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LOW-LYING EXCITED STATES OF ^{204}Tl AND ^{206}Tl POPULATED IN THERMAL NEUTRON CAPTURE*

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(*Presented by U. Fanger*)

Abstract

LOW-LYING EXCITED STATES OF ^{204}Tl AND ^{206}Tl POPULATED IN THERMAL NEUTRON CAPTURE.
New level diagrams of ^{204}Tl and ^{206}Tl are deduced from thermal neutron capture measurements on isotopically enriched samples. The agreement of the ^{206}Tl level scheme with theory is poor. This is attributed to the attempt of all computations to reproduce a low-lying 1^- state for which no evidence could be found experimentally.

When capture of thermal neutrons was first used as a method to study the properties of particular nucleides, it proved a powerful means to obtain new and most valuable information on nuclear structure, and the first data on the odd-odd isotopes of thallium were obtained via this reaction almost twenty yeary ago [1].

Considerable improvement of these early data in both accuracy and completeness has been achieved during the past decade by the application of a series of other processes the most important of which are, for the case of ^{204}Tl, the reactions ^{203}Tl(d,p)^{204}Tl and ^{205}Tl(d,t)^{204}Tl [2] and, for the case of ^{206}Tl, the reactions ^{205}Tl(d,p)^{206}Tl [2 ... 4], ^{208}Pb(d,α)^{206}Tl [5] and the α and β^- decays [6 ... 9, 10] of ^{210m}Bi and ^{206}Hg, respectively.

Despite these efforts, many details of the level structure of the two nucleides have remained either unknown or poorly established. For ^{204}Tl, a big step forward was achieved by Prestwich and collaborators [11] who used a Ge(Li) detector to observe the gamma spectrum from capture of thermal neutrons, but, because of the natural isotopic composition of the sample, attributed some γ rays to ^{204}Tl that did not arise from capture in ^{203}Tl.

For ^{206}Tl which, because of its simpler nucleonic structure, is of more direct use as a test case for different shell-model type calculations, a somewhat controversial situation had arisen whether or not a level with spin and parity 1^- existed a few keV above the ground state. This 1^- state, predicted by Sliv, Sogomonova and Kharitonov [12], was tentatively introduced into the measured level

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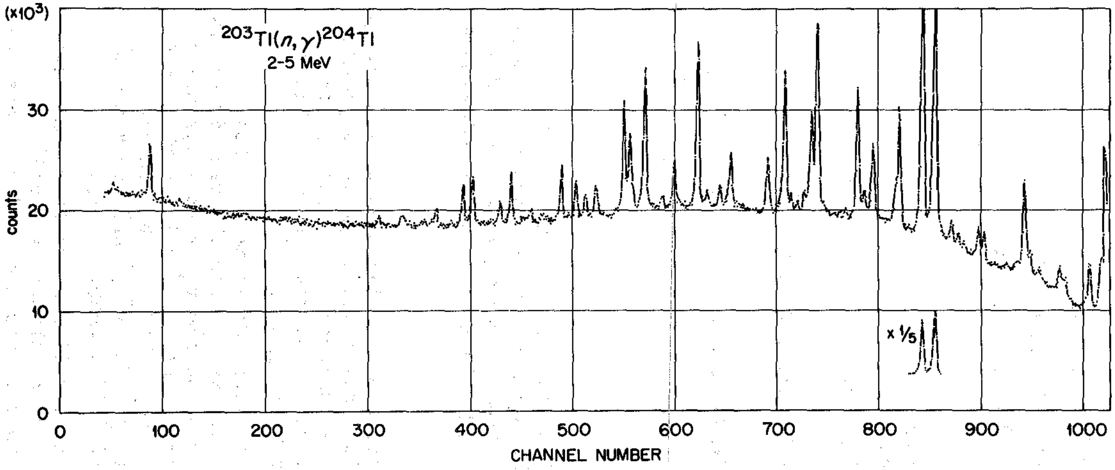


FIG. 1. High-energy part of the gamma spectrum from neutron capture in ^{203}Tl.

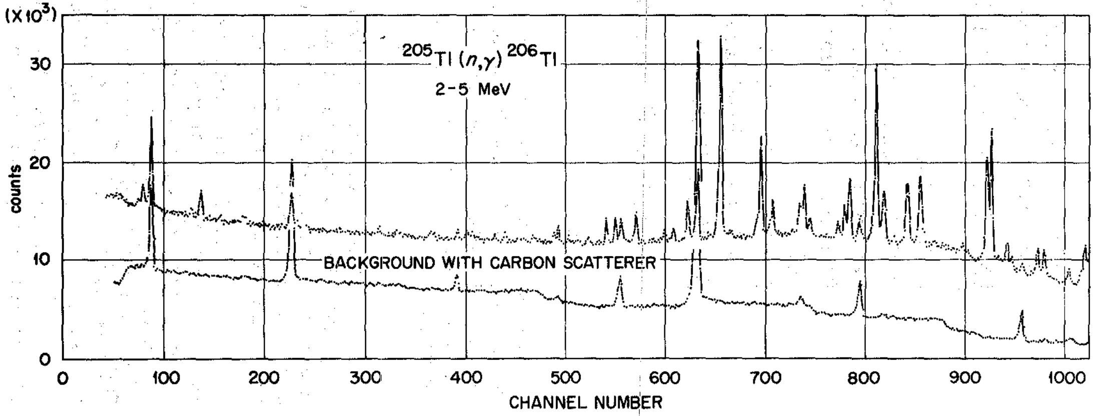


FIG. 2. High-energy part of the gamma spectrum from neutron capture in ^{205}Tl.

diagram of Rusinov et al. [7], and the authors of subsequent theoretical papers then tried to reproduce that level in their computations.

These calculations of systems with two nucleons outside a closed shell usually proceed in two steps. On account of the Pauli principle only the triplet-odd and singlet-even components of the residual nucleon-nucleon interaction contribute to the wave functions of those nuclei that are two like nucleons off a doubly magic "core" nucleus; so step 1 consists in an attempt to vary the magnitude of that half of the parameters until a best fit of the resulting level schemes with experiment is obtained. In step 2 the remaining parameters are fitted to the level diagrams of the nuclei that differ from the core nucleus by two different nucleons; to do this use is normally made of the unchanged parameters from step 1.

In the region of ^{208}Pb this procedure works well if the parameters determined for the even-even nuclei ^{210}Po, ^{210}Pb, ^{206}Pb, and ^{206}Hg are used to fit those of the odd-odd nuclei ^{210}Bi, ^{208}Bi, and ^{208}Tl. It fails, however, to give an adequate description of ^{206}Tl.

It was this failure that led us to a reexamination of the properties of the odd-odd isotopes of thallium, particularly ^{206}Tl. Our main interest centered on the following questions:

1) Is there a level in ^{206}Tl (presumably 1^-) 10 keV or less above the ground state, or is it possible to establish a smaller upper limit for such a hypothetical state?

2) Are there other levels observable in the energy range 0 to 800 keV in addition to the ones previously known?

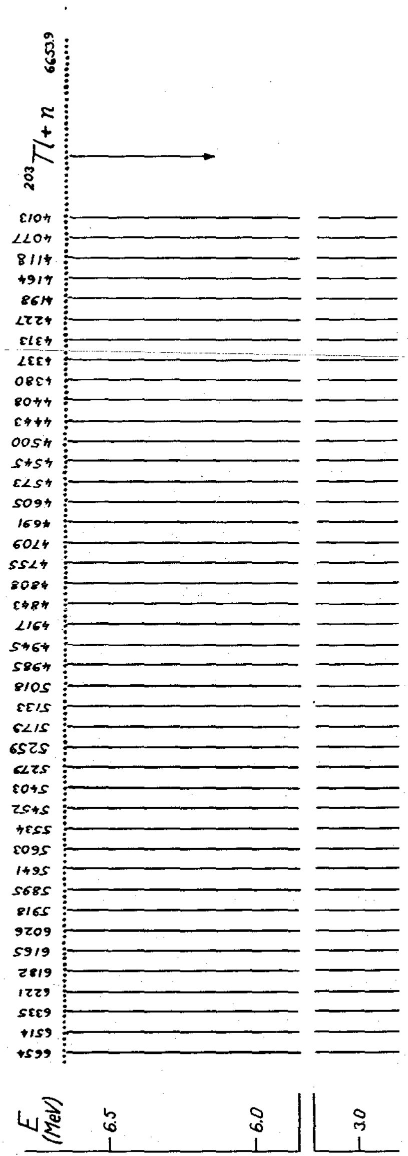
3) What is the excitation spectrum of ^{206}Tl in the energy range between 0.8 and 2 MeV which is not accessible from decay measurements?

4) Are gamma transition probabilities and branching ratios from the (n,γ) reaction compatible with the known spin values of the levels?

5) Is the "anomalous bump", i.e. the unusually intense group of gamma rays around 5.5 MeV in the (n,γ) and (d,pγ) spectra of nuclei with mass numbers between 180 and 208, observa ble for either of the two isotopes separately?

The experiment was done with Ge(Li) detectors of 6 and 30 cm^3 and isotopically enriched samples of ^{203}Tl (96.69 %) and ^{205}Tl (99.46 %) in an external thermal neutron beam of the ORR reactor.

Let us first look at Fig. 1 and 2 to get the answer to question 5. Fig. 1 shows the high-energy portion of the γ-ray spectrum from capture in ^{203}Tl which is very similar to the spectrum from natural thallium and clearly exhibits the group of intense peaks around 4.5 MeV (corresponding to γ-ray energies around 5.5 MeV), with few γ rays present between 2 and 4 MeV. The spectrum from capture in ^{205}Tl is shown in Fig. 2. Despite the high enrichment of the sample, about 30 % of the counting rate of this spectrum is due to capture in ^{203}Tl, but an evaluation shows that the gross behaviour of ^{206}Tl does not differ appreciably from that of ^{204}Tl, in complete agreement with the conclusions from Bartholomew's recent explanation of the effect [13].



E (MeV)
6.5
6.0
3.0
6654
6514
6335
6221
6182
6165
6026
5918
5895
5641
5603
5534
5452
5403
5273
5259
5173
5133
5018
4985
4945
4917
4843
4808
4755
4709
4691
4605
4573
4545
4500
4443
4408
4380
4337
4313
4227
4198
4164
4118
4077
4013
203Tl + n
6653.9

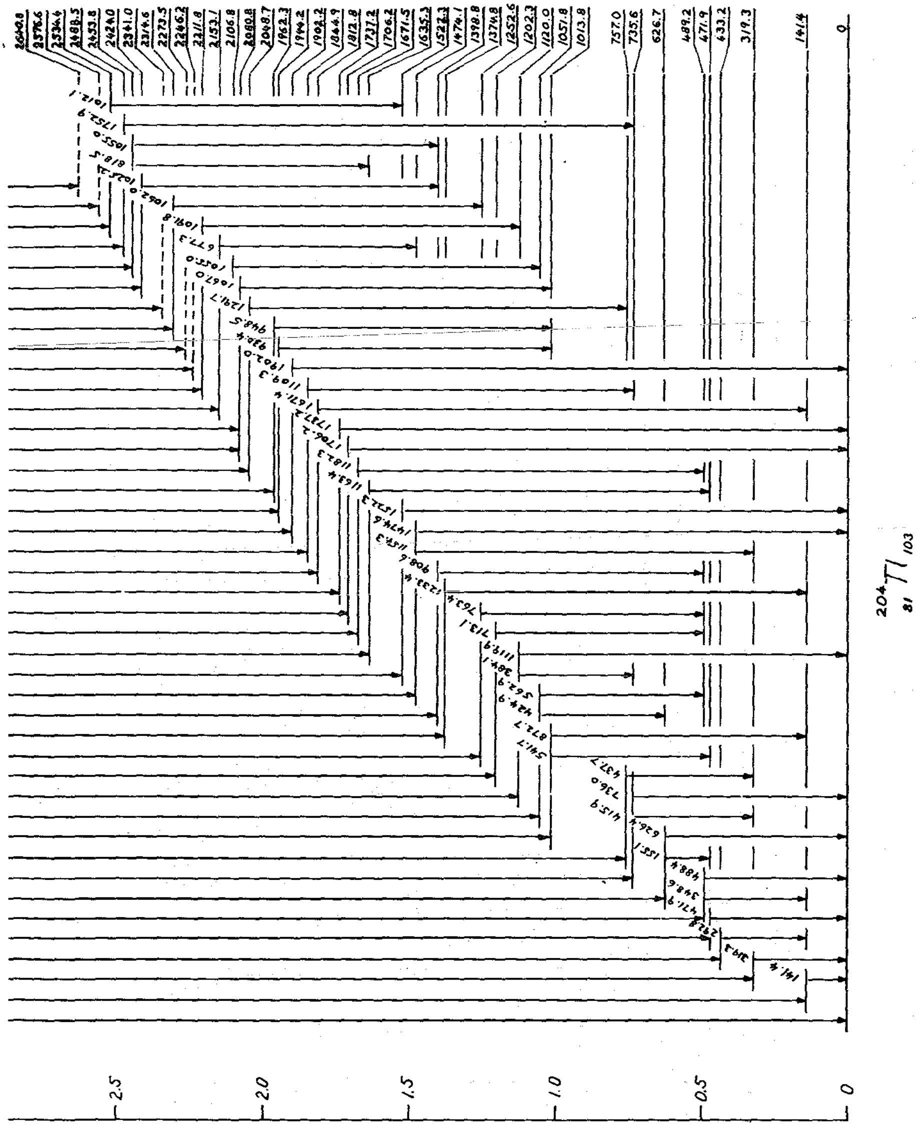


FIG.3. Transition diagram of ^{204}Tl.

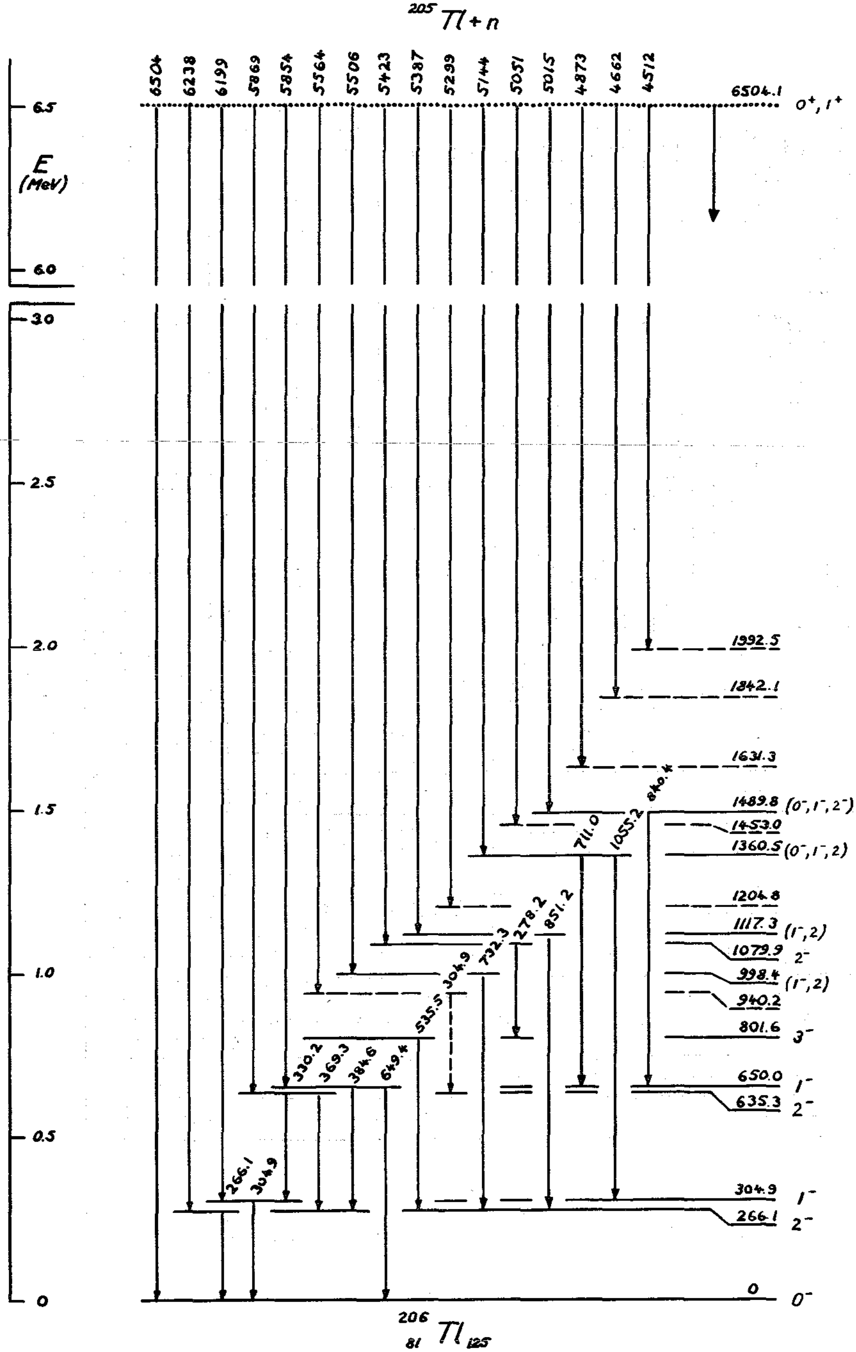


FIG.4. Transition diagram of ^{206}Tl.

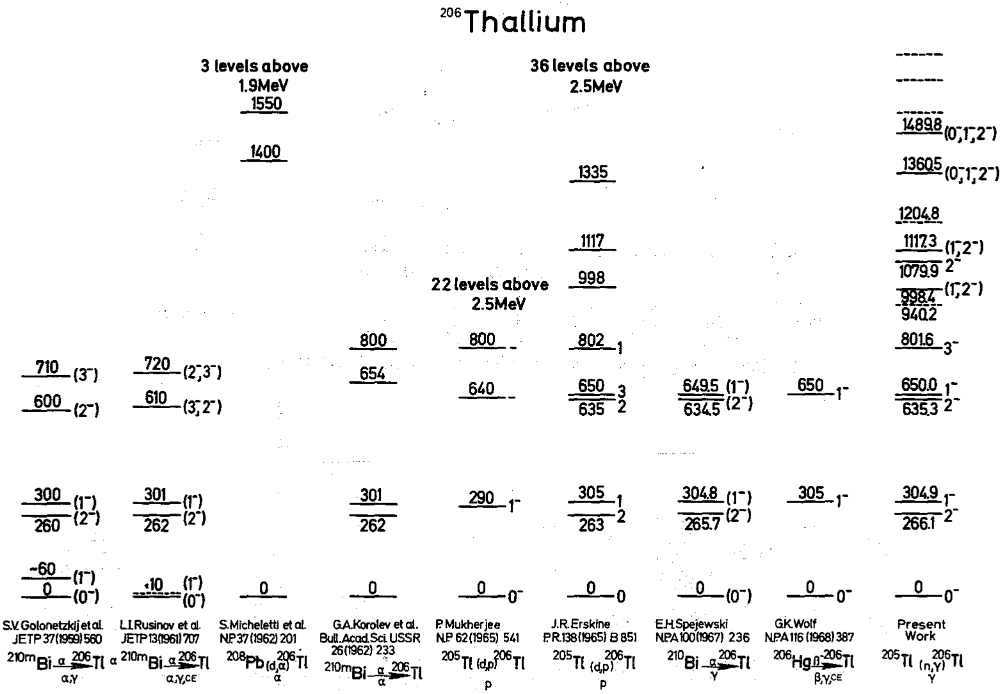


FIG.5. Comparison of ^{206}Tl level diagrams as measured from different reactions.

The transition diagram of ^{204}Tl is given in Fig. 3. Except for a state at 553 keV which was not observed in our measurements the agreement with the level diagram of Prestwich et al. /11/ is perfect. No evidence could be found for the existence of a long-lived metastable state in ^{204}Tl; this is not amazing, however, because if such a state existed its excitation energy must be low, its spin high compared to the ^{204}Tl ground state spin (2), and the probability of feeding it via neutron capture by a spin 1/2 target nucleus would be small. Horrock's half life measurement /14/ is therefore a stronger argument against the existence of a long-lived isomer in ^{204}Tl.

Fig. 4 shows the level diagram of ^{206}Tl. The presence of a low-lying 1^- level in ^{206}Tl should manifest itself by a splitting or broadening of at least some of the γ rays feeding the ground state. This broadening, if present, should be best visible for low-energy γ lines. To answer question 1 an analysis of the widths of the corresponding peaks was therefore done, and no evidence for a level $\simeq$ 2.3 keV above the ground state was found.

The answer to question 2 and 3 is given by Fig. 5 in which the ^{206}Tl level diagram as determined from the present work is compared to the results from other nuclear reactions. No new levels show up below 900 keV, but above, a series of previously unknown states could be found.

For question 4 let us once more look at the transition diagram of Fig. 4. As the energy dependence of the ^{205}Tl capture cross

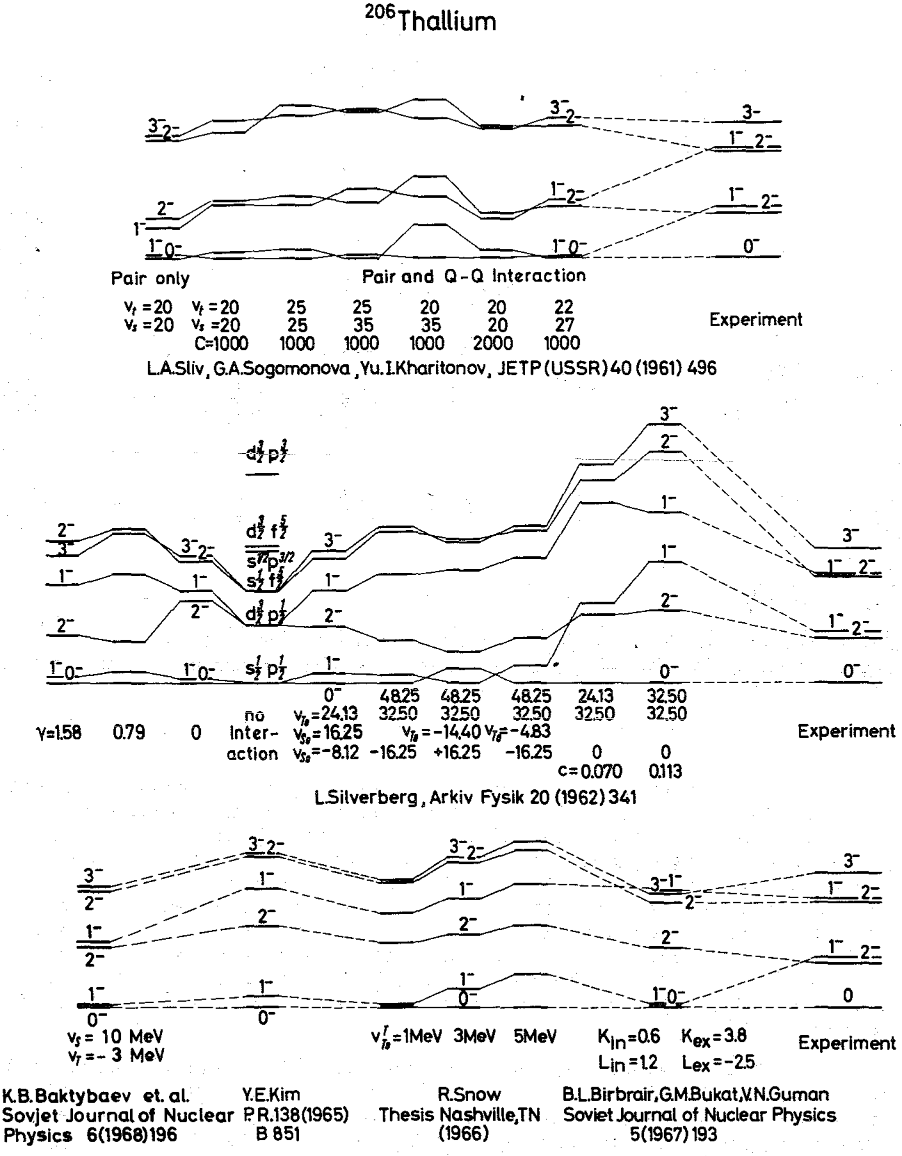


FIG.6. Comparison of calculated level diagrams of ^{206}Tl.

section is not well-known, both spin values of the capturing state must be admitted, and 0^-, 1^- and 2^- states can be fed by primary electric dipole radiation. Both feeding and deexcitation of the ground and first three excited states is consistent with Erskine's assignment of spins. The 650 keV level, however, is strongly populated from the capturing state; as it feeds both the 0^- ground and 2^- 266 keV states the only possible spin value is 1 if dipole transitions are assumed. The absence of a primary transition to the 802 keV level, on the other hand, and the deexcitation of this state to the 2^- 266 keV level only is strong evidence for the 802 keV state being the 3^- candidate that is expected in this region from theoretical considerations. This assignment of spins, although in contrast to Erskines interpretation, is but little outside the error bars of his data.

Fig. 6 shows a comparison of the results of different calculations [12, 16, ... 19] with experiment. For simplicity only the ground and lowest five excited states of ^{206}Tl are given which correspond to the proton-hole neutron-hole configurations ($s_{1/2}\ p_{1/2}$), ($d_{3/2}\ p_{1/2}$), and ($s_{1/2}\ p_{5/2}$). It follows from Fig. 6 that there has been no really good agreement so far although a great variety of shapes and of range and strength parameters were tried. This may be due to the fact that all calculations were biased by the endeavour to reproduce an almost degenerate 0^--1^- ground state doublet which till now was not established experimentally. It might be promising to try some of the approaches that worked so well in the case of other nuclei around ^{208}Pb with the newer experimental data now available for ^{206}Tl.

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