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PRESSURE DISPLACEMENTS IN THE SECOND SPECTRUM OF IRON

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ABSTRACT

The changes in wave length of the intense ultraviolet lines in the second spectrum of iron, resulting from changes of pressure upon the source amounting to 1 or 2 atmospheres, have been measured with Fabry-Perot interferometers. The primary purpose of the experiments was to obtain data that would permit adjustment of the Fe II wave lengths of Burns and Walters, which were obtained by measurements of lines emitted by a vacuum arc, to equivalent arc-in-air values, thus furnishing an additional set of independently determined wave lengths for consideration as international secondary standards. These pressure effects are observed to be extremely small; of the order of 1 part in 6,000,000 for 1-atmosphere pressure change, sufficient to affect the seventh figure of proposed secondary standards in the case of only one of the observed term combinations.

CONTENTS

I. PRESENT STATUS OF SECONDARY STANDARDS OF WAVE LENGTH IN THE ULTRAVIOLET REGION

A large majority of spectral lines from laboratory sources which are used as standards of wave length are emitted by the iron arc. The International Astronomical Union,[1] which sponsors the specification and adoption of such standards, requires three independent and concordant determinations of the wave length of any spectral line before it may be considered for adoption as an international secondary standard. The IAU [1] has repeatedly stressed the need of additional independent observations particularly in the ultraviolet region. The list of secondaries in the iron spectrum adopted in 1928 terminated at 3370 A [1],[2] and no additional iron standards of wave length shorter than 3370 A were adopted until 1938 [2]. In the meanwhile, three new sets of measurements of iron wave lengths in the ultraviolet

[1] The complete title will be abbreviated to IAU elsewhere in the paper.
[2] Figures in brackets indicate the literature references at the end of this paper.

appeared. These were by Burns and Walters [3], by Jackson [4], and by Meggers and Humphreys [5]. These results are all quoted in the transactions of the IAU [2]. Jackson's measurements end at 2327 A in the ultraviolet. Those of Burns and Walters and of Meggers and Humphreys terminate at 2100 A. There can be no adoption of standards between 2327 and 2100 A until further observations are made.

The vacuum arc is regarded by some observers as superior to the Pfund arc, specified by the IAU [6], as a source of standard wave lengths. Consequently, Burns and Walters used the former in their wave-length determinations. Wave lengths from these two sources are not strictly comparable, since they differ slightly owing to the pressure displacement resulting from a pressure difference of about 1 atmosphere.

An interferometric investigation of the pressure effect in the iron arc arising from a pressure difference of 1 atmosphere was made by Babcock [7]. Using these observations, he was able to calculate the relative pressure displacements of a large number of Fe I terms. Of the lines observed by Burns and Walters, those which are classified lines of Fe I, involving terms for which the pressure displacements are known, have been adjusted to the equivalent arc-in-air values by use of Babcock's data. Such lines, having thus satisfied the prerequisite of three independent, concordant determinations, were adopted as secondaries by the IAU in 1938 [2].

The majority of the intense lines between 2755 and 2327 A in the spectra obtained with iron-arc sources belong, however, to the second spectrum. The adoption of additional standards in this wave-length interval has been delayed pending the investigation of the pressure effect in Fe II. It was the object of this investigation to measure the pressure displacements of such Fe II lines as were suitable for examination with interferometers. The subsequent calculation of the Fe II term depressions permitted the conversion of the vacuum-arc wave lengths observed by Burns and Walters to arc-in-air values. An additional set of independent observations was thus made available.

It may be stated at this point that the pressure displacements in Fe II appear to be considerably smaller than those obtained by Babcock for Fe I. The displacement for conspicuous lines involving the normal state are of the order of 1 part in 6,000,000, or about 0.0004 A at 2400 A. This is of the same order of magnitude as the random variation associated with repeated measurements using identical sources. It was necessary, therefore, to limit the measurements to very favorably placed lines and to those which appeared sharpest; also to make a sufficient number of observations to minimize the probable error in the final averages. The international secondary iron standards are given only to seven figures. Meggers and Humphreys retained eight figures in cases where the procedure seemed justified by evidence from the combination principle and calculation of the probable error. It is clear, however, that if the pressure effect in Fe II is insufficient to affect the seventh figure, it becomes of little practical importance whether a Pfund arc or vacuum arc is chosen as a comparison source in the ultraviolet between 2300 and 2700 A if Fe II lines are to be used as standards.

II. GENERAL DISCUSSION OF THE PRESSURE EFFECT

1. RESUMÉ OF EXPERIMENTAL INVESTIGATIONS

The pressure effect was discovered by W. J. Humphreys and J. F. Mohler more than 40 years ago. These observers carried out an extensive series of observations of the pressure displacements exhibited by a number of lines in the spectra of each of 48 metals, using pressures up to 15 atmospheres as well as pressures less than 1 atmosphere. The spectrograph contained a Rowland concave grating of 21-foot focus and ruled 20,000 lines per inch.

The results were published by these observers conjointly and separately in a series of articles in the Astrophysical Journal [8]. Among the conclusions drawn from these early experiments were the following: (1) Increase of pressure causes all lines to shift toward the red end of the spectrum. (2) This shift is directly proportional to the increase of pressure. (3) It does not depend upon the partial pressure of the gas or vapor, but upon the total pressure. Dependence of the effect upon various physical properties of the element such as melting point, coefficient of expansion, and atomic volume was indicated. The effect for similar lines appeared to be a periodic function of atomic weight. These experiments were performed many years before the Bohr theory of atomic structure and radiation appeared, and term analyses had been made in empirical fashion for only a few relatively simple spectra. Consequently, the conclusions of the first workers in this field, regarding the correlation of the pressure effect with different regions of the spectra and with various types of lines, must be regarded as superseded by those of later observers who had a previous knowledge of the complete term scheme of the spectrum under investigation. The first three conclusions enumerated above, however, remain essentially unchanged. Following the work of Humphreys and Mohler, little attention was given the pressure effect until comparatively recent times. One reason for this is the fact that the effect is small, often completely masked by other effects such as Doppler broadening, Stark effect in certain high-voltage discharges, or pole effect in arcs. It is always accompanied by a line broadening which increases with increase of pressure making the measurement of the actual shift difficult. The smallness of the effect renders it of little importance in practical spectroscopic measurements, except where precise interferometric wave-length determinations are being made, or in cases where pressure changes of several atmospheres are involved. Another reason why the pressure effect has received little attention is that unlike many other atomic-radiation phenomena such as Zeeman effect, for instance, it does not lend itself readily to a simple explanation in accordance with accepted theories of atomic mechanics.

Babcock's investigation of the pressure effect in Fe I [7], which was mentioned above, constitutes the most important contribution to our knowledge concerning the relation between the observed pressure displacements and the energy-level scheme. His results are in essential conformity with those of Catalán [9], who made a similar study 3 years earlier in 1924, using the pressure effect data of Gale and Adams [10] and the Fe I classifications of Walters [11]. Babcock examined 130 Fe I lines with Fabry-Perot interferometers and was able to deduce relative pressure displacements for 44 terms. The wave lengths obtained from a vacuum arc were compared with those from a Pfund arc operated under conditions to eliminate any pole effect from the radiation utilized. In addition to substantiating earlier conclusions, that the effect of increased pressure was always a shift to the red, and that it was due to total rather than to partial pressure, Babcock showed that there was a relation between pressure effect on spectral terms of Fe I and their level in the atom. The results were presented in tabular and graphic form and showed an increasing term depression [3] for a given pressure change with elevation of the term. The graph indicated a slightly greater effect for the quintet and septet terms than for the triplets, although the evidence on this point can hardly be regarded as conclusive.

Grating measurements of the pressure displacements in two Fe I multiplets were reported by Beglinger [12] in 1934. His results indicated effects slightly larger than Babcock's, also a variation within the multiplets, dependent upon the wave lengths of the individual lines, which is in disagreement with the earlier findings.

2. THEORY OF THE PRESSURE EFFECT

It is not intended in this paper to give any detailed discussion of the theory of the pressure effect. There have been two distinct approaches to the problem. The first is an outgrowth of the theory of collision damping originally proposed by Lorentz [13] according to which, if an atom is emitting radiation, the phase and amplitude of the radiation may undergo considerable change during collision with another atom. The change of phase is associated with a change of frequency limited in time to the duration of the collision process. The other theoretical explanation of the effect is the statistical theory first proposed by Margenau in 1933 [14], according to which the phenomenon is explained by van der Waals forces between neighboring atoms which affect the magnitudes of the energy levels. The most complete development of this statistical theory has been given by Margenau and Watson [15]. Reference may be made to articles by Jablónski [16], by Kuhn [17], and to more recent papers by Margenau and his associates [18]. Very recently, Reinsberg [19] has derived both the Lorentz theory of collision damping and Margenau's statistical theory on a quantum-mechanical basis.

Observed pressure effects are explained as arising from unequal changes of elevation in the respective energy levels constituting the initial and final states involved in the production of any given line, these changes being caused by changes of pressure upon the emitting atoms. The effect invariably takes the form of an increase of wave length or, what amounts to the same thing, a decrease of frequency, with increase of pressure. Two alternative hypotheses as to the sense of the change of position of the energy levels are available, since only the indirect evidence of increased wave length is obtained by observation. The line displacement might be explained by an elevation of terms, the amount of elevation being relatively greater for the lower terms, or by a depression of terms, the amount of depression being relatively greater for the higher terms. Any reasonable theory of atomic mechanics would lead to the expectation that terms,

[3] The interpretation of the results obviously depends upon the choice between the elevation or depression hypotheses which is discussed below.

arising from electron configurations far removed from the core of the atom, would show an increasing sensitiveness to pressure effect with such removal. Consequently, universal acceptance of the term-depression hypothesis has resulted.

The amount of the pressure displacement is observed to be proportional to the relative density of the gas at the light source; that is, the ratio of the actual density to the density under normal atmospheric temperature and pressure conditions. It is not regarded as a partial pressure effect, in other words, not dependent upon an interaction between atoms of the same species, but rather a cumulative effect resulting from the total contribution of all particles present. The results obtained by surrounding a given source by different foreign gases indicate that the pressure shift depends to a slight extent upon the particular foreign gas introduced. This was demonstrated by Füchtbaur, Joos, and Dinkellacker [20], who studied the mercury resonance line, 2537 A, in absorption at pressures up to 50 atmospheres, using N_2 and CO_2, respectively, to maintain the desired pressures.

III. EXPERIMENTAL PROCEDURE

The experimental technique employed in this investigation was essentially the same as that described in several earlier publications reporting interferometric determinations of wave length, particularly the paper by Meggers and Humphreys [5] previously mentioned. Production of spectra under different conditions of pressure was effected by use of two sources, one, a Pfund arc conforming to the IAU specification [6] and described in the paper just referred to [5], the other an enclosed arc of the same design as that described and illustrated by Curtis [21], suitable for operation at either elevated or reduced pressures.

The same pair of crystal-quartz interferometer plates used in the earlier determination of iron wave lengths with the same evaporated aluminum coating were again used in these experiments. These were separated by invar etalons of 3, 5, and 7.5 mm in the various sets of observations.

A large Littrow mounting quartz spectrograph served to record the interference patterns. Optical accessories included two quartz-fluorite achromatic lenses, one of 25-cm and one of 50-cm focal length, employed to project the interference rings upon the spectrograph slit. The lens of longer focal length was used in making all the reported observations except one series with the 3-mm etalon. Images of the light sources were formed in the interferometer by means of a concave aluminized mirror of about 94-cm radius of curvature.

For the measurement of changes of wave length produced by a change of pressure, two possible methods are available. The first is the differential method by which the variation in ring diameters, occasioned by successive exposures to the respective sources, permits calculation of the change in fractional order of interference, and, consequently, the change of wave length. Attention is called to a method recently proposed by Williams and Gogate [22] for the simultaneous recording of the interference patterns from the two sources. The light from the respective sources would be polarized in mutually perpendicular planes. The overlapping sets of fringes which would appear with illumination of the interferometer by both sources at the same time would be separated on the photographic plate by placing a double-image prism in the parallel beam of the spectrograph.

The second method may be called the absolute method. In practice the wave lengths from each source could be determined by comparison with the same standard of wave length, such as the primary standard or group of noble-gas lines. The differential method has the advantages of speed and simplicity, and the fact that no corrections are required which would be occasioned by location of source and standard in widely separated spectral regions. The differential method was chosen for these experiments not because it was regarded as inherently superior, but because in the vicinity of 2500 A, it is not possible to make comparisons simultaneously with the primary standard. Refocusing the spectrograph for alternate exposures to different spectral regions and different sources is a time-consuming procedure which always entails uncertainty as to whether the conditions of observation, accompanying the successive exposures, remain unchanged.

The most extensive series of experiments was performed to determine the change in wave length resulting from the operation of the source at atmospheric pressure, and at the lowest pressure at which the enclosed arc may be operated without serious loss of intensity. This low pressure amounted to an equivalent of 5 to 7 cm of mercury, so that the pressure difference in these experiments was somewhat less than 1 atmosphere. Five exposures were made on each plate, three with one source and two with the other, the exposures to the respective sources being alternated. A simple method was devised to permit rapid change from one source to the other. The light was always reflected from the spherical mirror along the same line coincident with the spectrograph axis. The mirror was mounted, however, so as to permit rotation about a vertical axis in order to receive as desired the light from whichever of the two sources was being used. In reducing the measurements from a single plate, the fractional orders corresponding to each source were averaged together, the differences between these averages being assumed to be accounted for by pressure displacement. This procedure is intended, of course, to lessen the effect of small fluctuations in the length of the interference path when not fully under experimental control.

Inasmuch as the pressure effect is proportional to the total pressure upon the source, it would seem desirable to make observations at high pressures amounting to several atmospheres in order to obtain larger displacements. Unfortunately the line broadening associated with increased pressures makes this procedure unsuitable for interferometric measurements if the total pressure exceeds 2 atmospheres.

A number of observations were made utilizing pressure differences of 2 atmospheres, realized by alternately reducing the pressure to the lowest optimum point and raising it to 1-atmosphere excess pressure by introducing compressed nitrogen from a cylinder and taking exposures at the respective pressures. The pressure estimates were somewhat uncertain at the high level, partly because of the unsteadiness resulting from the maintenance of a sufficient flow of gas through the arc chamber to sweep out the smoke and prevent fogging of the quartz window, and partly because the pressure was read from the dial gage on the low-pressure side of the reducing valve, which was recalibrated at the beginning of the experiments but was still regarded as somewhat unreliable, because it was not very responsive to small pressure fluctuations. The low pressures were read from an aneroid gage which has been used in many previous investigations and gives entirely satisfactory performance.

IV. RESULTS

1. CLASSIFICATION OF OBSERVED LINES

The second spectrum of iron, Fe II, is strongly emitted in arcs along with the first spectrum. The lines are distributed throughout the spectrum, but the most intense multiplets occur in the ultraviolet. Almost all of the strong lines between 2413 and 2327 A, the region covered by the reported measurements, belong to the second spectrum. Fe II may now be ranked as one of the most completely analyzed spectra. Following the discovery of two multiplets by Meggers, Kiess, and Walters [23] in 1924, Russell [24] in 1926 published classifications of over 200 lines, comprising the conspicuous combinations of sextet and quartet terms. Later work by Dobbie [25] resulted in the discovery of most of the terms predicted by the Hund [26] theory, including the doublet system, and led to the classification of about 2,200 lines.

The term system of Fe II is discussed in this paper only to the extent necessary to indicate the quantum designations, origin, and relative positions of the terms which are involved in the production of lines that have been examined for pressure effect. The addition of an s electron to the $3d^6$ configuration of doubly ionized iron yields ^{6}D and ^{4}D terms of Fe II which are derived from ^{5}D of Fe III. The ^{6}D term is the lowest, or ground, term of Fe II and represents the normal state of singly ionized iron atoms. The $3d^7$ configuration yields ^{4}F and ^{4}P in addition to a large number of doublets. This ^{4}F term is located next to the lowest. The binding of a p-electron to the $3d^6$ configuration of Fe^{++} leads to the triads, ^{6}F, ^{6}D, ^{6}P, and ^{4}F, ^{4}D, ^{4}P, all derived from ^{5}D of Fe III. The lines for which pressure effects are reported here arise from combinations of two of these odd sextets, ^{6}F and ^{6}P with the ground term, and from combinations of two of the odd quartets, ^{4}F and ^{4}D with $3d^7\ ^4$F. The results for these lines, designated by appropriate symbols, are assembled in table 1.

About 20 additional lines were examined, for which pressure effects either were not found, or could not be measured because of lack of sharpness or unfavorable location too near other lines. Most of these are between 2755 and 2562 A, and include combinations of $3d^6$ (^{5}D) $4p$ ^{6}D° with the ground term, also combinations of the odd quartets from the configuration $3d^6\ 4p$ with the moderately low $3d^6$ (^{5}D) $4s$ ^{4}D term. Many other lines in the region studied, including those of the multiplet $3d^7\ ^4F-3d^6$ (^{5}D) $4p$ ^{4}P°, and numerous intersystem combinations, particularly transitions from the odd sextets to the low ^{4}F, are too faint for interferometric observations.

2. MEASURED PRESSURE DISPLACEMENTS

Pressure displacements of the lines for which measurable effects could be observed are reported in table 1. The wavelengths are quoted from the measurements of Meggers and Humphreys [5] except

2348.114 A, and 2348.301 A, which were determined relative to the other observed lines during this investigation. The lines are grouped by multiplets, since related lines are expected to show similar effects. Columns 4 and 5 contain the changes of wave length experienced by each line, corresponding to the pressure variation also noted at the top of the column. The same columns show the pressure displacements averaged for the respective multiplets.

TABLE 1.—*Pressure displacements of observed lines in the second spectrum of iron*

Term combination	Wave length (air)	Wave number (vac)	Change of wave length for 1-atmosphere pressure difference[1]	Change of wave length for 2-atmosphere pressure difference
	A	cm^{-1}	A	A
$a^6D_{1/2} - z^6F^\circ_{1\frac{1}{2}}$	2413. 3087	41424. 284	0. 0004	0. 0013
$a^6D_{1/2} - z^6F^\circ_{1/2}$	2411. 0663	41462. 808	. 0003	. 0015
$a^6D_{1\frac{1}{2}} - z^6F^\circ_{2\frac{1}{2}}$	2410. 5172	41472. 250	. 0005	----------
$a^6D_{1\frac{1}{2}} - z^6F^\circ_{1\frac{1}{2}}$	2406. 6593	41538. 728	. 0004	. 0014
$a^6D_{1\frac{1}{2}} - z^6F^\circ_{1/2}$	2404. 430	41577. 24	. 0006	. 0014
$a^6D_{2\frac{1}{2}} - z^6F^\circ_{2\frac{1}{2}}$	2399. 2396	41667. 176	. 0004	. 0010
$a^6D_{3\frac{1}{2}} - z^6F^\circ_{3\frac{1}{2}}$	2388. 6270	41852. 284	. 0003	. 0017
Average----	----------	----------	0. 0004	0. 0014
$a^6D_{2\frac{1}{2}} - z^6P^\circ_{3\frac{1}{2}}$	2380. 7591	41990. 584	0. 0002	0. 0010
$a^6D_{3\frac{1}{2}} - z^6P^\circ_{3\frac{1}{2}}$	2364. 8269	42273. 457	. 0002	. 0008
$a^6D_{1\frac{1}{2}} - z^6P^\circ_{2\frac{1}{2}}$	2359. 1039	42376. 000	. 0004	. 0013
$a^6D_{2\frac{1}{2}} - z^6P^\circ_{2\frac{1}{2}}$	2348. 301	42570. 93	. 0003	----------
$a^6D_{1/2} - z^6P^\circ_{1\frac{1}{2}}$	2344. 2802	42643. 934	. 0003	. 0015
$a^6D_{1\frac{1}{2}} - z^6P^\circ_{1\frac{1}{2}}$	2338. 0052	42758. 377	. 0002	. 0014
$a^6D_{3\frac{1}{2}} - z^6P^\circ_{2\frac{1}{2}}$	2332. 7972	42853. 827	. 0005	. 0015
$a^6D_{2\frac{1}{2}} - z^6P^\circ_{1\frac{1}{2}}$	2327. 3940	42953. 306	. 0001	. 0012
Average----	----------	----------	0. 0003	0. 0012
$a^4F_{1\frac{1}{2}} - z^4D^\circ_{1\frac{1}{2}}$	2384. 386	41926. 72	0. 0005	0. 0018
$a^4F_{3\frac{1}{2}} - z^4D^\circ_{3\frac{1}{2}}$	2379. 2756	42016. 766	. 0005	. 0022
$a^4F_{1\frac{1}{2}} - z^4D^\circ_{1/2}$	2375. 193	42088. 98	. 0006	. 0013
$a^4F_{2\frac{1}{2}} - z^4D^\circ_{1\frac{1}{2}}$	2368. 595	42206. 21	. 0008	. 0020
$a^4F_{3\frac{1}{2}} - z^4D^\circ_{2\frac{1}{2}}$	2360. 294	42354. 64	. 0004	. 0017
$a^4F_{4\frac{1}{2}} - z^4D^\circ_{3\frac{1}{2}}$	2348. 114	42574. 32	. 0008	----------
Average----	----------	----------	0. 0006	0. 0018
$a^4F_{3\frac{1}{2}} - z^4F^\circ_{3\frac{1}{2}}$	2362. 019	42323. 71	0. 0007	0. 0021
$a^4F_{4\frac{1}{2}} - z^4F^\circ_{4\frac{1}{2}}$	2359. 997	42359. 96	. 0005	. 0020
$a^4F_{2\frac{1}{2}} - z^4F^\circ_{1\frac{1}{2}}$	2354. 8888	42451. 843	. 0004	. 0016
$a^4F_{4\frac{1}{2}} - z^4F^\circ_{3\frac{1}{2}}$	2331. 3067	42881. 222	. 0005	. 0016
Average----	----------	----------	0. 0004	0. 0018

[1] The vacuum arc was operated at a pressure equivalent to a few centimeters of mercury to maintain satisfactory discharge conditions. Hence the pressure difference to which the effects in this column are attributed is somewhat less than 1 atmosphere.

The results for 1-atmosphere pressure difference represent the weighted mean of five sets of observations with the 3-mm etalon, nine with 5 mm, and five with 7.5 mm. By an observation is meant a set of five successive exposures on a single plate. The results for 2-atmosphere pressure difference are derived from five sets of observations all with the 5-mm etalon. This separation corresponds to the largest retardation permitting satisfactory resolution at this pressure.

The displacements for a 2-atmosphere pressure difference are considerably too large if the pressure effect is a linear function of pressure. The discrepancy may be partly accounted for by the necessity, previously noted, of operating the enclosed arc at low pressures of nearly one-tenth of an atmosphere rather than at negligibly low pressures. Hence, the results for 1-atmosphere pressure difference are actually obtained with pressure differences somewhat less than 1 atmosphere. On the other hand, the high-pressure observations were made with pressures slightly in excess of 1 atmosphere in order to obtain as nearly as possible a 2-atmosphere pressure difference. The measurements involving high-pressure observations are regarded as less reliable than the others, because, as mentioned previously, the pressure estimates may be in error. Furthermore, a slight underestimation of ring diameters in the measurement of poorly resolved interference fringes would lead to displacements apparently too large.

The general qualitative agreement of both sets of observations leaves no question of the genuinely positive character of the effect for the lines given in the table, a question which might possibly be raised if only the results for 1-atmosphere pressure difference were available.

3. TERM DEPRESSIONS IN Fe II

In order to apply the pressure-displacement correction to the wave length of any line in a spectrum, it is necessary to know the depressions for both levels involved in the transition. In practice we make the assumption that the ground level has no pressure displacement. The pressure displacements are then determined for lines involving transitions to the lowest state. We obtain in this manner the values of the pressure displacements of these combining levels relative to the lowest state. If these levels for which pressure displacements are known combine with a third set, the relative depressions of the latter become experimentally measurable. The method may be extended as far as intercombinations permit. Interferometric observations of the pressure displacements of the intersystem lines involving transitions between the odd sextets and the low ^4F term are lacking. The additional assumption is made that the latter term has negligible pressure displacement relative to the ground state, an assumption regarded as justifiable since the levels of this term lie from only 1,872 to 3,115 cm^{-1} above the ground level.

TABLE 2.—*Term depressions in* Fe II *resulting from a pressure increase of 1 atmosphere*

Designation	Term value	Depression
		cm^{-1}
$3d^6\ (^5D)\ 4s\ a\ ^6D_{4\frac{1}{2}}$	0.06	0.
$^6D_{3\frac{1}{2}}$	384.81	
$^6D_{2\frac{1}{2}}$	667.66	
$^6D_{1\frac{1}{2}}$	862.63	
$^6D_{\frac{1}{2}}$	977.03	
$3d^7\ a\ ^4F_{4\frac{1}{2}}$	1872.66	0.
$^4F_{3\frac{1}{2}}$	2430.14	
$^4F_{2\frac{1}{2}}$	2837.98	
$^4F_{1\frac{1}{2}}$	3117.51	
$3d^6\ (^5D)\ 4s\ a\ ^4D_{3\frac{1}{2}}$	7955.30	Not determined.
$^4D_{2\frac{1}{2}}$	8391.93	
$^4D_{1\frac{1}{2}}$	8680.51	
$^4D_{\frac{1}{2}}$	8846.77	
$3d^7\ a\ ^4P_{2\frac{1}{2}}$	13474.45	Not determined.
$^4P_{1\frac{1}{2}}$	13673.21	
$^4P_{\frac{1}{2}}$	13904.93	
$3d^6\ (^5D)\ 4p\ z\ ^6D^\circ_{4\frac{1}{2}}$	38459.07	Not determined.
$^6D^\circ_{3\frac{1}{2}}$	38660.09	
$^6D^\circ_{2\frac{1}{2}}$	38859.01	
$^6D^\circ_{1\frac{1}{2}}$	39013.23	
$^6D^\circ_{\frac{1}{2}}$	39109.34	
$3d^6\ (^5D)\ 4p\ z\ ^6F^\circ_{5\frac{1}{2}}$	41968.17	0.008.
$^6F^\circ_{4\frac{1}{2}}$	42114.85	
$^6F^\circ_{3\frac{1}{2}}$	42237.07	
$^6F^\circ_{2\frac{1}{2}}$	42334.85	
$^6F^\circ_{1\frac{1}{2}}$	42401.35	
$^6F^\circ_{\frac{1}{2}}$	42439.90	
$3d^6\ (^5D)\ 4p\ z\ ^6P^\circ_{3\frac{1}{2}}$	42658.27	0.005.
$^6P^\circ_{2\frac{1}{2}}$	43238.63	
$^6P^\circ_{1\frac{1}{2}}$	43621.01	
$3d^6\ (^5D)\ 4p\ z\ ^4F^\circ_{4\frac{1}{2}}$	44232.57	0.008.
$^4F^\circ_{3\frac{1}{2}}$	44753.84	
$^4F^\circ_{2\frac{1}{2}}$	45079.93	
$^4F^\circ_{1\frac{1}{2}}$	45289.85	
$3d^6\ (^5D)\ 4p\ z\ ^4D^\circ_{3\frac{1}{2}}$	44446.95	0.011.
$^4D^\circ_{2\frac{1}{2}}$	44784.80	
$^4D^\circ_{1\frac{1}{2}}$	45044.23	
$^4D^\circ_{\frac{1}{2}}$	45206.50	
$3d^6\ (^5D)\ 4p\ z\ ^4P^\circ_{2\frac{1}{2}}$	46967.47	Not determined.
$^4P^\circ_{1\frac{1}{2}}$	47389.83	
$^4P^\circ_{\frac{1}{2}}$	47626.17	

The average wave-number variation for each multiplet gives the relative depression of the upper term involved in the transition, assuming that all levels of a term are actually subject to the same displacements. These term depressions are indicated in table 2 to the extent permitted by the data. The level values and designations in this abridged Fe II term table are quoted from Dobble [25]. The results used in estimating term depressions were in all cases derived from observations with the respective sources operated at pressures differing by slightly less than 1 atmosphere.

4. CONCLUSIONS

The results indicate that a change of pressure of 1 atmosphere causes a shift of the Fe II lines in the neighborhood of 2400 A amounting to 0.0004 A on the average, or 1 part in 6,000,000. This is an extremely small effect. Except in case of the transitions, $a^4F-z^4D°$, for which slightly larger effects were observed, the pressure displacements arising from a pressure difference of 1 atmosphere are insufficient to affect the values of vacuum-arc wave lengths, unless the probable error of the wave-length measurements is less than 0.0005 A. The Burns-Walters published wave lengths, which were determined by comparison with noble-gas standards, are given to seven figures although eight figures were retained for calculating wave numbers. In the list of proposed secondary standards [2] the following five wave lengths from the data of Burns and Walters need to be increased by 0.001 A to make them comparable with arc-in-air values on the basis of this investigation; 2384.385, 2379.275, 2375.191, 2368.594, and 2360.292.

V. REFERENCES

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