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MASTER

Radiochemical Investigations of Nuclear Properties

Patrick J. Daly, Principal Investigator

Progress Report for the period October 1976 to September 1977

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Department of Chemistry

PURDUE UNIVERSITY
WEST LAFAYETTE, INDIANA
47907

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RADIOCHEMICAL INVESTIGATIONS OF NUCLEAR PROPERTIES

Progress Report

Patrick J. Daly

Purdue University, W. Lafayette, Indiana

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Abstract

Progress in experimental investigations of high-spin excitations in spherical and transitional nuclei in the A=180-204 mass range is described. Most of the experiments were performed by in-beam γ-ray spectroscopy using beams of ^{3}He, ^{4}He and ^{12}C ions from the Michigan State University cyclotron. The main results of studies of the nuclei $^{195,197,199,201,202,203}Pb$, $^{196,197,199,200}Hg$ and $^{186,187,188,189}Pt$ are summarized.

I. Research Activities

During the past year, we have continued our investigations of the high-spin level structures of transitional and spherical nuclei in the mass range A=180-204, and substantial progress has been made. As before, most of the experiments were performed at the Michigan State University cyclotron laboratory, in collaboration with T. L. Khoo and F. M. Bernthal. A summary of the more significant new results obtained is given in the following sections:

High Spin Excitations in Light Pb Nuclei

We have extended our investigations of the high-spin level spectra of light odd-A Pb nuclei by $(\alpha,xn\gamma)$ and $(^3He,xn\gamma)$ reactions. Nothing was known previously about the high-spin states of the five Pb nuclei with A=195, 197, 199, 201 and 203. Our initial systematic series of measurements established strong yrast cascades terminating in known $\nu i^{-1}_{13/2}$ isomeric states in all five nuclei, and many new isomeric states were identified and characterized. A brief description of these results was included in our last annual report[1].

During this year we have published a short first report[2] on these experiments, emphasizing the systematic features of the level spectra, which are generally well explained in terms of the weak coupling of an $\nu i_{13/2}$ hole to known states of the even-A core. A more detailed article dealing with the ^{203}Pb high-spin states and their interpretation as five neutron hole configurations has also been completed and it will appear in the December issue of Phys. Rev. C. Two other papers giving the complete results for $^{201,199}Pb$ and for $^{197,195}Pb$ are planned.

Recently, a shell model treatment[3] using experimental single particle energies and experimental two nucleon interactions has been developed by Blomqvist and coworkers, and applied with considerable success to nuclei in the neighbourhood of ^{208}Pb. We hope that by using similar methods we can obtain at least a semi quantitative understanding of the high-spin many neutron hole excitations in the lighter Pb nuclei. We have therefore started experiments aimed at locating and characterizing the seniority four and five high-spin states in ^{201}Pb and ^{202}Pb. In ^{202}Pb, we have started from the known ^{202}Pb 9^- level at 2170 keV and we have identified, using the ^{202}Hg(α,4nγ) reaction, three higher lying isomers with half-lives of 21, 139 and 106 ns. In ^{201}Pb we have investigated the level structure above the 540 ns $29/2^-$ isomer and have established many new high-spin levels including a 49 ns isomeric state. The detailed analysis of the results of these experiments is in progress and we intend to complete it in the coming year.

The High-spin Level Structure of Hg Nuclei

In our last report[1], we summarized the results of an intensive (α,2nγ) reaction study of the ^{200}Hg level structure, and drew attention to a puzzling nuclear structure problem involving the positive parity levels in this nucleus. The level sequences of the even-A Hg nuclei A=190-198 all exhibit a similar irregularity with closely spaced 8^+ and 10^+ levels intersecting the ground bands at excitation energies of about 2.5 MeV. These 8^+ and 10^+ levels are generally considered to be of rotation-aligned $h^{-2}_{11/2}$ two-proton character, although some workers[4,5] have proposed that the $i^{-2}_{13/2}$ two neutron configuration plays the dominant role in the case of ^{198}Hg. In our ^{200}Hg experiment, we were unable to locate a corresponding 8^+, 10^+ doublet even though the sensitivity of the measurement was very high. It was not quite certain however that this result implied a genuine nuclear structure difference in ^{200}Hg, since unlike the other Hg nuclei, ^{200}Hg could be studied by the $(\alpha,2n\gamma)$ reaction only.

To resolve this uncertainty we have studied the adjacent odd-A nuclei, using the $(\alpha,3n\gamma)$ reaction in both cases. The resulting level schemes shown in Figs 1, 2 contain a considerable amount of new nuclear structure information, most of which will not be discussed here. In regard to the central questions, the results are rather clear. In ^{197}Hg, the positive parity levels up to $37/2^+$ are fairly strongly populated, and $29/2^+$, $33/2^+$ levels cluster in the neighbourhood of 2.5 MeV above the $13/2^+$ bandhead, rather like the 8^+, 10^+ levels in the ^{198}Hg core nucleus (Fig. 3). Blocking arguments then indicate that the two-proton as well as the two-neutron rotation aligned structures must be included in an accurate description of the ^{198}Hg yrast levels. This finding conflicts with recent proposals[4,5] that the ^{198}Hg yrast structure is explainable in terms of the rotation aligned $i_{13/2}$ neutron pair alone.

In contrast to ^{197}Hg, the ^{199}Hg positive parity levels populated in $(\alpha,3n)$ terminate with the $25/2^+$ level, corresponding to the 6^+ ground band member of the ^{200}Hg core. This finding demonstrates that our inability to locate 8^+ and 10^+ levels in the $(\alpha,2n)$ study of ^{200}Hg cannot be explained as a reaction mechanisms effect. Instead, the experimental evidence points rather strongly to a sharp discontinuity between neutron numbers 118 and 120 in the yrast level systematics of the even-A Hg nuclei. Recent detailed calculations[5] of high-spin states in Hg nuclei do not give any theoretical indication of such a discontinuity. A dramatic increase in $10^+ \rightarrow 8^+$ B(E2) values from ^{192}Hg to ^{198}Hg also remains unexplained. These properties must be accounted for before the theoretical understanding of the Hg nuclei can be regarded as satisfactory.

We have also performed extensive measurements on the $^{196}Pt(\alpha,4n\gamma)$ reaction, which have added considerably to previous knowledge of the high-spin states in ^{196}Hg. Our work on this nucleus is continuing.

High-spin States in Pt Nuclei

Over the past few years, we have performed detailed $(\alpha,xn\gamma)$ and radioactivity measurements on the nine Pt nuclei in the range A=186-194. We have already published several papers on the results, dealing mainly with the topics

a) the intersection of the ground bands by rotation-aligned $\pi h_{11/2}^{-2}$ and $\nu i_{13/2}^{-2}$ structures

b) the evidence for triaxial shapes provided by the $\nu i_{13/2}^{-1}$ level families in the odd-A nuclei

With the publication of a recent paper[6)] on the ^{191}Pt and ^{193}Pt level spectra, our work on the five nuclei with A > 189 has been completed. However we have encountered severe and persistent difficulties in reaching a satisfactory understanding of the results for the lighter nuclei. These difficulties stem in part from the fact that the $(\alpha,xn\gamma)$ data for the more neutron deficient nuclei are less clean because of poorer target enrichment and of greater competition from (α,pxn) reaction channels. During this year we have performed new experiments aimed at solving these difficulties.

In ^{189}Pt the main problem has been to establish the identity and location of the low-spin levels fed by the several γ-ray cascades observed in the $(\alpha,3n\gamma)$ reaction. In this case we have now performed a reinvestigation of the radioactive decay of ^{189}Au to levels in ^{189}Pt, using sources produced in the reaction $^{191}Ir(^{3}He,5n)\ ^{189}Au$ reaction. We have also investigated in-beam the (low-spin) levels of ^{189}Pt populated in the reaction ^{191}Ir(p,3nγ). From the combined results of the (α,3nγ), (p,3nγ) and radioactivity measurements, we have been able to construct a partial ^{189}Pt level scheme, although there still are some problems to solve. In ^{189}Pt an extensive $i^{-1}_{13/2}$ level family is also found, with the unfavored $11/2^+$ level lying 11 keV above the $13/2^+$ bandhead.

We have further investigated the nuclei ^{187}Pt and ^{188}Pt using (^{12}C,xnγ) reactions on Hf targets. Analysis of the ^{187}Pt results from the ^{12}C and α-induced reactions led us to propose a ^{187}Pt level scheme which also has an extensive $i_{13/2}$ level family. In this nucleus, the $11/2^+$ level very probably lies lowest, 29 keV below the $13/2^+$ level. Since, however, the placement of the $11/2^+$ level rested on the correct identification of a single $15/2^+ \rightarrow 11/2^+$ transition and there was no chance to observe the key 29 keV transition as a γ-ray, the proposed level scheme did not seem adequately established by our data alone. However we have recently learned the results of delayed electron measurements by Bakke et al.[7)] using (^{16}O,xnγ) reactions at the Heidelberg Tandem Laboratory. They have observed an intense transition of 27±3 keV in ^{187}Pt and preliminary coincidence results indicate that this is identical with the missing transition in our level scheme. Consequently, we are now fairly certain that our proposed level scheme is correct. We have earlier shown that the energies and transition probabilities of the $\nu i_{13/2}$ family levels in ^{193}Pt and ^{191}Pt are very convincingly reproduced for $\gamma = 30°$ by the triaxial rotor model developed by Meyer-ter-Vehn[8)]. The $\nu i_{13/2}$ levels in ^{189}Pt are best fitted with $\gamma = 27°$. In the calculations, the $11/2^+$ level is found to drop below the $13/2^+$ level, as in ^{187}Pt, for γ - values less than 24°. Overall, these results indicate that the prolate to oblate transition in the Pt nuclei is not sudden, as some have proposed, but proceeds rather gradually through a series of triaxial shapes.

Prolonged contemplation of the (^{12}C,xnγ) and (α,xnγ) data for ^{188}Pt has also led finally to a breakthrough in understanding the ^{188}Pt high-spin level spectrum. Fig 4 shows a small portion of the ^{188}Pt scheme, which illustrates the key result. Unlike ^{190}Pt and ^{192}Pt, where the 10^+, 12^+ states of $\nu i^{-2}_{13/2}$ and $\pi h^{-2}_{11/2}$ character de-excite to the ground band, here the rotation-aligned states depopulate predominantly to 8^+ member of the γ-band, and the ground band population is very weak above the 10^+. Moreover, this result seems entirely reasonable when the $^{188, 190, 192}$Pt level systematics are reconsidered. The argument goes as follows. Nuclear structure factors in all cases favor de-excitation of the high-K rotation aligned states to K=2 states rather than K=0 states, but it is only in the more deformed ^{188}Pt that the 8^+_γ lies sufficiently low to be strongly populated. We are currently preparing a manuscript on the full ^{188}Pt level scheme.

We have also opened one other new line of investigation. In collaboration with N. Johnson and S. W. Yates, we have attempted to measure the half-life of the yrast 12^+ state in ^{188}Pt by the recoil distance technique using Ne beams from the ORIC. The (^{20}Ne,4nγ) ^{188}Pt measurement was not successful because the key γ-ray peaks could not be cleanly resolved. However we went on to test the (^{22}Ne,6nγ) reaction into ^{186}Pt and the results were much more promising. In the limited time available, a tentative value of the ^{186}Pt 12^+ half-life was determined, and we plan to perform the final measurement in the coming year.

Summary

The research performed during the contract year followed the outline submitted in our renewal proposal rather closely. The principal investigator devoted approximately 50% of his time and effort to this project during the contract period.

References

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3) J. Blomqvist et al., Phys. Rev. Lett. 38 (1977) 534

4) C. Günther et al., Phys. Rev. C15 (1977) 1298

5) H. L. Yadav et al., Phys. Rev. Lett. and private communication

6) S. K. Saha et al., Phys. Rev. C15 (1977) 94

7) H. Bakke, L. Richter et al., private communication

8) J. Meyer-ter-vehn, Nucl. Phys. A249 (1975) 111 and 141

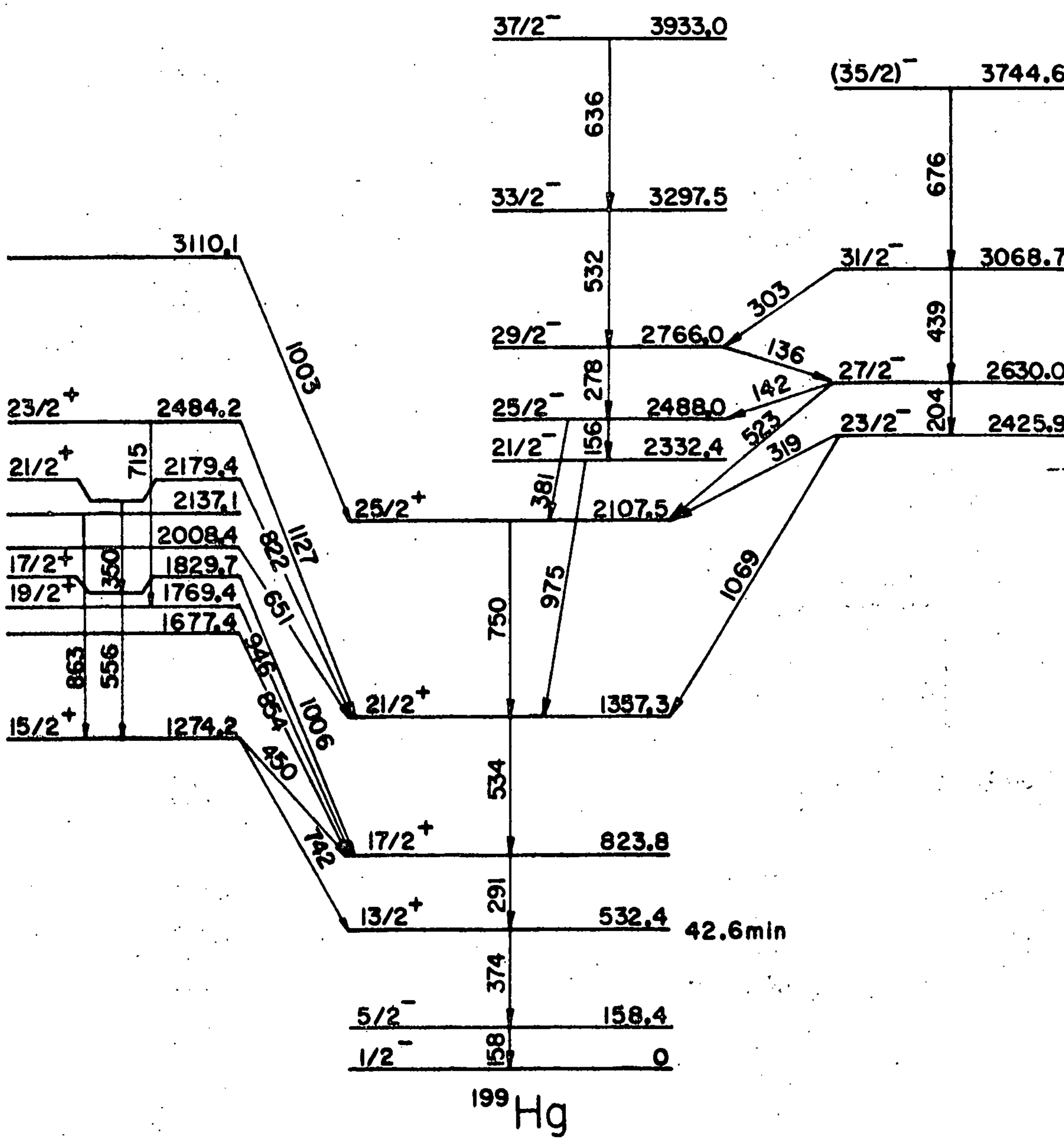
Figure Captions

Fig 1. The high-spin level structure of ^{199}Hg

Fig 2. The high-spin level structure of ^{197}Hg

Fig 3. A comparison of the positive parity yrast states in ^{197}Hg and the ^{198}Hg core nucleus

Fig 4. A detail of the ^{188}Pt level scheme illustrating the main de-excitation path from the yrast 12^+ state to the γ-band



37/2⁻ 3933.0
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(35/2)⁻ 3744.6
676
33/2⁻ 3297.5
532
3110.1
31/2⁻ 3068.7
303
439
1003
29/2⁻ 2766.0
136
278
27/2⁻ 2630.0
142
23/2⁺ 2484.2
25/2⁻ 2488.0
523
204
23/2⁻ 2425.9
21/2⁻ 2332.4
156
319
21/2⁺ 2179.4
715
2137.1
381
25/2⁺ 2107.5
2008.4
1127
17/2⁺ 1829.7
822
19/2⁺ 1769.4
350
651
975
1069
1677.4
750
863
556
946
854
1006
21/2⁺ 1357.3
15/2⁺ 1274.2
450
534
742
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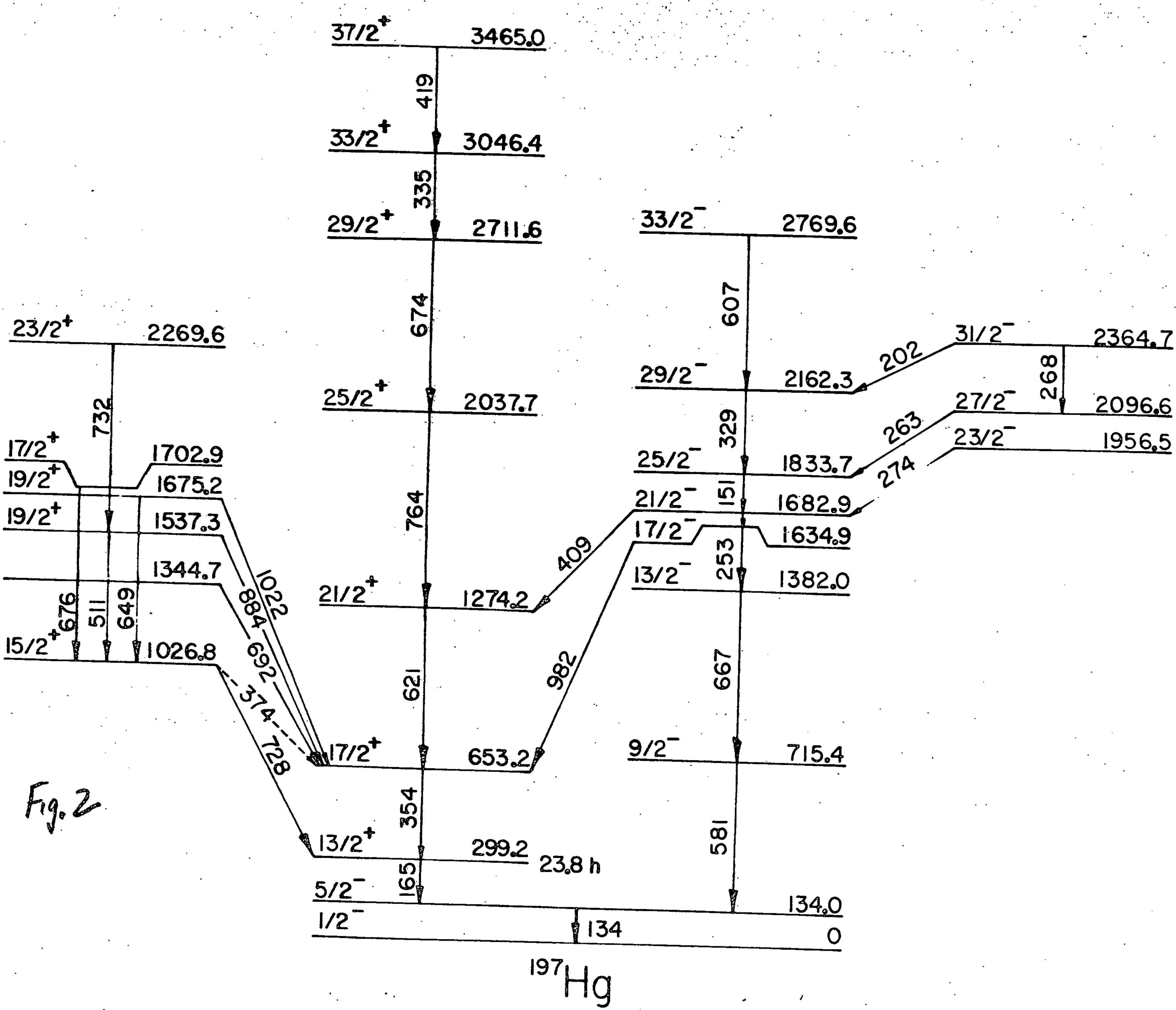
158
1/2⁻ 0
199Hg

Fig. 1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621
17/2+ 653.2
354
13/2+ 299.2
23.8 h
165
5/2− 134.0
1/2− 0
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23/2+ 2269.6
732
17/2+ 1702.9
19/2+ 1675.2
19/2+ 1537.3
1344.7
15/2+ 1026.8
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1022
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692
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728
33/2− 2769.6
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151
21/2− 1682.9
17/2− 1634.9
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13/2− 1382.0
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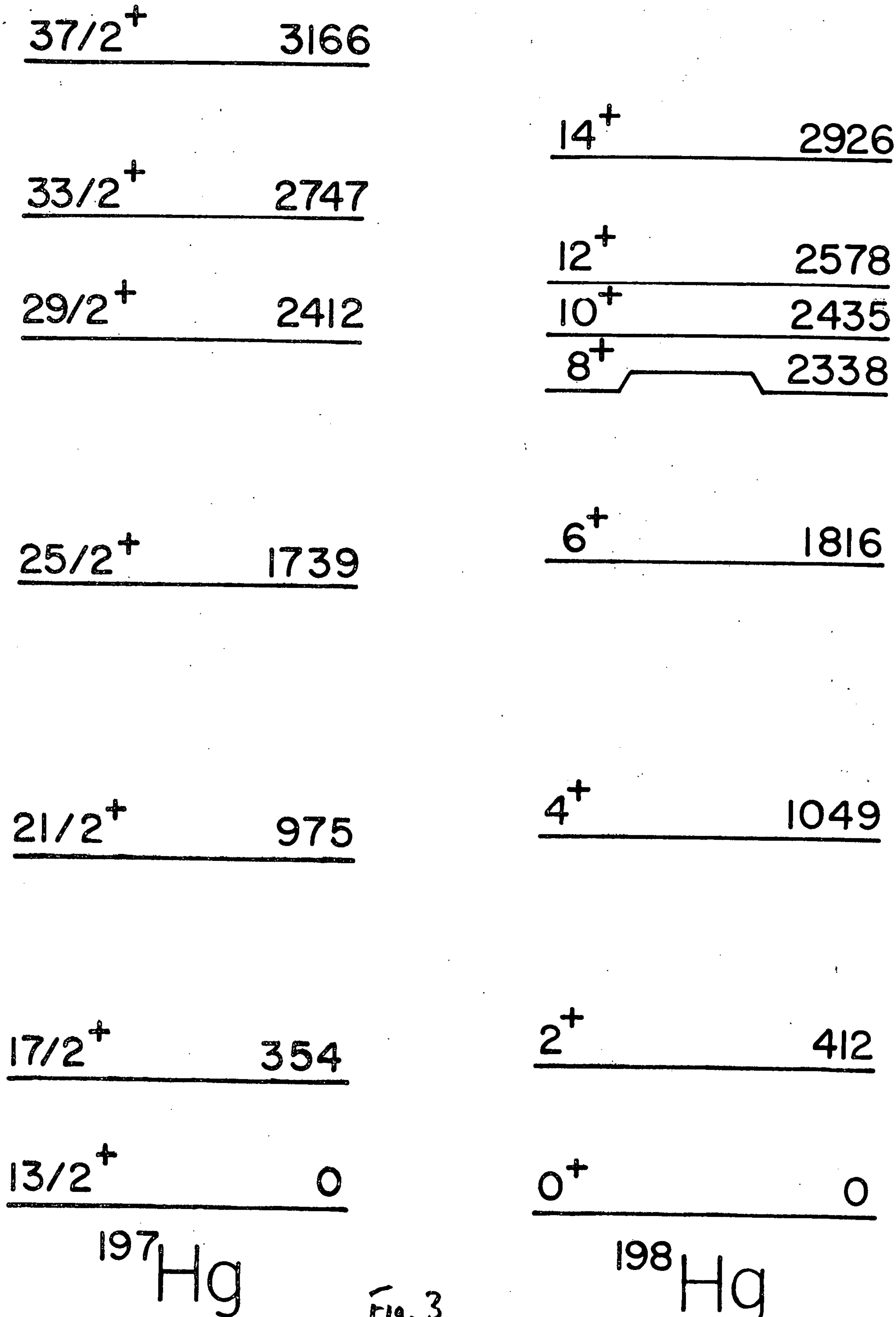
23/2− 1956.5
274
^{197}Hg

Fig. 2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12+ 2578
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8+ 2338
6+ 1816
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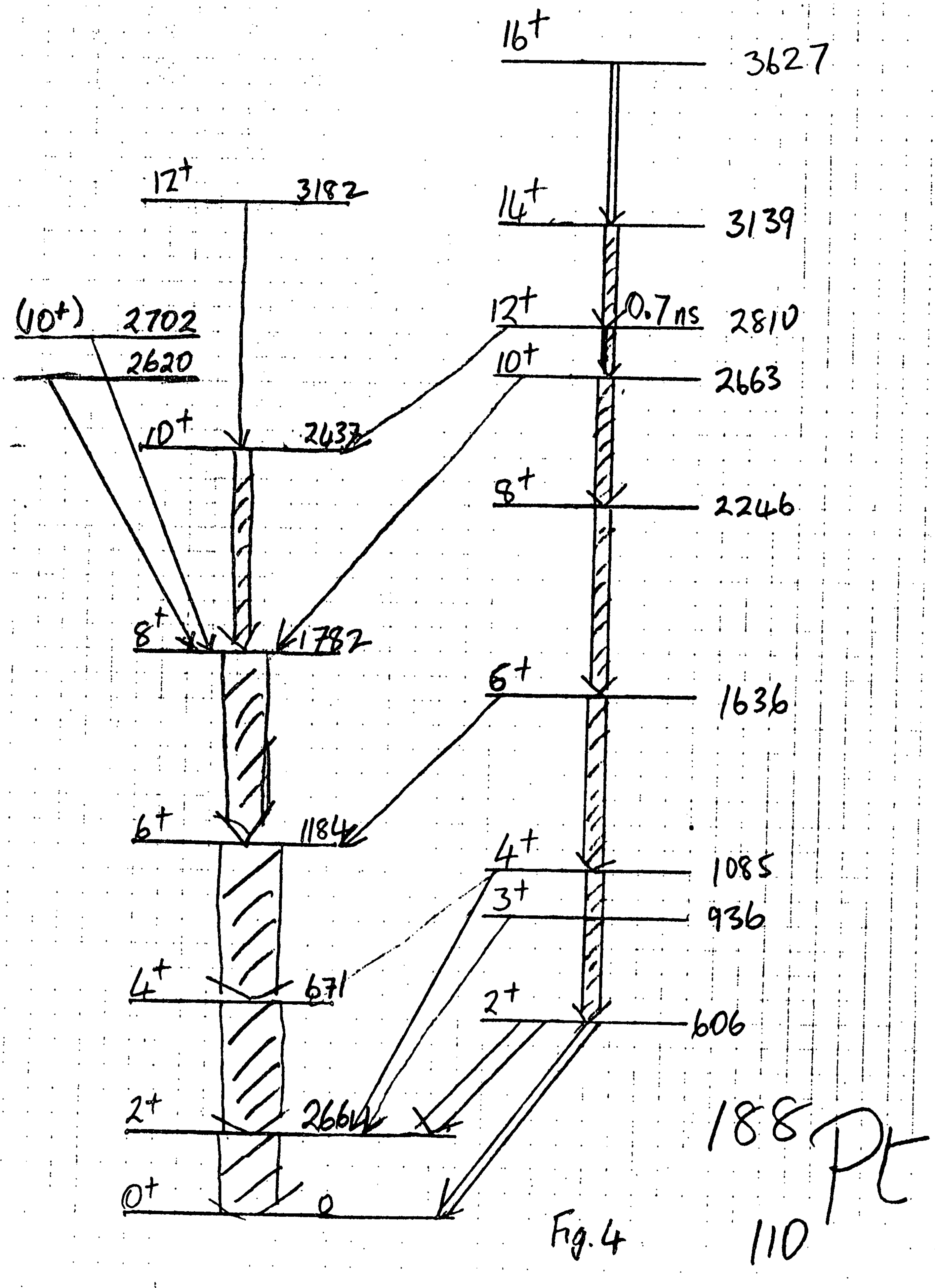
2+ 412
0+ 0
198Hg

Fig. 3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2620
10+ 2437
8+ 1782
6+ 1184
4+ 671
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0+ 0
188 Pt 110

Fig. 4