3. Atomic-Electron Binding Energies

The binding energies given in Table 2 are those reported by Larkins,[1] mainly from the compilations of Sevier[2] (for Z≤83) and of Porter and Freedman[3] (for Z≥84). All binding energies listed are for solid systems referenced to the Fermi level, except those for Ne, Cl, Ar, Br, Kr, Xe, and Rn. These latter binding energies are for vapor-phase systems referenced to the vacuum level.

The binding energies are accurate to better than 1-2 *eV* for most of the subshells in the lighter elements, and for the outer orbitals in the heavier elements. Uncertainties may be as large as 10 or 20 *eV* for the inner orbitals in the high-Z elements, and changes in chemical state can lead to substantial shifts in the binding energies of non-valence shells.[4] Bearden and Burr[5] reevaluated existing data on x-ray emission wavelengths and discussed binding energies determined from atomic energy-level differences.

Table 2. Atomic-Electron Binding Energies

El	K	L_1	L_2	L_3	M_1	M_2	M_3	M_4	M_5	N_1	N_2	N_3	N_4	N_5
1 H	0.0136													
2 He	0.0246													
3 Li	0.0548	0.0053												
4 Be	0.1121	0.0080												
5 B	0.1880	0.0126	0.0047	0.0047										
6 C	0.2838	0.0180	0.0064	0.0064										
7 N	0.4016	0.0244	0.0092	0.0092										
8 O	0.5320	0.0285	0.0071	0.0071										
9 F	0.6854	0.0340	0.0086	0.0086										
10 Ne	0.8701	0.0485	0.0217	0.0216										
11 Na	1.0721	0.0633	0.0311	0.0311	0.0007									
12 Mg	1.3050	0.0894	0.0514	0.0514	0.0021									
13 Al	1.5596	0.1177	0.0732	0.0727	0.0007	0.0055	0.0055							
14 Si	1.8389	0.1487	0.0995	0.0989	0.0076	0.0030	0.0030							
15 P	2.1455	0.1893	0.1362	0.1353	0.0162	0.0099	0.0099							
16 S	2.4720	0.2292	0.1654	0.1642	0.0158	0.0080	0.0080							
17 Cl	2.8224	0.2702	0.2016	0.2000	0.0175	0.0068	0.0068							
18 Ar	3.2060	0.3263	0.2507	0.2486	0.0292	0.0159	0.0158							
19 K	3.6074	0.3771	0.2963	0.2936	0.0339	0.0178	0.0178							
20 Ca	4.0381	0.4378	0.3500	0.3464	0.0437	0.0254	0.0254							
21 Sc	4.4928	0.5004	0.4067	0.4022	0.0538	0.0323	0.0323	0.0066	0.0066					
22 Ti	4.9664	0.5637	0.4615	0.4555	0.0603	0.0346	0.0346	0.0037	0.0037					
23 V	5.4651	0.6282	0.5205	0.5129	0.0665	0.0378	0.0378	0.0022	0.0022					
24 Cr	5.9892	0.6946	0.5837	0.5745	0.0741	0.0425	0.0425	0.0023	0.0023					
25 Mn	6.5390	0.7690	0.6514	0.6403	0.0839	0.0486	0.0486	0.0033	0.0033					
26 Fe	7.1120	0.8461	0.7211	0.7081	0.0929	0.0540	0.0540	0.0036	0.0036					
27 Co	7.7089	0.9256	0.7936	0.7786	0.1007	0.0595	0.0595	0.0029	0.0029					
28 Ni	8.3328	1.0081	0.8719	0.8547	0.1118	0.0681	0.0681	0.0036	0.0036					
29 Cu	8.9789	1.0961	0.9510	0.9311	0.1198	0.0736	0.0736	0.0016	0.0016					
30 Zn	9.6586	1.1936	1.0428	1.0197	0.1359	0.0866	0.0866	0.0081	0.0081					
31 Ga	10.3671	1.2977	1.1423	1.1154	0.1581	0.1068	0.1029	0.0174	0.0174	0.0015	0.0008	0.0008		
32 Ge	11.1031	1.4143	1.2478	1.2167	0.1800	0.1279	0.1208	0.0287	0.0287	0.0050	0.0023	0.0023		
33 As	11.8667	1.5265	1.3586	1.3231	0.2035	0.1464	0.1405	0.0412	0.0412	0.0085	0.0025	0.0025		
34 Se	12.6578	1.6539	1.4762	1.4358	0.2315	0.1682	0.1619	0.0567	0.0567	0.0120	0.0056	0.0056		
35 Br	13.4737	1.7820	1.5960	1.5499	0.2565	0.1893	0.1815	0.0701	0.0690	0.0273	0.0052	0.0046		
36 Kr	14.3256	1.9210	1.7272	1.6749	0.2921	0.2218	0.2145	0.0950	0.0938	0.0275	0.0147	0.0140		
37 Rb	15.1997	2.0651	1.8639	1.8044	0.3221	0.2474	0.2385	0.1118	0.1103	0.0293	0.0148	0.0140		
38 Sr	16.1046	2.2163	2.0068	1.9396	0.3575	0.2798	0.2691	0.1350	0.1331	0.0377	0.0199	0.0199		
39 Y	17.0384	2.3725	2.1555	2.0800	0.3936	0.3124	0.3003	0.1596	0.1574	0.0454	0.0256	0.0256	0.0024	0.0024
40 Zr	17.9976	2.5316	2.3067	2.2223	0.4303	0.3442	0.3305	0.1824	0.1800	0.0513	0.0287	0.0287	0.0030	0.0030
41 Nb	18.9856	2.6977	2.4647	2.3705	0.4684	0.3784	0.3630	0.2074	0.2046	0.0581	0.0339	0.0339	0.0032	0.0032
42 Mo	19.9995	2.8655	2.6251	2.5202	0.5046	0.4097	0.3923	0.2303	0.2270	0.0618	0.0348	0.0348	0.0018	0.0018
43 Tc	21.0440	3.0425	2.7932	2.6769	0.5440	0.4449	0.4250	0.2564	0.2529	0.0680	0.0389	0.0389	0.0020	0.0020
44 Ru	22.1172	3.2240	2.9669	2.8379	0.5850	0.4828	0.4606	0.2836	0.2794	0.0749	0.0431	0.0431	0.0020	0.0020
45 Rh	23.2199	3.4119	3.1461	3.0038	0.6271	0.5210	0.4962	0.3117	0.3070	0.0810	0.0479	0.0479	0.0025	0.0025
El	K	L_1	L_2	L_3	M_1	M_2	M_3	M_4	M_5	N_1	N_2	N_3	N_4	N_5

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Table 2. Atomic-Electron Binding Energies (continued)

El	K	L_1	L_2	L_3	M_1	M_2	M_3	M_4	M_5	N_1	N_2	N_3	N_4	N_5
46 Pd	24.3503	3.6043	3.3303	3.1733	0.6699	0.5591	0.5315	0.3400	0.3347	0.0864	0.0511	0.0511	0.0015	0.0015
47 Ag	25.5140	3.8058	3.5237	3.3511	0.7175	0.6024	0.5714	0.3728	0.3667	0.0952	0.0626	0.0559	0.0033	0.0033
48 Cd	26.7112	4.0180	3.7270	3.5375	0.7702	0.6507	0.6165	0.4105	0.4037	0.1076	0.0669	0.0669	0.0093	0.0093
49 In	27.9399	4.2375	3.9380	3.7301	0.8256	0.7022	0.6643	0.4508	0.4431	0.1219	0.0774	0.0774	0.0162	0.0162
50 Sn	29.2001	4.4647	4.1561	3.9288	0.8838	0.7564	0.7144	0.4933	0.4848	0.1365	0.0886	0.0886	0.0239	0.0239
51 Sb	30.4912	4.6983	4.3804	4.1322	0.9437	0.8119	0.7656	0.5369	0.5275	0.1520	0.0984	0.0984	0.0314	0.0314
52 Te	31.8138	4.9392	4.6120	4.3414	1.0060	0.8697	0.8187	0.5825	0.5721	0.1683	0.1102	0.1102	0.0398	0.0398
53 I	33.1694	5.1881	4.8521	4.5571	1.0721	0.9305	0.8746	0.6313	0.6194	0.1864	0.1227	0.1227	0.0496	0.0496
54 Xe	34.5644	5.4528	5.1037	4.7822	1.1487	1.0021	0.9406	0.6894	0.6767	0.2133	0.1455	0.1455	0.0695	0.0675
55 Cs	35.9846	5.7143	5.3594	5.0119	1.2171	1.0650	0.9976	0.7395	0.7255	0.2308	0.1723	0.1616	0.0788	0.0765
56 Ba	37.4406	5.9888	5.6236	5.2470	1.2928	1.1367	1.0622	0.7961	0.7807	0.2530	0.1918	0.1797	0.0925	0.0899
57 La	38.9246	6.2663	5.8906	5.4827	1.3613	1.2044	1.1234	0.8485	0.8317	0.2704	0.2058	0.1914	0.0989	0.0989
58 Ce	40.4430	6.5488	6.1642	5.7234	1.4346	1.2728	1.1854	0.9013	0.8833	0.2896	0.2233	0.2072	0.1100	0.1100
59 Pr	41.9906	6.8348	6.4404	5.9643	1.5110	1.3374	1.2422	0.9511	0.9310	0.3045	0.2363	0.2176	0.1132	0.1132
60 Nd	43.5689	7.1260	6.7215	6.2079	1.5753	1.4028	1.2974	0.9999	0.9777	0.3152	0.2433	0.2246	0.1175	0.1175
61 Pm	45.1840	7.4279	7.0128	6.4593	1.6500	1.4714	1.3569	1.0515	1.0269	0.3310	0.2420	0.2420	0.1204	0.1204
62 Sm	46.8342	7.7368	7.3118	6.7162	1.7228	1.5407	1.4198	1.1060	1.0802	0.3457	0.2656	0.2474	0.1290	0.1290
63 Eu	48.5190	8.0520	7.6171	6.9769	1.8000	1.6139	1.4806	1.1606	1.1309	0.3602	0.2839	0.2566	0.1332	0.1332
64 Gd	50.2391	8.3756	7.9303	7.2428	1.8808	1.6883	1.5440	1.2172	1.1852	0.3758	0.2885	0.2709	0.1405	0.1405
65 Tb	51.9957	8.7080	8.2516	7.5140	1.9675	1.7677	1.6113	1.2750	1.2412	0.3979	0.3102	0.2850	0.1470	0.1470
66 Dy	53.7885	9.0458	8.5806	7.7901	2.0468	1.8418	1.6756	1.3325	1.2949	0.4163	0.3318	0.2929	0.1542	0.1542
67 Ho	55.6177	9.3942	8.9178	8.0711	2.1283	1.9228	1.7412	1.3915	1.3514	0.4357	0.3435	0.3066	0.1610	0.1610
68 Er	57.4855	9.7513	9.2643	8.3579	2.2065	2.0058	1.8118	1.4533	1.4093	0.4491	0.3662	0.3200	0.1767	0.1676
69 Tm	59.3896	10.1157	9.6169	8.6480	2.3068	2.0898	1.8845	1.5146	1.4677	0.4717	0.3859	0.3366	0.1796	0.1796
70 Yb	61.3323	10.4864	9.9782	8.9436	2.3981	2.1730	1.9498	1.5763	1.5278	0.4872	0.3967	0.3435	0.1981	0.1849
71 Lu	63.3138	10.8704	10.3486	9.2441	2.4912	2.2635	2.0236	1.6394	1.5885	0.5062	0.4101	0.3593	0.2048	0.1950
72 Hf	65.3508	11.2707	10.7394	9.5607	2.6009	2.3654	2.1076	1.7164	1.6617	0.5381	0.4370	0.3804	0.2238	0.2137
73 Ta	67.4164	11.6815	11.1361	9.8811	2.7080	2.4687	2.1940	1.7932	1.7351	0.5655	0.4648	0.4045	0.2413	0.2293
74 W	69.5250	12.0998	11.5440	10.2068	2.8196	2.5749	2.2810	1.8716	1.8092	0.5950	0.4916	0.4253	0.2588	0.2454
75 Re	71.6764	12.5267	11.9587	10.5353	2.9317	2.6816	2.3673	1.9489	1.8829	0.6250	0.5179	0.4444	0.2737	0.2602
76 Os	73.8708	12.9680	12.3850	10.8709	3.0485	2.7922	2.4572	2.0308	1.9601	0.6543	0.5465	0.4682	0.2894	0.2728
77 Ir	76.1110	13.4185	12.8241	11.2152	3.1737	2.9087	2.5507	2.1161	2.0404	0.6901	0.5771	0.4943	0.3114	0.2949
78 Pt	78.3948	13.8805	13.2726	11.5638	3.2976	3.0270	2.6453	2.2015	2.1211	0.7240	0.6076	0.5191	0.3307	0.3138
79 Au	80.7249	14.3528	13.7336	11.9187	3.4249	3.1478	2.7430	2.2911	2.2057	0.7588	0.6437	0.5454	0.3520	0.3339
80 Hg	83.1023	14.8393	14.2087	12.2839	3.5616	3.2785	2.8471	2.3849	2.2949	0.8030	0.6810	0.5769	0.3785	0.3593
81 Tl	85.5304	15.3467	14.6979	12.6575	3.7041	3.4157	2.9566	2.4851	2.3893	0.8455	0.7213	0.6090	0.4066	0.3862
82 Pb	88.0045	15.8608	15.2000	13.0352	3.8507	3.5542	3.0664	2.5856	2.4840	0.8936	0.7639	0.6445	0.4352	0.4129
83 Bi	90.5259	16.3875	15.7111	13.4186	3.9991	3.6963	3.1769	2.6876	2.5796	0.9382	0.8053	0.6789	0.4636	0.4400
84 Po	93.1000	16.9280	16.2370	13.8100	4.1520	3.8440	3.2930	2.7940	2.6800	0.9870	0.8510	0.7150	0.4950	0.4690
85 At	95.7240	17.4820	16.7760	14.2070	4.3100	3.9940	3.4090	2.9010	2.7810	1.0380	0.8970	0.7510	0.5270	0.4990
86 Rn	98.3970	18.0480	17.3280	14.6100	4.4730	4.1500	3.5290	3.0120	2.8840	1.0900	0.9440	0.7900	0.5580	0.5300
87 Fr	101.1300	18.6340	17.8990	15.0250	4.6440	4.3150	3.6560	3.1290	2.9940	1.1480	0.9990	0.8340	0.5970	0.5670
88 Ra	103.9150	19.2320	18.4840	15.4440	4.8220	4.4830	3.7850	3.2480	3.1050	1.2080	1.0550	0.8790	0.6360	0.6030
89 Ac	106.7560	19.8460	19.0810	15.8700	4.9990	4.6550	3.9150	3.3700	3.2190	1.2690	1.1120	0.9240	0.6760	0.6400
90 Th	109.6500	20.4720	19.6930	16.3000	5.1820	4.8310	4.0460	3.4910	3.3320	1.3300	1.1680	0.9670	0.7130	0.6770
91 Pa	112.5960	21.1050	20.3140	16.7330	5.3610	5.0010	4.1740	3.6060	3.4420	1.3830	1.2170	1.0040	0.7430	0.7080
92 U	115.6020	21.7580	20.9480	17.1680	5.5480	5.1810	4.3040	3.7260	3.5500	1.4410	1.2710	1.0430	0.7790	0.7370
93 Np	118.6690	22.4270	21.6000	17.6100	5.7390	5.3660	4.4350	3.8490	3.6640	1.5010	1.3280	1.0850	0.8160	0.7710
94 Pu	121.7910	23.1040	22.2660	18.0570	5.9330	5.5470	4.5630	3.9700	3.7750	1.5590	1.3800	1.1230	0.8460	0.7980
95 Am	124.9820	23.8080	22.9520	18.5100	6.1330	5.7390	4.6980	4.0960	3.8900	1.6200	1.4380	1.1650	0.8800	0.8290
96 Cm	128.2410	24.5260	23.6510	18.9700	6.3370	5.9370	4.8380	4.2240	4.0090	1.6840	1.4980	1.2070	0.9160	0.8620
97 Bk	131.5560	25.2560	24.3710	19.4350	6.5450	6.1380	4.9760	4.3530	4.1270	1.7480	1.5580	1.2490	0.9550	0.8980
98 Cf	134.9390	26.0100	25.1080	19.9070	6.7610	6.3450	5.1160	4.4840	4.2470	1.8130	1.6200	1.2920	0.9910	0.9300
99 Es	138.3960	26.7820	25.8650	20.3840	6.9810	6.5580	5.2590	4.6170	4.3680	1.8830	1.6830	1.3360	1.0290	0.9650
100 Fm	141.9260	27.5740	26.6410	20.8680	7.2080	6.7760	5.4050	4.7520	4.4910	1.9520	1.7490	1.3790	1.0670	1.0000
101 Md	146.5260	28.3870	27.4380	21.3560	7.4400	7.0010	5.5520	4.8890	4.6150	2.0240	1.8160	1.4240	1.1050	1.0340
102 No	149.2080	29.2210	28.2550	21.8510	7.6780	7.2310	5.7020	5.0280	4.7410	2.0970	1.8850	1.4690	1.1450	1.0700
103 Lr	152.9700	30.0830	29.1030	22.3590	7.9300	7.4740	5.8600	5.1760	4.8760	2.1800	1.9630	1.5230	1.1920	1.1120
104 Rf	156.2880	30.8810	29.9860	22.9070	8.1610	7.7380	6.0090	5.3360	5.0140	2.2370	2.0350	1.5540	1.2330	1.1490

El	K	L_1	L_2	L_3	M_1	M_2	M_3	M_4	M_5	N_1	N_2	N_3	N_4	N_5

Table 2. Atomic-Electron Binding Energies (continued)

El	N_6	N_7	O_1	O_2	O_3	O_4	O_5	O_6	O_7	P_1	P_2	P_3	P_4	P_5
48 Cd			0.0022	0.0022	0.0022									
49 In			0.0001	0.0008	0.0008									
50 Sn			0.0009	0.0011	0.0011									
51 Sb			0.0067	0.0021	0.0021									
52 Te			0.0116	0.0023	0.0023									
53 I			0.0136	0.0033	0.0033									
54 Xe			0.0234	0.0134	0.0121									
55 Cs			0.0227	0.0131	0.0114									
56 Ba			0.0291	0.0166	0.0146									
57 La			0.0323	0.0144	0.0144									
58 Ce	0.0001	0.0001	0.0378	0.0198	0.0198									
59 Pr	0.0020	0.0020	0.0374	0.0223	0.0223									
60 Nd	0.0015	0.0015	0.0375	0.0211	0.0211									
61 Pm	0.0040	0.0040	0.0380	0.0220	0.0220									
62 Sm	0.0055	0.0055	0.0374	0.0213	0.0213									
63 Eu			0.0318	0.0220	0.0220									
64 Gd	0.0001	0.0001	0.0361	0.0203	0.0203									
65 Tb	0.0026	0.0026	0.0390	0.0254	0.0254									
66 Dy	0.0042	0.0042	0.0629	0.0263	0.0263									
67 Ho	0.0037	0.0037	0.0512	0.0203	0.0203									
68 Er	0.0043	0.0043	0.0598	0.0294	0.0294									
69 Tm	0.0053	0.0053	0.0532	0.0323	0.0323									
70 Yb	0.0063	0.0063	0.0541	0.0234	0.0234									
71 Lu	0.0069	0.0069	0.0568	0.0280	0.0280	0.0046	0.0046							
72 Hf	0.0171	0.0171	0.0649	0.0381	0.0306	0.0066	0.0066							
73 Ta	0.0275	0.0256	0.0711	0.0449	0.0364	0.0057	0.0057							
74 W	0.0379	0.0358	0.0771	0.0468	0.0356	0.0061	0.0061							
75 Re	0.0481	0.0457	0.0828	0.0456	0.0346	0.0035	0.0035							
76 Os	0.0538	0.0510	0.0837	0.0580	0.0454									
77 Ir	0.0640	0.0610	0.0952	0.0630	0.0505	0.0038	0.0038							
78 Pt	0.0745	0.0711	0.1017	0.0653	0.0510	0.0021	0.0021							
79 Au	0.0878	0.0841	0.1078	0.0717	0.0587	0.0025	0.0025							
80 Hg	0.1040	0.0999	0.1203	0.0840	0.0650	0.0098	0.0078							
81 Tl	0.1231	0.1188	0.1363	0.0996	0.0730	0.0153	0.0131							
82 Pb	0.1412	0.1363	0.1473	0.1048	0.0830	0.0218	0.0192			0.0031	0.0007	0.0007		
83 Bi	0.1624	0.1571	0.1593	0.1168	0.0930	0.0265	0.0244			0.0080	0.0027	0.0027		
84 Po	0.1840	0.1780	0.1760	0.1320	0.1020	0.0340	0.0300			0.0090	0.0040	0.0010		
85 At	0.2060	0.1990	0.1920	0.1440	0.1130	0.0410	0.0370			0.0130	0.0060	0.0010		
86 Rn	0.2290	0.2220	0.2080	0.1580	0.1230	0.0480	0.0430			0.0160	0.0080	0.0020		
87 Fr	0.2580	0.2490	0.2290	0.1780	0.1380	0.0600	0.0550			0.0240	0.0140	0.0070		0.0038
88 Ra	0.2870	0.2790	0.2510	0.1970	0.1530	0.0720	0.0660			0.0310	0.0200	0.0120		0.0047
89 Ac	0.3160	0.3070	0.2720	0.2170	0.1680	0.0840	0.0760			0.0370	0.0240	0.0150	0.0044	0.0054
90 Th	0.3440	0.3350	0.2900	0.2360	0.1800	0.0940	0.0870			0.0410	0.0240	0.0170	0.0055	0.0059
91 Pa	0.3660	0.3550	0.3050	0.2450	0.1880	0.0970	0.0900	0.0073		0.0430	0.0270	0.0170	0.0046	0.0056
92 U	0.3890	0.3790	0.3240	0.2570	0.1940	0.1040	0.0950	0.0085		0.0440	0.0270	0.0170	0.0046	0.0057
93 Np	0.4140	0.4030	0.3380	0.2740	0.2060	0.1090	0.1010	0.0097		0.0470	0.0290	0.0180	0.0046	0.0058
94 Pu	0.4360	0.4240	0.3500	0.2830	0.2130	0.1130	0.1020	0.0070		0.0460	0.0290	0.0160		0.0054
95 Am	0.4610	0.4460	0.3650	0.2980	0.2190	0.1160	0.1060	0.0079	0.0066	0.0480	0.0290	0.0160		0.0055
96 Cm	0.4840	0.4700	0.3830	0.3130	0.2290	0.1240	0.1100	0.0129	0.0113	0.0500	0.0300	0.0160	0.0045	0.0061
97 Bk	0.5110	0.4950	0.3990	0.3260	0.2370	0.1300	0.1170	0.0140	0.0122	0.0520	0.0320	0.0160	0.0044	0.0062
98 Cf	0.5380	0.5200	0.4160	0.3410	0.2450	0.1370	0.1220	0.0105	0.0087	0.0540	0.0330	0.0170		0.0057
99 Es	0.5640	0.5460	0.4340	0.3570	0.2550	0.1420	0.1270	0.0113	0.0094	0.0570	0.0350	0.0170		0.0058
100 Fm	0.5910	0.5720	0.4520	0.3730	0.2620	0.1490	0.1330	0.0170	0.0147	0.0590	0.0360	0.0170	0.0042	0.0065
101 Md	0.6180	0.5970	0.4710	0.3890	0.2720	0.1540	0.1370	0.0129	0.0105	0.0610	0.0370	0.0170		0.0059
102 No	0.6450	0.6240	0.4900	0.4060	0.2800	0.1610	0.1420	0.0136	0.0111	0.0630	0.0380	0.0180		0.0060
103 Lr	0.6800	0.6580	0.5160	0.4290	0.2960	0.1740	0.1540	0.0199	0.0170	0.0710	0.0440	0.0210	0.0039	0.0069
104 Rf	0.7250	0.7010	0.5350	0.4480	0.3190	0.1900	0.1710	0.0260	0.0228	0.0820	0.0550	0.0330	0.0050	0.0075

El	N_6	N_7	O_1	O_2	O_3	O_4	O_5	O_6	O_7	P_1	P_2	P_3	P_4	P_5