ABSORPTION SPECTRA OF IRON, COBALT, AND NICKEL

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The underwater spark absorption spectra, as well as the ordinary vapor absorptions, have been investigated by others, but not in sufficient detail in connection with the spectral structures of Fe, Co, and Ni. Employing high potential condensed sparks between electrodes of iron, cobalt, and nickel immersed in water, the underwater spark spectra of these metals were reexamined throughout the visible and ultra-violet regions. The spectrograms show 265 iron lines (2166 to 4404 A), 340 cobalt lines (2137 to 4121 A), and 225 nickel lines (2124 to 3858 A) absorbed in the source. In each case the majority of these are identical with the stronger lines of the arc-emission spectra, and practically all such lines are found to involve either the normal state or some low metastable state of the neutral atoms. These results confirm and extend the known spectral structures for neutral Fe, Co, and Ni; the normal states of these atoms are represented by ^5D, ^4F, and ^3F terms, respectively. The type of source used showed most of the metallic spark lines in emission, but certain groups were present in absorption with low intensity. The latter involve low energy states of the ionized atoms; these normal or metastable states are represented by ^6D, ^5F, and ^4F terms for ionized Fe, Co, and Ni, respectively.

CONTENTS

I. INTRODUCTION

Atoms in the vapor state emit radiation if they return from excited to lower energy values, and they may absorb energy from a continuous spectrum in the reverse process. The absorption lines occupy the same positions otherwise occupied by characteristic bright lines of the emission spectrum. Moreover, if the absorbing atoms are unexcited at the beginning they are capable of absorbing those lines which involve the energy change from the zero or normal state to some immediately excited state. In this fact lies the importance of absorption data for the analysis of spectral structures; they determine the order of the spectral terms and identify the one which describes the normal state of the atom.

The ideal experimental arrangement is one in which a continuous spectrum is photographed after the light has passed through a tube of metal vapor at a temperature to produce sufficient vapor pressure without appreciable excitation of the atoms. The continuous spectrum is then crossed by absorption lines which are coincident with prominent lines in the emission spectrum of the electric arc. Such experiments with the alkali metals (1)[1] have long been familiar and they have recently been performed with other elements (2) in connection with the analysis of more complex spectra. In particular the absorption spectra of iron, cobalt, and nickel were investigated in this manner by Angerer and Joos (3).

Metals such as those under discussion and others with very high boiling points are vaporized and studied only with great difficulty, so that easier methods of obtaining the same results have been sought. Under certain conditions the continuous spectrum produced when condensed high-voltage discharges pass between metallic electrodes submerged under water is interrupted by absorption lines characteristic of the metal, and these phenomena have laterly received considerable attention in connection with the analysis of complex spectra. The purpose of this paper is to report on our observations of the underwater spark absorption spectra of iron, cobalt, and nickel to show how these data confirm the known structures of the emission spectra and to present some extensions of the structural analyses.

II. UNDERWATER SPARK SPECTRA

The spectral characteristics of sparks between metallic electrodes immersed in liquids have been under investigation for a quarter of a century. The first experiments, those of Wilsing (4), of Lockyer (5), and of Hale (6), were inspired by problems in stellar spectra and were concerned mainly with spectral line displacements due to pressure and other causes. Extensive investigations with various metals were carried out by Konen (7), Finger (8), E. and L. Bloch (9), and Hulburt (10). Konen gave wave length data for Fe, Al, and Cu, and was the first to identify certain H_2O absorption bands which always occur in the spectra of underwater sparks. Finger observed that lines belonging to a spectral series behaved in the same way in respect to changes occuring in underliquid sparks. This rule was supported by his results with Cu, Ag, Ca, Zn, Cd, Al, and Tl. Similar conclusions were drawn from the detailed observations of E. and L. Bloch, who photographed the underwater spark spectra (5000 to 2200 A) of Zn, Cd, Hg, Mg, Ca, Cu, Ag, Al, Tl, Sn, Pb, Bi, Sb, and Fe. They found that, in general, two groups of lines, reversed and bright, appeared, the former being representative of the arc spectrum and the latter of the spark spectrum. In addition to series lines in

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

arc spectra, the so-called "single line" (intersystem combination or resonance line) was always absorbed. The suggestion was made that such observations might facilitate the search for spectral regularities.

In Hulburt's experiments the absorption lines were identified in the spectral region 4500 to 2000 A, those appearing in the underwater spark spectra of Al, Bi, Cd, Au, Ir, Pb, Mg, Pt, Rh, Ag, Sn, Zn were those which were reversed in the arc, no more and no less. For the metals Sb, Co, Cr, Cu, Fe, Mo, Ni, and W all the lines reversed in the arc appeared as absorption lines, and in addition, the underwater spark spectra of these elements exhibited altogether more than 400 absorption lines which are not listed as reversed in the arc, but complete details are not given for these.

An investigation of the physical and electrical conditions determining the characteristics of underwater sparks was recently made by Miss Stücklen (11), who studied the effect on Cd spectra of varying (*a*) external spark gap, 0.5 to 3 cm, (*b*) self-induction to change wave length from 300 to 1,100 m, and (*c*) diameter of electrodes, 3 to 8 mm, and concluded that the appearance of absorption lines was favored by increasing the frequency, decreasing the potential, and increasing the diameter of the electrodes. Under the conditions of Miss Stücklen's experiment the fundamental spark lines of Cd appeared also in absorption.

During the past year several attempts have been made (12) to correlate the regularities of complex spectra with absorption observations in the underwater spark; some of these will be referred to again in connection with the results of the present investigation.

A general survey of all the published data on lines absorbed in underwater spark spectra of various elements gives the impression that results obtainable by this method are more comparable with those of true absorption experiments than might be expected, since the simultaneous appearance of spark lines in emission is evidence that at least some of the atoms in such a source must be ionized. In addition to fundamental arc lines which are completely and symmetrically absorbed in the underwater spark, some of the lines involving the normal state of ionized atoms are indeed usually detected in the same source, although they are of relatively low intensity. It appears that a large majority of the atoms in the outer envelope of the spark are in the normal state, a smaller number are in low metastable states, and a few are ionized; but it may be concluded that the conditions in this source are not favorable to the production of the remaining intermediate energy states, since they play no part in the absorption phenomena.

The lines observed as absorbed in the underwater spark are also remarkably in accord with other observations which have been demonstrated to be very significant in identifying the low levels of energy.

1. All the lines observed as "reversals" in arc emission spectra are always observed as absorption lines in underwater spark spectra and sometimes many more.

2. Insofar as temperature classifications of emission lines have been studied in the electric furnace, it is evident that the lines ordinarily absorbed in the underwater spark spectra are always the lines of lowest temperature classes, those first to appear as the furnace temperature rises.

In the determination of absorption spectra by means of the underwater spark, two respects in which this method imposes limitations on the completeness of the results must be mentioned.

1. Bands assigned to water vapor always appear in absorption, and these may occasionally obscure absorbed lines characteristic of the metal electrodes. The band at 3063 A is especially prominent; it extends nearly to 3200 A and contains a large number of lines. This difficulty can be overcome by using some other liquid.

2. It has frequently been mentioned that the lines (both emission and absorption) in underwater spark spectra are widened, some are diffuse, and certain ones are displaced as compared with their appearance in ordinary sources. These effects make it difficult to resolve lines which are very close and sometimes lead to an uncertainty in identifying lines which appear absorbed.

III. APPARATUS AND EXPERIMENTAL DETAILS

The great violence of the powerful electric discharge between electrodes under water showed, in preliminary experiments with improvised apparatus, that it was necessary to build a rugged device for holding and adjusting the metal electrodes. The apparatus constructed for this purpose is shown in Figure 1. It consists of a block of bakelite to which the two electrode holders are attached. To adjust the electrodes so that they are opposite each other and the proper distance apart, the lower holder is adjustable horizontally and either or both of them may be moved up or down by means of one-half mm pitch screws, the latter motion being permitted, and frequently required, during the operation of the spark. This apparatus was placed in a wooden box of about 3 liters capacity, opposite sides of which were furnished with quartz windows. The spark was operated about 5 or 6 cm under water and about 2 cm from the window. Tap water flowed through the box continuously at the rate of 1 to 2 liters per minute to carry off the colloidal metal, which would otherwise pollute the water and render it less transparent.

A 40,000-volt transformer was supplied with 10 to 12 amperes, 60 cycle, alternating current at 110 volts, and the secondary was connected to the underwater spark with an adjustable air gap in series and some condensers of 0.006 μf capacity in parallel. The

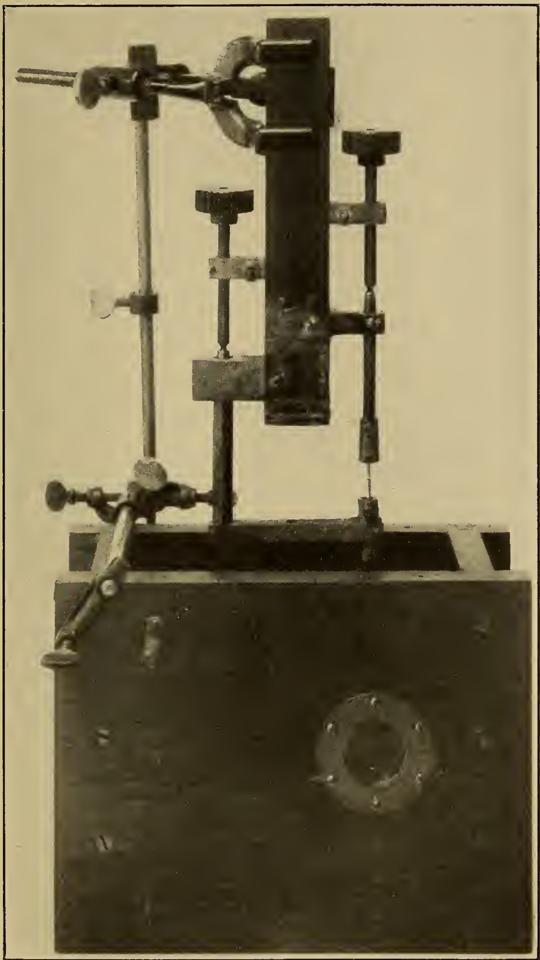

Fig. 1.—*Underwater-spark apparatus*

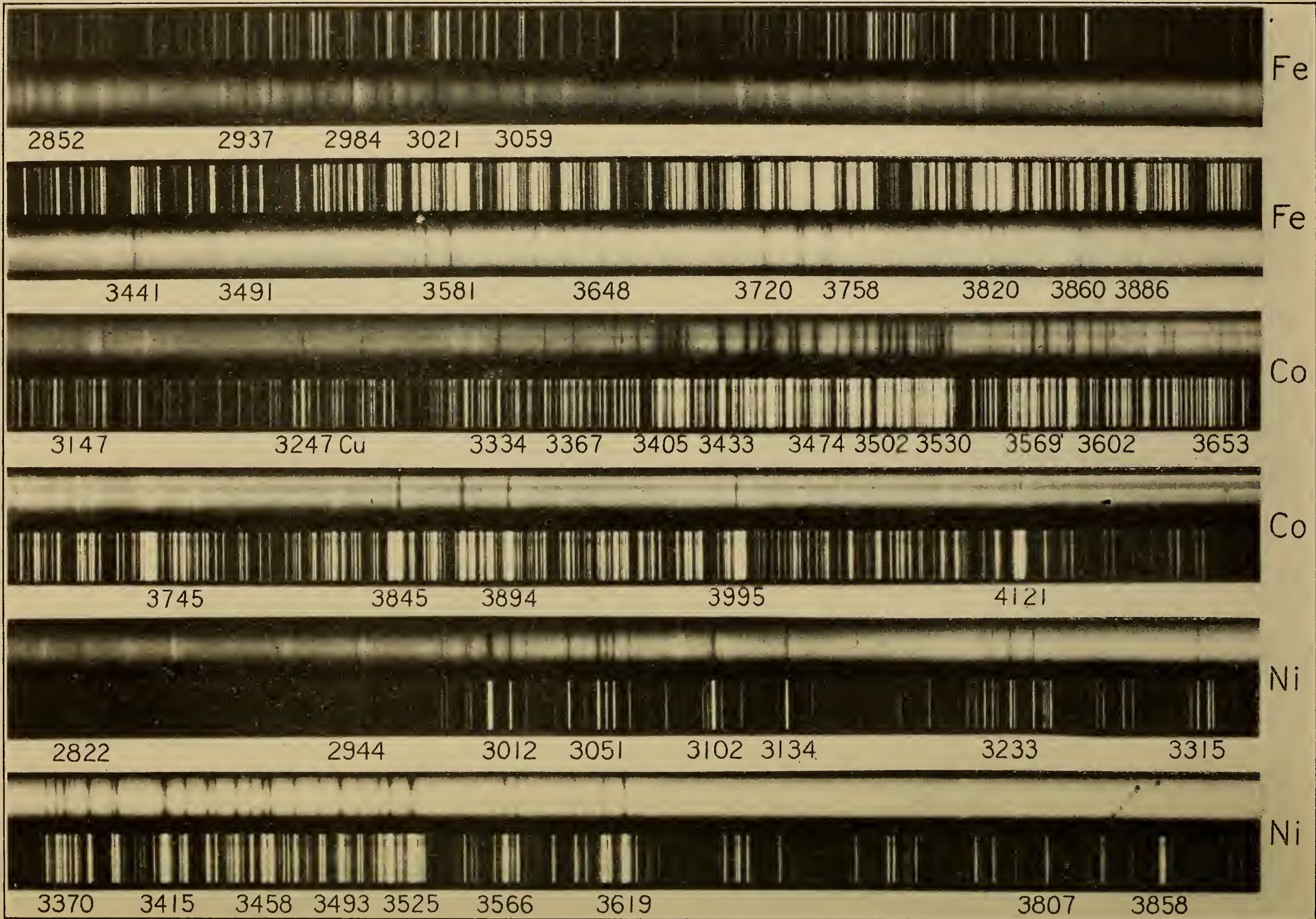

Fig. 2.—*Emission and absorption spectra of iron, cobalt, and nickel*

external spark gap was between zinc cylinders about 10 mm apart, and the distance between the electrodes of the underwater spark was about one-half mm. Under the conditions of our arrangement no marked effect assignable to the diameter of the electrodes was observed. For the most part ingots averaging 10 mm^2 cross section were employed.

An image of the underwater spark was focussed with a quartz condenser upon the slit of the spectrograph. Our concave gratings were used for observations in the visible and ultra-violet to 2400 A, below which a Hilger quartz spectrograph with lenses of about 60 cm focal length was employed. The exposures were usually only a few minutes, but about an hour was required to extend the spectra below 2300 A. Ordinary photographic plates were used except for the shortest waves, which were recorded on Schumann plates supplied by Hilger.

As has been shown by others, there are usually several types of lines to be distinguished; (*a*) emission lines, usually broadened and displaced, (*b*) symmetrical absorption lines, and (*c*) partial absorption, very unsymmetrical. The first class belongs to the spectrum of the ionized atom and is of no particular interest here. The latter classes, being characteristic of arc spectra, were carefully identified and are recorded in the following tables. The partial reversals are always on the violet side of the emission lines; they are designated *p* because of a suspicion that they might be penultimate lines in the sense that this word was proposed by Russell. It appears that such lines actually involve some one of the low metastable states, while lines actually associated with the normal state are broad and symmetrical reversals. These three classes of lines are illustrated in Figure 2, where portions of the underwater spark spectra and of the arc emission spectra of Fe, Co, and Ni are reproduced.

IV. RESULTS

For each of the three elements—iron, cobalt, and nickel—we give first a table of absorbed lines and their classifications and then a table of energy levels. In the first type of table the data presented in succeeding columns are wave lengths (λ), estimated intensities in absorption (A) and emission (E), vacuum wave numbers (ν), term combinations, and notes. Wave numbers were calculated from Kayser's Tabelle der Schwingungszahlen. The arc emission intensities accompanied by Roman numerals indicating the temperature classes are quoted from King. In the last column the lines observed as absorbed by Angerer and Joos (A) and by Gieseler and Grotrian (G) are noted. The notation for term combinations is the one which is now in common use for the description of spectral regularities; the letters S, P, D, F, G correspond to quantum numbers $l=0$, 1, 2, 3, 4, respectively; the superscript indicates the maximum multiplicity r of the system and the subscript is the inner quantum number j associated with the energy level. The tables of terms present values of all the known low energy levels calculated on the basis of zero energy for the lowest level which represents the normal state of the atom. The relative values of the higher levels referred to in the first type of table can be derived from the combinations, since the wave number of any line is represented by the difference of two levels, one of which in each case belongs to the low set listed in the second type of table. Electron configurations which on Hund's (13) theory are responsible for the various low energy terms are indicated in the last column of the term tables.

1. IRON (Fe=55.84; Z=26)

Cylindrical rods of iron, 3 mm diameter, were used as electrodes for the underwater spark. No impurities were detected spectrographically. The wave lengths shorter than 2373 A are quoted from Schumacher (14); the longer ones from Burns (15). To the violet of 3900 A a considerable number of the stronger iron lines are readily observed as partial reversals in the ordinary arc emission spectrum, and together with King's (16) temperature data these observations were of importnce in the detection of the first regularities among the arc lines of iron (17). The structural analysis of this spectrum was presented in more detail in subsequent papers (18). The term combinations in Table 1 are essentially those given in Laporte's papers, except that the notation has been modified to conform with recent practice and some new levels have been added.

Angerer and Joos (3) observed about 100 iron lines in absorption, 49 of which were recognized as involving levels of a quintet–D term assumed to represent the normal state of the iron atom. That this term describes the normal state of the Fe atom was also concluded by Gieseler and Grotrian (19), who observed 11 lines in absorption.

The underwater spark absorption spectrum of iron has recently been studied by Sur (12), who discussed his observations in connection with Laporte's analysis. He added nothing to this analysis, but believed that it was not complete with respect to the low energy levels. His objections were answered by Laporte (20), and it is now generally conceded that no terms of lower energy than a^5D are to be expected in this spectrum. Sur recorded 215 lines (2438 to 4072 A) absorbed in his underwater spark spectrograms of iron. In our spectrograms a somewhat different experimental arrangement showed 263 iron lines absorbed. This number constitutes about 6 per cent of the total number of lines occurring in the arc emission spectrum of iron. The most prominent absorption lines involve the above-mentioned ^{5}D term, a considerable number of lines of moderate intensity involve the low metastable state ^5F, and a few partial reversals near the end of the table begin with the higher ^3F term.

A few faint lines near 2400 A apparently originate with ionized atoms. The last are marked Fe^+ in Table 1. According to the analysis by Russell (21) these spark lines involve levels of the ^6D and ^4D terms, the former representing the normal state of the Fe^+ atom.

It is not altogether surprising that such fundamental lines should also be absorbed in a violent underwater spark, for the superposition of many bright spark lines on the continuous background indicates that some ionized atoms must be present, and our experience that even a small amount of an impurity in a metal can reveal absorption lines of the contaminating element resigns us to the belief that relatively few ionized atoms are required to produce absorption of the fundamental spark lines. Miss Stücklen had previously noted the appearance of the fundamental spark lines of Cd in underwater sparks, and we have frequently observed the H and K lines of Ca even when this element is present only as an impurity in other metallic electrodes.

The absorption data of the classified lines may be summarized briefly as follows: 120 lines the estimated intensities of which add up to 2,600 begin with the ^5D term, 76 lines with intensity totaling 770 begin with the ^5F, and 11 lines with total intensity of 84 originate with ^3F. Among spark lines, 28 with total intensity 122 arise from ^6D, 5 with intensity sum equal to 26 involve ^4D, but no lines from the terms ^4F and ^4P were observed in absorption, although ^4F is much lower than ^4D. There is apparently a connection between the lines observed in absorption and the electron configuration describing the initial energy states.

The value of underwater spark absorption spectra as an aid to the structural analysis of complex spectra is very well illustrated by the above data on iron. Out of a bewildering maze of 4,000 lines the underwater spark selects slightly more than 200 which are readily absorbed, and over half of these have one spectral term, namely that describing the normal state of the atom, in common.

40735°—27——2

TABLE 1.—*Underwater spark absorption spectrum of iron*

λ	ν	Intensities and class A	Intensities and class E	Combination	Notes
2166.60	46140.7	100	2 u	$a^5D_4-d^5P_3$*	A
66.79	136.6		2 u		
71.20	46043.0	5	4		
78.02	45898.8	100	4 u	$a^5D_3-d^5P_2$*	
86.43	722.3	80	3	$a^5D_3-d^5P_3$*	A
86.81	714.4		2		
87.11	708.1		4		
91.78	610.7	50	3 u	$a^5D_2-d^5P_2$*	A
2195.99	523.3	30	4	$a^5D_1-d^5P_1$*	
2200.34	433.3	40	3	$a^5D_2-d^5P_3$*	
00.69	45426.1		3	$a^5D_0-d^5P_1$*	
50.79	44415.0	2	2	$a^5D_4-1_4$*	
59.52	243.4	6	4	$a^5D_4-9_5$*	
67.08	44095.9	3	2	$a^5D_3-d^5P_2$*	
72.04	43999.7	1	3	$a^5D_3-1_4$*	
75.98	923.5	4	3	$a^5D_4-d^5\overline{D}_3$*	
84.06	768.1	3	5	$a^5D_3-d^5\overline{D}_2$*	A
87.27	706.7	3	3	$a^5D_2-d^5\overline{D}_1$*	
94.42	570.5	1	2	$a^5D_1-d^5\overline{D}_0$*	
94.69	565.4		5?		
2298.18	499.3	20	10 r, II	$a^5D_4-d^5\overline{D}_4$*	A
2301.66	433.5	1?	5	$a^5D_0-d^5\overline{D}_1$*	
03.43	400.1	3	2		
03.56	397.7		3, II		
08.99	295.6	5	2, III	$a^5D_1-d^5\overline{D}_2$*	A
13.07	219.3	10	2, III	$a^5D_2-d^5\overline{D}_3$*	A
20.33	43084.1	20	2, III	$a^5D_3-d^5\overline{D}_3$*	A
32.74	42854.9	5	6	$a^6D_4-a^6P_3$	Fe^+
37.99	758.6	3	6	$a^6D_2-a^6P_2$	Fe^+
43.50	658.1	10	7	$a^6D_5-a^6P_4$	Fe^+
44.31	643.4	2	4	$a^6D_1-a^6P_2$	Fe^+
48.14	573.8	8	5		
48.32	570.6		5	$a^6D_3-a^6P_3$	Fe^+
59.12	375.7	1	6	$a^5D_2-c^5P_1$? / $a^6D_2-a^6P_3$	Fe^+
59.97	360.4	1	4		
60.31	354.4	1	5 u		
64.82	273.6	5	8	$a^6D_4-a^6P_4$	Fe^+
69.47	190.6	2	2	$a^5D_1-c^5P_1$	
71.44	155.6	6	4	$a^5D_2-c^5P_2$	
73.624	116.80	10	4	$a^5D_3-c^5P_3$	
73.733	114.87		15, II	$a^6D_5-a^6F_5$	Fe^+
74.54	42100.6	2	?		
80.763	41990.53	1	4	$a^6D_3-a^6P_4$	Fe^+
81.85	971.4	4	2	$a^5D_1-c^5P_2$	
82.039	968.03	10	20, II	$a^6D_5-a^6F_6$	Fe^+
88.631	852.22	7	6	$a^6D_4-a^6F_4$	Fe^+
89.979	828.60	8	4	$a^5D_2-c^5P_3$	
95.628	729.99	8	8	$a^6D_4-a^6F_5$	Fe^+
2399.244	667.10	5	6	$a^6D_3-a^6F_3$	Fe^+
2404.888	41569.32	5	6	$a^6D_3-a^6F_4$	Fe^+

λ	ν	Intensities and class A	Intensities and class E	Combination	Notes
2410.526	41472.20	6	6	$a^6D_2-a^6F_3$	Fe^+
11.071	462.73	5	6	$a^6D_1-a^6F_1$	Fe^+
13.313	41424.21	4	6	$a^6D_1-a^6F_2$	Fe^+
39.746	40975.45	3	4		
57.602	677.75	6	6, II		
62.652	594.35	20	10 r, II	$a^5D_4-c^5F_4$	A
65.155	553.14	2?	6, III		
67.74	510.7	4	2	$a^5\overline{F}_3-11_2$*	
68.885	491.86	5	4, III		
72.875	426.54	20	5	$a^5D_2-c^5F_1$	A
72.910	425.97		12 R, II	$a^5D_3-c^5F_3$	
79.782	313.95	10	20 R, II	$a^5D_2-c^5F_2$	A
83.277	257.21	50	60 R, II	$a^5D_4-c^5F_5$	A
88.148	178.39	40	40 R, II	$a^5D_3-c^5F_4$	A
90.659	137.91	50	30 R, II	$a^5D_2-c^5F_3$	A
91.162	129.80		20 R, II	$a^5D_1-c^5F_2$	A
2496.539	40043.37	5?	6, III		
2501.135	39969.80	20	20 R, II	$a^5D_4-c^5\overline{D}_3$	A
07.904	861.93	3	6, III		
10.837	815.36	20	15 R, II	$a^5D_3-c^5\overline{D}_2$	A
12.366	791.14	5	5 r, III		
18.107	700.43	25	12 r, II	$a^5D_2-c^5\overline{D}_1$	A
22.855	625.71	40	40 R, II	$a^5D_4-c^5\overline{D}_4$	A
23.661	613.06	10			
24.291	603.17	15	8 r, II	$a^5D_1-c^5\overline{D}_0$	A
27.44	553.8	25	15 r, II	$a^5D_3-c^5\overline{D}_3$	A
29.137	527.30	15	10 r, II	$a^5D_2-c^5\overline{D}_2$	A
29.832	516.44	5	3, III	$a^5D_1-c^5\overline{D}_1$	A
35.610	426.40	15	8 r, III	$a^5D_0-c^5\overline{D}_1$	A
37.180	402.00	10	6		
40.976	343.14	20	10 R, III	$a^5D_1-c^5\overline{D}_2$	A
42.105	325.67	10	6, IV		
43.927	297.50	10	6, IV		
44.716	285.32	5	6, IV		
45.979	265.83	20	10 r, III	$a^5D_2-c^5\overline{D}_3$	A
49.616	209.82	15	10 r, III	$a^5D_3-c^5\overline{D}_4$	A
62.543	39012.05	1	5		Fe^+
76.699	38797.73	5	4, III	$a^5\overline{F}_5-c^5G_5$*	
84.544	679.98	10	8, III	$a^5\overline{F}_5-c^5\overline{G}_6$*	
85.886	659.90	5	20, IV	$a^6D_5-a^6\overline{D}_4$	Fe^+
98.380	474.03	6	7	$a_6D_4-a_6\overline{D}_3$	Fe^+
2599.405	458.86	15	6 r	$a^6D_5-a^6\overline{D}_5$	Fe^+
2605.687	366.14	2	6, III		
06.839	349.18	6	6, III	$a^5F_4-c^5\overline{G}_5$*	
07.099	345.37	4	7	$a^6D_3-a^6\overline{D}_2$	Fe^+
11.885	275.10	5	8	$a_6D_4-a_6\overline{D}_4$	Fe^+
13.835	246.55	2	8	$a_6D_2-a_6\overline{D}_1$	Fe^+
17.627	191.15	1	6	$a^6D_3-a^6\overline{D}_3$	Fe^+
18.027	185.32	4	5, III	$a^5\overline{F}_3-a^5\overline{G}_3$*	
2623.544	38105.02	6	5, III	$a^5\overline{F}_3-c^5\overline{G}_4$*	

TABLE 1.—*Underwater spark absorption spectrum of iron*—Continued

λ	ν	Intensities and class A	Intensities and class E	Combination	Notes
2625.676	38074.09	3	8	$a^6D_4-a^6\overline{D}_5$	Fe^+
28.303	38036.03	2	6	$a^6D_1-a^6\overline{D}_2$	Fe^+
31.053	37996.27	5	6	$a^6D_2-a^6\overline{D}_3$	Fe^+
31.332	992.25	5	6	$a^6D_3-a^6\overline{D}_4$	Fe^+
32.248	979.03	2	4, III	$a^5\overline{F}_2-c^5\overline{G}_2$*	
35.818	927.59	5	8, III	$a^5\overline{F}_2-c^5\overline{G}_3$*	
41.654	843.81	1	4, III		
44.008	810.12	5	8, III	$a^5\overline{F}_1-c^5\overline{G}_2$*	
66.818	486.74	5 (bracketed)	8, III	$a^5\overline{F}_5-1_4$*	
66.970	484.62		3, III		
79.066	315.37	10	10, III	$a^5\overline{F}_5-9_5$*	
89.220	174.48	5	8, III	$a^5\overline{F}_4-8_3$*	
2699.114	37038.22	2	6, III	$a^5\overline{F}_4-1_4$* $a^5\overline{F}_2-10_2$*	
2706.590	36935.91	4	8, III		
11.662	866.84	2	4, III	$a^5\overline{F}_4-9_5$*	
18.445	774.86	10	6, III	$a^5\overline{F}_2-7_1$*	
19.037	766.85	50	60 R, II	$a^5D_4-b^5P_3$	A, G
20.910	741.54	40	40 r, II	$a^5D_3-b^5P_2$	A
23.582	705.50	25	15, II	$a^5D_2-b^5P_1$	A
26.064	672.09	10	6, III	$a^5\overline{F}_5-4_4$*	
28.026	645.71	3	3, III	$a^5\overline{F}_4-5_4$*	
33.580	571.26	15	15, II	$a^5\overline{F}_5-d^5\overline{D}_4$*	
35.480	545.86	10	8, III	$a^5\overline{F}_4-d^5\overline{D}_3$*	
37.312	521.40	25	20 r, II	$a^5D_1-b^5P_1$	
39.551	491.55	5	9	$a^4D_4-a^4\overline{D}_4$	Fe^+
42.408	453.53	30	30 r, II	$a^5D_2-b^5P_2$	A
43.566	438.15	1	3, III	$a^5\overline{F}_4-3_2$*	
44.072	431.44	20	10, II	$a^5D_0-b^5P_1$	
44.531	425.34	5	8, III	$a^5\overline{F}_2-d^5\overline{D}_1$*	
46.486	399.42	4	7	$a^4D_2-a^4F_3$	Fe^+
46.988	392.76	5	20, III	$a^4D_3-a^4\overline{D}_3$	Fe^+
49.324	361.84	8	7	$a^4D_3-a^4F_4$	Fe^+
50.145	351.00	25	25 r, II	$a^5D_3-b^5P_3$	A
53.688	304.22	2	3, III	$a^5\overline{F}_2-6_1$* $a^5\overline{F}_1-d^5\overline{D}_0$*	
54.032	299.69	2	3, III		
55.736	277.24	4	8	$a^4D-a^4F_5$	Fe^+
56.332	269.40	10	20, I	$a^5D_1-b^5P_2$	
57.316	256.46	3	10, III	$a^5\overline{F}_1-d^5\overline{D}_1$*	
59.816	223.60	1?	4, III		
61.788	197.76	1?	18, III	$a^5\overline{F}_2-d^5\overline{D}_2$*	
62.029	194.59	2	15, III	$a^5\overline{F}_3-d^5\overline{D}_3$*	
63.107	180.48	1?	4, III	$a^5\overline{F}_3-3_2$*	
66.910	130.74	1?	2, III		
67.518	122.80	4	20, III	$a^5\overline{F}_4-d^5\overline{D}_4$*	
72.083	063.33	10 (bracketed)	20, II	$a^5\overline{F}_5-2_4$*	
72.112	36062.95		1, III	$a^5D_2-b^5P_3$	
78.226	35983.60	5	20, III	$a^5\overline{F}_5-b^5\overline{G}_5$	
88.108	856.06	15	30, II	$a^5\overline{F}_5-b^5\overline{G}_6$	
94.706	771.41	10 (bracketed)	2	$a^5\overline{F}_3-d^5\overline{D}_4$*	
2795.008	35767.55		3, III	$a^5D_4-a^3\overline{G}_4$	
2804.523	35646.20	4	20, II	$a^5\overline{F}_4-b^5\overline{G}_4$	
06.985	614.94	4	20, II	$a^5\overline{F}_4-2_4$*	
13.288	535.15	10	30 R, II	$a^5\overline{F}_4-b^5\overline{G}_5$	
23.276	409.45	2	20, II	$a^5\overline{F}_3-b^5\overline{G}_5$	
25.556	380.86	5 (bracketed)	20, II	$a^5\overline{F}_3-b^5\overline{G}_3$	
25.687	379.23		6, II	$a^5D_4-a^3\overline{G}_5$	
32.433	294.96	10	25 r, II	$a^5\overline{F}_3-b^5\overline{G}_4$	
38.118	224.28	2	10, III	$a^5\overline{F}_2-b^5\overline{G}_2$	
43.629	156.02	6	10, III	$a^5\overline{F}_4-c^5P_3$	
43.974	151.76	8	20 r, II	$a^5\overline{F}_2-b^5\overline{G}_3$	
51.798	35055.32	10	15 r, II	$a^5\overline{F}_1-b^5\overline{G}_2$	
63.866	34907.60	1	8, I	$a^5D_2-a^5\overline{G}_3$	
69.313	841.34	2	10, I	$a^5D_3-a^5\overline{G}_4$	
2874.176	782.39	5	10, I	$a^5D_4-a^5\overline{G}_5$	
2912.161	328.72	3	20 r, I	$a^5D_4-b^5F_3$	
29.006	131.31	5	25 r, I	$a^5D_3-b^5F_2$	
36.903	34039.54	20	60 R, I	$a^5D_4-b^5F_4$	A
41.343	33988.16	2	15 r, I	$a^5D_2-b^5F_1$	
47.876	912.84	25	60 R, I	$a^5D_3-b^3F_3$	A
53.943	843.18	20	50 R, II	$a^5D_2-b^5F_2$	A
57.370	803.98	10	30 R, II	$a^5D_1-b^5F_1$	
65.258	714.06	8	20, II	$a^5D_0-b^5F_1$	
66.902	695.38	50	125 R, II	$a^5D_4-b^5F_5$	A, G
69.364	667.43	2 (bracketed)	5, II	$a^5D_1-a^3P_0$	
69.482	666.09		10, I	$a^5\overline{F}_5-c^5F_4$	
70.107	659.02	10	40 R, I	$a^5D_1-b^5F_2$ $a^5D_2-a^3P_1$	A
73.137	624.72	50 (bracketed)	60 R, I	$a^5D_2-b^5F_3$	} A
73.236	623.60		60 R, I	$a^5D_3-b^5F_4$	G }
81.448	531.00	8	20 r, I	$a^5D_3-a^3P_2$	
83.571	507.13	75	125 R, I	$a^5D_4-b^5\overline{D}_3$	A
87.293	465.38	2	10, III	$a^5\overline{F}_4-c^5F_3$	
94.434	385.58	50	100 R, I	$a^5D_3-b^5\overline{D}_2$	A
2999.516	329.02	5	30 R, II	$a^5\overline{F}_5-c^5F_5$	
3000.951	313.09	40	100 R, I	$a^5D_2-b^5\overline{D}_1$	A
07.284	242.94	4	12 r, I	$a^5D_2-a^3P_2$	
08.142	233.46	20	60 R, I	$a^5D_1-b^5\overline{D}_0$	
09.575	217.63	4	25 r, II	$a^5\overline{F}_4-c^5F_4$	
17.630	128.96	3	15 r, I, A	$a^5D_1-b^5\overline{D}_1$	
20.495	097.54	100 (bracketed)	100 R, II	$a^5D_2-b^5\overline{D}_2$	}
20.643	095.92		200 R, I	$a^5D_4-b^5\overline{D}_4$	G } A
21.076	091.18	50	150 R, I	$a^5D_3-b^5\overline{D}_3$	G }
24.035	058.78	3	15 r, I, A	$a^5D_1-a^3P_2$	
25.846	33039.02	10	50 R, I	$a^5D_0-b^5\overline{D}_1$	
37.392	32913.43	20	80 R, I	$a^5D_1-b^5\overline{D}_2$	A
47.608	803.10	300	100 R, I	$a^5D_2-b^5\overline{D}_3$	A, G
57.451	697.50	10	40 R, II	$a^5\overline{F}_5-c^5\overline{D}_4$	
59.090	679.98	30	100 R, I	$a^5D_3-b^5\overline{D}_4$	
3067.250	32593.05	3	30 r, II	$a^5\overline{F}_4-c^5\overline{D}_3$	

TABLE 1.—*Underwater spark absorption spectrum of iron*—Continued

λ	ν	Intensities and class		Combination	Notes	λ	ν	Intensities and class		Combination	Notes
		A	E					A	E		
3075.725	32503.25	2	25 r, II	$a^5\overline{F}_3-c^5\overline{D}_2$		3737.135	26750.88	60	150 R, I	$a^5D_3-a^5F_4$	G
3083.745	32418.71	1	20, II	$a^5\overline{F}_2-c^5\overline{D}_1$		45.563	690.69	70	100 R, I	$a^5D_2-a^5F_3$	A,G
3236.231	30891.25	1?	20 r,I,A	$a^5D_3-o^3F_4$		45.900	688.29		40 r, I, A	$a^5D_0-a^5F_1$	
3440.614	29056.28	20	150 R, I	$a^5D_4-a^5P_3$	A	48.264	671.47	20	60 R, I,A	$a^5D_1-a^5F_2$	A
40.992	053.09	10	75 R, I	$a^5D_3-a^5P_2$		49.487	662.76	30	200 R, II	$a^5\overline{F}_4-b^5F_4$	
43.883	29028.70	5	50 r, I	$a^5D_2-a^5P_1$		58.234	600.71	20	150 R, II	$a^5\overline{F}_3-b^5F_3$	
65.864	28844.59	10	60 r, I	$a^5D_1-a^5P_1$		63.792	561.43	10	100 r, II	$a^5\overline{F}_2-b^5F_2$	
75.454	765.00	15	70 r, I	$a^5D_2-a^5P_2$		3767.194	537.44	8	80 r, II	$a^5\overline{F}_1-b^5F_1$	
76.705	754.66	5	40, I	$a^5D_0-a^5P_1$		3812.966	218.89	1?	40, II	$a^5\overline{F}_3-a^3P_2$	
90.577	640.40	25	100 r, I	$a^5D_3-a^5P_3$		15.844	199.60	10	100 r, II	$a^3\overline{F}_4-a^3\overline{D}_3$	
3497.842	580.90	5	40, I	$a^5D_1-a^5P_2$		20.430	167.67	30	250 R, II	$a^5\overline{F}_5-b^5\overline{D}_4$	
3513.821	450.93	1	30, II	$a^5\overline{F}_5-a^3\overline{G}_5$		24.444	140.20	10	50 r, I, A	$a^5D_4-a^5\overline{D}_3$	
21.264	390.80	1	25,II	$a^5\overline{F}_4-a^3\overline{G}_4$		25.886	130.35	20	200 R, II	$a^5\overline{F}_5-b^5\overline{D}_3$	
26.069	352.11	5	20, I	$a^5D_2-a^5P_3$		27.826	117.10	10	75 r, II	$a^3\overline{F}_3-a^3\overline{D}_2$	
26.167	351.34		15, II	$a^5\overline{F}_3-a^3\overline{G}_3$		34.227	073.51	10	100 r, II	$a^5\overline{F}_3-b^5\overline{D}_2$	
58.522	093.55	5	30, II	$a^5\overline{F}_2-a^3\overline{G}_3$		40.443	031.30	5	80 r, II	$a^5\overline{F}_2-b^5\overline{D}_1$	
65.383	039.50	20	60 r, II	$a^5\overline{F}_3-a^3\overline{G}_4$		41.052	26027.18	5	80 r, II	$a^3\overline{F}_2-a^3\overline{D}_1$	
70.102	28002.44	40	100 R, I	$a^5\overline{F}_4-a^3\overline{G}_5$		56.373	25923.78	5	50 r, I, A	$a^5D_3-a^5\overline{D}_2$	
81.197	27915.68	100	250 R, I	$a^5\overline{F}_5-a^5\overline{G}_6$		59.913	900.00	50	300 R, I	$a^5D_4-a^5\overline{D}_4$	A, G
85.322	883.56	4	30, II	$a^5\overline{F}_3-a^5\overline{G}_3$		78.578	775.38	5	100 r, II	$a^5D_2-a^5\overline{D}_1$	
85.708	880.57	3	20, II	$a^5\overline{F}_4-a^5\overline{G}_4$		86.287	724.24	30	40 R, I	$a^5D_3-a^5\overline{D}_3$	G
3586.989	870.61	3	30, II	$a^5\overline{F}_2-a^5\overline{G}_2$		3899.711	635.69	10	30 R, I	$a^5D_2-a^5\overline{D}_2$	
3608.860	701.70	30	100 r, I	$a^5\overline{F}_1-a^5\overline{G}_2$		3920.261	501.31	1	20 r, I	$a^5D_0-a^5\overline{D}_1$	
18.769	625.84	40	125 R, I	$a^5\overline{F}_2-a^5\overline{G}_3$		22.916	484.03	2	25 R, I	$a^5D_3-a^5\overline{D}_4$	
31.464	529.29	50	125 R, I	$a^5\overline{F}_3-a^5\overline{G}_4$		27.925	451.55	2	30 R, I	$a^5D_1-a^5\overline{D}_2$	
47.845	405.65	40	100 R, I	$a^5\overline{F}_4-a^5\overline{G}_5$		30.304	25436.15	2	25 R, I	$a^5D_2-a^5\overline{D}_3$	
79.915	166.84	5	40 r, I, A	$a^5D_4-a^5F_4$		45.822	24709.90	20 *p*	60 r, II	$a^3\overline{F}_4-a^3F_4$	
3687.458	27111.27	3	40 r, I	$a^5\overline{F}_5-b^5F_4$		63.604	601.78	10 *p*	45, II	$a^3\overline{F}_3-a^5F_3$	
3705.567	26978.77	10	100 r, I	$a^5D_3-a^5F_3$		4071.748	24552.57	5 *p*	40, II	$a^3\overline{F}_2-a^3F_2$	
09.250	951.99	5	75 r, II	$a^5\overline{F}_4-b^5F_3$		4271.764	23402.96	3 *p*	35, II	$a^3\overline{F}_4-a^3\overline{G}_5$	
19.938	874.55	100	250 R, I	$a^5D_4-a^5F_5$	A, G	4307.910	206.61	3 *p*	35, II	$a^3\overline{F}_3-a^3\overline{G}_4$	
22.565	855.59	8	50 r, I, A	$a^5D_2-a^5F_2$		25.770	23110.80	3 *p*	35, II	$a^3\overline{F}_2-a^3\overline{G}_3$	
27.622	819.15	3	50 r, II	$a^5\overline{F}_3-b^5F_2$		4383.548	22806.18	10 *p*	45 r, II	$a^3\overline{F}_4-a^5\overline{G}_4$	
33.319	778.23	10	40 r, I, A	$a^5D_1-a^5F_1$		4404.752	22696.40	5 *p*	30, II	$a^3\overline{F}_3-a^5\overline{G}_4$	
3734.869	26767.12	50	300 r, II	$a^5\overline{F}_5-b^5F_5$							

TABLE 2.—*Low levels in spectra of iron*

Spectrum	Value	Difference	Symbol	Electrons	Spectrum	Value	Difference	Symbol	Electrons
Fe I	0.000		a^5D_4	$4s^2, 3d^6$.	Fe II	0.00		a^6D_5	$4s, 3d^6$.
		415.936					384.80		
	415.936		a^5D_3			384.80		a^6D_4	
		288.072					282.85		
	704.008		a^5D_2			667.65		a^6D_3	
		184.132					194.90		
	888.140		a^5D_1			862.55		a^6D_2	
		89.946					114.41		
	978.086		a^5D_0			976.96		a^6D_1	
	6928.285		$a^5\overline{F}_5$	$4s, 3d^7$.		1872.56		$a^4\overline{F}_5$	$3d^7$.
		448.495					557.60		
	7376.780		$a^5\overline{F}_4$			2430.16		$a^4\overline{F}_4$	
		351.298					407.75		
	7728.078		$a^5\overline{F}_3$			2837.91		$a^4\overline{F}_3$	
		257.724					279.58		
	7985.802		$a^5\overline{F}_2$			3117.49		$a^4\overline{F}_2$	
		168.934							
	8154.736		$a^5\overline{F}_1$			7955.24		a^4D_4	$4s, 3d^6$.
							436.66		
	11976.270		$a^3\overline{F}_4$	$4s, 3d^7$.		8391.90		a^4D_3	
		584.696					288.47		
	12560.966		$a^3\overline{F}_3$			8680.37		a^4D_2	
		407.622					166.35		
	12968.588		$a^3\overline{F}_2$			8846.72		a^4D_1	
	17550.222		$a^5\overline{P}_2$	$4s, 3d^7$.		13474.36		$a^4\overline{P}_3$	$3d^7$.
		176.804					198.68		
	17727.026		$a^5\overline{P}_1$			13673.04		$a^4\overline{P}_2$	
		200.393					231.70		
	17927.419		$a^5\overline{P}_0$			13904.74		$a^4\overline{P}_1$	

2. COBALT (Co=58.97; Z=27)

Rods of cobalt metal about 3 mm square served as electrodes for underwater spark spectra. This metal contained a trace of nickel and a trace of copper; the well-known copper arc lines (3247 and 3274 A) were regularly found absorbed in our spectrograms. Besides these, about 340 absorption lines were identified as belonging to cobalt, and 20 or more of them almost certainly originate with ionized atoms. The complete list of absorbed lines is given in Table 3, in which the wave lengths below 2300 A are quoted from Piña (22), between 2300 and 2640 A from Exner and Haschek (23), and the longer ones from Dhein (24). The relative intensities in arc spectra are quoted from the same observers except above 2990 A, where King's (25) intensities and temperature classes begin. Lines certainly to be regarded as originating with ionized atoms are marked Co^+; those observed by Angerer and Joos in furnace vapor absorption are noted with the letter A, while those obtained by Sur and Majumdar (26) from an absorption furnace are marked S.

The structure of the Co I spectrum has been investigated by Walters (27) and by Catalán and Bechert (28). The combinations listed in Table 1 are in part those of Catalán and Bechert, but their notation has been revised. In addition, a considerable number of new levels have been found and confirmed by the absorption lines and other combinations. These new combinations are marked with asterisks.

The arc spectrum of cobalt is characterized by two quartet F terms of low energy value, one of which comes from the electron configuration (s^2, d^7) and represents the normal state of the atom. The other ^{4}F lies about half a volt higher in the energy diagram; it, as well as the next higher ^{2}F and ^{4}P terms, probably originates with the (s, d^8) configuration. Both ^{4}F terms are prominent in our absorption lines, but the ^{2}F term is represented by weaker lines, most of which are only partially reversed.

More than 2,500 lines have been observed in the emission spectrum of the cobalt arc. About 14 per cent of these are seen absorbed in the underwater spark, and they are distributed as follows: 118 lines of total intensity 1,920 from a^4F, 84 lines of total intensity 1,490 from b^4F, and 21 lines with intensity sum 330 from a^2F. Thus, notwithstanding the relative closeness of metastable states to the normal one, the latter still has some advantage in the production of absorption lines, although the preference is not so marked as for Fe.

The structure of the Co II spectrum is being investigated by Meggers and Burns, and the combinations for Co^+ lines in Table 3 are quoted from their preliminary results. A low metastable state of ionized cobalt is represented by a quintet F term arising from the configuration (s, d^7) after one of the s electrons of the normal atom has been removed. Practically all of the absorbed spark lines involve this term, and the additional fact that most of these lines have been observed self-reversed in the ordinary emission spectrum of a condensed spark between cobalt electrodes is experimental proof that a^5F is a term with low energy. The normal state of Co^+ is probably represented by a triplet F term originating with eight d electrons (*see* Laporte, Zeitschr. f. Phys., **39,** p. 123; 1926); it has not been identified because its chief combinations are expected to give shorter wave lengths than those in our list.

TABLE 3.—*Underwater spark absorption spectrum of cobalt*

λ	ν	Intensities and class		Combination	Notes
		A	E		
2137.82	46761.8	3	1	$a^4F_2-32^*$	
46.30	577.1	5	2	$a^4F_4-18_3^*$	
58.34	317.3	2	3		Ni?
63.60	204.7	10	3	$a^4F_3-31^*$	
65.14	171.8	3	2	$a^4F_2-30^*$	
66.86	135.2	5	2		
68.79	46094.1	8	3	$a^4F_4-29^*$	
73.89	45986.0	5	3	$a^4F_3-18_3^*$	
74.44	974.4	} 50	3		
74.67	969.5		3	$a^4F_5-11_4^*$	
78.08	897.6	4	1		
78.92	879.9	5	1		
80.01	856.9	10	3	$a^4F_4-15_3^*$	
81.12	833.6	3	3		
81.77	819.9	3	2		
82.57	803.2	2	3	$a^4F_2-31^*$	
84.31	766.7	1	1		
86.79	714.8	10	4		
90.3	614.5	2	3		Ni?
91.90	608.2	5	2		
96.59	510.8	40	5	$a^4F_4-28^*$	
2199.66	447.3	5	4		
2204.9	339.3	5	3		
07.89	277.9	10	5	$a^4F_3-16_2^*$	
08.59	263.6	5	3	$a^4F_3-15_3^*$	
12.38	186.1	4	4	$a^4F_4-12_3^*$	
13.92	154.6	20	6	$a^4F_4-11_4^*$ $a^4F_3-14_2^*$	
19.27	45045.8	1	2		
25.43	44921.1	} 10 d	3	$a^4F_3-28^*$	
25.77	914.3		3		
27.84	872.5	8	4		
29.87	831.7	8	3	$a^4F_5-27^*$	
32.54	778.1	2	3	$a^4F_3-13_2^*$	
33.83	752.2	3	3	$a^4F_2-14_2^*$	
34.86	731.6	4	4		
36.84	692.0	15	4		
45.17	526.2	1	4		
46.61	497.7	2	3	$a^4F_3-10_2^*$	
52.77	376.0	3	3	$a^4F_2-13_2^*$	
53.6	359.7	} 4	3		Ni?
53.91	353.6		3		
56.64	299.9	5	4	$b^4F_4-19_3^*$	
57.64	280.3	2	3	$a^4F_4-26^*$	
62.63	182.6	2	3	$a^4F_5-21_5^*$	
64.96	137.2	3	3		
67.17	094.2	1	2	$a^4F_2-10_2^*$	
68.24	073.3	6	3		
68.83	44061.9	1	3		
74.60	43950.2	8	5		A
2275.92	43924.7	4	3		A
2276.56	43912.3	15	6		A
79.53	855.1	4	4	$b^4F_3-20_2^*$	
84.96	750.9	3	3	$b^4F_2-19_3^*$	
85.50	740.6	3	3		
86.21	727.0	10	5	$a^5F_5-a^5G_6^*$	A, Co^+
87.87	695.3	20	6	a^4F_4-m	A
90.1	652.7	4	?	$a^4F_4-24^*$	Ni?
90.60	643.2	3	3		
91.50	626.1	10	5		
94.04	577.8	5	3	$a^4F_4-25^*$	
95.23	555.2	20	4	$a^4F_5-8_4^*$	
96.09	538.8	8	3		
96.74	526.5	10	3		
2298.39	495.3	6	4	$b^4F_2-32^*$	
2300.82	449.4	2	1		
03.99	389.6	15	1	$b^4F_5-17_4^*$	
05.18	367.2	10	1	$b^4F_2-19_3^*$ $a^4F_4-21_5^*$	
07.89	316.3	6	2	$a^5F_4-a^5G_5^*$	Co^+
09.03	294.9	30	1	$a^4F_5-b_5$	
11.38	250.9	} 10 d	1	$b^4F_4-18_3^*$	
11.65	245.8		2	$a^4F_2-1_3$ $a^5F_3-a^5G_4^*$	A Co^+
13.67	208.1	6	1		
14.07	200.6	5	2	$a^5F_2-a^5G_3^*$	Co^+
14.99	183.4	5	2	$a^5F_1-a^5G_2^*$	Co^+
16.12	162.4	6	1		
16.88	148.2	8	1	$a^4F_3-23^*$	
17.15	143.2	3	1		Ni?
20.04	089.4	20	1		Ni?
21.41	064.0	4	1	$a^4F_3-24^*$	
23.18	031.2	25	1	$a^4F_4-c_4$	A
24.36	43009.4	3	2	$a^5F_4-a^5\overline{F}_3^*$	Co^+
25.55	42987.4	15	1	$a^4F_3-25^*$	
26.15	976.3	2	2	$a^5F_3-a^5\overline{F}_4^*$	Co^+
26.47	970.4	4	2	$a^5F_5-a^5\overline{F}_4^*$	Co^+
29.12	921.5	4	1	$b^4F_3-31^*$	
29.97	905.8	4	1	$b^4F_2-30^*$	
32.2	864.8	2	?		
33.1	848.3	2	?	$b^4F_5-28^*$	
34.2	838.1	1	?		
35.98	795.4	20	1	$a^4F_3-i_3$	A
37.49	767.8	1	1	$b^4F_4-29^*$	
38.0	758.5	7	?		
38.65	746.6	8	1	$a^4F_2-23^*$	
39.05	739.3	6	1	$a^4F_4-8_4^*$	
44.29	643.8	2	1	$a^4F_2-n_1$ $a^5F_1-a^5\overline{F}_1^*$	A Co^+
45.57	620.5	8	1		
46.18	609.4	10	1	$a^4F_5-a_5$	A
47.43	586.7	8, d	2	$^4aF_2-25^*$ $a^5F_2-a^5\overline{F}_2^*$	 Co^+
50.32	534.4	6	1	$b^4F_2-31^*$	
2351.41	42514.6	6	1	$a^4F_3-9_3^*$	

TABLE 3.—*Underwater spark absorption spectrum of cobalt*—Continued

λ	ν	Intensities and class A	Intensities and class E	Combination	Notes
2352.89	42487.9	10	1	$b^4F_5-11_4$*	
53.43	478.2	10	2	$a^4F_4-b_5$ $a^5F_3-a^5\overline{F}_3$*	A Co^+
54.50	458.8	8	?	$a^4F_3-c_4$	A
58.21	392.1	7	1	$a^4F_2-i_3$	
63.81	291.6	6	2	$a^5F_4-a^5\overline{F}_4$*	Co^+
65.04	269.6	20	1	$a^4F_5-c^4G_5$	A
69.68	186.9	10	1	b^4F_4-28*	
70.52	171.9	6	1		
71.86	148.1	5	1	$a^4F_3-8_4$*	
72.87	130.2	3	1	$a^4F_3-7_3$*	
77.22	053.1	4	1		
78.62	42028.3	8	2	$a^5F_5-a^5D_4$*	Co^+
80.52	41994.8	15	1	$a^4F_4-c^4G_4$ $b^4F_3-16_2$*	A
83.47	942.8	5	2	$a^5F_4-a^5D_3$*	Co^+
84.89	917.9	20	1	$a^4F_5-c^4\overline{F}_4$	A
86.38	891.7	5	2	$a^5F_3-a^5D_2$*	Co^+
87.47	872.6	4	1	$b^4F_3-14_2$*	
88.17	860.3	5 d	1	$b^4F_4-12_3$*	
88.40	856.3		1	a^4F_3-22*	
88.93	847.0	8	2	$a^5F_5-a^5\overline{F}_5$*	Co^+
89.55	836.1	3	2	$a^4F_3-5_3$* $a^5F_2-a^5D_1$*	 Co^+
90.01	828.1	3	1	$b^4F_4-11_4$*	
91.43	803.2	5	1		
91.99	793.4	10	1	$a^4F_4-a_5$ $a^4F_3-c^4G_3$	A
2397.37	699.7	2	1		Co^+
2402.12	617.2	25	1	$a^4F_4-c^4\overline{F}_3$	A
04.17	518.7	1	2		Co^+
07.27	528.2	150	3 u	$a^4F_5-c^4G_6$	A, S
11.65	452.8	100	3 u	$a^4F_4-c^4G_5$	A
14.47	404.4	100	3 u	$a^4F_3-c^4G_4$	A
15.32	389.8		3 u	$a^4F_2-c^4G_3$ $a^4F_3-c^4\overline{F}_2$	A
17.67	349.6	4	2	b^4F_5-27* $a^5F_4-a^5D_4$*	 Co^+
19.15	324.3	10	1		
24.98	224.9	50	3 u	$a^4F_5-c^4\overline{F}_5$	A, S
32.20	102.6	40	3 u	$a^4F_4-c^4\overline{F}_4$	A
35.11	053.4	1	3		
36.43	031.2	30	1		
36.58	028.7		1	b^4F_5-m	
36.77	41025.5		1	$a^4F_3-c^4\overline{F}_3$	A
39.03	40987.5	20	1	$a^4F_2-c^4\overline{F}_2$	A
41.07	953.2	2	2	b^4F_4-26*	
42.92	922.2	3	1		
43.55	911.7		1	$b^4F_4-l_3$	
56.23	700.5	5	1	$b^4F_5-21_5$*	
2460.82	40624.6	5	1	$a^4F_2-c^4\overline{F}_3$	
2463.77	40575.9	2	1		
64.50	563.9	3	1		
64.63	561.8		1	$a^4F_3-2_3$*	
67.72	511.0	6	1	$a^4F_3-c^4\overline{F}_4$	
70.30	468.7	6	1		
72.94	425.5	1	1		
73.93	409.3	1	1	$a^4F_4-c^4\overline{F}_5$	
76.64	365.1	10	1	$b^4F_5-c_4$ $b^4F_3-l_3$	
83.61	251.8	20	1	b^4F_4-25*	
88.46	173.4	8	1	$a^4F_2-4_2$*	
89.27	160.3	2	1	$a^4F_2-3_1$*	
93.96	084.8	2	1	$a^2F_3-20_2$*	
94.74	072.2	2	1	$b^4F_5-8_4$*	
95.56	059.1	4	1	$b^4F_4-i_3$	
2496.71	40040.6	5	1	$a^4F_4-21_5$*	
2504.54	39915.5	8	1	$a^4F_2-6_4$*	
06.46	884.9	5	2		
07.17	873.6		1		
07.7	865.2	4	?		
11.03	812.3	20	2	$b^4F_5-b_5$	
12.92	782.4	5	1	b^4F_3-24*	
13.11	779.4		1	$b^4F_4-9_3$*	
17.81	705.1	8	2	$b^4F_4-c_4$	
21.40	648.6	100	3 u	$a^4F_5-c^4D_4$	A
28.97	529.9	70	3 u	$a^4F_4-c^4D_3$	A, S
30.13	511.8	3	1	$b^4F_3-i_3$	
32.17	479.9	5	2	b^4F_2-23*	
35.93	421.4	50	2	$a^4F_3-c^4D_2$	A
44.25	292.5	30	2	$a^4F_2-c^4D_1$	A, S
44.85	283.3	2	1		
48.31	229.9	5	2	$a^2F_4-15_3$*	
49.28	215.0	3	1		
53.00	157.9	5	2	$b^4F_3-c_4$	
53.35	152.5	5	2	$b^4F_4-b_5$	
55.06	126.3	4	2	$b^4F_5-a_5$ $b^4F_2-i_3$	
56.76	100.3	3	2	$b^4F_4-5_3$*	
59.39	060.1	1	2		
62.13	39018.3	20	2	$a^4F_2-c^4D_2$	
64.05	38989.1	2	2		Co^+
67.33	939.3	30	2	$a^4F_3-c^4D_3$	
72.23	865.1	2	1	$b^4F_3-8_4$*	
73.471	846.40	7	2?		
74.36	833.0	25	2	$a^4F_4-c^4D_4$	S
75.73	812.3	1	1	$a^4F_2-1_2$*	
80.34	743.0	4	3		Co^+
80.86	735.2	4	2		
82.26	714.2	2	2		Co^+
85.36	667.8	3	2	$b^4F_4-c^4G_4$	
2587.21	38640.1	2	2		Co^+

TABLE 3.—*Underwater spark absorption spectrum of cobalt*—Continued

λ	ν	Intensities and class		Combination	Notes
		A	E		
2590.61	38589.4	3	2		
91.69	573.3	3	1	$b^4F_3-22^*$	
2594.17	536.5	2	1	$a^4F_2-c^4D_3$	
2600.98	435.6	1	1	$b^4F_5-c^4\overline{F}_4$	
06.13	359.6	4	1		
13.89	245.8	4	1		
14.14	242.1	2	1	$a^4F_3-c^4D_4$	
17.86	187.8	2	1	$b^4F_2-22^*$	
19.27	167.2	2	1	$b^4F_2-5_3^*$	
22.06	126.6	}	1	$b^4F_4-c^4G_5$	
22.26	123.7	} 15	1	$b^4F_2-c^4G_3$	
22.45	120.9	}	1	$b^4F_3-c^4G_4$	
27.61	38046.1	10	2	$b^4F_5-c^4G_6$	
46.420	37775.66	4	4	$b^4F_4-c^4\overline{F}_4$	
48.648	743.89	10	4	{ $b^4F_5-c^4\overline{F}_5$ { $b^4F_3-c^4\overline{F}_3$	
49.940	725.49	1	3	$a^2F_3-13_2^*$	
50.271	720.77	3	4	$b^4F_2-c^4\overline{F}_2$	S
75.987	358.30	2	4	$b^4F_2-c^4\overline{F}_3$	
79.758	305.74	3	2		
85.340	228.20	4	3	$b^4F_3-c^4\overline{F}_4$	
2695.853	37083.03	7	4	$b^4F_4-c^4\overline{F}_5$	
2715.993	36808.06	4	3		
31.116	604.2	1	4		
40.470	479.32	2	3	$a^2F_4-9_3^*$	
45.108	417.69	2	4		
50.10	351.6	1	1		
61.375	203.17	2	3	$b^4F_4-c^4D_3$	
64.193	166.26	4	4	$b^4F_5-c^4D_4$	
66.225	36139.70	3	4	$b^4F_3-c^4D_2$	
78.830	35975.77	1	3		
2796.236	751.84	1?	3	$b^4F_2-c^4D_2$	
2803.775	655.72	2	3	$b^4F_3-c^4D_3$	
15.557	35506.52	2	4	$b^4F_4-c^4D_4$	
2886.448	34634.53	4	5	$a^4F_4-b^2\overline{F}_4$	
2928.819	34133.49	1	3	$a^4F_5-b^2G_4$	
87.172	33466.75	10	15 r, II	$a^4F_5-b^4\overline{F}_4$	S
2989.599	439.58	10	15 r, II	$a^4F_5-b^2G_5$	
3000.554	317.50	1	7, II	$a^4F_4-b^2G_4$	
13.598	173.30	3	8, II	$a^4F_5-b^4G_4$	
17.552	33129.83	10	15 r, II	$a^4F_4-b^4\overline{F}_3$	
34.426	32945.60	1	6, II	$a^4F_3-a_2D_2$	S
42.482	858.38	2	8, II	$a^4F_4-b^4G_3$	
44.007	841.91	30	30 R, II	$a^4F_5-b^4\overline{F}_5$	A, S
48.892	789.29	5	12 r, II	$a^4F_3-b^4\overline{F}_2$	S
61.825	650.80	20	20 r, II	$a^4F_4-b^4\overline{F}_4$	S
72.346	539.00	15	15 r, II	$a^4F_3-b^4\overline{F}_3$	
3082.614	32430.62	5	12 r, II	$a^4F_5-b^4G_6$	
3086.778	32386.87	10	15 r, II	$a^4F_2-b^4\overline{F}_2$	
89.593	357.36	6	10, II	$a^4F_4-b^4G_4$	
3098.195	267.52	1	10, II	$a^4F_3-b^4G_3$	
3110.817	136.61	1?	5, I	$a^4F_2-b^4\overline{F}_3$	
18.240	060.10	1	5, II	$a^4F_3-b^4\overline{F}_4$	
21.414	027.51 }	18	10, II	$a^4F_5-b^4D_4$	
21.560	32026.01 }		10, II	$a^4F_4-b^4\overline{F}_5$	
37.325	31865.08	5	10, II	$a^4F_2-b^4G_3$	S
39.943	838.52	5	12, II	$a^4F_4-b^4D_3$	
47.060	766.52	10	15, r II	$a^4F_3-b^4G_4$	
49.304	743.89	1	10, II	$a^4F_3-b^4D_2$	
54.785	688.74	5	10, II		
58.769	648.77	5	12, II	$a^4F_4-b^4G_5$	S
3159.660	639.85	2	10, II	{ $a^4F_2-b^4D_1$ { $a^4F_3-b^2F_3$	} S
3219.155	31055.11	1?	5, II	$a^4F_4-a^2F_4$	
32.890	30923.18	1			
37.028	883.65	3	8, II	$a^4F_4-b^2G_5$	
43.840	818.80	1	8, II		
3283.452	447.02	4	9, I		
3322.206	30091.85	1	8, III		
33.390	29990.90	1	10, I	$b^4F_4-b^2G_4$	
34.151	984.05	20	30, r II	$b^4F_5-b^4\overline{F}^4$	S
54.386	803.17	20	10, II	$b^4F_4-b^4\overline{F}_3$	S
67.114	690.53	20	30 r, II	$b^4F_5-b^4G_4$	S
70.330	662.20	2	10, I	$b^4F_3-a^2D_2$	
85.227	531.67	10	25 r, II	$b^4F_4-b^4G_3$	S
88.175	505.98	15	30 r, II	$b^4F_3-b^4\overline{F}_2$	
3395.378	443.38	25	40 r, II	$b^4F_3-b^2G_4$	S
3405.120	359.15	100	150 R, II	$b^4F_5-b^4\overline{F}_5$	A, S
09.176	324.22	20	60 r, II	$b^4F_4-b^4\overline{F}_4$	S
12.335	297.07 }	100 d	80 R, II	$b^4F_4-b^2G_5$	} A, S
12.636	294.48 }		80 R, II	$a^4F_5-a^4D_4$	}
17.158	255.72	30	50 r, II	$b^4F_3-b^4\overline{F}_3$	
31.579	132.79	30	50 r, II	$a^4F_4-a^4D_3$	
33.043	120.36	40	60 R, II	$b^4F_2-b^4\overline{F}_2$	S
42.924	036.79	30	40 r, II	$a^4F_3-a^4D_2$	
43.646	29030.70	50	80 R, II	$b^4F_4-b^4G_4$	A, S
49.171	28984.20 }	75 d	60 R, II	$b^4F_3-b^4G_3$	
49.443	981.92 }		60 R, II	$b^4F_5-b^4G_5$	S
53.513	947.76	150	200 R, II	$b^4F_5-b^4G_6$	A, S
55.236	933.32	10	25 r, I	$a^4F_2-a^4D_1$	
56.936	919.10	3	9, I	$a^4F_4-a^4G_4$	
62.807	870.07	40	60 r, II	$b^4F_2-b^4\overline{F}_3$	S
65.796	845.17	50	100 R, II	$a^4F_5-a^4G_6$	A, S
74.019	776.89	60	100 R, II	{ $a^4F_5-a^4\overline{F}_4$ { $b^4F_3-b^4\overline{F}_4$	} A, S
83.415	699.28	15	20, r, I	$b^4F_4-b^4\overline{F}_5$	S
89.406	650.00	30	60 r, II	$a^2F_4-b^2D_3$	S
90.741	639.04	2	10, I	$b^4F_4-a^2\overline{F}_3$	S
91.324	634.27	10	15, I	$a^4F_2-a^4D_2$	S
3495.685	28598.55	25	50 r, II	$b^4F_2-b^4G_3$	S

TABLE 3.—*Underwater spark absorption spectrum of cobalt*—Continued

λ	ν	Intensities and class A	Intensities and class E	Combination	Notes
3496.682	28590.39	10	15, I	$b^4F_4-a^2G_4$	
3502.281	544.68	75	100 R, II	$b^4F_5-b^4D_4$	A, S
06.315	511.84	50	80 R, II	$b^4F_4-b^4D_3$	S
09.844	483.18	25	50 r, II	$b^4F_3-b^4G_4$	S
10.419	478.51	20	30 r, I	$a^4F_4-a^4D_4$	A, S
12.643	460.48	40	60 R, II	$b^4F_3-b^4D_2$	S
13.483	453.68	30	50 R, II	$a^4F_4-a^4G_5$	S
18.353	414.29	20	50 R, II	$a^2F_3-b^2D_2$	S
20.087	400.30	10	15, II	$a^4F_4-a^4\overline{F}_3$	S
21.572	388.32	15	30 r, I	$b^4F_5-a^2\overline{F}_4$	S
23.438	373.28	20	25 r, I	$b^4F_2-b^4D_1$	S
26.856	345.79	50	100 R, I	$a^4F_5-a^4\overline{F}_5$	A, S
29.037	328.27	20	30 r, I	$a^4F_3-a^4G_4$	S
29.815	322.03	60	80 R, II	$b^4F_4-b^4G_5$	A, S
33.363	293.60	20	25 r, I	$a^4F_2-a^4G_3$	S
50.599	156.25	10	20 r, I	$a^4F_3-a^4\overline{F}_2$	
60.896	074.83	10	20 r, I	$b^4F_2-b^4D_2$	S
64.955	042.87	15	25 r, I	$b^4F_3-a^2G_4$	S
69.382	28008.09	50	80 R, II	$a^2F_4-b^4\overline{F}_4$	S
74.964	27964.36	15	25 r, I	$b^4F_3-b^4D_3$	S
75.361	961.25	25	60 r, II	$a^4F_2-a^4\overline{F}_4$	S
84.796	887.66	5	15, I	$a^4F_3-a^4D_4$	S
85.159	884.84	20	25 R, I	$b^4F_4-b^4D_4$	S
87.188	869.06	30	70 R, II	$a^2F_3-b^2\overline{F}_3$	
3594.869	809.52	20	50 R, II	$a^4F_3-a^4\overline{F}_3$	S

λ	ν	Intensities and class A	Intensities and class E	Combination	Notes
3602.081	27753.85	15	40 R, II	$a^4F_2-a^4\overline{F}_2$	S
05.367	728.55	10	20 r, I	$b^4F_4-a^2\overline{F}_4$	
27.807	557.04	15	25 r, I	$b^4F_4-a^2G_5$	S
31.340	530.22	10	20 r, I	$a^4F_4-a^4\overline{F}_5$	S
47.663	407.04	5	12, I	$a^4F_2-a^4\overline{F}_3$	
3652.544	27370.41	5	15, I	$a^4F_3-a^4\overline{F}_4$	
3704.061	26989.74	5	25, I	$a^2F_3-b^2\overline{F}_4$	
32.400	784.82	1	20, I		
3745.501	691.14	5	25, I	$a^2F_4-b^2G_4$	S
3842.056	26020.38	10	30, II	$a^2F_4-a^2D_3$	
45.474	25997.25	50	60, II	$a^2F_4-b^2G_5$	S
61.168	891.59	2 p	20, I	$a^2F_3-a^2D_2$	
73.117	811.71	30	60, II	$b^4F_5-a^4D_4$	S
73.957	806.11	25	40, II	$b^4F_4-a^4D_3$	S
76.840	786.92	1	20, I	$b^4F_5-a^4G_5$	
81.877	753.46 }	10	25, I	$b^4F_3-a^4D_2$	
81.911	753.24 }				
94.086	672.72	30	60, II	$a^2F_3-b^2G_4$	S
3894.981	666.82	10	20, II	$b^4F_2-a^4D_1$	S
3909.941	568.62	1	15, I	$a^4F_5-a\gamma_6$	S
35.974	399.51	8 p	30, II	$a^2F_4-b^4\overline{F}_5$	
95.312	022.29	25	60, II	$a^2F_4-b^4G_5$	S
3997.909	25006.03	10 p	40, II	$a^2F_3-b^4\overline{F}_4$	S
4092.397	24428.69	2 p	25, I	$a^2F_4-a^2\overline{F}_4$	
4110.544	320.85	1 p	25, I	$a^2F_3-a^2\overline{F}_3$	
18.784	272.18	15 p	50, II	$a^2F_3-a^2G_4$	
4121.329	24257.20	30 p	60, II	$a^2F_4-a^2G_5$	

TABLE 4.—*Low levels in the spectra of Co*

Spectrum	Value	Difference	Symbol	Electrons
Co I	0.00		a^4F_5	$4s^2, 3d^7$.
		815.98		
	815.98		a^4F_4	
		590.85		
	1406.83		a^4F_3	
		402.47		
	1809.30		a^4F_2	
	3482.76		b^4F_5	$4s, 3d^8$.
		659.85		
	4142.61		b^4F_4	
		547.49		
	4690.10		b^4F_3	
		385.65		
	5075.75		b^4F_2	
	7442.39		a^2F_4	$4s^2, 3d^7$.
		1018.38		
	8460.77		a^2F_3	
	13795.44		a^4P_3	$4s^2, 3d^7$.
		240.76		
	14036.20		a^4P_2	
		362.95		
	14399.15		a^4P_1	

Spectrum	Value	Difference	Symbol	Electrons
Co I	15183.98		b^4P_3	$4s, 3d^8$.
		589.96		
	15773.94		b^4P_2	
		421.60		
	16195.54		b^4P_1	
Co II	0.0		a^5F_5	$4s, 3d^7$.
		678.5		
	678.5		a^5F_4	
		531.9		
	1210.4		a^5F_3	
		389.3		
	1599.7		a^5F_2	
		254.5		
	1854.2		a^5F_1	
			a^3F_4	$4s, 3d^7$.
			a^3F_3	
			a^3F_2	

3. NICKEL (Ni=58.68; Z=28)

Strips of metal were first cut from nickel anode metal and used as electrodes in obtaining underwater spark spectrograms. This metal was known to contain a small amount of iron, and absorption lines due to this impurity appeared so prominently in the spectrograms that the observations were repeated with electrodes cut from specially purified electrolytic nickel slabs. Two hundred and twenty-five absorption lines appeared on the plates; they are listed in Table 5, in which the wave lengths shorter than 2300 A are quoted from Piña (29) and the longer one from Hamm (30). The arc emission intensities are from the same sources except for wave lengths greater than 2981 A, where King's (31) intensity estimates and temperature classes are used. The lines identified as absorption lines by Angerer and Joos are noted with the letter A, and a few lines which are identifiable with lines characteristic of the ionized atom are marked Ni^+.

Soon after our observations on the absorption spectrum of nickel in underwater sparks were completed we became aware of two similar investigations: Majumder (32) found 88 lines (2254–3858 A) absorbed in the underwater spark, and Narayan and Rao (33) described 180 lines (2121–3858 A) as absorbed. The data were discussed in relation to the published analyses of the structure of the nickel arc spectrum, but in neither case was any addition to this analysis made.

The structure of the nickel arc spectrum has been discussed by Walters (34) and by Bechert and Sommer (35), the term combinations in Table 5 being taken in large part from these papers but with a revision of the notation. The arc spectrum of nickel has three terms which account for all the arc lines identified in absorption; they are ^3F, ^3D, and ^1D in the order of increasing energy, but the first two completely overlap and all three have a range of only slightly more than one-third of a volt in the energy scale. The complete set of low terms is presented in table 6.

Approximately 1,200 lines are observed in the arc emission spectrum of Ni, and nearly 20 per cent of these were absorbed in our underwater spark spectra. A summary of the classified absorption lines shows that 60 with intensity sum 1,160 begin with a^3F, 77 with total intensity 2,410 originate with $a^3\overline{D}$, and 15 with intensity totaling 200 have a^1D as initial state. The levels of $a^3\overline{D}$ are entirely encompassed by those of a^3F, and a^3F_4 has the largest quantum numbers as well as the lowest energy level. Nevertheless, the $a^3\overline{D}$ term appears to have considerable advantage over the others in the production of absorption lines.

The spark spectrum of nickel is being analyzed by Dr. A. G. Shenstone, and he has kindly placed at our disposal the relative terms which he has found. The low-energy ^4F and ^2F terms are quoted in Table 6; the combinations of these with higher levels account for all of the lines of ionized nickel listed in Table 5. It is probable that a^4F and a^2F are low metastable states and that the normal state of Ni^+ is represented by a doublet D term arising from nine *d* electrons. (*See* Laporte, Zeitschr. f. Phys., **39**, p. 123; 1926.) The latter term has not yet been identified; its principal combinations probably gave wave lengths shorter than 2000 A.

TABLE 5.—*Underwater spark absorption spectrum of nickel*

λ	ν	Intensities and class		Combination	Notes
		A	E		
2124.84	47047.4	3	2		
25.68	47028.8	5	1	$a^3F_4-4_3^*$	
28.50	46966.5	3	3+		
28.59	964.6				
29.96	934.4	10	0+	$a^3\overline{D}_2-3_2^*$	
34.95	824.7	20	2	$a^3\overline{D}_3-4_3^*$	
47.78	545.0	40	2		
51.94	455.0	3	1		
52.22	449.0		1		
57.84	328.0	10	2		
58.34	317.3	30	3	$a^3\overline{D}_3-2_2^*$	
61.08	258.6	6	2	$a^3\overline{D}_2-3_2^*$	
61.25	254.9		2		
65.55	163.1	5	3	$a^4F_5-{}^4\overline{F}_5^*$	Ni+
66.14	150.5	5	1+	$a^3\overline{D}_2-4_3^*$	
69.05	46088.6	3	3	$a^4F_4-{}^4\overline{F}_4^*$	Ni+
74.44	45974.4	10	2		
74.64	970.2		3	$a^4F_4-{}^2G_5$	Ni+
75.11	960.2	2	3	$a^4F_3-{}^4\overline{F}_3^*$	Ni+
82.37	807.3	7	2	$a^3F_3-3_2^*$	
83.28	788.3	2	3		
83.73	778.8	2	3		
83.94	774.4		3		
84.55	761.6	2	3	$a^4F_2-{}^4\overline{F}_2^*$	Ni+
90.24	642.8	15	2	$a^3\overline{D}_2-2_2^*$	
2197.38	494.5	20	3		
2200.72	425.4	4	2	$a^3\overline{D}_1-3_2^*$	
01.40	411.4	8	3	$a^4F_2-{}^4\overline{F}_3^*$	Ni+
01.60	407.3		2		
06.75	301.3	3	3	$a^4F_3-{}^4\overline{F}_4^*$	Ni+
11.32	207.7	2	2		
12.17	190.3	2	2	$a^3F_3-2_2^*$	
16.48	102.5	9	3	$a^4F_5-{}^4G_6^*$	Ni+
16.65	099.0		2		
17.82	45075.2	2	2		
22.08	44988.8	5	2		
23.08	968.6	2	3	$a^4F_5-{}^4G_5^*$	Ni+
24.89	932.0	3	2+	$a^4F_4-{}^4G_4^*$	Ni+
31.03	808.4	3	2	$a^3\overline{D}_1-2_2^*$	
2244.51	44539.3	3	3	$a^3\overline{D}_2-c^3\overline{F}_2$	

λ	ν	Intensities and class		Combination	Notes
		A	E		
2251.52	44400.6	3	2	$a^3\overline{D}_2-v'$	
53.62	359.3	10	2	$a^3\overline{D}_3-c^3\overline{F}_3$	
53.91	353.6		3	$a^4F_2-{}^4G_3^*$	Ni+
54.84	335.3	8	2		
55.89	314.6	2	2	$a^3F_4-r'_4{}^*$	
58.16	270.1	6	3	$a^3\overline{D}_3-t'_2$	
59.56	242.7	7	3	$a^3\overline{D}_1-1_1^*$	
61.43	206.1	10	2+	$a^3F_4-q'_3$	
64.50	146.2	3	3	$a^4F_3-{}^4G_4^*$	Ni+
66.40	109.2	3	2	$a^3\overline{D}_3-r'_4{}^*$	
67.61	085.6	2	2	$a^3F_3-c^3\overline{F}_2$	
70.30	033.4	5	3	$a^4F_4-{}^4G_5^*$	Ni+
70.47	030.1		3		
71.96	44001.2	6	2	$a^3\overline{D}_3-q'_3$	
77.78	43888.8	2	1+		
78.79	869.4	3	2+	$a^2F_4-{}^2D_3^*$	Ni+
87.12	709.6	8	2	$a^2F_3-{}^2D_2^*$	Ni+
87.40	704.2		2	$a^3\overline{D}_1-c^3\overline{F}_2$	
88.46	684.0	4	3	$a^3\overline{D}_2-c^3\overline{F}_3$	
90.08	653.1	25	6	$a^3F_4-o'_3$	
93.15	594.7	5	3	$a^3\overline{D}_2-t'_2$	
96.54	530.3	2	3	$a^2F_4-{}^2\overline{F}_4^*$	Ni+
97.53	511.6	2	3	$a^4F_2-{}^4D_1$	Ni+
2298.26	497.7	4	3	$a^2F_3-{}^2\overline{F}_3^*$	Ni+
2300.773	450.25	20	2 u	$a^3\overline{D}_3-o'_3$	
02.973	408.76	10	3	$a^3\overline{D}_1-l_1^*$ $a^4F_4-{}^4D_3^*$	 Ni+
07.353	326.33	3	1		
09.486	286.33		1		
10.025	276.24	100	1		
10.955	258.83		3 R	$a^3F_4-c^3\overline{F}_4$	A
12.338	232.95	50	3 R	$a^3F_3-c^3\overline{F}_3$	A
13.656	208.33	100	2 u		A
13.982	202.24		2 u	$a^3F_2-c^3\overline{F}_2$	
16.040	163.86	10	2	$a^4F_5-{}^4D_4^*$	Ni+
17.158	143.03	50	2 R	$a^3F_3-t'_2$	A
20.034	089.55	100	5 R	$a^3F_4-n'_5$	A
21.387	43064.44	60	3 R	a^3F_2-v'	
25.799	42982.76	50	3 R	$a^3F_3-r'_4$	A
29.974	905.74	50	2	$a^3F_2-l_1^*$	
2331.704	42873.92	2	1	$a^3F_3-q'_3$	

TABLE 5.—*Underwater spark absorption spectrum of nickel*—Continued

λ	ν	Intensities and class A	Intensities and class E	Combination	Notes
2337.097	42774.99	50	1	$a^3\overline{D}_2-o'_3$	A
37.488	767.83		1	$a^3F_4-l'_3$	
38.500	749.33	2	1	$a^3\overline{D}_3-m'_2$	
45.545	620.94	30	2 R	$a^3F_4-e'_4$	A
46.635	601.14	4	1	a^3F_3-u'	
47.532	584.87	15	1	$a^3F_4-c'_4$	A
48.738	563.00	2	1	$a^3\overline{D}_3-l'_3$	
55.060	448.76	10	1	$a^3\overline{D}_3-k'_2$	
56.869	416.18	10	1	$a^3\overline{D}_3-e'_4$	
58.865	380.29	8	1	$a^3\overline{D}_3-c'_4$	
60.637	348.48	10	1	$a^3F_2-c^3\overline{F}_3$	
62.061	322.96	10	1	$a^3F_3-o'_3$	
65.677	258.27	1	1	$a^3F_2-t'_2$	
76.019	42074.35	7	1	$a^3\overline{D}_2-m'_2$	
80.787	41990.09	2	1	$a^3F_2-q'_3$	
84.400	926.47	6	1	$a^3F_3-c^3\overline{F}_4$	
85.015	915.66	3	1		
86.587	888.06	10	1	$a^3\overline{D}_2-l'_3$	
87.556	871.05	4	1		
92.963	776.46	15	1		
93.115	773.80		1	$a^3\overline{D}_2-k'_2$	
94.523	749.24	10	2	$a^2F_4-{}^2G_5$*	Ni+
96.385	716.80	3	1	a^3F_2-u'	
2396.637	712.42	3	1	$a^1\overline{D}_2-l_1$*	
2401.846	621.97	20	1	$a^3F_3-m'_2$	
12.647	435.64	10	1	$a^3F_2-l'_3$	
16.140	375.74	6	1	$a^2F_3-{}^2G_4$*	Ni+
19.310	321.54	20	1	$a^3F_3-k'_2$	
21.231	288.76	7	1	$a^3F_3-e'_4$	
23.330	253.00	4	1	$a^3F_3-c'_4$	
23.661	247.36	4	1		
24.025	241.17	5	1	$a^3\overline{D}_1-m'_2$	
32.222	102.19	2	1		
34.431	41064.89	2	1	$a^1\overline{D}_2-t'_2$	
41.832	40940.44	10	2	$a^3\overline{D}_1-k'_2$	
53.997	737.51	4	2	$a^3F_2-m'_2$	
65.279	551.09	2	1	$a^3F_2-l'_3$	
72.074	439.64	6	3		
72.917	425.85	4	1		
76.876	361.24	3	2	$a^3F_4-a'_3$	
79.489	318.71	3	1		
79.773	314.09		1		
83.285	257.08	10	1		
84.039	244.87	5	1	$a^1\overline{D}_2-o'_3$	
88.149	178.39	6	1		
89.51	156.4	1		$a^3\overline{D}_3-a'_3$	
90.689	137.42	4	1		
2491.184	40129.45	4	1		
2501.28	39969.91	3	1		
2510.885	39814.61	5	5	$a^2F_4-{}^4G_5$*	Ni+
24.221	604.27	5	1	$a^3\overline{D}_2-b'_2$	
40.027	357.84	1?	1	$a^1\overline{D}_2-l'_3$	
2545.927	39266.64	2	1	$a^2F_3-{}^4G_4$*	Ni+
2746.745	36395.98	5	4	$a^3\overline{D}_3-b^1D_2$	
2798.651	35720.98	10	4	$a^3\overline{D}_2-b^1D_2$	
2821.296	35434.30	15	4	$a^3\overline{D}_3-b^1F_3$	
2865.508	34887.61	1	5	$a^3\overline{D}_1-b^1D_2$	
2943.922	33958.39	25	6	$a^3\overline{D}_3-b^3D_3$	
81.652	528.69	20	20 R, II	$a^3\overline{D}_2-b^3D_1$	
84.129	500.87	10	12 R, II	$a^3F_4-b^3D_3$	
92.597	406.08	15	20 R, II	$a^3\overline{D}_3-b^3\overline{F}_3$	
2994.458	385.31	20	25 R, II	$a^3\overline{D}_3-a^1G_4$	
3002.492	295.98	80	100 R, II	$a^3\overline{D}_3-b^3D_3$	
03.628	283.40	40	60 R, II	$a^3\overline{D}_2-b^3D_2$	
12.007	190.81	60	75 R, II	$a^1\overline{D}_2-b^1D_2$	
19.150	33112.29	20	20 R, II	$a^3F_4-b^3\overline{F}_3$	
31.869	32973.38	10	10 r, II	$a^3F_4-b^3\overline{F}_4$	
37.940	907.49	60	60 R, II	$a^3\overline{D}_3-b^3\overline{F}_3$	
45.012	831.07	5	10 r, II	$a^3F_3-b^3D_2$	
50.828	768.49	100	100 R, II	$a^3\overline{D}_3-b^3\overline{F}_4$	
54.317	731.06	40	50 R, II	$a^3\overline{D}_2-b^3\overline{F}_2$	
57.647	695.41	50	50 R, II	$a^3\overline{D}_1-b^3D_1$	
64.626	620.95	20	25 R, II	$a^3\overline{D}_2-b^3D_3$	
80.758	450.15	10	20 R, II	$a^3\overline{D}_1-b^3D_2$	
97.120	278.72	6	15 r, II	$a^3F_3-b^3\overline{F}_2$	
3099.117	257.92	4	12 r, II	$a^3F_3-a^1G_4$	
3101.563	232.49	125	100 R, II	$a^3\overline{D}_2-b^3\overline{F}_3$	
01.881	229.18		40 R, II	$a^1\overline{D}_2-b^1F_3$	
05.466	191.98	5	15 r, II	$a^3F_2-b^3D_1$	
14.128	32102.44	2	20 R, II	$a^3\overline{D}_2-a^1\overline{P}_1$	
34.106	31897.81	50	60 R, II	$a^3\overline{D}_1-b^3F_2$	
45.707	780.18	1?	8, II	$a^3F_3-b^3F_3$	
3197.121	269.13	5	10 r, II	$a^3\overline{D}_1-a^1\overline{P}_1$	
3221.661	31030.96	10	10 r, II	$a^3F_4-a^1\overline{F}_3$	
25.030	30998.54	10	10 r, II	$a^1\overline{D}_2-b^3D_1$	
26.992	979.69	3	5, II	$a^3F_4-a^3G_4$	
32.945	922.65	25	25 R, II	$a^3F_4-a^3G_5$	
34.658	906.28	10	10 r, II	$a^3\overline{D}_2-a^3G_2$	
43.064	826.18	20	25 R, I	$a^3\overline{D}_3-a^1\overline{F}_3$	
48.43	775.2		8, II	$a^3\overline{D}_3-a^3G_4$	
50.749	753.30	2	9, II	$a^1\overline{D}_2-b^3D_2$	
71.118	561.81	2	10, II	$a^3\overline{D}_2-a^1D_2$	
82.701	453.98	2	8, II	$a^3F_3-a^3G_3$	
3286.953	414.58	1?	8, II	$a^3\overline{D}_3-1a^3\overline{F}_2$	
3315.668	151.19	30	30 R, II	$a^3\overline{D}_2-a^1\overline{F}_3$	
20.259	109.50	20	20 R, II	$a^3F_3-a^1D_2$	
22.316	30090.86	10	15 r, II	$a^1\overline{D}_2-b^3D_3$	
61.557	29739.60	20	20 R, II	$a^3\overline{D}_2-1a^3\overline{F}_2$	
3365.771	29702.37	10	15 r, II	$a^1\overline{D}_2-b^3\overline{F}_3$	

TABLE 5.—*Underwater spark absorption spectrum of nickel*—Continued

λ	ν	Intensities and class		Combination	Notes
		A	E		
3366.159	29698.86	20	20 R, II	$a^3F_3-a^1\overline{F}_3$	
69.576	668.83	50	80 R, II	$a^3F_4-a^3D_3$	A
71.995	647.55	15	15 r, II		
74.228	627.93	10	15 r, II	$a^3\overline{D}_3-a^3\overline{F}_3$	
80.577	572.28	80	80 R, II	$a^1\overline{D}_2-a^1\overline{P}_1$	
80.885	569.59		15 r, II		
91.051	480.95	25	50 R, II	$a^3F_4-1a^3\overline{F}_4$	
3392.993	464.08	50	100 R, II	$a^3\overline{D}_3-a^3D_3$	
3409.579	320.75	2	8, II	$a^3F_4-1a^3\overline{F}_3$	
13.478	287.26	10	25 R, II	$a^3F_3-1a^3\overline{F}_2$	
13.943	283.27	5	12 r, II	$a^3\overline{D}_2-a^3\overline{F}_2$	
14.771	276.17	150	150 R, II	$a^3\overline{D}_3-1a^3\overline{F}_4$	A
23.713	199.71	50	50 R, II	$a^3\overline{D}_1-a^3D_1$	
33.565	115.93	75	70 R, II	$a^3\overline{D}_3-1a^3\overline{F}_3$	A
37.283	084.44	30	30 R, II	$a^3F_4-a^3\overline{F}_4$	
46.263	29008.66	100	100 R, II	$a^3\overline{D}_2-a^3D_2$	A
52.891	28952.97	40	40 R, II	$a^3\overline{D}_2-a^3\overline{F}_3$	
58.467	906.29	100	125 R, II	$a^3\overline{D}_1-1a^3\overline{F}_2$	A
61.660	879.63	125	125 R, II	$a^3\overline{D}_3-a^3\overline{F}_4$	A
67.505	830.95	5	12, II	$a^3F_3-a^3\overline{F}_2$	
69.484	814.51	5	15, II	$a^3F_2-a^1\overline{F}_3$	
72.545	789.11	50	70 R, II	$a^3\overline{D}_2-a_3D_3$	
83.776	696.30	20	25 R, II	$a^3F_2-a^3D_1$	
85.892	678.88	1	10, II		
3492.965	28620.81	150	150 R, II	$a^3\overline{D}_2-a^3\overline{P}_1$	A
3500.852	28556.33	20	25 R, II	$a^3F_3-a^3D_2$	
02.604	542.05	1?	8, I		
10.340	479.15	50	80 R, II	$a^3\overline{D}_1-a^3\overline{P}_0$	
15.057	440.93	125	150 R, II	$a^3\overline{D}_2-1a^3\overline{F}_3$	A
19.776	402.81	10	20 R, II	$a^3F_2-1a^3\overline{F}_2$	
24.543	364.39	200	200 R, II	$a^3\overline{D}_3-a^3\overline{P}_2$	A
48.189	175.37	5	20 r, II	$a^3\overline{D}_1-a^3D_2$	
66.373	28031.72	60	100 R, II	$a^1\overline{D}_2-a^1D_2$	
71.871	27988.57	40	50 R, II	$a^3F_3-1a^3\overline{F}_3$	
3597.699	787.64	30	50 R, II	$a^3\overline{D}_1-a^3\overline{P}_1$	
3602.278	752.32	1	15, II	$a^3F_3-a^3\overline{F}_4$	
09.312	398.24	3	15, II	$a^3\overline{D}_2-a\gamma_3$	
10.45	689.5	25	60 R, II	$a^3\overline{D}_2-a^3\overline{P}_2$	
12.732	672.02	15	30 R, II	$a^3F_2-a^3D_2$	
19.391	621.11	100	150 R, II	$a^1\overline{D}_2-a^1\overline{F}_3$	
3624.733	27580.40	1	15, II	$a^3F_4-a\gamma_5$	
3775.562	26478.63	3 p	30 r, II	$a^1\overline{D}_2-a^3D_2$	
3783.521	422.93	3 p	30 r, II	$a^1\overline{D}_2-a^3\overline{F}_3$	
3807.135	26259.04	5 p	35 r, II	$a^1\overline{D}_2-a^3D_2$	
3858.284	25910.94	10 p	40 r, II	$a^1\overline{D}_2-1a^3\overline{F}_3$	

TABLE 6.—*Low levels in the spectra of nickel*

Spectrum	Value	Separation	Symbol	Electrons
Ni I	0.00		a^3F_4	$4s^2, 3d^8$.
		1332.15		
	204.82		$a^3\overline{D}_3$	$4s, 3d^9$.
		675.00		
	879.82		$a^3\overline{D}_2$	
	1332.15		a^3F_3	
		884.40		
	1713.11		$a^3\overline{D}_1$	
		833.29		
	2216.55		a^3F_2	
	3409.95		$a^1\overline{D}_2$	$4s, 3d^9$.
	13521.29		$b^1\overline{D}_2$	
	14728.92		a^1S_0	$3d^{10}$.
	15609.81		a^3P_2	$4s^2, 3d^8$.
		124.22		
Ni I	15734.03		a^3P_1	
		283.27		
	16017.30		a^3P_0	
Ni II	0.0		a^4F_5	$4s, 3d^8$.
		936.2		
	936.2		a^4F_4	
		785.2		
	1721.4		a^4F_3	
		548.3		
	2269.7		a^4F_2	
	5156.3		a^2F_4	$4s, 3d^8$.
		1444.9		
	6601.2		a^2F_3	

V. DISCUSSION

The results presented above confirm the conclusion already arrived at in other ways—that the normal state of the iron atom is represented by a quintet D spectroscopic term, that of cobalt by a quartet F term, and that of nickel by a triplet F term. Practically all of the absorbed lines involve either the normal state or some adjacent metastable state, and the fact that no prominent lines or groups of lines are unaccounted for indicates that the existence of other terms of lower energy is not probable. This indication is supported by the furnace absorption and by the astrophysical behavior of these elements, and it is, furthermore, in perfect accord with quantum-theoretical predictions. The latter are derived from a correlation of spectral terms with the electron configurations which produce them. Thus, for atoms with z valence electrons in incomplete shells ($z=8, 9, 10$ for Fe, Co, Ni, respectively) it has been shown that the following low levels are possible:

Electrons	$z=8$	$z=9$	$z=10$
s^2, d^{z-2}	^5D ^3H ^3G	^4F ^4P ^2H ^2G ^2F ^2D	^3F ^3P ^1G ^1D ^1S
s, d^{z-1}	^5F ^3F ^5P ^3P ^3H ^3G	^4F ^2P ^4P ^2P ^2G ^2D ^2S	^3D ^1D
d^z	^3F ^3P ^1G ^1D ^1S	^2D	^1S

Each arrangement of electrons is responsible for a set of terms, the most prominent ones of which are given above, starting at the left with the term which presumably has the least energy. In each spectrum terms from all three configurations of electrons will appear, but at present the one which will give the normal state can only be determined empirically.

Comparing the absorption data for the three spectra—iron, cobalt, and nickel—we see that the lowest energy term arises in each case from the electron configuration of two 4*s* electrons and $z-2$ electrons of 3*d* type, but with increasing z there is a progressive approach of the low metastable states to the normal one, and the lowest-energy term from the arrangement $4s, 3d^{z-1}$ acquires more and more prominence in absorption phenomena until in Ni it supersedes the normal state in this respect. Thus, the tendency for group configurations with a lesser number of 4*s* electrons to be preferred, which was noticed in describing the normal states of the Ru-Rh-Pd and Os-Ir-Pt triads of metals (36), is apparently already in operation in the Fe-Co-Ni triad.

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