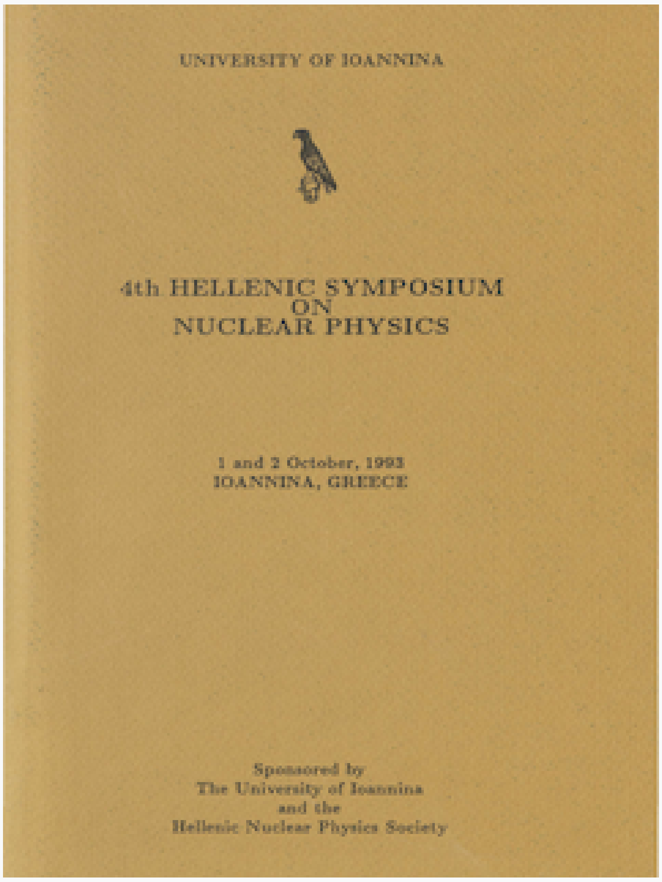
HNPS Advances in Nuclear Physics

Vol 4 (1993)

HNPS1993



High Spin States in 193Hg

N. Fotiades, - et al.

doi: 10.12681/hnps.2883

High Spin States in ^{193}Hg*

N.FOTIADES, S.HARISSOPULOS, C.A.KALFAS and E.KOSSIONIDES
Inst.of Nuclear Physics, NCSR Demokritos, 15310 Athens, Greece

C.T.PAPADOPOULOS, R.VLASTOU and M.SERRIS
National Technical University of Athens, 15773 Athens, Greece

J.F.SHARPEY-SCHAFER, M.J.JOYCE, C.W.BEAUSANG, P.J.DAGNALL, P.D.FORSYTH, S.J.GALE, P.M.JONES, E.S.PAUL, P.J.TWIN, D.M.CULLEN†, P.FALLON‡ and M.A.RILEY§
Oliver Lodge Lab., Univ. of Liverpool, Liverpool L69 3BX, U. K.

J. SIMPSON
Daresbury Lab., Warrington WA4 4AD, U. K.

Abstract

The high-spin structure of ^{193}Hg was investigated by in-beam γ-ray spectroscopic techniques. The tandem accelerator at Daresbury Laboratory, U. K., was used to populate excited states of ^{193}Hg through the reaction ^{150}Nd (^{48}Ca,5n) ^{193}Hg at a beam energy of 213 MeV and the EUROGAM detector array was used to detect the γ-rays emitted by the deexciting nuclei. The normal level scheme has been further extended and a new band has been observed. In addition two new $\Delta I = 1$ structures of competing dipole and quadrupole transitions were found which will be discussed in detail.

I. Introduction

The Hg isotopes exhibit small oblate deformations near their ground states with typical values $\epsilon_2 \sim 0.15$, $\gamma = -60°$ (Lund convention) and hence they are proved to be an excellent testing ground for comparison between cranked shell model(CSM) calculations and experimental results in oblate rotating systems [1].

The discovery of superdeformation in this region and the continuing research for additional superdeformed (SD) bands has led in the collection of extensive γ-γ coincidence data for these isotopes. At the same time these data were used in order to extend the normal decay scheme of these isotopes as far as possible, for the better the normal decay scheme is known the easier the search for connections of the SD

* Presented by N. Fotiades
† Present address: Oak Ridge National Laboratory, Oak Ridge, Tennessee 37831, U.S.A.
‡ Present address: Lawrence Berkeley Lab., 1 Cyclotron Road, Berkeley, CA 94720, U.S.A.
§ Present address: Florida State University, Tallahassee, Florida, FL 32306, U.S.A.

bands with the low lying yrast levels will be. The analysis of these data revealed the variety of shapes that can coexist in these nuclei which is in agreement with theoretical studies that suggest that these nuclei are rather 'γ - soft' [2].

Recently in the neighboring to the Hg isotopes neutron-deficient Pb nuclei reports on collective rotational $\Delta I = 1$ structures have been made [3,4,5,6]. These structures include dipole transitions which compete favourably with quadrupole crossover ones. The converion coefficients calculated for the dipole transitions suggest that they are of M1 nature and the B(M1)/B(E2) ratio which varies from 20 $\mu^2/(eb)^2$ to 40 $\mu^2/(eb)^2$ indicates how stronger the M1 transitions are in comparison to the respective crossover E2 transitions. The decay-out of these structures is in the majority of cases unknown and the excitation energy of their bandheads is roughly approximated between 5 MeV and 7 MeV. A similar $\Delta I = 1$ structure has been observed also in the neighbouring ^{202}Bi isotope [7] and recently the first collective $\Delta I = 1$ structure in the mercury isotopes was reported in ^{193}Hg [8].

The first shape change from oblate collective γ = -60° to prolate non-collective γ = -120° in the Hg isotopes was established in the case of ^{191}Hg [9]. Recently a similar non-collective $\Delta I = 1$ structure was reported in ^{193}Hg [10,11]. This very structure was the same to the one reported in ref. [8] as collective in origin but in contrast to this latter work it was proven here to be a single-particle structure. This $\Delta I = 1$ sequence is observed also in this work. Judging from our data we think that the single-particle scenario is more likely true but a tendancy to collective motion can be suggested in the upper part of this structure especially in our work where this part is observed with four transitions more.

In this work we report on the extension of the previously known normal decay scheme of the ^{193}Hg isotope. Moreover we report on two $\Delta I = 1$ new sequences of competing dipole and quadrupole transitions without being yet able to identify the lines which connect this sequences with the normal decay scheme.

II. Experimental Procedure

The reaction ^{150}Nd (^{48}Ca,5n) ^{193}Hg was used to populate high spin states of ^{193}Hg at beam energy E(^{48}Ca) = 213 MeV. The 20 MV tandem Van de Graff accelerator at the Nuclear Structure Facility at Daresbury , U.K., was used to attain this beam energy. The target consisted of two stacked self-supporting foils of isotopically enriched ^{150}Nd of 500 μg/cm^2 thickness each. Gamma-rays of the reaction were detected using the EUROGAM detector array which consisted at the time of the experiment (first phase of EUROGAM) of 44 large n-type hyperpure Ge detectors, each one surrounded by a BGO escape suppression shield. These detectors have a resolution of 2.1 KeV (for 1.33 MeV γ-rays), a relative efficiency of 75%, and are placed in a 4π geometry around the target (the angles of detectors available in this phase were 72°/108° , 86°/94° , 134° and 158°).

A Faraday cup placed at ~2m downstream from the target was used to stop the beam. Assuming a recoil velocity β of ~2% and a recoil cone of ~5° one estimates that the ^{193}Hg recoiling nuclei escape the sensitive detection volume in a few ns. This fact rendered impossible the detection of delayed γ-rays emanating from the decay of isomeric states characterized by lifetimes much longer than a few ns. Nevertheless a total of approximately 10^9 coincident events, of fold five or higher, were collected and stored on magnetic tapes for subsequent off-line analysis. The events were gain matched and stored into two two-dimensional 4096×4096 channel matrices. The first matrix, which was symmetrized, was used for analysis of coincidence relationships while the second one was especially built to establish the directional correlations of the γ-rays (DCO ratios).

The normal decay scheme of ^{193}Hg extracted from the analysis of the data is presented in Fig. 1. The two new ΔI = *1* structures are seen in Fig. 2. The first ΔI = *1* structure established in ^{193}Hg is presented in Fig. 3 as it was observed in this work.

III. Normal decay scheme of ^{193}Hg

The normal decay scheme of ^{193}Hg was extensively investigated primary by Hübel et al. [1]. In that work eight bands of this isotope had been identified up to 5758 keV level excitation. Recent works [8,10,11] enriched the level scheme with many sidefeeding and linking transitions between these bands but the upper energy level remained the same [1] and no new band was found. In our work the normal decay scheme is extended up to 7336 keV and a new band is reported as it will be explained analytically further below. The new transitions are reported beginning from the far left band (ABCEF) in the normal decay scheme and continuing to the right with the rest of the bands.

The band ABCEF was previously known with its first two transitions up to 3980 keV (spin $41/2^+$). Two new lines (769.4 keV and 808.2 keV) form the continuation of this band up to the 5557 keV level (spin $49/2^+$). A 843.5 keV transition which feeds the 3980 keV level is also established and since the analysis of DCO ratios supports a dipole character for this line the level above this line is assigned as 43/2.

Next to this band lies a totally new band which consists of three transitions (564.1 keV, 677.9 keV and 801.9 keV) and deexcites through the 943.5 keV and 549.5 keV lines towards the neighbouring ABC and ABCEF bands correspondingly. It is the second time that such a band is observed in the Hg isotopes. The first one to be observed was in ^{191}Hg in the work by Ye et al. [9]. It was named band ABCEF′, (π,α) = (+,1/2), and after comparison with theoretical total routhian surface (TRS) calculations the $(\nu i_{13/2})^3(\nu p_{3/2})(\nu h_{9/2})$ configuration was considered the most propable for this band. The two bands exhibit many similarities. They decay towards the same neighbouring bands ABC and ABCEF and they have the

[1] An extension to a 6397 keV level is present in the ref. [11] but since the results of our work disagree with this extension we consider the first lower-lying level from the 6397 keV level as the higher one and this happens to be again the 5758 keV level.

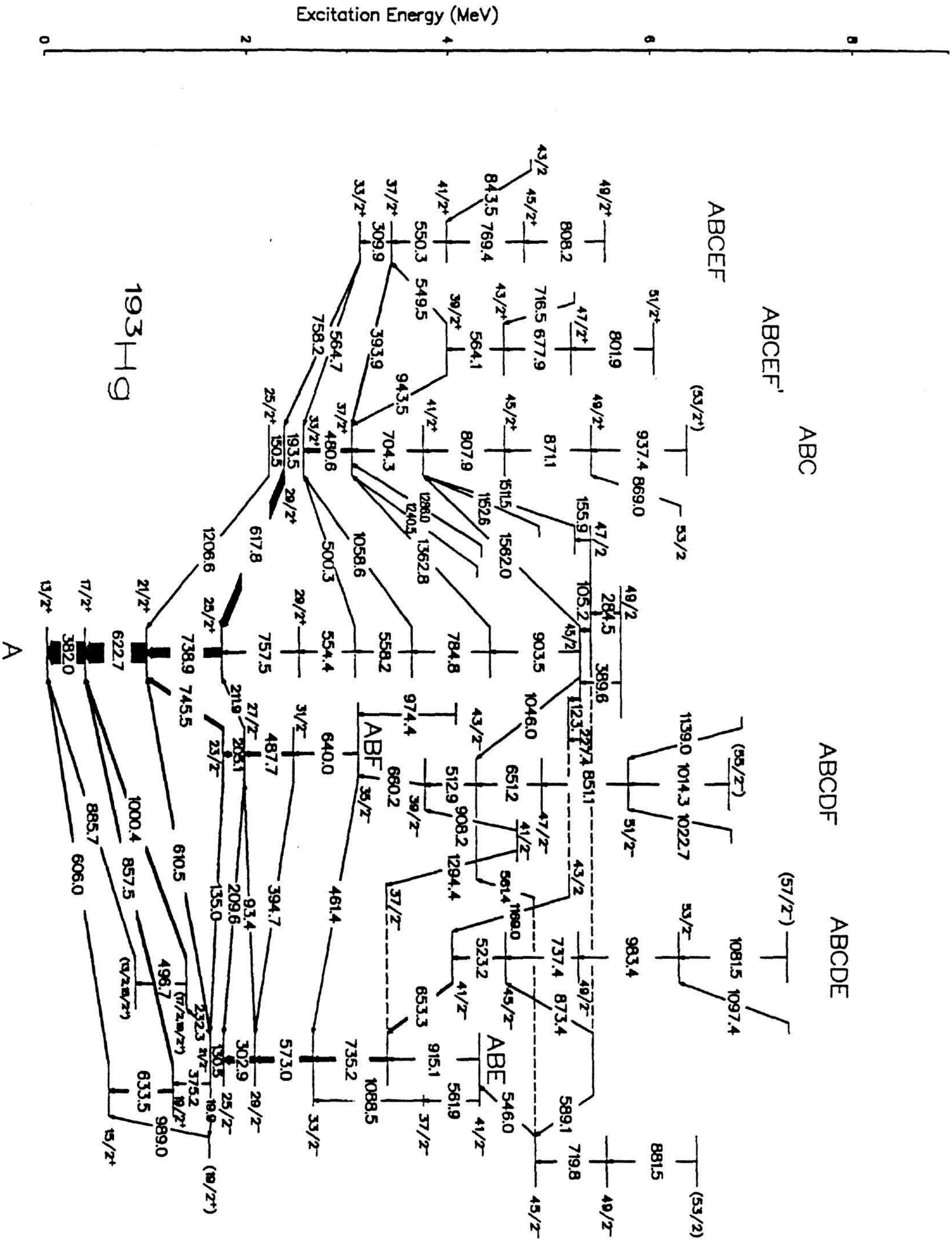


Fig. 1: *Normal decay scheme of* ^{193}Hg

same alignment, around 20 $\hbar$. This can be seen in Fig. 4 where the alignments of these bands together with the alignments of the neighbouring ones are present for isotopes ^{191}Hg and ^{193}Hg. These similarities speak for the same configuration being responsible for the two bands in these isotopes and for this reason the name ABCEF′ is used to characterize the new band in the ^{193}Hg isotope.

The ABC band has been extended both in its lower and upper parts. The continuation of this band before the BC alignment is the 150.5 keV transition and deexcitation towards band A takes place through 1206.6 keV line. Of course these two lines are very weak since the bulk of the intensity of the $29/2^+$ level is taken away by the 617.8 keV transition during the alignment leaving only a few percent of the intensity for these two lines. In the upper part a 871.1 keV line is present instead of the previous 868.8 keV [1,8,10,11] since the 871.1 keV line together with the 869.0 keV form a doublet in all gated spectra except in the gate of the 937.4 keV line where only the 871.1 keV transition is seen. The 937.4 keV line is the most possible continuation of this band while the 869.0 keV line defines a level with spin 53/2 since the multipolatrity of this transition is consistent with an E2 character. The levels $37/2^+$ and $41/2^+$ of this band are feeded with many transitions from the deexcitation of the previously known sequence, seen in Fig. 3, which takes place at the 5407 keV level. Two new sidefeeding transitions on this levels are 1562.0 keV arriving to the $41/2^+$ level from 5301 keV level and 1286.0 keV line feeding the $37/2^+$ level. Finally two new linking transitions (1058.6 keV and 500.3 keV) from neighbouring band A feed the level 33/2 of this band.

Bands A and ABF remained unchanged except from the addition of a new linking transition (211.9 keV) between them which connects the $27/2^-$ level of band ABF to the $25/2^+$ level of band A. A new 394.7 keV transition links the $31/2^-$ level of band ABF with the $29/2^-$ level of band ABE. In the upper part of band ABCDF three new lines (1014.3 keV, 1022.7 keV and 1139 keV) were observed. The 1014.3 keV line is the strongest among them and is the most possible candidate for the continuation of this band upwards. Two new lines (561.4 keV and 1046.0 keV) sidefeed the $43/2^-$ level of this band and connect this band with the sequence of Fig. 3.

Two new transitions, the 908.2 keV feeding the bandhead of band ABCDF and 1294.4 keV feeding the $37/2^-$ level of band ABE, define a 4651 keV level. The DCO ratios allow us to assign a 41/2 spin to this level while the parity is tentatively assumed to be negative. Two new dipole transitions (252.5 keV and 221.7 keV) together with the quadrupole crossover transition (474.2 keV) have been identified above this level. The intensity of this sequence, corrected for internal conversion, is ~25% of the intensity of the 382.0 keV line but only ~10% of this intensity is carried away by the two lines observed to deexcite the 4651 keV level. It was impossible to trace the rest ~90% of this intensity and hence it is not certain whether this sequence lies directly above the 4651 keV level or not. As it will be discussed in the next section, this sequence is seen in coincidence with the two new sequences of Fig. 2 and hence plays a significant role in their deexcitation. Henceforth the name

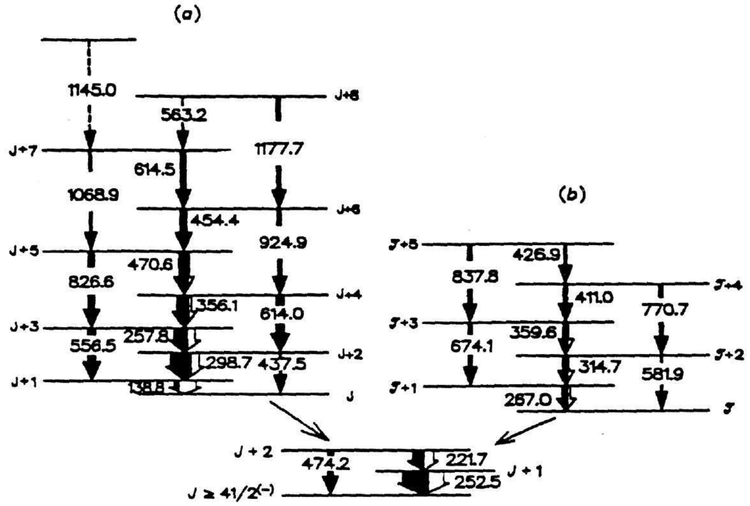


Fig. 2: *New* $\Delta I = 1$ *sequences of competing dipole and quadrupole transitions still floating above the normal decay scheme together with the "minor structure". The* γ*-ray transitions are labeled by their energy in units of keV. The width of the arrows represent the relative intensity of the transitions. The white part of the arrows is the correction due to the expected internal conversion. The arrows between the* $\Delta I = 1$ *bands and the "minor structure" represent still unassigned transitions (see text). The uncertainty on the* γ*-ray energies varies from 0.2 keV for the strong transitions to 1.0 keV for the weakest lines.*

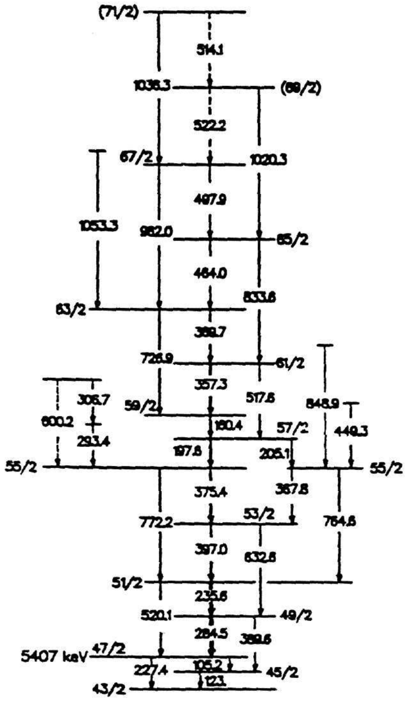


Fig. 3: *The third* $\Delta I = 1$ *structure in* ^{193}Hg *as observed in the present work. The* γ*-ray transitions are labeled by their energy in units of keV. The uncertainty on the* γ*-ray energies varies from 0.2 keV for the strong transitions to 0.5 keV for the weakest lines.*

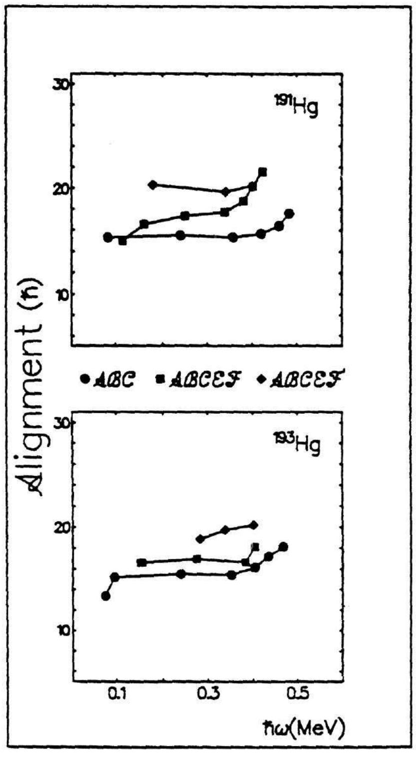


Fig. 4: *Alignment of bands ABC, ABCEF and ABCEF' in the* ^{191}Hg *and* ^{193}Hg *isotopes. The alignment of* ^{191}Hg *bands has been taken from ref.[9].*

" minor structure " will be used to refer to this sequence.

From the next ABCDE band only the first transition (523.2 keV) was previously known.[1] Three new transitions (737.4 keV, 983.4 keV and 1081.5 keV) form the continuation of this band upwards. The alignment found for this band is 19 $\hbar$ and it crosses with band ABE at rotational frequency $\hbar\omega = 0.32 MeV$. This implies that the addition of these lines did not affected significantly the values calculated for these quantities in the previous work by Hübel et al. [1]. A new 1097.4 keV transition feeds the $53/2^-$ level of this band. This line defines the highest lying level present in the normal decay scheme at 7351 keV excitation energy. Only the first two levels of this band, $41/2^-$ and $45/2^-$, are feeded from the deexcitation of the structure seen in Fig. 3 through the lines 1169. keV and 873.4 keV correspondingly.

In band ABE two new lines (561.9 keV and 1088.5 keV) parallel to the 735.2 keV and 915.1 keV lines have been observed. They connect levels $41/2^-$ and $33/2^-$ of this band and define a new $37/2^-$ level neighbouring to the $37/2^-$ level of the band. Their intensity is lesser than 2% of the intensity of the 382.0 line and hence they carry away only a few percent of the intensity of the $41/2^-$ level, the rest being taken away by the two parallel transitions of band ABE. Above the $41/2^-$ level a new bandcrossing seems to be present but it is not clear yet whether the observed 719.8 keV and 881.5 keV transitions form a band or not. It should be mentioned that we disagree with the continuation 298.6 keV, 561.7 keV and 719.6 keV given by Deng et al. [10] above the $45/2^-$ level. The 298.6 keV line does belong to this isotope but it is one of the dipole transitions involved in the two sequences seen in Fig. 2.

The last point to be discussed in the normal decay scheme is the 989.0 keV transition which feeds the 606 keV ($15/2^+$) level. This line was reported in ref. [1] as belonging in this isotope but a firm assignment of its place into the level scheme was impossible. In our data this line is seen to coincide not only with the 606.0 keV transition below it but also with band ABE. That is an indirect proof of the existance of the 19.9 keV line which connects the bandhead of band ABE with the 1595 keV level defined by the 989.0 keV line. A direct observation of the 19.9 keV transition is impossible because this line is strongly converted. Preliminary analysis of our data, analysed from the point of superdeformation, indicate that the 989.0 keV and 606.0 keV transitions are in coincidence with SD bands in this isotope and hence they must be involved in the deexcitation of these bands.

IV. $\Delta I = 1$ sequences in ^{193}Hg

The sequence seen in Fig. 3 was the first $\Delta I = 1$ sequence observed in ^{193}Hg. It is strongly populated (maximum intensity ~38% of the 382.0 keV line intensity) in this reaction and it was reported as collective in origin by Roy et al. [8] and then as a

[1] The 873.1 keV line, thought to be the second line of this band in ref [1], is proven to be of a dipole character in ref. [8,10,11] and from the analysis of our data.

single-particle structure by Deng et al. [10,11]. Here this structure is observed up to 9782 keV excitation energy. The 522.2 keV and 514.1 keV are not firmly established because they are obscured from the 520.1 keV line of this sequence and the 523.2 keV and 512.8 keV lines of the normal decay scheme. It is clear that the decay pattern of the lower part of this structure supports the single-particle scenario proposed by Deng et al. [10,11] but the upper part pattern tend to exhibit a certain collectivity. Only precise future measurements of the life times of this levels and calculations of the absolute B(E2) and B(M1) values will give an indisputable answer to the question of the nature of these lines.[1]

In Fig. 2 the two new $\Delta I = 1$ sequences reported in section 1 are presented. They consist of dipole transitions (138.8, 298.7, 257.8, 356.1, 470.6, 454.4, 614.5 and 563.2 keV for the first sequence and 267.0, 314.7, 359.6, 411.0 and 426.9 keV for the second) competing favorably with quadrupole ones (437.5, 556.5, 614.0, 826.6, 924.9, 1068.9 and 1177.7 keV for the first sequence and 581.9, 674.1, 770.7 and 837.8 keV for the second). The 614.5 keV and 563.2 keV transitions of the first sequence are still uncertain because the first one is obscured from the lower 614.0 keV line while the second is very weak. Very weak is also the 1145.0 keV line which is seen above the J+7 level of the first sequence.

The two sequences are not in coincidence to each other while both are seen in coincidence with the lines of the "minor structure" of the normal decay scheme but no direct linking towards these lines has been established. Not to be implied hither is the idea of some mysterious linking process; on the contrary, many new lines of this isotope have been observed in coincidence with the two sequences and the "minor structure" and it is believed that they play an important role in the linking but the pattern of lines seems to become very complicated in the region between the sequences and the "minor structure" rendering ambiguous a unique placing of the connecting lines. For this reason we restrict ourself in just quoting these lines, which, in keV units, are: 252.6(doublet with the one belonging in the "minor structure"), 274.2, 315.6, 327.7, 354.7, 363.6, 401.1, 403.2, 422.9, 442.6, 502.4, 507.0, 524.5, 561.8, 585.2, 602.9, 731.1, 777.6, 806.0, 818.2, 993.6 and 1064.8. In other words the two sequences feed bands ABE and ABF via the "minor structure".

A few percent (<10%) of the intensity of the first sequence feeds the 5536 keV (spin $49/2^-$) level (above 719.8 keV line) and ends up again in the same bands but this time without going through the "minor structure". The maximum intensity of the first sequence (intensity of 298.7 keV line, corrected for conversion, plus intensity of 556.5 keV line) is ~20% of the intensity of the 382.0 keV line while for the second one the corresponding value is ~6% (intensity of 267.0 and 581.9 keV lines).

The DCO analysis supports a scenario of direct dipole transitions (L=1) competing favorably with crossover quadrupole transitions (L=2) for both sequences. Intensity balance calculations favor an M1 multipolarity for the 138.8 keV and 257.8 keV dipole transitions.

[1] In ref.[10] an upper limit of a few Weisskopf units is given for the B(E2) values which could be an indication of non-collectivity in the lower part of the structure.

Assuming that all dipole and quadrupole transitions are M1 and E2 respectively B(M1)/B(E2) values can be measured for both sequences and for those levels for which such a calculation was possible the values are found to vary between 2 $\mu^2/(eb)^2$ and 4 $\mu^2/(eb)^2$ if one excludes the value of level J+6 which lies out of these limits but is characterized by a big error (see Fig.5). Worth mentioning here is the one order of magnitude difference of these values to the ones reported in the neighbouring Pb isotopes which vary from 20 $\mu^2/(eb)^2$ to 40 $\mu^2/(eb)^2$. This difference suggests that an increase in the collectivity takes place as one moves away from the doubly closed shell in ^{208}Pb which leads in an increase of B(E2), a decrease of B(M1) and hence a significant decrease of the B(M1)/B(E2) values.

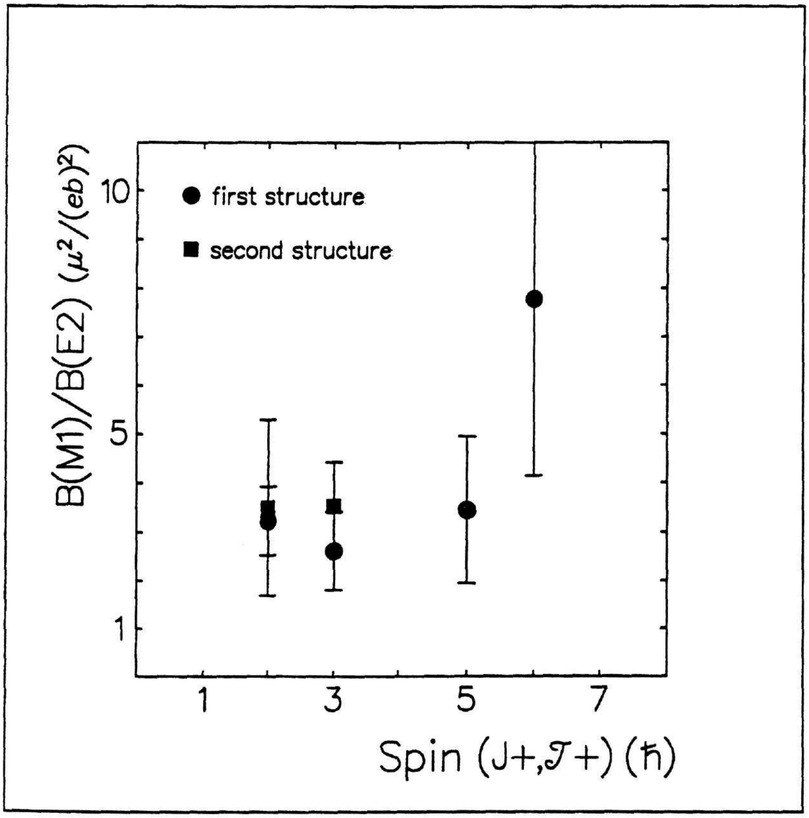


Fig. 5: *B(M1)/B(E2) values for some of the levels of the new structures seen in Fig.2.*

V. Conclusion

The normal level scheme of ^{193}Hg has been considerably enriched by this work. Furthermore two new $\Delta I = 1$ sequences have been found. They consist of competing dipole and quadrupole transitions and their maximum contribution to the reaction channel is altogether ~26%. Are these sequences a manifestation of a similar phenomenon to the collective structures reported recently in the neighbouring Pb isotopes or their nature is non-collective, as in the case of the neighbouring ^{191}Hg? An extensive investigation on this question will be published soon in a forthcoming paper [12]. Here we restrict ourself in pointing out that the results, which will be presented in this future publication, augment the evidence in favour of the collective scenario. Still, only lifetime measurements for these states will be enlightening and give a final indisputable answer to this question.

REFERENCES

[1] H. Hübel et al., Nucl. Phys. **A453** (1986)316

[2] R.R. Chasman, Phys. Lett. **B219** (1989)227

[3] B. Fant et al., J. Phys. G. Nucl. Part. Phys. **17** (1991)319

[4] A. Kuhnert et al., Phys. Rev. **C46** (1992)133

[5] T.F. Wang et al., Phys. Rev. Lett. **69** (1992)1737

[6] G. Baldsiefen et al., Phys. Lett. **B275** (1992)252

[7] R.M. Clark et al., J. Phys. G. Nucl. Part. Phys. **19** (1993)57

[8] N. Roy et al., Phys. Rev. **C47** (1993)930

[9] D. Ye et al., Nucl. Phys. **A537** (1992)207

[10] J.K. Deng et al., Phys. Lett. (submitted)

[11] J.H. Hamilton et al., Proceedings of the International conference on the future of Nuclear Spectroscopy, Crete 1993

[12] N. Fotiades et al., J. Phys. G (to be submitted)