WAVE-LENGTH MEASUREMENTS IN THE ARC SPECTRUM OF SCANDIUM

By William F. Meggers

ABSTRACT

The wave lengths corresponding to approximately 700 lines photographed in the 220-volt arc spectrum of scandium were measured relative to secondary standards in the iron spectrum. These values extend from 2540.87 in the ultra-violet to 8644.48 Å in the infra-red; the majority are lines characteristic of neutral scandium atoms, a considerable number of lines originate with singly ionized, and a few with doubly ionized, atoms. Bands characteristic of scandium oxide molecules appear very prominently in the longer wave portions of the spectrum.

CONTENTS

	Page
I. Introduction.....	61
II. Experimental.....	62
III. Results.....	63
IV. Bibliography.....	71

I. INTRODUCTION

Since 1914 the spectroscopy section of this bureau has followed a program of standard wave-length determination and spectroscopic analysis, the main object of which has been to describe what may be called the standard spectra of each of the pure chemical elements. The descriptions which have been available heretofore have often been of a qualitative character and sometimes lamentably incomplete, notwithstanding the great importance of more precise data for certain optical measurements, for the spectrochemical identification of the elements, and for the study of atomic structure and the mechanism of radiation. Since other investigators have also been engaged in improving these descriptions of spectra, our efforts in the past have been confined for the most part to the region of longer waves which has been almost entirely neglected by others. The application of photographic sensitizers to these spectroscopic investigations has resulted in extending the descriptions of the arc emission spectra of many of the chemical elements in the red and adjacent infra-red regions. Such data have already been published for lithium, sodium, potassium, rubidium, caesium, copper, strontium, calcium, barium, magnesium (1),¹ iron, cobalt, nickel (2), neon (3)

¹ The figures given in parentheses here and throughout the text relate to the reference numbers in the bibliography given at the end of this paper.

krypton, xenon (4), titanium, vanadium, chromium, manganese, molybdenum, tungsten, uranium (5), silver, aluminum, gold, bismuth, cadmium, mercury, lead, antimony, tin, zinc (6), yttrium, lanthanum, cerium (7), neodymium, samarium (8), gadolinium, dysprosium (9), ruthenium, rhodium, palladium, osmium, iridium, platinum (10), and zirconium (11). For the last-named element the spectra were investigated throughout the entire range of wave lengths accessible with our grating spectrographs (2200 to 9500 Å), and the same statement can now be made for scandium. The long wave portion of the arc spectrum of scandium was photographed and measured in this laboratory in 1923, at which time, since no spectra of this element had ever been measured in the new international scale of wave lengths, it was decided to extend the observations through the visible and ultra-violet regions. This work has been completed, and the purpose of the present paper is to present the results of wave-length measurements in the arc spectrum of scandium from the ultra-violet at 2300 Å to the infra-red near 9000 Å.

II. EXPERIMENTAL

Scandium ($\text{Sc}=45.1$; $Z=21$) has long been regarded by most chemists as one of the so-called "rare earth" family of elements, and it still remains one of these in the sense that it is very scarce and extremely difficult to obtain in purified form. The present observations were made with 1 g of scandium ammonium oxalate carefully purified by Auer von Welsbach and acquired as a part of a collection of chemicals and spectrograms purchased from Prof. J. M. Eder, of Vienna, in 1920, when he discontinued his spectroscopic researches.

For the excitation of the characteristic spectra of scandium, the material was used on electrodes of copper or of silver between which an electric arc of 4 to 6 amperes direct current was produced with a potential difference of 220 volts. Exposures were made with both kinds of electrodes throughout the entire spectral range to eliminate the possibility of overlooking Sc lines which might be masked by lines either of Cu or of Ag.

As pointed out in connection with wave-length measurements in arc spectra of certain metals of the Pd and Pt triads (12), the use of arc electrodes of Cu or Ag for the excitation of spectra of pure salts, metal sponges, etc., is especially convenient when the arc-stream color of the applied material is different from that of the metal electrodes. Silver and copper arcs both give an intense yellow-green flame, but scandium, on account of strong emission lines and bands in the red portion of the spectrum, imparts a very decided reddish tinge to the flame when it is carrying an effective part of the current. When the red disappears and only yellow green remains, it is an indication that no appreciable amount of scandium is being vaporized in the arc.

The wave lengths were derived from diffraction grating spectrograms, the arc spectrum of iron being either superposed or juxtaposed to supply the standard wave lengths from which the values for scandium lines were derived by interpolation. A blank spectrogram of the Cu or Ag electrodes was usually photographed on the same plate to avoid the necessity of measuring and subsequently eliminating the Cu or Ag spectra.

Two diffraction gratings, each 640 cm radius of curvature, were alternately used in making the spectrograms. They were used in parallel light in the mounting described in our earlier papers (13). For the red and infra-red regions a 6-inch grating ruled by Anderson with 7,500 lines per inch, giving a scale of 10 Å per mm, was employed, while the remainder of the spectrum was recorded with a similar grating, ruled by Rowland, with 20,000 lines per inch, which gave a dispersion of about 3.6 Å per mm in the first-order spectrum.

Photographic plates procured from Schleussner, of Frankfurt a. M., were used for all the exposures because they had sensitive emulsions coated on long strips of extra-thin glass (6 by 40 cm and less than 0.1 cm thick) which permitted bending them to fit the focal curve of the spectrograph. Three Sc exposures made by Eder on similar plates were found in the collection of spectrograms which he consigned to us. These extended over the interval 5500 to 6800 Å; they were measured and averaged with the results of our own spectrograms.

The observations extended in the ultra-violet to 2250 Å, but no scandium lines shorter than 2540 Å were photographed. For photographing the yellow and red portions of spectra the plates were bathed in solutions of pinaverdol and pinacyanol, and for recording the infra-red sensitizing solutions of dicyanin were employed. The line of greatest wave length thus recorded with exposures of one hour duration was 8644 Å. Very recently an attempt was made to photograph still longer waves of scandium with a neocyanin-bathed plate, but no new lines were found. This may, however, be attributed to excessive economy of exposure and of scandium, since the amount of material available had by that time dwindled to almost nothing.

III. RESULTS

Descriptions of scandium spectra in limited wave-length intervals have been made by various observers. The most reliable ones up to the year 1911 are quoted by Kayser in Volume VI of his *Handbuch der Spectroscopie*; they are by Lockyer and Baxandall (14) (arc spectrum from 3907.62 to 5717.54 Å), by Fowler (15) (arc spectrum 3933.55 to 6558.28 Å), by Exner and Haschek (16) (arc spectrum 2438.74 to 6604.88, and spark spectrum 2233.03 to 6604.90 Å), and by Eder and Valenta (17) (arc spectrum 5514.46 to 6835.20 Å). Reproductions of the spectra and additional lists of the stronger lines appeared in the *Atlas Typischer Spektren*, published by Eder

and Valenta, in 1911. They give three tables of wave lengths which contain 184 lines measured in the arc spectrum (3251.43 to 6835.30 Å), 180 lines observed in the spark spectrum (3429.59 to 6835.30 Å), and 65 heads of bands in the scandium oxide spectrum (4672.85 to 6700.64 Å). All of the above-mentioned measurements of scandium spectra were based on Rowland's system of standard wave lengths.

More recently, lists of wave lengths from the scandium arc were published by Crookes (18) and by Piña de Rubies (19). The first contains 101 lines (2420.025 to 6305.7 Å) and the second 185 lines (2232.0 to 3394.2 Å). Both are of doubtful value, because the measurements were made from relatively small-scale prism spectrograms and the results are very sketchy and qualitative.

In the Schumann region observations by Ireton (20) describe 45 lines in the spark spectrum of scandium (507.0 to 2233.7 Å). Smith (21) has supplemented these for the purpose of analyzing the structure of the Sc III spectrum by measuring several lines (730.60 to 2012.95 Å).

Three other investigations, which are of inestimable value as descriptions of scandium spectra, must be mentioned, although they contribute nothing to the wave-length data. They are (a) the electric furnace spectrum of scandium as reported by King (22), (b) magnetic resolutions in the scandium spectrum by Goudsmit, van der Mark, and Zeeman (23), and (c) the absorption spectrum of scandium as described by Gieseler and Grotrian (24). King's observations extend from 3015.50 to 6558.28 Å, the arc intensity, and furnace intensities at low, medium, and high temperatures being given for nearly 300 lines. In the second investigation mentioned the Zeeman effects for 30 scandium lines were determined. These identify the spectral terms which combine to produce the radiations, and are in perfect accord with the analyses of scandium spectra as reported by Russell and Meggers (25). Twenty-four scandium lines (3255.81 to 6413.57 Å) were found by Gieseler and Grotrian to be absorbed in scandium vapor at 2000° C.; these observations, in connection with the Zeeman effects just mentioned, firmly establish the fact that the normal state of the scandium atom is described by a doublet-D spectroscopic term.

The results of our measurements of approximately 700 wave lengths in the arc spectrum of scandium are presented in Table 1. Wave lengths under standard observing conditions appear in the first column, our intensity estimates and notes in the second, King's arc intensities and temperature classes in the third, and vacuum wave numbers in the last. The probable errors of the wave lengths obtained with the larger scale grating—that is, shorter than 6,000 Å—are rarely greater than 0.01 Å except for faint lines which were observed only once. In the red and infra-red, for which the scale of the spectrograms was nearly three times as compressed, the errors are naturally larger; they probably average between 0.02 and 0.03 Å.

This applies especially to heads of bands, the effective wave lengths of which, on account of their unsymmetrical character, varied considerably with the strength of the exposure. In making intensity estimates we have attempted to make finer gradations than are possible with the 1-10 scale which most spectroscopists use. The ratio of the weakest to the strongest lines was assumed to be 1 to 100, and lines of intermediate intensity were assigned intensities proportional to their estimated strength on this scale, except that a few very weak lines observed only on the strongest exposure are marked "0." Our relative intensities over restricted wave-length intervals appear to be roughly proportional to King's values, but the ratio of the two sets of estimates varies somewhat from one portion of the spectrum to another, probably on account of differences in the spectrographs, exposures, and photographic plates.

A suggested chemical symbol accompanies the intensity estimate when there is a possibility that a part of the line may be assigned to an impurity. The remaining symbols have the following meanings:

e=line enhanced at the negative electrode of the arc;	c=complex;
n=band head;	G=observed as absorption line by Gieseler and Grotrian;
p=part of band structure;	Z=Zeeman effect observed by Goudsmit, van der Mark, and Zeeman.
l=shaded to long wave lengths;	
h=hazy;	
d=double;	

The vacuum wave numbers in the last column of Table 1 are derived from the wave lengths in the first column with the aid of Kayser's *Tabelle der Schwingungszahlen*. They are printed especially for the benefit of those interested in the structures of the various spectra displayed in Table 1, since the combination principle reveals true spectral regularities only when frequencies or proportional wave numbers are employed. Without going into details concerning the structures of various spectra of scandium, it suffices to state that four distinct types of spectra are present in Table 1; they are (a) the banded spectrum characteristic of scandium oxide molecules, (b) a line spectrum (Sc I) coming from excited neutral atoms of scandium, (c) a second line spectrum (Sc II), originating with singly ionized atoms of scandium, and (d) a third line spectrum (Sc III) arising from doubly ionized scandium atoms. These various spectra are all represented among the radiations from a 220-volt arc in which scandium vapor is present, and Table 1, which is intended to present a faithful description of the so-called arc spectrum of scandium, is thus a composite picture of four distinct scandium spectra.

No attempt has as yet been made to interpret the band spectra of scandium compounds, but the line spectra have been very satisfactorily analyzed and interpreted. The latter are dealt with by Russell and Meggers in a forthcoming Bureau of Standards Scientific Paper.

TABLE 1.—Scandium spectra

λ A	Intensity and notes	Intensity and class	ν	λ A	Intensity and notes	Intensity and class	ν
2540.87	1, e		39344.79	3078.46	1		32474.37
45.24	5, e		277.24	79.95	1		458.66
52.38	10, e		167.37	80.23	1, e		455.71
55.84	6, e		114.35	81.56	1		441.70
60.26	9, e		046.84	82.57	2, e		431.07
2563.23	8, e		39001.59	83.28	1		423.61
2611.23	3, e		38284.71	85.30	1		402.38
67.73	1, e		37473.93	87.35	1		360.86
76.00	1, e		358.12	89.78	2, d		355.40
84.23	2, e		243.58	92.43	2		327.68
92.59	1?		127.96	92.52	2, e		326.72
2699.12	6, e		058.14	94.63	1		304.69
2700.81	1, e		37014.96	95.35	1		297.18
06.78	2		36933.33	96.82	2		281.85
07.95	1		917.38	98.60	1		263.30
11.36	2		870.95	3099.44	1		254.56
24.16	1, e?		697.71	3102.15	1		226.38
29.34	0		628.07	02.36	1		224.20
29.60	1, e		624.58	05.67	1		189.86
34.10	4, e		564.30	06.01	1		186.34
35.61	1, e		544.12	06.54	1		180.84
46.43	1, d?, e, Ag ⁺ ?		400.16	07.53	6, e		170.60
47.16	1, e		390.49	08.50	3, e		160.56
52.16	1, e		324.38	09.35	2		151.77
68.88	0, e		36105.04	10.24	1		142.56
82.34	3, e		35930.40	12.11	1, d?		123.25
89.20	5, e		842.02	13.36	1		110.36
2794.70	1, e		771.49	14.78	1		095.72
2801.35	6, e		686.58	17.20	0		070.80
07.91	1, e		603.21	17.82	2, d		064.41
19.56	5, e		456.11	19.67	1		045.41
22.17	7, e		423.32	22.54	1		015.96
26.69	10, e		366.68	22.98	3, e		011.45
27.81	2, e		352.68	23.95	1		32001.52
32.34	2, e, Th?		296.14	24.94	1		31991.36
33.36	1, e		283.43	26.02	1, e		980.32
37.32	2, e, Th?		35234.19	27.70	1		963.14
59.32	2, e		34963.11	28.29	5, e		957.11
63.67	2, e		910.00	33.12	8, e		907.85
64.15	1, e		904.15	33.31	2		905.91
66.04	4, e		881.13	38.36	2?		854.57
66.71	2, e		872.98	38.46	1, e?		853.57
70.46	1, e		827.43	39.76	10, e		840.37
70.90	2, e		822.09	40.74	1		830.44
84.30	1		660.32	46.91	1, e		768.03
2885.09	1		650.83	58.54	1, Ag?		651.06
2913.04	3, e		318.38	70.40	1		532.67
28.28	1		139.78	88.29	1		355.74
29.38	4, e, Ag ⁺ ?		126.96	90.41	2, e		334.90
34.07	2, e, Ag ⁺ ?		34072.41	91.01	5, e		329.01
42.87	1		33970.53	3199.38	10, e		247.06
49.92	1		889.35	3215.68	2, Ag?		088.67
61.16	1, Cu?		760.72	20.77	3, Ir?		039.54
65.86	2		707.22	33.22	1		31020.03
74.01	5		614.85	51.31	3	1 IV	30747.99
79.70	5, e		550.66	55.69	4, G	6 I A	706.63
80.74	6		538.96	69.91	10, G, Z	15 II A	573.10
2988.95	10, e+arc		446.84	3273.64	15, G	20 II A	538.27
3015.85		8 II	154.02	3311.73	3, e		187.04
19.38	10	10 II	33110.32	12.75	5, e		177.74
30.74	3	3 II	32985.67	13.57	0?		170.28
39.94	10, e	III A	885.85	16.79	1?		140.99
45.73	15, e		823.33	17.06	1, e		138.52
52.92	20, e		746.03	17.70	1, e		132.72
56.80	1	1 IV	709.82	20.44	3		107.86
60.53	3, e		664.61	20.72	1, e		105.33
63.74	0		650.39	31.09	3		30011.60
65.11	30, e		615.80	33.53	?	1 III A	29889.63
75.38	3, e		506.89	43.28	4	1 III A d?	902.13
3077.04	1		32489.36	3349.22	?	1 III A	29849.14

TABLE 1.—Scandium spectra—Continued

λ Å	Intensity and notes	Intensity and class	ν	λ Å	Intensity and notes	Intensity and class	ν
3351.20	?	1 IV A	29831.51	3833.08	3		26081.31
52.05	3	2 IV	823.95	36.51	1		057.99
53.73	25, Z	10 III	809.01	39.19	1		039.80
59.68	10, Z	6 III	756.22	43.06	4		013.58
60.26	1		751.08	44.22	1		26005.73
61.26	10	6 III	742.23	45.45	1		25097.41
61.94	12	6 III	736.22	46.66	1		989.24
63.52	1		722.25	52.39	1		950.58
64.87	?	1 III A	710.32	53.60	1		943.10
66.46	1		696.30	55.62	1		928.84
68.94	15	8 III	674.43	3894.98	1	1 IV A	666.82
72.14	20, Z	12 III	646.27	3907.49	40, G, Z	75 II	584.65
73.57	1?		633.71	11.81	60, G, Z	100 II	556.40
78.23	2		592.83	14.94	?	tr IV A	535.97
79.19	2, e		584.42	23.51	2		480.19
79.42	3		582.41	33.37	10, G	20 II	416.32
85.88	?	1 IV A	525.98	52.26	1	1 IV A	294.85
3394.29	1		452.82	76.30	1		141.92
3416.68	2	2 III A	259.82	89.06	2		061.50
19.35	1		236.97	3996.61	15, G, Z	30 I	25014.16
29.20	2	3 III A	152.99	4014.49	5	5 IV E	24902.75
29.48	2	3 III A	150.61	20.40	50, G, Z	75 II	866.14
31.36	2	3 III A	134.64	23.23	1	2 III A	848.65
35.56	3	5 III A	099.03	23.69	70, G, Z	100 II	845.81
39.41	?	1 III A	066.45	30.67	3		802.78
40.18	0	1 III A	059.94	31.38	2	2 III A	798.42
43.99	?	1 III A	29027.80	34.23	1	2 III A	780.90
48.48	?	1 III A	28990.00	36.87	0	2 IV	764.69
57.45	2	3 III A	914.80	43.79	3	2 III A	722.32
62.19	1	2 III A	875.21	46.48	3	2 III A	705.88
69.65	1	1 III A	813.13	47.79	10, G, Z	25 I	697.89
71.13	1		800.85	49.95	2	2 III A	684.71
80.37	1, Ag?		724.38	51.85	1	1 IV A	673.14
96.25	1		593.92	54.54	20, G	35 I	656.77
97.05	1		587.38	56.59	2	4 III A	644.31
3498.91	2	2 III A	572.18	67.00	2	2 III A	581.23
3505.01	1, h		522.46	74.96	3	2 III A	533.22
35.73	10, Z	6 III	274.65	78.56	2	2 III A	511.56
58.55	20, Z	7 II	28093.34	82.40	30, G	40 I	488.51
67.70	20, Z	6 II	28021.29	86.01	1	1 III A	466.87
72.53	50, Z	20 II	27983.41	86.66	3	4 III	462.98
76.35	35, Z	8 II	953.52	87.15	4	8 III	460.05
80.94	30, Z	7 II	917.69	93.12	1		424.37
89.64	20, Z	6 II	850.03	94.85	2	1 III A	414.06
3590.48	20, Z	6 II	843.51	4098.35	2		393.20
3604.80	1		732.91	4100.32	2		381.48
06.62	2		718.91	16.70	1		284.47
08.42	1		705.09	26.56	1		226.45
13.84	60, Z	30 II	663.54	33.00	5	8 III	188.70
30.76	50, Z	12 II	534.62	40.29	7	10 III	146.11
35.30	?	1 III	500.24	47.40	2		104.72
35.51	0		498.65	52.35	10	12 III	075.98
36.19	2		493.51	54.74	1		062.13
38.01	1		479.75	60.52	1		028.71
42.79	40, Z	25 II	443.69	61.87	1, Sr?		020.90
45.31	30, Z	10 III	424.72	65.20	10	12 III	24001.71
46.90	?	1 III A	412.77	71.55	1		23965.18
48.24	1		402.70	71.76	?	1 III A	963.97
51.80	25, Z	7 III	375.98	77.48	1, Y?		931.15
57.60	?	tr III A	332.57	86.45	1		879.88
64.25	1		282.97	87.62	2		873.21
66.54	3	2 III	265.93	90.66	1		855.89
75.26	1		201.24	97.07	0		819.46
76.60	0		191.33	4199.50	0		805.68
3678.36	2, e		27178.32	4202.19	1		790.43
3717.09	1		26895.14	04.54	1		777.14
3787.17	1		397.47	05.21	2		773.35
3800.02	2?		308.21	12.34	2		733.11
23.78	1		144.74	12.48	1		732.32
3828.19	1		26114.62	4216.10	2		23711.95

TABLE 1.—Scandium spectra—Continued

λ Å	Intensity and notes	Intensity and class	ν	λ Å	Intensity and notes	Intensity and class	ν
4218.25	2.....	2 III A.....	23699.86	4729.23	10.....	30 III.....	21139.20
19.72	2.....	2 III A.....	691.60	32.30	2.....	2 IV A.....	125.48
21.87	1.....	1 IV A.....	679.54	34.10	15.....	15 III.....	117.45
25.59	2d.....	2 III A.....	658.69	35.08	2.....	.....	113.08
31.64	1.....	.....	624.87	37.65	20.....	20 III.....	101.63
31.94	2.....	2 IV A.....	623.20	41.02	30.....	30 III.....	086.63
33.61	3.....	3 III A.....	613.88	43.81	40.....	40 III.....	074.23
35.30	1.....	.....	604.46	46.15	?.....	(1) IV A.....	063.84
37.83	2.....	2 IV.....	590.36	48.97	?.....	(1) IV A.....	051.33
38.06	5.....	6 III.....	589.19	53.16	12, G.....	15 I A.....	032.77
39.57	2.....	2 IV A.....	580.68	58.91	1.....	(1) III A.....	21007.36
46.11	?.....	1 IV A.....	544.36	63.12	1.....	(3) IV A.....	20988.79
46.83	100, Z.....	75 III E.....	540.37	71.44	?.....	(1) IV A.....	952.19
59.59	1.....	1 IV.....	469.85	79.35	20, G.....	20 I A.....	917.52
68.11	1.....	.....	423.01	91.50	5, G.....	4 I A.....	864.48
77.29	1.....	.....	372.74	4792.84	1, h.....	(0) IV.....	858.64
79.95	1.....	.....	358.21	4827.28	10.....	4 III A.....	709.83
82.02	1.....	.....	346.92	8.....	2.....	2 III A.....	682.50
83.56	2.....	2 IV A.....	338.53	39.44	15.....	10 III A.....	657.80
86.55	1.....	1 IV A.....	322.25	40.46	3.....	2 IV A.....	653.44
4294.77	8.....	10 IV E.....	277.61	40.86	1.....	tr III A.....	651.74
4305.71	10.....	10 IV E.....	218.46	47.67	7.....	3 III A.....	622.72
14.09	60, Z.....	100 III E.....	173.37	52.08	1.....	.....	603.98
20.73	50, Z.....	75 III E.....	137.75	52.67	7.....	2 III A.....	601.47
25.00	40, Z.....	50 III E.....	23114.91	57.78	5, n, l.....	.....	579.80
48.53	1.....	tr IV A.....	22989.83	58.07	6, n?.....	.....	578.58
52.14	1.....	tr IV A.....	970.77	59.17	?.....	(0) IV A.....	573.92
54.60	5.....	8 V E.....	957.79	78.16	1.....	(2) IV.....	493.83
58.64	2.....	4 III A.....	936.51	80.72	?.....	(1) IV A.....	483.08
59.07	2.....	2 III A.....	934.25	90.34	1.....	(1) IV A.....	442.78
59.64	1.....	1 IV A.....	931.25	4893.00	1.....	(1) IV A.....	431.67
64.91	2.....	1 III A.....	903.56	4906.65	2.....	(2) III A.....	374.83
74.46	40, Z.....	60 III E.....	853.56	09.75	5.....	3 III A.....	361.96
75.18	1.....	1 III A.....	849.80	22.84	4.....	(2) III A.....	307.82
81.24	1.....	tr III A.....	818.20	34.25	2.....	(1) IV A.....	260.86
81.85	1.....	.....	815.02	35.75	2.....	(1) III A.....	254.71
84.80	6.....	8 IV E?.....	799.67	41.31	6.....	2 III A.....	231.92
89.60	2.....	2 IV A.....	774.74	51.28	?.....	(1) IV A.....	191.18
4391.12	1.....	.....	766.86	51.68	1.....	(1) IV A.....	189.55
4400.38	30, Z.....	50 III E.....	718.95	54.06	15.....	5 III A.....	179.84
15.55	20, Z.....	40 III E.....	640.90	73.65	10.....	3 III A.....	100.36
20.66	2.....	.....	614.72	80.36	15.....	4 III A.....	073.29
4431.35	3.....	4 V E.....	560.17	83.44	7.....	2 III A d?.....	060.88
4542.55	2.....	2 III A.....	22007.92	90.11	0.....	.....	034.07
44.68	2.....	5 III A.....	21997.60	91.91	15.....	5 III A.....	026.84
57.23	3.....	5 III.....	937.02	4995.01	1.....	(1) IV A.....	20014.41
73.99	3.....	6 III.....	856.64	5005.08	0.....	.....	19974.14
78.98	1.....	1 IV A.....	832.82	05.56	0.....	.....	972.23
92.94	2.....	3 IV.....	766.47	14.12	2.....	.....	938.13
98.16	1.....	1 IV A.....	741.76	18.39	7.....	(2) III A.....	921.17
4598.46	1.....	3 IV.....	740.34	20.14	5.....	(2) IV.....	914.22
4604.72	1.....	(1) IV A.....	710.78	21.51	8.....	(2) IV A.....	908.79
09.53	1.....	(0) III A.....	688.13	26.64	0.....	.....	888.47
09.95	1.....	(0) III A.....	686.15	30.28	1.....	.....	874.08
10.41	0.....	.....	683.99	31.02	40.....	10 V E.....	871.16
65.85	0.....	.....	426.34	32.74	3.....	(1) IV.....	864.37
70.40	15.....	15 IV E.....	405.47	37.03	1.....	.....	847.45
72.54	5, n l.....	.....	395.67	44.42	1.....	.....	818.37
75.53	1.....	.....	381.99	53.96	1.....	.....	780.97
4680.49	2, h.....	.....	359.32	57.13	1.....	.....	768.56
4698.30	2, E & H.....	.....	278.36	64.31	20.....	10 III.....	740.54
4706.97	3.....	.....	239.16	66.38	2.....	.....	732.47
09.33	6.....	5 III.....	228.52	68.85	5.....	2 III.....	722.86
11.73	1.....	.....	217.71	70.21	30.....	40 III.....	717.57
13.86	1, p?.....	.....	208.12	75.81	15.....	10 III.....	695.82
14.36	1, p?.....	.....	205.87	80.07	0.....	.....	679.30
17.03	1.....	.....	193.87	81.56	75.....	125 II.....	673.53
19.34	1, p?.....	.....	183.50	83.72	60.....	80 II.....	665.17
20.82	?.....	(0) III A.....	176.86	85.54	50.....	40 II.....	658.13
4728.76	6.....	5 III.....	21141.30	5086.95	40.....	40 II.....	19652.68

TABLE 1.—Scandium spectra—Continued

λ Å	Intensity and notes	Intensity and class	ν	λ Å	Intensity and notes	Intensity and class	ν
5087.12	30-----	10 IV?	19652.03	5514.21	35-----	80 III	18129.94
87.87	2-----	-----	649.12	15.39	1-----	-----	126.06
89.89	10-----	8 IV	641.33	20.50	50-----	100 III	109.28
92.46	2-----	1 IV A?	631.42	26.06	4-----	-----	091.06
96.73	15-----	30 III	614.97	26.35	1-----	-----	090.12
5099.22	25-----	40 III	605.40	26.82	75-----	10 V E	088.58
5101.12	10-----	20 III	598.09	36.43	2-----	-----	057.18
07.37	1-----	-----	574.11	41.05	7-----	3 IV	042.12
09.06	3-----	3 III	567.63	46.40	4-----	1 IV	024.72
12.86	3-----	4 III	553.09	49.68	3-----	-----	014.07
16.69	15-----	10 III	538.45	50.40	3-----	-----	011.73
33.67	2, h	-----	473.83	51.84	2-----	-----	007.06
62.15	1, p?	-----	366.39	52.25	3-----	-----	005.73
65.07	1, p?	-----	355.45	53.57	5-----	-----	001.45
71.05	2, +p	-----	333.06	53.98	0-----	-----	18000.12
75.68	1, p?	-----	315.77	56.50	1-----	-----	17991.96
85.37	1, p?	-----	279.67	61.10	3-----	-----	977.07
5190.61	2-----	260.21	64.88	10-----	-----	4 III A	964.93
5210.52	10-----	20 IV	186.62	71.24	3-----	-----	944.36
11.28	0-----	(0) IV A	183.82	79.75	3-----	-----	916.99
18.89	?	(0) IV	155.84	91.34	12-----	15 IV A	879.85
19.67	?	10 IV	152.98	5593.39	5-----	-----	873.30
39.81	15-----	2 IV E	079.36	5604.19	3-----	1 IV	838.85
58.33	12-----	15 IV	19012.17	08.90	1-----	-----	823.87
84.97	2-----	tr IV A	18916.33	10.12	2-----	-----	820.00
85.76	8-----	10 IV	913.51	23.70	2-----	1 IV	776.96
5299.90	1-----	-----	863.05	24.01	1-----	-----	775.93
5301.94	4-----	2 II A	855.79	31.02	3-----	1 IV A?	753.86
14.68	1-----	tr IV A	810.59	34.82	2-----	-----	741.88
15.57	1-----	tr IV A	807.44	40.99	15-----	2 V E	722.43
18.35	3-----	1 IV E	797.60	46.37	5-----	4 IV	705.59
23.09	0-----	tr IV A	780.87	47.60	3-----	1 IV A	701.74
23.75	1-----	(0) IV	778.54	49.55	7-----	6 IV	695.63
25.36	0-----	-----	772.87	57.89	25-----	15 V E	669.54
31.77	6-----	3 IV A	750.30	58.35	8-----	2 V E	668.11
34.22	2-----	tr IV A	741.68	61.70	1-----	tr IV A	657.65
39.41	8-----	8 IV	723.47	67.16	10-----	2 V E	640.64
41.06	10-----	8 IV	717.68	69.05	12-----	2 IV E	624.76
42.96	9, G	10 II A	711.03	71.80	100-----	200 II	626.21
49.30	25-----	50 III	688.85	84.21	15-----	8 V E	587.73
49.71	7, G	15 II A	687.42	86.84	75-----	150 II	579.59
50.30	6-----	4 IV A	685.36	5691.33	?	(0) IV	565.72
55.75	7-----	8 III	666.34	5700.14	50-----	100 II	538.58
56.09	40-----	60 III	665.16	08.62	20-----	15 III A	512.52
57.18	2-----	-----	661.36	11.75	45-----	100 III A	502.92
75.34	20-----	20 III	598.31	17.30	35-----	15 III A	485.93
5392.08	25-----	30 III	540.53	20.95	1-----	tr IV	474.78
5402.72	1-----	-----	504.06	24.09	25-----	15 III A	465.19
16.12	5-----	2 III	458.28	35.20	1-----	-----	431.36
16.40	2-----	-----	457.33	36.85	5, n, l	-----	426.35
22.30	1-----	-----	437.25	39.30	2-----	2 IV A	418.91
25.57	8-----	2 III	426.13	41.36	2-----	1 IV A	412.66
29.40	7-----	2 III	413.14	64.45	3, n, l	-----	342.91
32.94	2?	-----	401.14	72.74	5, n, l	-----	318.00
33.23	5-----	2 III	400.16	75.32	2, n, l	-----	310.27
38.22	4-----	1 III A	383.28	5797.60	2-----	-----	243.75
39.03	6-----	2 III	380.54	5801.32	3, n, l	-----	232.69
42.59	10-----	2 III	368.51	09.84	3, n, c	-----	207.42
46.19	30-----	20 III	356.37	11.60	3, n, l	-----	202.21
47.39	3-----	1 IV	352.33	36.46	1, n, l	-----	128.94
48.84	0-----	-----	347.45	47.73	6, n, l	-----	095.93
51.34	15-----	6 III A	339.03	49.07	6, n, l	-----	092.01
55.21	3-----	1 III A	326.02	77.83	2, n, l	-----	008.38
65.20	3-----	tr IV A	292.52	80.61	2, p?	-----	17000.34
68.39	6-----	2 III	281.85	87.38	4, n, l	-----	16980.79
72.19	8-----	3 III	269.16	87.75	2-----	-----	979.72
74.64	2-----	-----	260.98	5894.63	3-----	(2) IV	959.90
81.99	40-----	100 III	236.50	5918.04	2, n, l	-----	892.81
84.61	30-----	80 III	227.79	19.11	5-----	tr IV A	839.76
5487.37	1?	-----	18218.62	5928.10	2, n, l	-----	16864.15

TABLE 1.—Scandium spectra—Continued

λ Å	Intensity and notes	Intensity and class	ν	λ Å	Intensity and notes	Intensity and class	ν
5931.23	4	-----	16855.25	6517.67	1, p?	-----	15333.68
40.68	2	-----	828.72	25.60	5 + n?	(3) IV?	320.04
52.20	5	-----	795.87	57.87	3	-----	244.65
59.01	1, n?	-----	776.67	58.05	2	-----	244.23
61.49	6	4 IV	769.69	66.85	3, n, l	15 IV	223.80
68.25	7	-----	750.70	75.89	3, n, c	-----	202.88
69.19	5	3 IV	748.06	6598.97	1, p?	-----	149.70
88.42	10	20 IV	694.28	6600.82	2, n, c	-----	145.44
5992.86	0	-----	681.91	04.60	10	-----	136.79
6002.34	2, p?	-----	655.57	09.98	4, n, l	-----	124.47
17.07	4, n, l	-----	614.80	17.90	2, n, l	-----	106.37
21.70	?	(0) IV	602.02	45.04	2, n, l	-----	044.67
26.18	7	15 IV	589.68	54.39	3, n, l	-----	023.53
36.17	10, n, l	-----	562.22	61.01	3, n, l	-----	15008.60
64.31	6, n, l	-----	485.37	90.59	1, n?	-----	14942.25
72.65	4, n, l	-----	462.73	91.15	2, n?	-----	941.00
73.13	1, p?	-----	461.43	6692.83	1	-----	937.25
6079.30	6, n, l	-----	444.72	6700.44	2, n, l	-----	920.28
6109.93	5, n, l	-----	362.28	05.93	3, n?	-----	908.07
15.97	5, n, l	-----	346.12	14.60	2	-----	888.82
40.32	2, n, l	-----	281.30	17.64	3	-----	882.08
46.25	4	(3) IV A	265.59	37.88	10	-----	837.38
48.70	2, n, l	-----	259.11	39.43	7	-----	833.96
53.93	2, n, l	-----	245.29	48.24	2	-----	814.60
88.09	2, p?	-----	155.61	6786.95	2, p?	-----	730.10
92.90	2, n, l	-----	143.07	6817.10	10	-----	664.95
93.66	2	(3) II A	141.09	19.51	20	-----	659.77
6198.44	4	-----	128.64	29.52	15	-----	638.29
6210.68	30, G	200 I A	096.85	35.03	25	-----	626.48
20.16	1, p?	-----	072.32	37.58	2, h, p?	-----	621.03
29.42	1, p?	-----	048.43	50.43	2, n?	-----	598.60
39.40	8	20 II A	022.76	64.67	2, h	-----	563.54
39.78	15, G	100 I A	021.78	74.31	3, h	-----	542.91
45.64	20	8 V B	16006.75	77.40	3, h	-----	536.38
49.96	10	15 IV	15995.68	81.10	4, h	-----	528.56
58.97	20, G	100 I A	972.65	85.30	5, h	-----	519.70
62.26	8	10 IV	964.27	89.82	7, h	-----	510.17
73.16	?	(0) IV	936.53	6890.93	3, h	-----	507.83
76.30	9, G	15 II A	928.56	6936.77	2, h	-----	411.96
79.74	15	-----	919.83	61.62	3, h	-----	360.62
80.17	3	-----	918.74	63.11	3, h, p?	-----	357.44
84.20	4	-----	908.53	80.61	1, n?	-----	321.45
84.45	?	5 IV	907.90	85.49	3, h	-----	311.45
84.78	6	-----	907.06	6990.70	5, n, l	-----	300.78
93.05	4	(2) IV	886.16	7005.51	3, n, l	-----	270.54
6297.79	?	(0) IV	874.20	25.70	3, n, l	-----	229.54
6309.70	6	-----	866.87	35.75	4, n, l	-----	209.21
05.68	40, G	400 I A	854.34	49.38	2, n?	-----	181.75
06.00	10	20 I A	853.54	72.39	2, n, l	-----	135.60
09.90	15	-----	843.74	82.40	3, n, l	-----	115.62
20.86	7	-----	816.27	7094.41	3, n?	-----	091.73
22.74	2	-----	811.56	7120.43	2, h	-----	040.23
32.23	1	(1) IV	787.87	30.61	3, h	-----	020.19
42.08	1	-----	763.34	38.13	6	-----	14005.42
44.84	3	5 II A	756.49	41.18	2, p?	-----	13999.44
61.78	1, p?	-----	714.54	69.13	8	-----	944.85
78.83	8, G	40 I A	672.53	80.69	3, h, n?	-----	922.40
6396.38	0	2 IV	629.53	7189.74	2, h, n?	-----	904.87
6403.16	0	2 IV	612.98	7233.14	2, h, n?	-----	821.45
08.42	3, n?	(1) IV	600.17	40.27	2, h, n?	-----	807.84
13.37	10, G	50 I A	588.12	57.56	6	-----	774.98
37.06	2, n, l	-----	530.76	7275.55	4, h	-----	740.88
46.26	2, n, l	-----	508.59	7300.65	3	-----	693.64
46.67	2, h	-----	507.61	7323.78	2	-----	550.40
48.10	2	1 II A	504.17	7332.53	1	-----	634.11
57.76	2, n, l	-----	480.98	7346.94	1	-----	607.36
76.55	1, n, l	-----	436.06	7521.74	4, h	-----	291.15
85.40	3, n, l	-----	415.00	24.11	7	-----	286.96
86.35	?	(0) IV A?	412.74	53.96	6	-----	234.45
6495.94	3, n, l	-----	15389.99	7563.55	1	-----	13217.67

TABLE 1.—Scandium spectra—Continued

λ A	Intensity and notes	Intensity and class	"	λ A	Intensity and notes	Intensity and class	"
7574.44	7-----	-----	13198.67	7848.55	2-----	-----	12737.71
7584.48	3-----	-----	131.20	8003.27	2-----	-----	491.46
7617.45	5-----	-----	124.15	-----	2-----	-----	486.53
65.72	4-----	-----	13041.50	-----	3-----	-----	468.77
7697.76	10-----	-----	12937.23	8043.44	1-----	-----	429.04
7727.09	2-----	-----	937.93	8178.92	2, Cu?-----	-----	223.20
29.73	7-----	-----	933.51	81.32	1-----	-----	219.60
38.18	2-----	-----	919.37	83.36	2-----	-----	216.56
41.20	20-----	-----	914.34	94.87	4-----	-----	199.46
42.82	1-----	-----	911.54	8196.98	3-----	-----	196.26
50.37	4-----	-----	899.07	8239.05	1-----	-----	133.99
52.72	3-----	-----	895.13	8241.13	4-----	-----	12130.93
71.06	4-----	-----	864.72	8408.01	2, h-----	-----	11890.16
85.17	6-----	-----	841.40	8644.48	0-----	-----	11564.90
94.68	5-----	-----	825.74	-----	-----	-----	-----
7798.75	1-----	-----	819.05	-----	-----	-----	-----
7800.44	15-----	-----	816.27	-----	-----	-----	-----
21.64	6-----	-----	781.54	-----	-----	-----	-----
30.78	1-----	-----	766.61	-----	-----	-----	-----
7839.47	1-----	-----	12752.45	-----	-----	-----	-----

IV. BIBLIOGRAPHY

1. Meggers, B. S. Sci. Papers (S312), **14**, p. 371; 1918.
2. Meggers and Kiess, B. S. Sci. Papers (S324), **14**, p. 637; 1918.
3. Burns, Meggers, and Merrill, B. S. Sci. Papers (S329), **14**, p. 765; 1918.
4. Merrill, B. S. Sci. Papers (S345), **15**, p. 251; 1919.
5. Kiess and Meggers, B. S. Sci. Papers (S372), **16**, p. 51; 1920.
6. Walters, B. S. Sci. Papers (S411), **17**, p. 161; 1921.
7. Kiess, B. S. Sci. Papers (S421), **17**, p. 318; 1921.
8. Kiess, B. S. Sci. Papers (S442), **18**, p. 201; 1922.
9. Kiess, B. S. Sci. Papers (S466), **18**, p. 695; 1923.
10. Meggers, B. S. Sci. Papers (S499), **20**, p. 19; 1925.
11. Kiess, B. S. Sci. Papers (S548), **22**, p. 47; 1927.
12. Meggers, B. S. Sci. Papers (S499), **20**, p. 19; 1925.
13. Meggers and Burns, B. S. Sci. Papers (S441), **18**, p. 191; 1922.
14. Lockyer and Baxandall, Proc. Roy. Soc., **74**, p. 538; 1905.
15. Fowler, Phil. Trans. A., **209**, p. 47; 1908.
16. Exner and Haschek, Die Spectren der Elemente bei normalem Druck.
17. Eder and Valenta, Wien, Ber., **119**, II a, p. 519; 1910.
18. Crookes, Proc. Roy. Soc., **95**, p. 438; 1919.
19. Piña, Anal. Soc. Esp. Fis. Quim., **24**, p. 41; 1926.
20. Ireton, Trans. Roy. Soc. Can., **18**, p. 103; 1924.
21. Smith, Proc. Nat. Acad. Sci., **13**, p. 65; 1927.
22. King, Astrophys. J., **54**, p. 28; 1921.
23. Goudsmit, van der Mark and Zeeman, Roy. Acad. Sci. Amsterdam, **33**, p. 975; 1924.
24. Gieseler and Grotrian, Zeitschr. Phys., **25**, p. 361; 1924.
25. Russell and Meggers, see forthcoming paper.

WASHINGTON, March 5, 1927.

AUTHOR

Scientific Papers of
the Bureau of Standards

TITLE

Vol. 22

DATE

BORROWER'S NAME

ROOM
NUMBER