THE SPARK SPECTRUM OF NICKEL (Ni II)

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Abstract

The analysis of the spark spectrum of nickel shows that the important atomic structures are d^8s and d^8p. The low set of terms comprises $^4F'$, $^2F'$, $^4P'$, $^2P'$, ^2D, ^2G of which $^4F^{5\prime}$ is lowest. The only expected term from the structure d^8s which has not been found is ^2S. All the intermediate terms (d^8p) have been found with the exception of a ^2P, and a doubtful ^2F and $^2S'$. A higher member of the $^4F'$ $^2F'$ series (d^8, s) has been found and indicates an I.P. of 17.4 volts from d^8s to d^8. The expected lowest term $^2D(d^9)$ has not been found. Terms are inverted with the following exceptions: (1) $a^4G^{6\prime}$ is higher than $a^4G^{5\prime}$, (2) $a^4P^{3\prime}$ is higher than $a^4P^{1\prime}$, (3) $b^4D^{4\prime}$ is higher than $b^4D^{1\prime}$, (4) triad b^2P, D', F is not inverted. Zeeman effects give some irregular g-values, but the g-sum rule is apparently satisfied. The g-sum rule is found to be not confined to terms built on the same ion term.

THE wave-lengths of the spark spectrum of nickel have been measured by various investigators[1] but none of the published lists are sufficiently complete for an extended analysis of the spectral structure. Some time ago Dr. Meggers of the Bureau of Standards made very complete measurements between λ3500 and λ2150 with a view to undertaking such an analysis. Subsequent circumstances, however, made it impossible to start the investigation, and he has been kind enough to allow the author of this paper the use of all of his material. The measurements down to λ2600 were made from plates taken with the Bureau concave grating; and from that point to λ2150 on an Hilger E.1 quartz spectrograph using the copper standards determined by Mitra.[2]

The author has extended the measurements to λ1944 on a similar instrument using the copper spark lines as standards. The frequencies of these lines were determined in the course of the author's analysis of Cu II.[3] The method of calculation was devised by Professor H. N. Russell and determines wave-numbers directly. The wave-lengths below λ2165 given in the table of lines (Table IV) were calculated from the wave-numbers. Three of the strong lines measured by Meggers have been found to be double and have been re-measured. They are noted in Table IV. Measurements were also made on a small Hilger quartz instrument to λ1830. These are, of course, much less accurate. There are, in all, twenty-eight lines which appear reversed in the spark. Most of these, including all the strong reversals, were observed by Meggers as absorption lines in the under-water spark. The line intensities are partly the author's rather rough estimates and partly Meggers'. They have been especially examined in all crucial cases.

[1] H. Kayser, "Handbuch der Spectroscopie," Vol. 6, p. 172.

[2] Mitra, Ann. d. Physique, **19**, 315 (1923).

[3] A. G. Shenstone, Phys. Rev. **29**, 380 (1926).

The structure of the spectrum is deducible from the principles given by Hund.[4] The predicted terms are given in Table I. The electron configurations are denoted by symbols in which small letters (s, p, d, etc.) are use to indicate the k-values of the orbits and indices the number of electrons: Closed groups of electrons are omitted for convenience.

TABLE I

Theoretical and empirical terms in the spectrum of Ni II

Structure	Terms (theoretical)	Terms (empirical)
d^9	^2D	
d^8s	$^4F'$ $^2F'$ $^4P'$ $^2P'$ ^2S ^2D ^2G	a^4F', a^2F', a^4P', a^2P' a^2D a^2G
d^8p	$^4D'$, F, G'. $^2D'$, F, G' $^4S'$, P, D'. $^2S'$, P, D' ^2P ^2P, D', F ^2F, G' H	a^4D', F, G'. a^2D', F, G'. b^4S', P, D' c^2S', P, D' b^2P, D', F c^2F, b^2G', b^2H
d^8, s	$^4F'$, $^2F'$, $^4P'$, $^2P'$ ^2S, ^2D, ^2G.	d^4F', d^2F'

The convention as to the "priming" of the spectral terms is that proposed by Heisenberg.[5] When the atomic structure contains an even number of p (and f) electrons, the terms are called S, P', D, etc.; when the number is odd, S', P, D', etc. Small letters have been used in the term notation merely to differentiate between terms of the same kind. The letters have no other significance.

The empirical terms are contained in Table II, the term values being given with reference to a^4F_5' taken as zero. The expected lowest term ^2D (d^9) has not been found and is discussed below. The lowest term found is a^4F' (d^8s). It is accompanied by a^2F' and combines very strongly with the related triad $a^{4,2}D'$, F, G'. The terms are all inverted and the interval rule holds approximately except for the fact that a^4G_6' is higher than a^4G_5'. This behaviour of the component term of highest j-value in a triad is paralleled in the corresponding terms of Cu II ($^3F_4$) and Ni I ($^3F_4$). The combination $a^4F_5' - a^4G_6'$ is extraordinarily strongly reversed, even appearing as a reversed line in the ordinary arc.

The remaining predicted terms from the low structure d^8s have all been found except ^2S, and are considerably higher than a^4F'. They combine very irregularly with the triad $a^{4,2}D'F\ G'$. Their strong combinations are with their own triads and lie in the same general region of the spectrum as the a^4F' multiplets. The three strongest lines are slightly reversed, namely: $a^2D_3 - b^2F_4$, $a^4P_3' - b^4D_4'$, $a^2G_5 - b^2H_6$. These lines were not observed by Meggers in the under-water spark.

[4] Hund, Linienspektra und Periodisches System der Elemente, Berlin, 1927, (Julius Springer).

[5] Heisenberg, Zeits. f. Physik. 32, 859 (1925).

TABLE II

Empirical terms in the spectrum of Ni II.

Type	Terms	Intervals		g	Type	Terms	Intervals		g
a^4F_5'	0.0	936.4		L	b^4P_3	58176.8	8.6		1.46
a^4F_4'	936.4	785.4		L	b^4P_2	58185.4	451.2		1.60?
a^4F_3'	1721.8	548.3		L	b^4P_1	58636.6			2.36
a^4F_2'	2270.1			L	b^2F_3	59300.1	436.8		.95
a^2F_4'	5156.2	1445.3		L	b^2F_4	59736.9			L
a^2F_3'	6601.5			L	b^2D_2'	59760.0	581.2		L
a^2D_3	14714.0	688.0		1.46	b^2P_1	59887.3		684.1	1.00
a^2D_2	15402.0			1.10	b^2D_3'	60341.2			L
a^4P_2'	16394.0	47.8		1.47	b^2P_2	60571.4			L
a^4P_1'	16441.8	−247.7		L	b^4D_3'	62241.1	71.4		L
a^4P_3'	16641.7			1.40	b^4D_2'	62312.5	41.9		L
a^2P_2'	20676.5	522.5		L	b^4D_1'	62354.4	−142.2		L
a^2P_1'	21199.0			L	b^4D_4'	62383.3			L
a^2G_5	24105.3	24.0		L	c^2D_3'	63376.8	604.2		L
a^2G_4	24129.3			L	c^2D_2'	63981.0			L
a^4D_4'	43164.0	1180.5		L	c^2P_2	64591.1	917.5		L
a^4D_3'	44344.5			L	c^2P_1	65508.6			?
a^4G_5'	44971.1	895.5	−131.6	L	c^2S_1'	65888.9			?
a^4G_6'	45102.7			L	b^4S_2'	65906.2			L
a^4D_2'	45241.0	541.0	897.5	L	b^2H_5	66755.5	572.0		L
a^4D_1'	45782.0			L	b^2H_6	67327.5			L
a^4G_4'	45868.6			L	c^2F_3	67495.4?	27.8		?
a^4F_5	46163.2		756.1	L	c^2F_4	67523.2?			L
a^4G_3'	46624.7	860.6		L	b^2G_4'	71428.6	101.1		L
a^2G_5'	46905.9			L	b^2G_5'	71529.7			L
a^4F_4	47023.8	657.3	1071.6	L	d^4F_5'	83404.4	525.4		
a^4F_3	47681.1			L	d^4F_4'	83929.8	1064.1		
a^2G_4'	47977.5	349.4		L	d^4F_3'	84993.9	677.1		
a^4F_2	48030.5			L	d^4F_2'	85671.0			
a^2F_4	48686.2	1412.7		L	d^2F_4'	85132.2	1200.8		
a^2D_3'	49025.6			L	d^2F_3'	86333.0			
a^2F_3	50098.9		1285.9	L					
a^2D_2'	50311.5			L					

The intermediate triads (d^8p) which are intimately connected with a^4P', a^2D and a^2G are complete except for the rather doubtful c^2S', and c^2F terms; but the ^2P which would compose the whole "triad" of the missing low ^2S has not been found. These missing terms are probably somewhat higher.

The high terms d^4F' and d^2F' are undoubtedly the second member of the sequences headed by a^4F' and a^2F'. The similarity with the corresponding series terms of Cu II, Ni I, Pd I[6] is striking. The over-all separation of the d^4F' is 2266.6 as compared with 2270.1 for a^4F'. Assuming a Rydberg series given by the two terms, the limits of the component series are as follows:

$^4F_5'$	140772	$^3F_4'$
$^4F_4'$	141152	$^3F_3'$
$^4F_3'$	142318	$^3F_2'$
$^4F_2'$	143037	
$^2F_4'$	141284	
$^2F_3'$	142398	

The brackets indicate the pairs of terms which should converge to identical limits in the next higher ion spectrum. It is evident that just as in the other spectra referred to above, there is no indication in the limits calculated from two members of such a convergence. The ionization potential calculated from the $^4F_5'$ is 17.4 volts from d^8s to d^8.

The nature of the terms a^4F', a^2F' and their triads can be deduced simply from a consideration of intensities. That is also true for the large majority of the other terms, but in some cases Zeeman effects have been found necessary to remove any ambiguity. Observations of the Z.E. have, therefore, been made, the patterns measured including the vast majority of the lines of the spectrum. The photographs were taken on a Hilger E.1 quartz spectrograph using Cramer Contrast and Hilger Schumann plates. The magnet was one made for this laboratory in the Ryerson Laboratory in Chicago and produces a field of about 34,000 gauss on continuous operation. The source used was an arc between a plane anode and a knife-edge cathode with a current of about 1.5 amperes. Such a source emits practically the complete spark spectrum. Exposures ranged from a few seconds to twenty minutes. Measurements were made on several plates and averages taken to reduce as far as possible the errors arising from the smallness of the separations. The actual resolving power is greater than 47,000.

Table III contains Zeeman effect of forty-four lines, including all those completely resolved. It seems unnecessary to reproduce the remaining large number of unresolved patterns, since those given are sufficient to fix the only doubtful cases. In the table, where it seems probable that the g-values of the terms agree with Lande's values, they are given as fractions. Where they are given as decimals they are in disagreement with Lande and are not to be considered as possessing great accuracy. Table III has been arranged to show the sequence by which the various g-values were determined.

The Z.E.'s show conclusively that the terms a^4F' a^2F' and their triads have g-values very close to those given by Lande's formula. The case is quite different when we consider a^4P' and a^2D. The two levels a^4P_3' and a^2D_3 should have g's equal to 8/5 and 6/5, whereas they have actually almost equal values. The intensities of their combinations are also irregular. For instance, a^2D_3 combines much more strongly with b^4P_3 than does a^4P_3';

[6] A. G. Shenstone, Phys. Rev. **29**, 380 (1926).

TABLE III

Zeman effect of forty-four lines in the spectrum of Ni II.

λ	$x-y$	Pattern	g_x	g_y	Remarks
2165.55	$a^4F_5'-a^4F_5$	Obs (0) 1.34 Cal (0) 1.33	$\frac{4}{3}$	$\frac{4}{3}$	
2169.10	$a^4F_4'-a^4F_4$	Obs (0) 1.24 Cal (0) 1.24	$\frac{78}{63}$	$\frac{78}{63}$	
2175.16	$a^4F_3'-a^4F_3$	Obs (0) 1.00 Cal (0) 1.03	$\frac{36}{35}$	$\frac{36}{35}$	
2184.61	$a^4F_2'-a^4F_2$	Obs (0) .39 Cal (0) .40	$\frac{2}{5}$	$\frac{2}{5}$	
2158.73	$a^4F_3'-a^4F_2$	Obs ($\bar{*}$.94) 0 ** $\overline{1.97}$ Cal ($\overline{.31}$ .94) .08 .71 1.34 $\overline{1.97}$	$\frac{36}{35}$	$\frac{2}{5}$	Outside components only measured. All present.
2201.41	$a^4F_2'-a^4F_3$	Obs ($\bar{*}$ .90) 0 ** $\overline{1.94}$ Cal ($\overline{.31}$ .94) .08 .71 1.34 $\overline{1.97}$	$\frac{2}{5}$	$\frac{36}{35}$	
2326.44	$a^4F_2'-a^4D_2'$	Obs (.40 $\overline{1.19}$) $\bar{0}$ .78 1.60 Cal (.40 1.20) 0 $\overline{.80}$ 1.60	$\frac{2}{5}$	$\frac{6}{5}$	Used as standard of Z. E.
2297.49	$a^4F_2'-a^4D_1'$	Obs (0) .55 Cal (.2) .2 .6	$\frac{2}{5}$	0	
2188.05	$a^4F_4'-a^4G_3'$	Obs ($\overline{**}$ 1.63) *** $\overline{2.86}$ Cal ($\overline{.33}$ 1.00 1.66) .24 .43 .90 1.57 2.24 $\overline{2.90}$	$\frac{78}{63}$	$\frac{4}{7}$	Six resolved σ components and 4 π components on each side.
2296.56	$a^2F_4'-a^2F_4$	Obs (0) 1.13 Cal (0) 1.14	$\frac{8}{7}$	$\frac{8}{7}$	
2298.28	$a^2F_3'-a^2F_3$	Obs (0) .86 Cal (0) .89	$\frac{6}{7}$	$\frac{6}{7}$	
2177.36	$a^4P_1'-b^4D_1'$	Obs (1.33) 1.34 Cal (1.33) 1.33	$\frac{8}{3}$	0	
2179.36	$a^4P_1'-b^4D_2'$	Obs (.74) $\overline{.50}$ 1.96 Cal (.73) $\overline{.47}$ 1.93	$\frac{8}{3}$	$\frac{6}{5}$	
2307.79	$a^4P_1'-b^2D_2'$	Obs (.90) $\bar{0}$ 1.80? Cal (.93) $\overline{.13}$ 1.73	$\frac{8}{3}$	$\frac{4}{5}$?	
2102.84	$a^4P_1'-c^2D_2'$	Obs (.98) 0 Cal (.93) $\overline{.13}$ 1.73	$\frac{8}{3}$	$\frac{4}{5}$	

Where g-values are apparently in agreement with Lande's they are given as fractions; where they are in disagreement they are stated in decimals and are considered as approximate. A * is used to denote the presence of a component which was either too faint to measure or the measurement of which would be inaccurate.

TABLE III. *continued.*

λ	$x-y$	Pattern	g_x	g_y	Remarks
2265.36	$a^4P_1'-b^2P_2$	Obs (.66) $\overline{.61}$ * Cal (.66) $\overline{.66}$ 2.00	$\frac{8}{3}$	$\frac{4}{3}$	
2020.98	$a^4P_1'-b^4S_2$	Obs (?) 1.67 Cal (.33) $\overline{1.67}$ 2.33	$\frac{8}{3}$	2	
2394.84	$a^4P_1'-b^4P_2$	Obs (.55) $\overline{1.03}$ 2.12 Cal (.53) $\overline{1.07}$ 2.13	$\frac{8}{3}$	~1.60	
2369.23	$a^4P_1'-b^4P_1$	Obs (0+) 2.51 Cal (.15) 2.51	$\frac{8}{3}$	~2.36	Used to calculate $g(b^4P_1)$
2366.56	$a^4P_2'-b^4P_1$	Obs (.40) $\overline{1.04}$ 1.97 Cal (.44) $\overline{1.04}$ 1.92	~1.47	~2.36	Gives $g(a^4P_2')$
2312.23	$a^2D_2-b^4P_1$	Obs (.64) $\overline{.46}$ 1.77? Cal (.63) $\overline{.47}$ 1.73	~1.10	~2.36	Gives $g(a^2D_2)$
2177.08	$a^4P_2'-b^4D_2'$	Obs (.39) 1.34 Cal (.14 $\overline{.41}$) 1.06 $\overline{1.34}$ 1.62	~1.47	$\frac{6}{5}$	In agreement with λ2366.
2129.14	$a^2D_2-b^4D_1'$	Obs (.52) * 1.65 Cal (.55) .55 $\overline{1.65}$	~1.10	0	In agreement with λ2312.
2247.24	$a^2D_2-b^2P_1$	Obs (0) 1.14 Cal (.05) 1.05 $\overline{1.15}$	~1.10	~1.00	The value of $g(b^2P_1)$ can be obtained only very roughly.
2298.50	$a^4P_2'-b^2P_1$	Obs (.20) * 1.65 Cal (.24) 1.24 $\overline{1.72}$	~1.47	~1.00	
2276.45	$a^2P_2'-c^2P_2$	Obs (0) 1.30 Cal (0) 1.33	$\frac{4}{3}$	$\frac{4}{3}$	
2308.52	$a^2P_2'-c^2D_2'$	Obs (.69) 1.09 Cal (.27 $\overline{.80}$) .53 $\overline{1.07}$ 1.60	$\frac{4}{3}$	$\frac{4}{5}$	Diffuse pattern.
2303.85	$a^2P_1'-c^2P_2$	Obs (.30) 1.10(?) $\overline{1.62}$ Cal (.33) 1.00 $\overline{1.67}$	$\frac{2}{3}$	$\frac{4}{3}$	See λ2276 above.
2236.08	$a^2P_1'-b^4S_2'$	Obs (.70) 1.36 $\overline{2.70}$ Cal (.67) 1.33 $\overline{2.66}$	$\frac{2}{3}$	2	See λ2020 above.
2275.70	$a^4P_3'-b^2P_2$	Obs (0) 1.48 Cal (0) 1.45 Blend	~1.40	$\frac{4}{3}$	The determinations of irregular g-values is less accurate in this section since only blend patterns are available.
2319.73	$a^4P_3'-b^2F_4$	Obs (0) .90 Cal (0) .94 Blend	~1.40	$\frac{8}{7}$	
2185.51	$a^4P_3'-b^4D_4'$	Obs (0) 1.40 Cal (0) 1.41 Blend	~1.40	$\frac{10}{7}$	

TABLE III. *continued.*

λ	$x-y$	Pattern	g_x	g_y	Remarks
2287.66	$a^4P_3'-b^2D_3'$	Obs (.23) 1.31 Cal (.40) 1.30 Blend	~1.40	$\frac{6}{5}$	
2179.99	$a^2D_3-b^2P_2$	Obs (0) 1.55 Cal (0) 1.56 Blend	~1.46	$\frac{4}{3}$	
2220.40	$a^2D_3-b^2F_4$	Obs (0) .72 Very diffuse Cal (0) .74 Blend	~1.46	$\frac{8}{7}$	
2054.32	$a^2D_3-c^2D_3'$	Obs (.50) 1.32 Cal (.54) 1.33 Blend	~1.46	$\frac{6}{5}$	
2343.48	$a^4P_3'-b^2F_3$	Obs (1.02) 1.18 Cal (.97) 1.18 Blend	~1.40	~ .95	
2300.10	$a^2D_3-b^4P_3$	Obs (0) 1.46 Cal (0) 1.46	~1.46	~1.46	
2392.58	$a^4P_2'-b^4P_3$	Obs (0) 1.45 Cal (0) 1.46 Blend	~1.47	~1.46	
2405.17	$a^2P_2'-b^4D_3'$	Obs (0) 1.38 Cal (0) 1.38 Blend	$\frac{4}{3}$	$\frac{48}{35}$	
2107.94	$a^2G_5-b^2G_5'$	Obs (0) 1.13 Cal (0) 1.11	$\frac{10}{9}$	$\frac{10}{9}$	
2113.51	$a^2G_4-b^2G_4'$	Obs (0) .88 Cal (0) .89	$\frac{8}{9}$	$\frac{8}{9}$	
2312.91	$a^2G_5-b^2H_6$	Obs (0) 1.03 Cal (0) 1.05 Blend	$\frac{10}{9}$	$\frac{12}{11}$	
2302.48	$a^2G_5-c^2F_4$	Obs (0) 1.02 Cal (0) 1.03 Blend	$\frac{10}{9}$	$\frac{8}{7}$	

but the combinations with b^2F_4 and b^4D_4' have the correct intensity relations and produce reversed lines where they would be expected. It is evidently a case such as occurs in other spectra, of two levels whose identities are more or less fused, and this is in spite of the fact that they arise from the addition of an s-electron to different terms of the next higher ion. It should be noted that the g-sum is correct within the experimental error, i.e., $1.46+1.40\sim 8/5+6/5$. The case of a^2D_2 and a^4P_2' is similar—the g-sum being again shared and the intensity relations being in some cases ambiguous. The balance of evidence is, however, in favor of the identification of terms as given in Table II in spite of the fact that it makes both a^4P' and b^4D' partially re-inverted, the component of largest j in each case being displaced completely over to the high side of the component of smallest j.

Table IV

Wave-lengths and classification of lines in spectrum of Ni II.

λ	Auth.	I	ν	Designation
4362.10	Ex	1	22918.3	$a^2G_5-a^4F_4$
4244.80	Ex	1	23551.6	$a^2G_4-a^4F_3$
4192.07	Ex	1	23847.9	$a^2G_4-a^2G'_4$
4067.04	Ex	3	24581.0	$a^2G_5-a^2F_4$
4015.50	Ex	1	24896.5	$a^2G_4-a^2D'_3$
3881.92	Ex	1	25753.2	$b^4P_3-d^4F'_4$
3849.54	Ex	2	25969.8	$a^2G_4-a^2F_3$
3769.45	Ex	5	26521.6	$a^4P'_3-a^4D'_4$
3576.76	Ex	3	27950.3	$a^4P'_2-a^4D'_3$
3513.95	Ex	8	28449.9	$a^2D_3-a^4D'_4$
3471.35	Ex	2	28799.0	$a^4P'_1-a^4D'_2$
3465.62	Ex	1	28846.6	$a^4P'_2-a^4D'_2$
3454.16	B	5	28942.3	$a^2D_2-a^4D'_3$
3407.30	B	8	29340.4	$a^4P'_1-a^4D'_1$
3401.76	B	2	29388.2	$a^4P'_2-a^4D'_1$
3397.82	B	1	29422.1	$a^2P'_2-a^2F_3$
3373.98	B	4	29630.2	$a^2D_3-a^4D'_3$
3350.42	B	5	29838.5	$a^2D_2-a^4D'_2$
3290.69	B	1	30380.1	$a^2D_2-a^4D'_1$
3290.54	B	1?	30381.4	$a^4P'_3-a^4F_4$
3274.90	B	3	30526.5	$a^2D_3-a^4D'_2$
3208.91	B	1	31154.3	$a^2D_3-a^4G'_4$
3087.07	B	20	32383.8	$a^4P'_3-a^2D'_3$
3063.93	B	2	32628.4	$a^2D_2-a^4F_2$
3032.44	B	2	32967.2	$a^2D_3-a^4F_3$
2988.05	B	5	33456.9	$a^4P'_3-a^2F_3$
2947.45	B	8	33917.7	$a^4P'_2-a^2D'_2$
2942.71	B	1	33972.4	$a^2D_3-a^2F_4$
2913.59	B	15	34311.9	$a^2D_3-a^2D'_3$
2882.54	B	1u	34681.5	$a^2D'_2-d^4F'_3$
2881.24	B	2	34697.1	$a^2D_2-a^2F_3$
2864.16	B	2U	34904.0	$a^2D'_3-d^4F'_4$
2863.69	B	25	34909.8	$a^2D_2-a^2D'_2$
2842.41	B	8	35171.1	$a^2G_4-b^2F_3$
2836.58	B	1U	35243.4	$a^2F_4-d^4F'_4$
2825.23	B	4	35385.0	$a^2D_3-a^2F_3$
2808.35	B	2	35597.6	$a^2D_3-a^2D'_2$
2805.67	B	10	35631.6	$a^2G_5-b^2F_4$
2775.31	B	6u	36021.4	$a^2D'_2-d^2F'_3$
2768.78	B	8u	36106.4	$a^2D'_3-d^2F'_4$
2760.67	B	2	36212.4	$a^2G_4-b^2D'_3$
2759.02	B	8u	36234.1	$a^2F_3-d^2F'_3$
2743.01	B	15u	36445.5	$a^2F_4-d^2F'_4$
2708.78	B	9u	36906.1	$a^4F_4-d^4F'_4$
2690.62	B	3u	37155.1	$a^2G'_4-d^2F'_4$
2684.41	B	20u	37241.1	$a^4F_5-d^4F'_5$
2679.25	B	6u	37312.8	$a^4F_3-d^4F'_3$
2670.33	B	3	37437.4	$a^2P'_1-b^4P_1$
2665.86	B	1	37500.2	$a^2P'_2-b^4P_3$
2665.25	B	6	37508.8	$a^2P'_2-b^4P_2$
2655.90	B	6u	37640.8	$a^4F_2-d^4F'_2$
2655.46	B	2u	37647.1	$a^2F_4-d^2F'_3$
2648.72	B	3	37742.9	$a^2F'_3-a^4D'_3$
2647.04	B	5u	37766.8	$a^4F_5-d^4F'_4$
2632.86	B	5u	37970.2	$a^4F_4-d^4F'_3$
2631.52	B	2u	37989.5	$a^4F_3-d^4F'_2$
2630.29	B	8	38007.3	$a^2F'_4-a^4D_4$
2626.57	B	4u	38061.1	$a^4G'_4-d^4F'_4$
2623.10	B	1	38111.5	$a^2G_4-b^4D'_3$
2615.20	B	15u	38226.6	$a^2G'_5-d^2F'_4$
2611.66	B	3	38278.4	$a^2G_5-b^4D'_4$
2610.08	B	25u	38301.6	$a^4G'_6-d^4F'_5$
2606.40	B	8u	38355.7	$a^2G'_4-d^2F'_3$
2605.45	B	3u	38369.6	$a^4G'_3-d^4F'_3$
2601.126	B	8u	38433.4	$a^4G'_5-d^4F'_5$
2592.54	B	1	38560.7	$a^2P'_1-b^2D'_2$
2588.31	B	2	38623.7	$a^2P'_2-b^2F_3$
2587.25	B	4	38639.5	$a^2F'_3-a^4D'_2$
2584.01	B	8	38688.0	$a^2P'_1-b^2P_1$
2566.08	B	15u	38958.3	$a^4G'_5-d^4F'_4$
2565.36	B	2u	38969.2	$a^4F_5-d^2F'_4$?
2560.30	B	10u	39046.2	$a^4G'_3-d^4F'_2$
2557.88	B	6	39083.2	$a^2P'_2-b^2D'_2$
2555.13	B	10u	39125.2	$a^4G'_4-d^4F'_3$
2551.04	B	5	39187.9	$a^2F'_4-a^4D'_3$
2549.56	B	8	39210.7	$a^2P'_2-b^2P_1$
2547.16	B	3	39247.6	$a^2G_4-c^2D'_3$
2545.90	B	20	39267.1	$a^2F'_3-a^4G'_4$
2539.09	B	7	39372.4	$a^2P'_1-b^2P_2$
2525.42	B	10u	39585.5	$a^4D'_3-d^4F'_4$
2520.33	B	2	39665.4	$a^2P'_2-b^2D'_3$
2514.75	B	6u	39753.5	$a^4D'_2-d^4F'_3$
2510.87	B	30	39814.8	$a^2F'_4-a^4G'_5$
2505.84	B	20	39894.8	$a^2P'_2-b^2P_2$
2497.80	B	6	40023.2	$a^2F'_3-a^4G'_3$
2484.32	B	10u	40240.3	$a^4D'_4-d^4F'_5$
2473.13	B	15	40422.4	$a^2F'_3-a^4F_4$
2459.32	B	4U	40649.3	$a^4D'_3-d^4F'_3$
2455.51	B	8	40712.4	$a^2F'_4-a^4G'_4$
2437.884	B	20	41006.7	$a^2F'_4-a^4F_5$
2433.57	B	10	41079.4	$a^2F'_3-a^4F_3$
2432.87	B	1u	41091.2	$a^4D'_2-d^2F'_3$
2431.57	B	8	41113.2	$a^2P'_1-b^4D'_2$
2416.13	B	50R	41375.9	$a^2F'_3-a^2G'_4$
2413.04	B	8	41428.9	$a^2F'_3-a^4F_2$
2412.25	B	5	41442.5	$a^4F'_3-a^4D'_4$
2410.74	B	4	41468.4	$a^2F'_4-a^4G'_3$
2406.89	B	6	41534.7	$a^4P'_3-b^4P_3$
2406.39	B	5	41543.4	$a^4P'_3-b^4P_2$
2405.17	B	15	41564.4	$a^2P'_2-b^4D'_3$
2398.62	B	2	41677.9	$a^2P'_2-b^4D'_1$
2394.84	B	12	41743.7	$a^4P'_1-b^4P_2$
2394.50	B	50R	41749.6	$a^2F'_4-a^2G'_5$
2392.58	B	10	41783.1	$a^4P'_2-b^4P_3$
2392.10	B	6	41791.5	$a^4P'_2-b^4P_2$
2387.77	B	25	41867.3	$a^2F'_5-a^4F_4$
2376.01	Ex	1	42074.5	$a^4F'_2-a^4D'_3$
2375.43	B	30	42084.8	$a^2F'_3-a^2F_4$
2369.23	B	6	42194.9	$a^4P'_1-b^4P_1$
2367.40	B	20	42227.5	$a^4F'_4-a^4D'_4$
2366.56	B	10	42242.5	$a^4P'_2-b^4P_1$
2356.41	B	25	42424.4	$a^2F'_3-a^2D'_3$
2350.84	B	8	42525.0	$a^2F'_4-a^4F_3$
2345.44	S	15	42622.9	$a^4F'_3-a^4D'_3$
2345.26	S	30	42626.1	$a^2G_4-b^2H_5$
2343.93	B	4	42650.3	$a^2G_5-b^2H_5$
2343.48	B	12	42658.5	$a^4P'_3-b^2F_3$
2341.18	B	40	42700.4	$a^2P'_2-c^2D'_3$
2336.70	S	15	42782.2	$a^2P'_1-c^2D'_2$
2336.59	S	5	42784.2	$a^2D_2-b^4P_2$
2334.56	B	30	42821.5	$a^2F'_4-a^2G'_4$
2326.44	B	15	42970.9	$a^4F'_2-a^4D'_2$
2319.73	B	12	43095.2	$a^4P'_3-b^2F_4$
2318.48	B	12	43118.4	$a^4P'_3-b^2D'_2$

TABLE IV. *continued.*

λ	Auth.	I	ν	Designation
2316.02	B	80R	43164.2	$a^4F'_5-a^4D'_4$
2312.91	B	20	43222.3	$a^2G_5-b^2H_6$
2312.23	S	4	43234.9	$a^2D_2-b^4P'_1$
2308.52	B	12	43304.5	$a^2P'_2-c^2D'_2$
2307.79	B	8	43318.1	$a^4P'_1-b^2D'_2$
2305.24	B	10	43366.1	$a^4P'_2-b^2D'_2$
				$a^2G_4-c^2F_3$?
2303.85	B	6	43392.2	$a^2P'_1-c^2P_2$
2302.98	B	60R	43408.6	$a^4F'_4-a^4D'_3$
2302.48	B	10	43418.0	$a^2G_5-c^2F_4$?
2301.01	B	4	43445.8	$a^4P'_1-b^2P_1$
2300.10	B	15	43463.0	$a^2D_3-b^4P_3$
2299.65	B	8	43471.5	$a^2D_3-b^4P_2$
2298.50	B	6	43493.2	$a^4P'_2-b^2P_1$
2298.28	B	30R	43497.4	$a^2F'_3-a^2F_3$
2297.49	B	20R	43512.3	$a^4F'_2-a^4D'_1$
2297.13	B	30R	43519.2	$a^4F'_3-a^4D'_2$
2296.56	B	30R	43529.9	$a^2F'_4-a^2F_4$
2287.66	B	10	43699.3	$a^4P'_3-b^2D'_3$
2287.10	B	20R	43710.0	$a^2F'_3-a^2D'_2$
2278.81	B	30R	43869.0	$a^2F'_4-a^2D'_3$
2377.31	B	10	43897.9	$a^2D_2-b^2F_3$
2276.45	B	5	43914.5	$a^2P'_2-c^2P_2$
2275.70	B	7	43928.9	$a^4P'_3-b^2P_2$
2274.75	B	8	43947.3	$a^4P'_2-b^2D'_3$
2270.24	B	40R	44034.6	$a^4F'_4-a^4G'_5$
2265.36	B	2	44129.4	$a^4P'_1-b^2P_2$
2264.47	B	30R	44146.8	$a^4F'_3-a^4G'_4$
2262.90	B	2	44177.4	$a^4P'_2-b^2P_2$
2256.15	B	8	44309.5	$a^2P'_1-c^2P_1$
2253.87	B	20R	44354.4	$a^4F'_2-a^4G'_3$
2253.67	B	6	44358.3	$a^2D_2-b^2D'_2$
2247.24	B	6	44485.2	$a^2D_2-b^2P_1$
2242.14	B	2	44586.4	$a^2D_3-b^2F_3$
2236.08	B	2	44707.2	$a^2P'_1-b^4S'_2$
2229.85	B	3u	44832.1	$a^2P'_2-c^2P_1$
2226.34	B	18R	44902.8	$a^4F'_3-a^4G'_3$
2224.88	B	20R	44932.2	$a^4F'_4-a^4G'_4$
2224.50	B	2	44939.9	$a^2D_2-b^2D'_3$
2224.36	B	6	44942.7	$a^2F'_4-a^2F_3$
2222.95	B	20R	44971.2	$a^4F'_5-a^4G'_5$
2220.40	B	10R	45022.9	$a^2D_3-b^2F_4$
2216.47	B	100R	45102.7	$a^4F'_5-a^4G'_6$
2213.19	B	7	45169.5	$a^2D_2-b^2P_2$
2211.09	B	8	45212.4	$a^2P'_2-c^2S'_1$?
2210.38	B	20R	45226.9	$a^4F'_4-a^4F_5$
2206.71	B	25R	45302.2	$a^4F'_3-a^4F_4$
2201.41	B	20R	45411.2	$a^4F'_2-a^4F_3$
2192.36	S	1	45598.6	$a^4P'_3-b^4D'_3$
2190.97	S	2	45627.5	$a^2D_3-b^2D'_3$
2188.91	B	1	45670.5	$a^4P'_3-b^4D'_2$
2188.05	B	6	45688.5	$a^4F'_4-a^4G'_3$
2185.51	B	12R	45741.6	$a^4P'_3-b^4D'_4$
2184.61	B	25R	45760.4	$a^4F'_2-a^4F_2$
2180.46	B	10	45847.5	$a^4P'_2-b^4D'_3$
2179.99	B	3	45857.4	$a^2D_3-b^2P_2$
2179.46	S	3	45868.5	$a^4F'_5-a^4G'_4$
2179.36	S	6	45870.7	$a^4P'_1-b^4D'_2$
2177.36	B	6	45912.7	$a^4P'_1-b^4D'_1$
2177.08	B	6	45918.7	$a^4P'_2-b^4D'_2$
2175.16	B	25R	45959.2	$a^4F'_3-a^4F_3$
2174.67	B	30R	45969.5	$a^4F'_4-a^2G'_5$
2169.10	B	30R	46087.6	$a^4F'_4-a^4F_4$
2165.55	B	40R	46163.1	$a^4F'_5-a^4F_5$
2161.21	B	10	46255.8	$a^4F'_3-a^2G'_4$
2158.73	B	8	46308.8	$a^4F'_3-a^4F_2$
2139.08	S	1	46734.2	$a^4P'_3-c^2D_3$
2138.60	S	10	46744.8	$a^4F'_4-a^4F_3$
2138.08	S	1	46756.1	$a^4F'_2-a^2D'_3$
2134.28	S	8	46839.4	$a^2D_2-b^4D'_3$
2131.27	S	3	46905.5	$a^4F'_5-a^2G'_5$
2131.02	S	2	46911.0	$a^2D_2-b^4D'_2$
2130.70	S	0	46918.2	$a^2P'_2-c^2F_3$?
2129.14	S	3	46952.4	$a^2D_2-b^4D'_1$
2128.57	S	12	46964.9	$a^4F'_3-a^2F_4$
2127.77	S	6	46982.6	$a^4P'_2-c^2D'_3$
2125.89	S	4	47024.1	$a^4F'_5-a^4F_4$
2125.12	S	8	47041.2	$a^4F'_4-a^2G_4$
2113.51	S	12	47299.5	$a^2G_4-b^2G'_4$
2113.29	S	1	47304.6	$a^4F'_3-a^2D'_3$
2112.45	S	1	47323.4	$a^2G_5-b^2G'_4$
2111.75	S	1	47338.9	$a^4P'_3-c^2D'_2$
2109.01	S	5	47400.5	$a^2G_4-b^2G'_5$
2107.94	S	18R	47424.5	$a^2G_5-b^2G'_5$
2103.39	S	5	47527.2	$a^2D_3-b^4D'_3$
2102.84	S	1	47539.6	$a^4P'_1-c^2D'_2$
2100.23	S	1	47598.6	$a^2D_3-b^4D'_2$
2097.08	S	12	47670.1	$a^2D_3-b^4D'_4$
2093.55	S	8	47750.6	$a^4F'_4-a^2F_4$
2090.14	S	5	47828.4	$a^4F'_2-a^2F_3$
2084.87	S	5	47949.3	$a^4P'_3-c^2P_2$
2083.76	S	2	47974.8	$a^2D_2-c^2D'_3$
2083.65	S	2	47977.3	$a^4F'_5-a^2G'_4$
2080.84	S	5	48042.1	$a^4F'_2-a^2D'_2$
2078.76	S	3	48090.2	$a^4F'_4-a^2D'_3$
2076.19	S	1	48149.8	$a^4P'_1-c^2P_2$
2074.13	S	2	48197.6	$a^4P'_2-c^2P_2$
2066.41	S	5	48377.5	$a^4F'_3-a^2F_3$
2057.81	S	0	48579.7	$a^2D_2-c^2D'_2$
2057.38	S	2	48589.9	$a^4F'_3-a^2D'_2$
2054.32	S	5	48662.3	$a^2D_3-c^2D'_3$
2053.30	S	5	48686.4	$a^4F'_5-a^2F_4$
2035.39	S	1	49114.7	$a^4P'_2-c^2P_1$
2033.42	S	3	49162.2	$a^4F'_4-a^2F_3$
2032.30	S	5	49189.4	$a^2D_2-c^2P_2$
2029.20	S	10	49264.5	$a^4P'_3-b^4S'_2$
2020.98	S	10	49465.0	$a^4P'_1-b^4S'_2$
2919.73	S	1	49495.4	$a^4P'_2-c^2S'_1$?
2019.03	S	10	49512.6	$a^4P'_2-b^4S'_2$
2004.27	S	5	49877.2	$a^2D_3-c^2P_2$
λ (vac)				
1995.74	S	4	50106.7	$a^2D_2-c^2P_1$
1980.73*	S	0	50486.4	$a^2D_2-c^2S'_1$?
1980.05	S	4	50503.8	$a^2D_2-b^4S'_2$
1965.37	S	8	50881.0	$a^4P'_3-c^2F_4$?
1956.97	S	6	51099.3	$a^4P'_2-c^2F_3$?
1953.43	S	8	51192.0	$a^2D_3-b^4S'_2$
1893.52*	S	1	52811.7	$a^2D_3-c^2F_4$?
1881.14*	S	4	53159.2	$a^2F'_3-b^2D'_2$
1812.07	Bl.	4	55185.4	$a^2F'_4-b^2D'_3$

B. Bureau of Standards.
Ex. Exner and Hascheck. (Kayser. "Handbuch der Spectroscopie." Vol. VI. p. 172)
S. Author.
* Measured on low dispersion.
Bl. Bloch. "Jour. d. Physique" Vol. VI., 105, 1925.

Amongst the intermediate set of terms there are further cases of the sharing of the g-sum, i.e., b^4P_3 and b^2F_3; b^4P_1 and b^2P_1. The term b^4P_2 has certainly $g<26/15$, the theoretical value, and would form a real exception unless b^2D_2' is also irregular, which is quite possible. The terms a^2P' and a^2G have Lande g's, as would be expected from their isolation from other terms. A consideration of all the cases of the sharing of the g-sum in Ni II, Cu II and Cu I indicate that the only necessities are identical j's and electron configurations. It is not essential that the terms should be members of series converging to the same ion term or that they should be particularly close. For instance in Ni II a^2D_3 and a^4P_3' are separated by nearly 2000 cm^{-1} and are built on ion terms ^1D and $^3P'$.

The division of the intermediate doublet terms into particular triads cannot be carried out with certainty, but it is reasonable to group them in the order of magnitude; i.e., b^2P, D', F with a^2D; c^2S', P, D' with a^2P; b^2G', b^2H and c^2F with a^2G. The arrangement is unsatisfactory in that the combinations of b^2D_3' with a^2D are much too faint; and that the grouping is rather closer than would be expected. The terms c^2S' and c^2F are both doubtful.

It is mentioned above that the lowest term of the spectrum would be expected to be a $^2D(d^9)$. The approximate position of this term can be fixed from the terms of the arc spectrum. In the arc, the low structures d^8s^2 and d^9s have practically the same energy. The removal of an s-electron from d^8s^2 (to d^8s), by analogy with other spectra, should require about 5000 to 10,000 cm^{-1} more "energy" than the removal from d^9s (to d^9).[7] But these are the two spark structures concerned in the difference $^2D(d^9)-a^4F'(d^8s)$. The ^2D should, therefore, lie about 5000 to 10,000 cm^{-1} lower than a^4F'. Since ^2D should be the lowest term, its combinations with d^8p might be expected to be very intense. A thorough search through the wave-length lists of L. & E. Bloch[8] has been made unsuccessfully. Some possible sets of lines have been found but nothing which can be accepted with any certainty at all. This point is, therefore, left open. A similar state of affairs exists in the case of Cu II where the lowest term $^1S(d^{10})$ has not been found in spite of a thorough search of the proper region using excellent wave-lengths measured by R. J. Lang at the University of Alberta, Canada. The apparent absence, or at any rate low intensity of the expected combinations in these two cases, requires explanation.

This analysis of Ni II accounts for the vast majority of the strong lines of the spectrum. There are still numerous diffuse lines unidentified but they are undoubtedly due to higher terms, which normally produce hazy lines.

Dr. H. N. Russell of the Department of Astronomy in this University has taken great interest in the progress of this analysis, and has been of the greatest assistence both practically and theoretically. The author thanks him very sincerely. Thanks are also due to Mr. J. J. Livingood for

[7] Laporte, Zeits. f. Physik. **39**, 127 (1926).

[8] L. & E. Bloch, Jour. d. Physique, **6**, 105 (1925).

his very considerable assistance in the experimental and computational work. As mentioned above, the analysis was made possible through the courtesy of Dr. Meggers of the Bureau of Standards in allowing the author full use of all of his observational material.

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June 16, 1927.