

October 1966

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Subshell of Atoms and Ions from B to Zn.

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IPP 1/54

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**I N S T I T U T F Ü R P L A S M A P H Y S I K**

**G A R C H I N G B E I M Ü N C H E N**

# INSTITUT FÜR PLASMAPHYSIK

GARCHING BEI MÜNCHEN

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## Abstract

Binding energies of the next inner subshell are given for most ionization stages of the elements boron through zinc ( $Z = 30$ ). These binding energies are calculated along isoelectronic sequences with due regard to experimental values. Similarities in the periodic table are taken into account. The calculation is analogous to that used in the report IPP 1/54.

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*Die nachstehende Arbeit wurde im Rahmen des Vertrages zwischen dem Institut für Plasmaphysik GmbH und der Europäischen Atomgemeinschaft über die Zusammenarbeit auf dem Gebiete der Plasmaphysik durchgeführt.*

Abstract

Binding energies of the next inner subshell are given for most ionization stages of the elements boron through zinc ( $Z = 30$ ). These binding energies are calculated along isoelectronic sequences with full regard to experimental values. Similarities in the periodic table are taken into account. The calculation is analogous to that used in the report IPP 1/49.

The problem for carbon-like ions then is to derive a value for the term  $P_{1/2}$  of the next higher ionization stage and to add this value to the  $\lambda$ -level ionization potential in order to get the binding energy of the  $2s$ -electrons. Corresponding binding energies of other atoms and ions can be found in a similar way by applying the appropriate term values.

## Introduction

For the calculation of electron impact ionization cross sections<sup>1</sup> knowledge not only of the ionization potentials of atoms and ions<sup>2</sup> but also of binding energies of inner shell electrons is essential. As data on these binding energies are very scarce especially for ions it was tried to calculate these from AEL<sup>3</sup>.

To illustrate the method to be used carbon may be taken as an example: The electron configuration of atomic carbon C I is  $1s^2 2s^2 2p^2$ . The (first) ionization potential is defined as the energy necessary to remove one of the two 2p-electrons which is 11.260 eV. The next inner subshell here is populated by two 2s-electrons which have a 5.332 eV higher binding energy than the 2p-electrons, namely 16.592 eV. The removal of one 2s-electron results in an excited carbon ion C II of the configuration  $1s^2 2s 2p^2$ , the lowest term of this configuration is  $^4P_{1/2}$  and the term value can be found in AEL (1958) to be  $43004 \text{ cm}^{-1} \triangleq 5.332 \text{ eV}$ .

The problem for carbon-like ions then is to derive a correct value for the term  $^4P_{1/2}$  of the next higher ionization stage and to add this value to the (first) ionization potential in order to get the binding energy of the 2s-electrons. Corresponding binding energies of other atoms and ions can be found in a similar way by applying the appropriate term values.

It was assumed that the "first difference" between term values is approaching a constant value near 5.9 eV. This assumption is in accordance with the few experimental data that seem to be reliable but might be questioned, more experimental data are needed to verify this assumption. A few term values are given as well in  $\text{cm}^{-1}$  in order to facilitate comparison with AEL.

### Calculation of Term Values

For boron-like through neon-like ions and for aluminum-like through argon-like ions the next inner subshell is populated by 2s- or 3s-electrons respectively. The binding energies of these electrons can be extracted from AEL by converting the above mentioned term values into electron volts with the conversion factor  $1 \text{ cm}^{-1} \cong 1.23981 \times 10^{-4} \text{ eV}$ . Missing values can be calculated along isoelectronic sequences by the difference method described in the report IPP 1/49<sup>2</sup>.

In table 2 to 13 term values not specially marked are derived directly from AEL Vol. I (1948) allowing for the corrections given in Vol. II (1952) and Vol. III (1958). Values marked with a star \* are from recent spectroscopic measurements. Values that are missing in AEL are underlined while values from AEL that have been found incorrect during calculations are underlined after the decimal point. These corrections are given only when the need for a correction was evident, if in doubt, the AEL values were preferred throughout.

For the Be-, B-, C-, Mg-, Al- and Si-sequence it was assumed that the "first difference" between term values is approaching a constant value near 1.8 eV. This assumption is in accordance with the few experimental data that seem to be reliable but might be questioned, more experimental data are needed to verify this assumption. A few term values are given as well in  $\text{cm}^{-1}$  in order to facilitate comparison with AEL.

The appropriate term values of the N-, O-, F-, P-, S-, and Cl-sequences are known more accurately and make extrapolations more reliable. Here the "third differences" tend to be rather small and constant.

Recent spectroscopic measurements yielded corrections to the term values of N IV<sup>4</sup>, Si III<sup>5</sup>, and S I<sup>6</sup>.

Values not specially marked are derived directly from AEL (1958). A star \* indicates that either the ionization potential or the respective term value stem from recent spectroscopic measurements. Underlining after the decimal point indicates corrections to AEL values while new values are underlined altogether.

Binding energies of rest inner (sub-)shells 1s, 2s and 2p cannot be extracted from AEL with the exception of K, L, M and in similar cases subionization from an excited level is indicated but the lowest subionization energies accurately shown only for 1s.

## Discussion

In table 1 the binding energy of the next inner subshell is given by adding the appropriate term value of table 2 to 13 to the ionization potential given in report IPP 1/49. (In table 14 a correction is given for the ionization potentials of the Si-sequence. Recently the ionization potential of N IV was determined to be<sup>4</sup> 77.471 eV and that of F II to be<sup>7</sup> 34.970 eV.)

Values not specially marked are derived directly from AEL (1958). A star \* indicates that either the ionization potential or the respective term value stem from recent spectroscopic measurements. Underlining after the decimal point indicates corrections to AEL values while new values are underlined altogether.

Binding energies of next inner (sub-)shells 1s, 2p and 3p cannot be extracted from AEL with the exception of K I. Here and in similar cases autoionization from an excited level is important but the lowest autoionization level is accurately known only for K I.

References

- <sup>1</sup>W.Lotz, Institut für Plasmaphysik, Garching bei München, report IPP 1/47, to be published in Astrophys. J. Suppl.
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- <sup>3</sup>C.E.Moore, Atomic Energy Levels (AEL), Nat. Bureau of Stand. Circular 467 (1949, 1952, and 1958).
- <sup>4</sup>R. Hallin, Ark. Fys. 32, 201 (1966).
- <sup>5</sup>Y.G. Toresson, Ark. Fys. 18, 389 (1960).
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Table 1: Binding Energies of the Vest Inner Subshell.

Calculated values are underlined, recent spectroscopic values are marked with a star. Values not specially marked are taken from [1].

$10^4 \text{ eV}$

Z	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	XIII	XIV	XV	XVI	XVII	XVIII	XIX	XX	XXI	XXII	XXIII	XXIV	XXV	XXVI	
1	12.12																										
2	16.54	30.57																									
3	20.33	35.63	45.36																								
4	26.43	47.59	61.21	67.22																							
5	37.35	53.80	70.22	77.29	82.22																						
6	48.47	60.41	78.12	85.18	90.12	94.12																					
7	60.69	70.26	89.13	96.19	101.13	105.13	109.13																				
8	74.02	85.18	104.05	111.11	116.05	120.05	124.05	128.05																			
9	88.45	100.61	119.48	126.54	131.48	135.48	139.48	143.48	147.48																		
10	103.88	116.04	134.91	141.97	146.91	150.91	154.91	158.91	162.91	166.91																	
11	120.31	132.47	151.34	158.40	163.34	167.34	171.34	175.34	179.34	183.34	187.34																
12	137.74	149.90	168.77	175.83	180.77	184.77	188.77	192.77	196.77	200.77	204.77	208.77															
13	156.17	168.33	187.20	194.26	199.20	203.20	207.20	211.20	215.20	219.20	223.20	227.20	231.20														
14	175.60	187.76	206.63	213.69	218.63	222.63	226.63	230.63	234.63	238.63	242.63	246.63	250.63	254.63													
15	196.03	208.19	227.06	234.12	239.06	243.06	247.06	251.06	255.06	259.06	263.06	267.06	271.06	275.06	279.06												
16	217.46	229.62	248.49	255.55	260.49	264.49	268.49	272.49	276.49	280.49	284.49	288.49	292.49	296.49	300.49	304.49											
17	239.89	252.05	270.92	277.98	282.92	286.92	290.92	294.92	298.92	302.92	306.92	310.92	314.92	318.92	322.92	326.92	330.92										
18	263.32	275.48	294.35	301.41	306.35	310.35	314.35	318.35	322.35	326.35	330.35	334.35	338.35	342.35	346.35	350.35	354.35	358.35									
19	287.75	299.91	318.78	325.84	330.78	334.78	338.78	342.78	346.78	350.78	354.78	358.78	362.78	366.78	370.78	374.78	378.78	382.78	386.78								
20	313.18	325.34	344.21	351.27	356.21	360.21	364.21	368.21	372.21	376.21	380.21	384.21	388.21	392.21	396.21	400.21	404.21	408.21	412.21	416.21							
21	339.61	351.77	370.64	377.70	382.64	386.64	390.64	394.64	398.64	402.64	406.64	410.64	414.64	418.64	422.64	426.64	430.64	434.64	438.64	442.64	446.64						
22	367.04	379.20	398.07	405.13	410.07	414.07	418.07	422.07	426.07	430.07	434.07	438.07	442.07	446.07	450.07	454.07	458.07	462.07	466.07	470.07	474.07	478.07					
23	395.47	407.63	426.50	433.56	438.50	442.50	446.50	450.50	454.50	458.50	462.50	466.50	470.50	474.50	478.50	482.50	486.50	490.50	494.50	498.50	502.50	506.50	510.50				
24	424.90	437.06	455.93	462.99	467.93	471.93	475.93	479.93	483.93	487.93	491.93	495.93	499.93	503.93	507.93	511.93	515.93	519.93	523.93	527.93	531.93	535.93	539.93	543.93	547.93		
25	455.33	467.49	486.36	493.42	498.36	502.36	506.36	510.36	514.36	518.36	522.36	526.36	530.36	534.36	538.36	542.36	546.36	550.36	554.36	558.36	562.36	566.36	570.36	574.36	578.36	582.36	
26	486.76	498.92	517.79	524.85	529.79	533.79	537.79	541.79	545.79	549.79	553.79	557.79	561.79	565.79	569.79	573.79	577.79	581.79	585.79	589.79	593.79	597.79	601.79	605.79	609.79	613.79	
27	519.19	531.35	550.22	557.28	562.22	566.22	570.22	574.22	578.22	582.22	586.22	590.22	594.22	598.22	602.22	606.22	610.22	614.22	618.22	622.22	626.22	630.22	634.22	638.22	642.22	646.22	
28	552.62	564.78	583.65	590.71	595.65	599.65	603.65	607.65	611.65	615.65	619.65	623.65	627.65	631.65	635.65	639.65	643.65	647.65	651.65	655.65	659.65	663.65	667.65	671.65	675.65	679.65	
29	587.05	599.21	618.08	625.14	630.08	634.08	638.08	642.08	646.08	650.08	654.08	658.08	662.08	666.08	670.08	674.08	678.08	682.08	686.08	690.08	694.08	698.08	702.08	706.08	710.08	714.08	
30	622.48	634.64	653.51	660.57	665.51	669.51	673.51	677.51	681.51	685.51	689.51	693.51	697.51	701.51	705.51	709.51	713.51	717.51	721.51	725.51	729.51	733.51	737.51	741.51	745.51	749.51	
31	658.91	671.07	690.94	697.00	701.94	705.94	709.94	713.94	717.94	721.94	725.94	729.94	733.94	737.94	741.94	745.94	749.94	753.94	757.94	761.94	765.94	769.94	773.94	777.94	781.94	785.94	
32	696.34	708.50	728.37	734.43	739.37	743.37	747.37	751.37	755.37	759.37	763.37	767.37	771.37	775.37	779.37	783.37	787.37	791.37	795.37	799.37	803.37	807.37	811.37	815.37	819.37	823.37	
33	734.77	746.93	766.80	772.86	777.80	781.80	785.80	789.80	793.80	797.80	801.80	805.80	809.80	813.80	817.80	821.80	825.80	829.80	833.80	837.80	841.80	845.80	849.80	853.80	857.80	861.80	
34	774.20	786.36	806.23	812.29	817.23	821.23	825.23	829.23	833.23	837.23	841.23	845.23	849.23	853.23	857.23	861.23	865.23	869.23	873.23	877.23	881.23	885.23	889.23	893.23	897.23	901.23	
35	814.63	826.79	846.66	852.72	857.66	861.66	865.66	869.66	873.66	877.66	881.66	885.66	889.66	893.66	897.66	901.66	905.66	909.66	913.66	917.66	921.66	925.66	929.66	933.66	937.66	941.66	
36	856.06	868.22	888.09	894.15	899.09	903.09	907.09	911.09	915.09	919.09	923.09	927.09	931.09	935.09	939.09	943.09	947.09	951.09	955.09	959.09	963.09	967.09	971.09	975.09	979.09	983.09	
37	898.49	910.65	930.52	936.58	941.52	945.52	949.52	953.52	957.52	961.52	965.52	969.52	973.52	977.52	981.52	985.52	989.52	993.52	997.52	1001.52	1005.52	1009.52	1013.52	1017.52	1021.52	1025.52	
38	941.92	954.08	973.95	979.01	983.95	987.95	991.95	995.95	999.95	1003.95	1007.95	1011.95	1015.95	1019.95	1023.95	1027.95	1031.95	1035.95	1039.95	1043.95	1047.95	1051.95	1055.95	1059.95	1063.95	1067.95	
39	986.35	998.51	1018.38	1023.44	1028.38	1032.38	1036.38	1040.38	1044.38	1048.38	1052.38	1056.38	1060.38	1064.38	1068.38	1072.38	1076.38	1080.38	1084.38	1088.38	1092.38	1096.38	1100.38	1104.38	1108.38	1112.38	
40	1031.78	1043.94	1063.81	1068.87	1073.81	1077.81	1081.81	1085.81	1089.81	1093.81	1097.81	1101.81	1105.81	1109.81	1113.81	1117.81	1121.81	1125.81	1129.81	1133.81	1137.81	1141.81	1145.81	1149.81	1153.81	1157.81	
41	1078.21	1090.37	1109.24	1114.30	1119.24	1123.24	1127.24	1131.24	1135.24	1139.24	1143.24	1147.24	1151.24	1155.24	1159.24	1163.24	1167.24	1171.24	1175.24	1179.24	1183.24	1187.24	1191.24	1195.24	1199.24	1203.24	
42	1125.64	1137.80	1156.67	1161.73	1166.67	1170.67	1174.67	1178.67	1182.67	1																	



Table 2: Be-Sequence,  $2s\ 2p\ ^3P_0$ .

Species	E (eV)	$\Delta$	E (cm <sup>-1</sup> )
Be I	2.725	1.904	21978
B II	4.629	1.864	37334
C III	6.493	1.840	52367
N IV	*8.333	1.822	67209
O V	<u>10.155</u>	1.822	8191 <sub>0</sub>
F VI	11.977	1.826	96601
Ne VII	<u>13.803</u>	1.825	11133 <sub>0</sub>
Na VIII	15.628	1.827	126053
Mg IX	17.455	1.815	140786
Al X	<u>19.27</u>	1.82	1554 <sub>00</sub>
Si XI	<u>21.09</u>	1.82	1701 <sub>00</sub>
P XII	<u>22.91</u>	1.82	1848 <sub>00</sub>
S XIII	<u>24.73</u>	1.82	
Cl XIV	<u>26.55</u>	1.82	
A XV	<u>28.37</u>	1.82	
K XVI	<u>30.19</u>	1.82	
Ca XVII	<u>32.01</u>	1.82	
Sc XVIII	<u>33.83</u>	1.82	
Ti XIX	<u>35.65</u>	1.82	
V XX	<u>37.47</u>	1.82	
Cr XXI	<u>39.29</u>	1.82	
Mn XXII	<u>41.11</u>	1.82	
Fe XXIII	<u>42.93</u>	1.82	
Co XXIV	<u>44.75</u>	1.82	
Ni XXV	<u>46.57</u>	1.82	
Cu XXVI	<u>48.39</u>	1.82	
Zn XXVII	<u>50.21</u>		

Table 3: B-Sequence,  $2s\ 2p^2\ 4P_{1/2}$  .

Species	E (eV)	$\Delta$	E (cm <sup>-1</sup> )
B I	3.571	1.761	28805
C II	5.332	1.759	43004
N III	7.091	1.775	57192
O IV	<u>8.866</u>	1.780	7151 <sub>0</sub>
F V	<u>10.646</u>	1.784	8587 <sub>0</sub>
Ne VI	<u>12.43</u>	1.79	1003 <sub>00</sub>
Na VII	<u>14.22</u>	1.80	1147 <sub>00</sub>
Mg VIII	<u>16.02</u>	1.81	1292 <sub>00</sub>
Al IX	<u>17.83</u>	1.82	1438 <sub>00</sub>
Si X	<u>19.65</u>	1.83	1585 <sub>00</sub>
P XI	<u>21.48</u>	1.83	1733 <sub>00</sub>
S XII	<u>23.31</u>	1.83	
Cl XIII	<u>25.14</u>	1.83	
A XIV	<u>26.97</u>	1.83	
K XV	<u>28.80</u>	1.83	
Ca XVI	<u>30.63</u>	1.83	
Sc XVII	<u>32.46</u>	1.83	
Ti XVIII	<u>34.29</u>	1.83	
V XIX	<u>36.12</u>	1.83	
Cr XX	<u>37.95</u>	1.83	
Mn XXI	<u>39.78</u>	1.83	
Fe XXII	<u>41.61</u>	1.83	
Co XXIII	<u>43.44</u>	1.83	
Ni XXIV	<u>45.27</u>	1.83	
Cu XXV	<u>47.10</u>	1.83	
Zn XXVI	<u>48.93</u>	1.83	

Table 4: C-Sequence,  $2s\ 2p^3\ ^5S_2$ .

Species	E (eV)	$\Delta$	E (cm <sup>-1</sup> )
C I	4.182		33735
N II	5.800	1.618	46785
O III	7.478	1.678	60312
F IV	<u>9.210</u>	1.732	7429 <sub>0</sub>
Ne V	<u>10.98</u>	1.77	885 <sub>60</sub>
Na VI	<u>12.78</u>	1.80	1031 <sub>00</sub>
Mg VII	<u>14.60</u>	1.82	1178 <sub>00</sub>
Al VIII	<u>16.43</u>	1.83	1325 <sub>00</sub>
Si IX	<u>18.26</u>	1.83	147 <sub>000</sub>
P X	<u>20.09</u>	1.83	162 <sub>000</sub>
S XI	<u>21.92</u>	1.83	
Cl XII	<u>23.75</u>	1.83	
A XIII	<u>25.58</u>	1.83	
K XIV	<u>27.41</u>	1.83	
Ca XV	<u>29.24</u>	1.83	
Sc XVI	<u>31.07</u>	1.83	
Ti XVII	<u>32.90</u>	1.83	
V XVIII	<u>34.73</u>	1.83	
Cr XIX	<u>36.56</u>	1.83	
Mn XX	<u>38.39</u>	1.83	
Fe XXI	<u>40.22</u>	1.83	
Co XXII	<u>42.05</u>	1.83	
Ni XXIII	<u>43.88</u>	1.83	
Cu XXIV	<u>45.71</u>	1.83	
Zn XXV	<u>47.54</u>	1.83	

Table 5: N-Sequence,  $2s 2p^4 4P_{5/2}$  .

Species	E(eV)	$\Delta$	$\Delta^2$
N I	10.924		
O II	14.858	3.934	
F III	18.832	3.974	
Ne IV	22.795	3.963	0.005
Na V	26.763	3.968	0.009
Mg VI	30.740	3.977	0.022
Al VII	34.739	3.999	0.027
Si VIII	38.765	4.026	0.031
P IX	42.822	4.057	0.038
S X	46.917	4.095	0.044
Cl XI	<u>51.056</u>	4.139	0.050
A XII	<u>55.245</u>	4.189	0.056
K XIII	<u>59.490</u>	4.245	0.062
Ca XIV	<u>63.797</u>	4.307	0.068
Sc XV	<u>68.172</u>	4.375	0.074
Ti XVI	<u>72.621</u>	4.449	0.080
V XVII	<u>77.150</u>	4.529	0.086
Cr XVIII	<u>81.765</u>	4.615	0.092
Mn XIX	<u>86.472</u>	4.707	0.098
Fe XX	<u>91.277</u>	4.805	0.104
Co XXI	<u>96.186</u>	4.909	0.110
Ni XXII	<u>101.205</u>	5.019	0.116
Cu XXIII	<u>106.340</u>	5.135	0.122
Zn XXIV	<u>111.597</u>	5.257	

Table 6: O-Sequence,  $2s 2p^5 3P_2$ .

Species	E(eV)	$\Delta$	$\Delta^2$
O I	15.655		
F II	20.432	4.777	
Ne III	25.328	4.896	
Na IV	30.212	4.884	0.017
Mg V	35.113	4.901	0.032
Al VI	40.046	4.933	0.047
Si VII	45.026	4.980	0.058
P VIII	50.064	5.038	0.070
S IX	<u>55.172</u>	5.108	0.082
Cl X	<u>60.362</u>	5.190	0.094
A XI	<u>65.646</u>	5.284	0.106
K XII	<u>71.036</u>	5.390	0.118
Ca XIII	<u>76.544</u>	5.508	0.130
Sc XIV	<u>82.182</u>	5.638	0.142
Ti XV	<u>87.962</u>	5.780	0.154
V XVI	<u>93.896</u>	5.934	0.166
Cr XVII	<u>99.996</u>	6.100	0.178
Mn XVIII	<u>106.274</u>	6.278	0.190
Fe XIX	<u>112.742</u>	6.468	0.202
Co XX	<u>119.412</u>	6.670	0.214
Ni XXI	<u>126.296</u>	6.884	0.226
Cu XXII	<u>133.406</u>	7.110	0.238
Zn XXIII	<u>140.754</u>	7.348	

Table 7: F-Sequence,  $2s\ 2p^6\ 2s_{1/2}$  .

Species	E(eV)	$\Delta$	$\Delta^2$
F I	21.055	5.855	0.005
Ne II	26.910	5.877	0.005
Na III	32.787	5.836	0.005
Mg IV	38.623	5.863	0.027
Al V	44.486	5.912	0.049
Si VI	50.398	5.980	0.068
P VII	56.378	6.058	0.078
S VIII	62.436	6.153	0.095
Cl IX	<u>68.589</u>	6.264	0.111
A X	<u>74.853</u>	6.391	0.127
K XI	<u>81.244</u>	6.534	0.143
Ca XII	<u>87.778</u>	6.693	0.159
Sc XIII	<u>94.471</u>	6.868	0.175
Ti XIV	<u>101.339</u>	7.059	0.191
V XV	<u>108.398</u>	7.266	0.207
Cr XVI	<u>115.664</u>	7.489	0.223
Mn XVII	<u>123.153</u>	7.728	0.239
Fe XVIII	<u>130.881</u>	7.983	0.255
Co XIX	<u>138.864</u>	8.254	0.271
Ni XX	<u>147.118</u>	8.541	0.287
Cu XXI	<u>155.659</u>	8.844	0.303
Zn XXII	<u>164.503</u>		

Table 8: Mg-Sequence, 3s 3p <sup>3</sup>P<sub>0</sub>.

Species	E(eV)	Δ	E(cm <sup>-1</sup> )
Mg I	2.709	1.927	21850
Al II	4.636	1.901	37393
Si III	*6.537	1.883	52725
P IV	8.420	1.879	67912
S V	10.299	1.869	83071
Cl VI	12.168	1.854	98147
A VII	14.022	1.844	113095
K VIII	15.866	1.818	127968
Ca IX	17.684	1.810	142635
Sc X	19.494	1.826	157230
Ti XI	<u>21.32</u>	1.82	172000
V XII	<u>23.14</u>	1.82	186700
Cr XIII	<u>24.96</u>	1.82	201300
Mn XIV	<u>26.78</u>	1.82	216000
Fe XV	<u>28.60</u>	1.82	231000
Co XVI	<u>30.42</u>	1.82	
Ni XVII	<u>32.24</u>	1.82	
Cu XVIII	<u>34.06</u>	1.82	
Zn XIX	<u>35.88</u>		

Table 9: Al-Sequence,  $3s\ 3p^2\ ^4P_{1/2}$  .

Species	E (eV)	$\Delta$	E (cm <sup>-1</sup> )
Al I	3.598		29020
Si II	5.309	1.711	42824
P III	7.057	1.748	56919
S IV	<u>8.83</u>	1.773	712 <sub>00</sub>
Cl V	<u>10.61</u>	1.78	856 <sub>00</sub>
A VI	12.40	1.79	1000 <sub>00</sub>
K VII	<u>14.19</u>	1.79	1145 <sub>00</sub>
Ca VIII	<u>15.99</u>	1.80	1290 <sub>00</sub>
Sc IX	<u>17.79</u>	1.80	1435 <sub>00</sub>
Ti X	<u>19.60</u>	1.81	
V XI	<u>21.4</u>	1.80	
Cr XII	<u>23.2</u>	1.8	
Mn XIII	<u>25.0</u>	1.8	
Fe XIV	<u>26.8</u>	1.8	
Co XV	<u>28.6</u>	1.8	
Ni XVI	<u>30.4</u>	1.8	
Cu XVII	<u>32.2</u>	1.8	
Zn XVIII	<u>34.0</u>	1.8	

Table 10: Si-Sequence,  $3s\ 3p^3\ ^5S_2$  .

Species	E (eV)	$\Delta$
Si I	4.132	
P II	5.666	1.534
S III	<u>7.28</u>	1.614
Cl IV	<u>8.96</u>	1.68
A V	<u>10.69</u>	1.73
K VI	<u>12.45</u>	1.76
Ca VII	<u>14.23</u>	1.78
Sc VIII	<u>16.02</u>	1.79
Ti IX	<u>17.8</u>	1.8
V X	<u>19.6</u>	1.8
Cr XI	<u>21.4</u>	1.8
Mn XII	<u>23.2</u>	1.8
Fe XIII	<u>25.0</u>	1.8
Co XIV	<u>26.8</u>	1.8
Ni XV	<u>28.6</u>	1.8
Cu XVI	<u>30.4</u>	1.8
Zn XVII	<u>32.2</u>	1.8

Table 11: P-Sequence,  $3s\ 3p^4\ ^4P_{5/2}$  .

Species	E(eV)	$\Delta$	$\Delta^2$
P I	7.381	2.462	
S II	9.843	2.372	
Cl III	12.215	2.361	
A IV	14.576	2.365	0.004
K V	16.941	2.374	0.009
Ca VI	19.315	2.388	0.014
Sc VII	21.703	2.407	0.019
Ti VIII	<u>24.110</u>	2.431	0.024
V IX	<u>26.541</u>	2.460	0.029
Cr X	<u>29.001</u>	2.494	0.034
Mn XI	<u>31.495</u>	2.533	0.039
Fe XII	<u>34.028</u>	2.577	0.044
Co XIII	<u>36.605</u>	2.626	0.049
Ni XIV	<u>39.231</u>	2.680	0.054
Cu XV	<u>41.911</u>	2.739	0.059
Zn XVI	<u>44.650</u>		

Table 12: S-Sequence,  $3s\ 3p^5\ ^3P_2$

Species	E(eV)	$\Delta$	$\Delta^2$
S I	*8.929	2.647	
Cl II	11.576	2.533	
A III	14.109	2.527	
K IV	16.636	2.539	0.012
Ca V	19.175	2.564	0.025
Sc VI	21.739	2.594	0.030
Ti VII	24.333	2.632	0.038
V VIII	<u>26.965</u>	2.678	0.046
Cr IX	<u>29.643</u>	2.732	0.054
Mn X	<u>32.375</u>	2.794	0.062
Fe XI	<u>35.169</u>	2.864	0.070
Co XII	<u>38.033</u>	2.942	0.078
Ni XIII	<u>40.975</u>	3.028	0.086
Cu XIV	<u>44.003</u>	3.122	0.094
Zn XV	<u>47.125</u>		

Table 13: Cl-Sequence,  $3s 3p^6 2s_{1/2}$  .

Species	E(eV)	$\Delta$	$\Delta^2$
Cl I	<u>10.77</u>		
A II	13.479	2.71	
K III	16.193	2.714	
Ca IV	18.898	2.705	0.021
Sc V	21.624	2.726	0.027
Ti VI	24.377	2.753	0.042
V VII	27.172	2.795	0.053
Cr VIII	30.020	2.848	0.064
Mn IX	<u>32.932</u>	2.912	0.075
Fe X	<u>35.919</u>	2.987	0.086
Co XI	<u>38.992</u>	3.073	0.097
Ni XII	<u>42.162</u>	3.170	0.108
Cu XIII	<u>45.440</u>	3.278	0.119
Zn XIV	<u>48.837</u>	3.397	

Co XIV

411

26.4

1.8

Ni XV

461

28.2

1.8

Cu XVI

520

30.0

1.8

Zn XVII

579

31.8

1.8

Table 14: Si-Sequence,  $3p^2 3p_0$ .  
 Corrected ionization potentials  
 (see IPP 1/49, Table 15).

Species	IP	$\Delta(\text{Na})$	$\Delta^2$
Si I	8.151	3.012	
P II	*19.725	4.690	1.678
S III	35.0	6.55	1.86
Cl IV	53.5	8.36	1.81
A V	<u>75.2</u>	10.18	1.82
K VI	<u>100.0</u>	12.0	1.82
Ca VII	<u>128.0</u>	13.8	1.8
Sc VIII	<u>159.0</u>	15.6	1.8
Ti IX	<u>193.2</u>	17.4	1.8
V X	<u>230.5</u>	19.2	1.8
Cr XI	<u>270.8</u>	21.0	1.8
Mn XII	<u>314.3</u>	22.8	1.8
Fe XIII	<u>361.0</u>	24.6	1.8
Co XIV	<u>411</u>	26.4	1.8
Ni XV	<u>464</u>	28.2	1.8
Cu XVI	<u>520</u>	30.0	1.8
Zn XVII	<u>579</u>	31.8	1.8