^{48}Ca(p,p′γ) 1969Te03,1970Be39,1975Ta16

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

Includes ^{1}H(^{48}Ca,p′γ) from 2014Ri04.

1969Te03: E=12 MeV. Measured σ(θ) and pγ coincidences; Si for protons, NaI for γ′s.

1970Be39: E=7-9 MeV proton beams. Protons were detected with an annular surface-barrier detector and γ rays were detected with Ge(Li) and NaI(Tl) detectors. Measured Eγ, pγ(θ), pγ(t), Doppler-shift attenuation. Deduced levels, J, $T_{1/2}$ for 3832, 4384 and 4507 levels.

1975Ta16: measured Eγ, Iγ, pγ-coin. Deduced levels, branching ratios. Confirmed the 4504 and 4507 doublet.

1972Ta23: E=8.1,10 MeV. Protons were detected with an annular Si near 180° and γ rays were detected with NaI and Ge(Li). Measured Eγ, pγ(θ), pγ(t), γγ-coin, Doppler-shift attenuation. Deduced J, π, $T_{1/2}$ for 4613 and 5152 levels. 1970Be39, 1972Ta23 and 1975Ta16 are from the same laboratory.

1977Lo06: E=28 MeV. Measured γγ-coin and γ(t) with pulsed beam. Deduced $T_{1/2}$ for the 4504 level.

1970Bo03: E=10.30 proton beam from the Heidelberg Tandem van de Graaff. Protons were detected with an annular Si detector and γ rays were detected with a NaI(Tl) detector. Measured Eγ, pγ(θ). Deduced spin for 4284 level.

Other: 1966Go33.

^{1}H(^{48}Ca,p′γ):

2014Ri04: E=130 MeV/nucleon ^{76}Ge beam from the Coupled-Cyclotron at NSCL-MSU impinged on 376-mg/cm^2 production target of ^{9}Be. Secondary products with Z=14-23 from fragmentation of ^{76}Ge beam were separated by A1900 fragment separator, and identified by energy loss and time-of-flight using S800 magnetic spectrograph. Secondary target was liquid hydrogen. Measured Eγ, Iγ, (^{48}Ca)γ-coin, Doppler-shift attenuation using GRETINA array of 28, 36-fold segmented HPGe crystals. Deduced levels, $T_{1/2}$, deformation parameters, M_n/M_p. Comparisons with coupled-channel calculations.

Information on levels and gammas above 5.2 MeV is from 1969Te03 (Eγ′s were not reported by 1969Te03 for γ′s above 5.2 MeV and, therefore, have been calculated by evaluator using reported excitation energies.).

^{48}Ca Levels

E(level)†	Jπ‡	$T_{1/2}$#	Comments
0.0	0^+		
3832.3 *5*	2^+	37 fs *17*	Jπ: spin=2 from pγ(θ) in 1970Be39. $T_{1/2}$: From DSAM in 1970Be39. Deformation length δ_2=0.78 fm *11* from σ=5.2 mb *19* (2014Ri04).
4284.2 *7*	0^+	223 ps *11*	Jπ: 0^+ from observation of E0 e+/e- pair emission to g.s. (1970Be39); spin=0 also from pγ(θ) in 1970Bo03. $T_{1/2}$: from pγ(t) in 1970Be39.
4504.4 *5*	4^+	1.53 ns *3*	$T_{1/2}$: from pγ(t) in 1972Ta23. Originally attributed to the 5147 state by 1972Ta23 but reassigned by 1977Lo06 who obtained 1.25 ns 28 and 1.32 ns *21* for the 4504 state.
4507.3 *5*	3^-	6.1 ps *+38−20*	Jπ: spin=3 from pγ(θ) in 1970Be39. $T_{1/2}$: from DSAM in 1970Be39. σ=6.8 mb *14* (2014Ri04).
4612.7 *5*	$3^{(+)}$	1.2 ps *4*	Jπ: spin=3 from γγ(θ) in 1972Ta23. $T_{1/2}$: from DSAM in 1972Ta23. configuration: $(\nu,p_{3/2}f_{7/2})^{-1}$. σ<3.2 mb (2014Ri04).
5147.3 *5*	3,4,5	<0.69 ns	Jπ: spin=3,4,5 from γγ(θ) in 1972Ta23. $T_{1/2}$: from 1977Lo06; see comment for $T_{1/2}$(4504).
5265 *10*	$4^{(-)}$		σ<1.9 mb (2014Ri04).
5322 *10*	$(1)^-$		
5376 *10*	3^-		σ<1.1 mb (2014Ri04).
5737 *10*	5^-		
6108 *10*	(2^+)		
6351 *10*	4^+		
6618 *10*	1^-		
6654 *10*	4^+		

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^{48}Ca(p,p′γ) 1969Te03,1970Be39,1975Ta16 (continued)

^{48}Ca Levels (continued)

E(level)†	Jπ‡	E(level)†	Jπ‡	E(level)†	Jπ‡	E(level)†	Jπ‡
6687 *10*	$2^{(-)}$	7402 *10*	(2^-)	8041 *10*	(1)	8527 *10*	3^-
6820 *10*	(3^-)	7444 *10*	$2,3^-$	8247 *10*	4^+	8586 *10*	
6896 *10*	(2^-)	7652 *10*	3^-	8276 *10*	$(1^-,2,3)$	8672 *10*	(3^+)
7028 *10*	$(3)^-$	7784 *10*	3^-	8384 *10*		8790 *10*	
7305 *10*	1^-	7957 *10*	$(4)^+$	8488 *10*	$3^+,4^+,5^+$		

† From 1975Ta16 for E(level)<5.2 MeV and from 1969Te03 above that, unless otherwise noted. Values from 1969Te03 are from their (p,p′) measurements.
‡ From Adopted Levels. Contributing arguments from these data are given in the Comments.
# From 1970Be39 for levels below 4.6 MeV and 1972Ta23 for levels above 4.6 MeV; based on analysis of direct timing and DSAM.

γ(^{48}Ca)

Coincidence data are from 1977Lo06 and 1969Te03.

E_i(level)	J_i^π	E_γ†	I_γ‡	E_f	J_f^π	Mult.	δ	$I_{(\gamma+ce)}$#	Comments
3832.3	2^+	3832.3@	100	0.0	0^+	E2			E_γ: other: 3842 *12* (2014Ri04). Mult.: Q from pγ(θ) in 1970Be39; M2 ruled out by RUL.
4284.2	0^+	451.9 *5*	77.5@ *8*	3832.3	2^+				
		4284@		0.0	0^+	E0		22.5@ *8*	Mult.: from observation of E0 e+/e- pair emission to g.s. (1970Be39).
4504.4	4^+	672.1 *2*	100	3832.3	2^+				
4507.3	3^-	675.0 *1*	73@ *2*	3832.3	2^+	D(+Q)	0.00 *3*		E_γ: other: 678 *2* (2014Ri04). I_γ: other: 72 *7* (2014Ri04). Mult.,δ: from pγ(θ) in 1970Be39.
		4507.0@	27@ *2*	0.0	0^+	E3			Mult.: Q from pγ(θ) in 1970Be39; M3 ruled out by RUL. I_γ: other: 28 *7* (2014Ri04).
4612.7	$3^{(+)}$	780.4 *2*	100	3832.3	2^+	D			E_γ: other: 782 *8* (2014Ri04). Mult.: from γγ(θ) in 1972Ta23.
5147.3	3,4,5	642.9 *2*	100	4504.4	4^+				
5265	$4^{(-)}$	648	71 *14*	4612.7	$3^{(+)}$				E_γ,I_γ: from 2014Ri04 only.
		754&a	29 *14*	4507.3	3^-				E_γ,I_γ: from 2014Ri04.
5322	$(1)^-$	810&a	20 *10*	4507.3	3^-				
		1490	80 *10*	3832.3	2^+				
5376	3^-	758		4612.7	$3^{(+)}$				E_γ: from 2014Ri04 only.
		864&a	40 *10*	4507.3	3^-				
		867		4504.4	4^+				E_γ: from 2014Ri04, with I(867γ)/I(864γ)<3/4.7 *30*.
		1544	60 *10*	3832.3	2^+				
5737	5^-	472	60 *10*	5265	$4^{(-)}$				
		1225&b	40 *10*	4504.4	4^+				
6108	(2^+)	1596&a		4507.3	3^-				
6351	4^+	1839&b		4504.4	4^+				
6618	1^-	6617	100 *10*	0.0	0^+				
6654	4^+	1278		5376	3^-				

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^{48}Ca(p,p′γ) 1969Te03,1970Be39,1975Ta16 (continued)

γ(^{48}Ca) (continued)

E_i(level)	J_i^π	E_γ †	I_γ ‡	E_f	J_f^π
6654	4^+	2142 &b		4504.4	4^+
6687	$2^{(-)}$	1311		5376	3^-
		2175 &c		4507.3	3^-
6896	(2^-)	1520		5376	3^-
		2384 &a		4507.3	3^-
7028	$(3)^-$	1763		5265	$4^{(-)}$
		2516 &a		4507.3	3^-
7305	1^-	7304	100 *10*	0.0	0^+
7402	(2^-)	2785		4612.7	$3^{(+)}$
7444	$2,3^-$	7443	100 *10*	0.0	0^+
7652	3^-	3140 *f* &g	*d*	4507.3	3^-
		3140 *f* &g	*d*	4504.4	4^+
		7651		0.0	0^+
7784	3^-	964	*d*	6820	(3^-)
7957	$(4)^+$	1137	*d*	6820	(3^-)
8041	(1)	3529 *f* &g	*e*	4507.3	3^-
		3529 *f* &g	*e*	4504.4	4^+
		8040		0.0	0^+
8247	4^+	3735 *f* &g		4507.3	3^-
		3735 *f* &g		4504.4	4^+
8276	$(1^-,2,3)$	1456		6820	(3^-)
		3764 *f* &g		4507.3	3^-
		3764 *f* &g		4504.4	4^+
		8275		0.0	0^+
8384		1564		6820	(3^-)
		8383		0.0	0^+
8488	$3^+,4^+,5^+$	3976 *f* &g		4507.3	3^-
		3976 *f* &g		4504.4	4^+
8527	3^-	4015 *f* &g		4507.3	3^-
		4015 *f* &g		4504.4	4^+
8586		4073 *f* &g		4507.3	3^-
		4073 *f* &g		4504.4	4^+
8672	(3^+)	4159 *f* &g		4507.3	3^-
		4159 *f* &g		4504.4	4^+
8790		4277 *f* &g		4507.3	3^-
		4277 *f* &g		4504.4	4^+

† Values with uncertainties are from 1975Ta16 and those without uncertainties are deduced from level-energy differences in 1969Te03 (by the evaluator) assuming ΔEγ=10 keV from uncertainty in E(level), unless otherwise noted. Level energies given by 1969Te03 are from their (p,p′) measurements.

‡ %Photon branching from each level. Quoted values are from 1969Te03, unless otherwise noted.

%Total transition branching from each level.

@ From 1970Be39. I(γ+ce)(4284) estimated from intensity of annihilation radiation resulting from internal pair production, corrected for yield due to external pairs produced by 3832γ.

& Resolution was not sufficient (1969Te03) to separate γ′s leading to the 4503 and 4507 states.

[a] Deexcitation to 4507 instead of 4504 state based on (n,n′γ) data (evaluator).

[b] Deexcitation to 4504 instead of 4507 state based on (n,n′γ) data (evaluator).

[c] Deexcitation to 4507 instead of 4504 state based on β^- decay data (evaluator).

[d] Primary decay mode.

[e] Strong transition.

[f] Multiply placed.

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

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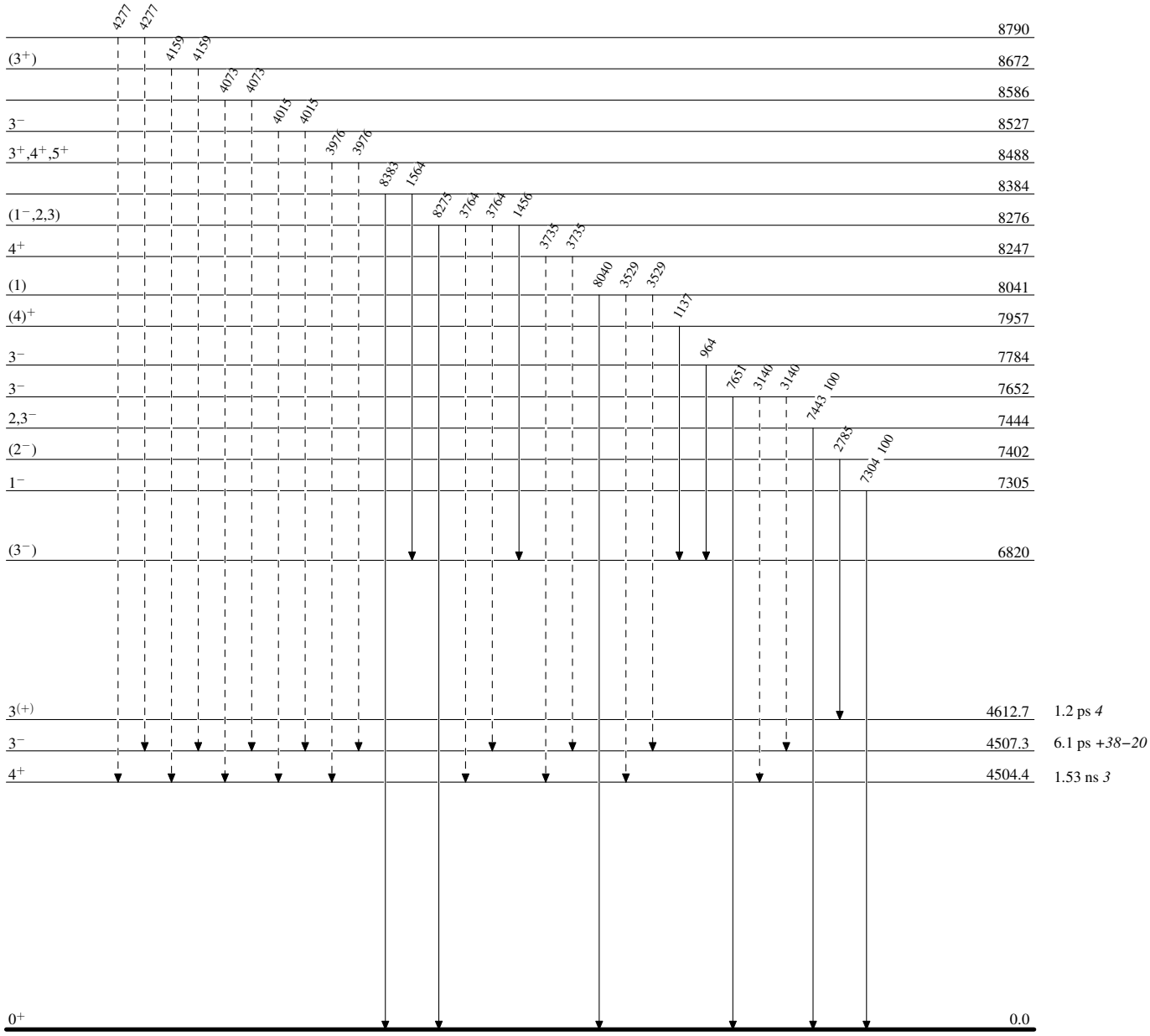
Legend

Level Scheme

Intensities: % photon branching from each level

– – – – – – ► γ Decay (Uncertain)



$^{48}_{20}Ca_{28}$

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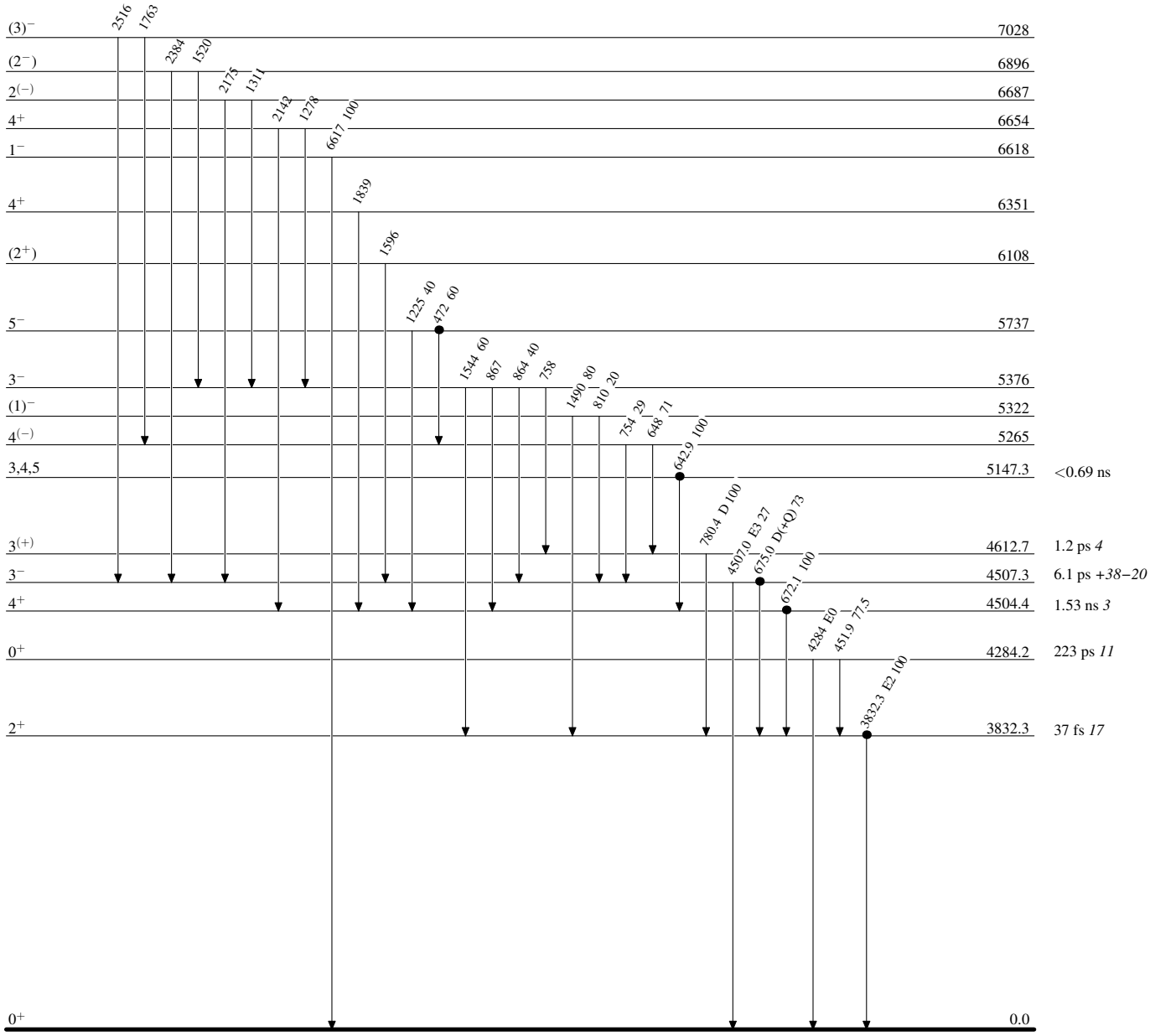
Legend

Level Scheme (continued)

Intensities: % photon branching from each level

● Coincidence



$^{48}_{20}Ca_{28}$