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Nuclear Structure of Sc^{43}. III. Lifetimes*

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The mean lifetimes of 15 excited states of Sc^{43} and upper and/or lower bounds for six others have been measured by the Doppler-shift attenuation method. The $Ca^{40}(\alpha, p\gamma)$ and Ca^{42}-(p,γ) reactions were used to populate the levels. For the $(\alpha, p\gamma)$ measurements, γ rays were detected at 90° to the α-particle beam in coincidence with protons detected at +110 and −110°. The Sc^{43} ions were stopped in thick carbon backings, the stopping power of which is known from previous experimental work. For the (p,γ) measurements, γ rays were detected at 0 and 135° to the proton beam. The Sc^{43} ions were stopped in the target material. The results yield the following mean lives, in fsec (with the level energies in MeV given in parentheses): 230 ± 70 (0.846), >620 (0.856), 800 ± 300 (0.880), 3100^{+2700}_{-1200} (1.158), 400 ± 190 (1.179), 850 ± 250 (1.336), 240 ± 50 (1.410), 330 ± 100 (1.651), 22 ± 7 (1.810), 300 ± 50 (1.827), 80 ± 50 (1.885), >800 (1.930), 100 ± 20 (1.963), 410 ± 150 (2.094), 260 ± 70 (2.143), 150 ± 50 (2.580), 80 ± 20 (2.986), <5 (3.289), <10 (3.452), <5 (3.807), and <5 (4.455). The lifetime results for the 1.158- and 1.652-MeV levels are used to remove ambiguities in the measured mixing ratios. All results are compared with theoretical predictions of Johnstone and co-workers.

I. INTRODUCTION

In this report, we present further results in a continuing experimental investigation into the properties of the energy levels of the nucleus Sc^{43}. In earlier papers[1,2] (hereafter referred to as I and II), we reported the results of γ-ray decay scheme studies together with angular-correlation and linear-polarization measurements using the Ca^{42}-$(p,\gamma)Sc^{43}$ reaction to populate the bound levels. Accurate level energies, consistent decay schemes, and definite J^π assignments were obtained for many of the bound levels. Figure 1 contains a summary of the presently available information on the levels in Sc^{43} including the results of the present experiment. We report here the results of lifetime measurements using the Doppler-shift attenuation method (DSAM).

In paper II, all available experimental information on the nuclear properties of the bound levels in Sc^{43} was compared with the predictions of various nuclear models. It was found that neither the conventional shell model[3,4] nor the cluster model[5] could account for the observed properties of Sc^{43}. The Coriolis coupling model[6–8] gives qualitative agreement with experiment; however, quantitative agreement requires modification of the model. Preliminary results[9] of a modified model calculation (one which includes pairing forces) appears to be in better agreement with the experiment. The most successful model is that due to Johnstone and co-workers.[10-12] The odd-parity states, with the exception of a few minor discrepancies, are well described by the model. However, the even-parity states are rather poorly described by the model; particularly those states identified as belonging to the $K^{\pi} = \frac{1}{2}^{+}$ band.

The particular interest in clarifying the nature of the even-parity states as well as supplying additional information on the odd-parity states motivated the present measurement of the mean lifetimes of the bound states in Sc^{43}. These lifetimes will be compared with the model predictions in Sec. V.

Prior to the present investigation, the mean lifetimes of only the first and second excited states were known, they being 630 ± 10 μsec[13] and 227 ± 19 psec,[14] respectively.

This paper reports the results of DSAM measurements which yield lifetime determinations for 15 bound states in Sc^{43} and upper and/or lower limits for six other levels. The levels were populated via the $Ca^{40}(\alpha, p\gamma)Sc^{43}$ and $Ca^{42}(p, \gamma)Sc^{43}$ reactions.

A word of caution concerning DSAM results. Currie, Earwaker, and Martin[15] have measured the lifetime of the first excited state in Si^{30} by DSAM using six different stopping materials. With a starting velocity v/c of approximately 0.9% for the Si ions, the electronic stopping dominates over nuclear stopping, so that stopping theory is expected to work well. However, their results for the various backing materials are only consistent within a factor of 1.5. They conclude that the rms error arising from this source will be at least 15% in a typical measurement. The errors

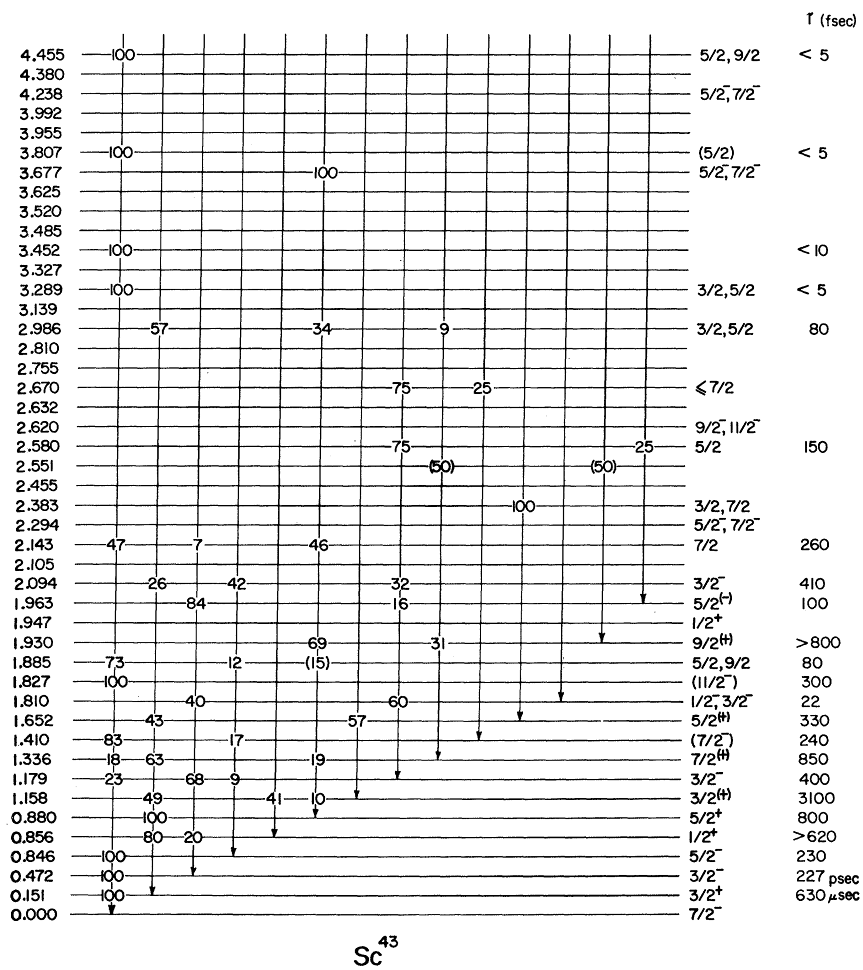

FIG. 1. A summary of the spin-parity assignments and electromagnetic decay properties of all bound levels in Sc^{43} below 4.45 MeV. The figure is from Ref. 2 with the addition of the lifetime results obtained in the present investigation.

quoted for our results reflect this uncertainty.

The experimental procedures are given in Sec. II. Section III deals with data analysis, Sec. IV contains the lifetime results, Sec. V contains a comparison of the results with model calculations, and Sec. VI summarizes the more important aspects of the results.

II. EXPERIMENTAL PROCEDURE

In order to (1) populate as many bound levels as possible and (2) to cover a wide range of lifetime values, both the $(\alpha, p\gamma)$ and (p, γ) reactions were selected. In the following, we discuss them separately.

A. DSAM via $Ca^{40}(\alpha, p\gamma)Sc^{43}$

Coincidence methods were used in these measurements; that is, γ rays were detected in coincidence with particles detected at two different angles. The advantages of this technique over the simpler noncoincidence technique are (1) the level of interest has little or no indirect feeding; (2) the directions of the recoiling nuclei are fixed by the kinematic conditions, so that no strong assumptions about the angular distributions of the reaction products need be made; (3) the γ-ray spectra coincident with each particle detector are taken simultaneously eliminating systematic errors due to electronic drift; and (4) the initial velocity of the ions can be made as high as the accelerator voltage, stopping material thickness, and counting rate permit.

The experimental arrangement is essentially the same as that described by Engelbertink and van Middelkoop,[16] and therefore only details pertaining to this experiment will be given here.

The $Ca^{40}(\alpha, p\gamma)Sc^{43}$ reaction was initiated by the doubly-charged α-particle beam from the Utrecht 2×6-MV tandem Van de Graaff at the energies $E_\alpha = 9.5$ and 11.0 MeV. Currents up to 0.25 μA were obtained on the target.

The targets were prepared by evaporating natural Ca in the form of $CaCO_3$ onto a 214-μg/cm^2-thick carbon backing. Carbon was chosen as the stopping material because the stopping of Sc ions in carbon has been measured.[17] Using a material with known stopping cross section should minimize the uncertainties associated with stopping theory pointed out in Sec. I. The target thickness

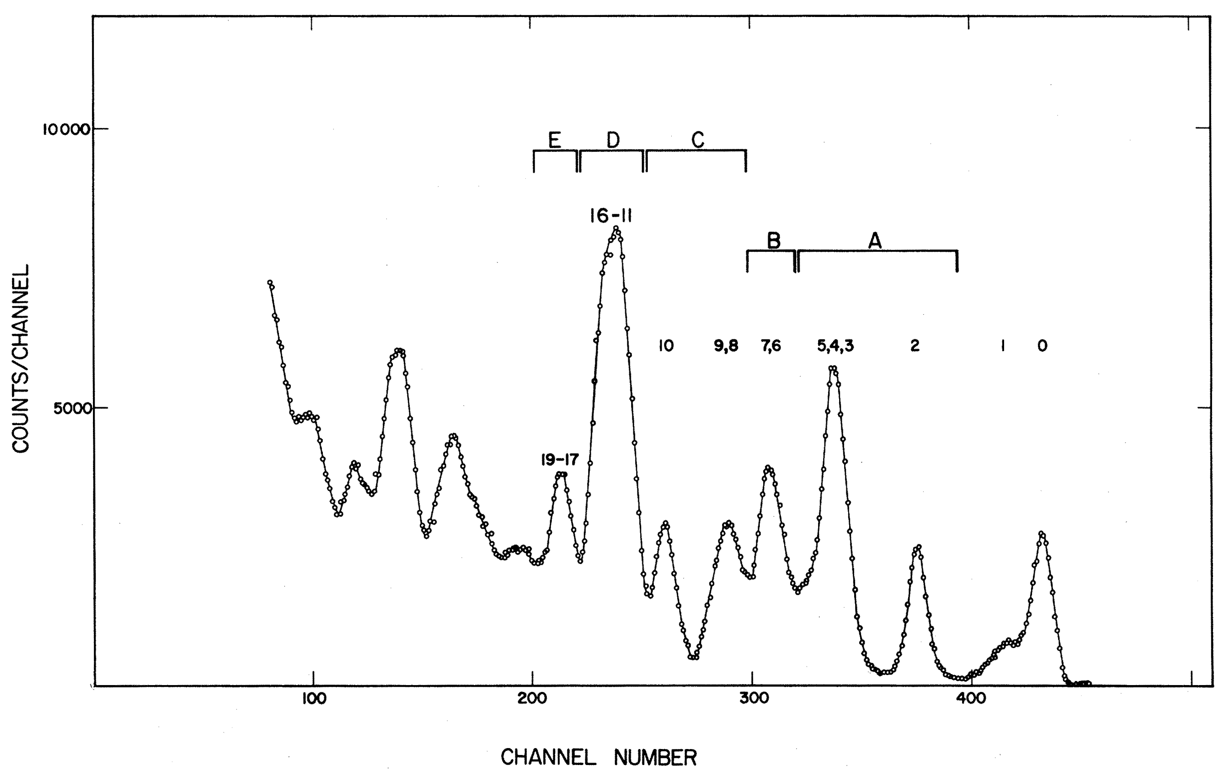

FIG. 2. The proton spectrum observed at $E_\alpha = 11.0$ MeV and $\theta_p = 110°$. A 13.5-mg/cm^2 aluminum absorber was placed in front of the detector. A, B, C, D, and E indicate the respective proton groups for each coincidence measurement. The numbers labeling the various peaks indicate the energy levels populated by the respective proton group (e.g., 2 means the second excited state at 0.472 MeV).

for this experiment was 84 $\mu g/cm^2$ and was in the form CaO. Both the target and backing thicknesses were determined by measuring the energy loss of α particles from a mixed Am^{241} and Cm^{244} source.

The protons were detected with two silicon surface-barrier detectors placed at the angles +110 and $-110°$ with respect to the α-particle beam and at a distance of 33 mm from the target. Rectangular collimators in front of the detectors limited the opening angles to 8.6 and 17° in the horizontal and vertical directions, respectively. The scattered α particles were stopped by a 13.5-mg/cm²-thick Al foil in front of each detector. A typical proton spectrum is shown in Fig. 2. In most cases, the full width at half maximum of 100 keV is not small enough to distinguish the proton groups to separate levels. The proton windows used in the experiment are indicated in Fig. 2 by A, B, C, D, and E.

The γ rays were detected with a 36-cc Ge(Li) detector placed at 90° with respect to the beam direction. The two coincidence γ-ray spectra were simultaneously stored in two 2048-channel subgroups of a 4096-channel analyzer via a routing system. Each total run lasted approximately 14 h, but the spectra were recorded every 2 h and separately analyzed.

For levels up to $E_x = 1.93$ MeV, the measurements were made with a beam energy of $E_\alpha = 9.5$ MeV. The Sc^{43*} ions with an initial velocity of $v/c \approx 0.76\%$ were stopped in the carbon backing having a thickness 30% greater than the projected range of the ions. Because of the low cross section for the higher levels, the experiment was repeated with $E_\alpha = 11.0$ MeV for the levels at $E_x = 1.827$, 1.885, 1.930, 2.094, and 2.143 MeV. For this case, the recoil ions with an initial velocity $v/c \simeq 0.82\%$ can have a projected range which is still 15% smaller than the thickness of the carbon backing.

Additional $Ca^{40}(\alpha, p\gamma)$ DSAM measurements were performed using the University of Kentucky Van de Graaff accelerator with a beam energy of $E_\alpha = 8.8$ MeV. Noncoincident techniques were used to measure the Doppler shift of the γ rays due to Sc^{43} ions recoiling into a 600-$\mu g/cm^2$ Au backing. The γ-ray singles spectra were measured with a 35-cc Ge(Li) detector placed at 0 and 138° with respect to the beam direction.

B. DSAM via $Ca^{42}(p, \gamma)Sc^{43}$

The $Ca^{42}(p, \gamma)Sc^{43}$ reaction was initiated by the proton beam from the Aerospace Research Laboratories (ARL) 2-MeV Van de Graaff accelerator. The average beam current used in most of the present work was approximately 30 μA.

Targets were prepared from samples of $CaCO_3$ enriched in Ca^{42}.[18] The enriched $CaCO_3$ was evaporated onto a 10-mil-thick Ag target backing which was soldered onto a 0.0625-in.-thick brass cooling disk. Target thicknesses were typically 15–20 keV for 1.5-MeV protons to insure that the recoil ions were stopped in the target material. In addition, care was taken to insure that the beam energy was always on the low-energy side of the thick-target excitation curve for each resonance studied. The final chemical form of the target material was CaO.

The γ rays were detected at 0 and 135° relative to the incident beam direction in a 38-cc Ge(Li) detector which had an energy resolution <2.5 keV for the Co^{60}, 1.33-MeV line. The spectra were recorded in a 4096-channel pulse-height analyzer. Special care was taken to correct for electronic drifts during individual runs by monitoring the energy dispersion and stability of the detector system with at least four radioactive source lines distributed over the entire energy range of the individual γ-ray spectra. The sources used were Cs^{137}, Co^{60}, Na^{22}, Bi^{209}, and Th^{228}. Several runs were made for each of the resonances studied and analyzed separately. The total time for each run was kept to a minimum to avoid electronic shifts that occur as a function of time.

III. SPECTRA ANALYSIS

The stopping of heavy ions in matter has been treated by Lindhard, Scharff, and Schiott[19] and by Blaugrund.[20] From the observed shift, the value of the function $F(\tau)$ defined by

$$E = E_0 \left[1 + \frac{v_0}{c} F(\tau) \cos\theta\right]$$

can be obtained. Here, E_0 is the energy of the γ ray emitted at 90° to the recoil ion direction, v_0 the initial velocity of the Sc^{43} ions, c the velocity of light, θ the angle between the recoil direction and the γ-ray direction, and τ the mean lifetime.

The stopping cross section of Sc ions in carbon has been measured by Hvelplund and Fastrup.[17] The electronic stopping power is given by

$$\frac{d\epsilon}{dp} = k\epsilon^p \text{ with } p = 0.5 .$$

The dimensionless energy ϵ and the distance ρ are defined in Ref. 20, while k is given by

$$k = 0.0793\xi_e \frac{Z_1^{1/2} Z_2^{1/2} (A_1 + A_2)^{3/2}}{(Z_1^{2/3} + Z_2^{2/3})^{3/4} A_1^{3/2} A_2^{1/2}},$$

where the indices 1 and 2 refer to the ion and the stopping material, respectively. Based on the data of Ref. 17, ξ_e can be approximated by

$$\xi_e = 2.65 - 101.6v/c$$

for the stopping of Sc ions in carbon. The experimental work of Ormrod, McDonald, and Duckworth[21] shows that ξ_e is independent of Z_2. Therefore, this same expression is used for the stopping of the Sc ions in the CaO target material.

The formulas outlined above apply to both the $(\alpha, p\gamma)$ and (p,γ) work. However, we have exploited the fact that the high initial recoil velocity ($v/c \simeq 0.8\%$) obtained in the $(\alpha, p\gamma)$ work makes this reaction ideal for long lifetimes ($\tau > 0.2$ psec), while the low velocity ($v/c \simeq 0.15\%$) obtained in the (p,γ) work is ideal for short lifetimes. In the following, specific features of the analysis used for both reactions will be discussed separately.

A. $Ca^{40}(\alpha, p\gamma)Sc^{43}$ Spectra

Before evaluating the centroid position of the observed peaks, a background determined at the high-energy side of the peak was subtracted. The energy dispersion was measured with Co^{60} and Y^{88} sources before and after each measurement. For each run, consisting of from five to eight different spectra, the final energy shift was computed as a weighted average of the separate shifts. The external or spread error was of approximately the same magnitude as the internal or statistical error. The error quoted for the observed shift is the larger of the two.

In computing the attentuation curve, it was assumed that the recoil ions were stopped in two media: first, a slowing down in the 84-μg/cm^2 CaO target material, and second, complete stopping in carbon.

The experimental $F(\tau)$ values were determined using the method described in Ref. 16. A 1.2% correction has been applied to the full shift to account for the solid angle of the Ge(Li) detector. The correction due to the solid angle of the particle detector was small (<1%) and was therefore neglected. In addition, the contribution of a possible particle angular distribution or a γ-ray angular correlation over the small solid angle of the detectors was assumed to be negligible.

B. $Ca^{42}(p,\gamma)Sc^{43}$ Spectra

The resonances were selected such that the level in question was strongly excited directly from the resonance. In addition, no resonances were

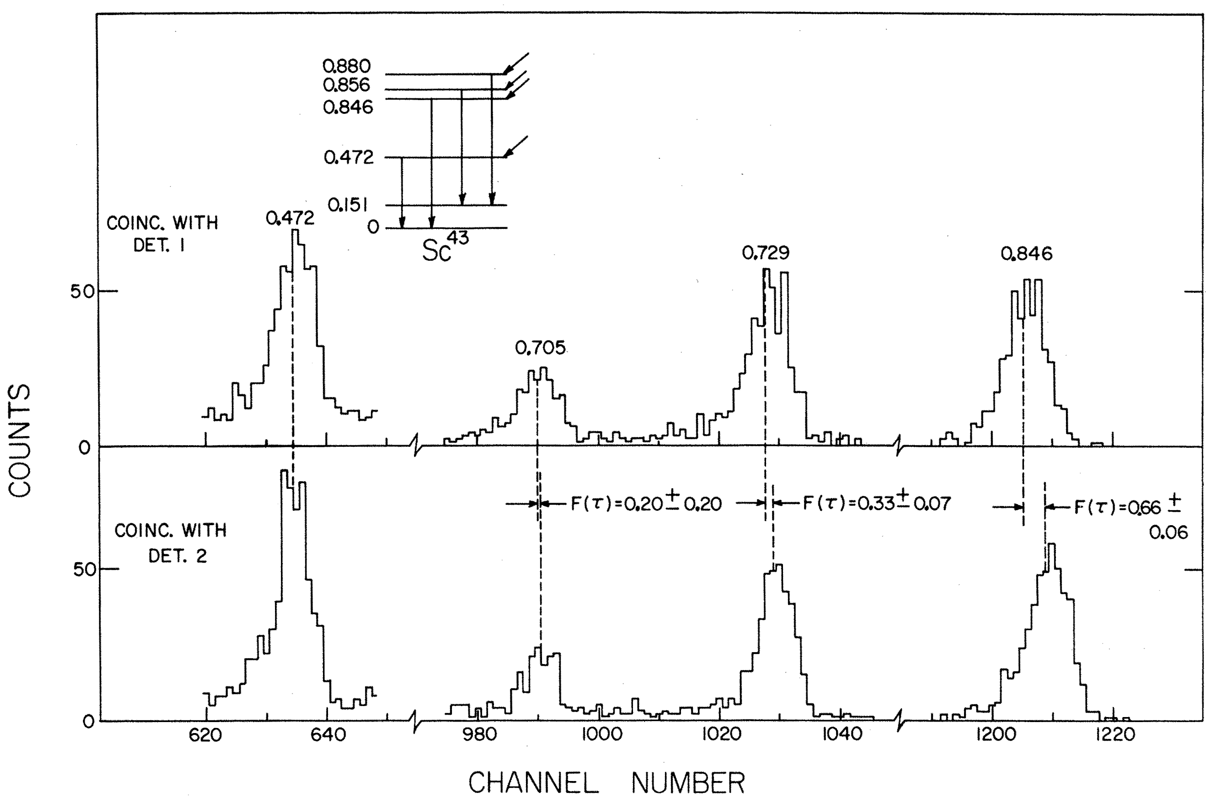

FIG. 3. The γ-ray spectra coincident with the proton groups from window A (see Fig. 2) observed at the energy $E_\alpha = 9.5$ MeV.

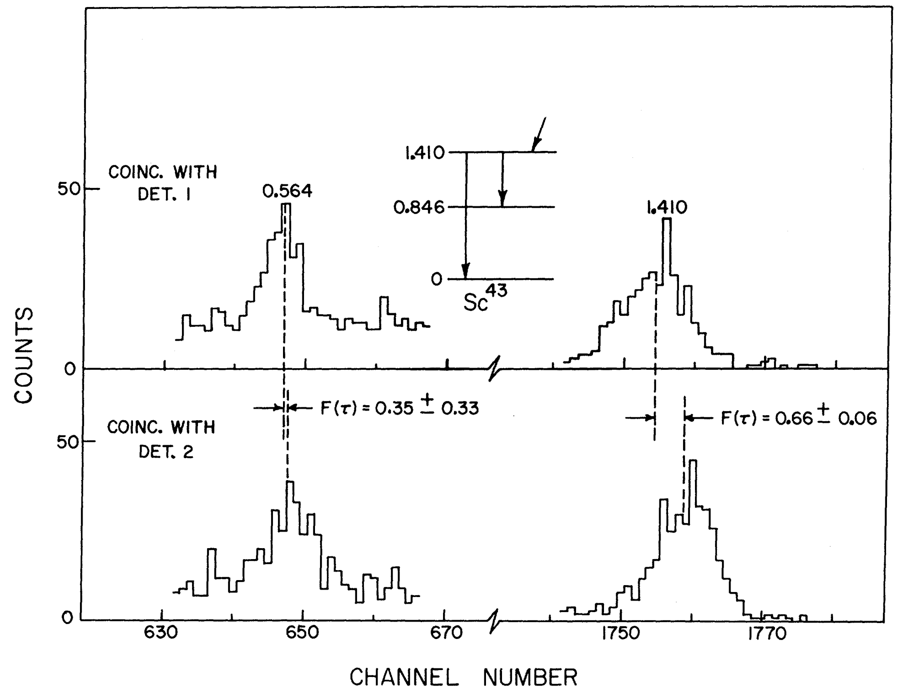

FIG. 4. The γ-ray spectra coincident with the proton group to the $E_x = 1.410$-MeV level observed at the energy $E_\alpha = 9.5$ MeV.

used where the level of interest was excited by more than a 10% secondary feeding compared to the primary feeding. Therefore, no correction was applied for the lifetime of the possible intermediate states which may feed the level of interest. The observed shift of the primary γ ray served as a calibration of the estimated full shift.

The measured centroid shift for the lines of interest in each run were corrected for any shift observed in the standard source lines. The correction due to the solid angle of the Ge(Li) detector was calculated to be <2% and was therefore neglected.

The attenuation curve was calculated according to the formulas outlined above. The target was assumed to be CaO with a density of 3.08 g/cm^3.

IV. RESULTS

A. $Ca^{40}(\alpha, p\gamma)Sc^{43}$

The measured coincident γ-ray spectra for the levels at $E_x = 0.472$, 0.846, 0.856, and 0.880 MeV are shown in Fig. 3. The 0.472-MeV level is known to have a long lifetime (227 ± 19 psec), so that one would expect to see no shift in the energy of the 0.472-MeV γ ray if the present measuring technique is correct. It is clear from the data shown in Fig. 3 that this is indeed the case. Figures 4, 5, and 6 show the coincident γ-ray spectra for the levels at $E_x = 1.410$, 1.885, and 1.930 MeV, respectively.

The results of this experiment are presented in Table I. For some levels, the lifetime was obtained from two different transitions so the final lifetime given is a weighted average. The good agreement between the lifetime values obtained

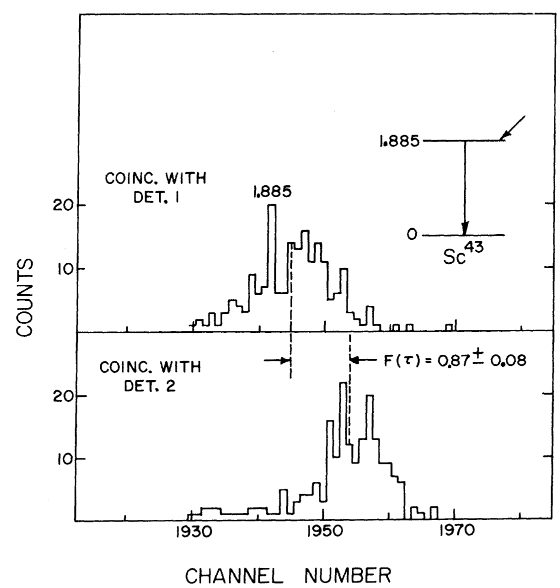

FIG. 5. The γ-ray spectra coincident with the proton group to the $E_x = 1.885$-MeV level observed at the energy $E_\alpha = 11.0$ MeV.

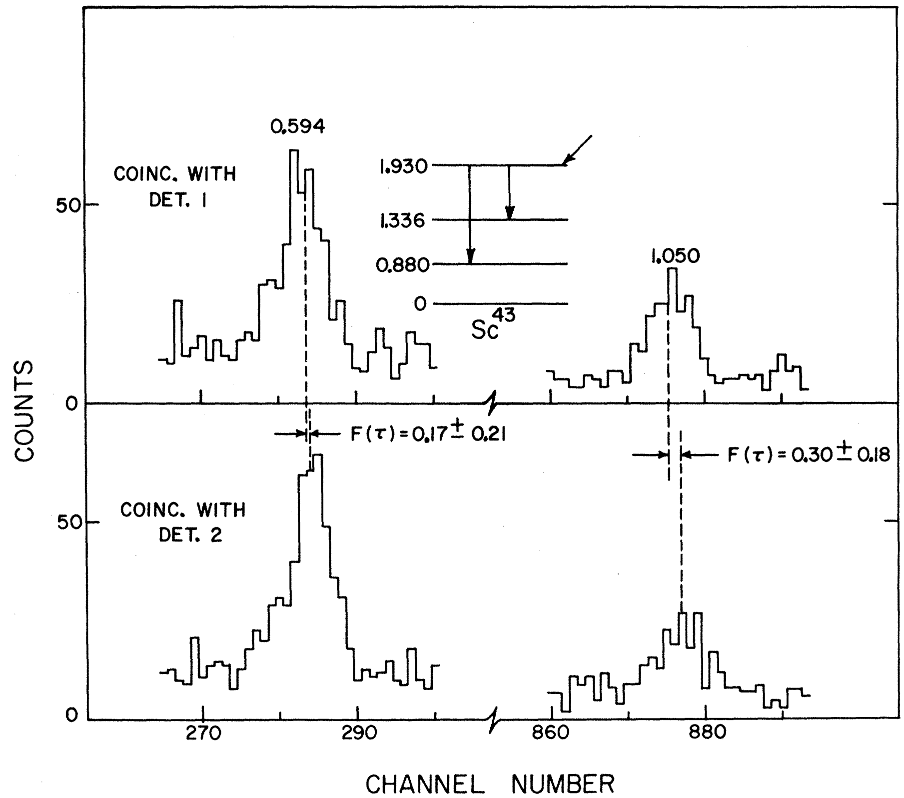

FIG. 6. The γ-ray spectra coincident with the proton group to the E_x=1.930-MeV level observed at the energy E_α=11.0 MeV.

TABLE I. Values or limits for the mean lifetime of Sc^{43} levels populated via the $(\alpha, p\gamma)$ reaction.

Transition E_i (MeV)	E_f (MeV)	E_α (MeV)	Doppler shift (keV)	$F(\tau)$	Lower limit	τ_{exp} (fsec)	Upper limit
0.472	→0	9.5	−0.18±0.23	−0.09±0.12		>110 00	
0.846	→0	9.5	2.23±0.19	0.66±0.06	190	240	295
0.856	→0.151	9.5	0.56±0.55	0.20±0.20		>620	
0.880	→0.151	9.5	0.96±0.20	0.33±0.07	620	810	1080
1.158	→0.151	9.5	0.42±0.22	0.11±0.06	1850	3050	6700
1.179	→0	9.5	1.22±1.44 }	0.46±0.10	340	490	720
	→0.472	9.5	1.31±0.29 }				
1.336	→0.151	9.5	1.40±0.32	0.32±0.07	630	840	1180
1.410	→0	9.5	3.47±0.31 }	0.66±0.06	195	240	295
	→0.846	9.5	0.74±0.69 }				
1.652	→0.151	9.5	3.22±0.55	0.60±0.10	200	295	420
1.827	→0	9.5	5.19±1.13	0.81±0.18	8	115	265
	→0	11.0	4.68±0.44	0.62±0.06	245	305	370
1.885	→0	9.5	6.60±0.49	1.02±0.08		<30	
	→0	11.0	6.75±0.62	0.87±0.08	30	83	143
1.930	→0.880	9.5	0.85±0.82	0.24±0.23	480	1200	∞
	→0.880	11.0	1.31±0.80 }	0.21±0.14	820	1520	5400
	→1.336	11.0	0.41±0.53 }				
2.094	→0.846	11.0	2.42±0.52	0.48±0.10	340	490	710
2.143	→0.880	11.0	3.27±0.68	0.65±0.13	150	275	440

for the levels at $E_x = 1.827$, 1.885, and 1.930 MeV at the two different bombarding energies clearly demonstrates the internal consistence of the data.

The results obtained from the noncoincident measurements are in agreement with the lifetimes given in Table I. However, these results have somewhat larger uncertainties, and are therefore not given.

B. $Ca^{42}(p,\gamma)Sc^{43}$

The data for the levels at $E_x = 1.810$ and 1.963 MeV are shown in Figs. 7 and 8, respectively. The source lines were included in the figures to indicate the magnitude of the corrections required due to drifts in the electronic system.

The results of this experiment are presented in Table II. For some levels, the lifetime was obtained from two different transitions so the final lifetime given is a weighted average.

For the levels at $E_x = 0.846$, 1.179, 1.652, 2.094, and 2.143 MeV, the lifetimes were obtained in both the $(\alpha, p\gamma)$ and the (p,γ) work. The agreement between the two experiments is good.

V. DISCUSSION

A summary of the lifetime results obtained in the present work together with theoretical predictions of Johnstone and co-workers is presented in Table III. An average value is given when more than one measurement is available.

The measured lifetimes can be used to remove the ambiguities in the γ-ray mixing ratios for some of the transitions reported in II (see Table III). For the transition $1.158 \rightarrow 0.880$, only the mixing ratio $\delta = -0.23 \pm 0.20$ is consistent with the measured lifetime. The alternate solutions ($\delta = -22.9$ or >5.7) require $E2$ enhancement factors in excess of 2000 W.u. (Weisskopf units). In the case of the transition $1.158 \rightarrow 0.856$, only the mixing ratio $\delta = -0.19 \pm 0.20$ is consistent with the lifetime. The alternate solution ($\delta = 2.9$) requires an $E2$ enhancement factor of ~3000 W.u. Finally, for the transition $1.652 \rightarrow 1.158$, only the mixing ratio $\delta = 0.00 \pm 0.20$ is consistent with the lifetime results. The alternate solution ($\delta = 2.4$) requires an $E2$ enhancement factor is excess of 2000 W.u. The mixing ratio ambiguities reported for other

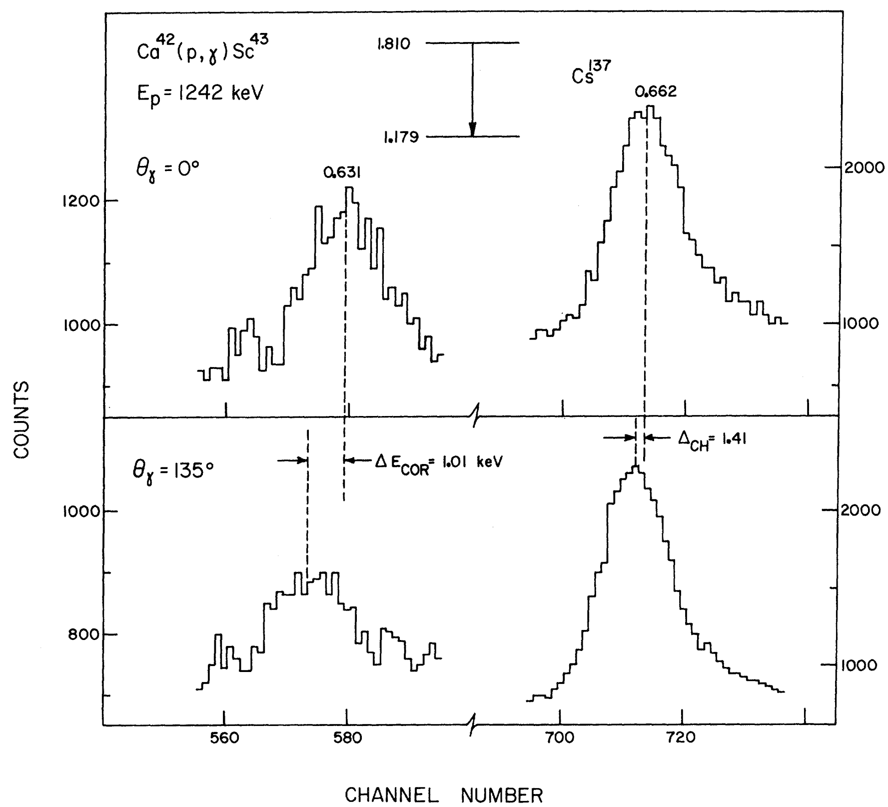

FIG. 7. The 0.631-MeV γ ray from the transition $1.810 \rightarrow 1.179$ MeV and the 0.662-MeV Cs^{137} γ ray observed at 0 and 135°. The quantity Δ_{CH} is the channel shift of the centroid observed for the standard line, and ΔE_{COR} is the energy shift of the 0.631-MeV γ ray corrected for the observed standard line.

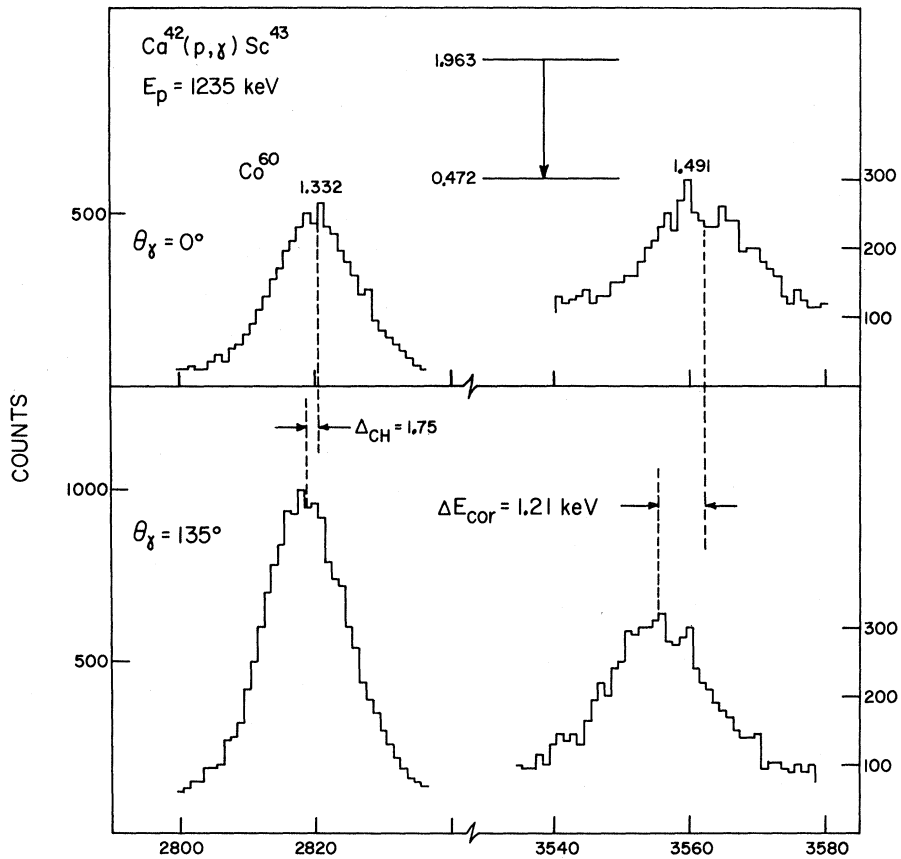

FIG. 8. The 1.491-MeV γ ray from the transition 1.963 → 0.472 MeV and the 1.332-MeV Co^{60} γ ray observed at 0 and 135°. The quantity Δ_{CH} is the channel shift of the centroid observed for the standard line, and ΔE_{COR} is the energy shift of the 1.491-MeV γ ray corrected for the observed shift of the standard line.

TABLE II. Values or limits for the mean lifetimes of Sc^{43} levels populated via the (p,γ) reaction.

Transition E_i (MeV)	E_f (MeV)	E_p (keV)	Doppler shift (keV)	$F(\tau)$	Lower limit	τ_{exp} (fsec)	Upper limit
0.846	→0	1242	0.34 ± 0.11	0.19 ± 0.06	170	236	365
	→0	2037	0.55 ± 0.08	0.25 ± 0.02	194	210	220
1.158	→0.151	1235	0 ± 0.13	0.00 ± 0.06			
1.179	→0	1242	0.34 ± 0.11	0.14 ± 0.04	250	335	470
1.652	→0.151	1235	0.39 ± 0.11	0.13 ± 0.03	280	365	470
1.810	→0.472	1242	1.01 ± 0.18	0.78 ± 0.14	7	20	37
	→1.179	1242	2.07 ± 0.18	0.75 ± 0.07	15	23	32
1.963	→0.472	1235	1.11 ± 0.12	0.36 ± 0.04	90	103	120
	→0.472	1235	1.21 ± 0.22	0.38 ± 0.08	70	96	130
2.094	→0.151	1242	0.57 ± 0.18	0.14 ± 0.05	235	335	540
2.143	→0.880	1423	0.53 ± 0.11	0.19 ± 0.04	196	248	332
2.580	→1.179	1235	0.80 ± 0.18	0.28 ± 0.06	110	145	195
2.986	→0.151	1242	2.56 ± 0.36	0.44 ± 0.06	62	77	93
3.289	→0	1242	7.04 ± 0.36	1.00		<5	
3.452	→0	1423	7.21 ± 0.36	0.94 ± 0.05	1	<10	10
3.807	→0	1242	7.89 ± 0.36	1.00		<5	
4.455	→0	2037	12.9 ± 0.41	1.00		<5	

transitions could not be removed on the basis of the present lifetime measurements.

As was reported in II, theory successfully accounts for the observed properties of most of the negative-parity states (see Fig. 1). However, the predicted lifetimes for the lowest $\frac{5}{2}^-$ state (0.846 MeV) and the lowest possible $\frac{7}{2}^-$ state (1.410 MeV) are not in agreement with experiment. This is particularly disturbing in the case of the 0.846-MeV level since all other predicted decay properties for the level agree with experimental results; the predicted decay properties for these levels are, however, fairly sensitive to the 5p-2h (five-particle–two-hole) admixtures. The situation for the $J^\pi = \frac{3}{2}^-$ states is much better. The agreement between predicted and observed lifetime values for the $J^\pi = \frac{3}{2}^-$ levels at $E_x = 0.472$ and 1.179 MeV indicates that the description of these states, and presumably the ground state, is in the main correct.

The agreement between predicted and observed lifetime values for the levels at $E_x = 1.810$ and 1.827 MeV tends to support the tentative $J^\pi = \frac{1}{2}^-$ and $\frac{11}{2}^-$ assignments. According to the Johnstone model description of these states, the lifetime values are not very sensitive to the amount of 5p-2h admixtures, and therefore, a large difference between the predicted and observed lifetimes would have introduced serious complications.

The large difference between the predicted and observed lifetime for the 1.885-MeV level is not too surprising. Earlier work (see II) indicated that it is probably a poor approximation to describe this state with a pure 5p-2h configuration. The $(fp)^3$ $J^\pi = \frac{9}{2}^-$ state predicted to lie a few hundred keV higher than the 1.885-MeV level could mix with this 5p-2h state and enhance the $M1$ transition to the ground state.

Previous work (see II) has clearly shown serious discrepancies in the description of the positive-parity states (see Fig. 1). The lifetime measurements seem to have increased the distance between experiment and theory. The predicted decay properties of those states identified with $K^\pi = \frac{1}{2}^+$ band structure are in serious disagreement with experiment. A measurement of the lifetime of the 0.856-MeV ($J^\pi = \frac{1}{2}^+$) level would be useful in determining the exact nature of these states.

The apparent agreement reported in II betw en the predicted and observed decay properties for those states identified with a $K = \frac{3}{2}^+$ band structure is not reflected as well in the lifetime results. The most disturbing aspect of the lifetime results is the rather large discrepancy between the predicted and observed lifetime of the 0.880-MeV level, since one expects it to be a good $K^\pi = \frac{3}{2}^+$ band state. To help clarify the nature of the $K^\pi = \frac{3}{2}^+$ band states it would be useful to determine the decay properties of the 2.551-MeV level since, presumably, this state belongs to $\frac{3}{2}^+$ band. This state is predicted to have $J^\pi = \frac{11}{2}^+$ and $\tau \sim 1$ psec. (For other predicted decay properties, see II.)

The measured lifetime and ground-state ($\frac{7}{2}^-$) branching ratio for the $J^\pi = \frac{7}{2}^+$ level at $E_x = 1.336$ MeV gives an $E1$ retardation of ~10^4. This is a weak $E1$ but significantly stronger than the $0.472(\frac{3}{2}^-) \rightarrow 0.151(\frac{3}{2}^+)$ $E1$ transition. An additional $E1$ retardation factor could be obtained from a measurement of the lifetime of the 0.856-MeV level and the branching ratio for the transition $0.856(\frac{1}{2}^+) \rightarrow 0.472(\frac{3}{2}^-)$. In this way, average $E1$ retardation factors in $f_{7/2}$ shell nuclei could be obtained.

TABLE III. Experimental values for the mean lifetimes of bound levels in Sc^{43} together with the values predicted by the Johnstone model.

E_x (MeV)	τ_{exp} (fsec)	τ_{theory} (fsec)
0.151	630 ± 10 μsec	
0.472	227 000 ± 19 000 [a]	230 000
0.846	230 ± 70	1600
0.856	>620	24 000
0.880	800 ± 300	5000(3100) [b]
1.158	3100^{+2700}_{-1200}	2500
1.179	400 ± 190	500
1.336	850 ± 250	2000(2000) [b]
1.410	240 ± 50	1300
1.652	330 ± 100	120
1.810	22 ± 7	20
1.827	300 ± 50	300
1.885	80 ± 50	900
1.930	>800	3200(2300) [b]
1.963	100 ± 20	
2.094	410 ± 150	
2.143	260 ± 70	1220
2.580	150 ± 50	
2.986	80 ± 20	
3.289	<5	
3.452	<10	
3.807	<5	
4.455	<5	

[a]Taken from Ref. 14.

[b]The numbers in parentheses are values obtained if one uses a $d_{3/2}$-$s_{1/2}$ gap of 2.54 MeV. All other lifetimes for positive-parity states have been calculated for a $d_{3/2}$-$s_{1/2}$ gap of 1.00 MeV.

VI. CONCLUSION

In the investigation, the mean lifetimes of 15 bound levels in Sc^{43} and upper and/or lower bounds for 6 others have been measured. The results obtained in this work together with the results reported in I and II were used to test the validity of the Johnstone model. The model appears to be quite successful in describing the properties of the negative-parity states, which is remarkable since the original intent of the model was to be more qualitative than quantitative. It seems clear that the description of the negative-parity states as $(fp)^3+(5p\text{-}2h)$ states is basically correct, and that more refined quantitative work should be possible. The poor agreement between theory and experiment for the $K^\pi=\frac{1}{2}^+$ and $\frac{3}{2}^+$ band states indicates that more theoretical work is required to achieve a satisfactory description of these states; it may be necessary to obtain more experimental data on Ti^{44} before a complete theoretical description of the positive-parity states in Sc^{43} can be realized.

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