MSUCL-717

In-Beam y-Ray Spectroscopy of Odd-Odd ^{176}Re: Doubly-Decoupled and Compressed Bands

by

W.-T. Chou, W.A. Olivier, Aracelys Ríos, and Wm. C. McHarris

National Superconducting Cyclotron Laboratory

and

Departments of Chemistry and Physics/Astronomy

Michigan State University

East Lansing, MI 48824

R. Aryaeinejad

Idaho National Engineering Laboratory/EG&G

Idaho Falls, ID 83415

and

E.S. Paul, D.B. Fossan, R. Ma, N. Xu, and Y. Liang

Department of Physics

State University of New York at Stony Brook

Stony Brook, NY 11794

Studies of deformed odd-odd nuclei have become more intense during the past few years, including a number of nuclei in the Ta-Re-Ir region.[1–4] The in-beam γ-ray spectra of these nuclei are simpler than might be expected at first, most likely because heavy-ion-induced reactions tend to populate states highly aligned with rotation, and the subsequent γ deexcitation favors similar (coriolis-connected) states.[1,5] The advantages of this are that only a selected subset of lower-lying bands is populated strongly, making the analysis much more tractable; the drawback, what we can learn from heavy-ion-induced reactions is limited more or less to these few bands. More often than not, the ground-state band is not strongly populated, and the strongly-populated bands feed into the lowest states via low-energy, highly-converted, and/or delayed transitions, the result being that very few such connections have been worked out. Thus, assigning spins and structures to the observed bands requires relying more than usual on understanding the neighboring odd-mass nuclei and on systematics.

Santos et al.[4] used the ^{169}Tm(^{12}C,5$n\gamma$) reaction for the first studies of ^{176}Re. Their level scheme included parts of two rotational bands. One of these is the so-called doubly-decoupled band, a type of band first observed in the Ta-Re-Ir region by Kreiner et al.[2] They interpreted it as a coupling of the $\pi 1/2^-[541]$ and $\nu 1/2^-[521]$ states, both of which drop to rather low excitation energies in the more neutron-deficient Re nuclei. The second band could be interpreted as a coupling of $\pi 5/2^+[402]$ and $\nu i_{13/2}$ states. A similar band had been found[5] in ^{180}Re, its main characteristic being that the moment of inertia changes rapidly with consecutive band members, especially toward the bottom of the band. Such behavior is typical of bands involving $i_{13/2}$ neutron states with strong coriolis coupling.

This paper presents initial results from our in-beam γ-ray spectroscopic a band has spacings similar to the K=1/2 decoupled bands in the odd-proton nuclei nearby, and the band-head is not the state with $J = K$. This analog behavior is useful when assigning spins to members of the doubly-decoupled band. A survey of all the known doubly-decoupled bands in this region[11] and their relations with the corresponding odd-proton nuclei suggests that the lowest member of the band in ^{176}Re should have $J^\pi = 3^+$. The two-quasiparticle-plus-rotor calculations carried out by Santos et al. also favor this assignment. However, the lowest experimentally-observed state has $J^\pi = 5^+$. Both Santos et al. and we believe that the $5^+ \rightarrow 3^+$ transition was not observed because it is a highly-converted, low-energy $E2$ transition, the same reason that prevents the $9/2^- \rightarrow 5/2^-$ transitions from having been seen in some odd-mass Re nuclei.

The IBFFA predictions[8] for this doubly-decoupled, $\Delta J = 2$ band, which has the structure, $\pi h_{9/2}1/2^-[541] \otimes \nu p_{3/2}1/2^-[521]$, are shown in Fig. 2, where the 3^+ state is again suggested to be the band-head. We have some faith in this prediction because of the excellent agreement with experiment for the higher members of the band. The calculations predict the energy of the $5^+ \rightarrow 3^+$ transition to be 82.9 keV. Such an $E2$ transition could be picked up by an experiment having very good statistics and a low threshold (an experiment somewhat incompatible with those designed to extend the bands to higher spins). However, we should point out that the energy of the analogous unknown[12] transition in ^{175}Re has a strong influence on the IBFFA prediction for ^{176}Re.

It is worth mentioning the success of the IBFFA method in predicting other aspects of doubly-decoupling phenomena. The entire band is nominally the $K = 1$ triplet coupling, with the favored-signature (odd-spin) members depressed in energy with respect to the unfavored (even-spin) members.

and neutron would simply be additive for odd-odd ^{176}Re. This appears to be so, with the result that the crossing-frequency shifts caused by the odd proton and odd neutron almost exactly cancel, so the crossing frequency is almost the same as for the even-even W nuclei. A similar situation was found for ^{172}Ta.[3]

We basically agree with Santos et al. for the energies of the transitions in the band shown on the right side of Fig. 1, but there is some uncertainty as to where the band starts, i.e., which state is the band-head. From our delay analysis and intensity ratios, the 99.6-keV transition appears to originate from a metastable state ($t_{1/2} = 21 \pm 7$ ns). Santos et al. did not perform delay analysis. A second point is that they observed a 70.5-keV transition, which we could not see because of its being obscured by x rays. Thus, it is a moot point as to whether the first transition in this second band is 122.4 or 70.5 keV.

In addition to the indication from our delay analysis, a band having its first intraband transition at 123.8 keV and very similar spacings to this second band has recently been seen in ^{178}Re.[20] This band was assigned the configuration, $\pi 9/2^-[514] \otimes \nu$it i$_{13/2}$, a so-called compressed band,[6,13] resulting from strong coriolis coupling from the $i_{13/2}$ neutron state but little contribution from the proton state. There are two other bands in ^{178}Re that also have the neutron in an $i_{13/2}$ state. Comparing the crossing frequencies of these three bands in ^{178}Re with the analog bands in ^{177}Re (cf. Fig. 2 of Ref. 20), we find that the $\pi 9/2^-[514] \otimes \nu i_{13/2}$ band shows quite different behavior from the other two bands and is not nearly so compressed as the $\pi 5/2^+[402] \otimes \nu i_{13/2}$ band. Thus, we think the assignment might not be appropriate, i.e., the neutron might not be in an $i_{13/2}$ state.

Now, if the 122.4-keV transition is the one between the first two members ing frequency is essentially the same as for the neighboring even-even cores. This comes about because the neutron and proton states have opposite driving effects, which cancel out almost exactly. This means that, although doubly-decoupled bands are indeed "decoupled," the decoupling is not so extreme as to preclude major effects by the odd particles on the behavior of the core. Second, IBFFA calculations, although certainly not a cure-all, can be a very useful aid in helping one decide among possible, likely odd-odd configurations.

The work was supported in part by the US National Science Foundation under Grant PHY-85-19653.

11. W.A. Olivier, W.-T. Chou, R. Aryaeinejad, A. Ríos, and Wm.C. McHarris, in *Exotic Nuclear Spectroscopy*, Ed. by Wm.C. McHarris (Plenum Press, New York, 1990), Chap. 25.

12. J.R. Leigh, J.O. Newton, L.A. Ellis, M.C. Evans, and M.J. Emmott, Nucl. Phys. A183, 177 (1972).

13. A.J. Kreiner, in *Exotic Nuclear Spectroscopy*, Ed. by Wm.C. McHarris (Plenum Press, New York, 1990), Chap. 26.

14. J.D. Garrett, J. Nybery. C.H. Yu, J.M. Espino, and M.J. Godfrey, in *Proceedings of the International Conference on Contemporary Topics in Nuclear Structure Physics, Cocoyoc, Mexico, 1988*, p. 699.

15. R. Bengtsson, ibid., p. 317.

16. C.X. Yang, J. Kownacki, J.D. Garrett, G.B. Hagemann, B. Herskind, J.C. Bacelar, J.R. Leslie, R. Chapman, J.C. Lisle, J.N. Mo, A. Simcock, J.C. Wilmott, W. Walus, L. Carlen, S. Johsson, J. Lyttkens, H. Ryde, P.O. Tjom, and P.M. Walker, Phys. Lett. 133B, 39 (1983).

17. G.D. Dracoulis, P.M. Walker, and A. Johnston, J. Phys. G. 4, 713 (1978).

18. P.M. Walker, G.K. Dracoulis, J. Johnson, J.R. Leigh, M.G. Slocombe, and I.F. Wright, J. Phys. G 4, 1655 (1978).

19. G.D. Dracoulis, C. Fahlander, and A.P. Byrne, Nucl. Phys. A401, 490 (1983).

20. A.J. Kreiner, V.R. Vanin, F.A. Beck, Ch. Bourgeois, Th. Byrski, D. Curien, G. Duchene, B. Haas, J.C. Merdinger, M.G. Porquet, P.

Table I.

Crossing Frequencies of the First Backbend in ^{176}Re and Other Related Bands

Nucleus	Band	$\hbar\omega$ (MeV)
^{176}Re	$\pi 1/2^-[541] \otimes \nu 1/2^-[521]$	0.29
^{174}W	ground-state	0.30
^{176}W	ground-state	0.30
^{175}W	$\nu 1/2^-[521]$	0.26
^{177}Os	$\nu 1/2^-[521]$	0.27
^{177}Re	$\pi 1/2^-[541]$	0.33

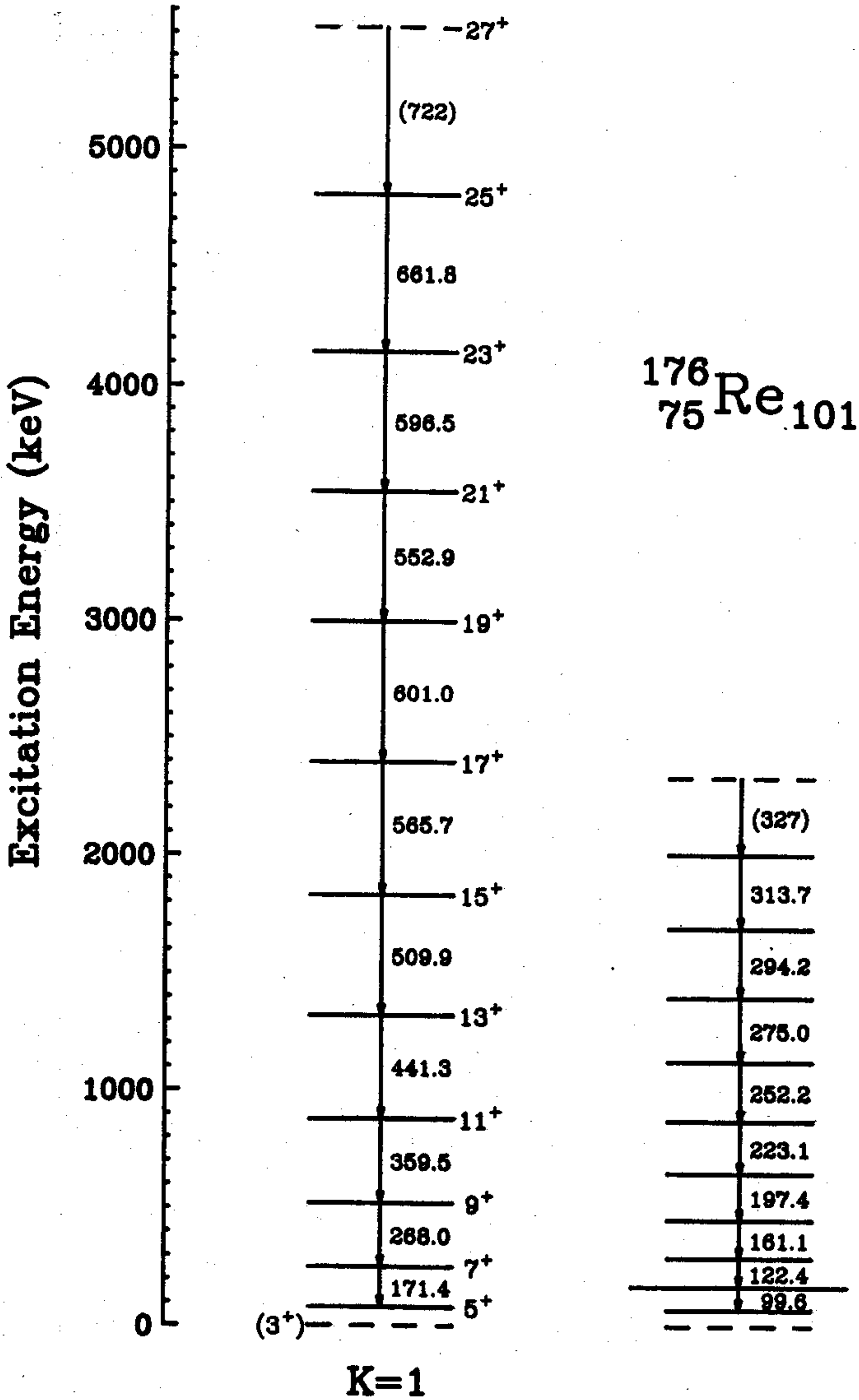
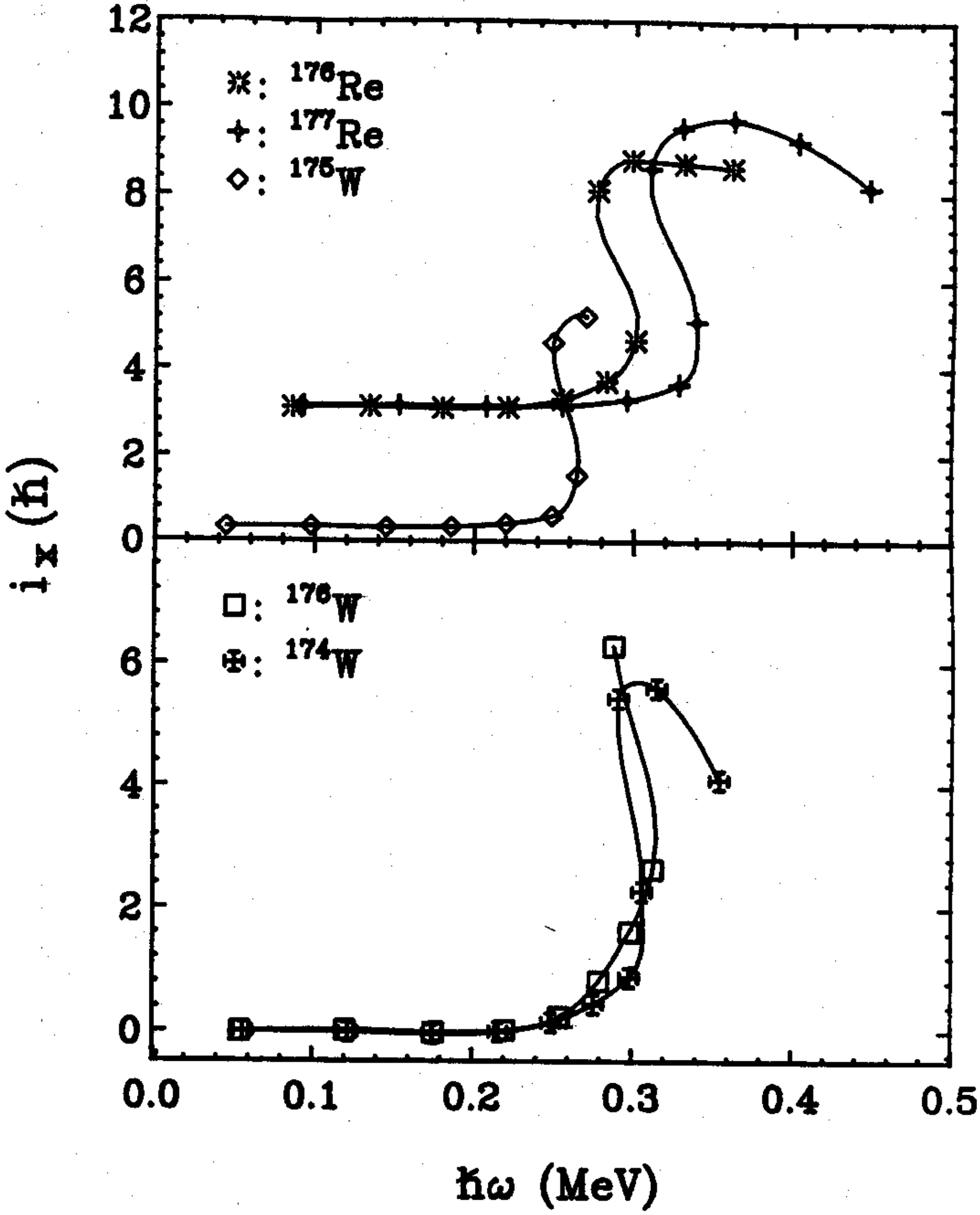

Excitation Energy (keV)
5000
4000
3000
2000
1000
0
27+
(722)
25+
661.8
23+
596.5
21+
552.9
19+
601.0
17+
565.7
15+
509.9
13+
441.3
11+
359.5
9+
268.0
7+
171.4
5+
(3+)
K=1
$^{176}_{75}Re_{101}$
(327)
313.7
294.2
275.0
252.2
223.1
197.4
161.1
122.4
99.6

Fig. 1



12
10
8
6
4
2
0
6
4
2
0
✳: 176Re
+: 177Re
◇: 175W
□: 176W
⊕: 174W
i x (ħ)
0.0
0.1
0.2
0.3
0.4
0.5
ħω (MeV)

Fig. 3

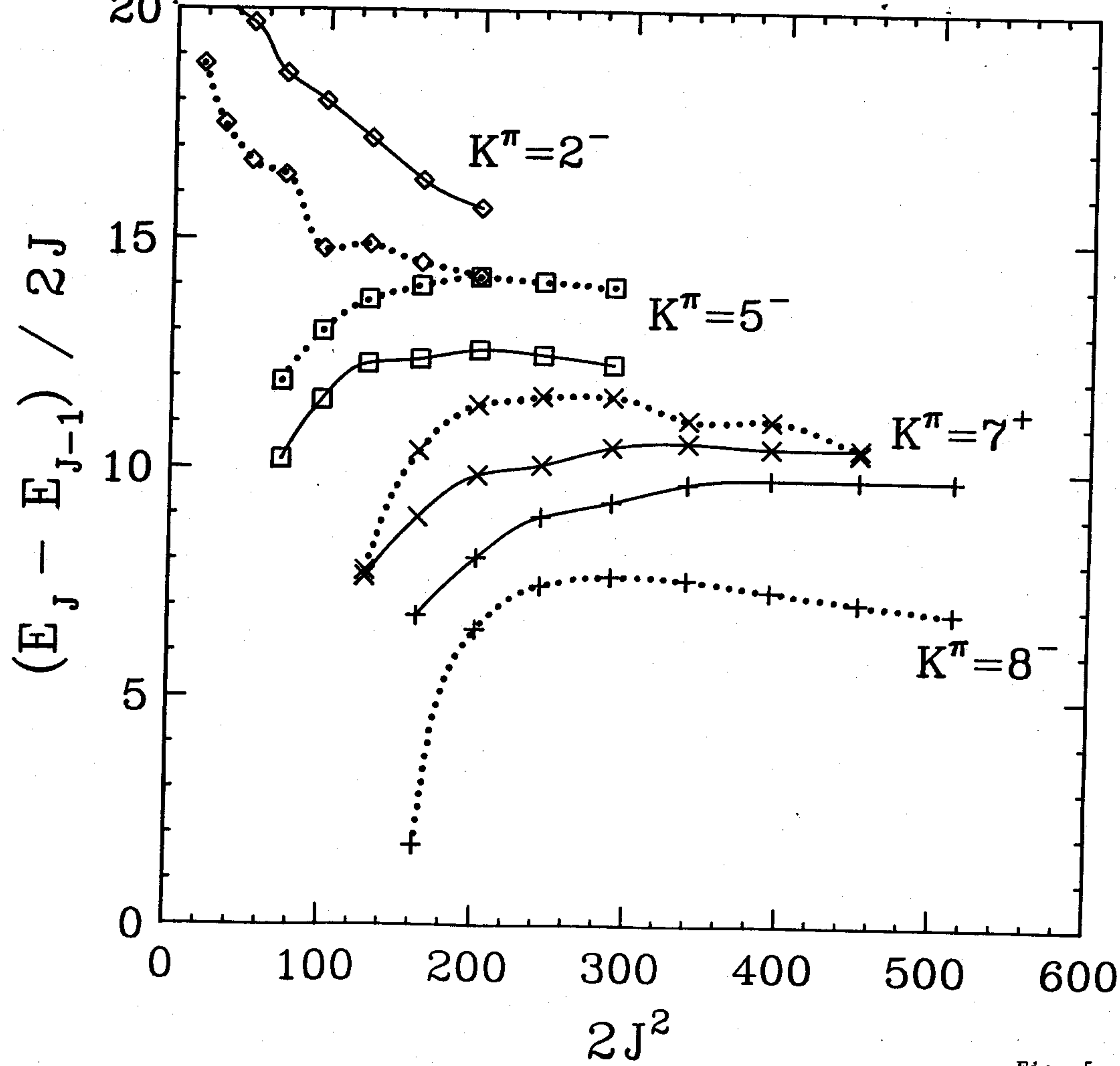


Fig. 5