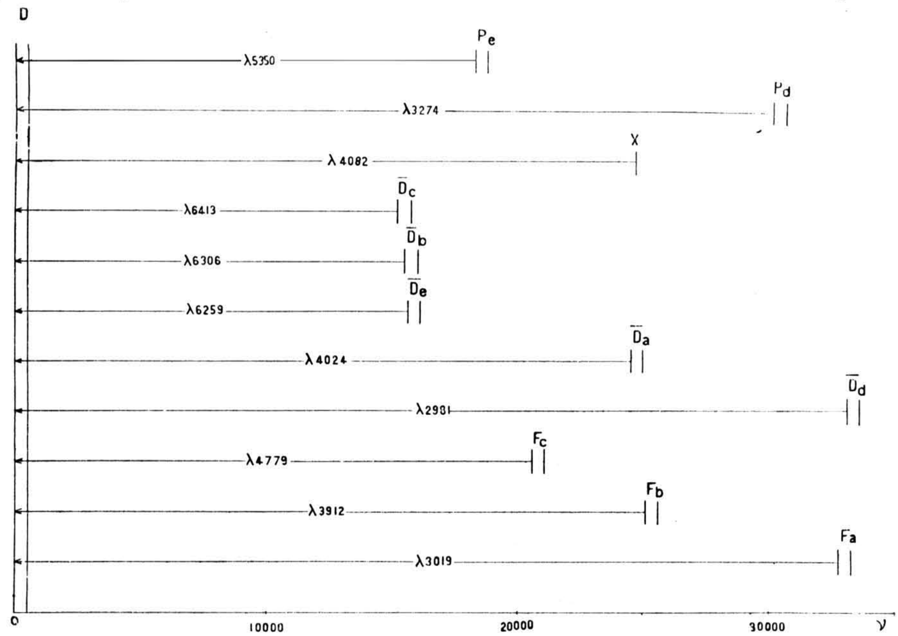
Physics. — "*Magnetic Resolution of the Scandium Spectrum*". (First Part).[1]) By S. GOUDSMIT, J. VAN DER MARK, and Prof. P. ZEEMAN.

(Communicated at the meeting of December 27, 1924).

Classification of the lines.

Several lines of the Scandium spectrum have been arranged into a term system by CATALÁN.[2]) According to him the spectrum of neutral Scandium contains a doublet and a quartet term system, that of ionized Scandium a triplet system. The classification of CATALÁN, however, contains a few inaccuracies, which were evidently also perceived by GIESELER and GROTRIAN[3]) in connection with their observations on the absorption in Scandium. From a theoretical point of view the rectification of the inaccuracies is important.

On account of the particular place which Scandium occupies in the periodic system of the elements — i.e. the first element in this system



Sc I Doubletsysteem.

Fig. 1.

1) Preliminary communications in Nature, Sept. 20, 1924, Naturw. 12, p. 743, 1924.

2) M. A. CATALÁN. An. Soc. Esp. 20, p. 606, 1922, and 21, p. 464, 1923.

3) H. GIESELER u. W. GROTRIAN. Zeitschr. f. Phys. 25, p. 342, 1924.

Note added to the Dutch proof. In the meantime a publication has appeared by CATALÁN with the corrected term system of ionized Scandium. An. Soc. Esp. 22, p. 497, 1924. Cf. also MEGGERS. Journal of the Washington Academy of Sciences, Vol. 14, N⁰. 18, Nov. 4. 1924.

Sc I. DOUBLET SYSTEM.

Doublet distance	Relative value of the term	Termsymbol	J	g
168.5	0	D_2	2	4/5
	168.5	D_1	3	6/5
84.1	15672.4	$\overline{D_2^c}$	2	4/5
	15756.5	$\overline{D_1^c}$	3	6/5
0.8	16021.9	$\overline{D_2^b}$	2	4/5
	16022.7	$\overline{D_1^b}$	3	6/5
44.0	16096.9	$\overline{D_2^e}$	2	4/5
	16140.9	$\overline{D_1^e}$	3	6/5
144.6	18711.1	P_2^e	1	2/3
	18855.7	P_1^e	2	4/3
53.1	21032.8	F_2^c	3	6/7
	21085.9	F_1^c	4	8/7
	24656.7	X	—	—
148.0	24866.1	$\overline{D_2^a}$	2	4/5
	25014.1	$\overline{D_1^a}$	3	6/5
140.1	25584.3	F_2^b	3	6/7
	25624.4	F_1^b	4	8/7
133.1	30573.7	P_2^d	1	2/3
	30706.8	P_1^d	2	4/3
124.4	33154.1	F_2^a	3	6/7
	33278.5	F_1^a	4	8/7
92.3	33614.8	$\overline{D_2^d}$	2	4/5
	33707.1	$\overline{D_1^d}$	3	6/5

in which completion of an internal group of electrons begins — it seemed of importance to us to confirm the classification of the lines through the examination of the magnetic resolutions, which is the chief end of this investigation.

ARRANGED LINES [1]). Sc I. DOUBLET SYSTEM.

Arc intensity	λ. I. Å.	$\nu_{vac.}$	Combination	Arc intensity	λ. I. Å.	$\nu_{vac.}$	Combination
2	2965.88	33707.0	$D_2 \ \overline{D}_1^d$	3	4753.16	21032.8	$D_2 \ F_1^c$
3	74.01	614.8	$D_2 \ \overline{D}_2^d$	3	79.41	20917.3	$D_1 \ F_1^c$
3	80.75	538.8	$D_1 \ \overline{D}_2^d$	1	91.56	864.2	$D_1 \ F_2^c$
2	89.00	446.3	$D_1 \ \overline{D}_2^d$	1	5301.97	18855.7	$D_2 \ P_1^e$
3	3015.34	33154.1	$D_2 \ F_2^a$	1	42.95	711.1	$D_2 \ P_2^e$
4	19.36	110.0	$D_1 \ F_1^a$	3	49.70	687.4	$D_1 \ P_1^e$
2	30.75	32985.6	$D_1 \ F_2^a$	—	6193.72	16140.9	$D_2 \ \overline{D}_1^e$
3	3255.67	30706.8	$D_2 \ P_1^d$	3	6210.68	096.9	$D_2 \ \overline{D}_2^e$
5	69.84	573.7	$D_2 \ P_2^d$	2	39.42	022.7	$D_2 \ \overline{D}_1^b$
5	73.65	538.2	$D_1 \ P_1^d$	2	39.78	021.8	$D_2 \ \overline{D}_2^b$
30	3907.54	25584.3	$D_2 \ F_2^b$	1	58.93	15972.8	$D_1 \ \overline{D}_1^e$
30	11.88	556.0	$D_1 \ F_1^b$	1	76.25	928.7	$D_1 \ \overline{D}_2^e$
6	33.44	415.9	$D_1 \ F_2^b$	10	6305.72	854.2	$D_1 \ \overline{D}_1^b$
15	3996.61	25014.1	$D_2 \ \overline{D}_1^a$	—	06.04	853.4	$D_1 \ \overline{D}_2^b$
20	4020.40	24866.2	$D_2 \ \overline{D}_2^a$	1	6344.82	15756.5	$D_2 \ \overline{D}_1^c$
30	23.68	845.9	$D_1 \ \overline{D}_1^a$	2	78.80	672.6	$D_2 \ \overline{D}_2^c$
10	47.81	697.8	$D_1 \ \overline{D}_2^a$	3	6413.32	588.2	$D_1 \ \overline{D}_1^c$
10	4054.56	24656.7	$D_2 \ X$	—	48.20	503.9	$D_1 \ \overline{D}_2^c$
15	82.44	488.3	$D_1 \ X$				

[1]) Wave-lengths and intensities according to EXNER and HASCHEK, corrected to I. Å.

Sc II. TRIPLET SYSTEM.

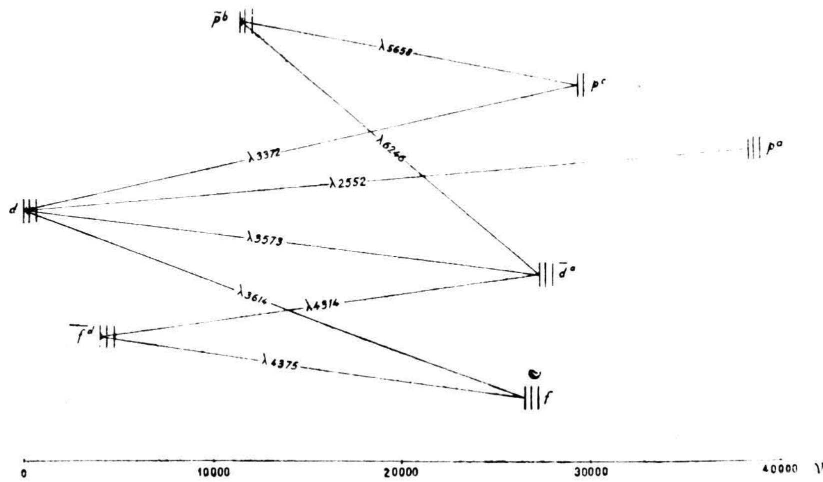
Triplet distance	Relative value of the term	Termsymbol	J	g
	0	d_3	$1\frac{1}{2}$	$\frac{1}{2}$
67.6				
	67.6	d_2	$2\frac{1}{2}$	$\frac{7}{6}$
110.2				
	177.8	d_1	$3\frac{1}{2}$	$\frac{4}{3}$
	4802.4	$\overline{f_3^d}$	$2\frac{1}{2}$	$\frac{2}{3}$
80.8				
	4883.2	$\overline{f_2^d}$	$3\frac{1}{2}$	$\frac{13}{12}$
104.3				
	4987.5	$\overline{f_1^d}$	$4\frac{1}{2}$	$\frac{5}{4}$
	12073.8	$\overline{p_3^b}$	$\frac{1}{2}$	$\frac{0}{0}$
27.5				
	12101.3	$\overline{p_2^b}$	$1\frac{1}{2}$	$\frac{3}{2}$
52.8				
	12154.1	$\overline{p_1^b}$	$2\frac{1}{2}$	$\frac{3}{2}$
	27443.9	f_3	$2\frac{1}{2}$	$\frac{2}{3}$
158.8				
	27602.7	f_2	$3\frac{1}{2}$	$\frac{13}{12}$
238.7				
	27841.4	f_1	$4\frac{1}{2}$	$\frac{5}{4}$
	27918.1	$\overline{d_3^a}$	$1\frac{1}{2}$	$\frac{1}{2}$
103.5				
	28021.6	$\overline{d_2^a}$	$2\frac{1}{2}$	$\frac{7}{6}$
139.4				
	28161.5	$\overline{d_1^a}$	$3\frac{1}{2}$	$\frac{4}{3}$
	29742.3	p_2^c	$1\frac{1}{2}$	—
81.9				
	29824.2	p_1^c	$2\frac{1}{2}$	$\frac{3}{2}$
	39002	p_3^a	$\frac{1}{2}$	$\frac{0}{0}$
113				
	39115	p_2^a	$1\frac{1}{2}$	$\frac{3}{2}$
231				
	39346	p_1^a	$2\frac{1}{2}$	$\frac{3}{2}$

Here follows first of all the corrected term scheme for the doublet and the triplet system.

The term d_3, which was put equal to 0 here, very probably belongs

ARRANGED LINES. Sc II. TRIPLET SYSTEM.

Spark intensity	λ. I. Å.	$\nu_{vac.}$	Combination	Spark intensity	λ. I. Å.	$\nu_{vac.}$	Combination
—	2540.86	39345.0	$d_3\ p_1^a$	1	4279.93	23358.3	$\overline{f_3^d}\ \overline{d_1^a}$
4	45.19	278.1	$d_2\ p_1^a$	5	94.78	277.6	$\overline{f_2^d}\ \overline{d_1^a}$
8	52.39	167.2	$d_1\ p_1^a$	6	4305.72	218.4	$\overline{f_3^d}\ \overline{d_2^a}$
4	55.82	114.6	$d_3\ p_2^a$	30	14.09	173.4	$\overline{f_1^d}\ \overline{d_1^a}$
6	60.28	046.5	$d_2\ p_2^a$	20	20.75	137.7	$\overline{f_2^d}\ \overline{d_2^a}$
4	63.21	002.0	$d_3\ p_3^a$	20	24.99	115.0	$\overline{f_3^d}\ \overline{d_3^a}$
2	3352.05	29824.5	$d_3\ p_1^c$	5	4354.61	22957.7	$\overline{f_2^d}\ f_1$
8	59.69	756.6	$d_2\ p_1^c$	30	74.51	853.3	$\overline{f_1^d}\ f_1$
8	61.31	742.3	$d_3\ p_2^c$	5	84.80	799.7	$\overline{f_3^d}\ f_2$
10	68.96	674.7	$a_2\ p_2^c$	20	4400.39	718.9	$\overline{f_2^d}\ f_2$
10	72.16	646.4	$d_1\ p_1^c$	20	15.55	640.9	$\overline{f_3^d}\ f_3$
20	3558.56	28093.3	$d_2\ \overline{d_1^a}$	2	20.66	614.7	$\overline{f_1^d}\ f_2$
20	67.72	021.1	$d_3\ \overline{d_2^a}$	3	31.36	560.1	$\overline{f_2^d}\ f_3$
50	72.57	27983.1	$d_1\ \overline{d_1^a}$	1	5641.00	17722.5	$\overline{p_2^b}\ p_1^c$
30	76.37	953.3	$d_2\ \overline{d_2^a}$	2	57.89	669.5	$\overline{p_1^b}\ p_1^c$
20	80.98	917.4	$d_3\ \overline{d_3^a}$	1	58.35	668.1	$\overline{p_3^b}\ p_2^c$
10	89.67	849.8	$d_2\ \overline{d_3^a}$	1	67.19	640.5	$\overline{p_2^b}\ p_2^c$
10	90.52	843.2	$d_1\ \overline{d_2^a}$	1	84.22	587.7	$\overline{p_1^b}\ p_2^c$
100	3613.83	27663.6	$d_1\ f_1$	1	6245.64	16006.8	$\overline{p_1^b}\ \overline{d_1^a}$
100	30.75	534.7	$d_2\ f_2$	1	79.74	15919.8	$\overline{p_2^b}\ \overline{d_2^a}$
50	42.96	443.6	$d_3\ f_3$	—	6300.64	867.0	$\overline{p_1^b}\ \overline{d_2^a}$
15	45.48	424.6	$d_1\ f_2$	1	09.94	843.6	$\overline{p_3^b}\ \overline{d_3^a}$
20	51.99	375.7	$d_2\ f_3$	—	20.85	816.3	$\overline{p_2^b}\ \overline{d_3^a}$
3	66.68	266.0	$d_1\ f_3$	—	42.02	763.5	$\overline{p_1^b}\ \overline{a_3^a}$



ScII Tripletsysteem.

Fig. 2.

to the lowest of the levels of energy discussed here. Whether it is also the lowest possible level of ionized Scandium cannot be decided as yet.

Experimental part.

In the investigation a concave Rowland grating was used as spectrograph, mounted in the way indicated by EAGLE [1]). The grating has 14438 lines to the inch; width 5 inches (originally 6 inches), a strip of 1 inch on one of the sides of the grating gave rise to disturbances, and was therefore covered when the photo was taken; radius of curvature 21 feet.

The photos were taken in the 2nd order on plates 50 cm. long, which covered an area of about 600 Å, so that the dispersion amounted to about 1,2 Å per mm. The drawback of the EAGLE mounting is that the photographic focussing must be made anew for every area. As source of light a MERTON vacuum iron arc lamp appeared to be very efficient [2]). With the ordinary iron arc in air the very delicate adjustment necessary for the photographing of the resolution figures, was much more difficult to attain on account of the lines being less fine.

The brightness of the grating is rather small, so that exposures of 5 hours appeared to be necessary.

The magnetic field was produced by a Weiss-magnet with water cooling which gave a field of about 41000 Gauss with the distance of the poles used and with a current of 100 Ampères. The current was supplied by a converter, with which the strength of the current could be kept sufficiently constant. The cooling of the magnet was very efficient, so much so that its temperature was lower than that of the room.

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[1]) Astroph. Journ. 31, p. 120, 1910.

[2]) Prof. MERTON was so kind as to put a drawing of his lamp at the disposal of one of us (P. Z.).

As source of light in the field a vacuum trembler was used, a modification of BACK'S Abreissbogen [1]). The modification consists in this that the mechanical arrangement that works the tungsten electrode in BACK'S experiment, has been discarded, and that the current itself works it. The arrangement is briefly this [2]): the tungsten electrode is fastened to a pendulum, which can move freely in the direction from pole to pole. By means of a feeble spring with a tension adjustable from the outside, the tungsten electrode is always pressed against the other, fixed electrode.

The whole apparatus is made so small that it can be contained inside the vacuum pot which is placed between the pole pieces, and fastened, like the other electrode, to a ground-in metal stopper, so as to render quick removal possible. Now the current must pass through a solenoid which is fastened to the pendulum, and the axis of which is at right angles to the direction of the lines of force between the polar pieces of the magnet. The solenoid is still in a very strong field, so that it need have only few turns to draw the tungsten electrode from the other and produce an interrupting spark or arc, if the current direction be chosen well.

The spark burned in hydrogen of low pressure, just as in BACK'S arrangement. We, however, admitted hydrogen through a narrow capillary, which was sucked off again by a slowly running Gaede pump, so that we experienced less trouble of small leakages, which are sometimes inevitable.

Scandium being unknown in metallic state, it was not possible to use a metal electrode for the spark. We were, therefore, obliged to have recourse to carbon electrodes. Carbon pieces, sawn out of arc-lamp carbon, appeared too much liable to breakage, on account of the required small dimensions (about $20 \times 1 \times 1.5$ mm.), and they contained too many contaminations. This induced us to make the carbon pieces ourselves. The material for them is soot, obtained from a smoking kerosene flame. This is mixed with anhydrous coal tar, kneaded, and at last beaten till a very stiff paste is obtained. By the aid of a very simple compressing cylinder with piston placed in a bench vice, this paste is spouted to a long thread with the required rectangular cross-section. This thread is cut to pieces of the desired length. The carbon pieces, which are still soft, are carefully packed in a crucible with graphite, and kept yellow-red hot for three quarters of an hour. After the outer crust of graphite had been ground off, strong metallic-sounding carbon pieces were obtained, which hardly ever broke.

Carbons, into which Scandium oxide had already been entered during the preparation, appeared to give only a feeble spectrum. Carbon soaked in the chloride, appeared to give a better result. In order to introduce as much Scandium into the carbons as possible, the carbons were first kept

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[1]) Ann. d. Phys. Bd. 70, 1923, p. 336.

[2]) A more detailed description will follow.

under vacuum for a long time, then a concentrated Scandium solution was admitted, after which the vacuum was broken. The carbons obtained in this way, contained only very weak contaminations, chiefly calcium.

The application of carbons in the vacuum trembler has a drawback, viz. that the tungsten electrode is pretty quickly consumed. This is the reason that we do not apply as BACK a ground tungsten electrode of a definite shape, but an ordinary tungsten filament (thickness 0,6 mm.) which can be easily replaced. The carbons themselves are only very slowly consumed, one carbon is sufficient for four hours' illumination.

The plates have been measured in four different ways;

1. with the comparator,
2. with the micro-photometer,
3. in the projected image.

For sharp lines of a certain degree of blackness the comparator appeared the most suitable method, the micro-photometer gave the best results for diffuse lines (pseudo-triplets and similar lines), the last method appearing to be the best for exceedingly weak lines. An image of the lines was thrown on a screen with a known magnification by micro-projection, and then measured. Very feeble lines for which the adjustment could not be made accurately in the comparator, and which could not be seen in consequence of the grain in the micro-photogram, could still be measured very well by this method. In the measurement of very diffuse lines the adjustment was made for the centre of gravity of the blackening; for some of these lines it was also still possible to make the adjustment for the sharp boundary line of the components, which measurement was then in good agreement with theory.

Measurements were made in the regions of 3900—4500 Å, and 3200—3900 Å. Other regions will follow. At the moment a new, much brighter grating arrangement is being constructed in the laboratory, which will be taken in use very soon. With this apparatus some other parts of the spectrum wil be examined, besides other lines, which are still doubtful. Between 3900—4500 Å the normal triplet distance has been calculated from the resolutions of the calcium triplet λ 4226 and the calcium quadruplet λ 3968. The calcium sextet λ 3933 also occurs on the photographic plates; at some tenths of Å there occurs a very feeble Scandium line, which all the same deforms the sextet perceptibly.

Starting from the region of 3200 Å there did not occur a single foreign line suitable for a determination of the intensity of the field. From the photographs in the preceding region it had, however, already been ascertained, what resolutions the Scandium lines $\lambda\lambda$ 3572, 3576, and 3581 would have to present. These lines give all three sharp triplets. We have used these lines for the determination of the intensity of the field. This appears to be justified on account of the good agreement presented by the resolutions of the other Scandium lines with the resolutions predicted.

We have, therefore, omitted to take a special photograph for the determination of the field intensity.

On the whole the Scandium lines, even the sharp triplets, are somewhat diffuse. Consequently the attainable accuracy is not very great. It is, of course, also different for different lines. As a general datum for the accuracy of the measurements it may be stated that the position of the components could be determined up to an average of 0,006 Å. For sharp lines the mean deviation from the mean value was 0,0025 mm. = 0,0033 Å for a series of 10 observations, it increased to 0,008 mm. = 0,010 Å for very hazy lines. When it is also stated that the widest resolution was ± 0,66 Å from central to outer component, and the narrowest ± 0,12 Å, it appears that the error which will be finally present in the result, can never be very small.

THE MAGNETIC RESOLUTIONS.

Sc I Doublet system.

Combinations *DD*

λ **3996.61** $D_2 \overline{D_1^a}$ $\qquad J = 2, \; g = \frac{4}{5}$ with $J = 3, \; g = {}^6/_5$

$$\text{type } \frac{(\mathbf{1}\ 3)\ 57\ \mathbf{9}}{5}$$

observed	**1.79**	1.40	1.00	(0.62)	(**0.19**)	(**0.19**)	(0.56)	0.98	1.40	**1.76**
calculated	**1.80**	1.40	1.00	(0.60)	(**0.20**)	(**0.20**)	(0.60)	1.00	1.40	**1.80**

λ **4020.40** $D_2 \overline{D_2^a}$ $\qquad J = 2, \; g = \frac{4}{5}$ with $J = 3, \; g = \frac{4}{5}$

$$\text{type } \frac{(0)\ 4}{5}$$

observed	0.80	(0)	0.81	sharp
calculated	0.80	(0)	0.80	sharp

λ **4023.68** $D_1 \overline{D_1^a}$ $\qquad J = 3, \; g = \frac{6}{5}$ with $J = 3, \; g = {}^6/_5$

$$\text{type } \frac{(0)\ 6}{5}$$ Fig. 3

observed	1.21	(0)	1.21	sharp
calculated	1.20	(0)	1.20	sharp

λ **4047.81** $D_1 \overline{D_2^a}$ $\qquad J = 3, \; g = {}^6/_5$ with $J = 2, g = {}^4/_5$

$$\text{type } \frac{(\mathbf{1}\ 3)\ 5 7 \mathbf{9}}{5}$$

observed	**1.77**	1.39	0.98	(0.59)	(**0.19**)	(**0.19**)	(0.56)	0.96	1.33	**1.71**
calculated	**1.80**	1.40	1.00	(0.60)	(**0.20**)	(**0.20**)	(0.60)	1.00	1.40	**1.80**

The observed resolution of this group fully agrees with the calculations.

This confirms, therefore, that we have really to do here with a doublet *DD*-group. The asymmetries are real.

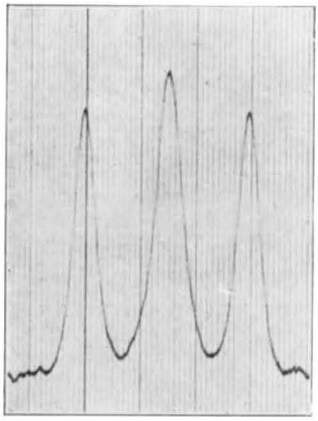

Fig. 3. λ 4023.68.

Accordingly these resolutions also confirm GIESELER and GROTRIAN's [1]) view that the fundamental term of *ScI* is a doublet *D*-term; for according to their absorption experiments it is the term D_2 put equal to 0 in our term system.

According to BOHR and COSTER [2]) the neutral Scandium atom must contain one 3_3- and two 4_1-electrons. If during the emission this 3_3-electron were still present in the atom rest, so-called terms "höherer Stufe" with entirely new resolutions would have to be expected according to LANDÉ [3]). As this is very certainly not the case, their 3_3-electron must necessarily be the emitting electron. This is also in harmony with STONER's [4]) electron system, according to which the fundamental term must then have the symbol 3_{32}. For the fundamental path J is actually $= 2$.

Except under special circumstances the splitting up of the group furnishes already an important support for the accuracy of the other term symbols. For from the way in which the other terms combine with the known *D*-fundamental term, it is possible to determine their quanta-values J, hence to establish the term symbol with pretty great certainty.

Further the following lines were split up:

λ **3907.54** $D_2 F_2^b$ $\qquad J = 2,\ g = {}^4/_5$ with $J = 3,\ g = {}^6/_7$

$$\text{type}\ \frac{(1\ 3)\quad 27\ 29\ 31\ \mathbf{33}}{35}$$

observed	0.90	(0)	0.91	pretty sharp
calculated	$<$ 0.94	(0)	$<$ 0.94	pretty sharp

λ **3911.88** $D_1 F_1^b$ $\qquad J = 3,\ g = {}^6/_5$ with $J = 4,\ g = {}^8/_7$

$$\text{type}\ \frac{(1\ 35)\quad \mathbf{35}\ 37\ 39\ 41\ 43\ 45}{35}$$

observed	1.07	(0)	1.06	sharp inside
calculated	$>$ 1.00	(0)	$>$ 1.00	sharp inside

1) loc. cit.

2) N. BOHR and D. COSTER, Zeitschr. f. Phys. 12, p. 342, 1923.

3) A. LANDÉ, Zeitschr. f. Phys., 17, p. 292, 1923.

4) E. C. STONER, Phil. Mag. 48, 719, 1924.

λ **3269.84** $D_2 P_2^d$ $J = 2$ $g = {}^4/_5$ with $J = 1$, $g = {}^2/_3$

type $\frac{(1)\ 11\ \mathbf{13}}{15}$

observed 0.87 (0) 0.76 feeble, vague

calculated 0.86 0.74 (0.07) (0.07) 0.74 0.86

Sc II Triplet system.

Combinations *dd*

λ **3558.56** $d_2 \overline{d_1^a}$ $J = 2\frac{1}{2}$ $g = {}^7/_6$ with $J = 3\frac{1}{2}$, $g = {}^4/_3$

type $\frac{(\mathbf{0}\ 1\ 2)\ 6\ 7\ 8\ 9\ \mathbf{10}}{6}$

observed 1.63 (0) 1.64 sharp outside

calculated $<$ 1.67 (0) $<$ 1.67 sharp outside

λ **3567.72** $d_3 \overline{d_2^a}$ $J = 1\frac{1}{2}$, $g = {}^1/_2$, with $J = 2\frac{1}{2}$, $g = {}^7/_6$

type $\frac{(\mathbf{0})\ 3\ (4)\ 7\ \mathbf{11}}{6}$

observed **1.83** 1.16 0.64 (**0**) 0.64 1.15 **1.82**

calculated **1.83** 1.17 (0.67) 0.50 (**0**) 0.50 (0.67) 1.17 **1.83**

The measurement was made on a plate on which the two polarisation states had been photographed at the same time. In consequence of this the stronger π component (0.67) had combined with the weak σ component 0.50. Fig. 4.

λ **3572.57** $d_1 \overline{d_1^a}$ $J = 3\frac{1}{2}$, $g = {}^4/_3$ with $J = 3^1/_2$, $g = {}^4/_3$

type $\frac{(0)\ 4}{3}$

observed 1.31 (0) 1.34 sharp

calculated 1.33 (0) 1.33 sharp

λ **3576.37** $d_2 \overline{d_2^a}$ $J = 2\frac{1}{2}$, $g = {}^7/_6$ with $J = 2\frac{1}{2}$, $g = {}^7/_6$

type $\frac{(0)\ 7}{6}$

observed 1.14 (0) 1.19 sharp

calculated 1.17 (0) 1.17 sharp

λ **3580.98** $d_3 \overline{d_3^a}$ $J = 1\frac{1}{2}$, $g = 1\frac{1}{2}$ with $J = 1\frac{1}{2}$, $g = \frac{1}{2}$

type $\frac{(0)\ 1}{2}$

observed 0.51 (0) 0.51 sharp

calculated 0.50 (0) 0.50 sharp

λ **3589.67** $d_2 \overline{d_3^a}$ $J = 2\frac{1}{2}$, $g = {}^7/_6$ with $J = 1\frac{1}{2}$, $g = {}^1/_2$

type $\frac{(\mathbf{0})\ 3\ (4)\ 7\ \mathbf{11}}{6}$

observed	**1.83**	1.17	0.65		**(0)**	0.61	1.18	**[1.76]**
calculated	**1.83**	1.17	(0.67)	0.50	(0)	0.50 (0.67)	1.17	**1.83**

Compare remark to λ 3567.72. The component [1.76] coincides with the component [1.42] of the following line. Fig. 5.

λ 3590.52 $d_1\,\overline{d_2^a}$ $\quad J = 3\frac{1}{2},\ g = {}^4/_3$ with $J = 2\frac{1}{2},\ g = {}^7/_6$

$$\text{type } \frac{(\mathbf{0}\ 1\ 2)\ 6\ 7\ 8\ 9\ \mathbf{10}}{6}$$

observed	[1.42]	(0)	1.51	sharp outside
calculated	$<$ 1.67	(0)	$<$ 1.67	sharp outside

Splitting up too simple, comp. λ 3558.56.

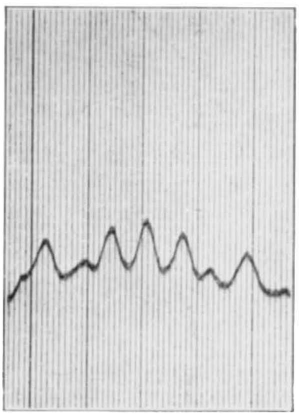

Fig. 4. λ 3567.62

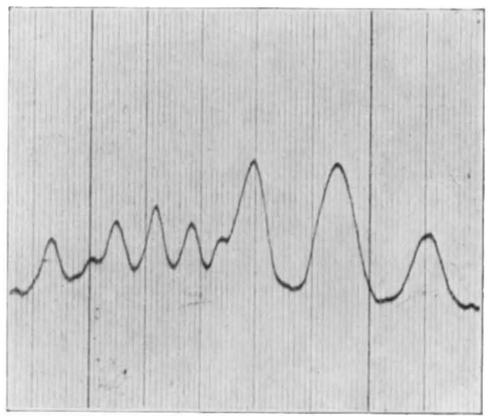

Fig. 5. λ 3589.67 and λ 3590.72.

Combinations *df*.

λ 3613.83 $d_1 f_1$ $\quad J = 3\frac{1}{2},\ g = {}^4/_3$ with $J = 4\frac{1}{2},\ g = {}^5/_4$

$$\text{type } \frac{(\mathbf{0}\ 1\ 2\ 3)\ \mathbf{12}\ 13\ 14\ 15\ 16\ 17\ 18}{12}$$

observed	1.11	(0)	1.12	sharp inside
calculated	$>$ 1.00	(0)	$>$ 1.00	sharp inside

λ 3630.75 $d_2 f_2$ $\quad J = 2\frac{1}{2},\ g = {}^7/_6$ with $J = 3\frac{1}{2},\ g = {}^{13}/_{12}$

$$\text{type } \frac{(\mathbf{0}\ 12\ 3)\ \mathbf{11}\ 12\ 13\ 14\ 15\ 16}{12}$$

observed	1.03	(0)	1.03	sharp inside
calculated	$>$ 0.92	(0)	$>$ 0.92	sharp inside

Splitting up too great comp. λ 4320.75.

λ 3642.96 $d_3 f_3$ $\quad J = 1\frac{1}{2},\ g = {}^1/_2$ with $J = 2\frac{1}{2},\ g = {}^2/_3$

$$\text{type } \frac{(\mathbf{0}\ 1)\ 3\ 4\ \mathbf{5}}{6}$$

observed	0.78	(0)	0.79	very broad
calculated	$<$ 0.83	(0)	$<$ 0.83	sharp outside

λ **3645.48** $d_1 f_2$ $\qquad J = 3\frac{1}{2},\ g = {}^4/_3$ with $J = 3\frac{1}{2},\ g = {}^{13}/_{12}$

type $\dfrac{(3\ 6\ \mathbf{9})\ 7\ 10\ \mathbf{13}\ \mathbf{16}\ 19\ 22}{12}$

observed	?	0.69	0.68	?	⊥ very vague
calculated	1.21	< (0.75)	< (0.75)	1.21	⊥ not sharp

λ **3651.99** $d_2 f_3$ $\qquad J = 2\frac{1}{2},\ g = {}^7/_6$ with $J = 2\frac{1}{2},\ g = {}^2/_3$

type $\dfrac{1\ (3)\ \mathbf{4}\ (\mathbf{6})\ \mathbf{7}\ 10}{6}$

observed	1.58	1.00		0.57				0.57		1.04		1.67
calculated	1.67	**1.17**	(**1.00**)	**0.67**	(0.50)	0.16	0.16	(0.50)	**0.67**	(**1.00**)	**1.17**	1.67

Cf. remark to λ 3567.72. Asymmetric, inner components too weak.

λ **4314.09** $\overline{f}{}^d_1\,\overline{d}{}^a_1$ $\qquad J = 4\frac{1}{2},\ g = {}^5/_4$ with $J = 3\frac{1}{2},\ g = {}^4/_3$

type $\dfrac{(\mathbf{0}\ 1\ 2\ 3)\ \mathbf{12}\ 13\ 14\ 15\ 16\ 17\ 18}{12}$

observed	1.09	(0)	1.10	sharp inside
calculated	> 1.00	(0)	> 1.00	sharp inside

λ **4320.75** $\overline{f}{}^d_1\,\overline{d}{}^a_2$ $\qquad J = 3\frac{1}{2},\ g = {}^{13}/_{12}$ with $J = 2\frac{1}{2},\ g = {}^7/_6$

type $\dfrac{(\mathbf{0}\ 1\ 2\ 3)\ \mathbf{11}\ 12\ 13\ 14\ 15\ 16}{12}$

observed	0.98	(0)	0.96	sharp inside
calculated	> 0.92	(0)	> 0.92	sharp inside

λ **4325.00** $\overline{f}{}^d_3\,\overline{d}{}^a_3$ $\qquad J = 2\frac{1}{2},\ g = {}^2/_3$ with $J = 1\frac{1}{2},\ g = {}^1/_2$

type $\dfrac{(\mathbf{0}\ 1)\ 3\ 4\ \mathbf{5}}{6}$

observed	0.79	(0)	0.79	sharp outside
calculated	< 0.83	(0)	< 0.83	sharp outside

Combinations ff.

λ **4374.51** $\overline{f}{}^d_1\,f_1$ $\qquad J = 4\frac{1}{2},\ g = {}^5/_4$ with $J = 4\frac{1}{2},\ g = {}^5/_4$

type $\dfrac{(0)\ 5}{4}$

observed	1.28	(0)	1.37	sharp
calculated	1.25	(0)	1.25	sharp

λ **4400.39** $\overline{f}{}^d_2\,f_2$ $\qquad J = 3\frac{1}{2},\ g = {}^{13}/_{12}$ with $J = 3\frac{1}{2},\ g = {}^{13}/_{12}$

type $\dfrac{(0)\ 13}{12}$

observed	1.09	(0)	1.10	sharp
calculated	1.08	(0)	1.08	sharp

λ 4415.55 $\bar{f}_1^{d} f_1$ $J = 2\frac{1}{2},\ g = {}^2/_3$ with $J = 2\frac{1}{2},\ g = {}^2/_3$

type $\frac{(0)\ 2}{3}$

observed	0.69	(0)	0.67	sharp
calculated	0.67	(0)	0.67	sharp

Combinations *dp*.

λ 3372.16 $d_1\, p_1^c$ $J = 3\frac{1}{2},\ g = {}^4/_3$ with $J = 2\frac{1}{2},\ g = {}^3/_2$

type $\frac{(\mathbf{0}\ 1\ 2)\ \mathbf{6}\ 7\ 8\ 9\ 10}{6}$

observed	1.16	(0)	1.13	sharp inside
calculated	> 1.00	(0)	> 1.00	sharp inside

λ 3359,69 $d_2\, p_1^c$ $J = 2\frac{1}{2},\ g = {}^7/_6$ with $J = 2\frac{1}{2},\ g = {}^3/_2$

type $\frac{(2\ \mathbf{4})\ 5\ \mathbf{7}\ \mathbf{9}\ 11}{6}$

observed	?	0.66	0.66	?	very vague
calculated	1.33 <	(0.67) <	(0.67)	1.33	$\perp$ broad, not sharp

Unclassified lines.

λ 3353,74

observed	1.00	(0)	1.00	not sharp

λ 3535,74

observed	0.98	(0)	1.02	sharp

λ 4246,88

observed	0.99	(0)	0.98	pretty sharp

Accordingly these lines, which give normal triplets, probably belong to the simple term system of ionized Scandium.

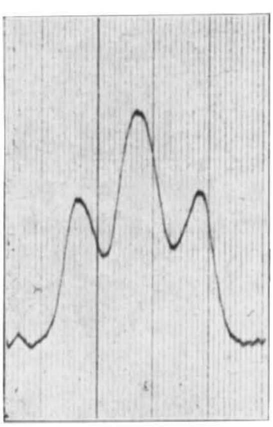

Fig. 6. λ 4325.00.

It may be pointed out here that splitting-up types, which in *sp*-combinations are still easily resoluble, can no longer be resolved in *dd*-, *df*- and other combinations, as also the original lines are generally much less sharp.

The investigation of some important lines is still in progress. These are first of all the *ScI*-lines λ 4054.56 and λ 4082.44. The intensity of these lines greatly decreases in the magnetic field, so that it was not yet possible to measure out the resolutions. Preliminary observations render it, however, probable that the effect met with here is the partial Paschen-Back effect, so that the term denoted by X in the term system is probably a doublet P, D or F term that has coincided.

More or less the same thing seems to be the case with the triplet term p^c. Probably *two* terms of this, p_2^c and p_3^c, seem to have almost coincided. The fuller examination of the resolution of the lines λ 3368 and λ 3361 must still confirm this.

The correctness of the classification of the lines of ionized Scandium appears from the resolutions given above. So far no terms "höherer Stufe" were found in this either. We may, therefore, refer to the recently analyzed spectrum of the allied ionized Lanthanum [1]). From earlier measurements of the magnetic resolution [2]) it appeared with certainty that there occur a number of these terms "höherer Stufe" in this spectrum. Possibly these are found only in feeble lines in the Scandium spectrum.

In conclusion we may express our cordial thanks to Messrs. Prof. BOHUSLAV BRAUNER, and Prof. ŠTĚRRA—BÖHM at Prague, who enabled us to carry out this investigation, by supplying us with perfectly pure Sc_2O_3.

Amsterdam, December 1924. *Laboratory "Physica"*.

[1]) S. GOUDSMIT, These Proceedings 28 p. 23, Naturw. 12, p. 851, 1924.

[2]) S. RYBAR, Phys. Zeitschr. 12, p. 889, 1911.