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Publication Date
1965-12-01

UCRL-16163

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AEC Contract No. W-7405-eng-48

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AN 8- ISOMERIC STATE IN THE 106-NEUTRON NUCLEI: ^{180}W, ^{182}Os, AND ^{184}Pt*

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Abstract

The decay of a two-neutron, 8-, isomeric state has been observed in three nuclei having 106 neutrons. The half-lives of these isomers are in the region of one millisecond. In each of the isotones, ^{180m}W, ^{182m}Os, and ^{184m}Pt, there were observed five prominent transitions. Four of these are the E2 transitions of the $8 \rightarrow 6 \rightarrow 4 \rightarrow 2 \rightarrow 0$ cascade in the ground-state band. The fifth transition is a very hindered E1 that de-excites an 8-, 8 isomeric level and populates the 8+, 0 level of the ground-state band. Despite the appreciable difference between the properties of these nuclei, as can be seen by comparing the well-developed rotational spectrum of ^{180}W with that of the poor rotor ^{184}Pt, the isomeric transitions seem to exhibit a striking similarity. In ^{184m}Pt, the isomeric decay also populates other levels. Among them were tentatively identified two members of the β-vibrational band. Their position relative to the ground-state band in this transitional-region nucleus is of special interest.

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*This work was performed under the auspices of the U. S. Atomic Energy Commission.

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1. Introduction

In the course of a continuing study of the gamma-ray cascades occurring after neutron emission in heavy-ion induced reactions, some neutron-deficient even-even isotopes of Yb, Hf, W, Os, Pt, and Hg have been investigated[1,2]. At the same time a search was conducted in these nuclei for heavily-populated isomeric states having half-lives in the range of milliseconds to minutes. The pulsed nature of the Hilac beam lends itself very well to such studies, and isomers were found in ^{182}Os and ^{184}Pt. Negative results were obtained in the other 16-18 nuclei studied. The ^{182}Os isomer has been observed in $(\alpha,4n)$ work at Amsterdam[3]), but the present study is more detailed, involving measurements of the conversion electron spectrum, of the gamma-ray spectrum with lithium-drifted Ge counters, and of γ-γ coincidences and angular distributions. Another previously known isomer with 106 neutrons, ^{180m}W (refs. 4, 5, 6), was reinvestigated to extend the information available on this isomeric state.

2. Experimental Procedure

Self-supporting metallic targets of ~1 mg/cm^2 were bombarded with beams of the appropriate heavy ions from the Lawrence Radiation Laboratory Hilac to produce the nuclei under investigation. The beam was monitored by a Faraday cup placed ~1 1/2 meters back of the target, and its energy was determined with a solid-state counter calibrated against the full-energy beam (10.4 MeV per nucleon). The energies are expected to be within ~2% of the measured values.

Conversion electrons emitted from the target at 90° to the beam direction were measured with a spectrometer of the single wedge-gap type[7]). This spectrometer and its semiautomatic operation has been described previously[1]). The beam struck the target at a grazing angle of 10° or 15° in order to minimize the degradation in energy of the emitted electrons in the target while maximizing the yield.

Gamma-ray spectra were taken using 5 cm × 5 cm NaI(Tl) detectors coupled to 400-channel pulse-height analyzers. For coincidence measurements, such counters were placed on each side of a target, at right angles to the beam direction, and 3-4 cm apart. A conventional fast-slow coincidence circuit was used ($2\tau = 3 \times 10^{-8}$ sec), with the slow output of one counter being single-channel analyzed and that of the other feeding a multi-channel analyzer.

Gamma-gamma angular distribution measurements were made using three 5 cm × 5 cm NaI(Tl) counters. One counter had a fixed position and was connected through independent coincidence circuits with each of the other two movable counters. The pulses of the fixed counter were single-channel analyzed, and the gated spectra of each of the other counters were recorded in multichannel analyzers. The positions of the movable counters with respect to the fixed counter were changed successively through angles of 90°, 135°, and 180°.

The gamma-ray spectra of ^{182m}Os and ^{184m}Pt were also observed with a lithium-drifted Ge solid-state detector. The counter had a rectangular cross-section of 4 cm^2 and a thickness of 8 mm. The detector system yielded a resolution of ~5 keV at 662 keV.

The targets were bombarded with 3 msec beam bursts of the Hilac at a repetition rate of 12 pulses per second. The analyzers could be gated to observe the conversion electron or gamma-ray spectra during the beam bursts or at variably-delayed time intervals after the beam. In some of the measurements, the operation of the photomultiplier tubes was blocked during the beam pulses in order to obtain better statistics for the out-of-beam spectra without overloading the electronic circuits while the beam was on.

3. Results

The isomeric level in ^{180}W was produced by means of the reaction $^{178}Hf(\alpha,2n)^{180}W$ with a foil of natural Hf irradiated with 23 MeV ^{4}He ions. The conversion electron spectrum from the target was measured by the wedge-gap spectrometer in the interval between beam bursts, and was recorded in a 400-channel analyzer operating as a multiscaler. The first three 100-channel sections of the analyzer accepted pulses during successive 3-msec time intervals starting 0.2 msec after the termination of the beam burst. The fourth section followed these, but was 30 msec long. One-tenth of this last spectrum was subtracted from the accumulated data in each of the first three sections of the analyzer to correct for the long-lived radioactivity produced during the bombardment. Figure 1 shows a conversion electron spectrum so obtained in the first 3 msec interval after the beam burst. Spectra of the same shape appeared in the two following sections of the analyzer, but with decreasing intensity, indicating the same lifetime for all the conversion lines observed.

The half-life deduced by comparing the intensities of the lines in the three sections is 5.2±0.2 msec in agreement with the previous value of 5.5±0.3 msec[4]).

Figure 2 shows the corresponding gamma-ray spectrum obtained with a 5 cm × 5 cm NaI(Tl) detector. The long-lived radioactivity has again been subtracted. It can be seen that the five transitions have about equal intensities.

Table I summarizes the conversion electron and gamma-ray data obtained for ^{180m}W. The first column gives the energy of the transition; the second column lists the energy of the electron line, and its assignment; the third, the relative intensity of the electron line; the fourth and fifth give the K/L ratio, experimental and theoretical. The sixth column lists the relative intensities of the gamma-rays; the seventh and eighth give the values of the K- or L-conversion coefficient, experimental and theoretical; the ninth lists the assigned multipolarity; and the last column lists the relative transition intensities. As can be seen from their K/L ratios, the 234 and 350 keV transitions appear to be E2. Interrelating the electron and gamma-ray intensities by using the theoretical E2 K-conversion coefficient for the 234 keV transition gives the experimental conversion coefficients listed for the other transitions. The 103, 350, and 448 keV transitions appear to be E2, and the 390 keV one is an E1. The similar intensities of the 350 and 390 keV transitions in the gamma-ray spectrum, but markedly different values in the conversion electron spectrum, are striking. The relative intensities of the five transitions obtained by summing the values of the gamma-ray intensities and those of the conversion lines (using theoretical conversion coefficients when necessary, and

assuming the M+N+... conversion lines to be 1/3 the intensity of the L-line) are given in the final column. They are all equal within experimental error. Gamma-gamma coincidence experiments verified that all five transitions are in coincidence with each other, and thus must all be placed in cascade.

In order to define the spin assignment of the isomeric level, γ-γ angular distribution measurements were carried out at angles of 90°, 135°, and 180° with respect to the fixed NaI(Tl) counter. The first 200 channels of the multi-channel pulse-height analyzers recording the spectra were gated to accept the coincident spectrum from the time interval 0.2-10.2 msec after the beam bursts, and the second 200 channels recorded the spectrum from the interval 10.2-40.2 msec after the beam. One-third of the latter was subtracted from the former spectrum to account for the long-lived activity. Table IV sums up the results obtained from the angular distribution measurements. The first column gives the single-channel analyzed transition and the second gives the coincident transition observed in the multi-channel analyzer. Since in the singles gamma-ray spectra (fig. 2) the 350 and 390 keV peaks are not completely resolved, they were analyzed together. The relative intensities of the accepted peaks were 0.55 and 0.45 for the 350 and 390 keV transitions respectively. Column three in Table IV gives the experimental value found for A_2, the coefficient of the $P_2(\cos\theta)$ term in the expansion of the angular distribution in Legendre polynomials, $W(\theta) = 1 + A_2P_2(\cos\theta) + A_4P_4(\cos\theta) + \ldots$. The last columns in Table IV give the calculated values of A_2 for four spin sequences.

The isomer, ^{182m}Os, was produced by the reaction ^{175}Lu(^{11}B,4n)^{182}Os, using ^{11}B beams of 52, 56, and 63 MeV energies. This three-point excitation function showed that the relative yield of the transitions was very similar to that of other (^{11}B,4n) reactions studied in this region. Furthermore,

the assignment of the isomer to ^{182}Os had already been made by Lark and Morinaga[3]) from the (α,4n) reaction on ^{182}W. The decay of the isomeric state was observed between beam pulses as described above for ^{180m}W. Figure 3 shows the conversion electron spectrum observed in the time interval 0.2-3.2 msec after the beam. The long-lived activity has again been subtracted. All the prominent lines observed had the same relative intensities at the various bombarding energies, and had the same half-life. The value of the half-life has been determined as 0.78±0.07 msec[8]). Figure 4 shows the out-of-beam gamma-ray spectrum (corrected for long-lived activities) measured with a lithium-drifted Ge solid-state counter. A gamma-ray spectrum taken with a 5 × 5 cm NaI(Tl) detector showed, in addition, a weak 1245 keV transition with the half-life of the isomer. By comparing the intensities of the 484 keV ($8^+ \rightarrow 6^+$) transition in-beam and out-of-beam and taking into account the lifetime of the isomeric state, it was found that the ratio of production of this transition through the isomeric state and through the fast ($<10^{-9}$ sec) in-beam cascade is 0.18±0.04. (It should be noted that (1) no account was taken of possible angular anisotropies of the (in-beam) radiations, and (2) essentially all of the isomeric decay but only ~0.6 of the prompt cascade pass through this transition, as indicated by the relative intensities of the 484 and 127 keV ($2^+ \rightarrow 0^+$) transitions.) This ratio seemed not to be very dependent on the energy of the bombarding particles over the range studied.

The data for the conversion electrons and gamma-rays observed in ^{182m}Os are listed in Table II, in much the same order as for ^{180m}W in Table I. The electron and gamma-ray intensities were normalized by using the theoretical E2 K-conversion coefficient for the 273 keV transition; the K/L electron intensity ratio for this transition does indicate an E2 multipolarity. In this manner

experimental conversion coefficients for the other transitions can be determined and compared with theory (columns seven and eight). It can be seen that the 127, 394, and 484 keV transitions are also E2, and that the 554 keV one is an E1. The relative intensities of the transitions, again a sum of the values calculated from the conversion electron and the gamma-ray data (by means of the appropriate theoretical conversion coefficients when necessary) are listed in the final column of Table II. These five transitions have almost equal intensities, but in contrast to the situation for ^{180m}W, there is a small and probably significant decrease for the two or three higher energy transitions. This, together with the presence of the 1245 keV transition, suggests a weak branching of the isomer to other levels in ^{182}Os.

Again γ-γ coincidence experiments showed that the five main transitions are in coincidence with one another and so must be placed in cascade. The γ-γ angular distribution measurements were carried out as described above for ^{180m}W. The time intervals used for observing the isomeric and long-lived activities were 0.2-2.2 msec and 2.2-12.2 msec after the beam, respectively. The two peaks of 483 and 555 keV were not resolved completely and were single-channel analyzed together. The relative intensities of the accepted peaks for the 484 and 554 keV transitions were 0.54 and 0.46 respectively. Table IV sums up the angular distribution results.

The ^{184m}Pt was produced by means of the following reactions on the indicated targets: $^{181}Ta(^{11}B,8n)^{184}Pt$ with 114 MeV ^{11}B; $^{175}Lu(^{14}N,5n)^{184}Pt$ with 84, 90, and 98 MeV ^{14}N; and $^{169}Tm(^{19}F,4n)^{184}Pt$ with 92 MeV ^{19}F. For the ^{14}N reaction on ^{175}Lu the limited excitation function again followed that of other

known (^{14}N,5n) reactions in this region. The conversion electron spectrum observed after the beam (corrected for long-lived activities) is shown in fig. 5. The four most prominent transitions appeared also in the in-beam spectrum (together with some additional lines). The ratio of production of the 431 keV transition (8+ → 6+) from the isomeric activity to that from the prompt cascade was 0.15±0.05. (It should again be noted that (1) no account was taken of possible angular anisotropies, and (2) only ~0.5 of the isomeric decay and ~0.6 of the prompt cascade pass through this transition, as indicated by the relative intensities of the 431 and 162 keV transitions.)

All the out-of-beam transitions except the weakest were verified as belonging together by their half-life. The half-life observed was 1.01±0.05 msec. A low energy conversion electron spectrum was measured using a target of evaporated ^{175}Lu, ~0.5 mg/cm^2 on ~0.5 mg/cm^{2}Al, placed at an inclination of 5° to the ^{15}N beam. Figure 6 shows the lower-energy region of the gamma-ray spectrum detected just after the beam burst by the Ge counter. The long-lived activity has been subtracted from this spectrum. Figure 7 shows the higher-energy region of the spectrum, with the long-lived activity drawn in as a solid line rather than subtracted.

Table III sums up the information from the electron and gamma-ray spectra. The electron and gamma-ray intensities have been normalized to each other by using the theoretical E2 K-conversion coefficient for the 361 keV transition. This was a compromise to using either the 272 or 431 keV transition's conversion coefficient as a standard, since they deviate in opposite directions. All of these three transitions have K/L intensity ratios indicating an E2 multipolarity. Experimental conversion coefficients can thus be determined for most of the transitions observed and then be compared with theoretical

values to aid in establishing the transitions' multipolarity. Our assignment of the multipolarity is given in column nine. The total relative intensities of the transitions, again a sum of the conversion electron and gamma-ray data (using theoretical conversion coefficients when necessary) are listed in the last column of Table III. It should be mentioned that weak and somewhat questionable transitions of ~121, ~126, and ~224 keV have been observed, and may also belong with ^{184m}Pt.

Gamma-gamma coincidence experiments established that the five most prominent transitions in ^{184m}Pt, the 610 keV E1 and the four E2 transitions of 431, 361, 272, and 162 keV, are all in coincidence with one another and so form a cascade similar to those observed with ^{180m}W and ^{182m}Os. But in this case the intensities of the transitions are not all the same, indicating side branches, and the large number of other transitions observed also requires a more complicated scheme. It was found that the 1235 keV transition is in coincidence with the 112 and/or 118, 162, and 272 keV transitions, but not with the 361, 431, 439, 610, or 1065 keV ones. The 1065 keV transition is in coincidence with the 112 and/or 118, 162, 431 and/or 439, and possible to a small extent with the 272 keV transitions, but not with the 361 and 610 keV ones. The unresolved 431 and 439 keV group, besides being in coincidence with the 610, 361, 272, and 162 keV peaks, is also in coincidence with the 1065 and 796 keV transitions. The 930 keV transition goes with the 361, 272, and 162 keV transitions, but not with the 431 keV one.

The γ-γ angular distributions in ^{184m}Pt were measured under the same conditions used for ^{182m}Os. The results are listed in Table IV and the comparison with the theoretical values of A_2 for different sequences is also presented there.

4. Level Schemes

4.1 ^{180m}W

Since the coincidence experiments showed that the five transitions observed in the decay of ^{180m}W are all in coincidence with one another, they must be in cascade. And since they all have the same intensity (Table I), this must be an unbranched cascade. Consider first the four E2 transitions. We have no direct evidence in this case as to their order in the cascade, but with the other two isomers studied we have also observed the four prominent E2 transitions in the in-beam (prompt) cascade. In these cases there is evidence (see the discussion of ^{182m}Os) that the E2 transitions are ordered in the cascade according to their energy (lowest energy lies lowest, etc.). It therefore seems reasonable that the E2 cascade in ^{180m}W is ordered in the same way. The resulting sequence of levels is that expected for the ground-state rotational band, as the spacing is very close to the I(I+1) spacing of a rigid rotor. The three lowest rotational transitions are known in ^{182}W from multiple Coulomb excitation experiments[9]) and are within 4-5 keV of the three lowest energy transitions in ^{180m}W. In addition, the only states known to occur at energies of a few hundred keV in deformed even-even nuclei in this region are the rotational ones; so that, we feel it is almost certain that the four E2 transitions are the $8 \rightarrow 6 \rightarrow 4 \rightarrow 2 \rightarrow 0$ cascade in that band. Then the E1 must be the gamma ray which de-excites the isomeric state and feeds into the rotational band at the 8+ level. Such an assignment requires the spin and parity of the isomeric state to be 7-, 8-, or 9-.

The γ-γ angular distribution measurements were made to determine which of these three spins is correct. In columns four, five and six of Table IV are

listed the theoretical values of A_2 for the sequences 8(1)8(2)6(2)4(2)2(2)0, 9(1)8(2)6(2)4(2)2(2)0, and 7(1)8(2)6(2)4(2)2(2)0. By comparing the experimental results with the theoretical predictions, it is obvious that of these three sequences, only the 8(1)8(2)6(2)4(2)2(2)0 one agrees with the measured values. It should be noted that the values deduced for A_4 were zero within the experimental limits of error (±0.09 on the average) in all cases for ^{180m}W and also for the other two isotopes. This fact is consistent with the preceding and all following conclusions drawn from the angular distribution data.

In order to obtain some idea of how well the angular distribution data specifies the entire spin sequence, other spins for the lower levels were considered. To limit the possibilities and make the problem tractable, two restrictions were made: (1) the transitions were assumed to be of pure multipole order (our experimental limits on the possible admixtures are actually not very low) and (2) the order of the transitions in the cascade was assumed to be that previously discussed (as in fig. 8). It was found that of nearly 250 possible cascades, the only other combination of spins that satisfied the experimental results was: 4(1)4(2)6(2)4(2)2(2)0. The values of A_2 for this sequence are listed in the last column of Table IV. However, because no cross-over radiations were detected, and for the other reasons given above, we feel that the correct sequence is 8(1)8(2)6(2)4(2)2(2)0 and that the decay scheme is as shown in fig. 8.

4.2 ^{182m}Os

In ^{182m}Os we again find an E1 and four E2 transitions in coincidence with one another, and thus in cascade. The intensities of the transitions are nearly enough equal to show that the cascade is predominantly unbranched,

although a weak side branch is suggested. The four E2 transitions are also seen in-beam in the prompt cascade which de-excites most of the ^{182}Os formed. In this spectrum the intensities fall off monotonically with increasing transition energy (unfortunately not completely outside the experimental limits of error for every pair); the overall decrease is almost a factor of two. Now, if we assume only that the prompt cascade and the isomeric decay both terminate at the ground state of ^{182}Os, then the absence of the E1 transition in-beam places it at the top of the cascade, and the in-beam intensities, together with the knowledge that the cascade itself has no significant branches, defines the order of the E2 transitions. This sequence corresponds to that for a rotational band.

As for ^{180m}W, the angular distribution measurements unambiguously define the spin of the isomer as 8, provided the E2 transitions comprise the ground state rotational cascade (see Table IV). For ^{182m}Os, however, the arguments for establishing the entire spin sequence are stronger for two reasons. First, there is good evidence for the order of the transitions in the cascade (previous paragraph); leaving as major assumption only the purity of the multipole order of the transitions. (We have not had the courage to examine how many cascades might be allowed if account is taken of the (M1) admixtures permitted in the transitions by our ~15% uncertainty in the conversion coefficients.) Secondly, in this case even the 4(1)4(2)6(2)4(2)2(2)0 sequence can be considered unlikely, since two of the A_2 values are outside the experimental limits of error. Thus the entire 8(1)8(2)6(2)4(2)2(2)0 sequence is established with a minimum of assumptions.

At least one transition in addition to the main sequence was detected at 1245 keV and found to belong to the isomeric activity of ^{182m}Os. Furthermore, the higher energy lines seem to be lower in intensity than the transitions that are situated at the bottom of the cascade. These facts indicate a more complicated structure than that for ^{180m}W. But due to the weak population of the side branch in ^{182m}Os, we have not pursued this investigation further; the position of the 1245 keV transition is not certain and the decay scheme shown in fig. 8 lists only the main cascade.

4.3 ^{184m}Pt

The decay of this isomer is more complicated. There is, as with the other isomers, a main cascade consisting of an E1 (610 keV) and four E2 transitions (431, 361, 272, 162 keV) all in coincidence with one another. The order of the transitions is again indicated by their intensities both in-beam and in the isomer: the argument is similar to that made for ^{182m}Os. Again the indicated order approximates the rotational spacings expected. The γ-γ angular distribution studies summarized in Table IV agree with the theoretical values expected for the 8(1)8(2)6(2)4(2)2(2)0 sequence, again completely ruling out 7 and 9 as possible spins for the isomeric state if the rotational sequence is assumed. However, the 4(1)4(2)6(2)4(2)2(2)0 combination cannot be excluded in this case. For the latter sequence we would expect cross-overs with the energies 792 keV, 1064 keV, and 1402 keV. Transitions with energies of 796±1 keV and 1065±5 keV were found in the singles spectrum, and the coincidence measurements showed that these two transitions do, indeed, terminate at the second and first excited states respectively. However, the possibility that

the 796 keV line is, in fact, the cross-over of the 431 keV and 361 keV transitions can be excluded. Besides the slight discrepancy in energy, a comparison between the prompt spectrum and the isomeric one showed that the relative intensities of the 431 and 796 keV transitions are quite different in the two spectra, indicating that both transitions cannot de-excite the same level. Similarly, a comparison of the relative intensities of the 1065 and 796 keV lines in the prompt and isomeric spectra show that they seem to go together, so that they appear to de-excite a different level (about 3 keV higher in energy) from that de-excited by the 431 keV transition. The most probable spin assignment for the main sequence of levels then remains 8(1)8(2)6(2)4(2)2(2)0.

Besides the main cascade in ^{184m}Pt, there are probably two side branches. The γ-γ coincidence studies establish the level described above at 1229 keV which de-excites to the first and second excited states at 162 and 434 keV by means of the 1065 and 796 keV transitions, respectively. A level at 1669 keV is suggested by the coincidence studies which indicate that the 1235 keV transition populates the 434 keV second excited state. The 439 keV transition is of the correct energy to connect the 1229 and 1669 keV levels. The two strong transitions of 118 and 49 keV sum to 167 keV, the difference in energy between the 1836 keV isomeric state and the 1669 keV level, and so probably go in cascade from the former state to the latter. The order of these two transitions is determined by the prompt ($T_{1/2} < 1.5 \times 10^{-9}$ sec) 272-118 keV coincidences. Since the 8- to 4+ (ground band) states are connected by the 1235 keV E1, the 118 keV E1-M2, and the 49 keV transitions, the last of these must be M2 (higher multipolarities are ruled out by the lifetime of the isomeric state). The above prompt coincidences preclude a 49 keV M2 transition coming between the 118 and 272 keV transitions. Thus a state is defined at 1787 keV, which

must itself have a measurable lifetime since it decays by the 118 keV E1-M2 transition. However, we have not been able to measure it due to the difficulty of working with the 49 keV transition.

The energy difference between the 839 and 667 keV transitions is 162 keV which corresponds to the energy of the first excited state. This suggests a level at 839 keV, which can then be connected with the 1229 keV level by the 390 keV transition.

Finally, the coincidence measurements suggest that the 930 keV transition terminates at the 795 keV state, indicating a level at 1724 keV. The 930 keV transition is also in coincidence with either the 112 or 118 keV transitions, and consideration of the possible energy sums shows it to be the 112 keV transition; as 112 + 1724 adds to the 1836 keV isomeric level. The alternate possibility of a 906 keV intermediate state is less likely, as discussed later. Thus the level structure shown in fig. 9 can be established reasonably unambiguously.

Considering next the spin, parity, and nature of the levels in ^{184}Pt populated by these side branches, we begin by noting that the above-mentioned sequence—1836 keV, 8- (49 keV, M2) 1787 keV (118 keV, E1-M2) 1669 keV (1235, E1) 434 keV, 4+—defines the spins of the 1787 and 1669 keV levels as 6+ and 5-, respectively. The 1787 keV state very likely has K=6, as otherwise it would preferentially de-excite to the lower members of its own band by E2 and/or M1 cascades (which we could not detect). Consideration of the Nilsson states possible in this region[10]) suggest that the two-neutron state (5/2-[512], 7/2-[514])$_{6+}$ should lie low and reasonably near the (7/2-[514], 9/2+[624])$_{8-}$ two-neutron state, which very probably (see below) is the isomeric level. This makes the 49 keV M2 transition correspond to the change: 9/2+[624] $\rightleftarrows$ 5/2-[512].

This M2 transition has also been seen in ^{181}W (366 keV) where its hindrance over the single particle value is 7×10^2 (ref. 10): in the present example, the hindrance is the same within a factor of two. So we shall tentatively assign the intermediate 1787 keV level to this two-neutron 6+, 6 state.

The nature of the 1669 keV, 5- state is less clear. The lifetime of this state is less than 1.5 nsec (see above), which suggests that it is not (predominantly) a K = 5, two-quasiparticle state. It is not likely to have K values of 3 or 4, because then the (unobserved) rotational transition(s) ought to compete favorably with the K-forbidden E1 transitions. If this level has a low K value, the implied low energy of the band head would almost require a collective nature. K values of 0 or 1, however, would tend to imply too long a half-life for the (highly K-forbidden) M2 component of the 118 keV transition from the 1787 keV level. Thus a reasonable guess for this state might be the 5- member of a K = 2 collective band; however, a number of other possibilities exist, particularly if mixed states are considered.

Energy sums and coincidence experiments establish the 112 keV E1-930 keV E2 branch; and since a 906 keV 6- or 7- level is not very plausible either as a two quasiparticle or a collective state, the alternative of a 1724 keV 7+ or 8+ level is adopted. In this case, the reasonably fast 930 keV E2 transition to the ground state band ($T_{1/2} \leq 1.5$ nsec) requires a low K value for this level and correspondingly a low K value implies a low-energy band head. Thus a collective nature is suggested for this band, which is supported by the lack of appropriate Nilsson levels in this vicinity to form a low-lying 7+ or 8+ two quasiparticle state. This line of reasoning suggests that the level may be a member of the (K=2) γ-vibrational band. If so, the 8+ assignment is unlikely, as then an E1 transition should be observed from the isomeric state to the lower-lying 7+ level, and no gamma ray corresponding to such a transition was observed.

Several other transitions may be placed so as to suggest additional members of this band, but solely on the basis of energy sums. Thus, if the 424 keV transition originates in the 1724 keV level, it would define another member (5+) of the band at 1301 keV from which the 867 keV transition could drop to the 4+ level of the ground-state band, the energy of the cascade agreeing to one keV with the difference in level energies. The 1301 keV level could also be reached (within 1 keV) by the 486 keV transition if it originates at the 6+, 6 level at 1787 keV. A possible intermediate 6+ level could be fed by the weak 286 keV transition from the 1787 keV level and by the questionable 224 keV transition from the 1724 keV level. The 775 keV transition could de-excite the 3+ level of this postulated γ-band to the 2+ level of the ground band (the feeding of this 3+ level from the above 5+ level would be obscured by the strong 361 keV transition). However, this scheme poses the problem of why no E2 transition is observed from the 1787 keV state to the 4+ member of the γ-band. Also one might expect E1 transitions from the 1669 keV 5- state to the γ-band, and these are not observed unless possibly the 554 keV gamma ray defines the 4+ member of that band. In summary we can say that while the γ-vibrational-band proposal seems like a reasonable working hypothesis for this branch of the isomeric decay, more evidence is needed before making this assignment.

The spin and parity of the 839 and 1229 keV levels are clearly indicated to be 2+ and 4+, respectively, both by the E0 transitions to the ground band, and by the gamma-ray cascades in which they are involved. The energies of these levels almost require a collective character, and the strong E0 transitions suggest that this is the β-vibrational band. It is of interest to see if the simplified (γ=0) centrifugal stretching model of Davydov and Chaban[11]) applies to this nucleus as well as it apparently does to the more deformed nuclei already

studied[1,12]). In fig. 10 are plotted theoretical curves (for $\gamma=0$) from this model for the energy ratios between any higher member of the ground-state rotational band and the first excited state, E_I/E_2, as a function of the "non-adiabaticity parameter", μ. Similar curves plotted for the beta-vibrational band are denoted by βI (the dash-dot curves). For a good correspondence between experiment and theory, the experimental levels of a nucleus have to intersect the corresponding theoretical curves at a constant value of μ. The two other nuclei studied here, ^{180}W and ^{182}Os, have also been included on fig. 10, and are in good agreement with the theory as can be seen from the almost vertical lines that connect the intersections for each of these nuclei.

For ^{184m}Pt, the values of μ are much larger and a curve, rather than a vertical line, is obtained. The former feature signifies that this nucleus is very "soft" with respect to beta-vibrations; and thus, the beta-band should lie relatively low in energy, as is indicated by the theoretical ratios for the β-band levels plotted in the figure. We attribute the curve in the ^{184}Pt line to: (1) the fact that the parabolic potential energy curve used by Davydov and Chaban cannot be realistic in this region of very soft nuclei; and (2) the gamma-vibrational band is probably also low in energy and so perturbs the ground-state band energies. For reason (1), which we feel is likely to be more important in this particular case, the change in the β-band and ground-state band ratios would be expected to deviate in the same direction, and so it might be hoped that both would be characterized by nearly the same value of μ at a particular excitation energy. In fact, the proposed β-vibrational band members found in ^{184m}Pt at 1229 and 839 keV are also indicated in fig. 10, and they do intersect the appropriate theoretical lines rather close to the curve defined by the ground-state band members.

We can also compare the branching ratios of the levels with the theoretical values. For the 1229 keV level, the theory at μ=0.5 gives[13]): $B(E2;4\beta\rightarrow 2\beta)|B(E2;4\beta\rightarrow 2g)|B(E2;4\beta\rightarrow 4g)|B(E2;4\beta\rightarrow 6g) = 110|1|6.7|36$. Converting these to intensities gives the theoretical values: $W(E2;4\beta\rightarrow 2\beta)|W(E2;4\beta\rightarrow 2g)|W(E2;4\beta\rightarrow 4g)|W(E2;4\beta\rightarrow 6g) = 0.72|1|1.5|0.41$; whereas the experimental values are: $0.9\pm0.4|1|0.9\pm0.3|$ masked. For the 839 keV level, the theory gives: $B(E2;2\beta\rightarrow 0\beta)|B(E2;2\beta\rightarrow 0g)|B(E2;2\beta\rightarrow 2g)|B(E2;2\beta\rightarrow 4g) = 28|1|2.9|14$; which gives the intensity ratios, taken in the same order: $0.12|1|1|0.37$. The experimental data are poorer here giving values of: unobs$|1|\leq 0.35|\leq 0.5$, where the energy of the $2\beta\rightarrow 0\beta$ transition is not known exactly so that a limit cannot be set. The E2 gamma-ray transitions, $2\beta\rightarrow 2g$ (677 keV) and $2\beta\rightarrow 4g$ (405 keV), were not observed, but limits could be set. These data are not very extensive nor precise; however, there is qualitative agreement between the theory and experiment. Particularly good is the relationship between the rotational transition $4\beta\rightarrow 2\beta$ and the interband E2 transitions from the 4+ level. The $I_\beta\rightarrow I_g$ transitions are outside the error limits from both levels. A possible explanation would be admixtures of the nearby γ-vibrational band if it has been correctly identified above; however, it does not seem reasonable to expect too much from the theory at these μ values since even the level spacings (fig. 10) are not given very accurately.

The E0 transition probabilities can also be compared with theory. We define:

$$\mu_K(I) = \frac{W(e_K^-;I_\beta\rightarrow I_g)}{W(E2;I_\beta\rightarrow I_g)} - \alpha_K(E2)$$

where $W(e_K^-; I_\beta \rightarrow I_g)$ and $W(E2; I_\beta \rightarrow I_g)$ are the intensities of K conversion electrons and E2 gamma rays, respectively, from the $I_\beta \rightarrow I_g$ transition, and $\alpha_K(E2)$ is the E2 conversion coefficient for the transition. Then $\mu_K(2)$ and $\mu_K(4)$ are experimentally ≥ 0.15 and 0.038 ± 0.012, respectively. The theoretical values[14] of 0.48 and 0.28, respectively, are several times larger than the experimental values, as has been found by Davidson[14] to be typical for nuclei in this region.

Although the simplified (γ=0) Davydov-Chaban calculation is still clearly useful for ^{184}Pt, we do not propose that it will be for all nuclei in this vicinity. In the heavier osmium and platinum nuclei where the γ-vibrational band drops well below the β-vibrational band, one will have to take explicit account of the γ-vibrations, and probably by a more sophisticated treatment involving the dynamic variation of γ, rather than by the use of a static non-axial deformation as in the Davydov-Chaban calculation.

5. Discussion

It is interesting to compare the isomeric states and their mode of de-excitation in the three isotopes studied. From the systematic appearance of the isomers it appears that the states are connected with an intrinsic configuration of the neutrons. In Table V are summarized the energies of the de-exciting E1 transitions of the three isotones and their hindrance with respect to the single proton value. Also listed are the additional 106-neutron isotones ^{176}Yb (ref. 15) and ^{178}Hf (ref. 16). It can be seen that in going from ^{176}Yb to ^{182}Os there appears to be a mild relaxation of the K-forbiddenness, a decrease in the hindrance factor. This is as expected, for in going from the deformed nuclei to the spherical, the validity of the K-quantum number diminishes. The

cause for the reversal of the trend at ^{184}Pt is not clear to us; perhaps, some other selection rule comes into play near the spherical nuclei.

Two 8- states have been found in ^{178}Hf at energies of 1480 and 1148 keV, while in ^{180}Hf an 8- state has been observed at an energy of 1142 keV[17]). The 1148 keV and the 1142 keV states are probably due to a two-proton configuration in ^{178}Hf and ^{180}Hf respectively. Gallagher and Nielsen[15]) have assigned them as the two-quasiparticle state formed from the Nilsson 7/2+[404], 9/2-[514] proton orbitals. These authors have also assigned the 1480 keV level in ^{178}Hf as a two-neutron state made up of the Nilsson 9/2+[624], 7/2-[514] orbitals. Gallagher and Soloviev[18]) found good agreement between the experimental energies and theoretical values calculated on the basis of a model which applies pairing correlations to nuclei with a deformed core.

Their neutron configuration assignment of the 1480 keV level in ^{178}Hf is supported by the systematic occurrence of the 8- isomeric states in the three 106-neutron nuclei described in the present work and in ^{176}Yb, and these other isomers most probably have the same 9/2+[624], 7/2-[514] neutron configuration. It is interesting to note, as is apparent from Table V, that the reduced transition probability of the de-exciting transitions from the two-neutron state to the ground rotational band is 3-4 orders of magnitude larger than that from the two-proton state (in ^{180m}Hf) to the ground band, despite the fact that both transitions have the same K-forbiddenness.

In ^{178}Hf, where both two-quasiparticle states occur, the two-neutron state de-excites to the two-proton level by an M1 transition[18]). This fact suggests a configuration mixing of the two states. The admixture is also supported by the intermediate value for the reduced transition probability of the de-exciting transition from the lower state. Adopting an interpolated reduced

transition probability for the neutron configuration from the data for ^{176}Yb and ^{180}W and the value for the proton state from ^{180}Hf, we can account for the transition probability from the lower (proton) state in ^{178}Hf by an admixture of about 35% (0.6 in amplitude) of the neutron configuration in the lower level. Probably the most unambiguous evidence on the mixing of these two levels comes from their electron capture feeding from 2.1 hr ^{178}Ta. Gallagher and Nielsen[16] have shown that complete mixing of the two levels is required by these data. Thus three independent pieces of evidence suggest mixing, and the two quantitative estimates both indicate essentially complete mixing of the two levels. To completely mix two levels 332 keV apart requires a large interaction and suggests that either two quasiparticle states in even-even nuclei are generally more heavily mixed than has been thought, or more likely, this case is special, due perhaps to the [514↑] proton and the [514↓] neutron.

Finally, mention should be made of the fact that in the heavy-ion production of ^{182}Os and ^{184}Pt performed in this work, the 8-,8 isomeric level is populated in-beam to about 18% and 30%, respectively, of the ground-band 8+,0 level. Clearly, compound nucleus evaporation calculations, to be accurate, must be able to account for this differentiation, either by K-selection rules, the difference in energy, or some other mechanism.

Acknowledgments

We are grateful to Prof. N. Lark for help in the initial stages of this study and to Dr. K. Kotajima for aid during the later phases. The work was aided greatly by the analyzer-programming system designed and built by Mr. Rich Leres. Finally, we would like to thank the crew of the Hilac for keeping the heavy-ion beams going during our runs.

References

1) F. S. Stephens, N. L. Lark, and R. M. Diamond, Phys. Rev. Letters 12 (1964) 225; Nucl. Phys. 63 (1965) 82

2) J. Burde, R. M. Diamond, and F. S. Stephens, to be published

3) N. L. Lark and H. Morinaga, Nucl. Phys. 63 (1965) 466

4) S. D. Softky, Phys. Rev. 98 (1955) 736

5) V. V. Remaev, Yu. S. Korda, and A. P. Klyucharev, Bull. Acad. Sci. USSR (translation) 27 (1965) 133

6) Conversion electron spectra for ^{180m}W similar to ours have been obtained at the Tandem Laboratory of the Niels Bohr Institute, University of Copenhagen, private communication from S. Bjørnholm, March 1964.

7) O. Kofoed-Hansen, J. Lindhard, and O. B. Nielsen, Kgl. Danske Videnskab. Selskab, Mat.-Fys. Medd 25 (1950) No. 16

8) K. Kotajima, private communication, October 1965

9) B. Elbek, G. Igo, F. S. Stephens, and R. M. Diamond, Proceedings of the Second Conference on Reactions between Complex Nuclei, ed. by A. Zucker, E. C. Halbert, and F. T. Howard, (John Wiley and Sons, Inc., New York, 1960), p. 102.

10) B. R. Mottelson and S. G. Nilsson, Kgl. Danske Videnskab. Selskab, Mat. Fys. Skrifter 1 (1959) No. 8

11) A. S. Davydov and A. A. Chaban, Nucl. Phys. 20, (1960) 499

12) R. M. Diamond, F. S. Stephens, and W. J. Swiatecki, Phys. Letters 11 (1964) 315

13) J. P. Davidson and M. G. Davidson, Phys. Rev. 138 (1965) B316

14) J. P. Davidson, to be published, Phys. Rev.; U. S. Naval Radiological Defense Laboratory Report USNRDL-TR-926 (1965)

15) J. Kantele, Phys. Letters 2 (1963) 293; M. Vergnes, G. Rotbard, G. Ronsin, and J. Kalifa, Phys. Letters 18 (1965) 325; S. Bjørnholm, private communication, January 1966

16) C. J. Gallagher and H. L. Nielsen, Phys. Rev. 126 (1962) 1520 and refs. given therein

17) Nuclear Data Sheets, Nuclear Data Group, Oak Ridge National Laboratory, and refs. cited therein

18) C. J. Gallagher and V. G. Soloviev, Kgl. Danske Videnskab. Selskab, Mat.-Fys. Skrifter 2 (1962) No. 2

Figure Captions

Fig. 1. Conversion electron spectrum of ^{180m}W. The long-lived background has been subtracted.

Fig. 2. Gamma-ray spectrum of ^{180m}W taken with a 5 cm × 5 cm NaI(Tl) counter. The long-lived background has been subtracted.

Fig. 3. Conversion electron spectrum of ^{182m}Os. The long-lived background has been subtracted.

Fig. 4. Gamma-ray spectrum of ^{182m}Os taken with a lithium-drifted Ge detector. The long-lived background has been subtracted.

Fig. 5. Conversion electron spectrum of ^{184m}Pt. The long-lived background has been subtracted.

Fig. 6. Low-energy gamma-ray spectrum of ^{184m}Pt taken with a lithium-drifted Ge detector. The long-lived background has been subtracted.

Fig. 7. High-energy gamma-ray spectrum of ^{184m}Pt taken with a lithium-drifted Ge detector. The long-lived background is not subtracted, but is shown as a thin solid curve.

Fig. 8. Basic decay schemes of the five 106-neutron isomers.

Fig. 9. Decay scheme of ^{184m}Pt.

Fig. 10. Plot of the energy ratio of the level having spin I to that of the first excited state (I=2), E_I/E_2, vs μ, the Davydov-Chaban non-adiabaticity parameter[11]). The approximately horizontal full curves are the Davydov-Chaban values for the ground-band levels; the approximately horizontal dash-dot lines are the theoretical curves for the levels of the β-vibrational band. The nearly vertical full lines connect the experimental points for the ground-band energies, and the dashed line connects the two experimental energy ratios for the β-band in ^{184}Pt.

Table I. Transitions in ^{180m}W.

Transition[a] (keV)	E_{e^-} and (Assignment)	I_{e^-}[b]	K/L exp.	K/L theor.[c] (E2)	I_γ[b]	α_i exp. $\times 10^2$	α_i theor.[c] $\times 10^2$	Multipolarity assigned	Transition intensity
102.8	91.8(L) 102.2(M)	46 14			19	242	(E2) 213	E2	100±20
233.8	164.4(K) 222.3(L) 231.6(M)	10.7 5.0 1.7	2.1±0.3	1.85	(100)	(10.7)	(E2) 10.7	E2	117±12
350.3	280.5(K) 337.6(L) 347.8(M)	4.0 1.3 0.5	3.1±0.4	3.0	110	3.6	(E2) 3.82	E2	116±12
390.0	320.5(K)	1.0			120	0.83	(E2) 3.0 (E1) 1.06	E1	121±12
448.3	378.9(K) 436.6(L) 447.8(M)	2.0 0.42 0.16	4.8±1.1	3.8	117	1.7	(E2) 2.10	E2	120±12

[a] The error in the energy is estimated to be ±0.3%.

[b] The error in the intensities is estimated to be ±10%, rising to ±20% for the weakest electron lines and for the 103 keV gamma ray.

[c] L. A. Sliv and I. M. Band, Coefficients of the internal conversion of gamma radiation, part I and II, (Academy of Sciences of the USSR, Moscow, Leningrad, 1956) as given in Report 57 ICC K1 and 58 ICC L1, University of Illinois, Urbana, Illinois.

Table II. Transitions in ^{182m}Os.

Transition[a] (keV)	E_{e^-} and (Assignment)	I_{e^-}[b]	K/L exp.	K/L theor.[c] (E2)	I_γ[b]	α_i exp. $\times 10^2$	α_i theor.[c] $\times 10^2$	Multi-polarity assigned	Transition intensity
126.6	114.6(L) 125.0(M)	42 11			34.8	121	(E2) 96	E2	111±20
273.0	199.2(K) 260.9(L) 270.1(M)	7.5 4.0 0.9	1.9±0.3	2.07	(100)	(7.5)	(E2) 7.5	E2	112±11
393.7	320.0(K) 380.7(L) 391.1(M)	3.3 1.0 0.4	3.3±0.7	3.1	103	3.2	(E2) 3.0	E2	108±11
483.6	409.7(K) 471.3(L)	1.7 0.55	3.1±0.8	3.7	92	1.85	(E2) 1.83	E2	95±11
553.5	479.1(K) 541.3(L)	0.48 0.08	6±1.5	(E1)6.5	95	0.51	(E1) 0.53	E1	96±11
~1245					4.5±2				4.5±2

[a]The error in the energy is estimated to be ±0.3%.

[b]The error in the intensities is estimated to be ±10% rising to 20% for the weakest electron lines and for the 127 keV gamma ray.

[c]L. A. Sliv and I. M. Band, Coefficients of the internal conversion of gamma radiation, part I and II, (Academy of Sciences of the USSR, Moscow, Leningrad, 1956) as given in Report 57 ICC K1 and 58 ICC L1, University of Illinois, Urbana, Illinois.

Table III. Transitions in ^{184m}Pt.

Transition[a] (keV)	E_{e^-} and (Assignment)	I_{e^-}[b]	K/L exp.	K/L theor.[c] (E2)	I_γ[b]	α_i exp. $\times 10^2$	α_i theor.[c] $\times 10^2$	Multipolarity assigned	Transition intensity
49	35.4(L_I)							(M2)	
	36.2(L_{II})								
	37.8(L_{III})								
	46.4(M)								
112	33.6(K)	<10			7.5	<133	(E2) 58 (E1) 25	E1	10±3
	(L)	<1.0				<13	(E2) 195 (E1) 5		
118	39.9(K)	~26			7	~370	(M2) 2100 (E1) 22	82% E1- 18% M2	46±10
	103.7(L)	10				150	(M2) 780 (E1) 4.1		
	114.6(M)								
162.4	84.0(K)	21	0.75±0.1	0.75	63			E2	120±15
	149.5(L)	28				44	(E2) 36		
	159.9(M)	8							
272.2	193.9(K)	8.70	1.8±0.3	1.82	100	8.7	(E2) 7.7	E2	115±12
	259.4(L)	4.9							
	269.5(M)	1.4							
286.5	208(K)	0.5			<2	>25	(M1) 29		2±1

(continued)

Table III. Continued.

Transition[a] (keV)	E_{e^-} and (Assignment)	I_{e^-}[b]	K/L exp.	K/L theor.[c] (E2)	I_γ[b]	α_i exp. $\times 10^2$	α_i theor.[c] $\times 10^2$	Multipolarity assigned	Transition intensity
360.8	282.5(K)	2.7	2.7±0.4	2.6	(71)	(3.8)	(E2) 3.8	E2	75±10
	347.6(L)	1.0							
~389.5	311(K)	0.18			7	2.6	(E2) 3.2	E2	7.3±3
424					5				5±3
431.0	352.5(K)	1.59	3.2±0.6	3.35	67	2.4	(E2) 2.6	E2	69±10
	418.0(L)	0.50							
439	360.6(K)	0.32	5.3±1.5	3.1 (E1) 6.3	24	1.3	(E1) 0.92	E1	24±5
	415.2(L)	0.06							
486.5	408(K)	0.33			11	3.0	(M1) 7.0 (E2) 2.0		11.4±3
~554	~472(K)	≤0.05			5.5	≤0.91	(E1) 0.55 (E2) 1.5	E1?	5.5±3
610.1	531.7(K)	0.235			64	0.37	(E1) 0.46	E1	64±10
676.5	598(K)	0.24			≤1.5	≥16	(M1) 2.9	E0(+E2)	≤1.8
~775	~697(K)	~0.02			1.9	~1	(E2) 0.7	E2?	2±1

(continued)

Table III. Continued.

Transition[a] (keV)	E_{e^-} and (Assignment)	I_{e^-}[b]	K/L exp.	K/L theor.[c] (E2)	I_γ[b]	α_i exp. $\times 10^2$	α_i theor.[c] $\times 10^2$	Multi-polarity assigned	Transition intensity
796	717.5(K)	0.33			7.3	4.5	(E2) 0.67 (M1) 1.9	E0-E2	7.7±2
839	760.5(K)	0.018			4.3	0.42	(E2) 0.61	E2	4.3±2
867	788.5(K)	0.018			5.8	0.31	(E2) 0.58 (E1) 0.23		5.8±2
930	851.5(K)	0.037			7.4	0.50	(E2) 0.50	E2	7.4±2
1065	987(K)	0.041			8.1	0.51	(E2) 0.39	E2	8.1±2
1235	1157(K)	0.026			20	0.13	(E1) 0.13	E1	20±3

[a] The error in the energy is estimated to be ±0.3% rising to twice that value for the less intense transitions.

[b] The estimated error in the transition intensity is indicated in column 10, and in most cases this reflects the error in the photon intensities. The error in the electron intensities is normally about the same.

[c] L. A. Sliv and I. M. Band, Coefficients of the internal conversion of gamma radiation, part I and II, (Academy of Sciences of the USSR, Moscow, Leningrad, 1956) as given in Report 57 ICC K1 and 58 ICC L1, University of Illinois, Urbana, Illinois.

Table IV. Angular distribution measurements.

Transition channeled (keV)	Coincident transition (keV)	Experimental value A_2	Theoretical value for 8(1)8(2)6(2) 4(2)2(2)0 A_2	Theoretical value for 9(1)8(2)6(2) 4(2)2(2)0 A_2	Theoretical value for 7(1)8(2)6(2) 4(2)2(2)0 A_2	Theoretical value for 4(1)4(2)6(2) 4(2)2(2)0 A_2
			^{180m}W			
234	350 + 390	+0.13±0.06	+0.132	+0.024	+0.0102	+0.127
234	448	+0.12±0.05	+0.102	+0.102	+0.102	+0.162
350 + 390	103	+0.19±0.10	+0.132	+0.024	+0.0102	+0.127
350 + 390	234	+0.17±0.06	+0.132	+0.024	+0.0102	+0.127
350 + 390	350 + 390	+0.21±0.07	+0.169	-0.0715	-0.102	+0.1585
350 + 390	448	+0.18±0.06	+0.132	+0.024	+0.0102	+0.134
			^{182m}Os			
484 + 554	127	+0.13±0.06	+0.133	+0.024	+0.0102	+0.160
484 + 554	273	+0.09±0.05	+0.133	+0.024	+0.0102	+0.160
484 + 554	394	+0.12±0.05	+0.133	+0.024	+0.0102	+0.160
484 + 554	484 + 554	+0.22±0.06	+0.169	-0.0715	-0.102	+0.10
			^{184m}Pt			
272	162	+0.18±0.07	+0.102	+0.102	+0.102	+0.102
272	361	+0.13±0.05	+0.102	+0.102	+0.102	+0.102
272	431	+0.13±0.05	+0.102	+0.102	+0.102	+0.162
272	610	+0.19±0.05	+0.169	-0.0715	-0.102	+0.159
610	162	+0.15±0.10	+0.169	-0.0715	-0.102	+0.159
610	272	+0.25±0.09	+0.169	-0.0715	-0.102	+0.159
610	361	+0.11±0.09	+0.169	-0.0715	-0.102	+0.159
610	431	+0.10±0.09	+0.169	-0.0715	-0.102	+0.10

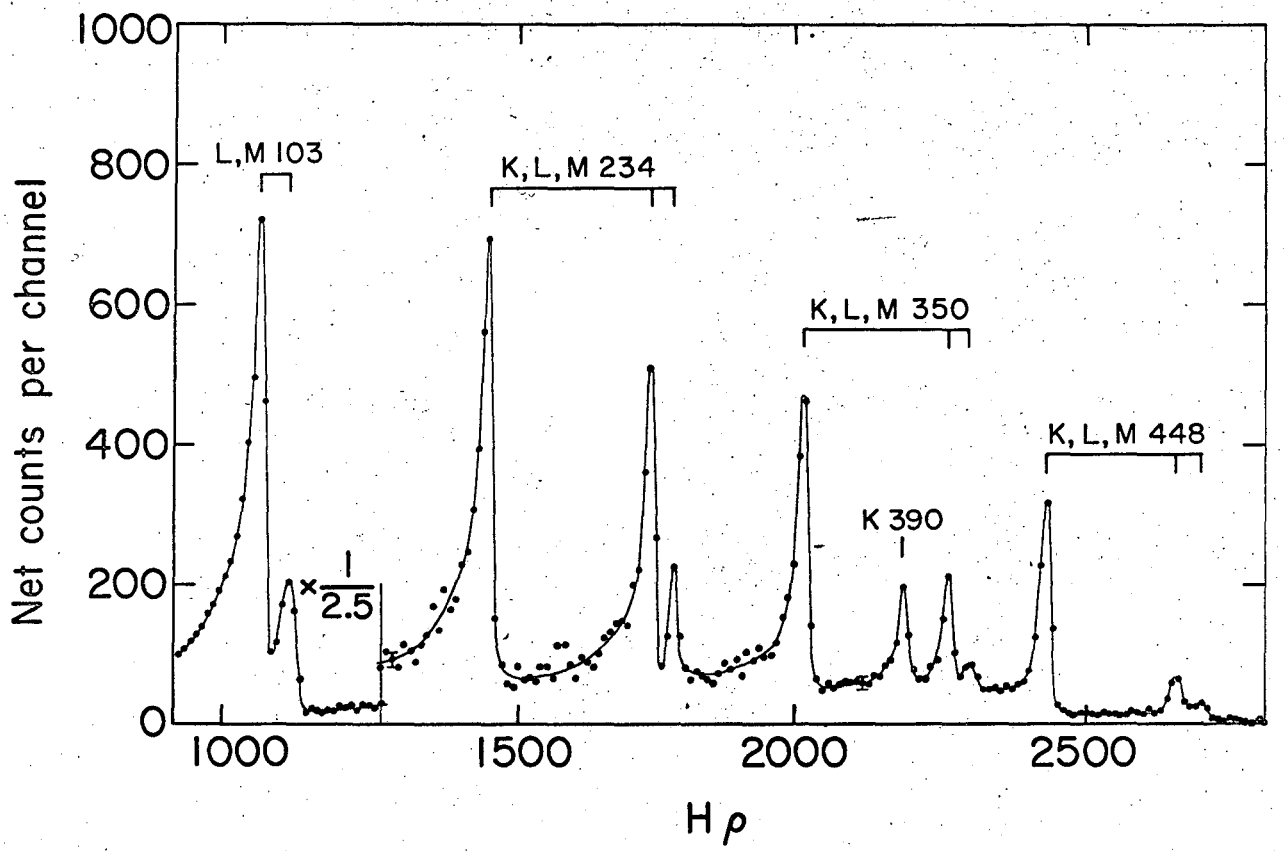
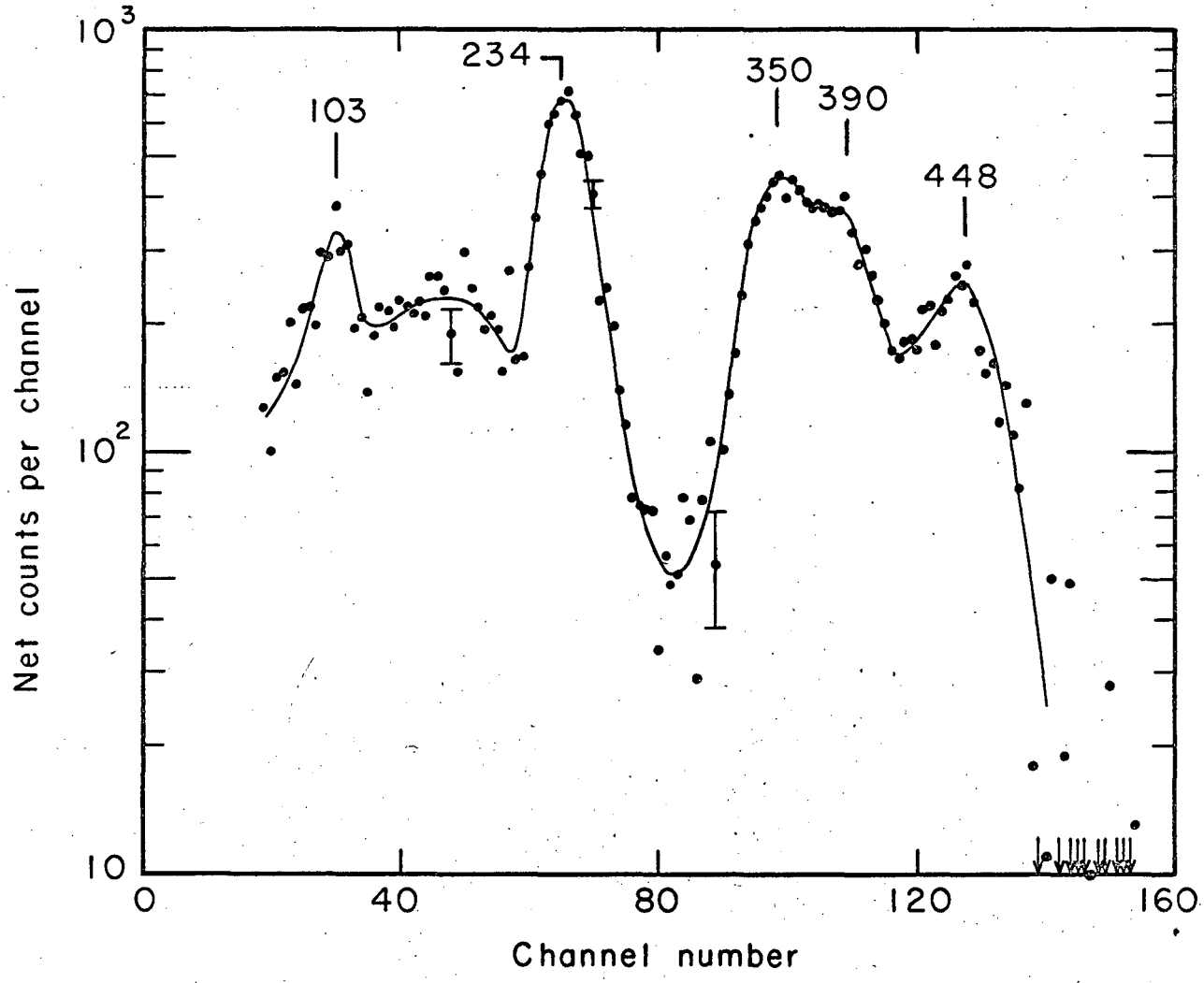

1000
800
600
400
200
0
Net counts per channel
L,M 103
K,L,M 234
K,L,M 350
K,L,M 448
K 390
× 1/2.5
1000
1500
2000
2500
Hρ
MUB-6274

Fig. 1



MUB-6271

Fig. 2

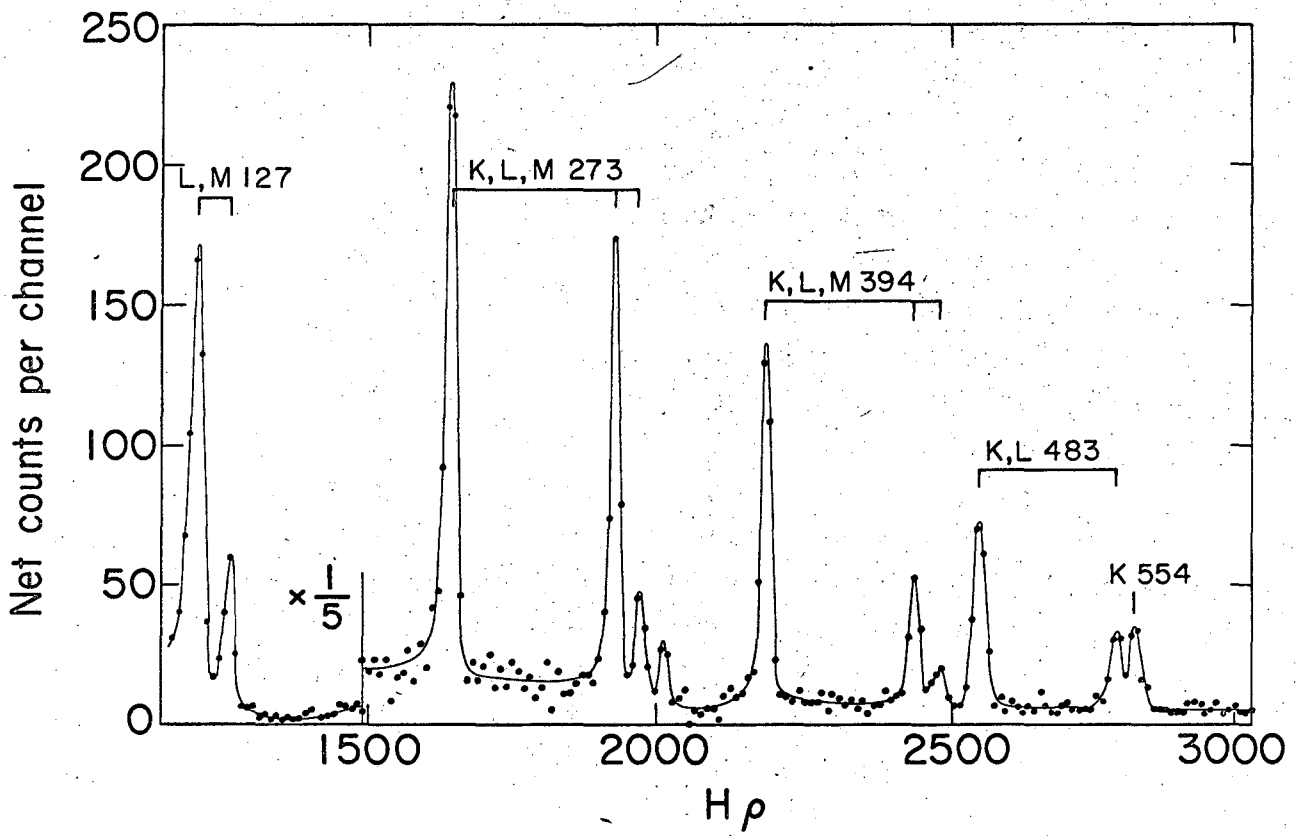

250
200
150
100
50
0
Net counts per channel
L, M 127
K, L, M 273
K, L, M 394
K, L 483
K 554
× 1/5
1500
2000
2500
3000
Hρ
MUB-6273

Fig. 3

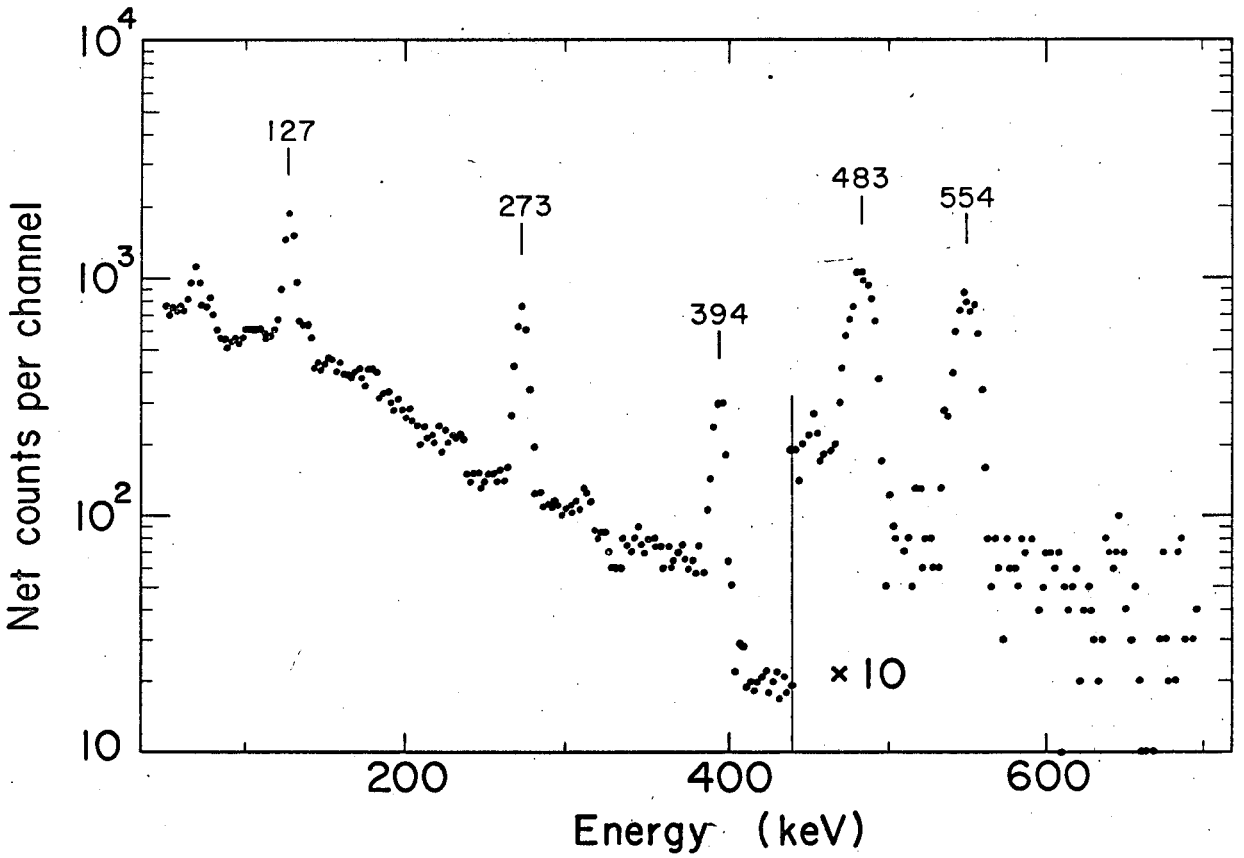

10^4
10^3
10^2
10
Net counts per channel
127
273
394
483
554
× 10
200
400
600
Energy (keV)
MUB-6272

Fig. 4

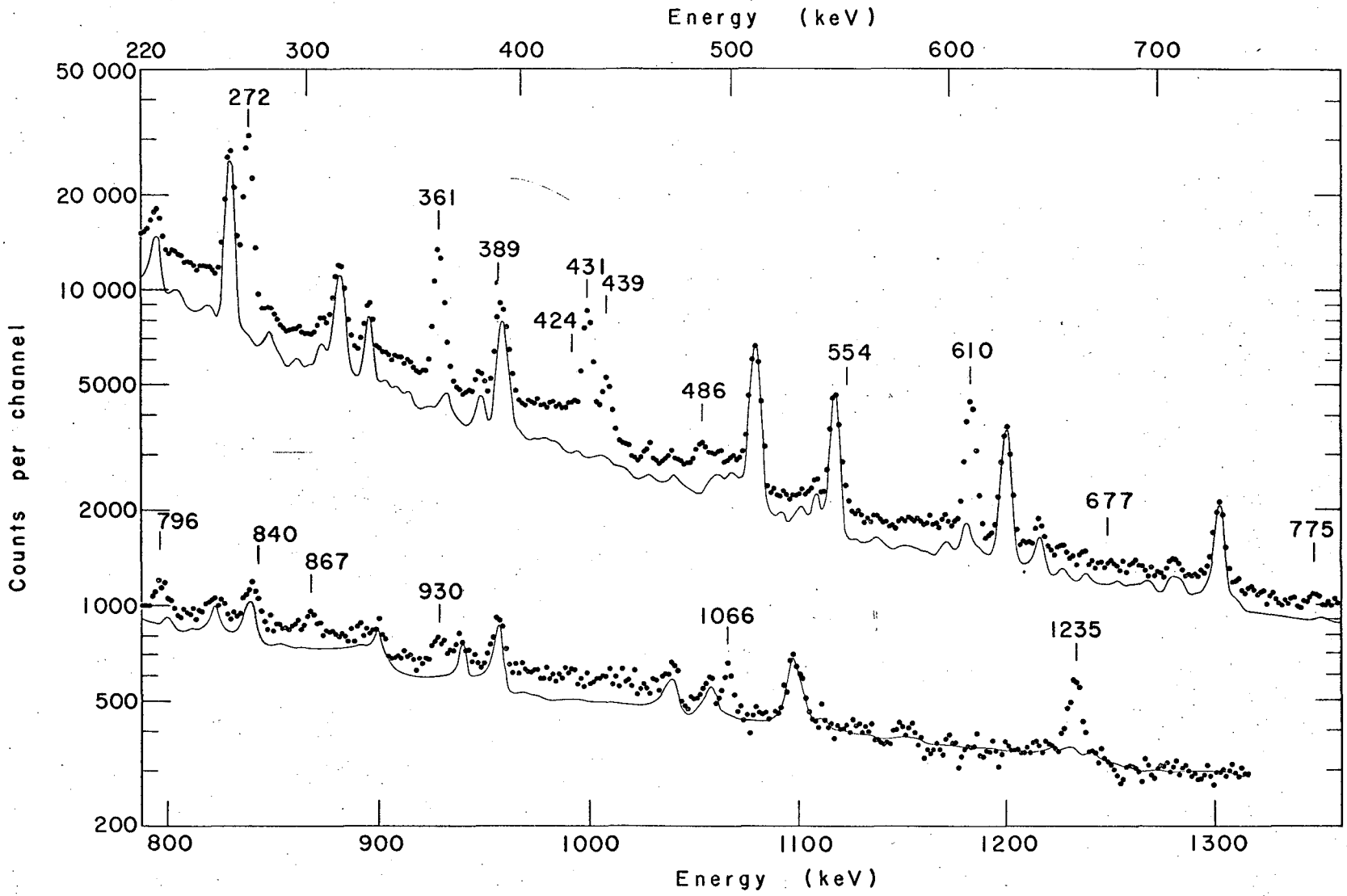

Energy (keV)
220
300
400
500
600
700
50 000
20 000
10 000
5000
2000
1000
500
200
Counts per channel
272
361
389
431
439
424
486
554
610
677
775
796
840
867
930
1066
1235
800
900
1000
1100
1200
1300
Energy (keV)

Fig. 7

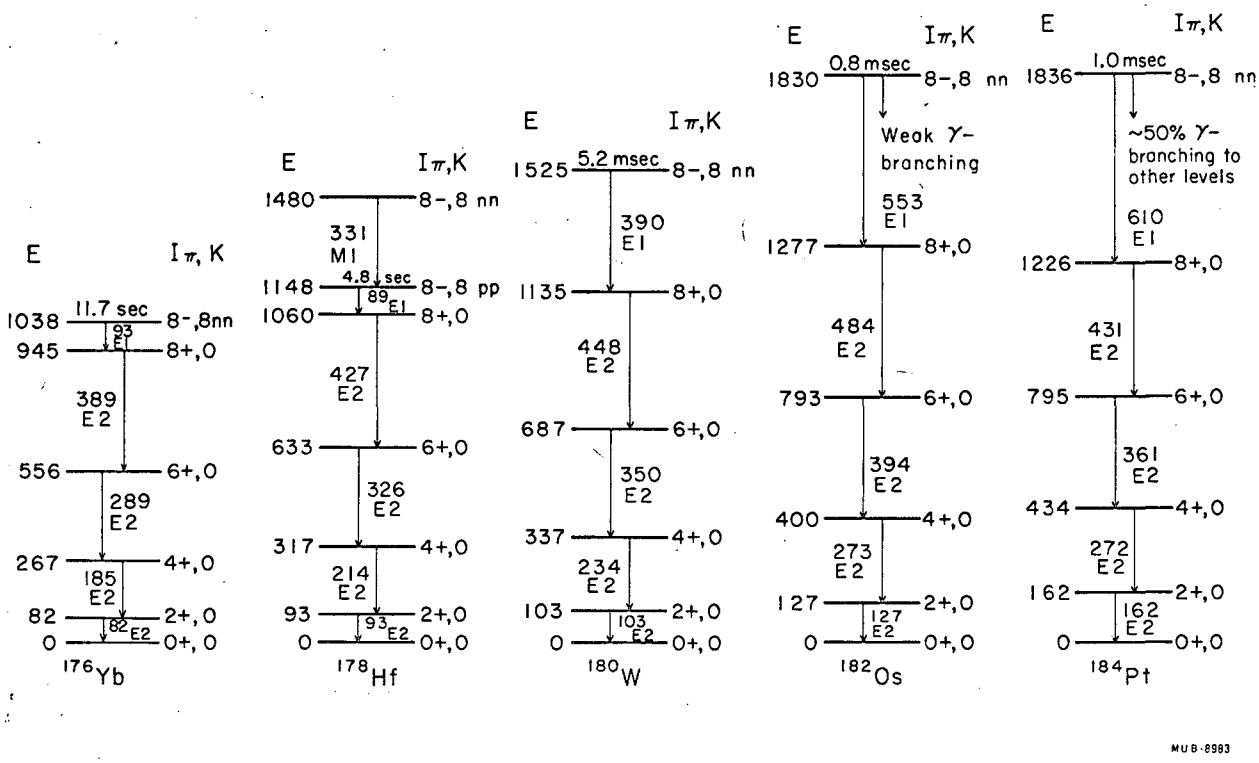

E
Iπ, K
11.7 sec
1038
8-,8nn
93 E1
945
8+,0
389 E2
556
6+,0
289 E2
267
4+,0
185 E2
82
2+,0
82 E2
0
0+,0
176Yb
E
Iπ,K
1480
8-,8 nn
331 M1
4.8 sec
1148
8-,8 pp
89 E1
1060
8+,0
427 E2
633
6+,0
326 E2
317
4+,0
214 E2
93
2+,0
93 E2
0
0+,0
178Hf
E
Iπ,K
5.2 msec
1525
8-,8 nn
390 E1
1135
8+,0
448 E2
687
6+,0
350 E2
337
4+,0
234 E2
103
2+,0
103 E2
0
0+,0
180W
E
Iπ,K
0.8 msec
1830
8-,8 nn
Weak γ-branching
553 E1
1277
8+,0
484 E2
793
6+,0
394 E2
400
4+,0
273 E2
127
2+,0
127 E2
0
0+,0
182Os
E
Iπ,K
1.0 msec
1836
8-,8 nn
~50% γ-branching to other levels
610 E1
1226
8+,0
431 E2
795
6+,0
361 E2
434
4+,0
272 E2
162
2+,0
162 E2
0
0+,0
184Pt
MUB-8983

Fig. 8

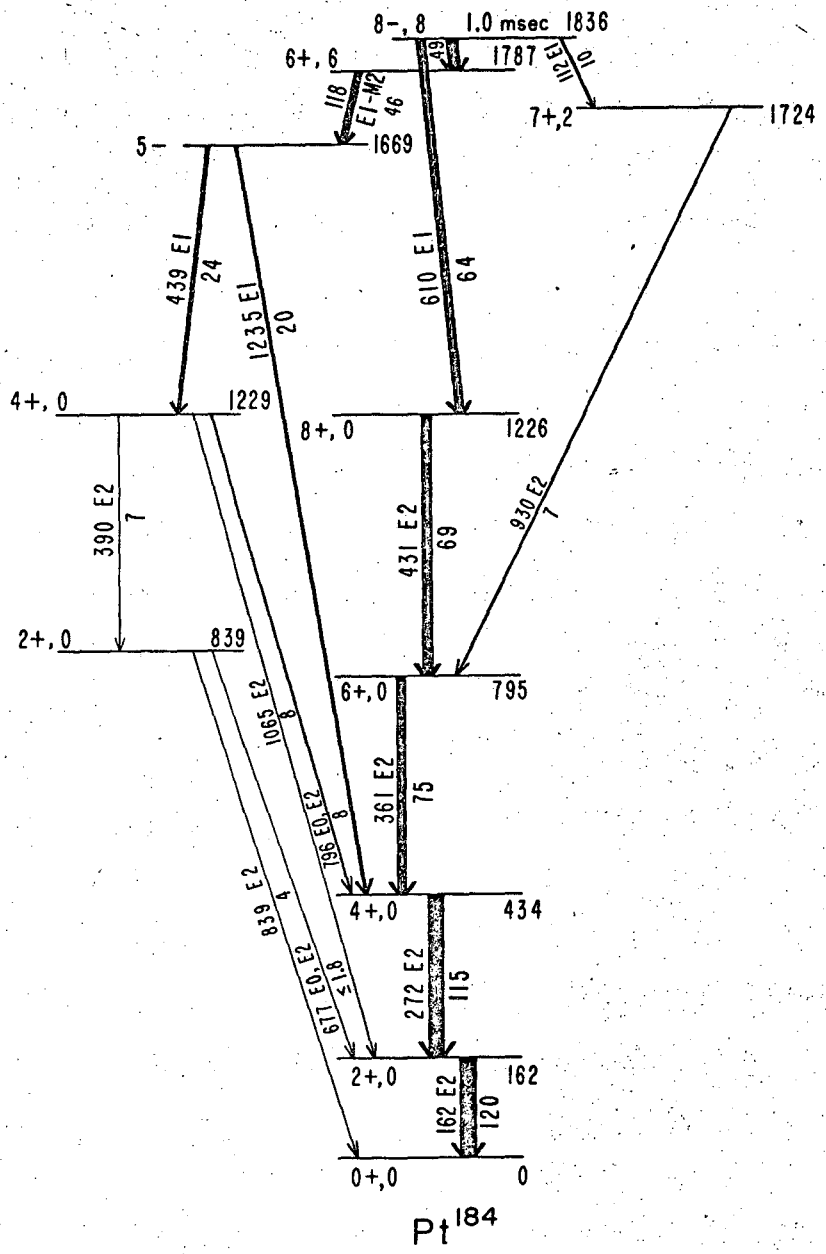

8−, 8
1.0 msec
1836
6+, 6
1787
49
112 E1
10
7+, 2
1724
118
E1-M2
46
5−
1669
439 E1
24
1235 E1
20
610 E1
64
4+, 0
1229
8+, 0
1226
930 E2
7
390 E2
7
431 E2
69
2+, 0
839
6+, 0
795
1065 E2
8
796 E0, E2
8
361 E2
75
839 E2
4
617 E0, E2
≤1.6
4+, 0
434
272 E2
115
2+, 0
162
162 E2
120
0+, 0
0
Pt184
MUB-6523

Fig. 9

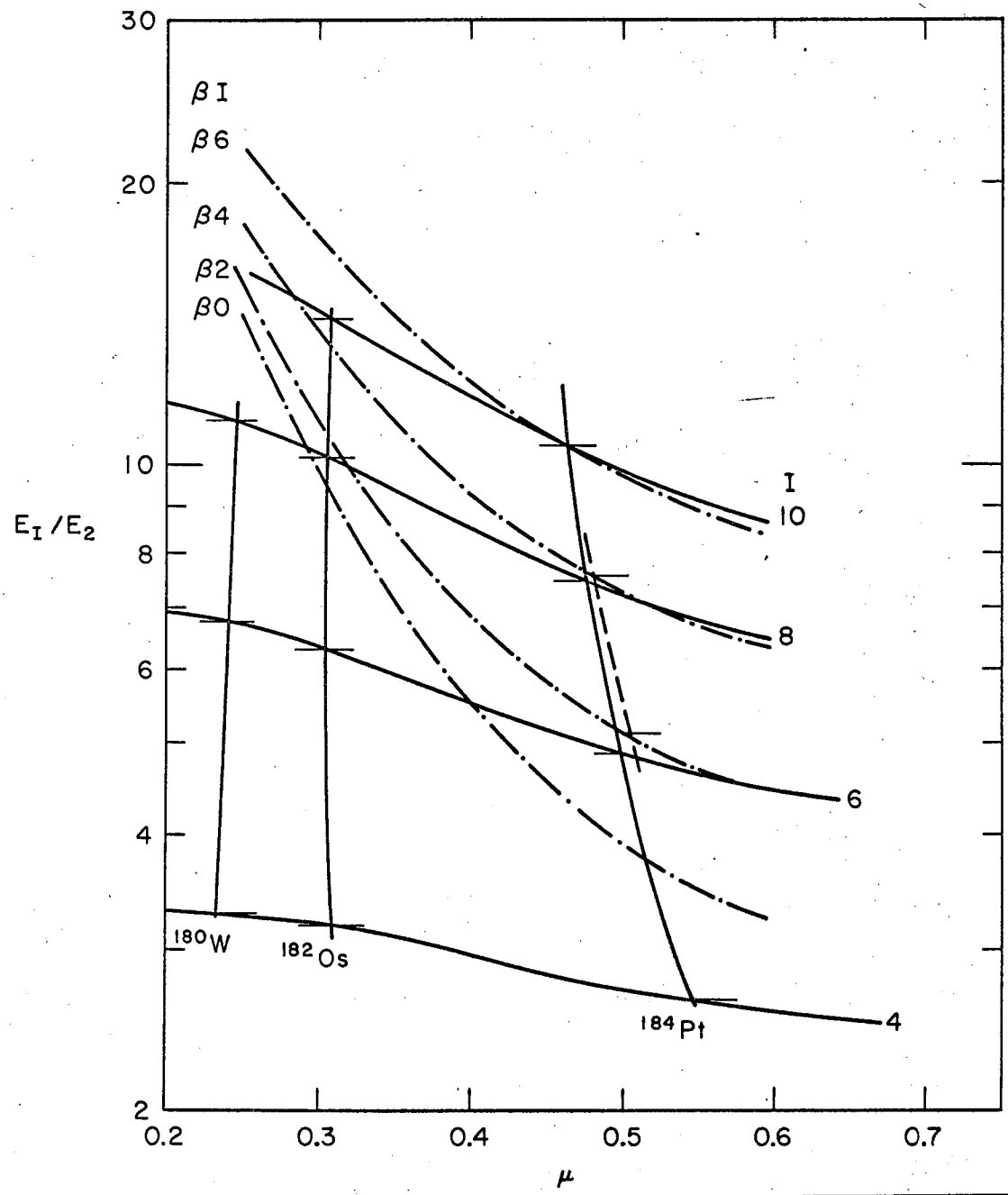

30
20
10
8
6
4
2
0.2
0.3
0.4
0.5
0.6
0.7
E_I / E_2
μ
βI
$\beta 6$
$\beta 4$
$\beta 2$
$\beta 0$
I
10
8
6
4
^{180}W
^{182}Os
^{184}Pt
MUB-8982

Fig. 10