Title
TABLE OF ALPHA-DISINTEGRATION ENERGIES OF THE HEAVY ELEMENTS

Authors
Asaro, Frank
Perlrnan, I.

Publication Date
1957-07-01

UNIVERSITY OF CALIFORNIA

Radiation Laboratory

BERKELEY, CALIFORNIA

UNIVERSITY OF CALIFORNIA

Radiation Laboratory
Berkeley, California

Contract No. W-7405-eng-48

TABLE OF ALPHA-DISINTEGRATION ENERGIES OF THE HEAVY ELEMENTS

Frank Asaro and I. Perlman

July, 1957

Printed for the U.S. Atomic Energy Commission

TABLE OF ALPHA-DISINTEGRATION ENERGIES OF THE HEAVY ELEMENTS

Frank Asaro and I. Perlman

Radiation Laboratory and Department of Chemistry
University of California, Berkeley, California

July, 1957

This compilation is a revision of the "Table of Alpha-Disintegration Energies of the Heavy Elements" published in this journal in 1954.[1] Included are new alpha emitters and revisions concerning those previously listed. The basis for inclusion in Table II of a previously listed alpha emitter is the availability of additional data which would change the alpha disintegration energy by more than 1 kev from that listed in Table I.[1] Polonium-211 (0.52 sec) is included but not the 25-sec isomer because it is now certain that the alpha group belonging to the 0.52-sec nuclide represents the transition between ground states.

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.

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 disintegration 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, $4E/(A-4)$, where E is the alpha-particle energy and A is the mass number of the emitter. The Q values were rounded off to values consistent with the precision of the energy measurements.

COLUMN 4

The absence of a notation under "intensity" means that no high-resolution instrument has been used to obtain evidence on complex structure. Otherwise the entry indicates the intensity of the group believed to represent the ground-state transition. The designation "~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: range determination in air.
range emuls: range of alpha tracks in a photographic emulsion.
spect: magnetic spectrograph.

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:

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.

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.

Table II.

Reaction	Adopted (Mev)	Highest-energy group measured (Mev)	Intensity (%)	Method	Energy ref.	Ident-ification	Comments
$Bi^{210} \rightarrow Tl^{206}$ 2.6×10^6 y	5.03	4.935		ion ch	2	A	
		4.97		ion ch	2a		
$Bi^{211} \rightarrow Tl^{207}$ 2.16 m	6.745	6.617	82.6	spect	2b	A	
		6.620		spect	3		
$Po^{197} \rightarrow Pb^{193}$ ~4 m	6.165	6.040		spect	4	D	ins evid
$Po^{198} \rightarrow Pb^{194}$ ~6 m	6.057	5.935		spect	4	D	e-e
$Po^{199} \rightarrow Pb^{195}$ 11 m	5.966	5.846		spect	4	B	ins evid
		5.84		ion ch	4a		
$Po^{200} \rightarrow Pb^{196}$ ~8 m	5.888	5.770		spect	4	B	e-e
$Po^{201} \rightarrow Pb^{197}$ 18 m	5.786	5.671		spect	4	B	ins evid
		5.70		ion ch	4b		
$Po^{202} \rightarrow Pb^{198}$ 51 min	5.689	5.575		spect	4	B	e-e
		5.60		ion ch	5		
		5.61		ion ch	6		
		5.59		ion ch	7		
$Po^{204} \rightarrow Pb^{200}$ 3.8 h	5.477	5.370		spect	4	B	e-e
		5.37		ion ch	7		
$Po^{211} \rightarrow Pb^{207}$ 0.52 s	7.58	7.442	99	spect	8	A	
		7.434		range air	9		
$Po^{213} \rightarrow Pb^{209}$ 4.2×10^{-6} s	8.51	8.35	~100	spect	11	A	ins evid
		8.336		ion ch	13		
$Po^{215} \rightarrow Pb^{211}$ 1.83×10^{-3} s	7.50	7.360	~100	spect	2b	A	
		7.365		range air	9		
		7.383		spect	13a		
$At^{209} \rightarrow Bi^{205}$ 5.5 h	5.752	5.642	~100	spect	14,15	B	ins evid
		5.65		ion ch	17		
$At^{217} \rightarrow Bi^{213}$ 0.018 s	7.18	7.05	~100	spect	18	A	
		7.02		ion ch	13		
		7.00		ion ch	19		
$Em^{204} \rightarrow Po^{200}$ 3 m	6.41	6.28		ion ch	5	D	e-e
$Em^{206} \rightarrow Po^{202}$ 6.2 m	6.37	6.25		ion ch	5	B	e-e
		6.25		ion ch	6		
$Em^{207} \rightarrow Po^{203}$ 11 m	6.24	6.12		ion ch	5	B	ins evid
		6.09		ion ch	6		

Reaction	Adopted Q (Mev)	Highest-energy group measured (Mev)	Intensity (%)	Method	Energy ref.	Ident-ification	Comments
$Em^{208} \xrightarrow[23\ m]{} Po^{204}$	6.261	6.141	~100	spect	20	B	e-e
$Em^{209} \xrightarrow[30\ m]{} Po^{205}$	6.155	6.037		spect	20	B	ins evid
$Em^{210} \xrightarrow[2.7\ h]{} Po^{206}$	6.155	6.037		spect	20	A	
$Em^{212} \xrightarrow[23\ m]{} Po^{208}$	6.384	6.264	~100	spect	20	A	
$Em^{221} \xrightarrow[25\ m]{} Po^{217}$	6.1	6.0		ion ch	21	A	ins evid
$Em^{219} \xrightarrow[3.92\ s]{} Po^{215}$	6.940	6.813	83	spect	2b	A	
		6.807		spect	21b		
$Fr^{212} \xrightarrow[19.3\ m]{} At^{208}$	6.534	6.411	37	spect	20	A	ins evid
$Fr^{221} \xrightarrow[4.8\ m]{} At^{217}$	6.449	6.332	84	spect	18	A	
		6.30		ion ch	13,21a		
$Fr^{223} \xrightarrow[21\ m]{} At^{219}$	5.44	5.34		range emuls	22	A	ins evid
$Ra^{223} \xrightarrow[11.2\ d]{} Em^{219}$	5.974	5.867	0.9	spect	2b	A	
		5.860		spect	22a		
$Ra^{222} \xrightarrow[38\ s]{} Em^{218}$	6.671	6.551	96	spect	23	A	
$Ac^{225} \xrightarrow[10.0\ d]{} Fr^{221}$	5.923	5.818	56	spect	24	A	
		5.80		ion ch	21a,13		
$Th^{226} \xrightarrow[30.9\ m]{} Ra^{222}$	6.444	6.330	79	spect	23	A	
$Th^{227} \xrightarrow[18.6\ d]{} Ra^{223}$	6.144	6.036	23	spect	2b	A	
		6.030		spect	22a		
$Th^{232} \xrightarrow[1.4x10^{10}y]{} Ra^{228}$	4.077	4.007		ion ch	25	A	
		4.006		range emuls	26		
$Pa^{231} \xrightarrow[3.43x10^{4}y]{} Ac^{227}$	5.138	5.049	8.7	spect	27	A	
		5.046		spect	28		
		5.042		spect	29		
$U^{230} \xrightarrow[20.8\ d]{} Th^{226}$	5.988	5.884	67.2	spect	23	A	
$U^{233} \xrightarrow[1.62x10^{5}y]{} Th^{229}$	4.900	4.816	83.5	spect	30	A	
		4.823		ion ch	13		
$U^{234} \xrightarrow[2.48x10^{5}y]{} Th^{230}$	4.851	4.768	72	spect	27	A	
		4.768		ion ch	25		
		4.763		ion ch	31		
$U^{235} \rightarrow Th^{231}$	4.63	4.552	7	spect	2b	A	
		4.58		ion ch	31a		
$U^{238} \xrightarrow[4.51x10^{9}y]{} Th^{234}$	4.267	4.195	77	ion ch	25	A	

Reaction	Adopted E_α (Mev)	Highest-energy group measured (Mev)	Intensity (%)	Method	Energy ref.	Identification	Comments
$Np^{235} \xrightarrow[410\ d]{} Pa^{231}$	5.23	5.06		ion ch	32	A	α-γ(33)
$Np^{237} \xrightarrow[2.2\times10^{6}\ y]{} Pa^{233}$	4.950	4.866 4.872	3	spect ion ch	34 35	A	
$Pu^{232} \xrightarrow[20\ m]{} U^{229}$	6.41	6.30		ion ch	36	B	ins evid
$Pu^{236} \xrightarrow[2.7\ y]{} U^{232}$	5.862	5.763	68.9	spect	37	A	
$Pu^{237} \xrightarrow[44\ d]{} U^{233}$	5.75	5.65	21	ion ch	36	A	ins evid
$Pu^{238} \xrightarrow[89.6\ y]{} U^{234}$	5.589	5.495 5.491	72	spect spect	38 27	A	
$Pu^{239} \xrightarrow[24,360\ y]{} U^{235}$	5.235	5.147 5.147 5.150	72.5	spect spect spect	27 39 40	A	isomeric state less than 1 kev 38a,b
$Pu^{240} \xrightarrow[6580\ y]{} U^{236}$	5.246	5.159 5.162	75.5	spect spect	30 40	~~A~~	
$Am^{232} \xrightarrow[12\ h]{} Np^{235}$	5.90	5.75		ion ch	41	A	α-γ(42)
$Am^{241} \xrightarrow[461\ y]{} Np^{237}$	5.628	5.535 5.541	0.42	spect spect	43 27	A	
$Am^{243} \xrightarrow[7.9\times10^{3}\ y]{} Np^{239}$	5.428	5.339	0.17	spect	44	A	ins evid
$Cm^{238} \xrightarrow[2.4\ h]{} Pu^{234}$	6.63	6.52 6.50		ion ch ion ch	41 45	B	e-e
$Cm^{240} \xrightarrow[26.8\ d]{} Pu^{236}$	6.38	6.27 6.25		ion ch ion ch	46 47	A	e-e
$Cm^{241} \xrightarrow[35\ d]{} Pu^{237}$	6.20	5.95		ion ch	46	A	α-γ(47a)
$Cm^{243} \xrightarrow[35\ y]{} Pu^{239}$	6.159	6.003 5.777	1 78	spect spect	48 48	A	(49)
$Cm^{245} \xrightarrow[1\times10^{4}\ y]{} Pu^{241}$	5.62	5.45 5.36 5.4	~10 ~82	ion ch ion ch ion ch	50 51 52	A	α-γ(48)
$Cm^{246} \xrightarrow[5\times10^{3}\ y]{} Pu^{242}$	5.46	5.373 5.37 5.39 5.4		ion ch ion ch ion ch ion ch	53 50 54 52	A	e-e
$Cm^{248} \xrightarrow[4.7\times10^{5}\ y]{} Pu^{244}$	5.14	5.056		ion ch	53	A	e-e
$Bk^{244} \xrightarrow[4.35\ h]{} Am^{240}$	6.78	6.67		ion ch	55	B	ins evid
$Bk^{245} \xrightarrow[4.95\ d]{} Am^{241}$	6.48	6.37 6.35 6.33	33	ion ch ion ch ion ch	56 55 57	A	ins evid
$Bk^{247} \xrightarrow[\sim10^{4}\ y]{} Am^{243}$	5.85	5.67	~40	ion ch	55	B	α-γ(58)

Reaction	Adopted Q_α (Mev)	Highest-energy group measured (Mev)	Intensity (%)	Method	Energy ref.	Identification	Comment
$Bk^{249} \xrightarrow[280\ d]{} Am^{245}$	5.53	5.40	~94	ion ch	55	A	α-γ(58)
		5.4		ion ch	59		
		5.4		ion ch	60		
$Cf^{244} \xrightarrow[\sim 25\ m]{} Cm^{240}$	7.29	7.17		ion ch	61	A	e-e
$Cf^{245} \xrightarrow[44\ m]{} Cm^{241}$	7.23	7.11		ion ch	61	A	
		7.15		ion ch	62		
$Cf^{249} \xrightarrow[5x10^2 y]{} Cm^{245}$	6.29	6.19	~3	ion ch	63	A	
		6.19		ion ch	64		
$Cf^{250} \xrightarrow[10\ y]{} Cm^{246}$	6.122	6.024	83	spect	66	A	
		6.025		ion ch	66a		
		6.033		ion ch	65		
		6.05		ion ch	67		
		6.03		ion ch	59		
$Cf^{252} \xrightarrow[2.2\ y]{} Cm^{248}$	6.211	6.112	84.5	spect	66	A	
		6.119		ion ch	66a		
		6.117		ion ch	65		
		6.15		ion ch	67		
		6.12		ion ch	59		
$E^{246} \xrightarrow[7.3\ m]{} Bk^{242}$	7.4	7.3		ion ch	68	D	ins evid
$E^{248} \xrightarrow[25\ m]{} Bk^{244}$	6.98	6.87		ion ch	72	B	ins evid
$E^{249} \xrightarrow[2\ h]{} Bk^{245}$	6.87	6.76		ion ch	73	B	ins evid
$E^{251} \xrightarrow[1.5\ d]{} Bk^{247}$	6.58	6.48		ion ch	73	B	ins evid
$E^{252} \xrightarrow[\sim 140\ d]{} Bk^{248}$	6.75	6.64		ion ch	73	B	ins evid
$E^{253} \xrightarrow[20.03\ d]{} Bk^{249}$	6.740	6.633	90.2	spect	74	A	
		6.636		ion ch	75		
		6.63		ion ch	67		
		6.61		ion ch	76		
$E^{254} \xrightarrow[\sim 300\ d]{} Bk^{250}$	6.52	6.42		ion ch	75	A	ins evid
		6.44		ion ch	77		
$Fm^{250} \xrightarrow[30\ m]{} Cf^{246}$	7.55	7.43		ion ch	78	B	e-e
		7.7		ion ch	79		
$Fm^{251} \xrightarrow[7\ h]{} Cf^{247}$	7.00	6.89		ion ch	78	B	ins evid
$Fm^{252} \xrightarrow[23\ h]{} Cf^{248}$	7.16	7.05		ion ch	78	B	e-e
		7.04		ion ch	80		
$Fm^{253} \xrightarrow[4.5\ d]{} Cf^{249}$	7.05	6.94		ion ch	81	B	ins evid
		6.85		ion ch	80		

Reaction	Adopted α (Mev)	Highest-energy group measured (Mev)	Intensity (%)	Method	Energy ref.	Identification	Comments
$Fm^{254} \xrightarrow{3.24\ h} Cf^{250}$	7.32	7.20		ion ch	75	A	
		7.22		ion ch	82		
		7.17		ion ch	76		
$Fm^{255} \xrightarrow{21.5\ h} Cf^{251}$	7.2	7.08		ion ch	75	B	ins evid
		7.1		ion ch	82		

REFERENCES

1. F. Asaro and I. Perlman, Revs. Mod. Phys. 26, 456 (1954).
2. H. B. Levy and I. Perlman, Phys. Rev. 94, 152 (1954).
2a. M. A. Rollier, Gazz. chim. ital. 84, 658 (1954); Chem. Abstr. 49-12983 f (1955).
2b. R. C. Pilger, Ph.D. thesis, University of California (1957).
3. G. H. Briggs, Revs. Mod. Phys. 26, 1 (1954).
This is a compilation of the best values for the energies of natural alpha particles.
4. S. Rosenblum and H. Tyrén, Compt. rend. 239, 1205 (1954).
4a. The authors (see reference 4b) assigned the 5.84 Mev group to Po^{199}. From the work of Rosenblum and Tyrén[4] an assignment to Po^{200} is more reasonable.
4b. Karraker, Ghiorso, and Templeton, Phys. Rev. 83, 390 (1951).
5. A. W. Stoner and E. K. Hyde, Journal of Inorganic and Nuclear Chemistry (In press-1957).
6. W. E. Burcham, Proc. Phys. Soc. A67, 555 (1954).
7. D. G. Karraker and D. H. Templeton, Phys. Rev. 81, 510 (1951).
8. S. Rosenblum, Compt. rend. 193, 848 (1931).
The energy was calculated by Briggs, see reference 3.
9. W. B. Lewis and B. V. Bowden, Proc. Roy. Soc. (London) A145, 235 (1934).
(Summarizes the results of various investigators. The values were recalculated according to reference 10).
10. M. G. Holloway and M. S. Livingston, Phys. Rev. 54, 18 (1938). Summarizes work of various investigators.
11. Stephens, Hummel, Asaro, and Perlman, unpublished data (1954). See also reference 12.
12. F. S. Stephens, Jr., Ph.D. thesis, University of California, (University of California Radiation Laboratory report UCRL-2970) June 1955.
13. T. E. Cranshaw and J. A. Harvey, Can. J. Research 26A, 243 (1948).
13a. M. Curie and S. Rosenblum, Compt. rend. 194, 1232 (1932).
(This energy was calculated by Briggs, see reference 3).
14. R. W. Hoff and F. Asaro, unpublished data (1954).
See also University of California Radiation Laboratory Unclassified Report UCRL-3157, p. 67 (Sept. 1955).

15. J. P. Hummel and A. W. Stoner, unpublished data (1955); A. W. Stoner, Ph.D. thesis, University of California, University of California Radiation Laboratory report UCRL-3471 (1956) See also reference 16.
16. J. P. Hummel, Ph.D. thesis, University of California, University of California Radiation Laboratory report UCRL-3456 (July 1956).
17. Barton, Ghiorso, and Perlman, Phys. Rev. 82, 13 (1951).
18. Stephens, Hummel, Asaro, and Perlman, unpublished data (1956). See also reference 12.
19. Hagemann, Katzin, Studier, Ghiorso, and Seaborg, Phys. Rev. 72, 252 (1947).
20. Momyer, Asaro, and Hyde, J. Inorg. Nucl. Chem. 1, 267 (1955).
21. F. F. Momyer, Jr. and E. K. Hyde, Phys. Rev. 102, 464 (1956).
21a. Hagemann, Katzin, Studier, Seaborg, and Ghiorso, Phys. Rev. 79, 435 (1950).
21b. Marie Curie and S. Rosenblum, Compt. rend. 196, 1598 (1933). This energy was recalculated by Briggs (See Ref. 3) using later values for the reference energies.
22. Jean-Pierre Adloff, Compt. rend. 240, 1421 (1955).
22a. Rosenblum, Perey, Valadares, and Guillot; mentioned in Revs. Mod. Phys. 25, 469 (1953) by Hollander, Perlman, and Seaborg.
23. F. Asaro and I. Perlman, Phys. Rev. 104, 91 (1956).
24. Stephens, Hummel, Asaro, and Perlman, unpublished data (1956). See also reference 16.
25. Harvey, Jackson, Eastwood, and Hanna, Can. J. Phys. (to be published 1957).
26. Philbert, Génin, and Vigneron, J. Phys. et radium 15, 16 (1954).
27. Goldin, Novikova, and Tretyakov, Conf. Acad. Sci. USSR on Peaceful Uses of Atomic Energy. Phys. Math. Sci. p. 226, July 1955, UCRL translation 242.
28. Hummel, Asaro, and Perlman, Phys. Rev. 98, 261A (1955).
29. Rosenblum, Cotton, and Bouissieres, Compt. rend. 229, 825 (1949).
30. Goldin, Novikova, and Tretyakov, Phys. Rev. 103, 1004 (1956).
31. Clark, Spencer-Palmer, and Woodward. British Declassified Report BR-522, Oct. (1944).
31a. A. Ghiorso, Phys. Rev. 82, 979 (1951).
32. James, Ghiorso, and Orth, Phys. Rev. 85, 369 (1952).
33. Hoff, Olsen, and Mann, Phys. Rev. 102, 805 (1956).
34. Goldin, Peker, and Novikova, USPEKHI FIZICHESKIKH NAUK 59, 449 (1956). This is a compilation of heavy-element decay characteristics.
35. Magnusson, Engelkemeir, Freedman, Porter, and Wagner, Phys. Rev. 100, 1237A (1955).
36. Thomas, Vandenbosch, Glass, and Seaborg, Phys. Rev. 106, 1228 (1957).
37. J. P. Hummel, F. Asaro, and G. H. Higgins, and I. Perlman, unpublished data (1956).
38. F. Asaro and I. Perlman, Phys. Rev. 94, 381 (1954).
38a. F. Asaro and I. Perlman, Phys. Rev. to be published July 1, 1957.
39. Rosenblum, Valadares, and Goldschmidt, Compt. rend. 230, 638 (1950).
40. F. Asaro and I. Perlman, Phys. Rev. 88, 828 (1952).

41. G. H. Higgins, Ph.D. thesis, University of California, University of California Radiation Laboratory Unclassified document UCRL-1796, June 1952.
42. Asaro, Stephens, Gibson, Glass, and Perlman, Phys. Rev. 100, 1541L (1955).
43. F. Asaro and I. Perlman, Phys. Rev. 93, 1423 (1954).
44. Hummel, Asaro, and Perlman, unpublished data. See also reference 16.
45. Street, Ghiorso, Orth, and Seaborg unpublished data (Oct. 1948).
46. R. A. Glass, Ph.D. thesis, University of California, University of California Radiation Laboratory Unclassified report UCRL-2560 (April 1954).
47. G. H. Higgins and K. Street, Jr., Phys. Rev. 86,252 (1952).
47a. Recoils from the alpha decay of Cm^{241} were founds to contain a 145 kev transition with 0.18 sec half life. Stephens, Asaro, Amiel, and Perlman, Phys. Rev. to be published (1957).
48. Asaro, Thompson, and Perlman, unpublished data (1954).
49. Hollander, Smith, and Mihelich, Phys. Rev. 102, 740 (1956). These authors deduced the level scheme of Pu^{239} from the decay of Np^{239}.
50. E. K. Hulet, J. Inorg. Nucl. Chem., to be published (1957).
51. Hulet, Thompson, and Ghiorso, Phys. Rev. 95, 1703 (1954).
52. Fields, Studier, Diamond, Mech, Inghram, Pyle, Stevens, Fried, Manning, Ghiorso, Thompson, Higgins, and Seaborg, Phys. Rev. 102, 180 (1956).
53. Butler, Eastwood, Jackson, and Schuman, Phys. Rev. 103, 965 (1956).
54. Browne, Hoffman, Crane, Balagna, Higgins, Barnes, Hoff, Smith, Mize, and Bunker, J. Inorg. Nucl. Chem. 1, 254 (1955).
55. A. Chetham-Strode, Jr., Ph.D. thesis, University of California, University of California Radiation Laboratory Unclassified report UCRL-3322, June 1956.
56. Magnusson, Friedman, Engelkemeir, Fields, and Wagner, Phys. Rev. 102, 1097 (1956).
57. Hulet, Thompson, Ghiorso, and Street, Phys. Rev. 84, 366 (1951).
58. Chetham-Strode, Stephens, and Asaro, unpublished data (1955). See also reference 55.
59. Diamond, Magnusson, Mech, Stevens, Friedman, Studier, Fields, and Huizenga, Phys. Rev. 94, 1083 (1954).
60. A. Ghiorso, private communication (1954).
61. Chetham-Strode, Choppin, and Harvey, Phys. Rev. 102, 747 (1956).
62. Thompson, Street, Ghiorso, and Seaborg, Phys. Rev. 80, 790 (1950). The Cf^{245} alpha group was tentatively assigned to Cf^{244} in this paper.
63. A. Ghiorso and B. G. Harvey, unpublished data (1954). Mentioned in reference 12.
64. The articles designated in references 65 and 56 give, respectively, the energy of the most abundant alpha group in Cf^{249} decay and the energy separation between this group and the highest energy one.
65. Magnusson, Studier, Fields, Stevens, Mech, Friedman, Diamond, and Huizenga, Phys. Rev. 96, 1576 (1954).

66. Asaro, Stephens, Harvey, and Perlman, Phys. Rev. 100, 137 (1955).

66a. Jones, Schuman, Butler, Cowper, Eastwood, and Jackson, KAPL-1378 (1955).

67. Ghiorso, Thompson, Higgins, Harvey, and Seaborg, Phys. Rev. 95, 293 (1954).

68. Ghiorso, Rossi, Harvey, and Thompson, Phys. Rev. 93, 257 (1954).
These authors tentatively assigned a 7.35 Mev to E^{247}. A subsequent investigation (69) indicated the mass number was less than 247. The most likely mass number (70) was thought to be 246.
In a later review article (71) the energy was listed as 7.3 rather than 7.35 Mev.

69. A. Chetham-Strode, private communication (1956).

70. A. Ghiorso and S. G. Thompson, private communication (1956).

71. Ghiorso, Thompson, Higgins, Harvey, and Seaborg, Phys. Rev. 95, 293 (1954).

72. A. Chetham-Strode, and L. W. Holm, Phys. Rev. 104, 1314 (1956).

73. Harvey, Chetham-Strode, Ghiorso, Choppin, and Thompson, Phys. Rev. 104, 1315 (1956).

74. Hummel, Asaro, Stephens, Thompson, and Perlman, unpublished data (1955).

75. Jones, Schuman, Butler, Cowper, Eastwood, and Jackson, Phys. Rev. 102, 203 (1956).

76. Fields, Studier, Mech, Diamond, Friedman, Magnusson, and Huizenga, Phys. Rev. 94, 209 (1954).

77. Harvey, Thompson, Choppin, and Ghiorso, Phys. Rev. 99, 337 (1955).

78. Amiel, Chetham-Strode, Choppin, Ghiorso, Harvey, Holm, and Thompson, Phys. Rev. 106, 553, (1957).

79. Atterling, Forsling, Holm, Melander, and Åström, Phys. Rev. 95L, 585 (1954).

80. Friedman, Gindler, Barnes, Sjoblom, and Fields, Phys. Rev. 102L, 585 (1956).

81. S. Amiel, Phys. Rev. 105L, 1412 (1957).

82. Choppin, Thompson, Ghiorso, and Harvey, Phys. Rev. 94, 1080 (1954).