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X-RAY DATA BOOKLET

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SECTION 1

X-RAY PROPERTIES OF THE ELEMENTS

1.1 ELECTRON BINDING ENERGIES

Gwyn P. Williams

Table 1-1 gives the electron binding energies for the elements in their natural forms. The energies are given in electron volts relative to the vacuum level for the rare gases and for H_2, N_2, O_2, F_2, and Cl_2; relative to the Fermi level for the metals; and relative to the top of the valence bands for semiconductors. Values have been taken from Ref. 1 except as follows:

*Values taken from Ref. 2, with additional corrections
†Values taken from Ref. 3.
[a]One-particle approximation not valid owing to short core-hole lifetime.
[b]Value derived from Ref. 1.

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Table 1-1. Electron binding energies, in electron volts, for the elements in their natural forms.

Element	K 1s	L_1 2s	L_2 $2p_{1/2}$	L_3 $2p_{3/2}$	M_1 3s	M_2 $3p_{1/2}$	M_3 $3p_{3/2}$	M_4 $3d_{3/2}$	M_5 $3d_{5/2}$	N_1 4s	N_2 $4p_{1/2}$	N_3 $4p_{3/2}$
1 H	13.6											
2 He	24.6*											
3 Li	54.7*											
4 Be	111.5*											
5 B	188*											
6 C	284.2*											
7 N	409.9*	37.3*										
8 O	543.1*	41.6*										
9 F	696.7*											
10 Ne	870.2*	48.5*	21.7*	21.6*								
11 Na	1070.8†	63.5†	30.65	30.81								
12 Mg	1303.0†	88.7	49.78	49.50								
13 Al	1559.6	117.8	72.95	72.55								
14 Si	1839	149.7*b	99.82	99.42								
15 P	2145.5	189*	136*	135*								
16 S	2472	230.9	163.6*	162.5*								
17 Cl	2822.4	270*	202*	200*								
18 Ar	3205.9*	326.3*	250.6†	248.4*	29.3*	15.9*	15.7*					
19 K	3608.4*	378.6*	297.3*	294.6*	34.8*	18.3*	18.3*					
20 Ca	4038.5*	438.4†	349.7†	346.2†	44.3 †	25.4†	25.4†					
21 Sc	4492	498.0*	403.6*	398.7*	51.1*	28.3*	28.3*					
22 Ti	4966	560.9†	460.2†	453.8†	58.7†	32.6†	32.6†					

23 V	5465	626.7†	519.8†	512.1†	66.3†	37.2†	37.2†					
24 Cr	5989	696.0†	583.8†	574.1†	74.1†	42.2†	42.2†					
25 Mn	6539	769.1†	649.9†	638.7†	82.3†	47.2†	47.2†					
26 Fe	7112	844.6†	719.9†	706.8†	91.3†	52.7†	52.7†					
27 Co	7709	925.1†	793.2†	778.1†	101.0†	58.9†	59.9†					
28 Ni	8333	1008.6†	870.0†	852.7†	110.8†	68.0†	66.2†					
29 Cu	8979	1096.7†	952.3†	932.7	122.5†	77.3†	75.1†					
30 Zn	9659	1196.2*	1044.9*	1021.8*	139.8*	91.4*	88.6*	10.2*	10.1*			
31 Ga	10367	1299.0*b	1143.2†	1116.4†	159.5†	103.5†	100.0†	18.7†	18.7†			
32 Ge	11103	1414.6*b	1248.1*b	1217.0*b	180.1*	124.9*	120.8*	29.8	29.2			
33 As	11867	1527.0*b	1359.1*b	1323.6*b	204.7*	146.2*	141.2*	41.7*	41.7*			
34 Se	12658	1652.0*b	1474.3*b	1433.9*b	229.6*	166.5*	160.7*	55.5*	54.6*			
35 Br	13474	1782*	1596*	1550*	257*	189*	182*	70*	69*			
36 Kr	14326	1921	1730.9*	1678.4*	292.8*	222.2*	214.4	95.0*	93.8*	27.5*	14.1*	14.1*
37 Rb	15200	2065	1864	1804	326.7*	248.7*	239.1*	113.0*	112*	30.5*	16.3*	15.3 *
38 Sr	16105	2216	2007	1940	358.7†	280.3†	270.0†	136.0†	134.2†	38.9†	21.3	20.1†
39 Y	17038	2373	2156	2080	392.0*b	310.6*	298.8*	157.7†	155.8†	43.8*	24.4*	23.1*
40 Zr	17998	2532	2307	2223	430.3†	343.5†	329.8†	181.1†	178.8†	50.6†	28.5†	27.1†
41 Nb	18986	2698	2465	2371	466.6†	376.1†	360.6†	205.0†	202.3†	56.4†	32.6†	30.8†
42 Mo	20000	2866	2625	2520	506.3†	411.6†	394.0†	231.1†	227.9†	63.2†	37.6†	35.5†
43 Tc	21044	3043	2793	2677	544*	447.6	417.7	257.6	253.9*	69.5*	42.3*	39.9*
44 Ru	22117	3224	2967	2838	586.1*	483.5†	461.4†	284.2†	280.0†	75.0†	46.3†	43.2†
45 Rh	23220	3412	3146	3004	628.1†	521.3†	496.5†	311.9†	307.2†	81.4*b	50.5†	47.3†
46 Pd	24350	3604	3330	3173	671.6†	559.9†	532.3†	340.5†	335.2†	87.1*b	55.7†a	50.9†
47 Ag	25514	3806	3524	3351	719.0†	603.8†	573.0†	374.0†	368.3	97.0†	63.7†	58.3†

Table 1-1. Electron binding energies (continued).

Element	K 1s	L_1 2s	L_2 $2p_{1/2}$	L_3 $2p_{3/2}$	M_1 3s	M_2 $3p_{1/2}$	M_3 $3p_{3/2}$	M_4 $3d_{3/2}$	M_5 $3d_{5/2}$	N_1 4s	N_2 $4p_{1/2}$	N_3 $4p_{3/2}$
48 Cd	26711	4018	3727	3538	772.0†	652.6†	618.4†	411.9†	405.2†	109.8†	63.9†a	63.9†a
49 In	27940	4238	3938	3730	827.2†	703.2†	665.3†	451.4†	443.9†	122.9†	73.5†a	73.5†a
50 Sn	29200	4465	4156	3929	884.7†	756.5†	714.6†	493.2†	484.9†	137.1†	83.6†a	83.6†a
51 Sb	30491	4698	4380	4132	946†	812.7†	766.4†	537.5†	528.2†	153.2†	95.6†a	95.6†a
52 Te	31814	4939	4612	4341	1006†	870.8†	820.0†	583.4†	573.0†	169.4†	103.3†a	103.3†a
53 I	33169	5188	4852	4557	1072*	931*	875*	630.8	619.3	186*	123*	123*
54 Xe	34561	5453	5107	4786	1148.7*	1002.1*	940.6*	689.0*	676.4*	213.2*	146.7	145.5*
55 Cs	35985	5714	5359	5012	1211*b	1071*	1003*	740.5*	726.6*	232.3*	172.4*	161.3*
56 Ba	37441	5989	5624	5247	1293*b	1137*b	1063*b	795.7†	780.5*	253.5†	192	178.6†
57 La	38925	6266	5891	5483	1362*b	1209*b	1128*b	853*	836*	274.7*	205.8	196.0*
58 Ce	40443	6549	6164	5723	1436*b	1274*b	1187*b	902.4*	883.8*	291.0*	223.2	206.5*
59 Pr	41991	6835	6440	5964	1511	1337	1242	948.3*	928.8*	304.5	236.3	217.6
60 Nd	43569	7126	6722	6208	1575	1403	1297	1003.3*	980.4*	319.2*	243.3	224.6
61 Pm	45184	7428	7013	6459	—	1471	1357	1052	1027	—	242	242
62 Sm	46834	7737	7312	6716	1723	1541	1420	1110.9*	1083.4*	347.2*	265.6	247.4
63 Eu	48519	8052	7617	6977	1800	1614	1481	1158.6*	1127.5*	360	284	257
64 Gd	50239	8376	7930	7243	1881	1688	1544	1221.9*	1189.6*	378.6*	286	271
65 Tb	51996	8708	8252	7514	1968	1768	1611	1276.9*	1241.1*	396.0*	322.4*	284.1*
66 Dy	53789	9046	8581	7790	2047	1842	1676	1333	1292.6*	414.2*	333.5*	293.2*
67 Ho	55618	9394	8918	8071	2128	1923	1741	1392	1351	432.4*	343.5	308.2*
68 Er	57486	9751	9264	8358	2207	2006	1812	1453	1409	449.8*	366.2	320.2*
69 Tm	59390	10116	9617	8648	2307	2090	1885	1515	1468	470.9*	385.9*	332.6*
70 Yb	61332	10486	9978	8944	2398	2173	1950	1576	1528	480.5*	388.7*	339.7*

Table 1-1. Electron binding energies (continued).

Element	N_4 $4d_{3/2}$	N_5 $4d_{5/2}$	N_6 $4f_{5/2}$	N_7 $4f_{7/2}$	O_1 5s	O_2 $5p_{1/2}$	O_3 $5p_{3/2}$	O_4 $5d_{3/2}$	O_5 $5d_{5/2}$	P_1 6s	P_2 $6p_{1/2}$	P_3 $6p_{3/2}$
48 Cd	11.7†	10.7†										
49 In	17.7†	16.9†										
50 Sn	24.9†	23.9†										
51 Sb	33.3†	32.1†										
52 Te	41.9†	40.4†										
53 I	50.6	48.9										
54 Xe	69.5*	67.5*	—	—	23.3*	13.4*	12.1*					
55 Cs	79.8*	77.5*	—	—	22.7	14.2*	12.1*					
56 Ba	92.6†	89.9†	—	—	30.3†	17.0†	14.8†					
57 La	105.3*	102.5*	—	—	34.3*	19.3*	16.8*					
58 Ce	109*	—	0.1	0.1	37.8	19.8*	17.0*					
59 Pr	115.1*	115.1*	2.0	2.0	37.4	22.3	22.3					
60 Nd	120.5*	120.5*	1.5	1.5	37.5	21.1	21.1					
61 Pm	120	120	—	—	—	—	—					
62 Sm	129	129	5.2	5.2	37.4	21.3	21.3					
63 Eu	133	127.7*	0	0	32	22	22					
64 Gd	—	142.6*	8.6*	8.6*	36	28	21					
65 Tb	150.5*	150.5*	7.7*	2.4*	45.6*	28.7*	22.6*					
66 Dy	153.6*	153.6*	8.0*	4.3*	49.9*	26.3	26.3					
67 Ho	160*	160*	8.6*	5.2*	49.3*	30.8*	24.1*					
68 Er	167.6*	167.6*	—	4.7*	50.6*	31.4*	24.7*					
69 Tm	175.5*	175.5*	—	4.6	54.7*	31.8*	25.0*					
70 Yb	191.2*	182.4*	2.5*	1.3*	52.0*	30.3*	24.1*					

Table 1-1. Electron binding energies (continued).

Element	K 1s	L_1 2s	L_2 $2p_{1/2}$	L_3 $2p_{3/2}$	M_1 3s	M_2 $3p_{1/2}$	M_3 $3p_{3/2}$	M_4 $3d_{3/2}$	M_5 $3d_{5/2}$	N_1 4s	N_2 $4p_{1/2}$	N_3 $4p_{3/2}$
71 Lu	63314	10870	10349	9244	2491	2264	2024	1639	1589	506.8*	412.4*	359.2*
72 Hf	65351	11271	10739	9561	2601	2365	2108	1716	1662	538*	438.2†	380.7†
73 Ta	67416	11682	11136	9881	2708	2469	2194	1793	1735	563.4†	463.4†	400.9†
74 W	69525	12100	11544	10207	2820	2575	2281	1872	1809	594.1†	490.4†	423.6†
75 Re	71676	12527	11959	10535	2932	2682	2367	1949	1883	625.4†	518.7†	446.8†
76 Os	73871	12968	12385	10871	3049	2792	2457	2031	1960	658.2†	549.1†	470.7†
77 Ir	76111	13419	12824	11215	3174	2909	2551	2116	2040	691.1†	577.8†	495.8†
78 Pt	78395	13880	13273	11564	3296	3027	2645	2202	2122	725.4†	609.1†	519.4†
79 Au	80725	14353	13734	11919	3425	3148	2743	2291	2206	762.1†	642.7†	546.3†
80 Hg	83102	14839	14209	12284	3562	3279	2847	2385	2295	802.2†	680.2†	576.6†
81 Tl	85530	15347	14698	12658	3704	3416	2957	2485	2389	846.2†	720.5†	609.5†
82 Pb	88005	15861	15200	13035	3851	3554	3066	2586	2484	891.8†	761.9†	643.5†
83 Bi	90524	16388	15711	13419	3999	3696	3177	2688	2580	939†	805.2†	678.8†
84 Po	93105	16939	16244	13814	4149	3854	3302	2798	2683	995*	851*	705*
85 At	95730	17493	16785	14214	4317	4008	3426	2909	2787	1042*	886*	740*
86 Rn	98404	18049	17337	14619	4482	4159	3538	3022	2892	1097*	929*	768*
87 Fr	101137	18639	17907	15031	4652	4327	3663	3136	3000	1153*	980*	810*
88 Ra	103922	19237	18484	15444	4822	4490	3792	3248	3105	1208*	1058	879*
89 Ac	106755	19840	19083	15871	5002	4656	3909	3370	3219	1269*	1080*	890*
90 Th	109651	20472	19693	16300	5182	4830	4046	3491	3332	1330*	1168*	966.4†
91 Pa	112601	21105	20314	16733	5367	5001	4174	3611	3442	1387*	1224*	1007*
92 U	115606	21757	20948	17166	5548	5182	4303	3728	3552	1439*b	1271*b	1043†

Table 1-1. Electron binding energies (continued).

Element	N_4 $4d_{3/2}$	N_5 $4d_{5/2}$	N_6 $4f_{5/2}$	N_7 $4f_{7/2}$	O_1 5s	O_2 $5p_{1/2}$	O_3 $5p_{3/2}$	O_4 $5d_{3/2}$	O_5 $5d_{5/2}$	P_1 6s	P_2 $6p_{1/2}$	P_3 $6p_{3/2}$
71 Lu	206.1*	196.3*	8.9*	7.5*	57.3*	33.6*	26.7*					
72 Hf	220.0†	211.5†	15.9†	14.2†	64.2†	38*	29.9†					
73 Ta	237.9†	226.4†	23.5†	21.6†	69.7†	42.2*	32.7†					
74 W	255.9†	243.5†	33.6*	31.4†	75.6†	45.3*b	36.8†					
75 Re	273.9†	260.5†	42.9*	40.5*	83†	45.6*	34.6*b					
76 Os	293.1†	278.5†	53.4†	50.7†	84*	58*	44.5†					
77 Ir	311.9†	296.3†	63.8†	60.8†	95.2*b	63.0*b	48.0†					
78 Pt	331.6†	314.6†	74.5†	71.2†	101.7*b	65.3*b	51.7†					
79 Au	353.2†	335.1†	87.6†	84.0	107.2*b	74.2†	57.2†					
80 Hg	378.2†	358.8†	104.0†	99.9†	127†	83.1†	64.5†	9.6†	7.8†			
81 Tl	405.7†	385.0†	122.2†	117.8†	136.0*b	94.6†	73.5†	14.7†	12.5†			
82 Pb	434.3†	412.2†	141.7†	136.9†	147*b	106.4†	83.3†	20.7†	18.1†			
83 Bi	464.0†	440.1†	162.3†	157.0†	159.3*b	119.0†	92.6†	26.9†	23.8†			
84 Po	500*	473*	184*	184*	177*	132*	104*	31*	31*			
85 At	533*	507	210*	210*	195*	148*	115*	40*	40*			
86 Rn	567*	541*	238*	238*	214*	164*	127*	48*	48*	26		
87 Fr	603*	577*	268*	268*	234*	182*	140*	58*	58*	34	15	15
88 Ra	636*	603*	299*	299*	254*	200*	153*	68*	68*	44	19	19
89 Ac	675*	639*	319*	319*	272*	215*	167*	80*	80*	—	—	—
90 Th	712.1†	675.2†	342.4†	333.1†	290*a	229*a	182*a	92.5†	85.4†	41.4†	24.5†	16.6†
91 Pa	743*	708*	371*	360*	310*	232*	232*	94*	94*	—	—	—
92 U	778.3†	736.2†	388.2*	377.4†	321*ab	257*ab	192*ab	102.8†	94.2†	43.9†	26.8†	16.8†

1.2 X-RAY EMISSION ENERGIES

Jeffrey B. Kortright and Albert C. Thompson

In Table 1-2, characteristic K, L, and M x-ray line energies are given for elements with $3 \leq Z \leq 95$. Only the strongest lines are included: $K\alpha_1$, $K\alpha_2$, $K\beta_1$, $L\alpha_1$, $L\alpha_2$, $L\beta_1$, $L\beta_2$, $L\gamma_1$, and $M\alpha_1$. Wavelengths, in angstroms, can be obtained from the relation $\lambda = 12{,}398/E$, where E is in eV. The data in the table were based on Ref. 1, which should be consulted for a more complete listing. Widths of the $K\alpha$ lines can be found in Ref. 2.

Table 1-3 provides a listing of these, and additional, lines (arranged by increasing energy), together with relative intensities. An intensity of 100 is assigned to the strongest line in each shell for each element. Figure 1-1 illustrates the transitions that give rise to the lines in Table 1-3.

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Table 1-2. *Photon energies, in electron volts, of principal K-, L-, and M-shell emission lines.*

Element	$K\alpha_1$	$K\alpha_2$	$K\beta_1$	$L\alpha_1$	$L\alpha_2$	$L\beta_1$	$L\beta_2$	$L\gamma_1$	$M\alpha_1$
3 Li	54.3								
4 Be	108.5								
5 B	183.3								
6 C	277								
7 N	392.4								
8 O	524.9								
9 F	676.8								
10 Ne	848.6	848.6							
11 Na	1,040.98	1,040.98	1,071.1						
12 Mg	1,253.60	1,253.60	1,302.2						
13 Al	1,486.70	1,486.27	1,557.45						
14 Si	1,739.98	1,739.38	1,835.94						
15 P	2,013.7	2,012.7	2,139.1						
16 S	2,307.84	2,306.64	2,464.04						
17 Cl	2,622.39	2,620.78	2,815.6						
18 Ar	2,957.70	2,955.63	3,190.5						
19 K	3,313.8	3,311.1	3,589.6						
20 Ca	3,691.68	3,688.09	4,012.7	341.3	341.3	344.9			
21 Sc	4,090.6	4,086.1	4,460.5	395.4	395.4	399.6			

Table 1-2. Energies of x-ray emission lines (continued).

Element	$K\alpha_1$	$K\alpha_2$	$K\beta_1$	$L\alpha_1$	$L\alpha_2$	$L\beta_1$	$L\beta_2$	$L\gamma_1$	$M\alpha_1$
22 Ti	4,510.84	4,504.86	4,931.81	452.2	452.2	458.4			
23 V	4,952.20	4,944.64	5,427.29	511.3	511.3	519.2			
24 Cr	5,414.72	5,405.509	5,946.71	572.8	572.8	582.8			
25 Mn	5,898.75	5,887.65	6,490.45	637.4	637.4	648.8			
26 Fe	6,403.84	6,390.84	7,057.98	705.0	705.0	718.5			
27 Co	6,930.32	6,915.30	7,649.43	776.2	776.2	791.4			
28 Ni	7,478.15	7,460.89	8,264.66	851.5	851.5	868.8			
29 Cu	8,047.78	8,027.83	8,905.29	929.7	929.7	949.8			
30 Zn	8,638.86	8,615.78	9,572.0	1,011.7	1,011.7	1,034.7			
31 Ga	9,251.74	9,224.82	10,264.2	1,097.92	1,097.92	1,124.8			
32 Ge	9,886.42	9,855.32	10,982.1	1,188.00	1,188.00	1,218.5			
33 As	10,543.72	10,507.99	11,726.2	1,282.0	1,282.0	1,317.0			
34 Se	11,222.4	11,181.4	12,495.9	1,379.10	1,379.10	1,419.23			
35 Br	11,924.2	11,877.6	13,291.4	1,480.43	1,480.43	1,525.90			
36 Kr	12,649	12,598	14,112	1,586.0	1,586.0	1,636.6			
37 Rb	13,395.3	13,335.8	14,961.3	1,694.13	1,692.56	1,752.17			
38 Sr	14,165	14,097.9	15,835.7	1,806.56	1,804.74	1,871.72			
39 Y	14,958.4	14,882.9	16,737.8	1,922.56	1,920.47	1,995.84			
40 Zr	15,775.1	15,690.9	17,667.8	2,042.36	2,039.9	2,124.4[r]	2,219.4	2,302.7	

41	Nb	16,615.1	16,521.0	18,622.5	2,165.89	2,163.0	2,257.4	2,367.0	2,461.8	
42	Mo	17,479.34	17,374.3	19,608.3	2,293.16	2,289.85	2,394.81	2,518.3	2,623.5	
43	Tc	18,367.1	18,250.8	20,619	2,424	2,420	2,538	2,674	2,792	
44	Ru	19,279.2	19,150.4	21,656.8	2,558.55	2,554.31	2,683.23	2,836.0	2,964.5	
45	Rh	20,216.1	20,073.7	22,723.6	2,696.74	2,692.05	2,834.41	3,001.3	3,143.8	
46	Pd	21,177.1	21,020.1	23,818.7	2,838.61	2,833.29	2,990.22	3,171.79	3,328.7	
47	Ag	22,162.92	21,990.3	24,942.4	2,984.31	2,978.21	3,150.94	3,347.81	3,519.59	
48	Cd	23,173.6	22,984.1	26,095.5	3,133.73	3,126.91	3,316.57	3,528.12	3,716.86	
49	In	24,209.7	24,002.0	27,275.9	3,286.94	3,279.29	3,487.21	3,713.81	3,920.81	
50	Sn	25,271.3	25,044.0	28,486.0	3,443.98	3,435.42	3,662.80	3,904.86	4,131.12	
51	Sb	26,359.1	26,110.8	29,725.6	3,604.72	3,595.32	3,843.57	4,100.78	4,347.79	
52	Te	27,472.3	27,201.7	30,995.7	3,769.33	3,758.8	4,029.58	4,301.7	4,570.9	
53	I	28,612.0	28,317.2	32,294.7	3,937.65	3,926.04	4,220.72	4,507.5	4,800.9	
54	Xe	29,779	29,458	33,624	4,109.9	—	—	—	—	
55	Cs	30,972.8	30,625.1	34,986.9	4,286.5	4,272.2	4,619.8	4,935.9	5,280.4	
56	Ba	32,193.6	31,817.1	36,378.2	4,466.26	4,450.90	4,827.53	5,156.5	5,531.1	
57	La	33,441.8	33,034.1	37,801.0	4,650.97	4,634.23	5,042.1	5,383.5	5,788.5	833
58	Ce	34,719.7	34,278.9	39,257.3	4,840.2	4,823.0	5,262.2	5,613.4	6,052	883
59	Pr	36,026.3	35,550.2	40,748.2	5,033.7	5,013.5	5,488.9	5,850	6,322.1	929
60	Nd	37,361.0	36,847.4	42,271.3	5,230.4	5,207.7	5,721.6	6,089.4	6,602.1	978
61	Pm	38,724.7	38,171.2	43,826	5,432.5	5,407.8	5,961	6,339	6,892	—
62	Sm	40,118.1	39,522.4	45,413	5,636.1	5,609.0	6,205.1	6,586	7,178	1,081

Table 1-2. Energies of x-ray emission lines (continued).

Element	$K\alpha_1$	$K\alpha_2$	$K\beta_1$	$L\alpha_1$	$L\alpha_2$	$L\beta_1$	$L\beta_2$	$L\gamma_1$	$M\alpha_1$
63 Eu	41,542.2	40,901.9	47,037.9	5,845.7	5,816.6	6,456.4	6,843.2	7,480.3	1,131
64 Gd	42,996.2	42,308.9	48,697	6,057.2	6,025.0	6,713.2	7,102.8	7,785.8	1,185
65 Tb	44,481.6	43,744.1	50,382	6,272.8	6,238.0	6,978	7,366.7	8,102	1,240
66 Dy	45,998.4	45,207.8	52,119	6,495.2	6,457.7	7,247.7	7,635.7	8,418.8	1,293
67 Ho	47,546.7	46,699.7	53,877	6,719.8	6,679.5	7,525.3	7,911	8,747	1,348
68 Er	49,127.7	48,221.1	55,681	6,948.7	6,905.0	7,810.9	8,189.0	9,089	1,406
69 Tm	50,741.6	49,772.6	57,517	7,179.9	7,133.1	8,101	8,468	9,426	1,462
70 Yb	52,388.9	51,354.0	59,370	7,415.6	7,367.3	8,401.8	8,758.8	9,780.1	1,521.4
71 Lu	54,069.8	52,965.0	61,283	7,655.5	7,604.9	8,709.0	9,048.9	10,143.4	1,581.3
72 Hf	55,790.2	54,611.4	63,234	7,899.0	7,844.6	9,022.7	9,347.3	10,515.8	1,644.6
73 Ta	57,532	56,277	65,223	8,146.1	8,087.9	9,343.1	9,651.8	10,895.2	1,710
74 W	59,318.24	57,981.7	67,244.3	8,397.6	8,335.2	9,672.35	9,961.5	11,285.9	1,775.4
75 Re	61,140.3	59,717.9	69,310	8,652.5	8,586.2	10,010.0	10,275.2	11,685.4	1,842.5
76 Os	63,000.5	61,486.7	71,413	8,911.7	8,841.0	10,355.3	10,598.5	12,095.3	1,910.2
77 Ir	64,895.6	63,286.7	73,560.8	9,175.1	9,099.5	10,708.3	10,920.3	12,512.6	1,979.9
78 Pt	66,832	65,112	75,748	9,442.3	9,361.8	11,070.7	11,250.5	12,942.0	2,050.5
79 Au	68,803.7	66,989.5	77,984	9,713.3	9,628.0	11,442.3	11,584.7	13,381.7	2,122.9
80 Hg	70,819	68,895	80,253	9,988.8	9,897.6	11,822.6	11,924.1	13,830.1	2,195.3
81 Tl	72,871.5	70,831.9	82,576	10,268.5	10,172.8	12,213.3	12,271.5	14,291.5	2,270.6

82 Pb	74,969.4	72,804.2	84,936	10,551.5	10,449.5	12,613.7	12,622.6	14,764.4	2,345.5
83 Bi	77,107.9	74,814.8	87,343	10,838.8	10,730.91	13,023.5	12,979.9	15,247.7	2,422.6
84 Po	79,290	76,862	89,800	11,130.8	11,015.8	13,447	13,340.4	15,744	—
85 At	81,520	78,950	92,300	11,426.8	11,304.8	13,876	—	16,251	—
86 Rn	83,780	81,070	94,870	11,727.0	11,597.9	14,316	—	16,770	—
87 Fr	86,100	83,230	97,470	12,031.3	11,895.0	14,770	14,450	17,303	—
88 Ra	88,470	85,430	100,130	12,339.7	12,196.2	15,235.8	14,841.4	17,849	—
89 Ac	90,884	87,670	102,850	12,652.0	12,500.8	15,713	—	18,408	—
90 Th	93,350	89,953	105,609	12,968.7	12,809.6	16,202.2	15,623.7	18,982.5	2,996.1
91 Pa	95,868	92,287	108,427	13,290.7	13,122.2	16,702	16,024	19,568	3,082.3
92 U	98,439	94,665	111,300	13,614.7	13,438.8	17,220.0	16,428.3	20,167.1	3,170.8
93 Np	—	—	—	13,944.1	13,759.7	17,750.2	16,840.0	20,784.8	—
94 Pu	—	—	—	14,278.6	14,084.2	18,293.7	17,255.3	21,417.3	—
95 Am	—	—	—	14,617.2	14,411.9	18,852.0	17,676.5	22,065.2	—

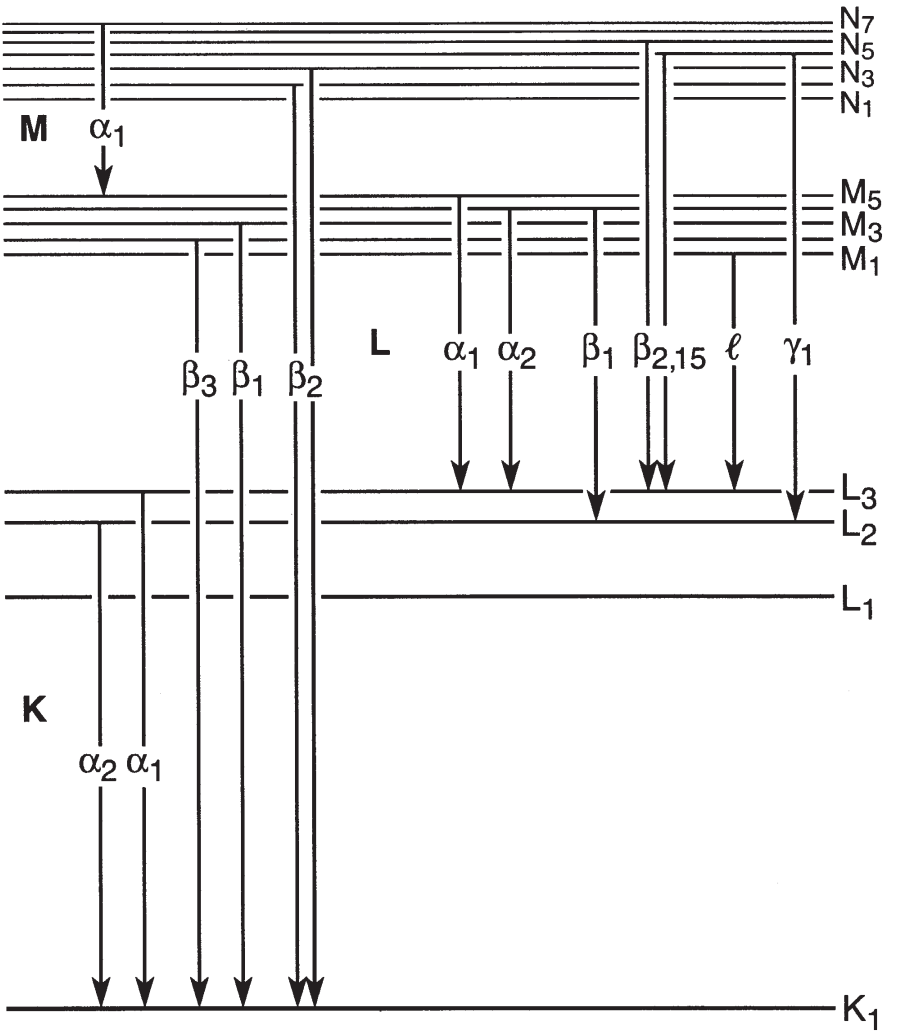


Fig. 1-1. *Transitions that give rise to the emission lines in Table 1-3.*

Table 1-3. *Photon energies and relative intensities of K-, L-, and M-shell lines shown in Fig. 1-1, arranged by increasing energy. An intensity of 100 is assigned to the strongest line in each shell for each element.*

Energy (eV)	Element	Line	Relative intensity
54.3	3 Li	$K\alpha_{1,2}$	150
108.5	4 Be	$K\alpha_{1,2}$	150
183.3	5 B	$K\alpha_{1,2}$	151
277	6 C	$K\alpha_{1,2}$	147
348.3	21 Sc	Ll	21
392.4	7 N	$K\alpha_{1,2}$	150
395.3	22 Ti	Ll	46
395.4	21 Sc	$L\alpha_{1,2}$	111
399.6	21 Sc	$L\beta_1$	77
446.5	23 V	Ll	28
452.2	22 Ti	$L\alpha_{1,2}$	111
458.4	22 Ti	$L\beta_1$	79
500.3	24 Cr	Ll	17
511.3	23 V	$L\alpha_{1,2}$	111
519.2	23 V	$L\beta_1$	80
524.9	8 O	$K\alpha_{1,2}$	151
556.3	25 Mn	Ll	15
572.8	24 Cr	$L\alpha_{1,2}$	111
582.8	24 Cr	$L\beta_1$	79
615.2	26 Fe	Ll	10
637.4	25 Mn	$L\alpha_{1,2}$	111
648.8	25 Mn	$L\beta_1$	77
676.8	9 F	$K\alpha_{1,2}$	148
677.8	27 Co	Ll	10
705.0	26 Fe	$L\alpha_{1,2}$	111
718.5	26 Fe	$L\beta_1$	66
742.7	28 Ni	Ll	9
776.2	27 Co	$L\alpha_{1,2}$	111
791.4	27 Co	$L\beta_1$	76
811.1	29 Cu	Ll	8
833	57 La	$M\alpha_1$	100
848.6	10 Ne	$K\alpha_{1,2}$	150
851.5	28 Ni	$L\alpha_{1,2}$	111
868.8	28 Ni	$L\beta_1$	68
883	58 Ce	$M\alpha_1$	100
884	30 Zn	Ll	7
929.2	59 Pr	$M\alpha_1$	100
929.7	29 Cu	$L\alpha_{1,2}$	111
949.8	29 Cu	$L\beta_1$	65
957.2	31 Ga	Ll	7
978	60 Nd	$M\alpha_1$	100
1,011.7	30 Zn	$L\alpha_{1,2}$	111
1,034.7	30 Zn	$L\beta_1$	65
1,036.2	32 Ge	Ll	6
1,041.0	11 Na	$K\alpha_{1,2}$	150
1,081	62 Sm	$M\alpha_1$	100
1,097.9	31 Ga	$L\alpha_{1,2}$	111
1,120	33 As	Ll	6
1,124.8	31 Ga	$L\beta_1$	66

Table 1-3. Energies and intensities of x-ray emission lines (continued).

Energy (eV)	Element	Line	Relative intensity
1,131	63 Eu	$M\alpha_1$	100
1,185	64 Gd	$M\alpha_1$	100
1,188.0	32 Ge	$L\alpha_{1,2}$	111
1,204.4	34 Se	Ll	6
1,218.5	32 Ge	$L\beta_1$	60
1,240	65 Tb	$M\alpha_1$	100
1,253.6	12 Mg	$K\alpha_{1,2}$	150
1,282.0	33 As	$L\alpha_{1,2}$	111
1,293	66 Dy	$M\alpha_1$	100
1,293.5	35 Br	Ll	5
1,317.0	33 As	$L\beta_1$	60
1,348	67 Ho	$M\alpha_1$	100
1,379.1	34 Se	$L\alpha_{1,2}$	111
1,386	36 Kr	Ll	5
1,406	68 Er	$M\alpha_1$	100
1,419.2	34 Se	$L\beta_1$	59
1,462	69 Tm	$M\alpha_1$	100
1,480.4	35 Br	$L\alpha_{1,2}$	111
1,482.4	37 Rb	Ll	5
1,486.3	13 Al	$K\alpha_2$	50
1,486.7	13 Al	$K\alpha_1$	100
1,521.4	70 Yb	$M\alpha_1$	100
1,525.9	35 Br	$L\beta_1$	59
1,557.4	13 Al	$K\beta_1$	1
1,581.3	71 Lu	$M\alpha_1$	100
1,582.2	38 Sr	Ll	5
1,586.0	36 Kr	$L\alpha_{1,2}$	111
1,636.6	36 Kr	$L\beta_1$	57
1,644.6	72 Hf	$M\alpha_1$	100
1,685.4	39 Y	Ll	5
1,692.6	37 Rb	$L\alpha_2$	11
1,694.1	37 Rb	$L\alpha_1$	100
1,709.6	73 Ta	$M\alpha_1$	100
1,739.4	14 Si	$K\alpha_2$	50
1,740.0	14 Si	$K\alpha_1$	100
1,752.2	37 Rb	$L\beta_1$	58
1,775.4	74 W	$M\alpha_1$	100
1,792.0	40 Zr	Ll	5
1,804.7	38 Sr	$L\alpha_2$	11
1,806.6	38 Sr	$L\alpha_1$	100
1,835.9	14 Si	$K\beta_1$	2
1,842.5	75 Re	$M\alpha_1$	100
1,871.7	38 Sr	$L\beta_1$	58
1,902.2	41 Nb	Ll	5
1,910.2	76 Os	$M\alpha_1$	100
1,920.5	39 Y	$L\alpha_2$	11
1,922.6	39 Y	$L\alpha_1$	100
1,979.9	77 Ir	$M\alpha_1$	100
1,995.8	39 Y	$L\beta_1$	57
2,012.7	15 P	$K\alpha_2$	50
2,013.7	15 P	$K\alpha_1$	100
2,015.7	42 Mo	Ll	5

2,039.9	40 Zr	$L\alpha_2$	11
2,042.4	40 Zr	$L\alpha_1$	100
2,050.5	78 Pt	$M\alpha_1$	100
2,122	43 Tc	Ll	5
2,122.9	79 Au	$M\alpha_1$	100
2,124.4	40 Zr	$L\beta_1$	54
2,139.1	15 P	$K\beta_1$	3
2,163.0	41 Nb	$L\alpha_2$	11
2,165.9	41 Nb	$L\alpha_1$	100
2,195.3	80 Hg	$M\alpha_1$	100
2,219.4	40 Zr	$L\beta_{2,15}$	1
2,252.8	44 Ru	Ll	4
2,257.4	41 Nb	$L\beta_1$	52
2,270.6	81 Tl	$M\alpha_1$	100
2,289.8	42 Mo	$L\alpha_2$	11
2,293.2	42 Mo	$L\alpha_1$	100
2,302.7	40 Zr	$L\gamma_1$	2
2,306.6	16 S	$K\alpha_2$	50
2,307.8	16 S	$K\alpha_1$	100
2,345.5	82 Pb	$M\alpha_1$	100
2,367.0	41 Nb	$L\beta_{2,15}$	3
2,376.5	45 Rh	Ll	4
2,394.8	42 Mo	$L\beta_1$	53
2,420	43 Tc	$L\alpha_2$	11
2,422.6	83 Bi	$M\alpha_1$	100
2,424	43 Tc	$L\alpha_1$	100
2,461.8	41 Nb	$L\gamma_1$	2
2,464.0	16 S	$K\beta_1$	5
2,503.4	46 Pd	Ll	4
2,518.3	42 Mo	$L\beta_{2,15}$	5
2,538	43 Tc	$L\beta_1$	54
2,554.3	44 Ru	$L\alpha_2$	11
2,558.6	44 Ru	$L\alpha_1$	100
2,620.8	17 Cl	$K\alpha_2$	50
2,622.4	17 Cl	$K\alpha_1$	100
2,623.5	42 Mo	$L\gamma_1$	3
2,633.7	47 Ag	Ll	4
2,674	43 Tc	$L\beta_{2,15}$	7
2,683.2	44 Ru	$L\beta_1$	54
2,692.0	45 Rh	$L\alpha_2$	11
2,696.7	45 Rh	$L\alpha_1$	100
2,767.4	48 Cd	Ll	4
2,792	43 Tc	$L\gamma_1$	3
2,815.6	17 Cl	$K\beta_1$	6
2,833.3	46 Pd	$L\alpha_2$	11
2,834.4	45 Rh	$L\beta_1$	52
2,836.0	44 Ru	$L\beta_{2,15}$	10
2,838.6	46 Pd	$L\alpha_1$	100
2,904.4	49 In	Ll	4
2,955.6	18 Ar	$K\alpha_2$	50
2,957.7	18 Ar	$K\alpha_1$	100
2,964.5	44 Ru	$L\gamma_1$	4
2,978.2	47 Ag	$L\alpha_2$	11
2,984.3	47 Ag	$L\alpha_1$	100
2,990.2	46 Pd	$L\beta_1$	53
2,996.1	90 Th	$M\alpha_1$	100
3,001.3	45 Rh	$L\beta_{2,15}$	10
3,045.0	50 Sn	Ll	4
3,126.9	48 Cd	$L\alpha_2$	11
3,133.7	48 Cd	$L\alpha_1$	100

Table 1-3. Energies and intensities of x-ray emission lines (continued).

Energy (eV)	Element	Line	Relative intensity
3,143.8	45 Rh	$L\gamma_1$	5
3,150.9	47 Ag	$L\beta_1$	56
3,170.8	92 U	$M\alpha_1$	100
3,171.8	46 Pd	$L\beta_{2,15}$	12
3,188.6	51 Sb	Ll	4
3,190.5	18 Ar	$K\beta_{1,3}$	10
3,279.3	49 In	$L\alpha_2$	11
3,286.9	49 In	$L\alpha_1$	100
3,311.1	19 K	$K\alpha_2$	50
3,313.8	19 K	$K\alpha_1$	100
3,316.6	48 Cd	$L\beta_1$	58
3,328.7	46 Pd	$L\gamma_1$	6
3,335.6	52 Te	Ll	4
3,347.8	47 Ag	$L\beta_{2,15}$	13
3,435.4	50 Sn	$L\alpha_2$	11
3,444.0	50 Sn	$L\alpha_1$	100
3,485.0	53 I	Ll	4
3,487.2	49 In	$L\beta_1$	58
3,519.6	47 Ag	$L\gamma_1$	6
3,528.1	48 Cd	$L\beta_{2,15}$	15
3,589.6	19 K	$K\beta_{1,3}$	11
3,595.3	51 Sb	$L\alpha_2$	11
3,604.7	51 Sb	$L\alpha_1$	100
3,636	54 Xe	Ll	4
3,662.8	50 Sn	$L\beta_1$	60
3,688.1	20 Ca	$K\alpha_2$	50
3,691.7	20 Ca	$K\alpha_1$	100
3,713.8	49 In	$L\beta_{2,15}$	15
3,716.9	48 Cd	$L\gamma_1$	6
3,758.8	52 Te	$L\alpha_2$	11
3,769.3	52 Te	$L\alpha_1$	100
3,795.0	55 Cs	Ll	4
3,843.6	51 Sb	$L\beta_1$	61
3,904.9	50 Sn	$L\beta_{2,15}$	16
3,920.8	49 In	$L\gamma_1$	6
3,926.0	53 I	$L\alpha_2$	11
3,937.6	53 I	$L\alpha_1$	100
3,954.1	56 Ba	Ll	4
4,012.7	20 Ca	$K\beta_{1,3}$	13
4,029.6	52 Te	$L\beta_1$	61
4,086.1	21 Sc	$K\alpha_2$	50
4,090.6	21 Sc	$K\alpha_1$	100
4,093	54 Xe	$L\alpha_2$	11
4,100.8	51 Sb	$L\beta_{2,15}$	17
4,109.9	54 Xe	$L\alpha_1$	100
4,124	57 La	Ll	4
4,131.1	50 Sn	$L\gamma_1$	7
4,220.7	53 I	$L\beta_1$	61
4,272.2	55 Cs	$L\alpha_2$	11
4,286.5	55 Cs	$L\alpha_1$	100
4,287.5	58 Ce	Ll	4
4,301.7	52 Te	$L\beta_{2,15}$	18
4,347.8	51 Sb	$L\gamma_1$	8
4,414	54 Xe	$L\beta_1$	60
4,450.9	56 Ba	$L\alpha_2$	11

4,453.2	59 Pr	Ll	4
4,460.5	21 Sc	$K\beta_{1,3}$	15
4,466.3	56 Ba	$L\alpha_1$	100
4,504.9	22 Ti	$K\alpha_2$	50
4,507.5	53 I	$L\beta_{2,15}$	19
4,510.8	22 Ti	$K\alpha_1$	100
4,570.9	52 Te	$L\gamma_1$	8
4,619.8	55 Cs	$L\beta_1$	61
4,633.0	60 Nd	Ll	4
4,634.2	57 La	$L\alpha_2$	11
4,651.0	57 La	$L\alpha_1$	100
4,714	54 Xe	$L\beta_{2,15}$	20
4,800.9	53 I	$L\gamma_1$	8
4,809	61 Pm	Ll	4
4,823.0	58 Ce	$L\alpha_2$	11
4,827.5	56 Ba	$L\beta_1$	60
4,840.2	58 Ce	$L\alpha_1$	100
4,931.8	22 Ti	$K\beta_{1,3}$	15
4,935.9	55 Cs	$L\beta_{2,15}$	20
4,944.6	23 V	$K\alpha_2$	50
4,952.2	23 V	$K\alpha_1$	100
4,994.5	62 Sm	Ll	4
5,013.5	59 Pr	$L\alpha_2$	11
5,033.7	59 Pr	$L\alpha_1$	100
5,034	54 Xe	$L\gamma_1$	8
5,042.1	57 La	$L\beta_1$	60
5,156.5	56 Ba	$L\beta_{2,15}$	20
5,177.2	63 Eu	Ll	4
5,207.7	60 Nd	$L\alpha_2$	11
5,230.4	60 Nd	$L\alpha_1$	100
5,262.2	58 Ce	$L\beta_1$	61
5,280.4	55 Cs	$L\gamma_1$	8
5,362.1	64 Gd	Ll	4
5,383.5	57 La	$L\beta_{2,15}$	21
5,405.5	24 Cr	$K\alpha_2$	50
5,408	61 Pm	$L\alpha_2$	11
5,414.7	24 Cr	$K\alpha_1$	100
5,427.3	23 V	$K\beta_{1,3}$	15
5,432	61 Pm	$L\alpha_1$	100
5,488.9	59 Pr	$L\beta_1$	61
5,531.1	56 Ba	$L\gamma_1$	9
5,546.7	65 Tb	Ll	4
5,609.0	62 Sm	$L\alpha_2$	11
5,613.4	58 Ce	$L\beta_{2,15}$	21
5,636.1	62 Sm	$L\alpha_1$	100
5,721.6	60 Nd	$L\beta_1$	60
5,743.1	66 Dy	Ll	4
5,788.5	57 La	$L\gamma_1$	9
5,816.6	63 Eu	$L\alpha_2$	11
5,845.7	63 Eu	$L\alpha_1$	100
5,850	59 Pr	$L\beta_{2,15}$	21
5,887.6	25 Mn	$K\alpha_2$	50
5,898.8	25 Mn	$K\alpha_1$	100
5,943.4	67 Ho	Ll	4
5,946.7	24 Cr	$K\beta_{1,3}$	15
5,961	61 Pm	$L\beta_1$	61
6,025.0	64 Gd	$L\alpha_2$	11
6,052	58 Ce	$L\gamma_1$	9
6,057.2	64 Gd	$L\alpha_1$	100
6,089.4	60 Nd	$L\beta_{2,15}$	21

Table 1-3. Energies and intensities of x-ray emission lines (continued).

Energy (eV)	Element	Line	Relative intensity
6,152	68 Er	Ll	4
6,205.1	62 Sm	$L\beta_1$	61
6,238.0	65 Tb	$L\alpha_2$	11
6,272.8	65 Tb	$L\alpha_1$	100
6,322.1	59 Pr	$L\gamma_1$	9
6,339	61 Pm	$L\beta_2$	21
6,341.9	69 Tm	Ll	4
6,390.8	26 Fe	$K\alpha_2$	50
6,403.8	26 Fe	$K\alpha_1$	100
6,456.4	63 Eu	$L\beta_1$	62
6,457.7	66 Dy	$L\alpha_2$	11
6,490.4	25 Mn	$K\beta_{1,3}$	17
6,495.2	66 Dy	$L\alpha_1$	100
6,545.5	70 Yb	Ll	4
6,587.0	62 Sm	$L\beta_{2,15}$	21
6,602.1	60 Nd	$L\gamma_1$	10
6,679.5	67 Ho	$L\alpha_2$	11
6,713.2	64 Gd	$L\beta_1$	62
6,719.8	67 Ho	$L\alpha_1$	100
6,752.8	71 Lu	Ll	4
6,843.2	63 Eu	$L\beta_{2,15}$	21
6,892	61 Pm	$L\gamma_1$	10
6,905.0	68 Er	$L\alpha_2$	11
6,915.3	27 Co	$K\alpha_2$	51
6,930.3	27 Co	$K\alpha_1$	100
6,948.7	68 Er	$L\alpha_1$	100
6,959.6	72 Hf	Ll	5
6,978	65 Tb	$L\beta_1$	61
7,058.0	26 Fe	$K\beta_{1,3}$	17
7,102.8	64 Gd	$L\beta_{2,15}$	21
7,133.1	69 Tm	$L\alpha_2$	11
7,173.1	73 Ta	Ll	5
7,178.0	62 Sm	$L\gamma_1$	10
7,179.9	69 Tm	$L\alpha_1$	100
7,247.7	66 Dy	$L\beta_1$	62
7,366.7	65 Tb	$L\beta_{2,15}$	21
7,367.3	70 Yb	$L\alpha_2$	11
7,387.8	74 W	Ll	5
7,415.6	70 Yb	$L\alpha_1$	100
7,460.9	28 Ni	$K\alpha_2$	51
7,478.2	28 Ni	$K\alpha_1$	100
7,480.3	63 Eu	$L\gamma_1$	10
7,525.3	67 Ho	$L\beta_1$	64
7,603.6	75 Re	Ll	5
7,604.9	71 Lu	$L\alpha_2$	11
7,635.7	66 Dy	$L\beta_2$	20
7,649.4	27 Co	$K\beta_{1,3}$	17
7,655.5	71 Lu	$L\alpha_1$	100
7,785.8	64 Gd	$L\gamma_1$	11
7,810.9	68 Er	$L\beta_1$	64
7,822.2	76 Os	Ll	5
7,844.6	72 Hf	$L\alpha_2$	11
7,899.0	72 Hf	$L\alpha_1$	100
7,911	67 Ho	$L\beta_{2,15}$	20
8,027.8	29 Cu	$K\alpha_2$	51

8,045.8	77 Ir	Ll	5
8,047.8	29 Cu	$K\alpha_1$	100
8,087.9	73 Ta	$L\alpha_2$	11
8,101	69 Tm	$L\beta_1$	64
8,102	65 Tb	$L\gamma_1$	11
8,146.1	73 Ta	$L\alpha_1$	100
8,189.0	68 Er	$L\beta_{2,15}$	20
8,264.7	28 Ni	$K\beta_{1,3}$	17
8,268	78 Pt	Ll	5
8,335.2	74 W	$L\alpha_2$	11
8,397.6	74 W	$L\alpha_1$	100
8,401.8	70 Yb	$L\beta_1$	65
8,418.8	66 Dy	$L\gamma_1$	11
8,468	69 Tm	$L\beta_{2,15}$	20
8,493.9	79 Au	Ll	5
8,586.2	75 Re	$L\alpha_2$	11
8,615.8	30 Zn	$K\alpha_2$	51
8,638.9	30 Zn	$K\alpha_1$	100
8,652.5	75 Re	$L\alpha_1$	100
8,709.0	71 Lu	$L\beta_1$	66

8,721.0	80 Hg	Ll	5
8,747	67 Ho	$L\gamma_1$	11
8,758.8	70 Yb	$L\beta_{2,15}$	20
8,841.0	76 Os	$L\alpha_2$	11
8,905.3	29 Cu	$K\beta_{1,3}$	17
8,911.7	76 Os	$L\alpha_1$	100
8,953.2	81 Tl	Ll	6
9,022.7	72 Hf	$L\beta_1$	67
9,048.9	71 Lu	$L\beta_2$	19
9,089	68 Er	$L\gamma_1$	11
9,099.5	77 Ir	$L\alpha_2$	11
9,175.1	77 Ir	$L\alpha_1$	100
9,184.5	82 Pb	Ll	6
9,224.8	31 Ga	$K\alpha_2$	51
9,251.7	31 Ga	$K\alpha_1$	100
9,343.1	73 Ta	$L\beta_1$	67
9,347.3	72 Hf	$L\beta_2$	20
9,361.8	78 Pt	$L\alpha_2$	11
9,420.4	83 Bi	Ll	6
9,426	69 Tm	$L\gamma_1$	12

9,442.3	78 Pt	$L\alpha_1$	100
9,572.0	30 Zn	$K\beta_{1,3}$	17
9,628.0	79 Au	$L\alpha_2$	11
9,651.8	73 Ta	$L\beta_2$	20
9,672.4	74 W	$L\beta_1$	67
9,713.3	79 Au	$L\alpha_1$	100
9,780.1	70 Yb	$L\gamma_1$	12
9,855.3	32 Ge	$K\alpha_2$	51
9,886.4	32 Ge	$K\alpha_1$	100
9,897.6	80 Hg	$L\alpha_2$	11
9,961.5	74 W	$L\beta_2$	21
9,988.8	80 Hg	$L\alpha_1$	100
10,010.0	75 Re	$L\beta_1$	66
10,143.4	71 Lu	$L\gamma_1$	12
10,172.8	81 Tl	$L\alpha_2$	11
10,260.3	31 Ga	$K\beta_3$	5
10,264.2	31 Ga	$K\beta_1$	66
10,268.5	81 Tl	$L\alpha_1$	100
10,275.2	75 Re	$L\beta_2$	22
10,355.3	76 Os	$L\beta_1$	67

Table 1-3. Energies and intensities of x-ray emission lines (continued).

Energy (eV)	Element	Line	Relative intensity
10,449.5	82 Pb	$L\alpha_2$	11
10,508.0	33 As	$K\alpha_2$	51
10,515.8	72 Hf	$L\gamma_1$	12
10,543.7	33 As	$K\alpha_1$	100
10,551.5	82 Pb	$L\alpha_1$	100
10,598.5	76 Os	$L\beta_2$	22
10,708.3	77 Ir	$L\beta_1$	66
10,730.9	83 Bi	$L\alpha_2$	11
10,838.8	83 Bi	$L\alpha_1$	100
10,895.2	73 Ta	$L\gamma_1$	12
10,920.3	77 Ir	$L\beta_2$	22
10,978.0	32 Ge	$K\beta_3$	6
10,982.1	32 Ge	$K\beta_1$	60
11,070.7	78 Pt	$L\beta_1$	67
11,118.6	90 Th	Ll	6
11,181.4	34 Se	$K\alpha_2$	52
11,222.4	34 Se	$K\alpha_1$	100
11,250.5	78 Pt	$L\beta_2$	23
11,285.9	74 W	$L\gamma_1$	13
11,442.3	79 Au	$L\beta_1$	67
11,584.7	79 Au	$L\beta_2$	23
11,618.3	92 U	Ll	7
11,685.4	75 Re	$L\gamma_1$	13
11,720.3	33 As	$K\beta_3$	6
11,726.2	33 As	$K\beta_1$	13
11,822.6	80 Hg	$L\beta_1$	67
11,864	33 As	$K\beta_2$	1
11,877.6	35 Br	$K\alpha_2$	52
11,924.1	80 Hg	$L\beta_2$	24
11,924.2	35 Br	$K\alpha_1$	100
12,095.3	76 Os	$L\gamma_1$	13
12,213.3	81 Tl	$L\beta_1$	67
12,271.5	81 Tl	$L\beta_2$	25
12,489.6	34 Se	$K\beta_3$	6
12,495.9	34 Se	$K\beta_1$	13
12,512.6	77 Ir	$L\gamma_1$	13
12,598	36 Kr	$K\alpha_2$	52
12,613.7	82 Pb	$L\beta_1$	66
12,622.6	82 Pb	$L\beta_2$	25
12,649	36 Kr	$K\alpha_1$	100
12,652	34 Se	$K\beta_2$	1
12,809.6	90 Th	$L\alpha_2$	11
12,942.0	78 Pt	$L\gamma_1$	13
12,968.7	90 Th	$L\alpha_1$	100
12,979.9	83 Bi	$L\beta_2$	25
13,023.5	83 Bi	$L\beta_1$	67
13,284.5	35 Br	$K\beta_3$	7
13,291.4	35 Br	$K\beta_1$	14
13,335.8	37 Rb	$K\alpha_2$	52
13,381.7	79 Au	$L\gamma_1$	13
13,395.3	37 Rb	$K\alpha_1$	100
13,438.8	92 U	$L\alpha_2$	11
13,469.5	35 Br	$K\beta_2$	1
13,614.7	92 U	$L\alpha_1$	100
13,830.1	80 Hg	$L\gamma_1$	14

14,097.9	38 Sr	$K\alpha_2$	52
14,104	36 Kr	$K\beta_3$	7
14,112	36 Kr	$K\beta_1$	14
14,165.0	38 Sr	$K\alpha_1$	100
14,291.5	81 Tl	$L\gamma_1$	14
14,315	36 Kr	$K\beta_2$	2
14,764.4	82 Pb	$L\gamma_1$	14
14,882.9	39 Y	$K\alpha_2$	52
14,951.7	37 Rb	$K\beta_3$	7
14,958.4	39 Y	$K\alpha_1$	100
14,961.3	37 Rb	$K\beta_1$	14
15,185	37 Rb	$K\beta_2$	2
15,247.7	83 Bi	$L\gamma_1$	14
15,623.7	90 Th	$L\beta_2$	26
15,690.9	40 Zr	$K\alpha_2$	52
15,775.1	40 Zr	$K\alpha_1$	100
15,824.9	38 Sr	$K\beta_3$	7
15,835.7	38 Sr	$K\beta_1$	14
16,084.6	38 Sr	$K\beta_2$	3

16,202.2	90 Th	$L\beta_1$	69
16,428.3	92 U	$L\beta_2$	26
16,521.0	41 Nb	$K\alpha_2$	52
16,615.1	41 Nb	$K\alpha_1$	100
16,725.8	39 Y	$K\beta_3$	8
16,737.8	39 Y	$K\beta_1$	15
17,015.4	39 Y	$K\beta_2$	3
17,220.0	92 U	$L\beta_1$	61
17,374.3	42 Mo	$K\alpha_2$	52
17,479.3	42 Mo	$K\alpha_1$	100
17,654	40 Zr	$K\beta_3$	8
17,667.8	40 Zr	$K\beta_1$	15
17,970	40 Zr	$K\beta_2$	3
18,250.8	43 Tc	$K\alpha_2$	53
18,367.1	43 Tc	$K\alpha_1$	100
18,606.3	41 Nb	$K\beta_3$	8
18,622.5	41 Nb	$K\beta_1$	15
18,953	41 Nb	$K\beta_2$	3
18,982.5	90 Th	$L\gamma_1$	16

19,150.4	44 Ru	$K\alpha_2$	53
19,279.2	44 Ru	$K\alpha_1$	100
19,590.3	42 Mo	$K\beta_3$	8
19,608.3	42 Mo	$K\beta_1$	15
19,965.2	42 Mo	$K\beta_2$	3
20,073.7	45 Rh	$K\alpha_2$	53
20,167.1	92 U	$L\gamma_1$	15
20,216.1	45 Rh	$K\alpha_1$	100
20,599	43 Tc	$K\beta_3$	8
20,619	43 Tc	$K\beta_1$	16
21,005	43 Tc	$K\beta_2$	4
21,020.1	46 Pd	$K\alpha_2$	53
21,177.1	46 Pd	$K\alpha_1$	100
21,634.6	44 Ru	$K\beta_3$	8
21,656.8	44 Ru	$K\beta_1$	16
21,990.3	47 Ag	$K\alpha_2$	53
22,074	44 Ru	$K\beta_2$	4
22,162.9	47 Ag	$K\alpha_1$	100
22,698.9	45 Rh	$K\beta_3$	8

Table 1-3. Energies and intensities of x-ray emission lines (continued).

Energy (eV)	Element	Line	Relative intensity
22,723.6	45 Rh	$K\beta_1$	16
22,984.1	48 Cd	$K\alpha_2$	53
23,172.8	45 Rh	$K\beta_2$	4
23,173.6	48 Cd	$K\alpha_1$	100
23,791.1	46 Pd	$K\beta_3$	8
23,818.7	46 Pd	$K\beta_1$	16
24,002.0	49 In	$K\alpha_2$	53
24,209.7	49 In	$K\alpha_1$	100
24,299.1	46 Pd	$K\beta_2$	4
24,911.5	47 Ag	$K\beta_3$	9
24,942.4	47 Ag	$K\beta_1$	16
25,044.0	50 Sn	$K\alpha_2$	53
25,271.3	50 Sn	$K\alpha_1$	100
25,456.4	47 Ag	$K\beta_2$	4
26,061.2	48 Cd	$K\beta_3$	9
26,095.5	48 Cd	$K\beta_1$	17
26,110.8	51 Sb	$K\alpha_2$	54
26,359.1	51 Sb	$K\alpha_1$	100
26,643.8	48 Cd	$K\beta_2$	4
27,201.7	52 Te	$K\alpha_2$	54
27,237.7	49 In	$K\beta_3$	9
27,275.9	49 In	$K\beta_1$	17
27,472.3	52 Te	$K\alpha_1$	100
27,860.8	49 In	$K\beta_2$	5
28,317.2	53 I	$K\alpha_2$	54
28,444.0	50 Sn	$K\beta_3$	9
28,486.0	50 Sn	$K\beta_1$	17
28,612.0	53 I	$K\alpha_1$	100
29,109.3	50 Sn	$K\beta_2$	5
29,458	54 Xe	$K\alpha_2$	54
29,679.2	51 Sb	$K\beta_3$	9
29,725.6	51 Sb	$K\beta_1$	18
29,779	54 Xe	$K\alpha_1$	100
30,389.5	51 Sb	$K\beta_2$	5
30,625.1	55 Cs	$K\alpha_2$	54
30,944.3	52 Te	$K\beta_3$	9
30,972.8	55 Cs	$K\alpha_1$	100
30,995.7	52 Te	$K\beta_1$	18
31,700.4	52 Te	$K\beta_2$	5
31,817.1	56 Ba	$K\alpha_2$	54
32,193.6	56 Ba	$K\alpha_1$	100
32,239.4	53 I	$K\beta_3$	9
32,294.7	53 I	$K\beta_1$	18
33,034.1	57 La	$K\alpha_2$	54
33,042	53 I	$K\beta_2$	5
33,441.8	57 La	$K\alpha_1$	100
33,562	54 Xe	$K\beta_3$	9
33,624	54 Xe	$K\beta_1$	18
34,278.9	58 Ce	$K\alpha_2$	55
34,415	54 Xe	$K\beta_2$	5
34,719.7	58 Ce	$K\alpha_1$	100
34,919.4	55 Cs	$K\beta_3$	9
34,986.9	55 Cs	$K\beta_1$	18
35,550.2	59 Pr	$K\alpha_2$	55
35,822	55 Cs	$K\beta_2$	6

36,026.3	59 Pr	$K\alpha_1$	100
36,304.0	56 Ba	$K\beta_3$	10
36,378.2	56 Ba	$K\beta_1$	18
36,847.4	60 Nd	$K\alpha_2$	55
37,257	56 Ba	$K\beta_2$	6
37,361.0	60 Nd	$K\alpha_1$	100
37,720.2	57 La	$K\beta_3$	10
37,801.0	57 La	$K\beta_1$	19
38,171.2	61 Pm	$K\alpha_2$	55
38,724.7	61 Pm	$K\alpha_1$	100
38,729.9	57 La	$K\beta_2$	6
39,170.1	58 Ce	$K\beta_3$	10
39,257.3	58 Ce	$K\beta_1$	19
39,522.4	62 Sm	$K\alpha_2$	55
40,118.1	62 Sm	$K\alpha_1$	100
40,233	58 Ce	$K\beta_2$	6
40,652.9	59 Pr	$K\beta_3$	10
40,748.2	59 Pr	$K\beta_1$	19
40,901.9	63 Eu	$K\alpha_2$	56
41,542.2	63 Eu	$K\alpha_1$	100
41,773	59 Pr	$K\beta_2$	6
42,166.5	60 Nd	$K\beta_3$	10
42,271.3	60 Nd	$K\beta_1$	19
42,308.9	64 Gd	$K\alpha_2$	56
42,996.2	64 Gd	$K\alpha_1$	100
43,335	60 Nd	$K\beta_2$	6
43,713	61 Pm	$K\beta_3$	10
43,744.1	65 Tb	$K\alpha_2$	56
43,826	61 Pm	$K\beta_1$	19
44,481.6	65 Tb	$K\alpha_1$	100
44,942	61 Pm	$K\beta_2$	6
45,207.8	66 Dy	$K\alpha_2$	56
45,289	62 Sm	$K\beta_3$	10
45,413	62 Sm	$K\beta_1$	19
45,998.4	66 Dy	$K\alpha_1$	100
46,578	62 Sm	$K\beta_2$	6
46,699.7	67 Ho	$K\alpha_2$	56
46,903.6	63 Eu	$K\beta_3$	10
47,037.9	63 Eu	$K\beta_1$	19
47,546.7	67 Ho	$K\alpha_1$	100
48,221.1	68 Er	$K\alpha_2$	56
48,256	63 Eu	$K\beta_2$	6
48,555	64 Gd	$K\beta_3$	10
48,697	64 Gd	$K\beta_1$	20
49,127.7	68 Er	$K\alpha_1$	100
49,772.6	69 Tm	$K\alpha_2$	57
49,959	64 Gd	$K\beta_2$	7
50,229	65 Tb	$K\beta_3$	10
50,382	65 Tb	$K\beta_1$	20
50,741.6	69 Tm	$K\alpha_1$	100
51,354.0	70 Yb	$K\alpha_2$	57
51,698	65 Tb	$K\beta_2$	7
51,957	66 Dy	$K\beta_3$	10
52,119	66 Dy	$K\beta_1$	20
52,388.9	70 Yb	$K\alpha_1$	100
52,965.0	71 Lu	$K\alpha_2$	57
53,476	66 Dy	$K\beta_2$	7

Table 1-3. Energies and intensities of x-ray emission lines (continued).

Energy (eV)	Element	Line	Relative intensity
53,711	67 Ho	$K\beta_3$	11
53,877	67 Ho	$K\beta_1$	20
54,069.8	71 Lu	$K\alpha_1$	100
54,611.4	72 Hf	$K\alpha_2$	57
55,293	67 Ho	$K\beta_2$	7
55,494	68 Er	$K\beta_3$	11
55,681	68 Er	$K\beta_1$	21
55,790.2	72 Hf	$K\alpha_1$	100
56,277	73 Ta	$K\alpha_2$	57
57,210	68 Er	$K\beta_2$	7
57,304	69 Tm	$K\beta_3$	11
57,517	69 Tm	$K\beta_1$	21
57,532	73 Ta	$K\alpha_1$	100
57,981.7	74 W	$K\alpha_2$	58
59,090	69 Tm	$K\beta_2$	7
59,140	70 Yb	$K\beta_3$	11
59,318.2	74 W	$K\alpha_1$	100
59,370	70 Yb	$K\beta_1$	21
59,717.9	75 Re	$K\alpha_2$	58
60,980	70 Yb	$K\beta_2$	7
61,050	71 Lu	$K\beta_3$	11
61,140.3	75 Re	$K\alpha_1$	100
61,283	71 Lu	$K\beta_1$	21
61,486.7	76 Os	$K\alpha_2$	58
62,970	71 Lu	$K\beta_2$	7
62,980	72 Hf	$K\beta_3$	11
63,000.5	76 Os	$K\alpha_1$	100
63,234	72 Hf	$K\beta_1$	22
63,286.7	77 Ir	$K\alpha_2$	58
64,895.6	77 Ir	$K\alpha_1$	100
64,948.8	73 Ta	$K\beta_3$	11
64,980	72 Hf	$K\beta_2$	7
65,112	78 Pt	$K\alpha_2$	58
65,223	73 Ta	$K\beta_1$	22
66,832	78 Pt	$K\alpha_1$	100
66,951.4	74 W	$K\beta_3$	11
66,989.5	79 Au	$K\alpha_2$	59
66,990	73 Ta	$K\beta_2$	7
67,244.3	74 W	$K\beta_1$	22
68,803.7	79 Au	$K\alpha_1$	100
68,895	80 Hg	$K\alpha_2$	59
68,994	75 Re	$K\beta_3$	12
69,067	74 W	$K\beta_2$	8
69,310	75 Re	$K\beta_1$	22
70,819	80 Hg	$K\alpha_1$	100
70,831.9	81 Tl	$K\alpha_2$	60
71,077	76 Os	$K\beta_3$	12
71,232	75 Re	$K\beta_2$	8
71,413	76 Os	$K\beta_1$	23
72,804.2	82 Pb	$K\alpha_2$	60
72,871.5	81 Tl	$K\alpha_1$	100
73,202.7	77 Ir	$K\beta_3$	12
73,363	76 Os	$K\beta_2$	8
73,560.8	77 Ir	$K\beta_1$	23
74,814.8	83 Bi	$K\alpha_2$	60

74,969.4	82 Pb	$K\alpha_1$	100
75,368	78 Pt	$K\beta_3$	12
75,575	77 Ir	$K\beta_2$	8
75,748	78 Pt	$K\beta_1$	23
77,107.9	83 Bi	$K\alpha_1$	100
77,580	79 Au	$K\beta_3$	12
77,850	78 Pt	$K\beta_2$	8
77,984	79 Au	$K\beta_1$	23
79,822	80 Hg	$K\beta_3$	12
80,150	79 Au	$K\beta_2$	8
80,253	80 Hg	$K\beta_1$	23

82,118	81 Tl	$K\beta_3$	12
82,515	80 Hg	$K\beta_2$	8
82,576	81 Tl	$K\beta_1$	23
84,450	82 Pb	$K\beta_3$	12
84,910	81 Tl	$K\beta_2$	8
84,936	82 Pb	$K\beta_1$	23
86,834	83 Bi	$K\beta_3$	12
87,320	82 Pb	$K\beta_2$	8
87,343	83 Bi	$K\beta_1$	23
89,830	83 Bi	$K\beta_2$	9

89,953	90 Th	$K\alpha_2$	62
93,350	90 Th	$K\alpha_1$	100
94,665	92 U	$K\alpha_2$	62
98,439	92 U	$K\alpha_1$	100
104,831	90 Th	$K\beta_3$	12
105,609	90 Th	$K\beta_1$	24
108,640	90 Th	$K\beta_2$	9
110,406	92 U	$K\beta_3$	13
111,300	92 U	$K\beta_1$	24
114,530	92 U	$K\beta_2$	9

SECTION 5

MISCELLANEOUS

5.1 PHYSICAL CONSTANTS

Table 5-1 was drawn from the recommendations of CODATA (the Committee on Data for Science and Technology). The full 1998 CODATA set of constants may be found at http://physics.nist.gov/cuu/Constants/index.html.

Table 5-1. *Physical constants.*

Quantity	Symbol, equation	Value	Uncert. (ppb)
speed of light	c (see note *)	299 792 458 m s^{-1} (10^{10} cm s^{-1})	exact
Planck constant	h	6.626 068 96(33)×10^{-34} J s (10^{-27} erg s)	50
Planck constant, reduced	$\hbar = h/2\pi$	1.054 571 628(53)×10^{-34} J s = 6.582 118 99(16)×10^{-22} MeV s	50, 25
electron charge magnitude	e	4.803 204 27(12)×10^{-10} esu = 1.602 176 87(40)×10^{-19} C	25, 25
conversion constant	$\hbar c$	197.326 9631(49) MeV fm (= eV nm)	25
electron mass	m_e	0.510 998 910(13) MeV/c^2 = 9.109 382 15(45)×10^{-31} kg	25, 50
proton mass	m_p	938.272 013(23) MeV/c^2 = 1.672 621 637(83)×10^{-27} kg	25, 50
		= 1.007 276 466 77(10) u = 1836.152 672 47(80) m_e	0.10, 0.43
deuteron mass	m_d	1875.612 793 (47) MeV/c^2	25
unified atomic mass unit (u)	(mass ^{12}C atom)/12 = (1 g)/(N_A mol)	931.494 028(23) MeV/c^2 = 1.660 538 782(83)×10^{-27} kg	25, 50
permittivity of free space	$\varepsilon_0 = 1/(\mu_0 c^2)$	8.854 187 817...×10^{-12} F m^{-1}	exact
permeability of free space	μ_0	4π×10^{-7} N A^{-2} = 12.566 370 614...×10^{-7} N A^{-2}	exact
fine-structure constant	$\alpha = e^2/4\pi\varepsilon_0\hbar c$	1/137.035 999 679(94)	0.68
classical electron radius	$r_e = e^2/4\pi\varepsilon_0 m_e c^2$	2.817 940 2894(58)×10^{-15} m	2.1
Bohr radius ($m_{nucleus} = \infty$)	$a_0 = 4\pi\varepsilon_0\hbar^2/m_e e^2 = r_e\alpha^{-2}$	0.529 177 208 59(36)×10^{-10} m (10^{-8} cm)	0.68
Rydberg energy	$hcR_\infty = m_e e^4/2(4\pi\varepsilon_0)^2\hbar^2$	13.605 691 93(34) eV	25
	$= m_e c^2\alpha^2/2$		

Thomson cross section	$\sigma_T = 8\pi r_e^2/3$	0.665 245 8558(27) barn (10^{-28} m^2)	4.1
Bohr magneton	$\mu_B = e\hbar/2m_e$	5.788 381 7555(79)×10^{-11} MeV T^{-1}	1.4
nuclear magneton	$\mu_N = e\hbar/2m_p$	3.152 451 2326(45)×10^{-14} MeV T^{-1}	1.4
electron cyclotron freq./field	$\omega_{cycl}^e/B = e/m_e$	1.758 820 150(44)×10^{11} rad s^{-1} T^{-1}	25
proton cyclotron freq./field	$\omega_{cycl}^p/B = e/m_p$	9.578 833 92(24)×10^7 rad s^{-1} T^{-1}	25
Avogadro constant	N_A	6.022 141 79(30)×10^{23} mol^{-1}	50
Boltzman constant	k	1.380 650 4(24)×10^{-23} J K^{-1} = 8.617 343(15)×10^{-5} eV K^{-1}	1700
molar volume, ideal gas at STP	$N_A k$ (273.15 K)/(101 325 Pa)	22.413 996(39)×10^{-3} m^3 mol^{-1}	1700

π = 3.141 592 653 589 793 238 e = 2.718 281 828 459 045 235 γ = 0.577 215 664 901 532 861

*The meter is the length of the path traveled by light in vacuum during a time interval of 1/299 792 458 of a second.

1 in. = 2.54 cm	1 newton = 10^5 dyne	1 eV/c^2 = 1.782 662×10^{-33} g	1 coulomb = 2.997 924 58×10^9 esu
1 Å = 10^{-8} cm	1 joule = 10^7 erg	hc/(1 eV) = 1.239 842 μm	1 tesla = 10^4 gauss
1 fm = 10^{-13} cm	1 cal = 4.184 joule	1 eV/h = 2.417 989×10^{14} Hz	1 atm = 1.013 25×10^6 dyne/cm^2
1 barn = 10^{-24} cm^2	1 eV = 1.602 176 5×10^{-12} erg	1 eV/k = 11 604.5 K	0°C = 273.15 K

The NIST Reference on Constants, Units, and Uncertainty: http://physics.nist.gov/cuu/Constants/index.html

5.2 PHYSICAL PROPERTIES OF THE ELEMENTS

Table 5-2 lists several important properties of the elements. Data were taken mostly from D. R. Lide, Ed., *CRC Handbook of Chemistry and Physics*, 80th ed. (CRC Press, Boca Raton, Florida, 1999). Atomic weights apply to elements as they exist naturally on earth; values in parentheses are the mass numbers for the longest-lived isotopes. Some uncertainty exists in the last digit of each atomic weight. Specific heats are given for the elements at 25°C and a pressure of 100 kPa. Densities for solids and liquids are given as specific gravities at 20°C unless otherwise indicated by a superscript temperature (in °C); densities for the gaseous elements are given in g/cm^3 for the liquids at their boiling points. The ionization energies were taken from http://physics.nist.gov/PhysRefData/IonEnergy/ionEnergy.html.

A periodic table of the elements follows Table 5-2, on page 5-10. A more detailed periodic table can be found at http://www.cxro.lbl.gov/.

Table 5-2. Properties of the elements.

Z	Element	Atomic weight	Density	Melting point (°C)	Boiling point (°C)	Ground-state configuration	Ground level	Ionization energy (eV)	Specific heat (J/g·K)
1	Hydrogen	1.00794	0.0708	–259.34	–252.87	$1s$	$^2S_{1/2}$	13.598	14.304
2	Helium	4.002602	0.122	—	–268.93	$1s^2$	$^1S_0$	24.587	5.193
3	Lithium	6.941	0.534	180.50	1342	$1s^2\ 2s$	$^2S_{1/2}$	5.392	3.582
4	Beryllium	9.012182	1.848	1287	2471	$1s^2\ 2s^2$	$^1S_0$	9.323	1.825
5	Boron	10.811	2.34	2075	4000	$1s^2\ 2s^2\ 2p$	$^2P°_{1/2}$	8.298	1.026
6	Carbon	12.0107	1.9–2.3 (graph)	4492[10.3 MPa]	3825[b]	$1s^2\ 2s^2\ 2p^2$	$^3P_0$	11.260	0.709
7	Nitrogen	14.00674	0.808	–210.00	–195.79	$1s^2\ 2s^2\ 2p^3$	$^4S°_{3/2}$	14.534	1.040
8	Oxygen	15.9994	1.14	–218.79	–182.95	$1s^2\ 2s^2\ 2p^4$	$^3P_2$	13.618	0.918
9	Fluorine	18.9984032	1.50	–219.62	–188.12	$1s^2\ 2s^2\ 2p^5$	$^2P°_{3/2}$	17.423	0.824
10	Neon	20.1797	1.207	–248.59	–246.08	$1s^2\ 2s^2\ 2p^6$	$^1S_0$	21.565	1.030
11	Sodium	22.989770	0.971	97.80	883	[Ne] $3s$	$^2S_{1/2}$	5.139	1.228
12	Magnesium	24.3050	1.738	650	1090	[Ne] $3s^2$	$^1S_0$	7.646	1.023
13	Aluminum	26.981538	2.6989	660.32	2519	[Ne] $3s^2\ 3p$	$^2P°_{1/2}$	5.986	0.897
14	Silicon	28.0855	2.33[25]	1414	3265	[Ne] $3s^2\ 3p^2$	$^3P_0$	8.152	0.705
15	Phosphorus	30.973761	1.82	44.15	280.5	[Ne] $3s^2\ 3p^3$	$^4S°_{3/2}$	10.487	0.769
16	Sulfur	32.066	2.07	119.6	444.60	[Ne] $3s^2\ 3p^4$	$^3P_2$	10.360	0.710
17	Chlorine	35.4527	1.56[–33.6]	–101.5	–34.04	[Ne] $3s^2\ 3p^5$	$^2P°_{3/2}$	12.968	0.479
18	Argon	39.948	1.40	–189.35	–185.85	[Ne] $3s^2\ 3p^6$	$^1S_0$	15.760	0.520
19	Potassium	39.0983	0.862	63.5	759	[Ar] $4s$	$^2S_{1/2}$	4.341	0.757
20	Calcium	40.078	1.55	842	1484	[Ar] $4s^2$	$^1S_0$	6.113	0.647
21	Scandium	44.955910	2.989[25]	1541	2836	[Ar] $3d\ 4s^2$	$^2D_{3/2}$	6.562	0.568
22	Titanium	47.867	4.54	1668	3287	[Ar] $3d^2\ 4s^2$	$^3F_2$	6.828	0.523
23	Vanadium	50.9415	6.11[18.7]	1910	3407	[Ar] $3d^3\ 4s^2$	$^4F_{3/2}$	6.746	0.489
24	Chromium	51.9961	7.18–7.20	1907	2671	[Ar] $3d^5\ 4s$	$^7S_3$	6.766	0.449
25	Manganese	54.938049	7.21–7.44	1246	2061	[Ar] $3d^5\ 4s^2$	$^6S_{5/2}$	7.434	0.479
26	Iron	55.845	7.874	1538	2861	[Ar] $3d^6\ 4s^2$	$^5D_4$	7.902	0.449

Table 5-2. Properties of the elements (continued).

Z	Element	Atomic weight	Density	Melting point (°C)	Boiling point (°C)	Ground-state configuration	Ground level	Ionization energy (eV)	Specific heat (J/g·K)
27	Cobalt	58.933200	8.9	1495	2927	[Ar] $3d^7$ $4s^2$	$^4F_{9/2}$	7.881	0.421
28	Nickel	58.6934	8.902[25]	1455	2913	[Ar] $3d^8$ $4s^2$	$^3F_4$	7.640	0.444
29	Copper	63.546	8.96	1084.62	2562	[Ar] $3d^{10}$ $4s$	$^2S_{1/2}$	7.726	0.385
30	Zinc	65.39	7.133[25]	419.53	907	[Ar] $3d^{10}$ $4s^2$	$^1S_0$	9.394	0.388
31	Gallium	69.723	5.904[29.6]	29.76	2204	[Ar] $3d^{10}$ $4s^2$ $4p$	$^2P°_{1/2}$	5.999	0.371
32	Germanium	72.61	5.323[25]	938.25	2833	[Ar] $3d^{10}$ $4s^2$ $4p^2$	$^3P_0$	7.899	0.320
33	Arsenic	74.92160	5.73	817[3.7 MPa]	603[b]	[Ar] $3d^{10}$ $4s^2$ $4p^3$	$^4S°_{3/2}$	9.789	0.329
34	Selenium	78.96	4.79	220.5	685	[Ar] $3d^{10}$ $4s^2$ $4p^4$	$^3P_2$	9.752	0.321
35	Bromine	79.904	3.12	–7.2	58.8	[Ar] $3d^{10}$ $4s^2$ $4p^5$	$^2P°_{3/2}$	11.814	0.226
36	Krypton	83.80	2.16	157.38[73.2 kPa]	–153.22	[Ar] $3d^{10}$ $4s^2$ $4p^6$	$^1S_0$	14.000	0.248
37	Rubidium	85.4678	1.532	39.30	688	[Kr] $5s$	$^2S_{1/2}$	4.177	0.363
38	Strontium	87.62	2.54	777	1382	[Kr] $5s^2$	$^1S_0$	5.695	0.301
39	Yttrium	88.90585	4.469[25]	1522	3345	[Kr] $4d$ $5s^2$	$^2D_{3/2}$	6.217	0.298
40	Zirconium	91.224	6.506	1855	4409	[Kr] $4d^2$ $5s^2$	$^3F_2$	6.634	0.278
41	Niobium	92.90638	8.57	2477	4744	[Kr] $4d^4$ $5s$	$^6D_{1/2}$	6.759	0.265
42	Molybdenum	95.94	10.22	2623	4639	[Kr] $4d^5$ $5s$	$^7S_3$	7.092	0.251
43	Technetium	(98)	11.50[a]	2157	4265	[Kr] $4d^5$ $5s^2$	$^6S_{5/2}$	7.28	—
44	Ruthenium	101.07	12.41	2334	4150	[Kr] $4d^7$ $5s$	$^5F_5$	7.360	0.238
45	Rhodium	102.90550	12.41	1964	3695	[Kr] $4d^8$ $5s$	$^4F_{9/2}$	7.459	0.243
46	Palladium	106.42	12.02	1554.9	2963	[Kr] $4d^{10}$	$^1S_0$	8.337	0.246
47	Silver	107.8682	10.50	961.78	2162	[Kr] $4d^{10}$ $5s$	$^2S_{1/2}$	7.576	0.235
48	Cadmium	112.411	8.65	321.07	767	[Kr] $4d^{10}$ $5s^2$	$^1S_0$	8.994	0.232
49	Indium	114.818	7.31	156.60	2072	[Kr] $4d^{10}$ $5s^2$ $5p$	$^2P°_{1/2}$	5.786	0.233
50	Tin	118.710	7.31	231.93	2602	[Kr] $4d^{10}$ $5s^2$ $5p^2$	$^3P_0$	7.344	0.228
51	Antimony	121.760	6.691	630.73	1587	[Kr] $4d^{10}$ $5s^2$ $5p^3$	$^4S°_{3/2}$	8.608	0.207
52	Tellurium	127.60	6.24	449.51	988	[Kr] $4d^{10}$ $5s^2$ $5p^4$	$^3P_2$	9.010	0.202
53	Iodine	126.90447	4.93	113.7	184.4	[Kr] $4d^{10}$ $5s^2$ $5p^5$	$^2P°_{3/2}$	10.451	0.145
54	Xenon	131.29	3.52	–111.79[81.6 kPa]	–108.12	[Kr] $4d^{10}$ $5s^2$ $5p^6$	$^1S_0$	12.130	0.158

Table 5-2. Properties of the elements (continued).

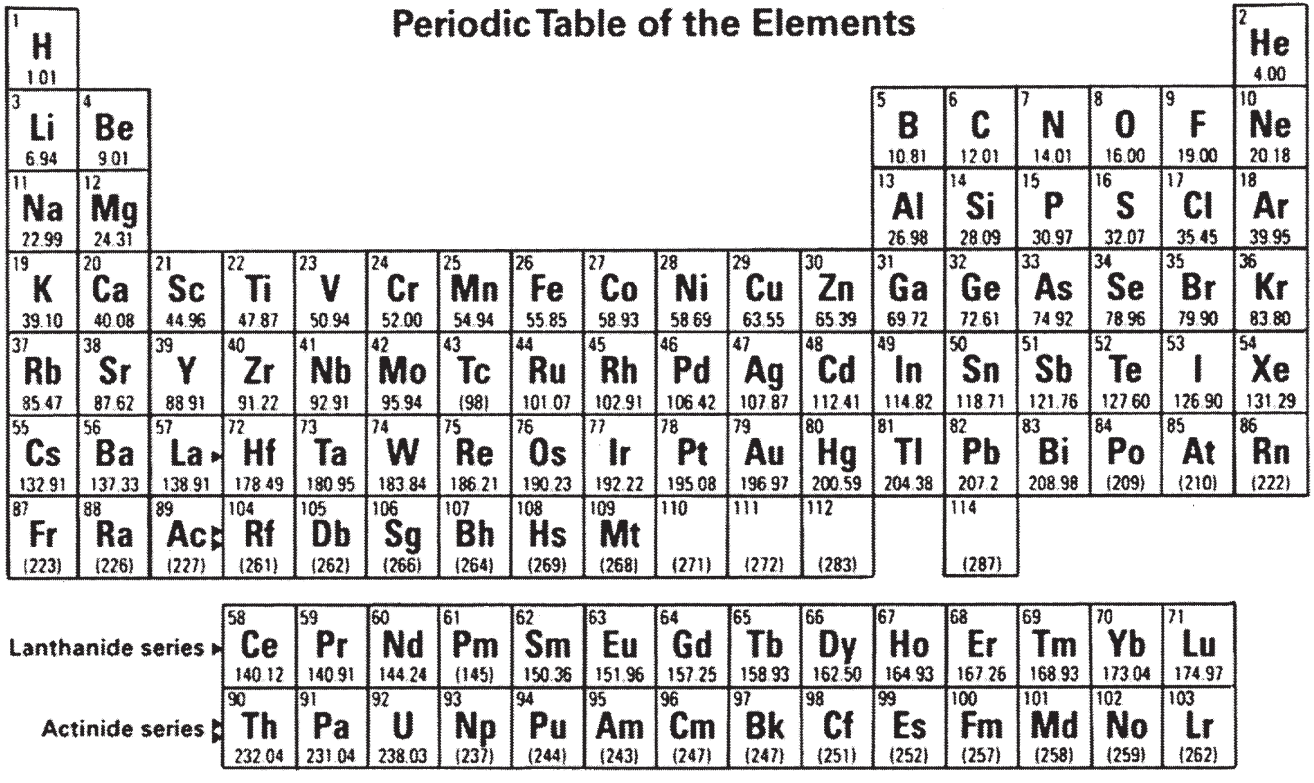
Z	Element	Atomic weight	Density	Melting point (°C)	Boiling point (°C)	Ground-state configuration	Ground level	Ionization energy (eV)	Specific heat (J/g·K)
55	Cesium	132.90545	1.873	28.5	671	[Xe] $6s$	$^2S_{1/2}$	3.894	0.242
56	Barium	137.327	3.5	727	1897	[Xe] $6s^2$	$^1S_0$	5.212	0.204
57	Lanthanum	138.9055	6.145[25]	918	3464	[Xe] $5d$ $6s^2$	$^2D_{3/2}$	5.577	0.195
58	Cerium	140.116	6.770[25]	798	3443	[Xe] $4f$ $5d$ $6s^2$	$^1G°_4$	5.539	0.192
59	Praseodymium	140.90765	6.773	931	3520	[Xe] $4f^3$ $6s^2$	$^4I°_{9/2}$	5.473	0.193
60	Neodymium	144.24	7.008[25]	1021	3074	[Xe] $4f^4$ $6s^2$	$^5I_4$	5.525	0.190
61	Promethium	(145)	7.264[25]	1042	3000	[Xe] $4f^5$ $6s^2$	$^6H°_{5/2}$	5.582	—
62	Samarium	150.36	7.520[25]	1074	1794	[Xe] $4f^6$ $6s^2$	$^7F_0$	5.644	0.197
63	Europium	151.964	5.244[25]	822	1529	[Xe] $4f^7$ $6s^2$	$^8S°_{7/2}$	5.670	0.182
64	Gadolinium	157.25	7.901[25]	1313	3273	[Xe] $4f^7$ $5d$ $6s^2$	$^9D°_2$	6.150	0.236
65	Terbium	158.92534	8.230	1356	3230	[Xe] $4f^9$ $6s^2$	$^6H°_{15/2}$	5.864	0.182
66	Dysprosium	162.50	8.551[25]	1412	2567	[Xe] $4f^{10}$ $6s^2$	$^5I_8$	5.939	0.170
67	Holmium	164.93032	8.795[25]	1474	2700	[Xe] $4f^{11}$ $6s^2$	$^4I°_{15/2}$	6.022	0.165
68	Erbium	167.26	9.066[25]	1529	2868	[Xe] $4f^{12}$ $6s^2$	$^3H_6$	6.108	0.168
69	Thulium	168.93421	9.321[25]	1545	1950	[Xe] $4f^{13}$ $6s^2$	$^2F°_{7/2}$	6.184	0.160
70	Ytterbium	173.04	6.966	819	1196	[Xe] $4f^{14}$ $6s^2$	$^1S_0$	6.254	0.155
71	Lutetium	174.967	9.841[25]	1663	3402	[Xe] $4f^{14}$ $5d$ $6s^2$	$^2D_{3/2}$	5.426	0.154
72	Hafnium	178.49	13.31	2233	4603	[Xe] $4f^{14}$ $5d^2$ $6s^2$	$^3F_2$	6.825	0.144
73	Tantalum	180.9479	16.654	3017	5458	[Xe] $4f^{14}$ $5d^3$ $6s^2$	$^4F_{3/2}$	7.550	0.140
74	Tungsten	183.84	19.3	3422	5555	[Xe] $4f^{14}$ $5d^4$ $6s^2$	$^5D_0$	7.864	0.132
75	Rhenium	186.207	21.02	3186	5596	[Xe] $4f^{14}$ $5d^5$ $6s^2$	$^6S_{5/2}$	7.834	0.137
76	Osmium	190.23	22.57	3033	5012	[Xe] $4f^{14}$ $5d^6$ $6s^2$	$^5D_4$	8.438	0.130
77	Iridium	192.217	22.42[17]	2446	4428	[Xe] $4f^{14}$ $5d^7$ $6s^2$	$^4F_{9/2}$	8.967	0.131
78	Platinum	195.078	21.45	1768.4	3825	[Xe] $4f^{14}$ $5d^9$ $6s$	$^3D_3$	8.959	0.133
79	Gold	196.96655	~19.3	1064.18	2856	[Xe] $4f^{14}$ $5d^{10}$ $6s$	$^2S_{1/2}$	9.226	0.129
80	Mercury	200.59	13.546	–38.83	356.73	[Xe] $4f^{14}$ $5d^{10}$ $6s^2$	$^1S_0$	10.438	0.140
81	Thallium	204.3833	11.85	304	1473	[Xe] $4f^{14}$ $5d^{10}$ $6s^2$ $6p$	$^2P°_{1/2}$	6.108	0.129
82	Lead	207.2	11.35	327.46	1749	[Xe] $4f^{14}$ $5d^{10}$ $6s^2$ $6p^2$	$^3P_0$	7.417	0.129

Table 5-2. Properties of the elements (continued).

Z	Element	Atomic weight	Density	Melting point (°C)	Boiling point (°C)	Ground-state configuration	Ground level	Ionization energy (eV)	Specific heat (J/g·K)
83	Bismuth	208.98038	9.747	271.40	1564	[Xe] $4f^{14}\ 5d^{10}\ 6s^2\ 6p^3$	$^4S°_{3/2}$	7.286	0.122
84	Polonium	(209)	9.32	254	962	[Xe] $4f^{14}\ 5d^{10}\ 6s^2\ 6p^4$	$^3P_2$	8.417 ?	—
85	Astatine	(210)	—	302	—	[Xe] $4f^{14}\ 5d^{10}\ 6s^2\ 6p^5$	$^2P°_{3/2}$	—	—
86	Radon	(222)	—	–71	–61.7	[Xe] $4f^{14}\ 5d^{10}\ 6s^2\ 6p^6$	$^1S_0$	10.748	0.094
87	Francium	(223)	—	27	—	[Rn] $7s$	$^2S_{1/2}$	4.073	—
88	Radium	(226)	—	700	—	[Rn] $7s^2$	$^1S_0$	5.278	—
89	Actinium	(227)	—	1051	3198	[Rn] $6d\ 7s^2$	$^2D_{3/2}$	5.17	0.120
90	Thorium	232.0381	11.72	1750	4788	[Rn] $6d^2\ 7s^2$	$^3F_2$	6.307	0.113
91	Protactinium	231.03588	15.37[a]	1572	—	[Rn] $5f^2(^3H_4)\ 6d\ 7s^2$	$(4,^3/_2)_{11/2}$	5.89	—
92	Uranium	238.0289	~18.95	1135	4131	[Rn] $5f^3(^4I°_{9/2})\ 6d\ 7s^2$	$(^9/_2,^3/_2)°_6$	6.194	0.116
93	Neptunium	(237)	20.25	644	—	[Rn] $5f^4(^5I_4)\ 6d\ 7s^2$	$(4,^3/_2)_{11/2}$	6.266	—
94	Plutonium	(244)	19.84[25]	640	3228	[Rn] $5f^6\ 7s^2$	$^7F_0$	6.026	—
95	Americium	(243)	13.67	1176	2011	[Rn] $5f^7\ 7s^2$	$^8S°_{7/2}$	5.974	—
96	Curium	(247)	13.51[a]	1345	3100	[Rn] $5f^7\ 6d\ 7s^2$	$^9D°_2$	5.992	—
97	Berkelium	(247)	14 (est.)	1050	—	[Rn] $5f^9\ 7s^2$	$^6H°_{15/2}$	6.198	—
98	Californium	(251)	—	900	—	[Rn] $5f^{10}\ 7s^2$	$^5I_8$	6.282	—
99	Einsteinium	(252)	—	860	—	[Rn] $5f^{11}\ 7s^2$	$^4I°_{15/2}$	6.42	—
100	Fermium	(257)	—	1527	—	[Rn] $5f^{12}\ 7s^2$	$^3H_6$	6.50	—
101	Mendelevium	(258)	—	827	—	[Rn] $5f^{13}\ 7s^2$	$^2F°_{7/2}$	6.58	—
102	Nobelium	(259)	—	827	—	[Rn] $5f^{14}\ 7s^2$	$^1S_0$	6.65	—
103	Lawrencium	(262)	—	1627	—	[Rn] $5f^{14}\ 7s^2\ 7p$?	$^2P°_{1/2}$?	4.9 ?	—
104	Rutherfordium	(261)	—	—	—	[Rn] $5f^{14}\ 6d^2\ 7s^2$?	$^3F_2$?	6.0 ?	—
105	Dubnium	(262)	—	—	—	—	—	—	—
106	Seaborgium	(266)	—	—	—	—	—	—	—
107	Bohrium	(264)	—	—	—	—	—	—	—
108	Hassium	(269)	—	—	—	—	—	—	—
109	Meitnerium	(268)	—	—	—	—	—	—	—

[a]Calculated [b]Sublimes

Periodic Table of the Elements



5.3 ELECTROMAGNETIC RELATIONS

	Gaussian CGS	SI
Units and conversions:		
Charge	$2.997\,92 \times 10^9$ esu	$= 1$ C $= 1$ A s
Potential	(1/299.792) statvolt $=$ (1/299.792) erg/esu	$= 1$ V $= 1$ J C^{-1}
Magnetic field	10^4 gauss $= 10^4$ dyne/esu	$= 1$ T $= 1$ N A^{-1} m^{-1}
Electron charge	$e = 4.803\,204 \times 10^{-10}$ esu	$= 1.602\,176 \times 10^{-19}$ C
Lorentz force	$\mathbf{F} = q\left(\mathbf{E} + \frac{\mathbf{v}}{c} \times \mathbf{B}\right)$	$\mathbf{F} = q(\mathbf{E} + \mathbf{v} \times \mathbf{B})$
Maxwell equations	$\nabla \cdot \mathbf{D} = 4\pi\rho$	$\nabla \cdot \mathbf{D} = \rho$
	$\nabla \times \mathbf{E} + \frac{1}{c}\frac{\partial \mathbf{B}}{\partial t} = 0$	$\nabla \times \mathbf{E} + \frac{\partial \mathbf{B}}{\partial t} = 0$
	$\nabla \cdot \mathbf{B} = 0$	$\nabla \cdot \mathbf{B} = 0$
	$\nabla \times \mathbf{H} - \frac{1}{c}\frac{\partial \mathbf{D}}{\partial t} = \frac{4\pi}{c}\mathbf{J}$	$\nabla \times \mathbf{H} - \frac{\partial \mathbf{D}}{\partial t} = \mathbf{J}$
Linear media	$\mathbf{D} = \varepsilon\mathbf{E}$, $\mathbf{B} = \mu\mathbf{H}$	$\mathbf{D} = \varepsilon\mathbf{E}$, $\mathbf{B} = \mu\mathbf{H}$
Permittivity of free space	$\varepsilon_{\text{vac}} = 1$	$\varepsilon_{\text{vac}} = \varepsilon_0$
Permeability of free space	$\mu_{\text{vac}} = 1$	$\mu_{\text{vac}} = \mu_0$
Fields from potentials	$\mathbf{E} = -\nabla V - \frac{1}{c}\frac{\partial \mathbf{A}}{\partial t}$	$\mathbf{E} = -\nabla V - \frac{\partial \mathbf{A}}{\partial t}$
	$\mathbf{B} = \nabla \times \mathbf{A}$	$\mathbf{B} = \nabla \times \mathbf{A}$
Static potentials (coulomb gauge)	$V = \sum_{\text{charges}} \frac{q_i}{r_i}$	$V = \frac{1}{4\pi\varepsilon_0}\sum_{\text{charges}} \frac{q_i}{r_i}$
	$\mathbf{A} = \frac{1}{c}\oint \frac{I\,d\ell}{\lvert \mathbf{r} - \mathbf{r}' \rvert}$	$\mathbf{A} = \frac{\mu_0}{4\pi}\oint \frac{I\,d\ell}{\lvert \mathbf{r} - \mathbf{r}' \rvert}$
Relativistic transformations ($\mathbf{v}$ is the velocity of primed system as seen in unprimed system)	$\mathbf{E}'_{\parallel} = \mathbf{E}_{\parallel}$	$\mathbf{E}'_{\parallel} = \mathbf{E}_{\parallel}$
	$\mathbf{E}'_{\perp} = \gamma\left(\mathbf{E}_{\perp} + \frac{1}{c}\mathbf{v} \times \mathbf{B}\right)$	$\mathbf{E}'_{\perp} = \gamma(\mathbf{E}_{\perp} + \mathbf{v} \times \mathbf{B})$
	$\mathbf{B}'_{\parallel} = \mathbf{B}_{\parallel}$	$\mathbf{B}'_{\parallel} = \mathbf{B}_{\parallel}$
	$\mathbf{B}'_{\perp} = \gamma\left(\mathbf{B}_{\perp} \pm \frac{1}{c}\mathbf{v} \times \mathbf{E}\right)$	$\mathbf{B}'_{\perp} = \gamma\left(\mathbf{B}_{\perp} - \frac{1}{c^2}\mathbf{v} \times \mathbf{E}\right)$

$$4\pi\varepsilon_0 = \frac{1}{c^2}\,10^7 \text{A}^2\,\text{N}^{-1} = \frac{1}{8.987\,55\ldots} \times 10^{-9}\text{F m}^{-1}$$

$$\frac{\mu_0}{4\pi} = 10^{-7}\text{N A}^{-1}\,;\, c = 2.997\,924\,58 \times 10^8\ \text{m s}^{-1}$$

5.4 RADIOACTIVITY AND RADIATION PROTECTION

The International Commission on Radiation Units and Measurements (ICRU) recommends the use of SI units. Therefore, we list SI units first, followed by cgs (or other common) units in parentheses, where they differ.

A. DEFINITIONS

Unit of activity = becquerel (curie):
1 Bq = 1 disintegration s^{-1} [= $1/(3.7 \times 10^{10})$ Ci]

Unit of absorbed dose = gray (rad):
1 Gy = 1 J kg^{-1} (= 10^4 erg g^{-1} = 100 rad)
= 6.24×10^{12} MeV kg^{-1} deposited energy

Unit of exposure, the quantity of x- or γ-radiation at a point in space integrated over time, in terms of charge of either sign produced by showering electrons in a small volume of air about the point:
= 1 C kg^{-1} of air (roentgen; 1 R = 2.58×10^{-4} C kg^{-1})
= 1 esu cm^{-3} (= 87.8 erg released energy per g of air)
Implicit in the definition is the assumption that the small test volume is embedded in a sufficiently large uniformly irradiated volume that the number of secondary electrons entering the volume equals the number leaving.

Unit of equivalent dose for biological damage = sievert. 1 Sv = 100 rem (*r*oentgen *e*quivalent for *m*an). The equivalent dose in Sv = absorbed dose in grays $\times$ w_R, where w_R is the radiation weighting factor (formerly the quality factor Q), which depends upon the type of radiation and other factors, as shown in Table 5-3. The equivalent dose expresses the long-term risk (primarily due to cancer and leukemia) from low-level chronic exposure.

B. RADIATION LEVELS

Natural annual background from all sources. In most of the world, the whole-body equivalent dose rate $\approx$ 0.4–4 mSv (40–400 mrem). It can range up to 50 mSv (5 rem) in certain areas. The U.S. average $\approx$ 3.6 mSv, including about 2 mSv ($\approx$ 200 mrem) from inhaled natural radioactivity, mostly

Table 5-3. Radiation weighting factors.

Type of radiation	w_R
X- and γ-rays, all energies	1
Electrons and muons, all energies	1
Neutrons:	
< 10 keV	5
10–100 keV	10
0.1–2 MeV	20
2–20 MeV	10
> 20 MeV	5
Protons (other than recoils), > 2 MeV	5
Alphas, fission fragments, and heavy nuclei	20

radon and radon daughters. This radon exposure value is for a typical house; radon exposure varies by more than an order of magnitude.

Cosmic ray background in counters (Earth's surface): $\sim 1\ \text{min}^{-1}\text{cm}^{-2}\ \text{sr}^{-1}$.

Man-made radiation dose: The greatest contribution to man-made radiation dose has been from irradiation from x-ray diagnostics in medicine, which accounts for about 20% of the average natural radiation dose.

Fluxes (per cm^2) to deposit one Gy, assuming uniform irradiation:

For photons:

$\approx 6.24 \times 10^9\ \lambda/Ef$, for photons of energy E [MeV], attenuation length λ (g cm^{-2}), and fraction $f \leq 1$ expressing the fraction of the photon's energy deposited in a small volume of thickness $<< \lambda$ but large enough to contain the secondary electrons.

$\approx 2 \times 10^{11}$ photons cm^{-2} for 1-MeV photons on carbon ($f \approx 0.5$).

For charged particles:

$\approx 6.24 \times 10^9/(dE/dx)$; where dE/dx [MeV $\text{g}^{-1}\ \text{cm}^2$), the energy loss per unit length, may be obtained from range-energy figures.

$\approx 3.5 \times 10^9\ \text{cm}^{-2}$ for minimum-ionizing singly-charged particles in carbon.

Quoted fluxes are good to about a factor of two for all materials.

Recommended exposure limits for radiation workers (whole-body dose):

ICRP: 20 mSv yr^{-1} averaged over 5 years, with the dose in any one year ≤ 50 mSv.

U.S.: 50 mSv yr^{-1} (5 rem yr^{-1}). Many laboratories in the U.S. and and elsewhere set lower limits.

Lethal dose: Whole-body dose from penetrating ionizing radiation resulting in 50% mortality in 30 days (assuming no medical treatment), about 5 Gy (500 rads) as measured internally on body longitudinal center line. Surface dose varies owing to variable body attenuation and may be a strong function of energy.

This section was adapted, with permission, from the 1999 web edition of the *Review of Particle Physics* (http://pdg.lbl.gov). For further information, see ICRP Publication 60, *1990 Recommendation of the International Commission on Radiological Protection* (Pergamon Press, New York, 1991) and E. Pochin, *Nuclear Radiation: Risks and Benefits* (Clarendon Press, Oxford,1983).

Additional information about
light sources around the world
can be found at
http://lightsources.org

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