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INTERFERENCE MEASUREMENTS IN THE INFRARED ARC SPECTRUM OF IRON

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ABSTRACT

Wave lengths of the stronger infrared radiations characteristic of integrated light from an iron arc at atmospheric pressure are measured relatively to neon standards by the Fabry-Perot interferometer method. Values are given for 91 lines ranging from 7164.469 to 10216.351 A. Spectral term combinations indicate that most of these lines require relatively high excitation energies, which accounts for their character and properties. Differences between values from integrated arc light at atmospheric pressure and from the vacuum arc are interpreted as pressure- and Stark-effects. It is suggested that the international system of secondary standards of wave length can be extended into the infrared by using integrated light from an iron arc at 1 atm pressure.

CONTENTS

I. INTRODUCTION

The iron arc at atmospheric pressure has served for many years as a source of secondary standards for wave-length measurements in optical spectra. Selected lines in the atomic spectrum of iron first attained the status of international secondary standards through the action of the International Union for Cooperation in Solar Research [1] in 1907, and were continued as such, after the war, by the International Astronomical Union. In 1928 the values were revised on the basis of new observations and 319 lines ranging from 3370.787 to 6750.156 A were adopted as iron arc secondary standards of wave length.[2] Provisional values for iron lines which may serve as standards among shorter waves to 2015 A have been proposed [3] but require confirmation before they can be adopted as international standards.

The first interference measurements of iron lines in the region of longer waves (to 8824 A) were made by Burns [4] in 1913. Similar results were reported by Meggers and Kiess [5] in 1924, since which

[1] Trans. I. U. S. R. **4**, 58 (1914).
[2] Trans. I. A. U. **3**, 86 (1928).
[3] Trans. I. A. U. **4**, 71, 74 (1932).
[4] K. Burns, Jour. de Phys. [5], **3**, 457 (1913).
[5] BS Sci. Pap. **19**, 273 (1924).

time no further interference observations appear to have been made on infrared iron lines. In recent years, the discovery of new dyes which impart infrared sensitivity to photographic emulsions has greatly extended the range of precision measurements in spectroscopy, and immediately created a need for standards in this range. After a preliminary description of the iron-arc spectrum extending to 10863 A had been obtained [6] it appeared desirable to refine the infrared measurements by means of interference observations and thus investigate further the practical utility of the iron arc as a source of secondary standards. This paper reports on interference measurements of 91 lines, with corresponding wave lengths ranging from 7164 to 10216 A, characteristic of integrated light from an arc, at atmospheric pressure, between 2 electrodes of iron.

II. APPARATUS AND METHODS

The apparatus and method devised by Fabry and Perot [7] for wave-length comparisons are too well known to justify detailed presentation here. A recent paper by Humphreys [8] gives an outline of the theory and describes a procedure in observing and measuring which was followed almost without variation in the present work. It is important, however, to give all essential facts about the light sources since it is now recognized that wave lengths derived from any source depend more or less on the exact specifications.

It may be recalled that the earliest interference measurements of iron lines were made before the importance of operating conditions was realized, and it was not until 1913 that the iron arc in air as a source of international standards was meticulously described [9] as follows: Length of arc, 6 mm; current of 6 amp for wave length greater than 4000 A, 4 amp or less for wave lengths shorter than 4000 A; direct current with positive pole above the negative, potential of 220 v; iron rods of 7 mm diameter for electrodes; axial part about 2 mm wide in center of arc to be used as a source of light; only lines of groups *a, b, c, d,* (Gale and Adams pressure groups) to be used as standards. Soon after these specifications were laid down, it was shown that certain iron lines exhibit a so-called "pole effect" represented by a change in wave length when light from the vicinity of an electrode is compared with that from the center of the arc, and the International Astronomical Union was persuaded [10] as follows with respect to the iron arc:

"In order to obtain lines of constant wave length, constant intensity distribution, and adapted to high orders of interference, the adoption is recommended of the Pfund arc [11] operated between 110 and 250 v., with 5 amp. or less, at a length of 12 to 15 mm used over a central zone not to exceed 1 to 1.5 mm in width, and with an iron rod 6 to 7 mm diameter as the upper pole and a bead of oxide of iron as the lower pole." At the same time it was recommended [12] that the arc previously described be retained as a source for waves longer than 6000 A, since

[6] W. F. Meggers and C. C. Kiess. BS J. Research, **9**, 309 (1932).
[7] Ann. chim. phys. [7], **25**, 98 (1902).
[8] BS J. Research **5**, 1041 (1930).
[9] Trans. I. U. S. R. **4**, 58 (1914).
[10] Trans. I. A. U. **1**, 36 (1922).
[11] Astrophys. J. **27**, 297 (1908).
[12] Trans. I. A. U. **1**, 36 (1922).

"the secondary standards to the red of λ6000 are all stable lines, and the exposures with the above-mentioned (long) arc may be rather long".

In view of the recent improvements in the sensitization of photographic emulsions to infrared light, I attempted in the present work to use the modified iron arc so that the long waves would be measured in the same source as the shorter ones. Unfortunately this was found to be entirely impractical even in the near infrared up to 8824 A which had previously been examined with the earlier (short) type of arc. The explanation is, no doubt, related to the fact that most of the infrared iron lines involve rather highly excited states and are, therefore, strongly developed only near the electrodes. Even the short arc (6 mm) was found to be impractical for interference observations beyond 9000 A when light was taken only from the central zone (2 mm) so that the apparatus was finally arranged in such a way that light from the entire arc, including that from the electrodes, was integrated in the interferometer. With this arrangement, it was found possible to record interference patterns for all of the stronger lines of iron up to wave length 10216 A with exposures of 1 to 2 hr on Eastman xenocyanine plates. The actual arrangement was as follows: The arc was placed at the principal focus of a collecting lens which then illuminated the interferometer with essentially parallel light. After passing through the interferometer the light was collected by an achromatic lens which projected, on the spectrograph slit, interference patterns of the individual radiations and also an image of the arc slightly magnified. By maintaining an electrode gap of about 12 mm in the arc, the electrode images on the slit were separated about 15 mm so that 5 or 6 rings of the interference patterns appeared between the continuous spectra from the electrodes. The arc was operated with a current of 8 amp, the applied potential being 240 v. The iron arc at atmospheric pressure consists of 2 flames coming from the electrodes, and Fabry and Buisson [13] have shown that the negative flame is much more brilliant than the positive, the difference being greatest for long waves. On account of this intensity difference it was necessary to alternate polarity during the exposure in order to obtain symmetrical illumination of the interference patterns. The exposures ranged from 5 to 10 min for the interval 7000 to 9500 A which was recorded on Eastman 144 RP plates, and 1 to 2 hr to photograph 8300 to 10800 A on Eastman 144 Q plates.

Instead of using the red radiation from cadmium as a primary standard for these wave-length comparisons it was found more convenient to utilize the yellow and orange lines of neon as emitted by a Geissler tube operated with a high-voltage transformer. Since it has been recognized that the mean of any 8 or more neon lines which have already been adopted as secondary standards is practically equivalent to the primary standard,[14] I have compared the infrared iron lines with such a group standard by determining the étalon thickness for each spectrogram from the best exposed neon lines between 5852 and 6304 A. The values actually used for this purpose were the 8-place means published by Jackson.[15] The neon exposures were made simultaneously with the iron by inserting between the arc collecting lens and the interferometer, a sheet of red (selenium) glass

[13] Jour. de. Phys. **9,** 229 (1910).
[14] Trans. I. A. U. **2,** 41 (1925).
[15] Proc. Royal Soc. A, **143,** 219 (1933).

transmitting arc light only of wave length >6400 A and reflecting neon light from its rear surface to illuminate the interferometer and spectrograph in like manner as the iron arc. A second collecting lens inserted between the neon lamp and the red glass filled the interferometer with parallel light and the capillary source was imaged on the slit simultaneously with the arc image. Thus the 2 overlapping settings of the spectrograph camera referred to above covered the entire range of infrared iron spectrum which could be photographed and each iron spectrogram was accompanied by a neon spectrogram (Eastman 144 F plate) representing the primary standard. In the first setting the neon spectrum was recorded in the grating's first order on the short-wave side of the iron, while in the second setting the neon was taken from the grating's second order on the long-wave side of the iron. This procedure brought both spectra near the axis of the grating and had the additional advantage of equalizing the exposures since the longer exposures for iron in the second range were fairly compensated by the lower brightness of the grating's second order spectrum. The grating spectrograph referred to here is the stigmatically mounted concave grating described in another paper.[16]

The interferometer consisted of silvered quartz plates of 6 cm aperture separated by invar étalons of 6.2, 10, or 15 mm length. Most of the measurements were made on spectrograms resulting from use of the 10 mm étalon, since the general character of many of the infrared lines of iron is such as to preclude orders of interference exceeding about 40000. The actual orders of interference for each line and each spectrogram were derived from measurements of the diameters of the first four rings in the interference patterns. When the first ring was estimated to yield a fractional order of 0.2 or less the fifth ring was measured instead.

Since the interferometer plates and silver films were the identical ones just previously used for interference measurements in the spectra of noble gases,[17] the last corrections for dispersion of phase at reflection determined in that work were applied to the present results for the spectrum of iron. For the 10 mm étalon this correction increased from −0.001 A at 7200 A to −0.004 A at 10000 A. The air temperature and barometric pressure were recorded for each exposure, but it was found that the corrections required to convert the wave lengths to standard atmospheric conditions (15° C, 760 mm) were usually less than 0.0005 A.

III. RESULTS

The results of my interference measurements of infrared wave lengths characteristic of integrated light from the iron arc at atmospheric pressure are presented in table 1. Column 1 contains the estimated relative intensities and the temperature classes as published by King.[18] In the next are presented the wave lengths in air at 15° C and 760 mm Hg pressure, the values being based upon neon standards. The third column shows the number of spectrograms on which each line was measured, each observation representing the average of measurements on 4 rings; the fourth column gives notes on the probable error of the arithmetical mean (column 2), the letters having sig-

[16] BS Sci. Pap. **18**, 191 (1922).
[17] W. F. Meggers and C. J. Humphreys, BS J. Research **13**, 293 (1934).
[18] A. S. King, Astrophys. J. **80**, 124 (1934).

nificance as follows: "*A*" indicates a probable error less than 0.0007 A, "*B*" 0.0007 to 0.0012 A, and "*C*" a still larger probable error. When the probable error exceeds 0.004 A the value entered in column 2 is limited to 2 decimal places. It may be pointed out that a given probable error expressed in Angstrom units is only half the percentage error for 10000 A that it is for 5000 A. This column also contains for certain lines a letter "*h*", which means that the interference patterns appear hazy or diffuse as compared with the remaining lines. The fifth column is derived from the second with the aid of Kayser's Tabelle der Schwingungszahlen, while the sixth and seventh represent data quoted from the paper on "Wave Lengths and Atomic Levels in the Spectrum of the Vacuum Iron Arc by Burns and Walters."[19] It is sufficient to quote only the value of the lower term, since the higher one can be derived from the former by adding the wave number of the line represented (column 5), the fractional part of this wave number being taken from column 8, to obtain the vacuum-arc value of the higher excited state. In the last column differences between the vacuum arc and the atmospheric arc are shown both in Angstrom units and in wave numbers. These differences have practical value in that they enable one to transform values from either source to the other, and they are of considerable theoretical interest in any discussion of their probable origin.

TABLE 1.—*Interference measurements in the infrared arc spectrum of iron*

Intensity and temperature class [a]	λ Integrated light of arc in air	Number of observations	Character of line and probable error	Wave-number in vacuum	Term combination [b]	Value of lower term [b]	Wave-number arc in vacuum		Difference vacuum arc—air arc	
							Observed	Computed	λA	νcm^{-1}
250 V	7164.469	6	*A*	13953.929	$b^5D^{\circ}_2$—b^5F^3	33801.608	.970	.963	−.017	+.034
800 V	7187.341	7	*B*	13909.525	$b^5D^{\circ}_4$—b^5F_5	33095.976	.569	.562	−.019	+.037
500 V	7207.406	7	*B*	13870.801	$b^5D^{\circ}_3$—b^5F_4	33507.161	.836	.830	−.015	+.029
80 V	7389.425	6	*B*	13529.132	$b^5F^{\circ}_1$—b^5F^1	34692.177		.175	−.024	+.043
4 IV	7401.689	3	*A*	13506.715						
100 V	7411.178	7	*B*	13489.422	$b^5F^{\circ}_2$—b^5F^2	34547.243	.458	.459	−.020	+.037
5 IV	7418.674	3	*A*	13475.792						
200 V	7445.776	8	*B*	13426.742	$b^5F^{\circ}_3$—b^5F_3	34328.787	.783	.784	−.023	+.042
400 V	7495.088	6	*A*	13338.404	$b^5F^{\circ}_4$—b^5F^4	34039.548	.440	.443	−.022	+.039
800 V	7511.045	5	*C*	13310.067	$b^5F^{\circ}_5$—b^5F_5	33695.429	.110	.109	−.024	+.042
60 V	7531.171	6	*B*	13274.498	$a_5G^{\circ}_4$—c^3F_3	35257.351		.545	−.027	+.047
30 V	7568.925	6	*C*	13208.285	$b^5F^{\circ}_2$—b^5F_3	34547.243		.328	−.025	+.043
50 IV	7583.796	6	*B*	13182.385	b^3G_3—$b^3F^{\circ}_2$	24338.805		.396	−.006	+.011
150 V	7586.044	8	*A*	13178.479	$a^5G^{\circ}_5$—c^3F_4	34782.454		.519	−.023	+.040
25 V	7620.538	4	h *B*	13118.827	$b^3D^{\circ}_3$—a^3D_3	38175.391		.871	−.026	+.044
30 V	7661.223	4	*A*	13049.160	$b^5F^{\circ}_3$—b^5F_4	34328.787		.204	−.026	+.044
80 IV	7664.302	8	*B*	13043.918	b^3G_4—$b^3F^{\circ}_3$	24118.854		.933	−.009	+.015
25 V	7710.390	4	*A*	12965.949	$b^5F^{\circ}_4$—b^5F_5	34039.548		.990	−.024	+.041
125 IV	7748.281	8	*A*	12902.543	b^3G_5—$b^3F^{\circ}_4$	23783.654		.563	−.012	+.020
300 V	7780.586	8	h *B*	12848.972	$a^3G^{\circ}_3$—c^3F_2	36079.411	9.013	9.012	−.024	+.040
400 V	7832.224	6	*B*	12764.259	$a^3G^{\circ}_4$—c^3F_3	35767.603	.296	.293	−.021	+.034
6 IIA	7912.866	3	*A*	12634.176	a^5F_5—$a^7D^{\circ}_4$	6928.272		.185	−.006	+.009
700 V	7937.166	6	*A*	12595.495	$a^5G^{\circ}_5$—$b^5F^{\circ}_4$	34782.454		.537	−.026	+.042
600 V	7945.878	6	*B*	12581.685	$a^3G^{\circ}_5$—c^3F_4	35379.246		.727	−.026	+.042
20 IV	7994.473	4	*A*	12505.207						
700 V	7998.972	6	*C*	12498.174	$a^5G^{\circ}_4$—b^5F_3	35257.351	.216	.220	−.030	+.046
50 V	8028.341	6	h *B*	12452.454	$a^3G^{\circ}_3$—c^3F_3	36079.411		.485	−.020	+.031
600 V	8046.073	6	*B*	12425.011	$a^5G^{\circ}_3$—b^5F_2	35611.656	.045	.046	−.023	+.035
10n V	8080.668	3	*A*	12371.817						
500 V	8085.200	6	*A*	12364.882	$a^5G^{\circ}_2$—b^5F_1	35856.431		.921	−.026	+.039

[a] A. S. King, Astrophys. J. **80**, 124 (1934).
[b] K. Burns and F. M. Walters, Jr., Pub. Allegheny Obs. **6**, 159 (1929).

[19] Pub. Allegheny Obs. **6**, 159 (1929).

TABLE 1.—*Interference measurements in the infrared arc spectrum of iron*—Continued

Intensity and temperature class [a]	λ Integrated light of arc in air	Number of observations	Character of line and probable error	Wave-number in vacuum	Term combination [b]	Value of lower term [b]	Wave-number arc in vacuum		Difference vacuum arc—air arc	
							Observed	Computed	λA	νcm−1
10 IV	8096.874	3	*A*	12347.055						
80 V	8198.951	7	h *A*	12193.335	$a^3G^\circ_4$—c^3F_4	35767.603		.370	−.024	+.035
40 V	8207.767	6	h *A*	12180.238	$a^5G^\circ_2$—b^5F_2	35856.431		.271	−.022	+.033
1500 V	8220.406	6	*B*	12161.510	$a^5G^\circ_6$—b^5F_5	34843.984	.549	.554	−.030	+.044
50 V	8232.347	6	h *B*	12143.870	$a^5G^\circ_3$—b^5F_4	35611.656		.915	−.030	+.045
8 IV	8239.130	5	*B*	12133.873	a^3P_1—$a^3D^\circ_2$	19552.493		.887	−.010	+.014
30 V	8248.151	6	h *C*	12120.602	$a^5G^\circ_4$—b^5F_4	35257.351		.640	−.026	+.038
20 V	8293.527	6	*B*	12054.287						
1200 II	8327.063	6	*A*	12005.741	a^5P_2—$a^5P^\circ_1$	17727.011	.751	.747	−.004	+.006
200 V	8331.941	6	h *B*	11998.712	$a^3G^\circ_5$—b^5F_4	35379.246		.745	−.023	+.033
80 V	8339.431	7	h *A*	11987.935	$a^3G^\circ_4$—b^5F_3	35767.603		.968	−.023	+.033
8 V	8360.822	4	h *A*	11957.265	$a^3G^\circ_3$—b^5F_2	36079.411		.291	−.018	+.026
25 IV	8365.642	6	*A*	11950.375						
1200 II	8387.781	10	*B*	11918.833	a^5P_3—$a^5P^\circ_2$	17550.207	.840	.837	−.003	+.004
20 V	8439.603	4	h *B*	11845.648	$b^3F^\circ_4$—c^3F_3	36686.217		.679	−.022	+.031
300 II	8468.413	13	*A*	11805.348	a^5P_1—$a^5P^\circ_1$	17927.408		.350	−.001	+.002
150 II	8514.075	13	*B*	11742.035	a^5P_2—$a^5P^\circ_2$	17727.011		.033	+.001	−.002
8 V8	8526.685	3	h *C*	11724.670	$c^5D^\circ_4$—c^5D_4	39625.847		.692	−.016	+.022
15 IV	8582.267	7	*A*	11648.737	b^3G_4—$a^3G^\circ_4$	24118.854		.749	−.009	+.012
40 III	8611.807	12	*A*	11608.780	b^3P_1—$a^3P^\circ_0$	22946.860		.761	+.014	−.019
10 IV	8621.612	5	*B*	11595.578	b^3G_5—$a^3G^\circ_5$	23783.654		.592	−.010	+.014
600 II	8661.908	12	*A*	11541.634	a^5P_1—$a^5P^\circ_2$	17927.408	.638	.636	−.002	+.002
60 III	8674.751	13	*A*	11524.547	b^3P_2—$a^3P^\circ_1$	22838.360		.541	+.005	−.006
1500 II	8688.633	12	*A*	11506.134	a^5P_3—$a^5P^\circ_3$	17550.207	.144	.145	−.008	+.011
25 IV	8757.192	12	*A*	11416.054	b^3P_1—$a^3P^\circ_1$	22946.860		.041	+.010	−.013
20n V	8764.000	10	h *B*	11407.186	$b^3F^\circ_2$—c^3F_2	37521.201		.219	−.025	+.033
25n V	8793.376	11	h *B*	11369.078	$b^3F^\circ_3$—c^3F_3	37162.787		.109	−.024	+.031
	8804.624	3	*A*	11354.554	a^3P_2—$a^5P^\circ_1$	18378.215		.543	+.009	−.011
250 II	8824.227	14	*A*	11329.330	a^5P_2—$a^5P^\circ_3$	17727.011	.338	.341	−.009	+.011
30 IV	8838.433	11	*A*	11311.120	$b^3P^\circ_0$—$a^3P^\circ_1$	23051.790		.111	+.007	−.009
60 V	8866.961	10	*A*	11274.729	$b^3F^\circ_4$—c^3F_4	36686.217		.756	−.021	+.027
10n V	8945.204	4	h *A*	11176.110	$c^5F^\circ_4$—c^5D_3	40594.453		.150	−.032	+.040
10 IV	8975.408	6	*B*	11138.500	b^3G_4—$a^5G^\circ_4$	24118.854		.497	+.002	−.003
200 III	8999.561	11	*A*	11108.607	b^3P_2—$a^3P^\circ_2$	22838.360		.605	+.002	−.002
10 V	9012.098	4	h *C*	11093.154	$c^5F^\circ_5$—c^5D_4	40257.367		.172	−.015	+.018
4 V	9079.599	3	h *C*	11010.683	$b^3F^\circ_2$—c^3F_3	37521.201		.695	−.010	+.012
50 IV	9088.326	8	*A*	11000.110	b^3P_1—$a^3P^\circ_2$	22946.860		.105	+.004	−.005
30 IV	9089.413	8	*B*	10998.795	b^3G_5—$a^5G^\circ_5$	23783.654		.800	−.004	+.005
25 IV	9118.888	8	*A*	10963.244	b^3P_2—$b^5D^\circ_2$	22838.360		.248	−.003	+.004
2n V	9147.800	3	h *B*	10928.594						
6 IV	9210.030	7	*B*	10854.752	b^3P_1—$b^5D^\circ_2$	22946.860		.748	+.003	−.004
10n V	9258.30	4	h *C*	10798.159	$b^3F^\circ_3$—c^3F_4	37162.787		.186	−.023	+.027
6 V	9350.46	4	h *C*	10691.730	$b^3F^\circ_4$—b^5F_4	36686.217		.774	−.039	+.044
3 IV	9359.420	3	*C*	10681.495	b^3F_4—$a^3D^\circ_3$	20641.144		.493	+.002	−.002
4 IV	9362.370	4	*C*	10678.129	a^3P_2—$a^5P^\circ_3$	18378.215		.137	−.007	+.008
6 IV	9372.900	7	*C*	10666.133	b^3F_4—$a^3F^\circ_4$	20641.144		.133	±.000	±.000
3 IV	9430.08	3	*C*	10601.46						
8n V	9513.24	4	h *C*	10508.78	$c^5F^\circ_4$—$18W_5$	40594.453		.784		
15n V	9569.960	4	h *A*	10446.502	$c^5F^\circ_5$—$28W_5$	40257.367		.545	−.040	+.043
12n V	9626.562	4	h *C*	10385.079	$c^5F^\circ_4$—$59W_3$	40594.453		.174	−.088	+.095
15 V	9653.143	7	h *C*	10356.483	$b^3D^\circ_3$—c^3F_3	38175.391		.505	−.021	+.022
100 V	9738.624	8	h *C*	10265.579	$c^5F^\circ_5$—$46W_6$	40257.367		.621	−.040	+.042
10 V	9753.129	4	h *A*	10250.311	$b^3D^\circ_2$—c^3F_2	38678.075		.348	−.035	+.037
10 V	9763.450	2	h *C*	10239.48	$c^5F^\circ_1$—$9W_2$	41130.663		.521		
12 V	9763.913	5	h *C*	10238.990	$c^5F^\circ_4$—$25W_5$	40594.453		9.032	−.040	+.042
8n V	9800.335	4	h *C*	10200.938	$c^5F^\circ_2$—$14W_3$	41018.056		1.003	−.063	+.065
12 V	9861.793	6	h *C*	10137.367	$c^5F^\circ_3$—$59W_3$	40842.185		.442	−.073	+.075
15 V	9889.082	6	h *C*	10109.393	$c^5F^\circ_4$—$28W_5$	40594.453		.459	−.065	+.066
30 V	10065.080	8	h *C*	9932.621	$b^3D^\circ_1$—c^3F_2	38995.771		.652	−.031	+.031
40 V	10145.601	8	h *C*	9853.790	$b^3D^\circ_2$—c^3F_3	38678.075		.821	−.031	+.031
50 V	10216.351	8	h *C*	9785.551	$b^3D^\circ_3$—c^3F_4	38175.391		.582	−.032	+.031

[a] A. S. King, Astrophys, J. **80**, 124 (1934).
[b] K. Burns and F. M. Walters, Jr., Pub. Allegheny Obs. **6**, 159 (1929).

A glance at table 1 shows that most of the infrared lines of iron require energies of 4 to 6 electron volts for their excitation. This accounts, at least qualitatively, for the low intensity of the arc flame at the center and near the anode since these radiations are strongly excited only near the cathode where the potential gradient is largest. Because these infrared lines involve high-excitation energies, they may be expected to exhibit relatively large pressure displacements, and because they are strongly excited only in the proximity of the cathode it may be assumed that they will show the so-called pole effect, which is undoubtedly to be interpreted as a true Stark effect arising from high electric fields near this electrode.

Precise measurements of the effect of pressure on the spectrum of the iron arc were made by Babcock [20] who compared the wave lengths of 130 iron lines (3896 to 6678 A) from the international arc with those from a vacuum arc. He found that increase of pressure displaces all classes of iron lines toward longer waves, the shift is the same for all lines of the same multiplet, and the amount of the displacement is a function of the spectral term magnitudes, being determined primarily by the upper term. These pressure effects are most conveniently expressed in wave numbers in which case they are correlated directly with the depression of spectral terms. The observed depressions due to a change of pressure from 0 to 1 atmosphere were published by Babcock for 34 iron terms, assuming that the depression for the ground term is zero, and general formulas were given for computing the depressions of any other iron terms.

Data in the last column of table 1 may be compared with Babcock's term depression data, but it must be remembered that my measurements relate to integrated arc light while his refer to a narrow central zone of a long arc which is free from pole-effect. Such a comparison is shown in table 2 for some of the prominent infrared multiplets of iron.

TABLE 2.—*Comparison of multiplet displacements in the iron arc*

Multiplet	Vacuum arc [a] minus integrated arc in air cm^{-1} (A)	Term depressions [b] cm^{-1}			Difference cm^{-1} (B)−(A)
		Lower	Higher	Difference higher-lower (B)	
$b^5D°—b^5F$	+0.040	+0.015	+0.033	+0.018	−0.022
$b^5F°—b^5F$	+.040	+.013	+.033	+.020	−.020
$a^3G°—c^3F$	+.037	+.014	+.029	+.015	−.022
$a^5G°—b^5F$	+.039	+.011	+.033	+.022	−.017
$a^5P—a^5P°$	+.006	+.003	+.012	+.009	−.003
$b^3P—a^3P°$	−.009	+.004	+.013	+.009	+.018
$b^3F°—c^3F$	+.032	+.015	+.029	+.014	−.018
$b^3D°—c^3F$	+.031	+.015	+.039	+.014	−.017

[a] K. Burns and F. M. Walters, Pub. Allegheny Obs. **6**, 159 (1929).
[b] H. D. Babcock, Astrophys. J. **67**, 167 (1928).

The displacements in the second column are seen to be in qualitative agreement with differences of term depressions. This agreement can be regarded as exact if the differences in the last column are interpreted as evidence for pole effect (Stark effect) in the integrated light from the arc. This interpretation is justified by the fact

[20] Astrophys. J. **67**, 167 (1928).

that Stark effect may be expected in these high-excitation lines, and that, in general, the differences here shown are of the same sign and the same order of magnitude as the so-called pole effect for other groups of iron lines. These pole effects have been identified especially with 2 groups of lines, the *d* group exhibiting a greater wave length near the pole than at the center of the arc, and the *e* group a smaller wave length at the pole. Accordingly, we may say that multiplet $a^5P - a^5P^\circ$ listed in table 2 shows little or no pole effect, while the remaining multiplets belong to group *d*, except $b^3P - a^3P^\circ$ which behaves like group *e*. In other words, most of the infrared iron lines are displaced to longer waves in high electric fields, but one multiplet is outstanding in that its lines are shifted to shorter waves.

The hazy character of so many infrared iron lines, as noted in table 1, appears to be a function primarily of the excitation energy or corresponding pressure shift and broadening, since almost without exception only lines whose lower terms exceed about 36000 give interferences which are hazy or less sharp than the others. The limiting order of interference for these lines is relatively low, many of them being difficult to measure when the order exceeds 30000 waves. However, in spite of the fact that integrated arc light contains line displacements due to pressure and to Stark effects, my experience indicates that the degree of reproducibility in measuring wave lengths in this source is of the same order as that obtainable either with the international arc or with the vacuum arc. The latest modification of the international arc was designed to eliminate pole effects from the measurements but it is still afflicted with pressure effects and is entirely useless in the infrared on account of the low intensity. The vacuum arc is free from both pressure and Stark effects, and is undoubtedly the correct source to use for producing truly "fundamental" wave lengths. From the standpoint of stability, reproducibility, and intensity, the integrated light from an iron arc at atmospheric pressure is not inferior to the other types of iron sources, and it certainly deserves consideration as a modification of the present international iron arc as a source of infrared standards conveniently obtainable with the identical equipment which now yields secondary standards of wave length in the interval 3370 to 6750 A.

WASHINGTON, November 21, 1934.