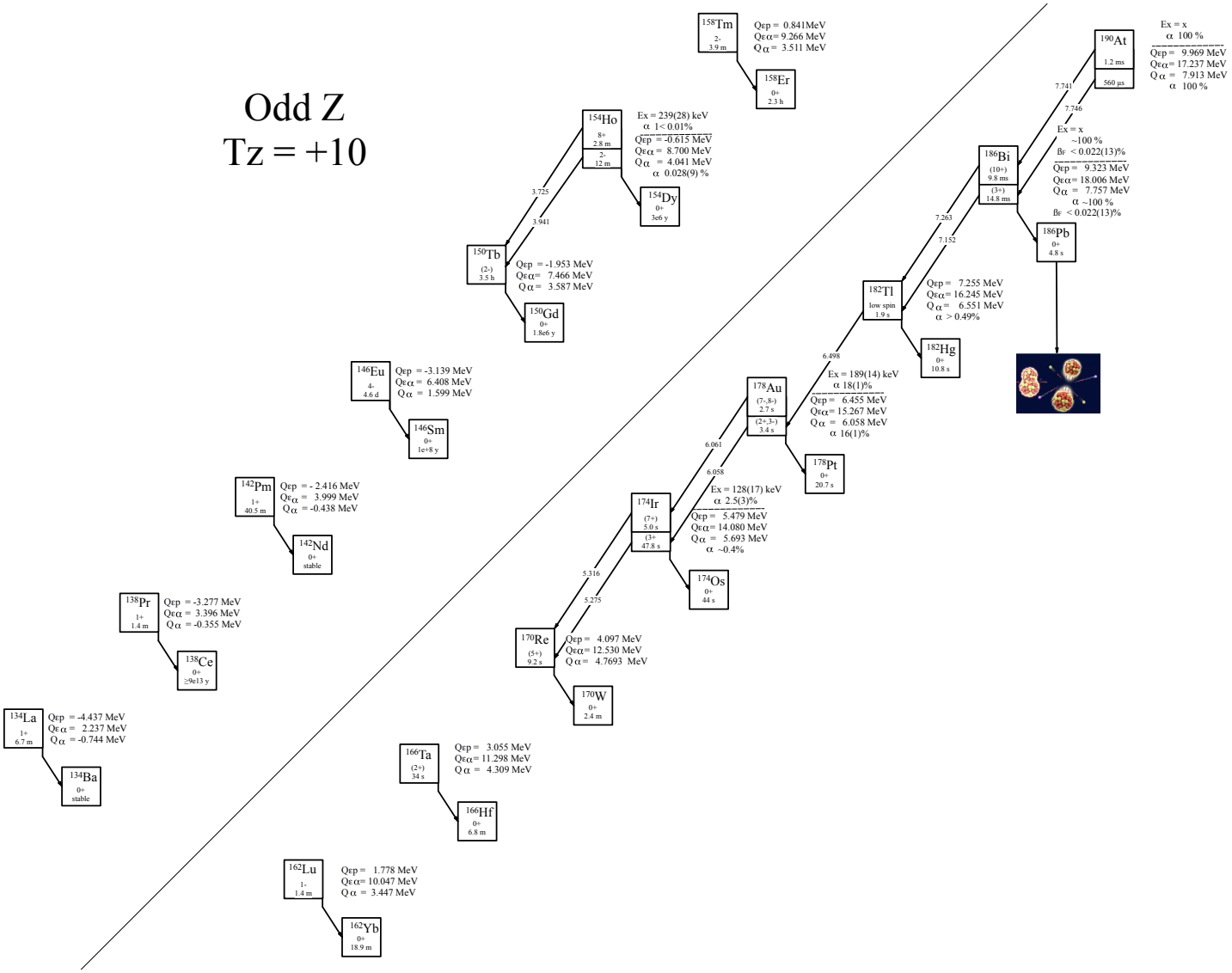


**Fig. 1**: Known experimental values for heavy particle emission of the odd-Z $T_z$= +10 nuclei.

Last updated 7/26/2023

**Table 1**
Observed and predicted $\beta$-delayed particle emission from the odd-$Z$, $T_z = +10$ nuclei. Unless otherwise stated, all Q-values are taken from [2021Wa16] or deduced from values therein. $J^\pi$ values for $^{134}$La, $^{138}$Pr, $^{142}$Pm, $^{146}$Eu, $^{150}$Tb, $^{154}$Ho, $^{158}$Tm, $^{162}$Lu, $^{166}$Ta, $^{170}$Re are taken from ENSDF.

| Nuclide | Ex | $J^\pi$ | $T_{1/2}$ | Q$_\varepsilon$ | $Q_{\varepsilon p}$ | $Q_{\varepsilon\alpha}$ | BR$_F$ | Experimental |
|---|---|---|---|---|---|---|---|---|
| $^{134}$La | | $1^+$ | 6.67(2) m | 3.731(20) | -4.437(20) | 2.237(20) | | [**1968Bi02**] |
| $^{138}$Pr | | $1^+$ | 1.44(8) m | 4.437(10) | -3.277(10) | 3.396(10) | | [**1971Ju01**] |
| $^{142}$Pm | | $1^+$ | 40.5(5) m | 4.809(24) | -2.416(24) | 3.999(24) | | [**1970Ar17**] |
| $^{146}$Eu | | $4^-$ | 4.62(4) d* | 3.879(6) | -3.139(6) | 6.408(6) | | [**1970Ch09, 1964Ta11**] |
| $^{150}$Tb | | $(2^-)$ | 3.48(16) h | 4.658(8) | -1.953(8) | 7.466(8) | | [**1973Vy01**] |
| $^{154}$Ho | | $2^-$ | 11.75(20 m | 5.755(10) | -0.615(9) | 8.700(10) | | [**1993Al03**] |
| $^{154m}$Ho | 0.239(28)** | $8^+$ | 2.80(13) m | 5.994(30) | -0.376(29) | 8.939(30) | | [**1993Al03**] |
| $^{158}$Tm | | $2^-$ | 3.94(6) m | 6.600(30) | 0.841(34) | 9.266(26) | | [**1993Al03**] |
| $^{162}$Lu | | $1^-$ | 1.37(2) m | 6.990(80) | 1.778(80) | 10.047(79) | | [**1983Ge08**] |
| $^{166}$Ta | | $(2)^+$ | 34.4(5) s | 7.760(40) | 3.055(39) | 11.298(32) | | [**1982Li17**] |
| $^{170}$Re | | $(5^+)$ | 9.2(2) s | 8.387(17) | 4.097(30) | 12.530(30) | | [**1992Me10**] |
| $^{174}$Ir | | $(3^+)$ | 7.8(6) s | 9.209(15) | 5.479(30) | 14.080(17) | | [**1992Bo21**] |
| $^{174m}$Ir | 0.129(17) | $(7^+)$ | 5.0(2) s*** | 9.338(23) | 5.608(34) | 14.209(24) | | [**2020Cu04, 1992Bo21, 1992Si16**] |
| $^{178}$Au | | $(2^+, 3^-)$ | 3.4(5) s | 9.694(14) | 6.455(22) | 15.267(14) | | [**2020Cu04**] |
| $^{178m}$Au | 0.189(14) | $(7^+, 8^-)$ | 2.7(5) s | 9.883(20) | 6.644(26) | 15.456(20) | | [**2020Cu04**] |
| $^{182}$Tl$^{@}$ | | low spin | 1.9(1) s | 10.250(15) | 7.255(23) | 16.245(16) | | [**2016Va01**] |
| $^{186}$Bi$^{@@}$ | | $(3^+)$ | 14.8(8) ms | 11.535(20) | 9.323(27) | 18.006(20) | 0.022(13)%$^{@@@}$ | [**2013La02, 2003An27**] |
| $^{186m}$Bi$^{@@}$ | x | $(10^+)$ | 9.8(4) ms | 11.535(20)+x | 9.323(27)+x | 18.006(20)+x | 0.022(13)%$^{@@@}$ | [**2013La02, 2003An27**] |
| $^{190}$At$^{@}$ | | low spin | $0.56^{+2.69}_{-0.16}$ms | 11.756(24)$^a$ | 9.969(29)$^a$ | 17.237(29)$^a$ | | [**2023AnXX, 2023Ko10**] |
| $^{190m}$At | x | high spin | $1.2^{+1.3}_{-0.4}$ms$^b$ | 11.756(24)+x$^a$ | 9.969(29)+x$^a$ | 17.237(29)+x$^a$ | | [**2023AnXX, 2023Ko10**] |

* Weighted average of 4.65(4) d [1970Ch09] and 4.59(4) d [1964Ta11].
** Based on $\alpha$ energies and the energy of the isomeric state in $^{150}$Tb.
*** Weighted average of 5.0(4) s [1992Bo21], 4.9(3) s, 5.5(6) s [1992Si16].
$^{@}$ May not be the ground state.
$^{@@}$ The ordering of these states is unknown.
$^{@@@}$ Value is for a combination of the two isomers.
$^a$ Deduced from mass excess of 7.193(20) for $^{190}$At (deduced from the $\alpha$ energy and the mass of the daughter $^{186}$Bi), and the mass excess for the daughter taken from [2021Wa16].
$^b$ Weighted average of $2.67^{+3.65}_{-0.98}$ms [2023AnXX] and $1.0^{+1.4}_{-0.4}$ms [2023Ko10].

**Table 2**
Particle separation, Q-values, and measured values for direct particle emission of the odd-$Z$, $T_z$ = +10 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 |
|---|---|---|---|---|---|
| $^{134}$La | 4.954(20) | 12.644(20) | -0.744(22) | —— | |
| $^{138}$Pr | 4.499(10) | 11.669(54) | -0.335(22) | —— | |
| $^{142}$Pm | 4.239(24) | 11.033(24) | -0.438(26) | —— | |
| $^{146}$Eu | 3.755(6) | 10.279(6) | 1.599(24) | | |
| $^{150}$Tb | 3.268(8) | 9.386(12) | 3.587(5) | | |
| $^{154}$Ho | 2.785(9) | 8.500(41) | 4.041(4) | 0.028(9)% | [**1974Sc19**, 1982To14, 1981ZuZU, 1981ZuZY, 1978AfZZ, 1974PeZS, 1974ToZQ, 1971To01, 1971ToZR, 1970ToZS, 1970ToZY, 1968Go13, 1967Ha34] |
| $^{154m}$Ho | 2.546(29) | 8.261(50) | 4.280(28) | <0.01% | [**1974Sc19**, 1971To01, 1968Go13] |
| $^{158}$Tm | 2.579(37) | 7.743(46) | 3.511(27) | | |
| $^{162}$Lu | 2.286(77) | 7.109(82) | 3.447(79) | | |
| $^{166}$Ta | 1.751(40) | 6.033(40) | 4.309(80) | | |
| $^{170}$Re | 1.275(19) | 5.088(30) | 4.769(30) | | |
| $^{174}$Ir | 0.637(19) | 3.797(37) | 5.693(16) | ≈0.4% | [**1992Sc16**] |
| $^{174m}$Ir | 0.508(25) | 3.668(41) | 5.822(23) | 2.5(3)% | [**1992Si16**, 1992MeZW, 1986Ke03, 1967Si02] |
| $^{178}$Au | 0.222(18) | 2.999(13) | 6.058(5) | 16(1)% | [**2020Cu04**, 2021Gi08, 1996Pa01, 1986Ke03, 1984Gr14, 1968Si01, 1965Si07] |
| $^{178m}$Au | 0.033(23) | 2.810(19) | 6.247(15) | 18(1)% | [**2020Cu04**, 2021Gi08] |
| $^{182}$Tl* | -0.045(19) | 2.280(13) | 6.551(6) | >0.49% | [**2016Va01**, 1993BoZK, 1992BlZW, 1991BoZZ, 1986Ke03] |
| $^{186}$Bi** | -1.107(23) | 0.840(20) | 7.757(12) | ≈100% | [**2003An27**, 2003AnZZ, 1997Ba21] |
| $^{186m}$Bi** | -1.107(23)-x | 0.840(20)-x | 7.757(12)+x | ≈100% | [**2003An27**, 2003AnZZ, 1997Ba21, 1984ScZQ] |
| $^{190}$At* | -1.326(30) | 0.190(23)[@] | 7.913(10)*** | 100% | [**2023AnXX, 2023Ko10**] |
| $^{190m}$At* | -1.326(30)-x[@] | 0.190(23)-x[@] | 7.913(10)+x*** | 100% | [**2023AnXX, 2023Ko10**] |

* May not be the ground state.
** The ordering of these states is unknown.
*** From $\alpha$ energy to $^{186}$Bi.
[a] Deduced from mass excess of 7.193(20) for $^{190}$At (deduced from the $\alpha$ energy and the mass of the daughter $^{186}$Bi), and the mass excess for the daughter taken from [2021Wa16].

**Table 3**
direct $\alpha$ emission from $^{154}$Ho*, $J^\pi = 2^-$, $T_{1/2}$ = 11.75(20 m**, $BR_\alpha$ = 0.028(9)%.

| $E_\alpha$(c.m.) | $E_\alpha$(lab) | $I_\alpha$(abs) | $J_f^\pi$ | $E_{daughter}$($^{150}$Tb) | coincident $\gamma$-rays | $R_0$ (fm) | HF |
|---|---|---|---|---|---|---|---|
| 4.046(5) | 3.941(5)*** | 0.028(9)% | $(2^-)$ | 0.0 | —— | 1.560(26)[@] | $9^{+7}_{-4}$ |

* All values from [1974Sc19], except where noted.
** [1993Al03].
*** 3.937 MeV in [1974Sc19], adjusted to 3.941 meV in [1991Ry01].
[@] Interpolated between 1.5796(54) fm $^{152}$Dy and 1.541(26) fm $^{156}$Er.

**Table 4**
direct $\alpha$ emission from $^{154m}$Ho*, Ex = 239(28) keV, $J^\pi = 8^+$, $T_{1/2}$ = 2.80(13) m**, $BR_\alpha$ = <0.01%.

| $E_\alpha$(c.m.) | $E_\alpha$(lab) | $I_\alpha$(abs) | $J_f^\pi$ | $E_{daughter}$($^{150}$Tb) | coincident $\gamma$-rays | $R_0$ (fm) | HF |
|---|---|---|---|---|---|---|---|
| 3.824(5) | 3.725(5)*** | <0.01% | | 0.461(27)[@] | | 1.560(26)[@@] | >0.18 |

* All values from [1974Sc19], except where noted.
** [1993Al03].
*** 3.721 MeV in [1974Sc19], adjusted to 3725 meV in [1991Ry01].
[@] [2013Ba31].
[@@] Interpolated between 1.5796(54) fm $^{152}$Dy and 1.541(26) fm $^{156}$Er.

**Table 5**
direct $\alpha$ emission from $^{174}$Ir*, $J^\pi = (3^+)$, $T_{1/2}$ = 7.8(6) s**, $BR_\alpha$ = ≈0.4%.

| $E_\alpha$(c.m.) | $E_\alpha$(lab) | $I_\alpha$(abs) | $J_f^\pi$ | $E_{daughter}$($^{170}$Re) | coincident $\gamma$-rays | $R_0$ (fm)$^{@}$ | HF |
|---|---|---|---|---|---|---|---|
| 5.399(10) | 5.275(10) | ≈0.4% | $(3^+)$ | 0.289*** | 0.224, 0.193, 0.031 | 1.571(14)*** | ≈ 2.7$^{@@}$ |

* All values from [1992Sc16], except where noted.
** [1992Bo21].
*** Reported as decaying to a 224.7(3) keV state, which then cascades to the ground state in [1992Sc16]. However this would imply an isomer energy of 193(12) keV in contrast to the measured value of 129(17) keV [2020Cu04]. It is suggested that the $\alpha$-decay is to a state 224.7-keV above an isomer in $^{170}$Re with an energy of 64(20) keV [2020Cu04].
$^{@}$ Interpolated between 1.583(13) fm $^{172}$Os and 1.5597(42) fm $^{176}$Pt.
$^{@@}$ Calculated assuming the isomer decays to the 370-keV state in $^{150}$Tb, (which then $\gamma$-cascades to the ground state), giving a $Q_\alpha$ = 5.688(23) MeV.

**Table 6**
direct $\alpha$ emission from $^{174m}$Ir*, Ex = 193(12) keV, $J^\pi = (7^+)$, $T_{1/2}$ = 5.0(2) s **, $BR_\alpha$ = 2.5(3)%.

| $E_\alpha$(c.m.) | $E_\alpha$(lab) | $I_\alpha$(rel) | $I_\alpha$(abs) | $J_f^\pi$ | $E_{daughter}$($^{170}$Re)*** | coincident $\gamma$-rays | $R_0$ (fm)$^{@}$ | HF |
|---|---|---|---|---|---|---|---|---|
| 5.441(10) | 5.316(10) | 100% | 2.2(3)% | | 0.3701(6)? | 0.210, 0.190, 0.159, 0.020 | 1.571(14)$^{@}$ | $0.52^{+0.21}_{-0.16}$ |
| 5.607(6) | 5.478(6)$^{@@}$ | ≈13% | ≈0.3% | $(7/2^+)$ | 0.2103(2)? | 0.210, 0.190, 0.020 | 1.571(14)$^{@}$ | $21^{+9}_{-7}$ |

* All values from [1992Sc16], except where noted.
** Weighted average of 5.0(4) s [1992Bo21], 4.9(3) s, 5.5(6) s [1992Si16].
*** [2018Ba41].
$^{@}$ Interpolated between 1.583(13) fm $^{172}$Os and 1.5597(42) fm $^{176}$Pt.
$^{@@}$ [1967Si02].

**Table 7**
direct $\alpha$ emission from $^{178}$Au*, $J^\pi = (2^+, 3^-)$, $T_{1/2}$ = 3.4(5) s, $BR_\alpha$ = 16(1)%.

| $E_\alpha$(c.m.) | $E_\alpha$(lab) | $I_\alpha$(rel) | $I_\alpha$(abs) | $J_f^\pi$ | $E_{daughter}$($^{174}$Ir) | coincident $\gamma$-rays | $R_0$ (fm)** | HF |
|---|---|---|---|---|---|---|---|---|
| 5.882(10) | 5.750(10) | 1.05(2)% | 0.15(1)% | | 0.1748(5) | 0.1748(5) | 1.5460(48)** | 41(8) |
| 5.945(10) | 5.811(10) | 2.01(3)% | 0.28(2)% | | 0.157(3) | 0.157(3) | 1.5460(48)** | 39(8) |
| 5.974(10) | 5.840(10) | 12.6(1)% | 1.7(1)% | | 0.0900(3) | 0.0900(3), 0.0828(3) | 1.5460(48)** | 8.0(15) |
| 6.058(5) | 5.922(5) | 100% | 13.8(9)% | $(3^+)$ | 0.0 | —— | 1.5460(48)** | 2.4(5) |

* All values from [2020Cu04].
** Interpolated between 1.5597(42) fm $^{176}$Pt and 1.5324(24) fm $^{180}$Hg.

**Table 8**
direct $\alpha$ emission from $^{178m}$Au*, Ex = 189(14) keV, $J^\pi = (7^+, 8^-)$, $T_{1/2}$ = 2.7(5) s, $BR_\alpha$ = 18(1)%.

| $E_\alpha$(c.m.) | $E_\alpha$(lab) | $I_\alpha$(rel) | $I_\alpha$(abs) | $J_f^\pi$ | $E_{daughter}$($^{174}$Ir) | coincident $\gamma$-rays | $R_0$ (fm)** | HF |
|---|---|---|---|---|---|---|---|---|
| 5.648(7) | 5.521(7) | 1.16(3)% | 0.18(1)% | | 0.601(17) | 0.472(1) | 1.5460(48)** | $0.54^{+0.17}_{-0.15}$ |
| 5.699(7) | 5.571(7) | 0.97(2)% | 0.15(1)% | | 0.550(17) | 0.421.4(10) | 1.5460(48)** | $1.13^{+0.35}_{-0.32}$ |
| 5.973(10) | 5.839(10) | 6.87(7)% | 1.07(6)% | | 0.277(17) | 0.1392(3), 0.0912(3), 0.0568(3) | 1.5460(48)** | 2.8(8) |
| 6.061(7) | 5.925(7) | 100% | 15.5(9)% | | 0.186(17) | 0.0568(3) | 1.5460(48)** | $0.48^{+0.14}_{-0.13}$ |
| 6.114(10) | 5.977(10) | 6.83(14)% | 1.06(6)% | $(7^+)$ | 0.129(17) | | 1.5460(48)** | $12^{+4}_{-3}$ |

* All values from [2020Cu04].
** Interpolated between 1.5597(42) fm $^{176}$Pt and 1.5324(24) fm $^{180}$Hg.

**Table 9**
direct $\alpha$ emission from $^{182}$Tl*, J$^{\pi}$ = low soin, T$_{1/2}$ = 1.9(1) s, $BR_{\alpha}$ = >0.49%.

| $E_{\alpha}$(c.m.) | $E_{\alpha}$(lab) | $I_{\alpha}$(rel) | $I_{\alpha}$(abs) | $J^{\pi}_{f}$ | $E_{daughter}$($^{178}$Au) | coincident $\gamma$-rays | R$_0$ (fm)** | HF |
|---|---|---|---|---|---|---|---|---|
| 6.096(5) | 5.962(5) | 21(3)% | >0.042% | | 0.446 | 0.4461(14), 0.2658(2), 0.2322(3), 0.2067(1), 0.1692(3), 0.1129(1) | 1.518(12) | <27 |
| 6.182(6) | 6.046(6) | 16(3)% | >0.032% | | 0.362 | 0.3615(1), 0.3126(1), 0.2967(3), 0.2478(7), 0.2318(2), 0.1975(8), 0.1827(3), 0.1693(2), 0.1534(2), 0.1317(4), 0.1129(1), 0.1020(5) | 1.518(12) | <80 |
| 6.304(6) | 6.165(6) | 62(10)% | >0.12% | | 0.247 | 0.2472(5), 0.2322(1), 0.1975(2), 0.1823(2), 0.1692(1), 0.1329(4), 0.1187(3), 0.1129(2) | 1.518(12) | <62 |
| 6.503(6) | 6.360(6) | 100% | >0.20% | | 0.046 | | 1.518(12) | <230 |
| 6.550(10) | 6.406(10 | 45(7)% | >0.09% | $(2^+, 3^-)$ | 0.0 | —— | 1.518(12) | <1600 |

* All values from [2016Va01].
** Interpolated between 1.5324(24) fm $^{180}$Hg and 1.504(11) $^{184}$Pb.

**Table 10**
direct $\alpha$ emission from $^{186}$Bi*, J$^{\pi}$ = $(3^+)$, T$_{1/2}$ = 14.8(8) s, $BR_{\alpha}$ ≈100%.

| $E_{\alpha}$(c.m.) | $E_{\alpha}$(lab) | $I_{\alpha}$(rel) | $I_{\alpha}$(abs) | $J^{\pi}_{f}$ | $E_{daughter}$($^{182}$Tl) | coincident $\gamma$-rays |
|---|---|---|---|---|---|---|
| 7.225-7.389 | 7.070-7.230** | | | | | 0.087, 0.098, 0.133, 0.215, 0.238, 0.276, 0.281, 0.371, 0.380, 0.444, 0.520 |
| 7.236(15) | 7.080(15) | 28(14)% | | | 0.520 | 0.520 |
| 7.276(15) | 71.20(15)*** | | | | | 0.133 |
| 7.309 (15) | 7.152(15) | 100% | | | 0.444 | 0.444 |
| 7.385(15) | 7.226 (15)*** | | | | | 0.238 |

* All values from [2003An27].
** Unresolved multiplet.
*** May belong to the other isomer.

**Table 11**
direct $\alpha$ emission from $^{186m}$Bi*, J$^{\pi}$ = $(10^-)$, T$_{1/2}$ = 9.8(4) s, $BR_{\alpha}$ ≈100%.

| $E_{\alpha}$(c.m.) | $E_{\alpha}$(lab) | $I_{\alpha}$(rel) | $I_{\alpha}$(abs) | $J^{\pi}_{f}$ | $E_{daughter}$($^{182}$Tl) | coincident $\gamma$-rays |
|---|---|---|---|---|---|---|
| 7.423(5) | 7.263(5) | 100% | ≈98% | | 0.1085 | 0.1085(5) |
| 7.531(10) | 7.369(10)** | <2% | <2% | | 0.0 | —— |

* All values from [2003An27].
** Tentative assignment.

**Table 12**
direct $\alpha$ emission from $^{190}$At*, J$^{\pi}$ = low spin,T$_{1/2}$ = $0.56^{+2.69}_{-0.16}$ ms, $BR_{\alpha}$ = 100%.

| $E_{\alpha}$(c.m.) | $E_{\alpha}$(lab) | $I_{\alpha}$(abs) | $J^{\pi}_{f}$ | $E_{daughter}$($^{186}$Bi) | coincident $\gamma$-rays | | |
|---|---|---|---|---|---|---|---|
| 7.913(10) | 7.746(10) | 100% | $(3^+)$ | 0.0 | —— | 1.551(15) | $1.0^{+5.0}_{-0.4}$ |

* All values taken from [2023AnXX]. In that paper, the authors present two scenarios. In the first, two $\alpha$ transitions 7.746(10) MeV (25%) and 7.739(10) MeV de-excite the same state, indicating that the $(10^-)$ $^{186m}$Bi isomer has an energy of 7 keV. This however, results in large HF for the two transitions of 15 and 5 respectively. The 2nd scenario is reflected here, combined with data from [2023Ko10], resulting in mostly unhindered transitions from two isomers in $^{190}$At.

**Table 13**
direct $\alpha$ emission from $^{190m}$At, $J^{\pi}$ = high spin, $T_{1/2} = 1.2^{+1.3}_{-0.4}$ ms*, $BR_{\alpha}$ = 100%.

| $E_{\alpha}$(c.m.) | $E_{\alpha}$(lab) | $I_{\alpha}$(abs) | $J^{\pi}_{f}$ | $E_{daughter}$($^{186}$Bi) | coincident $\gamma$-rays | | |
|---|---|---|---|---|---|---|---|
| 7.907(9) | 7.741(9)** | 100% | $(10^{-})$ | x | | 1.551(15) | $2.1^{+2.4}_{-0.9}$ |

* Weighted average of $2.67^{+3.65}_{-0.98}$ms [2023AnXX] and $1.0^{+1.4}_{-0.4}$ms [2023Ko10].
** Weighted average of 7.739(10) MeV [2023AnXX] and 7.750(20) MeV [2023Ko10].

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