Table of Alpha-Disintegration Energies of the Heavy Elements*†

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THIS compilation is a listing of total alpha-decay energies with some supporting information pertinent to the means by which the energies were derived. The only references given will be those relevant to the energy determinations. The decay energies are the Q values for the alpha transitions and can be transformed into mass differences by including the atomic mass of He^4.

The major uncertainty in many of the adopted Q values lies in the sphere of inadequate information on decay schemes. For example, there are relatively few cases in which measurements have been made showing that the highest-energy alpha groups are not in coincidence with gamma rays. In principle, therefore, it is possible in many cases that the alpha group used to define the decay energy does not represent the ground-state transition and that the true decay energy is greater than expressed.

There is now sufficient knowledge of the nature of alpha spectra to conclude that this uncertainty is not uniform among all of the nuclear species and probably serious for few, if any. In the first place, it is reasonably certain that for all *even-even* nuclei the most intense alpha group does indeed go to the ground state. The presence of other alpha groups of lower energy does not seriously distort the energy obtained for the main group even when the measuring instrument does not have sufficient resolution to separate the components of the complex spectrum.

For nuclei with odd nucleons, the principal alpha group will, more often than not, populate an excited state. It is in these cases that there is greatest uncertainty. However, because of the apparent close energy level spacing among nuclei of these types in the heavy element region, a state which can be heavily populated is generally found not far from the ground state. As implied here, there are selection processes which guide the population of various states, but in alpha decay the penalty for low energy is very severe and an abundant alpha group of several hundred kilovolts lower energy than the total decay energy is not to be expected. There are a few exceptions to this rule, such as Cm^{243} in which the principal alpha group is known to be of 277-kev lower energy than the transition to the ground state. Further comments will be made in the following discussion of the several columns of Table I.

We have limited this compilation to alpha energies which have actually been measured and because of this arbitrary condition have not entered some which can be calculated with substantial precision. Omitted, for example, is RaE, whose alpha-decay energy can be calculated by closing a decay cycle, and the actual alpha-decay process has been detected through the growth of the decay product. There are a number of other cases in which a fairly accurate calculation of this type can be made and a large number of cases for which estimations can be made based partly on the systematic behavior of alpha energies.

It should also be noted that the so-called "long-range alpha groups" of RaC′ and ThC′ are not used to determine decay energies, since these represent transitions from excited states of the respective nuclei.

COLUMN 1

This column indicates the alpha emitter and its product as well as the half-life which is given solely for purposes of further identification. These are the measured half-lives and not the partial alpha-decay half-lives for those cases in which there is more than one mode of decay. Since this table is not a compilation of general decay properties, no references are given for the half-lives cited.

COLUMNS 2 AND 3

In a large fraction of the cases the "highest-energy group" of column 3 is either known to be that of the ground-state transition or is assumed to be so in the absence of information regarding a complex spectrum for the purpose of calculating the decay energy of Column 2. The Q values, unless otherwise stated under "comments," were calculated by adding to the energy of Column 2 the recoil energy, $4E/(A\text{-}4)$, where E is the alpha-particle energy and A is the mass number of the emitter.

COLUMN 4

The absence of a notation under "intensity" means that no high-resolution instrument has been used to

* Prepared at the suggestion of the Subcommittee on Nuclear Constants of the Committee on Nuclear Science of the National Research Council as part of a program on the compilation of experimental data relating to atomic masses. Subcommittee members: T. P. Kohman, chairman, W. Whaling, vice-chairman, H. E. Duckworth, L. G. Elliott, G. Friedlander, A. O. C. Nier, I. Perlman, W. H. Sullivan, and K. Way.

† Reprints of this article combined with others on nuclear constants published at the suggestion of the Subcommittee on Nuclear Science of the National Research Council may be obtained from the Publications Office, National Research Council, 2101 Constitution Avenue, Washington 25, D. C.

TABLE I.

Reaction	Adopted Q (Mev)	Highest energy group measured	Intensity (%)	Method	Energy ref.	Identification	Comments
$Bi^{198} \rightarrow Tl^{194}$ 7 m	5.95	5.83		ion ch	1	B	ins evid
$Bi^{199} \rightarrow Tl^{195}$ ~25 m	5.58	5.47		ion ch range mica	1	B	ins evid
$Bi^{201} \rightarrow Tl^{197}$ 62 m	5.25	5.15		ion ch	1	B	ins evid
$Bi^{203} \rightarrow Tl^{199}$ 12 h	4.95	4.85		range emuls	2	B	ins evid
$Bi^{209} \rightarrow Tl^{205}$	3.1	3.15		range emuls	3		ins evid
$\sim 10^{17}$ y		2.9		range emuls	4		
$Bi^{210} \rightarrow Tl^{206}$ $\sim 10^{6}$ y	5.03	4.93		ion ch	5	A	
$Bi^{211} \rightarrow Tl^{207}$ 2.16 m	6.747	6.618 6.621	82.6	spect spect	6 7	A	
$Bi^{212} \rightarrow Tl^{208}$ 60.5 m	6.203	6.082 6.087 6.090 6.088	27.2	spect spect spect spect	8, 9 10 11 12	A	
$Bi^{213} \rightarrow Tl^{209}$ 47 m	5.97	5.86		ion ch	13	A	ins evid
$Bi^{214} \rightarrow Tl^{210}$ 19.7 m	5.610	5.505	45	spect	8	A	ins evid
$Po^{200} \rightarrow Pb^{196}$ 11 m	5.96	5.84		ion ch	14	B	e-e
$Po^{201} \rightarrow Pb^{197}$ 18 m	5.82	5.70		ion ch	14	B	ins evid
$Po^{202} \rightarrow Pb^{198}$ 52 m	5.70	5.59		ion ch	15	B	e-e
$Po^{204} \rightarrow Pb^{200}$ 3.8 h	5.48	5.37		ion ch	15	B	e-e
$Po^{205} \rightarrow Pb^{201}$ 1.5 h	5.3	5.2		ion ch	14	B	ins evid
$Po^{206} \rightarrow Pb^{202}$ 9 d	5.321	5.218	96	spect	16	B	e-e
$Po^{207} \rightarrow Pb^{203}$ 5.7 h	5.20	5.10		ion ch	14	B	ins evid
$Po^{208} \rightarrow Pb^{204}$ 2.93 y	5.208	5.108 5.109	 ~100	spect spect	17 16	A	
$Po^{209} \rightarrow Pb^{205}$ ~100 y	4.972	4.877	~100	spect	17	A	
$Po^{210} \rightarrow Pb^{206}$ 138.4 d	5.402	5.299 5.304 5.298	~100	spect spect spect	8, 10, 18 11 19	A	
$Po^{211} \rightarrow Pb^{207}$ 0.52 s	7.58	7.434 7.442	99	range air spect	8 20	A	It is not certain which Po^{211} group represents the ground state transition
$Po^{211} \rightarrow Pb^{207}$ 25 s		7.14		ion ch	23	D	
$Po^{212} \rightarrow Pb^{208}$ 3.04×10^{-7} s	8.949	8.776 8.780 8.786	~100	spect spect spect	8, 9 10 11	A	
$Po^{213} \rightarrow Pb^{209}$ 4.2×10^{-6} s	8.496	8.336		ion ch	24	A	ins evid
$Po^{214} \rightarrow Pb^{210}$ 1.637×10^{-4} s	7.827	7.680 7.683	~100	spect spect	9 19	A	
$Po^{215} \rightarrow Pb^{211}$ 1.83×10^{-3} s	7.52	7.365 7.383	~100	range air spect	8 25	A	
$Po^{216} \rightarrow Pb^{212}$ 0.158 s	6.903	6.774 6.775	~100	spect spect	9 26	A	
$Po^{217} \rightarrow Pb^{213}$ short	6.66	6.54		ion ch	27	C	ins evid
$Po^{218} \rightarrow Pb^{214}$ 3.05 m	6.110	5.998 5.996	~100	spect spect	9 28	A	

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TABLE I.—*Continued.*

Reaction	Adopted Q (Mev)	Highest energy group measured	Intensity (%)	Method	Energy ref.	Identification	Comments
$At^{203} \rightarrow Bi^{199}$ 7 m	6.22	6.10		ion ch	29	D	ins evid
$At^{205} \rightarrow Bi^{201}$ 25 m	6.02	5.90		ion ch	29	B	ins evid
$At^{207} \rightarrow Bi^{203}$ 2.0 h	5.86	5.75		ion ch	29	B	ins evid
$At^{208} \rightarrow Bi^{204}$ 1.7 h	5.76	5.65		ion ch	30	A	ins evid
$At^{209} \rightarrow Bi^{205}$ 5.5 h	5.76	5.65		ion ch	29	B	ins evid
$At^{210} \rightarrow Bi^{206}$ 8.3 h	5.626	5.519	32	spect	31	A	ins evid
$At^{211} \rightarrow Bi^{207}$ 7.5 h	5.975	5.862	~100	spect	31	A	
$At^{213} \rightarrow Bi^{209}$ short	9.4	9.2		range emuls	32	E	ins evid
$At^{214} \rightarrow Bi^{210}$ short	8.95	8.78		ion ch	33	B	ins evid
$At^{215} \rightarrow Bi^{211}$ $\sim 10^{-4}$ s	8.15	8.00		ion ch	33	A	ins evid
$At^{216} \rightarrow Bi^{212}$ $\sim 3 \times 10^{-4}$ s	7.94	7.79		ion ch	33	A	ins evid
$At^{217} \rightarrow Bi^{213}$ 0.018 s	7.14	7.02 7.00		ion ch ion ch	24 34	A	ins evid
$At^{218} \rightarrow Bi^{214}$ ~2 s	6.75	6.63		ion ch	35	E	ins evid
$At^{219} \rightarrow Bi^{215}$ 0.9 m	6.39	6.27		ion ch	36	A	ins evid
$Em^{204} \rightarrow Po^{200}$ ~3 m	6.4	6.3		ion ch	37	D	e-e
$Em^{206} \rightarrow Po^{202}$ 6.2 m	6.37	6.24 6.25		ion ch ion ch	37 38	B	e-e
$Em^{207} \rightarrow Po^{203}$ 10 m	6.22	6.11 6.09		ion ch ion ch	37 38	B	ins evid
$Em^{208} \rightarrow Po^{204}$ 23 m	6.258	6.138		spect	39	D	e-e
$Em^{209} \rightarrow Po^{205}$ 30 m	6.14	6.02		ion ch	40	B	ins evid
$Em^{210} \rightarrow Po^{206}$ 2.7 h	6.153	6.036	~100	spect	39	B	
$Em^{211} \rightarrow Po^{207}$ 16 h	5.960	5.847	33	spect	39	A	
$Em^{212} \rightarrow Po^{208}$ 23 m	6.382	6.262	~100	spect	39	A	
$Em^{215} \rightarrow Po^{211}$ short	8.8	8.6		ion ch	41	B	ins evid
$Em^{216} \rightarrow Po^{212}$ short	8.16	8.01		ion ch	42	A	e-e
$Em^{217} \rightarrow Po^{213}$ $\sim 10^{-3}$ s	7.89	7.74		ion ch	33	A	ins evid
$Em^{218} \rightarrow Po^{214}$ 0.019 s	7.260	7.127	~100	spect	43	A	
$Em^{219} \rightarrow Po^{215}$ 3.92 s	6.94	6.824 6.807	69	spect	44 45	A	ins evid
$Em^{220} \rightarrow Po^{216}$ 54.5 s	6.398	6.282 6.278	~100	spect spect	9 28	A	
$Em^{222} \rightarrow Po^{218}$ 3.825 d	5.587	5.486 5.482	~100	spect spect	9 28	A	
$Fr^{212} \rightarrow At^{208}$ 19.3 m	6.532	6.409	37	spect	46	A	

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TABLE I.—*Continued.*

Reaction	Adopted Q (Mev)	Highest energy group measured	Intensity (%)	Method	Energy ref.	Identification	Comments
$Fr^{217} \rightarrow At^{213}$ short	8.5	8.3		range emuls	32	E	ins evid
$Fr^{218} \rightarrow At^{214}$ short	8.00	7.85		ion ch	33	B	ins evid
$Fr^{219} \rightarrow At^{215}$ 0.02 s	7.44	7.30		ion ch	33	A	ins evid
$Fr^{220} \rightarrow At^{216}$ 27.5 s	6.81	6.69		ion ch	33	A	ins evid
$Fr^{221} \rightarrow At^{217}$ 4.8 m	6.42	6.30	75	ion ch	24, 47	A	ins evid
$Ra^{213} \rightarrow Em^{209}$ 2.7 m	7.03	6.90		ion ch	48	B	ins evid
$Ra^{219} \rightarrow Em^{215}$ short	8.1	8.0		ion ch	41	B	ins evid
$Ra^{220} \rightarrow Em^{216}$ short	7.57	7.43		ion ch	42	A	e-e
$Ra^{221} \rightarrow Em^{217}$ 30 s	6.83	6.71		ion ch	33	A	ins evid
$Ra^{222} \rightarrow Em^{218}$ 38 s	6.674	6.554	~100	spect	43	A	
$Ra^{223} \rightarrow Em^{219}$ 11.2 d	5.967	5.860 5.730	weak 9	spect spect	16 16	A	ins evid
$Ra^{224} \rightarrow Em^{220}$ 3.64 d	5.784	5.681 5.679	95	spect spect	9, 26 28	A	
$Ra^{226} \rightarrow Em^{222}$ 1622 y	4.863	4.777 4.778	94.3	spect spect	28 18	A	
$Ac^{221} \rightarrow Fr^{217}$ short	7.7	7.6		range emuls	32	E	ins evid
$Ac^{222} \rightarrow Fr^{218}$ 5.5 s	7.09	6.96		ion ch	33	B	ins evid
$Ac^{223} \rightarrow Fr^{219}$ 2.2 m	6.76	6.64		ion ch	33	A	ins evid
$Ac^{224} \rightarrow Fr^{220}$ 2.9 h	6.28	6.17		ion ch	33	A	ins evid
$Ac^{225} \rightarrow Fr^{221}$ 10.0 d	5.90	5.80		ion ch	47, 24	A	ins evid
$Ac^{227} \rightarrow Fr^{223}$ 22.0 y	5.031	4.942		spect	16	A	ins evid
$Th^{223} \rightarrow Ra^{219}$ short	7.69	7.55		ion ch	41	B	ins evid
$Th^{224} \rightarrow Ra^{220}$ short	7.26	7.13		ion ch	42	A	e-e
$Th^{225} \rightarrow Ra^{221}$ 8.0 m	6.69	6.57		ion ch	33	A	ins evid
$Th^{226} \rightarrow Ra^{222}$ 30.9 m	6.450	6.336	77	spect	43	A	
$Th^{227} \rightarrow Ra^{223}$ 18.6 d	6.138	6.030	19	spect	16	A	
$Th^{228} \rightarrow Ra^{224}$ 1.90 y	5.520	5.423 5.421	71	spect spect	49 50	A	
$Th^{229} \rightarrow Ra^{225}$ 7340 y	5.11	5.02	~10	ion ch	47	A	ins evid
$Th^{230} \rightarrow Ra^{226}$ 8.0×10^4 y	4.765	4.682	76.3	spect	51	A	
$Th^{232} \rightarrow Ra^{228}$ 1.39×10^{10} y	4.064	3.994 4.006	76	ion ch range emuls	52 53	A	

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TABLE I.—*Continued.*

Reaction	Adopted Q (Mev)	Highest energy group measured	Intensity (%)	Method	Energy ref.	Ident-ification	Comments
$Pa^{226} \rightarrow Ac^{222}$ 1.8 m	6.93	6.81		ion ch	33	B	ins evid
$Pa^{227} \rightarrow Ac^{223}$ 38.3 m	6.58	6.46		ion ch	33	A	ins evid
$Pa^{228} \rightarrow Ac^{224}$ 22 h	6.20	6.09	75	ion ch	33	A	ins evid
$Pa^{229} \rightarrow Ac^{225}$ 1.5 d	5.79	5.69 5.66		ion ch ion ch	54 55	A	ins evid
$Pa^{231} \rightarrow Ac^{227}$ 3.43×10^4 y	5.131	5.042	11	spect	56	A	
$U^{227} \rightarrow Th^{223}$ 1.3 m	6.9	6.8		ion ch	41	B	ins evid
$U^{228} \rightarrow Th^{224}$ 9.3 m	6.79	6.67		ion ch	42	A	e-e
$U^{229} \rightarrow Th^{225}$ 58 m	6.53	6.42		ion ch	33	A	ins evid
$U^{230} \rightarrow Th^{226}$ 20.8 d	5.992	5.888	68	spect	43	A	
$U^{231} \rightarrow Th^{227}$ 4.3 d	5.55	5.45		ion ch	57	A	ins evid
$U^{232} \rightarrow Th^{228}$ 73.6 y	5.411	5.318	68	spect	18	A	
$U^{233} \rightarrow Th^{229}$ 1.62×10^5 y	4.907	4.823	83	ion ch	24	A	
$U^{234} \rightarrow Th^{230}$ 2.48×10^5 y	4.845	4.762 4.763	74	ion ch ion ch	52 58	A	
$U^{235} \rightarrow Th^{231}$ 7.13×10^8 y	4.66	4.58	10	ion ch	59	A	
$U^{236} \rightarrow Th^{232}$ 2.39×10^7 y	4.577	4.499	73	ion ch	60	A	
$U^{238} \rightarrow Th^{234}$ 4.49×10^9 y	4.253	4.182	77	ion ch	52	A	
$Np^{231} \rightarrow Pa^{227}$ ~50 m	6.39	6.28		ion ch	61	A	ins evid
$Np^{233} \rightarrow Pa^{229}$ 35 m	5.63	5.53		ion ch	61	A	ins evid
$Np^{235} \rightarrow Pa^{231}$ 410 d	5.15	5.06		ion ch	62	A	ins evid
$Np^{237} \rightarrow Pa^{233}$ 2.20×10^6 y	4.85	4.77		ion ch	63	A	α-γ coin
$Pu^{232} \rightarrow U^{228}$ 36 m	6.70	6.58		ion ch	64	B	e-e
$Pu^{234} \rightarrow U^{230}$ 9.0 h	6.30	6.19	86	ion ch	64	A	
$Pu^{235} \rightarrow U^{231}$ 26 m	5.95	5.85		ion ch	64	B	ins evid
$Pu^{236} \rightarrow U^{232}$ 2.7 y	5.85	5.75 5.75	80	range air ion ch	65 63	A	
$Pu^{238} \rightarrow U^{234}$ 89.6 y	5.589	5.495	72	spect	66	A	
$Pu^{239} \rightarrow U^{235}$ 24360 y	5.238	5.150 5.147	69	spect spect	67 68	A	ins evid
$Pu^{240} \rightarrow U^{236}$ 6580 y	5.249	5.162	76	spect	67	A	

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TABLE I.—*Continued.*

Reaction	Adopted Q (Mev)	Highest energy group measured	Intensity (%)	Method	Energy ref.	Identification	Comments
$Pu^{241} \rightarrow U^{237}$ 13.0 y	4.976	4.893	75	spect	18	A	α-γ coin
$Pu^{242} \rightarrow U^{238}$ 1×10^6 y	4.980	4.898	80	spect	18	A	e-e
$Am^{237} \rightarrow Np^{233}$ ~1.3 h	6.11	6.01		ion ch	69	B	ins evid
$Am^{239} \rightarrow Np^{235}$ 12 h	5.85	5.75		ion ch	69	B	ins evid
$Am^{241} \rightarrow Np^{237}$ 470 y	5.628	5.535	0.3	spect	70	A	
$Am^{243} \rightarrow Np^{239}$ 7600 y	5.430	5.341	0.3	spect	71	A	
$Cm^{238} \rightarrow Pu^{234}$ 2.5 h	6.61	6.50		ion ch	72	B	e-e
$Cm^{240} \rightarrow Pu^{236}$ 26.8 d	6.36	6.25		ion ch	73	A	e-e
$Cm^{241} \rightarrow Pu^{237}$ 35 d	6.05	5.95		ion ch	74	A	ins evid
$Cm^{242} \rightarrow Pu^{238}$ 162.5 d	6.213	6.110 6.118	73.7	spect ion ch	75 52	A	
$Cm^{243} \rightarrow Pu^{239}$ 35 y	6.151	5.985	6	spect	76	A	α-γ coin
$Cm^{244} \rightarrow Pu^{240}$ 19 y	5.895	5.798	75	spect	76	A	
$Cm^{245} \rightarrow Pu^{241}$ 2×10^4 y	5.43	5.34		ion ch	77	B	ins evid
$Bk^{243} \rightarrow Am^{239}$ 4.5 h	6.83	6.72	30	ion ch	78	A	ins evid
$Bk^{245} \rightarrow Am^{241}$ 4.95 d	6.44	6.33	23	ion ch	79	B	ins evid
$Bk^{249} \rightarrow Am^{245}$ ~1 y	5.5	5.4		ion ch	80, 81	A	ins evid
$Cf^{244} \rightarrow Cm^{240}$ 45 m	7.27	7.15		ion ch	82	B	e-e
$Cf^{246} \rightarrow Cm^{242}$ 35.7 h	6.865	6.753	78	spect	83	A	
$Cf^{248} \rightarrow Cm^{244}$ 250 d	6.36	6.26		ion ch	84	B	e-e
$Cf^{249} \rightarrow Cm^{245}$ 500 y	6.10	6.00	10	ion ch	85	A	ins evid
$Cf^{250} \rightarrow Cm^{246}$ 11 y	6.14	6.05 6.03		ion ch ion ch	85 80	A	e-e
$Cf^{252} \rightarrow Cm^{248}$ 2.1 y	6.23	6.15 6.12		ion ch ion ch	85 80	A	e-e
$99^{247} \rightarrow Bk^{243}$ 7.3 m	7.4	7.3		ion ch	86	D	ins evid
$99^{253} \rightarrow Bk^{249}$ 19.3 d	6.73	6.63 6.61		ion ch ion ch	85 87	A	ins evid
$100^{254} \rightarrow Cf^{250}$ 3.3 h	7.31	7.22 7.17		ion ch ion ch	85 87	A	e-e
$100^{255} \rightarrow Cf^{251}$ 15 h	7.2	7.1		ion ch	85	D	ins evid

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obtain evidence on complex structure. Otherwise the entry indicates the intensity of the group believed to represent the ground-state transition. The designation "$\sim$100" means that careful search has been made for other groups and either none has been found or that the intensities of lower-energy groups are low.

COLUMN 5

This column refers to the method of energy determination.

ion ch	ionization chamber coupled with some form of pulse-height analyzer.
range air (*or* mica)	range determination in air (or mica).
range emuls	range of alpha tracks in a photographic emulsion.
spect	magnetic or electrostatic spectrograph.

It is difficult to assign meaningful limits of error for most of the individual measurements so this has not been attempted. In general, those measurements made with a spectrograph may be in error by as much as 15 kev, but a large number are perhaps accurate to within 5 kev; those made by the ionization chamber method will vary in accuracy from 10 to 75 kev; and range measurements in photographic emulsions are even more difficult to assess.

COLUMN 6

References are given for the energy measurements selected.

COLUMN 7

These letter ratings give the estimated degree of certainty of the isotopic assignments according to the following code: (No designation according to the code was made for Bi^{209} because the mass number is not uncertain, but the extremely low decay rate leaves some doubt that the few tracks observed were not spurious.)

A Element and mass number certain;
B Element certain and mass number probable;
C Element probable and mass number certain or probable;
D Element certain and mass number not well established;
E Element probable and mass number not well established or unknown.

COLUMN 8

The comments in this column for the most part reinforce the decision on the decay energy.

ins evid	Insufficient evidence to know whether or not the alpha energy measured is that of the ground-state transition.
e-e	No direct evidence, but since the nucleus is of the even-even type it can be assumed that the measured energy is that of the ground-state transition.
α-γ coinc	This designation indicates that coincidences have been observed between alpha particles and gamma rays (or conversion electrons) which show some doubt that the highest-energy alpha group is the ground-state transition. Where the evidence is not sufficiently definite to deduce a decay energy based on anything other than the highest-energy alpha group, this is reflected by the values in Columns 2 and 3 differing only by the recoil energy. Where the evidence is sufficiently definite to deduce the decay energy, it will be found that Columns 2 and 3 differ by more than the recoil energy.