MSUCL-146

COO-1779-149

02/1977

ODD-PARITY ROTATIONAL-BAND STRUCTURE IN ^{48}V

L. E. Samuelson* and W. H. Kelly,

Cyclotron Laboratory†

and Department of Physics, Michigan State University,

East Lansing, Michigan 48824

and

F. M. Bernthal, R. A. Warner, and Wm. C. McHarris‡

Department of Chemistry§, Cyclotron Laboratory†,

and Department of Physics, Michigan State University,

East Lansing, Michigan 48824.

---

* Present address: Department of Physics, Purdue University, Lafayette, Indiana 47907.

† Work supported in part by the U.S. National Science Foundation.

‡ Alfred P. Sloan Fellow, 1972-1976.

§ Work supported in part by the U.S. Atomic Energy Commission.

ABSTRACT:

An additional odd-parity rotational band in ${}^{48}_{23}V_{25}$, built on a 1099.1-keV state with $K^{\pi} = 4^{-}$, has been identified up to spin 8, and corrections are reported for the structure of the previously reported $K^{\pi} = 1^{-}$ band, now seen to spin 7. These bands can be interpreted as the singlet and triplet couplings, respectively, of the $\Omega^{\pi}[Nn_{z}\Lambda\Sigma] = 3/2^{+}[202\downarrow]$ proton and $5/2^{-}[312\uparrow]$ neutron orbitals.

In a recent Physical Review Letter an odd-parity rotational-like band built upon the $K^{\pi} = 1^{-}$, 519-keV state in the $^{48}_{23}V_{25}$ nucleus was reported by Haas and Taras.[1] In that paper no mention was made of a similar 4^{-} band which has been identified[2] to spin 8 in ^{48}V, and as we show in this Comment, some of the conclusions represented[1] for the 1^{-} band are apparently incorrect. Moreover, a Mottelson-Nilsson interpretation[3] of the ^{48}V levels was not offered, even though one is almost compelled to invoke such an interpretation to explain the available data. The purpose of the present note is therefore to make important corrections and additions to the ^{48}V data on odd-parity band structure and to offer an alternative interpretation of the corrected experimental data.

As a supplement to our $^{48}Ti(p,n\gamma)$ studies of low-spin ^{48}V states,[4] we have performed γ-γ coincidence experiments and measured γ-ray excitation functions using the $^{46}Ti(\alpha,pn\gamma)$ reaction to populate high-spin ^{48}V states. New ^{48}V γ rays were identified by their appearance in gates on peaks well-known from the $(p,n\gamma)$ work.[4]

A portion of the level scheme of ^{48}V showing the revised odd-parity band structure is shown in Fig. 1. Important coincidence spectra that help to establish this structure are shown in Fig. 2. The excitation functions of all placed γ rays except the cross-over transitions and the uppermost cascade members (all too weak to measure precisely) are compatible with their assignment to ^{48}V. The definite (unparenthesized) spin assignments shown are based upon previously reported $^{48}Ti(p,n\gamma)$ work,[4] while the remaining assignments are suggested by the work summarized here. The evidence supporting assignment of odd-parity to the 519-keV state has been cited by Haas and Taras.[1] The reasons for assigning odd-parity to the 1099-keV state are twofold. First, the 6.5 ± 0.5 psec mean life[5] of this state yields a $B(E1)$ of $(8.5 \pm 0.7) \times 10^{-5}$ W.u., very similar to the retarded $B(E1)$'s of $(7.6 \pm 0.2) \times 10^{-5}$ W.u. and $(1.26 \pm 0.03) \times 10^{-5}$ W.u. observed[6] for the 97.9- and 210.4-keV γ-rays, respectively, which deexcite the 519-keV, 1^- state. Second, a $J^\pi = 4^-$ assignment is compatible with a recent ^{48}Ti(^{3}He,t)^{48}V experiment[7] where the angular distribution data could only be fit with $l = 5$ ($J^\pi = 4^-, 5^-$) or $l = 6$ ($J^\pi = 5^+, 6^+$) angular momentum transfers.

Two important features of the revised ^{48}V level scheme of Fig. 1 should be pointed out. First, the 807-keV transition suggested by Haas and Taras[1] as belonging to the 1^- band in fact belongs instead to a cascade feeding the 4^-, 1099-keV state. The misplacement probably arose from their gate set on the 719-keV peak of the 1^- band. This peak is very close to the much more intense 713-keV peak of the 4^- band. We also find no evidence in our gated spectra for the weak 1222- and 1524-keV cross-over transitions[1] of the 1^- band. The second important feature is the rotational-like cascade feeding the 4^-, 1099-keV state. The ordering of the γ rays in this band is based upon γ-ray relative intensities observed in the gated coincidence spectra. The energy spacing of this band closely follows the $J(J+1)$ rule with an average rotational constant of ≈ 0.06 MeV, the same as that of the 1^- band. No evidence was found in the gated coincidence spectra for the existence of crossover transitions in the 4^- band.

It is instructive to look at the plots of $[E_J - E_{J-1}]/2J$ vs $2J^2$ for the 1^- and 4^- bands as shown in Fig. 3. Here, the intercept with the ordinate is the rotational constant, $\hbar^2/2\mathcal{J}$, and the slope is the semi-empirical second-order "B-term" correction to the rotational energy. In such a plot perturbation effects are emphasized. As can be seen, the 4^- band appears reasonably normal. Here the "B-term" is negative, and, hence, the effective moment of inertia increases slightly with increasing spin, as expected from a straightforward rotational-vibrational interaction or from the Coriolis decoupling effect. The 1^- band, however, is strongly perturbed, having a very large odd-even shift. Note that our suggested 7^- state of the 1^- band is consistent with the odd-even shift of the other members of the band.

The existence of very low-lying odd-parity states in an odd-odd $f_{7/2}$-shell nucleus, the existence of rotational-like band structure closely following the $J(J+1)$ rule (and furthermore, exhibiting odd-even perturbation effects), and the existence of two such bands having virtually identical rotational constants compels one to suggest an alternative to the usual shell-model explanations for the spectroscopic data in this region. Theoretical and experimental evidence is accumulating for the existence of permanent ground-state deformations in $f_{7/2}$ nuclei having both protons and neutrons outside the ^{40}Ca core. Recent calculations of potential-energy surfaces for some even-even, $N = Z$ nuclei by Leander and Larson[8] indicate a ground-state deformation of $\beta \approx 0.2$ in ^{44}Ti. An estimate of $\beta \approx 0.27$ can be deduced from the $B(E2) = 1.4 \times 10^{-50}$ cm^4 (i.e. $\tau = 6.3$ psec)[9] of the first excited 2^+, 983-keV state in even-even

^{48}Ti, and likewise, $\beta \approx 0.37$ can be inferred from $B(E2) = 3.5 \times 10^{-50}$ cm^4 (i.e. $\tau = 9.7 \pm 2.6$ psec)[10] for the first excited 2^+, 752.4-keV state in even-even ^{48}Cr. Collective model energy-level fits indicate for ^{49}V, $\beta \approx 0.20$ (Ref. 11) and for ^{49}Cr, $\beta \approx 0.24$ (Ref. 12).

If ^{48}V is prolate with $0.2 \leqslant \beta \leqslant 0.4$ the $d_{3/2}$, $3/2^+[202\downarrow]$ single-particle orbital approaches the $f_{7/2}$, $3/2^-[321\uparrow]$ orbital. If the odd proton is allowed to occupy the $d_{3/2}$, $3/2^+[202\downarrow]$ orbital (with little expense in energy) and the odd neutron remains in the ground-state $f_{7/2}$ $5/2^-[312\uparrow]$ orbital, a $K^\pi = 1^-$ state is obtained for the triplet coupling and is expected to lie lower in energy than the singlet coupling. The abnormally low-lying 519-keV 1^- level can be identified as the triplet coupled state. The $K^\pi = 4^-$ state at 1099 keV can then be identified as the singlet coupling of this same p-n configuration. The fact that this suggested 4^- band has a rotational constant almost identical to that of the 1^- band strengthens this assignment. It is interesting to note that the 4^+ ground state of ^{48}V is correctly predicted in this picture as the triplet coupling of the $f_{7/2}$, $3/2^-[321\uparrow]$ proton with the $f_{7/2}$, $5/2^-[312\uparrow]$ neutron. The 1^+, 420-keV state could then be identified as the singlet coupling of this configuration. [Note also that the three transition cascade seen side-feeding the 4^-, 1099-keV state (the ordering shown is based on γ ray relative intensities in the 1099-keV gated spectrum) and the 415-keV γ ray feeding the (8^-) 3983-keV state may well be associated with other thus far uncharacterized high-spin states in ^{48}V. Since none of the γ rays in this third cascade were seen in our $(p,n\gamma)$ experiment and since we should easily have observed all states up to $J = 5$ in these experiments, we have set a lower limit of $J = 6$ on these three states.]

The odd-even shift observed in the 1^- band is not unusual in odd-odd deformed nuclei, and in the case of ^{48}V it can be accounted for in the following manner. The residual proton-neutron interaction[13] causes an odd-even shift in a 0^- band formed by the proton remaining in the $d_{3/2}$, $3/2^+[202\downarrow]$ orbital and the odd neutron moving to the $f_{7/2}$, $3/2^-[312\uparrow]$ orbital. This odd-even displacement in the 0^- band is transmitted to the 1^- band as a first order perturbation by the Coriolis interaction. A quantitative treatment of the residual proton-neutron interaction in the case of ^{48}V is difficult because the perturbing 0^- band has not yet been located. However, ^{46}V may provide additional essential information for study of the residual interaction in this region since the 0^- band described above should be the lowest-lying odd-parity band in ^{46}V if similar deformations exist in that nucleus. To our knowledge the deformed model parameters necessary for quantitative Coriolis-coupling calculations have yet to be determined in this region. Calculations of potential-energy surfaces as a function of deformation are needed for the entire $f_{7/2}$ shell.

REFERENCES

[1] B. Haas and P. Taras, Phys. Rev. Letters 33, 105 (1974).

[2] L. E. Samuelson, F. M. Bernthal, W. H. Kelly, and Wm. C. McHarris, Bull. Amer. Phys. Soc. 19, 546 (1974).

[3] B. R. Mottelson and S. G. Nilsson, Mat. Fys. Skr. Dan. Vid. Selsk 1, No.8 (1959).

[4] L. E. Samuelson *et al.*, in *Proceedings of the International Conference on Nuclear Physics, Munich, 1973*, edited by J. de Boer and H. J. Mang (North-Holland, Amsterdam, 1973), Vol. 1.

[5] B. A. Brown, J. M. McDonald, K. A. Snover, and D. B. Fossan, Bull. Amer. Phys. Soc. 17, 933 (1972) and B. A. Brown, private communication.

[6] L. E. Samuelson, C. B. Morgan, T. L. Khoo, and W. H. Kelly, Bull. Amer. Phys. Soc. 18, 767 (1973).

[7] J. C. Manthuruthil and C. P. Poirier, Bull. Amer. Phys. Soc. 19, 545 (1974) and private communication.

[8] G. Leander and S. E. Larsson private communication.

[9] P. H. Stelson and L. Grodzins, Nucl. Data Tables A1, 21 (1965).

[10] W. Kutschera, R. B. Huber, C. Signorini, and P. Blasi, Nucl. Phys. A210, 531 (1973).

[11] S. L. Tabor and R. W. Zurmühle, Phys. Rev. C10, 35 (1974).

[12] R. W. Zurmühle, D. A. Hutcheon, and J. J. Weaver, Nucl. Phys. A180, 417 (1972).

[13] N. D. Newby, Jr., Phys. Rev. 125, 2063 (1962).

FIGURE CAPTIONS

Fig. 1 Odd-parity bands in ^{48}V and the even-parity states to which they deexcite. Transition energies are in keV.

Fig. 2 Spectra of γ rays in coincidence with the 504.7- and 776.9-keV transitions, showing most of the lines in the 1^- and 4^- bands respectively. The 199.3- and 427.9-keV lines (the strongest peaks in the singles spectrum) a-pear here as chance coincidences. For clarity, square-root scales are used for the ordinates.

Fig. 3. $(E_J - E_{J-1})/2J$ vs. $2J^2$ for each level assigned to the 1^- and 4^- bands in ^{48}V.

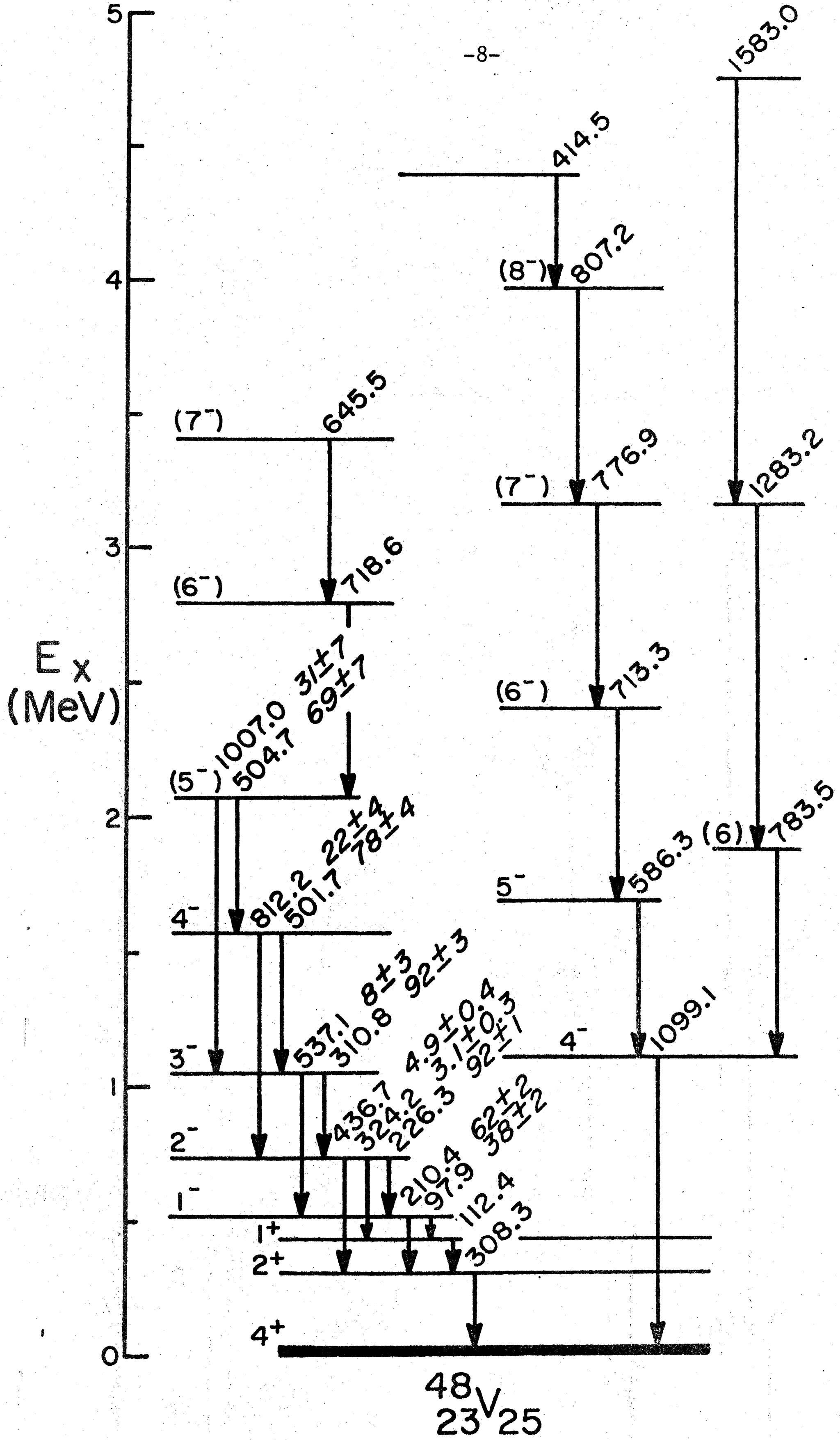
E x (MeV)
5
4
3
2
1
0
1583.0
414.5
(8⁻) 807.2
(7⁻) 645.5
(7⁻) 776.9
1283.2
(6⁻) 718.6
31±7
69±7
1007.0
504.7
(6⁻) 713.3
(5⁻)
22±4
78±4
812.2
501.7
(6) 783.5
5⁻ 586.3
4⁻
8±3
92±3
537.1
310.8
4.9±0.4
3.1±0.3
92±1
4⁻ 1099.1
3⁻
436.7
324.2
226.3
62±2
38±2
2⁻
210.4
97.9
112.4
1⁻
1⁺
308.3
2⁺
4⁺
48 23 V 25

Fig. 1

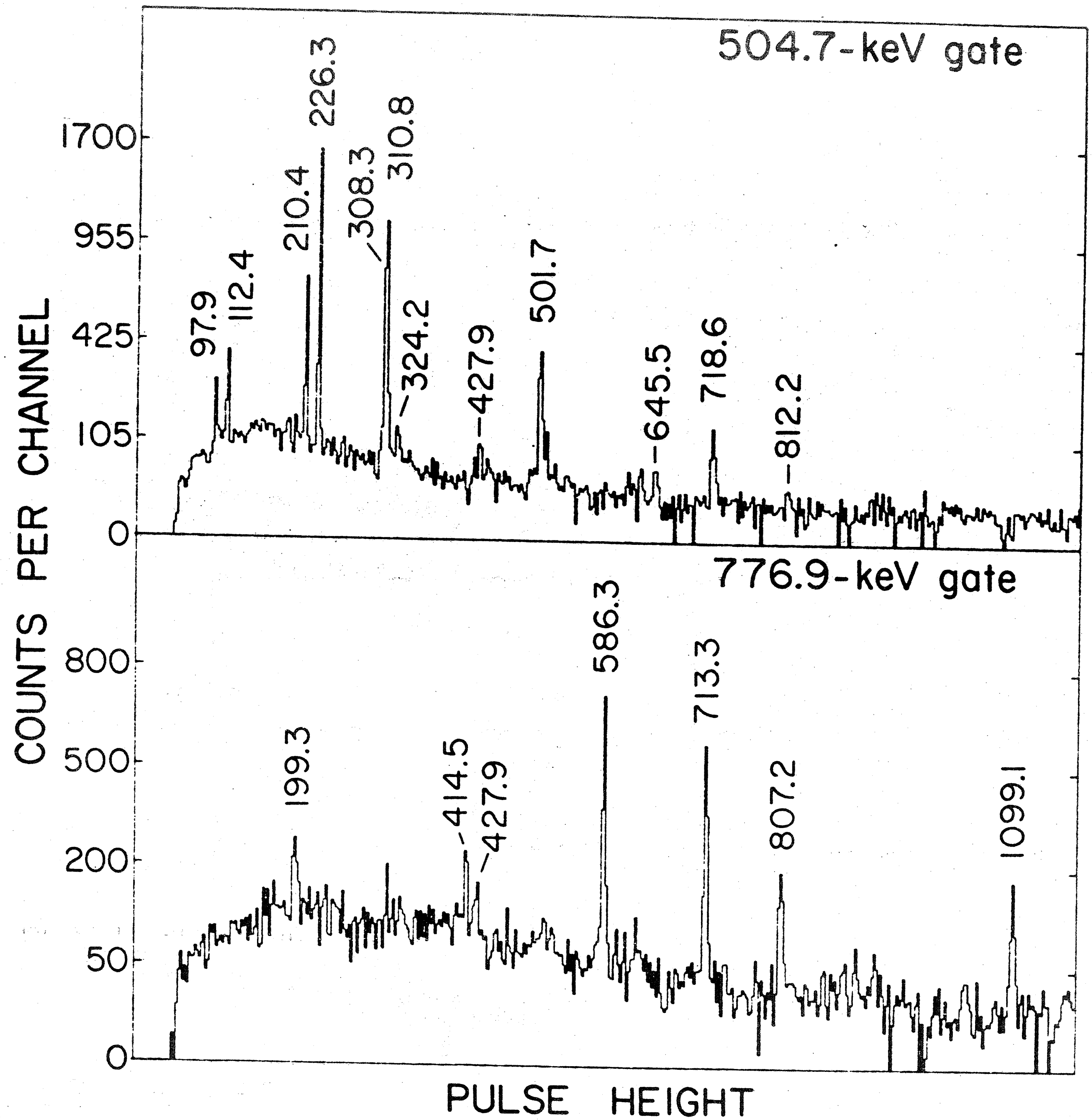
504.7-keV gate
776.9-keV gate
COUNTS PER CHANNEL
PULSE HEIGHT
1700
955
425
105
0
800
500
200
50
0
97.9
112.4
210.4
226.3
308.3
310.8
324.2
427.9
501.7
645.5
718.6
812.2
199.3
414.5
427.9
586.3
713.3
807.2
1099.1

Fig. 2

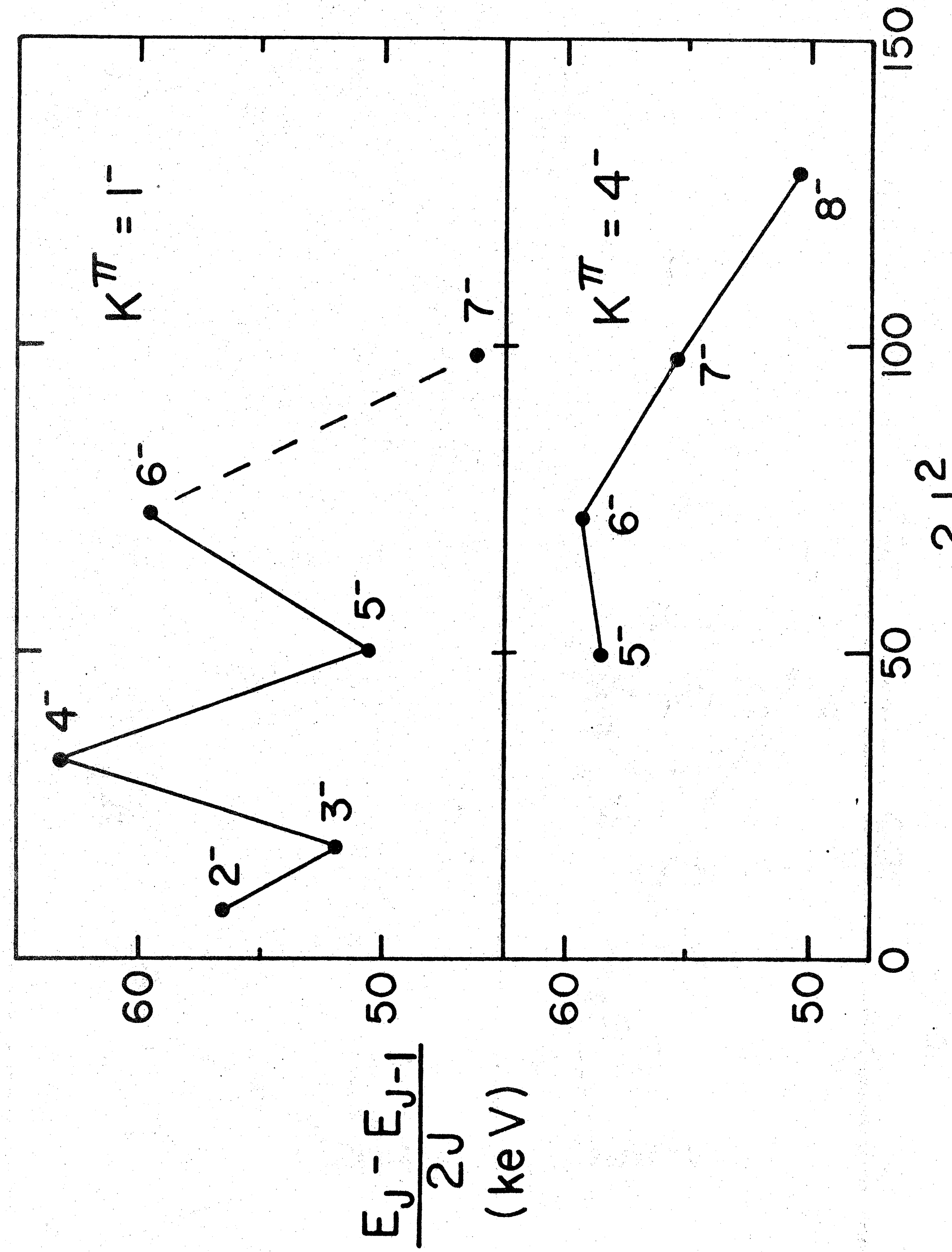

Fig. 3