^{48}Ti(p,p′γ) 1978DeYT,1973Ba02,1969Ka10

Type	Author	History Citation	Literature Cutoff Date
Full Evaluation	Jun Chen	NDS 179, 1 (2022)	30-Nov-2021

1978DeYT: E=6 MeV proton beam. Measured Eγ, Iγ, pγ-coin, Doppler-shift attenuation, with two proton detectors at 55° and between the direction of γ detection and that of the recoil nuclei. Deduced levels, $T_{1/2}$, γ-ray branching ratios. Report 24 transitions from levels up to 4036.

1973Ba02: E=5.0 and 6.4 MeV protons were produced from the Stanford University tandem Van de Graaff accelerator. Target was a 1 mg/cm^2 metallic foil of enriched ^{48}Ti. γ rays were detected with a Ge(Li) detector and a NaI(Tl) detector. Measured Eγ, Iγ, γγ-coin, γ(θ), Doppler-shift attenuation. Deduced levels, J, π, $T_{1/2}$, γ-ray multipolarities, mixing ratios. Comparisons with available data and theoretical calculations. 1973Ba02 also report $T_{1/2}$ of 2295 level from DSAM using ^{48}Ti(α,α′) and $T_{1/2}$ of 983 level using (^{35}Cl,^{35}Cl′). See details in Coulomb excitation. See also ^{48}V ε decay for decay data from 1973Ba02. Report 13 transitions for levels up to 3371.

1969Ka10: E=7.8 MeV proton beam was produced from the MIT cyclotron. Target was a 1 mg/cm^2 self-supporting foil of ^{48}Ti (99.6% enriched). γ rays were detected with a Ge(Li) detector and protons were detected with a annular surface-barrier Si detector near 180°. Measured Eγ, Iγ, pγ-coin, Doppler-shift attenuation. Deduced levels, J, π, $T_{1/2}$, transition strengths. Report 17 transitions from levels up to 3740.

1969Mo09,1968Mo20: E=6.1-6.9 MeV proton beams were produced from the University of Liverpool tandem accelerator. Target was ≈300 μg/cm^2 enriched ^{48}Ti. γ rays were detected with a Ge(Li) detector and NaI(Tl) crystals; protons were detected with an annular Si detector near 180°. Measured Eγ, Iγ, pγ-coin, pγ(θ). Deduced levels, J, γ-ray branching ratios, multipolarities, mixing ratios. Report 29 transitions for levels up to 4048.

1974Ba05: E=5 MeV with the same setup as 1973Ba02. Measured σ(Eγ), γ(θ). Statistical model analysis of γ(θ).

1966Ma31: E=4.2 MeV. Measured γγ(θ). Deduced mixing ratio for 1436γ.

Others: 1976Mo26, 1973BaYY (not same authors as 1973Ba02), 1969Ho33, 1967Ha37, 1965Hu04, 1961Ta01,

^{48}Ti Levels

Note that E(level) and Eγ for levels above 3371 reported in 1969Mo09 and 1968Mo20 are 10-18 keV higher than values in other studies, which should be taken into account when matching levels and gammas in the two papers to those in other studies. Also note that there are large inconsistencies in quoted E(level) and Eγ in the tables and level scheme in 1969Mo09. Therefore, E(level) and Eγ values from the two references are not used.

E(level)[†]	Jπ[‡]	$T_{1/2}$[@]	Comments
0.0	0$^+$		
983.65 *13*	2$^+$	2.9 ps *+21−13*	E(level): other: 983.4 *3* (1978DeYT). $T_{1/2}$: from 1973Ba02. Others: 0.8 ps *+35−2* (1969Ka10).
2295.85 *16*	4$^{+\#}$	0.69 ps *+42−21*	E(level): other: 2295.4 *3* (1978DeYT). $T_{1/2}$: other: 0.8 ps *+14−2* (1969Ka10).
2420.53 *14*	2$^{+\#}$	21 fs *5*	E(level): other: 2420.6 *3* (1978DeYT). $T_{1/2}$: weighted average of 11 fs *+7−11* (1969Ka10), 24 fs *5* (1973Ba02), and 19 fs *+11−9* (1978DeYT).
2997.69 *24*	0$^{+\#}$	105 fs *+21−16*	E(level): other: 2997.4 *4* (1978DeYT). $T_{1/2}$: weighted average of 87 fs *21* (1969Ka10), 111 fs *22* (1973Ba02), and 194 fs *+76−49* (1978DeYT).
3223.8 *3*	3$^{+\#}$	24 fs *+9−10*	E(level): other: 3223.1 *5* (1978DeYT). Jπ: 2,3 from pγ(θ) (1969Mo09), in contradiction to the definite J=4 assignment made by 1957Va08 on the basis of γγ(θ) following ^{48}V β$^+$ decay. 1969Mo09 thus propose existence of a doublet near 3224. However, a careful combined β$^+$ decay and (p,p′) experiment by 1973Ba02 suggests same state is populated in both ways, and that all data available are consistent with 3$^+$ assignment. π=+ from M1+E2 γ to 2$^+$

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^{48}Ti(p,p′γ) 1978DeYT,1973Ba02,1969Ka10 (continued)

^{48}Ti Levels (continued)

E(level)[†]	Jπ[‡]	$T_{1/2}$[@]	Comments
			(evaluator). $T_{1/2}$: weighted average of 17 fs *+9−11* (1969Ka10), 29 fs *+13−10* (1973Ba02), and 31 fs *+14−12* (1978DeYT).
3241.0 *6*	4+	40 fs *+14−11*	E(level): other: 3240.0 *3* (1978DeYT). $T_{1/2}$: weighted average of 69 fs *+37−29* (1969Ka10), 30 fs *+14−11* (1973Ba02), and 62 fs *+28−21* (1978DeYT).
3332.6? *20*	6+	221 fs *+48−44*	E(level): from 1978DeYT. $T_{1/2}$: from 1969Ka10. Note that the value obtained for $T_{1/2}$ is strongly at variance with recoil-distance measurement made using (α,pγ) reaction. 1973Ba02 find no evidence for γ decay of this level, but γ′s were reported by 1978DeYT.
3359.2 *6*	3−	181 fs *+28−21*	E(level): other: 3359.3 *4* (1978DeYT). $T_{1/2}$: weighted average of 173 fs *+38−34* (1969Ka10), 243 fs *62* (1973Ba02), and 173 fs *+55−42* (1978DeYT).
3371.0 *4*	2+#	15 fs *5*	E(level): other: 3369.8 *3* (1978DeYT). $T_{1/2}$: weighted average of 15 fs *9* (1969Ka10), 12 fs *5* (1973Ba02), and 30 fs *+13−9* (1978DeYT).
3615.0 *6*	2+#	53 fs *+21−14*	E(level): other: 3633 *2* (1969Mo09), 3630 (1969Ka10). Since the 3868 level is determined as the same as the 3852 level in 1978DeYT, the 3633 level from 1969Mo09 should match the 3615 level in 1978DeYT, same for the 3630 level in 1969Ka10, as also pointed out by 1993Ko57 in (n,n′γ). $T_{1/2}$: other: 10.3 fs *26* from 1969Ka10 is discrepant.
3698.3 *3*	1−#	24 fs *4*	Jπ: spin from pγ(θ) (1968Mo20). 2714.9γ M1+E2 to 2+ discrepant with adopted π=−. $T_{1/2}$: from 1969Ka10. Other: 24 fs *+28−21* (1978DeYT).
3740.5 *9*	1+#		E(level): other: 3750 *5* from 1969Mo09. $T_{1/2}$: 112 fs (1978DeYT) and 11 fs *3* (1969Ka10) are mutually discrepant and also discrepant with the adopted value.
3782.9 *6*	3−,4−	50 fs	$T_{1/2}$: discrepant with adopted value of 1.2 ps *+11−6*. Asymmetric uncertainty listed by 1978DeYT appears to be in error since no negative component given; positive component=163.
3851.7 *4*	3−#	39 fs *+14−11*	E(level): other: 3868 *6* from 1969Mo09.
4035.7 *11*	2+	26 fs *+28−21*	Jπ: spin=1 from pγ(θ) (1968Mo20) is discrepant.

[†] From a least-squares fit to γ-ray energies for levels up to 3371 and from 1978DeYT for levels above that, unless otherwise noted.
[‡] From Adopted Levels. Supporting arguments from this dataset are given in comments or footnotes where available.
[#] Spin from pγ(θ) in 1968Mo20 for spin=1 and in 1969Mo09 for other values.
[@] From DSAM in 1978DeYT, unless otherwise noted. Values are also available from DSAM in 1973Ba02 and 1969Ka10; average are taken as noted where applicable. Note that the systematic uncertainty due to the stopping power theory (typically 15%, as quoted in 1973Ba02) is not included by 1969Ka10, as can been seen in their FIG.7 for the F(τ) function used to extract τ and Δτ and also in some of their reported τ values that have <10% uncertainties. The evaluator has added a 15% additional uncertainty in quadrature to their reported uncertainties.

γ(^{48}Ti)

Coincidence data are from 1973Ba02.
A_2 and A_4 given under comments are from pγ(θ) in 1968Mo20 for spin=1 levels and in 1969Mo09 for other levels, unless otherwise noted. Additional A_2 and A_4 values for the same transitions but at different bombarding energies are also available in 1969Mo09 and not quoted here.

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^{48}Ti(p,p′γ) 1978DeYT,1973Ba02,1969Ka10 (continued)

γ(^{48}Ti) (continued)

E_i(level)	J_i^π	E_γ[†]	I_γ[†]	E_f	J_f^π	Mult.[‡]	δ[‡]	Comments
983.65	2+	983.50 *15*	100	0.0	0+	E2		Mult.: from γ(θ,pol) in 1976Mo26. A_2=+0.55 *7*, A_4=−0.43 *10*. A_2=+0.26 *1*, A_4=−0.15 *1*, POL=−0.39 *1* (1976Mo26).
2295.85	4+	1312.20 *10*	100	983.65	2+	E2		Mult.: Q from pγ(θ) (1969Mo09); M2 ruled out by RUL. A_2=+0.60 *6*, A_4=−0.32 *8*. A_2=+0.33 *3*, A_4=−0.11 *3* (1974Ba05).
2420.53	2+	1436.80 *10*	97 *1*	983.65	2+	M1+E2	+0.18 *9*	I_γ: others: 93 *2* (1969Mo09), 97 *1* (1969Ka10), and 94 *2* (1978DeYT). Mult.,δ: D+Q from γγ(θ) (1966Ma31); E1+M2 ruled out by RUL. Other: +0.11 *+13−11* from pγ(θ) (1969Mo09). A_2=+0.55 *3*, A_4=+0.02 *4*. A_2=+0.35 *3*, A_4=−0.03 *2* (1974Ba05).
		2420.70 *20*	3.4 *10*	0.0	0+	E2		I_γ: others: 7 *2* (1969Mo09), 3.4 *10* (1969Ka10), and 6 *2* (1978DeYT). Mult.: Q from pγ(θ) in 1969Mo09 and γ(θ) in 1974Ba05; M2 ruled out by RUL. A_2=+0.61 *9*, A_4=−0.40 *11*. A_2=+0.38 *3*, A_4=−0.15 *3* (1974Ba05).
2997.69	0+	2014.00 *20*	100	983.65	2+	(E2)		Mult.: isotropic pγ(θ) to 2+ (1969Mo09); M2 ruled out by RUL. A_2=−0.02 *3*, A_4=+0.00 *4*.
3223.8	3+	804.0 *12*	3.7 *8*	2420.53	2+			I_γ: other: 15 *5* (1969Ka10); not reported by 1978DeYT.
		928.4 *6*	24.3 *17*	2295.85	4+	D+Q[#]	−0.02[#] *2*	I_γ: others: 20 *3* (1969Ka10) and 29 *3* (1978DeYT). A_2=−0.08 *14*, A_4=+0.02 *16* (1974Ba05).
		2240.0 *3*	72.0 *22*	983.65	2+	M1+E2	+0.26 *5*	I_γ: others: 65 *3* (1969Ka10) and 71 *3* (1978DeYT). Mult.: D+Q from pγ(θ) (1969Mo09); E1+M2 ruled out by RUL. δ: from 1973Ba02, reanalysis of pγ(θ) in 1969Mo09; original δ=+3.5 *+6−4* from pγ(θ) in 1969Mo09. Other: +0.27 *4* or >60 from statistical model analysis (1974Ba05). A_2=+0.16 *3*, A_4=+0.14 *4*. A_2=+0.11 *4*, A_4=−0.01 *4* (1974Ba05).
3241.0	4+	945.1 *5*	100	2295.85	4+			I_γ: 1978DeYT report a 3241γ from the same level with Iγ(945γ)/Iγ(3241γ)=99.
3332.6?	6+	1037.2	100	2295.85	4+			I_γ: 1978DeYT report a 2349.2γ from the same level with I(1037.2γ)/I(2349.2γ)=25 *15*/75 *15*.
3359.2	3−	1064.0 *10*	14.8 *7*	2295.85	4+			I_γ: other: 13 *2* (1978DeYT).
		2374.8 *8*	85.2 *7*	983.65	2+	D+Q[#]	0.00[#] *4*	I_γ: other: 87 *2* (1978DeYT). A_2=−0.26 *5*, A_4=−0.05 *5* (1974Ba05).
3371.0	2+	2387.3 *3*	86.5 *10*	983.65	2+	D+Q[#]		I_γ: other: 83 *2* (1978DeYT). δ: −0.2 *1* or 4 *1* (1974Ba05). A_2=+0.07 *6*, A_4=−0.01 *5* (1974Ba05).
		3371.5 *12*	13.5 *9*	0.0	0+			I_γ: other: 17 *2* (1978DeYT). A_2=+0.47 *6*, A_4=−0.55 *9*.
3615.0	2+	2631.6	100	983.65	2+	M1+E2	−0.18 *4*	E_γ: other: 2648 from 1969Mo09. Note that 2650γ placed from a 3633 level in 1969Mo09 is suggested to be the same as the 2644γ from the 4940 state in (α,pγ) (1979Gl07) and (n,γ) E=thermal (1984Ru06).

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^{48}Ti(p,p′γ) 1978DeYT,1973Ba02,1969Ka10 (continued)

γ(^{48}Ti) (continued)

E_i(level)	J_i^π	E_γ[†]	I_γ[†]	E_f	J_f^π	Mult.[‡]	δ[‡]	Comments
								Mult.,δ: D+Q from pγ(θ) (1969Mo09), E1+M2 ruled out by RUL. A_2=+0.21 *3*, A_4=−0.02 *4*.
3698.3	1⁻	2714.9	65 *2*	983.65	2⁺	M1+E2	+0.9 *+14−5*	I_γ: others: 57 *6* (1968Mo20) and 71 *6* (1969Ka10). Mult.,δ: D+Q from pγ(θ) (1968Mo20); E1+M2 ruled out by RUL. However, it is discrepant with adopted multipolarity. A_2=+0.14 *4*, A_4=−0.04 *6*.
		3698.3	35 *2*	0.0	0⁺			I_γ: others: 43 *6* (1968Mo20) and 29 *6* (1969Ka10). A_2=+0.16 *4*, A_4=+0.01 *5*.
3740.5	1⁺	1316	8 *2*	2420.53	2⁺			E_γ: from level-energy difference; not reported in 1978DeYT. I_γ: from 1968Mo20.
		2757.2	27 *5*	983.65	2⁺	D(+Q)	−0.4 *+5−17*	I_γ: from 1968Mo20. A_2=+0.03 *7*, A_4=+0.00 *8*.
		3740.5	65 *5*	0.0	0⁺			I_γ: from 1968Mo20. 1978DeYT report a 100% branch to the g.s. A_2=−0.29 *2*, A_4=−0.05 *3*.
3782.9	3⁻,4⁻	423.6	19[@] *4*	3359.2	3⁻			
		1487.5	81[@] *4*	2295.85	4⁺			
3851.7	3⁻	1556.3	27 *5*	2295.85	4⁺			E_γ: other: 1571 (1969Mo09). I_γ: weighted average of 26 *5* (1969Mo09) and 29 *5* (1978DeYT).
		2868.3	73 *5*	983.65	2⁺	D+Q	0.00 *2*	E_γ: other: 2883 (1969Mo09). I_γ: weighted average of 75 *5* (1969Mo09) and 71 *5* (1978DeYT). A_2=−0.31 *3*, A_4=+0.06 *4*.
4035.7	2⁺	1615.1 *11*	100	2420.53	2⁺			A_2=+0.31 *5*, A_4=−0.08 *8*.

[†] From 1973Ba02 for transitions from level up to 3371 and from 1978DeYT above that, unless otherwise noted. Note that 1978DeYT report level energies determined based on their measured γ-ray energies, which however are not listed by the authors and therefore the quoted γ-ray energies are from level-energy differences.

[‡] From pγ(θ) in 1968Mo20 and 1969Mo09, unless otherwise noted.

[#] From statistical model analysis of γ(θ) (1974Ba05). Spin sequences were assumed.

[@] Evaluator notes that these branching ratios appear to be reversed when compared to (α,pγ) and (n,γ).

[&] Placement of transition in the level scheme is uncertain.

[x] γ ray not placed in level scheme.

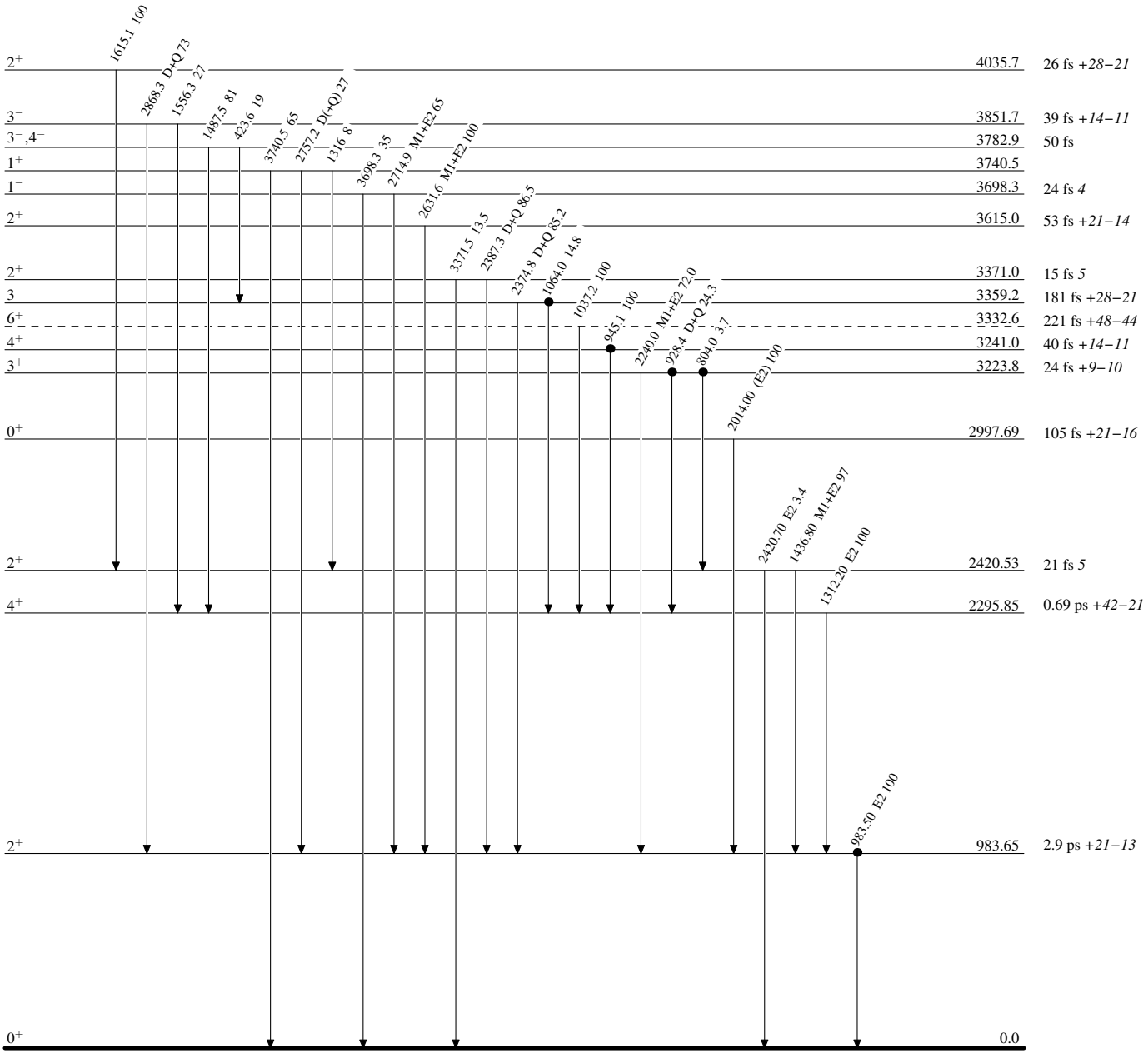
^{48}Ti(p,p′γ) 1978DeYT,1973Ba02,1969Ka10

Legend

Level Scheme

Intensities: % photon branching from each level

● Coincidence



$^{48}_{22}Ti_{26}$