Physics. — *The spectra of ionized Neon (Ne II) and ionized Argon (Ar II).* (Second Communication.) By T. L. DE BRUIN. (Communicated by Prof. P. ZEEMAN.)

(Communicated at the meeting of March 31, 1928).

1. *Introduction.*

In a former paper in these Proceedings [1]) I have classified in a termscheme a number of 180 lines of the spectrum of ionized Neon *(Ne II)*. The spectralstructure has been found in agreement with the theory of complex spectra developed by HEISENBERG, RUSSELI, SAUNDERS, PAULI and especially by HUND. It has been pointed out that the structure is analogous with the spectralstructure of a neutral halogenatom (Fluorine) as could be expected according to the theory of BOHR and the displacementlaw of KOSSEL and SOMMERFELD. The wavelengthmeasurements used for that analysis were taken from L. BLOCH, E. BLOCH and G. DÉJARDIN who produced the spectrum with the electrodeless discharge.

Now I have made some new experiments on the spectra of the ionized inert gases *Ne II* and *Ar II*. The spectra have been produced by passing heavy condensed discharges through a narrow vacuumcapilar (¾ mm). For more experimental details see a note in the Zeitschr. f. Phys. [2]). A comparison between the deep quartetterms of *Ne II* and *Ar II* forms the substance of the present paper.

2. *The spectrum of ionized Argon.*

In the same year (1895) that RAYLEIGH and RAMSAY had detected the element argon, CROOKES investigated the spectrum of it. CROOKES found that two spectra could be produced, the "red" and the "blue" spectrum. The blue spectrum was very intensive in the case of condensed discharges. Wave-length measurements of this blue spectrum have been made by

[1]) T. L. DE BRUIN: These Proceedings **31**, 2, 1928.
[2]) T. L. DE BRUIN: Zeitschr. f. Physik. **44**, 157. 1927. **46**. 856. 1928.

KAYSER [1]) and EDER and VALENTA [2]). Especially the measurements of KAYSER to λ 3000 given in 0.001 Å are very useful for the analysis. The data of EDER and VALENTA are not so exact but extend to λ 2000. L. BLOCH, E. BLOCH and G. DÉJARDIN [3]) have investigated which lines are due to the higher states of ionization. Little has been known on the structure of the blue Argonspectrum [4]). Only PAULSON [5]) found that different lines could be ordened in groups with the differences :

$$\triangle\nu: 844.49;\ 1611.33;\ 149.55 \text{ and } 153.97.$$

The analysis of the *Ne II* spectrum was the startingpoint for the analysis of the *Ar II* spectrum. The key for the analysis of *Ne II* was the identification of the following group of lines :

Ne II	$^4P_1$	299.1	$^4P_2$	517.7	$^4P_3$
$^4S_2$	4.3028.85 33006.2		6.3001.646 33305.3		7.2955.735 33822.7

This group is in the case of ionized Argon :

Ar II	$^4P_1$	515.70	$^4P_2$	844.40	$^4P_3$
$^4S_2$	7.3928.599 25447.24		8.3850.565 25962.88		9.3729.300 26807.09

In this note we shill compare the quartetterms in both spectra, whereas in a following paper we shill give an account of the doublet terms, the intercombinations, the absolute termvalues, etc.

3. *Theoretical scheme of terms.*

Theoretically, according to the theory of complex spectra the following terms may be deduced from the atomic configuration :

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1) H. KAYSER: Astrophys. Journ. **4**, 1. 1896. Sitzber. Akad. Berlin. 1896. Nr. 24; Handb. d. Spektr. V. pag. 61. These measurements have been used.

2) EDER et VALENTA: Denkschr. Wien. Akad. **64**, 1. 1897. Beitr. z. Photochem. 1904.

3) L. BLOCH, E. BLOCH et G. DÉJARDIN: Ann. d. Phys. **2**, 461. 1924.

4) K. W. MEISSNER investigated the structure of the "red" spectrum due to the neutral atom.

5) PAULSON: Astrophys. Journ. **41**. 75. 1915.

TABLE I. Theoretical termschemes Neon II and Argon II (Deep terms).

nk	Atomic configuration										Symbol	Basicterm: ^3P [1])	
												Terms.	
	1s	2s	2p	3s	3p	3d	4s	4p	4d	4f		Quartet	Doublet
Neon II	2	2	5								$s^2 p^5$		P
	2	2	4	1							$s^2 p^4 . 3s$	P	P
	2	2	4		1						$s^2 p^4 . 3p$	$D\ P\ S$	$D\ P\ S$
	2	2	4			1					$s^2 p^4 . 3d$	$F\ D\ P$	$F\ D\ P$
	2	2	4				1				$s^2 p^4 . 4s$	P	P
Argon II	2	2	6	2	5						$s^2 p^5$		P
	2	2	6	2	4	1					$s^2 p^4 . 3d$	$F\ D\ P$	$F\ D\ P$
	2	2	6	2	4		1				$s^2 p^4 . 4s$	P	P
	2	2	6	2	4			1			$s^2 p^4 . 4p$	$D\ P\ S$	$D\ P\ S$
	2	2	6	2	4				1		$s^2 p^4 . 4d$	$F\ D\ P$	$F\ D\ P$

The termarrangement of *Ar II* is similar to that of *Ne II* already reported by us, except for one group of terms. In *Ne II* only terms involving a displaced *s* electron exist in the group of terms above the fundamental $^2P_{21}$ state. In *Ar II* however, an excited $3d$ electron gives a group of terms $^{2,\,4}\,(F,\ D,\ P)$.

4. *Analogous multiplets. Termtable. Identification of terms.*

The following table 2 gives the analogous multiplets arising from the combinations between the deep quartetterms of *Ne II* and *Ar II*. In both spectra [2]) in the $^4P_{321}$ term the interval rule holds very well but in the $^4P'_{321}$-term the ratio is anomalous. In the $^4P_{321}$-term the three components go to the components of the basicterm $^3P_{012}$ but in the $^4P'_{321}$-term the components $^4P_1$ and $^4P_2$ go to $^3P_1$ while $^4P_3$ goes to $^3P_2$. In both spectra the $^4D_{12}$ and $^4F_{23}$ (in *Ne II* 144.1 and 145.5 in *Ar II* 260.5 and 266.3). have nearly the same value. These termseparations go to the component $^3P_0$ of the basicterm. Table 4 shows that in *Ar II* terms are present of the configuration $(s^2\,p^4)\ 3d$. A numerical comparison between wavenumbers of the analogous multiplets shows that the ratio diminishes for higher terms (Table 5). Table 3 gives some multiplets in both spectra which identification is not quite sure. Table 6 gives the relative term values in *Ne II* and *Ar II*. The last column gives all the theoretical terms.

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1) It is possible that also terms from the metastabile states ^1D and ^1S are present.

2) This is also in the *F I* spectrum. See T. L. DE BRUIN. These Proceedings **30**, p. 20 and 944, 1927; Zs. f. Phys. **38**, 94. 1926.

TABLE 2. *Neon II.* $3s\ ^4P_{123} - 3p\ ^4P_{123}$; $3s\ ^4P_{123} - 3p\ ^4D_{1234}$; $3s\ ^4P_{123} - 3p\ ^4S_2$.

	3s / 3p	$^4P_1$	299.1	$^4P_2$	517.7	$^4P_3$
1.	$^4P'_1$	5. 3751.26 26650.2	299.0	7. 3709.643 26949.1		—
	182.6					
	$^4P'_2$	8. 3777.162 26467.4	299.2	7. 3734.94 26766.6	517.6	9. 3664.089 27284.2
	222.6					
	$^4P'_3$	—		8. 3766.286 26543.8	517.8	10. 3694.22 27061.6
2.	$^4D_1$	5. 3344.43 29891.9	299.1	3. 3311.30 30191.0		—
	144.1					
	$^4D_2$	5. 3360.63 29747.8	299.2	5. 3327.162 30047.0	517.9	2. 3270.79 30564.9
	249.6					
	$^4D_3$	—		7. 3355.05 29797.4	517.7	7. 3297.74 30315.1
	337.2					
	$^4D_4$	—		—		10. 3334.837 29977.8
3.	$^4S_2$	4. 3028.85 33006.2	299.1	6. 3001.646 33305.3	517.4	7. 2955.735 33822.7

Argon II. $4s\ ^4P_{123} - 4p\ ^4P_{123}$; $4s\ ^4P_{123} - 4p\ ^4D_{1234}$; $4s\ ^4P_{123} - 4p\ ^4S_2$.

	4s / 4p	$^4P_1$	515.70	$^4P_2$	844.40	$^4P_3$
I.	$^4P'_1$	4. 4972.16[1] 20106.4	515.85	8. 4847.783 20622.25		—
	357.30					
	$^4P'_2$	8. 5062.019 19749.47	515.60	6. 4933.226 20265.07	844.42	6. 4735.885 21109.49
	307.78					
	$^4P'_3$	—		8. 5009.246 19957.53	844.03	10. 4805.993 20801.56
II.	$^4D_1$	6. 4379.657 22826.44	515.72	3. 4282.894 23342.16		—
	260.31					
	$^4D_2$	4. 4430.185 22566.11	515.74	8. 4331.194 23081.85	844.36	3. 4178.344 23926.21
	494.40					
	$^4D_3$	—		8. 4425.995 22587.23	844.38	8. 4266.524 23431.71
	439.40					
	$^4D_4$	—		—		10. 4348.062 22992.30
III.	$^4S_2$	7. 3928.599 25447.20	515.68	8. 3850.565 25962.88	844.21	9. 3729.300 26807.09

[1]) Measurement of the author.

TABLE 2 (*Continued*). *Neon II.* $3d\ ^4D_{1234} - 3p\ ^4P_{123}$; $3d\ ^4D_{1234} - 3p\ D_{1234}$.

	3d / 3p	$^4D'_1$	98.3	$^4D'_2$	106.3	$^4D'_3$	81.1	$^4D'_4$
4.	$^4P'_1$	3. 3045.58 32824.9	98.8	5. 3054.69 32727.1		—		—
	182.6							
	$^4P'_2$	4. 3028.85 [1] 33006.2	97.4	4. 3037.73 32909.8	106.3	6. 3047.57 32803.5		—
	222.5							
	$^4P'_3$	—		3. 3017.34 33132.2	106.2	4. 3027.04 33026.0	81.0	5. 3034.47^5 32945.0
5.	$^4D_1$	1. 3379.35 29583.0	97.8	3. 3390.56 29485.2		—		—
	194·1							
	$^4D_2$	2. 3362.98 [2] 29727.8	98.8	3. 3374.10 29629.0	106.2	1. 3386.24 29522.8		—
	249.3							
	$^4D_3$	—		2. 3345.95 29878.3	106.2	3. 3357.90 29772.0	82.2	6. 3367.20 [3] 29689.8
	337.2							
	$^4D_4$	—		—		2. 3320.29 30109.2	80.6	4. 3329.20 30028.6

Argon II. $4d\ ^4D_{1234} - 4p\ ^4P_{123}$; $4d\ ^4D_{1234} - 4p\ ^4D_{1234}$.

	4d / 4p	$^4D'_1$	107.50	$^4D'_2$	188.43	$^4D'_3$	121.85	$^4D'_4$
IV.	$^4P'_1$	5. 3521.950 28385.27	107.70	6. 3535.364 28277.57		—		—
	357.30							
	$^4P'_2$	6. 3478.260 28741.81	107.27	5. 3491.290 28634.54	188.50	8. 3514.426 28446.04		—
	307.76							
	$^4P'_3$	—		5. 3454.148 28954.44	188.37	8. 3476.776 28754.07	121.85	10. 3491.573 28632.22
V.	$^4D_1$	(3895.19) [4] (25665.45)	107.49	1. 3911.571 25557.96		—		—
	260.31							
	$^4D_2$	1. 3856.060 25925.88	107.90	2. 3872.176 25817.98	188.22	2. 3900.613 25629.76		—
	494.40							
	$^4D_3$	—		1. 3799.446 26312.18	188.25	3. 3826.826 26123.93	121.93	1. 3844.771 26002.00
	439.47							
	$^4D_4$	—		—		3. 3763.565 26563.03	121.56	6. 3780.868 26441.47

[1] Coincidence with; $^4P_1 - {}^4S_2$.

[2] Coincidence with; $^4S_2 - g\ ^4P_1$.

[3] Probably coincidence, Intensity too much.

[4] Wavelengths between brackets are calculated. *Note added to proof:* This line has been found on our plates. Observed: 1. 3895.22; 25665.2.

TABLE 2 (*Continued*). *Neon II.* $3d\ ^4F_{2345}-3p\ ^4P_{123}$; $3d\ ^4F_{2345}-3p\ ^4D_{1234}$; $3d\ ^4F_{2345}-3p\ ^4S_2$.

	3d / 3p	$^4F_2$	145.5	$^4F_3$	325.4	$^4F_4$	527.7	$^4F_5$
6.	$^4P'_1$	0. 2891.48 34374.2		—		—		—
	182.6							
	$^4P'_2$	3. 2876.43 dr. 34755.1	144.3	1. 2888.43 34610.8		—		—
	222.5							
	$^4P'_3$	1. 2858.02 34979.0	145.4	2. 2869.95 34833.6	325.9	2. 2997.05 34507.7		—
7.	$^4D_1$	2. 3190.89 31330.2		—		—		—
	144.1							
	$^4D_2$	3. 3176.17 31475.8	145.6	2. 3190.88 31330.2		—		—
	249.3							
	$^4D_3$	2. 3151.16 31725.2	145.7	2. 3165.70 31579.5	325.0	5. 3198.62 31254.5		—
	337.5							
	$^4D_4$	—		2. 3132.22 31917.2	325.4	3. 3164.46 31591.8	527.7	8. 3218.22 31064.1
8.	$^4S_2$	7. 3542.89 28217.5	145.4	4. 3561.24 28072.1		—		—

Argon II. $4d\ ^4F_{2345}-4p\ ^4P_{123}$; $4d\ ^4F_{2345}-4p\ ^4D_{1234}$; $4d\ ^4F_{2345}-4p\ ^4S_2$.

	4d / 4p	$^4F_2$	266.33	$^4F_3$	449.60	$^4F_4$	531.66	$^4F_5$
VI.	$^4P_1$	2. 3263.582 30632.37		—		—		—
	357.30							
	$^4P_2$	2. 3226.03 30988.94	266.33	(3275.31) (30722.61)		—		—
	307.78							
	$^4P_3$	1. 3194.270 31297.04	266.33	(3221.70) (31030.71)	449.57	(3269.04) (30581.14)		—
VII.	$^4D_1$	6. 3581.652 27912.14		—		—		—
	260.31							
	$^4D_2$	5. 3548.530 28172.66	266.33	6. 3582.397 27906.34		—		—
	494.40							
	$^4D_3$	(3487.30) (28666.99)	266.33	6. 3520.041 28400.66	449.55	8. 3576.658 27951.11		—
	439.47							
	$^4D_4$	—		4. 3466.383 28840.29	449.63	5. 3521.281 28390.66	531.66	10. 3588.483 27859.00
VIII.	$^4S_2$	2. 3952.742 25291.76	266.60	4. 3994.885 25025.16		—		—

TABLE 3. *Neon II.*

$3p$ \ $\begin{Bmatrix}3d\\4s\end{Bmatrix}?$	$g\ ^4P_1$	305.5	$f\ ^4P_2$	376.6	$e\ ^4P_3$
$^4P'_1$	2. 2770.60 36082.6	305.5	3. 2794.26 35777.1		—
182.6					
$^4P'_2$	3. 2756.64 36265.4	305.6	2. 2780.06 35959.8	376.6	4. 2809.50 35583.1
222.6					
$^4P'_3$	—		3. 2762.97 36182.3	376.9	5. 2792.05 35805.4
$^4D_1$	2. 3044.16 32840.2	305.5	1. 3072.70 32535.2		—
144.1					
$^4D_2$	2. 3030.85 32984.5	305.3	3. 3059.16 32679.2	376.3	(3094.8) (32302.9)
249.6					
$^4D_3$	—		3. 3035.98 32928.7	376.3	2. 3071.08 32552.4
337.2					
$^4D_4$	—		—		3. 3039.65 32889.0
$^4S_2$	2. 3362.89 29727.8	305.9	1. 3397.86 29421.9	377.0	1. 3441.96 29044.9

Argon II.

$4p$ \ $\begin{Bmatrix}4d\\5s\end{Bmatrix}?$	$g\ ^4P_1$	729.50	$f\ ^4P_2$	627.90	$e\ ^4P_3$
$^4P'_1$	3. 3669.550 27243.56	729.87	4. 3770.569 26513.69		—
357.30					
$^4P'_2$	6. 3622.204 27599.69	728.96	6. 3720.467 26870.73	627.99	6. 3809.499 26242.74
307.78					
$^4P'_3$	—		6. 3678.328 27178.54	627.84	8. 3765.313 26550.70
$^4D_1$	8. 4076.704 24522.72	730.96	1. 4201.946[1] 23791.76		—
260.31					
$^4D_2$	6. 4033.872 24783.10	729.04	6. 4156.135 24054.06	627.80	(4267.52)[2] (23426.26)
494.40					
$^4D_3$	—		5. 4072.429 24548.48	627.91	5. 4179.329 23920.57
439.40					
$^4D_4$	—		—		10. 4103.957 24359.88
$^4S_2$	3. 4564.37 21902.7	729.59	(4721.65)[2] (21173.11)	627.90	6. 4865.96 20545.21

[1]) Coincidence.

[2]) *Note added to proof.* These lines have been found on our plates. Observed: 3. 4267.49; 23426.4. 3. 4721.66; 21173.1.

TABLE 4. *Argon II* $3d\ {}^4D_{1234} - 4p\ {}^4P_{123}$; $3d\ {}^4D_{1234} - 4p\ {}^4D_{1234}$.

4p \ 3d	${}^4D'_1$	107.00	${}^4D'_2$	149.53	${}^4D'_3$	153.90	${}^4D'_4$
${}^4P'_1$	4. 4352.198 22970.46	106.91	3. 4332.035 23077.37		—		—
357.30							
${}^4P'_2$	1. 4420.943 22613.14	107.25	3. 4400.101 22720.39	149.51	4. 4371.334 22869.90		—
307.78							
${}^4P'_3$	—		2. 4460.512 22412.69	149.26	4. 4431.002 22561.95	153.86	5. 4400.986 22725.81
${}^4D_1$	2. 3891.400 25690.44	107.05	3. 3875.256 25797.49		—		—
260.31							
${}^4D_2$	2. 3931.232 25730.14	106.87	3. 3914.781 25537.01	149.61	4. 3891.978 25686.62		—
494.40							
${}^4D_3$	—		2. 3992.046 25042.75	149.57	4. 3968.346 25192.92	153.84	4. 3944.259 25346.16
439.47							
${}^4D_4$	—		—		2. 4038.816 24752.76	153.95	6. 4013.852 24906.71

TABLE 5.

Multiplet (*Neon II* $n=3$; *Argon II* $n=4$)	$\frac{\nu_{Ne\ II}}{\nu_{Ar\ II}}$
$ns\ {}^4P - np\ {}^4P$	1.315
$ns\ {}^4P - np\ {}^4D$	1.301
$ns\ {}^4P - np\ {}^4S$	1.281
$np\ {}^4P - nd\ {}^4P$	1.151
$np\ {}^4D - nd\ {}^4D$	1.143
$nd\ {}^4F - np\ {}^4P$	1.122
$nd\ {}^4F - np\ {}^4S$	1.118
$nd\ {}^4F - np\ {}^4D$	1.115

TABLE 6.

Neon II			Argon II		Neon II; $n = 3$ Argon II; $n = 4$	
Exper. Term	Termvalue (relative)	Term-difference	Termvalue (relative)	Term-difference	Atom-configuration	Theor. term
$^4D'_4$	—		101914.40	153.98		$3d\ ^4D_4$
$^4D'_3$	—		101760.42	149.62	$(s^2p^4).\ 3d$	$3d\ ^4D_3$
$^4D'_2$	—		101610.80	107.03		$3d\ ^4D_2$
$^4D'_1$	—		101503.77			$3d\ ^4D_1$
$^4P_3$	112500.0	517.8	100000.00	844.40		$ns\ ^4P_3$
$^4P_2$	111982.2	299.1	99155.60	515.70	$(s^2p^4).\ ns$	$ns\ ^4P_2$
$^4P_1$	111683.1		98639.90			$ns\ ^4P_1$
$^4P'_3$	85438.2	222.6	79198.25	307.75		$np\ ^4P_3$
$^4P'_2$	85215.6	182.5	78890.50	357.30		$np\ ^4P_2$
$^4P'_1$	85033.1		78533.20			$np\ ^4P_1$
$^4D_4$	82522.2	337.3	77007.70	439.36		$np\ ^4D_4$
$^4D_3$	82184.9	249.7	76568.34	494.57	$(s^2p^4).\ np$	$np\ ^4D_3$
$^4D_2$	81935.2	144.1	76073.77	260.32		$np\ ^4D_2$
$^4D_1$	81791.1		75813.45			$np\ ^4D_1$
$^4S_2$	78678.0		73192.72			$np\ ^4S_2$
$^4D'_4$	52493.9	81.5	50566.20	121.80		$nd\ ^4D_4$
$^4D'_3$	52412.4	106.2	50444.40	188.61		$nd\ ^4D_3$
$^4D'_2$	52306.2	98.3	50255.79	107.79		$nd\ ^4D_2$
$^4D'_1$	52207.9		50148.00		$(s^2p^4).\ nd$	$nd\ ^4D_1$
$^4F_5$	51458.6	528.1	49148.70	531.55		$nd\ ^4F_5$
$^4F_4$	50930.5	325.6	48617.15	449.59		$nd\ ^4F_4$
$^4F_3$	50604.9	145.5	48167.56	266.33		$nd\ ^4F_3$
$^4F_2$	50459.4		47901.23			$nd\ ^4F_2$
$e\ ^4P_3$	49633.0	376.7	52647.50	627.76	1)	$nd\ ^4P_3$
$f\ ^4P_2$	49256.8	305.5	52019.74	729.14	$(s^2p^4).\ nd?$	$nd\ ^4P_2$?
$g\ ^4P_1$	48950.8		51290.60			$nd\ ^4P_1$

1) In *Ne II* probably: $(s^2p^4).\ 4s$.

5. ZEEMAN-*effects*.

The ZEEMAN-effect of *Ne II* is never investigated. Now, we can calculate and predict the ZEEMAN-types from the classification and the theory of LANDÉ. In the case of *Ar II* the ZEEMAN-effect of some lines in the visible part of the spectrum is known by work of LÜTTIG. His results are only qualitative because he used a discharge perpendicular to the field. The magnetic field used by LÜTTIG was not very strong too. Now it will be very interesting to investigate the ZEEMAN-effect for checking the term-scheme especially in connexion with the g-values of the terms.

ZEEMAN-effect. Multiplet I:
Calculated [1]) ZEEMAN-effect from our classification, observed ZEEMAN-effect by LÜTTIG [2]).

Int.	λ	Term-combination	ZEEMAN-effect
8.	5062.019	${}^4P_1 - {}^4P'_2$	Calc. (**0.47**) **1.27** 2.20 Obs.: At 17000 Gausz the line splits up in four or six components. More components excluded.
8.	5009.246	${}^4P_2 - {}^4P'_3$	Calc.: (**0.07**) (0.20) **1.40** 1.53 1.67 1.80 Obs.: Diffuse triplet
4.	4972.16	${}^4P_1 - {}^4P'_1$	Calc. (0) 2.66 Obs.: Triplet.
6.	4933.226	${}^4P_2 - {}^4P'_2$	Calc.: (0) 1.73 Obs.: Triplet. More components excluded.
8.	4847.783	${}^4P_2 - {}^4P'_1$	Calc.: (**0.47**) **1.27** 2.20 Obs.: Quartet. Probably more components. Even type.
10.	4805.893	${}^4P_3 - {}^4P'_3$	Calc.: (0) 1.60 Obs.: (0) 1.60 ($H = \pm$ 6000)
6.	4735.885	${}^4P_3 - {}^4P'_2$	Calc.: (**0.07**) (0.20) **1.40** 1.53 1.67 1.80 Obs.: (0) 1.48 ($H = \pm$ 7000).

6. *Conclusion.*

A comparison has been made between the deep quarter terms of ionized *Neon (Ne II)* and ionized *Argon (Ar II)*. Nearly all the terms predicted by the theory of HEISENBERG and HUND have been detected and identified.

In conclusion the author wishes to express thanks to Prof. P. ZEEMAN for the valuable advise and helpful suggestions.

Laboratory "Physica" of the University of Amsterdam.

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[1]) The ZEEMAN-types have been calculated with the normal g-values. Anomalous g-values however can be present.

[2]) O. LÜTTIG: Dissertatie. Halle a. S. 1911. Ann. d. Phys. **38**, 69, 1912.