^{64}Zn(p,t) 2019Le11,1974Hi05,1973Ku05

History

Type	Author	Citation	Literature Cutoff Date
Full Evaluation	Balraj Singh, Huang Xiaolong, and Wang Xianghan	NDS 204,1 (2025)	30-Jun-2023

2019Le11 (also 2013Le25, 2018Ga22): E(p)=24 MeV from MP tandem Van de Graaff accelerator at the Maier-Leibnitz-Laboratory (MLL) of Ludwig-Maximilians-University (LMU) and Technical University of Munich (TUM) in Garching. Target was ≈100 μg/cm^2 thick, and >99% enriched in ^{64}Zn, with a 10 μg/cm^2 carbon backing. Tritons were momentum analyzed using Q3D magnetic spectrograph, and were detected using a cathode-strip detector, with FWHM of 10 keV. Measured energies and intensities of the triton peaks, and differential $\sigma(\theta)$ at eight angles from 10° to 50°. Deduced levels, J, and π. Comparison with finite-range, coupled-channel DWBA calculations of $\sigma(\theta)$ using FRESCO code for calculations of $\sigma(\theta)$, and with ab-initio shell-model calculations using chiral effective field theory (χEFT). The optical-model parameters for proton and triton were chosen to reproduce observed elastic scattering $\sigma(\theta)$ data. Relevance to nuclear structure data for $0^+ \rightarrow 0^+$ superallowed Fermi β decays.

1974Hi05: E=35 MeV, Enge split-pole magnetic spectrograph, measured $\sigma(\theta)$ from 3 to 90° (lab), photographic emulsions, FWHM=20 keV. DWBA analysis of $\sigma(\theta)$ distributions. Uncertainty in excitation energy is given as 10 keV up to about 4.2 MeV, and 20-30 keV for higher levels.

1973Ku05: E=51.9 MeV, 98.3% enriched target, broad range magnetic spectrometer, measured $\sigma(\theta)$ from 4.8 to 44.8° (lab) in 4° steps, FWHM=80 keV. Uncertainties in cross sections=20%. DWBA analysis of $\sigma(\theta)$ distributions. Uncertainty in excitation energy is given as 20 keV. Differential cross sections listed in Table I of 1973Ku05 are not specified as to the angle. From $\sigma(\theta)$ figures, these appear to be at 20.8° for which triton spectrum is shown in Fig. 1.

1972Fa08: E=27.5 MeV, 99% enriched target, measured $\sigma(\theta)$ from 8 to 110° (lab), ΔE-E Si telescope, FWHM=80-100 keV, DWBA analysis of $\sigma(\theta)$ distributions. Deduced transition strengths and enhancement factors from experimental and calculated (DWBA) cross sections, assuming $1f^2_{5/2}$ configuration of two neutrons in most cases.

Others:

1988Ca04: analyzed cross-section data for first excited 0^+ and g.s.

1985Mi06, 1980Or04: E=51.9 MeV. Measured ground state transition strength.

1976Gu08: E=23.3-42.4 MeV, 98.9% enriched target, measured $\sigma(\theta)$ from 12 to 90°(lab), ΔE-E Si detector telescope, FWHM=120 keV. DWBA calculations. Measurements for 0, 950, 2750+2810, 3160+3210 levels.

1970BrZI: E=40 MeV, measured $\sigma(\theta)$, ΔE-E Si telescope.

1966Mc15: E=17.5 MeV, measurement for g.s.

1964Ba34: E=39.8 MeV, measurements for g.s. and first excited 2^+ state.

^{62}Zn Levels

Cross sections from 1973Ku05 are at 20.8° (lab).

Cross sections from 1974Hi05 are at 12° (lab).

Transition strength N=$[d\sigma/d\Omega]_{expt}[2J+1]/[9.72*\sigma(DW)]$, units are arbitrary (1974Hi05).

Enhancement factors are from 1972Fa08. Deduced from experimental and calculated (DWBA) cross sections, assuming $1f^2_{5/2}$ configuration of two neutrons in most cases.

E(level)[†]	J$^\pi$[&]	L	$\delta\sigma/d\Omega$ (μb/sr)[c]	Comments
0.0	0^+[b]	0	684×10^1 *34*	$d\sigma/d\Omega$=6836 μb/sr *344* (2019Le11), 911 μb/sr (1974Hi05), 442 μb/sr *12* at 19° and E(p)=51.9 MeV (1985Mi06); 280.5 μb/sr (1973Ku05). L: from 2019Le11, 1976Gu08, 1974Hi05, 1973Ku05, 1972Fa08, 1966Mc15, 1964Ba34. Transition strength=490 (1974Hi05). Enhancement factor=71 (1972Fa08).
953.84 *9*	2^+	2	133 *7*	E(level): 2019Le11 quoted the value from 2012Ni08 evaluation, but was not in their energy calibration procedure. Others: 957 *5* (1972Fa08), 950 *20* (1973Ku05). L: from 2019Le11, 1976Gu08, 1974Hi05, 1973Ku05, 1972Fa08, 1964Ba34. $d\sigma/d\Omega$=150 μb/sr (1974Hi05); 46.4 μb/sr (1973Ku05). Transition strength=197 (1974Hi05). Enhancement factor=2.4 (1972Fa08).
1805.2 *4*	2^+	2	9.3 *7*	E(level): others: 1801 *7* (1972Fa08), 1800 *20* (1973Ku05).

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^{64}Zn(p,t) 2019Le11,1974Hi05,1973Ku05 (continued)

^{62}Zn Levels (continued)

E(level)[†]	J$^{\pi}$[&]	L	$\delta\sigma$/dΩ (μb/sr)[c]	Comments
				L: from 2019Le11, 1974Hi05, 1973Ku05, 1972Fa08. dσ/dΩ=19 μb/sr (1974Hi05); 6.4 μb/sr (1973Ku05). Transition strength=23 (1974Hi05). Enhancement factor=0.38 (1972Fa08).
2186.09 *5*	4^{+}[b]	4	5.0 *4*	E(level): others: 2180 *10* (1974Hi05), 2190 *20* (1973Ku05), 2170 *10* (1972Fa08). L: from 2019Le11, 1974Hi05, 1973Ku05, 1972Fa08; experimental $\sigma(\theta)$ to DWBA fits for L=4 are generally poor in all the studies. dσ/dΩ=2.6 μb/sr (1974Hi05); 6.1 μb/sr (1973Ku05). Transition strength=15 (1974Hi05). Enhancement factor=0.38 (1972Fa08).
2342.2 *5*	0^{+}	0	3.9 *4*	E(level): others: 2330 *10* (1974Hi05), 2380 *20* (1973Ku05), 2340 *20* (1972Fa08). Level in 1973Ku05 could correspond to 2384.3 in 2019Le11. L,J$^{\pi}$: from 1974Hi05, 1973Ku05. Other: L=2, $J^{\pi}=2^{+}$ in 2019Le11; however in the study of ^{62}Ga ε decay in 2020Ma59 (several authors same as in 2019Le11), this level was assigned 0^{+} from $\gamma\gamma(\theta)$ data. dσ/dΩ=1.5 μb/sr (1974Hi05), 0.7 μb/sr (1973Ku05). Transition strength=0.7 (1974Hi05).
2384.3 *3*			0.45 *11*	Level also discussed in 2018Ga22.
2743.71 *5*	4^{+}	4	4.2[d] *3*	E(level): others: 2750 *10* (1974Hi05), 2750 *20* (1973Ku05), 2740 *20* (1972Fa08). L: from 2019Le11 and 1974Hi05. Others: L=3,4 (1973Ku05); 3 (1972Fa08); 4+2 for 2750+2810 doublet (1976Gu08). dσ/dΩ=23 μb/sr (1974Hi05), 63.2 μb/sr for 2750+2800 (1973Ku05). Transition strength=130 (1974Hi05).
2802.87 *9*	2^{+}	2	27.6 *17*	E(level): others: 2810 *10* (1974Hi05), 2800 *20* (1973Ku05). L: from 2019Le11, 1974Hi05 and 1973Ku05. Other: L=4+2 for 2750+2810 doublet (1976Gu08). dσ/dΩ=43 μb/sr (1974Hi05), 63.2 μb/sr for 2750+2800 (1973Ku05). Transition strength=49 (1974Hi05).
2883.0 *3*	2^{+}	2	5.4 *4*	E(level): others: 2890 *10* (1974Hi05), 2870 *20* (1973Ku05), 2880 *20* (1972Fa08). L: from 2019Le11. L=(2) in 1974Hi05. dσ/dΩ=16 μb/sr; transition strength=18 (1974Hi05).
3045.5 *4*	0^{+}	0	10.3 *9*	E(level): other: 3060 *10* (1974Hi05). L: from 2019Le11. Other: L=2 (1974Hi05). dσ/dΩ=4.3 μb/sr; transition strength=4.9 (1974Hi05).
3146.21 *8*	[a]		2.5[d] *2*	
3181.1 *3*	2^{+}	2	4.3 *5*	E(level): others: 3160 *10* (1974Hi05). L: from 2019Le11 and 1974Hi05. Other: L=4+2 for 3160+3210 (1976Gu08). dσ/dΩ=11 μb/sr; transition strength=13 (1974Hi05).
3209.72 *5*	4^{+}	4	7.2 *6*	E(level),L: from 2019Le11. Others: L=4+2 for 3160+3210 (1976Gu08). Levels of 3216 with L=3 (1974Hi05); 3220 *20* (1973Ku05) with L=4+2; and 3216 *16* (1972Fa08) with L=4 probably correspond to 3209.72 (L=4) + 3223.72 (L=3) in 2019Le11.
3223.72 *5*	3^{-}	3	16.7 *11*	E(level),L: from 2019Le11. Others: levels of 3216 (1974Hi05) with L=3, but with poor fit for L=3 or 4; 3220 *20* (1973Ku05) with L=4+2; and 3216 *16* (1972Fa08) with L=4 probably correspond to 3209.72 (L=4) + 3223.72 (L=3) in 2019Le11. dσ/dΩ=39 μb/sr (1974Hi05), 38.3 μb/sr (1973Ku05). Enhancement factor=0.35 (1972Fa08).
3374 *2*	1^{-}	1	1.5[e] *2*	E(level): others: 3350 *20* (1974Hi05). L: from 2019Le11. L=(1) in 1974Hi05. dσ/dΩ=2.0 μb/sr (1974Hi05).
3406[@] *2*			0.22[e] *17*	
3443[@] *2*			0.48[e] *18*	
3474 *2*	2^{+}	2	8.1 *6*	E(level): others: 3470 *10* (1974Hi05), 3440 *20* (1973Ku05), 3440 *10* (1972Fa08). Levels in 1973Ku05 and 1972Fa08 could correspond to 3474+3443 in 2019Le11.

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^{64}Zn(p,t) 2019Le11,1974Hi05,1973Ku05 (continued)

^{62}Zn Levels (continued)

E(level)[†]	Jπ[&]	L	δσ/dΩ (μb/sr)[c]	Comments
				L: from 2019Le11, 1974Hi05, 1973Ku05, 1972Fa08. dσ/dΩ=19 μb/sr (1974Hi05), 5.9 μb/sr (1973Ku05). Transition strength=21 (1974Hi05).
3571[@] *2*			0.70 *15*	
3583 *2*		(2)	0.64 *15*	E(level): other: 3590 *10* (1974Hi05). L: from 1974Hi05, poor fit. dσ/dΩ=5.6 μb/sr, transition strength=6.1 (1974Hi05).
3621[@] *2*		2	0.94 *16*	E(level): others: 3640 *10* (1974Hi05). L: from 1974Hi05. dσ/dΩ=4.4 μb/sr, transition strength=4.8 (1974Hi05).
3689[@] *2*			0.43 *13*	E(level): other: 3690 *20* (1972Fa08). L: (2) (1972Fa08).
3708 *2*	6+*b*	6	0.16 *12*	E(level): other: 3730 *10* (1974Hi05). L: from 2019Le11, σ(θ) fits poorly with DWBA calculations. Other: L=(4,3) (1974Hi05). dσ/dΩ=1.9 μb/sr (1974Hi05).
3788[@] *2*	*a*		7.5 *5*	E(level): other: 3780 *20* (1973Ku05). L: 1,2 from 1973Ku05. dσ/dΩ=5.8 μb/sr (1973Ku05).
3817 *2*		2	0.39 *13*	E(level): other: 3830 *10* (1974Hi05). L: from 1974Hi05. dσ/dΩ=13 μb/sr, transition strength=14 (1974Hi05).
3862 *2*	0+*b*	0	2.0 *2*	L: from 2019Le11.
3884 *2*			0.12 *13*	
3936 *6*	0+	0	6.8 *6*	L: from 2019Le11. E(level),L: 2019Le11 matched this L=0 level with 4008.4 *7*, 0+ level in the ENSDF database, however, the energy matching is poor, difference being 72 keV *6*. Others: 3920 *10* with L=(4,3); and 4000 *10* with L=0 (1974Hi05); 3930 *20* with L=0 and 4000 *20* with L=(0) (1973Ku05); 3980 *20* with L=0 (1972Fa08). dσ/dΩ=6.1 mb/sr for 4000 *10* (1974Hi05); σ=2.7 μb for 3930 *20*, 3.4 μb/sr for 4000 (1973Ku05). Transition strength=1.5 for 4000 *10* (1974Hi05). Enhancement factor=1.4 for 3980 *20* (1972Fa08).
3994[@] *6*			0.32 *12*	
4021 *6*	*a*		5.8 *5*	
4141[@] *6*	*a*		3.5 *3*	Others: 4090 *10* with L=(4) and dσ/dΩ=3.8 μb/sr (1974Hi05); 4160 *20* with L=0,4 and σ=9.9 μb (1973Ku05); 4170 *10* with L=4 and enhancement factor=0.15 (1972Fa08).
4200[@] *6*			0.21 *11*	
4218 *6*			0.16 *10*	Other: 4220 *10* with L=(3) and dσ/dΩ=11 μb/sr (1974Hi05), level could correspond to 4218+4200 in 2019Le11.
4257[@] *6*			0.83 *16*	
4282[@] *6*			0.69 *15*	
4306[@] *6*	5−	5	0.38 *12*	L: from 2019Le11.
4331 *6*			1.8 *3*	Others: 4330 *20* with L=2 and dσ/dΩ=4.3 μb/sr (1974Hi05); 4320 *20* with L=3 and σ=4.0 μb/sr (1973Ku05); 4320 *20* (1972Fa08). Levels in 1974Hi05, 1973Ku05 and 1972Fa08 could correspond to 4331+4306 in 2019Le11.
4413[@] *9*			0.41 *15*	Other: 4380 *20* with L=(4) and dσ/dΩ=3.3 μb/sr (1974Hi05).
4432[@] *9*			0.31 *15*	Other: 4440 *20* (1974Hi05).
4483[@] *9*	1−	1	2.9 *2*	E(level): 2019Le11 matched this level with 4448.0 *3*, (1+) level in the ENSDF database, but the energy matching is poor, difference being 35 keV *9*. L: from 2019Le11.

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^{64}Zn(p,t) 2019Le11,1974Hi05,1973Ku05 (continued)

^{62}Zn Levels (continued)

E(level)[†]	Jπ[&]	L	δσ/dΩ (μb/sr)[c]	Comments
4518 *9*	6+	6	2.5 *2*	Other: 4500 *20* (1974Hi05). L: from 2019Le11.
4544 *9*			0.77 *13*	
4552[@] *9*	0+	0	6.4 *4*	L: from 2019Le11. L=0 for 4552 level in 2013Le25.
4576 *9*			0.30 *11*	
4590 *9*			0.75 *13*	Others: 4620 *20* with L=(0) and dσ/dΩ=10 μb/sr (1974Hi05); 4600 *20* with σ=5.6 μb (1973Ku05); 4570 *10* with L=0 and enhancement factor of 2.1 (1972Fa08). Level in 1972Fa08 could correspond to 4590+4576 in 2019Le11.
4670 *9*			1.65 *17*	
4688[@] *9*			0.36 *12*	Other: 4680 *10* with L=4 and dσ/dΩ=4.3 μb/sr (1974Hi05); level correspond to 4688+4670 in 2019Le11.
4725[@] *9*	2+	2	2.2[d] *2*	L: from 2019Le11.
4771 *9*	2+	2	3.9[e] *3*	L: from 2019Le11. Others: 4810 *30* (1974Hi05); 4750 *20* (1973Ku05); 4760 *20* with L=2,(3) (1972Fa08). Levels in 1974Hi05, 1973Ku05 and 1972Fa08 could correspond to 4771+4778 in 2019Le11.
4778[@] *9*			0.40[e] *20*	
4869 *9*	5−	5	0.93 *19*	L: from 2019Le11. Others: 4860 *30* with L=(3,4) and dσ/dΩ=3.9 μb/sr (1974Hi05); 4860 *20* (1973Ku05); 4860 *20* with L=(2) (1972Fa08). Levels in 1974Hi05, 1973Ku05 and 1972Fa08 could correspond to 4869+4894+4905 in 2019Le11.
4894 *9*			0.36 *19*	
4905 *11*			0.8 *2*	Other: 4910 *30* with L=(2) and dσ/dΩ=5.6 μb/sr (1974Hi05); level could correspond to 4905+4933+4894 in 2019Le11.
4933 *11*			0.2 *2*	
4997[@] *11*	*a*		2.1 *2*	
5018[@] *11*			0.46 *17*	Other: 5020 *20* with L=4 and σ=8.2 μb/sr (1973Ku05); level could correspond to 5018+5040+4997 in 2019Le11.
5040[@] *11*			0.80 *18*	
5059 *11*	2+	2	4.1 *3*	L: from 2019Le11. Others: 5050 *30* with L=(2) (1974Hi05); 5090 *20* (1973Ku05); 5050 *20* with L=2,(3) (1972Fa08). Levels in 1974Hi05 and 1972Fa08 could correspond to 5059+5040+5018 in 2019Le11; level in 1973Ku05 could correspond to 5059+5115+5059 in 2019Le11.
5115 *11*			0.49 *17*	
5151 *11*			0.40 *16*	
5194[@] *11*			0.64 *19*	Other: 5190 *30* (1974Hi05); level could correspond to 5194+5151 in 2019Le11.
5243 *11*	*a*		1.9 *2*	Other: 5240 *20* with L=(0) (1974Hi05).
5282[@] *11*			0.76 *20*	
5313 *11*			0.9 *2*	
5358 *11*	3−	3	4.4 *4*	L: from 2019Le11.
5387 *11*			1.2 *3*	Others: 5370 *20* with L=(4) and enhancement factor of 0.48 (1972Fa08); 5400 *20* with σ=8.2 μb/sr (1973Ku05). Levels in 1973Ku05 and 1972Fa08 could correspond to 5387+5410 in 2019Le11.
5410[@] *11*			0.2 *3*	
5560[#] *20*				
6360[#] *20*				
6590[#] *20*				
7200[‡]				
7340[#] *20*				

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^{64}Zn(p,t) 2019Le11,1974Hi05,1973Ku05 (continued)

^{62}Zn Levels (continued)

E(level)[†]
7400[‡]
7550[#] *20*
9800[‡]
10300[‡]
10800[‡]
13400[‡]

[†] From 2019Le11 unless otherwise stated. Evaluators′ note: below 3.3-MeV excitation, some of the energy uncertainties of 0.05 to 0.3 keV in the paper seem unrealistically low in consideration of 10 keV FWHM for the cathode-strip detector. It is possible that the uncertainties given by the authors are only statistical.

[‡] Level reported only by 1970BrZI.

[#] From 1973Ku05. Four levels above 6 MeV are only given in Fig. 1 of 1973Ku05, and not in authors′ Table I.

[@] New level proposed by 2019Le11.

[&] From 2019Le11, based on comparison of measured $\sigma(\theta)$ with the DWBA calculations of $\sigma(\theta)$ using FRESCO code. Exceptions are noted.

[a] The $\sigma(\theta)$ distribution is shown in Fig. 8 of 2019Le11, but from observed featureless pattern, no J^{π} assignment could be made.

[b] Evaluators′ note: it is not clear from $\sigma(\theta)$ distribution shown in authors′ Figs. 6 and 7, how a definite J^{π} assignment can be made, as the observed $\sigma(\theta)$ distribution seems to deviate significantly from the DWBA calculation.

[c] Values are from 2019Le11, measured at 10° with respect to the beam direction, unless otherwise stated. Authors have added 5% systematic uncertainty, arising from target thickness and other effects, in quadrature to statistical uncertainties.

[d] Value at 15°.

[e] Value at 20°.