SECTION 4

PROPERTIES OF ATOMS, RADICALS, AND BONDS

4.1 ELEMENTS

The electronic configuration for an element's ground state (Table 4.1) is a shorthand representation giving the number of electrons (superscript) found in each of the allowed sublevels (*s, p, d, f*) above a noble gas core (indicated by brackets). In addition, values for the thermal conductivity, the electrical resistance, and the coefficient of linear thermal expansion are included.

TABLE 4.1 Electronic Configuration and Properties of the Elements

Name	Symbol	Atomic number	Electronic configuration	Thermal conductivity, $W \cdot (m \cdot K)^{-1}$ at 25°C	Electrical resistivity, $\mu\Omega \cdot cm$ at 20°C	Coefficient of linear thermal expansion (25°C), $m \cdot m^{-1}(\times 10^6)$
Actinium	Ac	89	[Rn] $6d^2\ 7s$	12		
Aluminum	Al	13	[Ne] $3s^2\ 3p$	237	2.6548	23.1
Americium	Am	95	[Rn] $5f^7\ 7s^2$	10		
Antimony (stibium)	Sb	51	[Kr] $4d^{10}\ 5s^2\ 5p^3$	24.4	41.7	11.0
Argon	Ar	18	[Ne] $3s^2\ 3p^6$	0.017 72		
Arsenic	As	33	[Ar] $3d^{10}\ 4s^2\ 4p^3$	50.2	33.3	
Astatine	At	85	[Xe] $4f^{14}\ 5d^{10}\ 6s^2\ 6p^5$	1.7		
Barium	Ba	56	[Xe] $6s^2$	18.4	33.2	20.6
Berkelium	Bk	97	[Rn] $5f^8\ 6d\ 7s^2$	10		
Beryllium	Be	4	[He] $2s^2$	200	3.56	11.3
Bismuth	Bi	83	[Xe] $4f^{14}\ 5d^{10}\ 6s^2\ 6p^3$	7.97	129	13.4
Boron	B	5	[He] $2s^2\ 2p$	27.4	1.5×10^{12}	5–7
Bromine	Br	35	[Ar] $3d^{10}\ 4s^2\ 4p^5$	0.122	7.8×10^{18}	
Cadmium	Cd	48	[Kr] $4d^{10}\ 5s^2$	96.6	7.27 (22°C)	30.8
Calcium	Ca	20	[Ar] $4s^2$	201	3.36	22.3
Californium	Cf	98	[Rn] $5f^{10}\ 7s^2$			
Carbon	C	6	[He] $2s^2\ 2p^2$			
(amorphous)				1.59		
(diamond)				900–2320	0.8	
(graphite)				119–165	1375	
Cerium	Ce	58	[Xe] $4f\ 5d\ 6s^2$	11.3	82.8 (β, hex)	6.3
Cesium	Cs	55	[Xe] $6s$	35.9	20.5	
Chlorine	Cl	17	[Ne] $3s^2\ 3p^5$	0.0089	$>10^9$	
Chromium	Cr	24	[Ar] $3d^5\ 4s$	93.9	12.5	4.9
Cobalt	Co	27	[Ar] $3d^7\ 4s^2$	100	6.24	13.0
Copper (cuprum)	Cu	29	[Ar] $3d^{10}\ 4s$	401	1.678	16.5
Curium	Cm	96	[Rn] $5f^7\ 6d\ 7s^2$			
Dysprosium	Dy	66	[Xe] $4f^{10}\ 6s^2$	10.7	92.6	9.9
Einsteinium	Es	99	[Rn] $5f^{11}\ 7s^2$			
Erbium	Er	68	[Xe] $4f^{14}\ 6s^2$	14.5	86.0	12.2
Europium	Eu	63	[Xe] $4f^7\ 6s^2$	13.9	90.0	35.0

Fermium	Fm	100	[Rn] $5f^{12}$ $7s^2$			
Fluorine	F	9	[He] $2s^2$ $2p^5$	0.0277		
Francium	Fr	87	[Rn] $7s$			
Gadolinium	Gd	64	[Xe] $4f^7$ $5d$ $6s^2$	10.5	131	9.4 (100°C)
Gallium	Ga	31	[Ar] $3d^{10}$ $4s^2$ $4p$	29.4(lq) 40.6(c)	25.795 (30°C)	120
Germanium	Ge	32	[Ar] $3d^{10}$ $4s^2$ $4p^2$	60.2	53 000	6.0
Gold (aurum)	Au	79	[Xe] $4f^{14}$ $5d^{10}$ $6s$	318	2.214	14.2
Hafnium	Hf	72	[Xe] $4f^{14}$ $5d^2$ $6s^2$	23.0	33.1	5.9
Helium	He	2	$1s^2$	0.1513		
Holmium	Ho	67	[Xe] $4f^{11}$ $6s^2$	16.2	81.4	11.2
Hydrogen	H	1	$1s$	0.1805		
Indium	In	49	[Kr] $4d^{10}$ $5s^2$ $5p$	81.8	8.37	32.1
Iodine	I	53	[Kr] $4d^{10}$ $5s^2$ $5p^5$	449	1.3×10^{15} (0°C)	
Iridium	Ir	77	[Xe] $4f^{14}$ $5d^7$ $6s^2$	147	4.71	6.4
Iron (ferrum)	Fe	26	[Ar] $3d^6$ $4s^2$	80.4	9.61	11.8
Krypton	Kr	36	[Ar] $3d^{10}$ $4s^2$ $4p^6$	9.43		
Lanthanum	La	57	[Xe] $5d$ $6s^2$	13.4	61.5	12.1
Lawrencium	Lr	103	[Rn] $4f^{14}$ $6d$ $7s^2$			
Lead (plumbum)	Pb	82	[Xe] $4f^{14}$ $5d^{10}$ $6s^2$ $6p^2$	35.3	20.8	28.9
Lithium	Li	3	$1s^2$ $2s$	84.8	9.28	46
Lutetium	Lu	71	[Xe] $4f^{14}$ $5d$ $6s^2$	16.4	58.2	9.9
Magnesium	Mg	12	[Ne] $3s^2$	156	4.39	24.8
Manganese	Mn	25	[Ar] $3d^5$ $4s^2$	7.81	144	21.7
Mendelevium	Md	101	[Rn] $5f^{13}$ $7s^2$			
Mercury (hydrargyrum)	Hg	80	[Xe] $4f^{14}$ $5d^{10}$ $6s^2$	8.30	95.8(lq); 21(c)	
Molybdenum	Mo	42	[Kr] $4d^5$ $5s$	138	5.34	4.8
Neodymium	Nd	60	[Xe] $4f^4$ $6s^2$	16.5	64.3	9.6
Neon	Ne	10	$1s^2$ $2s^2$ $2p^6$	0.0491		
Neptunium	Np	93	[Rn] $5f^4$ $6d$ $7s^2$	6.3	122.0 (22°C)	
Nickel	Ni	28	[Ar] $3d^8$ $4s^2$	90.9	6.93	13.4
Niobium	Nb	41	[Kr] $4d^4$ $5s$	53.7	15.2 (0°C)	7.3
Nitrogen	N	7	$1s^2$ $2s^2$ $2p^3$	0.025 83		
Nobelium	No	102	[Rn] $5f^{14}$ $7s^2$			
Osmium	Os	76	[Xe] $4f^{14}$ $5d^6$ $6s^2$	87.6	8.12 (0°C)	5.1
Oxygen	O	8	$1s^2$ $2s^2$ $2p^4$	0.026 58 (g) 0.149 (lq)		
Palladium	Pd	46	[Kr] $4d^{10}$	71.8	10.54	11.8

TABLE 4.1 Electronic Configuration and Properties of the Elements (*Continued*)

Name	Symbol	Atomic number	Electronic configuration	Thermal conductivity, $W \cdot (m \cdot K)^{-1}$ at 25°C	Electrical resistivity, $\mu\Omega \cdot cm$ at 20°C	Coefficient of linear thermal expansion (25°C), $m \cdot m^{-1}(\times 10^6)$
Phosphorus (white)	P	15	[Ne] $3s^2\ 3p^3$	0.236 17	10	
Platinum	Pt	78	[Xe] $4f^{14}\ 5d^9\ 6s$	71.6	10.6	8.8
Plutonium	Pu	94	[Rn] $5f^6\ 7s^2$	6.74	146.0 (0°C)	46.7
Polonium	Po	84	[Xe] $4f^{14}\ 5d^{10}\ 6s^2\ 6p^4$	0.2	40.0 (0°C) alpha	
Potassium (kalium)	K	19	[Ar] $4s$	102.5	7.2	
Praseodymium	Pr	59	[Xe] $4f^3\ 6s^2$	12.5	70.0	6.7
Promethium	Pm	61	[Xe] $4f^5\ 6s^2$	17.9	64.0 (25°C)	est [11.]
Protactinium	Pa	91	[Rn] $5f^2\ 6d\ 7s^2$	47	19.1 (22°C)	
Radium	Ra	88	[Rn] $7s^2$	18.6	100	
Radon	Rn	86	[Xe] $4f^{14}\ 5d^{10}\ 6s^2\ 6p^6$	0.003 61		
Rhenium	Re	75	[Xe] $5f^{14}\ 5d^5\ 6s^2$	48.0	19.3	6.2
Rhodium	Rh	45	[Kr] $4d^8\ 5s$	150	4.33 (0°C)	8.2
Rubidium	Rb	37	[Kr] $5s$	58.2	12.8	
Ruthenium	Ru	44	[Kr] $4d^7\ 5s$	117	7.1 (0°C)	6.4
Samarium	Sm	62	[Xe] $4f^6\ 6s^2$	13.3	94.0	12.7
Scandium	Sc	21	[Ar] $3d\ 4s^2$	15.8	56.2	10.2
Selenium (amorphous)	Se	34	[Ar] $3d^{10}\ 4s^2\ 4p^4$	0.519	1.2 (0°C)	37
Silicon	Si	14	[Ne] $3s^2\ 3p^2$	149	10^5	

Silver (argentum)	Ag	47	[Kr] $4d^{10}$ $5s$	429	1.587	18.9
Sodium (natrium)	Na	11	[Ne] $3s$	142	4.77	71
Strontium	Sr	38	[Kr] $5s^2$	35.4	13.2	22.5
Sulfur (amorphous)	S	16	[Ne] $3s^2$ $3p^4$	0.205	2×10^{23}	
Tantalum	Ta	73	[Xe] $4f^{14}$ $5d^3$ $6s^2$	57.5	13.5	6.3
Technetium	Tc	43	[Kr] $4d^5$ $5s^2$	50.6	22.6 (100°C)	
Tellurium	Te	52	[Kr] $4d^{10}$ $5s^2$ $5p^4$	1.97–3.38	$(5.8–33) \times 10^3$	
Terbium	Tb	65	[Xe] $4f^9$ $6s^2$	11.1	115	10.3
Thallium	Tl	78	[Xe] $4f^{14}$ $5d^{10}$ $6s^2$ $6p$	46.1	18	29.9
Thorium	Th	90	[Rn] $6d^2$ $7s^2$	54.0	15.4 (22°C)	11.1
Thullium	Tm	69	[Xe] $4f^{13}$ $6s^2$	16.9	67.6	13.3
Tin (stannum)	Sn	50	[Kr] $4d^{10}$ $5s^2$ $5p^2$	66.8	11.5 (0°C)	22.0
Titanium	Ti	22	[Ar] $3d^2$ $4s^2$	21.9	42.0	8.6
Tungsten (wolframium)	W	74	[Xe] $4f^{14}$ $5d^4$ $6s^2$	173	5.28	4.5
Uranium	U	92	[Rn] $5f^3$ $6d$ $7s^2$	27.5	28.0 (0°C)	13.9
Vanadium	V	23	[Ar] $3d^3$ $4s^2$	30.7	19.7	8.4
Xenon	Xe	54	[Kr] $4d^{10}$ $5s^2$ $5p^6$	0.005 65		
Ytterbium	Yb	70	[Xe] $4f^{14}$ $6s^2$	38.5	25	26.3
Yttrium	Y	39	[Kr] $4d$ $5s^2$	17.2	59.6	10.6
Zinc	Zn	30	[Ar] $3d^{10}$ $4s^2$	116	5.9	30.2
Zirconium	Zr	40	[Kr] $4d^2$ $5s^2$	22.6	42.1	5.7

Source: Ho, C. Y., Powell, R. W., and Liley, P. E., *J. Phys. Chem. Ref. Data 3:*Suppl. 1 (1974), (thermal conductivity); Ho, C. Y., et al., *J. Phys. Chem. Ref. Data*, **12:**183 (1983); **13:**1069, 1097, 1131 (1984), (electrical resistivity); Touloukian, Y. S., *Thermophysical Properties of Matter*, Vol. 12, *Thermal Expansion*, Plenum, New York, 1975.

4.2 IONIZATION ENERGY

TABLE 4.2 Ionization Energy of the Elements

The minimum amount of energy required to remove the least strongly bound electron from a gaseous atom (or ion) is called the ionization energy and is expressed in MJ · mol^{-1}. Remember that 96.485 kJ = 1.000 eV = 23.0605 kcal. In Table 4.2 the successive stages of ionization are indicated by the heading of each column: I denotes first spectra arising from a neutral atom; viz.,

$$M(\text{gas}) \rightarrow M^{+}(\text{gas}) + e^{-}$$

II, second spectra from singly ionized atoms, and so on for successive stages of ionization.

At. no.	Element	Spectrum (in MJ · mol^{-1})					
		I	II	III	IV	V	VI
1	H	1.312					
2	He	2.372	5.251				
3	Li	0.520	7.298	11.815			
4	Be	0.899	1.757	14.849	21.007		
5	B	0.801	2.427	3.660	25.027	32.828	
6	C	1.086	2.353	4.620	6.223	37.832	47.191
7	N	1.402	2.856	4.578	7.475	9.445	53.268
8	O	1.314	3.388	5.300	7.469	10.989	13.326
9	F	1.681	3.374	6.147	8.408	11.022	15.164
10	Ne	2.081	3.952	6.122	9.370	12.177	15.238
11	Na	0.496	4.562	6.912	9.543	13.353	16.610
12	Mg	0.738	1.451	7.733	10.540	13.629	17.994
13	Al	0.578	1.817	2.745	11.577	14.831	18.377
14	Si	0.786	1.577	3.231	4.355	16.091	19.784
15	P	1.012	1.903	2.912	4.956	6.274	21.268
16	S	1.000	2.251	3.361	4.564	7.004	8.495
17	Cl	1.251	2.297	3.822	5.158	6.54	9.362
18	Ar	1.521	2.666	3.931	5.771	7.238	8.787
19	K	0.419	3.051	4.411	5.877	7.976	9.649
20	Ca	0.590	1.145	4.912	6.474	8.144	10.496
21	Sc	0.631	1.235	2.389	7.089	8.844	10.719
22	Ti	0.658	1.310	2.652	4.175	9.573	11.516
23	V	0.650	1.414	2.828	4.507	6.299	12.362
24	Cr	0.653	1.592	2.987	4.743	6.70	8.738
25	Mn	0.717	1.509	3.248	4.94	6.99	9.22
26	Fe	0.759	1.561	2.957	5.63	7.24	9.56
27	Co	0.758	1.646	3.232	4.95	7.67	9.84
28	Ni	0.737	1.753	3.393	5.30	7.34	10.4
29	Cu	0.745	1.958	3.555	5.536	7.70	9.9
30	Zn	0.906	1.733	3.833	5.73	7.95	10.4
31	Ga	0.579	1.979	2.963	6.2		
32	Ge	0.762	1.537	3.302	4.410	9.022	
33	As	0.947	1.798	2.735	4.837	6.043	12.31
34	Sc	0.941	2.045	2.974	4.143	6.99	7.883
35	Br	1.140	2.10	3.47	4.56	5.76	8.55
36	Kr	1.351	2.350	3.565	5.07	6.24	7.57
37	Rb	0.403	2.632	3.9	5.08	6.85	8.14
38	Sr	0.549	1.064	4.138	5.5	6.91	8.76
39	Y	0.616	1.181	1.980	5.96	7.43	8.97
40	Zr	0.660	1.267	2.218	3.313	7.75	

TABLE 4.2 Ionization Energy of the Elements (*Continued*)

At. no.	Element	Spectrum (in MJ · mol^{-1}) I	II	III	IV	V	VI
41	Nb	0.664	1.382	2.416	3.695	4.877	9.847
42	Mo	0.685	1.558	2.621	4.477	5.91	6.641
43	Tc	0.702	1.472	2.850			
44	Ru	0.711	1.617	2.747			
45	Rh	0.720	1.744	2.997			
46	Pd	0.805	1.875	3.177			
47	Ag	0.731	2.073	3.361			
48	Cd	0.868	1.631	3.616			
49	In	0.558	1.821	2.704	5.2		
50	Sn	0.709	1.412	2.943	3.930	6.974	
51	Sb	0.834	1.595	2.44	4.26	5.4	10.4
52	Te	0.869	1.795	2.698	3.610	5.668	6.82
53	I	1.008	1.846	3.2			
54	Xe	1.170	2.046	3.099			
55	Cs	0.376	2.234				
56	Ba	0.503	0.965				
57	La	0.538	1.067	1.850	4.820	5.94	
58	Ce	0.528	1.047	1.949	3.547	6.325	7.487
59	Pr	0.523	1.018	2.086	3.761	5.551	
60	Nd	0.530	1.035	2.13	3.90		
61	Pm	0.535	1.052	2.15	3.97		
62	Sm	0.543	1.068	2.26	3.99		
63	Eu	0.547	1.085	2.40	4.12		
64	Gd	0.592	1.167	1.99	4.26		
65	Tb	0.564	1.112	2.114	3.839		
66	Dy	0.572	1.126	2.20	3.99		
67	Ho	0.581	1.139	2.204	4.10		
68	Er	0.589	1.151	2.194	4.13		
69	Tm	0.596	1.163	2.285	4.13		
70	Yb	0.603	1.174	2.417	4.203		
71	Lu	0.524	1.34	2.022	4.366		
72	Hf	0.68	1.44	2.25	3.216		
73	Ta	0.761					
74	W	0.770					
75	Re	0.760					
76	Os	0.84					
77	Ir	0.88					
78	Pt	0.87	1.791				
79	Au	0.890	1.98				
80	Hg	1.007	1.810	3.30			
81	Tl	0.589	1.971	2.878			
82	Pb	0.716	1.450	3.081	4.083	6.64	
83	Bi	0.703	1.610	2.466	4.371	5.40	8.52
84	Po	0.812					
85	At						
86	Rn	1.037					
87	Fr						
88	Ra	0.509	0.979				
89	Ac	0.67	1.17				
90	Th	0.587	1.11	1.93	2.78		
91	Pa	0.568					

TABLE 4.2 Ionization Energy of the Elements (*Continued*)

At. no.	Element	Spectrum (in MJ · mol^{-1}) I	II	III	IV	V	VI
92	U	0.598					
93	Np	0.605					
94	Pu	0.585					
95	Am	0.578					
96	Cm	0.581					
97	Bk	0.601					
98	Cf	0.608					
99	Es	0.619					
100	Fm	0.627					
101	Md	0.635					
102	No	0.642					

Source: C. E. Moore, *National Standard Reference Data Series 34*, U.S. Government Printing Office, Washington, D.C., 1970; W. C. Martin, Zalubas, R., and Hagan, L., *J. Phys. Chem. Reference Data*, **3**:771 (1974) and National Standard Reference Data Series, National Bureau of Standards (U.S.), No. 60 (1978) for the Rare Earth Elements; and Cohen, E. R. and Taylor, B. N., *J. Phys. Chem. Reference Data*, **17**:1795 (1988).

TABLE 4.3 Ionization Energy of Molecular and Radical Species

This table gives the first ionization potential in MJ · mol^{-1} and in electron volts. Also listed is the enthalpy of formation of the ion at 25°C (298 K).

Compounds containing carbon

Species	Ionization energy		$\Delta_f H$ (ion)
	In MJ · mol^{-1}	In electron volts	in kJ · mol^{-1}
Acenaphthene	0.741	7.68	896
Acenaphthylene	0.793	8.22(4)	1053
Acetaldehyde	0.98696(7)	10.2290(7)	821
Acetamide	0.931(3)	9.65(3)	693
Acetic acid	1.029(2)	10.66(2)	596
Acetic anhydride	0.965	10.0	398
Acetone	0.9364	9.705	719
Acetonitrile	1.1766(5)	12.194(5)	1252
Acetophenone	0.896(3)	9.29(3)	810
Acetyl chloride	1.047(5)	10.85(5)	804
Acetyl fluoride	1.111(2)	11.51(2)	667
Acetylene	1.1000(2)	11.400(2)	1328
Allene	0.935(1)	9.69(1)	1126
Allyl alcohol	0.933(5)	9.67(5)	808
Allylamine	0.845	8.76	891
3-Amino-1-propanol	0.87	9.0	651
Aniline	0.7449(2)	7.720(2)	832
Anthracene	0.719(3)	7.45(3)	949
Azoxybenzene	0.78	8.1	1123
Azulene	0.715(2)	7.41(2)	1004
Benzaldehyde	0.916(2)	9.49(2)	878
Benzamide	0.912	9.45	811

TABLE 4.3 Ionization Energy of Molecular and Radical Species (*Continued*)

Species	Ionization energy		$\Delta_f H$ (ion) in kJ · mol^{-1}
	In MJ · mol^{-1}	In electron volts	
Benzene	0.89212(2)	9.2459(2)	975
Benzenethiol	0.801(2)	8.30(2)	913
Benzoic acid	0.914	9.47	620
Benzonitrile	0.928	9.62	1146
Benzophenone	0.873(5)	9.05(5)	923
p-Benzoquinone	0.969(2)	10.04(18)	847
Benzoyl chloride	0.920	9.54	816
Benzyl alcohol	0.82	8.5	720
Benzylamine	0.834(5)	8.64(5)	917
Biphenyl	0.767(2)	7.95(2)	950
Bromoacetylene	0.995(2)	10.31(2)	1242
Bromobenzene	0.866(2)	8.98(2)	971
Bromochlorodifluoromethane	1.141	11.83	702
Bromochloromethane	1.039(1)	10.77(1)	1085
Bromodichloromethane	1.02	10.6	973
Bromoethane	0.992	10.28	930
Bromoethylene	0.946(2)	9.80(2)	1025
Bromomethane	1.0171(3)	10.541(3)	979
1-Bromonaphthalene	0.781	8.09	956
Bromopentafluorobenzene	0.923(2)	9.57(2)	212
1-Bromopropane	0.982(1)	10.18(1)	898
2-Bromopropane	0.972(1)	10.07(1)	874
3-Bromopropene	0.972(1)	10.07(1)	1018
p-Bromotoluene	0.837(1)	8.67(1)	908
Bromotrichloromethane	1.02	10.6	980
Bromotrifluoromethane	1.10	11.4	451
1,2-Butadiene	0.871	9.03	1034
1,3-Butadiene	0.8750	9.069	985
Butanal	0.949(2)	9.84(2)	742
Butanenitrile	1.08	11.2	1110
2-Butanone	0.918(4)	9.51(4)	677
trans-2-Butenal	0.939(1)	9.73(1)	835
1-Butene	0.924(2)	9.58(2)	924
cis-2-Butene	0.8788(8)	9.108(8)	871
trans-2-Butene	0.8780(8)	9.100(8)	866
1-Buten-3-yne	0.924(2)	9.58(2)	1230
Butyl acetate	0.965	10.0	479
sec-Butyl acetate	0.955	9.90	453
Butyl ethyl ether	0.903	9.36	610
Butylbenzene	0.838(1)	8.69(1)	826
sec-Butylbenzene	0.837(1)	8.68(1)	820
tert-Butylbenzene	0.834(2)	8.64(2)	812
Butylcyclohexane	0.908	9.41	695
Butylcyclopentane	0.960(3)	9.95(3)	793
p-tert-Butylphenol	0.75	7.8	552
p-tert-Butyltoluene	0.799	8.28	745
1-Butyne	0.9821(5)	10.178(5)	1147
2-Butyne	0.9226(5)	9.562(5)	1068
Camphor	0.845(3)	8.76(3)	577
Caprolactam	0.875(2)	9.07(2)	629
Carbazole	0.730(3)	7.57(3)	961

TABLE 4.3 Ionization Energy of Molecular and Radical Species (*Continued*)

Species	Ionization energy		$\Delta_f H$ (ion) in kJ · mol^{-1}
	In MJ · mol^{-1}	In electron volts	
Carbon	1.0865	11.260	1803
Carbon (C_2)	1.188	12.31	2000
Carbon dioxide	1.3289(2)	13.773(2)	935
Carbon monoxide	1.35217	14.0139	1242
Carbon oxyselenide	1.000(1)	10.36(1)	929
Carbon oxysulfide	1.07812(15)	11.1736(15)	936
Carbon sulfide	0.97149(19)	10.0685(20)	1089
Carbon sulfide (CS)	1.093(1)	11.33(1)	1368
Carbonyl fluoride	1.257	13.03	617
Carbonyltrihydroboron (BH_3CO)	1.075(2)	11.14(2)	962
Chloroacetaldehyde	1.011(3)	10.48(3)	815
Chloroacetic acid	0.984	10.2	597
Chloroacetyl chloride	1.06	11.0	815
Chloroacetylene	1.021(2)	10.58(2)	1276
m-Chloroaniline	0.781(10)	8.09(10)	835
o-Chloroaniline	0.820	8.50	883
p-Chloroaniline	0.789	8.18	844
Chlorobenzene	0.874(2)	9.06(2)	929
Chlorodibromomethane	0.1022(1)	10.59(1)	1030
1-Chloro-1,1-difluoroethane	1.156(1)	11.98(1)	626
1-Chloro-2,2-difluoroethylene	0.946(4)	9.80(4)	628
Chlorodifluoromethane	1.18	12.2	693
Chloroethane	1.058(2)	10.97(2)	946
2-Chloroethanol	1.015	10.52	756
Chloroethylene	0.964(2)	9.99(2)	985
Chlorofluoromethane	1.130(1)	11.71(1)	870
Chloromethane	1.083(1)	11.22(1)	1001
Chloromethylene	0.949	9.84	1247
Chloromethylidine (CCl)	0.86(2)	8.9(2)	1244
1-Chloronaphthalene	0.784	8.13	906
m-Chloronitrobenzene	0.957(10)	9.92(10)	995
p-Chloronitrobenzene	0.961(10)	9.96(10)	999
Chloropentafluorobenzene	0.938(2)	9.72(2)	126
Chloropentafluoroethane	1.22	12.6	99
m-Chlorophenol	0.835	8.65	680
p-Chlorophenol	0.834	8.69	692
1-Chloropropane	1.044(3)	10.82(3)	912
2-Chloropropane	1.040(2)	10.78(2)	895
3-Chloropropene	0.96	9.9	950
m-Chlorotoluene	0.852(2)	8.83(2)	869
o-Chlorotoluene	0.852(2)	8.83(2)	869
p-Chlorotoluene	0.838(2)	8.69(2)	855
Chlorotrifluoroethylene	0.947	9.81(3)	373
Chlorotrifluoromethane	1.195	12.39	485
Chrysene	0.732	7.59(2)	1016
Coronene	0.703	7.29	1026
m-Cresol	0.800	8.29	668
o-Cresol	0.785	8.14	660
p-Cresol	0.784	8.13	659
cis-Crotonic acid	0.973	10.08	625
trans-Crotonic acid	0.96	9.9	604

TABLE 4.3 Ionization Energy of Molecular and Radical Species (*Continued*)

Species	Ionization energy		$\Delta_f H$ (ion) in kJ · mol^{-1}
	In MJ · mol^{-1}	In electron volts	
Cumene	0.842	8.73(1)	847
Cyanamide	1.00	10.4	1137
Cyanate (NCO)	1.135(1)	11.76(1)	1290
Cyanide (CN)	1.360	14.09	1795
Cyanoacetylene	1.123(1)	11.64(1)	1475
Cyanogen	1.290(1)	13.37(1)	1597
Cyanogen chloride	1.191(1)	12.34(1)	1329
Cyanogen fluoride	1.285(1)	13.32(1)	1323
Cyclobutane	0.957(5)	9.92(5)	986
Cyclobutanone	0.9025	9.354	815
Cyclobutene	0.910	9.43	1067
Cycloheptane	0.962	9.97	844
Cyclohexane	0.951(3)	9.86(3)	828
Cyclohexanol	0.941	9.75	651
Cyclohexanone	0.882(1)	9.14(1)	656
Cyclohexene	0.8631(10)	8.945(10)	859
Cyclohexylamine	0.832(23)	8.62(24)	727
Cyclohexylcyclohexane	0.908	9.41	690
Cyclooctane	0.942	9.76	817
Cyclopropane	0.951	9.86	1005
Cyclopropanecarbonitrile	0.989	10.25	1173
Cyclopropanone	0.88(1)	9.1(1)	895
Cyclopropene	0.930	9.67(1)	1209
Cyclopropylamine	0.84	8.7	916
Cyclopropylbenzene	0.806	8.35	956
cis-Decahydronaphthalene	0.893	9.26	724
trans-Decahydronaphthalene	0.892	9.24	710
Decane	0.931	9.65	682
1-Decene	0.909(1)	9.42(1)	786
Diazomethane	0.8683(1)	8.999(1)	1098
1,4-Dibromobutane	0.979	10.15	879
1,2-Dibromoethane	1.001	10.37	963
Dibromofluoromethane	1.069(3)	11.07(3)	687
Dibromomethane	1.013(2)	10.50(2)	1013
1,2-Dibromopropane	0.975	10.1	903
1,3-Dibromopropane	0.990	10.26	919
1,2-Dibromotetrafluoroethane	1.07	11.1	280
Dibutyl ether	0.910	9.43	575
Di-*sec*-butyl ether	0.879	9.11	511
Di-*tert*-butyl ether	0.850	8.81	486
Dibutyl sulfide	0.79	8.2	624
Di-*tert*-butyl sulfide	0.77	8.0	583
Dibutylamine	0.742(3)	7.69(3)	586
Dichloroacetyl chloride	1.06	11.0	819
Dichloroacetylene	0.974	10.09	1183
m-Dichlorobenzene	0.879(1)	9.11(1)	907
o-Dichlorobenzene	0.876(1)	9.08(1)	909
p-Dichlorobenzene	0.856(1)	8.89(1)	882
Dichlorodifluoromethane	1.134(4)	11.75(4)	656
Dichlorodimethylsilane	1.03	10.7	576
1,1-Dichloroethane	1.067	11.06	937

TABLE 4.3 Ionization Energy of Molecular and Radical Species (*Continued*)

Species	Ionization energy		$\Delta_f H$ (ion) in kJ · mol^{-1}
	In MJ · mol^{-1}	In electron volts	
1,2-Dichloroethane	1.065	11.04	931
1,1-Dichloroethylene	0.945(4)	9.79(4)	947
cis-1,2-Dichloroethylene	0.932(1)	9.66(1)	936
trans-1,2-Dichloroethylene	0.931(2)	9.65(2)	935
Dichlorofluoromethane	1.11	11.5	829
Dichloromethane	1.092(1)	11.32(1)	996
Dichloromethylene	1.000	10.36	1163
1,2-Dichloropropane	1.049(5)	10.87(5)	886
1,3-Dichloropropane	1.047(5)	10.85(5)	888
1,2-Dichlorotetrafluoroethane	1.18	12.2	252
Dicyclopropyl ketone	0.88	9.1	1041
1,1-Diethoxyethane	0.944	9.78	490
Diethyl oxalate	0.95	9.8	205
m-Diethylbenzene	0.819(1)	8.49(1)	798
o-Diethylbenzene	0.821	8.51	804
p-Diethylbenzene	0.810	8.40	790
Diethylene glycol dimethyl ether	0.96	9.8	448
m-Difluorobenzene	0.900(1)	9.33(1)	591
o-Difluorobenzene	0.895(1)	9.28(1)	602
p-Difluorobenzene	0.882(1)	9.14(1)	575
1,1-Difluoroethane	1.145(3)	11.87(3)	643
1,1-Difluoroethylene	0.993(1)	10.29(1)	650
cis-1,2-Difluoroethylene	0.987	10.23	690
Difluoromethane	1.226	12.71	774
Difluoromethylene	1.102(1)	11.42(1)	897
2,5-Dihydrothiophene	0.81	8.4	898
Diiodomethane	0.913(2)	9.46(2)	1030
Diisobutyl sulfide	0.807(5)	8.36(5)	627
Diisobutylamine	0.754	7.81	574
Diisopropyl ether	0.888(5)	9.20(5)	569
Diisopropyl sulfide	0.833(5)	8.63(5)	630
Diisopropylamine	0.746(3)	7.73(3)	602
Diketene	0.93(2)	9.6(2)	736
Dimethoxymethane	0.92	9.5	569
Dimethyl disulfide	0.71	7.4(3)	690
Dimethyl ether	0.9673(23)	10.025(25)	783
Dimethyl oxalate	0.965	10.0	287
o-Dimethyl phthalate	0.930(7)	9.64(7)	277
Dimethyl sulfide	0.838(1)	8.69(1)	801
Dimethyl sulfoxide	0.878	9.01	718
Dimethylamine	0.794(8)	8.23(8)	776
N,*N*-Dimethylaniline	0.687(2)	7.12(2)	787
2,2-Dimethylbutane	0.971	10.06	787
2,3-Dimethylbutane	0.967	10.02	791
3,3-Dimethyl-2-butanone	0.879(2)	9.11(2)	589
2,3-Dimethyl-1-butene	0.875(1)	9.07(1)	812
2,3-Dimethyl-2-butene	0.798(1)	8.27(1)	729
3,3-Dimethyl-1-butyne	0.946(5)	9.80(5)	1050
1,1-Dimethylcyclohexane	0.909	9.42	728
cis-1,2-Dimethylcyclohexane	<0.944	<9.78	772
cis-1,3-Dimethylcyclohexane	<0.963	<9.98	778

TABLE 4.3 Ionization Energy of Molecular and Radical Species (*Continued*)

Species	Ionization energy		$\Delta_f H$ (ion) in kJ · mol^{-1}
	In MJ · mol^{-1}	In electron volts	
cis-1,4-Dimethylcyclohexane	<0.958	<9.93	782
trans-1,2-Dimethylcyclohexane	0.908	9.41	728
trans-1,3-Dimethylcyclohexane	0.920	9.53	743
trans-1,4-Dimethylcyclohexane	0.922	9.56	738
cis-1,2-Dimethylcyclopentane	0.957(5)	9.92(5)	828
trans-1,2-Dimethylcyclopentane	0.960(5)	9.95(5)	823
N,*N*-Dimethylformamide	0.881(2)	9.13(2)	689
2,6-Dimethyl-4-heptanone	0.872(3)	9.04(3)	515
1,1-Dimethylhydrazine	0.702(4)	7.28(4)	786
2,4-Dimethyl-3-pentanone	0.864(1)	8.95(1)	552
2,3-Dimethylpyridine	0.854(2)	8.85(2)	922
2,4-Dimethylpyridine	0.854(3)	8.85(3)	918
2,5-Dimethylpyridine	0.849(5)	8.80(5)	916
2,6-Dimethylpyridine	0.847(3)	8.86(3)	913
3,4-Dimethylpyridine	0.883	9.15	953
3,5-Dimethylpyridine	0.893	9.25	965
N,*N*-Dimethyl-*o*-toluidine	0.714(2)	7.40(2)	814
1,3-Dioxane	0.95	9.8	607
1,4-Dioxane	0.887(1)	9.19(1)	571
1,3-Dioxolane	0.96	9.9	658
Diphenyl ether	0.781(3)	8.09(3)	766
Diphenylacetylene	0.762(2)	7.90(2)	1164
Diphenylamine	0.691(4)	7.16(4)	908
1,2-Diphenylethane	0.84(1)	8.7(1)	983
Diphenylmethane	0.825(3)	8.55(3)	963
Dipropyl ether	0.894(5)	9.27(5)	602
Dipropyl sulfide	0.801(2)	8.30(2)	676
Dipropylamine	0.746(3)	7.73(3)	641
Divinyl ether	0.84	8.7	827
5,7-Dodecadiyne	0.837	8.67	1079
Dodecafluorocyclohexane	1.27	13.2	−1095
Epichlorohydrin	0.98	10.2	875
1,2-Epoxybutane	0.98	10.15	862
Ethane	1.112(1)	11.52(1)	1027
1,2-Ethanediamine	0.83	8.6	812
Ethanethiol	0.8959(5)	9.285(5)	849
Ethanol	1.010(2)	10.47(2)	776
Ethanolamine	0.865	8.96	664
Ethyl benzoate	0.86	8.9	537
Ethyl formate	1.024(1)	10.61(1)	639
Ethyl methyl ether	0.938	9.72	722
Ethyl methyl sulfide	0.824(10)	8.54(10)	765
Ethyl pentyl ether	9.16	9.49	602
Ethyl vinyl ether	0.85	8.8	707
Ethylamine	0.855(2)	8.86(2)	808
N-Ethylaniline	0.740	7.67	794
Ethylbenzene	0.846(1)	8.77(1)	876
2-Ethyl-1-butene	0.874(2)	9.06(2)	818
Ethylcyclohexane	0.920	9.54	748
Ethylcyclopentane	0.976(2)	10.12(2)	850
Ethylene	1.0382(4)	10.507(4)	1066

TABLE 4.3 Ionization Energy of Molecular and Radical Species (*Continued*)

Species	Ionization energy		$\Delta_f H$ (ion) in kJ · mol^{-1}
	In MJ · mol^{-1}	In electron volts	
Ethylene glycol	0.980	10.16	593
Ethylene oxide	1.0195(10)	10.566(10)	967
Ethyleneimine	0.89(1)	9.2(1)	1014
p-Ethylphenol	0.756	7.84	613
Ethynyl (HC≡C)	1.13	11.7	1694
Fluoranthene	0.768(4)	7.95(4)	1057
Fluorene	0.761(3)	7.89(3)	950
Fluoroacetylene	1.086	11.26	1195
Fluorobenzene	0.8877(5)	9.200(5)	772
Fluoroethane	1.12	11.6	856
Fluoroethylene	1.0000(15)	10.363(15)	861
Fluoromethane	1.203(2)	12.47(2)	956
Fluoromethylene	1.012	10.49	1121
Fluoromethylidene (CF)	0.879(1)	9.11(1)	1134
p-Fluoronitrobenzene	0.955	9.90	826
1-Fluoropropane	1.09	11.3	806
2-Fluoropropane	1.069(2)	11.08(2)	776
3-Fluoropropene	0.975	10.11	821
m-Fluorotoluene	0.860(1)	8.91(1)	709
o-Fluorotoluene	0.860(1)	8.91(1)	709
p-Fluorotoluene	0.848(1)	8.79(1)	701
Formaldehyde	1.0492(2)	10.874(2)	940
Formamide	0.980(6)	10.16(6)	796
Formic acid	1.093(1)	11.33(1)	715
Fulminic acid (HCNO)	1.045	10.83	1263
Fulvene	0.807	8.36	1031
Fumaric acid	1.03	10.7	355
Furan	0.8571(3)	8.883(3)	822
Glyoxal	0.975	10.1	763
1-Heptanal	0.931(2)	9.65(2)	668
Heptane	0.957(5)	9.92(5)	770
1-Heptanol	0.949(3)	9.84(3)	614
2-Heptanol	0.936(3)	9.70(3)	580
3-Heptanol	0.934(3)	9.68(3)	578
4-Heptanol	0.927(3)	9.61(3)	572
2-Heptanone	0.897(1)	9.30(1)	596
1-Heptene	0.911	9.44	849
2-Heptene	0.853(2)	8.84(2)	782
3-Heptene	0.861	8.92	790
Hexachlorobenzene	0.866	8.98	822
Hexachloroethane	1.07	11.1	920
1,5-Hexadiene	0.896(5)	9.29(5)	980
Hexafluoroacetone	1.104	11.44	−294
Hexafluorobenzene	0.9558	9.906	10
Hexafluoroethane	1.29	13.4	−50
Hexafluoropropene	1.023(3)	10.60(3)	−103
Hexamethylbenzene	0.757	7.85	670
1-Hexanal	0.933(5)	9.67(5)	686
Hexane	0.977	10.13	810
Hexanoic acid	0.976	10.12	463
1-Hexanol	0.954(3)	9.89(3)	639

TABLE 4.3 Ionization Energy of Molecular and Radical Species (*Continued*)

Species	Ionization energy		$\Delta_f H$ (ion) in kJ · mol^{-1}
	In MJ · mol^{-1}	In electron volts	
2-Hexanol	0.946(3)	9.80(3)	611
3-Hexanol	0.929(3)	9.63(3)	599
2-Hexanone	0.902(2)	9.35(2)	626
3-Hexanone	0.880(2)	9.12(2)	600
1-Hexene	0.911(4)	9.44(4)	869
cis-2-Hexene	0.865(1)	8.97(1)	818
trans-2-Hexene	0.865(1)	8.97(1)	814
Hexylamine	0.833(5)	8.63(5)	699
1-Hexyne	0.960	9.95(5)	1081
Hydrogen cyanide (HCN)	1.312(1)	13.60(1)	1447
Hydrogen isocyanide (HNC)	1.21(1)	12.5(1)	1407
p-Hydroquinone	0.767(3)	7.95(3)	504
Imidazole	0.850(1)	8.81(1)	997
Indane	0.90	9.3	864
Indene	0.785(1)	8.14(1)	949
Iodobenzene	0.8380	8.685	1003
Iodoethane	0.9018	9.346	893
1-Iodohexane	0.8857	9.179	794
Iodomethane	0.9203	9.538	936
1-Iodopropane	0.8943	9.269	862
2-Iodopropane	0.8853	9.175	844
Isobutylbenzene	0.838(1)	8.68(1)	816
Isocyanic acid	1.120(3)	11.61(3)	1016
Isophthalic acid	0.963(20)	9.98(20)	268
Isopropylcyclohexane	0.900	9.33	704
Isoquinoline	0.8239(3)	8.539(3)	1032
Isoxazole	0.958(5)	9.93(5)	1038
Ketene	0.927(2)	9.61(2)	880
Maleic anhydride	1.04	10.8	645
Mesityl oxide	0.876(3)	9.08(3)	692
Methacrylic acid	0.979	10.15	611
Methane	1.207	12.51	1133
Methanethiol	9.108(5)	9.440(5)	888
Methanol	1.047(1)	10.85(1)	845
Methoxy	0.83	8.6	845
Methoxybenzene (Anisole)	0.792(2)	8.21(2)	724
2-Methoxyethanol	0.93	9.6	562
Methyl	0.949(1)	9.84(1)	1095
Methyl acetate	0.991(2)	10.27(2)	581
Methyl acrylate	0.96	9.9	611
Methyl azide	0.947(2)	9.81(2)	1227
Methyl benzoate	0.899(3)	9.32(3)	611
Methyl chloroacetate	0.99	10.3	575
Methyl 2,2-dimethylpropanoate	0.955(4)	9.90(4)	466
Methyl formate	1.0435(5)	10.815(5)	688
Methyl pentanoate	1.00(2)	10.4(2)	532
Methyl pentyl ether	0.933	9.67	657
Methyl vinyl ether	0.862(2)	8.93(2)	761
Methylacrylonitrile	0.998	10.34	1127
Methylamine	0.865(2)	8.97(2)	843
2-Methylaniline	0.718(2)	7.44(2)	772

TABLE 4.3 Ionization Energy of Molecular and Radical Species (*Continued*)

Species	Ionization energy		$\Delta_f H$ (ion) in kJ · mol^{-1}
	In MJ · mol^{-1}	In electron volts	
3-Methylaniline	0.724(2)	7.50(2)	778
4-Methylaniline	0.698(2)	7.24(2)	753
N-Methylaniline	0.707(2)	7.33(2)	791
Methylcyclohexane	0.930	9.64	775
1-Methylcyclohexanol	0.95(2)	9.8(2)	586
Methylcyclopentane	0.950(3)	9.85(3)	845
Methylcyclopropane	0.913	9.46	936
2-Methyldecane	0.934	9.68	685
Methylene	1.0031(3)	10.396(3)	1386
N-Methylformamide	0.945	9.79	756
2-Methylheptane	0.949	9.84	734
5-Methyl-2-hexanone	0.895(1)	9.28(1)	586
Methylhydrazine	0.740(2)	7.67(2)	835
Methylidyne	1.027(1)	10.64(1)	1622
Methylisocyanate	1.030(2)	10.67(2)	900
1-Methyl-4-isopropylbenzene (*p*-Cymene)	0.800	8.29	771
1-Methylnaphthalene	0.757	7.85	870
2-Methylnaphthalene	0.75	7.8	866
Methyloxirane	0.986(2)	10.22(2)	892
2-Methylpentane	0.976	10.12	802
3-Methylpentane	0.973	10.08	801
2-Methyl-3-pentanone	0.878(1)	9.10(1)	592
3-Methyl-2-pentanone	0.889(1)	9.21(1)	600
4-Methyl-2-pentanone	0.897(1)	9.30(1)	609
2-Methyl-1-pentene	0.876(1)	9.08(1)	817
2-Methyl-2-pentene	0.828	8.58	761
4-Methyl-1-pentene	0.912(1)	9.45(1)	862
4-Methyl-*cis*-2-pentene	0.866(1)	8.98(1)	809
4-Methyl-*trans*-2-pentene	0.865(1)	8.97(1)	804
2-Methylpropanal	0.9364(5)	9.705(5)	721
2-Methylpropanenitrile	1.09	11.3	1115
2-Methylpropenal	0.951	9.86	834
2-Methylpropene (Isobutene)	0.8915(3)	9.239(3)	875
2-Methylpyridine	0.870(3)	9.02(3)	970
3-Methylpyridine	0.872(3)	9.04(3)	979
4-Methylpyridine	0.872(3)	9.04(3)	976
Methylsilane	1.03	10.7	1003
m-Methylstyrene	0.786(2)	8.15(2)	908
o-Methylstyrene	0.888(2)	9.20(2)	908
p-Methylstyrene	0.78(1)	8.1(1)	895
Methyltrichlorosilane	1.096(3)	11.36(3)	548
Naphthalene	0.785(1)	8.14(1)	936
1-Naphthol	0.749(3)	7.76(3)	719
2-Naphthol	0.757(5)	7.85(5)	727
Nickel carbonyl	0.798(4)	8.27(4)	200
m-Nitroaniline	0.802(2)	8.31(2)	865
o-Nitroaniline	0.798(1)	8.27(1)	861
p-Nitroaniline	0.804(1)	8.34(1)	850
Nitrobenzene	0.951(2)	9.86(2)	1019
Nitroethane	1.050(5)	10.88(5)	948

TABLE 4.3 Ionization Energy of Molecular and Radical Species (*Continued*)

Species	Ionization energy		$\Delta_f H$ (ion) in kJ · mol^{-1}
	In MJ · mol^{-1}	In electron volts	
Nitromethane	1.063(4)	11.02(4)	988
m-Nitrophenol	0.86	9.0	755
o-Nitrophenol	0.88	9.1	782
p-Nitrophenol	0.88	9.1	761
1-Nitropropane	1.043(3)	10.81(3)	919
2-Nitropropane	1.033(5)	10.71(5)	894
m-Nitrotoluene	0.15(2)	9.48(2)	944
o-Nitrotoluene	0.912(4)	9.45(4)	966
p-Nitrotoluene	0.91	9.4	936
Nonane	0.938	9.72	710
2-Nonanone	0.884	9.16	545
5-Nonanone	0.875	9.07	530
Octafluoronaphthalene	0.854	8.85	−368
Octafluoropropane	1.291	13.38	−491
Octafluorotoluene	0.96	9.9	−233
Octane	0.948	9.82	739
1-Octene	0.910(1)	9.43(1)	829
1-Octyne	0.960(2)	9.95(2)	1040
2-Octyne	0.898(1)	9.31(1)	961
3-Octyne	0.890(1)	9.22(1)	952
4-Octyne	0.888(1)	9.20(1)	946
Oxazole	0.93	9.6	910
Oxetane	0.9328(5)	9.668(5)	853
2-Oxetanone	0.936(1)	9.70(1)	653
Oxomethyl (HCO)	0.782(5)	8.10(5)	826
Pentafluorobenzene	0.929	9.63	122
Pentafluorophenol	0.888(2)	9.20(2)	−71
2,3,4,5,6-Pentafluorotoluene	0.91	9.4	64
Pentanchloroethane	1.06	11.0	919
Pentylamine	0.837	8.67	728
Perylene	0.666(1)	6.90(1)	975
Phenanthrene	0.758(2)	7.86(2)	963
Phenetole	0.784(2)	8.13(2)	683
Phenol	0.817	8.47	721
Phenylacetic acid	0.797	8.26	479
m-Phenylenediamine	0.689	7.14	777
o-Phenylenediamine	0.69	7.2	787
p-Phenylenediamine	0.663(5)	6.87(5)	759
Phthalic anhydride	0.96	10.0	593
α-Pinene	0.779	8.07	808
Propanal	0.9603(5)	9.953(5)	773
Propanamide	0.92	9.5	720
Propane	1.057(5)	10.95(5)	952
Propanenitrile	1.142(2)	11.84(2)	1194
1-Propanethiol	0.8872(5)	9.195(5)	819
2-Propanethiol	0.882	9.14	806
Propanoic acid	1.0155(3)	10.525(3)	568
1-Propanol	0.986(3)	10.22(3)	731
2-Propanol	0.976(8)	10.12(8)	704

TABLE 4.3 Ionization Energy of Molecular and Radical Species (*Continued*)

Species	Ionization energy		$\Delta_f H$ (ion) in kJ · mol^{-1}
	In MJ · mol^{-1}	In electron volts	
Propenal	0.975(6)	10.103(6)	900
Propene	0.939(2)	9.73(2)	959
Propenenitrile	1.053(1)	10.91(1)	1237
Propenoic acid	1.023	10.60	701
1-Propylamine	0.847(2)	8.78(2)	777
2-Propylamine	0.841(3)	8.72(3)	758
Propylbenzene	0.841(1)	8.72(1)	849
Propylcyclohexane	0.913	9.46	720
Propylcyclopentane	0.965(4)	10.00(4)	817
Propyleneimine	0.87	9.0	960
Propynal	1.04	10.8	1155
Propyne	1.000(1)	10.36(1)	1186
2-Propyn-1-ol	1.014	10.51	1060
Pyrene	0.715	7.41	933
Pyridazine	0.834	8.64	1112
Pyrimidine	0.891	9.23	1087
Pyrrole	0.7920(5)	8.208(5)	900
2-Pyrrolidone	0.89	9.2	674
Quinoline	0.832(1)	8.62(1)	1041
cis-Stilbene	0.753(2)	7.80(2)	1005
trans-Stilbene	0.743(3)	7.70(3)	977
Styrene	0.813(6)	8.43(6)	961
Succinic anhydride	1.02	10.6	500
Succinonitrile	1.158(24)	12.10(25)	1377
Terephthalic acid	0.951(20)	9.86(20)	232
m-Terphenyl	0.773(1)	8.01(1)	1057
o-Terphenyl	0.77	8.0	1056
p-Terphenyl	0.751(1)	7.78(1)	1035
Tetrabromomethane	0.995(2)	10.31(2)	1079
Tetrachloro-1,2-difluoroethane	1.09	11.3	563
1,1,1,2-Tetrachloroethane	1.07	11.1	920
1,1,2,2-Tetrachloroethane	1.121	11.62	971
Tetrachloroethylene	0.899	9.32	887
Tetrachloromethane	1.107(1)	11.47(1)	1011
Tetraethylsilane	0.86	8.9	595
1,2,3,4-Tetrafluorobenzene	0.920(1)	9.53(1)	284
1,2,3,5-Tetrafluorobenzene	0.920(1)	9.53(1)	263
1,2,4,5-Tetrafluorobenzene	0.902(1)	9.35(1)	254
Tetrafluoroethylene	0.976(2)	10.12(2)	315
Tetrahydrofurane	0.908(2)	9.41(2)	724
1,2,3,4-Tetrahydronaphthalene	0.817	8.47	842
1,2,4,5-Tetramethylbenzene	0.776(1)	8.04(1)	730
2,2,3,3-Tetramethylbutane	0.95	9.8	720
Thiacyclobutane	0.838	8.69	899
Thiophene	0.856(4)	8.87(4)	971
p-Tolualdehyde	0.900(5)	9.33(5)	825
Toluene	0.851(1)	8.82(1)	901
m-Toluic acid	0.910(20)	9.43(20)	579
o-Toluic acid	0.88	9.1	558
p-Toluic acid	0.891(20)	9.23(20)	560

TABLE 4.3 Ionization Energy of Molecular and Radical Species (*Continued*)

Species	Ionization energy		$\Delta_f H$ (ion) in kJ · mol^{-1}
	In MJ · mol^{-1}	In electron volts	
m-Tolunitrile	0.901	9.34	1085
o-Tolunitrile	0.905	9.38	1085
p-Tolunitrile	0.899	9.32	1083
Tribromomethane	1.011(2)	10.48(2)	1035
Tributylamine	0.71	7.4	492
Trichloroacetyl chloride	1.06	11.0	827
1,2,4-Trichlorobenzene	0.872	9.04	880
1,3,5-Trichlorobenzene	0.899(2)	9.32(2)	899
1,1,1-Trichloroethane	1.06	11.0	917
1,1,2-Trichloroethane	1.06	11.0	911
Trichloroethylene	0.914(1)	9.47(1)	895
Trichlorofluoromethane	1.136(2)	11.77(2)	868
Trichloromethane	1.097(2)	11.37(2)	992
Trichloromethylbenzene	0.926	9.60	914
1,1,2-Trichlorotrifluoroethane	1.157(2)	11.99(2)	429
Triethanolamine	0.76	7.9	206
Triethylamine	0.724	7.50	631
Trifluoroacetic acid	1.106	11.46	75
Trifluoroacetonitrile	1.337	13.86	838
1,1,1-Trifluoro-2-bromo-2-chloroethane	1.06	11.0	362
1,1,1-Trifluoroethane	1.24(1)	12.9(1)	496
Trifluoroethylene	0.978	10.14	489
Trifluoroiodomethane	0.987	10.23	397
Trifluoromethane	1.337	13.86	643
Trifluoromethyl (CF_3)	0.86	8.9	399
Trifluoromethylbenzene	0.9345(4)	9.685(4)	335
3,3,3-Trifluoropropene	1.05	10.9	437
Triiodomethane	0.893(2)	9.25(2)	1010
Trimethylamine	0.755462	7.82960	731
1,2,3-Trimethylbenzene	0.812(2)	8.42(2)	803
1,2,4-Trimethylbenzene	0.798(1)	8.27(1)	784
1,3,5-Trimethylbenzene	0.811(1)	8.41(1)	796
Trimethylborate	0.96	10.0	65
Trimethylchlorosilane	0.979	10.15	624
3,5,5-Trimethylcyclohex-2-en-1-one	0.875	9.07	670
2,2,4-Trimethylpentane	0.951	9.86	713
2,2,4-Trimethyl-3-pentanone	0.849(1)	8.80(1)	511
2,4,6-Trimethylpyridine	0.88(1)	8.9(1)	580
Trioxane	0.99	10.3	528
Undecane	0.922	9.56	650
Urea	0.94	9.7	690
Vinyl acetate	0.887	9.19	572
m-Xylene	0.826(1)	8.56(1)	843
o-Xylene	0.826(1)	8.56(1)	844
p-Xylene	0.814(1)	8.44(1)	832
2,3-Xylenol	0.797	8.26	640
2,4-Xylenol	0.77	8.0	609
2,6-Xylenol	0.777(2)	8.05(2)	615
3,4-Xylenol	0.781	8.09	624

TABLE 4.3 Ionization Energy of Molecular and Radical Species (*Continued*)

Inorganic compounds

Species	Ionization energy		$\Delta_f H$ (ion) in kJ · mol^{-1}
	In MJ · mol^{-1}	In electron volts	
Aluminum tribromide	1.00	10.4	593
Aluminum trichloride	1.159	12.01	573
Aluminum trifluoride	1.394	14.45	282
Aluminum triiodide	0.88	9.1	673
Amidogen (NH_2)	1.075(1)	11.14(1)	1264
Ammonia	0.980(1)	10.16(1)	934
Antimony trichloride	0.97(1)	10.1(1)	661
Arsenic trichloride	1.018(3)	10.55(3)	754
Arsenic trifluoride	1.239(5)	12.84(5)	452
Arsine	0.954	9.89	1021
Barium oxide	0.667(6)	6.91(6)	543
Bismuth trichloride	1.00	10.4	736
Borane (BH_3)	1.19(1)	12.3(1)	1287
Boron dioxide (BO_2)	1.30(3)	13.5(3)	1001
Boron oxide (B_2O_3)	1.303(14)	13.50(15)	460
Boron tribromide	1.014(2)	10.51(2)	809
Boron trichloride	1.119(2)	11.60(2)	718
Boron trifluoride	1.501(3)	15.56(3)	365
Boron triodide	0.893(3)	9.25(3)	964
Bromine (Br_2)	1.0146(5)	10.515(5)	1046
Bromine chloride (BrCl)	1.062	11.01	1079
Bromine fluoride (BrF)	1.136(1)	11.77(1)	1077
Bromine pentafluoride	1.271(1)	13.17(1)	840
Bromosilane ($BrSiH_3$)	1.02	10.6	943
Calcium oxide	0.67	6.9	691
Cesium chloride	0.756(5)	7.84(5)	510
Cesium fluoride	1.221(1)	12.65(1)	1170
Cesium fluoride	0.849(10)	8.80(10)	489
Chlorine (Cl_2)	1.1424(5)	11.840(5)	1108
Chlorine difluoride	1.232(5)	12.77(5)	1128
Chlorine dioxide	1.000(2)	10.36(2)	1096
Chlorine oxide	1.057	10.95	1159
Chlorine trifluoride	1.221(5)	12.65(5)	1057
Chlorosilane ($ClSiH_3$)	1.10	11.4	899
Chromyl chloride (CrO_2Cl_2)	1.12	11.6	580
Diborane (B_2H_6)	1.098(3)	11.38(3)	1134
Dichlorosilane (Cl_2SiH_2)	1.10	11.4	765
Difluoramine (HNF_2)	1.112(8)	11.53(8)	1046
Difluoroamidogen (NF_2)	1.122(1)	11.628(1)	1155
Difluorosilane (F_2SiH_2)	1.18	12.2	386
Dioxygen fluoride	1.22(2)	12.6(2)	1228
Disilane	0.94	9.7	1015
Disulfur oxide	1.017(4)	10.54(4)	967
Fluorine (F_2)	1.5146(3)	15.697(3)	1515
Fluorosilane ($FSiH_3$)	1.13	11.7	752
Gallium bromide	1.003	10.40	711
Gallium chloride	1.112	11.52	648
Gallium triiodide	0.907	9.40	765
Gallium(I) fluoride	0.93(5)	9.6(5)	700

TABLE 4.3 Ionization Energy of Molecular and Radical Species (*Continued*)

Species	Ionization energy		$\Delta_f H$ (ion) in kJ · mol^{-1}
	In MJ · mol^{-1}	In electron volts	
Germane (GeH_4)	1.093	11.33	1185
Germanium oxide (GeO)	1.085(1)	11.25(1)	1044
Germanium sulfide (GeS)	0.963(2)	9.98(2)	1055
Germanium tetrachloride	1.1270(5)	11.68(5)	629
Germanium tetrafluoride	1.50	15.5	307
Germanium tetraiodide	0.909	9.42	850
Hafnium bromide	1.05	10.9	366
Hafnium chloride	1.13	11.7	246
Hexaborane (B_6H_{10})	0.87	9.0	965
Hydrazine	7.82(14)	8.10(15)	877
Hydrazoic acid (HN_3)	1.0344(24)	10.720(25)	1328
Hydrogen (H_2)	1.488413(5)	15.42589(5)	1488
Hydrogen bromide	1.125(3)	11.66(3)	1087
Hydrogen chloride	1.2299	12.747	1137
Hydrogen fluoride	1.5481(3)	16.044(3)	1276
Hydrogen iodide	1.0004(1)	10.368(1)	1028
Hydrogen peroxide	1.017	10.54	881
Hydrogen selenide	0.9535(1)	9.882(1)	983
Hydrogen sulfide	1.0085(8)	10.453(8)	988
Hydroperoxy (HOO)	1.095(1)	11.35(1)	1106
Hydroxyl (OH)	1.254	13.00	1293
Hydroxylamine (NH_2OH)	0.947	10.00	923
Hypochlorous acid (HOCl)	1.073(1)	11.12(1)	993
Hypofluorous acid (HOF)	1.226(1)	12.71(1)	1130
Imidogen (NH)	1.302(1)	13.49(1)	1678
Iodine (I_2)	0.90694(12)	9.3995(12)	969
Iodine bromide	0.9446(4)	9.790(4)	986
Iodine chloride	0.9734(10)	10.088(10)	991
Iodine fluoride	1.025	10.62	930
Iodine pentafluoride	1.2488(5)	12.943(5)	408
Lead oxide (PbO)	0.976(10)	9.08(10)	939
Lead(II) chloride	0.96	10.0	789
Lead(II) fluoride	1.11	11.5	679
Lead(II) sulfide	0.825	8.5(5)	954
Lithium bromide	0.84	8.7	685
Lithium chloride	0.923	9.57	727
Lithium hydride	0.74	7.7	882
Lithium iodide	0.72	7.5	633
Lithium oxide	0.815	8.45(20)	895
Magnesium fluoride	1.29	13.4	569
Magnesium oxide	0.93	9.7	992
Mercapto (SH)	1.001	10.37	1140
Mercury(II) bromide	1.019(3)	10.560(3)	935
Mercury(II) chloride	1.0988(3)	11.380(3)	952
Mercury(II) iodide	0.91748(22)	9.5088(22)	900
Molybdenum hexafluoride	1.40(1)	14.5(1)	−159
Molybdenum(V) chloride	0.84	8.7	392
Niobium(V) chloride	1.058	10.97	656
Nitric acid	1.153(1)	11.95(1)	1019

TABLE 4.3 Ionization Energy of Molecular and Radical Species (*Continued*)

Species	Ionization energy		$\Delta_f H$ (ion) in kJ · mol^{-1}
	In MJ · mol^{-1}	In electron volts	
Nitric oxide	0.893900(6)	9.26436(6)	985
Nitrogen (N_2)	1.59336	15.5808	1503
Nitrogen dioxide	0.941(1)	9.75(1)	974
Nitrogen pentoxide	1.15	11.9	1161
Nitrogen tetroxide	1.04(2)	10.8(2)	1050
Nitrogen trichloride	0.9765(10)	10.12(10)	1244
Nitrogen trifluoride	1.254(2)	13.00(2)	1125
Nitrosyl bromide	0.981(3)	10.17(3)	1065
Nitrosyl chloride (NOCl)	1.049(1)	10.87(1)	1099
Nitrosyl fluoride (NOF)	1.219(3)	12.63(3)	1152
Nitrous acid (HONO)	1.09	11.3	977
Nitrous oxide (N_2O)	1.2433	12.886	1325
Nitryl chloride (NO_2Cl)	1.142	11.84	1155
Nitryl fluoride (NO_2F)	1.263	13.09	1154
Osmium tetroxide	1.1895	12.320	850
Oxygen (O_2)	1.1647(1)	12.071(1)	1165
Oxygen dichloride	1.056	10.94	1135
Oxygen difluoride (OF_2)	1.265(1)	13.11(1)	1290
Oxygen fluoride	1.232	12.77	1341
Ozone (O_3)	1.199	12.43	1342
Pentaborane (B_5H_9)	0.955(4)	9.90(4)	1028
Perchloryl fluoride (ClO_3F)	1.2490(5)	12.945(5)	1224
Phosphine (PH_3)	0.9522(2)	9.869(2)	958
Phosphorus (P_2)	1.016	10.53	1160
Phosphorus nitride	1.143	11.85	1248
Phosphorus pentachloride	1.03	10.7	656
Phosphorus pentafluoride	1.46	15.1	−137
Phosphorus sulfur trichloride ($PSCl_3$)	0.956	9.91	668
Phosphorus tribromide	0.94	9.7	798
Phosphorus trichloride	0.956	9.91	668
Phosphorus trifluoride	1.104	11.44	146
Phosphoryl chloride ($POCl_3$)	1.096(2)	11.36(2)	540
Phosphoryl trifluoride (POF_3)	1.231(1)	12.76(1)	−24
Potassium bromide	0.757(10)	7.85(10)	578
Potassium chloride	0.77(4)	8.0(4)	557
Potassium iodide	0.696(29)	7.21(30)	570
Rhenium(VII) oxide	1.23(2)	12.7(2)	125
Rubidium bromide	0.766(3)	7.94(3)	583
Rubidium chloride	0.820(3)	8.50(3)	590
Ruthenium tetroxide	1.172(3)	12.15(3)	988
Silane	1.124	11.65	1158
Silicon oxide (SiO)	1.103	11.43	1002
Silicon tetrachloride	1.136(1)	11.79(1)	527
Silicon tetrafluoride	1.51	15.7	−100
Silver chloride	0.973	10.08	1065
Silver fluoride	1.06(3)	11.0(3)	1071
Sodium bromide	0.802(10)	8.31(10)	660
Sodium chloride	0.861(6)	8.92(6)	681
Sodium iodide	0.737(2)	7.64(2)	659
Stibine (SbH_3)	0.920(3)	9.54(3)	1067

TABLE 4.3 Ionization Energy of Molecular and Radical Species (*Continued*)

Species	Ionization energy		$\Delta_f H$ (ion) in kJ · mol^{-1}
	In MJ · mol^{-1}	In electron volts	
Strontium oxide	0.675(14)	7.00(15)	662
Sulfur (S_2)	0.9027(2)	9.356(2)	1031
Sulfur chloride pentafluoride	1.1921(5)	12.335(5)	144
Sulfur dichloride	0.912(3)	9.45(3)	895
Sulfur difluoride	0.973	10.08	676
Sulfur dioxide	1.189(2)	12.32(2)	892
Sulfur hexafluoride	1.479(3)	15.33(3)	259
Sulfur oxide (SO)	0.996(2)	10.32(2)	1001
Sulfur pentafluoride	1.01(1)	10.5(1)	97
Sulfur trioxide	1.235(4)	12.80(4)	839
Sulfuryl chloride (SO_2Cl_2)	1.163	12.05	807
Sulfuryl fluoride (SO_2F_2)	1.110	11.5	679
Tantalum(V) chloride	1.069	11.08	348
Tetraborane (B_4H_{10})	1.038(4)	10.76(4)	1105
Tetrafluorohydrazine (gauche)	1.152(3)	11.94(3)	1119
Thallium(I) bromide	0.882(2)	9.14(2)	844
Thallium(I) chloride	0.936(3)	9.70(3)	869
Thallium(I) fluoride	1.015	10.52	835
Thionitrosyl fluoride (NSF)	1.111(4)	11.51(4)	1090
Thionyl chloride	1.058	10.96	844
Thionyl fluoride	1.182	12.25	688
Thiophosphoryl trifluoride (PSF_3)	1.066(4)	11.05(4)	58
Thorium(IV) oxide	0.847(14)	8.70(15)	342
Tin(II) bromide	0.87	9.0	830
Tin(II) chloride	0.965	10.0	760
Tin(II) fluoride	1.07	11.1	586
Tin(II) oxide	0.926(2)	9.60(2)	944
Tin(II) sulfide	0.85	8.8	966
Tin(IV) bromide	1.02	10.6	709
Tin(IV) chloride	1.146(5)	11.88(5)	673
Tin(IV) hydride	1.037	10.75	1200
Titanium(IV) bromide	0.99	10.3	375
Titanium(IV) chloride	1.124(14)	11.65(15)	363
Titanium(IV) oxide	0.920(10)	9.54(10)	623
trans-Difluorodiazine	1.24	12.8	1315
Trifluoramine oxide (NOF_3)	1.279(1)	13.26(1)	1116
Trifluorosilane (F_3SiH)	1.35	14.0	150
Trisilane	0.89	9.2	1009
Tungsten(VI) chloride	0.92	9.5	348
Uranium hexafluoride	1.350(10)	14.00(10)	−796
Uranium(IV) oxide	5.2(1)	5.4(1)	57
Uranium(VI) oxide	1.01(5)	10.5(5)	214
Vanadium(IV) chloride	0.89	9.2	210
Vanadium(V) oxychloride ($VOCl_3$)	1.120	11.61	425
Water	1.2170(10)	12.612(10)	975
Xenon difluoride	1.192(1)	12.35(1)	1083
Xenon tetrafluoride	1.221(10)	12.65(10)	1016
Zirconium bromide	1.03	10.7	388
Zirconium chloride	1.08	11.2	392

Source: Sharon, G., et al., *J. Phys. Chem. Ref. Data*, **17**:Suppl. No. 1 (1988).

4.3 ELECTRON AFFINITY

TABLE 4.4 Electron Affinities of Atoms, Molecules, and Radicals

Electron affinity of an atom (molecule or radical) is defined as the energy difference between the lowest (ground) state of the neutral and the lowest state of the corresponding negative ion in the gas phase.

$$A(g) + e^- = A^-(g)$$

Data are limited to those negative ions which, by virtue of their positive electron affinity, are stable. Uncertainty in the final data figures is given in parentheses. Calculated values are enclosed in brackets.

A. Atoms

Atom	Electron affinity, in eV	Electron affinity, in kJ · mol^{-1}
Aluminum	0.441(10)	42.5(10)
Antimony	1.046(5)	100.9(5)
Arsenic	0.81(3)	78.(3)
Astatine	[2.8(3)]	[270.(30)]
Barium	[0.15]	[14.]
Bismuth	0.946(10)	91.3(10)
Boron	0.277(10)	26.7(10)
Bromine	3.363590(3)	324.5367(3)
Calcium	0.0185(25)	1.78(24)
Carbon	1.2629(3)	121.85(3)
Cesium	0.471626(25)	45.5048(24)
Chlorine	3.61269	348.570
Chromium	0.666(12)	64.3(12)
Cobalt	0.662(3)	63.9(3)
Copper	1.235(5)	119.2(5)
Fluorine	3.401190(4)	328.1638(4)
Francium	[0.46]	[44]
Gallium	0.30(15)	29.(15)
Germanium	1.233(3)	119.0(3)
Gold	2.30863(3)	222.748(3)
Hafnium	[≈0.]	[≈0.]
Hydrogen	0.75195(19)	72.552(18)
Hydrogen-d_1 deuterium	0.75459(7)	72.807(7)
Indium	0.3(2)	29.(2)
Iodine	3.05904(1)	295.151(1)
Iridium	1.565(8)	151.0(8)
Iron	0.151(3)	14.6(3)
Lanthanum	[0.5(3)]	[48.(30)]
Lead	0.364(8)	35.1(8)
Lithium	0.6180(5)	59.63(5)
Molybdenum	0.748(2)	72.2(2)
Nickel	1.156(10)	111.5(10)
Niobium	0.893(25)	86.2(24)
Osmium	[0.2(1)]	[19.(10)]
Oxygen	1.4611103(7)	140.97523(7)
Palladium	0.562(5)	54.2(5)
Phosphorus	0.7465(3)	72.03(3)
Platinum	2.128(2)	205.3(2)
Polonium	[1.9(3)]	[183.(30)]

TABLE 4.4 Electron Affinities of Atoms, Molecules, and Radicals (*Continued*)

A. Atoms (*continued*)

Atom	Electron affinity, in eV	Electron affinity, in kJ · mol^{-1}
Potassium	0.50147(10)	48.384(10)
Rhenium	[0.15(15)]	[14.(14)]
Rubidium	0.48592(2)	46.884(2)
Ruthenium	[1.05(15)]	[101.(14)]
Scandium	0.188(20)	18.1(19)
Selenium	2.020670(25)	194.9643(24)
Silver	1.302(7)	125.6(7)
Sodium	0.547926(25)	52.86666(24)
Strontium	0.048(6)	4.6(6)
Sulfur	2.077104(1)	200.4094(1)
Tantalum	0.322(12)	31.1(12)
Technetium	[0.55(20)]	[53.(19)]
Tellurium	1.9708(3)	190.15(3)
Thallium	0.2(2)	19.(19)
Tin	1.112(4)	107.3(4)
Titanium	0.079(14)	7.6(14)
Tungsten	0.815(2)	78.6(2)
Vanadium	0.525(12)	50.7(12)
Yttrium	0.307(12)	29.6(12)
Zirconium	0.426(14)	41.1(14)

B. Molecules

Molecule	Electron affinity, in eV	Electron affinity, in kJ · mol^{-1}
BF_3	2.65	256
BH_3	0.038(15)	3.7(15)
1,4-Benzoquinone	1.91(10)	184.(10)
Br_2	2.55(10)	246.(10)
$CBrF_3$	0.91(20)	89.(19)
CF_3I	1.57(20)	151.(19)
COS	0.46(20)	44.(19)
CS_2	0.895(20)	86.3(19)
C_6F_6 hexafluorobenzene	0.52(10)	50.(10)
1,2-$C_6H_4(NO_3)_2$ (also 1,3-)	1.65(10)	159.(10)
1,4-$C_6H_4(NO_3)_2$	2.00(10)	193.(10)
C_6H_5Br bromobenzene	1.15(11)	111.(11)
C_6H_5Cl chlorobenzene	0.82(11)	79.(11)
C_6H_5I iodobenzene	1.41(11)	136.(11)
$C_6H_5NO_2$ nitrobenzene	1.01(10)	97.(10)
1,4-$C_6H_4(CN)NO_2$	1.72(10)	166.(10)
Cl_2	2.38(10)	229.(10)
CoH_2	1.450(14)	139.9(13)
CsCl	0.455(10)	43.9(10)
CuO	1.777(6)	171.5(6)
F_2	3.08(10)	297.(10)
FeO	1.493(5)	144.1(5)
I_2	2.55(5)	246.(5)

TABLE 4.4 Electron Affinities of Atoms, Molecules, and Radicals (*Continued*)

B. Molecules (*continued*)

Molecule	Electron affinity, in eV	Electron affinity, in kJ · mol^{-1}
IBr	2.55(10)	246.(10)
IrF_6	6.5(4)	627.(40)
KBr	0.642(10)	61.9(10)
KCl	0.582(10)	56.1(10)
KI	0.728(10)	70.2(10)
LiCl	0.593(10)	54.3(10)
LiH	0.342(12)	33.0(12)
MoO_3	2.9(2)	280.(20)
NO	0.026(5)	2.5(5)
NO_2	2.273(5)	219.3(5)
N_2O	0.22(10)	21.(10)
NaBr	0.788(10)	76.0(10)
NaCl	0.727(10)	70.1(10)
NaI	0.865(10)	83.5(10)
NaK	0.465(30)	44.9(30)
O_2	0.451(7)	43.5(7)
O_3	2.103(3)	202.9(9)
OsF_6	6.0(3)	579.(29)
PBr_3	1.59(15)	153.(14)
PCl_3	0.82(10)	79.(10)
PF_5	0.75(15)	72.(14)
$POCl_3$	1.41(2)	136.(2)
PbO	0.722(6)	69.7(6)
PtF_6	7.0(4)	675.(40)
RbCl	0.544(10)	52.5(10)
RuF_6	7.5(3)	724.(28)
SF_4	1.5(2)	145.(19)
SF_6	1.05(10)	101.(10)
SO_2	1.107(8)	106.8(8)
SeF_6	2.9(2)	280.(19)
SeO	1.456(20)	140.5(l9)
SeO_2	1.823(50)	175.9(48)
TeF_6	3.34(17)	322.(16)
TeO	1.695(22)	163.5(21)
UF_6	5.1(2)	492.(19)
V_4O_{10}	4.2(6)	405.(60)
WO_3	3.9(2)	376.(19)

C. Radicals

Radical	Electron affinity, in eV	Electron affinity, in kJ · mol^{-1}
AsH_2	1.27(3)	123.(3)
CCl_2	1.591(10)	153.5(10)
CF_2	0.165(10)	15.9(10)
CH	1.238(8)	119.4(8)
CHBr	1.454(5)	140.3(5)
CHCl	1.210(5)	117.5(5)
CHF	0.542(5)	52.3(5)

TABLE 4.4 Electron Affinities of Atoms, Molecules, and Radicals (*Continued*)

C. Radicals (*continued*)

Radical	Electron affinity, in eV	Electron affinity, in kJ · mol^{-1}
CHI	1.42(17)	137.(17)
CHO_2	3.498(5)	337.5(5)
CH_2	0.652(6)	62.9(6)
CH_2S	0.465(23)	44.9(22)
CH_2═SiH	2.010(10)	193.9(10)
CH_3	0.08(3)	7.7(3)
CH_3CH_2O ethoxide	1.726(33)	166.5(32)
CH_3O	1.570(22)	151.5(21)
CH_3S	1.861(4)	179.6(4)
CH_3SCH_2	0.868(51)	83.7(49)
CH_3Si	0.852(10)	82.2(10)
CH_3SiH_2	1.19(4)	115.(4)
C_2F_2 difluorovinylidene	2.255(6)	217.6(6)
C_2H_2 vinylidene	0.490(6)	47.3(6)
CH_2═CH vinyl	0.667(24)	64.3(23)
C_2H_3O acetaldehyde enolate	1.82476(12)	176.062(12)
CH_3CH_2S	1.953(6)	188.4(6)
HC≡C—CH_2	0.893(25)	86.2(24)
CH_3CHCN	1.247(12)	120.3(12)
C_2H_5O ethoxide	1.726(33)	166.5(31)
C_2H_5S ethyl sulfide	1.953(6)	188.4(6)
C_3H_3 propargyl radical	0.893(25)	86.2(24)
CH_3CH—CN	1.247(12)	120.3(12)
C_3H_5 allyl	0.362(19)	34.9(18)
C_3H_5O acetone enolate	1.758(19)	169.2(18)
propionaldehyde enolate	1.621(6)	156.4(6)
$C_3H_5O_2$ methyl acetate enolate	1.80(6)	174.(6)
C_3H_7O propoxide	1.789(33)	172.6(31)
isopropyl oxide	1.839(29)	177.4(28)
C_3H_7S propyl sulfide	2.00(2)	193.(2)
isopropyl sulfide	2.02(2)	195.(2)
C_4H_5O cyclobutanone enolate	1.801(8)	173.8(8)
C_4H_7O butyraldehyde enolate	1.67(5)	161.(5)
C_4H_9O *tert*-butoxyl	1.912(54)	184.5(52)
C_4H_9S butyl sulfide	2.03(2)	196.(2)
tert-butyl sulfide	2.07(2)	200.(2)
C_5H_5 cyclopentadienyl	1.804(7)	174.1(7)
C_5H_7 pentadienyl	0.91(3)	88.(3)
C_5H_7O cyclopentanone enolate	1.598(7)	154.2(7)
C_5H_9O 3-pentanone enolate	1.69(5)	163.(5)
$C_5H_{11}S$ pentyl sulfide	2.09(2)	202.(2)
C_6H_5 phenyl	1.096(6)	105.7(6)
C_6H_5NH anilide	1.70(3)	164.(3)
C_6H_5O phenoxyl	2.253(6)	217.4(6)
C_6H_5S thiophenoxide	≤2.47(6)	≤238.(6)
$C_6H_5CH_2$ benzyl	0.912(6)	88.0(6)
$C_6H_5CH_2O$ benzyl oxide	2.14(2)	206.(2)
C_6H_9O cyclohexanone enolate	1.526(10)	147.2(10)
H_2C═CH—CH═CH—CH═CH—CH_2 heptatrienyl	1.27(3)	122.(3)
CN	3.862(4)	372.6(4)

TABLE 4.4 Electron Affinities of Atoms, Molecules, and Radicals (*Continued*)

C. Radicals (*continued*)

Radical	Electron affinity, in eV	Electron affinity, in kJ · mol^{-1}
$CNCH_2$ cyanomethyl	1.543(14)	148.9(14)
CO_3	2.69(14)	259.(14)
CS	0.205(21)	19.8(20)
ClO	2.275(6)	219.5(6)
HCO	0.313(5)	30.2(5)
HNO	0.338(15)	32.6(14)
HO_2	1.078(17)	104.0(6)
FO	2.272(6)	219.2(6)
N_3	2.70(12)	260.(12)
NCO	3.609(5)	348.2(5)
NCS	3.537(5)	341.3(5)
NH	0.370(4)	35.7(4)
NO_3	3.937(14)	379.9(14)
NS	1.194(11)	115.2(11)
O_2Aryl	0.52(2)	50.(2)
OClO	2.140(8)	206.5(8)
OH	1.82767(2)	176.343(2)
OIO	2.577(8)	248.6(8)
PH	1.028(10)	99.2(10)
PH_2	1.27(1)	123.(1)
PO	1.092(10)	105.4(10)
PO_2	3.42(1)	330.(1)
SF	2.285(6)	220.5(6)
SH	2.314344(4)	223.300(4)
SO	1.125(5)	108.5(5)
SeH	2.21252(3)	213.475(3)
SiF_3	$\leq$2.95(10)	285.(10)
SiH	1.277(9)	123.2(9)
SiH_2	1.124(20)	108.4(19)
SiH_3	1.406(14)	106.7(14)

Source: H. Hotop and W. C. Lineberger, *J. Phys. Chem. Reference Data* **14**:731 (1985).

4.4 ELECTRONEGATIVITY

Electronegativity χ is the relative attraction of an atom for the valence electrons in a covalent bond. It is proportional to the effective nuclear charge and inversely proportional to the covalent radius:

$$\chi = \frac{0.31(n + 1 \pm c)}{r} + 0.50$$

where n is the number of valence electrons, c is any formal valence charge on the atom and the sign before it corresponds to the sign of this charge, and r is the covalent radius. Originally the element fluorine, whose atoms have the greatest attraction for electrons, was given an arbitrary electronegativity of 4.0. A revision of Pauling's values based on newer data assigns 3.90 to fluorine. Values in Table 4.5 refer to the common oxidation states of the elements.

TABLE 4.5 Electronegativities of the Elements

H																
2.20																
Li	Be										B	C	N	O	F	
0.98	1.57										2.04	2.55	3.04	3.44	3.90	
Na	Mg										Al	Si	P	S	Cl	
0.93	1.31										1.61	1.90	2.19	2.58	3.16	
K	Ca	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br
0.82	1.00	1.36	1.54	1.63	1.66	1.55	1.83	1.88	1.91	1.90	1.65	1.81	2.01	2.18	2.55	2.96
Rb	Sr	Y	Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd	In	Sn	Sb	Te	I
0.82	0.95	1.22	1.33	1.6	2.16	2.10	2.2	2.28	2.20	1.93	1.69	1.78	1.96	2.05	2.1	2.66
Cs	Ba	La	Hf	Ta	W	Re	Os	Ir	Pt	Au	Hg	Tl	Pb	Bi	Po	At
0.79	0.89	1.10	1.3	1.5	1.7	1.9	2.2	2.2	2.2	2.4	1.9	1.8	1.8	1.9	2.0	2.2
Fr	Ra	Ac														
0.7	0.9	1.1														

Lanthanides	Ce	Pr	Nd		Sm		Gd		Dy	Ho	Er	Tm		Lu
	1.12	1.13	1.14		1.17		1.20		1.22	1.23	1.24	1.25		1.0
Actinides	Th	Pa	U	Np	Pu	Am	Cm	Bk	Cf	Es	Fm	Md	No	
	1.3	1.5	1.7	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	

Source: L. Pauling, *The Chemical Bond*, Cornell University Press, Ithaca, New York, 1967; L. C. Allen, *J. Am. Chem. Soc.* **111:**9003 (1989); A. L. Allred, *J. Inorg. Nucl. Chem.* **17:**215 (1961).

The greater the difference in electronegativity, the greater is the ionic character of the bond. The amount of ionic character I is given by:

$$I = 0.46 \mid \chi_A - \chi_B \mid + 0.035(\chi_A - \chi_B)^2$$

The bond is fully covalent when $(\chi_A - \chi_B) < 0.5$ (and $I < 6\%$).

4.5 BOND LENGTHS AND STRENGTHS

4.5.1 Atom Radius

The *atom radius* of an element is the shortest distance between like atoms. It is the distance of the centers of the atoms from one another in metallic crystals and for these materials the atom radius is often called the metal radius. Except for the lanthanides (CN = 6), CN = 12 for the elements. The atom radii listed in Table 4.6 are taken mostly from A. Kelly and G. W. Groves, *Crystallography and Crystal Defects*, Addison-Wesley, Reading, Mass., 1970.

TABLE 4.6 Atom Radii and Effective Ionic Radii of Elements

Element	Atom radius, pm	Ion charge	Effective ionic radii, pm			
			Coordination number			
			4	6	8	12
Actinium	187.8	3+		111		
Aluminum	143.1	3+	39	53.5		
Americium	173	2+			126	
		3+		97.5	109	
		4+		89	95	
		5+		86		
		6+		80		
Antimony	145	3−		245		
		1+		89		
		3+	76	76		
		5+		60		
Arsenic	124.8	3−		222		
		3+		58		
		5+	33.5	46		
Astatine		1−		227		
		5+		57		
		7+		62		
Barium	217.3	2+		136	142	160
Berkelium		2+		118		
		3+		98		
		4+		87	93	
Beryllium	111.3	1−	195			
		2+	27	45		
Bismuth	154.7	3−		213		
		3+		103	111	
		5+		76		
Boron	86	1+	35			
		3+	11	27		
Bromine		1−		196		
		3+	59			
		5+	31*	47		
		7+		25		
Cadmium	148.9	2+	78	95	110	131
Calcium	197	2+		100	112	135
Californium	186(2)	2+		117		
		3+		95		
		4+		82.1		
Carbon		4−	260			
		4+	15	16		
Cerium	181.8	3+		102	114.3	134
		4+		87	97	114
Cesium	265	1+		167	174	188
Chlorine		1−		181		
		5+	34			
		7+	8	27		
Chromium	128	1+	81			
		2+		73 LS 80 HS		
		3+		61.5		

* CN = 3

TABLE 4.6 Atom Radii and Effective Ionic Radii of Elements (*Continued*)

Element	Atom radius, pm	Effective ionic radii, pm				
		Ion charge	Coordination number			
			4	6	8	12
Chromium (*continued*)		4+	41	55		
		5+	34.5	49	57	
		6+	26	44		
Cobalt	125	2+	38	65 LS	90	
				74.5 HS		
		3+		54.5 LS		
				61 HS		
		4+	40	53 HS		
Copper	128	1+	60	77		
		2+	57	73		
		3+		54 LS		
Curium	174	3+		97		
		4+		85	95	
Dysprosium	178.1	2+		107	119	
		3+		91.2	102.7	
Einsteinium	186(2)	3+		98		
Erbium	176.1	3+		89.0	100.4	
Europium	208.4	2+		117	125	135
		3+		94.7	106.6	
Fluorine	71.7	1−	131	133		
		7+		8		
Francium	270	1+		180		
Gadolinium	180.4	3+		93.8	105.3	
Gallium	135	2+		120		
		3+	47	62.0		
Germanium	128	2+		73		
		4+	39.0	53.0		
Gold	144	1+		137		
		3+	68	85		
Hafnium	159	4+	58	71	83	
Holmium	176.2	3+		90.1	101.5*	112
Hydrogen		1−		154		
Indium	167	1+		140		
		3+	62	80.0	92	
Iodine		1−		220		
		5+		95		
		7+	42	53		
Iridium	135.5	3+		68		
		4+		62.5		
		5+		57		
Iron	126	2+		61 LS		
			63 HS	78 HS	92 HS	
		3+		55 LS		
			49 HS	64.5 HS	78 HS	
		4+		58.5		
		6+	25			
Lanthanum	183	3+		103.2	116.0	136

* CN = 10

TABLE 4.6 Atom Radii and Effective Ionic Radii of Elements (*Continued*)

Element	Atom radius, pm	Ion charge	Effective ionic radii, pm			
			Coordination number			
			4	6	8	12
Lead	175	2+	98	119	129	149
		4+		78	94	
Lithium	152	1+	59	76		
Lutetium	173.8	3+		86.1	97.7	
Magnesium	160	2+	57	72.0	89	
Manganese	127	2+	66 HS	67 LS	96	
				83 HS		
		3+		58 LS		
				64.5 HS		
		4+	39	53		
		5+	33			
		6+	25.5			
		7+	25	46		
Mercury	151	1+	111*	119		
		2+	96	102	114	
Molybdenum	139	3+		69		
		4+		65.0		
		5+	46	61		
		6+	41	59	73†	
Neodymium	181.4	2+			129	
		3+		98.3	110.9	127
Neptunium	155	2+		110		
		3+		101		
		4+		87	98	
		5+		75		
		6+		72		
		7+		71		
Nickel	124	2+	55	69.0		
		3+		56 LS		
				60 HS		
		4+		48 LS		
Niobium	146	3+		72		
		4+		68	79	
		5+	48	64	74	
Nitrogen		3−	146			
		1+	25			
		3+		16		
		5+		13		
Nobelium		2+		110		
Osmium	135	4+		63.0		
		5+		57.5		
		6+		54.5		
		7+		52.5		
		8+	39			
Oxygen		2−	138	140	142	
Palladium	137	2+	64	86		
		3+		76		
		4+		61.5		

* CN = 3
† CN = 7

TABLE 4.6 Atom Radii and Effective Ionic Radii of Elements (*Continued*)

Element	Atom radius, pm	Effective ionic radii, pm				
		Ion charge	Coordination number			
			4	6	8	12
Phosphorus	108	3−		212		
		3+		44		
		5+	17	38		
Platinum	138.5	2+		80		
		4+		62.5		
		5+		57		
Plutonium	159	3+		100		
		4+		86	96	
		5+		74		
		6+		71		
Polonium	164	2−		(230)		
		4+		94	108	
		6+		67		
Potassium	232	1+	137	138	151	164
Praseodymium	182.4	3+		99	112.6	
		4+		85	96	
Promethium	183.4	3+		97	109.3	
Protoactinium	163	3+		104		
		4+		90	101	
		5+		78	91	
Radium	(220)	2+			148	170
Rhenium	137	4+		63		
		5+		58		
		6+		55		
		7+	38	53		
Rhodium	134	3+		66.5		
		4+		60		
		5+		55		
Rubidium	248	1+		152	161	172
Ruthenium	134	3+		68		
		4+		62.0		
		5+		56.5		
		7+	38			
		8+	36			
Samarium	180.4	2+			127	
		3+		95.8	107.9	124
Scandium	162	3+		74.5	87.0	
Selenium	116	2−		198		
		4+		50		
		6+		42		
Silicon	118	4+	26	40.0		
Silver	144	1+	100	115	130	
		2+	79	94		
		3+	67	75		
Sodium	186	1+	99	102	118	139
Strontium	215	2+		118	126	144
Sulfur	106	2−		184		
		4+		37		
		6+	12	29		
Tantalum	146	3+		72		

TABLE 4.6 Atom Radii and Effective Ionic Radii of Elements (*Continued*)

Element	Atom radius, pm	Ion charge	Effective ionic radii, pm			
			Coordination number			
			4	6	8	12
Tantalum		4+		68		
(*continued*)		5+		64	74	
Technetium	136	4+		64.5		
		5+		60		
		7+	37	56		
Tellurium	142	2−		221		
		4+	66	97		
		6+	43	56		
Terbium	177.3	3+		92.3	104.0	
		4+		76	88	
Thallium	170	1+		150	159	170
		3+	75	88.5	98	
Thorium	179	4+		94	105	121
Thullium	175.9	2+		103		
		3+		88.0	99.4	105*
Tin	151	2+		118		
		4+	55	69.0	81	
Titanium	147	2+		86		
		3+		67.0		
		4+	42	60.5	74	
Tungsten	139	4+		66		
		5+		62		
		6+	42	60		
Uranium	156	3+		102.5		
		4+		89	100	117
		5+		76		
		6+	52	73	86	
Vanadium	134	2+		79		
		3+		64.0		
		4+		58	72	
		5+	35.5	54		
Xenon		8+	40	48		
Ytterbium	193.3	2+		102	114	
		3+		86.8	98.5	104*
Yttrium	180	3+		90.0	101.9	108*
Zinc	134	2+	60	74.0	90	
Zirconium	160	4+	59	72	84	89*

* CN = 11

4.5.2 Ionic Radii

One of the major factors in determining the structures of the substances that can be thought of as made up of cations and anions packed together is ionic size. It is obvious from the nature of wave functions that no ion has a precisely defined radius. However, with the insight afforded by electron

density maps and with a large base of data, new efforts to establish tables of ionic radii have been made, the most successful being those of Shannon and Prewitt. Pertinent references: R. D. Shannon and C. T. Prewitt, *Acta Crystallographica* **B25:**925 (1969); **B26:**1046 (1970) and R. D. Shannon, *Acta Crystallographica* **A32:**751 (1976).

Shannon and Prewitt base their *effective ionic radii* on the assumption that the ionic radius of O^{2-} (CN 6) is 140 pm and that of F^- (CN 6) is 133 pm. Also taken into consideration is the coordination number (CN) and electronic spin state (HS and LS, high spin and low spin) of first-row transition metal ions. These radii are empirical and include effects of covalence in specific metal-oxygen or metal-fluorine bonds. Older "crystal ionic radii" were based on the radius of F^- (CN 6) equal to 119 pm; these radii are 14–18 percent larger than the effective ionic radii.

4.5.3 Covalent Radii

Covalent radii (Table 4.7) are the distance between two kinds of atoms connected by a covalent bond of a given type (single, double, etc.).

TABLE 4.7 Covalent Radii for Atoms

Element	Single-bond radius, pm*	Double-bond radius, pm	Triple-bond radius, pm
Aluminum	126		
Antimony	141	131	
Arsenic	121	111	
Beryllium	106		
Boron	88		
Bromine	114	104	
Cadmium	148		
Carbon	77.2	66.7	60.3
Chlorine	99	89	
Copper	135		
Fluorine	64	54	
Gallium	126		
Germanium	122	112	
Hydrogen	30		
Indium	144		
Iodine	133	123	
Magnesium	140		
Mercury	148		
Nitrogen	70	60	55
Oxygen	66	55	
Phosphorus	110	100	93
Silicon	117	107	100
Selenium	117	107	
Silver	152		
Sulfur	104	94	87
Tellurium	137	127	
Tin	140	130	
Zinc	131		

* Single-bond radii are for a tetrahedral (CN = 4) structure.

TABLE 4.8 Octahedral Covalent Radii for CN = 6

Atom	Octahedral covalent radius, pm	Atom	Octahedral covalent radius, pm
Cobalt(II)	132	Nickel(III)	130
Cobalt(III)	122	Nickel(IV)	121
Gold(IV)	140	Osmium(II)	133
Iridium(III)	132	Palladium(IV)	131
Iron(II)	123	Platinum(IV)	131
Iron(IV)	120	Rhodium(III)	132
Nickel(II)	139	Ruthenium(II)	133

TABLE 4.9 Bond Lengths between Carbon and Other Elements

Bond type	Bond length, pm
Carbon-carbon	
Single bond	
Paraffinic: —C—C—	154.1(3)
In presence of —C═C— or of aromatic ring	153(1)
In presence of —C═O bond	151.6(5)
In presence of two carbon-oxygen bonds	149(1)
In presence of two carbon-carbon double bonds	142.6(5)
Aryl-C═O	147(2)
In presence of one carbon-carbon triple bond: —C—C≡C—	146.0(3)
In presence of one carbon-nitrogen triple bond: —C—C≡N	146.6(5)
In compounds with tendency to dipole formation, e.g., C═C—C═O	144(1)
In aromatic compounds	139.5(3)
In presence of carbon-carbon double and triple bonds: —C═C—C≡C—	142.6(5)
In presence of two carbon-carbon triple bonds: —C≡C—C≡C—	137.3(4)
Double bond	
Single: —C═C—	133.7(6)
Conjugated with a carbon-carbon double bond: —C═C—C═C—	133.6(5)
Conjugated with a carbon-oxygen double bond: —C═C—C═O	136(1)
Cumulative: —C═C═C— or —C═C═O	130.9(5)
Triple bond	
Simple: —C≡C—	120.4(2)
Conjugated: —C≡C—C═C—, —C≡C—C═O, or —C≡C—aryl	120.6(4)

Bond type	Bond length, pm			
Carbon-halogen				
	Fluorine	Chlorine	Bromine	Iodine
Paraffinic: R—X	137.9(5)	176.7(2)	193.8(5)	213.9(1)
Olenfinic: —C═C—X	133.3(5)	171.9(5)	189(1)	209.2(5)
Aromatic: Ar-X	132.8(5)	170(1)	185(1)	205(1)
Acetylenic: —C≡C—X	(127)	163.5(5)	179.5(10)	199(2)

TABLE 4.9 Bond Lengths between Carbon and Other Elements (*Continued*)

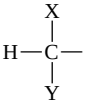
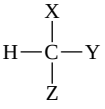
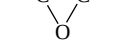
Bond type	Bond length, pm
Carbon-hydrogen	
Paraffinic	
In methane (in CD_4, 109.2)	109.4
In monosubstituted carbon: H—C—Y	109.6(5)
In disubstituted carbon: 	107.3(5)
In trisubstituted carbon: 	107.0(7)
Olefinic	
Simple: H—C═C—	108.3(5)
Cumulative carbon-carbon double bonds: H—C═C═C—	107(1)
Cumulative carbon-carbon-oxygen double bonds: H—C—C═C═O	108(1)
Aromatic	108.4(5)
Acetylenic (in C_2H_2, 105.9)	105.5(5)
In small rings	108.1(5)
In presence of a carbon triple bond: H—C≡C—	111.5(4)
Carbon-nitrogen	
Single bond	
Paraffinic:	
3-covalent nitrogen: RNH_2, R_2NH, R_3N	147.2(5)
4-covalent nitrogen: RNH_3^+, R_3N-BX_3	147.9(5)
In —C—N═	147.5(10)
In aromatic compounds	143(1)
In conjugated heterocyclic systems (partial double bond)	135.3(5)
In —N—C═O (partial double bond)	132.2(5)
Double bond: —C═N—	132
Triple bond (in CN radical, 117.74): —C≡N	115.7(5)
Carbon-oxygen	
Single bond	
Paraffinic and saturated heterocyclic: —C—O—	142.6(5)
Strained, as in epoxides: 	143.5(5)
In aromatic compounds, as Ar-OH	136(1)
Longer bond in carboxylic acids and esters (HCOOH, 131.2)	135.8(5)
In conjugated heterocyclics, as furan	137.1(16)
Double bond	
In CO^+	111.5
In CO	112.8
In CO_2^+	117.7
In HCO	119.8(8)
In carbonyls	114.5(10)
In aldehydes and ketones	121.5(5)

TABLE 4.9 Bond Lengths between Carbon and Other Elements (*Continued*)

Bond type	Bond length, pm
Carbon-oxygen (*continued*)	
In acyl halides: R—CO—X	117.1(4)
Shorter bond in carboxylic acids and esters	123.3(5)
In zwitterion forms	126(1)
In O═C═	116.0(1)
In isocyanates: RN═C═O	117(1)
In conjugated systems, as in partial triple bond: O═C—C═C	121.5(5)
In 1,4-quinones	115(2)
In metal acetylacetonates	128(2)
In calcite: $CaCO_3$	129(1)
Carbon-selenium	
Single bond	
Paraffinic: —C—Se—	198(2)
In presence of fluorine, as in perfluorocompounds: —CF—Se—	195(2)
Double bond	
In Se═C═, as SeCS and SeCO	170.9(3)
In CSe radical	167
Carbon-silicon	
Alkyl substituent: H_3C—Si or H_2C—Si	187.0(5)
Aryl substituent: aryl—Si	184.3(5)
Electronegative substituent: R—Si—X	185.4(5)
Carbon-sulfur	
Single bond	
Paraffinic: —C—S—	181.7(5)
In presence of fluorine, as in perfluoro compounds: —CF—S—	183.5(1)
In heterocyclic systems: partial double bonds	171.8(5)
Double bonds	
In S═C; thiophene, S═CR_2	171(1)
In sulfoxides and sulfones	180(1)
In presence of second carbon-carbon double bond: S═C—C═C—	155.5(1)
In SC radical [in CS_2^+, 155.4(5)]	153.49(2)

Bond type	Bond length, pm	Bond type	Bond length, pm
Other elements and carbon			
C-Al	224(4)	C-Cr	192(4)
C-As	198(1)	C-Fe	184(2)
C-B	156(1)	C-Ge	
C-Be	193	Alkyl	193(3)
C-Bi	230	Aryl	194.5(5)
C-Co	183(2)		

TABLE 4.9 Bond Lengths between Carbon and Other Elements (*Continued*)

Bond type	Bond length, pm	Bond type	Bond length, pm
Other elements and carbon (*continued*)			
C-Hg	207(1)	C-Sn	
in $Hg(CN)_2$	199(2)	Alkyl	214.3(5)
C-In	216(4)	Electronegative substituent	218(2)
C-Mo	208(4)	C-Te	190.4
C-Ni	210.7(5)	C-Tl	270.5(5)
C-Pb (alkyl)	230(1)	C-W	206
C-Pd	227(4)		
C-Sb (paraffinic)	220.2(16)		

TABLE 4.10 Bond Lengths between Elements Other than Carbon

Elements	Bond type	Bond length, pm	Elements	Bond type	Bond length, pm
Boron			Nitrogen		
B-B	B_2H_6	177(1)	N-Cl	NO_2Cl	179(2)
B-Br	BBr_3	187(2)	N-F	NF_3	136(2)
B-Cl	BCl_3	172(1)	N-H	NH_4^+	103.4(3)
B-F	BF_3, R_2BF	129(1)		NH_3, RNH_2	101.2
B-H	Boranes	121(2)		H_2NNH_2	103.8
	Bridge	139(2)		R—CO—NH_2	99(3)
B-N	Borazoles	142(1)		HN═C═S	101.3(5)
B-O	$B(OH)_3$, $(RO)_3B$	136(5)	N-D	ND (N^2H)	104.1
Hydrogen			N-N	HN_3	102(1)
				R_2NNH_2	145.1(5)
				N_2O	112.6(2)
				N_2^+	111.6
H-Al	AlH	164.6	N-O	NO_2Cl	124(1)
H-As	AsH_3	151.9		RO—NO_2	136(2)
H-Be	BeH	134.3		NO_2	118.8(5)
H-Br	HBr	140.8	N═O	N_2O	118.6(2)
H-Ca	CaH	200.2		RNO_2	122(1)
H-Cl	HCl	127.4		NO^+	106.19
H-F	HF	91.7	N-Si	SiN	157.2
H-Ge	GeH_4	153	Oxygen		
H-I	HI	160.9			
H-K	KH	224.4			
H-Li	LiH	159.5			
H-Mg	MgH	173.1	O-H	H_2O	95.8
H-Na	NaH	188.7		ROH	97(1)
H-Sb	H_3Sb	170.7		OH^+	102.89
H-Se	H_2Se	146.0		HOOH	96.0(5)
H-Sn	SnH_4	170.1		D_2O (^2H_2O)	95.75
D-Br	DBr (^{2}HBr)	141.44		OD	96.99
D-Cl	DCl	127.46	O-O	HO—OH	148(1)
D-I	DI	161.65		O_2^+	122.7
T-Br	TBr (^{3}HBr)	141.44		O_2^-	126(2)
T-Cl	TCl	127.40		O_2^{2-}	149(2)

TABLE 4.10 Bond Lengths between Elements Other than Carbon (*Continued*)

Elements	Bond type	Bond length, pm
	Oxygen (*continued*)	
	O_3	127.8(5)
O-Al	AlO	161.8
O-As	As_2O_6 bridges	179
O-Ba	BaO	190.0
O-Cl	ClO_2	148.4
	OCl_2	168
O-Mg	MgO	174.9
O-Os	OsO_4	166
O-Pb	PbO	193.4
	Phosphorus	
P-Br	PBr_3	223(1)
P-Cl	PCl_3	200(2)
P-F	$PFCl_2$	155(3)
P-H	PH_3, PH_4^+	142.4(5)
P-I	PI_3	252(1)
P-N	Single bond	149.1
P-O	Single bond	144.7
	p^3 bonding	167
	sp^3 bonding	154(4)
P-S	p^3 bonding	212(5)
	sp^3 bonding	208(2)
	In rings	220(3)
P-C	Single bond	156.2
	p^3 bonding	187(2)
	Silicon	
Si-Br	$SiBr_4$, R_3SiBr	216(1)
Si-Cl	$SiCl_4$, R_3SiCl	201.9(5)
Si-F	SiF_4, R_3SiF	156.1(3)
	SiF_6	158
Si-H	SiH_4	148.0(5)
	R_3SiH	147.6(5)
Si-I	SiI_4	234
	R_3SiI	246(2)
Si-O	R_3SiOR	153.3(5)
Si-Si	H_3SiSiH_3	230(2)
	Sulfur	
S-Br	$SOBr_2$	227(2)
S-Cl	S_2Cl_2	158.5(5)
S-F	SOF_2	158.5(5)
S-H	H_2S	133.3
	RSH	132.9(5)
	D_2S	134.5
S-O	SO_2	143.21
	$SOCl_2$	145(2)
S-S	RSSR	205(1)

TABLE 4.11 Bond Dissociation Energies

The bond dissociation energy (enthalpy change) for a bond A—B which is broken through the reaction

$$AB \rightarrow A + B$$

is defined as the standard-state enthalpy change for the reaction at a specified temperature, here at 298 K. That is,

$$\Delta Hf_{298} = \Delta Hf_{298}(A) + \Delta Hf_{298}(B) - \Delta Hf_{298}(AB)$$

All values refer to the gaseous state and are given at 298 K. Values of 0 K are obtained by subtracting $\frac{3}{2}RT$ from the value at 298 K.

To convert the tabulated values to kcal/mol, divide by 4.184.

Bond	ΔHf_{298}, kJ/mol
Aluminum	
Al—Al	186(9)
Al—As	180
Al—Au	326(6)
Al—Br	439(8)
Al—C	255
Al—Cl	494(13)
AlCl—Cl	402(8)
$AlCl_2$—Cl	372(8)
AlO—Cl	515(84)
Al—Cu	216(10)
Al—D	291
Al—F	664(6)
AlF—F	546(42)
AlF_2—F	544(46)
AlO—F	761(42)
Al—H	285(6)
Al—I	368(4)
Al—Li	176(15)
Al—N	297(96)
Al—O	512(4)
AlCl—O	540(41)
AlF—O	582
Al—P	213(13)
Al—Pd	259(12)
Al—S	374(8)
Al—Se	334(10)
Al—Si	251(3)
Al—Te	268(10)
Al—U	326(29)
Antimony	
Sb—Sb	299(6)
Sb—Br	314(59)
Sb—Cl	360(50)
Sb—F	439(96)
Sb—N	301(50)
Sb—O	372(84)
Sb—P	357
Sb—S	379
Sb—Te	277.4(38)
Arsenic	
As—As	382(11)
As—Cl	448
As—Ga	209.6(12)
As—H	272(12)
As—N	582(126)
As—O	481(8)
As—P	534(13)
As—S	(478)
As—Se	96
As—Tl	198(15)
Astatine	
At—At	(115.9)
Barium	
Ba—Br	370(8)
Ba—Cl	444(13)
Ba—F	487(7)
Ba—I	>431(4)
Ba—O	563(42)
Ba—OH	477(42)
Ba—S	400(19)
Beryllium	
Be—Be	59
Be—Br	381(84)
Be—Cl	388(9)

TABLE 4.11 Bond Dissociation Energies (*Continued*)

Bond	ΔHf_{298}, kJ/mol
Beryllium (*continued*)	
BeCl—Cl	540(63)
Be—F	577(42)
Be—H	226(21)
Be—O	448(21)
Be—S	372(59)
Bismuth	
Bi—Bi	197(4)
Bi—Br	267(4)
Bi—Cl	305(8)
Bi—D	284
Bi—F	259(29)
Bi—Ga	159(17)
Bi—H	279
Bi—O	343(6)
Bi—P	280(13)
Bi—Pb	142(15)
Bi—S	316(5)
Bi—Sb	251(4)
Bi—Se	280(6)
Bi—Te	232(11)
Bi—Tl	121(13)
Boron	
B—B	297(21)
$H_3B—BH_3$	146
OB—BO	506(84)
B—Br	435(21)
B—C	448(29)
B—Cl	536(29)
BO—Cl	460(42)
B—D	341(6)
B—F	766(13)
BF—F	523(63)
BF_2—F	557(84)
B—H	330(4)
B—I	384(21)
B—N	389(21)
B—O	806(5)
BCl—O	715(41)
B—P	347(17)
B—S	581(9)
B—Se	462(15)
B—Si	289(29)
B—Te	354(20)

Bond	ΔHf_{298}, kJ/mol
Bromine	
Br—Br	193.870(4)
Br—C	280(21)
$Br—CH_3$	284(8)
$Br—CH_2Br$	255(13)
$Br—CHBr_2$	259(17)
$Br—CBr_3$	209(13)
$Br—CCl_3$	218(13)
$Br—CF_3$	285(13)
$Br—CF_2CF_3$	287.4(63)
$Br—CF_2CF_2CF_3$	278.2(63)
$Br—CHF_2$	289
Br—Cl	218.84(4)
Br—CN	381
$Br—CO—C_6H_5$	268
Br—F	233.8(2)
Br—N	276(21)
$Br—NF_2$	222
Br—NO	120.1(63)
Br—O	235.1(4)
Cadmium	
Cd—Cd	11.3(8)
Cd—Br	159(96)
Cd—Cl	206.7(34)
Cd—F	305(21)
Cd—H	69.0(4)
Cd—I	138(21)
Cd—In	138
Cd—O	142(42)
Cd—S	196
Cd—Se	310
Calcium	
Ca—Ca	14.98(46)
Ca—Br	321(23)
Ca—Cl	398(13)
Ca—F	527(21)
Ca—H	167.8
Ca—I	285(63)
Ca—O	464(84)
Ca—S	314(19)
Carbon	
C—C	607(21)
$H_3C—CH_3$	368

TABLE 4.11 Bond Dissociation Energies (*Continued*)

Bond	ΔHf_{298}, kJ/mol
Carbon (*continued*)	
$(CH_3)_2C—CH_3$	335
$(CH_3)_2C—C(CH_3)_2$	282.4
$CH_3—C_6H_5$	389
$CH_3—CH_2C_6H_5$	301
$(CH_3)_3C—C(C_6H_5)_3$	63
CH_3—allyl	301
CH_3—vinyl	121
$CH_3—C\equiv CH$	490
$CH_2=CH—CH=CH_2$	418
$HC\equiv C—C\equiv CH$	628
$H_2C=CH_2$	682
$HC\equiv CH$	962
$CH_3—CN$	506(21)
$CH_3—CH_2CN$	305(8)
$CH_3—CH(CH_3)CN$	331(8)
$CH_3—C(C_6H_5)CN(CH_3)$	251
$CH_3CH_2—CH_2CN$	321.8(71)
$NC—CN$	603(21)
$C_6H_5—C_6H_5$	418
$CH_3—CF_3$	423.4(46)
$CH_2F—CH_2F$	368(8)
$CF_3—CF_3$	406(13)
$CF_2=CF_2$	318(13)
$CF_3—CN$	501
$CH_3—CHO$	314
$CH_3—CO$	342.7
$CH_3CO—CF_3$	308.8
$CH_3CO—COCH_3$	280(8)
$C_6H_5CO—COC_6H_5$	277.8
Aryl—CH_2COCH_2—aryl	273.6
$C_6H_5CH_2—COOH$	284.9
$(C_6H_5CH_2)_2CH—COOH$	248.5
C—Cl	397(29)
C—F	536(21)
C—H	337.2(8)
C—I	209(21)
C—N	770(4)
$CF_3—NF_2$	272(13)
$CH_3—NH_2$	331(13)
$C_6H_5CH_2—NH_2$	301(4)
$CH_3—NHC_6H_5$	285
$CH_3—N(CH_3)C_6H_5$	272
$C_6H_5CH_2—NHCH_3$	289(4)
$C_6H_5CH_2—N(CH_3)_2$	255(4)
$CH_3—(N=NCH_3)$	219.7
$C_2H_5—(N=NC_2H_5)$	209.2
$(CH_3)_3C—N=NC(CH_3)_3$	182.0
Aryl—$CH_2N=NCH_2$—aryl	157
$CF_3—(N=NCF_3)$	231.0
$H_2C=NH$	644(21)
$HC\equiv N$	937
$CH_3—NO$	174.9(38)
$C_2H_5—NO$	175.7(54)
$C_3H_7—NO$	167.8(75)
$(CH_3)_2CH—NO$	171.5(54)
n-$C_4H_9—NO$	215.5(42)
$C_6H_5—NO$	215.5(42)
$Cl_3C—NO$	134
$F_3C—NO$	130
$C_6F_5—NO$	211.3(42)
$NC—NO$	121(13)
$CH_3—NO_2$	247(13)
$C_2H_5—NO_2$	259
C—O	1076.5(4)
$CH_3—OCH_3$	335
$CH_3—OC_6H_5$	381
$CH_3—OCH_2C_6H_5$	280
$C_2H_5—OC_6H_5$	213
$C_6H_5CH_2—OCOCH_3$	285
$C_6H_5CH_2—OCOC_6H_5$	289
$CH_3CO—OCH_3$	406
$CH_3—OSOCH_3$	280
$CH_2=CHCH_2—OSOCH_3$	209
$C_6H_5CH_2—OSOCH_3$	222
C=O	749
$H_2C=O$	732
OC=O	532.2(4)
SC=O	628
C≡O	1075
C—P	513(8)
C—S	699(8)
$CH_3—SH$	305(13)
$CH_3—SC_6H_5$	285(8)
$CH_3—SCH_2C_6H_5$	247(8)
OC—S	310.4
C—Se	582(96)
Cerium	
Ce—Ce	243(21)
Ce—F	582(42)
Ce—N	519(21)
Ce—O	795(13)
Ce—S	573(13)
Ce—Se	495(15)
Ce—Te	389(42)

TABLE 4.11 Bond Dissociation Energies (*Continued*)

Bond	ΔHf_{298}, kJ/mol
Cesium	
Cs—Cs	41.75(93)
Cs—Br	397.5(42)
Cs—Cl	439(21)
Cs—F	514(8)
Cs—H	178.1(38)
Cs—I	339(4)
Cs—O	297(25)
Cs—OH	385(13)
Chlorine	
Cl—Cl	242.580(16)
Cl—C	338(42)
Cl—CH_3	339(21)
Cl—CH_3^+	213
Cl—$C(CH_3)_3$	328.4
Cl—CH_2Cl	310(13)
Cl—CCl_3	293(21)
Cl—CF_3	360(33)
Cl—CCl_2F	305(8)
Cl—$CClF_2$	318(8)
Cl—CF_2CF_2	346.0(71)
Cl—CH=CH_2	351
Cl—CN	439
Cl—COCl	328
Cl—$COCH_3$	349.4
Cl—COC_6H_5	310(13)
Cl—Cl^+	393
Cl—ClO	143.3(42)
O_3Cl—ClO_4	243
Cl—F	250.54(8)
O_3Cl—F	255
Cl—N	389(50)
Cl—NCl	280
Cl—NCl_2	381
Cl—NF_2	*ca.* 134
Cl—NH_2	251(25)
Cl—NO	159(6)
Cl—NO_2	142(4)
Cl—O	272(4)
OCl—O	243(13)
O_2Cl—O	201(4)
Cl—P	289(42)
Cl—$SiCl_3$	464
Chromium	
Cr—Cr	155(21)
Cr—Br	328(24)
Cr—Cl	366(24)
Cr—Cu	155(21)
Cr—F	437(20)
Cr—Ge	170(29)
Cr—H	280(50)
Cr—I	287(24)
Cr—N	378(19)
Cr—O	427(29)
OCr—O	531(63)
O_2Cr—O	477(84)
Cr—S	339(21)
Cobalt	
Co—Co	167(25)
Co—Br	331(42)
Co—Cl	398(8)
Co—Cu	162(17)
Co—F	435(63)
Co—Ge	239(25)
Co—I	235(81)
Co—O	368(21)
Co—S	343(21)
Copper	
Cu—Cu	202(4)
Cu—Br	331(25)
Cu—Cl	383(21)
Cu—F	431(13)
Cu—Ga	216(15)
Cu—Ge	209(21)
Cu—H	280(8)
Cu—I	197(21)
Cu—Ni	206(17)
Cu—O	343(63)
Cu—S	285(17)
Cu—Se	293(38)
Cu—Sn	177(17)
Cu—Te	176(38)
Curium	
Cm—O	736
Dysprosium	
Dy—F	527(21)
Dy—O	611(42)
Dy—Se	322(42)
Dy—Te	234(42)

TABLE 4.11 Bond Dissociation Energies (*Continued*)

Bond	ΔHf_{298}, kJ/mol
Erbium	
Er—F	565(17)
Er—O	611(13)
Er—S	418(42)
Er—Se	326(42)
Er—Te	239(42)
Europium	
Eu—Eu	33.5(165)
Eu—Cl	*ca.* 326
Eu—F	528(18)
Eu—O	557(13)
Eu—S	364(15)
Eu—Se	301(15)
Eu—Te	243(15)
Fluorine	
F—F	156.9(96)
$F—F^+$	>251
$F—CH_3$	452(21)
$F—C(CH_3)_3$	439
$F—C_6H_5$	485
$F—CCl_3$	444(21)
$F—CCl_2F$	460(25)
$F—CClF_2$	490(25)
$F—CF_3$	523(17)
$F—COCH_3$	498
F—FO	272(13)
$F—FO_2$	81.0
F—N	301(42)
F—NF	318(25)
$F—NF_2$	243(8)
F—NO	235.6(42)
$F—NO_2$	197(25)
Gadolinium	
Gd—F	590(27)
Gd—O	716(17)
Gd—S	525(15)
Gd—Se	431(15)
Gallium	
Ga—Ga	138(21)
Ga—Br	444(17)
$(CH_3)_3Ga—CH_3$	253
Ga—Cl	481(13)
Ga—F	577(15)
Ga—H	<274
Ga—I	339(10)
Ga—O	285(63)
Ga—P	230(13)
Ga—Sb	209(13)
Ga—Te	251(25)
Germanium	
Ge—Ge	274(21)
Ge—Br	255(29)
Ge—Cl	431.8(4)
Ge—F	485(21)
Ge—H	321.3(8)
Ge—O	662(13)
Ge—S	551.0(25)
Ge—Se	490(21)
Ge—Si	301(21)
Ge—Te	402(8)
Gold	
Au—Au	221.3(21)
Au—B	368(11)
Au—Be	285(8)
Au—Bi	293(84)
Au—Cl	343(10)
Au—Co	215(13)
Au—Cr	215(6)
Au—Cu	232(9)
Au—Fe	187(17)
Au—Ga	294(15)
Au—Ge	277(15)
Au—H	314(10)
Au—La	80(5)
Au—Li	68.0(16)
Au—Mg	243(42)
Au—Mn	185(13)
Au—Ni	274(21)
Au—Pb	130(42)
Au—Pd	143(21)
Au—Rh	231(29)
Au—S	418(25)
Au—Si	312(12)
Au—Sn	244(17)
Au—Te	247(67)
Au—U	318(29)
Hafnium	
Hf—C	548(63)
Hf—N	534(29)
Hf—O	791(8)

TABLE 4.11 Bond Dissociation Energies (*Continued*)

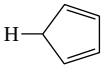
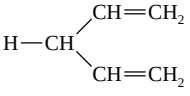
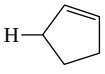
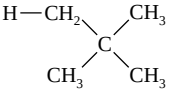
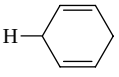
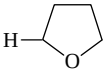
Bond	ΔHf_{298}, kJ/mol
Hydrogen	
H—H	436.002(4)
H—^{2}H or H—D	439.446(4)
^{2}H—^{2}H or D—D	443.546(4)
H—Br	365.7(21)
H—C	337.2(8)
H—CH	452(33)
H—CH_2	473(4)
H—CH_3	431(8)
^{2}H—C^{2}H$_3$ or D—CD_3	442.75(25)
H—C≡CH	523(4)
H—CH═CH_2	427
H—CH_2CH_3	410(4)
H—CH_2C≡CH	392.9(50)
H—CH_2CH═CH_2	356
H—cyclopropyl	423(13)
H—$CH_2CH_2CH_3$	410(8)
H—$CH(CH_3)_2$	395.4
H—cyclobutyl	397(13)
H—$CH_2CH(CH_3)_2$	360
H—$CH(CH_3)CH_2CH_3$	397(4)
H—$C(CH_3)_3$	381
	339(4)
	335(4)
	343(4)
	414(4)
H—$C(CH_3)_2CH$═CH_2	331
H—cyclopentyl	395(42)
H—$CH_2C(CH_3)_3$	418(4)
H—C_6H_5	431
H—$CH_2C_6H_5$	356(4)
H—$C(C_6H_5)_3$	314
	310
H—cyclohexyl	399.6(42)
H—cycloheptyl	387.0(42)
H—norbornyl	406(13)
H—CH_2Br	410(25)
H—$CHBr_2$	435
H—CH_2Cl	423
H—$CHCl_2$	414.2
H—CCl_3	377(8)
H—CBr_3	377(8)
H—CCl_2CHCl_2	393(8)
H—CH_2F	423(8)
H—CHF_2	423(8)
H—CF_3	444(13)
H—CF_2Cl	435(4)
H—CH_2CF_3	446(45)
H—CF_2CH_3	416(4)
H—CF_2CF_3	431(63)
H—CH_2I	431(8)
H—CHI_2	431(8)
H—CN	540(25)
H—CH_2CN	*ca.* 389
H—$CH(CH_3)CN$	377(8)
H—$C(CH_3)_2CN$	364(8)
H—CH_2NH_2	397(8)
H—$CH_2Si(CH_3)_3$	414(4)
H—CH_2COCH_3	393(75)
H—Cl	431.8(4)
H—CO	126(8)
H—CHO	364(4)
H—COOH	377
H—$COCH_3$	364(4)
H—$COCH_2CH_3$	364(4)
	385
H—COC_6H_5	364(4)
H—$COCF_3$	381(8)
H—F	568.6(13)
H—I	298.7(8)
H—N	314(17)
H—NH	377(8)
H—NH_2	435(8)
H—$NHCH_3$	431(8)
H—$N(CH_3)_2$	397(8)
H—NHC_6H_5	335(13)
H—$N(CH_3)C_6H_5$	310(13)
HNF_2	318(13)
H—N_3	356
H—NO	<205
H—O	428.0(21)
H—OH	498.7(8)
H—OCH_3	436.8(42)
H—OCH_2CH_3	436.0
H—$OC(CH_3)_3$	439(4)
H—OC_6H_5	368(25)
H—ONO	327.6(25)

TABLE 4.11 Bond Dissociation Energies (*Continued*)

Bond	ΔHf_{298}, kJ/mol
Hydrogen (*continued*)	
H—ONO_2	423.4(25)
H—OOH	374(8)
H—$OOCCH_3$	469(17)
H—$OOCCH_2CH_3$	460(17)
H—$OOCC_3H_7$	431(17)
H—P	343(29)
H—S	344(12)
H—SH	381(4)
H—SCH_3	*ca.* 368
H—Se	305(2)
H—Si	298.49(46)
H—SiH_3	393(13)
H—$Si(CH_3)_3$	377(13)
H—Te	268(2)
Indium	
In—In	100(8)
In—Br	418(21)
In—Cl	439(8)
In—F	506(15)
In—O	360(21)
In—P	197.9(85)
In—S	289(17)
In—Sb	152(11)
In—Se	247(17)
In—Te	218(17)
Iodine	
I—I	152.549(8)
I—Br	179.1(4)
I—CH_3	232(13)
I—C_2H_5	223.8
I—$CH(CH_3)_2$	222
I—$C(CH_3)_3$	207.1
I—CH_2CF_3	234(4)
I—CF_2CH_3	216(4)
I—C_3F_7	209(4)
I—$CH{=}CHCH_3$	172
I—C_6H_5	268(4)
I—C_6F_5	276
I—Cl	213.3(4)
I—$COCH_3$	219.7
I—CN	305(4)
I—F	280(4)
I—N	159(17)
I—NO	71(4)
I—NO_2	75(4)
I—O	184(21)
Iridium	
Ir—O	352(21)
Ir—Si	463(21)
Iron	
Fe—Fe	100(21)
Fe—Br	247(96)
Fe—Cl	*ca.* 352
Fe—O	409(13)
Fe—S	339(21)
Fe—Si	297(25)
Krypton	
Kr—Kr	5.4(8)
Kr—F	54
Lanthanum	
La—La	247(21)
La—C	506(63)
La—F	598(42)
La—N	519(42)
La—O	799(13)
La—S	577(25)
Lead	
Pb—Pb	339(25)
Pb—Br	247(38)
$Pb(CH_3)_3$—CH_3	207(42)
Pb—Cl	301(29)
Pb—F	356(8)
Pb—H	176(21)
Pb—I	197(38)
Pb—O	378(4)
Pb—S	346.0(17)
Pb—Se	303(4)
Pb—Te	251(13)
Lithium	
Li—Li	106(4)
Li—Br	423(21)
Li—Cl	469(13)
Li—F	577(21)
Li—H	247
Li—I	352(13)
Li—Na	88
Li—O	341(6)
Li—OH	427(21)

TABLE 4.11 Bond Dissociation Energies (*Continued*)

Bond	ΔHf_{298}, kJ/mol
Lutetium	
Lu—Lu	142(34)
Lu—F	569(42)
Lu—O	695(13)
Lu—S	507(15)
Lu—Te	326(17)
Magnesium	
Mg—Mg	8.522(4)
Mg—Br	297(63)
Mg—Cl	318(13)
Mg—F	462(21)
MgF—F	569(42)
Mg—H	197(50)
Mg—I	*ca.* 285
Mg—O	394(35)
Mg—OH	238(21)
Mg—S	310(75)
Manganese	
Mn—Mn	42(29)
Mn—Br	314(10)
Mn—Cl	361(10)
Mn—F	423(15)
Mn—I	283(10)
Mn—Cu	159(17)
Mn—O	402(34)
Mn—S	301(17)
Mn—Se	201(13)
Mercury	
Hg—Hg	17.2(21)
Hg—Br	72.8(42)
CH_3—$HgCH_3$	240.6
C_2H_5—HgC_2H_5	182.8(42)
C_3H_7—HgC_3H_7	197.1
Isopropyl—Hgisopropyl	170.3
C_6H_5—HgC_6H_5	285
Hg—Cl	100(8)
Hg—F	130(38)
Hg—H	39.8
Hg—I	38
Hg—K	8.24(21)
Hg—Na	>6.7
Hg—S	213
Hg—Se	(167)
Hg—Te	(142)

Bond	ΔHf_{298}, kJ/mol
Molybdenum	
Mo—I	372
Mo—O	607(34)
MoO—O	678(84)
MoO_2—O	565(84)
Neodymium	
Nd—F	545(13)
Nd—O	703(34)
Nd—S	474(15)
Nd—Se	385(17)
Nd—Te	305(17)
Neon	
Ne—Ne	3.93
Neptunium	
Np—O	720(29)
Nickel	
Ni—Ni	261.9(25)
Ni—Br	360(13)
Ni—Cl	372(21)
Ni—F	435
Ni—H	289(13)
Ni—I	293(21)
Ni—O	391.6(38)
Ni—S	360(21)
Ni—Si	318(17)
Niobium	
Nb—O	753(13)
Nitrogen	
N—N	945.33(59)
N—Br	276(21)
ON—Br	28.7(15)
N—Cl	389(50)
ON—Cl	159(6)
O_2N—Cl	142(4)
N—F	301(42)
FN—F	318(21)
F_2F—N	243(8)
ON—F	236(4)
O_2N—F	188(21)

TABLE 4.11 Bond Dissociation Energies (*Continued*)

Bond	ΔHf_{298}, kJ/mol
Nitrogen (*continued*)	
N—I	159(17)
F_2N—NF_2	88(4)
H_2N—NH_2	297(8)
H_2N—$NHCH_3$	271
H_2N—$N(CH_3)_2$	264
H_2N—NHC_6H_5	213
HN—N_2	38
ON—N	480.7(42)
ON—NO_2	39.8(8)
O_2N—NO_2	57.3(21)
HN═NH	456(42)
N≡N	946
N—O	630.57(13)
HN═O	481
NN—O	167
ON—O	305
N—P	617(21)
N—S	464(21)
Osmium	
O_3Os—O	301(21)
Oxygen	
O—O	498.34(20)
O—Br	235.1(4)
HO—CH_3	377(13)
HO—CH═CH_2	364
HO—CH_2CH═CH_2	456
HO—C_6H_5	431
HO—$CH_2C_6H_5$	322
HO—CHO	402(13)
HO—$COCH_3$	452(21)
HO—COC_2H_5	180
O—Cl	272(4)
HO—Cl	251(13)
O—F	222(17)
O—FO	467
FO—OF	261(84)
O—I	184(21)
HO—I	234(13)
O—N	630.57(13)
HO—NCH_3	209
HO—$OC(CH_3)_3$	192(8)
HO—OH	213.8(21)
O—OH	268(4)
CF_3O—OCF_3	192
CH_3O—OCH_3	157.3(8)
C_2H_5O—OC_2H_5	159
C_3H_7O—OC_3H_7	155
Palladium	
Pd—O	234(29)
Phosphorus	
P—P	490(11)
P—Br	266.5
P—C	513(8)
P—Cl	289(42)
P—F	439(96)
P—H	343(29)
P—N	617(21)
P—O	596.6
Br_3P═O	498(21)
Cl_3P═O	510(21)
F_3P═O	544(21)
P—S	346.0(17)
P═S	347
P—Se	363(10)
P—Te	298(10)
Platinum	
Pt—B	478(17)
Pt—H	352(38)
Pt—O	347(34)
Pt—P	417(17)
Pt—Si	501(18)
Potassium	
K—K	57.3(42)
K—Br	383(8)
K—Cl	427(8)
K—F	497.5(25)
K—H	183(15)
K—I	331(13)
K—Na	63.6(29)
K—O	239(34)
K—OH	343(8)
Praseodymium	
Pr—F	582(46)
Pr—O	753(17)
Pr—S	492.5(46)

TABLE 4.11 Bond Dissociation Energies (*Continued*)

Bond	ΔHf_{298}, kJ/mol
Praseodymium (*continued*)	
Pr—Se	446(23)
Pr—Te	326(42)
Promethium	
Pm—F	540(42)
Pm—O	674(63)
Pm—S	423(63)
Pm—Se	339(63)
Pm—Te	255(63)
Radium	
Ra—Cl	343(75)
Rhodium	
Rh—Rh	285(21)
Rh—B	476(21)
Rh—C	583.7(63)
Rh—O	377(63)
Rh—Si	395(18)
Rh—Ti	391(15)
Rubidium	
Rb—Rb	45.6(21)
Rb—Br	389(13)
Rb—Cl	448(21)
Rb—F	494(21)
Rb—H	167(21)
Rb—I	335(13)
Rb—O	255(84)
Rb—OH	351(8)
Ruthenium	
Ru—O	481(63)
$O_3Ru—O$	439
Ru—Si	397(21)
Ru—Th	592(42)
Samarium	
Sm—Cl	423(13)
Sm—F	531(18)
Sm—O	619(13)
Sm—S	389
Sm—Se	331(15)
Sm—Te	272(15)
Scandium	
Sc—Sc	163(21)
Sc—Br	444(63)
Sc—C	393(63)
Sc—Cl	318
Sc—F	589(13)
Sc—N	469(84)
Sc—O	674(13)
Sc—S	478(13)
Sc—Se	385(17)
Sc—Te	289(17)
Selenium	
Se—Se	332.6(4)
Se—Br	297(84)
Se—C	582(96)
Se—Cl	322
Se—F	339(42)
Se—H	305(2)
Se—N	381(63)
Se—O	423(13)
Se—P	364(10)
Se—S	381(21)
Se—Si	531(25)
Se—Te	268(8)
Silicon	
Si—Si	327(10)
Si—Br	343(50)
Si—C	435(21)
Si—Cl	456(42)
Si—F	540(13)
Si—H	298.49(46)
Si—I	339(84)
Si—N	439(38)
Si—O	798(8)
Si—S	619(13)
Si—Se	531(25)
$H_3Si—SiH_3$	339(17)
$(CH_3)_3Si—Si(CH_3)_3$	339
$(Aryl)_3Si—Si(aryl)_3$	368(31)
Si—Te	506(38)
Silver	
Ag—Ag	163(8)
Ag—Au	203(9)
Ag—Bi	193(42)

TABLE 4.11 Bond Dissociation Energies (*Continued*)

Bond	ΔHf_{298}, kJ/mol
Silver (*continued*)	
Ag—Br	293(29)
Ag—Cl	341.4
Ag—Cu	176(8)
Ag—F	354(16)
Ag—Ga	180(15)
Ag—Ge	175(21)
Ag—H	226(8)
Ag—I	234(29)
Ag—In	176(17)
Ag—O	213(84)
Ag—Sn	136(21)
Ag—Te	293(96)
Sodium	
Na—Na	77.0
Na—Br	370(13)
Na—Cl	410(8)
Na—F	481(8)
Na—H	201(21)
Na—I	301(8)
Na—K	63.6(29)
Na—O	257(17)
Na—OH	381(13)
Na—Rb	59(4)
Strontium	
Sr—Br	332(19)
Sr—Cl	406(13)
Sr—F	542(7)
Sr—H	163(8)
Sr—I	263(42)
Sr—O	454(15)
Sr—OH	381(42)
Sr—S	314(21)
Sulfur	
S—S	429(6)
S—Cl	255
S—F	343(5)
O_2S—F	71
S—N	464(21)
S—O	521.70(13)
OS—O	551.4(84)
O_2S—O	348.1(42)
HS—SH	272(21)
Tantalum	
Ta—N	611(84)
Ta—O	805(13)
Tellurium	
Te—B	354(20)
Te—H	268(2)
Te—I	193(42)
Te—O	391(8)
Te—P	298(10)
Te—S	339(21)
Te—Se	268(8)
Terbium	
Tb—F	561(42)
Tb—O	707(13)
Tb—S	515(42)
Tb—Te	339(42)
Thallium	
Tl—Tl	63
Tl—Br	333.9(17)
Tl—Cl	372.8(21)
Tl—F	445(19)
Tl—H	188(8)
Tl—I	272(8)
Thorium	
Th—Th	289
Th—C	484(25)
Th—N	577.4(21)
Th—O	854(13)
Th—P	377
Thullium	
Tm—F	569(42)
Tm—O	557(13)
Tm—S	368(42)
Tm—Se	276(42)
Tm—Te	276(42)
Tin	
Sn—Sn	195(17)
Sn—Br	339(4)

TABLE 4.11 Bond Dissociation Energies (*Continued*)

Bond	ΔHf_{298}, kJ/mol
Tin (*continued*)	
$BrSn—Br$	326
$Br_3Sn—Br$	272
$(C_2H_5)_3Sn—C_2H_5$	*ca.* 238
Sn—Cl	406(13)
Sn—F	467(13)
Sn—H	267(17)
Sn—I	234(42)
Sn—O	548(21)
Sn—S	464(3)
Sn—Se	401.3(59)
Sn—Te	319.2(8)
Titanium	
Ti—Ti	141(21)
Ti—Br	439
Ti—C	435(25)
Ti—Cl	494
Ti—F	569(34)
Ti—H	*ca.* 159
Ti—I	310(42)
Ti—N	464
Ti—O	662(16)
Ti—S	426(8)
Ti—Se	381(42)
Ti—Te	289(17)
Tungsten	
W—Cl	423(42)
W—F	548(63)
W—O	653(25)
OW—O	632(84)
$O_2W—O$	598(42)
W—P	305(4)
Uranium	
U—O	761(17)
OU—O	678(59)
$O_2U—O$	644(88)
U—S	523(10)
Vanadium	
V—V	242(21)
V—Br	439(42)
V—C	469(63)
V—Cl	477(63)
V—F	590(63)
V—N	477(8)
V—O	644(21)
V—S	490(16)
V—Se	347(21)
Xenon	
Xe—Xe	6.53(30)
Xe—F	13.0(4)
Xe—O	36.4
Ytterbium	
Yb—Cl	322
Yb—F	521(10)
Yb—H	159(38)
Yb—O	397.9(63)
Yb—S	167
Yttrium	
Y—Y	159(21)
Y—Br	485(84)
Y—C	418(63)
Y—Cl	527(42)
Y—F	605(21)
Y—N	481(63)
Y—O	715.1(30)
Y—S	528(11)
Y—Se	435(13)
Y—Te	339(13)
Zinc	
Zn—Zn	29
Zn—Br	142(29)
$C_2H_5C—C_2H_5$	*ca.* 201
Zn—Cl	229(20)
Zn—F	368(63)
Zn—H	85.8(21)
Zn—I	138(29)
Zn—O	284.1
Zn—S	205(13)
Zn—Se	136(13)
Zn—Te	205

TABLE 4.11 Bond Dissociation Energies (*Continued*)

Bond	ΔHf_{298}, kJ/mol	Bond	ΔHf_{298}, kJ/mol
Zirconium		Zirconium (*continued*)	
Zr—C	561(25)	Zr—O	760(8)
Zr—F	623(63)	Zr—S	575(17)
Zr—N	565(25)		

Source: T. L. Cottrell, *The Strengths of Chemical Bonds*, 2d ed., Butterworth, London, 1958; B. deB. Darwent, *National Standard Reference Data Series*, National Bureau of Standards, no. 31, Washington, 1970; S. W. Benson, *J. Chem. Educ.* **42:**502 (1965); and J. A. Kerr, *Chem. Rev.* **66:**465 (1966).

4.6 BOND AND GROUP DIPOLE MOMENTS

All bonds between equal atoms are given zero values. Because of their symmetry, methane and ethane molecules are nonpolar. The principle of bond moments thus requires that the CH_3 group moment equal one H—C moment. Hence the substitution of any aliphatic H by CH_3 does not alter the dipole moment, and all saturated hydrocarbons have zero moments as long as the tetrahedral angles are maintained.

TABLE 4.12 Bond Dipole Moments

Bond	Moment, D*	Bond	Moment, D*
H—C		C—N, aliphatic	0.45
Aliphatic	0.3	C═N	1.4
Aromatic	0.0	C≡N (nitrile)	3.6
C—C	0.0	NC (isonitrile)	3.0
C≡C	0.0	N—H	1.31
C—O		N—O	0.3
Ether, aliphatic	0.74	N═O	2.0
Alcohol, aliphatic	0.7	N (lone pair on sp^3 N)	1.0
C═O		C—P, aliphatic	0.8
Aliphatic	2.4	P—O	(0.3)
Aromatic	2.65	P═O	2.7
O—H	1.51	P—S	0.5
C—S	0.9	P═S	2.9
C═S	2.0	B—C, aliphatic	0.7
S—H	0.65	B—O	0.25
S—O	(0.2)	Se—C	0.7
S═O		Si—C	1.2
Aliphatic	2.8	Si—H	1.0
Aromatic	3.3	Si—N	1.55

* To convert debye units D into coulomb-meters, multiply by 3.33564×10^{-30}.

TABLE 4.12 Bond Dipole Moments (*Continued*)

Bond	Moment, D*	Bond	Moment, D*
H—Sb	−0.08	Br—F	1.3
H—As	−0.10	Cl—F	0.88
H—P	0.36	Li—C	1.4
H—I	0.38	K—Cl	10.6
H—Br	0.78	K—F	7.3
H—Cl	1.08	Cs—Cl	10.5
H—F	1.94	Cs—F	7.9
C—Te	0.6		
N—F	0.17	Dative (coordination) bonds	
P—I	0.3		
P—Br	0.36	N → B	2.6
P—Cl	0.81	O → B	3.6
As—I	0.78	S → B	3.8
As—Br	1.27	P → B	4.4
As—Cl	1.64	N → O	4.3
As—F	2.03	P → O	2.9
Sb—I	0.8	S → O	3.0
Sb—Br	1.9	As → O	4.2
Sb—Cl	2.6	Se → O	3.1
S—Cl	0.7	Te → O	2.3
Cl—O	0.7	P → S	3.1
I—Br	1.2	P → Se	3.2
I—Cl	1	Sb → S	4.5
Br—Cl	0.57		

* To convert debye units D into coulomb-meters, multiply by 3.33564×10^{-30}.

The group moment always includes the C—X bond. When the group is attached to an aromatic system, the moment contains the contributions through resonance of those polar structures postulated as arising through charge shifts around the ring.

All values for bond and group dipole moments in Tables 4.12 and 4.13 were obtained in benzene solutions.

TABLE 4.13 Group Dipole Moments

Group	Moment, D*	
	Aromatic C—X	Aliphatic C—X
C—CH_3	0.37	0.0
C—C_2H_5	0.37	0.0
C—$C(CH_3)_3$	0.5	0.0
C—CH═CH_2	<0.4	0.6
C—C≡CH	0.7	0.9
C—F	1.47	1.79

* To convert debye units D into coulomb-meters, multiply by 3.33564×10^{-30}.

TABLE 4.13 Group Dipole Moments (*Continued*)

Group	Moment, D*	
	Aromatic C—X	Aliphatic C—X
C—Cl	1.59	1.87
C—Br	1.57	1.82
C—I	1.40	1.65
C—CH_2F	1.77	
C—CF_3	2.54	2.32
C—CH_2Cl	1.85	1.95
C—$CHCl_2$	2.04	1.94
C—CCl_3	2.11	1.57
C—CH_2Br	1.86	1.96
C—C≡N	4.05	3.4
C—NC	3.5	3.5
C—CH_2CN	1.86	2.0
C—C═O	2.65	2.4
C—CHO	2.96	2.49
C—COOH	1.64	1.63
C—CO—CH_3	2.96	2.49
C—CO—OCH_3	1.83	1.75
C—CO—OC_2H_5	1.9	1.8
C—OH	1.6	1.7
C—OCH_3	1.28	1.28
C—OCF_3	2.36	
C—$OCOCH_3$	1.69	
C—OC_6H_5	1.16	1.16
C—CH_2OH	1.58	1.68
C—NH_2	1.53	1.46
C—$NHCH_3$	1.71	
C—$N(CH_3)_2$	1.58	0.86
C—$NHCOCH_3$	3.69	
C—$N(C_6H_5)_2$	(0.3)	−0.3
C—NCO	2.32	2.8
C—N_3	1.44	
C—NO	3.09	
C—NO_2	4.01	2.70
C—CH_2NO_2	3.3	3.4
C—SH	1.22	1.55
C—SCH_3	1.34	1.40
C—SCF_3	2.50	
C—SCN	3.59	3.6
C—NCS	2.9	3.3
C—SC_6H_5	1.51	1.5
C—SF_5	3.4	
C—$SOCF_3$	3.88	
$(C—)_2SO_2$	5.05	4.53
$(C—)_2SO_2CH_3$	4.73	
$(C—)_2SO_2CF_3$	4.32	
C—SeH	1.08	
C—$SeCH_3$	1.31	1.32
C—$Si(CH_3)_3$	0.44	0.4

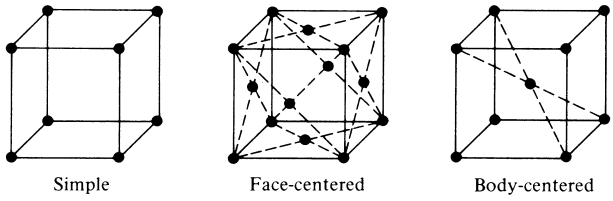
* To convert debye units D into coulomb-meters, multiply by 3.33564×10^{-30}.

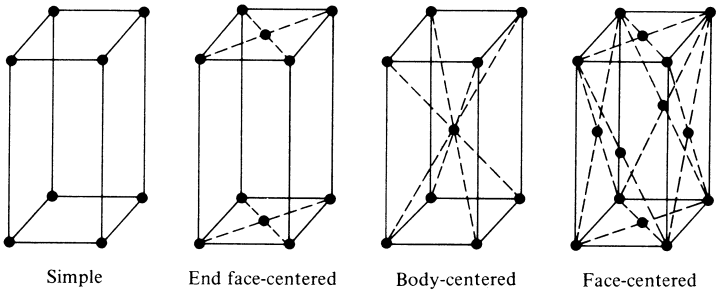
4.7 MOLECULAR GEOMETRY

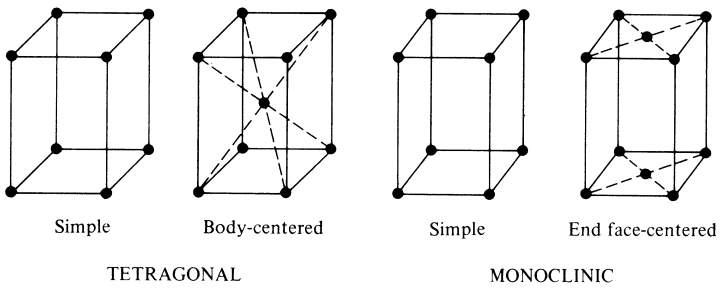
TABLE 4.14 Spatial Orientation of Common Hybrid Bonds

On the assumption that the pairs of electrons in the valency shell of a bonded atom in a molecule are arranged in a definite way which depends on the number of electron pairs (coordination number), the geometrical arrangement or shape of molecules may be predicted. A multiple bond is regarded as equivalent to a single bond as far as molecular shape is concerned.

Coordination Number	Orbitals Hybridized	Geometrical Arrangement	Minimum Radius Ratio
2	sp dp	Linear	
	p^2 ds d^2	Bent (angular)	
3	sp^2 ds^2	Trigonal planar	0.155
	p^3 d^2p	Trigonal pyramidal	
	sp^2d p^2d^2	Square planar	
4	sp^3 d^3s	Tetrahedral	0.225
	d^4	Tetragonal pyramidal	
5	sp^3d d^3sp	Trigonal bipyramidal	0.155
6	d^2sp^3	Octahedral	0.414
	d^4sp	Trigonal prism	
7		One atom above the face of an octahedron, which is distorted chiefly by separating the atoms at the corners of this face.	0.592
8	d^4sp^3	Square antiprism (dodecahedral)	0.645
		Cube	0.732
9		Formed by adding atoms beyond each of the vertical faces of a right triangular prism.	0.732
12		Cube-octahedron	1.000







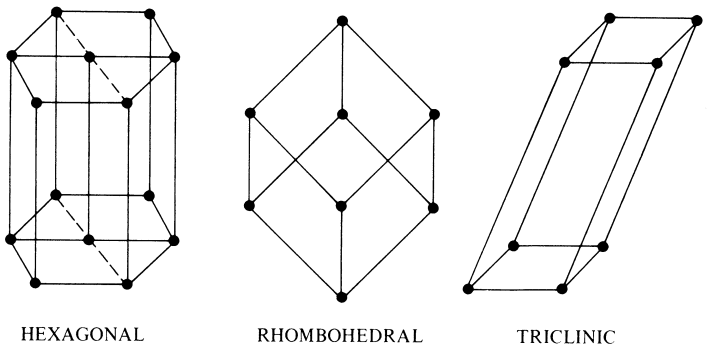


FIGURE 4.1 Crystal lattice types.

TABLE 4.15 Crystal Structure

Unit cells of the different lattice types in each system are illustrated in Fig. 4.1.

System	Characteristics	Essential Symmetry	Axes in Unit Cell	Angles in Unit Cell
Cubic	Three axes equal and mutually perpendicular	Four threefold axes	$a = b = c$	$\alpha = \beta = \gamma = 90°$
Tetragonal	Two equal axes and one unequal axis mutually perpendicular	One fourfold axis	$a = b \neq c$	$\alpha = \beta = \gamma = 90°$
Orthorhombic (or rhombic)	Three unequal axes mutually perpendicular	Three mutually perpendicular twofold axes, or two planes intersecting in a twofold axis	$a \neq b \neq c$	$\alpha = \beta = \gamma = 90°$
Hexagonal or trigonal	Three equal axes inclined at 120° with a fourth axis unequal and perpendicular to the other three	One sixfold axis or one threefold axis	$a = b \neq c$ $a = b = c$	$\alpha = \beta = 90°$; $\gamma = 120°$ $\alpha = \beta = \gamma \neq 90°$
Monoclinic	Two axes at an oblique angle with a third perpendicular to the other two	One twofold axis or one plane	$a \neq b \neq c$	$\alpha = \beta = 90°$; $\gamma \neq 90°$
Triclinic	Three unequal axes intersecting obliquely	No planes or axes of symmetry	$a \neq b \neq c$	$\alpha \neq \beta \neq \gamma \neq 90°$
Rhombohedral	Two equal axes making equal angle with each other			

4.8 NUCLIDES

TABLE 4.16 Table of Nuclides

Explanation of Column Headings

Nuclide. Each nuclide is identified by element name and the mass number *A*, equal to the sum of the numbers of protons *Z* and neutrons *N* in the nucleus. The *m* following the mass number (for example, ^{69m}Zn) indicates a metastable isotope. An asterisk preceding the mass number indicates that the radionuclide occurs in nature.
Half-life. The following abbreviations for time units are employed: y = years, d = days, h = hours, min = minutes, s = seconds, ms = milliseconds, and ns = nanoseconds.
Natural abundance. The natural abundances listed are on an "atom percent" basis for the stable nuclides present in naturally occurring elements in the earth's crust.
Thermal neutron absorption cross section. Simply designated "cross section," it represents the ease with which a given nuclide can absorb a thermal neutron (energy less than or equal to 0.025 eV) and become a different nuclide. The cross section is given here in units of barns (1 barn = 10^{-24} cm^2). If the mode of reaction is other than (n,γ), it is so indicated.
Major radiations. In the last column are the principal modes of disintegration and energies of the radiations in million electronvolts (MeV). Symbols used to represent the various modes of decay are:

α, alpha particle emission	K, electron capture
β^-, beta particle, negatron	IT, isomeric transition
β^+, positron	x, X-rays of indicated element (e.g., O-x,
γ, gamma radiation	oxygen X-rays, and the type, K or L)

For β^- and β^+, values of E_{max} are listed. Radiation types and energies of minor importance are omitted unless useful for identification purposes. For detailed decay schemes the literature should be consulted.

TABLE 4.16 Table of Nuclides (*Continued*)

Element	*A*	Half-life	Natural abundance, %	Cross section, barns	Radiation (MeV)
Hydrogen	1		99.985(1)	0.332(2)	
	2		0.015(1)	0.000 52(1)	
	3	12.32 y			β^-(0.0186)
Beryllium	7	53.28 d			K, γ(0.478)
	9		100	0.008(1)	
	10	1.52×10^6 y			β^-(0.555)
Boron	10		19.9(2)	3837(10)(n, α)	
	11		80.1(6)	0.005(3)	
Carbon	11	20.3 min			β^+(0.961)
	12		98.89(1)	0.0035(1)	
	14	5715 y			β^-(0.156)
Nitrogen	13	9.965 min			β^+(1.190)
	14		99.634(9)	1.8(1)(n, p)	
Oxygen	15	122.2 s			β^+(2.754)
	19	26.9 s			β^-(4.82); γ(0.197, 1.357)
Fluorine	18	1.8295 h			β^+(0.635); K, O-x
	19		100	0.0095(7)	β^+(2.754)
	20	11.00 s			β^-(5.40); γ(1.63)
Sodium	22	2.605 y		2800.(300)(n, p)	β^+(0.545, 1.83); K, Ne-x, γ(1.275)
	23		100	0.53	
	24	14.659 h			β^-(1.39); γ(2.75, 1.37)
Magnesium	24		78.89(3)	0.053(6)	
	25		10.00(1)	0.17(5)	
	27	9.45 min		0.07(2)	β^-(1.75, 1.59); γ(0.844, 1.014)
	28	20.90 h			β^-(0.459); γ(1.342, 0.942, 0.401, 0.031)
Aluminum	26	7.1×10^5 y			β^+(1.16); K, Mg-x; γ(1.809)
	27		100	0.230(2)	
	28	2.25 min			β^-(2.865); γ(1.778)
Silicon	28		92.23(2)	0.17(1)	
	29		4.67(2)	0.12(1)	
	30		3.10(1)	0.107(4)	
	31	2.62 h		0.073(6)	β^-(1.471); γ(1.266)
	32	1.6×10^2 y			β^-(0.213)
Phosphorus	30	2.50 min			β^+(3.245)
	31		100	0.16(2)	
	32	14.28 d			β^-(1.710)
	33	25.3 d			β^-(0.249)
Sulfur	32		95.02(9)	0.55(2)	
	34		4.21(8)	0.29(6)	
	35	87.51 d			β^-(0.167)
	37	5.05 min			β^-(4.75, 1.64); γ(3.103, 0.908)
	38	2.84 h			β^-(1.00, 3.0); γ(1.942, 0.196)

TABLE 4.16 Table of Nuclides (*Continued*)

Element	*A*	Half-life	Natural abundance, %	Cross section, barns	Radiation (MeV)
Chlorine	35		75.77(5)	43.7(4)	
	36	3.01×10^5 y		46.(2)	β^-(0.709); K, S-x
	37		24.23(5)	0.4	
	38	37.24 min			β^-(4.91, 1.11, 2.77); γ(2.168, 1.642)
	39	55.6 min			β^-(1.91, 2.18, 3.45); γ(1.267, 0.250, 1.52)
Argon	37	35.0 d			K, Cl-x
	39	268 y			β^-(0.565)
	40		99.600(3)	0.64(3)	
	41	1.82 h		0.5(1)	β^-(1.20, 2.49); γ(1.29)
	42	33 y			β^-(0.60)
Potassium	39		93.258(4)	2.1(2)	
	*40	1.26×10^9 y	0.0117(1)	30.(8)	β^-(1.312); K, Ar-x; γ(1.461)
	41		6.730(4)	1.46(3)	
	42	12.360 h			β^-(3.523, 1.97); γ(1.525)
	43	22.3 h			β^-(0.825, 0.45, 1.24, 1.814); γ(0.618, 0.373, 0.39, 0.221)
Calcium	40		96.941(18)	0.41(3)	
	42	1.02×10^5 y		≈4	
	43		0.135(6)	6.(1)	
	44		2.086(12)	0.8(2)	
	45	162.7 d		≈15	β^-(0.257)
	47	4.536 d			β^-(1.98, 0.684); γ(1.297)
	49	8.72 min			β^-(1.95, 0.89); γ(3.084, 4.07)
Scandium	42*m*	61.6 s			β^+(2.82); γ(0.438, 1.227, 1.524)
	43	3.89 h			β^+(1.22)
	44*m*	2.442 d			IT, Sc-x; γ(0.271)
	44	3.927 h			β^+(1.47); K, γ(1.16)
	45		100	27	
	46*m*	19.5 s			γ(0.142)
	46	83.81 d		8.(1)	β^-(0.357); γ(1.12, 0.889); Ti-x
	47	3.341 d			β^-(0.439, 0.60); γ(0.159)
	48	1.821 d			β^-(0.65); γ(1.31, 1.04, 0.984)
Titanium	44	47.3 y			K, γ(0.68, 0.078)
	45	3.08 h			β^+(1.044); K, Sc-x
	48		73.72(3)	7.9(9)	
	49		5.41(2)	1.9(5)	
	50		5.18(2)	0.179(3)	
	51	5.76 min			β^-(2.14, 1.50); γ(0.320, 0.928)
Vanadium	48	16.0 d			β^+(0.698); γ(0.511, 0.945, 0.983, 1.312, 2.24)

TABLE 4.16 Table of Nuclides (*Continued*)

Element	*A*	Half-life	Natural abundance, %	Cross section, barns	Radiation (MeV)
Vanadium	49	330 d			K, Ti-x
(*cont.*)	50	$>1.4 \times 10^{17}$ y	0.250(2)	40.(20)	
	51		99.750(2)	4.9(1)	
	52	3.75 min			β^-(2.47); γ(1.434)
Chromium	48	21.6 h			K, V-x; γ(0.116, 0.305)
	50		4.345(13)	15.(1)	
	51	27.70 d			K, V-x; γ(0.320)
	52		83.79(2)	0.8(1)	
	53		9.50(2)	18.(2)	
Manganese	51	46.2 min			β^+(2.2); γ(0.749, 1.15)
	52	5.60 d			β^+(0.575); γ(0.511, 0.744, 1.434)
	53	3.7×10^6 y		70.(10)	
	54	312.2 d		<10	γ(0.834)
	55		100	13.3(1)	
	56	2.5785 h			β^-(1.028, 1.03, 0.718); γ(0.847, 1.81, 2.11)
Iron	52	8.275 h			β^+(0.804); K, Mn-x; γ(0.169)
	54		5.85(4)	2.7(5)	
	55	2.73 y		13.(2)	K, Mn-x
	56		91.75(4)	2.6(2)	
	57		2.12(1)	2.5(5)	
	59	44.51 d		13.(3)	β^-(0.273, 0.475); γ(1.10, 1.29)
Cobalt	55	17.53 h			β^+(1.04, 1.50); K, Fe-x; γ(0.932, 0.480, 1.41)
	56	77.3 d			β^+(1.46); K, Fe-x; γ(0.847, 1.04, 1.24, 1.77, 2.60, 3.26, 2.02)
	57	271.77 d			K, Fe-x; γ(0.136, 0.122)
	58*m*	9.1 h		$1.4(1) \times 10^5$	γ(0.025)
	58	70.88 d		$1.9(2) \times 10^3$	K, β^+(0.474); Fe-x; γ(0.811)
	59		100	19	
	60*m*	10.47 min		58.(8)	β^-(1.55)
	60	5.271 y		2.0(2)	β^-(0.318); γ(1.173, 1.332)
	61	1.650 h			β^-(1.22); γ(0.842–0.909)
Nickel	56	6.08 d			K, Co-x; γ(0.158, 0.270, 0.480, 0.75, 0.812, 1.56)
	57	35.6 h			K, β^+(0.849, 0.712); Co-x, γ(1.378, 0.0127, 1.76)
	58		68.077(9)	4.6(4)	
	60		26.22(1)	2.9(3)	
	63	100 y		24.(3)	β^-(0.067)

TABLE 4.16 Table of Nuclides (*Continued*)

Element	*A*	Half-life	Natural abundance, %	Cross section, barns	Radiation (MeV)
Nickel (*cont.*)	64		0.926(1)	1.8(1)	
	65	2.517 h		22.(2)	β^-(2.14, 0.65, 1.020); γ(1.48, 0.366, 1.116)
	66	2.275 d			β^-(0.23)
Copper	61	3.408 h			β^+(1.220); K, Ni-x; γ(0.283, 0.656)
	63		69.17(3)	4.5(2)	
	64	12.701 h		≈270	β^-(0.578); β^+(0.65); Ni-x; γ(1.346)
	65		30.83(3)	2.17(3)	
	66	5.07 min		$1.4(1) \times 10^2$	β^-(2.74); γ(1.039)
	67	2.580 d			β^-(0.395, 0.484, 0.577); γ(0.185, 0.092)
Zinc	62	9.26 h			K, β^+(0.66); Cu-x; γ(0.041, 0.597)
	64		48.6(3)	0.46	
	65	243.8 d		66.(8)	K, β^+(0.325), Cu-x; γ(1.116)
	66		27.9(2)	1.0(2)	
	67		4.1(1)	6.9(1)	
	68		18.8(4)	0.87	
	69*m*	13.76 h			IT, Zn-x, γ(0.439)
	69	56 min			β^-(0.905)
	71*m*	3.97 h			β^-(1.45); γ(0.386, 0.487, 0.620)
	72	46.5 h			β^-(0.30, 0.25); γ(0.145, 0.191)
Gallium	66	9.5 h			β^+(1.84, 4.153); γ(1.039, 2.752)
	67	3.260 d			K, Zn-x; γ(0.093, 0.184, 0.300)
	68	1.130 h			β^+(1.83); K, Zn-x; γ(1.077)
	69		60.108(9)	1.68(7)	
	70	21.1 min			β^-(1.65); γ(0.175, 1.042)
	71		39.892(9)	4.7(2)	
	72	14.10 h			β^-(0.64, 1.51, 2.52, 3.15); γ(0.63, 2.20, 2.50)
	73	3.120 d			β^-(1.59); γ(0.053, 0.297)
Germanium	66	2.66 h			K, β^+(1.02); Ga-x; γ(0.044, 0.382)
	68	270.8 d			Ga, K-x
	69	1.63 d			β^+(0.70, 1.22); γ(1.107, 0.574)
	71	11.2 d			Ga-x
	72		27.66(3)	0.9(2)	
	73		7.73(1)	15.(1)	
	74		35.94(2)	0.3	
	75	1.380 h			β^-(1.19); γ(0.265, 0.419)

TABLE 4.16 Table of Nuclides (*Continued*)

Element	*A*	Half-life	Natural abundance, %	Cross section, barns	Radiation (MeV)
Germanium (*cont.*)	77	11.30 h			β^-(0.71, 1.38, 2.19); γ(0.211, 0.215, 0.264)
	78	1.45 h			β^-(0.95); γ(0.277, 0.294)
Arsenic	71	2.70 d			K, β^+(0.81); Ge-x; γ(0.175, 1.096)
	72	1.083 d			β^+(3.339, 2.498, 1.884); K, Ge-x; γ(0.834, 1.051)
	73	80.30 d			K, γ(0.0534, 0.0133)
	74	17.78 d			β^+(0.94); β^-(0.71, 1.35); γ(0.596, 0.635)
	75		100	4.0(4)	
	76	1.096 d			β^-(2.97, 2.41, 1.79); γ(0.559, 0.657)
	77	38.8 h			β^-(0.683); γ(0.239, 0.250, 0.521)
	78	91 min			β^-(4.21); γ(0.614, 0.70, 1.31)
Selenium	72	8.40 d			K, As-x; γ(0.046)
	73	7.1 h			β^+(1.32); γ(0.361, 0.067)
	74		0.89(2)	50.(4)	
	75	119.78 d			K, γ(0.265, 0.136); As-x
	77*m*	17.5 s			γ(0.162)
	77		7.63(6)	42.(4)	
	80		49.61(10)	0.5	
	81	18.5 min			β^-(1.58); γ(0.276, 0.290, 0.828)
Bromine	75	1.62 h			β^+(3.03); γ(0.287)
	76	16.2 h		224.(42)	β^+(1.9, 3.68); K, Se-x; γ(0.559, 1.86)
	77	2.376 d			γ(0.239, 0.521)
	79		50.69(7)	10.8	
	80*m*	4.42 h			IT, Br-x; γ(0.037, 0.049)
	80	17.66 min			β^-(1.997, 1.38); K, β^+(0.85), Se-x; γ(0.617)
	81		49.31(7)	2.6	
	82	1.4708 d			β^-(0.444); γ(0.554, 0.619, 0.776)
Krypton	76	14.8 h			K, γ(0.252)
	77	1.24 h			β^+(1.875, 1.700, 1.550); K, Br-x; γ(0.130, 0.147)
	79	1.455 d			β^+(1.626); γ(0.261, 0.398, 0.606)
	81*m*	13 s			IT, Kr-x; γ(0.190)
	81	2.10×10^5 y			K, Br-x; γ(0.276)
	83		11.5(1)	183.(30)	
	84		57.0(3)	0.10	
	85*m*	4.48 h			β^-(0.83); γ(0.151, 0.305)

TABLE 4.16 Table of Nuclides (*Continued*)

Element	*A*	Half-life	Natural abundance, %	Cross section, barns	Radiation (MeV)
Krypton	85	10.72 y			β^-(0.67); γ(0.517)
(*cont.*)	87	1.27 h			β^-(3.49, 0.389, 1.38); γ(0.403, 2.55)
	88	2.84 h			β^-(2.91); γ(0.196, 2.392)
Rubidium	84	32.9 d			β^-(0.894); β^+(2.681); γ(0.882)
	85		72.17(2)	0.5	
	86	18.65 d		< 20	β^-(1.775); γ(1.08)
	87	4.88×10^{10} y	27.83(2)	0.10(1)	β^-(0.283)
	88	17.7 min		1.2(3)	β^-(5.31); γ(1.836, 0.898)
	89	15.4 min			β^-(1.26, 2.2, 4.49); γ(1.032, 1.248, 2.196)
Strontium	82	25.36 d			K, Rb-x
	85*m*	1.126 h			K, Rb-x, Sr-x; γ(0.150, 0.231)
	85	64.84 d			K, Rb-x; γ(0.514)
	87*m*	2.795 h			IT, γ(0.388)
	88		82.58(1)	0.0058(4)	
	89	50.52 d		0.42(4)	β^-(1.497); γ(0.909)
	90	29.1 y		0.0097(7)	β^-(0.546)
	91	9.5 h			β^-(1.09, 1.36, 2.66); γ(0.556, 0.750, 1.024)
	92	2.71 h			β^-(0.55, 1.5); γ(1.383)
Yttrium	85*m*	4.86 h			β^+(2.24); K, Sr-x; γ(0.767, 0.232, 2.124)
	85	2.68 h			β^+(1.58, 1.15); K, Sr-x; γ(0.504, 0.232)
	86	14.74 h			β^+(5.24); γ(0.307, 0.628, 1.077, 1.153, 1.921)
	87*m*	12.9 h			Y-x; γ(0.381)
	88	106.6 d			β^-(0.76); γ(0.898, 1.836, 2.734, 3.219)
	90	2.67 d		< 7	β^-(2.28); γ(2.186)
	91*m*	49.71 min			Y-x; IT; γ(0.556)
	91	58.5 d		1.4(3)	β^-(1.545); γ(1.21)
	92	3.54 h			β^-(3.64); γ(0.448, 0.561, 0.934, 1.405)
	93	10.2 h			β^-(2.88); γ(0.267, 0.947, 1.918)
Zirconium	86	16.5 h			K, Y-x; γ(0.243, 0.612)
	87	1.73 h			β^+(2.260); K, Y-x; γ(0.381, 1.228)
	88	83.4 d			K, Y-x; γ(0.393)
	89	3.27 d			K, β^+(0.897); Y-x; γ(0.909)
	91		11.22(4)	1.2(3)	
	93	1.5×10^6 y			β^-(0.091)
	95	64.02 d			β^-(0.366, 0.400); γ(0.724, 0.757)
	97	16.90 h			β^-(1.91); γ(0.743)

TABLE 4.16 Table of Nuclides (*Continued*)

Element	*A*	Half-life	Natural abundance, %	Cross section, barns	Radiation (MeV)
Niobium	89	2.03 h			β^+(3.320); γ(1.627)
	90	14.60 h			β^+(1.50); K, Zr-x; γ(0.141, 1.129, 2.186, 2.319)
	91*m*	62 d			IT, Nb-x; γ(0.1045, 1.205)
	91	700 y			Mo-x
	92*m*	10.15 d			K, γ(0.913, 0.934, 1.848)
	93*m*	16.1 y			Nb-x
	93		100	1.1	
	94*m*	6.26 min			γ(0.871)
	94	2.4×10^4 y			β^-(0.473); γ(0.703, 0.871)
	95*m*	3.61 d			γ(0.204, 0.236)
	95	35.0 d		<7	β^-(0.160); γ(0.765)
	96	23.4 h			β^-(0.748, 0.500); γ(0.778, 1.091)
	97*m*	58.1 s			IT; γ(0.766)
	97	1.23 h			β^-(1.267); γ(0.481, 0.658)
Molybdenum	90	5.67 h			K, β^+(1.085); Nb-x; γ(0.122, 0.257)
	93*m*	6.85 h			IT, Mo-x; γ(0.264, 0.685, 1.477)
	95		15.92(5)	13.4(5)	
	97		9.55(3)	2.5(3)	
	98		24.13(7)	0.14(1)	
	99	2.75 d			β^-(1.357); Tc-x; γ(0.181, 0.366, 0.739)
	101	14.6 min			β^-(2.23, 0.7); γ(0.192, 0.591)
Technetium	93	2.73 h			β^+(0.81); γ(1.363, 1.477, 1.520)
	94	4.88 h			β^+(4.256); γ(0.449, 0.703, 0.850, 0.871)
	95*m*	61 d			β^+(0.71); γ(0.204, 0.582, 0.835)
	95	20.0 h			K, Mo-x; γ(0.766, 1.074)
	96	4.3 d			K, Mo-x; γ(0.778, 0.813, 0.850, 1.122)
	97*m*	90 d			K, Tc-x; γ(0.0965)
	97	2.6×10^6 y			K, Mo-x
	98	4.2×10^6 y			β^-(0.40); γ(0.652, 0.745)
	99*m*	6.012 h			IT, Tc-x; γ(0.141, 0.143)
	99	2.13×10^5 y		20	β^-(0.292)
Ruthenium	95	1.64 h			β^+(1.20, 0.91); γ(0.290, 0.336, 0.627)
	97	2.88 d			K, Tc-x; γ(0.216, 0.324, 0.461)
	100		12.6(1)	5.8(6)	

TABLE 4.16 Table of Nuclides (*Continued*)

Element	*A*	Half-life	Natural abundance, %	Cross section, barns	Radiation (MeV)
Ruthenium	101		17.0(1)	5.(1)	
(*cont.*)	102		31.6(2)	1.2(1)	
	103	39.27 d		<20	β^-(0.12, 0.223); γ(0.295, 0.4444, 0.497, 0.557, 0.610)
	105	4.44 h			β^-(1.187, 0.11, 1.134); γ(0.149, 0.263, 0.317, 0.469, 0.676, 0.724)
	106	1.020 y			β^-(0.0394)
Rhodium	99*m*	4.7 h			β^+(0.74); γ(0.277, 0.341, 0.618, 1.261)
	99	16 d			β^+(0.54, 0.68); γ(0.089, 0.353, 0.528)
	100	20.8 h			β^+(2.62, 2.07); γ(0.446, 0.540, 0.588, 0.823, 1.553, 2.376)
	101*m*	4.35 d			K, IT, Ru-x, Rh-x; γ(0.127, 0.307, 0.545)
	101	3.3 y			K, Ru-x; γ(0.127, 0.198, 0.325)
	102*m*	207 d			β^-(1.15); β^+(1.29, 0.82); γ(0.469, 0.475, 0.557, 0.628, 1.103)
	102	2.9 y			K, Ru-x; γ(0.475, 0.631, 0.697, 0.767, 1.047, 1.103)
	103*m*	56.12 min			IT, Rh-x, γ(0.0.040)
	103		100	145	
	104*m*	4.36 min		800.(100)	γ(0.051, 0.097, 0.556)
	104	42.3 s		40.(30)	β^-(2.44), γ(0.358, 0.556, 1.237)
	105*m*	40 s			IT, Rh-x; γ(0.130)
	105	35.4 h		$1.1(3) \times 10^4$	β^-(0.567, 0.247); γ(0.280, 0.306, 0.319)
	106*m*	2.18 h			β^-(0.92); γ(0.222, 0.451, 0.512, 0.616, 0.717, 0.784, 1.046, 1.528)
	106	29.80 s			β^-(3.54, 3.0, 2.4); γ(0.512, 0.622)
Palladium	100	3.63 d			K, Rh-x; γ(0.0748, 0.0840, 0.0327)
	101	8.47 h			K, Rh-x; β^+(0.776); γ(0.296, 0.590)
	103	16.99 d			K, Rh-x; γ(0.357, 0.497)
	105		22.33(8)	22.(2)	
	107	6.5×10^6 y		1.8(2)	β^-(0.03)
	108		26.46(9)	8.7	
	109	13.5 h			β^-(1.028); Ag-x; γ(0.088, 0.311, 0.636)

TABLE 4.16 Table of Nuclides (*Continued*)

Element	*A*	Half-life	Natural abundance, %	Cross section, barns	Radiation (MeV)
Palladium (*cont.*)	111*m*	5.5 h			β^-(0.35, 0.77); γ(0.070, 0.172, 0.391)
	111	23.4 min			β^-(2.2); γ(0.060, 0.245, 0.580, 0.650, 1.389, 1.459)
	112	21.4 h			β^-(0.28); γ(0.018)
Silver	103	1.10 h			β^+(1.7, 1.3); γ(0.119, 0.148)
	104	69 min			β^+(0.99); γ(0.556, 0.926, 0.942)
	105	41.29 d			K, Pd-x; γ(0.064, 0.280, 0.344, 0.443)
	106*m*	8.4 d			K, Pd-x; γ(0.451, 0.512, 0.717, 1.046)
	107*m*	44.2 s			K, Ag-x; γ(0.093)
	107		51.839(7)	35	
	108*m*	130 y			γ(0.434, 0.614, 0.723)
	108	2.42 min			β^-(1.65); β^+(0.90); γ(0.434, 0.619, 0.633)
	109		48.161(7)	91	
	110*m*	249.8 d		82.(11)	β^-(0.087, 0.530); IT, γ(0.658, 0.764, 0.885, 0.937, 1.384)
	111*m*	1.08 min			K, Ag-x; γ(0.060, 0.245)
	111	7.47 d		3.(2)	β^-(1.04); γ(0.245, 0.342)
	112	3.13 h			β^-(3.94, 3.4); γ(0.607, 0.617, 1.39)
Cadmium	107	6.52 h			β^+(0.302); K, Ag-x; γ(0.093, 0.829)
	109	462 d			K, Ag-x; γ(0.088)
	111*m*	48.5 min			K, Cd-x; γ(0.151, 0.245)
	111		12.80(8)	24.(3)	
	113*m*	14.1 y			β^-(0.59); γ(0.264)
	113	9×10^{15} y	12.22(6)	20 060.(40)	
	115*m*	44.6 d			β^-(1.62); γ(0.934, 1.29, 0.485)
	115	2.228 d			β^-(1.11, 0.593); In-x; γ(0.231, 0.260, 0.336, 0.492, 0.528)
	117*m*	3.4 h			β^-(0.72); γ(0.159, 0.553); In-x
	117	2.49 h			β^-(0.67, 2.2); γ(0.221, 0.273, 0.345, 1.303)
Indium	109	4.2 h			K, Cd-x; β^+(0.79); γ(0.203, 0.623)
	110*m*	4.9 h			γ(0.658, 0.885, 0.937)
	110	1.15 h			β^+(2.22); K, Cd-x; γ(0.658)
	111	2.805 d			K, Cd-x; γ(0.171, 0.245)

TABLE 4.16 Table of Nuclides (*Continued*)

Element	*A*	Half-life	Natural abundance, %	Cross section, barns	Radiation (MeV)
Indium (*cont.*)	113*m*	1.658 h			IT, In-x; γ(0.392)
	114*m*	49.51 d			IT, K, In-x; γ(0.190)
	114	1.1983 min			β^-(1.99); K, Cd-x, β^+(0.40); γ(0.558, 0.573, 1.30)
	115*m*	4.486 h			β^-(0.83); K, In-x; γ(0.336, 0.497)
	*115	4.4×10^{14} y	95.71(2)	205	β^-(0.495)
	116*m*	54.1 min			β^-(1.00); γ(0.138, 0.417, 1.09, 1.293)
	117*m*	1.94 h			β^-(1.77); γ(0.159, 0.315, 0.553)
	117	44 min			β^-(0.74); γ(0.159, 0.397, 0.553)
Tin	110	4.1 h			K, In-x; γ(0.283)
	113	115.1 d		≈9	K, In-x, γ(0.392, 0.255)
	116		14.53(11)	1.1(1)	
	117*m*	13.60 d			K, Sn-x; γ(0.159)
	119*m*	293 d			K, Se-x; γ(0.239)
	119		8.59(4)	2.(1)	
	121*m*	≈55 y			β^-(0.354); K, In-x; γ(0.0372)
	121	1.128 d			β^-(0.383)
	123	129.2 d			β^-(1.42); γ(0.160, 1.030, 1.089)
	125	9.63 d			β^-(2.35); γ(1.067)
	127	2.10 h			β^-(2.42, 3.2); γ(0.823, 1.096)
Antimony	115	32.1 min			β^+(1.51); γ(0.499)
	116*m*	1.00 h			β^+(1.16); γ(0.407, 0.543, 0.973, 1.293)
	117	2.80 h			β^+(0.57); γ(0.159)
	118*m*	5.00 h			γ(0.254, 1.051, 1.280)
	118	3.6 min			β^+(2.65); γ(1.230)
	119	38.1 h			γ(0.0239)
	120	15.89 min			β^+(1.72); γ(0.704, 1.171)
	121		57.21(5)	6	
	122	2.72 d			β^-(1.414); β^+(1.980); γ(0.564, 0.693, 1.141, 1.257)
	123		42.7(9)	3.3	
	124	60.20 d			β^-(0.61, 2.301); γ(0.603, 0.646, 1.69, 0.723)
	126	12.4 d			β^-(1.9); γ(0.279, 0.415, 0.666, 0.695, 0.720)
	127	3.84 d			β^-(0.89, 1.10, 1.50); γ(0.252, 0.291, 0.412, 0.437, 0.686, 0.784)
	128	9.1 h			β^-(2.3); γ(0.215, 0.314, 0.527, 0.743, 0.754)

TABLE 4.16 Table of Nuclides (*Continued*)

Element	*A*	Half-life	Natural abundance, %	Cross section, barns	Radiation (MeV)
Antimony (*cont.*)	129	4.40 h			β^-(0.65); γ(0.181, 0.359, 0.460, 0.545, 0.813, 0.915, 1.030)
Tellurium	116	2.49 h			γ(0.0937)
	117	1.03 h			β^+(1.78); γ(0.920, 1.716, 2.300)
	119*m*	4.69 d			γ(0.154, 0.271, 1.213)
	119	16.0 h			β^+(0.627; γ(0.644, 0.700)
	121*m*	≈154 d			γ(0.212)
	121	16.8 d			γ(0.508, 0.573)
	123*m*	119.7 d			γ(0.159)
	125		7.139(6)	1.6(2)	
	127*m*	109 d			β^-(0.77); γ(0.088)
	127	9.35 h			β^-(0.696); γ(0.360)
	129*m*	33.6 d			β^-(1.60); γ(0.460, 0.696)
	129	1.160 h			β^-(1.453, 0.989); I-x, γ(0.460, 0.487)
	131*m*	1.35 d			β^-(0.42); IT, Te-x, I-x; γ(0.150, 0.774, 0.794, 0.852)
	131	25.0 min			β^-(2.14, 1.69, 1.35); I-x; γ(0.150, 0.453, 0.493)
	132	25.0 min			β^-(0.215); γ(0.050, 0.112, 0.228)
Iodine	121	2.12 h			β^+(1.2); γ(2.12)
	122	3.6 min			β^+(3.1); γ(0.564)
	123	13.2 h			K, Te-x; γ(0.159)
	124	4.18 d			β^+(1.54, 2.14, 0.75); γ(0.603, 0.723, 1.691)
	125	59.4 d		$9.(1) \times 10^2$	K, Te-x; γ(0.035)
	126	13.0 d			β^+(1.13); β^-(0.87, 1.25); γ(0.389, 0.662)
	127		100	6.15(10)	
	128	24.99 min		22.(4)	β^-(2.13); γ(0.443, 0.527)
	129	1.7×10^7 y			β^-(0.15); γ(0.040)
	130	12.36 h		18.(3)	β^+(1.13); β^-(0.87, 1.25); γ(0.389, 0.662)
	131	8.040 d		≈0.7	β^-(0.606); γ(0.284, 0.364, 0.637)
	132	208 h			β^-(0.80, 1.03, 1.2, 1.6, 2.16); γ(0.098, 0.506, 0.523, 0.630, 0.651, 0.667, 0.723, 0.955)
	133	20.8 h			β^-(1.24); γ(0.511, 0.530, 0.875)
	135	6.57 h			β^-(0.9, 1.3); γ(0.418, 0.527, 1.132, 1.260)
Xenon	123	2.00 h			β^+(1.51); γ(0.149, 0.178)
	125	17.1 h			γ(0.188, 0.243)

TABLE 4.16 Table of Nuclides (*Continued*)

Element	*A*	Half-life	Natural abundance, %	Cross section, barns	Radiation (MeV)
Xenon (*cont.*)	127*m*	1.15 min			γ(0.127, 0.173)
	127	36.4 d			γ(0.172, 0.203, 0.375)
	129*m*	8.89 d			γ(0.040, 0.197)
	129		26.4(6)	22.(5)	
	131*m*	11.9 d			γ(0.164)
	131		21.2(4)	90.(10)	
	133*m*	2.19 d			γ(0.233)
	133	5.243 d		190.(90)	β^-(0.346); Cs-x; γ(0.081)
	135*m*	15.3 min			γ(0.527)
	135	9.1 h			β^-(0.91); γ(0.250, 0.608)
Cesium	126	1.64 min			β^+(3.4, 3.7); γ(0.0389, 0.491, 0.925)
	127	6.2 h			β^+(0.65, 1.06); γ(0.125, 0.412)
	128	3.62 min			β^+(2.44, 2.88); γ(0.443)
	129	1.336 d			γ(0.372, 0.412)
	132	6.48 d			γ(0.465, 0.630, 0.668)
	133		100	28	
	134*m*	2.91 h			IT, K, Cs-x; γ(0.127)
	134	2.065 y		140.(10)	β^-(0.658, 0.089); γ(0.563, 0.569, 0.605, 0.796)
	135	2.3×10^6 y		8.9(5)	β^-(0.205)
	136	13.16 d			β^-(0.341); γ(0.341, 0.819, 1.048)
	137	30.2 y			β^-(0.514); K, Ba-x; γ(0.662)
Barium	126	1.65 h			γ(0.218, 0.234, 0.258)
	128	2.43 d			γ(0.273); K, Cs-x
	129*m*	2.17 h			γ(0.177, 0.182, 0.202, 1.459)
	129	2.2 h			β^+(1.42); γ(0.129, 0.214, 0.221)
	131	11.7 d			γ(0.124, 0.216, 0.496)
	133*m*	1.621 d			γ(0.276)
	133	10.53 y		4.(1)	γ(0.081, 0.356)
	135*m*	1.196 d			IT, Ba-x; γ(0.268)
	135		6.59(2)	5.8	
	137		11.23(4)	5.(1)	
	137*m*	2.552 min			IT, K, Ba-x; γ(0.662)
	138		71.70(7)	0.41(2)	
	139	1.396 h		5.1	β^-(2.27, 2.14); K, La-x; γ(0.166, 1.254, 1.421)
	140	12.75 d			β^-(0.48, 1.02); γ(0.163, 0.305, 0.537)
	142	10.7 min			β^-(1.0, 1.1); γ(0.231, 0.255, 0.309, 1.204)

TABLE 4.16 Table of Nuclides (*Continued*)

Element	*A*	Half-life	Natural abundance, %	Cross section, barns	Radiation (MeV)
Lanthanum	131	59 min			β^+(1.42, 1.94); γ(0.526, 0.109, 0.366)
	132	4.8 h			β^+(2.6, 3.2, 3.7); γ(0.465, 0.567)
	133	3.91 h			β^+(1.2); γ(0.279, 0.290, 0.302)
	134	6.5 min			β^+(2.67); γ(0.605)
	135	19.5 h			γ(0.481)
	136	8.87 min			β^+(1.8); γ(0.816)
	*138	1.06×10^{11} y		57.(6)	
	139		99.9098(2)	9.2(2)	
	140	1.68 d		2.7(3)	β^-(1.670, 1.35)
	141	3.90 h			β^-(2.43)
	142	1.54 h			β^-(2.11, 2.98, 4.52)
Cerium	132	3.5 h			γ(0.154, 0.182)
	133	5.4 h			β^+(1.3); γ(0.058, 0.131, 0.472, 0.510)
	135	17.7 h			β^+(0.8); γ(0.266, 0.300, 0.607)
	137*m*	1.43 d			IT K, Ce-x; γ(0.169, 0.254)
	137	9.0 h			γ(0.447)
	139	137.6 d			γ(0.166)
	140		88.43(10)	0.58(4)	
	141	32.50 d			β^-(0.436, 0.581); K, Pr-x; γ(0.145)
	142		11.13(10)	0.97(3)	
	143	1.38 d		6.1(7)	β^-(1.404, 1.110); K, Pr-x; γ(0.293)
	144	284.6 d		1.0(1)	β^-(0.318, 0.185); K, Pr-x; γ(0.080, 0.134)
Praseodymium	136	13.1 min			β^+(2.98); γ(0.540, 0.552)
	137	1.28 h			β^+(1.68); γ(0.434, 0.514, 0.837)
	138*m*	2.1 h			β^+(1.65); γ(0.304, 0.789, 1.038)
	139	4.41 h			β^+(1.09); γ(0.255, 1.347, 1.631)
	141		100	11.5	
	142	19.12 h		20.(3)	β^-(2.164); γ(1.576)
	143	13.57 d		90.(10)	β^-(0.933); γ(0.742)
	145	5.98 h			β^-(1.80); γ(0.073, 0.676, 0.748)
Neodymium	139*m*	5.5 h			β^+(1.17); γ(0.114, 0.738)
	141	2.49 h			β^+(0.802)
	142		27.13(2)	19.(1)	
	143		12.18(6)	220.(10)	
	*144	2.1×10^{15} y	23.8(1)	3.6(3)	
	145		8.3(6)	47.(6)	

TABLE 4.16 Table of Nuclides (*Continued*)

Element	*A*	Half-life	Natural abundance, %	Cross section, barns	Radiation (MeV)
Neodymium	146		17.19(9)	1.5(2)	
(*cont.*)	147	10.98 d		440.(150)	β^-(0.805); γ(0.091, 0.531)
	149	1.73 h			β^-(1.03, 1.13); γ(0.211, 0.114)
Promethium	143	265 d			K, Nd-x; γ(0.742)
	144	360 d			K, Nd-x; γ(0.618, 0.696)
	146	5.53 y		$8.4(2) \times 10^3$	K, β^-(0.795); Nd-x; γ(0.453, 0.75)
	147	2.6234 y		180	β^-(0.224); γ(0.122, 0.197)
	148*m*	41.29 d		$106.(8) \times 10^2$	β^-(0.69, 0.50, 0.40); IT, Pm-x, Sm-x; γ(0.550, 0.630, 0.726)
	148	5.37 d		≈1000	β^-(1.02, 2.47); γ(0.550, 0.915, 1.465)
	149	2.212 d		$14.(2) \times 10^2$	β^-(1.072, 0.78); γ(0.286, 0.591, 0.859)
	150	2.68 h			β^-(1.6, 2.3, 1.8); γ(0.334, 1.166, 0.132)
	151	1.183 d		≈150	β^-(0.84); γ(0.168, 0.275, 0.340)
Samarium	142	1.208 h			β^+(1.0); K, Pr-x
	144		3.1(1)	1.6(1)	
	145	340 d		280.(20)	γ(0.061, 0.492); K, Pm-x
	146	1.03×10^8 y			α(2.50)
	*147	1.06×10^{11} y	15.0(2)	56.(4)	α(2.23)
	148	7×10^{15} y	11.3(1)	2.4(6)	α(1.96)
	149	10^{16} y	13.8(1)	$401.(6) \times 10^2$	
	150		7.4(1)	102.(5)	
	151	90 y			β^-(0.076)
	152		26.7(2)	206.(15)	
	153	1.929 d		420.(180)	β^-(0.64, 0.69); γ(0.103)
	154		22.7(2)	7.5(3)	
	155	22.2 min			β^-(1.52); γ(0.104)
	156	9.4 h			β^-(0.43, 0.71); γ(0.166, 0.204)
Europium	148	54.5 d			β^+(0.92); γ(0.550, 0.630)
	149	93.1 d			K, Sm-x; γ(0.277, 0.328)
	150*m*	12.8 h			β^-(1.013); γ(0.334, 0.407)
	150	36 y			γ(0.334, 0.439, 0.584)
	151		47.8(5)	9000	
	152*m*	9.30 h			β^-(1.85); γ(0.122, 0.841, 0.963)
	152	13.48 y		$11.(2) \times 10^3$	K, β^-(1.47, 0.690); K, Gd-x, K, Sm-x; γ(0.122, 0.344, 1.408)
	153		52.2(5)	320.(20)	

TABLE 4.16 Table of Nuclides (*Continued*)

Element	*A*	Half-life	Natural abundance, %	Cross section, barns	Radiation (MeV)
Europium (*cont.*)	154	8.59 y		$1.5(3) \times 10^3$	β^-(0.27, 0.58, 0.843, 1.87); γ(0.123, 0.723, 1.274)
	155	4.76 y		$3.9(2) \times 10^3$	β^-(0.15); γ(0.087, 0.105)
	156	15.2 d			β^-(0.30, 0.49, 1.2, 2.45); γ(0.089, 0.646, 0.723, 0.812)
	157	15.13 h			β^-(1.30); γ(0.064, 0.371, 0.411)
	158	45.9 min			β^-(2.5); γ(0.898, 0.944, 0.977)
Gadolinium	146	48.3 d			β^+(0.35); γ(0.115, 0.155)
	147	1.588 d			β^+(0.93); γ(0.229, 0.370, 0.396, 0.929)
	151	124 d			α(2.73); γ(0.154, 0.243)
	153	241.6 d			γ(0.94, 0.103)
	155		14.80(5)	$61.(1) \times 10^3$	
	157		15.65(3)	$2.54(3) \times 10^5$	
	158		24.84(12)	2.3(5)	
	159	18.56 h			β^-(0.971); Tb-x; γ(0.363)
	160		21.86(4)	1.5(7)	
Terbium	158	180 y			γ(0.944, 0.962)
	159		100	23.2(5)	
	160	72.3 d		$5.7(11) \times 10^2$	β^-(0.57, 0.86); γ(0.299, 0.879, 0.966)
Dysprosium	159	144 d		$8.(2) \times 10^3$	K, Tb-x; γ(0.326)
	161		18.9(2)	600.(150)	
	162		25.5(2)	170.(20)	
	163		24.9(2)	120.(10)	
	164		28.2(2)	2000	
	165	2.33 h		$3.5(3) \times 10^3$	β^-(1.29); Ho-x; γ(0.095)
	165*m*	1.26 min			γ(0.108, 0.515)
Holmium	156	56 min			γ(0.138, 0.267)
	159	33.0 min			γ(0.121, 0.132, 0.253, 0.310)
	167	3.1 h			β^-(0.31, 0.62, 0.96); γ(0.238, 0.321, 0.347)
	165		100	61	
	166*m*	1.2×10^3 y		$9.14(65) \times 10^3$	Er-x; γ(0.810, 0.712, 0.184)
	166	1.117 d			β^-(1.855, 1.776); γ(1.379)
Erbium	166		33.6(2)	20	
	167		22.95(15)	$7.(2) \times 10^2$	
	168		26.8(2)	2.0(6)	
	169	9.40 d			β^-(0.35)
	170		14.9(2)	6.2(2)	

TABLE 4.16 Table of Nuclides (*Continued*)

Element	*A*	Half-life	Natural abundance, %	Cross section, barns	Radiation (MeV)
Erbium (*cont.*)	171	7.52 h		370.(40)	β^-(1.49); Tm-x; γ(0.112, 0.296, 0.308)
	172	2.05 d			β^-(0.28, 0.36); γ(0.407, 0.610)
Thullium	166	7.70 h			γ(0.184, 0.779, 1.273, 2.052)
	169		100	106	
	170	128.6 d		100.(20)	β^-(0.968, 0.884)
	171	1.92 y		≈160	β^-(0.096); γ(0.067)
	172	2.65 d			β^-(1.79, 1.86); γ(1.387, 1.466, 1.530, 1.609)
	173	8.2 h			β^-(0.80, 0.86); γ(0.399, 0.461)
Ytterbium	165	9.9 min			β^+(1.58); γ(1.090)
	166	2.363 d			γ(0.184, 0.779, 1.273, 2.052)
	169	32.03 d		$3.6(3) \times 10^3$	γ(0.110, 0.177, 0.198)
	171		14.3(2)	50.(10)	
	173		16.12(21)	16.(2)	
	174		31.8(4)	120	
	175	4.19 d			β^-(0.466); Lu-x; γ(0.396)
	176		12.7(2)	3.1(2)	
	177	1.9 h			β^-(1.40); K, Lu-x; γ(0.150)
	178	1.23 h			β^-(0.25); γ(0.141, 0.325, 0.352, 0.381, 0.613)
Lutetium	164	3.14 min			β^+(1.6, 3.8); γ(0.124, 0.262, 0.740, 0.864, 0.880)
	165	16.7 min			β^+(2.06); γ(0.121, 0.132, 0.174, 0.204)
	175		97.41(2)	24	
	176*m*	3.66 h			β^-(1.229, 1.317); Hf-x; γ(0.0884)
	176	3.8×10^{16} y		2100	γ(0.202, 0.307)
	177	6.75 d		$10.(3) \times 10^2$	β^-(0.497), Hf-x; γ(0.113, 0.208)
Hafnium	178		27.297(4)	85	
	179		13.629(6)	46	
	†179m_1	18.7 s			γ(0.161, 0.214)
	†179m_2	25.1 d			γ(0.123, 0.146, 0.363, 0.454)
	180		35.100(7)	13.(1)	
	180*m*	5.519 h			IT, Hf-x; γ(0.215, 0.332, 0.443)
	181	42.4 d		30.(25)	β^-(0.408); Ta-x; γ(0.133, 0.346, 0.482)

† Two different metastable states possessing the same mass number but different half-lives.

TABLE 4.16 Table of Nuclides (*Continued*)

Element	*A*	Half-life	Natural abundance, %	Cross section, barns	Radiation (MeV)
Hafnium (*cont.*)	183	1.07 h			β^-(1.18, 1.54); γ(0.459, 0.784)
	184	4.1 h			β^-(0.74, 0.85, 1.10); γ(0.139, 0.345)
Tantalum	181		99.988(2)	20	
	182*m*	16.5 min			γ(0.147, 0.172, 0.184)
	182	114.43 d		$8.2(6) \times 10^3$	β^-(0.25, 0.44, 0.52); γ(0.068, 1.121)
	183	5.1 d			β^-(0.62); γ(0.108, 0.246, 0.304)
	184	8.7 h			β^-(1.17); γ(0.253, 0.414)
Tungsten	182		26.50(3)	20.(1)	
	183		14.31(1)	10.5(3)	
	184		30.64(1)	2	
	185	74.8 d		≈3.3	β^-(0.433); γ(0.125)
	186		28.43(4)	37.(2)	
	187	23.9 h		70.(10)	β^-(1.315, 0.624; K, Re-x; γ(0.072, 0.480, 0.686)
	188	69.4 d			β^-(0.349); γ(0.227, 0.291)
Rhenium	182*m*	12.7 h			β^+(0.55, 1.74); γ(1.121, 1.221)
	184	38 d			γ(0.790, 0.903)
	185		37.40(2)	110	
	186	3.718 d			β^-(1.07, 0.933); K, W-x, Os-x; γ(0.123, 0.137, 0.632, 0.768)
	*187	4.2×10^{10}	62.60(2)	74	
	188	16.94 h			β^-(2.12, 1.96); Os-x; γ(0.155)
	189	24 h			β^-(1.01); γ(0.147, 0.22, 0.245)
Osmium	186	2×10^{15} y	1.58(2)	≈80	
	188		13.3(1)	≈5	
	190*m*	9.9 min			IT, Os-x; γ(0.187, 0.361, 0.503, 0.616)
	190		26.4(2)	13	
	191	15.4 d		$3.8(6) \times 10^2$	β^-(0.143); Os-x; γ(0.129)
	192		41.0(3)	3.(1)	
	193	30.5 h			β^-(1.04); Ir-x; γ(0.139, 0.460)
	196	34.9 min			β^-(0.84); γ(0.126, 0.408)
Iridium	184	3.0 h			β^+(2.3, 2.9); γ(0.120, 0.264, 0.390)
	185	14 h			γ(0.254, 1.829)
	186	15.7 h			γ(0.137, 0.296, 0.435)
	188	1.72 d			γ(0.155, 0.478, 0.633, 2.215)

TABLE 4.16 Table of Nuclides (*Continued*)

Element	*A*	Half-life	Natural abundance, %	Cross section, barns	Radiation (MeV)
Iridium	189	13.2 d			K, Os-x; γ(0.245)
(*cont.*)	190	11.8 d			γ(0.187, 0.407, 0.519, 0.558, 0.605)
	191		37.27(9)	920	
	192	73.83 d			β^-(0.672); K, Pt-x; γ(0.316, 0.468)
	193		62.73(9)	116	
	194	19.3 h		$1.5(3) \times 10^3$	β^-(2.25); γ(0.294, 0.328, 0.645)
	195*m*	3.9 h			β^-(0.41, 0.97); γ(0.320, 0.365, 0.433, 0.685)
Platinum	187	2.35 h			γ(0.105, 0.110, 0.201, 0.285, 0.709)
	188	10.2 d			γ(0.188, 0.195)
	189	10.89 h			K, Ir-x; γ(0.094, 0.608, 0.721)
	194		32.9(6)	1.2	
	195*m*	4.02 d			IT, Pt-x; γ(0.099)
	195		33.8(6)	28.(1)	
	196		25.3(6)	55	
	197*m*	1.573 h			IT, Pt-x; γ(0.053, 0.346)
	197	18.3 h			β^-(0.719); K, Au-x; γ(0.191, 0.269)
	199*m*	14.1 s			γ(0.392)
	199	30.8 min		$\approx$16	β^-(0.90, 1.14); γ(0.186, 0.317, 0.494, 0.549)
	200	12.5 h			γ(0.136, 0.227, 0.244)
Gold	197		100	98.7(1)	
	197*m*	7.8 s			IT, K, Au-x; γ(0.130, 0.279)
	198	2.694 d		$26.5(15) \times 10^3$	β^-(0.961); K, Hg-x; γ(0.412)
	199	3.139 d			β^-(0.292, 0.250); K, Hg-x; γ(0.158, 0.208)
	200*m*	18.7 h			β^-(0.56); γ(0.111, 0.368, 0.498, 0.597, 0.760)
	200	48.4 min			β^-(2.2); γ(0.368, 1.225)
Mercury	196		0.15(1)	3150	
	197*m*	23.8 h			IT, K, Hg-x; γ(0.134)
	197	2.6725 d			K, Au-x; γ(0.077)
	199*m*	42.6 min			γ(0.158)
	199		16.87(10)	$2.1(2) \times 10^3$	
	200		23.10(16)	$<$60	
	202		29.86(20)	4.9(5)	
	203	46.61 d			β^-(0.213); γ(0.279)
Thallium	201	3.040 d			K, Hg-x; γ(0.135, 0.167)
	202	12.23 d			K, Hg-x; γ(0.440)
	203		29.52(1)	11.(1)	
	204	3.78 y		22.(2)	β^-(0.763); K, Hg-x

TABLE 4.16 Table of Nuclides (*Continued*)

Element	*A*	Half-life	Natural abundance, %	Cross section, barns	Radiation (MeV)
Thallium	205		70.48(1)	0.11(2)	
(*cont.*)	*206	4.20 min			β^-(1.53); K, Pb-x; γ(0.803)
	*207	4.77 min			β^-(1.43); γ(0.897)
	208	3.053 min			β^-(1.796, 1.28, 1.52); γ(0.277, 0.511, 0.583, 0.614)
	209	2.16 min			β^-(1.8); γ(1.567, 0.465)
	210	1.30 min			β^-(1.9, 1.3); γ(0.298, 0.798)
Lead	201	9.33 h			γ(0.331, 0.361)
	203	2.1615 d			γ(0.279)
	204*m*	1.120 h			IT, Pb-x; γ(0.375, 0.899, 0.912)
	207		22.1(1)	0.70(1)	
	209	3.253 h			β^-(0.645)
	*210	22.6 y			α(3.72)
	*211	36.1 min			β^-(1.36); γ(0.405, 0.427, 0.832)
	*212	10.64 h			β^-(0.569, 0.28); Bi-x; γ(0.239)
	*214	26.9 min			β^-(0.67, 0.73); γ(0.24, 0.30, 0.352)
Bismuth	205	15.31 d			γ(0.703, 1.764)
	206	6.243 d			γ(0.516, 0.803, 0.881)
	209		100	0.034	
	*210	5.013 d			β^-(1.16); γ(0.266, 0.352)
	212	1.0092 h			β^-(2.25); γ(0.288, 0.727, 0.786, 1.621); Tl-x; α(6.05, 6.09)
	*214	19.7 min			β^-(3.26); γ(0.609, 1.120, 1.764)
Polonium	204	3.53 h			γ(0.270, 0.884, 1.016)
	205	1.7 h			γ(0.837, 0.850, 0.872, 1.001)
	206	8.8 d			α(5.233); γ(0.286, 0.312, 0.807)
	208	2.898 y			α(5.116)
	209	102 y			α(4.88); IT, K, Bi-x; γ(0.260, 0.896)
	210	138.38 d			α(5.304); γ(0.803)
	212	298 ns			α(8.784)
	214	0.1637 ms			α(7.686)
	216	145 ms			α(6.778)
	218	3.04 min			α(5.18)
Astatine	207	1.81 h			α(5.76); γ(0.168, 0.588, 0.814)
	208	1.63 h			α(5.641); K, Po-x, γ(0.177, 0.660, 0.685, 0.845, 1.028)

TABLE 4.16 Table of Nuclides (*Continued*)

Element	*A*	Half-life	Natural abundance, %	Cross section, barns	Radiation (MeV)
Astatine (*cont.*)	209	5.41 h			α(5.65), K, Po-x; γ(0.545, 0.782, 0.790)
	210	8.1 h			K, Po-x; γ(0.245, 0.528, 1.181, 1.437, 1.483)
	211	7.214 h			α(5.87); K, Po-x; γ(0.669, 0.742)
Radon	210	2.4 h			α(6.039); γ(0.196, 0.458, 0.571, 0.649)
	211	14.68 h			α(5.784, 5.851); γ(0.169, 0.250, 0.370, 0.674, 0.678, 1.363)
	212	24 min			α(6.260)
	220	55.6 s			α(6.288)
	222	2.8235 d		0.74(5)	α(5.49); γ(0.510)
Francium	212	20 min			α(6.41, 6.26); γ(1.186, 1.275)
	220	27.4 s			α(6.686, 0.641, 6.582); γ(0.106, 0.154, 0.162)
	221	4.8 min			α(6.341); γ(0.218, 0.409)
	222	14.3 min			β^-(0.178)
	223	22.0 min			β^-(0.117)
Radium	*224	3.66 d		12.0(5)	α(5.685, 5.45); K, Rn-x; γ(0.241, 0.409, 0.650)
	*226	1599 y		$\approx$13	α(4.78, 4.60); K, Rn-x; γ(0.186, 0.262)
	*228	5.76 y		36.(5)	γ(0.0135)
Actinium	*227	21.77 y		$8.8(7) \times 10^2$	β^-(0.045); α(4.95, 4.94); K, Th-x; γ(0.084, 0.160, 0.270)
	*228	6.15 h			β^-(2.18, 1.85, 1.11); K, Th-x; γ(0.339, 0.911, 0.969)
Thorium	226	30.6 min			α(6.337, 6.228); γ(0.206, 0.242)
	228	1.913 y		$1.2(2) \times 10^2$	α(5.42, 5.34, 5.18); K, Ra-x
	*230	7.54×10^4 y		23.4(5)	α(4.68, 4.62); K, Ra-x; γ(0.068)
	231	1.063 d			β^-(0.305, 0.218, 0.138)
	*232	1.405×10^{10} y		7.37(4)	α(4.01, 3.95); γ(0.059)
	233	22.3 min		$1.5(1) \times 10^3$	β^-(1.245); γ(0.459)
	*234	24.10 d		1.8(5)	β^-(0.198, 0.102); K, Pa-x
Protactinium	230	17.4 d		$1.5(3) \times 10^3$	β^-(0.51); γ(0.444, 0.455, 0.899, 0.952)
	*231	3.25×10^4 y		$2.0(1) \times 10^2$	α(5.06, 5.03, 5.01, 4.95, 4.73); K, Ac-x; γ(0.260, 0.284, 0.300, 0.330)

TABLE 4.16 Table of Nuclides (*Continued*)

Element	*A*	Half-life	Natural abundance, %	Cross section, barns	Radiation (MeV)
Protactinium (*cont.*)	232	1.31 d		$4.6(10) \times 10^2$	$\beta^-(1.34)$; $\gamma(0.109, 0.150, 0.894, 0.969)$
	233	27.0 d			$\beta^-(0.256, 0.15, 0.568)$; K,L U-x; $\gamma(0.300, 0.312, 0.341)$
	234*m*	1.17 min			$\beta^-(2.29)$; IT, K, U-x
	235	24.4 min			$\beta^-(1.4)$
Uranium	230	20.8 d			$\alpha(5.89, 5.82)$
	232	68.9 y		73.(2)	$\alpha(5.320, 5.263)$
	233	1.592×10^5 y		47.(2)	$\alpha(4.825, 4.783)$; L, Th-x; $\gamma(0.029, 0.042, 0.055, 0.097, 0.119, 0.146, 0.164, 0.22, 0.291, 0.32)$
	*234	2.454×10^5 y	0.0055(5)	96.(2)	$\alpha(4.776, 4.723)$; L, Th-x; $\gamma(0.121)$
	*235	7.037×10^8 y	0.720(1)	95.(5)	$\alpha(4.40, 4.37, 4.22)$; K,L Th-x; $\gamma(0.14, 0.16, 0.186, 0.20)$
	237	6.75 d		≈100	
	*238	4.46×10^9 y	99.2745(15)	2.7(1)	$\alpha(4.196, 4.147)$
	239	23.47 min		22.(2)	$\beta^-(1.21, 1.29)$
Neptunium	236	1.55×10^5 y			$\beta^-(0.49)$, $\gamma(0.104, 0.160)$
	237	2.14×10^6 y		180	$\alpha(4.79, 4.77)$; K,L Pa-x
	238	2.117 d		51	$\beta^-(1.2)$; $\gamma(0.984, 1.029)$
	239	2.355 d		$5.1(2) \times 10^2$	$\beta^-(0.438, 0.341)$; $\gamma(0.228, 0.278)$
Plutonium	237	45.7 d			K,L Np-x
	238	87.74 y			$\alpha(5.50, 5.46)$; K, U-x; $\gamma(0.0435)$
	239	2.411×10^4 y		$2.7(1) \times 10^2$	$\alpha(5.16, 5.14, 5.11)$; K, U-x; $\gamma(0.375, 0.414, 0.129)$
	240	6.537×10^3 y		$2.9(1) \times 10^2$	$\alpha(5.168, 5.124)$; L, U-x
	242	3.763×10^5 y		19.(1)	$\alpha(4.90, 4.86)$; $\gamma(0.045, 0.103)$
	244	8.2×10^7 y		1.7(1)	$\alpha(4.59, 4.55)$; L, U-x
	246	10.85 d			$\beta^-(0.150, 0.35)$; $\gamma(0.224)$
Americium	241	432.2 y		600	$\alpha(5.49, 5.44)$; $\gamma(0.12, 0.14)$
	243	7370 y		80	$\alpha(5.277, 5.234)$; $\gamma(0.075)$
Curium	242	162.8 d		≈20	$\alpha(6.113, 6.069)$; L, Pu-x
	243	28.5 y		$1.3(1) \times 10^2$	$\alpha(5.786, 5.742)$
	244	18.11 y		15.(1)	$\alpha(5.805, 5.753)$; $\gamma(0.099, 1.526)$
Berkelium	247	1.4×10^3 y			$\alpha(5.532, 5.678, 5.712)$
	249	320 d		$7.(1) \times 10^2$	$\alpha(5.42)$; $\beta^-(0.125)$
	250	3.217 h			$\beta^-(0.74)$; $\gamma(0.989, 1.032)$

TABLE 4.16 Table of Nuclides (*Continued*)

Element	*A*	Half-life	Natural abundance, %	Cross section, barns	Radiation (MeV)
Californium	251	900 y		$2.9(2) \times 10^2$	α(5.677, 5.851, 6.014)
	252	2.645 y		20.(2)	α(6.118, 6.076); L, Cm-x; γ(0.043, 0.100)
Einsteinium	253	20.47 d		186	α(6.64); γ(0.389)
	254	275.7 d		28.(3)	α(6.43)
	255	40 d		$\approx$55	β^-(0.29); α(6.26)
Fermium	255	20.1 h		26.(3)	α(7.023)
	257	100.5 d			α(6.519); L, Cf-x; γ(0.179, 0.241)
Mendelevium	258	51.5 d			α(6.718, 6.763); γ(0.368)
	260	32 d			
Nobelium	255	3.1 min			α(8.12, 7.93); γ(0.187)
	259	58 min			α(7.52, 7.55)
Lawrencium	260	3 min			
	261	40 min			
	262	3.6 h			

Source: R. B. Firestone and V. S. Shirley, eds., *Table of Isotopes,* 8th ed., Wiley, New York, 1997, and V. S. Shirley, ed., *Table of Radioactive Isotopes,* 8th ed., Wiley-Interscience, New York, 1986.

4.9 WORK FUNCTION

TABLE 4.17 Work Functions of the Elements

The work function ϕ is the energy necessary to just remove an electron from the metal surface in thermoelectric or photoelectric emission. Values are dependent upon the experimental technique (vacua of 10^{-9} or 10^{-10} torr, clean surfaces, and surface conditions including the crystal face identification).

Element	ϕ, eV	Element	ϕ, eV
Ag	4.64	Eu	2.5
Al	4.19	Fe	4.65
As	(3.75)	Ga	4.25
Au	5.32	Ge	5.0
B	(4.75)	Gd	3.1
Ba	2.35	Hf	3.65
Be	5.08	Hg	4.50
Bi	4.36	In	4.08
C	(5.0)	Ir	5.6
Ca	2.71	K	2.30
Cd	4.12	La	3.40
Ce	2.80	Li	3.10
Co	4.70	Mg	3.66
Cr	4.40	Mn	3.90
Cs	1.90	Mo	4.30
Cu	4.70	Na	2.70

TABLE 4.17 Work Functions of the Elements (*Continued*)

Element	ϕ, eV	Element	ϕ, eV
Nb	4.20	Si	4.85
Nd	3.1	Sm	2.95
Ni	5.15	Sn	4.35
Os	4.83	Sr	2.76
Pb	4.18	Ta	4.22
Pd	5.00	Tb	3.0
Po	4.6	Te	4.70
Pr	2.7	Th	3.71
Pt	5.40	Ti	4.10
Rb	2.20	Tl	4.02
Re	4.95	U	3.70
Rh	4.98	V	4.44
Ru	4.80	W	4.55
Sb	4.56	Y	3.1
Sc	3.5	Zn	4.30
Se	5.9	Zr	4.00

Source: S. Trasatti, *J. Chem. Soc. Faraday Trans. I* **68:**229 (1972); N. D. Lang and W. Kohn, *Phys. Rev. B* **3:**1215 (1971).

4.10 RELATIVE ABUNDANCES OF NATURALLY OCCURRING ISOTOPES

TABLE 4.18 Relative Abundances of Naturally Occurring Isotopes

Element	Mass number	Percent	Element	Mass number	Percent
Aluminum	27	100	Cadmium	112	24.13(14)
Antimony	121	57.21(5)		113	12.22(8)
	123	42.79(5)		114	28.7(3)
Argon	36	0.337(3)		116	7.49(9)
	38	0.063(1)	Calcium	40	96.941(18)
	40	99.600(3)		42	0.647(9)
Arsenic	75	100		43	0.135(6)
Barium	130	0.106(2)		44	2.088(12)
	132	0.101(2)		46	0.004(3)
	134	2.42(3)		48	0.187(4)
	135	6.59(2)	Carbon	12	98.89(1)
	136	7.85(4)		13	1.11(1)
	137	11.23(4)	Cerium	136	0.19(1)
	138	71.70(7)		138	0.25(1)
Beryllium	9	100		140	88.43(10)
Bismuth	209	100		142	11.13(10)
Boron	10	19.9(2)	Cesium	133	100
	11	80.1(2)	Chlorine	35	75.77(7)
Bromine	79	50.69(7)		37	24.23(7)
	81	49.31(7)	Chromium	50	4.345(13)
Cadmium	106	1.25(4)		52	83.79(2)
	108	0.89(2)		53	9.50(2)
	110	12.49(12)		54	2.365(7)
	111	12.80(8)	Cobalt	59	100

TABLE 4.18 Relative Abundances of Naturally Occurring Isotopes (*Continued*)

Element	Mass number	Percent	Element	Mass number	Percent
Copper	63	69.17(3)	Krypton	78	0.35(2)
	65	30.83(3)		80	2.25(2)
Dysprosium	156	0.06(1)		82	11.6(1)
	158	0.10(1)		83	11.5(1)
	160	2.34(6)		84	57.0(3)
	161	18.9(2)		86	17.3(2)
	162	25.5(2)	Lanthanum	138	0.0902(2)
	163	24.9(2)		139	99.9098(2)
	164	28.2(2)	Lead	204	1.4(1)
Erbium	162	0.14(1)		206	24.1(1)
	164	1.61(2)		207	22.1(1)
	166	33.6(2)		208	52.4(1)
	167	22.95(15)	Lithium	6	7.5(2)
	168	26.8(2)		7	92.5(2)
	170	14.9(2)	Lutetium	175	97.41(2)
Europium	151	47.8(5)		176	2.59(2)
	153	52.2(5)	Magnesium	24	78.99(3)
Fluorine	19	100		25	10.00(1)
Gadolinium	152	0.20(1)		26	11.01(2)
	154	2.18(3)	Manganese	55	100
	155	14.80(5)	Mercury	196	0.15(1)
	156	20.47(4)		198	9.97(8)
	157	15.65(3)		199	16.87(10)
	158	24.84(12)		200	23.10(16)
	160	21.86(4)		201	13.18(8)
Gallium	69	60.108(9)		202	29.86(20)
	71	39.892(9)		204	6.87(4)
Germanium	70	21.23(4)	Molybdenum	92	14.84(4)
	72	27.66(3)		94	9.25(3)
	73	7.73(1)		95	15.92(5)
	74	35.94(2)		96	16.68(5)
	76	7.44(2)		97	9.55(3)
Gold	197	100		98	24.13(7)
Hafnium	174	0.162(3)		100	9.63(3)
	176	5.206(5)	Neodymium	142	27.13(12)
	177	18.606(13)		143	12.18(6)
	178	27.297(4)		144	23.80(12)
	179	13.629(6)		145	8.30(6)
	180	35.100(7)		146	17.19(9)
Helium	4	100		148	5.76(3)
Holmium	165	100		150	5.64(3)
Hydrogen	1	99.985(1)	Neon	20	90.48(3)
	2	0.015(1)		21	0.27(1)
Indium	113	4.29(2)		22	9.25(3)
	115	95.71(2)	Nickel	58	68.077(9)
Iodine	127	100		60	26.223(8)
Iridium	191	37.27(9)		61	1.140(1)
	193	62.73(9)		62	3.634(2)
Iron	54	5.85(4)		64	0.926(1)
	56	91.75(4)	Niobium	93	100
	57	2.12(1)	Nitrogen	14	99.634(9)
	58	0.26(1)		15	0.366(9)

TABLE 4.18 Relative Abundances of Naturally Occurring Isotopes (*Continued*)

Element	Mass number	Percent	Element	Mass number	Percent
Osmium	184	0.020(3)		78	23.78(9)
	186	1.58(2)		80	49.61(10)
	187	1.6(4)		82	8.73(6)
	188	13.3(1)	Silicon	28	92.23(2)
	189	16.1(1)		29	4.67(2)
	190	26.4(2)		30	3.10(1)
	192	41.0(3)	Silver	107	51.839(7)
Oxygen	16	99.76(1)		109	48.161(7)
	17	0.04	Sodium	23	100
	18	0.20(1)	Strontium	84	0.56(1)
Palladium	102	1.02(1)		86	9.86(1)
	104	11.14(8)		87	7.00(1)
	105	22.33(8)		88	82.58(1)
	106	27.33(3)	Sulfur	32	95.02(9)
	108	26.46(9)		33	0.75(4)
	110	11.72(9)		34	4.21(8)
Phosphorus	31	100		36	0.02(1)
Platinum	190	0.01(1)	Tantalum	180	0.012(2)
	192	0.79(6)		181	99.988(2)
	194	32.9(6)	Tellurium	120	0.096(2)
	195	33.8(6)		122	2.603(4)
	196	25.3(6)		123	0.908(2)
	198	7.2(2)		124	4.816(6)
Potassium	39	93.258(4)		125	7.139(6)
	40	0.0117(1)		126	18.952(11)
	41	6.730(3)		128	31.687(11)
Praseodymium	141	100		130	33.799(10)
Protoactinium	230	100	Terbium	159	100
Rhenium	185	37.40(2)	Thallium	203	29.52(1)
	187	62.60(2)		205	70.48(1)
Rhodium	103	100	Thorium	228	100
Rubidium	85	72.17(2)	Thullium	169	100
	87	27.83(2)	Tin	112	0.97(1)
Ruthenium	96	5.52(6)		114	0.65(1)
	98	1.88(6)		115	0.34(1)
	99	12.7(1)		116	14.53(11)
	100	12.6(1)		117	7.68(7)
	101	17.0(1)		118	24.23(11)
	102	31.6(2)		119	8.59(4)
	104	18.7(2)		120	32.59(10)
Samarium	144	3.1(1)		122	4.63(3)
	147	15.0(2)		124	5.79(5)
	148	11.3(1)	Titanium	46	8.25(3)
	149	13.8(1)		47	7.44(2)
	150	7.4(1)		48	73.72(3)
	152	26.7(2)		49	5.41(2)
	154	22.7(2)		50	5.4(1)
Scandium	45	100	Tungsten	180	0.12(1)
Selenium	74	0.89(2)		182	26.50(3)
	76	9.36(11)		183	14.31(1)
	77	6.63(6)		184	30.64(1)

TABLE 4.18 Relative Abundances of Naturally Occurring Isotopes (*Continued*)

Element	Mass number	Percent	Element	Mass number	Percent
Tungsten (*cont.*)	186	28.43(4)		171	14.3(2)
Uranium	234	0.0055(5)		172	21.9(3)
	235	0.720(1)		173	16.12(2)
	238	99.275(2)		174	31.8(4)
Vanadium	50	0.250(2)		176	12.7(2)
	51	99.750(2)	Yttrium	89	100
Xenon	124	0.10(1)	Zinc	64	48.6(3)
	126	0.09(1)		66	27.9(2)
	128	1.91(3)		67	4.1(1)
	129	26.4(6)		68	18.8(4)
	130	4.1(1)		70	0.6(1)
	131	21.2(4)	Zirconium	90	51.45(3)
	132	26.9(5)		91	11.22(4)
	134	10.4(2)		92	17.15(2)
	136	8.9(1)		94	17.38(4)
Ytterbium	168	0.13(1)		96	2.80(2)
	170	3.05(6)			

Source: A. H. Wapstra and G. Audi, *"The 1983 Atomic Mass Evaluation,"* Nucl. Phys., **A432:1-54** (1985) and references cited for Table 4.16.