



Fig. 1: Known experimental values for heavy particle emission of the odd-Z T<sub>z</sub> = +13 nuclei.

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**Table 1**

Observed and predicted  $\beta$ -delayed particle emission from the odd-Z,  $T_z = +13$  nuclei. Unless otherwise stated, all Q-values are taken from [2021Wa16] or deduced from values therein.

Nuclide	Ex.	$J^\pi$	$T_{1/2}$	$Q_\epsilon$	$Q_{\epsilon p}$	$Q_{\epsilon\alpha}$	$BR_{\beta F}$	Experimental
$^{144}\text{Pr}^*$		$0^-$	17.27(4) m	-0.319(4)	—	—		[1957Pe09]
$^{148}\text{Pm}^*$		$1^-$	5.370(15) d	0.542(6)	-8.711(17)	1.141(6)		[1970Ca09]
$^{152}\text{Eu}^{**}$		$3^-$	13.506(8) d	1.874(1)	-6.791(5)	2.095(2)		[2010Sc08]
$^{156}\text{Tb}$		$3^-$	5.35(10) d	2.444(4)	-5.562(4)	2.247(4)		[1959He44]
$^{160}\text{Ho}$		$5^+$	25.6(3) m	3.290(15)	-4.139(15)	3.728(15)		[1965St08]
$^{164}\text{Tm}$		$1^+$	1.9(1) m <sup>***</sup>	4.034(25)	-2.820(25)	5.339(25)		[1965Ba40, 1963Ra15, 1960Wi17]
$^{168}\text{Lu}$		$6^-$	5.5(1) m	4.510(40)	-1.819(38)	6.445(38)		[1972Ch44]
$^{172}\text{Ta}$		$(3^+)$	36.7(4) ms	5.070(40)	-0.790(28)	7.825(28)		[1972Ch45]
$^{176}\text{Re}$		$(3^+)$	5.2(4) m	5.580(40)	0.057(40)	8.914(37)		[1977Ha24]
$^{180}\text{Ir}$		$(3^+)$	1.5(1) m	6.379(27)	1.318(33)	10.239(35)		[1972Ak03]
$^{184}\text{Au}$		$5^+$	21(1) s	7.014(27)	2.594(33)	11.613(27)		[1977Za03]
$^{184m}\text{Au}$	0.06846(4)	$2^+$	46.4(10) s <sup>@</sup>	7.082(27)	2.662(33)	11.681(27)		[1977Za03, 1992Ro21, 1995Bi01]
$^{188}\text{Tl}$		$(2^-)$	71(2) s	7.860(30)	3.403(37)	12.571(33)		[1984Co17]
$^{192}\text{Bi}$		$(3^+)$	34.6(7) s	9.020(30)	5.459(31)	14.239(31)		[1991Va04]
$^{192m}\text{Bi}$	0.140(30)	$(10^-)$	39.7(4) s <sup>@@</sup>	9.160(42)	5.599(43)	14.379(43)		[1988Hu03, 1991Va04, 2017Au03]
$^{196}\text{At}$		$(3^+)$	371(5) ms	9.560(30)	6.823(31)	16.214(31)	$9(1)\times 10^{-3}\%$	[2016Tr07]
$^{200}\text{Fr}$		$(3^+)$	48(4) ms <sup>@@@</sup>	10.130(30)	7.668(31)	17.177(31)	$> 1.4\%$	[2014Ka23, 2005De01]
$^{204}\text{Ac}$		$(3^+)$	$75^{+23}_{-15}$ ms	10.600(34) <sup>a</sup>	8.496(34) <sup>a</sup>	18.237(34) <sup>a</sup>		[2022Hu12]

\* 100%  $\beta^-$  emitter.

\*\* 72%  $\beta^+$ , 23%  $\beta^-$  emitter.

\*\*\* Weighted average of 2.0(1) m [1965Ba40], 1.8(1) m [1963Ra15] and 2.04(10) m [1960Wi17].

@ Weighted average of 48(1) s [1977Za03], 45(1) s [1992Ro21] and 45.8(18) s [1995Bi01].

@@ Weighted average of 39.6(4) s [1988Hu03], 40.6(9) s [1991Va04].

@@@ Weighted average of 46(4) ms [2014Ka23] and 49(4) ms [2005De01].

<sup>a</sup> Deduced from  $^{204}\text{Ac}$   $\alpha$  energy [2022Hu12] and values from [2021Wa16].

**Table 2**

Particle separation, Q-values, and measured values for direct particle emission of the odd-Z,  $T_z = +13$  nuclei. Unless otherwise stated, all S and Q-values are taken from [2021Wa16] or deduced from values therein.

Nuclide	$S_p$	$S_{2p}$	$Q_\alpha$	$BR_\alpha$	Experimental
$^{144}\text{Pr}$	6.433(3)	15.305(7)	1.137(3)		
$^{148}\text{Pm}$	6.008(6)	14.770(35)	1.460(6)		
$^{152}\text{Eu}$	5.601(1)	13.869(20)	1.552(6)		
$^{156}\text{Tb}$	5.310(4)	12.931(4)	0.373(4)		
$^{160}\text{Ho}$	4.504(15)	11.489(15)	1.284(15)		
$^{164}\text{Tm}$	4.031(25)	10.446(25)	2.049(29)		
$^{168}\text{Lu}$	3.772(38)	9.764(40)	2.411(45)		
$^{172}\text{Ta}$	3.188(40)	8.602(33)	3.318(47)		
$^{176}\text{Re}$	2.719(40)	7.900(40)	3.842(40)		
$^{180}\text{Ir}$	2.246(27)	6.902(35)	4.660(35)		
$^{184}\text{Au}$	1.834(26)	5.845(31)	5.193(5)*		
$^{184m}\text{Au}$	1.766(26)	5.777(31)	5.305(5)	0.013(3)%	[1995Bi01, 1995BiZZ, 1993BiZY, 1992BiZZ, 1970Ha18, 1970HaZT]
$^{188}\text{Tl}$	1.507(33)	5.199(37)	5.557(37)		
$^{192}\text{Bi}$	0.532(31)	3.746(31)	6.377(4)	12(5)%	[1991Va04, 2016Tr07, 2013Ny01, 1988Hu03, 1985HuZY, 1974Le02, 1972Ga27, 1970Ta14]
$^{192m}\text{Bi}$	0.393(43)	3.606(43)	6.517(30)	10(3)%	[1991Va04, 1988Hu03, 2016Tr07]
$^{196}\text{At}$	0.085(31)	2.468(31)	7.196(3)	97.5(3)%	[2016Tr07, 2022Hu12, 2019Gh11, 2014Ka23, 2013Ny01, 2005De01, 2004DeZV, 1997Pu01, 1996En01, 1995Mo14, 1967Tr04, 1967Tr06]
$^{200}\text{Fr}$	-0.404(31)	1.736(31)	7.622(4)	$> 97.5\%$	[2014Ka23, 2022Hu12, 2013Uu01, 2005De01, 2004DeZV, 1996En01, 1996MoZV, 1995LeZY, 1995Mo14, 1995NoZW]
$^{204}\text{Ac}$	-0.771(35)***	1.019(34)***	8.107(15)***	$\approx 100\%^{**}$	[2022Hu12]

\* Deduced from  $\alpha$  energy, 5.234(5) in [2021Wa16].

\*\* Based on short half-life.

\*\*\* Deduced from  $^{204}\text{Ac}$   $\alpha$  energy [2022Hu12] and values from [2021Wa16].

**Table 3**direct  $\alpha$  emission from  $^{184m}\text{Au}^*$ ,  $J_f^\pi = 2^+$ ,  $\text{Ex} = 68.46(4)$  keV\*\*,  $T_{1/2} = 46.4(10)$  s\*\*\*,  $BR_\alpha = 0.013(3)\%$ .

$E_\alpha$ (c.m.)	$E_\alpha$ (lab)	$I_\alpha$ (rel)	$I_\alpha$ (abs)	$J_f^\pi$	$E_{\text{daughter}}(^{180}\text{Ir})$	coincident $\gamma$ -rays	$R_0$ (fm) <sup>@</sup>	HF
5.051(5)	4.980(5)	23(1)%	$1.4(3) \times 10^{-3}\%$		0.212	0.0897, 0.1304, 0.1717, 0.1838, 0.1979, 0.2124	1.527(18)	$4.7_{-1.8}^{+2.7}$
5.096(5)	5.024(5)	22(1)%	$1.3(3) \times 10^{-3}\%$		0.167	0.0502, 0.1426	1.527(18)	$9_{-3}^{+5}$
5.137(15)	5.065(15)	14(1)%	$9(2) \times 10^{-4}\%$		0.114	0.1135	1.527(18)	$26_{-10}^{+16}$
5.182(5)	5.109(5)	100(1)%	$6.1(14) \times 10^{-3}\%$		0.0804	0.0553, 0.0804	1.527(18)	$5.5_{-2.1}^{+3.1}$
5.261(5)	5.187(5)	55(1)%	$3.3(8) \times 10^{-3}\%$	(3 <sup>+</sup> )	0.0	—	1.527(18)	$27_{-19}^{+15}$

\* All values from [1995Bi01], except where noted.

\*\* [2005Sa40].

\*\*\* Weighted average of 48(1) s [1977Za03], 45(1) s [1992Ro21] and 45.8(18) s [1995Bi01].

@ Interpolated between 1.5539(68) fm  $^{182}\text{Pt}$  and 1.500(17)  $^{186}\text{Hg}$ .**Table 4**direct  $\alpha$  emission from  $^{192}\text{Bi}^*$ ,  $J_f^\pi = (3^+)$ ,  $T_{1/2} = 34.6(7)$  s,  $BR_\alpha = 12(5)\%$ .

$E_\alpha$ (c.m.)	$E_\alpha$ (lab)	$I_\alpha$ (rel)	$I_\alpha$ (abs)	$J_f^\pi$	$E_{\text{daughter}}(^{188}\text{Tl})$	coincident $\gamma$ -rays	$R_0$ (fm)**	HF
6.189(5)	6.060(5)	100%	11.6(5)%	(3 <sup>+</sup> )	0.1846	0.1846	1.608(14)	$11_{-5}^{+9}$
6.378(5)	6.245(5)	3.1(6)%	0.36(17)%	(2 <sup>-</sup> )	0.0	—	1.608(14)	$2.1_{-9}^{+20} \times 10^3$

\* All values from [1991Va04], except where noted.

\*\* Interpolated between 1.4923(55) fm  $^{190}\text{Pb}$  and 1.724(13)  $^{194}\text{Po}$ .**Table 5**direct  $\alpha$  emission from  $^{192m}\text{Bi}^*$ ,  $J_f^\pi = (10^-)$ ,  $\text{Ex} = 140(30)$  keV\*\*,  $T_{1/2} = 39.7(4)$  s\*\*\*,  $BR_\alpha = 120(3)\%$ .

$E_\alpha$ (c.m.)	$E_\alpha$ (lab)	$I_\alpha$ (rel)	$I_\alpha$ (abs)	$J_f^\pi$	$E_{\text{daughter}}(^{188}\text{Tl})$	coincident $\gamma$ -rays	$R_0$ (fm) <sup>@</sup>	HF
6.181(5)	6.052(5)	100%	9(3)%	10 <sup>-</sup>	0.337(30)	0.0336, 0.1031, 0.2688	1.608(14)	$15_{-5}^{+9}$
6.210(10)	6.081(10)	7.2(7)%	0.65(21)%	9 <sup>-</sup>	0.304(30)	0.1031, 0.2688	1.608(14)	$280_{-100}^{+160}$
6.386(5)	6.253(5)	0.6(2)%	0.05(2)%	6 <sup>+</sup>	0.138(30)	0.1031	1.608(14)	$1.8_{-0.7}^{+1.9} \times 10^4$
6.483(5)	6.348(5)	2.5(2)%	0.23(7)%	7 <sup>+</sup>	0.035(30)	—	1.608(14)	$1.0_{-0.4}^{+0.6} \times 10^4$

\* All values from [1991Va04], except where noted.

\*\* [2017Au03].

\*\*\* Weighted average of 39.6(4) s [1988Hu03], 40.6(9) s [1991Va04].

@ Interpolated between 1.4923(55) fm  $^{190}\text{Pb}$  and 1.724(13) fm  $^{194}\text{Po}$ .**Table 6**direct  $\alpha$  emission from  $^{196}\text{At}^*$ ,  $J_f^\pi = (3^+)$ ,  $T_{1/2} = 371(5)$  ms,  $BR_\alpha = 97.5(3)\%$ .

$E_\alpha$ (c.m.)	$E_\alpha$ (lab)	$I_\alpha$ (rel)	$I_\alpha$ (abs)	$J_f^\pi$	$E_{\text{daughter}}(^{192}\text{Bi})$	coincident $\gamma$ -rays	$R_0$ (fm)**	HF
6.782(8)	6.644(8)	0.14(3)%	0.14(3)%		0.409(8)	0.200, 0.221	1.743(13)	$5.5_{-1.7}^{+2.3} \times 10^3$
6.887(5)	6.746(5)	1.84(6)%	1.79(6)%		0.316	0.116, 0.200, 0.316	1.743(13)	$940_{-5210}^{+270}$
6.997(6)	6.854(6)	0.27(3)%	0.26(3)%		0.200	0.200	1.743(13)	$1.7_{-0.4}^{+0.5} \times 10^4$
7.200(5)	7.053(5)	100.0(1)%	97.5(3)%	(3 <sup>+</sup> )	0.0	—	1.743(13)	$220_{-50}^{+60}$

\* All values from [2016Tr07].

\*\* Interpolated between 1.724(13) fm  $^{194}\text{Po}$  and 1.7622(23) fm  $^{198}\text{Rn}$ .**Table 7**direct  $\alpha$  emission from  $^{200}\text{Fr}^*$ ,  $J_f^\pi = (3^+)$ ,  $T_{1/2} = 48(4)$  ms\*\*,  $BR_\alpha = \approx 100\%$ .

$E_\alpha$ (c.m.)	$E_\alpha$ (lab)	$I_\alpha$ (abs)	$J_f^\pi$	$E_{\text{daughter}}(^{196}\text{At})$	coincident $\gamma$ -rays	$R_0$ (fm)***	HF
7.622(5)	7.470(5)	$\approx 100\%$	(3 <sup>+</sup> )	0.0	—	1.778(23)	$250_{-90}^{+140}$

\* All values from [2014Ka23], except where noted.

\*\* Weighted average of 46(4) ms [2014Ka23] and 49(4) ms [2005De01].

\*\*\* Interpolated between 1.7622(23) fm  $^{198}\text{Rn}$  and 1.794(23) fm  $^{202}\text{Ra}$ .

**Table 8**direct  $\alpha$  emission from  $^{204}\text{Ac}^*$ ,  $T_{1/2} = 75_{-15}^{+23}$  ms,  $BR_{\alpha} = >97.5\%$ .

$E_{\alpha}$ (c.m.)	$E_{\alpha}$ (lab)	$I_{\alpha}$ (abs)	$E_{\text{daughter}}(^{200}\text{Fr})$	coincident $\gamma$ -rays	$R_0$ (fm)	HF
8107(15)	7.948(15)	$\approx 100\%$	0.0	—		

\* All values from [2014Ka23].

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