Lifetimes and Branching Ratios in Ti^{48}†

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The Doppler-shift attenuation method has been used to study levels in Ti^{48} up to 3.74-MeV excitation energy. Backscattered protons from the $(p, p'\gamma)$ reaction were detected in coincidence with deexcitation γ rays. A 32-cc Ge(Li) detector was used to measure γ-ray Doppler shifts, and to obtain branching ratios. Eleven levels in Ti^{48} were observed below 3.74 MeV. Transition rates in single-particle units are given for twelve transitions. The 0^+ level at 3.000 MeV was observed to decay with a transition rate of $(8\pm2)\times 10^{12}$ sec^{-1}, indicating a collective admixture for this state and suggesting that it is formed by the mixing of rotational and shell-model states.

I. INTRODUCTION

THE reasonable expectation that nuclei in the $f_{7/2}$ "shell" could be understood in terms of coupling of the rather few nucleons outside the doubly-magic Ca^{40} core, although satisfied in many respects,[1] has not been borne out in detail. Recent observations of low-lying 0^+ states in Ca^{40}, Ca^{42}, and Ca^{44} led to the proposal[2,3] that, similar to the situation for O^{16} and O^{18}, nuclear deformations be invoked to explain the spectra of these nuclei, even at low excitation energies. In order to decide whether a given state is predominantly formed by coupling of relatively few nucleons, as in the scheme proposed by McCullen *et al.*[1] for the $f_{7/2}$ shell, or if it contains an appreciable collective admixture (as would a deformed state), the detailed properties of the state must be measured (e.g., spectroscopic factors, transition rates). It is generally recognized that a determination of energies and spins of excited states provides the least sensitive test of any proposed theory.

There have been several recent experimental studies of the Ti^{48} level structure,[4–6] but as yet relatively little is known concerning the lifetimes and transition probabilities in the important region up to 4 MeV or so. Bernstein *et al.*[6] have obtained transition probabilities for some of the levels based on a distorted-wave Born approximation (DWBA) analysis of inelastic α-particle scattering. Determination of the lifetime of the 0.9833-MeV (2^+) first excited state has been made by a number of workers.[7–9] Recently, Akkerman *et al.*[10] have measured the lifetime of the 2.295-MeV (4^+) second excited state.

In view of the continued interest in the $f_{7/2}$ region, it was felt that a measurement of nuclear lifetimes and branching ratios in Ti^{48} would be of general interest. Furthermore, it was hoped that measurement of transition rates would serve to indicate to what extent collective admixtures were important in determining the properties of the low-lying states.

II. EXPERIMENTAL PROCEDURE

The experimental arrangement used in this study has been described in detail elsewhere,[11] and only a brief description is given here. A self-supporting titanium foil (1 mg/cm^2) enriched to 99.6% in Ti^{48} was bombarded with 7.8-MeV protons from the MIT Cyclotron. An annular surface-barrier detector located around the incident beam served to detect back-scattered protons from inelastic scattering events. A 32-cc Ge(Li) detector placed outside the scattering chamber was used to detect the associated deexcitation γ rays. "Fast" signals from each detector were used to generate a coincidence pulse which gated a dual 4096 ADC operated in the buffer-tape mode. In this mode of operation, proton and γ-ray energy data for each coincidence event were stored on magnetic tape in a 128×2048 form. Doppler shifts of the γ rays were measured by placing the γ detector in turn at a "front" position ($55°\pm2°$ with respect to the incident beam) and at a "back" position ($125°\pm2°$).

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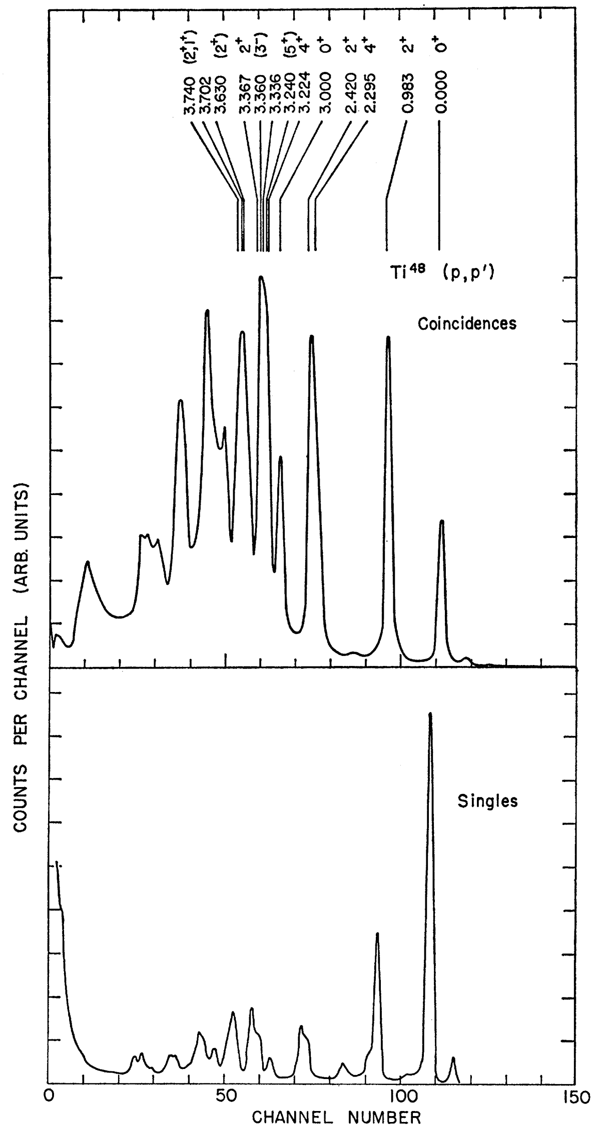

FIG. 1. Spectrum of protons inelastically scattered from Ti^{48} at a lab angle of approximately 160° (see text) both with and without a coincidence with a γ ray.

Periodic gain checks were made with a number of radioactive sources. In several cases, appreciable gain (or zero) shifts were noted which necessitated discarding an appropriate portion of the γ-ray data. The buffer-tape method of data storage is especially valuable in this connection, since events are stored in time sequence, making it possible to determine at what point in the data collection process the shifts occurred.

III. RESULTS

Figure 1 shows the inelastic proton spectrum observed in the surface barrier detector, in coincidence with γ rays. Figure 2 shows the level scheme for Ti^{48} up to 3.75 MeV, together with the transitions observed in this experiment. As is evident, the proton resolution [about 120 keV, full width at half-maximum (FWHM)] is not sufficient to resolve many of the levels. However, the resolution of the Ge(Li) is sufficiently good ($\approx$8 keV at 1-MeV γ energy) that there usually is no ambiguity in deciding which levels are involved in a given transition. For example, in Fig. 3, we display the spectrum of γ rays in coincidence with protons of energy above 0.5 MeV. Although the 2.295- and 2.42-MeV levels cannot be resolved in the proton spectrum, the respective γ transitions to the 0.9833-MeV level are well separated in the γ spectrum.

A comparison of Figs. 4(a) and (b) serves to indicate the advantage of being able to gate the γ spectrum on selected regions of the proton spectrum, especially when attempting to analyze Doppler shifts of weak transitions. Such transitions might well be obscured in data such as that of Fig. 4(b), where we have shown the spectrum of γ rays in coincidence with protons of any energy above 0.5 MeV. In Fig. 4(a), we show the same spectral region, but this time gated only on protons which excite the 0.9833-MeV level of Ti^{48}. The reduction in background height and in the number of peaks is quite dramatic. As a further aid in this regard, running conditions of the experiment were controlled so as to give a true-to-chance ratio of approximately 10:1.

Figures 5 and 6 present two examples of Doppler-shift data, obtained from the γ spectra at "forward" and "backward" positions of the Ge(Li) detector, gated on the appropriate proton groups. In arriving at life-

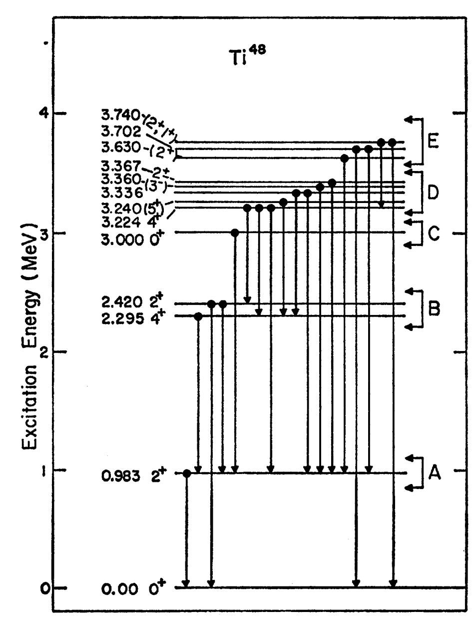

FIG. 2. Decay scheme for Ti^{48}. Energies of levels are based on a comparison of the results of this experiment with results reported in Refs. 4 and 5.

times for the γ-emitting levels, the centroids of the peaks are first computed. The front-back shifts in the centroid positions lead to experimental values for $S(\tau)$, which can then be compared with Eq. (2) (Sec. IV) to give a value for τ. The error associated with the determination of the centroid position is estimated to be typically (e.g., the 0.9833 MeV 2^+) 0.25 keV, which implies an 0.4-keV error in the shift. This is only the statistical error, and we therefore are assuming that we have successfully rejected all data with systematic fluctuations. The implied error in τ depends on which portion of the $S(\tau)$-versus-τ curve one is working on (see Fig. 7, for example).

Table I contains a listing of lifetimes obtained from Doppler-shift data like that of Figs. 5 and 6. The branching ratios are based on ratios of integrated peak areas (corrected for detector efficiency), and in most instances represent averages of the "front" and "back" data. Since a complete angular correlation of the γ rays was not taken, there, of course, arises a question concerning the accuracy of the branching ratios for transitions which could be anisotropic. In this connection, it should be noted that the Ge(Li) detector angles are close to 55° and 125°, which are zeros of $P_2(\cos\theta)$, so that the only departure from isotropy expected would be from a term $A_4P_4(\cos 55°)$, where $W(\theta)=A_0+A_2P_2(\cos\theta)+A_4P_4(\cos\theta)$. At 55° the value of P_4 is -0.38. Errors in the quoted lifetimes and branching ratios are assigned following the procedure discussed in Ref. 11.

IV. ANALYSIS

The method of determining nuclear meanlifetimes (τ) from observed Doppler-shift data has been described in an earlier paper.[11] Briefly, the mean Doppler shift expected for a γ ray of energy E_0 emitted from a recoiling nucleus which slows down in the target is given by

$$\bar{\Delta}E\ (\tau)=\frac{E_0}{c}\int_0^\infty \bar{v}(t)\,\langle\cos\lambda(t)\,\rangle_{\text{av}}\,\frac{e^{-t/\tau}dt}{\tau},\qquad(1)$$

where $v(t)$ is the (time-dependent) velocity of the recoiling excited nucleus, $\lambda(t)$ is the angle between the velocity vector of the recoiling nucleus and the direction of the emitted γ ray, and τ is the mean lifetime of the emitting state. The indicated averages reflect the consideration which must be given to the multiple scattering experienced by the recoiling nucleus, and to the finite angular aperature (149°–172°) subtended by the proton detector.[11]

In order to carry out the integration in (1), the slowing-down theory developed by Blaugrund[12] and Lindhard *et al.*[13] was employed. A computer code was written which performed a numerical integration of

[12] A. E. Blaugrund, Nucl. Phys. **88**, 501 (1966).

[13] J. Lindhard, M. Scharff, and H. E. Schiott, Kgl. Danske Videnskab. Selskab, Mat.-Fys. Medd. **33**, 14 (1963).

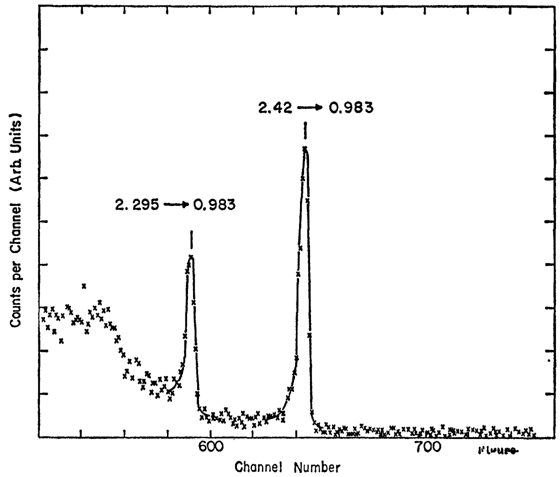

FIG. 3. Spectrum of γ rays in coincidence with protons of any energy above 0.5 MeV, for the region around $E_\gamma=1.5$ MeV.

(1) and then generated the function $S(\tau)$, where

$$S(\tau)=1-\bar{\delta}E/\bar{\delta}E_0.\qquad(2)$$

Here, $\bar{\delta}E$ is the average front-back shift $[\bar{\Delta}E(\text{forward})-\bar{\Delta}E(\text{backward})]$ and $\bar{\delta}E_0$ is the average corresponding shift for a γ ray emitted before the nucleus begins to slow down. Such a γ ray would exhibit the "full" Doppler shift $\bar{\Delta}E_0$,

$$\bar{\Delta}E_0=[\bar{v}(t=0)/c]E_0\langle\cos\lambda(t=0)\,\rangle_{\text{av}},\qquad(3)$$

where again suitable geometric averages must be taken. The function $S(\tau)$ may then be compared with the experimental value $S_{\text{expt}}=1-\bar{\delta}E_{\text{expt}}/\bar{\delta}E_0$ to yield a value for τ. Figure 7 shows a typical result for $S(\tau)$, together with the indicated value of S_{expt} and the resultant lifetime, τ.

It should be noted here that if a resonance in the p, p' cross section occurs in such a way as to cause the reaction to take place predominantly on the downstream side of the target, some of the recoiling nuclei will escape into vacuum and will not further slow down. If resonance structure is pronounced and sharp, this would affect the results for about 1 in 10 of the lifetime measurements. It will, of course, not affect the branching ratios and will cause errors in lifetimes only on the fast side. Some investigation of this problem was made for Ca^{42}.[11] It was concluded that at least for the isolated peaks there was no strong energy dependence at our energy. For Ti^{48} one would expect less energy dependence since the (p, n) Q value is less negative and hence resonance widths would be broader.

V. DISCUSSION

A. 0.9833-MeV 2^+ Level

The mean lifetime (or equivalently, the transition rate) for this level has been determined previously

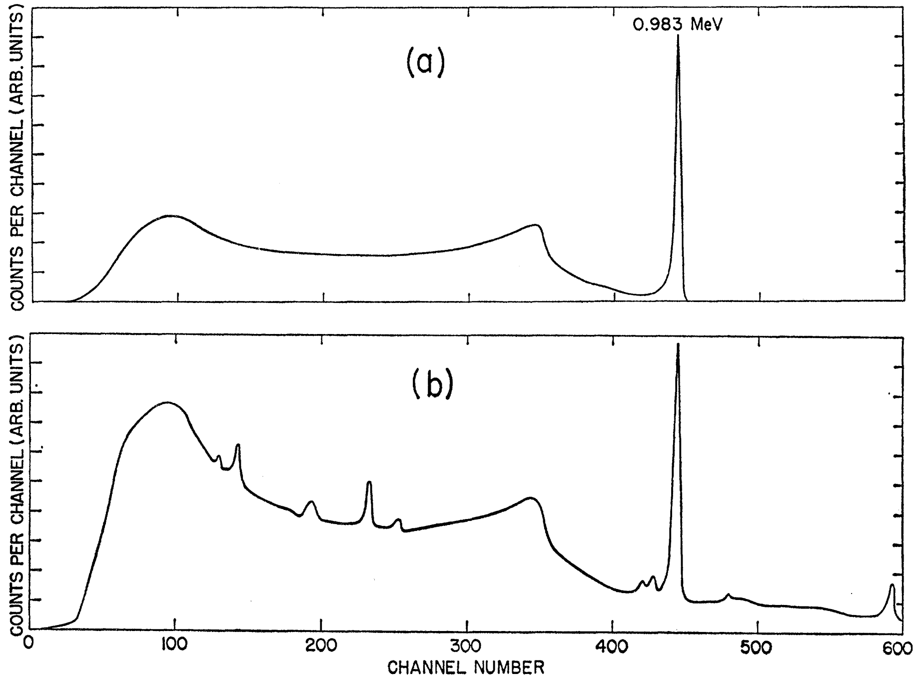

FIG. 4. (a) Spectrum of γ rays in coincidence with protons from group "A" of Fig. 1. (b) Spectrum of γ rays in coincidence with protons of any energy above 0.5 MeV.

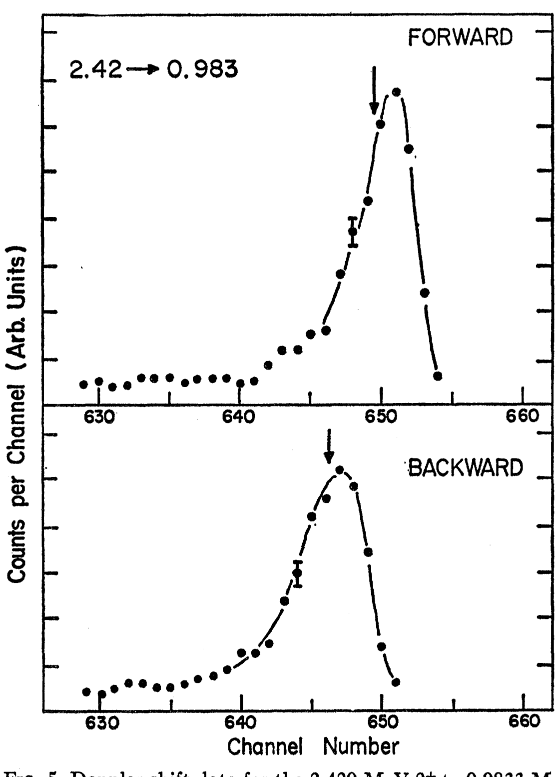

FIG. 5. Doppler-shift data for the 2.420-MeV 2^+ to 0.9833-MeV 2^+ transition, obtained from the γ-ray events in coincidence with protons from group "B" of Fig. 1. The arrows indicate the computed positions of the peak centroids. A tail on the low-energy side of the peak causes the mean to not correspond to the maximum.

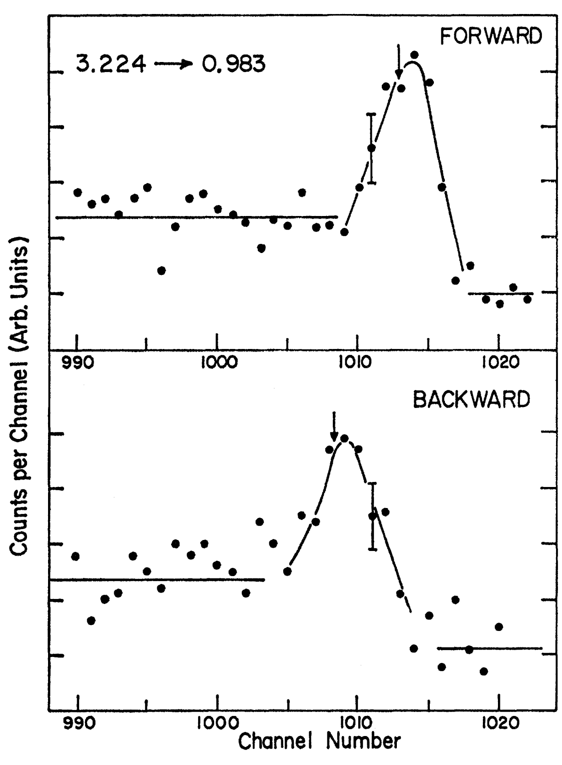

FIG. 6. Doppler-shift data for the 3.224-MeV 4^+ to 0.9833-MeV 2^+ transition, obtained from the γ-ray events in coincidence with protons from group "D" of Fig. 1. The arrows indicate the computed positions of the peak centroids. A tail on the low-energy side of the peak causes the mean to not correspond to the maximum.

TABLE I. Mean lifetimes and branching ratios of Ti^{48}.

Initial state J^π	Initial state E (MeV)	Final state J^π	Final state E (MeV)	S	Lifetime expt (10^{-13} sec)	$B(\sigma\lambda)$ e^2f^4	Assumed ($\sigma\lambda$)	τ^a Weisskopf	% branch	$\lambda_{expt}/\lambda_{Weisskopf}$
2^+	0.9833	0^+	0.00	0.85±0.09	12_{-3}^{+60}	740_{-600}^{+250}	$E2$	868	100	72_{-58}^{+24}
4^+	2.295	2^+	0.9833	0.85±0.07	12_{-3}^{+20}	175_{-120}^{+60}	$E2$	205	100	17_{-11}^{+6}
2^+	2.420			0.05±0.07	$0.16_{-0.16}^{+0.25}$					
		2^+	0.9833			$0.028_{-0.0105}^{+\infty}$	$M1$	0.109	97±1	$0.061_{-0.5}^{+\infty}$ [b]
						$258_{-0.220}^{+\infty}$	$E2$	128		$3.3_{-2.7}^{+\infty}$
		0^+	0.000			$21_{-17}^{+\infty}$	$E2$	9.55	3.4±1	$2_{-1.5}^{+\infty}$
0^+	3.000	2^+	0.9833	0.35±0.05	$1.25-_{0.25}^{+0.25}$	194±40	$E2$	23.9[c]	100	19_{-3}^{+4} [b]
4^+	3.224			0.08±0.04	$0.24_{-0.16}^{+0.12}$					
		2^+	2.420			$12\,000_{-4000}^{+24\,000}$	$E2$	1880	15±5	1200_{-400}^{+2400}
		4^+	2.295			$0.0065_{-0.022}^{+0.013}$	$M1$	0.405	20±3	$0.34_{-0.11}^{+0.33}$
		2^+	0.9833			390_{-130}^{+800}	$E2$	14	65±5	38_{-16}^{+74}
(5^+)	3.240	4^+	2.295	0.30±0.11	$1.00_{-0.38}^{+0.50}$	$0.0074_{-0.0025}^{+0.0045}$	$M1$	0.381	100	$0.38_{-0.13}^{+0.22}$
	3.336			0.63±0.04	$3.20_{-0.4}^{+0.5}$					
		2^+	0.9833						75±15	
		4^+	2.295						25±15	
(3^-)[d]	3.360	2^+	0.9833	0.56±0.04	$2.5_{-0.3}^{+0.4}$	$1.9\pm0.03\times10^{-4}$	$E1$	5.5×10^{-4}	100	$(2.2_{-0.2}^{+0.3})\times10^{-4}$
2^+[e]	3.367	2^+	0.9833	0.07±0.04	$0.22_{-0.12}^{+0.13}$				100	
2^+	3.63	2^+	0.9833	$0.47_{-0.11}^{+0.09}$	0.15±0.03				100	
	3.702			$1.15_{-0.12}^{+0.15}$	0.35±0.03					
		2^+	0.9833						71±6	
		0^+	0.00						29.6	
$2^+, 1^+$	3.740	0^+	0.00	$0.51_{-0.10}^{+0.08}$	0.16±0.03				100	

[a] These Weisskopf lifetimes are the same as those, e.g., given by Wilkinson, in *Nuclear Spectroscopy*, edited by Fay Ajzenberg-Selove (Academic Press Inc., New York, 1960), Part B, pp. 859 and 860. They do not have initial or final spin dependence. The reduced matrix elements, $B(\sigma\lambda)$ are for the observed transition direction.

[b] Using the mixing ration of Matin *et al.* (Ref. 14).

[c] It would perhaps be preferable here to consider $\tau_w/(2J_f+1)=4.76$ and hence $\lambda_{expt}/\lambda_w'$ as $3.8_{-0.6}^{+0.8}$.

[d] We assume (3^-) for this level.

[e] R. N. Horoshko (private communication).

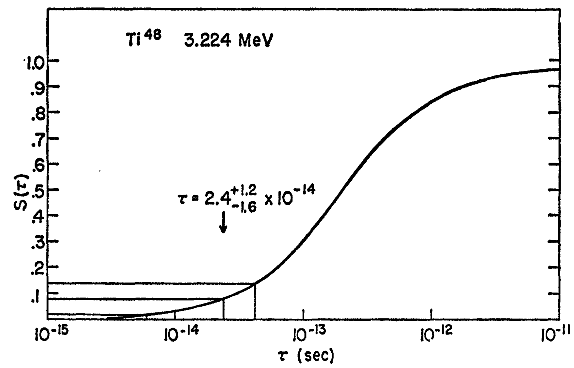

FIG. 7. The function $J(\tau)$, obtained from Eq. (2) as described in the text, for γ rays emitted from the 2.420 MeV 2^+ level of Ti^{48}.

by a number of experiments.[7–9] Booth,[9] for example, employing resonance fluorescence, obtains $\tau=3.6\pm 1.5\times 10^{-12}$ sec. From an examination of Fig. 7, it is obvious that the present technique is poorly suited to a measurement of such a long lifetime, for with a typical error in S, the corresponding error in τ will be quite large. The value obtained in the present experiment is $\tau=1.2_{-0.3}^{+5}\times 10^{-12}$ sec, which agrees, within the rather large error limits, to the previously obtained value.

B. 2.295-MeV 4^+ Level

Akkerman *et al.*[10] have obtained a value of $2_{-0.7}^{+0.9}\times 10^{-12}$ sec for the lifetime of this level by measuring the dependence of the cross section for resonance scattering of γ rays on source density. The value obtained here, $\tau=1.2_{-0.3}^{+2}\times 10^{-12}$ sec, is in agreement with the earlier result, and corresponds to a transition rate of about 10 times the single-particle rate. In a recent (α, α') experiment,[6] an anomalous angular distribution was observed for this state, suggesting a possible close-lying doublet. However, no evidence for such a doublet was observed in the present experiment, nor was there any indication of a ground-state transition.

C. 2.420-MeV 2^+ Level

The Doppler shift for the decay of this state was observed to be nearly equal to the "full" shift ΔE_0. In this case, the Doppler-shift attenuation method (DSAM) essentially determines only an upper limit on the lifetime, i.e., $\tau=0.16_{-0.16}^{+0.25}\times 10^{-13}$ sec Matin *et al.*[14] have measured the $E2{:}M1$ mixing ratio for the 2.420 (2^+) to 0.9833 2^+ transition, obtaining $\delta=-0.18\pm 0.09$. From this information a lower limit to the transition strength can be given. The results for the decay of the 2.420-MeV state to the ground state and to the 0.9833-MeV state are given in Table I.

[14] S. M. Matin, D. J. Church, and G. E. Mitchell, Phys. Rev. **150**, 906 (1966).

D. 3.000-MeV 0^+ Level

The (t, p) work of Hinds *et al.*[15] strongly suggested that the spin and parity of this state are (0^+). A later measurement by Church *et al.*[16] confirmed this assignment. The appearance of a 0^+ state at this low excitation is analogous to the situation in Ca^{42}, where collective oscillations have been suggested to explain this phenomenon.[2,3] If this explanation is correct, one would expect to observe collective enhancements in the decay of such states. In the present case, the transition strength is found to be $\frac{1}{5}(19\pm 4)$ single-particle units. The results of a lifetime measurement[17] for the 1.836-MeV 0^+ state in Ca^{42} gave 13 ± 0.8 single-particle units. These results furnish convincing evidence of the collective nature of these levels though perhaps less so for Ti^{48}.

E. 3.224-MeV 4^+ Level

Three branches were observed for the decay of this state: $15\pm 5\%$ to the 2.420-MeV 2^+ level; $20\pm 3\%$ to the 2.295-MeV 4^+ level; and $65\pm 5\%$ to the 0.9833-MeV 2^+ level.

An extremely strong enhancement is observed for the decay to the 2.420-MeV level (1200_{-400}^{+2400} single-particle units), indicating a strong collective admixture for the two states. Similarly, an enhancement for the decay to the 0.9833-MeV 2^+ level is observed, though not so strong. The decay to the 2.295-MeV 4^+ level could either be $E2$ or $M1$ in character. Since the Weisskopf estimate for the $M1$ transition is 10^4 larger than that for $E2$, the transition strength shown in Table I has been computed assuming pure $M1$. The value ($\lambda=0.34_{-0.11}^{+0.33}$ single-particle units) indicates a substantial inhibition for the $M1$ branch, as compared to the two $E2$ branches. However, inhibited $M1$ transitions seem to be a feature of this region of the Periodic Table.[18]

F. 3.240-MeV (5^+) Level

The spin assignment for this level is tentative, and is based on the β-decay work of Ristinen *et al.*[19] The fact that the only decay mode observed in the present study is via the 2.295-MeV 4^+ level is consistent with this assignment.

G. 3.336-MeV Level

This region of excitation energy in Ti^{48} has been in some confusion as the result of several recent studies. Barnes *et al.*[5] suggest the possibility of a doublet near

[15] S. Hinds and R. Middleton, Nucl. Phys. **92**, 422 (1966).

[16] D. J. Church, R. N. Honoshko, and G. E. Mitchell, Phys. Rev. **160**, 894 (1967).

[17] P. C. Simms, N. Benczer-Koller, and C. S. Wu, Phys. Rev. **121**, 1169 (1961).

[18] G. Morpurgo, in *Nuclear Spectroscopy*, edited by G. Racah (Academic Press Inc., New York, 1962).

[19] R. A. Ristinen, A. A. Bartlett, and J. J. Kraushaar, Nucl. Phys. **45**, 321 (1963).

this energy, one level of $J^{\pi}=6^{+}$, the other of positive parity and with $1\leq J\leq 4$. Belote,[4] however, in a p, p' experiment at 7 MeV sees no evidence for such a level. The fact that a level at this energy is observed in the present experiment is not necessarily in disagreement with Belote's results, since we observe the γ decay, which in certain circumstances can be observable even when the (p, p') cross section to the level is very weak.

It is unlikely that with 7.8-MeV protons incident on Ti^{48}, a level with $J=6$ could be excited (it is perhaps even surprising that we could observe the 5^{+} level at 3.240 MeV). Furthermore, the 75% branch to the 0.9833-MeV 2^{+} level rules out the 6^{+} possibility. Our observations would thus seem to support the suggestion of Barnes *et al.* To further complicate the situation, Wilhjelm *et al.*,[20] on the basis of their results, conclude that the measurements of Barnes *et al.* do not necessarily imply a doublet near 3.34 MeV. It seems evident, however, that there must be at least another state at this excitation energy because the observed decay precludes the 6^{+} possibility.

H. 3.360- and 3.367-MeV States

Matsuda reports a 3^{-} state at this energy in a (p, p') study.[21] Bernstein *et al.*[6] find that the angular distribution for the inelastic α-particle scattering for this energy does not resemble that of other 3^{-} states. A 3^{-} identification was obtained by analyzing the angular distribution as that for a 3^{-} state and an unresolved positive-parity state. The resolution of this latter (α, α') experiment was such that a number of states could have contributed to the observed yield: Levels have so far been reported at 3.240 MeV (5^{+}),[19] 3.336 MeV (this study), 3.340 MeV (6^{+}),[19] 3.360 MeV (this study), 3.340 MeV, 3.367 MeV (this study), and 3.377 MeV.[5] Horoshko[22] reports that the 3.367-MeV level has $J^{\pi}=2^{+}$, therefore it seems probable that the 3.360-MeV level has $J^{\pi}=(3^{-})$. The reduced matrix element for the 3.360-MeV level in Table I has been computed on this basis. Such an inhibition is to be expected, since the 3^{-} is probably a vibrational state, and the one-body radiation operator would not couple to those components of the 0.9833-MeV state made from either deformed or simple shell-model configurations. The lifetimes and branching ratios, however, do not rule out possible spin parities of $0^{\pm}$, $1^{\pm}$, $2^{\pm}$, 3^{+}, or 4^{+}.

An interesting observation has been made recently concerning the decay mode of the 3^{-} state in Ti^{46}.[23] In a $(p, p'\gamma)$ experiment, the first 3^{-} state (3.06 MeV) in Ti^{46} was observed to decay with a very high probability to the second 2^{+} state (2.96 MeV) rather than the first 2^{+} (0.89 MeV). It was proposed that this unusual decay mode could be explained qualitatively on the basis of the isospin structure of the two 2^{+} states. The significance of this proposal for the present work is that in a pure $(f_{7/2})^{n}$ configuration, the 2^{+} states in Ti^{48} differ from those in Ti^{46}. In Ti^{48}, the $2^{+}{}_{1}$ state is pure isoscalar and the $2^{+}{}_{2}$ is pure isovector, whereas in Ti^{46} the two 2^{+} states have mixed isospin nature. As is not expected in this picture, the candidate for the 3^{-} state in Ti^{48} shows a strong preference for decay to the $2^{+}{}_{1}$ state. However, in view of the important role collective admixtures play in explaining certain features of the decay scheme of "$f_{7/2}$ shell" nuclei, it is not clear what importance can be attached to selection rules based on the assumption of a pure $(f_{7/2})^{n}$ configuration. No indication was seen of a decay of either member of the doublet to the $2^{+}{}_{2}$ state at 2.420 MeV.

I. 3.520-MeV [(5–8)$^{+}$] Level

A level at this energy of possible spin [(5–8)$^{+}$] was not observed in the present experiment, which is perhaps due to the large angular momentum of the state. Belote[4] in a 7-MeV (p, p') experiment similarly did not observe this level.

J. 3.63-MeV (2^{+}) Level

Brown *et al.*[24] assign spin and parity of 2^{+} to this level, a result corroborated by the (t, p) work of Hinds *et al.*[15] The only decay mode observed here was via the 0.9833-MeV 2^{+} level. The ground-state $E2$ transition rate is less than half a single-particle unit. This state was not observed in an (α, α') experiment.[6]

K. 3.702-MeV Level

This is probably the level reported by Brown *et al.*[24] at 3.708 MeV in a recent (p, α) experiment. They suggest a spin assignment of $J\leq 2$. The observed branch of 30% to the ground state, of course, rules out $J=0$. Of the remaining spin and parity candidates we can rule out 2^{-} on the basis of the transition rate to the ground state. This leaves us with the possibilities $(2^{+}, 1^{\pm})$.

L. 3.740-MeV Level

Brown *et al.*[24] report a level at 3.749 MeV with a probable $J^{\pi}=1^{+}$. Our observation of decay to the ground state is not inconsistent with this inference. From the decay rate the spin must be 2 or 1 and from the stripping state[5,20] the parity must be even so we have $J^{\pi}=2^{+}$ or 1^{+}.

VI. SUMMARY

A measurement of transition rates between levels in Ti^{48} has revealed some features which are not accounted

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for in an $(f_{7/2})^n$ coupling scheme. The 0^+ state at 3.000-MeV decay rate is fairly strong to the first excited state, indicating that it may be similar in nature to the deformed states in the Ca isotopes. Transitions involving the first 2^+ state at 0.9833 MeV also seem to show collective enhancements. The second 2^+ state at 2.420 MeV, seems to be collectively related to the 4^+ at 3.224 MeV and the (d, p) stripping data[5,20] rule out pure $(f_{7/2})^n$ wave functions[1] for this state and suggest a large $p_{3/2}$ neutron component to the wave function. Thus there does not seem to be much support for the interpretation of either of the 2^+ levels being simply $(f_{7/2})^n$ configurations, and therefore it is questionable whether the mode of decay of the 3^- state at 3.36 MeV via these two levels can furnish a good example of the proposed isospin selection rules.[23] The $E1$ rate for this state does show strong inhibition similar to the cases for Ca^{42} [11] and Ni^{58}.[25] The 4^+ states, as indicated, are collectively related to the 2^+ states, as are the 2^+ states to the 0^+ states so it is quite clear that collective admixtures are important in the low-lying levels of Ti^{48}.

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Elastic Scattering of 21-MeV Protons from Nitrogen-14, Oxygen-16, Argon-40, Nickel-58, and Tin-116

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Differential cross sections were measured for 21-MeV incident protons elastically scattered from ^{14}N, ^{16}O, ^{40}Ar, ^{58}Ni, and ^{116}Sn. An optical-model analysis was performed on these data as well as on previously measured elastic polarizations of 21-MeV incident protons scattered from the same nuclei. The optical potential used in this analysis included a real central term, a surface absorption term, and a real spin-orbit term. Good fits to both the cross sections and polarizations for all nuclei except ^{16}O were obtained by allowing the nine parameters of the optical potential to vary from nucleus to nucleus. The diffuseness parameters derived to fit the ^{14}N and ^{16}O data in general differ considerably from those derived to fit the scattering from the heavier nuclei. These results are compared with those of two other calculations in which two different sets of nonunique constant geometrical optical-model parameters were assumed and only the three potential strengths were obtained by searching. As expected, these constant-geometry calculations gave poorer agreement with the data. The disagreement with the polarizations of ^{14}N and ^{16}O was very pronounced.

INTRODUCTION

It is known[1] that the optical model can reproduce rather well the experimentally measured cross sections and polarizations, provided the parameters in the optical-model potential are allowed to vary as a function of energy and nucleus. Considerable efforts are being made to find a universal optical-model potential, or at least establish trends in the parameters of the potential with changes in incident proton energy, atomic number, and/or mass number.[2–8] In evolving such a potential, data are more useful if they include both cross sections and polarizations measured at the same incident proton energy. Consequently, in this paper elastic cross sections for 21-MeV incident protons

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