REVIEWS OF MODERN PHYSICS VOLUME 26, NUMBER 4 OCTOBER, 1954

Mass Spectroscopic Atomic Mass Differences*†

HENRY E. DUCKWORTH, BENJAMIN G. HOGG,‡ AND EDWIN M. PENNINGTON§

Department of Physics, Hamilton College, McMaster University, Hamilton, Ontario, Canada

1. INTRODUCTION

THESE tables are concerned with atomic mass differences which have been obtained mass spectroscopically by the doublet method. They are a part of a program[1] designed to present in convenient form data pertaining to atomic masses.

2. THE DOUBLET METHOD OF MASS COMPARISON

The mass spectroscopic comparison of atomic masses is usually accomplished by studying "doublets." A doublet is a pair of mass spectral lines produced by two species of ions whose e/m values are almost, but not quite, equal. Thus, for example, a doubly charged ion, which appears on a mass spectrum at a point corresponding to one-half its mass, will frequently form a doublet with a lighter, singly charged ion. If the mass of one of the doublet members is known, the mass of the other can be computed from a knowledge of the doublet spacing and the dispersion of the mass spectrograph.

In principle, it is possible to compare the masses of atoms even if their mass spectral lines are widely separated. However, in practice, it is difficult to achieve a uniform dispersion over a large distance, whereas it is not difficult to do so for the region represented by the doublet spacing. For this reason, these tables list doublet measurements almost exclusively, manifesting the opinion of the authors that large mass differences cannot be measured with accuracy.

3. THE BRACKET METHOD OF MASS COMPARISON

This policy precludes the inclusion of the many "bracket" measurements made[2] by Dempster and his students. In this work, for example, the three lines formed by doubly charged Ag^{107} and Ag^{109}, and by singly charged Fe^{54}, were photographed, the first two lines bracketing the third. From these photographs the difference between the packing fraction of Fe^{54} and the average packing fraction of Ag^{107} and Ag^{109} could be approximately determined. Although measurements of this sort were most helpful to Dempster in constructing his celebrated packing fraction curve, the errors involved were large, and the measurements are probably now of historical interest only. A complete list of all bracket results has been given by Mattauch and Flammersfeld in their 1949 Isotope Report.[3]

4. TABLES I AND II—SECONDARY STANDARDS OF ATOMIC MASS

In a few instances, e.g., doubly charged S^{32}, triply charged Ti^{48}, etc., it is possible to compare directly the mass of a nuclide to O^{16}, but, in general, this is not possible. As a rule, the doublet member whose mass is known is not O^{16}, but is some atom whose mass has been deduced from that of O^{16} by one or more doublet comparisons, and can be regarded as a secondary standard.

The most useful secondary standards are H^1 and C^{12}, since combinations of these atoms can serve as reference masses at many mass numbers. It was natural, therefore, that many of the efforts of Aston, Bainbridge, and Mattauch during the 1930's were directed toward the accurate measurement of these masses. The three "fundamental doublets" used in these experiments were[4]

$$H_2{}^1 - D^2$$

$$D_3{}^2 - C^{12}$$

$$C^{12}H_4{}^1 - O^{16},$$

from which the masses of the so-called "substandards" H^1, D^2, and C^{12} were calculated.

By 1940 much careful work had been done with these doublets. The situation was well summarized[5] at the time by Mattauch and was subsequently thoroughly studied[6] by Bainbridge, who calculated "best values" for H^1, D^2, and C^{12} on the basis of all the prewar data. The various masses computed during this period for these secondary standards are shown in the upper half of Table I. There is seen to be good agreement in the case of both H^1 and D^2, but the C^{12} values are far from being consistent.

---

* This work has been supported by the Office of Scientific Research, Air Research and Development Command, United States Air Force.

† 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.

‡ Postdoctorate fellow under contract AF18(600)-484 with McMaster University. Now at the Royal Military College of Canada, Kingston, Ontario.

§ Holder of National Research Council of Canada Scholarship.

[1] 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.

[2] References De 38, De 38a, Gr 39, Du 42, and Ra 48.

[3] Isotope Report, Z. Naturforsch., Tubingen (1949).

[4] F. W. Aston, Nature **135**, 541 (1935).

[5] J. Mattauch, Phys. Rev. **57**, 1155 (1940).

[6] K. T. Bainbridge, Proc. 7th Solvay Conference in Chemistry (1947).

TABLE I. Masses of the secondary standards H^1, D^2, C^{12}.

	H^1	D^2	C^{12}	Reference
Aston (1936)	1.00812 ±4	2.01471 ±7	12.00355 ±15	a
Bainbridge and Jordan (1937)	1.00813 ±2	2.01473 ±2	12.00398 ±10	b
Mattauch and Bönisch (1938)	1.008132 ±4	2.014726 ±7	12.00387 ±3	c
Mattauch (1940)	1.008130 ±3	2.014722 ±6	12.003861 ±24	d
Bainbridge (1947)	1.0081283±28	2.0147186±55	12.003856 ±19	e
Ewald (1951)	1.008141 ±2	2.0147315±33	12.003807 ±11	Ew 51
Collins, Nier, and Johnson (1952)	1.008146 ±3	2.014740 ±6	12.003842 ±4	Co 52
Ogata and Matsuda (1953)	1.008145 ±2	2.014741 ±3	12.003844 ±6	Og 53
Mattauch and Bieri (1954)	1.0081459±5	2.0147444±9	12.0038231±33	Ma 54
Li *et al.* (nuclear reactions, 1951)	1.008142 ±3	2.014735 ±6	12.003804 ±17	f

[a] F. W. Aston, Nature **137**, 357L (1936).
[b] M. S. Livingston and H. A. Bethe, Revs. Modern Phys. **9**, 373 (1937).
[c] J. Mattauch, Z. tech. Phys. **19**, 578 (1938).
[d] Footnote 5.
[e] Footnote 6.
[f] C. W. Li *et al.*, Phys. Rev. **83**, 512 (1951).

These masses have been remeasured since the war with greater accuracy and have also been computed from precision nuclear reaction data. The results of these recent studies are shown in the lower section of Table I. The mass spectrographic values of Ewald are in splendid agreement with the masses computed from nuclear reaction data by Li *et al.* in the case of all three substandards. These values, however, are in each case lower than ones obtained mass spectrographically by both Nier and his co-workers and by Ogata and Matsuda, which in turn, agree remarkably well with each other. Although the discrepancies are not too serious for H^1 and D^2, the results for C^{12} have not seemed capable of reconciliation. Into this picture have come the recent values of Mattauch and Bieri which carry with them the lowest stated errors of any measurements to date. These are in substantial agreement with the values of Nier and Ogata for H^1 and D^2, but in the worrisome matter of C^{12} their value agrees with neither the high nor the low group but practically coincides with their arithmetic mean.

TABLE II. Doublets used to obtain the masses of the secondary standards H^1, D^2, C^{12}.

Doublet	ΔM in mMU	Reference	Doublet	ΔM in mMU	Reference
H_2-D	1.53 ±4	Ba 36	CH_4-O	36.3899±41	Sm 53a
	(1.539 ±2)	Ma 38		36.4086±38	Ma 54
	1.52 ±4	Ast 42	C_2H_4-CO	36.443 ±22	Ni 51
	1.549 ±6	Ro 50		(36.451 ±6)	Og 51
	1.5519±17	Ro 51		36.423 ± 8	Og 53
	1.5503±15	Ew 51		36.3877±41	Sm 53
	1.545 ±8	So 51	CH_3OH-O_2	36.3748±38	Da 53
	1.5492±8	Og 53	$C_3H_8-CO_2$	72.968 ±44	Ni 51
	1.5473±7	Ma 54		72.967 ±41	Ni 51a
$D_3-\frac{1}{2}C$	42.19 ±5	Ba 37		72.854 ±15	Co 52
	(42.239 ±21)	Ma 38		72.7752±82	Da 53
	42.36 ±18	Ast 42	O_2-S^{32}	17.7 ±3	Ast 42
	42.291 ±12	Ew 51		(19.15 ±11)	Ok 41a
	42.301 ±9	Og 53		17.7 ±10	Sm 51
	42.3254±52	Ma 54		17.63 ±10	Du 51
CH_4-O	36.49 ±8	Jo 36		17.716 ±20	Ew 51
	36.406 ±40	Ma 38		17.764 ±7	Co 51
	36.42 ±9	Asa 39		17.725 ±8	Og 53
	36.320 ±35	Jo 41		*17.7629±71	Sm 53b
	36.01 ±16	Ast 42	CO_2-CS	(18.94 ±23)	Ok 41a
	36.371 ±12	Ew 51		17.782 ±25	Ni 51a
	36.478 ±22	Ni 51		17.7643±41	Sm 53a
	(36.443 ±5)	Og 51	C_4-SO	33.182 ±7	Ni 51a
	36.427 ±8	Co 51		33.132 ±13	Co 51
	36.415 ±8	Og 53		33.122 ±22	Og 53
	36.399 ±28	Eng 53	$C_6H_4-CS_2$	87.326 ±58	Ni 51a

The present authors have neither the omniscience nor the desire to suggest which of the various masses suggested for the secondary standards are "best" values. We prefer to list in Table II all of the doublet measurements which would be useful in such a calculation. We thus include all published values for the three fundamental doublets named in the foregoing. It will be seen that the CH_4-O mass difference is given not only by measurements of this doublet, but also by the C_2H_4-CO mass difference, where the carbon atom is common to both ions, by the CH_3OH-O_2 mass difference, where oxygen is common to both, and by one-half the $C_3H_8-CO_2$ mass difference. We also list in Table II the measured values for the CO_2-CS, C_4-SO, and $C_6H_4-CS_2$ doublets, which provide a means of obtaining the masses of H^1 and C^{12} which is completely independent of the fundamental doublet route. This cycle, involving sulfur rather than deuterium, was introduced by Nier in 1951.

We have not included in Table II the doublets $O-\frac{1}{3}Ti^{48}$ and $C-\frac{1}{4}Ti^{48}$ which have been suggested[6] by Bainbridge as another approach to the C mass. This approach has not yet been effectively exploited and the measured values do not compare in precision with those listed in Table II. Instead, they are listed in Table III as a means of calculating the mass of Ti^{48}.

A few doublet differences in Table II appear in parentheses. These differences have been stated to us by the individuals responsible for the original measurements to be either incorrect or highly suspect, and are included here parenthetically for the sake of completeness.

5. TABLE III—OTHER DOUBLET MEASUREMENTS

In Table III we have listed nearly all of the nonfundamental doublet differences which have been published, together with a few which have yet to appear in print. The only differences which have been intentionally omitted are a few of the very early ones

TABLE III OTHER DOUBLET MEASUREMENTS

Element Z A	Doublet	ΔM in mMU	Reference
2 He 4	D_2-He4	25.61 ± 4	Ba 37
		25.51 ± 8	Ast 42
		25.604 ± 8	Ew 50
		25.612 ± 9	Ni 51
		25.603 ± 6	Og 53
		25.6060 ± 47	Ma 54
	D_2H-He4H	25.6074 ± 26	Ma 54
	2He4-1/2 O	7.72 ± 12	Ba 38
	He4D-1/2 C12	16.7141 ± 34	Ma 54
3 Li 6	D_3-Li6	26.41 ± 30	Ba 33
7	Li7-1/2 N	14.43 ± 10	Ba 37
4 Be 9	Be9H-B10	6.96 ± 20	Jo 37
	Be9H-1/2 Ne20	23.91 ± 20	Jo 37
5 B 10	B10-1/2 Ne20	16.75 ± 15	Jo 37
		16.84 ± 15	Ast 42
		16.722 ± 8	Og 53
	Be9H-B10	6.96 ± 20	Jo 37
	B10H-1/2 Ne22	25.1 ± 5	Jo 37
	B10H-B11	11.60 ± 10	Jo 37
		11.447 ± 14	Og 53
	B10H_2-C	28.75 ± 20	Jo 37
	B10D-C	27.016 ± 20	Og 53
	B10F19-Si29	34.2 ± 6	Ast 42
	B10HF19-B11F19	11.450 ± 15	Og 53
11	B10H-B11	11.60 ± 10	Jo 37
		11.447 ± 14	Og 53
	B11-1/2 Ne22	13.60 ± 15	Jo 37
		13.620 ± 8	Og 53
	B11H-C	17.14 ± 10	Jo 37
		17.115 ± 6	Og 53
	B10HF19-B11F19	11.450 ± 15	Og 53
6 C 13	CH-C13	4.5 ± 1	Ba 36
		(4.47)	Ma 37a
		4.410 ± 8	Ew 46
		4.496 ± 10	Ew 53
	C_2H_2-CC13H	4.484 ± 10	Og 53
	B10F19-C13O	13.049 ± 15	Og 53
	C_4C13H_3-Ni64	102.5 ± 5	Sh 49
7 N 14	Li7-1/2 N14	14.43 ± 10	Ba 37
	CH_2-N14	12.74 ± 8	Jo 36
		12.581 ± 23	Ma 38
		12.57 ± 6	Asa 39
		12.560 ± 15	Jo 41
		12.45 ± 7	Ast 42
		12.522 ± 12	Ew 46
		12.586 ± 13	Ni 51
		(12.594 ± 2)	Og 51
		12.564 ± 10	Ew 51
		12.584 ± 5	Og 53
		12.591 ± 13	Eng 53
		12.5999 ± 36	Ma 54
	CH_3-N14H	12.563 ± 27	Ma 38
		12.563 ± 13	Jo 41
	N14H-N15	10.74 ± 20	Jo 36a
		10.772 ± 20	Ew 46
	CH_4-N14H_2	12.550 ± 13	Jo 41
7 N 14	N14H_2-O	23.69 ± 15	Jo 36
		23.780 ± 32	Ma 38
	N14H_3-OH	23.661 ± 39	Ma 38
	C_2H_4-N14_2	25.170 ± 25	Ni 51
		(25.199 ± 5)	Og 51
		25.161 ± 11	Og 53
		25.1493 ± 41	Sm 53
		25.177 ± 21	Eng 53
	N14_2-CO	11.17 ± 20	Jo 36
		11.222 ± 40	Ma 38
		11.280 ± 13	Ni 51
		11.254 ± 9	Og 53
		11.2372 ± 21	Sm 53
	N14_2O-CO_2	11.2371 ± 21	Sm 53b
	C_2H_6-N14O	48.9623 ± 55	Sm 53
15	CH_3-N 15	(23.82 ± 8)	Ma 36
		23.308 ± 20	Ew 46
		(23.395 ± 5)	Og 51
		23.377 ± 6	Og 53
	N14H-N 15	10.74 ± 20	Jo 36a
		10.772 ± 20	Ew 46
8 O 17	D_2HO-D_2O17	3.634 ± 15	Ew 51
18	H_2O-O18	(12.57 +18)	Ma 36
		(12.0)	Ma 37b
		(10.44 ± 18)	Ast 42
	D_2O-H_2O18	8.312 ± 12	Ew 51
		8.309 ± 18	Og 53
	H_2O18-Ne20	22.391 ± 10	Ew 51
9 F 19	ODH-F19	18.33 ± 29	Ast 42
	D_2O-F19H	16.909 ± 15	Ew 51
	B10F19-C13O	13.049 ± 15	Og 53
	B10F19-Si29	34.2 ± 6	Ast 42
	CF19-P31	24.4 ± 5	Ast 42
	Si29$F_3$19-Sr86	(77.)	Ma 37
	Si30$F_3$19-Sr87	(74.)	Ma 37
10 Ne 20	Be9H-1/2 Ne20	23.91 ± 20	Jo 37
	B10-1/2 Ne20	16.75 ± 15	Jo 37
		16.84 ± 15	Ast 42
		16.722 ± 8	Og 53
	D_2O-Ne20	30.65 ± 10	Jo 37
		30.83 ± 40	Ast 42
		30.688 ± 10	Ew 51
		30.721 ± 39	Ni 51
		30.710 ± 11	Og 53
	CD_4-Ne20	63.82 ± 50	Ma 38
	H_2O18-Ne20	22.391 ± 10	Ew 51
	Ne20-1/2 A40	11.30 ± 20	Jo 37
		11.14 ± 38	Ma 38
		10.88 ± 30	Ast 42
		11.280 ± 18	Ni 51
	Ne20H-Ne21	7.26 ± 20	Jo 37
21	D_2HO-Ne21	37.212 ± 20	Ew 51
	Ne20H-Ne21	7.26 ± 20	Jo 37
22	B10H-1/2 Ne22	25.1 ± 5	Jo 37
	B11-1/2 Ne22	13.60 ± 15	Jo 37
		13.620 ± 8	Og 53
	D_3O-Ne22	45.867 ± 15	Ew 51

TABLE III—*Continued.*

Element Z A	Doublet	ΔM in mMU	Reference
13 Al 27	C_2H_3-Al 27	(40.5)	Ast 42
		42.350 ± 65	Fl 43
		42.014 ± 18	Og 53
14 Si 28	C_2H_4-Si28	54.46 ± 17	Du 50c
	CO-Si28	17.2 ± 6	Ast 42
		18.06 ± 8	Du 50c
		18.015 ± 30	Ew 51
		18.018 ± 14	Og 53
	Si28-1/2 Fe56	9.30 ± 6	Du 50
29	C13O-Si29	21.800 ± 17	Og 53
	B10F19-Si29	34.2 ± 6	Ast 42
	Si29-1/2 Ni58	8.90 ± 6	Du 50
	Si29$F_3$19-Sr86	(77)	Ma 37
30	CH_3-1/2 Si30	(36.80 ± 8)	Du 50b
	B11F19-Si30	33.948 ± 20	Og 53
	Si30-1/2 Ni60	8.70 ± 6	Du 50
	Si30-1/3 Zr90	5.64 ± 12	Du 50b
	Si30$F_3$19-Sr87	(74)	Ma 37
15 P 31	O_2-P31H	8.249 ± 30	Ew 51
		8.245 ± 12	Og 53a
	CF19-P31	24.4 ± 5	Ast 42
	P31H-S32	9.495 ± 10	Ew 51
		9.500 ± 10	Og 53a
	P31H_2-S32H	9.491 ± 12	Og 53a
	P31H_3-S32H_2	9.510 ± 11	Ew 51
	P31H_3-S34	29.275 ± 20	Ew 51
16 S 32	O_2-S32	17.7 ± 3	Ast 42
		(19.15 ± 11)	Ok 41a
		17.7 ± 10	Sm 51
		17.63 ± 10	Du 51
		17.716 ± 20	Ew 51
		17.764 ± 7	Co 51
		17.725 ± 8	Og 53
		* 17.7629 ± 71	Sm 53b
	P31H-S32	9.495 ± 10	Ew 51
	S32-1/2 Ni64	8.48 ± 6	Du 51b
	P31H_3-S32H_2	9.510 ± 11	Ew 51
	S32H_2-S34	20.04 ± 32	Ok 41a
		19.847 ± 22	Og 53
	CO_2-CS32	(18.94 ± 23)	Ok 41a
		17.782 ± 25	Ni 51a
		17.7643 ± 41	Sm 53a
	CS32H_2-Ti46	34.9 ± 10	Ok 41a
		35.40 ± 4	Co 52
	CS32H_3-Ti47	44.4 ± 9	Ok 41a
		43.83 ± 9	Co 52
	C_4-S32O	33.182 ± 7	Ni 51a
		33.132 ± 13	Co 51
		33.122 ± 22	Og 53
		* 33.0621 ± 66	Sm 53b
	S32O_2-Ni64	34.69 ± 7	Co 52
	S32O_2-Zn64	32.682 ± 20	Co 52
	C_6H_4-CS32_2	87.326 ± 58	Ni 51a
33	S33H_2-S34H	11.377 ± 32	Og 53
	C_4H-S33O	41.385 ± 46	Co 51
34	P31H_3-S34	29.275 ± 20	Ew 51
	S32H_2-S34	20.04 ± 32	Ok 41a
		19.847 ± 22	Og 53
	S33H_2-S34H	11.377 ± 32	Og 53
16 S 34	C_3-S34H_2	16.545 ± 22	Og 53
	H_2S34-HCl 35	6.740 ± 25	Ew 51
	C_4H_2-S34O	52.900 ± 40	Co 51
17 Cl 35	C_3-HCl 35	22.5 ± 7	Ast 42
		24.67 ± 17	Ok 40
		23.341 ± 44	Co 51
		23.323 ± 12	Og 53
	H_2S34-HCl 35	6.740 ± 25	Ew 51
37	C_3H-Cl 37	41.2 ± 7	Ast 42
		42.17 ± 9	Ok 40
		42.001 ± 14	Og 53
	C_3H_2-HCl 37	41.98 ± 11	Ok 40
		42.014 ± 46	Co 51
		42.003 ± 14	Og 53
	CH_3Cl 37-Cr52	47.9 ± 8	Ast 42
18 A 36	H_2O-1/2 A36	(27.1 ± 4)	Ast 42
		26.702 ± 40	Ni 51
		26.819 ± 28	Co 51
	C_3-A36	32.6 ± 7	Ast 42
		32.501 ± 33	Co 51
38	C_3H_2-A38	52.910 ± 40	Co 51
40	D_2O - 1/2 A40	41.89 ± 20	Jo 37
		41.967 ± 18	Ni 51
		41.953 ± 12	Ew 51
		41.918 ± 14	Og 53
	Ne20-1/2 A40	10.9 ± 3	Ast 42
		11.30 ± 20	Jo 37
		11.14 ± 38	Ma 38
		11.280 ± 18	Ni 51
	C_3H_4-A40	67.9 ± 6	Ast 42
		(67.93 ± 7)	Ok 40
		68.877 ± 35	Ni 51
		68.937 ± 28	Og 53
		69.057 ± 41	Eng 53
	C_2O-A40	32.752 ± 9	Jn 52a
	C_3H_5-A40H	(69.30 ± 23)	Ok 40
19 K 39	C_3H_3-K39	59.905 ± 26	Co 51
40	C_2O-K40	31.140 ± 81	Jn 52a
41	C_3H_5-K41	77.361 ± 33	Co 51
20 Ca 40	C_3H_4-Ca40	68.539 ± 46	Ni 51
	C_2O-Ca40	32.557 ± 9	Jn 52a
42	C_3H_6-Ca42	88.247 ± 34	Co 51
43	C_3H_7-Ca43	96.040 ± 52	Co 51
44	CO_2-Ca44	34.607 ± 59	Co 51
48	C_4-Ca48	47.59 ± 10	Co 51
21 Sc 45	$C_2O_2H_5$-Sc45O	78.317 ± 41	Co 51
22 Ti 46	CS32H_2-Ti46	34.9 ± 10	Ok 41a
		35.40 ± 4	Co 52
47	CS32H_3-Ti47	44.4 ± 9	Ok 41a
		43.83 ± 9	Co 52
	1/3 Pr141-Ti47	17.11 ± 14	Du 51b
		16.96 ± 10	Ho 53
48	C-1/4 Ti48	11.8 ± 5	De 38
	O-1/3 Ti48	11.55 ± 6	De 38
		12.16 ± 11	Du 42
		(11.98 ± 6)	Du 51a

TABLE III—*Continued.*

Element Z A	Doublet	ΔM in mMU	Reference
22 Ti 48	O-1/3 Ti48	12.3 ± 1	Ho 53
	C_2-1/2 Ti48	24.5 ± 4	Ast 42
	C_4-Ti48	52.16 ± 46	Ok 41a
		52.20 ± 6	Co 52
	1/3 Nd144-Ti48	22.23 ± 10	Ho 53
49	C_4H-Ti49	58.83 ± 51	Ok 41a
		59.93 ± 5	Co 52
50	C_4H_2-Ti50	69.46 ± 36	Ok 41a
		70.892 ± 29	Co 52
		70.927 ± 27	Jn 52
	1/3 Nd150-Ti50	25.8 ± 5	De 38a
		28.40 ± 17	Ho 53
23 V 50	C_4H_2-V50	68.36 ± 12	Jn 52
51	C_4H_3-V51	79.28 ± 5	Co 52
24 Cr 50	C_2H-1/2 Cr50	(35.75 ± 7)	Du 50a
	C_4H_2-Cr50	67.32 ± 37	Og 49
		69.56 ± 6	Co 52
		69.634 ± 46	Jn 52
52	C_2H_2-1/2 Cr52	45.42 ± 6	Du 50a
	C_4H_4-Cr52	92.03 ± 42	Og 49
		90.88 ± 9	Co 52
	CH_3Cl 37-Cr52	47.9 ± 8	Ast 42
	1/2 Pd104-Cr52	(12.0 ± 2)	Du 50a
	1/3 Gd156-Cr52	33.1 ± 6	Gr 39
		33.46 ± 13	Ho 54
53	C_4H_5-Cr53	100.87 ± 41	Og 49
		98.38 ± 8	Co 52
	1/2 Pd106-Cr53	10.55 ± 16	Du 50a
54	C_4H_6-Cr54	110.00 ± 46	Og 49
		107.9 ± 2	Co 52
25 Mn 55	C_4H_7-Mn55	116.58 ± 11	Co 52
	1/2 Pd110-Mn55	14.8 ± 3	Du 50a
	1/2 Cd110-Mn55	13.92 ± 17	Du 50c
	1/3 Ho165-Mn55	28.3 ± 3	Ho 54
26 Fe 54	C_2H_3-1/2 Fe54	53.76 ± 11	Du 50a
	C_4H_6-Fe54	106.53 ± 47	Og 49
		107.20 ± 5	Co 52
	1/2 Pd108-Fe54	12.15 ± 11	Du 50a
56	N14-1/4 Fe56	17.2 ± 6	De 38
	C_2H_4-1/2 Fe56	64.20 ± 20	Du 50c
	CO-1/2 Fe56	27.44 ± 6	Du 50c
	Si28-1/2 Fe56	6.80 ± 6	Du 50
	C_4H_8-Fe56	(123.5 ± 17)	Ok 40
		127.13 ± 23	Og 49
		127.82 ± 10	Co 52
	1/2 Cd112-Fe56	(17.14 ± 11)	Du 50c
	1/3 Er168-Fe56	42.00 ± 15	Ho 54
57	C_4H_9-Fe57	133.81 ± 50	Og 49
		135.09 ± 9	Co 52
	1/2 Cd114-Fe57	(16.42 ± 17)	Du 50c
58	C_4H_{10}-Fe58	145.88 ± 47	Og 49
		144.8 ± 4	Co 52
	1/4 Th232-Fe58	76.4 ± 3	St 52
27 Co 59	1/2 Sn118-Co59	17.64 ± 12	St 52
28 Ni 58	C_2H_5-1/2 Ni58	72.38 ± 20	Sh 49
		71.72 ± 12	Du 50c
	COH-1/2 Ni58	35.06 ± 12	Du 50c
28 Ni 58	Si29-1/2 Ni58	8.90 ± 6	Du 50
		8.95 ± 6	St 52
	C_4H_{10}-Ni58	137.12 ± 40	Ok 41
		143.38 ± 9	Co 52
	1/2 Cd116-Ni58	17.46 ± 12	Du 50c
	1/2 Sn116-Ni58	15.43 ± 6	Du 50c
		(16.01 ± 12)	Du 51a
		15.35 ± 9	St 52
60	Si30-1/2 Ni60	8.70 ± 3	Du 50
	C_5-Ni60	69.59 ± 31	Ok 41
		71.4 ± 5	Sh 49
		70.20 ± 29	Co 52
	1/2 Sn120-Ni60	(21.66 ± 18)	Du 51a
		20.07 ± 15	Du 52
	1/3 Hf180-Ni60	51.42 ± 18	Du 51b
61	C_5H-Ni61	73.5 ± 15	Ok 41
		80.8 ± 5	Sh 49
		78.29 ± 23	Co 52
	1/2 Sn122-Ni61	22.6 ± 6	Du 51a
		22.2 ± 4	Du 52
	1/2 Te122-Ni61	20.90 ± 15	Ho 52a
	1/3 W183-Ni61	(51.79 ± 12)	Du 50
62	C_5H_2-Ni62	86.07 ± 37	Ok 41
		91.4 ± 3	Sh 49
		88.69 ± 8	Co 52
	1/2 Sn124-Ni62	(26.2 ± 3)	Du 51a
		23.78 ± 12	Ho 52
	1/2 Te124-Ni62	22.97 ± 19	Ho 52
	1/3 W186-Ni62	(55.99 ± 12)	Du 50
64	O_2-1/2 Ni64	26.40 ± 10	Du 51b
	S32-1/2 Ni64	8.48 ± 6	Du 51b
	C_5H_4-Ni64	104.48 ± 54	Ok 41
	C_4C13H_3-Ni64	102.5 ± 5	Sh 49
	S32O_2-Ni64	34.69 ± 7	Co 52
	1/2 Te128-Ni64	24.40 ± 15	Ho 52a
	1/3 Os192-Ni64	59.90 ± 24	Pen 54
29 Cu 63	C_5H_3-Cu63	94.39 ± 5	Co 52
	1/2 Te126-Cu63	22.7 ± 5	Du 51b
	1/3 Os189-Cu63	56.6 ± 3	Pen 54
65	C_5H_5-Cu65	111.59 ± 5	Co 52
	1/2 Te130-Cu65	25.9 ± 4	Du 51b
		25.7 ± 2	Ho 52a
	1/3 Pt195-Cu65	58.0 ± 7	De 38
		(69.8 ± 13)	Du 42
		60.00 ± 10	Du 50
30 Zn 64	O-1/4 Zn64	12.29	De 48
		(12.70)	Du 50
	O_2-1/2 Zn64	25.246 ± 22	Co 52
		* 25.38 ±	Kr 54
	C_5H_4-Zn64	98.2 ± 7	Og 49
	SO_2-Zn64	32.682 ± 20	Co 52
	1/2 Te128-Zn64	(25.0 ± 5)	Du 51b
	1/3 Pt192-Zn64	(59.1 ± 2)	Du 50
66	C_5H_6-Zn66	121.4 ± 4	Og 49
		120.87 ± 5	Co 52
	1/3 Pt198-Zn66	62.2 ± 3	Du 50
	1/3 Hg198-Zn66	* 63.10	Kr 54
67	C_5H_7-Zn67	128.0 ± 6	Og 49
		128.08 ± 5	Co 52
	1/3 Hg201-Zn67	* 62.91	Kr 54
68	OH-1/4 Zn68	21.13	De 48

TABLE III—*Continued.*

Element Z A	Doublet	ΔM in mMU	Reference
30 Zn 68	C_5H_8-Zn68	135.6 ± 6	Og 49
		137.51 ± 6	Co 52
	1/3 Hg204-Zn68	* 66.57 ±	Kr 54
70	C_5H_{10}-Zn70	134.6 ± 16	Og 49
		152.88 ± 5	Co 52
31 Ga 69	C_5H_9-Ga69	144.75 ± 4	Co 54
	1/2 Ba138-Ga69	26.56 ± 20	Ho 54
	1/3 Pb207-Ga69	65.53 ± 20	Ho 53
71	C_5H_{11}-Ga71	161.30 ± 8	Co 54
32 Ge 70	C_5H_{10}-Ge70	154.30 ± 6	Co 54
	1/2 Ce140-Ge70	(29.8 ± 2)	Du 51b
		28.4 ± 3	Ho 53
72	C_5H_{12}-Ge72	172.35 ± 5	Co 54
	1/2 Nd144-Ge72	(34.9 ± 5)	Du 51b
		33.15 ± 10	Ho 53
	1/2 Sm144-Ge72	33.4 ± 4	Ho 54
73	C_6H-Ge73	84.51 ± 3	Co 54
	1/2 Nd146-Ge73	(33.9 ± 6)	Du 51b
		32.90 ± 20	Ho 54
74	C_6H_2-Ge74	94.68 ± 6	Co 54
	1/2 Nd148-Ge74	37.40 ± 10	Ho 54
	1/2 Sm148-Ge74	35.95 ± 20	Ho 54
76	C_6H_4-Ge76	110.05 ± 4	Co 54
	1/2 Sm152-Ge76	38.10 ± 10	Ho 53
33 As 75	C_6H_3-As75	101.79 ± 4	Co 54
	1/2 Nd150-As75	38.55 ± 20	Ho 53
		38.70 ± 20	Ho 54
	1/2 Sm150-As75	36.2 ± 4	Ho 54
34 Se 74	C_6H_2-Se74	93.14 ± 7	Co 54
	1/2 Nd148-Se74	36.15 ± 20	Ho 54
	1/2 Sm148-Se74	35.0 ± 3	Ho 54
76	C_6H_4-Se76	112.06 ± 4	Co 54
	1/2 Sm152-Se76	40.7 ± 3	Ho 53
77	1/2 Sm154-Se77	40.90 ± 15	Ho 54
	1/2 Gd154-Se77	40.50 ± 10	Ho 54
78	1/2 Gd156-Se78	43.75 ± 10	Ho 54
80	C_6H_9-HSe80	146.17 ± 4	Co 54
	1/2 Gd160-Se80	47.15 ± 10	Ho 54
	1/2 Dy160-Se80	45.50 ± 40	Ho 54
82	C_6H_{12}-H_2Se82	161.66 ± 4	Co 54
	1/2 Dy164-Se82	47.6 ± 4	Ho 54
	1/2 Er164-Se82	48.2 ± 2	Ho 54
35 Br 79	C_6H_7-Br79	136.42 ± 5	Co 54
	1/2 Br79-C_3H_3	†436.18 ± 23	Og 49
	1/2 Gd158-Br79	43.30 ± 10	Ho 54
81	C_6H_9-Br81	154.05 ± 5	Co 54
	1/2 Br81-C_3H_4	†427.00 ± 16	Og 49
	1/2 Dy162-Br81	46.4 ± 3	Ho 54
36 Kr 78	C_3H_3-1/2 Kr78	63.5 ± 8	Ast 42
		63.37 ± 9	Co 53
		63.40 ± 4	Co 54
80	C_3H_4-1/2 Kr80	72.89 ± 5	Co 53
82	C_3H_5-1/2 Kr82	82.8 ± 6	Ast 42
		(82.90 ± 13)	Ke 51
		82.45 ± 5	Co 53
		82.65 ± 15	Ho 53
		82.419 ± 28	Co 54
83	1/2 Kr83-C_3H_5	†418.70 ± 20	Co 53
36 Kr 83	C_6H_{11}-Kr83	172.07 ± 5	Co 54
84	C_3H_6-1/2 Kr84	91.3 ± 6	Ast 42
		(91.01 ± 13)	Ke 51
		91.30 ± 5	Co 53
		91.30 ± 15	Ho 53
		91.220 ± 26	Co 54
86	C_3H_7-1/2 Kr86	99.3 ± 6	Ast 42
		99.44 ± 5	Co 53
		99.407 ± 32	Co 54
	C_2OH_3-1/2 Kr86	(63.66 ± 15)	Ke 51
	1/3 Xe129-1/2 Kr86	(13.57 ± 13)	Ke 51
		12.75 ± 15	Ho 53
37 Rb 85	C_6H_{13}-Rb85	189.75 ± 6	Co 54
	1/2 Er170-Rb85	55.8 ± 4	Ho 54
87	$C_5H_{11}O$-Rb87	171.73 ± 17	Co 54
38 Sr 84	C_6H_{12}-Sr84	180.70 ± 15	Co 54
86	C_3H_7-1/2 Sr86	(101.0 ± 3)	Du 51a
	C_2OH_3-1/2 Sr86	64.0 ± 4	Du 51a
	C_6H_{14}-Sr86	200.25 ± 10	Co 54
	Si29$F19_3$-Sr86	(77)	Ma 37
	1/2 Yb172-Sr86	53.3 ± 13	Gr 39
87	$C_5H_{11}O$-Sr87	172.05 ± 6	Co 54
	Si30$F19_3$-Sr87	(74)	Ma 37
	1/2 Yb174-Sr87	53.8 ± 13	Gr 39
88	CO_2-Sr88	37.00 ± 18	Du 51a
	$C_4H_8O_2$-Sr88	146.46 ± 11	Co 54
	1/2 Hf176-Sr88	(62.6 ± 4)	Du 51b
		64.4 ± 3	Ho 54
39 Y 89	C_8H_9-Y89	169.84 ± 11	Co 54
	1/2 Hf178-Y89	(62.9 ± 4)	Du 51b
		65.8 ± 3	Ho 54
40 Zr 90	Si30-1/3 Zr90	5.64 ± 12	Du 50b
	C_7H_6-Zr90	142.66 ± 25	Co 54
	1/2 Hf180-Zr90	(69.3 ± 3)	Du 51b
		68.55 ± 15	Ho 54
91	1/2 W182-Zr91	71.4 ± 18	De 38
		67.8 ± 4	Du 51b
		67.75 ± 15	Ho 54
94	1/2 Os188-Zr94	71.34 ± 12	Ge 53
96	1/2 Os192-Zr96	71.8 ± 2	Ge 53
41 Nb 93	C_7H_9-Nb93	164.81 ± 8	Co 54
	1/2 W186-Nb93	69.7 ± 3	Kr 54
42 Mo 92	1/2 W184-Mo92	68.4 ± 2	Ge 53
94	1/3 Pr141-1/2 Mo94	(16.2 ± 2)	Du 51b
	1/2 Os188-Mo94	73.1 ± 28	De 38
		72.56 ± 16	Ge 53
95	1/2 Os190-Mo95	73.7 ± 29	De 38
		73.0 ± 2	Ho 54
96	C_2-1/4 Mo96	23.71 ± 7	Du 50b
	1/3 Nd144-1/2 Mo96	17.57 ± 14	Du 51b
	1/2 Os192-Mo96	72.8 ± 29	De 38
		75.46 ± 14	Ge 53
	1/2 Pt192-Mo96	79.7 ± 29	De 38
97	1/2 Pt194-Mo97	74.7 ± 19	De 38
		75.47 ± 19	Du 51a
98	1/2 Pt196-Mo98	75.3 ± 20	De 38
		77.6 ± 3	Du 51a
100	C_2H-1/4 Mo100	31.18 ± 8	Du 50b

TABLE III—*Continued.*

Element Z A	Doublet	ΔM in mMU	Reference
42 Mo 100	1/3Nd150-1/2 Mo100	20.45 ± 20	Du 51b
44 Ru 96	1/2 Os192-Ru96	75.9 ± 19	De 38
		73.4 ± 13	Gr 39
		72.44 ± 17	Ge 53
98	1/2 Pt196-Ru98	77.03 ± 25	Pen 54
99	1/2 Pt198-Ru99	81.8 ± 20	De 38
		78.4 ± 10	Gr 39
		76.33 ± 20	Pen 54
102	1/2 Pb204-Ru102	82.4 ± 3	Ho 52b
104	1/2 Pb208-Ru104	82.83 ± 15	Ho 52b
45 Rh 103	1/2 Pb206-Rh103	82.0 ± 15	De 38
		81.76 ± 10	Ho 52b
46 Pd 102	C_4H_3-1/2 Pd102	71.06 ± 4	Ha 52
	1/2 Pb204-Pd102	82.3 ± 20	De 38
		81.0 ± 4	Ho 52b
104	C_2H_2-1/4 Pd104	39.88 ± 10	Du 50a
	C_4H_4-1/2 Pd104	79.68 ± 5	Ha 52
	1/2 Pd104-Cr52	(12.0 ± 2)	Du 50a
	1/2 Pb208-Pd104	82.8 ± 16	De 38
		(84.8 ± 4)	Du 51a
		83.77 ± 10	Ho 52b
105	C_8H_9-Pd105	165.65 ± 14	Ha 52
106	C_4H_5-1/2 Pd106	87.83 ± 9	Ha 52
	1/2 Pd106-Cr53	10.55 ± 16	Du 50a
	C_8H_{10}-Pd106	175.11 ± 18	Ha 52
108	C_2H_3-1/4 Pd108	47.90 ± 8	Du 50a
	C_4H_6-1/2 Pd108	95.24 ± 5	Ha 52
	1/2 Pd108-Fe54	12.15 ± 11	Du 50a
110	C_4H_7-1/2 Pd110	102.56 ± 6	Ha 52
	1/2 Pd110-Mn55	14.8 ± 3	Du 50a
48 Cd 106	C_4H_5-1/2 Cd106	86.18 ± 7	Ha 52
108	C_4H_6-1/2 Cd108	94.94 ± 5	Ha 52
110	C_4H_7-1/2 Cd110	103.10 ± 6	Ha 52
	1/2 Cd110-Mn55	13.92 ± 16	Du 50c
111	C_8H_{15}-Cd111	213.15 ± 8	Ha 52
112	C_4H_8-1/2 Cd112	110.98 ± 5	Ha 52
	1/2 Cd112-Fe56	(17.14 ± 11)	Du 50c
	C_8H_{16}-Cd112	222.43 ± 9	Ha 52
113	C_8H_{17}-Cd113	228.61 ± 9	Ha 52
114	C_4H_9-1/2 Cd114	118.66 ± 7	Ha 52
	C_3H_5O-1/2 Cd114	82.30 ± 6	Ha 52
	1/2 Cd114-Fe57	(16.42 ± 17)	Du 50c
116	C_3H_6O-1/2 Cd116	89.39 ± 6	Ha 52
	1/2 Cd116-Ni58	17.46 ± 12	Du 50c
49 In 113	C_8H_{17}-In113	228.77 ± 10	Ha 52
115	C_9H_7-In115	151.20 ± 10	Ha 52
50 Sn 115	C_9H_7-Sn115	151.46 ± 25	Ha 52
116	C_3H_6O-1/2 Sn116	90.78 ± 9	Ha 52
	1/2 Sn116-Ni58	15.43 ± 6	Du 50c
		(16.01 ± 12)	Du 51a
		15.35 ± 9	St 52
	C_9H_8-Sn116	160.47 ± 14	Ha 52
	1/2 Th232-Sn116	117.6 ± 12	De 38
		116.7 ± 4	St 52
117	C_3H_3-1/3 Sn117	55.26 ± 16	Du 51a
	C_9H_9-Sn117	167.37 ± 9	Ha 52
	1/2 U234-Sn117	117.1 ± 3	St 52
50 Sn 118	C_3H_7O-1/2 Sn118	98.63 ± 13	Ha 52
	1/2 Sn118-Co59	17.64 ± 12	St 52
	C_9H_{10}-Sn118	176.29 ± 19	Ha 52
119	C_9H_{11}-Sn119	182.97 ± 11	Ha 52
	1/2 U238-Sn119	123.9 ± 12	De 38
		120.4 ± 11	Gr 39
		121.2 ± 3	St 52
120	C_5-1/2 Sn120	48.92 ± 7	Ha 52
	1/2 Sn120-Ni60	(21.66 ± 18)	Du 51a
		20.07 ± 15	Du 52
122	C_5H-1/2 Sn122	56.11 ± 7	Ha 52
	1/2 Sn122-Ni61	22.6 ± 6	Du 51
		22.2 ± 4	Du 52
124	C_5H_2-1/2 Sn124	63.05 ± 5	Ha 52
	1/2 Sn124-Ni62	(26.2 ± 3)	Du 51a
		23.78 ± 12	Ho 52
52 Te 120	C_9H_{12}-Te120	189.45 ± 15	Ha 52
122	C_5H-1/2 Te122	56.39 ± 4	Ha 52
	1/2 Te122-Ni61	20.9 ± 3	Ho 52a
123	1/2 Te123-C_5H	†444.49 ± 20	Ha 52
124	C_5H_2-1/2 Te124	64.11 ± 5	Ha 52
	1/2 Te124-Ni62	22.97 ± 19	Ho 52
125	1/2 Te125-C_5H_2	†436.80 ± 16	Ha 52
126	C_5H_3-1/2 Te126	71.56 ± 3	Ha 52
	1/2 Te126-Cu63	22.7 ± 5	Du 51b
128	1/2 Te128-Zn64	(25.0 ± 5)	Du 51b
	1/2 Te128-Ni64	24.4 ± 3	Ho 52a
	$C_{10}H_8$-Te128	157.09 ± 12	Ha 52
130	C_5H_5-1/2 Te130	85.67 ± 4	Ha 52
	1/2 Te130-Cu65	25.9 ± 4	Du 51b
		25.7 ± 2	Ho 52a
	1/3 Pt195-1/2 Te130	35.4 ± 7	Du 51b
53 I 127	$C_{10}H_7$-I127	150.16 ± 12	Ha 52
54 Xe 124	C_5H_2-1/2 Xe124	62.61 ± 3	Ha 52
126	C_3H_3-1/2 Xe126	71.27 ± 7	Ha 52
128	$C_{10}H_8$-Xe128	159.13 ± 7	Ha 52
129	C_3H_7-1/3 Xe129	86.7 ± 4	Ast 42
		86.65 ± 13	Ke 51
		86.54 ± 4	Ha 52
	C_2OH_3-1/3 Xe129	50.22 ± 13	Ke 51
	1/3 Xe129-1/2 Kr86	(13.57 ± 13)	Ke 51
		12.75 ± 15	Ho 53
130	C_5H_5-1/2 Xe130	87.43 ± 4	Ha 52
131	CO_2-1/3 Xe131	†354.93 ± 14	Ha 52
132	C_2H_4O-1/3 Xe132	(57.56 ± 13)	Ke 51
	CO_2-1/3 Xe132	21.59 ± 9	Ke 51
		21.80 ± 5	Ha 52
	C_5H_6-1/2 Xe132	95.00 ± 6	Ha 52
134	C_5H_7-1/2 Xe134	102.22 ± 5	Ha 52
136	C_5H_8-1/2 Xe136	109.15 ± 4	Ha 52
56 Ba 138	1/3 Ba138-1/2 Zr92	16.5 ± 2	Du 51b
	1/2 Ba138-Ga69	26.56 ± 20	Ho 54
	1/3 Pb207-1/2 Ba138	38.8 ± 3	St 52
		38.97 ± 13	Ho 54
58 Ce 140	1/2 Ce140-Ge70	(29.8 ± 2)	Du 51b
		28.4 ± 3	Ho 53
59 Pr 141	1/3 Pr141-Ti47	17.11 ± 14	Du 51b

TABLE III—*Continued.*

Element Z A	Doublet	ΔM in mMU	Reference
59 Pr 141	1/3 Pr141-Ti47	16.97 ± 10	Ho 54
	1/3 Pr141-1/2 Mo94	(11.9 ± 2)	Du 51b
60 Nd 144	1/3 Nd144-Ti48	22.23 ± 10	Ho 53
	1/3 Nd144-1/2 Mo96	17.57 ± 14	Du 51b
	1/2 Nd144-Ge72	(34.9 ± 5)	Du 51b
		33.15 ± 10	Ho 53
146	1/2 Nd146-Ge73	32.90 ± 20	Ho 54
148	1/2 Nd148-Ge74	37.40 ± 10	Ho 54
	1/2 Nd148-Se74	36.15 ± 20	Ho 54
150	1/3 Nd150-Ti50	25.8 ± 5	De 38a
		28.40 ± 17	Ho 53
	1/3 Nd150-1/2 Mo100	20.45 ± 20	Du 51b
	1/2 Nd150-As75	38.55 ± 20	Ho 53
		38.70 ± 20	Ho 54
62 Sm 144	1/2 Sm144-Ge72	33.4 ± 4	Ho 54
148	1/2 Sm148-Ge74	35.95 ± 20	Ho 54
	1/2 Sm148-Se74	35.0 ± 3	Ho 54
150	1/2 Sm150-As75	36.2 ± 4	Ho 54
152	1/2 Sm152-Ge76	38.10 ± 10	Ho 54
	1/2 Sm152-Se76	40.7 ± 3	Ho 54
154	1/2 Sm154-Se77	40.90 ± 15	Ho 54
64 Gd 154	1/2 Gd154-Se77	40.50 ± 10	Ho 54
156	1/3 Gd156-Cr52	33.1 ± 6	Gr 39
		33.46 ± 13	Ho 54
	1/2 Gd156-Se78	43.75 ± 10	Ho 54
158	1/2 Gd158-Br79	43.30 ± 10	Ho 54
160	1/2 Gd160-Se80	47.15 ± 10	Ho 54
66 Dy 160	1/2 Dy160-Se80	45.5 ± 4	Ho 54
162	1/2 Dy162-Br81	46.4 ± 3	Ho 54
164	1/2 Dy164-Se82	47.6 ± 4	Ho 54
67 Ho 165	1/3 Ho165-Mn55	28.3 ± 3	Ho 54
68 Er 164	1/2 Er164-Se82	48.25 ± 20	Ho 54
168	1/3 Er168-Fe56	42.00 ± 10	Ho 54
170	1/2 Er170-Rb85	55.8 ± 4	Ho 54
70 Yb 172	1/2 Yb172-Sr86	53.3 ± 13	Gr 39
174	1/2 Yb174-Sr87	53.8 ± 12	Gr 39
72 Hf 176	1/2 Hf176-Sr88	(62.6 ± 4)	Du 51b
		64.4 ± 3	Ho 54
178	1/2 Hf178-Y89	(62.9 ± 4)	Du 51b
		65.8 ± 3	Ho 54
180	1/3 Hf180-Ni60	51.42 ± 18	Du 51b
	1/2 Hf180-Zr90	(69.3 ± 3)	Du 51b
		68.55 ± 15	Ho 54
74 W 182	1/2 W182-Zr91	71.4 ± 18	De 38
		67.8 ± 4	Du 51b
		67.75 ± 15	Ho 54
183	1/3 W183-Ni61	(51.79 ± 12)	Du 50
184	1/2 W184-Zr92	74.1 ± 18	De 38
		69.3 ± 4	Du 51b
		69.79 ± 14	Ge 53
186	1/3 W186-Ni62	(55.99 ± 12)	Du 50
	1/2 W186-Nb93	69.7 ± 3	Kr 54
76 Os 188	1/2 Os188-Zr94	71.34 ± 12	Ge 53
76 Os 188	1/2 Os188-Mo94	73.1 ± 28	De 38
		72.56 ± 16	Ge 53
189	1/3 Os189-Cu63	56.6 ± 3	Pen 54
190	1/2 Os190-Mo95	73.7 ± 29	De 38
		73.00 ± 20	Ho 54
192	1/3 Os192-Ni64	59.90 ± 24	Pen 54
	1/2 Os192-Zr96	71.8 ± 2	Ge 53
	1/2 Os192-Mo96	72.8 ± 29	De 38
		75.46 ± 14	Ge 53
	1/2 Os192-Ru96	75.9 ± 19	De 38
		73.4 ± 13	Gr 39
		72.44 ± 17	Ge 53
78 Pt 192	1/3 Pt192-Zn64	(59.14 ± 19)	Du 50
	1/2 Pt192-Mo96	79.7 ± 29	De 38
194	1/2 Pt194-Mo97	74.7 ± 19	De 38
		75.47 ± 19	Du 51a
195	C_3H_3-1/5 Pt195	30.65 ± 12	Du 50a
	1/3 Pt195-Cu65	58.0 ± 7	De 38
		(69.81 ± 13)	Du 42
		60.00 ± 10	Du 50
	1/3 Pt195-1/2 Te130	35.4 ± 7	Du 51b
196	1/2 Pt196-Mo98	75.3 ± 20	De 38
		77.6 ± 3	Du 51a
	1/2 Pt196-Ru98	77.03 ± 25	Pen 54
198	1/3 Pt198-Zn66	62.2 ± 3	Du 50
	1/2 Pt198-Ru99	81.8 ± 20	De 38
		78.4 ± 10	Gr 39
		76.33 ± 20	Pen 54
80 Hg 198	1/3 Hg198-Zn66	* 63.10	Kr 54
201	1/3 Hg201-Zn67	* 62.91	Kr 54
204	1/3 Hg204-Zn68	* 66.57	Kr 54
82 Pb 204	1/2 Pb204-Ru102	82.4 ± 3	Ho 52b
	1/2 Pb204-Pd102	82.3 ± 20	De 38
		81.0 ± 4	Ho 52b
206	1/2 Pb206-Rh103	82.0 ± 16	De 38
		81.76 ± 10	Ho 52b
207	1/3 Pb207-Ga69	65.53 ± 20	Ho 53
	1/3Pb207-1/2 Ba138	38.8 ± 4	St 52
		38.96 ± 13	Ho 54
208	1/2 Pb208-Ru104	82.83 ± 15	Ho 52b
	1/2 Pb208-Pd104	82.8 ± 16	De 38
		(84.8 ± 4)	Du 51a
		83.77 ± 10	Ho 52b
90 Th 232	1/4 Th232-Fe58	76.4 ± 3	St 52
	1/2 Th232-Sn116	117.6 ± 12	De 38
		116.7 ± 4	St 52
92 U 234	1/2 U234-Sn117	117.1 ± 3	St 52
238	1/2 U238-Sn119	123.9 ± 12	De 38
		120.4 ± 11	Gr 39
		121.2 ± 3	St 52

which were later superseded by improved values in the same laboratory. Thus, instead of listing all of the mass differences reported by Aston at one time or another, we have included only those given by him in *Mass Spectra and Isotopes*,[7] which he obviously considered to be his best values. Among more recent results all doublet differences which have been published have been included. This leads to the inclusion of two or more values from the same laboratory for certain doublets. Here the reader should assume that the most recent value supersedes the earlier ones. Parentheses have the same significance as in Table II. An asterisk indicates a tentative unpublished result and a † indicates a value not properly a doublet.

In Table III the doublet measurements are arranged by elements in order of increasing atomic number Z, and all doublets except those involving C, H, and O are entered twice. Thus, for example, the doublet $\mathrm{Ne}20-\frac{1}{2}\mathrm{A}40$ appears under both neon and argon (with the mass number A placed on the line rather than as a superscript). Within a particular element group the doublets are arranged by isotopes and the various values for any one doublet are listed in chronological order.

As in Table II there are no "best values" given in Table III. This is not a problem in the many cases where there is only one measurement of the doublet. However, in the many other cases, where there are discordant values, we are not attempting to select one as being superior to the others. The problem of reconciling discrepant results here is similar to that described in the preceding section in connection with the fundamental doublets, although it is not as acute, since there has not been as concerted an attack upon the doublets containing heavier atoms.

TABLE IV. Nondoublet time-of-flight mass measurements.

Z	Element	Isotope	Mass (a.m.u.)	Reference
16	Sulfur	32	31.983 ±1	Hay 51a
17	Chlorine	35	34.9805±5	Hay 51a
19	Potassium	41–39	2.000 ±1	Hay 51
		41	40.975 ±2	Hay 51a
35	Bromine	79	78.944 ±1	Hay 51a
		81	80.943 ±1	Hay 51a
36	Krypton	84	83.938 ±1	Hay 51a
37	Rubidium	85	84.9310±15	Hay 51a
		87	86.9295±20	Hay 51a
		87–85	1.999 ±1	Hay 51
53	Iodine	127	(126.9415±25)	Hay 51a
			126.946 ±1	Hay 52
54	Xenon	129	128.9455±15	Hay 51a
		130	129.945 ±2	Hay 51a
		131	130.944 ±2	Hay 51a
		132	131.945 ±2	Hay 51a
		134	133.947 ±2	Hay 51a
82	Lead	208	208.0416±15	Ri 52
83	Bismuth	209	209.0466±15	Ri 52

6. TABLE IV—NONDOUBLET TIME-OF-FLIGHT MEASUREMENTS

A number of important atomic mass measurements have been made by Hays, Richards, and Goudsmit using a helical orbit mass spectrometer which measures the time-of-flight of ions describing a number of revolutions in a uniform magnetic field. In this work the instrument has been calculated by use of two known masses, several mass units apart, lying in the same general range as the atom under study. The results of these experiments are listed in Table IV.

7. ACKNOWLEDGMENTS

The preparation of these tables has been greatly assisted by much prepublication data and also by many candid comments by individuals concerning the reliability of their own work. Persons to whom thanks are due on these counts include T. L. Collins, H. Ewald, S. A. Goudsmit, J. T. Kerr, J. Mattauch, A. O. C. Nier, K. Ogata, and L. G. Smith. In checking the completeness of this tabulation the authors have made frequent use of Aston's *Mass Spectra and Isotopes*,[7] Mattauch and Flammersfeld's "1949 Isotope Report,"[3] and Bainbridge's article on mass spectroscopy in *Experimental Nuclear Physics*, Volume I.[8]

BIBLIOGRAPHY

Asa 39 Asada, Okuda, Ogata, and Yoshimoto, Nature **143**, 797 (1939); Proc. Phys. Math. Soc. Japan **22**, 41 (1940).
Ast 42 F. W. Aston, *Mass Spectra and Isotopes* (Edward Arnold and Company, London, 1942).
Ba 33 K. T. Bainbridge, Phys. Rev. **44**, 56 (1933).
Ba 36 K. T. Bainbridge, and E. B. Jordan, Phys. Rev. **49**, 883 (1936).
Ba 37 K. T. Bainbridge and E. B. Jordan, Phys. Rev. **51**, 384 (1937).
Ba 38 K. T. Bainbridge, Phys. Rev. **53**, 922 (1938).
Bo 39 A. Bönisch, dissertation, Wien, 1939.
Co 51 Collins, Nier, and Johnson, Phys. Rev. **84**, 717 (1951).
Co 52 Collins, Nier, and Johnson, Phys. Rev. **86**, 408 (1952).
Co 53 T. L. Collins, "Mass Spectroscopy in Physics Research," Natl. Bur. Standards Circ. No. 522 (1953).
Co 54 Collins, Johnson, and Nier, Phys. Rev. **94**, 398 (1954).
Da 53 C. C. Damm and L. G. Smith, Phys. Rev. **91**, 482 (1953).
De 38 A. J. Dempster, Phys. Rev. **53**, 64 (1938).
De 38a A. J. Dempster, Phys. Rev. **53**, 869 (1938).
De 48 A. J. Dempster, Phys. Rev. **74**, 1225 (1948).
Du 42 H. E. Duckworth, Phys. Rev. **62**, 19 (1942).
Du 50 Duckworth, Johnson, Preston, and Woodcock, Phys. Rev. **78**, 386 (1950).
Du 50a Duckworth, Woodcock, and Preston, Phys. Rev. **78**, 479 (1950).
Du 50b Duckworth, Preston, and Woodcock, Phys. Rev. **79**, 188 (1950).
Du 50c H. E. Duckworth and R. S. Preston, Phys. Rev. **79**, 402 (1950).
Du 51 Duckworth, Stanford, Olson, and Kegley, Phys. Rev. **81**, 286 (1951).
Du 51a H. E. Duckworth and R. S. Preston, Phys. Rev. **82**, 468 (1951).
Du 51b Duckworth, Kegley, Olson, and Stanford, Phys. Rev. **83**, 1114 (1951).
Du 52 H. E. Duckworth, "Atomic Masses for Elements with $Z>21$," U. S. Atomic Energy Commission—NYO—981 (April 18, 1952).

---

[7] Reference Ast 42.

[8] K. T. Bainbridge, *Experimental Nuclear Physics*, E. Segrè, editor (John Wiley and Sons, Inc., New York, 1953), Vol. I.

Eng 53 A. Engler and H. Hintenberger, Helv. Phys. Acta **26**, 657 (1953).

Ew 46 H. Ewald, Z. Naturforsch. **1**, 131 (1946).

Ew 50 H. Ewald, Z. Naturforsch. **5a**, 1 (1950).

Ew 51 H. Ewald, Z. Naturforsch. **6a**, 293 (1951).

Ew 53 H. Ewald, Z. Naturforsch. **8a**, 447 (1953).

Fl 43 S. Flügge and J. Mattauch, Physik. Z. **44**, 181 (1943).

Ge 53 Geiger, Hogg, Duckworth, and Dewdney, Phys. Rev. **89**, 621 (1953).

Gr 39 A. C. Graves, Phys. Rev. **55**, 863 (1939).

Hay 51 Hays, Richards, and Goudsmit, Phys. Rev. **82**, 345 (1951).

Hay 51a Hays, Richards, and Goudsmit, Phys. Rev. **84**, 824 (1951).

Hay 52 Hays, Richards, and Goudsmit, Phys. Rev. **85**, 1065 (1952).

Ha 52 R. E. Halstead, Phys. Rev. **88**, 666 (1952).

Ho 52 B. G. Hogg and H. E. Duckworth, Phys. Rev. **86**, 567 (1952).

Ho 52a B. G. Hogg and H. E. Duckworth, Can. J. Phys. **30**, 628 (1952).

Ho 52b B. G. Hogg and H. E. Duckworth, Can. J. Phys. **30**, 637 (1952).

Ho 53 B. G. Hogg and H. E. Duckworth, Can. J. Phys. **31**, 942 (1953).

Ho 54 B. G. Hogg and H. E. Duckworth, Can. J. Phys. **32**, 65 (1954).

Jn 52 W. H. Johnson, Jr., Phys. Rev. **87**, 166 (1952).

Jn 52a W. H. Johnson, Jr., Phys. Rev. **88**, 1213 (1952).

Jo 36 E. B. Jordan and K. T. Bainbridge, Phys. Rev. **49**, 883 (1936).

Jo 36a E. B. Jordan and K. T. Bainbridge, Phys. Rev. **50**, 98 (1936).

Jo 37 E. B. Jordan and K. T. Bainbridge, Phys. Rev. **51**, 385 (1937).

Jo 40 E. B. Jordan, Phys. Rev. **58**, 1009 (1940).

Jo 41 E. B. Jordan, Phys. Rev. **60**, 710 (1941).

Ke 51 C. L. Kegley and H. E. Duckworth, Nature **167**, 1025 (1951).

Kr 54 J. T. Kerr, (unpublished).

Ma 36 J. Mattauch, Sitzber. Akad. Wiss. Wien Math. naturw. Kl. Abt. IIa, 145, 461 (1936); Phys. Rev. **50**, 617 (1936).

Ma 37 J. Mattauch, Naturwissenschaften **25**, 170 (1937).

Ma 37a J. Mattauch and R. Herzog, Naturwissenschaften **25**, 747 (1937).

Ma 37b J. Mattauch, Physik. Z. **38**, 951 (1937).

Ma 38 J. Mattauch, Physik. Z. **39**, 892 (1938).

Ma 54 J. Mattauch and R. Bieri, Z. Naturforsch. **9a**, 303 (1954).

Ne 46 E. P. Ney and A. K. Mann, Phys. Rev. **69**, 239 (1946).

Ni 51 A. O. C. Nier and T. R. Roberts, Phys. Rev. **81**, 507 (1951).

Ni 51a A. O. C. Nier, Phys. Rev. **81**, 624 (1951).

Og 49 K. Ogata, Phys. Rev. **75**, 200 (1949).

Og 53 K. Ogata and H. Matsuda, Phys. Rev. **89**, 27 (1953).

Og 53a K. Ogata and H. Matsuda, Phys. Rev. **89**, 333 (1953).

Ok 40 Okuda, Ogata, Aoki, and Sugawara, Phys. Rev. **58**, 578 (1940).

Ok 41 Okuda, Ogata, Kuroda, Shima, and Shindo, Phys. Rev. **59**, 104 (1941).

Ok 41a T. Okuda and K. Ogata, Phys. Rev. **60**, 690 (1941).

Pen 54 E. M. Pennington, (unpublished).

Ra 48 W. Rall, Phys. Rev. **73**, 1222 (1948).

Ri 52 Richards, Hays, and Goudsmit, Phys. Rev. **85**, 630 (1952).

Ro 50 T. R. Roberts, and A. O. C. Nier, Phys. Rev. **77**, 746 (1950).

Ro 51 T. R. Roberts, Phys. Rev. **81**, 624 (1951).

Sh 49 A. E. Shaw, Phys. Rev. **75**, 1011 (1949).

Sm 51 L. G. Smith, Phys. Rev. **81**, 295 (1951).

Sm 53 L. G. Smith and C. C. Damm, Phys. Rev. **90**, 324 (1953).

Sm 53a L. G. Smith (1953, unpublished).

Sm 53b L. G. Smith and C. C. Damm, (1953, unpublished).

So 51 Sommer, Thomas, and Hipple, Phys. Rev. **82**, 697 (1951).

St 52 Stanford, Duckworth, Hogg, and Geiger, Phys. Rev. **85**, 1039 (1952).

Erratum: The Energies of Natural Alpha Particles

G. H. Briggs
Division of Physics, National Standards Laboratory,
Commonwealth Scientific and Industrial Research Organization,
Sydney, Australia

[Revs. Modern Phys. **26**, 1 (1954)]

In Table III, for "Collins *et al.*, Weight 4," read "Collins *et al.*, Weight 3."

In Table IV, last line, read "Mean 3.31649±0.0008 S.E."

In Table V, read

Z	Isotope	$H\rho$ 10^5 oe cm	Alpha-particle energy, Mev	Disintegration energy, Mev
83	Bi^{214} α_0			5.6100
	(RaC) α_1			5.5478
84	Po^{210}	3.31649	5.3007	5.4037
	Po^{215}			7.523
	(AcA)			
86	Rn^{219}			
	(An) α_1			6.664

Erratum: On the Convergence of Born Expansions

Walter Kohn
Institute for Theoretical Physics, Copenhagen, Denmark, and Department of Physics, Carnegie Institute of Technology, Pittsburgh 13, Pennsylvania

[Revs. Modern Phys. **26**, 292 (1954)]

The captions for Figs. 1–3 were unfortunately interchanged. The proper captions are:

Fig. 1. Radius of convergence, λ_c, for the square well, $l=0$. For $k<2.3$ the singularity of smallest absolute value is positive (attractive potential), for $k>2.3$, negative. Thus the portions I and II represent the absolute values of two different singularities.

Fig. 2. Radius of convergence, λ_c, for the square well, $l=1$. Note the initial decrease of λ_c.

Fig. 3. Radius of convergence, λ_c, for the square well, $l=2$.

It may also be helpful to point out that the printer uses the symbol **n** to denote a bold face η (see headings on pp. 292, 293, 309).