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Odd-parity rotational band structure in ^{48}V[†]

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A second odd-parity rotational band in the $f_{7/2}$-shell nucleus $^{48}_{23}V_{25}$, based on a 1099.1 keV state with $K^\pi = 4^-$, has been identified up to the 8^- member. Also, corrections are given for the previously reported 1^- band. These bands can be interpreted as the singlet and triplet couplings of the $\Omega^\pi[Nn_Z\Lambda\Sigma] = 3/2^+[202\downarrow]$ proton and $5/2^-[312\uparrow]$ neutron Nilsson orbitals, indicating prolate deformation.

[NUCLEAR REACTIONS ^{46}Ti(α,pn), ^{48}Ti(p,n); measured γ-γ coin, ce, ^{48}V deduced levels, J, π, Λ, ICC. Splitting of Nilsson levels.]

An odd-parity rotational-like band built on a proposed $J^\pi = 1^-$, 518.7-keV state in $^{48}_{23}V_{25}$ has been reported by Haas and Taras.[1] We have outlined arguments in favor of associating the 1099.1-keV state in ^{48}V with a related $K^\pi = 4^-$ rotational band.[2] In view of the apparently contradictory data regarding the proposed 4^- assignment, however, we undertook to measure α_K, the K-shell internal conversion coefficient, for the 1099.1-keV transition that depopulates this state to the 4^+ ground state. In this case, such a measurement is definitive with respect to the parity.

Here we report the unambiguous characterization of the 1099.1-keV transition as $E1$ and the confirmation of the 4^- assignment for the 1099.1-keV state. To our knowledge this is the first reported in-beam application of the conversion-coefficient technique to such a low-Z nucleus. Moreover, the ^{48}V data provide a very clear example of one of the few singlet-triplet coupling doublets to be identified in such a light nucleus, and they give a clear indication of permanent prolate deformation at low energies in a nucleus close to the $Z = 20$, $N = 28$ closed shells. We also show that the 1^- band built on the 518.7-keV state is strongly perturbed with a large odd-even shift.

We have performed γ-γ coincidence experiments and measured γ-ray excitation functions using the ^{46}Ti(α,$pn\gamma$) and ^{45}Sc(α,$n\gamma$) reactions 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.[3] The ^{48}Ti(p,ne^-) studies reported here were specifically aimed at determining the parity of the 1099.1-keV state. Details of all of these experiments will be published later with the results for both positive and negative parity levels.

A portion of the level scheme of ^{48}V showing the revised and extended odd-parity band structure is shown in Fig. 1. Important coincidence spectra

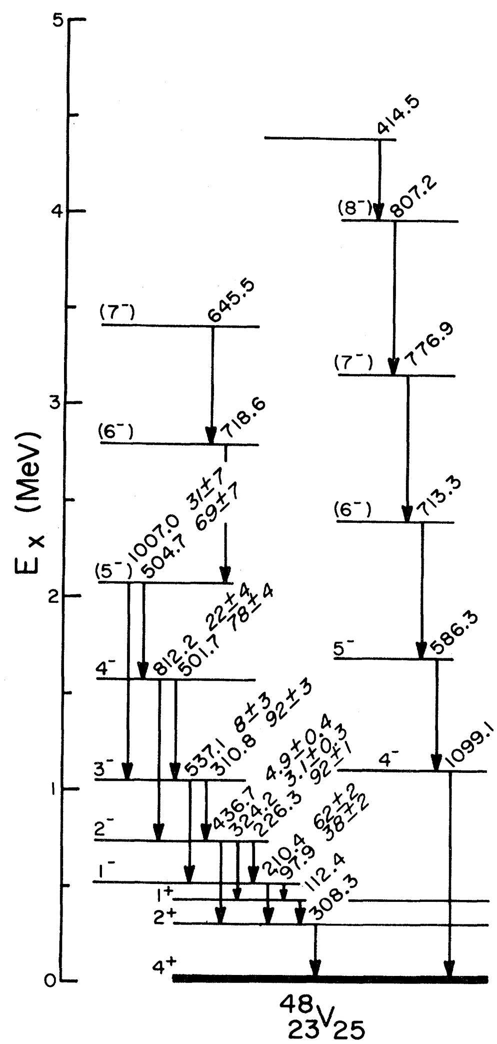

FIG. 1. A partial level scheme of ^{48}V showing odd-parity band structures and their decay modes.

that help to establish this structure are shown in Fig. 2. The excitation functions of all placed γ transitions except the crossover transitions and the uppermost cascade members (all too weak to measure precisely) are compatible with their assignment to ^{48}V. The definite (without parentheses) spin assignments shown are based upon our previously reported ^{48}Ti($p,n\gamma$) work,[3] while the remaining assignments are suggested by our ^{45}Sc($\alpha,n\gamma$) excitation function work. The evidence supporting assignment of odd parity to the 518.7 keV state has been cited by Haas and Taras.[1]

The most compelling evidence for the odd-parity assignment for the 1099.1-keV state is the internal conversion coefficient for the transition to the ground state. We measure $\alpha_K = (4.0 \pm 0.6) \times 10^{-5}$ for that transition, normalized to the theoretical K-conversion coefficients[4] of the pure $E2$ transitions at 983.3 and 1311.7 keV, corresponding to the $2^+ \to 0^+$ and $4^+ \to 2^+$ transitions in ^{48}Ti. The number is clearly in agreement with the theoretical value 4.5×10^{-5} for a pure $E1$ multipole and in disagreement with the values 8.0×10^{-5} and 9.9×10^{-5} expected for $M1$ and $E2$ multipoles, respectively. The relevant portion of the ^{48}V conversion electron data is shown in Fig. 3.

The ^{48}Ti($p,n\gamma$)^{48}V angular distribution and excitation function data[3] also favor the 4^- assignment over a 5^+ as proposed in Ref. 5. Results from a recent linear polarization experiment by Rickel *et al.*[6] are consistent with either a 4^- or 5^+ assignment. A number of transfer reaction experiments have yielded inconclusive or conflicting results with regard to the parity of the 1099.1-keV state.[7,8] Finally, we note that 6.5 ± 0.5-psec mean life of this state implies a $B(E1)$ value of $(8.5 \pm 0.7) \times 10^{-5}$ W.u. (Weisskopf units),[9] very similar to the retarded $B(E1)$ values of $(7.6 \pm 0.2) \times 10^{-5}$ and $(1.26 \pm 0.03) \times 10^{-5}$ W.u. we observed for the 97.9- and 210.4-keV γ rays deexciting the 518.7-keV $K^\pi = 1^-$ state.[10]

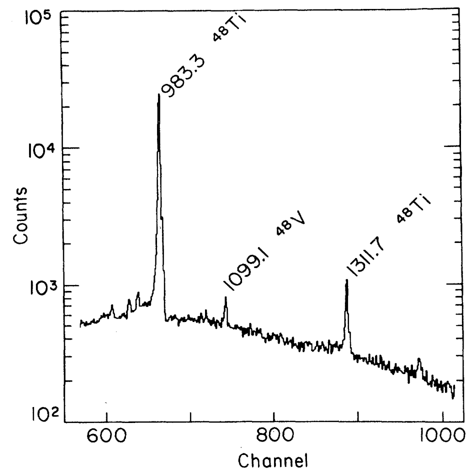

FIG. 3. A portion of the ^{48}Ti(p,ne^-)^{48}V conversion-electron spectrum taken with a 3-mm Si(Li) detector and a solenoidal electron guide. The proton energy was 6 MeV. Theoretical K-conversion coefficients for the 983- and 1312-keV $E2$ transitions in ^{48}Ti are 1.14×10^{-4} and 5.87×10^{-5}, respectively.

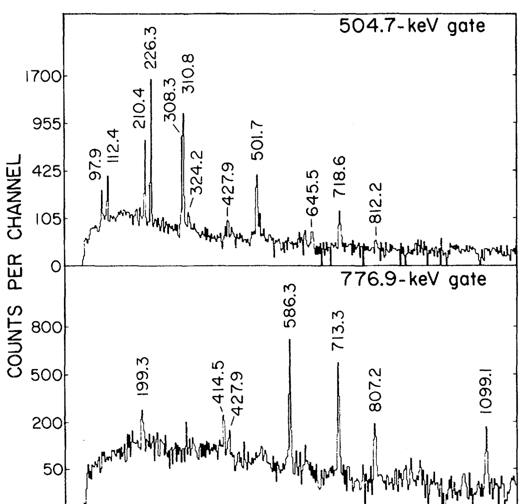

FIG. 2. Spectra of γ rays in coincidence with the 504.7- and 776.9-keV transitions, showing most of the lines in the 1^- and 4^- bands, respectively. Although these spectra are uncorrected for chance events, the weak appearance of the 199.3- and 427.9-keV lines, by far the most intense transitions in the γ-ray spectrum, indicates chance events were relatively unimportant.

Other corrections to the ^{48}V level scheme should be pointed out. First, the 776.9-keV coincidence data clearly indicate the 806.6-keV transition suggested by Haas and Taras[1] as depopulating the 7^- state of the 1^- band in fact belongs to a cascade feeding the 4^-, 1099.1-keV state. Perhaps the 1523.5-keV transition suggested to arise from this same 7^- state is a misplacement of the Doppler broadened 1524.2-keV transition we observe to feed the 9^+, 2626-keV state in ^{48}V.

A plot of $[E_J - E_{J-1}]/2J$ vs $2J^2$ for the 1^- and 4^- bands is shown in Fig. 4. In a plot such as this, the intercept is the rotational constant $\hbar^2/2\mathcal{I}$, the slope is the semiempirical second-order "B term" correction to the rotational energy, and perturbation effects are emphasized. As can be seen, the 4^- band appears reasonably normal, with an average rotational constant very similar to that of the 1^- band. The B term is negative, i.e., the effective moment of inertia shows the expected slight increase with spin. The 1^- band, however, is strongly perturbed, having a very large odd-even shift. Note that our suggested 7^- member of the 1^- band is consistent with the odd-even shift of

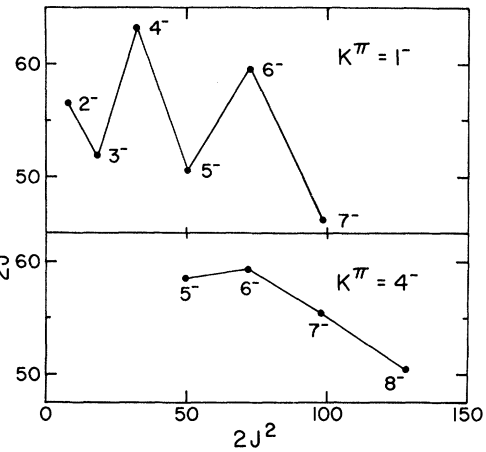

FIG. 4. The rotational band spacing as a function of J^2 for the 1^- and 4^- bands in ^{48}V.

the other members of this band.

If ^{48}V is prolate with $\beta \approx 0.2$, the $d_{3/2}\frac{3}{2}^+[202\downarrow]$ single-particle orbital approaches the $f_{7/2}\frac{3}{2}^-[321\uparrow]$ orbital. When the odd proton is promoted to the low-lying $d_{3/2}\frac{3}{2}^+[202\downarrow]$ orbital and the odd neutron remains in the ground-state $f_{7/2}\frac{5}{2}^-[312\uparrow]$ orbital, a $K^\pi = 1^-$ state is obtained for the triplet p-n coupling and is expected to lie lower in energy than the singlet state.[11] The low-lying 518.7-keV 1^- level in ^{48}V can be identified as this triplet state. The $K^\pi = 4^-$ state at 1099.1 keV then is almost certainly the singlet of this same p-n configuration. (It is interesting to note that the 4^+ ground state can also be fitted into this picture as the triplet coupling of an $f_{7/2}\frac{3}{2}^-[321\uparrow]$ proton with an $f_{7/2}\frac{5}{2}^-[312\uparrow]$ neutron.)

The odd-even shift observed in the 1^- band is well known in odd-odd deformed nuclei. It arises from components in the residual proton-neutron interaction which in ^{48}V caused an odd-even shift in the unseen $\frac{3}{2}^+[202\downarrow]_\pi \frac{3}{2}^-[321\uparrow]_\nu$, $K^\pi = 0^-$ band.[12] This displacement in the 0^- band is transmitted to the 1^- band as a second-order perturbation by the Coriolis interaction. A quantitative treatment of the n-p residual interaction is difficult here because the perturbing 0^- band has not yet been located. Useful data may also be provided by ^{46}V, since the 0^- band should be the lowest-lying odd-parity band if similar deformations exist in that nucleus. The identification of additional triplet-singlet coupling doublets and/or $K^\pi = 0^-$ bands in nuclei in this region should provide further useful tests of the effective residual interaction in light nuclei.

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