
X-Ray Data Booklet

Section 1.8 ENERGY LEVELS OF FEW-ELECTRON IONIC SPECIES

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Table 1-4 presents ionization energies for selected few-electron ions with $6 \leq Z \leq 54$. Table 1-5 gives the energies of the resonant $2p$ transitions in hydrogen- and heliumlike ions. The energy values in this section have been generated using the relativistic Hartree-Fock code of I. P. Grant and collaborators [1] with a correction term of the form $A + B/(Z - Q)$ added to bring about agreement with the experimental values known for low atomic numbers. Nuclear size effects, radiative corrections, and the Breit interaction accounting for retardation and the magnetic electron-electron interaction are included in the calculations. The hydrogenic values are uncorrected as they come from the code, but to the accuracy given here, they agree with more detailed calculations. The values in Table 1-4 for Co-, Ni-, and Cu-like ions are based on data from C. E. Moore [2], J. Sugar and A. Musgrove [3], and others referenced therein.

REFERENCES

1. I. P. Grant, B. J. McKenzie, P. H. Norrington, D. F. Mayers, and N. C. Pyper, "An Atomic Multiconfigurational Dirac-Fock Package," *Comput. Phys. Commun.* **21**, 207 (1980).
2. C. E. Moore, *Ionization Potentials and Ionization Limits Derived from the Analysis of Optical Spectra*, NBS Pub. NSRDS-NBS 34 (1970).
3. J. Sugar and A. Musgrove, "Energy Levels of Zinc, Zn I through Zn XXX," *J. Phys. Chem. Ref. Data* **24**, 1803 (1995).

X-Ray Data Booklet Table 1-4. *Ionization energies, in electron volts, for selected few-electron ionic species.*
Each column is labeled with the number of electrons in the ion before ionization and with the symbol for the neutral atom with the same number of electrons.

Element	1 (H)	2 (He)	3 (Li)	4 (Be)	10 (Ne)	11 (Na)	12 (Mg)	27 (Co)	28 (Ni)	29 (Cu)
6 C	490.0	392.1	64.49	47.89						
7 N	667.1	552.1	97.89	77.48						
8 O	871.4	739.3	138.11	113.90						
9 F	1103.1	953.9	185.18	157.15						
10 Ne	1362.2	1195.8	239.09	207.26	21.564					
11 Na	1648.7	1465.1	299.86	264.21	47.286	5.139				
12 Mg	1962.7	1761.8	367.5	328.0	80.143	15.035	7.646			
13 Al	2304.2	2086.0	442.0	398.7	119.99	28.447	18.828			
14 Si	2673.2	2437.7	523.4	476.3	166.42	45.12	33.64			
15 P	3070	2816.9	611.7	560.8	220.31	65.02	51.50			
16 S	3494	3224	707.0	652.1	281.00	88.05	72.59			
17 Cl	3946	3658	809.2	750.5	348.5	114.20	96.84			
18 Ar	4426	4121	918.4	855.8	422.8	143.46	124.24			
19 K	4934	4611	1034.6	968.0	503.9	175.82	154.75			
20 Ca	5470	5129	1157.7	1087.3	591.9	211.28	188.38			
21 Sc	6034	5675	1288.0	1213.6	686.6	249.84	225.13			
22 Ti	6626	6249	1425.3	1346.9	788.2	291.50	264.98			
23 V	7246	6851	1569.7	1487.3	896.6	336.3	307.9			
24 Cr	7895	7482	1721.2	1634.8	1011.8	384.2	354.0			
25 Mn	8572	8141	1879.9	1789.5	1133.8	435.2	403.2			
26 Fe	9278	8828	2045.8	1951.3	1262.7	489.3	455.6			
27 Co	10012	9544	2218.9	2120.4	1398.3	546.6	511.0	7.86		
28 Ni	10775	10289	2399.3	2296.7	1540.8	607.0	569.7	18.17	7.63	
29 Cu	11568	11063	2587.0	2480.2	1690.2	670.6	631.4	36.83	20.29	7.73
30 Zn	12389	11865	2782.0	2671.1	1846.4	737.3	696.4	59.57	39.72	17.96
31 Ga	13239	12696	2984.4	2869.4	2009.4	807.3	764.5	86.0	63.4	30.7
32 Ge	14119	13557	3194	3075	2179.3	880.4	835.8	115.9	90.5	45.72
33 As	15029	14448	3412	3288	2356.0	956.8	910.3	149.2	121.2	62.3
34 Se	15968	15367	3637	3509	2539.6	1036.3	988.1	185.5	155.4	81.7
35 Br	16937	16317	3869	3737	2730.1	1119.1	1069.1	225.4	192.8	103.0

Table 1-4. Ionization energies, in electron volts, for selected few-electron ionic species. Each column is labeled with the number of electrons in the ion before ionization and with the symbol for the neutral atom with the same number of electrons.

Element	1 (H)	2 (He)	3 (Li)	4 (Be)	10 (Ne)	11 (Na)	12 (Mg)	27 (Co)	28 (Ni)	29 (Cu)
36 Kr	17936	17296	4109	3973	2927.4	1205.2	1153.3	268.2	233.4	125.9
37 Rb	18965	18306	4357	4216	3132	1294.5	1240.8	314.2	277.1	150.7
38 Sr	20025	19345	4612	4467	3343	1387.2	1331.5	363.3	324.1	177.3
39 Y	21115	20415	4876	4726	3561	1483.1	1425.6	413.6	374.0	205.9
40 Zr	22237	21516	5147	4993	3786	1582.4	1523.0	471	427.4	236.2
41 Nb	23389	22648	5426	5268	4017	1684.9	1623.7	530	483.8	268.5
42 Mo	24572	23810	5713	5550	4256	1790.9	1727.8	592	541.7	302.6
43 Tc	25787	25004	6008	5841	4502	1900.3	1835.2	656	605.8	338.5
44 Ru	27033	26230	6312	6140	4754	2013.0	1946.1	724	671.4	376.3
45 Rh	28312	27487	6623	6447	5014	2129.2	2060.3	795	740.1	416.0
46 Pd	29623	28776	6943	6762	5280	2248.9	2178.0	869	811.8	457.5
47 Ag	30966	30097	7271	7086	5553	2372.0	2299.2	946	886.6	500.9
48 Cd	32341	31451	7608	7418	5834	2498.6	2423.9	1026	964.5	546.2
49 In	33750	32837	7953	7758	6121	2628.8	2552.1	1109	1045.4	593.3
50 Sn	35192	34257	8307	8107	6415	2762.5	2683.9	1196	1129.1	642.3
51 Sb	36668	35710	8670	8465	6717	2899.8	2819.2	1285	1215.3	693.2
52 Te	38177	37196	9041	8832	7025	3041	2958.1	1377	1306.3	746.1
53 I	39721	38716	9421	9207	7340	3185	3101	1472	1399.3	800.8
54 Xe	41300	40271	9810	9591	7663	3334	3247	1571	1495.4	857.4

X-Ray Data Booklet Table 1-5. Transition energies, in electron volts, for transitions from the $n = 2$ states to the $n = 1$ ground state of H- and He- like ions.

Element	Hydrogenlike		Heliumlike	
	$2p_{1/2}$	$2p_{3/2}$	$2p\ ^3P_1$	$2p\ ^1P_1$
5 B	255.17	255.20	202.78	205.37
6 C	367.5	367.5	304.3	307.8
7 N	500.3	500.4	426.3	430.7
8 O	653.5	653.7	568.7	574.0
9 F	827.3	827.6	731.5	737.8
10 Ne	1021.5	1022.0	914.9	922.1
11 Na	1236.3	1237.0	1118.8	1126.9
12 Mg	1471.7	1472.7	1343.2	1352.3
13 Al	1727.7	1729.0	1588.3	1598.4
14 Si	2004.3	2006.1	1853.9	1865.1
15 P	2301.7	2304.0	2140.3	2152.6
16 S	2619.7	2622.7	2447.3	2460.8
17 Cl	2958.5	2962.4	2775.1	2789.8
18 Ar	3318	3323	3124	3140
19 K	3699	3705	3493	3511
20 Ca	4100	4108	3883	3903
21 Sc	4523	4532	4295	4316
22 Ti	4966	4977	4727	4750
23 V	5431	5444	5180	5205
24 Cr	5917	5932	5655	5682
25 Mn	6424	6442	6151	6181
26 Fe	6952	6973	6668	6701
27 Co	7502	7526	7206	7242
28 Ni	8073	8102	7766	7806
29 Cu	8666	8699	8347	8392
30 Zn	9281	9318	8950	8999
31 Ga	9917	9960	9575	9628
32 Ge	10575	10624	10221	10280
33 As	11255	11311	10889	10955
34 Se	11958	12021	11579	11652
35 Br	12682	12753	12292	12372
36 Kr	13429	13509	13026	13114
37 Rb	14199	14288	13783	13880
38 Sr	14990	15090	14562	14669
39 Y	15805	15916	15364	15482
40 Zr	16643	16765	16189	16318
41 Nb	17503	17639	17036	17178
42 Mo	18387	18537	17907	18062
43 Tc	19294	19459	18800	18971
44 Ru	20224	20406	19717	19904
45 Rh	21178	21377	20658	20861
46 Pd	22156	22374	21622	21843
47 Ag	23157	23396	22609	22851
48 Cd	24183	24444	23621	23884
49 In	25233	25518	24657	24942
50 Sn	26308	26617	25717	26027