THE ABSORPTION SPECTRA OF Ga, In, Mn, Cr, Ni and Co IN UNDER-WATER SPARKS

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ABSTRACT

The absorption of gallium, indium, manganese, chromium, nickel and cobalt has been studied in under-water spark spectra. Many new lines, not previously found in absorption spectra, have been located. The results confirm and extend the observations on the absorption of these elements in the vapor state. For indium and gallium they confirm the conclusion that the normal state of the atom is the $2p$ state and for manganese, the conclusion that the ground level of the valence electron is the $1s$ septet level. For chromium, nickel and cobalt they afford a verification of the assignment of lines and arrangement of terms with respect to the ground level as given by Catalan and Gieseler for chromium, by Bechert and Sommer for nickel and by Catalan and Bechert for cobalt.

INTRODUCTION

A STUDY of the line absorption spectra of the different elements has become important in view of the information which it affords concerning atomic structure, especially the normal state of the last valence electron of the neutral atom. One of the principal methods of obtaining line absorption spectra of metals consists in observing the spectra which are emitted from oscillatory discharges passed between two metallic electrodes, immersed in water. Under these conditions, if oscillatory discharges of sufficiently high frequency are used, the spectrum of the metal consists of a continuous background on which the arc lines appear as reversed lines. Since it is the arc lines which are absorbed by the neutral atom, the lines which are reversed in the under-water spark give the same kind of information with respect to the neutral atom as is obtained by observing the absorption produced by a vapor of the metal in its normal state. Hence this method of obtaining absorption spectra of metals offers a means of extending and verifying results obtained by passing light through the normal vapor of the metal.

The absorption spectra of a large number of metals have previously been examined in under-water sparks. Finger[1] made the first important study of such spectra for seventeen metals. L. and E. Bloch[2] made similar observations on many of the same metals studied by Finger and extended the observations to some additional metals. Hulburt[3] also made similar observations on many metals studied both by Finger and L. and E. Bloch and on some additional metals but the results are not interpreted in terms of spectral series. Buffam and Ireton[4] and Clark and Cohen[5] continued this work, extending it to

[1] Finger, Zeits. f. wiss. Photo., **7**, 329 and 369 (1909).
[2] L. and E. Bloch, C. R. **174**, 1456 (1922). Jour. de Phys. et Rad. (3), **6**, 308 (1922).
[3] Hulburt, Phys. Rev. (2), **24**, 129 (1924).
[4] Buffam and Ireton, Roy. Soc. Can. Trans. (3), **19**, 113 (1925).
[5] Clark and Cohen, Roy. Soc. Can. Trans. (3), **20**, 1 (1926).

shorter wave-lengths and adding some elements not previously studied. The work of Clark and Cohen is devoted to the palladium-platinum group of metals.

The series relationships which have been recently worked out for a number of elements give a new meaning to such observations on line absorption. The recent work of Sur[6] on iron, and of Stucklen[7] on copper and cadmium suggests the importance of a more intensive study of some of the elements previously examined in order to obtain information concerning the corectness of the present assignment of the lines in spectral series and the arrangement of energy levels in the atom.

Experimental Method

The arrangement of the apparatus (Fig. 1) was similar to that used by Hulburt.[3] The condenser C was charged by means of a 20 kv 2.5 kw Thordarson transformer and then discharged through an auxilliary spark gap S

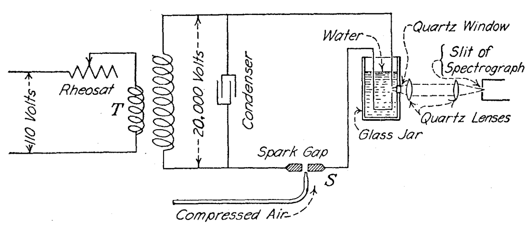

Fig. 1. Diagram of apparatus.

and the under-water spark in series. To insure an abrupt discharge compressed air was forced between the terminals of the auxilliary spark gap S. The primary of the transformer was connected to the 60-cycle, 110-volt-mains. The electrodes of the under-water spark were made of the metal whose absorption spectrum was being examined. Radiation from the under-water spark passed directly through the quartz window in the side of the glass jar and then through two quartz lenses by means of which it was brought to a focus on the slit of a Fery quartz spectrograph. The spectrum thus obtained was essentially continuous except for the absorption lines which belong to the arc spectrum of the metal from which the electrodes were made. Absorption lines due to the water were also observed and it is possible that a few absorption lines which do not belong to the arc spectrum of the metal may have been present.

For the ultra-violet region of the spectrum between about 2400A and 2100A distilled water was used in the jar. By refilling the jar with fresh distilled water several times during a single exposure it was possible under favorable conditions to photograph the spectrum as far as 2100A. For the region of the spectrum between the visible and about 2400A ordinary tap water was circulated rapidly through the jar. Care was taken to vary the

[6] Sur, Phil. Mag. (7), **1,** 433 (1926).

[7] Stucklen, ZS. f. Phys., **30,** 24 (1924); **34,** 8 (1925).

conditions of excitation by varying the inductance and capacity to bring out the maximum number of absorption lines. The times of exposure ranged from a few seconds for the visible portions of the spectrum to several minutes for the extreme ultra-violet.

The wave-lengths of the absorption lines were determined by comparison with the wave-lengths of the emission lines in the spectrum of the copper arc which was always photographed on the same film as the absorption spectrum of the metal in the under-water spark. The distances of the absorption lines from each other and from the known lines in the emission spectrum of copper were measured with a travelling microscope and the unknown wave-lengths calculated in the usual manner. It was possible thus to identify the absorption lines with certainty.

Experimental Results

Indium. The absorption of indium in the normal vapor is known from the work of Grotrian,[8] Rao[9] and Frayne and Smith.[10] Its absorption has not been previously studied in the spectra of under-water sparks. The observed wave-lengths for which absorption occurs in the under-water spark are recorded in Table I. It is noticed that those lines are found which are to be

TABLE I

Absorption spectrum of indium.

$\nu=2p_2-ms$			$\nu=2p_2-md$			$\nu=2p_1-ms$			$\nu=2p_1-md_{1,2}$		
λ	m	Notes	λ	m	Notes	λ	m	Notes	λ	m	Notes
4101.72	2	1,2,3	3039.34	3	1,2,3	4511.27	2	1,2,3	3258.52*	3	1,2,3
2753.87	3	1,2,3	2560.16	4	1,2,3	2932.60	3	1,2,3	56.03*	3	1,2
2460.06	4	1,2,3	2389.56	5	1,2,3	2601.75	4	1,3	2713.95	4	1,2,3
						2468.01	5	1,3	10.28	4	1,2
						2399.25	6	1,3	2522.99*	5	1,2,3
									2521.36*	5	1,2
									2430.7	6	1,3
									29.68	6	1,4
									2379.66†	7	

* Lines unresolved but both seem to be present
† New lines
[1] Grotrian in vapor
[2] Rao in vapor
[3] Frayne and Smith in vapor
[4] Not found by authors in under-water spark.

expected from the series relationship and from previous observations on the absorption of light by the normal metallic vapor. A number of lines which have been previously observed as absorption lines in the vapor of indium were not found. These lines are with two exceptions in the far ultra-violet where the intensity of the spectrum from the under-water spark is too small for satisfactory observations. Besides these recorded lines two unclassified lines (λ2957.02 and λ2836.90) were observed. The recorded wave-lengths are those used by Fowler.[11]

[8] Grotrian, ZS. f. Phys., **12,** 218 (1922).
[9] Rao, Phys. Soc. Lond. Proc., **37,** 259 (1924).
[10] Frayne and Smith, Phys. Rev. (2), **27,** 23 (1926).
[11] Fowler, Report on Series in Line Spectra, pp. 158–9.

Gallium. Because of the low melting point of gallium it was necessary to use it in the form of a gallium-tin alloy. The absorption spectrum of tin was first examined in the under-water spark. Then the absorption spectrum of the alloy of gallium and tin was studied. By the elimination of the absorption lines of tin from the spectrum of the alloy, the identification of the absorption lines of gallium was made possible. The absorption of the normal vapor of gallium is known from the work of Grotrian[8] and Frayne and Smith.[10] Table II shows the results. The recorded wave-lengths of gallium are those given by Klein.[12] For the shorter wave-lengths where the intensity of the under-water spectrum is small some wave-lengths previously observed as

TABLE II

Absorption spectrum of gallium

$\nu=2p_2-ms$			$\nu=2p_2-md$			$\nu=2p_1-ms$			$\nu=2p_1-md_{1,2}$		
λ	m	Notes	λ	m	Notes	λ	m	Notes	λ	m	Notes
4032.98	2	1,2	2874.24	3	1,2	4172.06	2	1,2	2944.18*	3	1,2
2659.87	3	2	2450.08	4	2	2819.66	3	2	43.7*	3	1
2371.33	4	2	2294.20	5	2	2418.70	4	2	2500.71	4	2
2255.03	5	2	18.04	6	2	2297.87	5	2,3	2338.60	5	2
						36.10	6	2,3	2259.23	6	2,3

* Lines unresolved but both seem to be present
[1] Grotrian in vapor
[2] Frayne and Smith in vapor
[3] Not found by authors in underwater spark.

absorption lines in the vapor were not located. This failure as in the similar case of indium is to be attributed to the faintness of the lines in that region of the spectrum. Except for this difference these observations confirm those made on absorption in the vapor.

Manganese. The electrodes were made of commercially pure manganese ground to suitable dimensions. The emission spectrum of managanese is known from the work of Catalan[13] and Fuchs.[14] In Table III these wave-

TABLE III

Absorption spectrum of manganese.

λ	Combination	Notes	λ	Combination	Notes
4032.49	$1^6S_3-1^6P_2$	1,2	2605.70	$1^7S_3-1^7P_2$	†
33.07	$1^6S_3-1^6P_3$	1,2	2593.72	$1^7S_3-1^7P_3$	†
30.76	$1^6S_3-1^6P_4$	1,2	2576.80	$1^7S_3-1^7P_4$	†
2801.08	$1^6S_3-2^6P_2$	1,2	2221.80	$1^6S_3-3^6P_2$	1
2798.27	$1^6S_3-2^6P_3$	1,2	13.80	$1^6S_3-3^6P_3$	1
2794.82	$1^6S_3-2^6P_4$	1,2	08.73	$1^6S_3-3^6P_4$	1

† New lines
[1] Zumstein in vapor
[2] Grotrian in vapor

lengths have been recorded out to two decimal places. The notation of the series classification has been modified to conform to modern usage. Table III

[12] Klein, Astrophys. Jour. **56,** 373 (1922).
[13] Catalan, Phil. Trans. A, **223,** 127 (1922).
[14] Fuchs, ZS. f. wissensch. Phot. **14,** 263 (1914).

shows a comparison of the absorption of manganese in the under-water spark and its absorption in the vapor phase. Both Grotrian[15] and Zumstein[16] have studied the line absorption of manganese in the vapor state. No previous observations on the absorption spectrum of manganese in under-water sparks are available. Grotrian observed absorption at six wave-lengths as indicated in Table III. Zumstein found a large number of additional absorption lines but for the sake of brevity only a few of these have been included in Table III. Many of them have wave-lengths which are too short to come within the region of these observations.

It will be seen from Table III that the three prominent triplets which Zumstein found to be absorbed in the vapor are also absorbed in the under-water spark. In addition to these triplets there is found the triplet $1^7S_3-1^7P_{2,3,4}$, which both Catalan and Back[17] have attributed to singly ionized manganese. According to de Gramont[18] these lines are *raies ultimes* in the spark spectrum of manganese. If these lines are correctly attributed to the singly ionized atom of manganese, they are the only absorption lines found in these observations on under-water absorption spectra which did not arise from the neutral atom. Stucklen[7] seems to have found absorption by singly ionized cadmium in a under-water spark.

On account of the brittleness of the manganese the under-water spark did not behave as well as it did in the case of the other metals. This fact doubtless accounts for the failure to observe as many absorption lines for manganese in the under-water spark as were observed by Zumstein in the vapor.

Chromium. The wave-lengths in Table IV are from papers on the arc spectrum of chromium by Catalan[19] and Gieseler.[20] The series combinations are taken either directly from Gieseler or when the multiplets are given only by Catalan his notation is changed to that of Gieseler in which the superscript at the left of the letter gives the multiplicity of the term and the subscript at the right of the letter gives the inner quantum number. The absorption of chromium vapor has been studied by Gieseler and Grotrian[21] and by Zumstein.[22] Observations on the absorption spectra in the underwater sparks are available from the work of Finger[1] and Hulburt.[3] Two prominent triplets have been found in the vapor and in the under-water spark. A third triplet further removed toward the ultra-violet was observed by Zumstein in chromium vapor. It is found here in the under-water spark spectrum. A large number of new absorption lines are also found. They are in agreement with the series combination given by Gieseler and Catalan. Besides these lines a number of unclassified lines were observed. These were distributed throughout the spectrum.

[15] Grotrian, ZS. f. Phys., **18,** 169 (1923).
[16] Zumstein, Phys. Rev. (2), **26,** 765 (1925).
[17] Back, ZS. f. Phys., **15,** 206 (1923).
[18] de Gramont, C.R. **171,** 1106 (1920).
[19] Catalan, Anales de Fisica Y Quimiea, **21,** 84 (1923).
[20] Giesler, ZS. f. Phys., **22,** 228 (1924).
[21] Grotrian and Giesler, ZS. f. Phys., **22,** 245 (1924).
[22] Zumstein, Phys. Rev. (2), **27,** 562 (1926).

TABLE IV

Absorption spectrum of chromium

λ	Combination	λ	Combination	λ	Combination	λ	Combination
4964.92	$4^5S_2-4a^7P_2$	3853.19	$4^5D_4-4b^5P_3$	3013.72	$4^5D_1-5a^5P_2$	2690.26	$4^5D_3-6^5F_3$
4829.36	————	31.03	$4^5D_3-4b^5P_2$	13.04	$4^5D_0-5a^5P_1$	84.72	$4^5D_4-6^5F_5$
4652.17	$4^5D_2-4a^5P_2$	22.08	$4^5D_3-4b^5P_3$	2996.58	$4^5D_2-2(II)^5D_j$	84.31	$4^5D_2-6^5F_2$
51.30	$4^5D_2-4a^5P_1$	14.62	$4^5D_2-4b^5P_1$	95.79	$4^5S_2-5a^5P_1$	82.52	$4^5D_3-6a^6P_3$
26.19	$4^5D_1-4a^5P_1$	06.70	$4^5D_2-4b^5P_2$	94.07	$4^5S_2-5a^5P_2$	80.74	$4^5D_3-6^5F_4$
13.37	$4^5D_0-4a^5P_1$	3615.65	————	91.90	$4^5D_1-1(II)^5D_j$	78.15	$4^5D_2-6^5F_3$
00.75	$4^5D_3-4a^5P_3$	05.33*	$4^7S_3-4a^7P_2$	88.67	$4^5S_2-5a^5P_3$	71.07	$4^5D_2-6a^5P_1$
4591.40	$4^5D_1-4a^5P_2$	3593.48*	$4^7S_3-4a^7P_3$	85.99	$4^5D_3-4(II)^5D_j$	70.52	$4^5D_2-6a^5P_2$
80.06	$4^5S_2-4a^5P_1$	78.69*	$4^7S_3-4a^7P_4$	85.86	$4^5D_2-3(II)^5D_j$	69.38	$4^5D_2-6a^5P_3$
65.53	————	10.53	————	80.79	$4^5D_0-2(II)^5D_j$	62.78	$4^5D_1-6a^5P_1$
46.04	$4^5S_2-4a^5P_2$	3494.96	————	75.48	$4^5D_1-3(II)^5D_j$	62.21	$4^5D_1-6a^5P_2$
14.53	————	81.30	————	71.11	$4^5D_2-4(II)^5D_j$	58.52	$4^5D_0-6a^5P_1$
4496.86	$4^5S_2-4a^5P_3$	60.43	————	67.64	$4^5D_3-5(II)^5D_j$	38.90	————
29.45	$4^5D_2-4^5F_3$	3266.55	$4^5D_4-5^5P_j$	11.14	$4^5D_4-4(III)^5D_j$	18.28	————
4391.76	$4^5D_3-4^5F_2$	44.14	$4^5D_3-5^5D_j$	10.90	$4^5D_3-5(III)^5D_j$	2591.86	$4^5D_4-n^5P_3$
84.98	$4^5D_4-4^5F_4$	3065.07	————	05.49	$4^5D_1-1(III)^5D_j$	77.66	$4^5D_3-n^5P_3$
73.27	$4^5D_2-4^5F_1$	53.88	$4^5D_4-5a^5P_3$	2899.21	$4^5D_1-2(III)^5D_j$	71.76	$4^5D_3-n^5P_2$
71.28	$4^5D_3-4^5F_3$	37.05	$4^5D_4-5^5F_4$	93.26	$4^5D_3-4(III)^5D_j$	66.55	$4^5D_2-n^5P_3$
51.78	$4^5D_4-4^5F_5$	34.19	$4^5D_3-5a^5P_3$	89.26	$4^5D_4-5(III)^5D_j$	60.71	$4^5D_2-n^5P_2$
44.51	$4^5D_3-4^5F_4$	30.25	$4^5D_3-5^5F_3$	86.99	$4^5D_1-3(III)^5D_j$	57.14	$4^5D_2-n^5P_1$
39.72	$4^5D_0-4^5F_1$	29.17	$4^5D_2-5a^5P_1$	79.27	$4^5D_2-4(III)^5D_j$	53.05	$4^5D_1-n^5P_2$
37.56	$4^5D_1-4^5F_2$	24.36	$4^5D_2-5a^5P_2$	71.64	$4^5D_3-5(III)^5D_j$	49.51	$4^5D_1-n^5P_1$
4289.73*	$4^7S_3-4^7P_2$	21.57	$4^5D_4-5^5F_5$	2780.69	$4^5D_4-nb^5P_3$	45.63	$4^5D_0-n^5P_1$
74.80*	$4^7S_3-4^7P_3$	20.67	$4^5D_1-5^5F_1$	69.91	$4^3D_3-nb^5P_2$	44.71	$4^5S_2-nc^5P_j$
54.34	$4^7S_3-4^7P_4$	18.83	$4^5D_2-5a^5P_3$	66.54	————	38.97	$4^5S_2-nc^5P_j$
3991.12	————	18.50	$4^5D_1-5a^5P_1$	64.35	$4^5D_3-nb^5P_3$	35.27	$4^5S_2-nc^5P_j$
83.91	————	15.20	$4^5D_0-5a^5F_1$	61.75	$4^5D_2-nb^5P_1$	2366.85†	$4^7S_3-5^7P_2$
41.59	$4^5D_4-4(I)^5D_j$	14.93	$4^5D_2-5^5F_3$	57.10	$4^5D_2-nb^5P_2$	65.16†	$4^7S_3-5^7P_3$
28.64	$4^5D_4-3(I)^5D_j$	14.77	$4^5D_1-5^5F_2$	52.87	$4^5D_1-nb^5P_1$	64.74†	$4^7S_3-5^7P_4$
				48.29	$4^5D_1-nb^5P_2$		

Bracketed lines are unresolved but both seem to be present.
* Observed by Hulburt in under-water spark, by Finger in under-water spark, Gieseler and Grotrian in vapor, by Zumstein in vapor.
† Observed by Zumstein in vapor.

Nickel. Finger[1] as well as Buffam and Ireton[4] has studied the under-water absorption spectrum of nickel. Angerer and Joos[23] have made observations on the line absorption of his element in the vapor phase. Table V shows the absorption lines observed in this investigation. The wave-lengths are those used by Bechert and Sommer[24] in their analysis of the nickel spectrum. It is to be noted that many new lines have been observed. These lines as well as those which have been previously observed are in agreement

[23] Angerer and Joos, Ann. d. Phys. **74**, 743 (1924).
[24] Bechert and Sommer, Ann. d. Phys. **77**, 351 and 537 (1925).

TABLE V

Absorption spectrum of nickel.

λ	Notes	λ	Notes	λ	Notes	λ	Notes	λ	Notes	λ	Notes
4466.54*	†	3571.87	1	3369.58	3	3057.65	1,2	2437.82*	†	2321.96	†
4202.33*	†	66.37	1,2	66.16	1	54.32	1,2	34.43	†	21.39	†
4074.89	†	61.75	†	65.77	1	50.83	1,2	24.03	†	20.03	†
10.14*	†	27.99	†	61.56	1	45.01	†	23.33	†	17.16	3
3973.55	†	24.54	1,2,3	22.32	1	37.94	1,2	21.33	†	13.98	3
72.16	†	23.44	†	20.26	1	31.87	1	19.31	†	12.34	2,3
3858.28	1	19.78	1	15.67	1,2	19.15	1	12.67	2	10.96	3
32.87	†	15.06	1,3	3282.70	†	12.01	1,2	10.68*	†	07.35	†
31.69	†	13.95	†	71.12	†	03.63	1,2	06.82*	†	06.45*	†
07.14	1	10.34	1	48.43	1	02.49	1,2	01.85	†	01.57	†
3793.60	†	07.70	†	43.06	1	2994.46	1	2396.39	2	00.77	†
92.33	†	00.85	1	34.66	1	92.60	1	94.50*	2	2298.23*	†
83.52	†	3492.97	1,2,3	32.95	1,2	84.13	1	93.12	†	96.54*	2
75.56	†	83.78	1	25.03	1	81.65	1	87.56	2	93.11	†
72.52	†	72.55	1	21.66	1	43.92	1	86.59	†	89.98	†
36.81	†	69.48	1	3197.12	1	14.01	1	84.40	†	88.39	†
22.48	†	61.66	1,2,3	95.58	†	07.46	†	76.02	†	87.32	†
3693.93	†	58.47	1,3	59.52	†	2865.51	†	69.22*	†	74.65	†
88.41	†	52.89	1,3	45.71 }	†	34.55	†	65.68	†	71.94	†
74.11	†	46.26	1,3	45.12 }		21.30	†	62.06	2	67.55	†
70.42	†	37.28	1	34.11	1,2	2798.65	†	60.64	†	61.41	†
64.09	†	33.57	1,3	29.31	†	46.75	†	58.87	†	59.45*	†
61.94	†	23.71	1	16.84*	†	2561.43	†	56.87	†	58.13	2
3649.63*	†	14.77	1,3	14.13	1	53.38	†	55.06	†	53.97*	†
34.94	†	13.94 }	1	05.47	1	47.42	†	48.74	†	53.55	2
24.73	†	13.48 }	1	01.88 }	1,2	24.22	†	47.53	3	51.47	†
19.39	1	09.48	†	01.56 }	1,4	2489.51	†	46.64	†	47.31*	2
12.73	1	3392.99	1,2	3099.12	1	84.04	†	45.55	†	13.29*	†
10.45	1	91.05	1	97.12	1	76.88	†	38.50	†	11.16*	2
09.31	1	85.34*	†	87.06*	1	72.24	†	37.49	3	06.80*	†
02.28	†	80.89 }	1	80.76	1,2	66.97	†	34.57*	2	01.55*	2
3597.70	1	80.58 }		75.85*	†	54.00	†	31.70	3	2191.04*	2
87.93	†	74.23	1	66.43*	†	50.48	†	2326.43*	†	84.70*	2
77.21	†	71.99	1	64.63	†	41.83	†	25.80	2,3	84.42*	†
										75.22*	2

Bracketed lines are unresolved but both seem to be present.
* Not classified by Bechert and Sommer. † New lines. 1. Finger in under-water spark. 2. Buffam and Ireton in under-water spark. 3. Angerer and Joos in vapor.

with the analysis of the spectrum as given by Bechert and Sommer. In addition to these classified lines a number of unclassified lines were found.

Cobalt. Table VI gives the results for cobalt together with the series classification as given by Catalan and Bechert.[25] The wave-lengths are

[25] Catalan and Bechert, ZS. f. Phys., **32**, 336 (1925).

those given by Dhein.[26] They are recorded only to two decimal places. Observations on the absorption spectrum of cobalt in under-water sparks have been previously made by Finger,[1] and also by Buffam and Ireton.[4] Both Angerer and Joos and Sur and Majumdar[27] have examined the absorption of this element in the vapor state. Except for minor departures the results of the present investigation confirm the earlier observations

TABLE VI

Absorption spectrum of cobalt.

λ	Notes	λ	Notes	λ	Notes	λ	Notes	λ	Notes	λ	Notes
4339.64*	†	05.37	†	33.04	1,2,4	62.20	†	2572.24*	2	65.04	3
20.37*	†	02.08	1,4	31.58	1	3061.83	1,4	67.33	†	2363.53*	2
03.24	†	3594.87	1,4	17.80	†	54.72	†	59.41*	2	58.21	†
4285.79	†	87.19	1,2	17.16	1	54.14		55.06	†	55.50	3
68.03	†	85.16	1,4	15.53	1	48.89	1,4	53.35	2	54.83*	4
52.30	†	84.80	4	14.74	†	44.01	1,2,3,4	53.00		53.43	3
34.00	†	79.03*	†	12.64	1,2,3,4	42.48	†	44.25	3,4	50.78*	2
4190.71	4	75.36	†	12.34	1,4	34.43	2,4	41.95*	2	46.58*	†
50.44	†	74.96		3409.18	1,4	17.55	2	38.78	†	46.18	3
21.33	1,2	69.38	†	05.12	1,2,3,4	13.60	†	35.93	3	45.05*	3
10.54	†	64.96	1,4	02.07*	†	05.77*	2	28.98	3,4	44.29	†
4092.40	†	60.90	1,4	3395.38	1,2,4	00.55	†	25.57*	2	35.98	3
76.13	4	58.78	†	90.80*	†	2989.60	1	21.40	3	29.15*	†
45.40	†	52.72	†	88.18	†	87.17	1,2,4	17.81	†	24.80*	†
20.90	†	50.60	†	85.23	1,4	29.52*	2	11.03	2	23.18	3
3997.91	2,4	42.98	†	83.92*	†	11.56	†	06.92*	†	21.26*	†
95.31	1,4	33.36	1,4	77.06*	†	2895.48*	†	00.51	2	19.27	†
87.12	†	29.82	1,3,4	70.33	2	86.45	†	2495.56	†	15.95*	†
65.24	†	29.04	1,4	67.11	†	50.96	2	76.64	†	13.71*	†
65.02		26.86	1,3,4	54.39	1,2,4	42.39*	4	76.43		11.65	2,3
57.94	†	23.44	1,4	46.94*	†	34.43*	†	73.92	†	09.03	†
52.92	†	21.74		34.15	1,4	33.93*	4	70.28*	†	04.22	†
35.97	†	21.57	1,4	33.39	†	20.00	†	67.71	†	2299.73*	†
33.92	2	20.09	1,4	25.24*	†	14.98	4	64.21*	†	96.25*	†
22.76	†	18.35	1,2,4	19.48*	†	11.53*	2	60.81	†	95.30*	3
3894.98	1,4	13.48	1,4	18.40*	†	2803.78	2	41.04*	†	93.05*	3
94.09	1	12.64	1,4	07.15*	†	2796.24	†	2439.03	3	2292.05*	†
3885.28	†	10.42	1,2,3,4	79.25*	†	74.96	†	36.77	3	90.35	†
84.61		09.84	1,4	65.35	†	64.19	†	32.20	3	88.84*	†
3873.96	1,4	06.32	1,3,4	64.84		52.07*	†	27.00*	†	87.86	3
73.12	1,4	02.62	1	49.99	4	45.11*	†	24.98	3,4	86.25*	2,3
45.47	1,2,4	02.28	1,2,3,4	47.18*	1,2,4	15.99*	†	23.63*	2	83.09*	†

[26] Dhein, ZS. wiss. Photo., **19,** 289 (1920).
[27] Sur and Majumdar, Phil. Mag. (7), **1,** 451 (1926).

TABLE VI (continued)

λ	Notes	λ	Notes	λ	Notes	λ	Notes	λ	Notes	λ	Notes
42.06	1,4	3496.69	1	43.84*	†	05.86*	†	22.57*	2	79.33*	†
41.46	†	95.69	1,4	37.03	†	2695.58	†	19.13*	†	76.75*	3
11.07	†	91.32	1,4	3186.35	†	94.68*	2	15.32	3	75.90*	3
08.11	†	90.74	4	74.91	†..	85.34	2	14.47	3	74.70*	3
01.23*	†	89.41	1,4	59.66	4	80.11*	†	12.88*	3	67.17*	2
3745.50	4	85.71*	†	58.77	4	75.99	2	11.65	3	65.82*	†
04.06	2	83.42	1,4	54.79*	2	63.53*	4	08.74*	†	62.63*	†
3693.48	†	76.37*	2	49.30	†	50.27	2,4	07.27	3,4	61.81*	†
93.12		74.02	1,3,4	47.06	4	48.65	2	02.12	3	37.25*	†
90.72*	†	65.80	1,2,3,4	39.94	2	46.42	†	2396.24*	†	34.86*	2
77.98	†	62.81	1,4	37.33	4	29.98*	2	91.99	3	29.12*	†
56.97	†	60.73	†	21.56	2,4	23.45	†	89.58*	†	27.84*	†
52.54	†	55.24	1	21.41		22.43	†	84.89	3	24.16*	2
47.66	4	53.51	1,2,3,4	03.99	†	22.25		83.45*	2	12.38*	2
31.34	1,4	49.44	1,3,4	86.78	†	2590.61*	†	80.52	3	07.89*	†
27.81	4	49.17	1,4	82.61	2	80.84*	2	78.62*	†	2204.9 *	†
24.96	4	43.65	1,4	72.35	1,4	78.93*	†	73.40*	†	2196.59*	†
18.01	†	42.92	1,2	71.95		74.36	2,4	71.76*	†	87.29*	†
15.39*	†	36.97*	†	64.38	2,4			71.40*	†	2181.12*	†

Bracketed lines not clearly resolved, though both seem to be present.
* Not classified by Catalan and Bechert. † New lines. 1. Finger in under-water spark. 2. Buffam and Ireton in under-water spark. 3. Angerer and Joos in vapor. 4. Sur and Majundar in vapor.

whether the absorption was obtained by means of the under-water spark or by means of the vapor of the metal. However, many lines not previously reported have been located and a more adequate confirmation of the series classification of Catalan and Bechert has thus been obtained. A number of new unclassified lines was observed and the presence of other unclassified lines confirmed.

DISCUSSION OF RESULTS

Indium and Gallium. The absorption lines found in the under-water spark spectra of indium and gallium confirm the results obtained from a study of the absorption by vapors of indium and gallium and in agreement with these results indicate that the normal state of the valence electron in both of these atoms is the *2p* state.

Manganese. The three prominent triplets characteristic of the absorption of manganese vapor have been found in the under-water spark spectrum of this element. The fact that all these triplets originate from the *1s* sextet level, shows that this term represents the normal state of the valence electron. A fourth triplet, ordinarily attributed to singly ionized manganese, has also been located.

Chromium. A large number of absorption lines not previously reported have been located in the under-water spark spectrum of chromium. These lines give a rather complete verification of the arrangement of the energy levels in the chromium atom, above the ground $4S$ septet level. Not only were the three triplets arising from this term absorbed, but also almost all the classified multiplets whose final levels on emission, the quintet $4S$ and $4D$ terms, lie nearest the $4S$ septet level. The fact that the multiplets $4S$ originating from the $4S$ and $4D$ levels were absorbed, and those from other terms, such as the P-terms, were not absorbed, must be interpreted as showing the correctness of the assignment of the $4S$ and $4D$ levels as the next lowest to the $4^7\,S$ level.

Nickel. In both nickel and cobalt more than a hundred lines were found which have not previously been observed in absorption. In each of these metals there is a group of terms relatively near the lowest or ground term. In nickel, according to the classification and notation of Bechert and Sommer the ground triplet term f_4^1 is followed successivley by the triplet terms $\bar{d}_3^1$, $\bar{d}_2^1$, f_3^1, $\bar{d}_1^1$ and f_2^1 and the singlet $\overline{D}_2^1$ which is separated by 0.4 volt from the term f_4^1. Since the singlet term $\overline{D}_2^2$ which immediately follows the $\overline{D}_2^1$ term is separated by 1.6 volts from the f_4^1 term, it would be expected that in the under-water spark the absorption lines would start from the f^1, $\bar{d}^1$, and $\overline{D}_2^1$ levels. The absorption lines as recorded in Table V start from these levels. Furthermore this table includes nearly all the lines of appreciable intensity which, according to the classification of Bechert and Sommer, originate from these levels. Hence these results seem to strongly confirm their assignment of terms and levels for nickel.

Cobalt. In cobalt above the ground term f_5^1 there are, in the notation of Bechert and Sommer, successively the quartet terms $f_4^1, f_3^1, f_2^1, f_5^2, f_4^2, f_3^2$ and f_2^2 and the doublet terms F_4^1 and F_3^1. The greatest separation to these terms from the ground level f_5^1 is about one volt but the p_3^1 term which is immediately above the F_3^1 term is separated by about 1.6 volts from the f_5^1 term. Hence the absorption lines to be expected on the basis of this classification should start from the f^1 or the F^1 levels. Because of the much greater separation of the p^1 levels from the f^1 levels, the lines which start from the p^1 levels are not to be expected. Almost every line of appreciable intensity Table VI corresponding to an initial level of f_4^1, f_3^1, f_2^1, f_5^2, f_4^2, f_3^2 and f_2^2 has actually been observed as an absorption line in the under-water spark. This fact gives a verification of the correctness of the term assignment of these lines and the arrangement of terms with respect to the ground level as given by Catlan and Bechert.

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NOTE. Since the above was written a paper by Majumdar on the absorption spectrum of nickel appeared in Zeit. f. Physik, **39**, 562 (1926). On the basis of about one-half as many lines as are recorded in Table V, he concludes that there is not sufficient data available to determine the ground level of the nickel atom. At the Annual Meeting of the American Physical Society, Dec. 28–30, 1926, Meggers and Walters reported on the absorption spectra of iron, nickel and cobalt in under-water sparks. (Phys. Rev. (2) **29**, 358, 1927.)