Coulomb excitation 2019He07,1995Ka29,1974Ba80

History

Type	Author	Citation	Literature Cutoff Date
Full Evaluation	Balraj Singh, Jun Chen and Ameenah R. Farhan	NDS 194,3 (2024)	8-Jan-2024

Reactions: ^{208}Pb(^{76}Se,^{76}Se′),E=3.55,4.07 MeV/nucleon; ^{76}Se(^{208}Pb,^{208}Pb′),E=934 MeV; ^{48}Ti(^{76}Se,^{76}Se′),E=186 MeV; ^{76}Se(^{40}Ca,^{40}Ca′),E=70,85 MeV; ^{76}Se(^{16}O,^{16}O′), E=39.2 MeV; ^{76}Se(^{14}N,^{14}N′); ^{76}Se(α,α′),E=6.6,7.3 MeV; ^{76}Se(p,p′).

2019He07: (^{76}Se,^{76}Se′),E=4.07 MeV/nucleon and 3.55 MeV/nucleon. Target=^{208}Pb, enriched, 0.92 mg/cm^2 thick. Scattered ^{76}Se and target-like ions were detected in the JANUS apparatus consisting of pair of S3-type annular Si detectors, and γ rays detected by SeGA array of 32-fold segmented HPGe detectors at the NSCL-MSU facility. Measured Eγ, Iγ, γ-ray yields, (scattered particles)(Doppler-corrected γ)-coin. Deduced Coulomb excitation yields, and analyzed using least-squares fitting code GOSIA. Deduced 19 E2 and four M1 matrix elements between the low-lying even-parity states of ^{76}Se, and static quadrupole moments for the first two 2$^+$ states, and the first 4$^+$ state. Comparison with predictions of geometric models, and a model-independent evaluation using rotational invariants, based on which the ground state of ^{76}Se is predicted to have a triaxial deformation component. In the GOSIA analysis, authors used the following data from literature: from ^{76}Se Adopted Levels in the ENSDF database (1995 update): 1. level energies and J^π values of the first three 2$^+$ and 4$^+$ states, first excited 0$^+$, 3$^+$, 5$^+$, 6$^+$ and 8$^+$ states; 2. level lifetimes of the first three 2$^+$ states, and the first 4$^+$ and 6$^+$ states; 3. E2+M1 mixing ratios for three 2$^+$ to 2$^+$ transitions and one 4$^+$ to 4$^+$ transition; 4. γ-ray branching ratios for transitions from the first excited 0$^+$, second and third 2$^+$ states, and the second 4$^+$ state. Comparison with literature values in the ENSDF database (1995 update), and with relevant data in 1995Ka29 and 2019Mu04.

1995Ka29: (^{76}Se,^{76}Se′γ) at 186 MeV on a 0.4 mg/cm^2 thick ^{48}Ti target, and ^{76}Se(^{208}Pb,^{208}Pb′γ) at 934 MeV on a 0.76 mg/cm^2 thick ^{76}Se target. The ^{76}Se beam experiment was done at Uppsala cyclotron facility, and the ^{208}Pb beam at SuperHILAC facility in Berkeley. Measured γ, (particle)$\gamma(\theta)$, (particle)(particle)$\gamma(\theta)$, Coulomb-excitation cross sections. Levels at 559,2$^+$; 1119,0$^+$; 1216,2$^+$; 1331,4$^+$; 1787,2$^+$; 2026,4$^+$ observed in the experiment. Other levels assumed in the GOSIA analysis of results are: 6$^+$, 8$^+$ and 10$^+$ of the g.s. band; 6$^+$ state of the γ band; and 4$^+$ state of the β band; some of these levels as virtual excitations. In the analysis 122 experimental γ-ray yields were used, in addition to following data from the literature (from Nuclear Data Sheets for A=76, 1984Si14): level energies of eleven excited states, ten lifetimes (for first two 2$^+$ and 6$^+$ states, second 0$^+$, first three 4$^+$ states, first 8$^+$ and 10$^+$ states), seven branching ratios (for second and third 2$^+$ states, and second 4$^+$ state), and three δ(E2/M1) values. A total of 21 E2 matrix elements (18 transition and 3 static), and two M1 matrix elements were deduced.

1998Sp03: measurement of g factors of first two 2$^+$ states, and first 4$^+$ state by transient-field technique in Coulomb excitation using E=230, 253 MeV ^{76}Se beam at Yale tandem accelerator facility. Measured Eγ, particle spectra, (particle)γ-coin; deduced cross sections, g factors.

Static quadrupole moment measurement by reorientation effect: 1977Le11: (^{16}O,^{16}O′),E=30-34 MeV; and 1976VoZY: (^{40}Ca,^{40}Ca′),E=70,85 MeV.

g-factor measured by ion-implanted perturbed angular correlation method: 1969He11: (^{16}O,^{16}O′),E=33-38 MeV.

Others:

1976Kr16, 1975NeZR: (p,p′),E<3 MeV.

1970AgZV: (α,α′),E=7 MeV.

1965Ro09, 1962St02, 1962Mc03: (α,α′),E=5-8 MeV.

1964By02: (^{16}O,^{16}O′),E=37 MeV.

1962Ga13, 1962Ga10, 1960An09, 1960An07, 1960Le07: (^{14}N,^{14}N′),E=16.3,36.0 MeV, (α,α′),E=8.5 MeV.

1956Te26: (α,α′),E=7 MeV.

^{76}Se Levels

E(level)‡	J$^\pi$†	T$_{1/2}$#	Comments
0.0	0$^+$		
559.07 *13*	2$^+$	12.3 ps *2*	Q=−0.34 *7* (1977Le11); g=0.40 *11* (1969He11); g=0.403 *23* (1998Sp03) B(E2)↑=0.422 *5* (1977Le11,1974Ba80). Others: 0.419 *+6−7* (2019He07), 0.42 *4* (from E2 matrix element in 1995Ka29), 0.45 *4* (1970AgZV), 0.48 *5* (1962St02), 0.45 *4* (1962Ga13), 0.43 (1956Te26), 0.41 *4* (1975NeZR). Q: others: −0.35 *4* (2019He07), −0.30 *8* (1976VoZY). β_2=0.309 (1974Ba80), 0.319 (1970AgZV). E2 matrix element (0,0$^+$ to 559,2$^+$)=+0.647 *33* (1995Ka29). Diagonal E2 matrix element (559,2$^+$ to 559,2$^+$)=−0.45 *7* (1995Ka29).

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Coulomb excitation 2019He07,1995Ka29,1974Ba80 (continued)

^{76}Se Levels (continued)

E(level)‡	Jπ†	$T_{1/2}$#	Comments
			E2 matrix element (0,0$^+$ to 559,2$^+$)=+0.647 *5* (2019He07).
			Diagonal E2 matrix element (559,2$^+$ to 559,2$^+$)=−0.463 *+52−53* (2019He07).
1119.1 *10*	0$^+$	12.1 ps *+39−24*	$T_{1/2}$: from B(E2)(from 559,2$^+$)=0.017 *4*, weighted average of 0.044 *+23−17* from E2 matrix element in 1995Ka29, 0.0163 *+30−29* in 2019He07.
			E2 matrix element (559,2$^+$ to 1119,0$^+$)=+0.47 *+11−10* (1995Ka29).
			E2 matrix element (from 1216,2$^+$ to 1119,0$^+$)=+0.15 *+8−18*.
			E2 matrix element (559,2$^+$ to 1119,0$^+$)=+0.285 *+26−27* (2019He07).
			Level given by 1964By02, 1995Ka29 and 2019He07.
			$T_{1/2}$: Other: from unresolved (560γ)(559γ) cascade, 1964By02 deduced B(E2)(559,2$^+$ to 1109,0$^+$)/B(E2)(g.s. to 559,2$^+$)=0.042 *15* from which $T_{1/2}$ is deduced as 11 ps *5*.
1216.22 *16*	2$^+$	3.3 ps *3*	Q=+0.19 *4* (2019He07); g=0.35 *6* (1998Sp03)
			$T_{1/2}$: from B(E2)(from 0,0$^+$)=0.0120 *5*, weighted average of 0.0125 *14* (1995Ka29) and 0.0119 *5* (2019He07).
			B(E2)(from 0,0$^+$)=0.0125 *14* from E2 matrix element in 1995Ka29.
			B(E2)(from 559,2$^+$)=0.089 *10* from E2 matrix element in 1995Ka29.
			E2 matrix element (0,0$^+$ to 1216,2$^+$)=+0.112 *6* (1995Ka29).
			E2 matrix element (559,2$^+$ to 1216,2$^+$)=+0.667 *36* (1995Ka29).
			E2 matrix element (1331,4$^+$ to 1216,2$^+$)=+0.09 *+12−9* (1995Ka29).
			Diagonal E2 matrix element (1216,2$^+$ to 1216,2$^+$)=+0.24 *+6−8* (1995Ka29).
			B(E2)(from 0,0$^+$)=0.0119 *5* (2019He07).
			B(E2)(from 559,2$^+$)=0.0820 *30* (2019He07).
			B(E2)(from 1122,0$^+$)=0.033 *+13−15* (2019He07).
			B(M1)(from 559,2$^+$)=0.00091 *+8−7* (2019He07).
			E2 matrix element (0,0$^+$ to 1216,2$^+$)=+0.110 *2* (2019He07).
			E2 matrix element (559,2$^+$ to 1216,2$^+$)=+0.640 *11* (2019He07).
			E2 matrix element (1122,0$^+$ to 1216,2$^+$)=+0.182 *+33−47* (2019He07).
			Diagonal E2 matrix element (1216,2$^+$ to 1216,2$^+$)=+0.245 *+57−60* (2019He07).
			M1 matrix element (from 559,2$^+$ to 1216,2$^+$)=+0.067 *3* (2019He07).
1330.9 *3*	4$^+$	1.52 ps *3*	Q=−0.29 *4* (2019He07); g=0.64 *9* (1998Sp03)
			$T_{1/2}$: from B(E2)(from 559,2$^+$)=0.2450 *50* (2019He07).
			B(E2)(from 559,2$^+$)=0.26 *3* from E2 matrix element in 1995Ka29.
			E2 matrix element (559,2$^+$ to 1331,4$^+$)=+1.14 *6* (1995Ka29).
			Diagonal E2 matrix element (1331,4$^+$ to 1331,4$^+$)=−0.36 *+24−14* (1995Ka29).
			B(E2)(from 1216,2$^+$)=0.00045 *+122−38* (2019He07).
			E2 matrix element (559,2$^+$ to 1331,4$^+$)=+1.108 *+12−11* (2019He07).
			E2 matrix element (1216,2$^+$ to 1331,4$^+$)=+0.047 *+44−29* (2019He07).
			Diagonal E2 matrix element (1331,4$^+$ to 1331,4$^+$)=−0.387 *+55−53* (2019He07).
1688.9 *3*	3$^+$		
1787.9 *5*	2$^+$	1.5 ps *+5−4*	$T_{1/2}$: from B(E2)(from 559,2$^+$)=0.0017 *2* in 2019He07 and adopted γ branching ratios and mixing rtios in Adopted Gammas.
			B(E2)(from 0,0$^+$)=0.0004 *+12−4* from E2 matrix element in 1995Ka29.
			B(E2)(from 559,2$^+$)=0.00098 *+30−26* from E2 matrix element (1995Ka29).
			B(E2)(from 1119,0$^+$)=0.35 *+44−33* from E2 matrix element in 1995Ka29.
			B(E2)(from 1216,0$^+$)=0.087 *+64−33* from E2 matrix element in 1995Ka29.
			E2 matrix element (0,0$^+$ to 1788,2$^+$)=+0.02 *+2−4* (1995Ka29).
			E2 matrix element (559,2$^+$ to 1788,2$^+$)=+0.07 *1* (1995Ka29).
			E2 matrix element (1119,0$^+$ to 1788,2$^+$)=+0.59 *+30−74* (1995Ka29).
			E2 matrix element (1216,2$^+$ to 1788,2$^+$)=0.66 *+21−14* (1995Ka29).
			E2 matrix element (2026,4$^+$ to 1788,2$^+$)=+0.79 *+27−13* (1995Ka29).
			B(E2)(from 0,0$^+$)=0.0016 *1* (2019He07).
			B(E2)(from 559,2$^+$)=0.0017 *2* (2019He07).
			B(E2)(from 1119,0$^+$)=0.283 *+22−19* (2019He07).
			B(E2)(from 1216,2$^+$)=0.014 *+8−4* (2019He07).
			B(E2)(from 1331,4$^+$)=0.0190 *+20−10* (2019He07).
			B(M1)(from 559,2$^+$)=0.0070 *3* (2019He07).

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Coulomb excitation 2019He07,1995Ka29,1974Ba80 (continued)

^{76}Se Levels (continued)

E(level)‡	Jπ†	T1/2#	Comments
			B(M1)(from 1216,2+)=0.006 *+3−1* (2019He07).
			E2 matrix element (0,0+ to 1788,2+)=+0.040 *1* (2019He07).
			E2 matrix element (559,2+ to 1788,2+)=−0.093 *+7−6* (2019He07).
			E2 matrix element (1119,0+ to 1788,2+)=+0.532 *+21−18* (2019He07).
			E2 matrix element (1216,2+ to 1788,2+)=+0.26 *+7−4* (2019He07).
			E2 matrix element (1331,4+ to 1788,2+)=+0.418 *+18−15* (2019He07).
			M1 matrix element (from 559,2+ to 1788,2+)=+0.186 *+4−5* (2019He07).
			M1 matrix element (from 1216,2+ to 1788,2+)=+0.168 *+4−2* (2019He07).
2026.2 *4*	4+	1.6 ps *2*	T1/2: from B(E2)(from 1216,2+)=0.120 *11*, weighted average of 0.118 *11* (2019He07) and 0.169 *+52−68* (1995Ka29).
			B(E2)(from 559,2+)=0.0029 *+43−27* from E2 matrix element in 1995Ka29.
			B(E2)(from 1216,2+)=0.169 *+52−68* from E2 matrix element in 1995Ka29.
			B(E2)(from 1331,4+)=0.0011 *+14−7* from E2 matrix element in 1995Ka29.
			E2 matrix element (559,2+ to 2026,4+)=+0.12 *+7−9* (1995Ka29).
			E2 matrix element (1216,2+ to 2026,4+)=+0.92 *+13−21* (1995Ka29).
			E2 matrix element (1331,4+ to 2026,4+)=+0.10 *+5−4* (1995Ka29).
			B(E2)(from 559,2+)=0.0003 *+8−1* (2019He07).
			B(E2)(from 1216,2+)=0.118 *11* (2019He07).
			B(E2)(from 1331,4+)=0.060 *+9−6* (2019He07).
			B(M1)(from 1331,4+)=0.003 *+2−1* (2019He07).
			E2 matrix element (559,2+ to 2026,4+)=+0.039 *+35−7* (2019He07).
			E2 matrix element (1216,2+ to 2026,4+)=+0.768 *+36−37* (2019He07).
			E2 matrix element (1331,4+ to 2026,4+)=+0.73 *+51−38* (2019He07).
			M1 matrix element (1331,4+ to 2026,4+)=+0.158 *+5−3* (2019He07).
2262.4 *3*	6+	0.56 ps *5*	T1/2: from B(E2)(from 1331,4+)=0.210 *+20−18*, weighted avearge of 0.261 *+56−61* from E2 matrix element in 1995Ka29, and 0.2050 *+200−180* (2019He07).
			E2 matrix element (1331,4+ to 2262,6+)=+1.53 *+16−19* (1995Ka29).
			E2 matrix element (1331,4+ to 2262,6+)=+1.390 *+64−58* (2019He07).
2429.2 *3*	3−	8.7 ps *+15−12*	T1/2: from B(E3)=0.040 *5* and adopted γ-ray branching ratios.
			β3=0.185 (1974Ba80).
2976.2 *4*	6+	1.1 ps *4*	T1/2: B(E2)=0.092 *+65−26* from E2 matrix element in 1995Ka29.
			E2 matrix element (2026,4+ to 2976,6+)=+0.91 *+28−14* (1995Ka29).
3269.8 *5*	8+	0.34 ps *8*	T1/2: B(E2)=0.207 *+59−36* from E2 matrix element in 1995Ka29.
			E2 matrix element (2262,6+ to 3270,8+)=+1.64 *+22−15* (1995Ka29).

† From Adopted Levels.
‡ From a least-squares fit to Eγ data.
# From B(E2)↑ values and adopted branching ratios and mixing ratios from Adopted Gammas, as noted under comments.

γ(^{76}Se)

Ei(level)	Jiπ	Eγ†	Iγ†	Ef	Jfπ	Mult.	Comments
559.07	2+	559.12 *15*	100	0.0	0+	[E2]	B(E2)=0.082 *2* (1974Ba80).
1119.1	0+	560 *1*		559.07	2+	[E2]	B(E2)=0.09 *4* (1964By02).
1216.22	2+	657.2 *2*	100	559.07	2+	[E2+M1]	B(E2)=0.082 *2*; β22=0.216 (1974Ba80). M1 matrix element=+0.069 *+6−4* (1995Ka29).
		1216.1 *2*	62.8 *21*	0.0	0+	[E2]	B(E2)=0.0024 *1*; β20=0.052 (1974Ba80).
1330.9	4+	771.8 *2*	100	559.07	2+	[E2]	B(E2)=0.136 *4*; β42=0.278 (1974Ba80). (772γ+810γ)(^{16}O)(θ): A2=+0.43 *7*, A4=−0.21 *12* (1964By02). These coefficients are consistent with Jπ=4+.
1688.9	3+	1129.8 *3*		559.07	2+		
1787.9	2+	456.8		1330.9	4+	[E2]	Eγ: from Adopted Gammas.

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Coulomb excitation **2019He07,1995Ka29,1974Ba80 (continued)**

$\gamma(^{76}Se)$ (continued)

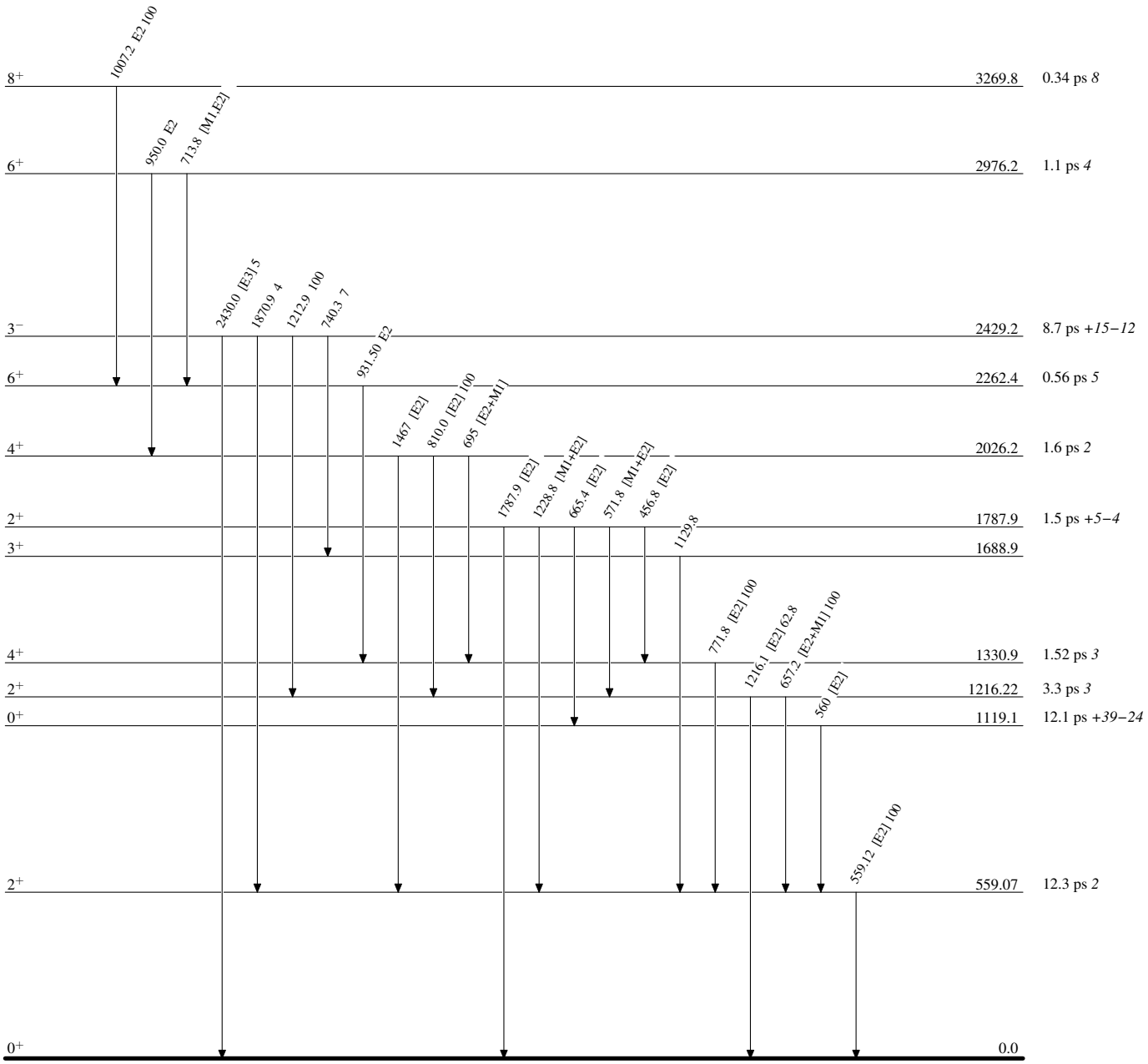
E_i(level)	J_i^π	E_γ[†]	I_γ[†]	E_f	J_f^π	Mult.	Comments
1787.9	2^+	571.8[‡]		1216.22	2^+	[M1+E2]	
		665.4		1119.1	0^+	[E2]	E_γ: from Adopted Gammas.
		1228.8 *7*		559.07	2^+	[M1+E2]	B(E2)=0.002 *1* (1974Ba80 assume pure E2). Using δ=−0.49 *5* (from Adopted Gammas), evaluators deduce B(E2)=0.0004 *2*. M1 matrix element=−0.14 *2* (1995Ka29).
		1787.9[‡]		0.0	0^+	[E2]	
2026.2	4^+	695		1330.9	4^+	[E2+M1]	E_γ: from Adopted Gammas.
		810.0 *3*	100	1216.22	2^+	[E2]	B(E2)=0.0039 *+6−24* (1974Ba80). See comment for 772γ for $\gamma(\theta)$. Adopted $T_{1/2}$=1.8 ps *4* gives B(E2)=0.09 *2*. β_{42}=0.050 (1974Ba80).
		1467		559.07	2^+	[E2]	E_γ: from Adopted Gammas.
2262.4	6^+	931.50[#] *20*		1330.9	4^+	E2[#]	
2429.2	3^-	740.3 *3*	7 *4*	1688.9	3^+		
		1212.9 *3*	100	1216.22	2^+		
		1870.9 *8*	4 *2*	559.07	2^+		
		2430.0 *15*	5 *3*	0.0	0^+	[E3]	
2976.2	6^+	713.8 *5*		2262.4	6^+	[M1,E2]	
		950.0[#] *5*		2026.2	4^+	E2[#]	
3269.8	8^+	1007.2[#] *5*	100[#]	2262.4	6^+	E2[#]	

[†] From 1974Ba80, unless otherwise stated. Intensities are relative photon branching ratios.
[‡] Transition not seen in Coul. Ex. (1974Ba80). Energies taken by 1974Ba80 from β decay studies.
[#] Transition not in 1974Ba80. Data taken from Adopted Gammas.

Coulomb excitation 2019He07,1995Ka29,1974Ba80

Level Scheme

Intensities: % photon branching from each level



$^{76}_{34}Se_{42}$