PHYSICAL REVIEW C VOLUME 23, NUMBER 5 MAY 1981

# $\gamma$ decay and lifetimes of excited levels in $^{49}$Ti

P. A. Mandò, G. Poggi, P. Sona, and N. Taccetti
*Istituto di Fisica dell'Università, Firenze, Italy*
*and Istituto Nazionale di Fisica Nucleare, Sezione di Firenze, Italy*

(Received 12 August 1980)

The decay scheme of $^{49}$Ti up to 5.2 MeV excitation energy was investigated by the $(d,p\gamma)$ and $(p,p'\gamma)$ reactions and by Coulomb excitation. Singles spectra and $p$-$\gamma$ coincidences were recorded. Lifetimes or lifetime limits were determined for 15 levels by Coulomb excitation or by the Doppler shift attenuation method. A consistent decay scheme for levels up to $E_x = 5.2$ MeV was deduced including many so far unobserved transitions. On the basis of these results $J^\pi$ assignments are proposed and a comparison is made with the predictions of the deformed configuration mixing model.

NUCLEAR REACTIONS $^{48}$Ti$(d,p\gamma)$, $^{49}$Ti$(p,p'\gamma)$, Coulomb excitation by alpha bombardment. $E_d = 6$ MeV, $E_p = 6$ MeV, $E_\alpha = 5.25$–$5.8$ MeV. Enriched $^{49}$Ti target. $p$-$\gamma$ coincidences. Doppler shift attenuation. Measured level energies, decay scheme, lifetimes.

## INTRODUCTION

The experimental knowledge of the decay properties of the excited levels in $^{49}$Ti was, up to now, mostly based on information from the $^{48}$Ti$(n,\gamma)$ reaction[1] and, for the 1623 and 1762 keV levels, on resonant bremsstrahlung-absorption experiments.[2] In the $(n,\gamma)$ experiment, no $\gamma$-$\gamma$ coincidences had been performed; this circumstance resulted in several ambiguities and uncertainties in the proposed $\gamma$-decay scheme, which was limited to a small part of the known levels up to $E_x \sim 5$ MeV.

Further spectroscopic information is therefore necessary to allow a meaningful comparison with theoretical models, and, in particular, with the deformed configuration mixing (DCM) model, which has proved to be very successful in reproducing the properties of the neighboring odd-$A$ isotopes $^{45}$Ti and $^{47}$Ti.[3]

In the present work, we have investigated the decay properties of excited levels in $^{49}$Ti by means of the $^{48}$Ti$(d,p\gamma)$ and $^{49}$Ti$(p,p'\gamma)$ reactions, and Coulomb excitation by alpha particles, performing in the first two cases $p$-$\gamma$ coincidence measurements, which made it possible to give a more complete and consistent decay scheme up to $\sim 5.2$ MeV excitation energy. By the Coulomb excitation and the $(p,p'\gamma)$ reaction, we also measured several lifetimes or lifetime limits for levels up to $\sim 3$ MeV. All our measurements have been performed at the 7 MV CN Van de Graaff accelerator of the Laboratori Nazionali di Legnaro.

## EXPERIMENTAL PROCEDURES

### $^{48}$Ti$(d,p\gamma)$ measurements

A target of natural titanium oxide (40 $\mu$g/cm$^2$ thick, deposited onto a 20 $\mu$g/cm$^2$ carbon foil) was bombarded by a 6 MeV deuteron beam. A silicon surface barrier detector (1 mm thick) was used at +30° to the beam direction for particle detection; a Ge(Li) gamma detector ($\sim 4$ keV resolution at 1.3 MeV) was placed at −90° to the beam direction, in the reaction plane. In addition to singles proton and gamma spectra measurements, two runs of $p$-$\gamma$ coincidences were performed in the standard three parameter mode. In one of the runs, the elastic deuterons were stopped by placing a proper screen in front of the silicon detector. This drastically reduced the total counting rate, thus making it possible to increase the beam current and to collect much better statistics on the proton peaks, though with a poorer energy resolution. In the other run, the detector was left unscreened to optimize energy resolution at the price of collecting much fewer statistics. By combining the results of the two runs and the detailed information on level population from the proton singles spectrum, the decay mode of the most intensely populated levels was deduced.

### $^{49}$Ti$(p,p'\gamma)$ measurements

A proton beam of $E_p = 6$ MeV and $i_p$ ranging from 20 to 50 nA was used. Two runs of proton-gamma coincidences were performed placing the particle detector at +90° to the beam direction and a Ge(Li) detector first at −90° and then at +90° in the reaction plane [positions (a) and (b) respectively, of Fig. 1]. The target used was a 1 mg/cm$^2$ thick Ti foil (81.6% enriched in $^{49}$Ti).

Levels in $^{49}$Ti were significantly populated up to an excitation energy of about 3.7 MeV. The results of these measurements were used both to provide further information on the decay scheme and to deduce lifetimes by the Doppler shift attenuation method (DSAM), comparing the centroid

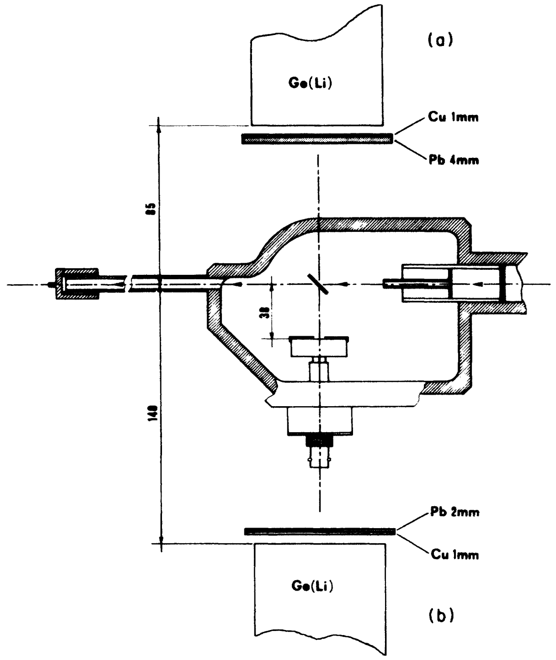

FIG. 1. Experimental setup in the two runs [Ge(Li) in positions (a) and (b), respectively] of $p'$-$\gamma$ coincidences in the $(p,p'\gamma)$ reaction. The lead shields in front of the Ge(Li) were used to reduce selectively the counting rate due to lower energy $\gamma$ rays, most of those of interest being over 1.4 MeV.

positions of $\gamma$ peaks in the true coincidence spectra. Zero level and gain drifts from one run to the other were found to be almost negligible. A correction was, in any case, deduced from the comparison between the two chance-coincidence $\gamma$ spectra, which included gamma peaks from radioactive sources and from the strong $(p,n)$ reaction. In some cases, where statistics were higher, it was possible to perform a consistency check by comparing the centroid positions of the same transition in the true-coincidence and chance-coincidence spectra of each run. An example of this comparison is shown in Fig. 2. Shifts obtained by this procedure were always found to be in agreement with the ones observed in the comparison between the true-coincidence spectra.

### Coulomb excitation

For these measurements, the same target as in the $(p,p'\gamma)$ experiment was used. It was bombarded by a $^4$He$^+$ beam of about 100 nA, at energies ranging from 5.25 to 5.8 MeV. At these energies nuclear reaction effects are negligible.[4] Singles $\gamma$ spectra were collected by means of a Ge(Li) coaxial detector (~3 keV resolution at 1.33 MeV) placed at 90° to the beam direction. The levels at 1382 and 1542 keV in $^{49}$Ti and the one at 983 keV in $^{48}$Ti (also present in the target in the amount of 14.6%) were significantly populated via Coulomb excitation. By measuring the relative yield of the two $\gamma$ lines deexciting the $^{49}$Ti levels with respect to the 983 keV line [whose $B(E2)\downarrow$ is known from the literature[5]], a value for the $B(E2)\downarrow$ of the two transitions in $^{49}$Ti was obtained. More details are given in Ref. 4, where the results concerning the 1382 keV level have been reported.

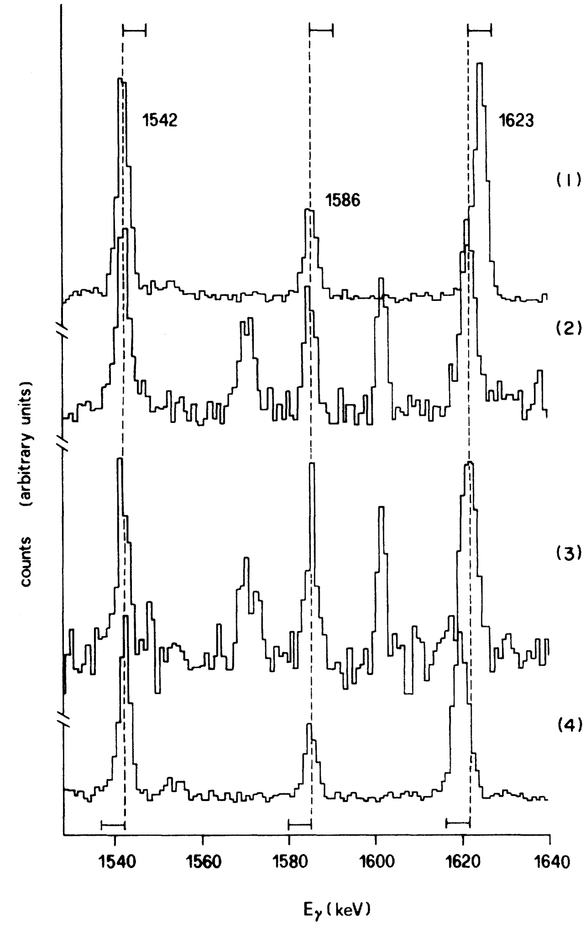

FIG. 2. Gamma spectra from $p'$-$\gamma$ coincidences in the $(p,p'\gamma)$ reaction. (1) and (4): true coincidences in geometry (a) and (b), respectively, of Fig. 1. The gate on the proton spectrum is set on the peaks feeding the 1542, 1586, and 1623 keV states [see Fig. 5(a)]. (2) and (3): corresponding chance coincidences spectra. The horizontal bars show the calculated full Doppler shifts.

## EXPERIMENTAL RESULTS

### Decay scheme

The most significant results of the $(d,p)$ experiment are shown in Figs. 3 and 4. In the particle spectrum of Fig. 3 all the prominent peaks

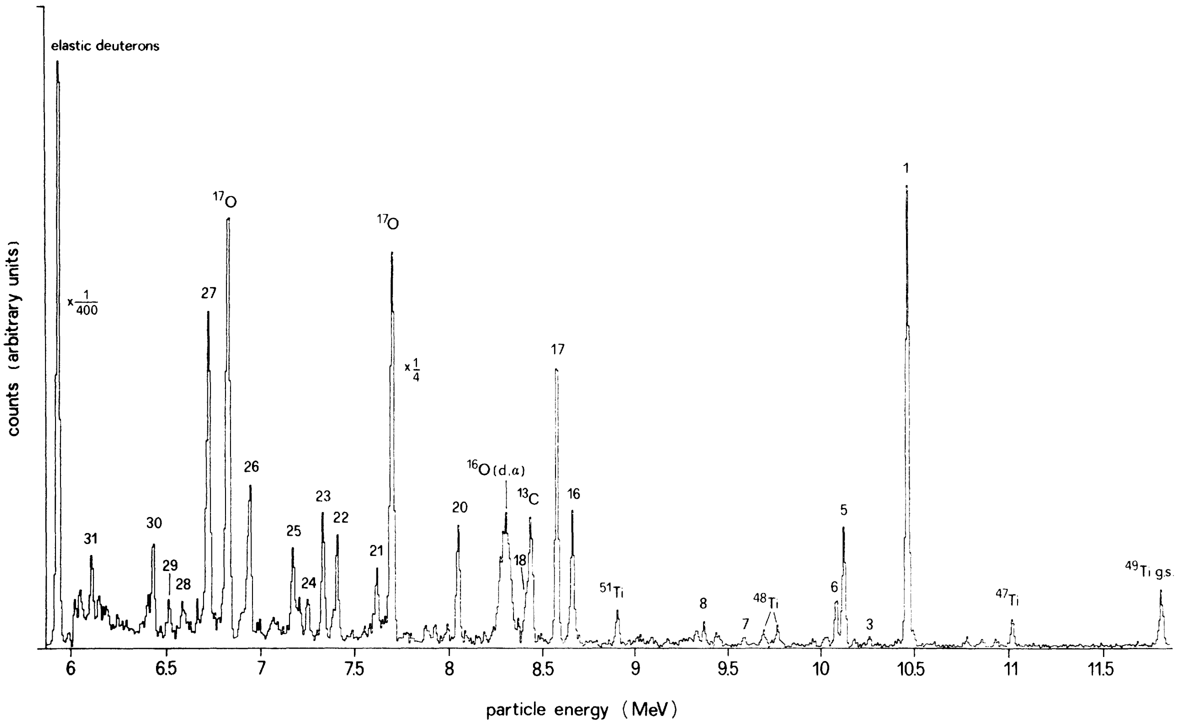

FIG. 3. Particle spectrum from the $(d,p)$ reaction performed at $E_d = 6$ MeV, $\theta = 30°$. Peaks due to levels excited in $^{49}$Ti are labeled by the number given in Table I. Peaks due to levels excited by the $(d,p)$ reactions in other Ti isotopes or O and C are indicated by the corresponding final nucleus.

were identified with levels of Ti isotopes reached through the $(d,p)$ reactions on the natural target or levels populated via reactions on $^{16}$O and $^{12}$C. The deduced excitation energies in $^{49}$Ti are reported in Table I. The energy calibration was performed by using, as reference values, energies of $^{49}$Ti levels which were known from independent evidence. In particular, values from the $(n,\gamma)$ measurements[1] were taken for levels over 3 MeV only if the decay mode given in Ref. 1 had been found consistent with our coincidence measurements in the $(d,p)$ reaction.

Figure 4 shows $\gamma$ spectra in coincidence with different proton peaks, obtained in the run with better proton energy resolution and poorer statistics. However, the following remarks and the data on the decay scheme shown in Fig. 6 are based on information gathered in both runs. Gate (a), set on protons feeding the 3176 keV level, shows that its decay proceeds, besides via the known 1794-1382 keV cascade, also via a 1589-1586 keV cascade. Gate (b), on the proton peak corresponding to the 3787 keV level, clearly shows a 2201-1586 keV cascade. This level probably decays also through a weaker 2025-1762 keV cascade, while no evidence is found for a 361 keV $\gamma$ ray connecting the 3787 and 3427 keV levels (as reported in Refs. 6 and 7). From gate (c), on protons feeding the 4507 keV level, a 3125-1382 keV cascade is apparent. Finally, gate (d) shows that the decay of the 5116 keV level mainly proceeds via the 3734-1382 keV cascade, while a weaker 3530-1586 keV cascade can only be hypothesized and not definitely established due to the very poor statistics. A third branch in the $\gamma$ decay of this level probably proceeds via a 2612-1122-1382 keV cascade. It is also to be noted that no evidence is found for a 1650 keV $\gamma$ ray connecting this level to the 3466 keV level, as reported in Refs. 6 and 7.

Figure 5 shows the main results from the coincidence measurements in the $(p,p')$ experiment. In part (a), the total proton true-coincidence spectrum, recorded in the geometry of Fig. 1(a), is reported. The overall resolution is ~60 keV. Parts (b) – (e) of the same figure show $\gamma$ spectra in coincidence with groups of peaks, as indicated in (a). From these spectra, most of the information on the decay scheme can be deduced. However, to make full use of the energy resolution in the proton spectrum, a "matrix-type" analysis was performed in each case. From this analysis, the information on the $\gamma$ decay of low-lying levels was extended to all the known levels up to an excitation energy of $E_x = 3042$ keV.

Moreover, using both singles and coincidence

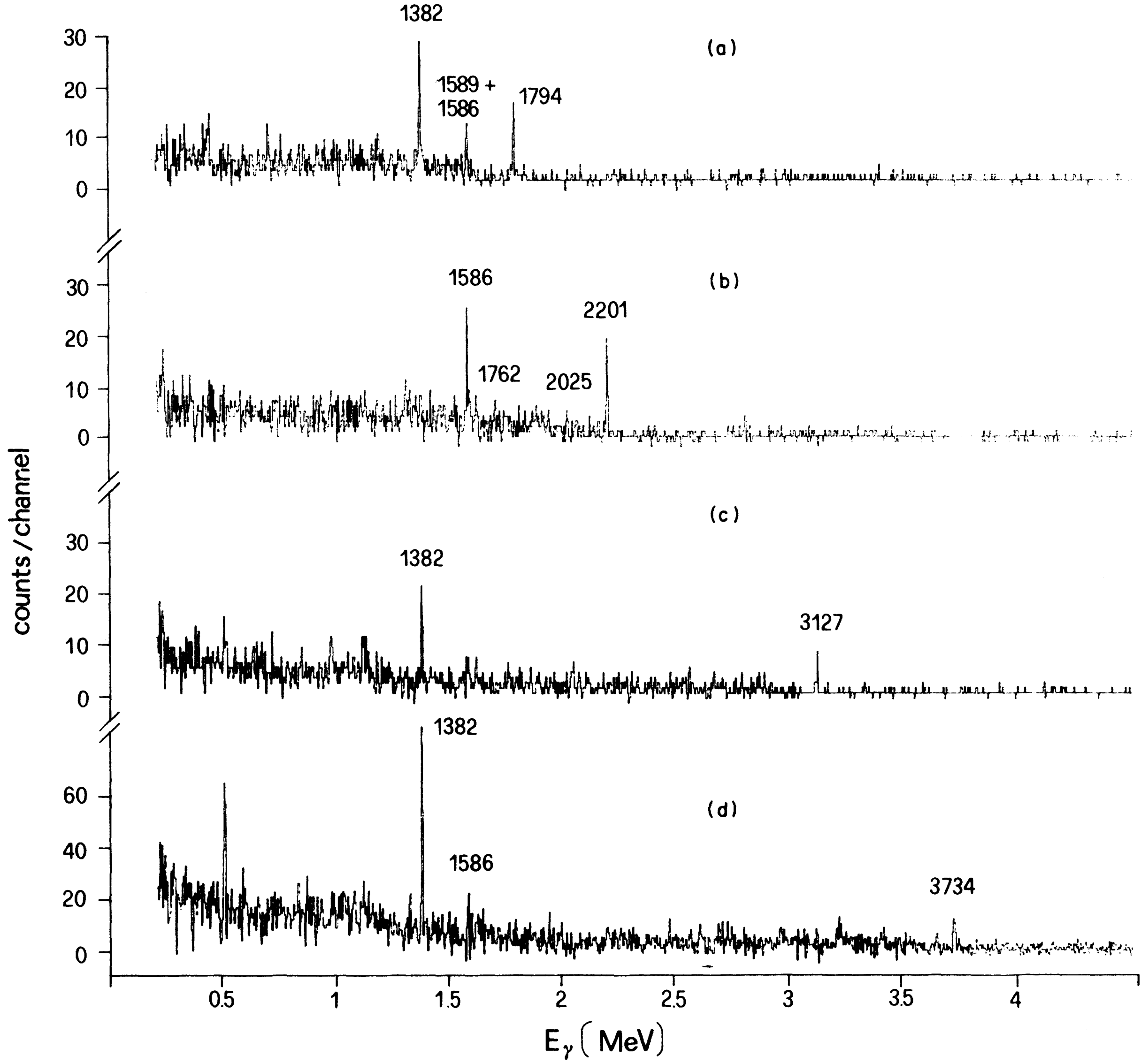

FIG. 4. Gamma spectra from $p$-$\gamma$ coincidences in the $(d,p)$ reaction (see text).

$\gamma$ spectra, it was possible to deduce accurate values for the level energies, which are reported in Table I. Figure 6 summarizes the decay scheme as deduced from all our measurements.[8]

### Lifetimes

Results concerning the lifetimes $\tau_m$ of excited states are reported in Table II.

The lifetimes of the 1382 and 1542 keV levels were deduced from the $B(E2)$ values of the corresponding transitions to the ground state, obtained from the Coulomb excitation by alpha bombardment. In this deduction, spin and parity for the 1542 keV level were assumed to be $J^\pi = \frac{11}{2}^-$, as given in Ref. 6. No Coulomb excitation of the $J^\pi = \frac{3}{2}^-$ 1586 keV state was observed, which implies for its lifetime the quoted limit.

All the other values were obtained by the DSAM in the $p$-$\gamma$ coincidence measurements from the $(p,p'\gamma)$ reaction. In the adopted geometries (Fig. 1) the recoil direction was defined to better than ± 2°. The standard stopping power theory of Lindhard *et al.*[9] and the Blaugrund procedure[10] for the treatment of the slowing down process of recoiling nuclei were used to deduce the lifetimes from the measured attenuation factor $F$.

When branches in the decay of a level were present with reasonable intensities, $\tau_m$ was deduced from a weighted average of the $F$ values pertaining to the single branches.

The errors on the lifetimes quoted in Table II

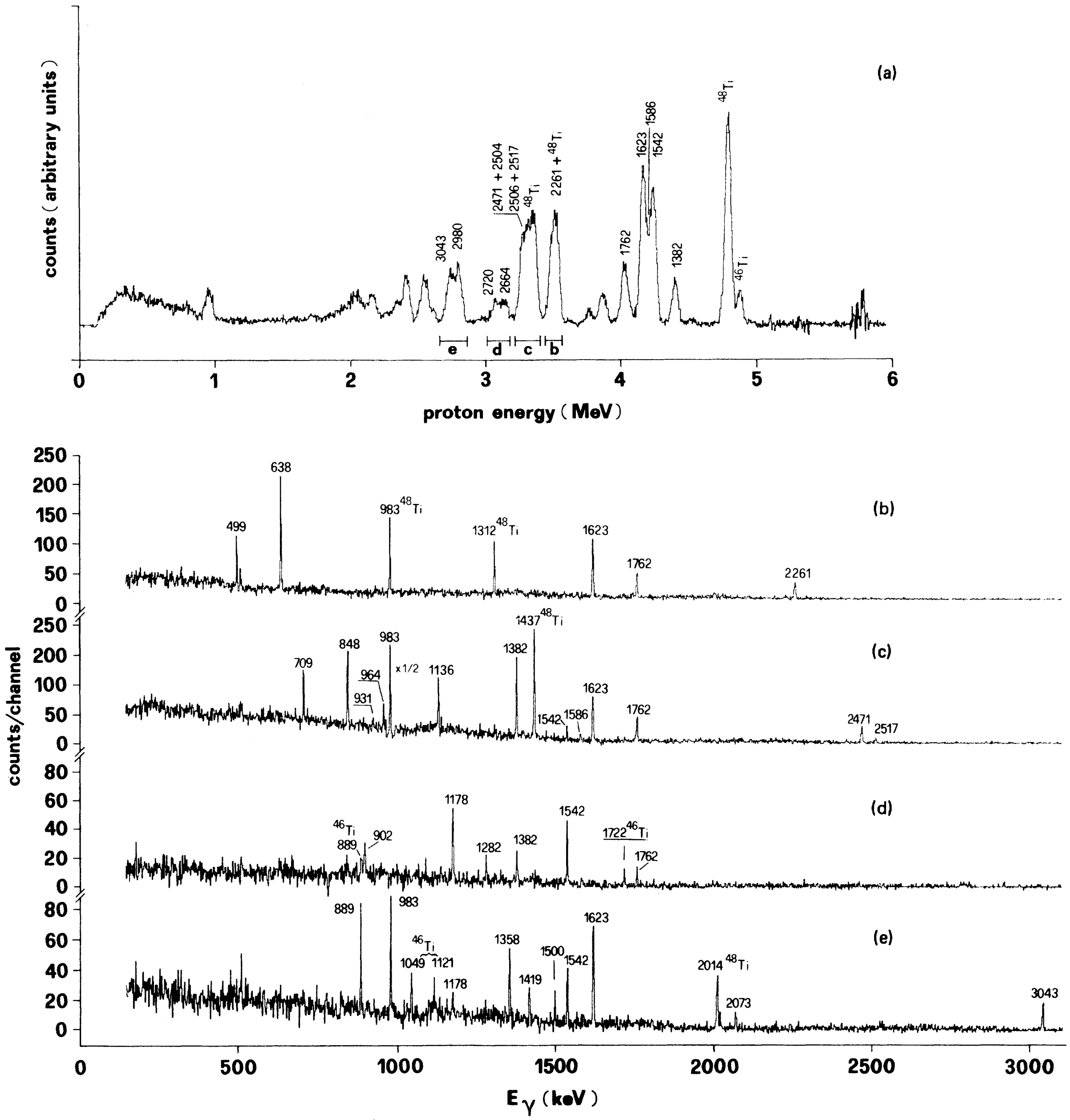

FIG. 5. (a) Spectrum of protons in true coincidence with $\gamma$ rays, obtained in the $(p,p'\gamma)$ measurements. Peaks are identified by the energy of the corresponding level in $^{49}$Ti. (b)–(e) Gamma spectra corresponding to the gates shown in (a). Randoms have been subtracted. While the spectra refer to geometry (a) of Fig. 1, the reported energies of the gamma rays are the mean of the values obtained in the two geometries, to cancel Doppler shifts.

were obtained as a linear sum of the statistical error on $F$ and of the assumed $\pm 15\%$ uncertainty in the electronic part of the energy loss.

As to the lower limits for $\tau_m$ reported in Table II, they correspond to an $F$ value increased by one standard deviation with respect to the experimental datum (and, conservatively, with respect to $F = 0$ when the latter was negative), referred to an $F(\tau)$ curve calculated with an electronic energy loss increased by 15%.

In any case, one should consider that the evaluation of a lifetime or of its lower limit from small values of $F$ is very critical, due to the extreme sensitivity of the induced error on $\tau_m$ to even slight variations of the $F$-error estimate. For this reason, lifetime values for the 1382,

TABLE I. Excitation energies in $^{49}$Ti (keV). Entries under heading *a* are from the particle single spectrum in the (*d*,*p*) experiment. An asterisk indicates levels used as reference points for energy calibration (see text). Entries under heading *b* are from γ-ray energies observed in singles and/or coincidence measurements in the (*p*,*p*′γ) experiment. A weighted average of the values deduced from parallel cascades was adopted. For levels populated only via the (*d*,*p*) reaction, no accurate determination of level energies was possible by a similar procedure, since the *p*-γ coincidences were recorded in only one geometry, thus not allowing correction of possible Doppler shifts of γ rays.

| | *a* | *b* | | *a* | *b* |
|---|---|---|---|---|---|
| 1 | 1381.8 ± 0.3* | 1381.77 ± 0.04 | 17 | 3259.5 ± 0.5* | |
| 2 | | 1542.15 ± 0.04 | 18 | 3425.6 ± 1.9 | |
| 3 | 1585.1 ± 2 | 1586.00 ± 0.04 | 19 | | (3746.5 ± 0.6) |
| 4 | | 1622.93 ± 0.05 | 20 | 3786.9 ± 0.8 | |
| 5 | 1723.3 ± 0.5* | 1723.3 ± 0.2 | 21 | 4221.1 ± 1.6* | |
| 6 | | 1762.3 ± 0.3 | 22 | 4433.0 ± 1 | |
| 7 | 2258.0 ± 2 | 2261.3 ± 0.1 | 23 | 4507.1 ± 2.7 | |
| 8 | 2471.4 ± 1.2 | 2471.4 ± 0.2 | 24 | 4589.8 ± 1.3 | |
| 9 | | 2504.2 ± 0.45 | 25 | 4669.2 ± 1.2 | |
| 10 | | 2506.15 ± 0.5 | 26 | 4909.8 ± 1.3 | |
| 11 | | 2517.4 ± 0.25 | 27 | 5115.8 ± 1.1 | |
| 12 | | 2664.1 ± 0.35 | 28 | 5254.5 ± 2.5 | |
| 13 | | 2720.55 ± 0.25 | 29 | 5325.8 ± 1.3 | |
| 14 | | 2980.5 ± 0.3 | 30 | 5411.7 ± 1.1 | |
| 15 | | 3042.5 ± 0.5 | 31 | 5737.9 ± 1.2 | |
| 16 | 3175.8 ± 0.7* | | | | |

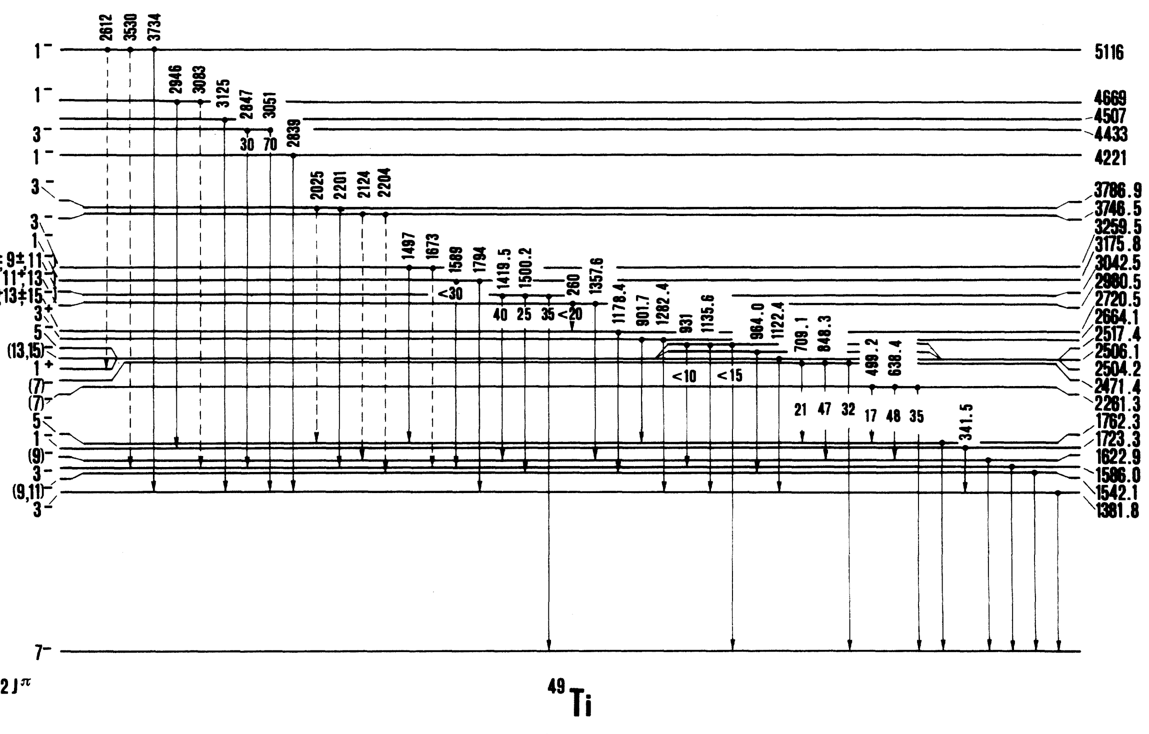

FIG. 6. Experimental decay scheme of excited levels in $^{49}$Ti. Dotted lines indicate transitions not sufficiently well established due to poor statistics. Branching ratios, where indicated, are based on coincidence measurements and do not take into account angular correlation effects. For $J^\pi$ assignments, see text.

TABLE II. Lifetimes of levels in $^{49}$Ti. Values are in fs.

| Level energy (keV) | $\gamma$-ray energy (keV) | $F(\tau)$ | $\tau$ (DSAM) | $\tau$ (Coul. exc.) | $\tau$ (Ref. 2) |
|---|---|---|---|---|---|
| 1382 | 1382 | $0.002 \pm 0.026$ | >4000 | $4830 \pm 640$ | |
| 1542 | 1542 | $0.100 \pm 0.022$ | $1070^{+360}_{-240}$ | $1450 \pm 150$ | |
| 1586 | 1586 | $0.072 \pm 0.044$ | $1520^{+2700}_{-640}$ | >8000 | |
| 1623 | 1623 | $0.756 \pm 0.024$ | $51^{+8}_{-7}$ | | $55 \pm 7$ |
| 1723 | 341 | $-0.023 \pm 0.186$ | >500 | | |
| 1762 | 1762 | $0.748 \pm 0.039$ | $52^{+12}_{-11}$ | | $36 \pm 4.3$ |
| 2261 | 2261 | $0.680 \pm 0.124$ | $85^{+24}_{-19}$ | | |
| | 638 | $0.615 \pm 0.071$ | | | |
| | 499 | $0.534 \pm 0.175$ | | | |
| 2471 | 2471 | $0.633 \pm 0.086$ | $75^{+25}_{-20}$ | | |
| | 848 | $0.685 \pm 0.158$ | | | |
| | 709 | $0.652 \pm 0.135$ | | | |
| 2504 | 1122 | $-0.210 \pm 0.220$ | >400 | | |
| 2506 | 964 | $-0.160 \pm 0.280$ | >300 | | |
| 2517 | 1136 | $0.080 \pm 0.077$ | >600 | | |
| 2664 | 1282 | $0.111 \pm 0.145$ | >310 | | |
| | 902 | $0.240 \pm 0.290$ | | | |
| 2720 | 1178 | $0.627 \pm 0.100$ | $82^{+39}_{-29}$ | | |
| 2980 | 1357 | $0.392 \pm 0.111$ | $185^{+115}_{-65}$ | | |
| 3043 | 3043 | $0.886 \pm 0.132$ | $34^{+21}_{-20}$ | | |
| | 1500 | $0.649 \pm 0.181$ | | | |
| | 1419 | $0.868 \pm 0.195$ | | | |

1542, and 1586 keV levels obtained from Coulomb excitation measurements appear to be more reliable than the corresponding values from the DSAM.

Possible effects due to the fraction of nuclei recoiling into vacuum (estimated to be less than 0.5% in our geometry) would be of some consequence only for long-living levels and in the presence of strong resonance effects in the very last downstream layer of the target. However, $(p,p')$ yield measurements performed with a thin target did not show any evidence for pronounced resonance behaviors.

Finally, we remark that no delayed $\gamma$ transition was observed in the coincidence measurements from the $(p,p'\gamma)$ reaction. This fact implies an upper limit of $\tau_m < 10$ ns for the lifetime of all the levels reported in Table II.

## DISCUSSION

The more extensive information on lifetimes and $\gamma$ decay from our results allows, when combined with the previously established $J^\pi$ assignments for the ground state and the 1382, 1586 1723, and 1762 keV levels ($\frac{7}{2}^-$, $\frac{3}{2}^-$, $\frac{3}{2}^-$, $\frac{1}{2}^-$, and $\frac{5}{2}^-$, respectively[6,7]), the formulation of reasonable suggestions for a set of spin and parity assignments to some other levels. These assignments, though not based on strong arguments, are found to be consistent, whenever a comparison is possible, with previous tentative attributions from independent evidence.

As a first consideration, all the levels which do not show any decay branch to the $\frac{7}{2}^-$ ground state, nor to the $\frac{3}{2}^-$ 1382 and 1586 keV, $\frac{1}{2}^-$ 1723 and $\frac{5}{2}^-$ 1762 keV levels, have most probably $J^\pi = \frac{11}{2}^+$ or $J \geq \frac{13}{2}$. This is the case of the 2506, 2720, and 2980 keV states. It is to be noted that such an attribution is quite consistent with the fact that all these levels are very weakly (or not at all) populated in the $(d,p)$ reaction.[6]

On the other hand, the lifetime values we measured for the levels at 2720 and 2980 keV are only compatible with a decay proceeding via $E1$, or $M1$, or $E2$ transitions. Therefore, the $J^\pi$ restrictions stated above imply as a consequence for the 1542 and 1623 keV states, $J^\pi = \frac{7}{2}^+$ or $J \geq \frac{9}{2}$. The 1542 keV level was, however, Coulomb excited by alpha bombardment, implying $J^\pi = (\frac{3}{2} - \frac{11}{2})^-$. Therefore, $J^\pi = \frac{9}{2}^-$ or $\frac{11}{2}^-$ are the only possibilities which are left. The latter had been already proposed from a $^{48}$Ca($\alpha, 3n\gamma$) experiment.[11]

As to the 1623 keV level, $J^\pi$ values had been previously restricted[2] to $(\frac{5}{2}, \frac{7}{2}, \frac{9}{2})^-$, which, combined with the above-mentioned restriction, gives $J^\pi = \frac{9}{2}^-$.

These assignments, in turn, together with the consideration at the beginning, imply:

(a) For the 2506 keV level, which decays to the 1542 keV state and is known to have negative parity (Refs. 6 and 7), $J^\pi = \frac{13}{2}^-$ or $\frac{15}{2}^-$. Multipolarities higher than 2 are in fact excluded for the 964 keV transition, due to the 10 ns upper limit on $\tau_m$.

(b) For the 2720 keV level, which decays to the 1542 keV state, $J^\pi = \frac{11}{2}^+$, or $\frac{13}{2}^\pm$, or $\frac{15}{2}^-$ [if $l = 3$ in $^{50}$V($t, \alpha$)$^{49}$Ti (Ref. 12) is accepted, only the negative parity assignments are left].

(c) For the 2980 keV level, which decays to the 1623 keV state, $J^\pi = \frac{11}{2}^+$ or $\frac{13}{2}^-$.

For the 3043 keV level, decaying also to the $\frac{7}{2}^-$ ground state, the possible $J^\pi$ values are $\frac{7}{2}^\pm$, $\frac{9}{2}^\pm$, and $\frac{11}{2}^-$ [$\frac{7}{2}^+$ being only consistent with $J^\pi(1542) = \frac{9}{2}^-$].

Finally, the decays from the 2261, 2471, 2504, 2517, and 2664 keV levels, as observed in the present work, are consistent with the previously reported $J^\pi$ assignments[6,7] and, in particular, further support a $\frac{7}{2}^-$ value for the first two.

On the basis of the measured lifetimes and of the observed branchings, leading to the $J^\pi$ values suggested above, a comparison with the predictions of the DCM model[3] can be attempted, at least for low-lying levels. The 1382, 1542, 1623, 1762, and 2261 keV states are very probably to be identified with the $\frac{3}{2}^-_1$, $\frac{11}{2}^-_1$, $\frac{9}{2}^-_1$, $\frac{5}{2}^-_1$, and $\frac{7}{2}^-_2$ states given in Ref. 3. In fact, their lifetimes agree within a factor of 2 or better from the predicted values and the observed branchings (in particular the ones of the $\frac{7}{2}^-$ 2261 keV level) compare quite well with the theory.

On the other hand, the identification of the 1586 and 1723 keV levels with the $\frac{3}{2}^-_2$ and $\frac{1}{2}^-_1$ states, which according to Ref. 3 are the lowest members of an excited $K = \frac{1}{2}^-$ band, is suggested by the experimental lifetime limits but is strongly disfavored by the 100% decay of the 1723 keV to the 1382 keV level (while a 75% branch to the $\frac{3}{2}^-_2$ state was predicted).

As to the higher excited levels for which a high spin value has been proposed in the present work, a detailed comparison with the theory would not be at the moment very significant. In fact, spin and parity assignments should be further restricted experimentally and theoretical calculations should be extended to their electromagnetic properties before drawing meaningful conclusions.

## ACKNOWLEDGMENTS

Warm thanks are due to Prof. T. Fazzini and P. Maurenzig for discussions and suggestions, to Mr. F. Celletti, Mr. P. Del Carmine, and Mr. A. Pecchioli for technical assistance throughout the work, and to the whole staff of the CN accelerator in Legnaro for their help and their politeness during the measurements.

---

[1] P. Fettweis and M. Saidane, Nucl. Phys. A139, 113 (1969).

[2] V. K. Rasmussen, Phys. Rev. C 13, 631 (1976).

[3] A. K. Dhar, D. R. Kulkarni, and K. H. Bhatt, Nucl. Phys. A285, 93 (1977).

[4] P. A. Mandò, P. Sona, N. Taccetti, and G. Liberati, Lett. Nuovo Cimento 22, 709 (1978).

[5] O. Hausser, D. Pelte, T. K. Alexander, and H. C. Evans, Nucl. Phys. A150, 417 (1970).

[6] M. L. Halbert, Nucl. Data Sheets 24, 175 (1978).

[7] *Table of Isotopes*, 7th ed., edited by C. M. Lederer and V. S. Shirley (Wiley, New York, 1978).

[8] The 260 keV $\gamma$ ray connecting the 2980 and 2720 keV levels is not seen in Fig. 5(e), but was directly observed from the ($p, p'\gamma$) reaction in a separate coincidence run performed without any shielding in front of the Ge(Li) detector.

[9] J. Lindhard, M. Scharff, and H. E. Schiott, K. Dan. Vidensk. Selsk. Mat.-Fys. Medd. 33, 14 (1963).

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

[11] E. Ventura, M. Behar, A. Filevich, G. Garcia Bermudez, and M. A. J. Mariscotti, Bull. Am. Phys. Soc. 21, 981 BE 12 (1976).

[12] S. A. Andersen, O. Hansen, L. Vistisen, R. Chapman, and S. Hinds, Nucl. Phys. A125, 65 (1969).