



Fig. 1: Known experimental values for heavy particle emission of the odd-Z $T_z = +22$ nuclei.

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Table 1

Observed and predicted β -delayed particle emission from the odd-Z, $T_z = +22$ nuclei. Unless otherwise stated, all Q-values are taken from [2021Wa16] or deduced from values therein.

Nuclide	Ex.	J^π	$T_{1/2}$	Q_ε	$Q_{\varepsilon p}$	$Q_{\varepsilon \alpha}$	$BR_{\varepsilon f}$	Experimental
^{210}Bi		1^-	5.013(5) d	-0.064(1)	—	—		[1956Ro18]
^{210m}Bi	0.2713(1)	9^-	$3.04(6) \times 10^6$ y	0.207(1)	-8.271(6)	4.000(20)		[1976TuZY]
^{214}At		(2^-)	558(10) ns	1.091(4)	-5.436(6)	8.924(4)		[1982Ew01]
$^{214m1}\text{At}$	0.059(9)		265(30) ns	1.150(10)	-5.377(11)	8.983(10)		[1982Ew01]
$^{214m2}\text{At}$	0.233(6)	(9^-)	760(15) ns	1.324(7)	-5.203(8)	9.157(7)		[1982Ew01]
^{218}Fr		1^-	$1.3^{+0.5}_{-0.4}$ ms	1.842(4)	-4.624(6)	9.104(4)		[1982Ew01]
^{218m}Fr	0.088(5)	(8^-)	22.0(5) ms	1.930(6)	-4.536(8)	9.192(6)		[1982Ew01]
^{222}Ac		1^-	4.9(5) s*	2.302(6)	-3.944(7)	8.979(5)		[1958To25, 1952Me13]
^{222m}Ac	x		64(2) s***	2.302(6)+x	-3.944(7)+x	8.979(5)+x		[1973Mo07, 1972Es03]
^{226}Pa			1.8(2) m	2.836(12)	-2.893(12)	9.288(12)		[1951Me10]
^{230}Np			4.6(3) m	3.620(60)	-1.949(55)	9.614(55)		[1968Ha14]
^{234}Am			2.32(8) m	4.11(16)#	-0.78(17)#	10.42(16)#	$6.6(18) \times 10^{-3}$	[1990Ha02, 1972SoXX]
^{238}Bk			144(5) s	4.77(26)#	0.36(26)#	11.44(26)#	0.048(2)%	[1994Kr03, 1994La25]
^{242}Es			16.9(8) s	5.41(26)#	1.53(31)#	12.93(26)#	1.5(4)%	[2024KhXX, 2010An08, 2000Sh10, 1997ShZZ, 1985HiZU]
$^{246}\text{Md}^{***}$			0.9(2) s	5.92(26)#	2.51(31)#	14.30(26)#		[2010An08]
^{246m}Md	x		4.4(8) s	5.92(26)#+x	2.51(31)#+x	14.30(26)#+x	> 10%	[2010An08]

* Weighted average of 4.2(5) s [1958To25] and 5.5(5) s [1952Me13].

** Weighted average of 62(3) s [1973Mo07] and 66(3) s [1972Es03].

*** May not be the ground state.

Table 2

Particle separation, Q-values, and measured values for direct particle emission of the odd-Z, $T_z = +22$ nuclei. Unless otherwise stated, all S and Q-values are taken from [2021Wa16] or deduced from values therein.

Nuclide	S_p	S_{2p}	Q_α	BR_α	Experimental
$^{210}\text{Bi}^*$	4.466(1)	12.620(2)	5.036(1)	$1.32(10) \times 10^{-4}\%$	[1969La18, 1962Ka27, 1959Wa05, 1969La18, 1969LaZY, 1960Wa14, 1958Go89]
^{210m}Bi	4.195(1)	12.349(2)	5.307(1)	100%	[1976TuZY, 1975TuZW, 1975Sp07, 1969La01, 1969La18, 1969LaZY, 1968LaZZ, 1967Sp07, 1962Ko12, 1961Ru02, 1960Wa14, 1959Go77, 1954Le60, 1953Hu42]
^{214}At	4.015(5)	9.839(4)	8.988(4)	100%	[1982Ew01, 2009Vi09, 1999Sh03, 1982Bo04, 1981HaZN, 1973BoXW, 1968Ha14, 1964Mc21, 1958To25, 1951Me10, 1949Me54]
$^{214m1}\text{At}$	3.956(10)	9.780(10)	9.047(10)	$\approx 100\%$	[1982Ew01, 2009Vi09]
$^{214m2}\text{At}$	3.782(8)	9.606(7)	9.221(7)	$\approx 100\%$	[1982Ew01, 2009Vi09, 1999Sh03, 1981HaZN]
^{218}Fr	3.888(6)	9.775(5)	8.014(1)	100%	[1999Sh03, 1982Ew01, 2014Bu06, 1982Bo04, 1981HaZN, 1973BoXL, 1972Es03, 1968Ha14, 1964Mc21, 1958To25, 1951Me10, 1949Me54]
^{218m}Fr	3.800(8)	9.687(7)	8.102(5)	100%	[1999Sh03, 1982Ew01, 2014Bu06, 1981HaZN]
^{222}Ac	3.631(6)	9.438(6)	7.137(2)	$\approx 100\%$	[1964Mc21, 1988Hu08, 1973BoXL, 1973BoXW, 1972Es03, 1970GhZY, 1968Ha14, 1958To25, 1952Me13, 1949Me54]
^{222m}Ac	3.631(6)-x	9.438(6)-x	7.137(2)+x	>97%	[1972Es03, 1982Bo04, 1973Mo07]
^{226}Pa	3.566(12)	8.778(12)	6.987(10)	74%	[1964Mc21, 1991Ga28, 1968Ha14, 1951Me10, 1949Me54]
^{230}Np	3.263(55)	8.265(55)	6.778(54)	$\approx 3\%$	[1968Ha14]
^{234}Am	2.88(17)#	7.48(19)#	6.80(15)#	0.039(12)%	[1990Ha02, 2004Sa05, 1974ArYU]
^{238}Bk	2.32(27)#	6.40(28)#	7.33(20)#		
^{242}Es	1.81(32)#	5.44(30)#	8.160(20)	49(3)%**	[2024KhXX, 2010An08, 2000Sh10, 1996Ni09, 1994HoZW, 1994La25, 1985HiZU]
$^{246}\text{Md}^{***}$	1.37(33)#	4.49(32)#	8.889(41)	100%	[2020An08, 1996Ni09, 2003HeZY, 1994HoZW, 1994La25]
^{246m}Md	1.37(33)#-x	4.49(32)#-x	8.889(41)+x	< 23%	[2020An08]

* 100% β^- emitter.

** Weighted average of 41(3)% [2024KhXX] and 57(3)% [2010An08].

*** May not be the ground state.

Table 3
direct α emission from ^{210}Bi , $J^\pi = 1^-$, $T_{1/2} = 5.013(5)$ d*, $BR_\alpha = 1.32(10) \times 10^{-4}\%$ **.

E_α (c.m.)	E_α (lab)**	I_α (rel)***	I_α (abs)	J_f^π @	$E_{\text{daughter}}(^{206}\text{Tl})$ @	coincident γ -rays@	R_0 (fm)	HF
4.750(10)	4.660(10)	100%	$\approx 7.9 \times 10^{-4}\%$	1^-	0.3049	0.3049		
4.791(10)	4.700(10)	$\approx 67\%$	$\approx 5.3 \times 10^{-4}\%$	2^-	0.2658	0.2658		

* [1956Ro18].
** [1962Ka27].
*** [1969La18].
@ [2008Ko21].

Table 4
direct α emission from ^{210m}Bi *, Ex. = 271.3(1) keV**, $J^\pi = 9^-$, $T_{1/2} = 3.04(6) \times 10^6$ y, $BR_\alpha = 100\%$.

E_α (c.m.)	E_α (lab)	I_α (rel)	I_α (abs)	J_f^π	$E_{\text{daughter}}(^{206}\text{Tl})$ ***	coincident γ -rays***	R_0 (fm)	HF
≈ 4.180	≈ 4.100	3.6×10^{-3}	2×10^{-3}	(1^-)	1.120(2)	0.2658, 0.8514, 1.120		
≈ 4.312	≈ 4.230	1.5×10^{-3}	8×10^{-4}	(2^-)	0.9982	0.2658, 0.7323		
4.351(10)	4.268(10)	0.011%	$6 \times 10^{-3}\%$	(4^-)	0.9522	0.2658, 0.6863		
4.506(10)	4.420(10)	0.38%	0.21%	(3^-)	0.8014	0.2658, 0.5355		
4.657(20)	4.568(20)	7.1%	3.9%	(1^-)	0.6494(1)	0.2658, 0.3049, 0.3445, 0.3840, 0.6494		
4.671(20)	4.582(20)	2.5%	1.4%	(2^-)	0.6350(1)	0.2658, 0.3049, 0.3301, 0.3692, 0.6343		
5.004(10)	4.909(10)	71.8%	39.5%	(1^-)	0.3049	0.3049		
5.042(10)	4.946(10)	100%	55.0%	(2^-)	0.2658	0.2658		
5.308(10)	5.207(10)	$< 2 \times 10^{-4}\%$	$< 1 \times 10^{-4}\%$	(0^-)	0.0	—		

* All values from [1976TuZY], except where noted.
** [2014Ba14].
*** [2008Ko21].

Table 5
direct α emission from ^{214}At *, $J^\pi = (1^-)$, $T_{1/2} = 558(10)$ ns, $BR_\alpha = 100\%$.

E_α (c.m.)	E_α (lab)	I_α (rel)	I_α (abs)	J_f^π	$E_{\text{daughter}}(^{210}\text{Bi})$ **	coincident γ -rays**	R_0 (fm)***	HF
8.428(5)	8.270(5)	0.32(3)%	0.32(3)%		0.5632(1)	0.0465, 0.5166, 0.5632	1.5438(59)	$21.4^{+3.4}_{-3.2}$
8.642(6)	8.480(6)	0.59(4)%	0.58(4)%	3^-	0.3480	0.3480	1.5438(59)	42(6)
8.669(7)	8.507(7)	0.15(4)%	0.15(4)%	2^-	0.3197	0.3197	1.5438(59)	190^{+80}_{-50}
8.987(4)	8.819(4)	100%	98.95(6)%	1^-	0.0	—	1.5438(59)	1.8(2)

* All values from [1982Ew01], except where noted.
** [2014Ba41].
*** Interpolated between 1.52177(18) (^{212}Po) and 1.5658(59) fm (^{216}Rn).

Table 6
direct α emission from $^{214m1}\text{At}$ *, Ex. = 59(9) keV, $T_{1/2} = 265(30)$ ns, $BR_\alpha = \approx 100\%$.

E_α (c.m.)	E_α (lab)	I_α (abs)	J_f^π	$E_{\text{daughter}}(^{210}\text{Bi})$	coincident γ -rays	R_0 (fm)**	HF
9.046(8)	8.877(8)	$\approx 100\%$	1^-	0.0	—	1.5438(59)	1.14(19)

* All values from [1982Ew01], except where noted.
** Interpolated between 1.52177(18) (^{212}Po) and 1.5658(59) fm (^{216}Rn).

Table 7direct α emission from $^{214m2}\text{At}^*$, Ex. = 233(16) keV, $J^\pi = (9^-)$, $T_{1/2} = 760(15)$ ns, $BR_\alpha \approx 100\%$.

E_α (c.m.)	E_α (lab)	I_α (rel)	I_α (abs)	J_f^π	$E_{daughter}(^{210}\text{Bi})$	coincident γ -rays	R_0 (fm)***	HF
8.550(6)	8.390(6)	0.18(3)%	0.18(3)%	10^-	0.669(5)**	0.3977(5)**	1.5438(59)	111^{+29}_{-22}
8.784(5)	8.620(5)	0.65(5)%	0.64(5)%		0.436(4)		1.5438(59)	120^{+19}_{-17}
8.949(5)	8.782(5)	100%	99.18(6)%	9^-	0.2713(1)		1.5438(59)	$1.94^{+0.25}_{-0.23}$

* All values from [1982Ew01], except where noted.

** [2014Ba41].

*** Interpolated between 1.52177(18) (^{212}Po) and 1.5658(59) fm (^{216}Rn).**Table 8**direct α emission from $^{218}\text{Fr}^*$, $J^\pi = 1^-$, $T_{1/2} = 1.3^{+0.5}_{-0.4}$ ms**, $BR_\alpha = 100\%$.

E_α (c.m.)	E_α (lab)	I_α (rel)	I_α (abs)	J_f^π	$E_{daughter}(^{214}\text{At})$	coincident γ -rays	R_0 (fm)***	HF
7.519(6)	7.381(6)	1.1(5)%	1.0(0.5)%		0.494(6)		1.5599(82)	11^{+19}_{-7}
7.672(8)	7.531(8)	0.5(2)%	0.5(2)%	(2^-)	0.334(8)	0.147, 0.187	1.5599(82)	70^{+90}_{-40}
7.710(5)	7.569(5)	5.4(11)%	5(1)%	$1(-)$	0.303(5)	0.117, 0.187	1.5599(82)	9^{+7}_{-5}
7.870(7)	7.726(7)	1.6(5)%	1.5(5)%	$(2)^-$	0.143(7)	0.145	1.5599(82)	90^{+100}_{-5}
8.013(2)	7.866(2)	100%	92(2)%	0.0	—	1.5599(82)	3.9(16)	

* All values from [1999Sh03], except where noted.

** [1982Ew01].

*** Interpolated between 1.5658(59) fm (^{216}Rn) and 1.5539(57) fm (^{220}Ra).**Table 9**direct α emission from $^{218m}\text{Fr}^*$, Ex. = 88(5) keV, $J^\pi = (8^-)$, $T_{1/2} = 22.0(5)$ ms, $BR_\alpha = 100\%$.

E_α (c.m.)	E_α (lab)	I_α (rel)	I_α (abs)	J_f^π **	$E_{daughter}(^{214}\text{At})$	coincident γ -rays**	R_0 (fm)***	HF
6.965(7)	6.837(7)	0.10(2)%	0.04(1)%		1.136(7)		1.5599(82)	55^{+23}_{-16}
7.085(5)	6.955(5)	1.24(8)%	0.51(3)%		1.016(5)		1.5599(82)	$11.8^{+2.5}_{-2.1}$
7.128(8)	6.997(8)	0.09(4)%	0.040(15)%		0.972(8)		1.5599(82)	220^{+140}_{-70}
7.219(15)	7.087(15)	0.80(56)%	0.33(23)%		0.881(15)		1.5599(82)	50^{+130}_{-30}
7.239(5)	7.106(5)	3.92(55)%	1.61(22)%		0.862(4)		1.5599(82)	$12.9^{+3.5}_{-2.8}$
7.312(6)	7.178(6)	2.17(32)%	0.89(13)%		0.788(5)		1.5599(82)	42^{+12}_{-9}
7.375(5)	7.240(5)	23.4(12)%	9.6(4)%	(8^-)	0.725(4)	0.046, 0.451, 0.496	1.5599(82)	$6.3^{+1.3}_{-1.1}$
7.469(15)	7.332(15)	1.6(5)%	0.65(20)%		0.631(15)		1.5599(82)	190^{+100}_{-60}
7.536(5)	7.398(5)	8.3(6)%	3.4(2)%		0.564(4)	0.083, 0.145, 0.337	1.5599(82)	61(12)
7.597(5)	7.458(5)	3.2(3)%	1.3(1)%		0.503(4)	0.083, 0.145, 0.276	1.5599(82)	250(50)
7.646(6)	7.506(6)	2.3(3)%	0.93(10)%		0.454(5)		1.5599(82)	500^{+120}_{-100}
7.690(5)	7.549(5)	1.8(2)%	0.76(9)%		0.411(4)		1.5599(82)	830^{+210}_{-170}
7.758(5)	7.616(5)	100.0%	41.1(13)%	(8^-)	0.342(4)	0.111	1.5599(82)	25(5)
7.800(7)	7.657(7)	29.0(52)%	11.9(21)%	(6^-)	0.300(6)	0.074, 0.083, 0.145	1.5599(82)	120^{+40}_{-30}
7.825(7)	7.681(7)	39.2(53)%	16.1(21)%	(7^-)	0.276(6)	0.046	1.5599(82)	102^{+27}_{-22}
7.869(6)	7.725(6)	10.9(17)%	4.5(7)%	(9^-)	0.233(6)		1.5599(82)	490^{+140}_{-110}
7.915(5)	7.770(5)	2.8(3)%	1.14(11)%	(3^-)	0.185(4)	0.187	1.5599(82)	$2.7(6) \times 10^3$
7.956(5)	7.810(5)	3.9(3)%	1.6(1)%	$(2)^-$	0.145(4)	0.145	1.5599(82)	$2.6(5) \times 10^3$
8.022(5)	7.875(5)	3.4(5)%	1.4(2)%	0^-	0.078(4)	0.078	1.5599(82)	$4.6^{+1.3}_{-1.0} \times 10^3$
8.101(5)	7.952(5)	5.8(3)%	2.4(1)%	1^-	0.0	—	1.5599(82)	$4.5^{+0.9}_{-0.8} \times 10^3$

* All values from [1982Ew01], except where noted.

** [1999Sh03].

*** Interpolated between 1.5658(59) fm (^{216}Ra) and 1.5539(57) fm (^{220}Th).

Table 10direct α emission from $^{222}\text{Ac}^*$, $J^\pi = (2^-)$, $T_{1/2} = 4.9(5)$ s**, $BR_\alpha \approx 100\%$.

E_α (c.m.)	E_α (lab)	I_α (rel)	I_α (abs)	J_f^π	$E_{\text{daughter}}(^{218}\text{Fr})$	coincident γ -rays	R_0 (fm) [@]	HF
7.082(10)	6.954(10)***	6(1)%	6(1)%		0.047(14)		1.5462(63)	28^{+11}_{-9}
7.128(10)	7.000(10)***	100%	100%	1^-	0.0	—	1.5462(63)	2.7(5)

* All values from [1964Mc21], except where noted.

** Weighted average of 4.2(5) s [1958To25] and 5.5(5) s [1952Me13].

*** Value recommended by [1991Ry01]. Original values were 6.952(10) MeV and 6.998(10) MeV respectively.

[@] Interpolated between 1.5539(57) fm (^{220}Ra) and 1.5385(27) fm (^{224}Th).**Table 11**direct α emission from $^{222m}\text{Ac}^*$, Ex.= unk., $T_{1/2} = 64(2)$ s**, $BR_\alpha = >97\%$.

E_α (c.m.)	E_α (lab)	I_α (rel)	I_α (abs)	J_f^π	$E_{\text{daughter}}(^{218}\text{Fr})$	coincident γ -rays	R_0 (fm)***	HF
6.579(20)	6.460(20)	7(5)%	2(1)%		0.550(28)+x		1.5462(63)	$< 13^{+15}_{-6}$
6.833(20)	6.710(20)	30(18)%	8(4)%		0.295(28)+x		1.5462(63)	$< 30^{+40}_{-20}$
6.874(20)	6.750(20)	56(28)%	15(5)%		0.255(28)+x		1.5462(63)	$< 25^{+17}_{-10}$
6.935(20)	6.810(20)	100(37)%	27(10)%		0.193(28)+x		1.5462(63)	$< 24^{+18}_{-10}$
6.966(20)	6.840(20)	37(23)%	10(5)%		0.163(28)+x		1.5462(63)	$< 90^{+100}_{-40}$
7.016(20)	6.890(20)	56(28)%	15(5)%		0.112(28)+x		1.5462(63)	$< 90^{+60}_{-40}$
7.098(20)	6.970(20)	30(16)%	8(3)%		0.031(28)+x		1.5462(63)	$< 330^{+250}_{-140}$
7.128(20)	7.000(20)	56(28)%	15(5)%		0.0+x		1.5462(63)	$< 230^{+140}_{-80}$

* All values from [1972Es03], except where noted.

** Weighted average of 62(3) s [1973Mo07] and 66(3) s [1972Es03].

*** Interpolated between 1.5539(57) fm (^{220}Ra) and 1.5385(27) fm (^{224}Rn).**Table 12**direct α emission from $^{226}\text{Pa}^*$, $T_{1/2} = 1.8(2)$ m**, $BR_\alpha = 74\%$.

E_α (c.m.)	E_α (lab)	I_α (rel)	I_α (abs)	J_f^π **	$E_{\text{daughter}}(^{222}\text{Ac})$	coincident γ -rays**	R_0 (fm)***	HF
6.844(10)	6.723(10)	2%	1%		0.137		1.5311(58)	80
6.941(10)	6.818(10)	88%	46%		0.041		1.5311(58)	4.0
6.982(10)	6.858(10)	100%	52%	(2^-)	0.0	—	1.5311(58)	5.1

* All values from [1964Mc21], except where noted. Uncertainties for branching ratios was not provided.

** [1951Me10].

*** Interpolated between 1.5385(27) fm (^{224}Th) and 1.5237(51) fm (^{228}U).**Table 13**direct α emission from $^{230}\text{Np}^*$, $T_{1/2} = 4.6(3)$ m, $BR_\alpha \approx 3\%$.

E_α (c.m.)	E_α (lab)	I_α (abs)	J_f^π	$E_{\text{daughter}}(^{226}\text{Pa})$	coincident γ -rays	R_0 (fm)**	HF
6.778(20)	6.660(20)	100%		0.0?		1.506(50)	≈ 3

* All values from [1968Ha14], except where noted.

** Interpolated between 1.5237(51) fm (^{228}U) and 1.487(50) fm (^{232}Pu).**Table 14**direct α emission from $^{234}\text{Am}^*$, $T_{1/2} = 2.32(8)$ m, $BR_\alpha = 0.039(12)\%$.

E_α (c.m.)	E_α (lab)	I_α (abs)	J_f^π	$E_{\text{daughter}}(^{226}\text{Pa})$	coincident γ -rays	R_0 (fm)**	HF
6.57	6.46	100%		0.0?		1.503(50)	11^{+26}_{-9}

* All values from [1990Ha02], except where noted.

** Interpolated between 1.487(50) fm (^{232}Pu) and 1.5181(67) fm (^{236}Cm).

Table 15direct α emission from ^{242}Es , $T_{1/2} = 16.9(8)$ s*, $BR_{\alpha} = 49(3)\%^{**}$.

E_{α} (c.m.)	E_{α} (lab)	I_{α} (rel)	I_{α} (abs)	J_f^{π}	$E_{\text{daughter}}(^{238}\text{Bk})^{***}$	coincident γ -rays ^{***}	R_0 (fm)	HF
8.053(20)	7.920(20) ^{***}	100% ^{***}	$\approx 47\%$		0.107	0.0866, 0.1070, 0.1224		
8.160(20)	8.025(20) ^{***}	$\approx 5\%$ ^{***}	$\approx 2\%$		0.0	—		

* [2024KhXX].

** Weighted average of 41(3)% [2024KhXX] and 57(3)% [2010An08].

*** [2010An08].

Table 16direct α emission from $^{246}\text{Md}^*$, $T_{1/2} = 0.9(2)$ s, $BR_{\alpha} = 100\%$.

E_{α} (c.m.)	E_{α} (lab)	I_{α} (rel)	I_{α} (abs)	J_f^{π}	$E_{\text{daughter}}(^{242}\text{Es})$	coincident γ -rays	R_0 (fm)	HF
8.671(30)	8.530(30) ^{**}	$\approx 33\%$	$\approx 25\%$		0.215(33)			
8.886(14)	8742(14) ^{***}	100%	$\approx 75\%$		0.0?			

* All values from [2010An08], except where noted. This isomer may not be the ground state.

** [1996Ni09].

*** Weighted average of 8.744(20) MeV [2010An08] and 8.740(20) MeV [1996Ni09].

Table 17direct α emission from $^{246m}\text{Md}^*$, $T_{1/2} = 4.4(8)$ s, $BR_{\alpha} = <23\%$.

E_{α} (c.m.)	E_{α} (lab)	I_{α} (abs)	J_f^{π}	$E_{\text{daughter}}(^{242}\text{Es})$	coincident γ -rays	R_0 (fm)	HF
8.313(10)	8.178(10)	$<23\%$					

* All values from [2010An08], except where noted.

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