Physics. — *"Determinations of the Terms in the Lanthanum Spectrum"* [1]).
By S. GOUDSMIT. (Communicated by Prof. P. EHRENFEST).

(Communicated at the meeting of October 25, 1924).

Most earlier measurements of the ZEEMAN effect in not classified spectra are insufficient to successfully apply LANDÉ's rules [2]) to them with a view to arrange the lines. An exception to this are the accurate measurements by S. RYBAR [3]) in the spectrum of Lanthanum.

In this same spectrum groups of lines with equal frequency differences have been found by E. PAULSON [4]).

Starting from these investigations a number of lines could be arranged in a term system, the relative term values could be determined, and the corresponding "innere Quantenzahl" J and factor of resolution g could be found for every term. Of the groups of lines found by PAULSON only those have been taken which were sufficiently certain by the observed ZEEMAN effects. Also several other lines have been classified, which did not occur in PAULSON's groups of lines.

From the ZEEMAN resolutions it appeared first of all that all classified lines belong to odd term-systems, hence that according to KOSSEL and SOMMERFELD's law of displacement they all are due to the *ionized* Lanthanum atom.

When the "innere Quantenzahl" J and the resolution factor g of a term are known from the ZEEMAN effects, it is generally possible to determine also the quanta values K and R by the aid of LANDÉ's formulae or table, i.e. the term symbol s, p, d etc. and also the term system, doublet, triplet, etc. can be found.

For some terms found in the Lanthanum spectrum this does not apply, however. Evidently these are the terms "höherer Stufe" examined of late by LANDÉ and HEISENBERG [5]). Of these terms the relation between g and the quanta values is not yet known, hence their term symbols could not be determined. They are indicated by Roman numerals in the tables.

Nor is it excluded that some of the ordinary terms of the first rank found are in reality terms of higher rank, which happen to have

1) Preliminary communication in Die Naturwissenschaften. 12, 851, 1924.
2) A. LANDÉ, Zeitschr. f. Phys. 15, 189, 1923.
3) S. RYBAR, Diss. Budapest and Phys. Zeit. 12, 889, 1911.
4) E. PAULSON, Ann. der Phys. 45, 1203, 1914.
5) W. HEISENBERG, Zeitschr. f. Phys. 26, 291, 1924. A. LANDÉ u. W. HEISENBERG, Zeitschr. f. Phys. 25, 279, 1924.

corresponding J and g values. This might e.g. be the case with the triplet terms $\overline{d_1}$ and $\overline{d_2}$, as the corresponding term $\overline{d_3}$ could not be found.

The occurrence of such terms of higher rank means, according to LANDÉ, that in the state in question the atom rest — i.e. the atom without the emitting electron — contains electron groups with azimuthal quanta values greater than 1, which do not form a closed configuration without moment of momentum. In the case of ionized Lanthanum this means very probably that the non-emitting electron of the two outer ones can sometimes describe a 6_1- and sometimes a 5_3-path. In the former case the ordinary terms are obtained, in the latter case those of higher rank.

TERM TABLE.

Relative value of the term	Term symbol	J	g
0	p_1	$2^1/_2$	$^3/_2$
1043.4	p_2	$1^1/_2$	$^3/_2$
1418.8	p_3	$^1/_2$	$^0/_0$
3705.8	I	$2^1/_2$	1.50 ± 0.01 (tripl. p_1 of quint. d_3?)
4888.7	$\overline{d_1}$	$3^1/_2$	$^4/_3$
5049.5	II	$1^1/_2$	1.28 ± 0.03
5780.3	III	$1^1/_2$	0.87 ± 0.01
5815.8	$\overline{d_2}$	$2^1/_2$	$^7/_6$
6790.1	IV	$2^1/_2$	0.84 ± 0.04
7231.0	V	$1^1/_2$	0.78 ± 0.02
8681.5	VI	$3^1/_2$	1.05 ± 0.03 (tripl. f_2?)
8741.4	VII	$2^1/_2$	0.88 ± 0.04
26975.5	$\overline{p_1}$	$2^1/_2$	$^3/_2$
27484.7	$\overline{p_2}$	$1^1/_2$	$^3/_2$
27953.1	$\overline{p_3}$	$^1/_2$	$^0/_0$
29952.4	d_1	$3^1/_2$	$^4/_3$
30611.6	d_2	$2^1/_2$	$^7/_6$
31308.6	d_3	$1^1/_2$	$^1/_2$
31808.4	D	$2^1/_2$	1
33202.8	VIII	$2^1/_2$	0.73 ± 0.02

THE COMBINATION $p\bar{p}$

λ	I	$\nu_{vac.}$	ZEEMAN effect observed	ZEEMAN effect calculated
3855.10	3	25932.3	(0) 1.49	(0) 1.50
3835.29	5	26066.3	(0) 1.51	(0) 1.50
3780.85	3r	26441.6	(0) 1.40	(0) 1.50
3715.03	3	26910.0	(0) 1.53	(0) 1.50
3706.02	5	26975.5	(0) 1.50	(0) 1.50
3637.35	3	27484.7	(0) 1.50	(0) 1.50

	$p_1\ 2\frac{1}{2}$		$p_2\ 1\frac{1}{2}$		$p_3\ \frac{1}{2}$
$\bar{p}_1\ 2\frac{1}{2}$	26975.5	**1043.2**	25932.3		
	509.2		**509.3**		
$\bar{p}_2\ 1\frac{1}{2}$	27484.7	**1043.1**	26441.6	**375.3**	26066.3
			468.6		
$\bar{p}_3\ \frac{1}{2}$			26910.0		

THE COMBINATION $p\,d$

λ	I	$\nu_{vac.}$	ZEEMAN effect observed	ZEEMAN effect calculated
3381.10	10	29567.7	(0) (0.40) 0.82 1.17 1.59	(0) (0.33) 0.83 1.17 1.50
3344.71	7	29889.4	(0) 0.52	(0) 0.50
3337.67	15	29952.4	(0) 1.13	(0) 1.00 1.17 1.33.....
3303.26	5	30264.4	0.52 (1.00) 1.53	(0.50) (1.00) 1.53
3265.79	4	30611.6	(0.67) 0.76 1.15 1.59 1,97	(0.67) 0.83 1.17 1.50 1.83
3193.09	1	31308.6	(0) (1.04) 1.42? 2.50	(0) (1.00) 1.50 2.50

	$p_1\ 2\frac{1}{2}$		$p_2\ 1\frac{1}{2}$		$p_3\ \frac{1}{2}$
$d_1\ 3\frac{1}{2}$	29952.4				
	659.2				
$d_2\ 2\frac{1}{2}$	30611.6	**1043.9**	29567.7		
	697.0		**696.7**		
$d_3\ 1\frac{1}{2}$	31308.6	**1044.2**	30264.4	**375.0**	29889.4

It is seen in these groups that the ratios of the term differences depart greatly from the interval rule of LANDÉ. They also give a good idea of the agreement between observed and calculated ZEEMAN effects.

It is remarkable that in his interesting paper on triplet combinations S. POPOW [1]) already suspected that the last group was a triplet *pd* combination.

In the calculation of the relative term-values the term p_1 was put equal to 0; it is, however, uncertain whether this term represents the highest or the lowest of the levels of energy.

TABLE A. OTHER COMBINATIONS.

Combination	λ	I	$\nu_{vac.}$	ZEEMAN effect observed	ZEEMAN effect calculated
$\overline{p}_1$ 2½ with					
I 2½	4296.21	8*r*	23269.8	(0) 1.49	(0) 1.50
$\overline{d}_1$ 3½	4526.30	5	22086.9	(0) 1.11	(0) 1.00 1.17 1.33...
II 1½	4559.51	2	21926.0	(0) 1.67	(0) 1.72
III 1½	4716.59	(8)	21195.8	(0) (0.65) 0.86 1.45 2.13	(0) (0.63) 0.85 1.50 2.13
$\overline{d}_2$ 2½	4724.57	(5)	21160.0	—	—
IV 2½ ?	4952.21	(4)	20187.4	(0) 1.21	0 84 (1.32) 1.50
V 1½	5063.07	(2)	19745.4	—	—
VI 3½	5464.57	(5)	18294.6	—	—
VII 2½	5482.47	(6)	18255.0	—	—
$\overline{p}_2$ 1½ with					
I 2½	4204.23	4*r*	23778.9	(0) 1.48	(0) 1.50
II 1½	4455.99	2	22435.4	(0.20) 1.40	(0.22) 1.28 1.50
III 1½	4605.99	2	21704.8	(0.62) 0 85 1.51	(0.63) 0.87 1.50
$\overline{d}_2$ 2½	4613.57	4	21669.1	—	—
IV 2½ ?	4830.68	(2)	20695.2	(0) 0.76	(0) 0.18 (0.66) 0.84 1.50
V 1½	4935.77	(2)	20254.6	—	—
VII 2½	?				
$\overline{p}_3$ ½ with					
II 1½	4364.84	3	22903.9	(0) 1.27	(0) 1.28
III 1½	?				
V 1½	4824.22	(8)	20723.0	(0) 0.78	(0) 0.78

[1]) S. POPOW, Ann. der Phys. 45, 147, 1914.

The calculated resolutions of the terms treated above were the starting-point for the calculation of the other term resolutions of the combinations following. As these resolutions could be calculated from different combi-

TABLE A (continued).

Combination	λ	I	$\nu_{vac.}$	ZEEMAN effect observed	ZEEMAN effect calculated
d_1 $3^1/_2$ with					
I $2^1/_2$	3808.89	2	26246.9	**(0)** 1.20	(0) **1.00** 1.17 1.33...
$\bar{d}_1$ $3^1/_2$	3988.66	30	25064.0	(0) 1.32	**(0)** 1.33
$\bar{d}_2$ $2^1/_2$	4141.90	10	24142.6	(0) 1.49	**(0)** **1.67** 1.40
IV $2^1/_2$	4316.07	1	23162.7	(0) (0.55) (1.10) 1.98 **2.35**	**(0)** (0.50) (1.00) 1.55 **2.35**
VI $3^1/_2$	4699.80	(2)	21271.6	—	—
VII $2^1/_2$	4713.08	(8)	21211.6	(0) (0.47) (0.92) 1.83 **2.26**	(0) (0.45) (0.91) 1.79 **2.24**
d_2 $2^1/_2$ with					
I $2^1/_2$	3715.67	4	26905.3	(0.64) 0.81 **1.15** **1.51** 1.78?	(0.67) 0.83 **1.16** **1.50** 1.84
$\bar{d}_1$ $3^1/_2$	3886.51	15	25722.7	(0) 1.53	(0) **1.67** 1.40...
II $1^1/_2$	3910.95	(2)	25562.0	(0) 1.05	(0) 1.05
III $1^1/_2$	4026.03	4	24831.4	(0) 1.33	(0) **1.46** 1.16...
$\bar{d}_2$ $2^1/_2$	4031.86	7	24795.5	(0) 1.15	(0) 1.16
IV $2^1/_2$	4196.74	10	23821.3	(0.39) 0.52 **(0.60)** **0.81** **1.14** [1.41	(0.32) 0.52 **(0.64)** **0.84** **1.16** [1.49
V $1^1/_2$	4275.80	4	23380.9	(0) (0.36) 1.13 **1.51**	**(0)** (0.38) 1.16 **1.55**
VI $3^1/_2$	4558.66	4	21930.2	(0) 0.93	(0) **0.82** 0.94 1.05...
VII $2^1/_2$	4571.14	(2*u*)	21870.4	(0.43) 1.00	(0.57) 0.88 **1.16**
d_3 $1^1/_2$ with					
I $2^1/_2$	3621.96	1	27601.4	(0) (1.06) 2.52	**(0)** (1.00) 2.50
II $1^1/_2$	?				
III $1^1/_2$	3916.21	10	25527.7	(0.38) **0.47** 0.89	(0.37) **0.50** 0.87
$\bar{d}_2$ $2^1/_2$	3921.71	10	25491.9	**(0)** 0.57 (0.64) 1.19 **1.82**	**(0)** 0.50 (0.66) **1.16** 1.87
IV $2^1/_2$	4077.51	15	24517.9	**(0)** (0.37) 0.50 0.84 **1,18**	(0) (0.34) 0.50 0.84 **1.18**
V $1^1/_2$	4152.17	10	24077.0	(0.29) 0.48 **0.78**	(0.28) **0.50** 0.78
VII $2^1/_2$	4430.11	8	22566.5	**(0)** (0.43)... 0 90? **1.34**	**(0)** (0.38) 0.50 0.90 **1.26**

nations, the means of the g values found were given in the term table with the possible deviations. This was, of course, not necessary for the ordinary terms of the first rank of which the exact values of g have been given by LANDÉ.

Table A gives the other combinations between the terms given above with the observed and the calculated ZEEMAN effects. The latter have been calculated with the mean g-values given in the term-table.

TABLE A (continued).

Combination	λ	I	$\nu_{vac.}$	ZEEMAN effect observed	ZEEMAN effect calculated
D 2½ with					
p_1 2½	3142.99	1	31807.6	—	—
p_2 1½	3249.33	3	30765.1	(0) **0.47** (0.49) 1.02	(0) **0.50** (0.50) 1.00
I 2½	3557.40	1	28102.4	—	—
$\bar{d}_1$ 3½	3713.71	6	26919.6	(0) (0.32) (0.64) 1.72 **2.06**	(0) (0.33) (0.67) 1.67 **2.00**
II 1½	3736.02	5	26758.9	—	—
III 1½	3840.92	5	26028.0	(0) 1.05	(0) **1.13** 1.00
$\bar{d}_2$ 2½	3846.16	3	25992.6	(0.28) 1.12	(0.33) 1.00 1.16
IV 2½	3995.91	5r	25018.6	(0.27) 0.90	(0.32) 0.84 1.00
V 1½	4067.52	8	24578.1	(0) 1.09	(0) **1.22** 1.00
VI 3½	4322.69	5	23127.3	(0) 1.08	(0) **1.15** 1.10 1.05
VII 2½	4333.97	15	23067.0	(0.19) 0.95	(0.24) 0.88 1.00
VIII 2½ with					
p_1 2½	3010.92	(2)	33202.8	—	—
p_2 1½	3108.57	(2)	32159.8	—	—
I 2½	?				
$\bar{d}_1$ 3½	3530.80	1	28274.1	—	—
II 1½	3550.98	1	28153.2	—	—
III 1½	3645.57	8	27422.7	(0) 0.63	(0) 0.59
$\bar{d}_2$ 2½	3650.31	4	27394.6	0.29 **0.73** (0.87) **1.17** 1.60	0.30 **0.73** (0,87) **1.16** 1.60
IV 2½	3784.95	2	26413.0	(0.17) 0.79	(0.22) 0.73 0.84
V 1½	3849.20	10	25972.1	(0) 0.69	(0) 0.68
VI 3½	4076.85	2	24521.8	(0) (0.35) (0.61) 1.33 **1.67**	(0) (0.32) (0.64) 1.37 **1.69**
VII 2½	4086.90	20	24461.5	(0.27) 0.81	(0.30) 0,73 **0.88**

TABLE B. LINES WITH KNOWN ZEEMAN EFFECT, WHICH HAVE NO PLACE AS YET IN THE TERM SYSTEM.

λ	I	$\nu_{vac.}$	ZEEMAN effect observed	Combination J_1	g_1	with J_2	g_2
3104.76	1	32199.3	(0) (0.50)... 1.49	2½	1.00	1½	0.50
3513.06	1	28457.1	0.54 (0.57) 1.08	1½	0.54	1½	1.08
3725.24	3	26836.3	(**0**) (0.39) (0.74) **1.47** 1.82	2½	0.73	3½	1.10
4152.97	5	24072.4	0.32 **0.64** (0.76) **1.05** 1.42	2½	0.66	2½	1.05
4238.57	10	23586.2	(0.64) **0,73** **1.00** **1.30** 1.60	2½	**1.00**	2½	1.30
4250.17	6	23521.8	(0.65) 0.66 **0.98** **1.30** 1.60	2½	1.00	2½	1.32
4300.59	3	23246.1	**0** **0.73** (0.73) **1.46** (**1.50**) 2.18	2½	0.73	2½	1.46
4383.62	5	22805.8	(**0**) (0.42) (0.87) 1.50 **1.89**	2½	0.64	3½	1.06
4436.02	1	22536.4	(**0**) (0.57) (1.19) 1.80 **2.43**	2½	0.60	3½	1.20
4474.72	(3)	22341.5	(**0**) (0.76) 1.11 **1.84**	2½	1.10	1½	0.36
4575.08	4	21851.4	(0.48) 0.51 **0.95** (**0.98**) **1.46** 2.07	2½	0.98	2½	1.48
4647.64	1	21510.3	(**0**) (0.44) (0.86) 1.74 **2.15**	2½	0.88	3½	1.30
4669.10	3	21411.4	(**0**) (0.40) (0.72) 1.51 **1.86**	2½	0.75	3½	1.12
4728.55	(10)	21142.2	(**0**) (0.39) (1.59) 1.89	2½	**1.11**	1½	0.72
4804.22	(7)	20809.2	0.55 (0.93) 1.43	1½	0.55	1½	1.43
4946.60	(5)	20210.3	(0) (0.62) 1.17 1.81	2½	**1.17**	1½	**0.54**
4986.99	(6)	20046.6	(0) (0.46) 0.95 **1.40**	2½	0.95	1½	**0.50**

TABLE C. CLASSIFIED LINES.

λ	I	$\nu_{vac.}$	Combination	λ	I	$\nu_{vac.}$	Combination
3010.92	(2)	33202.8	p_1 VIII	3513.06	1	28457.1	—
3104.76	1	32199.3	—	3530.80	1	28274.1	$\bar{d}_1$ VIII
3108.57	(2)	32159.8	p_2 VIII	3550.98	1	28153.2	II VIII
3142.99	1	31807.6	p_1 D	3557.40	1	28102.4	I D
3193.09	1	31308.6	p_1 d_3	3621.97	1	27601.4	I d_3
3249.49	3	30765.1	p_2 D	3637.35	3	27484.7	p_1 $\bar{p}_2$
3265.79	4	30611.6	p_1 d_2	3645.57	8	27422.7	III VIII
3303.26	5	30264.4	p_2 d_3	3650.31	4	27394.6	$\bar{d}_2$ VIII
3337.67	15	29952.4	p_1 d_1	3706.02	5	26975.5	p_1 $\bar{p}_1$
3344.71	7	29889.4	p_3 d_2	3713.71	6	26919.6	$\bar{d}_1$ D
3381.10	10	29567.7	p_2 d_2	3715.03	3	26910.0	p_2 $\bar{p}_3$

The wave-lengths and intensities are borrowed from the Handbuch of KAYSER according to EXNER and HASCHEK's observations, (spark

λ	I	$\nu_{vac.}$	Combination	λ	I	$\nu_{vac.}$	Combination
3715.67	4	26905.3	I d_2	4316.07	1	23152.7	IV d_1
3725.24	3	26836.3	—	4322.69	5	23127.3	VI D
3736.02	5	26758.9	II D	4333.97	15	23057.0	VII D
3780.85	3*r*	26441.6	p_2 $\bar{p}_2$	4364.85	3	22903.9	II $\bar{p}_3$
3784.95	2	26413.0	IV VIII	4383.62	5	22805.8	—
3808.89	2	26246.9	I d_1	4430.11	8	22566.5	VII d_3
3835.29	5	26066.3	p_3 $\bar{p}_1$	4436.02	1	22536.4	—
3840.92	5	26028.0	III D	4455.99	2	22435.4	II $\bar{p}_2$
3846.16	3	25992.6	$\bar{d}_2$ D	4474.72	(3)	22341.5	—
3849.20	10	25972.1	V VIII	4526.30	5	22086.9	$\bar{d}_1$ $\bar{p}_1$
3855.10	3	25932.3	p_2 $\bar{p}_1$	4558.66	4	21930.2	VI d_2
3886.51	15	25722.7	$\bar{d}_1$ d_2	4559.51	2	21926.0	II $\bar{p}_1$
3910.95	(2)	25562.0	II d_2	4571.14	(2*u*)	21870.4	VII d_2
3916.21	10	25527.7	III d_3	4575.08	4	21851.4	—
3921.71	10	25491.9	$\bar{d}_2$ d_3	4605.99	2	21704.8	III $\bar{p}_2$
3988.66	30	25064.0	$\bar{d}_1$ d_1	4613.57	4	21669.1	$\bar{d}_2$ $\bar{p}_2$
3995.91	5*r*	25018.6	IV D	4647.64	1	21510.3	—
4026.03	4	24831.4	III d_2	4669.10	3	21411.4	—
4031.86	7	24795.5	$\bar{d}_2$ d_2	4699.80	(2)	21271.6	VI d_1
4067.52	8	24578.1	V D	4713.08	(8)	21211.6	VII d_1
4076.85	2	24521.8	VI VIII	4716.59	(8)	21195.8	III $\bar{p}_1$
4077.51	15	24517.9	IV d_3	4724.57	(5)	21160.0	$\bar{d}_2$ $\bar{p}_1$
4086.90	20	24461.5	VII VIII	4728.55	(10)	21142.2	—
4141.90	10	24142.6	$\bar{d}_2$ d_1	4804.22	(7)	20809.2	—
4152.17	10	24077.0	V d_3	4824.22	(8)	20723.0	V $\bar{p}_3$
4152.97	5	24072.4	—	4830.68	(2)	20695.2	IV $\bar{p}_2$?
4196.74	10	23821.3	IV d_2	4935.77	(2)	20254.6	V $\bar{p}_2$
4204.23	4*r*	23778.9	I $\bar{p}_2$	4946.60	(5)	20210.3	—
4238.57	10	23586.2	—	4952.21	(4)	20187.4	IV $\bar{p}_1$?
4250.17	6	23521.8	—	4986.99	(6)	20046.6	—
4275.80	4	23380.9	V d_2	5063.07	(2)	19745.4	V $\bar{p}_1$
4296.21	8*r*	23269.8	I $\bar{p}_1$	5464.57	(5)	18294.6	VI $\bar{p}_1$
4300.59	3	23246.1	—	5482.47	(6)	18255.0	VII $\bar{p}_1$

spectrum), those where the intensities are placed between brackets according to WOLFF, (arc-spectrum).

Table B gives the lines, for which the observed ZEEMAN effect renders a calculation of J and g for initial and final state possible, but which cannot yet be classed in the above-given term system. For some of these lines the result is uncertain, possibly because not yet all the parallel components have been observed.

Table C gives the classified lines.

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