Physics. — *The* ZEEMAN-*effect in the spectrum of ionized Neon* (*Ne II*).
By C. J. BAKKER. (Communicated by Prof. P. ZEEMAN.)

(Communicated at the meeting of November 24, 1928)

1. *Introduction.* In a former paper in these Proceedings [1]) the results of the experimental investigation of the ZEEMAN-effect in the spectrum of ionized Argon (*Ar II*) have been communicated. It appeared that different terms in the energy scheme of ionized Argon have „anomalous" g-values, which shows that there are deviations from the normal coupling scheme of RUSSELL-SAUNDERS. [2])

After this investigation on the coupling relations in the energy scheme of ionized Argon (*Ar II*) it was important to perform an analogous investigation concerning the spectra of the ionized atoms of the other inert gases, to get in this way a survey concerning the deviations dependent on the atomic number.

According to theoretical considerations one expects that the deviations for analogous terms increase with the atomic number. This paper gives the investigation of the ZEEMAN-effect in the spectrum of ionized Neon (*Ne II*) and is directly related to the investigations on spectra with and without magnetic field in the laboratory of Prof. ZEEMAN.

2. *Experimental part.* I can refer for the greater part to the communication on the ZEEMAN-effect of ionized Argon (*Ar II*), because for the investigation of ionized Neon (*Ne II*) the same method and mounting has been used. The Neon gas was led into a copper vacuum box enclosing the poles of the large magnet of the laboratory. The pressure of the Neon in the vacuum space must be 2 à 3 cm for getting brilliant discharges.

In connection with the small sputtering coefficient of Aluminium I used *Al* electrodes in the magnetic field. The longest times of exposure amounted to 6 hours; on account of the impurities, which come free with such discharges of long duration and which oppress the pure noble gas spectrum it was necessary to renew the Neon filling each $1^1/_2$ hour. I used an uncondensed high potential alternating current furnished by a large transformer. This discharging method in the magnetic field gives the spectrum of *Ne II* weaker than formerly the spectrum of *Ar II*.

[1]) C. J. BAKKER, T. L. DE BRUIN and P. ZEEMAN: These Proceedings **31**, 780, 1928. Zeitschr. f. Phys. **51**, 114, 1928; **52**, 299, 1928.

[2]) C. J. BAKKER: These Proceedings **31**, 1041, 1928.

This must be due to the higher ionization potential of *Ne I* (*Ne I* 21,5 Volt [1]) and *Ar I* 15,7 Volt [2])) and the higher excitation potentials of *Ne II*.

The largest strength of the magnetic field, attained during this investigation was 41400 ± 150 Gauss (diameter of the pole tips of the magnet 5 mm, distance ± 6 mm).

The exposures and measurements of the magnetic separations are made in the 2nd and 3rd order of a large 6 inch ROWLAND-grating mounted in the stigmatic grating mounting of the laboratory. Special attention is given to the constant temperature of the grating during the exposures (l.c. Argon *II*).

3. *Investigation and results.*

In the spectrum of ionized Argon (*Ar II*) the *g*-values of the term groups arising from the 4*s*, 4*p* and 5*s* electron are investigated. The goal of the investigation here given has been to fix in the spectrum of ionized Neon (*Ne II*) the *g*-values arising from the 3*s*, 3*p* and 4*s* electron. However the terms arising from the 4*s* electron are accessible only with difficulty for the investigation of the magnetic separation, because the spectral lines arising from these terms by combination with the 3*p* terms are weak lines of the spectrum (intensity < 4), lying in the neighbourhood of 3000 Å. Therefore I had to limit myself to the investigation of the 3*s* and 3*p* terms.

The coupling of a 3*s* electron with the atomic core of *Ne II* gives $3s\,^4P_{321}$ and $3s\,^2P_{21}$, the coupling of a 3*p* electron gives $3p\,^4D_{4321}$, $3p\,^4P_{321}$, $3p\,^4S_2$ and $3p\,^2D_{32}$, $3p\,^2P_{21}$, $3p\,^2S_1$. The quartet terms are known by the extensive analysis of the spectrum by DE BRUIN [3]), the doublet combinations are found by me by means of the ZEEMAN effect in agreement with the classification presumed by DE BRUIN and given by RUSSELL, COMPTON and BOYCE [4]).

In the following tables the ZEEMAN effect of the spectral lines is given after the multiplets in which those lines are classified.

In the 3rd column is:

L = ZEEMAN effect calculated with LANDÉ's *g*-formula.

obs. = observed ZEEMAN effect.

calc. = ZEEMAN effect calculated with anomalous *g*-values.

The last column refers to the theoretical *g*-values (theor.) calculated with LANDÉ's *g*-formula and to the *g*-values (obs.) calculated from the observed ZEEMAN effect.

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1) G. HERTZ: Zeitschr. f. Phys. **18**, 307, 1923; Naturw. **12**, 1211, 1924. G. HERTZ and R. K. KLOPPERS: Zeitschr. f. Phys. **31**, 463, 1925.

2) K. W. MEISSNER: Zeitschr. f. Phys. **37**, 238, 1926; **39**, 172, 1926; **40**, 839, 1927.

3) T. L. DE BRUIN: These Proceedings **31**, 2, 1928; **31**, 593, 1928. Zeitschr. f. Phys. **44**, 157, 1927; **46**, 856, 1928.

4) H. N. RUSSELL, K. T. COMPTON and J. C. BOYCE: Proc. Nat. Ac. of Sc. Am. **14**, 280, 1928.

Besides the magnetic separations given in the tables there are some more upon my plates (e.g. those of spectral lines which are combinations between the doublet terms of the $3p$ and $3d$ electron) I shall give those in a following communication.

As strong triplet there is in the first order the ZEEMAN effect of the strongest line of the arc spectrum of Neon $\lambda = 5852,487$ ($3s\,{}^1P_1 - 3p\,{}^3P_0$) I measured (0,00) $1,03^5$ which agrees very well with the measurement of BACK (0,00) 1,034 [1]).

The tables show that the doublet lines

$$\begin{matrix} 3557.84 & 3s\,{}^2P_1 - 3p\,{}^2S_1 \\ 3481.93 & 3s\,{}^2P_2 - 3p\,{}^2S_1 \end{matrix} \quad \text{and} \quad \begin{matrix} 3378.28 & 3s\,{}^2P_1 - 3p\,{}^2P_1 \\ 3309.78 & 3s\,{}^2P_2 - 3p\,{}^2P_1 \end{matrix}$$

have ZEEMAN effects that deviate from the ZEEMAN effect calculated with LANDÉ's g-formula. Thus we see that there are anomalous g-values here, which can be calculated from the observed ZEEMAN effect with

3p \ 3s	$^4P_1$	299.1	$^4P_2$	517.7	$^4P_3$
$^4P_1$	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
$^4D_1$	5. 3344.43 29891.9	299.1	3. 3311.30 30191.0		—
144.1					
$^4D_2$	5. 3360.63 29747.8	299.2	5 3327.16 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
$^4S_2$	4. 3028.85 33006.2	293.1	6. 3001.646 33305.3	517.4	7. 2955.735 33822.7

1) E. BACK: Ann. der Phys. **76**, 817, 1925.

λ	Termcomb. x—y		ZEEMAN-effect	g_x theor.	g_x obs.	g_y theor.	g_y obs.	Remarks
3777.162	$3s\,^4P_1 - 3p\,^4P_2$	L	(**0.47**) **1.26** 2.20					
		obs.	(**0.46**^{5}) **1.25** 2.19^5	2.67	2.67	1.73	1.73	1)
3766.286	$3s\,^4P_2 - 3p\,^4P_3$	L	(**0.07**) (0.20) **1.40** 1.53 1.67 1.80					
		obs.	(**0.00**) **1.45**	1.73	1.73	1.60	1.60	2)
3751.26	$3s\,^4P_1 - 3p\,^4P_1$	L	(0.00) 2.67					
		obs.	(0.00) 2.66^5	2.67	2.67	2.67	2.67	3)
3734.94	$3s\,^4P_2 - 3p\,^4P_2$	L	(0.00) 1.73					
		obs.	(0.00) 1.72^5	1.73	1.73	1.73	1.73	4
3709.643	$3s\,^4P_2 - 3p\,^4P_1$	L	(**0.47**) **1.26** 2.20					
		obs.	(**0.46**) 1.26 2.20	1.73	1.73	2.67	2.67	5
3694.22	$3s\,^4P_3 - 3p\,^4P_3$	L	(0.00) 1.60					
		obs.	(0.00) 1.60	1.60	1.60	1.60	1.60	6)
3664.089	$3s\,^4P_3 - 3p\,^4P_2$	L	(**0.07**) (0.20) **1.40** 1.53 1.67 1.80					
		obs.	(**0.00**) **1.48**	1.60	1.60	1.73	1.73	7)
3360.63	$3s\,^4P_1 - 3p\,^4D_2$	L	**0.47** (**0.73**) 1.93					
		obs.	**0.60**	2.67	2.67	1.20	1.20	8)
3355.05	$3s\,^4P_2 - 3p\,^4D_3$	L	(**0.18**) (0.54) **0.83** 1.19 1.55 1.91^5					
		obs.	(**0.19**) **0.85**	1.73	1.73	1.37	1.37	9)
3344.43	$3s\,^4P_1 - 3p\,^4D_1$	L	(1.33) 1.33					
		obs.	(1.33) 1.33	2.67	2.67	0.00	0.00	10)
3334.837	$3s\,^4P_3 - 3p\,^4D_4$	L	(**0.09**) (0.26) (0.43) **1.00** 1.17 1.34 1.51 1.69 1.86					
		obs.	(**0.00**) **1.12**	1.60	1.60	1.43	1.43	11)
3327.16	$3s\,^4P_2 - 3p\,^4D_2$	L	(0.27) (**0.80**) 0.93 **1.47** 2.00					
		obs.	(0.78^5) **1.48**	1.73	1.73	1.20	1.20	12)
3297.74	$3s\,^4P_3 - 3p\,^4D_3$	L	(0.11) (0.34) (**0.57**) 1.03 1.26 **1.49** 1.71 1.94					
		obs.	(**0.51**) **1.51**	1.60	1.60	1.37	1.37	13)

REMARKS.

1. Very sharp sextet. See photogram 2.
2. „Pseudotriplet". Central component enlarged; in both the other large components decrease of intensity clearly to the outside.
3. Sharp, wide triplet.
4. Sharp triplet.
5. Very sharp sextet. See photogram 4.
6. Strong, sharp triplet. See photogram 5.
7. „Pseudotriplet" just as 3766, 286 ($3s\,^4P_2$—$3p\,^4P_3$).
8. Weak diffuse doublet.
9. Weak, diffuse quartet.
10. Very sharp doublet. See photogram 9.
11. „Pseudotriplet". Central component enlarged; in both the other large components decrease of intensity to the outside. See photogram 10.
12. Weak, diffuse quartet.
13. Weak, diffuse quartet.

3p \ 3s	$^2P_2$	612.5	$^2P_1$
$^2D_3$	10. 3713.089 26924.0		—
511.4			
$^2D_2$	5. 3643.89 27435.4	612.5	9. 3727.08 26822.9
$^2S_1$	6. 3481.93 28711.5	612.6	4. 3557.84 28098.9
$^2P_2$	7. 3323.74 30077.9	612.2	6. 3392.80 29465.7
126.8			
$^2P_1$	3. 3309.78 30204.8	612.5	5. 3378.28 29592.3

λ	Termcomb. $x-y$		ZEEMAN-effect	g_x theor.	g_x obs.	g_y theor.	g_y obs.	Remarks
		L	(**0.07**) 0.73 **0.87**					
3727.08	$3s\ ^2P_1 - 3p\ ^2D_2$	obs.	(**0.00**) **0.82^5**	0.67	0.67	0.80	0.80	1)
		L	(**0.07**) (0.20) **1.00** 1.13 1.27 1.40					
3713.089	$3s\ ^2P_2 - 3p\ ^2D_3$	obs.	(**0.00**) **1.07**	1.33	1.33	1.40	1.40	2)
		L	(0.27) 0.53 (**0.80**) **1.07** 1.60					
3643.89	$3s\ ^2P_2 - 3p\ ^2D_2$	obs.	**0.83^5**	1.33	1.33	1.40	1.40	3)
		L	(0.67) 1.33					
3557.84	$3s\ ^2P_1 - 3p\ ^2S_1$	obs.	(0.64) 1.32	0.67	0.67	2.00	1.96	4)
		calc.	(0.64^5) 1.31^5					
		L	1.67 **1.00** (**0.33**) (**0.33**) **1.00** 1.67					
3481.93	$3s\ ^2P_2 - 3p\ ^2S_1$	obs.	1.64 **1.02** (**0.29^5**) (**0.29^5**) **1.02** 1.61	1.33	1.33	2.00	1.96	5)
		calc.	1.64 **1.02** (**0.29**) (**0.29**) **1.02** 1.64					
		L	(**0.33**) 1.00 **1.67**					
3392.80	$3s\ ^2P_1 - 3p\ ^2P_1$	obs.	(**0.33^5**) 0.99^5 **1.66**	0.67	0.67	1.33	1.33	6)
		L	(0.00) 0.67					
3378.28	$3s\ ^2P_1 - 3p\ ^2P_2$	obs.	(0.00) 0.68^5	0.67	0.67	0.67	0.71	7)
		calc.	(0.02) 0.69					
		L	(0.00) 1.33					
3323.74	$3s\ ^2P_2 - 3p\ ^2P_2$	obs.	(0.00) 1.33	1.33	1.33	1.33	1.33	8)
		L	**1.67** 1.00 (**0.33**) (**0.33**) 1.00 **1.67**					
3309.78	$3s\ ^2P_2 - 3p\ ^2P_1$	obs.	**1.62^5** (**0.30^5**) (**0.30^5**) **1.64**	1.33	1.33	0.67	0.71	9)
		calc.	**1.64^5** 1.02 (**0.31**) (**0.31**) 1.02 **1.64^5**					

REMARKS.

1. Somewhat diffuse triplet.
2. „Pseudotriplet". Central component enlarged; in both the other large components decrease of intensity to the outside. See photogram 3.
3. Weak, diffuse doublet. Decrease of intensity to the outside.
4. Very sharp quartet. See photogram 6.
5. Very sharp sextet. See photogram 7.
6. Very sharp sextet. See photogram 8.
7. Sharp triplet.
8. Sharp triplet.
9. Weak, sharp quartet.

the method as given for instance in our communication on the ZEEMAN effect of ionized Argon (*Ar II*) l.c.

The tables 3 and 4 contain the *g*-values calculated from LANDÉ's *g*-formula (g_L) and the observed *g*-values (g_{obs}) for the terms arising from the coupling of a 3*s* and 3*p* electron. The last column refers to the *g*-sums of LANDÉ. One must expect namely that in each of both tables 3 and 4 the sum of the *g*-values of the terms with the same inner quantum number *j* is equal to the sum of LANDÉ's *g*-values for these terms, also when the *g*-values of the separate terms deviate from those of LANDÉ.

The terms of the 3*s* electron all have normal *g*-values. This agrees with what has been found for ionized Argon (*Ar II*), then the analogous terms arising from the 4*s* electron all have normal *g*-values. The *g*-sum rule is of course fulfilled.

Among the terms of the 3*p* electron both the terms $3p\,^2S_1$ and $3p\,^2P_1$ have anomalous *g*-values. The *g*-sum rule is fulfilled.

In connection with the anomalous *g*-values of the two 3*p* terms it is remarkable that in the spectrum of ionized Argon (*Ar II*) just the analogous terms of the 3*p* electron $4p\,^2S_1$ and $4p\,^2P_1$ are those which

TABLE 3. TERMS OF THE 3s-ELECTRON

		$^4P_3$	$^4P_2$	$^4P_1$	$^2P_2$	$^2P_1$	
j = 1	g_L			2.67		0.67	$\Sigma g_L = 3.34$
	$g_{obs.}$			2.67		0.67	$\Sigma g_{obs.} = 3.34$
j = 2	g_L		1.73		1.33		$\Sigma g_L = 3.06$
	$g_{obs.}$		1.73		1.33		$\Sigma g_{obs.} = 3.06$
j = 3	g_L	1.60					$\Sigma g_L = 1.60$
	$g_{obs.}$	1.60					$\Sigma g_{obs.} = 1.60$

TABLE 4. TERMS OF THE 3P-ELECTRON.

		$^4P_3$	$^4P_2$	$^4P_1$	$^4D_4$	$^4D_3$	$^4D_2$	$^4D_1$	$^2D_3$	$^2D_2$	$^4S_2$	$^2S_1$	$^2P_2$	$^2P_1$	
$j = 1$	g_L			2.67				0.00				2.00		0.67	$\Sigma g_L = 5.34$
	$g_{obs.}$			2.67				0.00				1.96		0.71	$\Sigma g_{obs.} = 5.34$
$j = 2$	g_L		1.73				1.20			0.80	2.00		1.33		$\Sigma g_L = 7.06$
	$g_{obs.}$		1.73				1.20			0.80	2.00*		1.33		$\Sigma g_{obs.} = 7.06$
$j = 3$	g_L	1.60				1.37			1.20						$\Sigma g_L = 4.17$
	$g_{obs.}$	1.60				1.37			1.20						$\Sigma g_{obs.} = 4.17$
$j = 4$	g_L				1.43										$\Sigma g_L = 1.43$
	$g_{obs.}$				1.43										$\Sigma g_{obs.} = 1.43$

*) Not experimentally fixed.

show in there g-values the largest deviations from the normal g-values of LANDÉ.

Table 5 shows that the deviation of the g-value of LANDÉ for those analogous terms of ionized Neon (*Ne II*) and ionized Argon (*Ar II*) goes in the same direction and increases from Neon (atomic number 10) to Argon (atomic number 18).

TABLE 5.

TERM Neon II $n = 3$ Argon II $n = 4$	g-values		
	LANDÉ	*Ne* II	*Ar* II
$np\,^2P_1$	0.67	0.71	0.99
$np\,^2S_1$	2.00	1.96	1.68

4. *Summary.*

The ZEEMAN effect of the spectrum of ionized Neon (*Ne II*) has been investigated. The g-values of the terms arising from the $3s$ and $3p$ electron are tested by the g-values of LANDÉ for these terms. Some anomalous g-values are found and compared with the g-values of the analogous terms in the energy scheme of ionized Argon (*Ar II*).

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

Laboratory "Physica" University of Amsterdam.

November, 1928.

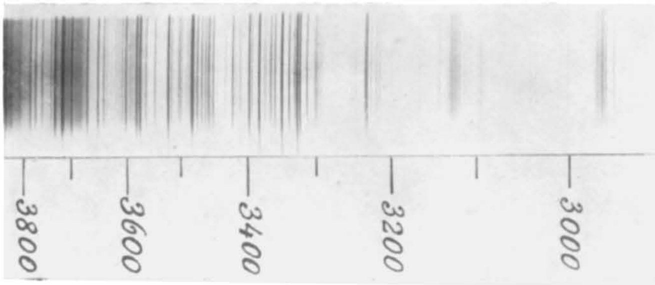
DESCRIPTION OF THE PLATE.

1. is an exposure with a HILGER quartz spectrograph (type E 3) and gives a survey of the investigated part of the spectrum of ionized Neon (*Ne II*), as it is excited by a discharge parallel the magnetic field of $\pm$ 41000 Gauss.

The photograms are made with a photometer (made by the firm of ZEISS), provided with photo-electric cell and electrometer.

2.	3777.162	$3s\ {}^4P_1 - 3p\ {}^4P_2$	7.	3481.93	$3s\ {}^2P_2 - 3p\ {}^2S_1$
3.	3713.089	$3s\ {}^2P_2 - 3p\ {}^2D_3$	8.	3392.80	$3s\ {}^2P_1 - 3p\ {}^2P_2$
4.	3709.643	$3s\ {}^4P_2 - 3p\ {}^4P_1$	9.	3344.43	$3s\ {}^4P_1 - 3p\ {}^4D_1$
5.	3694.22	$3s\ {}^4P_3 - 3p\ {}^4P_3$	10.	3334.837	$3s\ {}^4P_3 - 3p\ {}^4D_4$
6.	3557.84	$3s\ {}^2P_1 - 3p\ {}^2S_1$			

C. J. BAKKER: THE ZEEMAN-EFFECT IN THE SPECTRUM OF IONIZED NEON (NE II).



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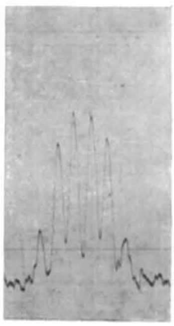

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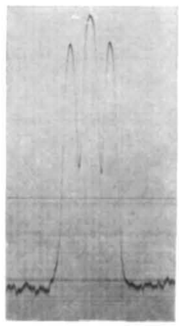

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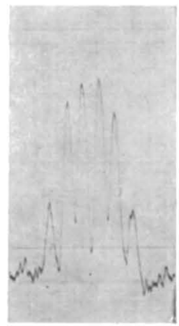

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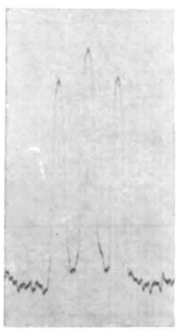

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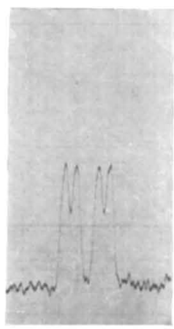
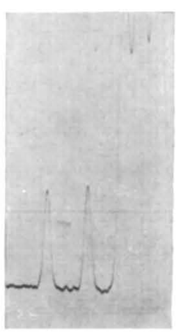


6.

7.

8.



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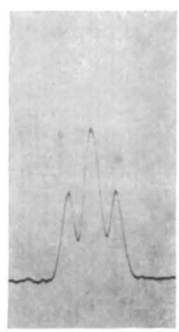

10.