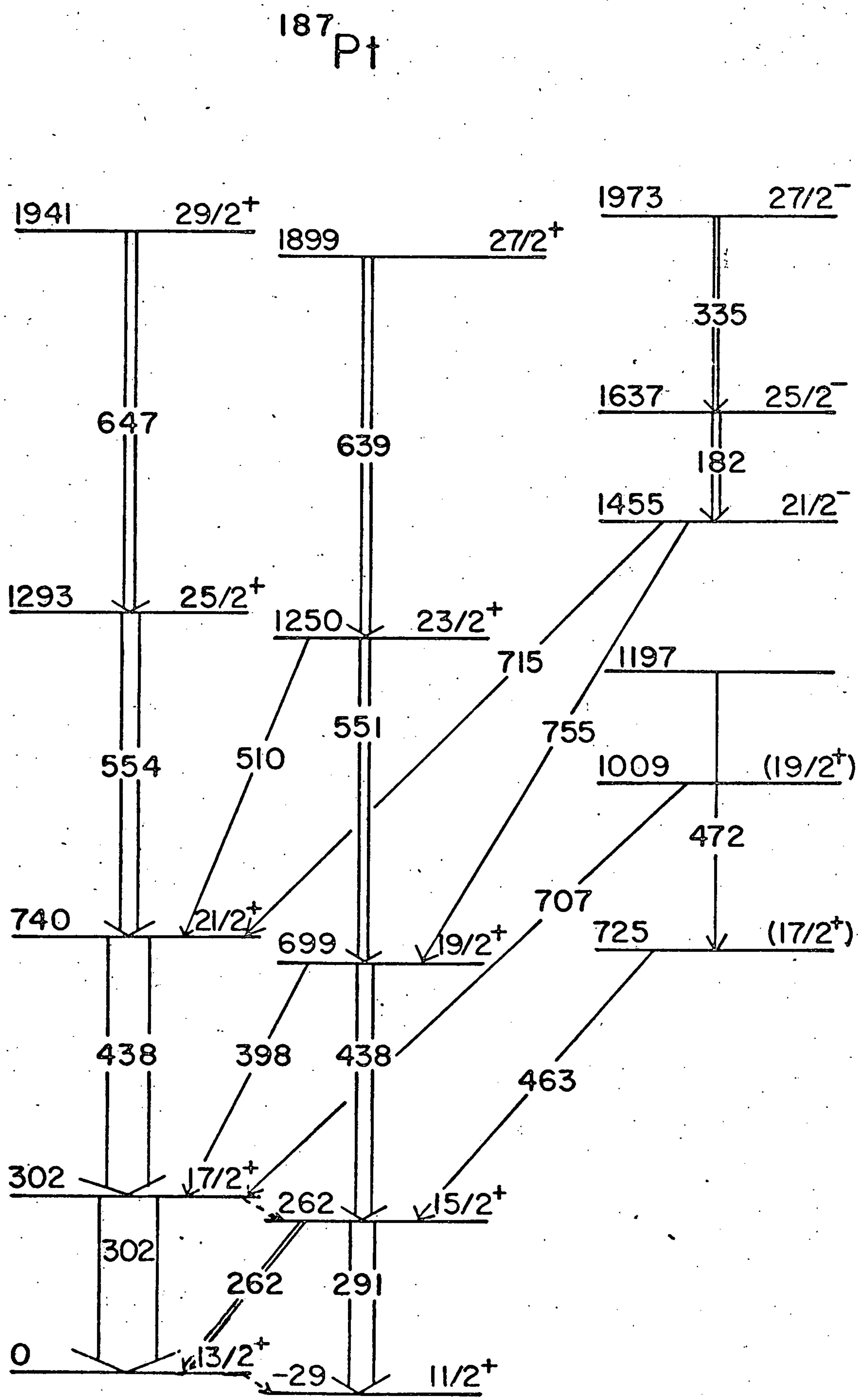
Fig. 2 The level schemes of the odd-A nuclei ^{187}Pt and ^{189}Pt

Fig. 3 The ^{146}Gd level scheme, configuration assignments and theoretical level energies; the empirical single particle level spectra in this region are also shown.

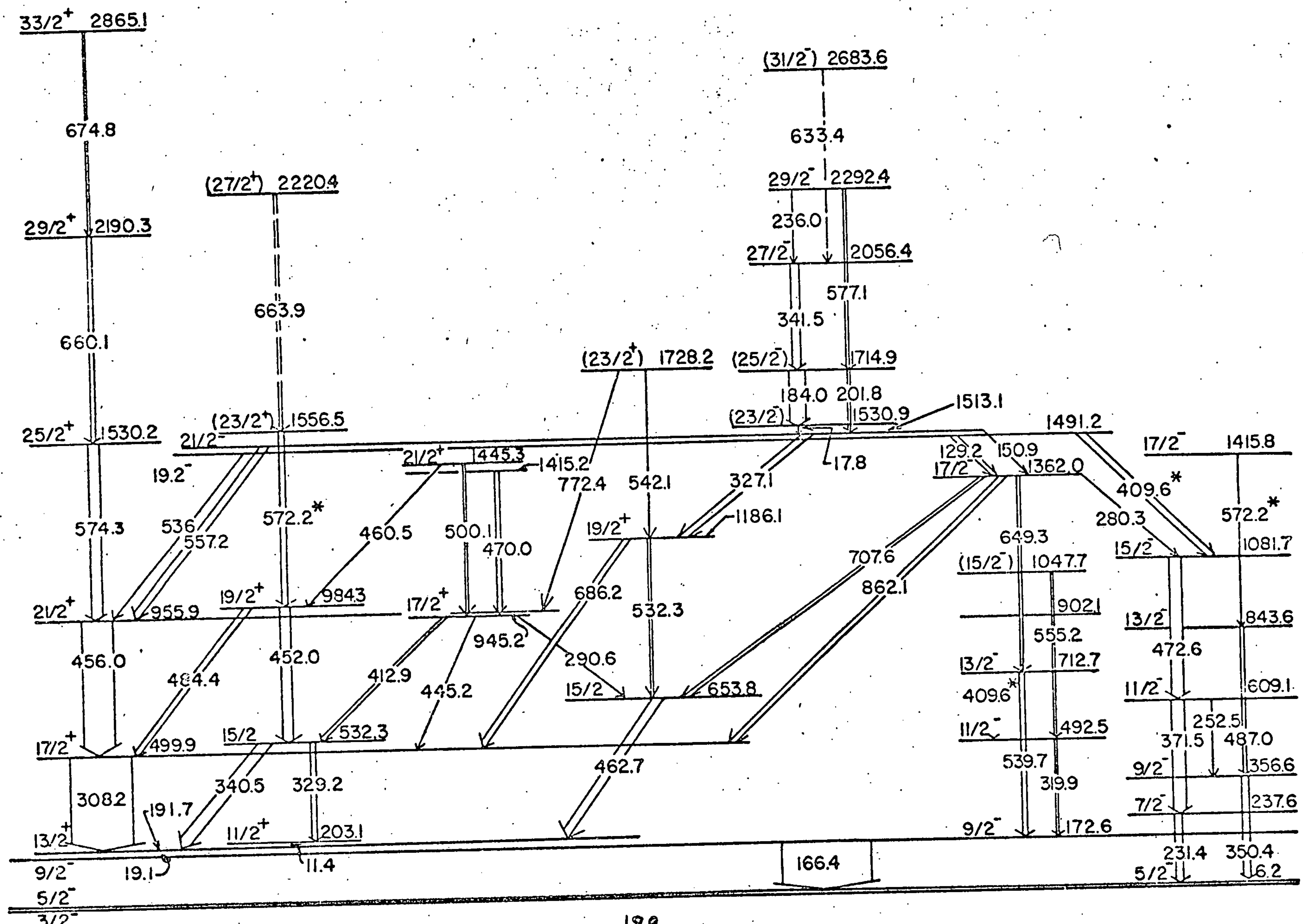


(16⁻) 4174.4
(15⁻) 3946.7
549
(14⁻) 3625.4
622
523
13⁻ 3325.0
(12⁻) 3102.0
553
471
11⁻ 2772.5
10⁻ 2630.8
460
451
9⁻ 2312.4
8⁻ 2179.7
544
412
7⁻ 1768.0
0.6ns
203
5⁻ 1565.3
381
216
3⁻ 1349.6
584
895
679
1084
16⁺ 3627.1
488
14⁺ 3138.9
329
12⁺ 2809.9
0.7ns
147
10⁺ 2663.3
417
8⁺ 2246.2
611
6⁺ 1635.7
551
4⁺ 1084.8
3⁺ 936.2
330
479
2⁺ 605.7
340
606
132
451
480
414
671
819
9⁻ 2456.8
689
12⁺ 3182.3
3103.5
2980.1
666
745
2766.1
329
373
543
(10⁺) 2702.1
2619.7
10⁺ 2437.1
838
920
655
881
8⁺ 1782.2
598
6⁺ 1184.2
513
4⁺ 670.9
405
2⁺ 265.7
266
0⁺
0

^{188}Pt

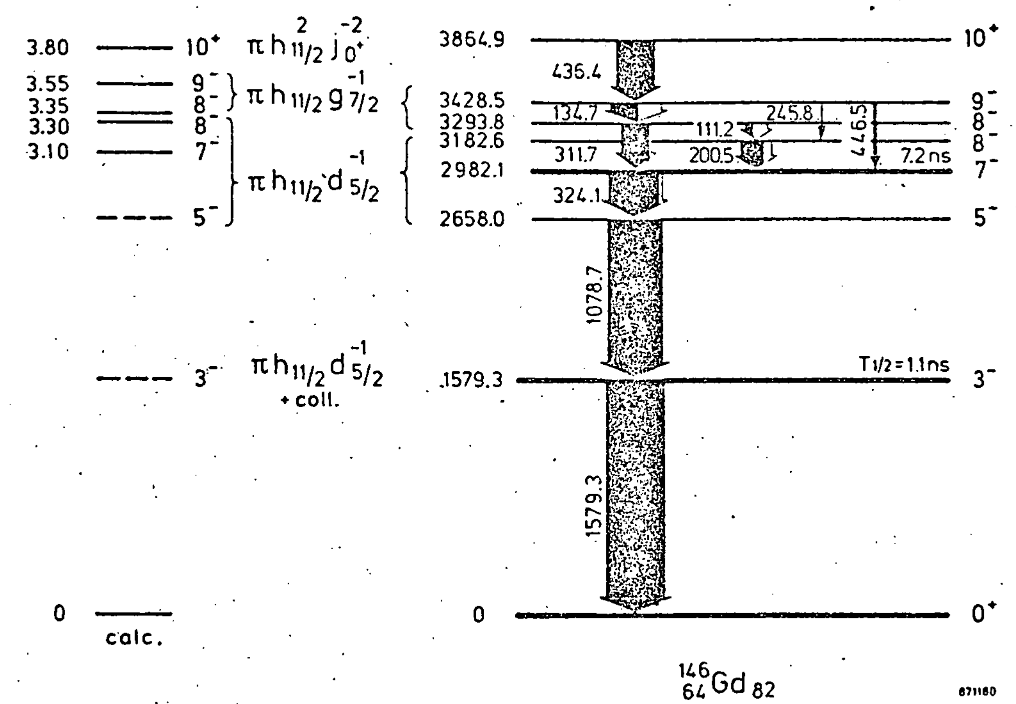


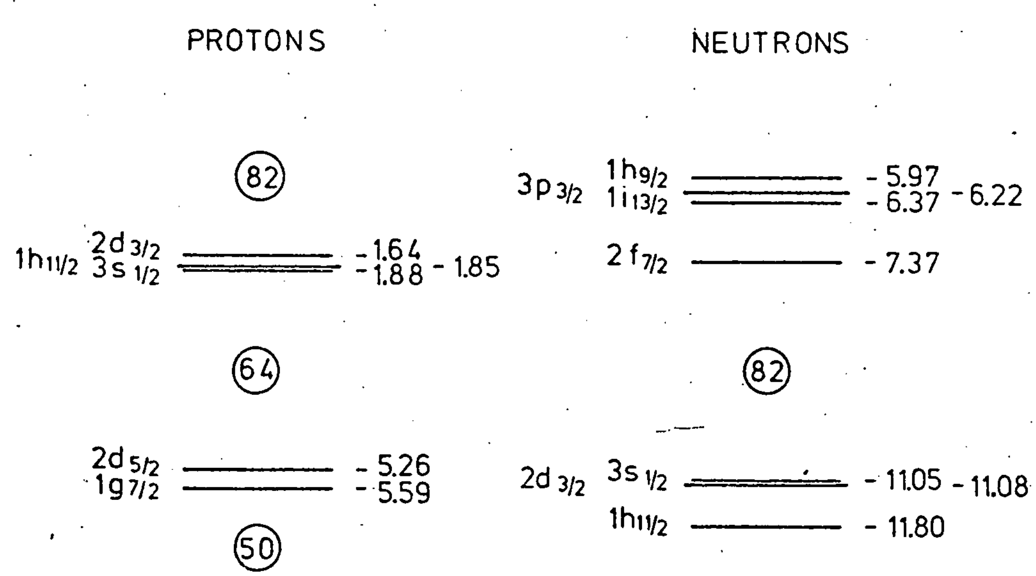
187Pt
1941 29/2+
1899 27/2+
1973 27/2−
335
1637 25/2−
647
639
182
1455 21/2−
1293 25/2+
1250 23/2+
715
1197
551
755
554
510
1009 (19/2+)
472
707
740 21/2+
699 19/2+
725 (17/2+)
438
398
438
463
302 17/2+
262 15/2+
302
262
291
0 13/2+
−29 11/2+



33/2+ 2865.1
674.8
29/2+ 2190.3
660.1
25/2+ 1530.2
574.3
21/2+ 955.9
456.0
17/2+ 499.9
308.2
13/2+
9/2-
5/2-
3/2-
(27/2+) 2220.4
663.9
(23/2+) 1556.5
21/2-
19.2-
536
557.2
572.2*
19/2+ 984.3
452.0
484.4
15/2 532.3
340.5
329.2
191.7
19.1
11/2+ 203.1
11.4
21/2+ 1445.3
1415.2
460.5
500.1
470.0
17/2+
945.2
412.9
445.2
290.6
772.4
(23/2+) 1728.2
542.1
19/2+
1186.1
686.2
532.3
15/2 653.8
462.7
(31/2-) 2683.6
633.4
29/2- 2292.4
236.0
27/2- 2056.4
577.1
341.5
(25/2-) 1714.9
184.0 201.8
(23/2-) 1530.9
1513.1
17.8
327.1
707.6
862.1
1491.2
129.2
150.9
17/2- 1362.0
409.6*
280.3
649.3
(15/2-) 1047.7
902.1
555.2
13/2- 712.7
409.6*
11/2- 492.5
539.7
319.9
9/2- 172.6
166.4
17/2- 1415.8
572.2*
15/2- 1081.7
13/2- 843.6
472.6
11/2- 609.1
252.5
371.5
487.0
9/2- 356.6
7/2- 237.6
231.4
350.4
5/2- 6.2

189 Pt


3.80
3.55
3.35
3.30
3.10
0
calc.
10⁺
9⁻
8⁻
8⁻
7⁻
5⁻
3⁻
+coll.
3864.9
3428.5
3293.8
3182.6
2982.1
2658.0
1579.3
436.4
134.7
111.2
245.8
446.5
311.7
200.5
7.2ns
324.1
1078.7
1579.3
T1/2=1.1ns
0⁺
146 64 Gd 82
071160


PROTONS
NEUTRONS
82
1h11/2
2d3/2
3s1/2
-1.64
-1.88
- 1.85
64
2d5/2
1g7/2
- 5.26
- 5.59
50
3p3/2
1h9/2
1i13/2
- 5.97
- 6.37
- 6.22
2f7/2
- 7.37
82
2d3/2
3s1/2
- 11.05
- 11.08
1h11/2
- 11.80
071160

III. Personel

Senior Staff

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

Dr. C. L. Dors, Research Associate

Graduate Students

S.K. Saha†

J. Wilson

Service Staff

J. Hoffman, part-time electronics technician

J.H. Biddle, part-time secretary

†Terminated Feb. 1978 on obtaining Ph.D. degree.

reprints removed

IV. Publications and Talks

High-Spin Level Structure of the Five Neutron Hole Nucleus ^{203}Pb, S. K. Saha, H. Helppi, P. J. Daly, S. R. Faber, T. L. Khoo and F. M. Bernthal, Phys. Rev. C 16 (1977) 2159

Production of High Multiplicity Yrast Isomers in ^{147}Gd and ^{146}Gd in α-Particle Induced Reactions, R. Broda, M. Ogawa, S. Lunardi, M. R. Maier, P. J. Daly and P. Kleinheinz, Z. Physik A285 (1978) 423

Properties of the 3^- First Excited State in the Doubly Closed Shell Nucleus ^{146}Gd, P. Kleinheinz, M. Ogawa, R. Broda, P. J. Daly, D. Haenni, H. Beuscher and A. Kleinrahm, Z. Physik A286 (1978) 27

Lowest 2^+ State in $^{146}_{64}Gd_{82}$ and the Energy Gap at Z=64, M. Ogawa, R. Broda, K. Zell, P. J. Daly and P. Kleinheinz, Phys. Rev. Lett. 41 (1978) 289

A 0.5 μs 10^+ Isomer in ^{148}Dy and the $\pi h_{11/2}$ Effective E2 Charge, P. J. Daly, P. Kleinheinz, R. Broda, A. M. Stefanini, S. Lunardi, H. Backe, L. Richter, R. Willwater and F. Weik, Z. Physik, A288 (1978) 103

Particle Hole Yrast States in ^{146}Gd and ^{147}Gd and the Z=64 Shell Closure, P. Kleinheinz, R. Broda, P. J. Daly, S. Lunardi, M. Ogawa and J. Blomqvist, Z. Physik (1979) in press

- -

Extensive $\nu i_{13/2}$ Level Families in ^{187}Pt and ^{189}Pt, Am. Physical Society, Washington, D.C., April 1978; abstract published in Bull. Am. Phys. Soc. 23 (1978) 628 - given by C. L. Dors.

High-Spin Level Structure of ^{188}Pt, Am. Physical Society, Washington, D.C., April 1978; abstract published in Bull. Am. Phys. Soc. 23 (1978) 628 - given by C. L. Dors.

A Touch of Magic at Z=64, Physics Departmental Colloquium, Jyväskylä University, Finland, May 1978 - given by P. J. Daly.

A Touch of Magic at Z=64, Nuclear Chemistry Seminar, Purdue University, Sept. 1978 - given by P. J. Daly.

Nuclear Shells, Shapes and Structures, Physical Chemistry Seminar, Purdue University, October 1978 - given by P. J. Daly.

A Touch of Magic at Z=64, Nuclear Physics Seminar, Argonne National Laboratory, November 1978 - given by P. J. Daly.