Coulomb excitation 2020Bu01

History

Type	Author	Citation	Literature Cutoff Date
Full Evaluation	Balraj Singh, M. S. Basunia, Jun Chen et al. ,	NDS 192,315 (2023)	25-Sep-2023

Dataset prepared by Balraj Singh, Jun Chen, and IAEA-ICTP-workshop participants: Diwanshu and B. Rohila.

2020Bu01 (also 2020Bu20, 2019Bu29): 4.31 MeV/nucleon ^{222}Ra beam obtained in spallation reaction by bombarding uranium carbide target with 1.4-GeV protons from the CERN PS Booster, followed by extraction of ions from a tungsten surface ion source, stripped to 51^+ charge state, and accelerated in HIE-ISOLDE. Targets was 2.1 mg/cm^2 thick ^{60}Ni and ^{120}Sn. γ rays were detected using Miniball array of 24 HPGe, sixfold segmented detectors, arranged in eight triple clusters. Scattered projectiles and target recoils were detected in a highly segmented silicon detector. Measured Eγ, E(X-ray), Iγ, (recoils)γ-coin, γ-ray yields. Deduced levels, J, π, band structures, matrix elements and corresponding intrinsic electric (quadrupole, octupole, dipole) moments using GOSIA code. Systematics of neighboring Ra isotopes.

A total of 114 experimental yields for ^{222}Ra were fitted to 42 variables, with random (but within reasonable limits) initial values for each of the freely varied matrix elements. The E4 matrix elements were also considered in the fitting procedure, by assuming the rotational model and a constant value of the hexadecapole moment obtained from the theoretical values for β_4. For ^{222}Ra, observed E3 matrix elements consistent with pear shape and stable octupole deformation.

^{222}Ra Levels

Units of matrix elements (M.E.): eb$^{1/2}$ for E1, eb for E2 and eb$^{3/2}$ for E3. Values of E1 matrix elements are from supplemental material of 2020Bu01.

B(E1), B(E2), and B(E3) values deduced by evaluators from corresponding transitional matrix elements M(Eλ)(from J) using B(Eλ)↑(from J)=[M(Eλ)]^2/(2J+1). Units are: eb for B(E1), e^{2}b^2 for B(E2) and e^{3}b^3 for B(E3).

Q_0(rotational model)=5.78 eb *18* (2020Bu01); weighted average of all the experimental values.

O_0(rotational model)=3.12 eb$^{3/2}$ *19* (2020Bu01); weighted average of all the experimental values.

E(level)[†]	J$^\pi$[@]	T$_{1/2}$[&]	Comments
0.0[a]	0^+		
111[a]	2^+		Q=−0.75 *+29−28* Q: from diagonal E2 M.E. (111,2^+ → 111,2^+)=−1.3 *5*. Intrinsic electric quadrupole moment (Q_0)=3.3 eb *14*.
242[b]	1^-	9.5 ps *+21−16*	T$_{1/2}$: deduced from B(E1)↑(0,0^+ → 242.1−)=0.000067 *+12−11*. Other: 9.6 ps *+24−36* from B(E1)↑(111,2^+ → 242,1^-)=0.000026 *+13−4*. Note that the contribution from the experimental B(E3) value for the 131-keV transition is negligible as deduced from B(E3,131γ)/B(E1,242γ) ratio. E1 M.E. (0,0^+ → 242,1^-)=+0.0082 *7*; B(E1)↑=0.000067 *+12−11*. E1 M.E. (111,2^+ → 242,1^-)=−0.0114 *+9−25*; B(E1)↑=0.000026 *+13−4*. E3 M.E. (111,2^+ → 242,1^-)=+0.85 *24*; B(E3)↑=0.15 *+9−7*. Intrinsic E1 moment: D_0(0,0^+ → 242,1^-)=0.0168 eb$^{1/2}$ *14*. Intrinsic E1 moment: D_0(111,2^+ → 242,1^-)=0.0165 eb$^{1/2}$ *+37−13*. Intrinsic E3 moment: O_0(111,2^+ → 242,1^-)=2.00 eb$^{3/2}$ *60*.
301[a]	4^+	135 ps *+17−14*	Q=−1.59 *+29−28* Q: from diagonal E2 M.E. (301,4^+ → 301,4^+)=−2.8 *5*. T$_{1/2}$: deduced from B(E2)(111,2^+ → 301,4^+)=1.78 *18*. Note that the contribution from the experimental B(E3) value for the 59-keV transition is negligible as deduced from β(E3,59γ)/β(E2,190γ) ratio. E2 M.E. (111,2^+ → 301,4^+)=+2.98 *15*, coupled to 0^+ → 2^+ M.E.; B(E2)↑=1.78 *18*. E3 M.E. (242,1^- → 301,4^+)=−2.1 *5*, coupled to higher-lying matrix elements; B(E3)↑=0.49 *+26−21*. Intrinsic E2 moment: Q_0(301,4^+ → 301,4^+)=5.80 eb *10*. Intrinsic E2 moment: Q_0(111,2^+ → 301,4^+)=5.90 eb *30*. Intrinsic E3 moment: O_0(242,1^- → 301,4^+)=4.4 eb$^{3/2}$ *10*.
317[b]	3^-	4.7 ps *+26−14*	T$_{1/2}$: deduced from B(E1)(111,2^+ → 317,3^-)=0.000135 *+57−47*. Other: 4.7 ps *+34−18* from

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Coulomb excitation 2020Bu01 (continued)

^{222}Ra Levels (continued)

E(level)[†]	Jπ[@]	$T_{1/2}$[&]	Comments
			B(E2)(242,1^- → 317,3^-)=1.84 *+36−48*. Note that contributions from the experimental B(E1) and B(E3) values for the 15.8-keV transition, and experimental B(E3) values for the 206- and 317-keV transitions are negligible as deduced from respective ratios of transition probabilities. E1 M.E. (111,2^+ → 317,3^-)=+0.026 *5*; B(E1)↑=0.000135 *+57−47*. E1 M.E. (301,4^+ → 317,3^-)=−0.027 *26*; B(E1)↑=0.0000810 *+2311−809*. E2 M.E. (242,1^- → 317,3^-)=+2.35 *22*; B(E2)↑=1.84 *+36−48*. E3 M.E. (0,0^+ → 317,3^-)=+1.13 *9*; B(E3)↑=1.28 *+21−41*. E3 M.E. (111,2^+ → 317,3^-)=−0.9 *5*; B(E3)↑=0.16 *+23−13*. E3 M.E. (301,4^+ → 317,3^-)=+2.6 *+6−9*, coupled to higher-lying matrix elements; B(E3)↑=0.75 *+39−43*. Intrinsic E1 moment: D_0(111,2^+ → 317,3^-)=0.031 eb$^{1/2}$ *6*. Intrinsic E1 moment: D_0(301,4^+ →317,3^-)=0.028 eb$^{1/2}$ *26*. Intrinsic E2 moment: Q_0(242,1^- → 317,3^-)=5.60 eb *50*. Intrinsic E3 moment: O_0(0,0^+ → 317,3^-)=3.03 eb$^{3/2}$ *24*. Intrinsic E3 moment: O_0(111,2^+ → 317,3^-)=2.1 eb$^{3/2}$ *12*. Intrinsic E3 moment: O_0(301,4^+ → 317,3^-)=5.5 eb$^{3/2}$ *+13−18*.
474[b]	5^-	24 ps *+5−9*	$T_{1/2}$: deduced from B(E1)(301,4^+ → 474,5^-)=0.000036 *+22−7*; and considering deduced branching ratio from B(E2)/B(E1) ratio for an unobserved 156.5γ. E1 M.E. (301,4^+ → 474,5^-)=+0.0180 *+48−19*; B(E1)↑=0.000036 *+22−7*. E2 M.E. (317,3^- → 474,5^-)=+3.1 *4*; B(E2)↑=1.37 *+38−33*. E3 M.E. (111,2^+ → 474,5^-)=+1.79 *20*; B(E3)↑=0.64 *+15−14*. E3 M.E. (301,4^+ → 474,5^-)=−1.7 *10*, coupled to higher-lying matrix elements; B(E3)↑=0.32 *+49−27*. Intrinsic E1 moment: D_0(301,4^+ → 474,5^-)=0.0165 eb$^{1/2}$ *+44−18*. Intrinsic E2 moment: Q_0(317,3^- → 474,5^-)=5.30 eb *70*. Intrinsic E3 moment: O_0(111,2^+ → 474,5^-)=3.10 eb$^{3/2}$ *40*. Intrinsic E3 moment: O_0(301,4^+ → 474,5^-)=3.2 eb$^{3/2}$ *18*.
550[a]	6^+	34 ps *+6−5*	$T_{1/2}$: weighted average of 37 ps *+6−5* deduced from B(E2)(301,4^+ → 550,6^+)=1.42 *+15−14* and 29 ps *+8−6* from B(E1)(474,5^- → 550,6^+)=0.0000698 *+57−54*. E1 M.E. (474,5^- → 550,6^+)=+0.0277 *11*; B(E1)↑=0.0000698 *+57−54*. E2 M.E. (301,4^+ → 550,6^+)=+3.57 *18*; B(E2)↑=1.42 *+15−14*. Intrinsic E1 moment: D_0(474,5^- → 550,6^+)=0.0231 eb$^{1/2}$ *10*. Intrinsic E2 moment: Q_0(301,4^+ → 550,6^+)=5.59 eb *28*.
703[b]	7^-	15 ps *5*	$T_{1/2}$: weighted average of 17 ps *5* deduced from B(E1)(550,6^+ → 703,7^-)=0.0000573 *+92−85* and 9 ps *+10−5* from B(E2)(474,5^- → 703,7^-)=1.76 *+34−31*. E1 M.E. (550,6^+ → 703,7^-)=+0.0273 *21*; B(E1)↑=0.0000573 *+92−85*. E2 M.E. (474,5^- → 703,7^-)=+4.4 *4*; B(E2)↑=1.76 *+34−31*. E3 M.E. (301,4^+ → 703,7^-)=+3.3 *+3−5*, coupled to higher-lying matrix elements; B(E3)↑=1.21 *+23−34*. Intrinsic E1 moment: D_0(550,6^+ → 703,7^-)=0.0211 eb$^{1/2}$ *16*. Intrinsic E2 moment: Q_0(474,5^- → 703,7^-)=6.30 eb *60*. Intrinsic E3 moment: O_0(301,4^+ → 703,7^-)=4.60 eb$^{3/2}$ *+50−60*.
843[a]	8^+	11.1 ps *+31−24*	$T_{1/2}$: weighted average of 10.5 ps *+31−24* from B(E2)(550,6^+ → 843,8^+)=1.32 *+15−14* and 11.8 ps *+31−27* from B(E1)(703,7^- → 843,8^+)=0.0000670 *+78−74*. E1 M.E. (703,7^- → 843,8^+)=+0.0317 *18*; B(E1)↑=0.0000670 *+78−74*. E2 M.E. (550,6^+ → 843,8^+)=+4.15 *23*; B(E2)↑=1.32 *+15−14*. Intrinsic E1 moment: D_0(703,7^- → 843,8^+)=0.0230 eb$^{1/2}$ *13*. Intrinsic E2 moment: Q_0(550,6^+ → 843,8^+)=5.60 eb *30*.
914[#c]	0^+		
992[b]	9^-	5.1 ps *+17−13*	$T_{1/2}$: weighted average of 4.9 ps *+17−13* from B(E1)(843,8^+ → 992,9^-)=0.000136 *+24−22* and 5.9 ps *+40−22* from B(E2)(703,7^- → 992,9^-)=2.40 *+87−73*. E1 M.E. (843,8^+ → 992,9^-)=+0.048 *4*; B(E1)↑=0.000136 *+24−22*.

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Coulomb excitation 2020Bu01 (continued)

^{222}Ra Levels (continued)

E(level)[†]	Jπ[@]	$T_{1/2}$[&]	Comments
			E2 M.E. (703,7⁻ → 992,9⁻)=+6.0 *10*; B(E2)↑=2.40 +*87*−*73*. Intrinsic E1 moment: D_0(843,8⁺ → 992,9⁻)=0.0326 $eb^{1/2}$ *25*. Intrinsic E2 moment: Q_0(703,7⁻ → 992,9⁻)=7.6 eb *12*.
1000?[‡d]	(2⁺)		
1025[#c]	2⁺		
1050?[‡d]	(3⁺)		
1150?[‡d]	(4⁺)		
1173[a]	10⁺	5.0 ps +*24*−*17*	$T_{1/2}$: weighted average of 5.3 ps +*27*−*17* from B(E2)(843,8⁺ → 1173,10⁺)=1.30 +*29*−*26* and 5.0 ps +*24*−*17* from B(E1)(992,9⁻ → 1173,10⁺)=0.000084 +*23*−*20*. E1 M.E. (992,9⁻ → 1173,10⁺)=+0.040 *5*; B(E1)↑=0.000084 +*23*−*20*. E2 M.E. (843,8⁺ → 1173,10⁺)=+4.7 *5*; B(E2)↑=1.30 +*29*−*26*. Intrinsic E1 moment: D_0(992,9⁻ → 1173,10⁺)=0.026 $eb^{1/2}$ *3*. Intrinsic E2 moment: Q_0(843,8⁺ → 1173,10⁺)=5.60 eb *60*.
1200?[‡c]	(4⁺)		
1331[b]	11⁻	3.6 ps +*18*−*12*	$T_{1/2}$: deduced from B(E1)(1173,10⁺ → 1331,11⁻)=0.000119 +*30*−*27*. E1 M.E. (1173,10⁺ → 1331,11⁻)=+0.050 *6*; B(E1)↑=0.000119 +*30*−*27*. Intrinsic E1 moment: D_0(1173,10⁺ → 1331,11⁻)=0.031 $eb^{1/2}$ *4*.
1500?[‡c]	(6⁺)		
1537[a]	12⁺	4.6 ps +*26*−*16*	$T_{1/2}$: deduced from B(E1)(1331,11⁻ → 1537,12⁺)=0.000042 +*11*−*10*. E1 M.E. (1331,11⁻ → 1537,12⁺)=+0.031 *4*; B(E1)↑=0.000042 +*11*−*10*. Intrinsic E1 moment: D_0(1331,11⁻ → 1537,12⁺)=0.0182 $eb^{1/2}$ *22*.
2000?[‡c]	(8⁺)		

[†] Rounded values from Adopted Levels.
[‡] A level at an assumed energy included in the extraction of matrix elements in the GOSIA analysis of experimental Coulomb excitation yields. This level is not included in the Adopted Levels.
[#] A known level from literature included in the extraction of matrix elements in the GOSIA analysis of experimental Coulomb excitation yields. This level is not included in the Adopted Levels.
[@] As given in 2020Bu01 based on previous assignment in literature.
[&] Deduced by evaluators from B(E2)↑ and B(E1)↑ values deduced from corresponding matrix elements in 2020Bu01, and adopted γ-ray branching ratios from Adopted Gammas.
[a] Band(A): g.s. band.
[b] Band(B): Octupole band.
[c] Band(C): Band based on 914, 0⁺. Levels above 2⁺ are assumed.
[d] Band(D): Assumed γ band.

γ(^{222}Ra)

Total conversion coefficients are from the Adopted Levels, Gammas dataset, where Eγ values are given more precisely than the rounded values in this dataset, taken from 2020Bu01.

E_i(level)	J^π_i	Eγ[†]	Iγ[‡]	E_f	J^π_f	Mult.[‡]	α[@]	Comments
111	2⁺	111	100	0.0	0⁺	E2	6.12 *9*	
242	1⁻	131	31.2 *15*	111	2⁺	(E1)	0.2500 *35*	Iγ(131γ,E3)/Iγ(242γ,E1)=1.9×10⁻⁹ *7*, deduced by evaluators from B(E3)/B(E1) ratio.
		242	100.0 *30*	0.0	0⁺	E1	0.0575 *8*	
301	4⁺	(59)	7.7×10⁻⁹ *38*	242	1⁻	[E3]	5.2×10³ *6*	Iγ(59γ,E3)/Iγ(190γ,E2)=7.7×10⁻¹¹ *38* deduced by evaluators from B(E3)/B(E2) ratio. This γ is

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Coulomb excitation 2020Bu01 (continued)

$\gamma(^{222}Ra)$ (continued)

E_i(level)	J^π_i	E_γ[†]	I_γ[‡]	E_f	J^π_f	Mult.[‡]	α[@]	Comments
								not included in the Adopted Levels, Gammas dataset.
301	4+	190	100	111	2+	E2	0.700 *10*	
317	3−	(15.8 *1*)	<0.2	301	4+	[E1]	3.77 *9*	E_γ: from level-energy difference in the Adopted Levels; γ not included in the Adopted dataset. I_γ: from B(E1,15.8γ)/B(E1,206γ). Iγ(15.8γ,E3)/Iγ(206γ,E1)=10×10^{-16} *5*, deduced by evaluators from B(E3)/B(E1) ratio.
		75[‡]	0.017 *4*	242	1−	[E2]	36.8 *5*	
		206	100.0 *32*	111	2+	E1	0.0839 *12*	Iγ(206γ,E3)/Iγ(75γ,E2)<11×10^{-5}, deduced by evaluators from B(E3)/B(E2) ratio.
		(317)	2.5×10^{-5} *12*	0.0	0+	[E3]	0.747 *15*	I_γ: from B(E3,317γ)/B(E1,206γ); γ not included in the Adopted dataset.
474	5−	(156.5 *1*)	4.3 *23*	317	3−	[E2]	1.480 *21*	E_γ: from level-energy difference in the Adopted Levels. Iγ deduced by evaluators from B(E2,156.5γ)/B(E1,172γ) ratio.
		172	100	301	4+	[E1]	0.1288 *18*	Iγ(173γ,E3)/Iγ(173γ,E1)=30×10^{-9} *+60−29*, deduced by evaluators from B(E3)/B(E1) ratio.
		(363)	5.8×10^{-4} *29*	111	2+	[E3]	0.433 *8*	I_γ: from B(E3,363γ)/B(E1,172γ); γ not included in the Adopted dataset.
550	6+	77	29[#] *4*	474	5−	[E1]	0.2211 *31*	E_γ: new γ ray in the present work.
		249	100[#]	301	4+	[E2]	0.276 *4*	
703	7−	153	100 *32*	550	6+	[E1]	0.1715 *28*	
		229	18 *6*	474	5−	[E2]	0.362 *6*	
		(402)	0.0025 *6*	301	4+	[E3]	0.295 *5*	I_γ: from B(E3,402γ)/B(E1,153γ); γ not included in the Adopted dataset.
843	8+	140	100 *18*	703	7−	[E1]	0.2126 *31*	
		293	92 *8*	550	6+	[E2]	0.1636 *23*	
992	9−	149	100 *16*	843	8+	[E1]	0.1822 *30*	
		289	88 *10*	703	7−	[E2]	0.1705 *26*	
1173	10+	181	100 *23*	992	9−	[E1]	0.1147 *16*	
		330	75 *7*	843	8+	[E2]	0.1147 *16*	
1331	11−	157	64 *10*	1173	10+	[E1]	0.1604 *26*	
		338[‡]	100 *10*	992	9−	[E2]	0.1069 *16*	
1537	12+	206[‡]	64 *12*	1331	11−	[E1]	0.0839 *13*	B(E1)(W.u.)=0.00164 *+93−62*
		364[‡]	100 *10*	1173	10+	[E2]	0.0871 *13*	

[†] From supplemental material of 2020Bu01, unless otherwise indicated.
[‡] From the Adopted Levels, Gammas dataset, with exceptions noted. Energies are rounded values.
[#] Branching ratio deduced by evaluators from B(E2)↑/B(E1)↑ ratio.
[@] 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.

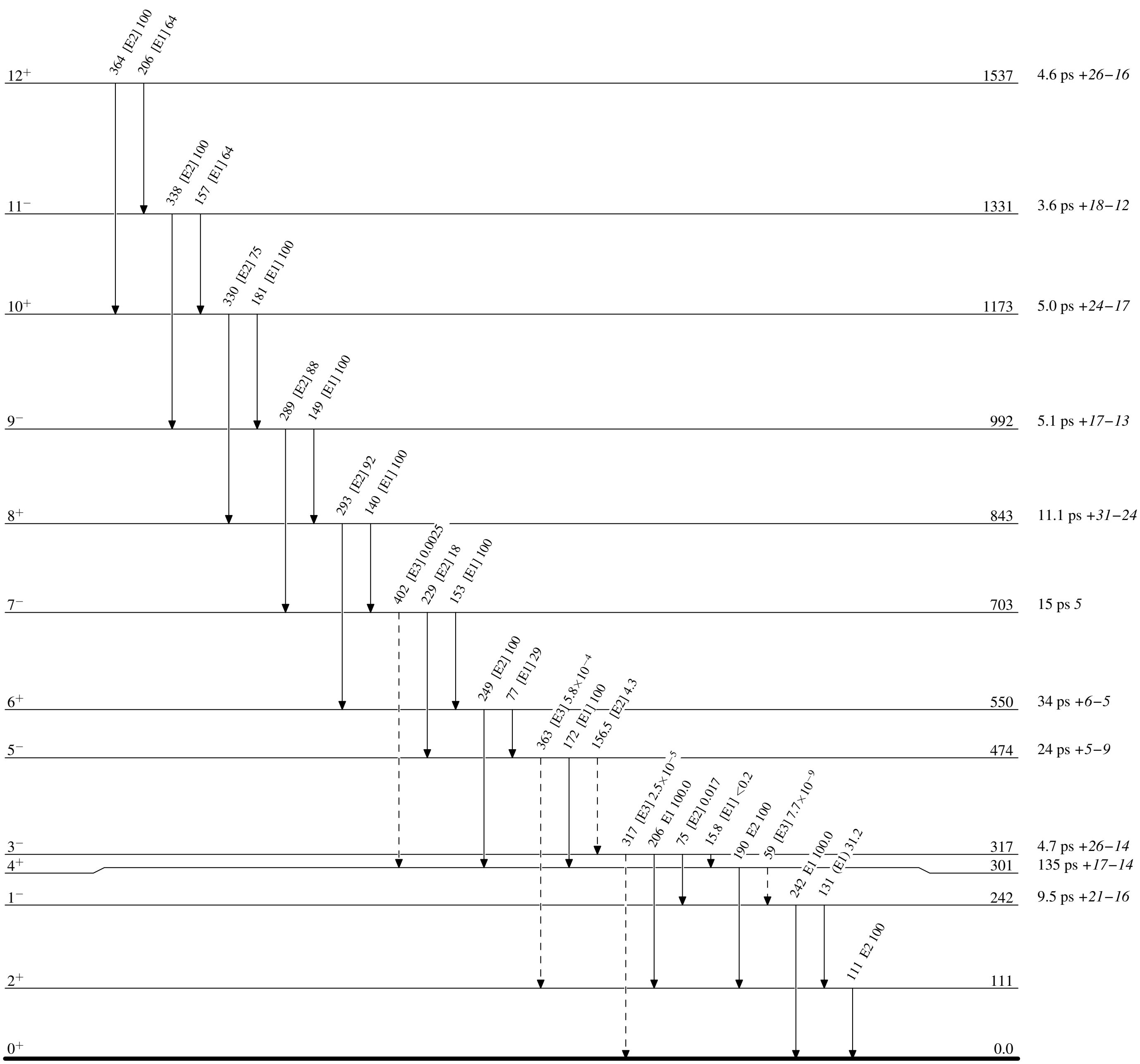
Coulomb excitation 2020Bu01

Legend

Level Scheme

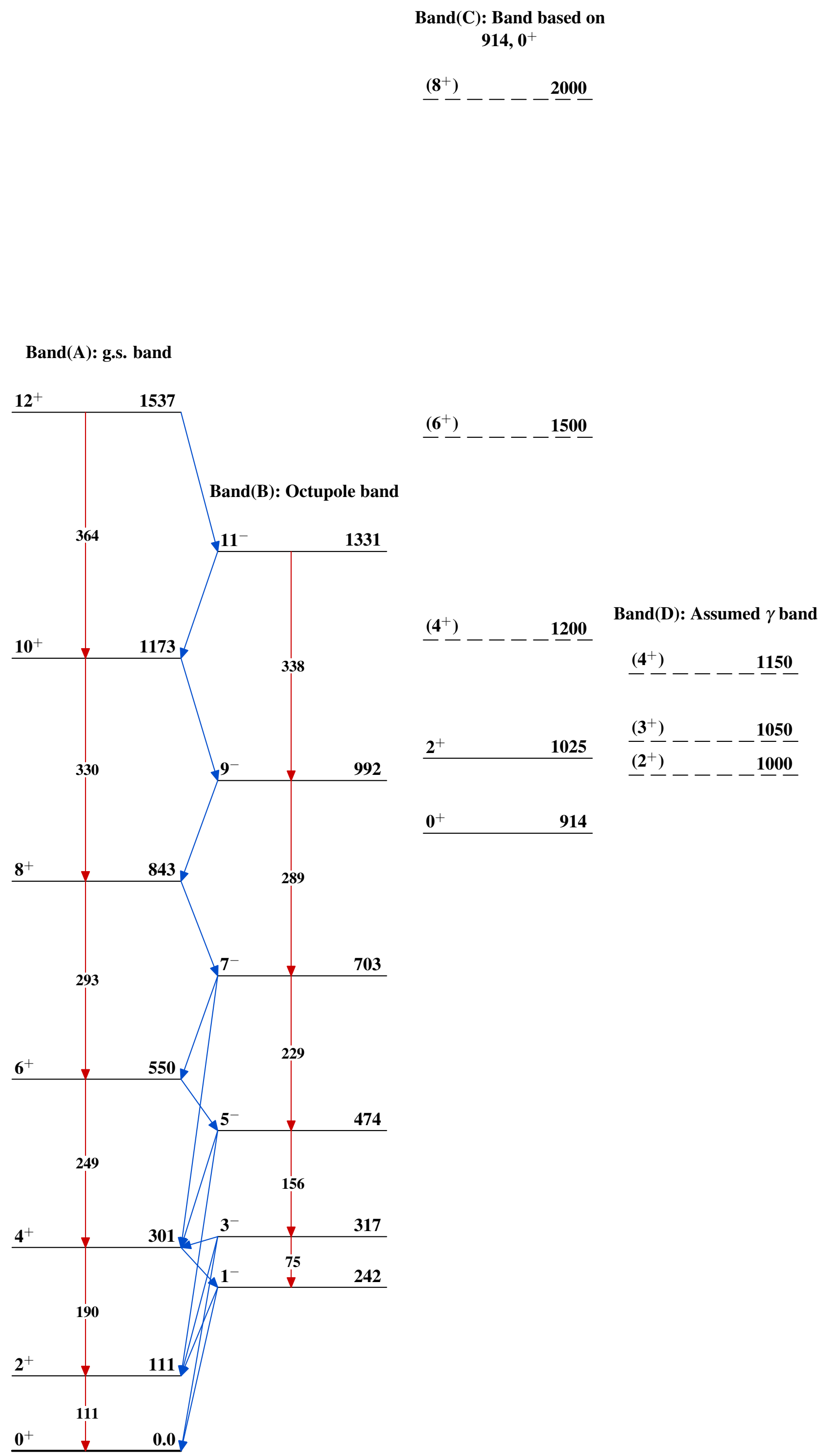
Intensities: Relative photon branching from each level

γ Decay (Uncertain)



$^{222}_{88}Ra_{134}$

Coulomb excitation 2020Bu01



$^{222}_{88}Ra_{134}$