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Mean lives and other properties of some levels in Ti†

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Several levels in ^{46,47,48,49,50}Ti from 1.5 to 4.3 MeV are observed in the resonant scattering of bremsstrahlung by natural Ti. Six levels may be given immediate isotope assignments from verified branching to first excited states, seven may be assigned by close agreement of energies and other characteristics with levels observed in other reactions, one has a possible dual assignment, and one cannot be assigned. Widths and mean lives are given as well as information on spins, mixing ratios, and branching ratios.

[NUCLEAR REACTIONS ^{46,47,48,49,50}Ti(γ,γ), (γ,γ'), E_x =1.3–4.7 MeV; measured $\sigma(96°)$, $\sigma(126°)$; deduced levels, Γ_0, Γ, mixing ratios, spins, parities.]

I. INTRODUCTION

Monahan *et al.*[1] have reported a pair of spin 1 levels in ^{48}Ti at 3.71 and 3.75 MeV. Since there were reports that the levels had opposite parity[2,3] and significant branching to the ground state, they were of some interest for evaluating methods of measuring γ-ray polarization. The resonant scattering of bremsstrahlung by natural Ti (73.49% ^{48}Ti) was looked at. The expected lines were seen, although not with the desired counting rates, and several other lines were also seen. A survey for γ-ray energies from 1.3 to 4.7 MeV and bremsstrahlung end-point energies of 1.6 to 4.75 MeV was made. Widths, angular distributions, and branchings were measured for the levels observed.

It will be noted that the statistical accuracy of the data is not always all that could be desired. Improvement is possible in many cases, if it should turn out to be of interest. It should also be pointed out that, as is the case for many γ-ray spectra, there may be distortion by other lines too weakly excited to be resolved from background.

II. EXPERIMENTAL PROCEDURES

The study of nuclear levels by observation of the resonant scattering of bremsstrahlung has been discussed in previous publications.[4,5] Two Ge(Li) detectors, arranged as shown in Fig. 1, were used in most of the present work. A gated integrator[6] was used to improve performance at high counting rates, with separate preamplifiers, amplifiers, and first gates, and a common integrating gate followed by a multichannel analyzer with appropriate routing circuits. With the gates opening only for pulses >0.6–1 MeV and an anticoincidence requirement, clean spectra from each detector, with no observable cross talk, could be acquired even though the total counting rate (predominantly at annihilation radiation and below) was high. The total rate was limited so that the measured correction for counting rate loss was less than 10%. Electron currents ranged from 5–20 μA. Energies quoted have a probable error of 1 keV.

Observation at only two angles is not, in principle, sufficient to establish an angular correlation function if the coefficient of the $P_4(\cos\theta)$ term is nonzero. In practice, it can be quite useful, especially for spin 0 ground states where we will be able to observe only spin 1 or 2 excited states with $W(90°)/W(126°) = 0.8$ or 2. The determination of spin 1 or 2 is thus easily made in any case where the ground state transition is clearly observed. For other ground state spins, the situation is, in general, more ambiguous, but the introduction of a third detector would not give enough additional information to compensate for the additional nontrivial complications and costs.

As before, scattering cross sections were evaluated by comparison with the scattering via several "standard" levels of known width and branching listed in Table I. The titanium scatterer was assembled from four 7.62-cm-diam × 0.671-cm-thick metal disks of 99.7% purity. "Standard" scatterers were of the same diameter and appropriate thickness and of the pure element. Counting rates in the line of interest were measured at 100 keV above threshold or corrected for small departures from this energy by using an empirical slope of 0.27% per keV. Relative detector efficiencies are based predominantly on intensities from a ^{56}Co source.

Better statistics for angular distributions and branchings were generally obtained from data at energies greater than 100 keV above threshold. Branchings were verified by noting that both lines disappeared below threshold.

Linear polarization measurements were made with the Ge(Li) slab Compton polarimeter previously described[7] and by using the partial linear polarization of the off-axis bremsstrahlung beam[5] and the analyzing power of the 0-1-0 γ transition[8] for which the 90° scattered intensity is zero either perpendicular or parallel to the plane of polarization of the incident beam, depending on the parity change. The experimental procedure for the second method is to rotate a pair of off-axis scatterers around the beam, alternating the production plane perpendicular and parallel to the scattering plane.

After most of the data were taken, the 30-cm^3 detector was replaced by a 55-cm^3 detector. Much improved angular distribution data were then obtained in several cases.

Errors given on widths, etc. include reasonable estimates of all contributions we are aware of, except two which cannot be estimated. One is the possibility that the detector energy calibration varies during a run by somewhat more than the linewidth and then returns to the original value. There have been isolated instances where peaks have contained 10–20% fewer counts than expected, which may reflect such behavior, but this has never been verified. Our calibrations are generally quite stable over terms of several hours or more except for possible temperature effects when the ambient temperature is controlled neither by the air conditioning nor the heating system, or by incipient failure of some part of the electronics. Either of these conditions soon becomes quite apparent. At any rate, an undetected shift would always give a measured width less than the correct width. The other error not included involves the effect of other unknown lines not resolvable from background.

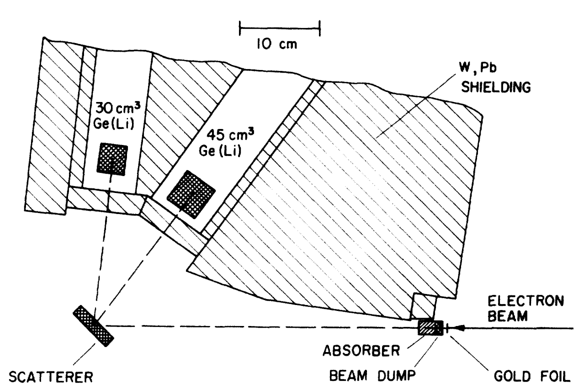

FIG. 1. Key elements of the experimental arrangement. The beam dump (Li and C) is inside the beam vacuum pipe; the absorber (used in self-absorption measurements) is outside.

TABLE I. Relevant characteristics of levels used to evaluate Bremsstrahlung flux.

Nuclear	Energy (MeV)	$g\Gamma_0^2/\Gamma$ (meV)	Γ_0/Γ
^{25}Mg	1.61	42 ± 6 [a]	1.00 [a]
^{27}Al	2.21	21.9 ± 2.2 [a]	1.00 [a]
	2.98	73 ± 5 [a]	0.99 [a]
	3.96	101 ± 9 [b]	0.84 [b]
	4.41	140 ± 10 [c]	0.57 [c]
^{55}Mn	2.56	49.7 ± 3.6 [d]	1.00 [d]
^{56}Fe	3.45	330 ± 30 [e]	0.77 [e]

[a] Endt and van der Leun, Ref. 9.

[b] Reference 5 and F. R. Metzger, B. Brunner, P. Georgopolous, and V. K. Rasmussen (unpublished). The mean value for this width given in Ref. 9 is in error.

[c] F. R. Metzger, Phys. Rev. 139, B1464 (1965). Metzger's value of Γ_0/Γ is used rather than $\Gamma_0/\Gamma=0.70\pm0.05$ since the latter introduces a large discrepancy between the scattering and self-absorption results.

[d] F. R. Metzger (private communication).

[e] V. K. Rasmussen, self-absorption measurement (unpublished).

III. RESULTS

The principal results of this study are summarized in Table II and details are discussed below. If the assignment to a given isotope should turn out to be incorrect, the lifetime given is to be multiplied by the ratio of the new to the old abundance.[9] Other corrections will be small.

A typical spectrum is given in Fig. 2.

A. ^{46}Ti

The highest energy γ-ray observed was at 4316 keV. Comparison of the angular distribution (in an arrangement differing somewhat from Fig. 1) with that for the ^{32}S 4284-keV 2^+ level established that this was not a 0-2-0 transition. Lutz *et al.*[3] have reported a spin 1 level in ^{48}Ti at 4315 keV. The Nuclear Data Sheets[10] list a level in ^{46}Ti at 4316 keV, and Assimakopoulos *et al.*[11] observe a 4316-keV γ-ray in ^{46}Ti. They also observed a 3427-keV γ-ray which could be the transition to the first excited state, but did not report a branching ratio because they were using a borrowed detector of unknown efficiency. From their original data one sees that Γ_1 and Γ_0 are very roughly equal. Their data do not completely rule out a contribution from ^{48}Ti, however. Recently Pronko *et al.*[12] reported a 2^+ level in ^{50}Ti at 4311 ± 3 keV which decays 25% to the ground state and 75% to the first

TABLE II. Mean lives of some levels in the titanium isotopes.

Mass no., ground state, spin, & abund.	Level energy (keV)	Level spin	Γ_0 (meV)	τ (pres. meas.) (fs)	τ (other) (fs)
46, 0^+	3168	1^-	7.3 ± 2.0	41 ± 12	71 ± 12 [a]
7.95%	4316	1	$(172 \pm 26)\Gamma/\Gamma_0$	0.96 ± 0.14 [b]	<44 [a]
47, $\frac{5}{2}^-$	2162	$\frac{3}{2}^-$	18 ± 5	38 ± 10	31 ± 8 [c]
7.75%	2297	$(\frac{5}{2}^-, \frac{7}{2}^-)$	$\{104 \pm 10$ or [d] 78 ± 8	4.7 ± 0.5 or [d] 6.3 ± 0.7	11 ± 7 [c]
	2548	$\frac{3}{2}^-$	72 ± 8	9 ± 1	
48, 0^+	2421	2_2^+	0.74 ± 0.18	44 ± 12	35 ± 7 [e]
73.45%					$\{\Gamma_0 = 0.66 \pm 0.11$ meV and 0.77 ± 0.14 [f]
	3371	2_3^+	5.5 ± 0.6	16.1 ± 2.1	18 ± 7 [e]
	3700	$1^{(+)}$	20.4 ± 2.3	15.1 ± 1.6	35 ± 3 [g]
	3739	1^+	101 ± 10	4.2 ± 0.4	16 ± 3 [g]
49, $\frac{7}{2}^-$	1623	$(\frac{9}{2}^-, \frac{5}{2}^-, \frac{7}{2}^-)$	11.4 ± 1.5 [h]	55 ± 7	
5.51%	1763	$\frac{5}{2}^-$	18.3 ± 2.2	36 ± 4.3	
50, 0^+	1554	2_1^+	0.52 ± 0.15	1300 ± 400	$\Gamma = 0.48 \pm 0.04$ meV [i]
5.34%	(4311)	2^+	85 ± 60	$1 < \tau < 6$	<80 [j]
(47, 49)	3917		$(90 \pm 20)\Gamma/g\Gamma_0$ [k]		
	2810		$(29 \pm 4)\Gamma/g\Gamma_0$ [k]		

[a] Reference 11.
[b] Assuming $\Gamma_0/\Gamma = 0.50$.
[c] Reference 18.
[d] The larger width and shorter lifetime correspond to spin $\frac{5}{2}$.
[e] Reference 23.
[f] Coulomb excitation and (e, e'), J. Heisenberg, J. S. McCarthy, and I. Sick, Nucl. Phys. A164, 353 (1971).
[g] C. D. Kavaloski and W. J. Kossler, Phys. Rev. 180, 971 (1969).
[h] Assuming spin $\frac{9}{2}$.
[i] From Coulomb excitation results of C. W. Towsley, D. Cline, and R. Horoshko, Nucl. Phys. A250, 381 (1975).
[j] Reference 12.
[k] Calculated as if ^{49}Ti, g is the statistical factor.

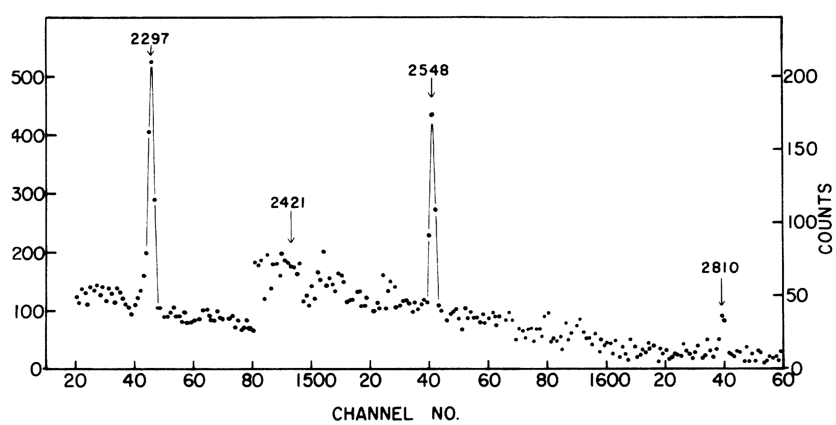

FIG. 2. Part of the pulse height spectrum seen in the 45-cm^3 detector when bremsstrahlung of maximum energy 2.914 MeV irradiates a titanium scatterer. Total irradiation corresponded to 0.25 C of electrons at an average current of 12.1 μA. The 2810-keV line is seen in many other runs, most of them at somewhat higher energy. A line is expected at 2421 keV, but not seen at this or more favorable (lower) energies, as discussed in Sec. III C.

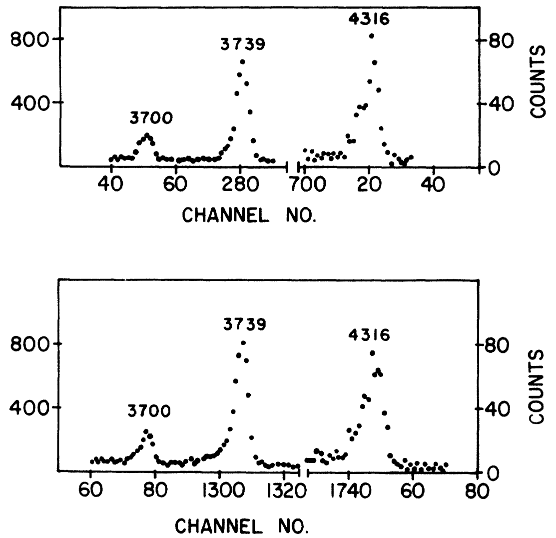

FIG. 3. 4316-4311 keV doublet at 0.77 channels/keV, along with single lines at 3739 and 3700 keV for comparison. See Sec. III A. Upper spectrum from the 96° (55 cm^3) detector, lower from the 126° detector.

excited state. For our data, this last transition unfortunately coincides with the considerably stronger 3739-983 transition in ^{48}Ti. Further data were obtained after the 30-cm^3 detector was replaced by the 55-cm^3 detector, and are shown in Fig. 3 along with the 3739-keV, presumably single, line from the same run. A doublet is certainly suggested, although one may note that statistical fluctuations in the 96° data result in the higher energy peak looking a bit narrower than it should be. The separate contributions of the two isotopes may be estimated by requiring that the observed 96°/126° intensity ratio be fitted by a weighted sum of the 0-1-0 and 0-2-0 correlations, with the result that (88 ± 8)% of the total scattered intensity is attributed to ^{46}Ti. This corresponds to 21% of the 96° counts and 8% of the 126° counts coming from ^{50}Ti. There is a definite suggestion of a 3427-keV line, but the background is too large to allow a meaningful determination of the branching ratio.

The 3168-keV 1^- level[20, 11] was not observed in the survey. It was seen in two later dedicated and rather long runs (0.452 and 0.425 C of electrons) (see Fig. 4). The 55%[20] branch to the first excited state was not seen. As to the angular correlation, it can only be said that this is clearly *not* a 0-2-0 sequence. It will be noted that this level is approaching the threshold of observability for the natural ^{46}Ti abundance.

B. ^{47}Ti

Four or five of the observed γ rays fit with what is known of the level scheme of this isotope.

A 2548-keV γ ray is identified with a $\frac{3}{2}^-$ [13,14] level emitting a 2548 ± 0.5-keV γ ray in the transition to the $\frac{5}{2}^-$ ground state, no other transitions being observed.[15] The coefficient of $P_2(\cos\theta)$ in the angular distribution is $0 < A_2 < 0.4$ (where it will be noted that $A_2 < 0$ is impossible for any symmetric up-down cascade), corresponding to an $E2/M1$ mixing ratio[16] $\delta < 0.5$ or $\delta > 4$. For this energy $\Gamma_W(E2) = 0.9$ meV,[17] so that the second value of δ is rather improbable.

A 2162-keV γ ray is identified with a 2164- or 2162-keV $\frac{3}{2}^-$ [13,15] level decaying 95% to the ground state and 5% to the 160-keV $\frac{7}{2}^-$ first excited state.[15] The 96° data were of poor statistical accuracy. It

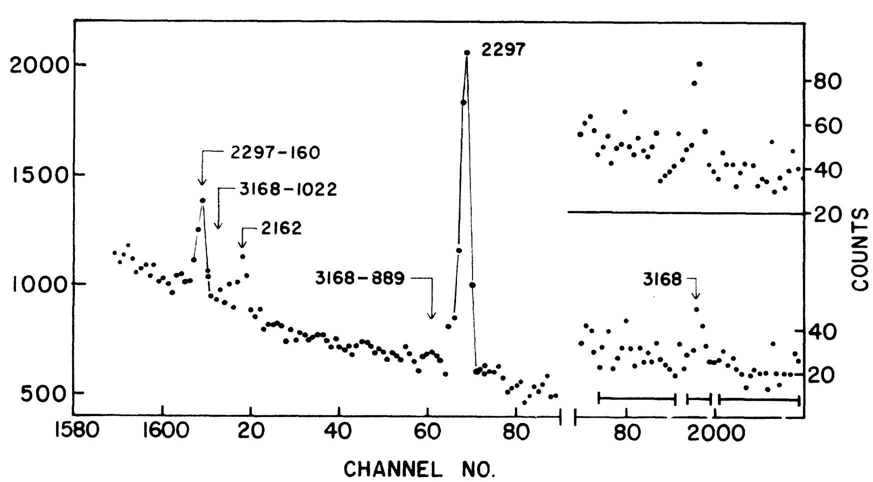

FIG. 4. One of the runs in search of the 3168-keV line (see Sec. III A). The spectrum in the upper right-hand corner is the sum of two runs. The channels that were assumed to correspond to the peak and to background are indicated.

TABLE III. Allowed mixing ratios for angular distributions characterized by $R_1 = 0.78 \pm 0.04$ and $R_2 = 1.04 \pm 0.1$ as found for the 2297-keV level of ^{47}Ti. Cases where $|\delta| > 2$ have been neglected. Ranges of δ_2 are given for the lower limit, the mean, and the upper limit of each range of δ_1.

Spin sequence	Range of δ_1	Range of δ_2
$\frac{5}{2} \xrightarrow{\delta_1} \frac{5}{2} \xrightarrow{\delta_1} \frac{5}{2}$	0.2	$-0.3 < \delta_2 < 0.3$
	0.6	$-0.2 < \delta_2 < 0.2$
$\xrightarrow{\delta_2} \frac{7}{2}$	1.0	$-0.3 < \delta_2 < 0.3$
$\frac{5}{2} \xrightarrow{\delta_1} \frac{7}{2} \xrightarrow{\delta_1} \frac{5}{2}$	-0.24	$\delta_2 < -0.1$ or >1.2
	-0.20	$\delta_2 < 0.1$ or >0.9
$\xrightarrow{\delta_2} \frac{7}{2}$	-0.16	$\delta < 0.2$ or >0.4
	0.6	$\delta_2 < -0.3$
	0.9	$\delta_2 < -0.4$
	1.2	$\delta_2 < -0.6$

was consistent with isotropy as is the mixing ratio $\delta = 0.0 \pm 0.1$ given by Weaver *et al.*[18] The 5% branch was, not unexpectedly, not seen. It does seem to be well established in ^{47}V β decay[15] which rules out the spin $\frac{1}{2}$ assignment of Choudhury and Sen Gupta.[14]

2297- and 2137-keV γ rays are associated with the decay of a level at 2297 keV to the ground and first excited states. Weaver *et al.*[18] give a mean life of 11 ± 7 fs for this level, allowing spins and parities $\frac{3}{2}^-$, $\frac{5}{2}$, $\frac{7}{2}$, $\frac{9}{2}^-$. They find that the decays are 75% to the ground state and 25% to the 160-keV state, without any correction for angular correlations.

With the assumption that there are no other decay modes, we find from the 126° data $\Gamma_0/\Gamma = 0.77 \pm 0.03$, but have used 0.75 in calculations.

The ground state angular distribution was found to be rather anisotropic. Additional data were obtained with the 55-cm^3 detector to reduce the statistical error.

Since the P_4 term is not always negligible, we give the experimental result in terms of the angular distribution ratio

$$R = \frac{1 + A_2 \bar{P}_2(A) + A_4 \bar{P}_4(A)}{1 + A_2 \bar{P}_2(B) + A_4 \bar{P}_4(B)} = \frac{W(A)}{W(B)} ,$$

where A designates the nominal 96° detector and B the nomianl 126° detector. R is the experimental counting rate ratio corrected for geometric effects, efficiencies, attenuations, etc. For the ground state transition $R_1 = 0.78 \pm 0.04$, and for the excited state transition $R_2 = 1.04 \pm 0.1$. This rules out $\frac{5}{2} - \frac{9}{2} - \frac{5}{2}$, for which the expected $R_1 = 0.959$. Intermediate spin $\frac{3}{2}$ can be ruled out by the width of the $\frac{3}{2} - \frac{7}{2}$ branch of 140 $\Gamma_W(E2)$, which is larger than the recommended upper limit (RUL) of 100 Γ_W given by Endt and van der Leun.[21] Positive parity (i.e., an $M2/E1$ mixed transition) for the $\frac{5}{2}$, $\frac{7}{2}$ possibilities left can be ruled out by noting that $\delta^2 < 10^{-3}$, corresponding to $\Gamma(M2) < 8\Gamma_W$ (the RUL is $3\Gamma_W$), requires $R_1 \geq 0.90$.

It does not appear that any reasonable improvement of our data would distinguish between $\frac{5}{2}$ and $\frac{7}{2}$. We give in Table III the allowed mixing ratios δ_1 for the ground state transition and δ_2 for the excited state transition.

The ground state decay of a level at 3917 keV is observed, but not any branching. Meyer-Schützmeister *et al.*[19] report a $(\frac{1}{2}^-, \frac{3}{2}^-)$ level at 3.919 MeV from ^{45}Sc (^{3}He, p)^{47}Ti. On the other hand, Ball *et al.*[22] observe a 3.916-MeV level in ^{49}Ti (p, p'). Apparently this is the first time the γ decay of this level has been observed, and there is no clear indication of which isotope to assign it to—indeed, both may be involved.

C. ^{48}Ti

Six γ rays could be assigned to known levels in ^{48}Ti.

A 1439-keV γ ray is associated with the 2421-keV 2_2^+ to 983-keV 2_1^+ transition. The 5%[23] ground state branch is not clearly seen, in part because of the 2426-keV γ ray excited in ^{29}Si in the concrete walls. The background under the 1439-keV line was large and rather uncertain, even after subtracting out the beam-independent ^{40}K line 21 keV higher, and contributes substantially to the error given. The width given is from the 126° data only, and includes the assumption, consistent with the mixing ratio adopted by Bardin, Becker, and Fisher,[23] that $W(126°) = 1.00$.

The 3371-keV 2_3^+ level is reported by Bardin *et al.*[23] to decay 86.5% to the 983-keV level and 13.5% to ground. We observe the 86.5% branch but not the ground state branch (< 5%). We assume that their data are superior to ours for the purpose of determining branching ratios and use their values. If different values of these branching ratios should be established, our value of Γ_0 is to be multiplied[24] by $0.865\Gamma/\Gamma_1$ and τ is to be appropriately corrected. For this 2387-keV $2_3^+ \to 2_1^+$ transition we find $W(96°)/W(126°) = 0.76 \pm 0.09$ which corresponds[16] to $0.1 < \delta < 0.8$.

Gamma rays at 3700 and 2717 keV are assigned to one of the spin 1 levels reported by Monahan *et al.*[1] The branch can be unambiguously identified only below threshold for the 3739-keV line discussed below, since it coincides in energy (within ~$\frac{1}{2}$ keV) with the two-escape peak of that line. For the branching we find $\Gamma_0/\Gamma = 0.48 \pm 0.03$, in agreement with the result of Monahan *et al.* ($\Gamma_0/\Gamma = 0.43 \pm 0.06$) and have used the weighted mean $\Gamma_0/\Gamma = 0.47 \pm 0.027$. The angular distributions are, within the rather large statistical error, in agreement with the results of Monahan *et al.* Lutz *et al.*[3] assign negative parity to this level. It is not observed by Jamshidi and Alford[25] in ^{48}Ti(α, α'), suggesting a 1^+ assignment—but they do not, apparently, see it in ^{49}Ti(d, t) either, and do not refer to this level at all. We have polarization data from measurements of the 3739-keV level discussed below, but the counting rate is too low, by a factor of almost 4, to allow a meaningful conclusion. A strong argument for positive parity follows from the finding of Monahan *et al.* that $\delta^2 > 0.14$ which implies that the minimum quadrupole width is 3.2 meV, consistent[21] with an electric quadrupole transition ($\Gamma_W = 1.3$ meV) but not with magnetic quadrupole, for which $\Gamma_W = 0.029$ meV.

Lines at 3739 and 2756 keV are attributed to the 3.752-MeV spin 1 level of Monahan *et al.*[1] Two other possible origins for γ rays near 3740 keV should be mentioned. Assimakopoulos *et al.*[11] report a 3738-keV γ ray and assign it to a 3738-keV level in ^{46}Ti. They do not report a lifetime for this level since it shows no Doppler broadening. We take this to imply $\tau \gg 100$ fs, in which case it would not affect our data. Ball *et al.*[22] report a 3743 keV, tentatively $\frac{7}{2}^-$, level in ^{49}Ti. No decay data seem to be available. Monahan *et al.*[1] find for the ^{48}Ti level that $(65 \pm 5)\%$ of the decays go to the ground state, $(27 \pm 5)\%$ go to the 983-keV 2_1^+ level, and $(8 \pm 2)\%$ go to the 2421-keV 2_2^+ level. This last transition would be very difficult for us to observe, but we can compare our value of $\Gamma_1/\Gamma_0 = 0.40 \pm 0.40$ with the value 0.42 that follows from Monahan's branching to find an indication that the ^{49}Ti level is not contributing strongly to our data.

The parity of this level is even, as shown in both pickup and stripping reactions.[25] It has been used, as noted in the Introduction and Sec. II, in examining alternate ways of measuring the linear polarization of γ rays. Both methods give even parity, to better than two standard deviations.

It may be noted that Monahan *et al.*[1] report a third spin 1 state in ^{48}Ti at 4048 keV which decays >90% to the ground state. We have looked, with some care, for this level, do not observe it, and estimate $\Gamma_0 < 2$ meV.

D. ^{49}Ti

Lines at 1623 and 1763 keV are attributed to levels reported in ^{49}Ti at 1624 and 1766 keV. The 1763-keV level has spin and parity $\frac{5}{2}^-$,[22] and is observed in neutron capture-γ spectra[26] to decay only to the $\frac{7}{2}^-$ ground state. The ratio $W(96°)/W(126°) = 0.89 \pm 0.08$. The allowed values of the quadrupole/dipole mixing ratio are then $0.1 < \delta < 0.04$ or $\delta < -0.3$.

TABLE IV. Allowed values of the quadrupole/dipole mixing ratio for the 1623-keV level of ^{49}Ti from the observed correlation $1 + (0.44 \pm 0.08)P_2(\cos\theta)$.

Spin sequence	δ	Remarks
$\frac{7}{2}^- - \frac{9}{2}^- - \frac{7}{2}^-$	$0.6 < \delta < 0.8$	
	$-0.24 < \delta < -0.18$	
	$\lvert\delta\rvert \sim 2$	$\Gamma(E2) \sim 100\Gamma_w$
$\frac{7}{2}^- - \frac{7}{2}^- - \frac{7}{2}^-$	$0.36 < \delta < 0.8$	$\Gamma(E2) \geq 20\Gamma_w$
$\frac{7}{2}^- - \frac{5}{2}^- - \frac{7}{2}^-$	$0.36 < \delta < 0.5$	$\Gamma(E2) \geq 25\Gamma_w$

The 1623-keV level has odd parity[22] but no spin assignment has been made and the decay has not been previously observed. It is assumed that all decays are to the ground state. The angular distribution is quite anisotropic, with $W(96°)/W(126°) = 0.78 \pm 0.04$. This rules out the sequences $\frac{7}{2} - \frac{3}{2} - \frac{7}{2}$, for which this ratio is 0.99, and $\frac{7}{2} - \frac{11}{2} - \frac{7}{2}$, for which the ratio is 0.95. Mixing ratios for the other possibilities are given in Table IV. It is seen that spin $\frac{9}{2}$ is somewhat favored. Also, the negative parity assignment is verified, since the required quadrupole strengths are much too great for a magnetic transition.

Some of our data suggest that the 1623-keV level is also fed by the previously reported[22] 2471-keV, $\frac{7}{2}^-$ level. This is difficult for us to verify, but as a precaution the angular correlation data used were taken with E_{e-} below 2.47 MeV.

As noted in the ^{47}Ti discussion, the 3917-keV line may also be associated with ^{49}Ti.

E. ^{50}Ti

Some of the low-energy data suggested that the 1554-keV 2_1^+ level of ^{50}Ti was being excited. Further data were obtained when the 55-cm^3 detector became available. The ratio $W(96°)/W(126°) \sim 2.3 \pm 1.1$ is consistent with spin 2.

The assignment of some of the intensity at 4316 keV to ^{50}Ti is discussed in Sec. III A.

F. Isotope not assigned

We are unable to make an isotope assignment for a 2810-keV line. It is anisotropic, with $A_2 = 0.36 \pm 0.3$. No branching to excited states is observed.

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