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NUCLEAR REACTIONS ^{165}Ho, ^{169}Tm, ^{175}Lu, ^{181}Ta, (^{11}B,xnγ), (^{14}N,xnγ), (^{19}F,xnγ) ^{178,180,182}Os, ^{182,184,186,188}Pt, ^{188,190}Hg; measured E_γ, E_{ce}, I_γ, I_{ce}. Deduced levels, J, π.

GROUND-STATE (QUASI-) ROTATIONAL LEVELS IN LIGHT Os, Pt, AND Hg NUCLEI[+]

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Abstract

Energy levels in some neutron-deficient even-even nuclei in the platinum region have been studied following heavy-ion reactions. Information on the ground state rotational (or quasirotational) bands in ^{178,180,182}Os, ^{182,184,186,188}Pt, and ^{188,190}Hg is presented. The levels suggest that the light platinum nuclei are very soft axially-symmetric rotors, rather different from the well-known γ-unstable or tri-axial heavy osmium nuclei. The energy-level systematics of this region are compared with those of the samarium region, and it is concluded that the two regions are basically similar, with the well-known 88-90 neutron discontinuity reasonably well duplicated between neutron deficient osmium and platinum nuclei (proton number 76-78).

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1. Introduction

The present work represents a continuation of studies of the gamma-ray cascade de-exciting the final nucleus produced in heavy-ion nuclear reactions. In a previous work[1]), reactions were studied where the final nuclei (of Yb, Hf, and W) all had stable equilibrium deformations and consequently well-defined rotational spectra. The aim of the present work was to extend the region of study upward in atomic number (to Os, Pt, and Hg), and thus come into a region where the product nuclei do not have stable equilibrium deformations in their ground states.

Recently Lark and Morinaga[2]) have looked at gamma rays (using NaI detectors) from nuclei of W, Os, and Pt following (α,xn) reactions; and Sakai and co-workers[3,4]) have studied conversion electrons from Os, Pt, and Hg nuclei following (p,xn) reactions. The present work using heavy ions as projectiles differs from these studies in two respects. First, the use of heavy ions results in the production of more neutron-deficient product nuclei than are obtained with protons or alpha particles. Thus our heaviest Os and Pt nuclei correspond to the lightest ones studied by Lark and Morinaga, and we have not studied any of the same nuclei as Sakai et al. The second difference is that the heavy ion should bring much more angular momentum into the system, permitting, in general, the population of higher-spin states. This was found to be the case in the rotational nuclei studied previously, but is not so obvious among the (low-lying, heavily-populated) levels observed in this study, particularly in the spherical nuclei.

A difference in technique between this and our previous study is that we now have available reasonably large Ge(Li-drifted) detectors, so that for all the nuclei reported, both electron and high-resolution gamma-ray spectra were taken. This has permitted us to assign multipolarities to the observed transitions, and thus to establish our partial level schemes with considerably greater certainty.

2. Experimental

Self-supporting metallic foils of ^{165}Ho, ^{169}Tm, ^{175}Lu, and ^{181}Ta, 1-5 mg/cm^2 thick, provided the targets used in this work; and were bombarded by 10^{-3}–10^{-1} μA beams of ^{11}B, ^{14}N, or ^{19}F accelerated by the Lawrence Radiation Laboratory Hilac. The beam energies were measured using a solid-state counter and are expected to be accurate to about 2%. The Hilac is a pulsed machine, producing 3 msec beam bursts 15 times per second (subsequent modifications have made much larger duty cycles available). The presently reported data on the prompt de-excitation of the final nuclei are, of course, taken during the 3 msec beam burst. However the targets were also observed in the interval between beam pulses, and two metastable states thus observed during the course of this work have been reported elsewhere$^{5)}$. For each product nucleus studied, electron spectra were taken at three or four projectile energies 5-10 MeV apart (centered around the expected optimum energy). This limited excitation function enabled us to group the conversion lines by nuclide, and also established the optimum bombarding energy for that particular product nucleus.

The operation of the single-gap wedge-type electron spectrometer was unchanged from the previous studies. Momentum resolutions of ~0.6% were usually employed. The Ge detector (6 cm^2 in area by 0.8 cm deep) was usually placed about 2-3 cm from the target, and some absorber was generally used to reduce the x-ray counting rate. The full width of the ^{137}Cs 662-keV peak at half-maximum height was about 5 keV. Both the electron and gamma-ray spectra gave energies accurate to about ±0.3%, and the agreement between the two methods was normally quite good. The final averaged energies are estimated to be accurate to ±0.25%.

Both the electrons and the gamma rays were observed at reasonably well-defined angles of 90° with respect to the beam. Since there are known to be sizeable angular anisotropies of the radiations emitted following heavy-ion reactions, our relative intensities will not be quite correct; and, the conversion coefficients deduced by comparing the electron and gamma-ray spectra of a given product nucleus will contain this error. However, even though the angular effects are rather large, the cascading rotational transitions are normally found to be affected in much the same way; so that by normalizing the electron and gamma-ray spectra with one of these (as E2), the error in the other conversion coefficients would not exceed 10%. The uncertainty can be greater for other transitions, however. Non-rotational E2 transitions would also normally be affected by less than 10%, M1 transitions (or M1-E2 mixtures) by as much as 25%, and E1 transitions could have apparent conversion coefficients almost a factor of two different from the correct value. Thus errors in assignment are not likely, but could possibly occur with E1 transitions.

3. Results

The electron and gamma-ray spectra of ^{178}Os, ^{188}Pt, and ^{190}Hg are shown in figs. 1, 2, and 3, as more or less typical of the group. In general we found here, as in the previous work, that the cleanest spectra are associated with those reactions in which the fewest neutrons are emitted. The assignment of the lines to a given element could be immediately proposed according to the simple rule that charged particles are not emitted (at these excitation energies and distances from beta-stability) in sufficient intensity so that their product nuclei can give rise to strong lines. For most of the low-energy transitions the K- to L-conversion line separation could be measured sufficiently accurately to confirm this. The mass assignments could be rather unambiguously made from the very regular behavior of the excitation functions. Thus in both this and the previous work, using the β-stable, odd Z, even N targets, the optimum (best peak to background ratio) bombarding energy was within about 5 MeV of the following values: (^{11}B,4n), 55 MeV; (^{11}B,6n), 85 MeV; (^{14}N,5n), 93 MeV; (^{19}F,6n), 120 MeV. In many cases cross checks were possible, where a given product was made by two or even three reactions.

In each nucleus the K/L ratio of one of the two lowest cascade transitions could be measured with sufficient accuracy to identify it unambiguously as E2. This transition then served as the basis for normalizing the gamma-ray and electron spectra, so that multipolarities for all the transitions seen in both spectra could be deduced. The only reservation here has to do with the angular effects previously mentioned.

Almost all the intense lower-energy transitions were found to be E2, to behave very regularly in their energy spacings, and to decrease monotonically (but sometimes not very regularly) in intensity with increasing energy. In the deformed nuclei these transitions undoubtedly comprise the ground-state rotational band, and in the nondeformed nuclei, they define a "quasirotational" band, which, in the harmonic oscillator limit, would become just the highest-spin member of each vibrational multiplet. In this work we have been primarily interested in these transitions, and they are summarized in table 1. The classification, A or B, following the energy indicates a confidence of 95 or 75%, respectively, in the assignment of the transition to the (quasi) rotational sequence. We have also listed in table 1 the relative intensities of the transitions in each nucleus. These are expected to be accurate to about 20%.

Although spin determinations are in general absent, they were made in two cases up through the 8+ state. These cases were the 106 neutron nuclei, ^{182}Os, and ^{184}Pt, where weakly-populated 8- isomers exist with half-lives around one millisecond. These isomers, discussed in detail elsewhere$^{5)}$, de-excite predominantly to the 8+ member of the ground-state rotational band, and then on down the ground-state band. Angular distribution measurements established reasonably unambiguously the spin sequence in the isomers, and the ground-state rotational band transitions thus identified in the isomers coincided with the first four strong E2 transitions observed in the prompt in-beam spectra of these nuclei. Thus, in at least these two cases, the expected spin sequence can be considered independently established up through the 8+ state.

In the group of nuclei reported here, the occurrence of prominent nonrotational-band transitions was much more frequent than in the previously-studied group of Yb, Hf, and W nuclei. Some of these transitions have been summarized in table 2, together with their intensities and probable multipolarities. These intensities will be in error if the angular distribution of the gamma rays differs from that of the rotational transitions; and, as mentioned earlier, it is possible that an E1 transition could be misassigned (as E2). This list is by no means complete; only a few of the most intense transitions whose mass assignments are unambiguous have been included.

One case requires special comment. In ^{184}Pt it is difficult to decide whether the 497-keV transition belongs in the rotational cascade (12 → 10) or not. It has been included there because: 1) it is E2, and of sufficient intensity to make placement elsewhere difficult, and 2) the angular distribution of the line was that expected for a rotational transition (as were those of the other assigned ^{184}Pt rotational lines). However, it gives somewhat unusual rotational spacings for ^{184}Pt, and appears weaker, though within experimental error, than the 521 keV line. This assignment and the higher ones in ^{184}Pt, are given B rather than A classifications in table 1 due to this uncertainty.

4. Discussion

4.1. POPULATION OF LEVELS

One of the reasonably clear results of this study is that we could generally not identify states of so high a spin in these transition- and vibrational-region nuclei as in the previous study of rotational nuclei. This is most apparent in the mercury isotopes, where spins no higher than six could be found. At least in the case of ^{190}Hg, the spectra are reasonably good, and it is clear (fig. 3) that the higher transitions are not simply obscured. Since we are able to identify a state only if it is populated heavily (at least 10-20% of the time), the above result says only that whereas the high-spin (14-20) rotational states do receive this much population in regions of well-deformed nuclei, no single high-spin state receives this much population in the vibrational nuclei.

It seems likely to us that this change is due to the rather dramatically different level structure of the vibrational nuclei rather than to any sudden change in the reaction mechanism. One obvious explanation for not observing higher-spin states would be that the appropriate collective states simply do not exist. It is clear that the 8+ vibrational state in ^{190}Hg (estimated to be at 2.5 MeV) is well above the energy gap and hence lies in a region where there are likely to be two-quasiparticle states having spins as high as 8 or 10. Under such conditions the collective character may be spread over a number of states, no one of which receives enough population to be observed. A second related explanation might be that although these collective states exist the fact that they lie at energies as high as or higher than two quasiparticle states of the same spin makes them no longer the uniquely favored pathway to the ground state. This second explanation would imply that the collective levels are favored only because they lie at lower energies than the quasiparticle states of the same spin. Thus in the deformed region where the 8+ rotational state (at ~1 MeV) lies well below the gap, it is heavily populated; and, in fact, here the two quasiparticle states, with a maximum spin of 8 or 10, lie well above the rotational states of the same spin and hence the rotational-band population is not cut off at the gap energy (~1.5 MeV). Our knowledge of the four- and higher-quasiparticle states is not good enough to decide if this kind of argument can explain the onset of heavy population in the rotational band at about spin 16 or 18, but it seems possible.

There may be other important factors, however, which are not considered in the above discussion. For instance, K, the projection of the spin along the nuclear symmetry axis, probably becomes a good quantum number near the end of the cascade, and might then have an appreciable effect on the distribution of population. Or the detailed nature of the states initially populated in the final nucleus (or possibly in the compound nucleus) might play important roles. Thus we have to conclude that we do not yet have enough information to establish even the most important causes of the observed populations. It is clear that more direct experimental information is needed on the kind of levels feeding the ground band.

The case of ^{182}Os seems to be sufficiently unusual to warrant special mention. Here the 10+ member of the ground band receives heavy population (44% of the 2+ level), whereas the 12+ member, if it lies at all near the expected energy, is no more than one tenth so heavily populated. This, in itself, might not be so unusual if there were some unique pathway by which the 10+ level is fed. However, neither a single nor even a few transitions of sufficient intensity to feed the 10+ level can be found. It thus seems that the evidence suggests a number of pathways feeding the 10+ level but essentially none feeding the 12+ level. It is not easy to understand why this should be the case. An added, but seemingly unrelated, complication is a weakly-fed 8- isomeric state at about the same energy as the 10+ rotational level.

4.2. ENERGY-LEVEL SYSTEMATICS

In previous works^{1}) the rotational levels of a number of well-deformed nuclei in the rare-earth region have been studied as populated following heavy-ion nuclear reactions. Rotational levels as high as spin 16 or 18 were identified reasonably unambiguously, and the spacings of these levels were best accounted for in terms of centrifugal stretching of the rotating nuclei. In particular the experimental results were compared with the calculations of centrifugal stretching made by Davydov and Chaban^{6}). Subsequent careful comparison in several cases$^{7-10}$) of the properties of the beta vibrational (0+) band with those calculated using this model has shown that whereas the energy of the band and its relative E2 transition probabilities to the ground band are reasonably well given, the absolute E2 transition probabilities to the ground band are calculated to be as much as an order of magnitude too high. There can be reasons why these E2 rates would be lowered (mixing of the beta band with nearby bands), but the large discrepancy observed may indicate a behavior more complicated than centrifugal stretching. It should now be possible to measure directly the quadrupole moments of the higher rotational states in Coulomb excitation studies, and thus provide an unambiguous answer to this question.

The present data will not be compared quantitatively with the Davydov-Chaban theory because 1) the use there of simple parabolic potentials must fail, we feel, as the vibrational region is approached, and 2) it is clear that in the Os-Pt region a large dynamic variation of the γ-coordinate is very important and is not treated adequately by Davydov and Chaban. A previous suggestion^{11}) of using potentials from the Swiatecki-Myers mass formula considers only the deformation, β, and therefore would probably also be inadequate in this

Pt-Os region for reason 2) above, and in addition because, at least for the low-spin states, a quantum-mechanical treatment becomes necessary as the vibrational region is approached. To get meaningful results here it seems one must go to the method of Kumar and Baranger[12)], who solve numerically the full Bohr Hamiltonian for any potential (and also any values for the six inertial functions). The present data will, therefore, be discussed qualitatively rather than compared quantitatively with theoretical calculations.

In fig. 4 we have plotted the rotational constant, $A_I = (E_I - E_{I-2})/(4I-2)$, versus the spin, I, of the upper rotational level. As in previous analyses[1)], A_I is defined from the transition energy rather than the rotational state energy. A few nuclei besides those of the present study have been included for comparison in fig. 4. The previously-studied group of nine rotational nuclei has, for the sake of clarity, not been included in fig. 4; however, perhaps the most striking feature exhibited by those nuclei on a plot such as this is the tendency of the lines to converge (i.e., the rotational spacings to become similar) at the higher spins. The open circles in fig. 4 represent average A_I values around which these nine rotational nuclei cluster. It seems clear that six of the presently-studied nuclei also converge reasonably well, and to very nearly the same (broad) line as the previous set of nuclei. It is obviously the more vibrational nuclei that do not converge to this line.

If we examine particularly the osmium nuclei, then it is apparent from fig. 4 that the failure to converge to the "common" line occurs (probably gradually) between ^{182}Os and ^{190}Os. It is well-known[13,14)] that in just these osmium nuclei the gamma-vibrational band drops very rapidly to become the second excited state in ^{192}Os at 489 keV. The question arises as to whether this may be connected with the failure to "converge" in fig. 4; and such a connection seems plausible. It is reasonably clear that all of the previously-studied group of nuclei have stable prolate deformations. Thus the convergence described above is a process (perhaps centrifugal stretching) which occurs as these prolate nuclei rotate. From the behavior of the γ vibrational band, however, the heavier Os nuclei very likely lose this preference for a prolate shape as neutrons are added, until the heaviest Os nuclei become γ-unstable or even possibly tri-axial.15) Rotation of a γ-unstable nucleus would hardly be expected to produce, at least initially, the same kind of effects as rotation of a prolate nucleus. Thus we might tentatively suggest that a failure to converge to the common line in fig. 4 may be associated with the loss of stability of the prolate shape. If so, this happens gradually in osmium between ^{184}Os and ^{190}Os (already suspected from the behavior of the gamma-vibrational band), but rather suddenly in platinum between ^{186}Pt and ^{188}Pt.

There is another nuclear property which one may be able to assess qualitatively from fig. 4. In a previous publication1) it was shown that there appears to be a close relationship in many rotational nuclei between the ratio of the energy of the 4+ state to that of the 2+ state (E_{4+}/E_{2+}) and the energy of the lowest 0+ state (beta-vibrational band head). In fact, the relationship is given approximately correctly by the Davydov-Chaban calculation6), and here simply reflects the fact that both these quantities depend on the width of the (parabolic in DC) potential energy curve. That is, the more nearly E_{4+}/E_{2+} approaches the perfect rotor value of 3.33, the less change is implied in β with increasing spin, and the steeper (or narrower) the potential energy curve must be. Clearly, the vibrational energy in this potential (beta-vibration) also increases as the potential becomes steeper. The slope of the first part of each line in fig. 4 is simply related to the ratio E_{4+}/E_{2+}, and even for these nuclei it may still represent some measure of the width of the potential energy curve; or, in different language, of how soft the nucleus is toward changes in deformation; although probably the quantitative relationship between these quantities derived by Davydov and Chaban would be poorer here than in the rotational nuclei. A look at fig. 4 then shows that all the platinum nuclei are initially very soft toward increasing deformation—about as soft, in fact, as any of the mercury nuclei. One thus wonders if any of the platinum nuclei have stable equilibrium deformations in their ground states; that is, sufficiently deep potentials to confine the nucleus with its zero-point vibrational energy, into a permanently-deformed shape. However, fig. 4 would suggest that ^{186,184,182}Pt have potentials preferring prolate shapes, and are rather quickly stretched out under rotation to be similar to the nuclei which started with (larger) stable prolate deformations. The osmium nuclei studied here have much flatter initial slopes than the platinum nuclei, and thus are presumably much stiffer toward changes in deformation.

Two comments can be made relevant to the previous paragraph. First, levels of a band which is very likely the beta-vibrational band have been seen$^{5)}$ in ^{184}Pt following the decay of an isomeric state. The energy of this band is rather close to that given by the Davydov-Chaban calculation based on the E_{4+}/E_{2+} ratio. Thus the relationship between E_{4+}/E_{2+} and the lowest 0+ state seems still to be holding up rather well there. Secondly, the large static quadrupole moment recently observed$^{16)}$ for the lowest 2+ level in the (vibrational) cadmium nuclei is consistent with the implication here that these "vibrational" nuclei are pulled out to deformed shapes under the influence of the angular-momentum-carrying collective motion. It will be of interest to see if these large static moments are characteristic of the "vibrational" nuclei in general.

In fig. 5 we have plotted the ratio, E_{4+}/E_{2+}, for a number of nuclei at both ends of the rare-earth region of deformed nuclei. In each plot the abcissa is the less-critical nucleon number: neutrons in the platinum region and protons in the samarium region. The plots are arranged so that the nearest closed shell in that nucleon number is to the right. Thus neutron numbers increase to the right in the platinum region; whereas proton numbers decrease to the right in the samarium region. In both plots, lines connect the points constant in the more critical nucleon number: protons in the platinum region and neutrons in the samarium region. In both plots solid points correspond to beta-stable nuclides. The horizontal alignment of the plots is somewhat arbitrary, but was chosen to align the highest osmium point with the highest 90-neutron point.

One of the main points to be made from these plots is that they are rather similar. The gap between 88- and 90-neutrons has long been recognized; however such a gap has not always been clearly recognized in the platinum region. On the basis of the E_{4+}/E_{2+} ratio, it appears that this is more an accident of the location of beta-stability (the readily studied nuclei) than it is a basic difference between the two regions. Thus, it is true that comparing 116-neutron nuclei in the platinum region with samarium isotopes (Z=62) one sees no large discontinuity in the former case, but a sharp one in the latter case; however, 110-neutron nuclei show at least as large a discontinuity in fig. 5 between osmium and platinum as do the samarium nuclei between 88- and 90-neutron. Furthermore the plot suggests that the 88-90 neutron discontinuity might well be largely washed out in cerium or barium nuclei (Z=58 or 56) as it is in 114- and 116-neutron nuclei; however, the nuclei to determine this are too far from beta-stability to be studied. In energy of first-excited state, we find: 416, 266, 137, and 111 keV for

^{190}Hg, ^{188}Pt, ^{186}Os, and ^{184}W, respectively; and 562, 337, 122, and 82 keV for ^{148}Sm, ^{150}Sm, ^{152}Sm, and ^{154}Sm respectively. There is a little but not very much evidence here to favor a greater gap at 88-90 neutrons. It seems plausible that proton number would be more critical for these neutron deficient nuclei in the Pt-Os region (Pt has four proton holes, whereas 110-neutron nuclei have 16 neutron holes); however, for the neutron excess nuclei, where the neutron number is much nearer the 126-neutron shell, the situation could be expected to be different. It is not our intention to argue for identical behavior in these two regions—there is no reason to suppose that the properties observed will not be affected by differences in such things as 1) the relative distances of proton and neutron shells and 2) the particular orbitals involved in each region. In fact, one can easily see differences such as the rather sharp rise in the E_{4+}/E_{2+} ratio with decreasing proton number along the 88-neutron line. No such rise is observed in the platinum isotopes, and only a slow rise in the mercury isotopes. Our point here is rather that there is very probably no great dissimilarity between these two regions when a sufficiently wide range of nuclei is studied in each region.

We can summarize our conclusions about the osmium-platinum region by reference to fig. 5(b). In the light tungsten and osmium nuclei (upper-left) we find stable prolate deformations. Moving to the right, the main change is the loss of stability of the prolate shape (heavy osmiums); whereas the equilibrium deformation, though becoming smaller, is probably stable for all these nuclei. The result, gamma-unstable (or possibly tri-axial) nuclei, has been previously suggested^{15}), and is recognized by the low second 2+ state. We add here only that the failure to converge to the "common" line in fig. 4 may also signal this change. The heavy mercury and platinum nuclei (lower-right) are the typical "vibrators", having no stable deformation (at least in their ground states) and no preference for a prolate shape. Moving to the left, we find the light platinum isotopes ($N \lesssim 108$) very likely do prefer the prolate shape, but may well not have stable deformations in their ground states (E_4/E_2 remains low). This is to say that the potential at larger deformations has a minimum for prolate shapes much like that of the light osmium or tungsten nuclei, but the central bump (at the spherical shape) may be so small that in the ground state the zero-point vibration carries over it. Restated in terms of the potential we would conclude that in moving out of the deformed region the barrier in the gamma direction is a function of both proton and neutron number (the latter being more apparent); whereas the deformation (controlled by the central bump in the potential) is mainly a function proton number; and, in fact, changes dramatically between osmium and platinum over most of the region for which there is information.

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Figure Captions

Fig. 1. Conversion electron (a) and gamma ray (b) spectra of ^{178}Os observed following the ^{169}Tm(^{14}N,5n)^{178}Os reaction at 93 MeV bombarding energy.

Fig. 2. Conversion electron (a) and gamma ray (b) spectra of ^{188}Pt observed following the ^{181}Ta(^{11}B,4n)^{188}Pt reaction at 56 MeV bombarding energy.

Fig. 3. Conversion electron (a) and gamma ray (b) spectra of ^{190}Hg observed following the ^{181}Ta(^{14}N,5n)^{190}Hg reaction at 93 MeV bombarding energy.

Fig. 4. Rotational constants, A_I, defined from the transition energies, plotted against the spin of the upper level, I. The solid lines are for osmium nuclei, the dashed lines for platinum nuclei, and the dotted lines for mercury nuclei. The open circles are the average A_I values from the previously-studied rotational nuclei.

Fig. 5. The ratio of the energy of the lowest 4+ state to that of the lowest 2+ state is plotted (a) against proton number in the samarium region with lines connecting nuclei of constant neutron number, and (b) against neutron number in the platinum region with lines connecting nuclei of constant proton number. The solid points represent β-stable nuclei.

Table 1

Ground-state (quasi-) rotational band transitions

Transition (rel. inten.)	^{178}Os	^{180}Os	^{182}Os	^{182}Pt	^{184}Pt	^{186}Pt	^{188}Pt	^{188}Hg	^{190}Hg
2 → 0	131.6 A (100)	132.2 A (100)	126.9 A (100)	153.7 A (b)	162.1 A (100)	191.1 A (100)	265.9 A (100)	412.6 A (100)	416.4 A (100)
4 → 2	266.1 A (94)	276.3 A (88)	273.3 A (92)	262.5 A	272.7 A (87)	298.5 A (98)	405.4 A (84)	489.9 A (84)	625.1 A (108)
6 → 4	363.1 A (89)	386.6 A (74)	393.7 A (70)	355.2 A	362.5 A (66)	387.2 A (65)	513.3 A (53)		730.2 A (91)
8 → 6	432.9 A (79)	462.2 A (72)	483.0 A (63)	431.0 A	431.6 A (58)	464.3 A (51)	597.7 B (27)		
10 → 8	488.0 A (43)	510.2 A (42)	532.7 A (44)	493 B	475.8 A (55)	514.6 A (43)	654.0 B (18)		
12 → 10	536.8 B (28)	541.0 A (34)		543 B	496.6 B (43)	551 B (9)			
14 → 12		566.4 B (25)			521.5 B (47)				
16 → 14					554 B (29)				

[a] Energies are expected to be accurate to ±0.25% and intensities to ~20%.

[b] This spectrum was not sufficiently clean to give intensities accurate to 20%.

Table 2

Prominent non-rotational transitions

Nucleus	Energy	Intensity[a]	Probable multipolarity
^{178}Os	623	45	E2
^{180}Os	365	35	E1
	618	30	E1
	643	17	M1
^{182}Os	493	15	E2
^{186}Pt	477	37	E2
	489	21	E2
^{188}Pt	412	11	M1
	417	18	E2
	582	20	E1
	892	27	E1
^{190}Hg	661	30	E2

[a] Relative to the intensities of Table 1.

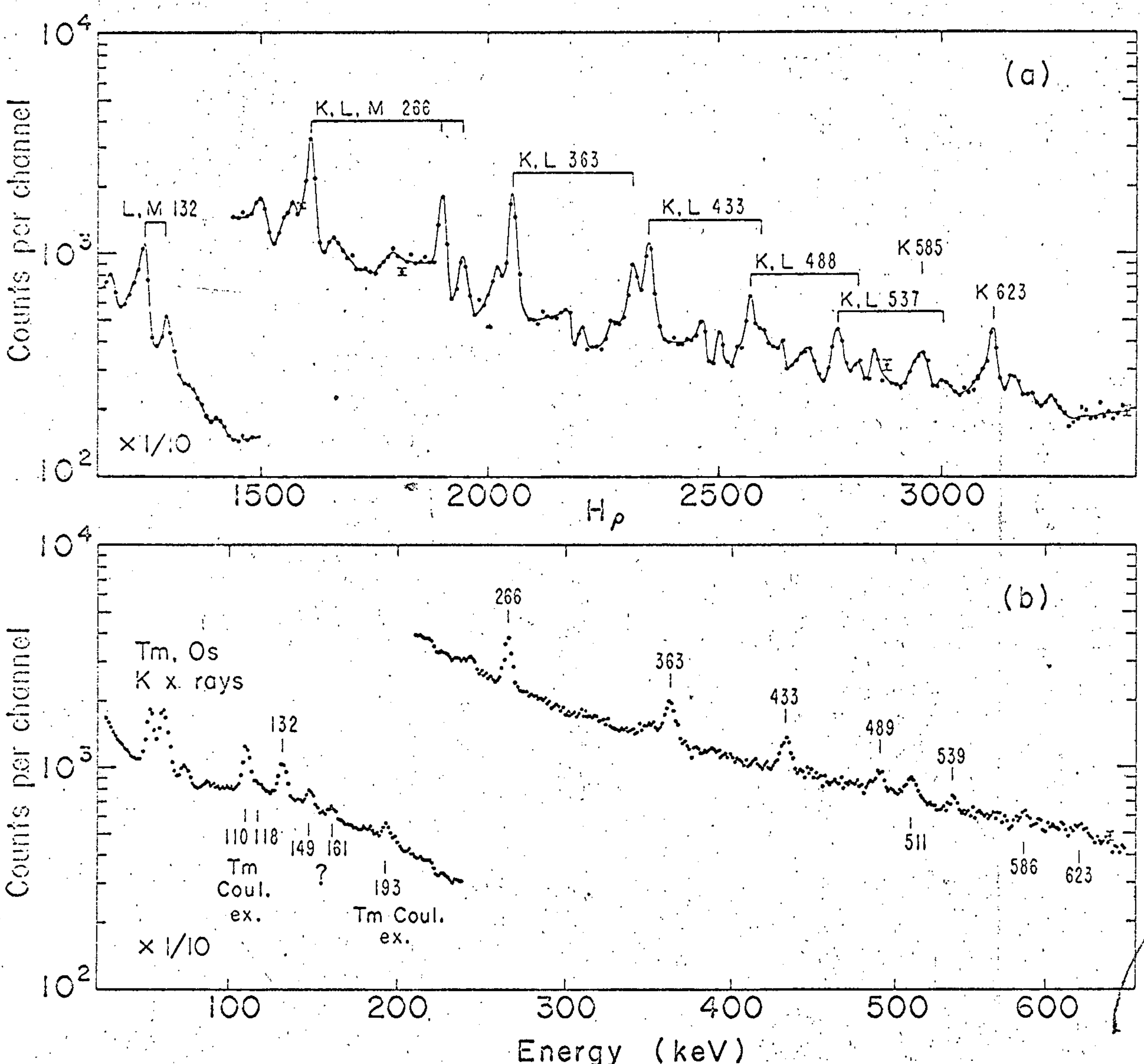
(a)
Counts per channel
10^4
10^3
10^2
L, M 132
K, L, M 266
K, L 363
K, L 433
K, L 488
K, L 537
K 585
K 623
× 1/10
1500
2000
2500
3000
Hρ
(b)
Counts per channel
10^4
10^3
10^2
Tm, Os
K x rays
132
110
118
Tm
Coul.
ex.
149
161
?
193
Tm Coul.
ex.
× 1/10
266
363
433
489
539
511
586
623
100
200
300
400
500
600
Energy (keV)

Fig. 1

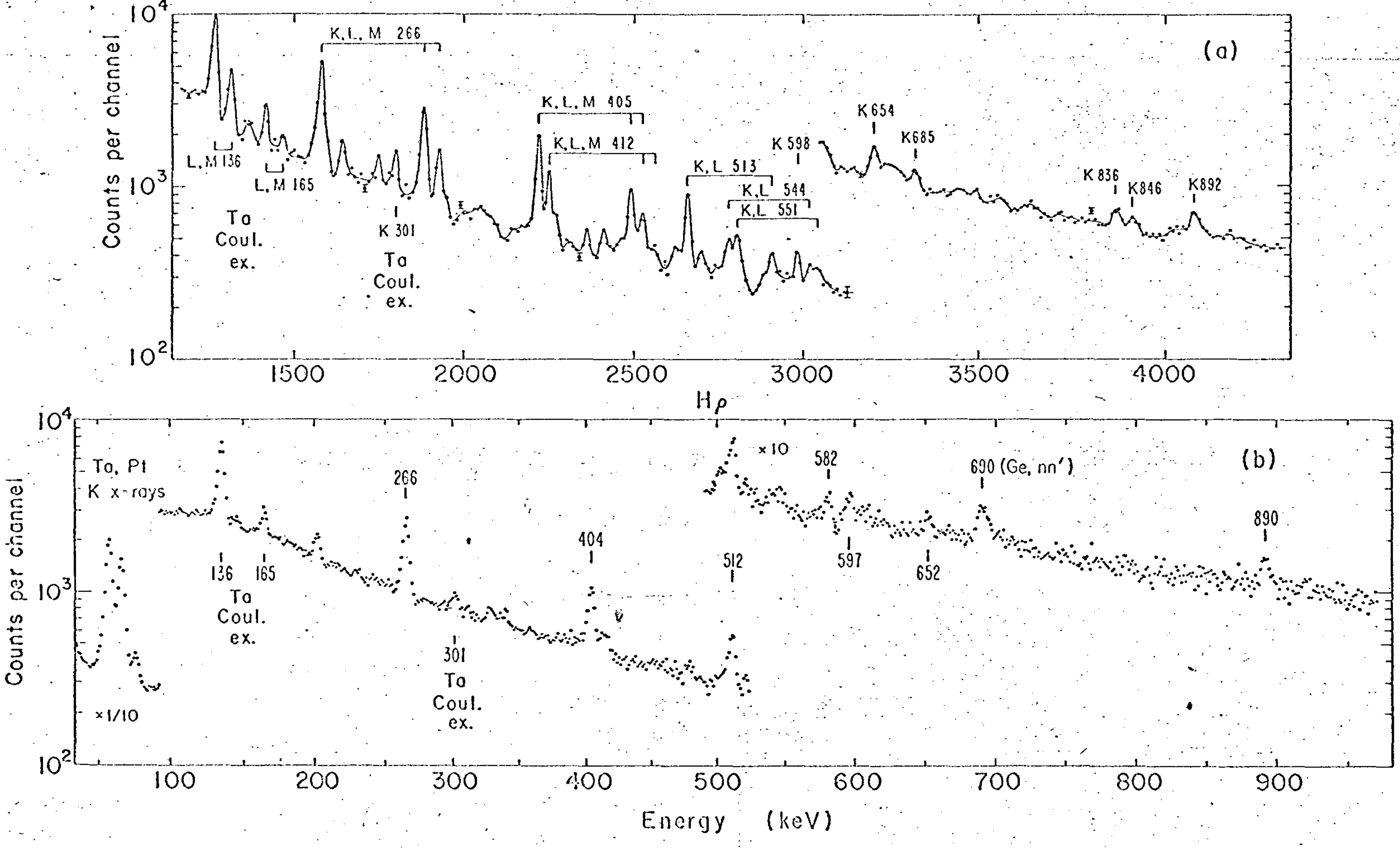
(a)
Counts per channel
10^4
10^3
10^2
L, M 136
L, M 165
Ta Coul. ex.
K, L, M 266
K 301
Ta Coul. ex.
K, L, M 405
K, L, M 412
K, L 513
K 598
K, L 544
K, L 551
K 654
K 685
K 836
K 846
K 892
1500
2000
2500
3000
3500
4000
Hρ
(b)
Counts per channel
10^4
10^3
10^2
Ta, Pt K x-rays
×1/10
136
165
Ta Coul. ex.
266
301
Ta Coul. ex.
404
512
×10
582
597
652
690 (Ge, nn')
890
100
200
300
400
500
600
700
800
900
Energy (keV)

Fig. 2

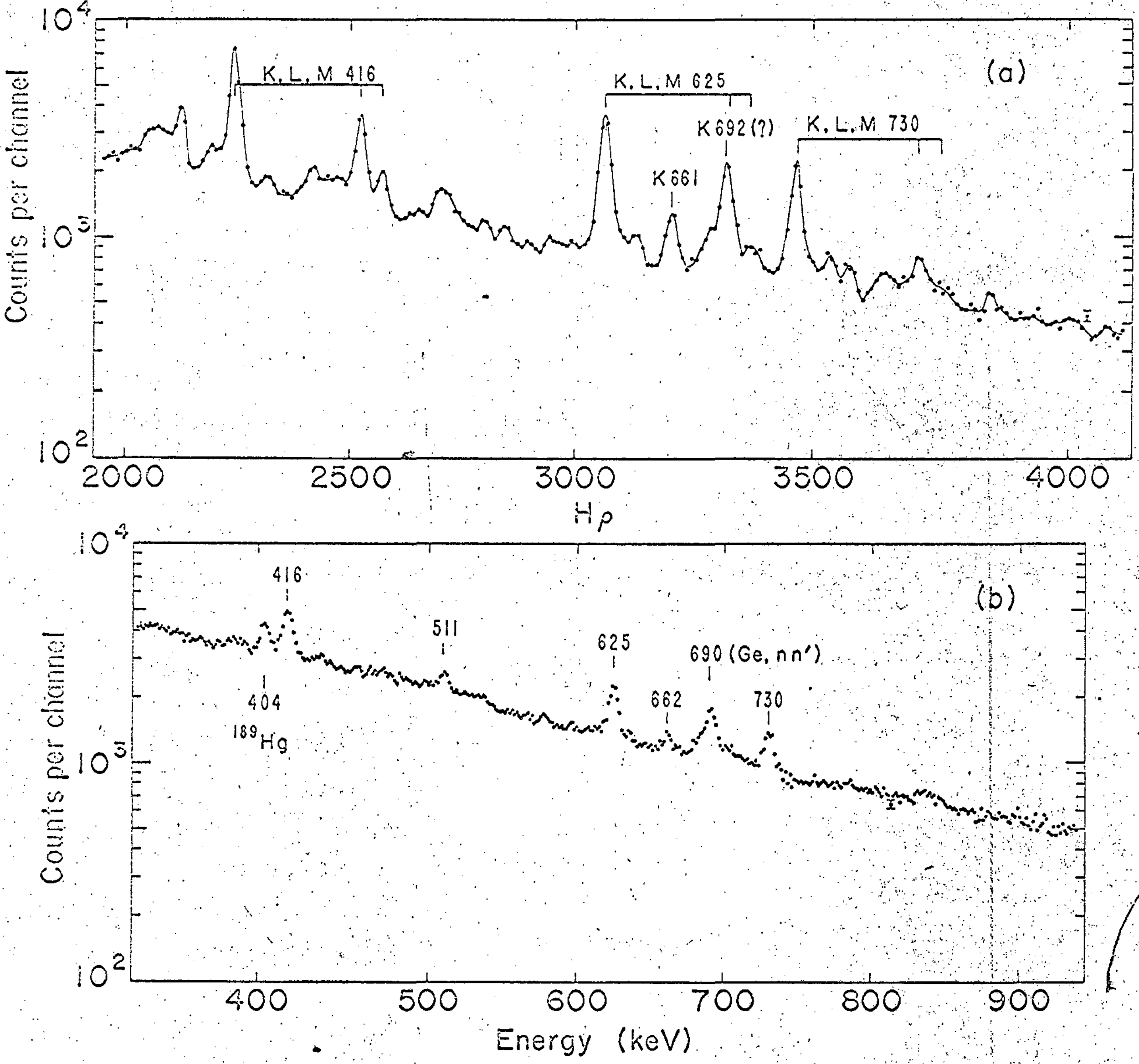
(a)
Counts per channel
10^4
10^3
10^2
K, L, M 416
K, L, M 625
K 692 (?)
K 661
K, L, M 730
2000
2500
3000
3500
4000
Hρ
(b)
Counts per channel
10^4
10^3
10^2
416
404
189Hg
511
625
662
690 (Ge, nn′)
730
400
500
600
700
800
900
Energy (keV)

Fig. 3

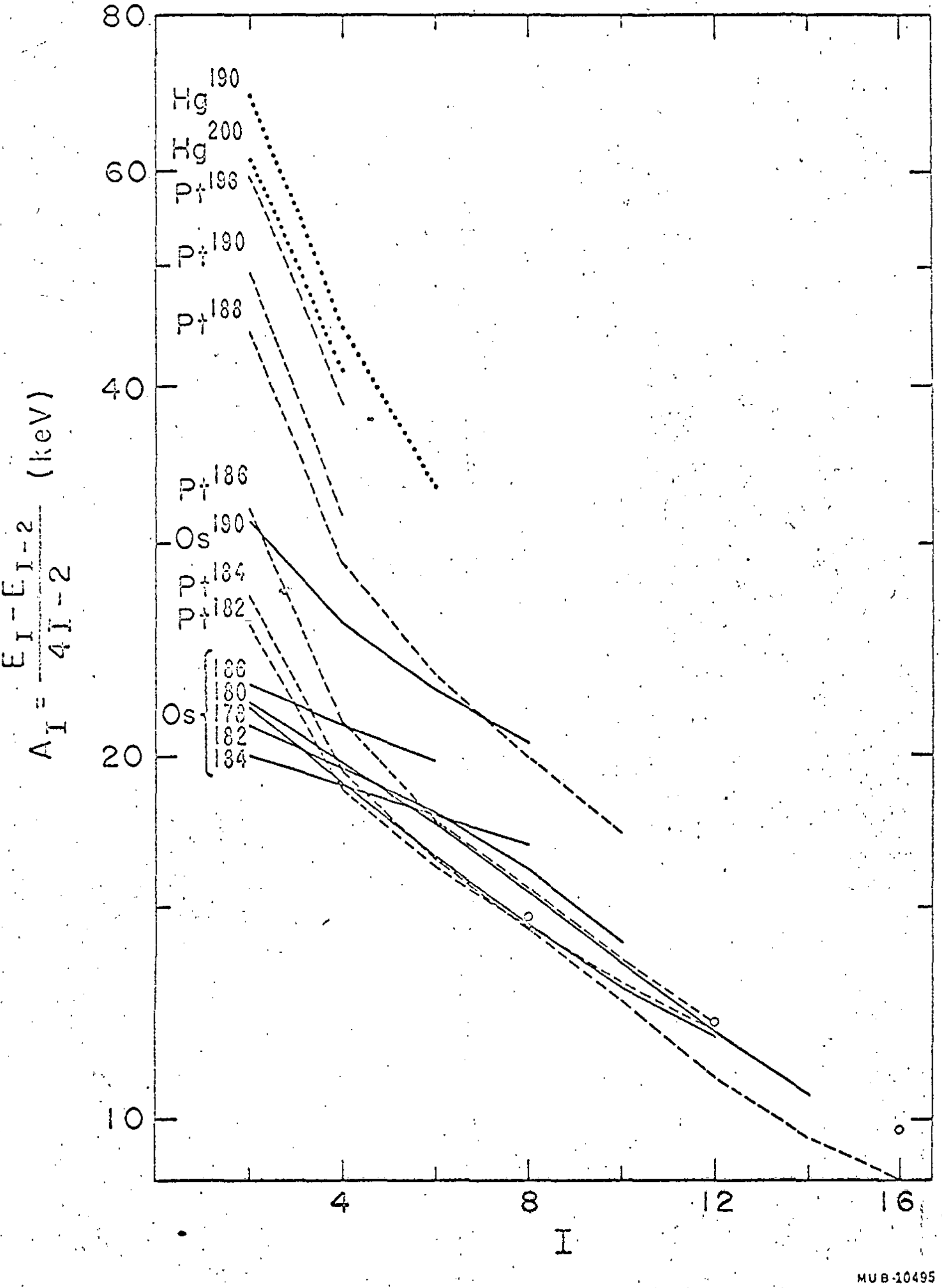
80
60
40
20
10
$A_I = \frac{E_I - E_{I-2}}{4I-2}$ (keV)
Hg190
Hg200
Pt196
Pt190
Pt188
Pt186
Os190
Pt184
Pt182
Os 186 180 178 182 184
4
8
12
16
I
MUB-10495

Fig. 4

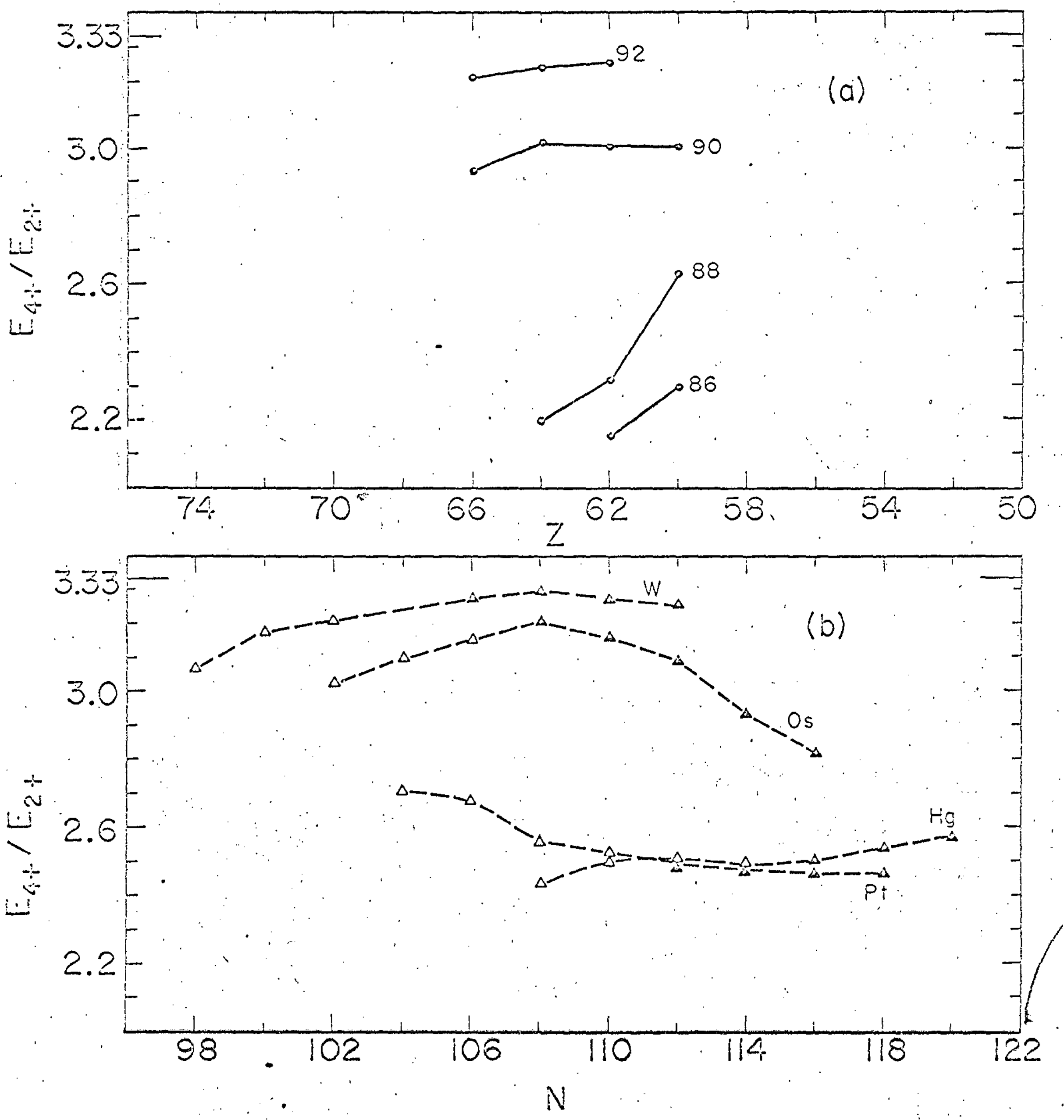
(a)
(b)
E_{4+}/E_{2+}
3.33
3.0
2.6
2.2
92
90
88
86
74
70
66
62
58
54
50
Z
W
Os
Hg
Pt
98
102
106
110
114
118
122
N
MUB-9206

Fig. 5