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INTERFERENCE MEASUREMENTS OF WAVE LENGTHS IN THE ULTRAVIOLET SPECTRUM OF IRON

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ABSTRACT

The wave lengths of 252 ultraviolet lines (3498 to 2101 A) characteristic of the international iron arc were measured relative to cadmium, krypton or neon standards. These measurements were made with Fabry-Perot étalon interferometers and stigmatic spectrographs. Invar étalons of 2, 3, 5, 7.5, or 10 mm length, and aluminized quartz plates were used. The spectrographs consisted of a concave grating, a Littrow quartz, or a Cornu quartz instrument. With the first, simultaneous exposures were obtained of red neon lines in the first-order spectrum, and of ultraviolet iron lines in the overlapping second-order spectrum. The use of quartz spectrographs required alternate exposures of primary and secondary sources. The final values in many cases are given to eight figures since calculations of probable error and tests of relative value by means of the combination principle indicated average errors smaller than 0.0005 A.

CONTENTS

I. INTRODUCTION

Nearly half a century ago Kayser and Runge [1][1] proposed the arc spectrum of iron as a source of wave-length standards for spectroscopic measurements. Since that time very considerable effort has been exerted to select suitable standards, refine their values, and to extend measurements throughout a long range of spectrum [2]. Although steady progress has been made toward the establishment of a trustworthy, homogeneous system of standards, the task is still unfinished.

The greatest advance followed the invention and use of interferometers, a primary standard being thus determined by comparing the red radiation from cadmium with the meter, and secondary standards from the arc spectrum of iron being measured relative to this primary standard. Since 1919 this program has been sponsored by the International Astronomical Union, which, in 1928, adopted 244 values (3370.787 to 6677.993 A) of iron lines as international secondary standards, and recommended that the system be extended both to longer and to shorter waves [3]. Interference measurements of the shorter waves of iron have since been published by Burns and Walters

[1] Numbers in brackets refer to literature citations at the end of this paper.

[4] and by C. V. Jackson [5], but according to rule no line may be considered for adoption as an international secondary standard until three independent and concordant determinations exist. In the present paper another series of measurements in the ultraviolet spectrum of iron (3500 to 2100 A) is reported. Other measurements by Buisson and Fabry [6], by Burns [7], and by Pressentin [8] will not be considered here since they cover only a part of this range with relatively few observations, and have been adequately discussed by Jackson [5].

II. EXPERIMENTS

The results reported in this paper were derived from interference spectrograms of cadmium, neon, krypton, and iron spectra obtained by employing combinations of Fabry-Perot interferometers and stigmatic spectrographs.

The primary sources consisted of cadmium lamps of the type specified by the International Committee on Weights and Measures [9] or of Geissler tubes containing pure neon or krypton. On account of frequent fracture of the cadmium lamps owing to unfortunate choice of glass whose expansion differed from that of the sealed-in wires, the majority of spectrograms were exposed either to neon or to krypton sources.

The secondary source was the iron arc specified by the International Astronomical Union for the production of secondary and tertiary standards [10]. It consisted of an iron arc operated at 220 volts with 5 amperes at a length of 15 mm, an iron rod 7 mm in diameter serving as the upper pole (cathode), and a bead of iron oxide on a massive iron rod as the lower pole (anode). The upper rod was surrounded by a 2-inch brass cylinder bored with vertical holes to act as a heat radiator. An image of threefold magnification was projected on the interferometer with an aluminized mirror of 1-m focal length, and a diaphragm selected light from the central 1.5-mm zone of the 15-mm-arc flame.

Crystal quartz plates coated with evaporated aluminum were used in the étalon type of Fabry-Perot interferometer. The two plates produce respectively right-handed and left-handed polarization, both plates being cut with faces perpendicular to the optic axes and polished accurately plane. A small angle between surfaces of each plate prevented intersurface reflections. Étalons of three invar rods separated the aluminized surfaces either 2, 3, 5, 7.5, or 10 mm.

An excellent quartz-fluorite achromatic lens (made by Carl Zeiss) of 25-cm focal length was employed for imaging interference patterns on the spectrograph slits.

Three different spectrographs were used in making the observations. The first was an Anderson ruled grating of 650-cm radius mounted to perform stigmatically [11]. A compromise between horizontal and vertical focus was adopted for 15 cm on either side of the axis or grating normal, and observations were made simultaneously in the first two orders of grating spectra. Since the dispersion is 10 A/mm in the first order, it was possible to record on a 10-inch plate 4700 to 7200 A in this order and simultaneously 2350 to 3600 A in the second order. By filtering the iron light through a piece of Corex A glass the ultraviolet spectrum was photographed in the second order, and simultaneously in the first order the neon spectrum was superposed

when neon light was reflected from the rear surface of the Corex A filter or from a plane quartz mirror. The transmission of the Corex A filter set a limit on the iron spectrum near 2600 A. It was found that the dispersion was sufficient to prevent confusion of overlapping orders if the slit was not too wide, so that many exposures were made with both orders of iron spectra present as well as the neon spectrum. Line identification was facilitated by the difference in scale of interference patterns in first- and second-order grating spectra. From these grating spectrograms, measurements of iron lines down to 2388 A were secured. This series of iron and neon comparisons is the most reliable because of strict simultaneity of exposure under identical optical conditions and no disturbance of the apparatus.

In order to observe the shorter ultraviolet these grating spectrograms were supplemented by alternate exposures to krypton and iron with a Littrow type quartz spectrograph (Hilger *E1*). Since it is impossible with an instrument of this type to observe the visible (4400 A) and the ultraviolet (below 2500 A) with a single adjustment, we tried the procedure which Jackson used [5]. The krypton (or cadmium) spectrum was photographed with the spectrograph set for visible light, and then the spectrograph was changed (prism rotated, lens refocused, and the plate tilted) to record the ultraviolet iron spectrum, followed by a return to the first setting for a second krypton (or cadmium) exposure. In this way, the iron lines (2700 to 2100 A) were compared with krypton standards (4273 to 4502 A) or with the cadmium standard (6438 A). By selecting for measurement only those spectrograms which showed no serious differences between the first and last exposures self-consistent results were obtained, but when these were compiled, it was distressing to find them systematically 0.0025 A higher than for the same lines measured relative to neon with the grating spectrograph.

Then the ultraviolet (2813 to 2100 A) of iron was compared again with krypton standards (4273 to 4502 A) by exposing them alternately in a Cornu prism spectrograph (Hilger *E2*) which covers the entire range with a 10-inch plate. In this case, it was necessary only to rack the plate down for successive exposures without otherwise changing the spectrograph adjustments. The results of these measurements were in good agreement with those of the grating spectrograms, and it was concluded that those obtained with the *E1* spectrograph were 0.0025 A too large. Seeking the explanation for this discrepancy we investigated the effect of spectrograph focus on the fractional order of interference and found variations of this order of magnitude. It appears that systematic errors may be introduced unless exactly the same type of focus is used in spectrograph settings for different spectral regions. The values of *E1* spectrograms were finally reduced by 0.0025 A and averaged with the other two series.

Finally, another series of observations was made with the *E1* spectrograph after careful investigation of its horizontal and vertical focus for different spectral regions and choosing the same compromise in each. In this last series the interval 2400 to 2100 A was remeasured relative to krypton standards (4273 to 4502 A) with 2-, 3-, and 5-mm étalons, the dispersion of phase at reflection being determined again from 2- and 5-mm values. After applying the proper corrections for standard air density and dispersion of phase, these results were averaged with the others.

For the grating spectrograms we employed Eastman *144F* plates. The same, or Eastman *33*, emulsions were used in making the prism spectrograms, except in the shortest ultraviolet (2400 to 2100 A) where observations were made with Schumann plates having greater sensitivity and contrast.

On account of the considerable range of intensity of iron lines suitable as standards, the best interference measurements require a variety of exposures, short ones for strong lines, long ones for weak lines, and intermediate ones for the remainder. The exposures with the grating spectrograph ranged from 5 minutes to an hour. With the prism spectrographs they ranged from 5 seconds to 30 minutes for iron and averaged about 5 minutes for cadmium or krypton. When making long exposures to the iron arc a quartz cell containing water was usually placed near the interferometer to absorb most of the heat radiation.

Accurate alignment of the light sources, condensers, interferometer, ring telescope, and spectrographs was effected in each case by placing an incandescent lamp at the center of the plate holder and centering each piece of apparatus in the light beam emerging from the slit in reverse order. Mirrors and lenses were so placed that each light source was first focused on the interferometer and again on the grating or prism of the spectrograph.

The interferometer plates were adjusted parallel by observing Haidinger's fringes when diffusely illuminated by light from a mercury lamp or a neon lamp. After adjustment they were allowed to stand for some hours and tested. If no further adjustment was required they were oriented so that the center of the interference patterns fell on the center of the spectrograph slit. This was accomplished in each case by observing, with magnification at the focus, the images of a wide slit and then reducing the slit width to $\frac{1}{10}$ or $\frac{1}{20}$ mm for exposures. If the fringes are not accurately centered on the slit systematic errors will appear in their measurement.

Typical interference spectrograms are reproduced in figures 1 and 2.

III. MEASUREMENTS

These interference spectrograms were measured with a micrometer originally designed by Dr. Keivin Burns and constructed in the Bureau's instrument shop about 24 years ago. All interference measurements of wave lengths reported by our spectroscopic laboratory have been made with it, but its description has been neglected. It has a screw of ½ mm pitch, a revolution counter [2] and head with 100 divisions, which moves a microscope (and reticule) across the interference pattern. Figure 3 illustrates this interference measuring device.

In measuring the grating spectrograms the diameters of three neon rings and five iron rings were determined. The same is true of cadmium and iron rings on prism spectrograms, but the number of krypton and iron rings measured was usually three and four respectively. This procedure resulted in measuring about the same over-all size of interference patterns for both primary and secondary standards, which was thought advisable to minimize errors due to possible distortion in the image forming systems. Such distortion would be

[2] The adaptation of a commercial counter was suggested by Mr. O. G. Lange, chief of the Bureau's instrument shop.

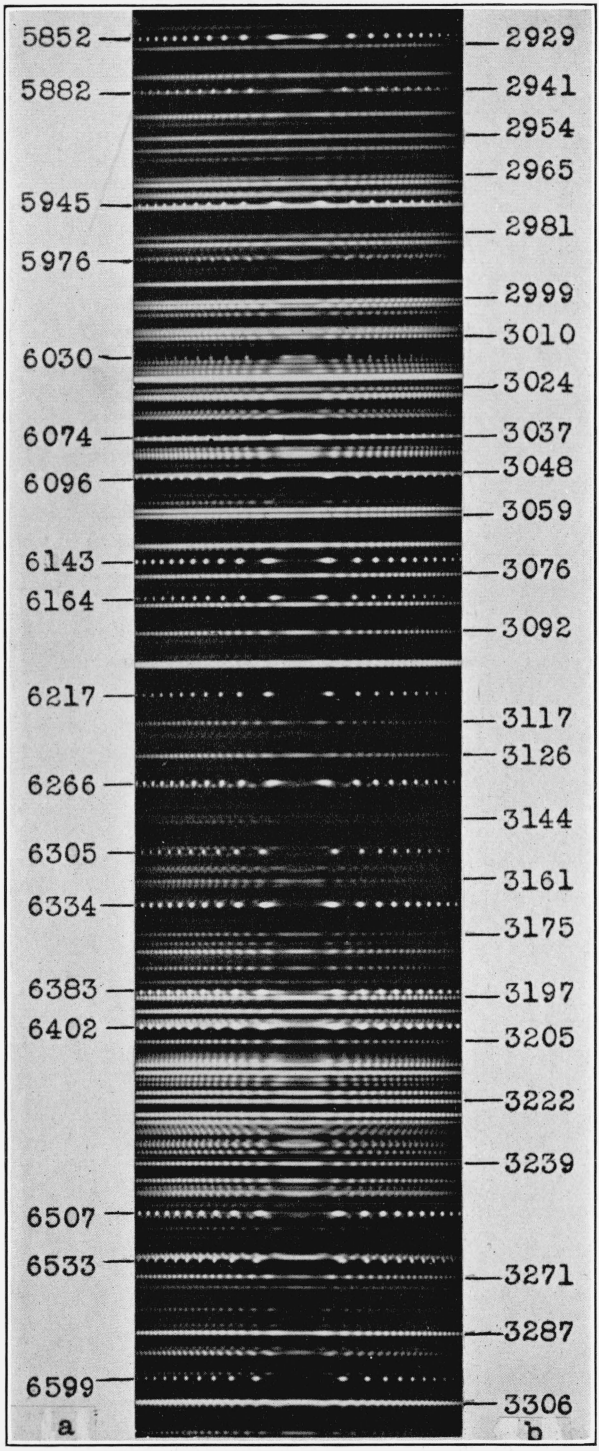

FIGURE 1.—*Fabry-Perot interference patterns of neon and iron (5-mm étalon) photographed simultaneously, (a) neon spectrum in gratings first order, and (b) iron in second.*

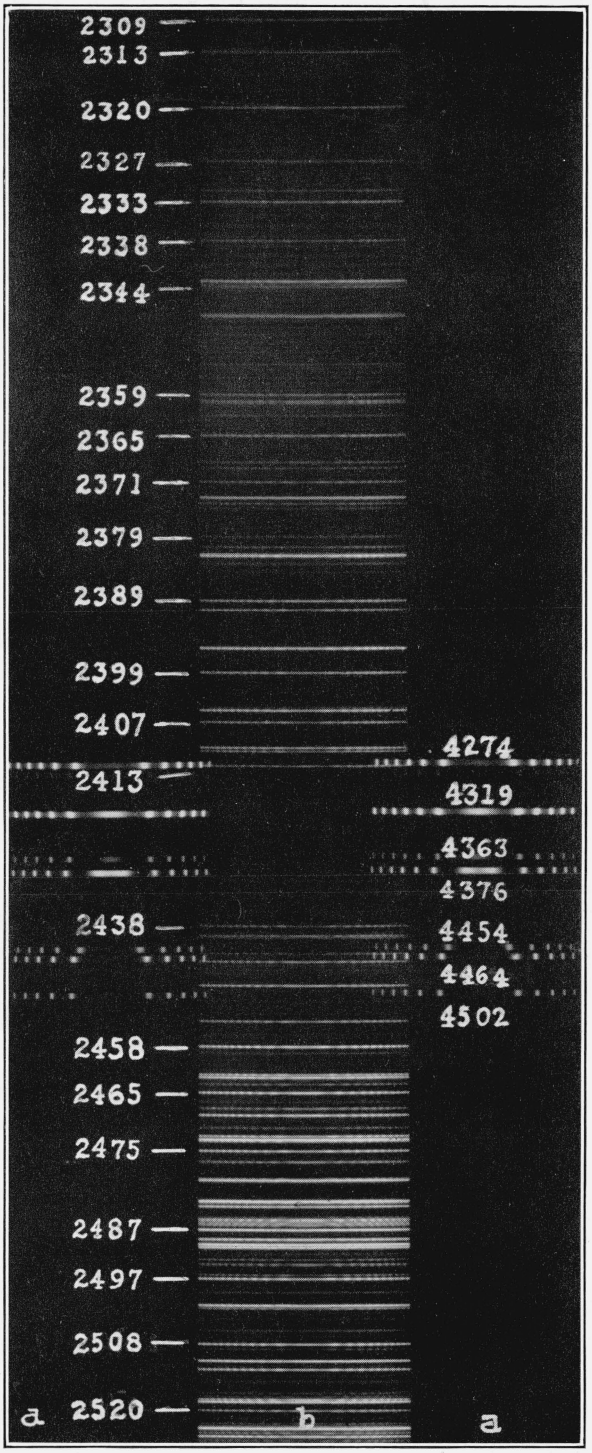

FIGURE 2.—*Fabry-Perot interference patterns of (a) krypton, and (b) iron (5 mm étalon) photographed alternately with different settings of quartz Littrow spectograph.*

revealed by slightly different fractional orders of interference from successive ring diameters, but no differences of this kind could be detected. The measured ring diameters were squared with the aid of Gauss's table of squares, and the average difference of squares for each line was plotted against wave length. A straight line was drawn to fit these points and for each wave length the value indicated by this line was divided into the successive squares of measured ring diameters to obtain the fractional order of interference at the center of the pattern. Although the interpolated value rarely differed from the observed by more than 1 percent, this procedure causes all the measurements on each plate to contribute to the accuracy of determining the fractional-order denominator for each wave length. For making the divisions a 20-inch slide rule was found most convenient and rapid.

The interference path or double étalon distance was found either from cadmium, krypton, or neon lines, the correct order number in every case being readily deduced by the method illustrated for neon by Meggers [12]. When cadmium was used, the value 6438.4696 A for its red radiation served as the primary standard. When neon was employed, a group of six lines (6304.7892, 6334.4279, 6382.9914, 6506.5279, 6532.8824, 6598.9529 A), with the center of gravity at 6437 A, was regarded as identical with the primary standard [13]. Substituting krypton for the primary standard, the separation of interferometer plates was determined from six to eight blue lines (4273.9700, 4318.5525, 4319.5797, 4362.6423, 4376.1220, 4453.9179, 4463.6902, 4502.3547 A), whose values have been accurately measured relative to cadmium or neon and have been adopted as standards by the International Astronomical Union [14]. Within the error of observation, our comparisons of iron wave lengths with these three different primary standards all yielded the same final values.

Since the general theory and method of comparing wave lengths with the Fabry-Perot interferometer have been given many times in other papers [15] no further details are required here.

IV. CORRECTIONS

Interference comparisons of wave lengths require corrections for deviations of atmospheric density from standard conditions (dry air at 15° C and 760 mm), and for the dispersion of phase change at reflection from the interferometer surfaces. Both corrections are important when the primary and secondary standards are in different spectral regions, and are especially large for the ultraviolet, where the dispersion curve of air rises steeply and the reflecting properties of surfaces usually change most rapidly with wave length.

The first correction was derived from observations of the mean air temperature and barometric pressure for each exposure. The air temperature near the interferometer was usually between 23 and 24° C, and the barometer was generally a little under normal so that these corrections were always negative, amounting to −0.0032 A for 2100 A relative to 4400 A in extreme cases. When ultraviolet lines are measured relative to blue krypton lines instead of red cadmium or neon the corrections are reduced by the difference of their values at 4400 and 6400 A. In all cases our corrections for standard air density were taken from the tables prepared for this purpose by Meggers and Peters [16]. Separate tables of corrections for temperature deviations and

for pressure deviations from normal were calculated relative to 6000 A by Jackson [17], who was apparently unaware that the combined result is obtainable relative to any fixed point from the tables referred to above.

After correcting to standard atmospheric conditions the apparent wave lengths calculated from interference measurements require an adjustment for the dependence of phase change at reflection upon wave length. This phase correction is readily obtained from the wave-length comparisons, if these are made with a variety of étalons [12]. In the present instance consistent and reliable results were given by a comparison of the data from 7.5- and 2-mm étalons, or from 5- and 2-mm étalons.

For our aluminized quartz plates this phase correction was always negative in the ultraviolet, −0.0008 A at 3500 A, but increased rapidly beyond 2900 A, and amounted to −0.0040 A at 2500 A for the 5-mm étalon. The largest correction of this type amounted to −0.0205 A for 2100 A measured with 2-mm étalons. The phase correction was extrapolated beyond 2153 A because no measurements were made there with étalons greater than 3 mm. Only when these corrections are properly determined and applied will the final values for homogeneous lines be the same from all étalons.

V. RESULTS

Although the primary standard is defined to eight significant figures (6438.4696 A) and some eight-place values of secondary standards from noble gas spectra (neon, krypton) have been adopted [13, 14], the published values of iron lines have heretofore been restricted to seven-place values for the reason that iron lines excited in a high-temperature arc are intrinsically less sharp and more difficult to measure.[3] The Doppler width of iron lines is 5 to 10 times that of the primary line, or of certain neon and krypton lines, and moreover the wave lengths of some iron lines have been found to vary from arc center to pole [18, 19]. This pole effect is eliminated by taking light from a narrow central zone of a long arc flame and the sharpness $\lambda/\Delta\lambda$ of the average iron line is closely described by its limiting order of interference, $N=100{,}000$ approximately. This means that the total width of a line at 3000 A is about 0.03 A, and to evaluate the wave length to ±0.0003 A requires that the center of gravity be determined within 1/100 of the width. Fortunately, no trouble on account of hyperfine structure need be feared because according to DeGier and Zeeman [20] the isotopic constitution of iron consists of 90.2 percent mass number 56; 6.5 percent mass number 54; 0.5 percent mass number 58; and 2.8 percent mass number 57. It may be assumed that observed spectral lines are due to mass 56 and any lines due to isotopes 54, 57, and 58 will be too faint to affect wave-length measurements of those from isotope 56. The principal factor limiting the precision of wave-length measurement of iron lines (aside from pole effect and line width) is the overlapping of interference patterns of very close lines of comparable intensity. We presume that this explains a number of cases in which consistent results were obtained with individual étalons, but the final mean values from different étalons disagreed by many times the probable error of each.

[3] Burns and Walters [4] and Jackson [5] have published eight-place wave numbers taken from eight-place wave lengths before reducing to seven, but no analysis was presented to justify this procedure.

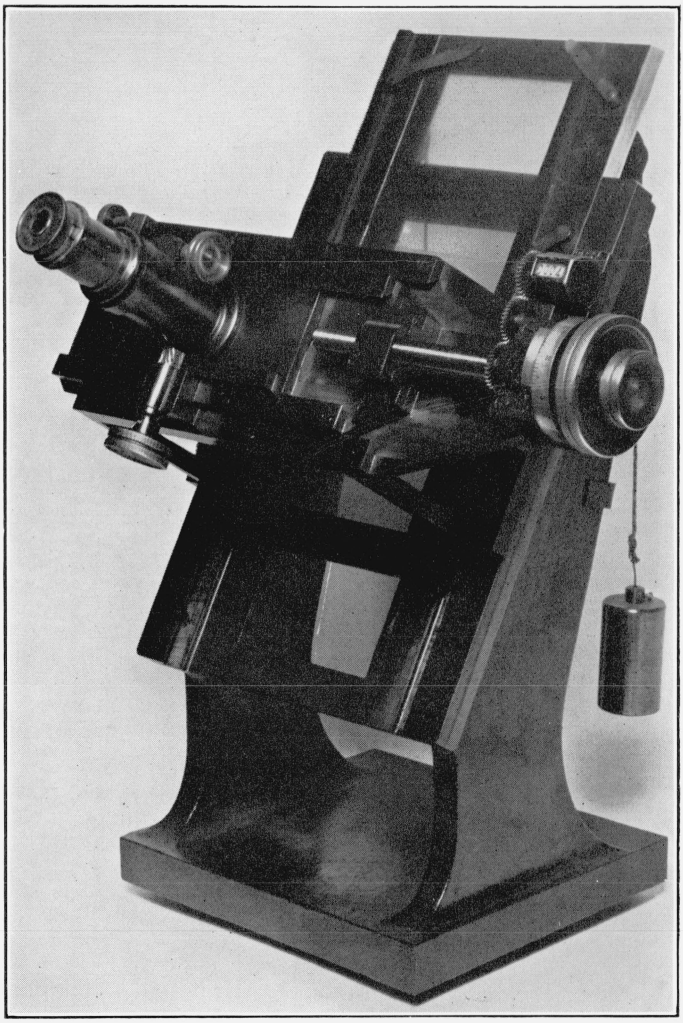

FIGURE 3.—*Interference measuring machine.*

TABLE 1.—*Individual values for various étalons* [1]

Wave length	Étalon			
	2 mm	5 mm	7.5 mm	10 mm
A				
3497.8418	8423	8404	8419	8411
	8414	8406	8420	8423
	8428	8421	8420	--------
	8408	8433	8421	--------
	8412	--------	--------	--------
3370.7845	7841	7837	7858	7858
	7829	7838	7846	7847
	7845	7835	7847	--------
	7840	7835	7839	--------
	7862	7852	7831	--------
	-------	7853	7849	--------
	-------	7848	7837	--------
	-------	7858	--------	--------
3217.3796	3787	3800	3800	3798
	3789	3793	3798	3792
	3815	3795	3786	--------
	3785	3790	3795	--------
	3829	3798	3794	--------
	-------	3781	3800	--------
	-------	3787	3793	--------
	-------	3796	--------	--------
2851.7970	7981	7973	7984	7973
	7975	7962	7978	7974
	7968	7973	7966	--------
	7961	7958	7963	--------
	7946	7967	7975	--------
	-------	7964	7972	--------
	-------	7958	--------	--------
	-------	7970	--------	--------

[1] The whole number is shown only in the first column.

The concordance of fractional-order determinations from four or five successive rings for each line induced us to carry the wave-length calculations and corrections to the fourth-place decimal of an angstrom. When the corrected results were assembled and averaged the fourth-decimal place was retained with the intention of rounding to three places for publication. Since most of the lines were observed on 10 to 20 or more spectrograms and each value was based upon four or five measured ring diameters, each final value rests on from 80 to 200 bisections of ring segments. Where so many observations exist, it would seem that the least squares calculation of probable error might have physical significance. In taking the final means, the individual values from each étalon were given equal weight, and then the various étalon mean values were averaged by weighting according to the number of observations with each. For the majority of lines the calculated probable error of the mean was less than 0.0005 A both for étalon means (table 1) and for final means (table 2). Now the term analyses of iron spectra permit a crucial test of the precision of wave-length measurements by means of the

combination principle. Most of the lines we have measured have been classified and among them are 20 pairs of eight-figure values where wave-number differences measure the level separations of low atomic-energy states. These are listed in table 3.

TABLE 2.—*Mean values from various étalons* [a]

Wave length	2 to 3 mm	Obs.	5 mm	Obs.	7.5 mm	Obs.	10 mm	Obs.
A								
3497.8418	8417	5	8415	4	8420	4	8417	2
3401.5196	5197	4	5193	8	5198	6	5200	2
3355.2285	2281	2	2283	6	2287	3	2293	2
3286.7538	7533	5	7542	7	7538	6	7544	2
3217.3796	3801	5	3793	8	3795	7	3795	2
3175.4465	4469	5	4460	8	4464	7	4469	2
3091.5777	5768	5	5777	8	5781	6	5782	2
3015.9129	9132	5	9128	8	9129	6	9134	2
2959.9924	9928	5	9921	8	9921	6	9930	2
2912.1581	1572	5	1587	8	1577	5	1586	2
2851.7970	7966	5	7966	8	7974	6	7974	2
2804.5200	5193	5	5202	10	5203	7	5205	2
2755.7366	7357	5	7360	7	7376	4	7364	2
2706.5812	5804	4	5816	5	5808	1	5820	1
2643.9972	9966	3	9965	6	9976	4	9986	1
2413.3087	3088	10	3084	6	3090	2	--------	-----
2327.3940	3940	15	3941	8	3935	2	--------	-----

[a] The whole number is shown only in the first column.

TABLE 3.—*Energy-level differences*

Term symbols	Wave numbers	Differences	Term symbols	Wave numbers	Differences
			$a^7D_4-a^7D_5^\circ$	31027.036−30815.486	211.550
$a^5D_0-a^5D_1^\circ$	28844.618−28754.676	89.942		31072.250−30860.694	211.556
	33804.031−33714.093	89.938		31482.556−31271.012	211.544
	43523.036−43433.091	89.945			
			$a^6D_1-a^6D_2^\circ$	38246.715−38132.274	114.441
$a^5D_1-a^5D_2^\circ$	29028.750−28844.618	184.132		41538.728−41424.284	114.445
	33988.163−33804.031	184.132		42758.377−42643.934	114.443
	43479.629−43295.502	184.127			
	43707.159−43523.036	184.123	$a^6D_2-a^6D_3^\circ$	41667.176−41472.250	194.926
				42953.306−42758.377	194.929
$a^5F_4-a^5F_5^\circ$	35983.665−35535.177	448.488			
	37315.443−36866.941	448.502	$a^6D_3-a^6D_4^\circ$	38474.191−38191.328	282.863
	41001.740−40553.249	448.491		42273.457−41990.584	282.873

The average deviation from the mean is 0.0034 wave number, which corresponds to an average probable error of less than 0.0004 A in the relative values of these wave lengths. We feel that these experiences justify the retention of the fourth decimal place when the probable error of the final mean is less than 0.0005 A. Our final values are exhibited in table 4, together with values quoted from Burns and Walters [4] and from Jackson [5] for purposes of comparison. The values measured by Burns and Walters apply to the iron arc at reduced pressure, and are not strictly comparable with the others unless corrected for pressure displacement. Comparison of 219 B and W

lines and 108 J lines with our values shows the following differences in Angstrom units:

	NBS—B and W	NBS—J
Systematic difference	+0.0008	±0.0000
Accidental difference	±0.0014	±0.0011

The systematic difference is of the expected order and sign for the displacement due to atmospheric pressure, but the accidental differences are two or three times our average probable error. If correction is made for the former, the averaging of three independent and concordant observations will yield satisfactory seven-place secondary standards of wave length throughout a considerable range of ultraviolet.

Our observations were purposely extended above 3370 A to test the agreement of the present series with the values adopted by the IAU [10]. For 13 lines (3370.7 to 3497.8 A) there is an accidental difference of 0.0010 A, and a systematic difference (NBS−IAU)= −0.0009 A. This discrepancy would appear to be larger than the probable error of either set, but we are unable to account for it. It illustrates again the extreme difficulty of accurately determining the relative values of wave lengths widely separated in the spectrum. Assuming that this difference is not due to errors of focus for the primary and secondary lines and that the corrections for standard air density and dispersion of phase have been correctly made in each case, the only uncertainty (neglecting error of measurement) is a secondary correction due to water vapor in the air since interference measurements are always made in moist air. But the corrections for standard air density are taken from data applying to dry air. Considering the data on refraction and dispersion of steam by C. and M. Cuthbertson [21], it is obvious that the correction for absolute humidity of average air must be a differential one of negligible magnitude for ordinary interference comparisons.

It may be recalled that the scale of secondary standards adopted by the IAU in 1928 was somewhat lower than the values of 1922. This revision [22] ranged from −0.001 A for 3370 to 4000 A to −0.009 A for 6663 to 6750 A. It appears probable from our measurements that the ultraviolet values may still be 1 part in 4 million too large.

Our final results are displayed in the first column of table 4, the second column of which indicates the number of spectrograms on which each line was measured. The fractional values and number of observations reported by Burns and Walters [4] and by Jackson [5] are quoted in columns 3 and 4, respectively. In column 3 the letter c means computed value. Spectral-term combinations as given by Burns and Walters [4], by Catalán [23], and by Russell [24] are entered in column 5. Here odd multiplicities designate lines due to neutral atoms and even multiplicities designate those characteristic of singly ionized atoms. Vacuum wave numbers calculated from the data in column 1 with the aid of Kayser's Tabelle der Schwingungszahlen appear in the last column.

136221—37——4

TABLE 4.—*Interference measurements of wave length in the ultraviolet spectrum of iron*

λ_{air} A NBS	Number of observations N	Burns and Walters		Jackson		Term combination	Wave number in vacuum
		λ	N	λ	N		
3497. 8418	15	841	7	843	3	$a^5D_1-a^5P^\circ_2$	28580. 909
3490. 5746	5	574	4	575	3	$a^5D_3-a^5P^\circ_3$	28640. 411
3485. 3415	20	339	8	342	4	$a^5P_2-a^5P^\circ_1$	28683. 413
3476. 7035	14	702	6	703	1	$a^5D_0-a^5P^\circ_1$	28754. 676
3465. 8622	9	860	5	863	3	$a^5D_1-a^5P^\circ_1$	28844. 618
3445. 1506	20	148	11	150	2	$a^5P_2-19R^\circ_3$	29018. 021
3443. 8774	13	878	6	878	3	$a^5D_2-a^5P^\circ_1$	29028. 750
3427. 1207	16	119	9	121	5	$a^5P_3-18R^\circ_4$	29170. 679
3413. 1335	20	131	11			$a^5P_2-d^3D^\circ_3$	29290. 219
3407. 4608	18	460	9			$a^5P_3-c^3F^\circ_4$	29338. 979
3401. 5196	20	518	8	522	4	$a^5F_4-b^5P^\circ_3$	29390. 221
3399. 3343	21	333	10	337	4	$a^5P_2-d^3D^\circ_2$	29409. 115
3396. 9772	19	974	5			$a^5F_3-b^5P^\circ_2$	29429. 520
3383. 9808	22	979	8			$a^5P_3-c^3F^\circ_3$	29542. 543
3380. 1111	18	110	8			(Fe I)	29576. 364
3370. 7845	22	784	8	786	4	(Fe I)	29658. 195
3355. 2285	13	228	7	229	4	(Fe I)	29795. 697
3347. 9262	11	926	3	928	4	$a^3P_2-4R^\circ_3$	29860. 682
3340. 5659	13	565	3	566	4	$a^3P_2-2R^\circ_2$	29926. 473
3337. 6655	10	666	2	667	4	(Fe I)	29952. 476
3328. 8669	19	867	5	866	4	(Fe I)	30031. 644
3323. 7374	19	735	6	737	4	(Fe I)	30077. 990
3314. 7421	21	741	7	741	4	(Fe I)	30159. 610
3306. 356	3	352	8			$a^5P_1-e^5P^\circ_2$	30236. 10
3305. 971	3	970	9			$a^5P_2-e^5P^\circ_3$	30239. 62
3298. 1328	19	132	9	131	6	$a^5P_1-4R^\circ_2$	30311. 488
3286. 7538	20	753	10	754	6	$a^5P_3-e^5P^\circ_3$	30416. 425
3284. 5892	9	588	5	587	5	$a^5P_2-e^5P^\circ_2$	30436. 469
3280. 2613	19	260	8	261	5	(Fe I)	30476. 624
3271. 0014	21	0. 999	10	001	7	$a^5P_2-e^5P^\circ_1$	30562. 898
3257. 5937	19	593	7	592	5	$a^5P_3-4R^\circ_2$	30688. 685
3254. 3628	20	363	8	362	5	(Fe I)	30719. 153
3244. 1887	21	187	10	190	7	$a^7D^\circ_4-34W_5$	30815. 486
3239. 4362	21	434		437	7	$a^7D^\circ_4-33W_4$	30860. 694
3236. 2226	22	223	10	222	7	$a^5D_3-a^3F^\circ_4$	30891. 337
3225. 7883	17	788	10	790	7	$a^7D^\circ_5-53W_6$	30991. 256
3222. 0682	19	067	10	069	7	$a^7D^\circ_5-34W_5$	31027. 036
3217. 3796	22	377	9	381	7	$a^7D^\circ_5-33W_4$	31072. 250
3215. 9398	18	939	9	940	7	$a^7D^\circ_2-20W_2$	31086. 159
3205. 3992	20	399	9	400	7	$a^7D^\circ_1-43W_1$	31188. 380
3200. 4741	9	471	10	474	7	$a^7D^\circ_2-17W$	31236. 375
3196. 9288	8	927	11	930	8	$a^7D^\circ_4-25W_5$	31271. 012
3191. 6583	9	659	9	660	7	$a^5D_4-a^3D^\circ_3$	31322. 649
3184. 8948	22	894	8	896	7	$a^5D_3-a^3F^\circ_3$	31389. 164
3178. 0137	16	013	6	016	7	$a^7D^\circ_2-27W_4$	31457. 126
3175. 4465	22	445	8	447	7	$a^7D^\circ_5-25W_5$	31482. 556
3160. 6582	22	659	6	657	2	$a^7D^\circ_4-16W_4$	31629. 854
3157. 0388	17	038	4	042	2	$a^7D^\circ_4-13W_4$	31666. 113
3143. 9896	12					(Fe I)	31797. 540
3134. 1113	21	108	7	111	7	$a^5F_3-c^5D^\circ_4$	31897. 757

TABLE 4.—*Interference measurements of wave length in the ultraviolet spectrum of iron*—Continued

λ_{air} A NBS	Number of observations N	Burns and Walters		Jackson		Term combination	Wave number in vacuum
		λ	N	λ	N		
[a] 3125. 653	14	652	3	658	7	$a^7D_5^\circ$–10W_4	31984. 07
3116. 6329	22	632	8	633	7	a^5F_1–$c^5D_2^\circ$	32076. 636
3091. 5777	21	577	11	579	12	a^5F_1–$c^5D_0^\circ$	32336. 585
3083. 7419	21	741	12	743	12	a^5F_2–$c^5D_1^\circ$	32418. 751
3075. 7204	20	721	9	722	9	a^5F_3–$c^5D_2^\circ$	32503. 296
3067. 2433	14	244	9	245	10	a^5F_4–$c^5D_3^\circ$	32593. 122
3059. 0874	16	090	2	085	2	a^5D_3–$b^5D_4^\circ$	32680. 015
3057. 4452	12	447	6	447	9	a^5F_5–$c^5D_4^\circ$	32697. 567
3055. 2631	22	264	8			a^3F_3–$c^3D_2^\circ$	32720. 920
3047. 6059	12	607	2	605	2	a^5D_2–$b^5D_3^\circ$	32803. 128
3040. 4281	22	427	11			a^5F_4–$c^5F_5^\circ$	32880. 566
3037. 3891	9	394	2	387	3	a^5D_1–$b^5D_2^\circ$	32913. 462
3030. 1491	22	148	10			(Fe I)	32992. 100
3024. 0330	21	033	10			a^5D_1–$a^3P_2^\circ$	33058. 823
3015. 9129	16					(Fe I)	33147. 826
3009. 5698	20	570	11			a^5F_4–$c^5F_4^\circ$	33217. 689
3003. 0311	22	031	9			a^5F_3–$c^5F_2^\circ$	33290. 012
2999. 5123	10	514	9	513	7	a^5F_5–$c^5F_5^\circ$	33329. 065
2990. 3923	9	391	9			(Fe I)	33430. 705
2987. 2919	21	292	12	291	9	a^5F_4–$c^5F_3^\circ$	33465. 401
2981. 4448	13	445	8	446	8	a^5D_3–$a^3P_2^\circ$	33531. 028
2965. 2551	11	255		255	10	a^5D_0–$b^5F_1^\circ$	33714. 093
2959. 9924	21	991	14			(Fe I)	33774. 031
2957. 3654	11	366	17	365	9	a^5D_1–$b^5F_1^\circ$	33804. 031
2953. 9400	18	939	9	940	8	a^5D_2–$b^5F_2^\circ$	33843. 229
2941. 3430	14	344	19	343	2	a^5D_2–$b^5F_1^\circ$	33988. 163
2929. 0081	17	008	16	008	10	a^5D_3–$b^5F_2^\circ$	34131. 291
2920. 6906	14	689	19			a^5F_2–$c^3F_2^\circ$	34228. 484
2912. 1581	20	159	21	158	11	a^5D_4–$b^5F_3^\circ$	34328. 767
2899. 4156	13	414	21			(Fe I)	34479. 631
2895. 0352	13	034	19			a^3F_3–$c^3F_3^\circ$	34531. 798
2894. 5050	15	504	19			(Fe I)	34538. 122
2877. 3005	12	301	19			a^3F_4–18R_4°	34744. 631
2874. 1722	21	172	19			a^5D_4–$a^5G_5^\circ$	34782. 445
2869. 3075	20	308	18	307	8	a^5D_3–$a^5G_4^\circ$	34841. 412
2863. 864	10	864	15			a^5D_2–$a^5G_3^\circ$	34907. 63
2851. 7970	21	797	22	797	11	a^5F_1–$b^5G_2^\circ$	35055. 334
2845. 5945	15	595	18			a^5F_3–$c^5P_2^\circ$	35131. 740
2838. 1193	22	119	21	120	7	a^5F_2–$b^5G_2^\circ$	35224. 266
2832. 4350	21	437	21	436	10	a^5F_3–$b^5G_4^\circ$	35294. 951
2823. 2753	22	274	21	276	3	a^5F_3–$b^5G_3^\circ$	35409. 455
2813. 2861	17	287	19	288	9	a^5F_4–$b^5G_5^\circ$	35535. 177
2806. 9840	16	985	22	985	8	a^5F_4–80B	35614. 955
2804. 5200	25	521	21	521	5	a^5F_4–$b^5G_4^\circ$	35646. 244
2797. 7751	11	775	20			a^5F_4–83B	35732. 175
2781. 8347	6	836	18			a^5F_2–$d^5D_3^\circ$	35936. 917
2778. 2205	25	221	18	220	10	a^5F_5–$b^5G_5^\circ$	35983. 665
2767. 5208	19	522	15	525	9	a^5F_4–$d^5D_4^\circ$	36122. 776
2763. 1078	7	108	19			a^5F_2–52R_3°	36180. 464
2755. 7366	19	738	19			a^4D_4–$a^4F_3^\circ$	36277. 237

TABLE 4.—*Interference measurements of wave length in the ultraviolet spectrum of iron*—Continued

λ_{air} A NBS	Number of observations N	Burns and Walters		Jackson		Term combination	Wave number in vacuum
		λ	N	λ	N		
2749. 325	12	322	11			$a^4D_3-a^4F^\circ_4$	36361. 83
2746. 9823	13	983	18			$a^4D_3-a^4D^\circ_3$	36392. 842
2746. 4833	14	482	18			$a^4D_2-a^4F^\circ_3$	36399. 454
2739. 5467	25	546	19			$a^4D_4-a^4D^\circ_4$	36491. 611
2735. 473	15	475	19	476	5	$a^5F_4-d^5D^\circ_3$	36545. 95
2727. 540	4	538	19			$a^4D_3-a^4D^\circ_2$	36652. 24
2723. 5770	6	576	11	577	2	$a^5D_2-b^5P^\circ_1$	36705. 568
2718. 4352	12	435	15			$a^5F_2-47R^\circ_1$	36774. 989
2714. 413	6	411	16			$a^4D_4-a^4D^\circ_3$	36829. 48
2711. 6548	9	654	17			$a^5F_4-50R^\circ_5$	36866. 941
2706. 5812	11	582	19			$a^5F_3-51R^\circ_2$	36936. 043
2699. 1060	16	104	17	108	8	$a^5F_4-49R^\circ_4$	37038. 333
2689. 2117	26	212	14	212	7	$a^5F_4-48R^\circ_3$	37174. 597
2679. 0608	26	061	20	063	9	$a^5F_5-50R^\circ_5$	37315. 443
2673. 2127	6	213	6			$a^5F_1-c^3D^\circ_1$	37397. 072
2662. 0563	14	056	14			$a^5F_3-c^3D^\circ_2$	37553. 789
2651. 7059	7	706	12			$a^5F_3-b^3G^\circ_4$	37700. 363
2647. 5576	10	557	13			$a^5D_3-b^3D^\circ_3$	37759. 431
2643. 9972	22	999	15	4. 005	7	$a^5F_1-c^5G^\circ_2$	37810. 273
2635. 8082	15	808	15	807	8	$a^5F_2-c^5G^\circ_3$	37927. 736
2628. 2923	27	292	11	292	3	$a^6D_1-a^6D^\circ_2$	38036. 188
2625. 6663	24	666	18	668	5	$a^6D_4-a^6D^\circ_5$	38074. 227
2621. 6690	8	667	21			$a^6D_1-a^6D^\circ_1$	38132. 274
2617. 6160	16	615	17			$a^6D_3-a^6D^\circ_3$	38191. 328
2613. 8240	13	823	23	822	2	$a^6D_2-a^6D^\circ_1$	38246. 715
2611. 8725	14	873	19	872	3	$a^6D_4-a^6D^\circ_4$	38275. 290
2598. 3689	8	368	20	369	9	$a^6D_4-a^6D^\circ_3$	38474. 191
2585. 8753	9	877	19	876	10	$a^6D_5-a^6D^\circ_4$	38660. 066
2584. 5349	7	538	19	535	8	$a^5F_5-c^5G^\circ_6$	38680. 115
2576. 1033	6					(Fe I)	38806. 705
2575. 7442	7	744	23			(Fe I)	38812. 116
2562. 5348	11	533	17	534	8	$a^4D_4-a^4P^\circ_3$	39012. 172
2551. 0936	11	090	23			(Fe I)	39187. 122
2542. 1007	11	101	17	102	2	(Fe I)	39325. 739
2530. 6938	10	691	14	692	1	(Fe I)	39502. 984
2519. 6279	11	627	19			(Fe I)	39676. 464
2507. 8987	11	898	20	900	7	(Fe I)	39862. 013
2496. 5324	11	534	20	533	8	(Fe I)	40043. 485
2487. 0643	8	064	17			(Fe I)	41195. 915
2474. 8131	11	813	16	814	8	(Fe I)	40394. 883
2468. 8782	11	878	20	879	7	(Fe I)	40491. 982
2465. 1479	11	148	22	148	8	a^5F_4-142B	40553. 249
2457. 5956	10	595	18	595	8	(Fe I)	40677. 862
2453. 4746	11	472	20			(Fe I)	40746. 181
2447. 7086	10	707	17	708	5	$a^5D_4-c^5F^\circ_3$	40842. 159
2443. 8707	8	870	18			$a^5F_5-26R^\circ_4$	40906. 292
2442. 5674	9	567	19			(Fe I)	40928. 117
2438. 1811	11	179	15			a^5F_5-142B	41001. 740
2431. 025	4	023	12			(Fe I)	41122. 43
2413. 3087	18	308	18	309	10	$a^6D_1-a^6F^\circ_2$	41424. 284
2411. 0663	17	064	22	066	7	$a^6D_1-a^6F^\circ_1$	41462. 808
2410. 5172	11	518	13	517	8	$a^6D_2-a^6F^\circ_3$	41472. 250
2406. 6593	20	659	18	657	3	$a^6D_2-a^6F^\circ_2$	41538. 728
2404. 430	3	429	19			$a^6D_2-a^6F^\circ_1$	41577. 24
2399. 2396	12	239	19	238	5	$a^6D_3-a^6F^\circ_3$	41667. 176

TABLE 4.—*Interference measurements of wave length in the ultraviolet spectrum of iron*—Continued

λ_{air} A NBS	Number of observations N	Burns and Walters		Jackson		Term combination	Wave number in vacuum
		λ	N	λ	N		
2389. 9713	15	970	19			$a^5D_2-c^5P^\circ_3$	41828. 746
2388. 6270	18	627	16	625	2	$a^6D_4-a^6F^\circ_4$	41852. 284
2384. 386	3	385	17			$a^4F_2-a^4D^\circ_2$	41926. 72
2380. 7591	17	759	18	757	3	$a^6D_3-a^6P^\circ_4$	41990. 584
2379. 2756	20	275	17	273	3	$a^4F_4-a^4D^\circ_4$	42016. 766
2375. 193	2	191	19			$a^4F_2-a^4D^\circ_1$	42088. 98
2374. 517	2	516	17			$a^5D_0-c^5P^\circ_1$	42100. 96
2371. 4285	18	427	19			$a^5D_2-c^5P^\circ_2$	42155. 787
2370. 497	2	495	12			$a^4F_2-a^4F^\circ_2$	42172. 35
2368. 595	20	594	19			$a^4F_3-a^4D^\circ_2$	42206. 21
2366. 592	3	590	10			$a^4F_3-a^4F^\circ_3$	42241. 93
2364. 8269	21	826	20	825	4	$a^6D_4-a^6P^\circ_4$	42273. 457
2362. 019	4	019	15			$a^4F_4-a^4F^\circ_4$	42323. 71
2360. 294	2	292	19			$a^4F_4-a^4D^\circ_3$	42354. 64
2359. 997	2	997	18			$a^4F_5-a^4F^\circ_5$	42359. 96
2359. 1039	23	104		102	3	$a^6D_2-a^6P^\circ_3$	42376. 000
2354. 8888	17	888	14			$a^4F_3-a^4F^\circ_2$	42451. 843
2344. 2802	19	279	24			$a^6D_1-a^6P^\circ_2$	42643. 934
2338. 0052	25	005	21	002	2	$a^6D_2-a^6P^\circ_2$	42758. 377
2332. 7972	22	796	22	795	3	$a^6D_4-a^6P^\circ_3$	42853. 827
2331. 3067	25	305	19	305	3	$a^4F_5-a^4F^\circ_4$	42881. 222
2327. 3940	25	394	22	392	3	$a^6D_3-a^6P^\circ_2$	42953. 306
2320. 3561	15	355	19			$a^5D_3-d^5D^\circ_4$	43083. 575
2313. 1022	16	102	22			$a^5D_2-d^5D^\circ_3$	43218. 672
2308. 9971	16	996	21			$a^5D_1-d^5D^\circ_2$	43295. 502
2303. 579	6	577	19			$a^5D_1-45R^\circ_2$	43397. 32
2303. 4225	6	422	17			(Fe I)	43400. 274
2301. 6818	18	681	16			$a^5D_0-d^5D^\circ_1$	43433. 091
2300. 1397	18	139	18			$a^5D_2-52R^\circ_3$	43462. 210
2299. 2180	16	218	17			$a^5D_2-d^5D^\circ_2$	43479. 629
[b]2297. 785	5	787	13			$a^5D_3-d^5D^\circ_3$	43506. 74
2296. 9247	14	926	10			$a^5D_1-d^5D^\circ_1$	43523. 036
2294. 4059	16	406	10			$a^5D_1-d^5D^\circ_0$	43570. 812
2293. 8454	8	847	3			(Fe I)	43581. 457
2292. 5227	16	523	20			$a^5D_3-53R^\circ_4$	43606. 601
2291. 122	5	117	11			(Fe I)	43633. 26
2287. 632	5	628	9			(Fe I)	43699. 82
2287. 2477	9	248	20			$a^5D_2-d^5D^\circ_1$	43707. 159
2284. 087	10	083	20			$a^5D_3-d^5D^\circ_2$	43767. 63
2283. 653	2	652	9			$a^5D_1-51R^\circ_2$	43775. 95
[c]2279. 922	7	927	7			$a^5D_2-48R^\circ_3$	43847. 58
2277. 098	9	094	7			(Fe I)	43901. 96
2276. 0247	9	023	10			$a^5D_4-d^5D^\circ_3$	43922. 654
2274. 0885	12	087	8			$a^5D_2-51R^\circ_2$	43960. 047
2272. 0670	8	065	12			$a^5D_3-49R^\circ_4$	43999. 157
2271. 781	6	778	9			(Fe I)	44004. 69
2270. 8601	14	858	5			$a^5D_4-53R^\circ_4$	44022. 538
[d]2265. 053	12	047	8			$a^5D_3-48R^\circ_3$	44135. 39
2264. 3894	15	390	8			(Fe I)	44148. 324
2260. 079	12	078	6			$a^6D_5-a^4F^\circ_5$	44232. 51
2259. 511	7	511	12			(Fe I)	44243. 63
2255. 861	5	859	6			(Fe I)	44315. 21
2253. 1251	18	122	4			$a^6D_4-a^4F^\circ_4$	44369. 017
2249. 177	8	173	4			$a^6D_5-a^4D^\circ_4$	44446. 89
2248. 858	8	855	5			(Fe I)	44453. 20

TABLE 4.—*Interference measurements of wave length in the ultraviolet spectrum of iron*—Continued

λ_{air}A NBS	Number of observations N	Burns and Walters		Jackson		Term combination	Wave number in vacuum
		λ	N	λ	N		
2245. 651	12	646	3			$a^5D_2-c^3D^\circ_3$	44516. 67
2240. 627	9					(Fe I)	44616. 48
2231. 211	13	211	5			$a^5D_3-c^3D^\circ_3$	44804. 75
2228. 1704	13	164	3			$a^5D_3-c^3D^\circ_2$	44865. 880
2211. 234	5	232	c			$a^5D_2-c^5G^\circ_3$	45209. 48
2210. 686	7	684	c			$a^5D_4-c^3D^\circ_3$	45220. 69
2207. 068	5	063	c			$a^5D_4-b^3G^\circ_5$	45294. 81
2201. 117	5	113	c			$a^5D_3-c^5G^\circ_4$	45417. 26
2200. 7227	8	721	6			$a^5D_1-d^5P^\circ_2$	45425. 393
2196. 040	5	037	6			$a^5D_1-d^5P^\circ_1$	45522. 24
2191. 202	10	201	2			a^5D_0–20 R°_1	45622. 74
2187. 192	4	188	6			$a^5D_2-d^5P^\circ_1$	45706. 38
2186. 890	7	888	5			a^5D_1–20R°_1	45712. 69
2183. 979	9					(Fe I)	45773. 61
2180. 866	6	863	c			$a^5D_1-b^3P^\circ_2$	45838. 94
2176. 837	11	835	c			$a^5D_0-b^3P^\circ_1$	45923. 77
2173. 212	12	208	3			a^5D_1–16R°_2	46000. 37
2172. 581	10	579	c			$a^5D_1-b^3P^\circ_1$	46013. 72
2165. 861	4	859	3			(Fe I)	46156. 48
2164. 547	8	543	c			a^5D_2–16R°_2	46184. 49
2163. 860	7	856	c			a^5D_0–10R°_1	46199. 15
2163. 368	5	363	1			(Fe I)	46209. 66
2161. 577	11	574	c			$a^5D_1-d^3D^\circ_2$	46247. 94
2157. 792	9	793	4			a^5D_3–19R°_3	46329. 06
[d]2154. 458	3					(Fe I)	46400. 74
2153. 004	11	001	c			$a^5D_2-d^3D^\circ_2$	46432. 07
2151. 099	5	095	c			$a^5D_3-c^3F^\circ_4$	46473. 19
2150. 182	4	179	c			$a^5D_2-c^3F^\circ_2$	46493. 01
2147. 787	2					(Fe I)	46544. 84
2145. 188	9	185	c			$a^5D_3-d^3D^\circ_3$	46601. 23
2141. 715	7	713	c			$a^5D_3-c^3F^\circ_3$	46676. 79
2139. 695	9	693	c			a^5D_4–18R°_4	46720. 85
2138. 589	7	587	c			a^5D_4–19R°_3	46745. 01
2135. 957	5					(Fe I)	46802. 60
2132. 015	9	011	c			$a^5D_4-c^3F^\circ_4$	46889. 13
2130. 962	7					(Fe I)	46912. 29
2115. 168	5	164	c			$a^5D_2-e^5P^\circ_3$	47262. 54
[d]2112. 966	2	963	c			$a^5D_0-e^5P^\circ_1$	47311. 79
2110. 233	6					(Fe I)	47373. 06
2108. 955	5	954	c			$a^5D_1-e^5P^\circ_1$	47401. 76
2102. 349	3	349	c			$a^5D_3-e^5P^\circ_3$	47550. 69
2100. 795	4	792	c			$a^5D_2-e^5P^\circ_1$	47585. 86

NOTES TO TABLE 4

[a] Mean value from 5- and 7.5-mm étalons. 3160.060 from 2 mm and 0.049 from 10 mm. Possibly 3 lines, a^3G_4–163B, $a^5F_2-c^5D^\circ_3$, and $a^7D^\circ_5$–10W_4.
[b] Probably double.
[c] Spark line $a^6D_4-a^4F^\circ_5$ at 43847.76.
[d] Measured only with 2-mm étalons.

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