^{64}Ni(p,nγ) 1976Gr13,1972Gu17

History

Type	Author	Citation	Literature Cutoff Date
Full Evaluation	Balraj Singh and Jun Chen	NDS 178, 41 (2021).	12-Nov-2021

1976Gr13: E=2.75-3.75 MeV, γ, γ(θ), linear polarization γγ(θ), levels to 927 keV.
1972Gu17: E=3.47-5.19 MeV. Measured γ, levels to 2534 keV. See also 1979Gu17 for some revised results for levels below 1320 keV.
Others:
1984Fe05: E=3 MeV. Measured γ, γγ, γ(θ). Details are not available.
1976Wh01 (also 1974Wh09): E=5 MeV, $T_{1/2}$ measurements by pulsed beam technique.
1976KuZS: E=2.5-4.5 MeV, γ, γ(θ), levels to 927 keV.
1974Ca14: E=3.20 MeV, $T_{1/2}$ measurement by DSAM.
1973Za07: E=3 MeV, linear polarization, levels to 344 keV.
1972Na27: E=6 MeV, γ(θ), levels to 1850 keV.
1971Mi15 (also 1971Mi24): E≤3.1 MeV, γ, γ(θ), nγ(θ), levels to 362 keV.
1971We02 (also 1970WeZY): E≈3.1 MeV, γ(θ), γγ(θ), levels to 663 keV.
1970Da01: E=2.75-3.50 MeV, γ, γ(θ), levels to 927 keV.
1961Va19: measured γ.

^{64}Cu Levels

A level at 1457 proposed by 1972Na27 has not been confirmed in other studies.

E(level)†	Jπ‡	$T_{1/2}$#	Comments
0.0	1^+		
159.07 *19*	2^+@	21 ps *4*	
278.32 *19*	2^+@&	<9 ps	
343.73 *22*	1^+@	<4 ps	Jπ: J=1 or 2 from γ(θ) and γγ(θ), but 344γ(lin pol) rules out J=2 and 1^-.
361.89 *23*	3^+@	<4 ps	
574.3 *4*	$(4)^+$@	<17 ps	Jπ: based on weak excitation, J=4 is favored.
608.66 *23*	2^+@&	<9 ps	$T_{1/2}$: other: >0.12 ps (1974Ca14).
662.94 *25*	1^+@	<8 ps	$T_{1/2}$: other: >0.12 ps (1974Ca14).
739.0 *3*	2^+@	<11 ps	
746.3 *4*	$(3)^+$@	<13 ps	
878.2 *3*	$(0)^+$@	<15 ps	Jπ: J=1 assignment (1970Da01) ruled out by 1976Gr13.
896.5 *3*	$(3)^+$@	<20 ps	
927.0 *3*	1^+@	<11 ps	
1241.0 *3*	$1^{(+)},2^{(+)}$		
1241.2 *5*			Level based on (n,γ) E=th results.
1288.0 *3*			
1297.8 *3*	$(1)^+$		
1320.1 *3*			
1354.2 *4*	$(3)^+$		
1363.5 *5*			
1438.1 *4*	$(1)^+$		
1461.9 *6*			
1499.3 *4*	$(2)^-$		
1521.3 *4*	$(2)^+$		
1550.9 *4*	$(1^+,2^+,3^+)$		
1594.4 *4*	$(1^+,2)$		
1606.5 *5*			

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^{64}Ni(p,nγ) 1976Gr13,1972Gu17 (continued)

^{64}Cu Levels (continued)

E(level)†	Jπ‡	E(level)†	Jπ‡	E(level)†	Jπ‡	E(level)†
1683.4 *3*		1970 *2*		2221 *2*	(3+)	2355.5 *15*
1701.4 *5*	(1,2+)	2021.2 *6*		2244 *2*		2381.2 *15*
1742 *2*		2041.6 *7*		2263.4 *20*		2417 *2*
1780.3 *20*	(1+,2+)	2060 *2*		2274.8 *10*		2457.1 *20*
1851.9 *15*	(1+,2+)	2080.0 *15*		2300.8 *5*		2491.1 *15*
1900.4 *20*	(1+)	2139.7 *7*		2309.4 *10*	(3+)	2504.1 *20*
1940 *2*		2184.2 *6*	(3+)	2319.0 *20*		2534.1 *20*

† From a least-squares fit to Eγ data.
‡ From the Adopted Levels, except when noted.
# From pulsed-beam method (1976Wh01).
@ From the Adopted Levels, but γ(θ), γγ(θ) and γ(lin pol) results used for final assignments.
& Negative parity unlikely because of implied large M2 admixture.

γ(^{64}Cu)

A_2, A_4 coefficients from γ(θ) and γγ(θ) and pol from γ(linear pol) are those reported by 1976Gr13. The coefficients from γγ(θ) were reported for two different geometries. Only one set of values is given here. See 1972Na27 and 1970Da01 for other values of A_2 and A_4 from γ(θ).

Following γ rays reported by 1972Na27 were not confirmed in other studies: 571 *2*, 1093 *2*, 1180 *3*, 1455 *2*, 1485, 1610 *3*.

Branching ratios (1979Gu17,1976Gr13)

Level (keV)	Eγ (keV)	Branching 1979Gu17	Branching 1976Gr13	Comment
159	159	100	100	
278	278	100	100	
344	185	5	4 *1*	
	344	95	96 *1*	
362	203	98	98 *1*	
	362	2	2 *1*	
574	212	100	100	
609	265	8	6 *1*	
	331	3	4 *1*	
	450	9	8 *1*	
	609	80	82 *2*	
663	320	7	6 *1*	
	384	36	35 *2*	
	504	27	27 *2*	
	663	30	32 *2*	
739	377	19	13 *1*	
	395	3	4 *1*	
	461	10	6 *1*	
	580	61	77 *1*	
	739	7		see 897 level
746	137			uncertain γ
	468	100	100	
878	534	43	42 *2*	
	719		3 *1*	
	878	57	55 *2*	
897	617	89	49 *4*	
	738		40 *4*	
	897	11	11 *4*	

927	565	4		
	649	70	≈	59
	768	17	≈	32
	927	9	≈	9
1241	495	32		
	633	17		
	963	19		
	1082	19		
	1241	13		γ from another 1242 level
1288	1128	100		
1298	558	3		
	954	9		
	1020	25		
	1139	48		
	1298	15		
1320	712	8		
	977	10		
	1042	6		
	1320	76		

Uncertainty in branching ratio from 1979Gu17 is 20 to 50%

E_γ[†]	I_γ[#]	E_i(level)	J_i^π	E_f	J_f^π	Mult.[‡]	δ[‡]	Comments
137.4[h] *5*	8	746.3	$(3)^+$	608.66	2^+			E_γ: from 1972Gu17, not reported in the later work (1979Gu17).
159.3 *5*	407	159.07	2^+	0.0	1^+	M1+E2	+0.12 *4*	A_2=−0.29 *1*; A_4=0.00 *1* δ: others: +0.02 *1* (1973Za07), +0.04 *4* (1971Mi15), 0.02 *4* (1971We02), −0.01 *2* (1970Da01).
184.5 *5*	7	343.73	1^+	159.07	2^+	D(+Q)	+0.10 *10*	A_2=−0.02 *2*; A_4=−0.01 *2* (184γ)(159γ)(θ): A_2=−0.17 *6*, A_4=+0.10 *7*. δ: or −3.0 to −7.1. Other: ≤0 (1971Mi15). RUL(E2) does not allow large E2 admixture.
202.9 *5*	240	361.89	3^+	159.07	2^+	M1+E2	+0.06 *3*	A_2=−0.42 *1*; A_4=+0.02 *1* δ: others: +0.049 *12* (1971Mi15), 0.00 *1* (1971We02), +0.04 *4* (1970Da01).
212.2 *5*	64	574.3	$(4)^+$	361.89	3^+	D(+Q)	+0.01 *3*	A_2=−0.28 *2*; A_4=+0.02 *2* (212γ)(203γ)(θ): A_2=−0.39 *4*, A_4=+0.04.
259.3 *5*	2.6	2300.8		2041.6				
264.8 *5*	5.4	608.66	2^+	343.73	1^+	M1+E2	+0.24[e] *17*	A_2=−0.27 *3*; A_4=−0.04 *4*
278.2 *5*	315	278.32	2^+	0.0	1^+	M1+E2	+0.10 *2*	A_2=−0.35 *1*; A_4=+0.02 *1*; pol=−0.22 *4* δ: for J(278)=2^+; δ=2.14 (for J=2^-). Others: +0.02 *2* (1973Za07); +0.03 *3* (1970Da01).
319.8 *5*	16	662.94	1^+	343.73	1^+	M1+E2		A_2=−0.02 *2*; A_4=0.00 *2* δ: +0.2 to +5.7.
330.9 *5*	2.4	608.66	2^+	278.32	2^+			
343.8 *5*	100	343.73	1^+	0.0	1^+			A_2=+0.01 *3*; A_4=+0.02 *3*; pol=+0.06 *3* δ: 0 to ∞ (1976Gr13). Others: +0.14 *7* (1973Za07), +0.12 *11* or >+3 (1971Mi15), >0 (1970Da01).
361.8 *5*	7	361.89	3^+	0.0	1^+			
376.9 *5*	9	739.0	2^+	361.89	3^+	D(+Q)	−0.11 *18*	A_2=−0.11 *2*; A_4=+0.04 *3*
384.4 *5*	38	662.94	1^+	278.32	2^+	D(+Q)		A_2=+0.02 *2*; A_4=+0.03 *3* (1976Gr13) Value of A_2=−0.42 *20* (1972Na27) is in disagreement but A_2=0.00 *4* (1970Da01) agrees. (384γ)(278γ)(θ): A_2=−0.18 *3*, A_4=+0.04 *3*. δ: +0.07 *5* or −2.9 to −4.7.
394.8 *5*	[a]	739.0	2^+	343.73	1^+			
449.5 *5*	12	608.66	2^+	159.07	2^+	D(+Q)	+0.02 *7*	A_2=+0.15 *1*; A_4=−0.01 *2* (1976Gr13)

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^{64}Ni(p,nγ) 1976Gr13,1972Gu17 (continued)

γ(^{64}Cu) (continued)

E_γ[†]	I_γ[#]	E_i(level)	J_i^π	E_f	J_f^π	Mult.[‡]	δ[‡]	Comments
								A_2=+0.40 *8* (1970Da01) (450γ)(159γ)(θ): A_2=+0.44 *13*, A_4=+0.14 *15*. δ: other:−0.05 *10* (1970Da01).
461.0 *5*	9	739.0	2^+	278.32	2^+	D(+Q)	−0.29 *25*	A_2=+0.28 *6*; A_4=+0.14 *7* Value of A_2=−0.06 *10* (1970Da01) is in disagreement. (461γ)(278γ)(θ): A_2=+0.46 *17*, A_4=0.00 *18*. δ: other: +0.4 *1* (1970Da01).
467.9 *5*	64	746.3	$(3)^+$	278.32	2^+	M1+E2	+0.08 *3*	A_2=−0.39 *2*; A_4=+0.03 *2* (468γ)(278γ)(θ): A_2=−0.46 *7*, A_4=−0.02 *7*. δ: other: −0.04 *4* (1970Da01).
494.8 *5*	12	1241.0	$1^{(+)},2^{(+)}$	746.3	$(3)^+$			
503.8 *5*	26	662.94	1^+	159.07	2^+			
533.9 *5*	21	878.2	$(0)^+$	343.73	1^+			A_2=0.00 *1*; A_4=−0.02 *2* Placement established by γγ (1976Gr13,1970Da01). (534γ)(344γ)(θ): A_2=+0.27 *6*, A_4=−0.02 *6*.
558.2 *5*	1.8	1297.8	$(1)^+$	739.0	2^+			
565.0[b] *5*	6	927.0	1^+	361.89	3^+			γ not reported by 1976Gr13.
574[h]		574.3	$(4)^+$	0.0	1^+			E_γ: reported by 1976KuZS only, highly questionable as required mult=[M3] not allowed by RUL.
579.7 *5*	55	739.0	2^+	159.07	2^+	M1+E2	−0.18 *11*	A_2=+0.28 *1*; A_4=+0.02 *2* Value of A_2=−0.15 *6* (1972Na27) is in disagreement but A_2=+0.31 *4* (1970Da01) agrees well. (580γ)(159γ)(θ): A_2=+0.50 *12*, A_4=−0.07 *15*. δ: other: +0.05 *4* (1970Da01).
608.7 *5*	96	608.66	2^+	0.0	1^+	M1+E2	+0.30 *8*	A_2=−0.34 *1*; A_4=+0.01 *1*; pol=−0.34 *14* δ: +1.30 for J(609)=2^-. Other: +0.03 *3* (1970Da01) for J=2^+.
617.4 *5*	43	896.5	$(3)^+$	278.32	2^+	M1+E2		A_2=−0.85 *14*; A_4=+0.18 *16* δ: +0.07 to +2.5 (1976Gr13). Other: 0.0 *1* (1970Da01).
624.7 *5*	5	1288.0		662.94	1^+			
633.2 *5*	6.4	1241.0	$1^{(+)},2^{(+)}$	608.66	2^+			
648.8 *5*	45	927.0	1^+	278.32	2^+	D(+Q)	+0.04 *11*	A_2=−0.06 *8*; A_4=+0.16 *10* (649γ)(278γ)(θ): A_2=−0.18 *5*, A_4=0.00 *5*. δ: or −2.5 to −5.7 for J(927)=1. δ=−0.11 *5* for J=3.
663.1 *5*	34	662.94	1^+	0.0	1^+			A_2=0.00 *2*; A_4=+0.03 *3*
711.7[bc] *5*	4	1320.1		608.66	2^+			
719 *2*	1.4	878.2	$(0)^+$	159.07	2^+			A_2=−0.16 *15*; A_4=+0.22 *18* E_γ: from 1976Gr13. Also reported by 1972Na27 but not by 1979Gu17 and 1972Gu17. I_γ: from branching=3% *1* (1976Gr13).
738.3[g] *5*	≈5[g]	739.0	2^+	0.0	1^+			Placement based on (n,γ) E=th results.
738.3[g] *5*	≈5[g]	896.5	$(3)^+$	159.07	2^+			A_2=−0.75 *3*; A_4=0.00 *3* δ: +0.40 *13* (1976Gr13) for a possible doublet.
756.3 *5*	1.5	1683.4		927.0	1^+			
767.9 *5*	11	927.0	1^+	159.07	2^+			A_2=+0.12 *14* (1970Da01)

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^{64}Ni(p,nγ) 1976Gr13,1972Gu17 (continued)

γ(^{64}Cu) (continued)

E_γ †	I_γ #	E_i(level)	J_i^π	E_f	J_f^π	Comments
780.0[bc] 5	9	2021.2		1241.0	$1^{(+)},2^{(+)}$	
805.0[f] 5	≤1.0[f]	1683.4		878.2	$(0)^+$	
805.0[f] 5	≤1.0[f]	1701.4	$(1,2^+)$	896.5	$(3)^+$	
812.0 5	1.2	1550.9	$(1^+,2^+,3^+)$	739.0	2^+	
823.0 5	2.1	1701.4	$(1,2^+)$	878.2	$(0)^+$	
830.0 5	1.0	2184.2	(3^+)	1354.2	$(3)^+$	
859.0 5	2.1	1521.3	$(2)^+$	662.94	1^+	
878.3 5	23.0	878.2	$(0)^+$	0.0	1^+	A_2=−0.05 4; A_4=+0.05 4
890.5[b] 5	10	1499.3	$(2)^-$	608.66	2^+	
896.7 5	4.7	896.5	$(3)^+$	0.0	1^+	Alternate placement (1972Gu17) from 1241 level not supported by branching ratio data. In (n,γ) E=th, based on energy agreement an 897.06γ was placed from a 3629 level, not from 896 level.
912.0 5	2.1	1521.3	$(2)^+$	608.66	2^+	
926.5 5	14	927.0	1^+	0.0	1^+	Alternate placement (1972Gu17) from 1288 level not shown in the later work (1979Gu17).
937.0 5	3	1683.4		746.3	$(3)^+$	
947.0[c] 5	20	1521.3	$(2)^+$	574.3	$(4)^+$	
954.0[bh] 5		1297.8	$(1)^+$	343.73	1^+	
958.0[c] 5	17	1320.1		361.89	3^+	
963.0 5		1241.0	$1^{(+)},2^{(+)}$	278.32	2^+	
976.5[c] 5	5	1320.1		343.73	1^+	
992.5 5	10	1354.2	$(3)^+$	361.89	3^+	
998.0[b] 5	6	1606.5		608.66	2^+	
1010.0 5	4.4	1288.0		278.32	2^+	
1019.7[b] 5	8	1297.8	$(1)^+$	278.32	2^+	
1032.0[@] 5		1606.5		574.3	$(4)^+$	
1041.5 5	1.8	1320.1		278.32	2^+	
1060.0 5	1.0	2300.8		1241.0	$1^{(+)},2^{(+)}$	
1076.3[c] 5	15	1438.1	$(1)^+$	361.89	3^+	
1081.8 5	≤12[d]	1241.0	$1^{(+)},2^{(+)}$	159.07	2^+	
1085.3 5	≤12[d]	1363.5		278.32	2^+	
1100.0 5	5	1461.9		361.89	3^+	
1128.4 5	11	1288.0		159.07	2^+	
1138.8[c] 5	14	1297.8	$(1)^+$	159.07	2^+	
1159.3[fc] 5	≤16[f]	1438.1	$(1)^+$	278.32	2^+	
1159.3[fb] 5	≤16[f]	1521.3	$(2)^+$	361.89	3^+	
1195.0 5	15	1354.2	$(3)^+$	159.07	2^+	
1221.0 5	13	1499.3	$(2)^-$	278.32	2^+	
1232.4 5	18	1594.4	$(1^+,2)$	361.89	3^+	
1241.2 5	17	1241.2		0.0	1^+	
1250.8 5	2	1594.4	$(1^+,2)$	343.73	1^+	
1272.6 5	13	1550.9	$(1^+,2^+,3^+)$	278.32	2^+	
1279.6 5	7	1438.1	$(1)^+$	159.07	2^+	
1297.9[c] 5	4	1297.8	$(1)^+$	0.0	1^+	
1320.0 5	19	1320.1		0.0	1^+	
1340.0[b] 5	10	1683.4		343.73	1^+	
1363[b] 1	9	1363.5		0.0	1^+	
1373 1	1.4	2300.8		927.0	1^+	
1391.5 10	2.8	1550.9	$(1^+,2^+,3^+)$	159.07	2^+	
1400.5[bc] 10	4	2139.7		739.0	2^+	
1418.5 10	2.6	1780.3	$(1^+,2^+)$	361.89	3^+	

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^{64}Ni(p,nγ) 1976Gr13,1972Gu17 (continued)

γ(^{64}Cu) (continued)

E_γ †	I_γ #	E_i(level)	J_i^π	E_f	J_f^π	E_γ †	I_γ #	E_i(level)	J_i^π	E_f	J_f^π
1437.7 *10*	4.7	1438.1	$(1)^+$	0.0	1^+	2021 *2*	3.2	2021.2		0.0	1^+
1449@*h* *1*		1606.5		159.07	2^+	2029 *2*	3	2309.4	(3^+)	278.32	2^+
1477 *1*	2.2	2139.7		662.94	1^+	2043 *2*	5.5	2041.6		0.0	1^+
1500 *2*	7.7	1499.3	$(2)^-$	0.0	1^+	2060 *2*	0.5	2060		0.0	1^+
1509 *2*	4.3	1851.9	$(1^+,2^+)$	343.73	1^+	2080 *2*	3.5	2080.0		0.0	1^+
1521 *2*	6	1521.3	$(2)^+$	0.0	1^+	2102 *2*	0.7	2381.2		278.32	2^+
1557 *2*	8	1900.4	(1^+)	343.73	1^+	2117 *2*	2.1	2274.8		159.07	2^+
1575 *2*	8.5	2184.2	(3^+)	608.66	2^+	2139*b* *2*	0.9	2139.7		0.0	1^+
1594 *2*	5.8	1594.4	$(1^+,2)$	0.0	1^+	2152*b* *2*	0.6	2309.4	(3^+)	159.07	2^+
1616 *2*	5.8	2355.5		739.0	2^+	2184 *2*	2.6	2184.2	(3^+)	0.0	1^+
1647 *2*	2.3	2309.4	(3^+)	662.94	1^+	2221 *2*	3.3	2221	(3^+)	0.0	1^+
1683 *2*	26	1683.4		0.0	1^+	2244 *2*	1.2	2244		0.0	1^+
1718 *2*	3.4	2080.0		361.89	3^+	2275 *2*	2.1	2274.8		0.0	1^+
1742 *2*	1.8	1742		0.0	1^+	2300 *2*	2.5	2300.8		0.0	1^+
1754 *2*	1.8	2417		662.94	1^+	2309 *2*	0.5	2309.4	(3^+)	0.0	1^+
1780*b* *2*	6	1780.3	$(1^+,2^+)$	0.0	1^+	2319 *2*	0.4	2319.0		0.0	1^+
1851 *2*	25	1851.9	$(1^+,2^+)$	0.0	1^+	2332 *2*	0.8	2491.1		159.07	2^+
1900& *2*	21	1900.4	(1^+)	0.0	1^+	2345 *2*	0.9	2504.1		159.07	2^+
1930 *2*	7.3	2274.8		343.73	1^+	2356 *2*	0.3	2355.5		0.0	1^+
1940 *2*	1	1940		0.0	1^+	2382 *2*	0.3	2381.2		0.0	1^+
1953 *2*	1	2300.8		343.73	1^+	2457 *2*	3.0	2457.1		0.0	1^+
1970*b* *2*	4.4	1970		0.0	1^+	2491 *2*	12	2491.1		0.0	1^+
1985 *2*	1.7	2263.4		278.32	2^+	2534 *2*	0.5	2534.1		0.0	1^+
1996 *2*	2.5	2274.8		278.32	2^+						

† From 1972Gu17.
‡ From γ(θ) and γγ(θ) data (1976Gr13). M1+E2 favored over E1+M2 based on RUL for E2 and M2 transition.
# At θ=90° and E(p)=5.13 MeV (1972Gu17). See also 1979Gu17 and 1976Gr13 for branching ratios and 1972Na27 for Iγ data at E(p)=6 MeV. Uncertainties are ≈20%, but ≈50% for weaker lines (1972Gu17). When available, branching ratios from 1976Gr13 or 1979Gu17 as given in the table of Branching ratios have been considered in Adopted Gammas.
@ Unresolved.
& Doublet.
a Weak.
b For alternative placement (based on (n,γ)), see adopted gammas.
c Alternate placement (1972Na27) not supported by energy sums based on more precise Eγ values from 1976Gr13.
d Iγ(1082γ+1085γ)=12.
e 1976Gr13 quoted this value for 331γ which is probably a mistake since no γ(θ) data were reported for 331γ. The A_2 and A_4 quoted for 265γ and δ=+0.24 *17* are in better agreement for a J=2 to J=1 transition (265γ) than for a J=2 to J=2 transition (331γ).
f Multiply placed with undivided intensity.
g Multiply placed with intensity suitably divided.
h Placement of transition in the level scheme is uncertain.

^{64}Ni(p,nγ) 1976Gr13,1972Gu17

Level Scheme

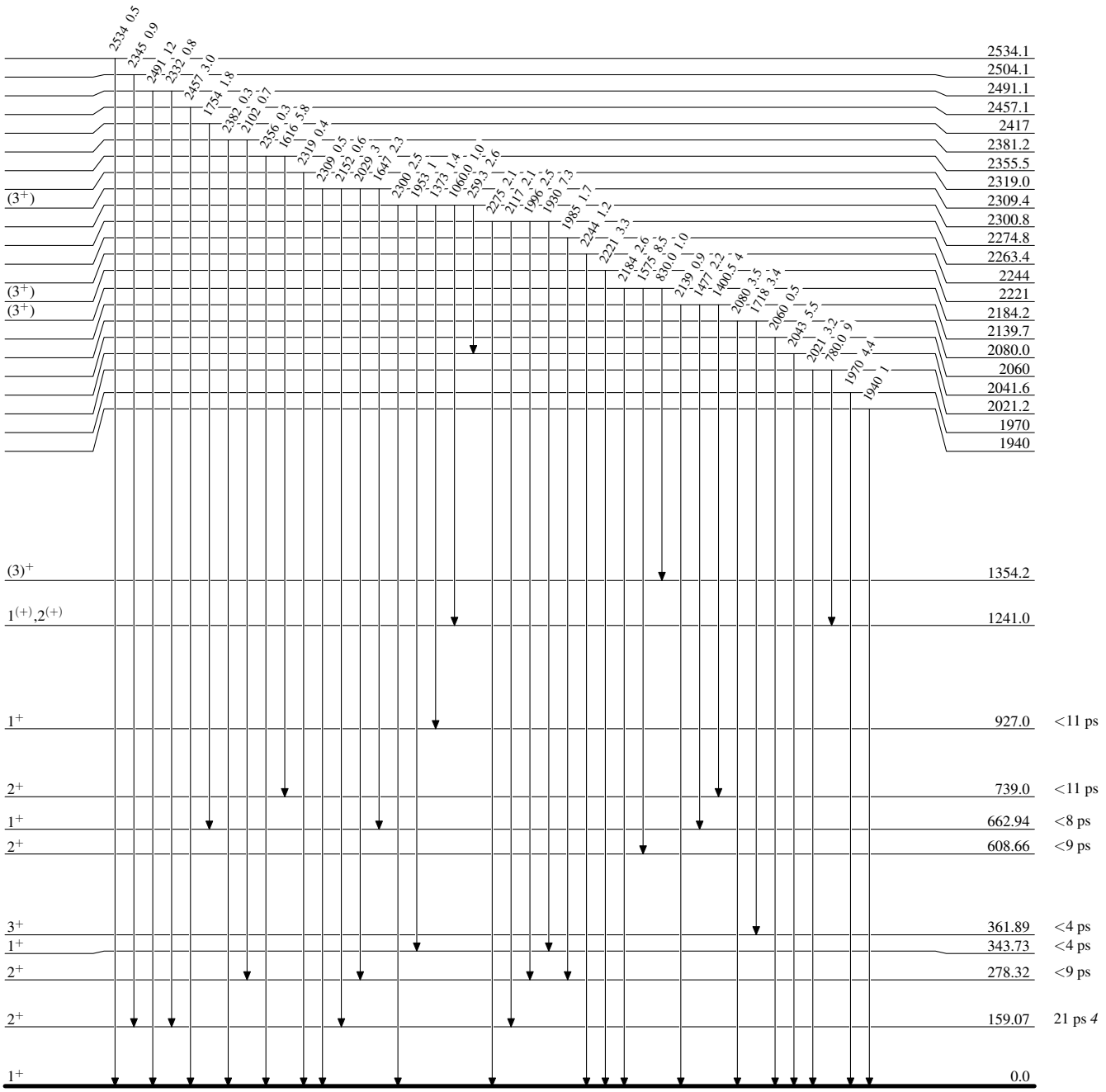
Intensities: Relative I_γ

Legend

$I_\gamma < 2\% \times I_\gamma^{max}$

$I_\gamma < 10\% \times I_\gamma^{max}$

$I_\gamma > 10\% \times I_\gamma^{max}$



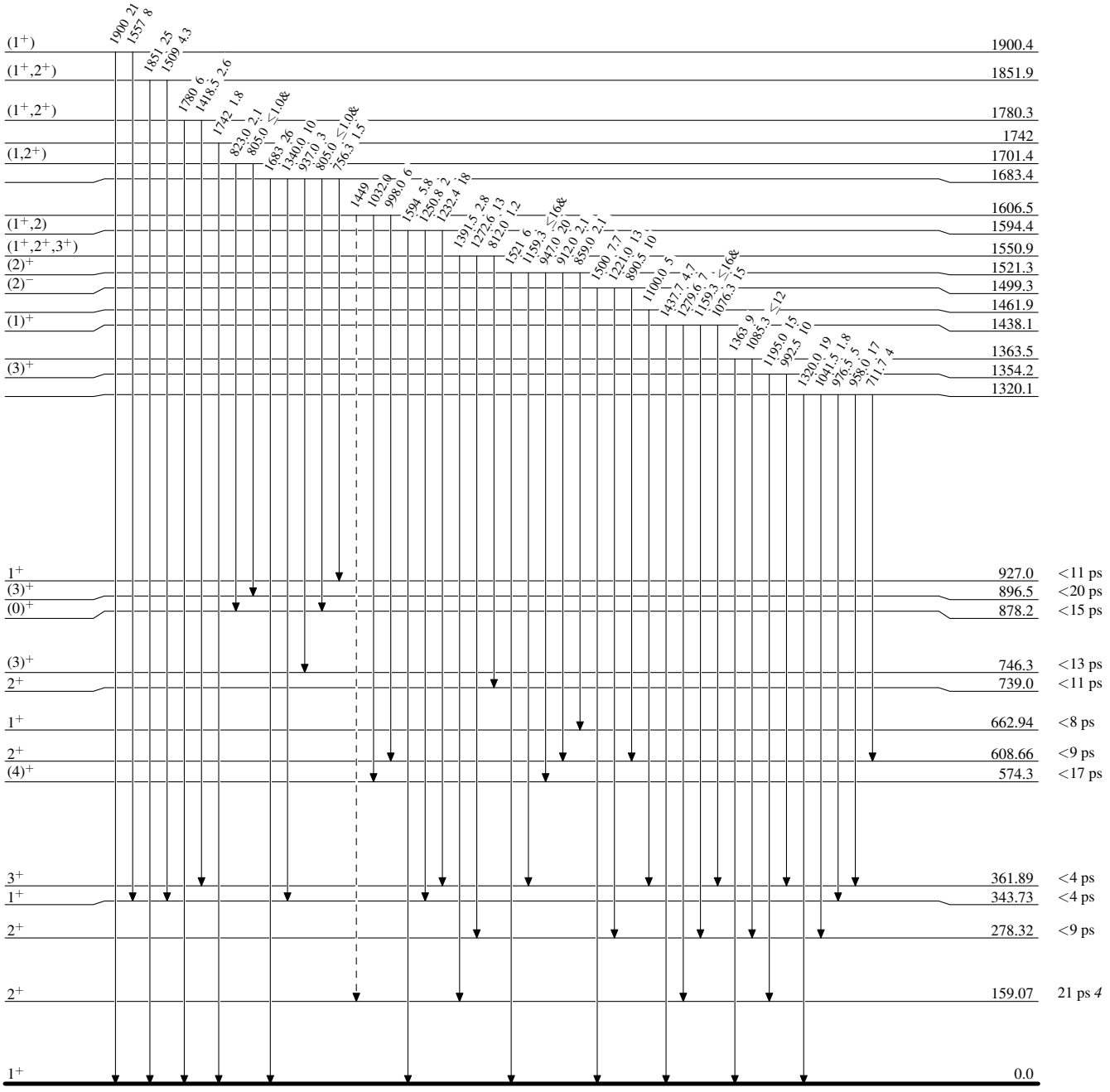
$^{64}_{29}Cu_{35}$

^{64}Ni(p,nγ) 1976Gr13,1972Gu17

Level Scheme (continued)

Intensities: Relative I_γ
& Multiply placed: undivided intensity given

Legend
- $I_\gamma < 2\% \times I_\gamma^{max}$
- $I_\gamma < 10\% \times I_\gamma^{max}$
- $I_\gamma > 10\% \times I_\gamma^{max}$
- γ Decay (Uncertain)



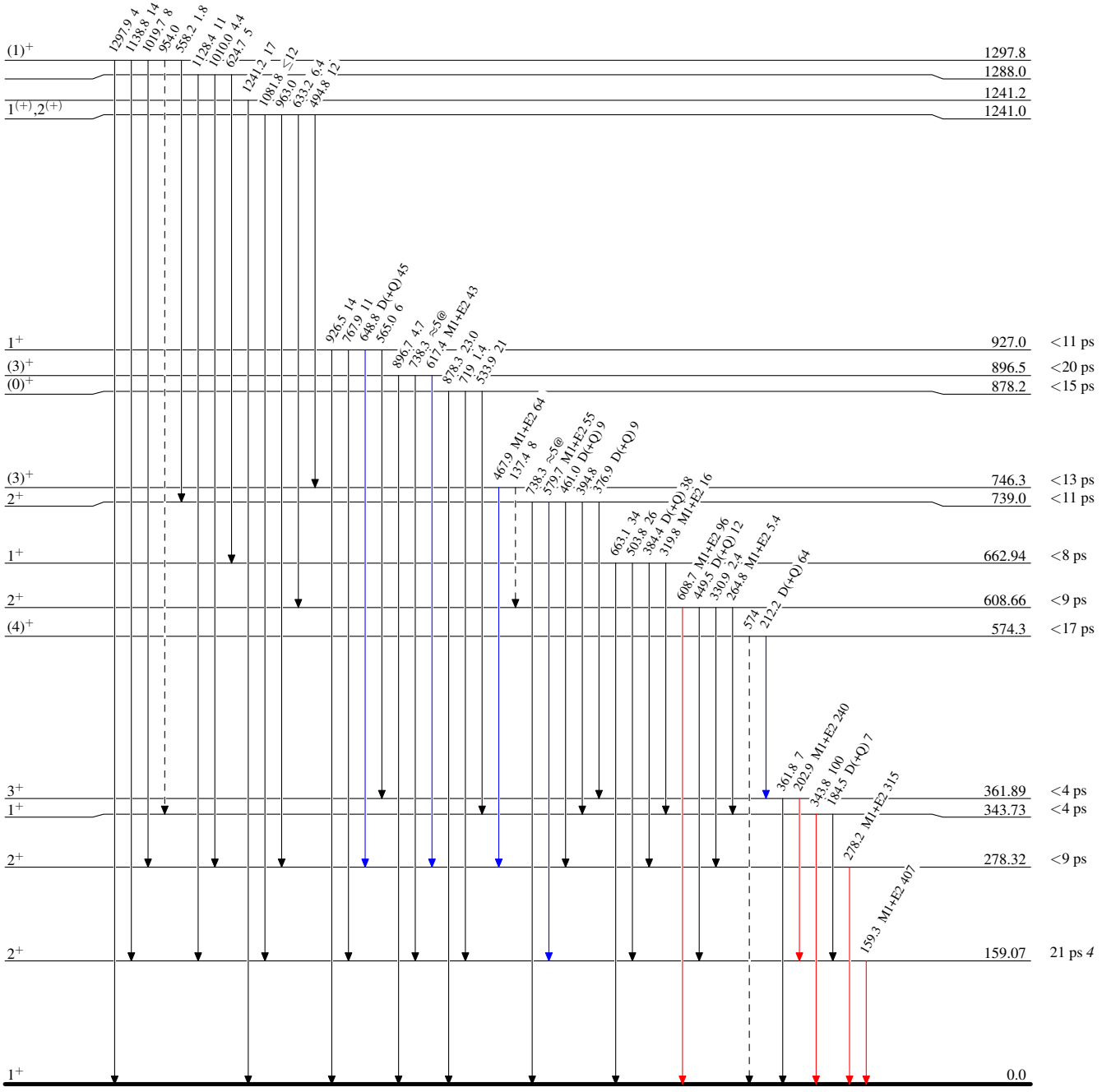
$^{64}_{29}Cu_{35}$

^{64}Ni(p,nγ) 1976Gr13,1972Gu17

Level Scheme (continued)

Intensities: Relative I_γ
& Multiply placed: undivided intensity given
@ Multiply placed: intensity suitably divided

Legend
$I_\gamma < 2\% \times I_\gamma^{max}$
$I_\gamma < 10\% \times I_\gamma^{max}$
$I_\gamma > 10\% \times I_\gamma^{max}$
γ Decay (Uncertain)



$^{64}_{29}Cu_{35}$