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β decay of ^{43}Sc[†]

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The spectrum of γ rays following the β decay of ^{43}Sc has been measured with a 65 cm^3 Ge(Li) detector. β-decay branches to the following states in ^{43}Ca were observed (log*ft* values in parentheses); ground state (5.03), 373 keV (4.97), and 1931 keV (5.66). The last β-decay branch has not been previously reported. In contrast to earlier works, β branches to the 593 ($J^\pi = \frac{3}{2}^-$) and 990 keV ($J^\pi = \frac{3}{2}^+$) levels were not observed and upper limits on these decay branches were obtained.

[RADIOACTIVITY ^{43}Sc[from ^{40}Ca(α, p)]; measured E_γ, I_γ; deduced log*ft*. ^{43}Ca deduced levels, J, π. Ge(Li) detector.]

I. INTRODUCTION

We have investigated the β decay of ^{43}Sc as part[1] of a study of the spectroscopy of ^{43}Ca. Since only states in ^{43}Ca with $J^\pi = \frac{5}{2}^-$, $\frac{7}{2}^-$, or $\frac{9}{2}^-$ can be populated by allowed β decay, a study of this decay might provide additional information about the spin and parity of levels in ^{43}Ca.

The most recent compilation[2] shows only two levels in ^{43}Ca which are populated in the β decay of ^{43}Sc. However, all studies of this decay were carried out prior to 1965 and none utilized a large volume Ge(Li) detector which could reveal weak β or electron-capture branches. In addition we wished to investigate a reported[3] β branch to the 593 keV $\frac{3}{2}^-$ state with a log*ft* value of 4.6, since the existence of an allowed β branch to this state conflicts with its spin assignment.

In brief, our study has revealed a previously unreported β-decay branch to the 1931 keV level in ^{43}Ca which restricts its spin-parity to $\frac{5}{2}^-$ or $\frac{7}{2}^-$. A comparison with model predictions suggests that core excitations are important in the description of this state. The conflict with the spin assignment to the 593 keV level has been resolved since we have not observed such a β branch, and our lower limit on the log*ft* value of this branch is consistent with forbidden decay.

II. EXPERIMENTAL PROCEDURE

Sources of ^{43}Sc were produced via the ^{40}Ca(α, p)-^{43}Sc reaction using a 12 MeV α beam from the University of Pennsylvania tandem accelerator. Targets consisted of approximately 10 mg of natural CaO encapsulated between a 250 μm Ta backing and a 6.3 μm Ta window. Targets were irradiated for periods of between 30 min and 2 h, then counted for similar periods. Two targets were used so that these processes could be carried out simultaneously. Total data accumulation time was about 14 hours. γ rays were detected using a 65 cm^3 Ge(Li) detector used in the antiannihilation arrangement described by van Lieshout *et al.*[4] In addition, to measure the relative intensity of annihilation radiation, a γ spectrum was accumulated with the ^{43}Sc source sandwiched between 6.4 mm thick Plexiglas blocks which stopped positrons near the source. A periodic energy calibration was provided by measuring the ^{88}Y spectrum between irradiations. In addition, room background γ rays from ^{40}Ar ($E_\gamma = 1460.8$ keV) and ^{208}Pb ($E_\gamma = 2614.5$ keV) and a γ ray from a reaction on a target impurity leading to ^{22}Ne ($E_\gamma = 1274.6$ keV) were used as an energy calibration since these were accumulated simultaneously with the data. Other details regarding methods of data accumulation and detector efficiency calibration may be found in a previous report.[5]

III. RESULTS

The higher energy portion of the spectrum of γ rays following the β decay of ^{43}Sc is shown in Fig. 1. γ rays from ^{43}Ca were identified by their energy and by their approximate lifetime. They are labeled in the figure with both their energy in keV and the corresponding transition. Lines from other activities produced in the target and from the room background are labeled by their energy and the nucleus in which the observed γ transition takes place. A summary of the intensities of the observed ^{43}Ca γ rays is presented in Table I. Intensities have been corrected for detector efficiency and are normalized to that of the 373 keV γ ray. It should be noted that the lines above 1 MeV have

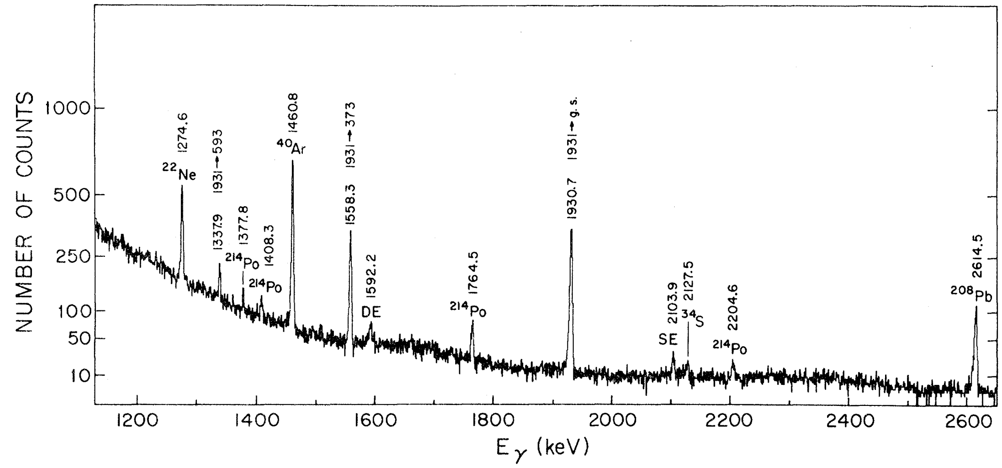

FIG. 1. The spectrum of γ rays emitted following the β decay of ^{43}Sc. The square root of the number of counts is plotted along the y axis and the labeling of the peaks is discussed in the text. The γ rays labeled "SE" and "DE" are the single- and double-escape peaks of the ^{208}Pb γ ray.

not been previously reported in β decay studies. A diagram of levels populated in the β decay of ^{43}Sc is shown in Fig. 2. The level at 593 keV is included only to complete the γ decay scheme. There is no evidence that this level is directly populated in the decay. Transitions in ^{43}Ca are labeled by their observed γ-ray energies and the number of transitions per 100 decays of ^{43}Sc. The 593 to 373 keV transition was too weak to be observed directly and the branching ratio in the figure is taken from Ref. 2. The β-decay and electron-capture branching ratios and the logft values are listed in Fig. 2. The measured γ-ray intensities were used to determine the β-decay branching ratios to excited states. The ground state β-decay branching ratio was deduced from the annihilation radiation intensity, which is twice the positron intensity, after correction for β decays to the first excited state. The calculation of the logft values and the ratios of β-decay to electron-capture rates follows that of Gove and Martin.[6] The adopted value[2] of 3.89 h was used for the ^{43}Sc half-life.

TABLE I. Relative intensities of γ rays from the β decay of ^{43}Sc.

E_γ (keV)	Relative intensity	Identification
372.9± 0.3	100	373→g.s.
511	783± 24	$\gamma^\pm$
593.3± 0.7	$(9.5 \pm 3.2) \times 10^{-3}$	593→g.s.
1337.9± 0.7	$(8.0 \pm 1.0) \times 10^{-3}$	1931→593
1558.3± 0.6	$(3.75 \pm 0.22) \times 10^{-2}$	1931→373
1930.7± 0.6	$(6.72 \pm 0.34) \times 10^{-2}$	1931→g.s.

IV. DISCUSSION

The strong β-decay branches to the ground state and to the first excited state at 373 keV have been reported previously in several investigations.[3,7-10] Our β branching ratios of 77.5% to the ground state

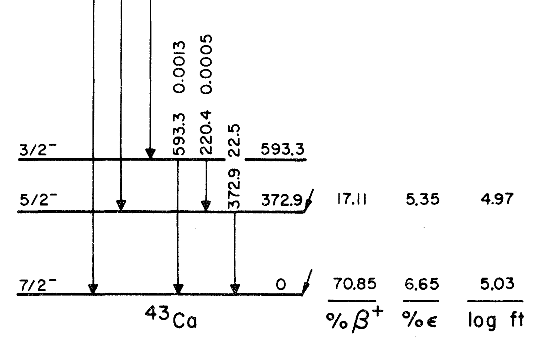

FIG. 2. β-decay scheme of ^{43}Sc. Only levels populated in the β decay are shown except for the 593.3 keV level. Transitions in ^{43}Ca are labeled by their observed γ-ray energies and the number of transitions per 100 decays of ^{43}Sc. The branching ratio for the 593.3 keV state and Q_{EC} are taken from Ref. 2.

and 22.5% to the 373 keV state are in excellent agreement with one of the more recent studies of this decay by Dubois and Broman,[10] who reported branches of 78% and 22%, respectively. The derived log*ft* values of 5.03 ± 0.02 for the ground state and 4.97 ± 0.03 for the 373 keV level indicate allowed decays[11] to these levels. They are thus consistent with the accepted values $J^{\pi} = \frac{7}{2}^{-}$ for the ground state and $J^{\pi} = \frac{5}{2}^{-}$ for the 373 keV state.

Decay branches to other levels have been reported by some workers. In particular, Baskova *et al.*[3] found a 7% branch to a level at 620 keV (presumably the 593 keV level) with a log*ft* value of 4.6 and a weak transition to the 990 keV level with an unspecified log*ft*. Of course, the log*ft* value for the branch to the 593 keV level is incompatible with the $J^{\pi} = \frac{3}{2}^{-}$ assignment to that level. Since $J^{\pi} = \frac{3}{2}^{+}$ for the 990 keV level, the observation of a

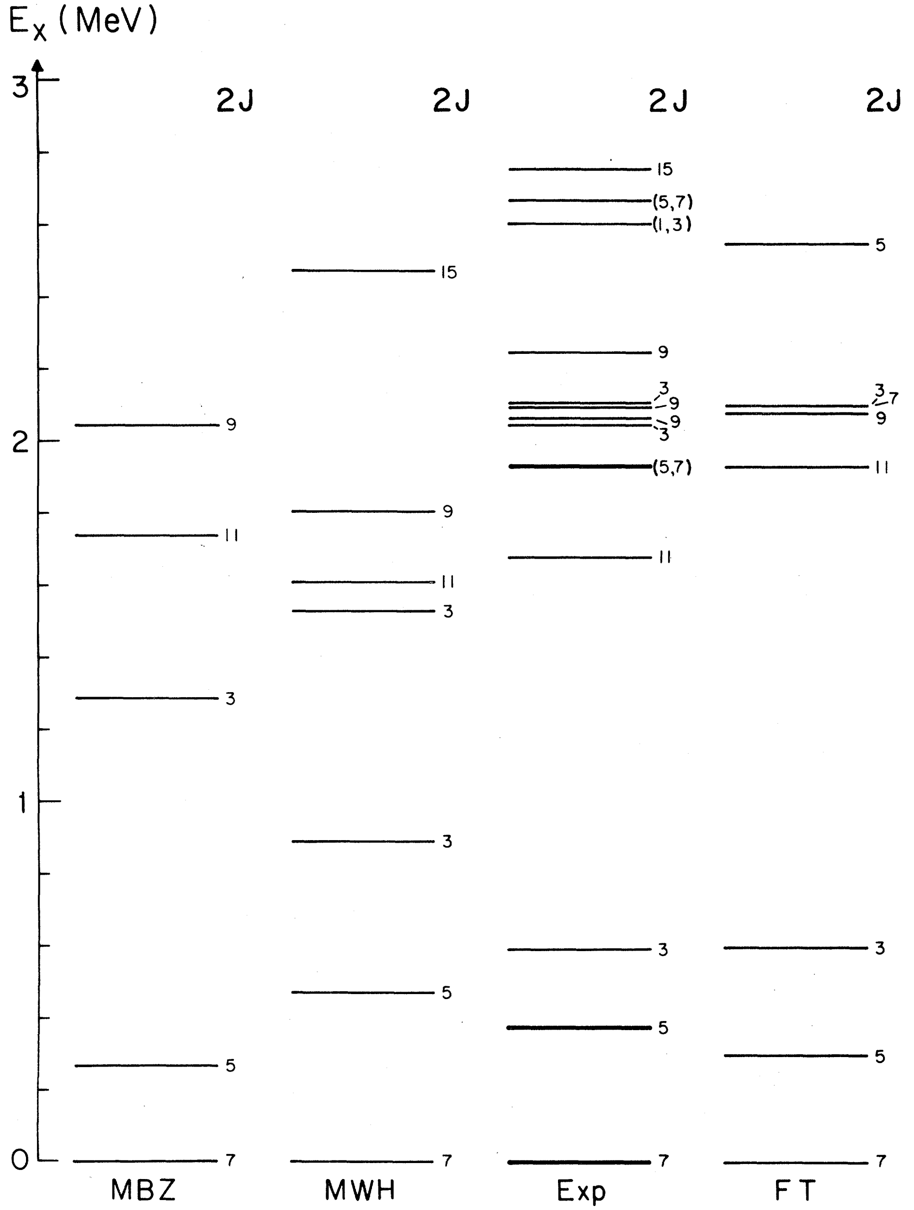

FIG. 3. Calculated and experimental negative-parity energy spectra in ^{43}Ca. All known negative-parity levels below 2.76 MeV are shown in the experimental level scheme. The experimental energies and spins are taken from this work and Refs. 12, 17, and 18. Levels to which β-decay branches have been observed are shown with heavier lines. The calculated energy levels below 3 MeV are taken from Refs. 16 (MBZ), 19 (MWH), and 20 (FT).

branch to it would also be quite surprising. We see no evidence for a direct β branch to the 593 keV state, since the intensity feeding this level from the 1931 keV state and the intensity of 593 keV γ rays are equal within errors. We can place an upper limit of 0.0016% on the β branching ratio to this state ($\log ft > 8.7$). Similarly, there is no evidence for any of the decay branches of the 990 keV level. We obtain an upper limit of 0.0018% for this branching ratio ($\log ft > 8.1$). These limits are consistent with the spin assignments for these states.

The weak electron capture branch to the 1931 keV state has not been reported previously. All three known γ branches are clearly visible in the spectrum, although they are of the same low intensity as room background lines in the shielded Ge(Li) detector. Indeed, the β-decay branching ratio is only about 10^{-3} times as strong as the branch to the 373 keV level. γ branching ratios determined in the present work for the 1931 keV state are $60 \pm 2\%$ to the ground state, $33 \pm 2\%$ to the 373 keV, and $7 \pm 1\%$ to the 593 keV states. These are in excellent agreement with the values reported by Grupelaar and Smulders[12] of $59 \pm 5\%$, $33 \pm 5\%$, and $9 \pm 4\%$ for the same decays. Similarly, our value for the excitation energy of the state of 1931.0 ± 0.4 keV agrees fairly well with their value of 1931.4 ± 0.2 keV.

The derived $\log ft$ value of 5.66 ± 0.03 for the β branch to the 1931 keV state implies an allowed decay to this level and limits J^{π} to $\frac{5}{2}^{-}$, $\frac{7}{2}^{-}$, or $\frac{9}{2}^{-}$. The lifetime measurement reported in Ref. 12 for this level of 0.16 ± 0.04 psec, along with the $1931 \rightarrow 593$ keV branching ratio, rules out $J^{\pi} = \frac{9}{2}^{-}$. Thus $J^{\pi} = \frac{5}{2}^{-}$ or $\frac{7}{2}^{-}$ for the 1931 keV level. The single-nucleon transfer reactions[13-15] provide no further information since the angular distributions to this state do not show a strong direct reaction component.

The ^{43}Ca spectrum calculated by McCullen, Bayman, and Zamick,[16] using only $(f_{7/2})^3$ configurations, is shown in Fig. 3 for comparison with the experimental ^{43}Ca spectrum.[12, 17, 18] The $\log ft$ values for the ^{43}Sc β decay calculated in this model, 4.58 for the $\frac{7}{2}^{-}$ ground state branch and 4.45 for the $\frac{5}{2}^{-}$ 373 keV state branch, are somewhat lower than the measured values.

The pure $(f_{7/2})^3$ model does not predict any state which can be identified with the 1931 keV level in ^{43}Ca, so it is interesting to look for such a state in a large-basis shell-model calculation. Part of the spectrum calculated by McGrory, Wildenthal, and Halbert,[19] using a model space in which all four f-p-shell orbitals are active, is included in Fig. 3. This model also fails to predict a state with spin $\frac{5}{2}^{-}$ or $\frac{7}{2}^{-}$ within 1 MeV of the observed state even though the $\log ft$ value for the β branch to the 1931 keV state indicates a reasonable overlap with the ^{43}Sc ground state. (States with these spins are predicted above 3 MeV.)

Also shown in Fig. 3 is the spectrum calculated by Federman and Talmi[20] using deformed as well as $f_{7/2}$ and $p_{3/2}$ shell-model configurations. They predict a $\frac{7}{2}^{-}$ state at 2.10 MeV and a $\frac{5}{2}^{-}$ state at 2.55 MeV. Either of these might correspond to the 1931 keV level, but the $\frac{7}{2}^{-}$ state is more likely since it lies closer in energy. Thus it would seem that an appreciable amount of core-excited components may be necessary to describe the 1931 keV level. It would be desirable to calculate the β-decay $\log ft$ values and γ-ray transition strengths in this model for further comparison with experiment.

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