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High-spin states in ^{44}Ti and ^{44}Sc†

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We have investigated high-spin states in ^{44}Ti and ^{44}Sc with the ^{28}Si(^{19}F, $p2n\gamma$)^{44}Ti and ^{28}Si(^{19}F, $2pn\gamma$)^{44}Sc reactions at 45–55 MeV. Angular distribution, linear polarization, and γ-γ coincidence data on the emitted γ rays allowed us to construct decay schemes for states in ^{44}Ti and ^{44}Sc, and to suggest likely spin and parity assignments for most of these states. In each case, positive parity levels with spins up to the maximum value permitted within a $(f_{7/2})^4$ shell-model space were populated. Results of lifetime measurements for several of these states are given, and a comparison is presented of the level energies and some transition strengths to the predictions of shell-model calculations.

[NUCLEAR REACTIONS ^{28}Si(^{19}F, $p2n\gamma\gamma\cdots$), E=45–55 MeV, ^{28}Si(^{19}F, $2pn\gamma\gamma\cdots$), E=45–45 MeV; measured $\gamma\gamma$ coin.; deduced levels in ^{44}Ti, ^{44}Sc; measured $\sigma(E_\gamma, \Theta)$ and P_γ; deduced J^π for high-spin levels; measured recoil distance; deduced $T_{1/2}$, $B(E2)$, effective charges. Natural targets, Ge(Li) detectors.]

I. INTRODUCTION

In a recent letter[1] Simpson, Dixon, and Storey suggested that the energy levels of the ground-state band in ^{44}Ti, and the intraband $E2$ transitions, are very well described by an asymmetric-rotor model with asymmetry parameter $\gamma \sim 20°$. Such quasirotational behavior might at first be expected in view of the fact that ^{44}Ti occupies a position in the f-p shell analogous to that of the well-known rotational nucleus ^{20}Ne in the s-d shell; i.e., both consist of an "α particle" outside a closed core. However, Bhatt and McGrory[2] have shown that single-particle energies, and in particular the location of the $p_{3/2}$ single-particle state relative to the $f_{7/2}$ state, are crucial to the formation of rotational bands in ^{44}Ti, and they concluded that it should not display a rotational spectrum. As a matter of fact, the shell-model calculation of McCullen, Bayman, and Zamick[3] (MBZ) does reasonably well in accounting for the location of the states in the ^{44}Ti ground band, as illustrated in Fig. 1, though it includes only the $(f_{7/2})^4$ configuration. The present experiment was prompted by the question of whether the asymmetric-rotor model or the MBZ shell-model calculations gives a more accurate description of the higher-spin states in the ground-state band. To answer this question, we investigated the γ radiation produced from ^{19}F + ^{28}Si at 45–55 MeV incident ^{19}F energy. This is a very prolific reaction yielding 195 discrete γ rays between 105 and 4020 keV[4] of which 10 have been identified with transitions in ^{44}Ti, and 23 with transitions in ^{44}Sc, which will also be discussed in this communication. The techniques used to identify these γ rays have been presented in previous papers.[5,6] The most intense of these γ rays were also observed via the ^{27}Al(^{19}F, $2n$)^{44}Ti and ^{27}Al(^{19}F, np)^{44}Sc reactions.[4]

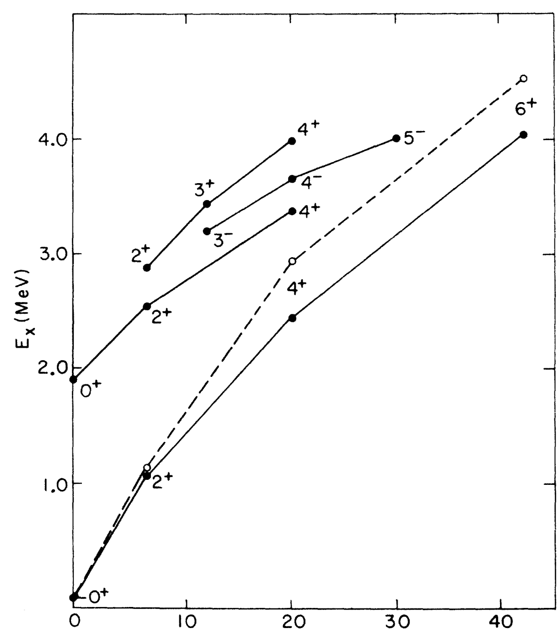

FIG. 1. Low-lying quasirotational bands in ^{44}Ti from Ref. 1 (closed circles connected by solid lines). The open circles connected by dashed lines are the prediction of MBZ (Ref. 3).

II. ^{44}Ti

Typical γ-γ coincidence spectra for transitions in ^{44}Ti are shown in Fig. 2. These data establish the existence of three new levels above the well-known 6^+ state at 4015 keV. The angular distributions (Table I) and linear polarizations[7] of the three new γ rays are consistent with stretched $E2$ transitions and thus yield most likely J^π assignments of (8^+), (10^+), and (12^+) to the states at 6508, 7671, and 8040 keV, respectively. These multipolarities and spin assignments are also consistent with the "ratio test" for stretched $E2$ transitions.[8] Given the experimental angular distributions, which are characteristic of $J \pm L \rightarrow J$ transitions of multipolarity L, the γ-γ coincidence data is usually sufficient to rule out $\Delta J = 0$ for dipole transitions and $\Delta J = \pm 1$ for quadrupole transitions, for any quadrupole/dipole mixing ratio, under the assumption of a Gaussian substate distribution in the population of the initial γ-emitting level via the fusion-evaporation reaction. We then select the most likely spin on the basis of the fact that yrast states are selectively populated in these reactions.[5] These are clearly not rigorous arguments so we have enclosed our spin assignments in parentheses in conformity with past practice.[5,6]

With the J^π assignments suggested above, it is at once clear that the excitation energies of the levels in the ^{44}Ti ground-state band do not continue to follow the quasirotational prediction above the 6^+ state. In fact, the pattern breaks down immediately with the 8^+ state which is more than 500 keV above its expected position. Thereafter, the transition energies rapidly decrease from 2.5 MeV for the $8^+ \rightarrow 6^+$ transition to less than 400 keV for the $12^+ \rightarrow 10^+$ transition. Interestingly enough, this is exactly the behavior expected from the MBZ shell-model calculations (Fig. 3). From this point of view, a measurement of the electromagnetic transition matrix elements for the new states is of some interest. Unfortunately, because of the rather small side feeding to states below the 12^+ level, all of the ground band transitions display the lifetime appropriate to the $12^+ \rightarrow 10^+$ transition, and this transition is too slow to be accurately measured with our recoil-distance techniques.[5,6] However, we have been able to determine a lower lim-

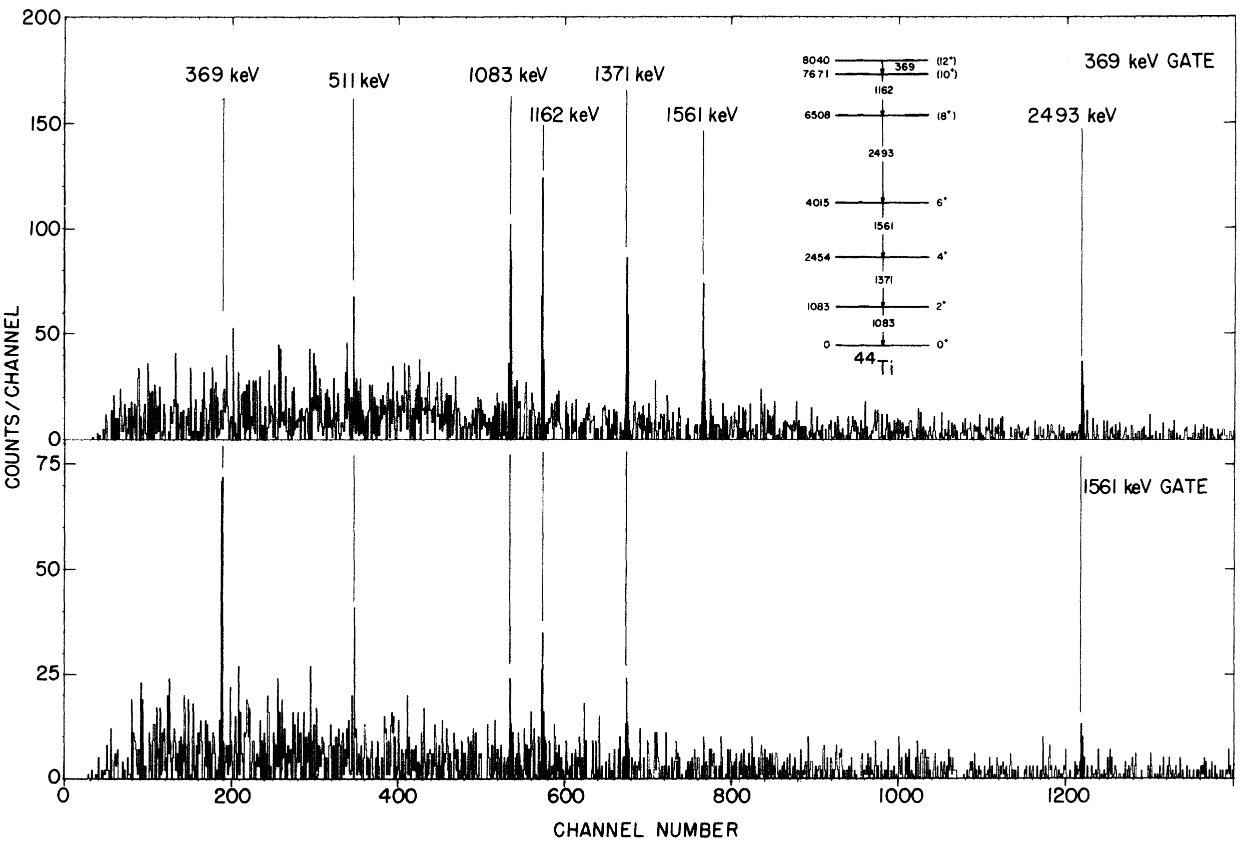

FIG. 2. Typical coincidence spectra from $^{19}F + ^{28}Si$ at 45 MeV. These spectra establish the existence of transitions from three new states in ^{44}Ti.

it of 2 ns (at the 2 standard deviation limit) and a best-fit value of 7 ns for the $12^+ \to 10^+$ transition, corresponding to enhancements of <6.3 and 1.8 W.u. (Weisskopf units), respectively.

A comparison of the present lifetime result (and those of Ref. 1 for the lower-spin levels) to the predictions of various models is shown in Table II. The $B(E2)$ values for both the MBZ and Bhatt-McGrory calculations were computed with the same state-independent one-body additional effective charge of $0.5e$ for both neutrons and protons.[2,9,10] It is clear that the $(f_{7/2})^4$ shell-model space is too small to adequately represent the electromagnetic transition matrix operator for the three lowest states: An average effective charge of $1.3 \pm 0.3e$ is necessary to reproduce the observed $B(E2)$ values. The agreement improves considerably when the $p_{3/2}$ single-particle level is included in the basis: The required effective charge is reduced to $0.6 \pm 0.2e$. The MBZ calculation is, however, consistent with the "best fit" $B(E2)$ value for the $12^+ \to 10^+$ transition with an effective charge of $0.5e$. The strong-coupling rotational model, on the other hand, predicts a $B(E2)$ which is much larger than the experimental limit. The presently observed decrease in the collective enhancement of the $E2$ transition strength for higher-spin levels has been previously observed[10,11] for nuclei in this mass region, and perhaps results from the fact that there are few configurations involving the $p_{3/2}$ single-particle level which can contribute to such high-spin states.

Of the three remaining quasirotational bands in ^{44}Ti discussed in Ref. 1, only the $K^\pi = (3^-)$ band was significantly populated in this experiment. The low cross section for populating the other two bands shown in Fig. 1 is not surprising in view of the fact that the heavy-ion induced fusion-evaporation reaction selectively populates yrast states,[5] but it means that we were unable to add to what is

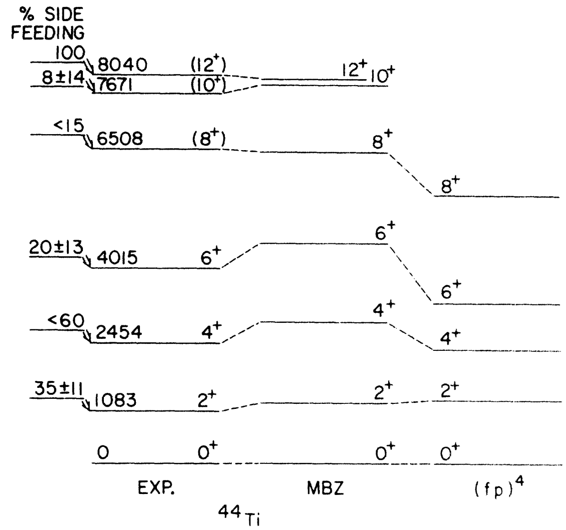

FIG. 3. Comparison of the extended ground-state band in ^{44}Ti to the shell-model predictions of MBZ (Ref. 3) and of Bhatt and McGrory (Ref. 2). The latter calculations are labeled $(fp)^4$ in this figure. In both cases, only the yrast states are shown.

already known about the rotational band built on the deformed 0^+ intruder state at 1904 keV, or the $K^\pi = 2^+$ band based on the state at 2886 keV. Our results for the (3^-) band, summarized in Table III, are in agreement with those of Ref. 1 except for the excitation energy of the (5^-) level which we find to be 4062.0 ± 0.4 keV, i.e., 3 keV higher than that given in Ref. 1. Because of accidental degeneracies of the transitions from the 4062- and 3176-keV states with γ rays from other nuclei,[4] we were unable to derive definitive results either for the lifetimes or the parities of these states. The lifetime of the 3646-keV level was measured to be 3.9 ± 1.3 ps, corresponding to an $M1$ transition strength of 0.08 ± 0.03 W.u.

TABLE I. Transitions within the ^{44}Ti ground band observed in the ^{28}Si(^{19}F,$p2n\gamma\gamma\cdots$)^{44}Ti reaction.

E_i (keV)	Transition [a] E_f (keV)	E_γ (keV)	J^π_i	J^π_f	Multipolarity	τ [b] Initial level (ps)	Angular distribution coefficients a_2 (%)	a_4 (%)	α_2 [c]	χ^2
8039.89(38)	7671.09	368.80(10)	(12^+)	(10^+)	$E2$	>2000	27.5 ± 3.8	-11.2 ± 4.4	0.69	1.7
7671.09(37)	6508.58	1162.49(15)	(10^+)	(8^+)	$(E2)$		27.8 ± 7.0	-4.0 ± 6.9	0.68	1.1
6508.58(34)	4015.34	2493.16(25)	(8^+)	6^+	$(E2)$		28.0 ± 6.2	-8.0 ± 6.8	0.68	0.6
4015.34(23)	2454.41	1560.90(15)	6^+	4^+	$E2$	0.56 ± 0.08	16.7 ± 4.3	-3.2 ± 4.7	0.37	0.8
2454.41(18)	1083.18	1371.21(15)	4^+	2^+	$E2$	0.60 ± 0.11	25.4 ± 2.9	-4.2 ± 3.6	0.50	1.6
1083.18(10)	0	1083.17(10)	2^+	0^+	$E2$	4.5 ± 1.1	14.7 ± 1.6	-5.2 ± 1.6	0.21	1.6

[a] The excitation energies are derived by applying a recoil correction to the γ-ray energies.

[b] From Ref. 1, except for the 369-keV transition which was measured in the present experiment.

[c] Ratio of the experimental a_2 coefficients to the theoretical coefficients for pure $E2$ transitions from completely aligned states.

TABLE II. $B(E2)$ values within the ^{44}Ti ground band.

Transition E_i (keV)	E_f (keV)	J^{π}_i	J^{π}_f	$\|M(E2)\|^2$ [a] (W.u.)	$B(E2)$ (e^2 fm^4) Exp [a]	MBZ	$(fp)^4$ [b]	SC [c]
8039.89	7671.09	(12$^+$)	(10$^+$)	<6.3	<60	17		206
7671.09	6508.58	(10$^+$)	(8$^+$)			32		203
6508.58	4015.34	(8$^+$)	6$^+$			35	104	197
4015.34	2454.41	6$^+$	4$^+$	17	157 ± 22	38	139	190
2454.41	1083.18	4$^+$	2$^+$	30	280 ± 60	85	162	172
1083.18	0	2$^+$	0$^+$	13	120 ± 30	58	116	120

[a] From Ref. 1, except for the 8040 → 7671 transition for which the indicated limit was determined in the present experiment. The best-fit value $\tau = 7000$ ps corresponds to a $B(E2)$ of 17 W.u.

[b] K. H. Bhatt and J. B. McGrory, Phys. Rev. C 3, 2293 (1971).

[c] $B(E2)$ values for a $K = 0$ rotational band in the strong-coupling (SC) rotational model, normalized to the 1083 → 0 ($2^+ \to 0^+$) transition.

III. ^{44}Sc

The information on γ-ray transitions in ^{44}Sc from the present experiment is summarized in Table IV. This nucleus has also been investigated via the ^{27}Al(^{19}F, $pn\gamma\gamma\cdots$) reaction,[4,7] and these data provided supporting evidence to that presented here for ^{19}F + ^{28}Si. Our most important results for ^{44}Sc concern three new high-spin states at excitation energies above 1.5 MeV. However, we shall first discuss the electromagnetic decays of the low-lying states which have previously been investigated by Arnell and Selin[12] and also by Dracoulis, Durell, and Gelletly.[13] Our results (Fig. 4) are in good agreement with those of Refs. 12 and 13 except perhaps for the 425-keV state which will be discussed in more detail below. The linear polarization data (Table V and Ref. 7) confirm positive parity for the $(4)^+$ state at 350 keV and negative parity for the $(4)^-$ state at 631 keV and the $(2)^-$ state at 235 keV. Dracoulis *et al.*[13] have made definite J^{π} assignments of 4^+, 4^-, and 2^- to these states. With these assignments, the γ-γ coincidence data require $J = 5$ for the state at 1197 keV with a large mixing ratio for the 566-keV transition ($0.50 \leq x \leq 1.0$). It then follows from the linear polarization data that there is no parity change in the transition to the 4^- state at 631 keV, so that we can definitely assign $J^{\pi} = 5^-$ to the level at 1197 keV based only on the assumption of an approximately Gaussian substate distribution in the formation of this state via the fusion-evaporation reaction.[5,6]

Our results for the 425-keV level conflict somewhat with the spin-parity assignment ($J^{\pi} = 3^-$) of Refs. 12 and 13. First of all, the linear polarization data suggest positive parity for this level (with mixing ratio $x = 0$) at the 1 standard deviation level. This assignment, however, would require a 772-keV ($M2/E3$) transition from the 1197-

TABLE III. Decay of the $K^{\pi} = (3^-)$ band of ^{44}Ti observed in the ^{28}Si(^{19}F, $p2n\gamma\gamma\cdots$)^{44}Ti reaction.

Transition [a] E_i (keV)	E_f (keV)	E_{γ} [b] (keV)	J^{π}_i	J^{π}_f	Multipolarity	τ Initial level (ps)	Angular distribution coefficients a_2 (%)	a_4 (%)
4062.05(40)	2454.41	[1607.24(50)]	(5$^-$)	4$^+$	($E1$)		−27(5)	−15(5)
4062.05	3646.28	⋯	(5$^-$)	(4$^-$)	not observed			
4062.05	3176.42	886.37(50)	(5$^-$)	(3$^-$)	($E2$)		14(9)	29(10)
3646.28(82)	3176.42	469.86(10)	(4$^-$)	(3$^-$)	($M1$)	3.9 ± 1.3	−26(3)	0
3176.42(81)	1083.18	[2093.19(80)]	(3$^-$)	2$^+$	($E1$)		−32(4)	0

[a] The excitation energies are derived by applying a recoil correction to the γ-ray energies.

[b] The γ-ray energies in brackets were obtained from the centroids of known multiplets. In both cases, the γ rays were close enough in energy that the degeneracy was not apparent at our instrumental resolution (2 keV), and it could only be determined from the γ-γ coincidence data.

keV state to compete with the other decays from this state which are all dipole. The situation is further complicated by the fact that our lifetime measurement on the 425-keV γ ray exhibits a two-component decay curve corresponding to mean lifetimes of 15.2 ± 3.7 ps and ≥ 0.5 ns, respectively. The latter result is consistent with the value of 0.546 ± 0.060 ns given for the lifetime of this state in Ref. 13, but the 15 ps mean life requires $\sim 7 \times 10^3$ W.u. for the $E2$ transition to the 68-keV state though it is not inconsistent with the transitions to the ground state and the 235-keV state. The γ-γ coincidence data show no clear evidence for a doublet at 425 keV, but it is possible that we are dealing with an accidental degeneracy with a γ-ray transition in this or another nucleus.

Three new high-spin states in ^{44}Sc observed in the present experiment (Fig. 4) extend the yrast band to the state of highest angular momentum permitted in the $(f_{7/2})^4$ shell-model basis. The angular distributions and linear polarizations of the 895- and 1703-keV γ rays yield most likely J^π assignments of $(11)^+$ and $(9)^+$ to the states at 3567 and 2672 keV, respectively. The ratio test[8] is also consistent with these assignments. The dipole nature of the 546-keV transition (Table IV) restricts the spin of the 4113-keV state to $J = (10, 11, 12)$. The parity of this state has not been determined in the present experiment. If it is negative, all three spin possibilities are equally likely. If, on the other hand, the 4113-keV level has positive parity, the most probable assignment is $J^\pi = 10^+$ on the basis of the selective population of yrast levels in these heavy-ion reactions and the fact that $J = 11$ is the maximum allowed spin for $(f_{7/2})^4$ configurations in the ground-state band. Our suggestion of $J^\pi = (10^+)$ for the 4113-keV state is based on these considerations and on the fact

TABLE IV. Transitions in ^{44}Sc observed in the ^{28}Si(^{19}F, $2pn\gamma\gamma\cdots$)^{44}Sc reaction.

Transition[a] E_i[b] (keV)	E_f (keV)	E_γ[c] (keV)	J^π_i	J^π_f	Multipolarity	τ[d] Initial level (ps)	Angular distribution coefficients a_2 (%)	a_4 (%)
4113(1)	3567.05	546(1)	(10, 11, 12)	$(11)^+$	$(M1, E1)$[e]	<0.5		
3975.27(37)	3567.05	408.22(15)					29(5)	0
3567.05(34)	2671.55	[895.49(12)]	$(11)^+$	$(9)^+$	$E2$	69.7 ± 2.4	30(3)	−12(3)
2671.55(32)	968.20	1703.31(20)	$(9)^+$	7^+	$E2$	2.4 ± 0.4	29(4)	−12(3)
1727.97(46)	1046.91	681.05(40)					25(23)	0
1197.44(12)	271.16	926.35(15)	5^-	6^+	$E1$		−11(4)	−4(8)
1197.44(12)	349.87	848(1)	5^-	4^+			···	···
1197.44(12)	424.77	772.50(15)	5^-	(3^-)	$E2$		11(8)	−5(7)
1197.44(12)	631.09	566.39(15)	5^-	4^-	$M1$		−97(7)	4(4)
1046.91(22)	349.87	[697.04(20)]					−39(4)	3(3)
968.20(25)	271.16	[697.04(20)]	7^+	6^+	$M1$	<5	−39(4)	3(3)
631.09(18)	234.85	[396.26(12)]	4^-	2^-	$E2$		23(4)	−10(3)
631.09(18)	349.87	281.20(20)	4^-	4^+	$E1$		30(11)	−2(10)
631.09(18)	424.77	206.36(50)	4^-	(3^-)	$(M1)$		−16(6)	0
531.69(32)	0	[530.95(15)]	3^-	2^+	$E1$		−54(6)	0
531.69(32)	234.85	296.84(20)	3^-	2^-	$M1$		−30(11)	−4(9)
424.77(8)	0	424.74(12)	(3^-)	2^+	$(E1)$	546 ± 60	−30(9)	0
424.77(8)	68	356.94(12)	(3^-)	1^-	$(E2)$		13(7)	1(6)
424.77(8)	234.85	190.03(80)	(3^-)	2^-			···	···
349.87(10)	0	349.87(10)	4^+	2^+	$E2$	4500 ± 400	17(6)	−3(5)
271.16(15)	0	271.16(15)	6^+	2^+	$E4$		4(8)	−10(6)
234.85(25)	0	234.85(25)	2^-	2^+			7(4)	3(4)
234.85(25)	68	167(1)	2^-	1^-			···	···

[a] The excitation energies are derived by applying a recoil correction to the γ-ray energies.

[b] The 408-keV transition from the "3975-keV" state could instead be from a state at 4521 keV. See the text for further discussion.

[c] The bracketed γ-ray energies were obtained from the centroids of known multiplets. However, in each case the γ rays were close enough in energy that the degeneracy was not apparent at our instrumental resolution (2 keV), and it could only be determined from the γ-γ coincidence data.

[d] From the present experiment except for the lifetimes of the 425- and 350-keV states, which are from Ref. 13. Our data for the latter two levels yield a lower limit of 0.5 ns for both lifetimes, in agreement with Ref. 13.

[e] The 546-keV transition is assumed to be dipole on the basis of its short lifetime (which would require an $E2$ transition of $>4 \times 10^3$ W.u.) and the 0°/90° coincidence ratio (Ref. 8).

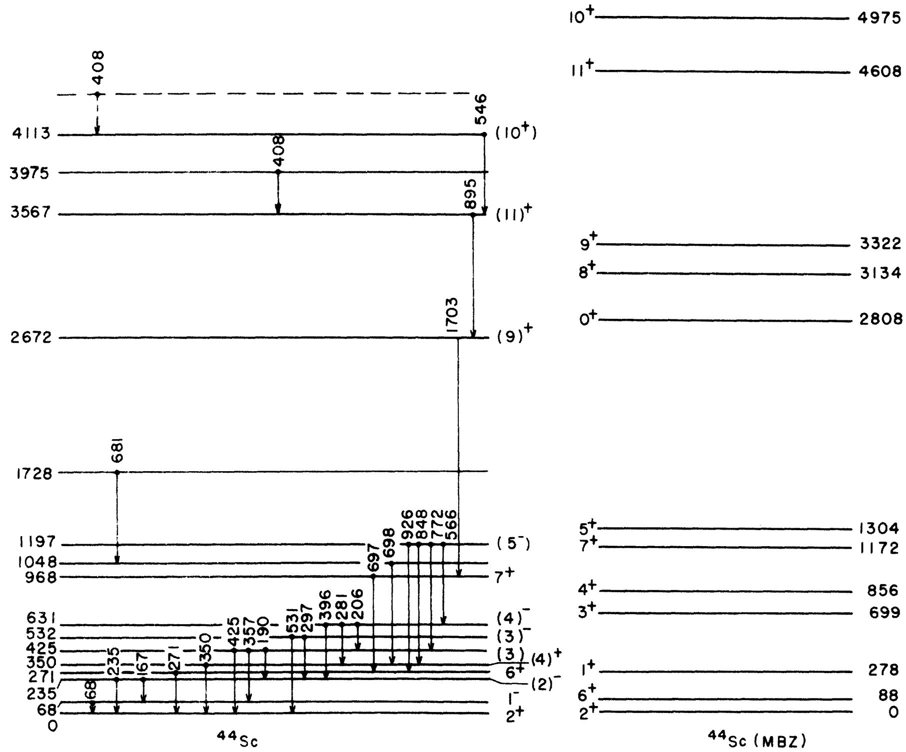

FIG. 4. Comparison of the experimental level scheme for ^{44}Sc to the yrast levels predicted by MBZ (Ref. 3).

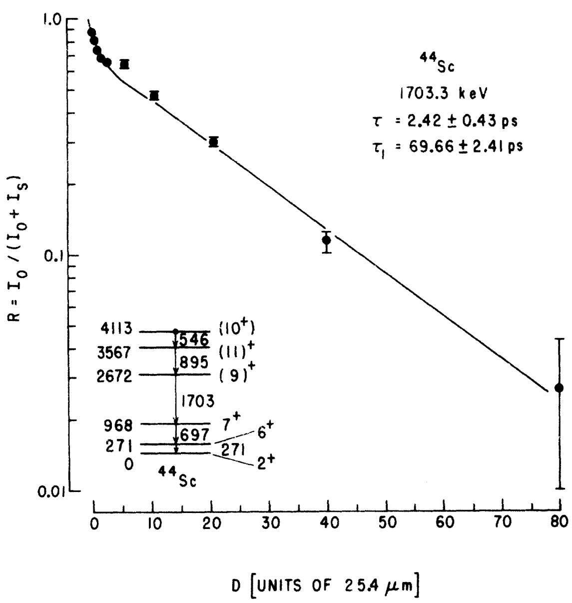

FIG. 5. Lifetimes in the high-spin cascades in ^{44}Sc. This graph is typical of the recoil-distance method data. The technique is discussed in detail in Ref. 6.

that the 10^+ member of the ground-state band is expected in this region of excitation energy.

The agreement with the MBZ predictions (Fig. 4) is not as good for ^{44}Sc as for ^{44}Ti. Although the experimentally observed ordering of the 10^+ and 11^+ levels is reproduced, the entire spectrum is more compressed than predicted. This problem, which occurs for other $T \neq 0$ nuclei, has apparently been corrected in more recent shell-model calculations by Zamick[14] using a different residual force. The lifetimes of the $(9)^+$ and $(11)^+$ states have been measured (Fig. 5), and the $B(E2)$ values predicted by MBZ require an average effective charge of $0.9 \pm 0.1e$ to make them agree with the experimental values (Table IV) of 2.5 ± 0.4 and 2.16 ± 0.07 W.u., respectively. This is again not as good agreement as for ^{44}Ti where the effective charge for the high-spin states was $0.5e$, but it is consistent with previous measurements of effective charges in this mass region.[15] The decay curve for the 697-keV transition is nearly identical to that for the 1703-keV state, so that we can only place an upper limit of 5 ps on the lifetime of the 7^+ state. The 546-keV $(10^+) \rightarrow (11)^+$ transition was found to be strongly Doppler shifted in the

TABLE V. Linear polarizations of transitions in ^{44}Sc and ^{44}Ti as observed in the ^{28}Si(^{19}F, $2pn\gamma\gamma\cdots$)^{44}Sc and ^{28}Si(^{19}F, $p2n\gamma\gamma\cdots$)^{44}Ti reactions.

E_γ [a] (keV)	Relative [b] intensity	Polarization Exp [c]	Pred [d]
	^{44}Ti		
1083.17	1555	+25(11)	+21(5)
1371.21	593	−14(40)	+40(8)
1560.90	310(+^{45}Ti)	−6(64)	+26(9)
1607.24	461(+^{41}Ca)	0(34)	−46(8)
	^{44}Sc		
234.85	709	−37(17)	+12(8)
271.16	1632	+1(5)	0(15)
281.20	496	−64(26)	+51(25)
349.87	1649	+31(9)	+26(13)
396.26	513(+^{43}Ca)	+12(12)	+33(10)
408.22	215	+10(16)	+50(12)
424.74	157	−47(70)	−39(12)
566.39	344	+20(12)	−95(7)
697.04	4941	−19(4)	−46(11)
772.50	516	+22(19)	+14(16)
895.49	3081(+^{45}Ti)	+50(11)	+46(8)
1703.31	4321	+49(11)	+44(10)

[a] The linear polarization for γ rays not listed were not accurately measured in the present experiment.

[b] Intensities corrected for detector efficiency. The estimated accuracy of the relative yields for two intense lines varies with their energy separation from <1% to ~15%. For weak lines, the uncertainty may be as much as 50%.

[c] Experimental polarization in percent computed according to Ref. 7.

[d] Predicted polarization in percent calculated from the experimental angular distribution according to Ref. 7, assuming pure $M1$ or $E2$ radiation. The opposite sign would obtain for pure $E1$ or $M2$ radiation. The prediction is not valid for mixed transitions or for pure multipoles with $L > 2$.

γ-γ coincidence experiment and we are therefore able to place an upper limit of 0.5 ps on the lifetime of the (10^+) state, corresponding to a transition strength >0.3 W.u. This is rather strong for a $M1$ transition, and does not seem to be in very good agreement with the MBZ prediction of 0.15 W.u. for this transition. However, it is of the same order of magnitude as the $M1$ strength given in Ref. 13 for low-lying members of the positive-parity yrast band. It should be noted, on the other hand, that we cannot exclude the possibility that the 546-keV transition is an $E1$ transition in which case the lifetime limit would not be at all surprising.

Two additional γ-ray transitions at 408 and 681 keV have also been placed in ^{44}Sc from the γ-γ coincidence data. They fit into the decay scheme in the manner shown in Fig. 4, but are so weak that we cannot extract any other information about them from the present experiment. Note that the former transition can be placed into the decay scheme in two different ways, since the 408- and 546-keV γ rays may or may not be in coincidence.

IV. CONCLUSION

We have located several new high-spin states in ^{44}Ti and ^{44}Sc and compared their excitation energies and transition strengths to the predictions of MBZ. In the case of ^{44}Ti, the agreement was very good for the excitation energies of the ground-state band, which do not follow a quasirotational pattern above the 6^+ state. The $E2$ transition strengths for the lower-spin states required an average effective charge of $1.3 \pm 0.3e$ to be accounted for in the $(f_{7/2})^4$ basis, but this value was reduced to $0.6 \pm 0.2e$ when $p_{3/2}$ configurations were included.[2] The (12^+) $\rightarrow$ (10^+) transition, on the other hand, was well reproduced by the MBZ calculation with an effective charge of $0.5e$. In the case of ^{44}Sc, the excitation energies and transition strengths were not so well reproduced as for ^{44}Ti. In particular, an effective charge of $0.9 \pm 0.1e$ was required even for the high-spin states, and the entire spectrum was observed to be substantially more compressed than the predictions of MBZ. Finally, there are still some open questions about the spin assignments to the lower-spin states in ^{44}Sc which could be resolved by particle-γ coincidence measurements.

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