COMPLETE $(f_{7/2})^2$ SPECTRUM OF Sc^{42}*

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In a recent Letter[1] it was shown that the $(f_{7/2})$-$(f_{7/2})^{-1}$ particle-hole spectrum of Sc^{48} predicts, via a particle-hole transformation, a degeneracy of the two $(f_{7/2})^2$ states with spins 3 and 5 in Sc^{42} at about 1500 keV in excitation. It was also noted that such a degeneracy would resolve the apparently conflicting results of several experimental attempts to determine the two-body $(f_{7/2})^2$ spectrum of Sc^{42}. Recent results of $Ca^{42}(He^3,t)Sc^{42}$ experiments[2,3] also suggest a doublet at 1.51 MeV. In the present Letter, it is reported that a pair of levels with the probable spins of 3 and 5 have indeed been found at about 1500 keV in Sc^{42}.

A high-resolution study of Sc^{42} has been made by bombarding a 10-μg/cm^2 Ca^{42}-enriched target (on a 5-μg/cm^2 C^{12} backing) with the 26-MeV He^3 beam from the University of Rochester's High Voltage Engineering Corporation model MP tandem Van de Graaff. Emergent tritons were detected on emulsions placed in the focal plane of a new split-pole magnetic spectrograph[4] over the angular range of 10°-50°. A typical spectrum is shown in Fig. 1. A doublet at 1500 keV is now cleanly resolved at the excitation energies of 1498 ± 3 and 1518 ± 3 keV. The peak at 615 keV is shown below to be predominantly due to a state with spin 1. The triton group representing transitions to this state is noticeably broadened on the low-energy side at 35° indicating the presence of an additional lower-energy triton group. This latter group presumably corresponds to the 7^+ state, which has been considered to lie very close to the 1^+ state.[5-7] The contribution of this latter group increases at larger angles until, at 50°, it is comparable with the intensity of the higher-energy group leading to the 1^+ state. At this angle, as shown in the insert to Fig. 1, these two peaks form a group 5 keV wider than the 9-keV resolution observed for single peaks. This would indicate that the 7^+ state lies above the 1^+ state by no more than 9 and no less than 5 keV, a reasonable estimate therefore being 7 ± 2 keV. This agrees with a separation of 6.7 keV determined by a least-squares fit of the data at 35°, 45°, and 50° to a peak shape formed by the sum of two Gaussians. Nelson, Busch, and Plendl[8] recently reported that the 7^+ state lies at 532 keV. In the present study, no triton group corresponding to such an excitation energy is found to exist with a cross section greater than 3% of the peak cross section observed for transitions to the 1518-keV level.

A further high-resolution study of Sc^{42} has been made with the reaction $Ca^{40}(He^3,p\gamma)Sc^{42}$ using the 12.0-MeV He^3 beam from the Argonne National Laboratory tandem Van de Graaff. Emergent gamma rays were detected in a Ge(Li)

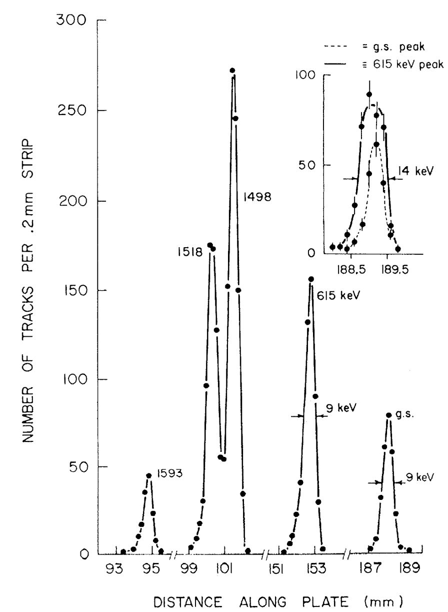

FIG. 1. $Ca^{42}(He^3,t)Sc^{42}$: portion of triton spectrum at 25°. Insert shows broadening of 615-keV group as compared with ground-state group at 50°.

counter at 90° to the scattering plane and in coincidence with protons at 50°. A (616 ± 2)-keV gamma ray was found to be in prompt coincidence with protons leading to Sc^{42} levels lying between 500 and 700 keV in excitation. Though the two states with spins 1 and 7 in Sc^{42} are degenerate at about 600 keV, the 616-keV γ ray determines the 1^+ state to be at 616 ± 2 keV since the 7^+ state decays by β^+ emission and would not be observed in this coincidence measurement. In addition, three gamma rays at 616 ± 2, 884 ± 2, and 894 ± 2 keV were found to be in prompt coincidence with protons leading to Sc^{42} levels lying between 1400 and 1520 keV in excitation; and two gamma rays at 616 ± 2 and 978 ± 2 keV were found to be in prompt coincidence with protons leading to Sc^{42} levels lying between 1560 and 1680 keV in excitation. When the Ge(Li) counter and particle detector are placed at 0° and 176°, respectively, no Doppler shift is observed for the 884- and 894-keV γ rays, while the maximum possible Doppler shift of 10 keV is observed for the 978-keV γ ray. The characteristic stopping time of the recoil Sc^{42} ions in the target is approximately 10^{-12} sec.

The 978-keV γ ray evidently results from the transition between the 1593- and 615-keV levels. Since the 615-keV level and the near-degenerate spin-7 state are the only known states in Sc^{42} lying below 1400 keV in excitation, the 884- and 894-keV γ rays are assumed to feed one or both of these two states. However, the intensities of the 884- and 894-keV γ rays are about equal, and their summed intensity is about twice the intensity of the 616-keV γ ray. Thus, it is reasonable to conclude that the 884- and 894-keV γ rays feed both the spin-1 and spin-7 states approximately equally. This, of course, suggests that these two γ rays come from two different levels at about 1500 keV or from a single level with spin 4. The latter suggestion leads to the assumption of octopole transitions which would be expected to have lifetimes at least two orders of magnitude longer than the 30-nsec resolving time of the coincidence circuit used in this measurement. It is thus concluded that the 884- and 894-keV γ rays result from the decay of the 1498- and 1518-keV levels to the 1^+ and 7^+ state, respectively. Since the energy separation of the two γ rays is 10 ± 2 keV and the energy separation of the 1500-keV doublet is 20 ± 1 keV, the 7^+ must lie 10 ± 2 keV above the 1^+ level. This is quite consistent with the separation of 7 ± 2 keV suggested by the $Ca^{42}(He^3, t)Sc^{42}$ spectra described above. Considered together, the two measurements then yield a value of 624 ± 3 keV for the excitation energy of the 7^+ state.

The 1500-keV doublet is also seen strongly, though unresolved, in the reaction $Ca^{40}(\alpha, d)Sc^{42}$.[5] Since this reaction should strongly populate only isospin-singlet states, at least one member of the doublet must have an odd spin. In addition, one recent study[6] of Sc^{42} by the (He^3, p) reaction suggests that a spin-3 level lies at 1500 keV, while the (α, d) measurements[5] suggest a spin-5 state at 1500 keV. It is therefore suggested that the 1498- and 1518-keV levels most probably have spins 3 and 5, respectively. This is consistent with the relatively more forward-peaked angular distribution of transitions to the lower-lying member of this doublet, as shown in Fig. 2. It is also consistent with the observation of a negligible Doppler shift in γ decay of these two states, since the single-particle transition rates from $E(2)$ transitions would be about 10^{-10} sec.

Observation of the maximum possible Doppler shift for the 978-keV γ ray indicates that the transition is primarily dipole. The 1593-keV level must then have spin 0, 1, or 2. However, the analog to the first 2^+ state in Ca^{42} should fall at about 1500 keV. If, as suggested, the 1498- and 1518-keV levels have spins of 3^+ and 5^+, the 1593-keV level is most prob-

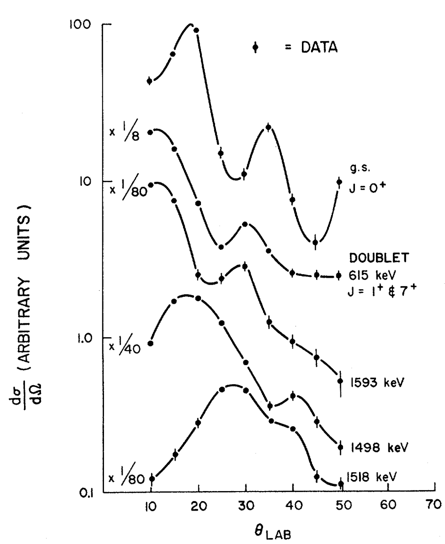

FIG. 2. $Ca^{42}(He^3, t)Sc^{42}$: angular distributions of transitions to levels lying under 1600 keV in excitation.

Table I. Suggested $(f_{7/2})^2$ level scheme in Sc^{42}.

J	E_x (keV)
0	0
1	615
2	1593
3	1498
4	~2800[a]
5	1518
6	~3200[a]
7	625

[a]Energies not experimentally established but approximated values inferred from known analog states in Ca^{42}.

ably the 2^+ state. This is supported by a comparison of the angular distributions shown in Fig. 2, which indicates that the 1593- and 615-keV levels are reached with the same orbital angular-momentum transfer. This may be $l=0$ and/or 2, since the 615-keV peak is predominantly due to the state with spin 1. However, the angular distributions of transitions to these two levels bear no resemblance to that of the $l=0$ transitions to the ground state and, therefore, are presumably $l=2$ transitions. (It is of interest to note that, where two l values can contribute to the angular distributions, the higher l value appears to make the larger contribution in the experimental data.) The final $(f_{7/2})^2$ level scheme suggested for Sc^{42} is shown in Table I.

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TEST OF $M1$-$E2$ MIXING IN THE DECAY OF $2^{+\prime}$ BETA VIBRATIONAL STATES

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The simple intensity predictions of Alaga et al.[1] for the ratios of reduced transition probabilities from a vibrational excited state to different members of the ground-state band are modified when there is mixing of the bands. Nielsen[2] first analyzed data from the decay of gamma vibrational states and found that the experimental data could be fitted with a single mixing parameter Z_2, which is a measure of the rotation-vibration interaction. Initial studies[3] of the beta band in ^{154}Gd indicated that a single value of Z_0 could explain the results there too, but the limits of error were large.

Very recently, however, Riedinger, Johnson, and Hamilton[4] and Liu, Nielsen, Salling, and Skilbried[5] have obtained more accurate gamma-ray intensities in ^{152}Sm and ^{154}Gd with Ge(Li) detectors. The gamma-band results[4,5] are still consistently explained by a single Z_2 for a given nucleus but the beta-band data[4,5] cannot be fitted by a single Z_0 unless the gamma intensity of the $2^{+\prime}\rightarrow 2^+$ transition is reduced by approximately 50%. As suggested by Liu et al.,[5] one is tempted to attribute this to $M1$ radiation, which is allowed by spin and parity selection rules. Such an admixture is forbidden, however, in the characterization of these states as symmetric quadrupole vibrations[6] although such could be allowed if one admixed some $K=1^+$ state in the two bands. There has not been a direct test of the long-standing theoretical prediction[6] that the transitions depopulating the beta vibrational states should be essentially $E2$ as has been verified for the gamma band from γ-γ directional correlation studies (for example, see Debrunner and Kundig[7]). In the gamma bands the $M1$ admixtures in the $2^{+\prime\prime}\rightarrow 2^+$ transitions are of the order of a few percent