Adopted Levels, Gammas

History

Type	Author	Citation	Literature Cutoff Date
Full Evaluation	Balraj Singh and Jun Chen	NDS 188,1 (2023)	17-Jan-2023

Q(β^-)=4618 *3*; S(n)=7806.1 *18*; S(p)=10786.2 *26*; Q(α)=−9814 *7* 2021Wa16
S(2n)=13117.5 *20*, S(2p)=26900 *90* (2021Wa16).
Mass measurement: 2007Gu09.
Other measurements:
1983Ru06: produced by ^{76}Ge on W, E=9 MeV/nucleon, on-line mass separation and tape-transport system; measured half-life.
1999Pr10: production in ^{76}Ge fragmentation.
2008St01: E=1 GeV proton beam provided by CERN PS booster. ^{71}Cu beam was obtained using the ISOLDE fragment separator and implanted in the NICOLE detector system. The refrigerator temperature was varied between 1 K and 11-12 mK. Measured nuclear dipole moment of g.s. using β-NMR method on oriented nuclei at low temperatures.
2009Fl03, 2010Vi07: in-source laser spectroscopy and collinear laser spectroscopy at ISOLDE-CERN facility. Measured spin, and static magnetic moment and static quadrupole moment of the ground state.
2016Bi08: ^{71}Cu isotope was produced by bombarding UC_x target with 1.4 GeV proton beam at the CERN-ISOLDE facility. Cu isotopes were selectively ionized by the RILIS laser ion source, accelerated to 30 keV, mass separated with the high-resolution mass separator, and injected into the gas-filled linear Paul trap. Measured isotope shift with respect to ^{65}Cu using the collinear laser spectroscopy setup. Studied systematics of isotope shifts on $^{58-75}$Cu isotopes. Compared with droplet model predictions.
2020De21: ^{71}Cu isotope was produced by bombarding ^{238}U target with neutrons produced by impinging a 1.4 GeV proton beam on a neutron converter at the CERN-ISOLDE facility. Cu isotopes were selectively ionized by the RILIS laser ion source, accelerated to 30 keV for mass separation with high-resolution mass separator, and injected into ISCOOL gas-filled linear Paul trap. Measured isotope shift with respect to ^{65}Cu using collinear resonance ionization spectroscopy.
Additional information 1.
Theoretical calculations:
2022Ba29, 2021Ro19: calculated energies of the ground-state and the first-excited state, J^π of g.s. using simple effective interaction (SEI) with and without the addition of a short-range tensor force to SEI and SIII-T, SLy5-T, SAMi-T Skyrme and D1MTd Gogny effective interaction.
2022Ma30: calculated ground state energy, electric quadrupole moment, charge radius using shell model and other theoretical approaches.
2020Bo22: calculated charge radius using the self-consistent theory of finite Fermi systems and the family of energy density functionals.
2018Mi22: calculated M1 γ-strength function using large-scale shell model.
2018Na18: calculated potential energy curves, binding energy per nucleon, deformation parameters, total quadrupole moments, $T_{1/2}$, radius, electron- and positron-capture rates using the density-dependent relativistic mean field (RMF) model.
2015Ka46: calculated binding energy, effective single-particle energies of proton orbit, level energies of low-lying, low spin states and B(E2) values, magnetic moments and electric quadrupole moments using shell model.
2012Sr02, 2012Sr03: calculated low-lying level energies, J^π, B(E2) using shell model.
2010Da06: calculated low-lying levels, J^π using shell model.
2010Si11: calculated levels, J^π, neutron and proton orbital occupancies, magnetic moments, g factors using large-scale shell model.
2005Li54: calculated level energies, J^π using shell model.
2004Sm03: calculated level energies, spectroscopic factors, monopole shift using shell model.
2003Ji09: calculated deformation, superdeformed configurations using relativistic mean-field approach.

^{71}Cu Levels

Cross Reference (XREF) Flags

A	^{71}Ni β^- decay (2.56 s)	E	Coulomb excitation
B	^{71}Ni β^- decay (2.3 s)	F	^{198}Pt(^{76}Ge,Xγ)
C	^{2}H(^{72}Zn,^{3}He)	G	^{208}Pb(^{70}Zn,Xγ)
D	^{9}Be(^{76}Ge,Xγ),Ni(^{86}Kr,Xγ)	H	^{238}U(^{64}Ni,Xγ)

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Adopted Levels, Gammas (continued)

^{71}Cu Levels (continued)

E(level)[†]	J^{π}[‡]	$T_{1/2}$	XREF	Comments
0.0[#]	$3/2^{(-)}$	19.4 s *16*	ABcDEFGH	$\%\beta^-$=100 μ=+2.2772 *8* (2009Fl03,2010Vi07,2019StZV) Q=−0.200 *17* (2010Vi07,2016St14,2021StZZ) Change in radius $\delta<r^2>(^{65}Cu,^{71}Cu)$=+0.44 fm^2 *2*(stat) *7*(syst). Isotope shift $\delta\nu(\nu^{71}Cu-\nu^{65}Cu)$=+2787 MHz *4* (2020De21, ISOLDE-CERN, RILIS ion source and ISCOOL gas-filled linear Paul trap). See also review article 2017Ne04 about Collinear laser spectroscopy at ISOLDE-CERN. Change in radius $\delta<r^2>(^{65}Cu,^{71}Cu)$=+0.407 fm^2 *11*(stat) *44* (syst). Isotope shift $\delta\nu(\nu^{71}Cu-\nu^{65}Cu)$=+1526.5 MHz *91* (2016Bi08, ISOLDE-CERN, RILIS ion source and ISCOOL gas-filled linear Paul trap). μ: from in-source laser spectroscopy and collinear laser spectroscopy at CERN, ISOLDE facility (2009Fl03, 2010Vi07); measured value of +2.2747 *8* is evaluated by 2019StZV to +2.2772 *8*. Other: +2.28 *1* from β-NMR method on nuclei oriented at low temperatures (2008St01) is in agreement. See also 2011Go17 for analysis of magnetic moments from laser spectroscopy and nuclear magnetic resonance frequencies from β-NMR experiments; and 2017Ne04 review article. Q: from in-source laser spectroscopy and collinear laser spectroscopy at CERN, ISOLDE facility (2010Vi07), measured value of −0.190 *16* in this work is re-evaluated by 2016St14 to −0.200 *17*. See also 2017Ne04 review article about Collinear laser spectroscopy at ISOLDE-CERN. J^{π}: from in-source laser spectroscopy and collinear laser spectroscopy at CERN, ISOLDE facility (2009Fl03, 2010Vi07). Negative parity is suggested by dominant $\pi 2p_{3/2}$ orbital assignment from comparison of measured static magnetic and quadrupole moments with large-scale shell-model calculations (2010Vi07), as well as L(d,^{3}He)=1+3 from 0^+ target for an unresolved level at 110 *190* populated in ^{2}H(^{72}Zn,^{3}He). $T_{1/2}$: from timing of γ rays; weighted average of 19 s *3* (1999Pr10) and 19.5 s *16* (1983Ru06). Configuration: $\pi 2p^1_{3/2}\otimes\nu 1g^2_{9/2}$ (2008St01).
454.20 *10*	$(1/2^-)$		B E	J^{π}: level is Coulomb excited from $3/2^{(-)}$. $T_{1/2}$: measured B(E2)(W.u.) in 2008St04 (listed in Adopted Gammas) could not be used to obtain level half-life since $\delta(454\gamma)$ is unknown.
534.37[@] *7*	$(5/2^-)$		A cDEFGH	J^{π}: level is Coulomb excited from $3/2^{(-)}$; L(d,^{3}He)=1+3 from 0^+ target for an unresolved level at 110 *190* populated in ^{2}H(^{72}Zn,^{3}He), which, in comparison with neighboring nuclei such as ^{69}Cu, corresponds to g.s., $3/2^{(-)}$ + 534 level, $\pi f_{5/2}$, and not 454, $(1/2^-)$ level. $T_{1/2}$: measured B(E2)(W.u.) in 2008St04 (listed in Adopted Gammas) could not be used to obtain level half-life since $\delta(534\gamma)$ is unknown.
981.33[@] *8*	$(7/2^-)$	14 ps *6*	A D GH	XREF: D(?). J^{π}: 981.3γ to $3/2^{(-)}$; band member. $T_{1/2}$: from RDDS in (^{64}Ni,Xγ) (2015Sa09).
1189.39[#] *8*	$(7/2^-)$	1.15 ps *13*	A DEFGH	J^{π}: level is Coulomb excited from $3/2^{(-)}$; configuration=$\pi 2p_{3/2}\otimes(2^+$ in ^{70,72}Ni) consistent with B(E2) values (2008St04). $T_{1/2}$: deduced (evaluators) from B(E2)(W.u.)=10.7 *12* (2008St04) and branching ratio.
1453.31[@] *10*	$(9/2^-)$		A GH	J^{π}: 472.0γ to $(7/2^-)$; band member.
1633.3? *7*			D	
1786.28 *10*	$(9/2^-)$		A D F H	J^{π}: 1251.8γ to $(5/2^-)$; 341.8γ from 2128, $(11/2^-)$ level; shell-model prediction in 2009St05.
1845.69 *12*	$(7/2^-,9/2^-)$		A c	J^{π}: L(d,^{3}He)=3 for 1860 *150* suggests $5/2^-,7/2^-$, with preference for

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Adopted Levels, Gammas (continued)

^{71}Cu Levels (continued)

E(level)[†]	Jπ[‡]	$T_{1/2}$	XREF	Comments
				7/2$^-$, $\pi f_{7/2}$ orbital (by 2015Mo22) for 1846 and/or 1895 levels.
1895.10 *21*	(7/2$^-$)		A c	Jπ: see comment for 1845.69 level.
1973.67[@] *18*	(11/2$^-$)		A GH	Jπ: 472.0γ to (9/2$^-$); band member.
2128.29[#] *13*	(11/2$^-$)		A D FGH	Jπ: 939.1γ to (7/2$^-$); band member.
2151.6? *4*			D	
2289.73? *13*			A	
2551.4 *10*	(7/2$^+$)		A	Jπ: allowed β transition (log *ft*=5.4) from (9/2$^+$) parent; 2017.0γ to (5/2$^-$).
2576.7[@] *8*	(13/2$^-$)		G	Jπ: 603γ to (11/2$^-$); band member.
2599.79 *11*			A	
2623.14[#] *19*	(15/2$^-$)	328 ps *17*	D FGH	Jπ: 495.0γ to 11/2$^-$); band member. $T_{1/2}$: from γ(t) (2003Ma50) in ^{9}Be(^{76}Ge,X) reaction.
2686.40 *14*			A	
2751.12 *23*			A	
2756.1[#] *4*	(19/2$^-$)	0.271 μs *14*	D FGH	%IT=100 Jπ: 132.9γ to (15/2$^-$); band member. Proposed configuration=$\nu g^2_{9/2}\bullet\pi p_{3/2}$ (1998Is11). $T_{1/2}$: weighted average of 0.275 μs *14* from Ni(^{86}Kr,Xγ) and 0.25 μs *3* from ^{198}Pt(^{76}Ge,Xγ).
2805.88 *11*	(7/2$^+$,9/2$^+$,11/2$^+$)		A	Jπ: allowed β transition (log *ft*=5.2) from (9/2$^+$) parent.
2867.3 *8*	(7/2$^+$,9/2$^+$)		A	Jπ: allowed β transition (log *ft*=5.5) from (9/2$^+$) parent; 1885.9γ to (7/2$^-$).
2925.19 *23*	(7/2$^+$,9/2$^+$,11/2$^+$)		A	Jπ: allowed β transition (log *ft*=5.7) from (9/2$^+$) parent.
2971.7[@] *8*	(15/2$^-$)		G	Jπ: 998γ to (11/2$^-$); possible band member.
3034.47 *12*	(7/2$^+$,9/2$^+$,11/2$^+$)		A	Jπ: allowed β transition (log *ft*=5.2) from (9/2$^+$) parent.
3.24×10^3 *20*	(7/2)$^-$		c	Jπ: L(d,^{3}He)=3; 7/2$^-$ with $\pi f_{7/2}$ orbital preferred by 2015Mo22.
3430.7[@] *13*	(17/2$^-$)		G	Jπ: 459γ to (15/2$^-$); band member.
4.36×10^3 *17*	(7/2)$^-$		c	E(level),Jπ: wide peak which may contain more than one state, however, angular distribution is well fitted with only L(d,^{3}He)=3; 7/2$^-$ with $\pi f_{7/2}$ orbital preferred by 2015Mo22.
4776.5 *6*	(23/2$^-$)		H	Jπ: 2020.3γ to (19/2$^-$); proposed configuration=$\pi p_{3/2}\otimes\nu((fp)^{10}g^4_{9/2})$ (2009St05).
5330.7 *8*	(25/2,27/2$^-$)		H	Jπ: 554.2γ to (23/2$^-$); yrast pattern of population.
5.92×10^3 *18*	1/2$^+$&(3/2)$^+$		c	E(level),Jπ: doublet with L(d,^{3}He)=0+2, $\pi s^{-1}_{1/2}$ for 1/2$^+$ and (3/2)$^+$ with $\pi d^{-1}_{3/2}$ orbitals preferred by 2015Mo22.

† From a least-squares fit to Eγ data, assuming ΔEγ=0.5 keV for Eγ quoted to nearest tenth keV and 1 keV for Eγ quoted to keV, where ΔEγ not given.

‡ In addition to the arguments given with individual levels, assignments for many levels are also supported by shell-model calculations by 2021Pe08, 2015Li33, 2015Mo22, 2009St05 2008St04 and 1998Is11 in ^{71}Ni decay, ^{2}H(^{72}Zn,^{3}He), Coulomb excitation, and several heavy-ion reaction studies.

Band(A): Band based on 3/2$^{(-)}$. Configuration=$\pi p_{3/2}\otimes\nu(g^2_{9/2})$.

@ Band(B): ΔJ=1 band based on (5/2$^-$).

$\gamma(^{71}Cu)$

E_i(level)	J^π_i	E_γ[†]	I_γ[†]	E_f	J^π_f	Mult.	α[&]	Comments
454.20	(1/2⁻)	454.2 1	100	0.0	3/2$^{(-)}$	[M1+E2]	0.0018 6	B(E2)(W.u.)=20.4 22 (2008St04) E_γ: from Coulomb excitation.
534.37	(5/2⁻)	534.4 1	100	0.0	3/2$^{(-)}$			B(E2)(W.u.)=3.9 5 (2008St04). E_γ: others: 534.4 6 from (^{76}Ge,Xγ) and 534.3 2 from (^{64}Ni,Xγ).
981.33	(7/2⁻)	447.0 1	30.0 22	534.37	(5/2⁻)	[M1,E2]	0.0019 7	If M1, B(M1)(W.u.)=0.0041 +29−13. If E2, B(E2)(W.u.)=30 +22−9. E_γ: weighted average of 446.9 1 from ^{71}Ni β^- decay (2.56 s) and 447.2 2 from (^{64}Ni,Xγ). I_γ: other: 29 5 from (^{64}Ni,Xγ).
		981.3 1	100 3	0.0	3/2$^{(-)}$	[E2]		B(E2)(W.u.)=2.0 +14−6 E_γ,I_γ: other: 981.5 2 with Iγ=100 10 from (^{64}Ni,Xγ).
1189.39	(7/2⁻)	655.1 1	10.1 11	534.37	(5/2⁻)	[M1,E2]		If M1, B(M1)(W.u.)=0.0063 +10−9. If E2, B(E2)(W.u.)=21.4 +35−31. E_γ: other: 654.9 2 from (^{64}Ni,Xγ). I_γ: weighted average of 9.6 18 from ^{71}Ni β^- decay (2.56 s), 10.4 11 from (^{64}Ni,Xγ), and 9.6 18 from Coulomb excitation.
		1189.4 1	100 3	0.0	3/2$^{(-)}$	[E2]		B(E2)(W.u.)=10.7 12 (2008St04) E_γ: weighted average of 1189.5 1 from ^{71}Ni β^- decay (2.56 s), 1189.1 4 from ^{198}Pt(^{76}Ge,Xγ), and 1189.2 2 from (^{64}Ni,Xγ). I_γ: from ^{71}Ni β^- decay (2.56 s). Others: 100 4 from (^{64}Ni,Xγ) and 100.0 30 from Coulomb excitation.
1453.31	(9/2⁻)	472.0 1	100	981.33	(7/2⁻)			E_γ: other: 471.9 2 from (^{64}Ni,Xγ).
1633.3?		652[@a]		981.33	(7/2⁻)			
1786.28	(9/2⁻)	1251.8 1	100	534.37	(5/2⁻)			E_γ: weighted average of 1251.7 1 from ^{71}Ni β^- decay (2.56 s) and 1252.2 2 from (^{64}Ni,Xγ). Other: 1251.6 9 from (^{76}Ge,Xγ).
1845.69	(7/2⁻,9/2⁻)	1311.3 1	100	534.37	(5/2⁻)			
1895.10	(7/2⁻)	705.7 2	100	1189.39	(7/2⁻)			
1973.67	(11/2⁻)	520.3 2	100	1453.31	(9/2⁻)			E_γ: weighted average of 520.2 1 from ^{71}Ni β^- decay (2.56 s) and 520.6 2 from (^{64}Ni,Xγ).
		992[#]		981.33	(7/2⁻)			
2128.29	(11/2⁻)	341.8[‡] 2	11.8 15	1786.28	(9/2⁻)			E_γ: other: 342.4 9 from ^{198}Pt(^{76}Ge,Xγ). I_γ: weighted average of 16 8 from ^{198}Pt(^{76}Ge,Xγ) and 11.6 15 from (^{64}Ni,Xγ).
		495[@a]		1633.3?				
		674.9[‡] 5	1.9[‡] 6	1453.31	(9/2⁻)			
		939.1 2	100 6	1189.39	(7/2⁻)			E_γ: weighted average of 939.5 2 from ^{71}Ni β^- decay (2.56 s), 939.1 4 from ^{198}Pt(^{76}Ge,Xγ), and 939.1 2 from (^{64}Ni,Xγ). I_γ: from (^{64}Ni,Xγ). Other: 100 10 from ^{198}Pt(^{76}Ge,Xγ).
2151.6?		2151.0[@a]		0.0	3/2$^{(-)}$			
2289.73?		161.4 1	100	2128.29	(11/2⁻)			

γ(^{71}Cu) (continued)

E_i(level)	J^π_i	E_γ[†]	I_γ[†]	E_f	J^π_f	Mult.	α[&]	Comments
2551.4	(7/2$^+$)	2017.0 *10*	100	534.37	(5/2$^-$)			
2576.7	(13/2$^-$)	603[#]		1973.67	(11/2$^-$)			
2599.79		1410.4 *1*	100	1189.39	(7/2$^-$)			
2623.14	(15/2$^-$)	471.0[@a]		2151.6?				
		495.0 *2*	100	2128.29	(11/2$^-$)	[E2]	1.87×10^{-3} *3*	B(E2)(W.u.)=2.18 +*13*−*12* E_γ: weighted average of 494.7 *3* from ^{198}Pt(^{76}Ge,Xγ) and 495.1 *2* from (^{64}Ni,Xγ).
		649.4[‡] *2*	52[‡] *4*	1973.67	(11/2$^-$)			
2686.40		1497.1 *2*	100	1189.39	(7/2$^-$)			
2751.12		1297.8 *2*	100	1453.31	(9/2$^-$)			
2756.1	(19/2$^-$)	132.9 *2*	100	2623.14	(15/2$^-$)	[E2]	0.2079 *34*	B(E2)(W.u.)=2.38 +*13*−*12* α(K)=0.1844 *30*; α(L)=0.02049 *34*; α(M)=0.00285 *5* α(N)=7.28×10^{-5} *12* E_γ: weighted average of 133.0 *3* from ^{198}Pt(^{76}Ge,Xγ) and 132.8 *2* from (^{64}Ni,Xγ).
2805.88	(7/2$^+$,9/2$^+$,11/2$^+$)	206.1 *1*	26 *6*	2599.79				
		1019.0 *3*	84 *7*	1786.28	(9/2$^-$)			
		1352.6 *1*	100 *9*	1453.31	(9/2$^-$)			
2867.3	(7/2$^+$,9/2$^+$)	1885.9 *8*	100	981.33	(7/2$^-$)			
2925.19	(7/2$^+$,9/2$^+$,11/2$^+$)	1138.9 *2*	100	1786.28	(9/2$^-$)			
2971.7	(15/2$^-$)	395[#]		2576.7	(13/2$^-$)			
		998[#]		1973.67	(11/2$^-$)			
3034.47	(7/2$^+$,9/2$^+$,11/2$^+$)	348.1 *1*	27 *5*	2686.40				
		744.7 *1*	19 *5*	2289.73?				
		1248.2 *1*	100 *11*	1786.28	(9/2$^-$)			
		1581.0 *4*	31 *7*	1453.31	(9/2$^-$)			
3430.7	(17/2$^-$)	459[#]		2971.7	(15/2$^-$)			
4776.5	(23/2$^-$)	2020.3[‡] *5*		2756.1	(19/2$^-$)			
5330.7	(25/2,27/2$^-$)	554.2[‡] *5*		4776.5	(23/2$^-$)			

[†] From ^{71}Ni β^- decay (2.56 s), unless otherwise noted.

[‡] From ^{238}U(^{64}Ni,Xγ).

[#] From ^{208}Pb(^{70}Zn,Xγ).

[@] From ^{9}Be(^{76}Zn,Xγ),Ni(^{86}Kr,Xγ).

[&] Total theoretical internal conversion coefficients, calculated using the BrIcc code (2008Ki07) with Frozen orbital approximation based on γ-ray energies, assigned multipolarities, and mixing ratios, unless otherwise specified.

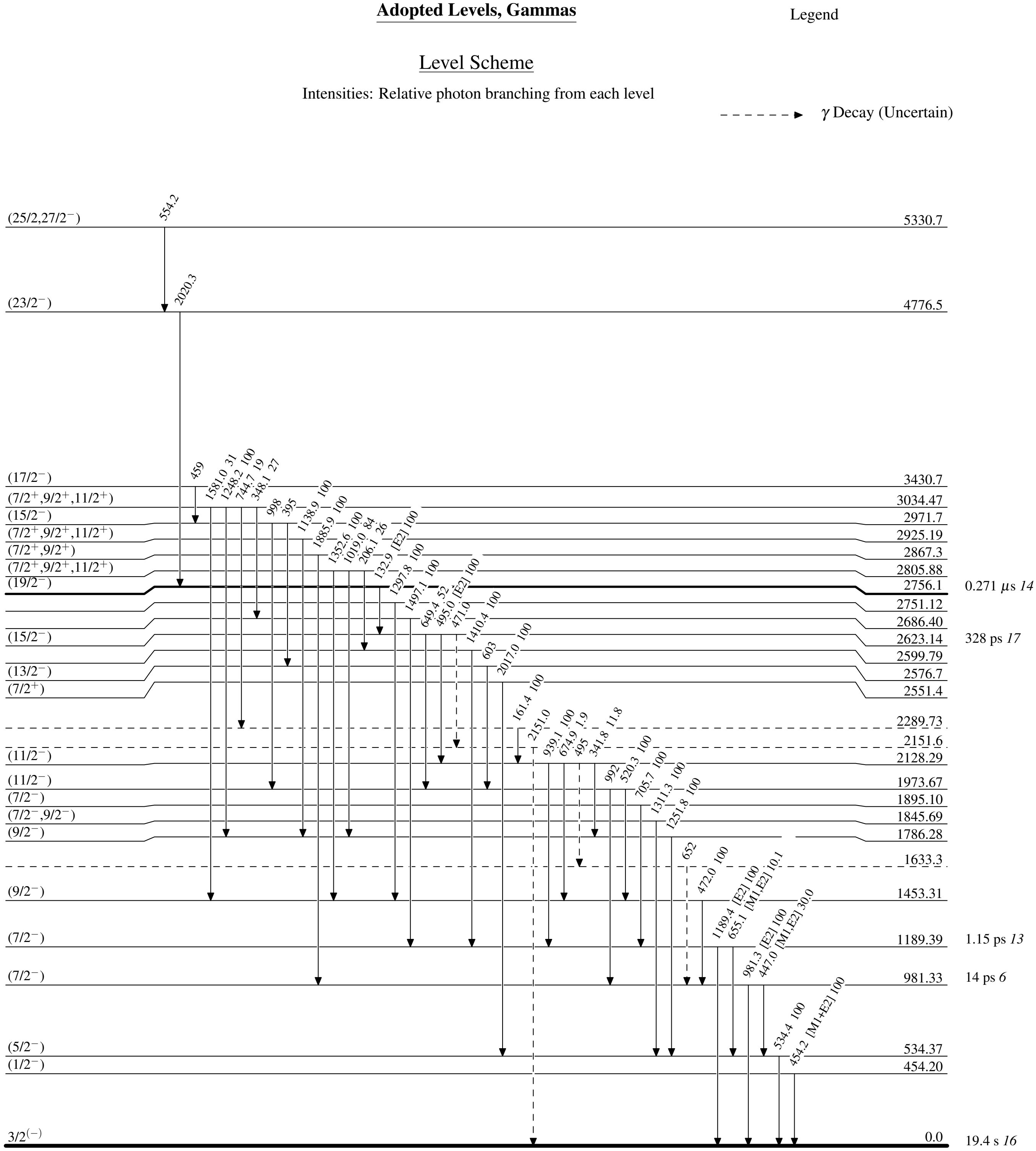
[a] Placement of transition in the level scheme is uncertain.

$^{71}_{29}Cu_{42}$-5

Adopted Levels, Gammas

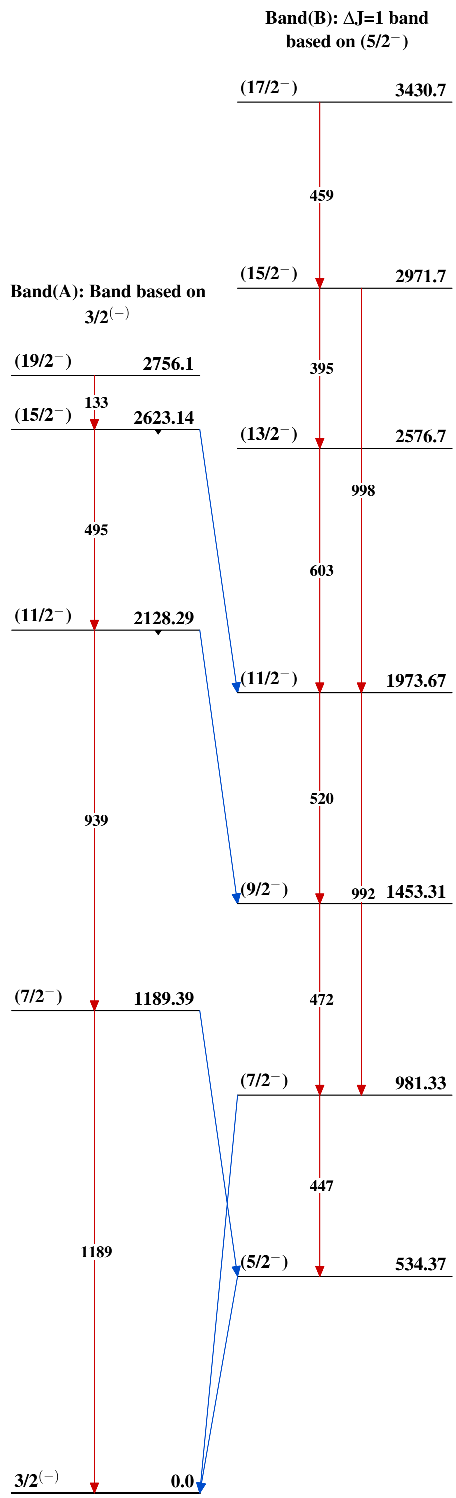
Level Scheme

Intensities: Relative photon branching from each level



$^{71}_{29}Cu_{42}$

Adopted Levels, Gammas



$^{71}_{29}Cu_{42}$