Section 7

ATOMIC AND MOLECULAR PHYSICS[1]

H. M. CROSSWHITE, Editor

The Johns Hopkins University

CONTENTS

[1] Sections 7a through 7d were originally prepared by the previous editor, the late G. H. Dieke. Where no contributor is specifically mentioned, the material was compiled by the section editor.

7a. The Periodic System

TABLE 7a-1. ALPHABETICAL LIST OF THE ELEMENTS

In later tables the elements are arranged according to increasing order number Z. This table gives in alphabetical order the names of the elements in English, French, and German, together with the chemical symbol, year of discovery, and order number of each. (A dash means that the name of the element in French or German is the same as in English.)

English	Name in French	Name in German	Year of discovery	Symbol	Z
Actinium	—	—	1899	Ac	89
Alabamine*	.....	.....	....	(Ab)	(85)
Alumin(i)um	Aluminium	Aluminium	1827	Al	13
Americium	Américium	—	1945	Am	95
Antimony	Antimoine	Antimon	Old	Sb	51
Argentum*	.....	.....	....	Ag	47
Argon	—	—	1894	A	18
Arsenic	—	Arsen	Old	As	33
Astatine	—	—	1940	At	85
Barium	—	Baryum	1808	Ba	56
Berkelium	—	—	1950	Bk	97
Beryllium	Béryllium	—	1798	Be	4
Bismuth	—	Wismut	1753	Bi	83
Boron	Bore	Bor	1808	B	5
Bromine	Brome	Brom	1826	Br	35
Cadmium	—	—	1817	Cd	48
Calcium	—	—	1808	Ca	20
Californium	—	—	1950	Cf	98
Carbon	Carbone	Kohlenstoff	Old	C	6
Cassiopeium*	.....	.....	....	Lu	71
Celtium*	.....	.....	....	(Ct)	(72)
Cerium	Cérium	Cer	1803	Ce	58
Cesium	Césium	Caesium	1860	Cs	55
Chlorine	Chlore	Chlor	1774	Cl	17
Chromium	Chrome	Chrom	1797	Cr	24
Cobalt	—	—	1735	Co	27
Columbium*	.....	.....	....	(Cb)	41
Copper	Cuivre	Kupfer	Old	Cu	29
Curium	—	—	1944	Cm	96
Deuterium	—	—	1930	D	1
Dysprosium	—	—	1886	Dy	66
Einsteinium	—	—	1955	Es	99
Emanation*	.....	.....	....	Rn	86
Erbium	—	—	1843	Er	68

TABLE 7a-1. ALPHABETICAL LIST OF THE ELEMENTS (*Continued*)

English	Name in French	Name in German	Year of discovery	Symbol	*Z*
Europium	—	—	1896	Eu	63
Fermium	—	—	1955	Fm	100
Ferrum*	.....	.....	....	Fe	26
Fluorine	Fluor	Fluor	1771	F	9
Francium	—	—	1939	Fr	87
Gadolinium	—	—	1880	Gd	64
Gallium	—	—	1875	Ga	31
Germanium	—	—	1886	Ge	32
Gold	Or	—	Old	Au	79
Hafnium	—	—	1923	Hf	72
Helium	Hélium	—	1895	He	2
Holmium	—	—	1879	Ho	67
Hydrogen	Hydrogéne	Wasserstoff	1766	H	1
Illinium*	.....	.....	....	(Il)	(61)
Indium	—	—	1863	In	49
Iodine	Iode	Jod	1811	I	53
Iridium	—	—	1803	Ir	77
Iron	Fer	Eisen	Old	Fe	26
Kalium*	.....	.....	....	K	19
Krypton	—	—	1898	Kr	36
Lanthanum	Lanthane	Lanthan	1839	La	57
Lawrencium	—	—	1961	Lw	103
Lead	Plomb	Blei	Old	Pb	82
Lithium	—	—	1817	Li	3
Lutetium	Lutétium	—	1907	Lu	71
Magnesium	Magnésium	—	1755	Mg	12
Manganese	Manganèse	Mangan	1774	Mn	25
Masurium*	.....	.....	....	(Ma)	(43)
Mendelevium	—	—	1955	Md	101
Mercury	Mercure	Quecksilber	Old	Hg	80
Molybdenum	Molybdène	Molybdän	1778	Mo	42
Natrium*	.....	.....	....	Na	11
Nebulium*					
Neodymium	Néodyme	Neodym	1885	Nd	60
Neon	Néon	—	1898	Ne	10
Neptunium	—	—	1940	Np	93
Nickel	—	—	1751	Ni	28
Niobium	—	—	1801	Nb	41
Niton	.....	.....	....	Rn	86
Nitrogen	Nitrogène	Stickstoff	1772	N	7
Nobelium	—	—	1958	No	102
Osmium	—	—	1803	Os	76
Oxygen	Oxygène	Sauerstoff	1774	O	8
Palladium	—	—	1803	Pd	46
Phosphorus	Phosphore	Phosphor	1669	P	15
Platinum	Platine	Platin	1735	Pt	78
Plumbum*	.....	.....	....	Pb	82
Plutonium	—	—	1940	Pu	94
Polonium	—	—	1898	Po	84
Potassium	—	Kalium	1807	K	19
Praseodymium	Praséodyme	Praseodym	1879	Pr	59
Prometheum	Prométheum	—	1947	Pm	61
Protactinium	—	—	1917	Pa	91
Radium	—	—	1898	Ra	88
Radon	—	—	1900	Rn	86
Rhenium	—	—	1925	Re	75
Rhodium	.....	.....	1803	Rh	45

TABLE 7a-1. ALPHABETICAL LIST OF THE ELEMENTS (*Continued*)

English	Name in French	Name in German	Year of discovery	Symbol	*Z*
Rubidium	—	—	1861	Rb	37
Ruthenium	Ruthenium	—	1844	Ru	44
Samarium	—	—	1879	Sm	62
Scandium	—	—	1879	Sc	21
Selenium	Sélénium	Selen	1817	Se	34
Silicon	Silicium	Silicium	1823	Si	14
Silver	Argent	Silber	Old	Ag	47
Sodium	—	Natrium	1807	Na	11
Stannum*	.....	.....	....	Sn	50
Stibium*	.....	.....	....	Sb	51
Strontium	—	—	1790	Sr	38
Sulfur	Soufre	Schwefel	Old	S	16
Tantalum	Tantale	Tantal	1802	Ta	73
Technetium	—	—	1937	Tc	43
Tellurium	Tellure	Tellur	1782	Te	52
Terbium	—	—	1843	Tb	65
Thallium	—	—	1861	Tl	81
Thorium	—	—	1828	Th	90
Thulium	—	—	1870	Tm	69
Tin	Etain	Zinn	Old	Sn	50
Titanium	Titane	Titan	1791	Ti	22
Tritium	—	—	....	T	1
Tungsten	Tungstène	Wolfram	1781	W	74
Uranium	—	Uran	1789	U	92
Vanadium	—	—	1830	V	23
Virginium*	.....	.....	....	(Vi)	(87)
Wolfram*	.....	.....	....	W	74
Xenon	Xénon	—	1898	Xe	54
Ytterbium	—	—	1878	Yb	70
Yttrium	—	—	1794	Y	39
Zinc	—	Zink	1746	Zn	30
Zirconium	—	Zircon	1789	Zr	40

* Alternate or obsolete names. An order number between parentheses means that the discovery of the element was an error and another element has taken its place. Element symbols between parentheses have been given up.

TABLE 7a-2. PERIODIC SYSTEM OF THE ELEMENTS

1 H 2																2 He 1, 3
3 Li 2	4 Be 1, 3											5 B 2	6 C 1, 3	7 N 2, 4	8 O 1, 3, 5	9 F 2, 4	10 Ne 1, 3
11 Na 2	12 Mg 1, 3											13 Al 2	14 Si 1, 3	15 P 2, 4	16 S 3, 5	17 Cl 2, 4	18 A 1, 3
19 K 2	20 Ca 1, 3	21 Sc 2, 4	22 Ti 1, 3, 5	23 V 2, 4, 6	24 Cr 1, 3, 5, 7	25 Mn 2, 4, 6, 8	26 Fe 1, 3, 5, 7	27 Co 2, 4, 6	28 Ni 1, 3, 5	29 Cu 2, 4	30 Zn 1, 3	31 Ga 2, 4	32 Ge 1, 3	33 As 2, 4	34 Se 3, 5	35 Br 2, 4	36 Kr 1, 3
37 Rb 2	38 Sr 1, 3	39 Y 2, 4	40 Zr 1, 3, 5	41 Nb 2, 4, 6	42 Mo 1, 3, 5, 7	43 Tc 4, 6, 8	44 Ru 3, 5, 7	45 Rh 2, 4	46 Pd 1, 3, 5	47 Ag 2, 4	48 Cd 1, 3	49 In 2, 4	50 Sn 1, 3	51 Sb 2, 4	52 Te 1, 3, 5	53 I 2, 4	54 Xe 1, 3
55 Cs 2	56 Ba 1, 3	57 La 2, 4	* 72 Hf 1, 3, 5	73 Ta 4, 6	74 W 5, 7	75 Re 4, 6, 8	76 Os 3, 5, 7	77 Ir 4, 6	78 Pt 1, 3, 5	79 Au 2	80 Hg 1, 3	81 Tl 2	82 Pb 1, 3	83 Bi 2, 4	84 Po 3	85 At	86 Rn 1, 3
87 Fr 2	88 Ra 1, 3	89 Ac 2	†														

*Lanthanides (rare earths)	58 Ce 1, 3, 5	59 Pr 4	60 Nd 5	61 Pm 6	62 Sm 7, 9	63 Eu 6, 8, 10	64 Gd 7, 9, 11	65 Tb 6, 8	66 Dy 5	67 Ho 4	68 Er 1, 3, 5	69 Tm 2	70 Yb 1, 3	71 Lu 2, 4
†Actinides	90 Th 3, 5	91 Pa 4	92 U 5, 7	93 Np 6	94 Pu 7	95 Am 8	96 Cm 9	97 Bk	98 Cf	99 Es	100 Fm	101 Md	102 No	103 Lw

The numbers under the elements indicate the observed multiplicity in the first spectrum. The value for the ground state is underlined.

TABLE 7a-3. PROPERTIES OF ELEMENTS*

Z	Symbol	Element	Atomic wt.†	Valency	Atomic diam in Å	Mass No. and (abundance)
(1)	(2)	(3)	(4)	(5)	(6)	(7)
1	H	Hydrogen	1.00797	1	3.0	1(99.985), 2(0.0146)
2	He	Helium	4.0026	0	.....	4(100), 3(1.3 × 10^{-4})
3	Li	Lithium	6.939	1	3.13	7(92.48), 6(7.52)
4	Be	Beryllium	9.0122	2	2.25	9(100)
5	B	Boron	10.811	3	.....	11(81.17), 10(18.83)
6	C	Carbon	12.01115	±4, 2	1.54	12(98.9), 13(1.1)
7	N	Nitrogen	14.0067	−3, 5, 2	1.06	14(99.635), 15(0.365)
8	O	Oxygen	15.9994	−2	.....	16(99.76), 18(0.204), 17(0.039)
9	F	Fluorine	18.9984	−1	1.36	10(100)
10	Ne	Neon	20.183	0	3.20	20(90.92), 22(8.82), 21(0.257)
11	Na	Sodium	22.9898	1	3.83	23(100)
12	Mg	Magnesium	24.312	2	3.20	24(78.60), 26(11.29), 25(10.11)
13	Al	Aluminum	26.9815	3	2.82	27(100)
14	Si	Silicon	28.086	4	2.34	28(92.28), 29(4.67), 30(3.05)
15	P	Phosphorus	30.9738	5, ±3	2.16	31(100)
16	S	Sulfur	32.064	6, 4, −2	2.12	32(95.018), 34(4.215), 33(0.74), 36(0.016)
17	Cl	Chlorine	35.453	±1, 7, 5	1.94	35(75.4), 37(24.6)
18	A	Argon	39.948	0	3.82	40(99.60), 36(0.337), 38(0.060)
19	K	Potassium	39.102	1	4.76	39(93.1), 41(6.9), 40‡(0.012)
20	Ca	Calcium	40.08	2	3.93	40(96.96), 44(2.06), 42(0.64), 48(0.19), 43(0.15), 46(0.0033)
21	Sc	Scandium	44.956	3	3.20	45(100)
22	Ti	Titanium	47.90	4, 3	2.93	48(73.45), 46(7.95), 47(7.75), 49(5.51), 50(5.34)
23	V	Vanadium	50.942	5, 4, 2	2.71	51(99.76), 50(0.24)
24	Cr	Chromium	51.996	6, 3, 2	2.57	52(83.76), 53(9.55), 50(4.31), 54(2.38)
25	Mn	Manganese	54.9380	7, 4, 2, 6, 3	2.5	55(100)
26	Fe	Iron	55.847	3, 2	2.52	56(91.64), 54(5.81), 57(2.21), 58(0.34)
27	Co	Cobalt	58.9332	3, 2	2.50	59(100)
28	Ni	Nickel	58.71	2, 3	2.49	58(67.76), 60(26,16), 62(3.66), 61(1.25), 64(1.16)
29	Cu	Copper	63.54	2, 1	2.551	63(69.09), 65(30.91)
30	Zn	Zinc	65.37	2	2.746	64(48.89), 66(27.81), 68(18.61), 67(4.07), 70(0.620)
31	Ga	Gallium	69.72	3	2.7	69(60.2), 71(39.8)
32	Ge	Germanium	72.59	4	2.788	74(36.74), 72(27.37), 70(20.55), 76(7.67), 73(7.61)
33	As	Arsenic	74.9216	5, ±3	2.50	75(100)
34	Se	Selenium	78.96	6, 4, −2	2.32	80(49.82), 78(23.52), 82(9.19), 76(9.02), 77(7.58), 74(0.87)
35	Br	Bromine	79.909	±1, 5	2.26	79(50.5), 81(49.5)
36	Kr	Krypton	83.80	0	4.0	84(56.90), 86(17.37), 82(11.55), 83(11.56), 80(2.27), 78(0.354)
37	Rb	Rubidium	85.47	1	5.02	85(72.15), 87(27.85)
38	Sr	Strontium	87.62	2	4.29	88(82.56), 86(9.86), 87(7.02), 84(0.56)
39	Y	Yttrium	88.905	3	3.62	89(100)
40	Zr	Zirconium	91.22	4	3.19	90(51.46), 94(17.40), 92(17.11), 91(11.23), 96(2.80)
41	Nb	Niobium	92.906	5, 3	2.94	93(100)
42	Mo	Molybdenum	95.94	6, 3, 5	2.80	98(23.75), 96(16.5), 92(15.86), 95(15.7), 100(9.62), 97(9.45), 94(9.12)
43	Tc	Technetium	(99)	7		
44	Ru	Ruthenium	101.07	3, 4, 6, 8	2.67	102(31.34), 104(18.27), 101(16.98), 99(12.81), 100(12.70), 96(5.7), 98(2.22)
45	Rh	Rhodium	102.905	3, 4	2.7	103(100)
46	Pd	Palladium	106.4	2, 4	2.745	106(27.2), 109(26.8), 105(22.6), 110(13.5), 104(9.3), 102(0.8)
47	Ag	Silver	107.870	1	2.883	107(51.35), 109(48.65)

TABLE 7a-3. PROPERTIES OF ELEMENTS* (*Continued*)

Z	Symbol	Element	Atomic wt.†	Valency	Atomic diam in Å	Mass No. and (abundance)
(1)	(2)	(3)	(4)	(5)	(6)	(7)
48	Cd	Cadmium	112.40	2	3.042	114(28.86), 112(24.07), 111(12.75), 110(12.39), 113(12.26), 116(7.58), 106(1.215), 108(0.875)
49	In	Indium	114.82	3	3.14	115(95.77), 113(4.23)
50	Sn	Tin	118.69	4, 2	3.164	120(33.03), 118(23.98), 116(14.07), 119(8.62), 117(7.54), 124(6.11), 122(4.78), 112(0.90), 114(0.61), 115(0.35)
51	Sb	Antimony	121.75	3, 5	3.228	121(57.25), 123(42.75)
52	Te	Tellurium	127.60	4, 6, −2	2.9	130(34.46), 128(31.72), 126(18.72), 125(7.01), 124(4.63), 122(2.49), 123(0.89), 120(0.091)
53	I	Iodine	126.9044	−1, 5, 7	2.7	127(100)
54	Xe	Xenon	131.30	0	4.4	132(26.96), 129(26.44), 131(21.17), 134(10.44), 136(8.95), 130(4.07), 128(1.90), 124(0.094), 126(0.088)
55	Cs	Cesium	132.905	1	5.40	133(100)
56	Ba	Barium	137.34	2	4.48	138(71.66), 137(11.32), 136(7.81), 135(6.59), 134(2.42), 130(0.101), 132(0.097)
57	La	Lanthanum	138.91	3	3.741	139(99.91) 138(0.089)
58	Ce	Cerium	140.12	3, 4	3.64	140(88.48), 142(11.07), 138(0.250), 136(0.193)
59	Pr	Praesodymium	140.907	3	3.65	141(100)
60	Nd	Neodymium	144.24	3	3.63	142(27.13), 144(23.87), 146(17.18), 143(12.20), 145(8.30), 148(5.72), 150(5.60)
61	Pm	Promethium	(145)	3		
62	Sm	Samarium	150.35	3	.....	152(26.63), 154(22.53), 147(15.07), 149(13.84), 148(11.27), 150(7.47), 144(3.16)
63	Eu	Europium	151.96	3, 2	4.08	153(52.23), 151(47.77)
64	Gd	Gadolinium	157.25	3	3.59	158(24.78), 160(21.79), 156(20.59), 157(15.71), 155(14.78), 154(2.15), 152(0.20)
65	Tb	Terbium	158.924	3	3.54	159(100)
66	Dy	Dysprosium	162.50	3	3.54	164(28.18), 162(25.53), 163(24.97), 161(18.88), 160(2.294), 158(0.0902), 156(0.0524)
67	Ho	Holmium	164.930	3	3.52	165(100)
68	Er	Erbium	167.26	3	3.50	166(33.41), 168(27.07), 167(22.94), 170(14.88), 164(1.56), 162(0.1)
69	Tm	Thulium	168.934	3	3.48	169(100)
70	Yb	Ytterbium	173.04	3, 2	3.87	174(31.84), 172(21.82), 173(16.13), 171(14.26), 176(12.73), 170(3.03), 168(0.14)
71	Lu	Lutetium	174.97	3	3.47	175(97.5), 176(2.5)
72	Hf	Hafnium	178.49	4	3.17	180(35.11), 178(27.10), 177(18.47), 179(13.85), 176(5.30), 174(0.18)
73	Ta	Tantalum	180.948	5	2.94	181(100)
74	W	Wolfram	183.85	6	2.82	184(30.68), 186(29.17), 182(25.77), 183(14.24), 180(0.122)
75	Re	Rhenium	186.2	7, 4, −1	2.75	187(62.93), 185(37.07)
76	Os	Osmium	190.2	4, 6, 8	2.70	192(41.0), 190(26.4), 189(16.1), 188(13.3), 187(1.64), 186(1.59), 184(0.018)
77	Ir	Iridium	192.2	3, 4, 6	2.709	193(61.5), 191(38.5)
78	Pt	Platinum	195.09	4, 2	2.769	195(33.7), 194(32.8), 196(25.4), 198(7.23), 192(0.78), 190(0.012)
79	Au	Gold	196.967	3, 1	2.878	197(100)

TABLE 7a-3. PROPERTIES OF ELEMENTS* (*Continued*)

Z	Symbol	Element	Atomic wt.†	Valency	Atomic diam in Å	Mass No. and (abundance)
(1)	(2)	(3)	(4)	(5)	(6)	(7)
80	Hg	Mercury	200.59	2, 1	3.10	202(29.80), 200(23.13), 199(16.84), 201(13.2), 198(10.02), 204(6.85), 196(0.15)
81	Tl	Thallium	204.37	1, 3	3.42	205(70.5), 203(29.5)
82	Pb	Lead	207.19	2, 4	3.49	208(52.3), 206(23.6), 207(22.6), 204(1.5), 202(<0.0004)
83	Bi	Bismuth	208.980	3, 5	3.64	209(100)
84	Po	Polonium	(210)	2, 4	.....	210‡
85	At	Astatine	(210)	.....	.....	206‡, 215‡
86	Rn	Radon	(222)	0	.....	222‡
87	Fr	Francium	(223)	1	.....	223‡
88	Ra	Radium	(226.05)	2	.....	226‡, 228‡, 224‡, 223‡
89	Ac	Actinium	(227)	3	.....	227‡, 228‡
90	Th	Thorium	232.038	4	3.6	232‡(100)
91	Pa	Protactinium	(231)	5	.....	231‡
92	U	Uranium	238.03	6, 5, 4, 3	3.0	238‡(99.28), 235‡(0.715), 234‡(0.0058)
93	Np	Neptunium	(237)	6, 5, 4, 3	.....	237‡, 239‡
94	Pu	Plutonium	(242)	6, 5, 4, 3	.....	238‡, 239‡, 242‡
95	Am	Americium	(243)	3	.....	243‡
96	Cm	Curium	(247)	3	.....	247‡
97	Bk	Berkelium	(249)	4, 3	.....	249‡
98	Cf	Californium	(251)	3	.....	251‡
99	Es	Einsteinium	.....	.....	.....	254‡
100	Fm	Fermium	.....	.....	.....	255‡
101	Md	Mendelevium	.....	.....	.....	256‡
102	No	Nobelium	.....	.....	.....	255‡
103	Lw	Lawrencium	.....	.....	.....	257‡

* Much of the material in this table was taken from Henry D. Hubbard and William F. Meggers, "Key to Periodic Chart of the Atoms," 1950. Courtesy of W. M. Welch Manufacturing Company, Chicago.

† Official 1961 values based on carbon-12; courtesy of the International Union of Pure and Applied Chemistry and Butterworth Publications. The atomic weight of some elements varies because of natural variations in the isotope composition. The observed ranges are B, ±0.003; C, ±0.00005; H, ±0.00001; O, ±0.0001; Si, ±0.001; S, ±0.003. In order to convert the atomic weights given in the table for those based on oxygen-16, multiply by 1.0003203.

‡ Radioactive element; mass number of the most abundant or most stable isotope.