RP4

INTERFEROMETER MEASUREMENTS OF WAVE LENGTHS IN THE VACUUM ARC SPECTRA OF TITANIUM AND OTHER ELEMENTS

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ABSTRACT

Wave-length determinations by means of the Fabry-Perot interferometer have been made for the vacuum arc spectrum of titanium. More than 300 lines have been measured between 6743 A in the red and 2941 A in the ultra-violet. For many of the lines the accuracy of measurement exceeds 1 part in 6,000,000; for the majority it exceeds 1 part in 4,500,000. Using only the wave numbers of lines of wave lengths longer than 4700 A, and constant wave-number differences as determined in various parts of the spectrum, a set of terms has been derived, which have been used to calculate the wave lengths of the blue and violet lines. The comparison of calculated with observed wave lengths indicates that no difference in scale exists between the red and violet regions. In addition to titanium some wave lengths were measured for iron, copper, calcium, barium, and other elements.

CONTENTS

I. INTRODUCTION

In the summer of 1923 the Allegheny Observatory and the spectroscopy section of the Bureau of Standards entered upon a cooperative program for the determination of standard solar wave lengths by interference methods. The results of that work, wave lengths of more than 700 Fraunhofer lines included between 3592 and 7148 A, have now been published.[1] From the earlier results of the solar work it became apparent that a comparison of solar with laboratory wave lengths would have significance only if the latter were obtained from sources unaffected by conditions not present in the sun. It was,

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[1] Publ. Allegheny Observatory, **6**, p. 105; 1926; pp. 125 and 141; 1927.

therefore, decided to enlarge the scope of the program to include the determination of the vacuum arc wave lengths of the more prominent elements appearing in the solar spectrum.

In the present paper are given the results which have been obtained for the element titanium from 6743 A in the red to 2941 A in the ultra-violet. Some wave lengths of other elements were also measured during the course of the work, and these are presented at this time because of their significance for the solar problem.

II. METHOD OF OBSERVATION

Light rays from the vacuum arc and from the neon tube, which served as the source of standards, were delivered simultaneously to the Fabry-Perot interferometer. The vacuum arc was identical with that designed and described by Curtis.[2] The beam from the arc, perpendicular to the line joining the Ne tube and the slit of the spectrograph, was collimated with the beam from the Ne lamp by means of a thinly silvered diagonal mirror placed about 20 cm in front of the interferometer. The arrangement of the sources was in all respects similar to that used previously in the redetermination of secondary standards from the iron arc.[3]

The material used in the arc was powdered titanium carbide which was packed into a cored graphite rod that served as the lower and positive electrode. The upper, negative electrode was usually a copper rod, but for a few exposures, an upper graphite electrode was employed. The arc operated at 240 volts, d. c. and 8 amperes, and was struck when the bell surrounding it was partially exhausted. When the chamber was reduced to about 10 mm Hg pressure, as indicated by a vacuum gauge, the arc burned steadily for periods approximating an hour without renewal or readjustment of the electrodes. When exposures were in progress the electrodes were separated by 1 cm, and the image projected onto the diaphragm of the interferometer was enlarged about 2.5 times.

Three series of observations were made in all. The first two were obtained with glass interferometer plates with Ag films cathodically deposited. For these two series a glass achromat was used to project the light from the interferometer onto the slit of the spectrograph. Invar etalons of 5, 7.5, 12, 15, 20, and 25 mm thickness were used to separate the plates. In the first series of observations the small camera which takes a flat plate 6 by 20 cm was used. The region covered was from 5500 to 7500 A. In the second and third series of observations the large camera was used. This takes a thin plate 6 by 40 cm, which can be bent over a template to fit the

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[2] J. Opt. Soc. Am. and Rev. Sci. Inst., 8, p. 697; 1924.

[3] B. S. Sci. Papers, No. 478, 19, p. 263; 1924.

focal curve of the grating. The second set of observations extended from 3650 to 6550 A, and the third from 2820 to 6550 A. The interferometer plates used for the third set were of crystalline quartz and were thinly sputtered with Pt films, and for projecting the rings it was necessary to use the quartz-fluorite achromat. Etalons of 3, 5, 6, 7.5, 8, 12, 15, and 20 mm were used as separators for the quartz plates.

The spectrograph used for all the work was the one carrying the 7,500-lines per inch Anderson concave grating. It has been described elsewhere.[4] The first series of observations was obtained on Eastman 33 plates sensitized with pinacyanol. For the second and third series either experimental plates prepared in the bureau's emulsion laboratory or Schleussner ultrarapid plates were used. Half of each long plate was panchromatized by bathing in a mixture of pantochrome and pinacyanol for recording the green, yellow, and red rays.

For the first series of plates the method of reduction employed in previous work was followed.[5] For the second and third series, however, a slight modification of that described by Robertson[6] or by Childs[7] was adopted. A similar procedure was adopted for the reduction of some of the solar observations mentioned above.[8]

III. RESULTS FOR TITANIUM

1. DESCRIPTION OF BUREAU OF STANDARDS WAVE LENGTHS

Table 1 contains the wave lengths which have been measured in the vacuum arc spectrum of titanium in terms of the neon standards. The values of the Ne lines used for finding the interferometer thicknesses are those of Burns, Meggers, and Merrill.[9] The justification for using these lines as standards instead of the primary standard, the red ray of cadmium, lies not only in the ease and economy with which they may be produced, but also in the fact that in the determination of secondary standards in spectra where exceedingly high orders of interference are not possible, they lead to results of the same precision as is obtained with the use of the Cd standard. This is demonstrated by the recent work of Babcock[10] on the iron spectrum.

The wave lengths entered in the first column of Table 1 are the means of the individual results derived from all the plates. These values are for air at 15° C. and 760 mm Hg pressure. The results

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[4] B. S. Sci. Papers, Nos. 312, 441, and 499.

[5] B. S. Sci. Papers, Nos. 251, 274, 302, 327, 329, 441, 478, and 479.

[6] J. Opt. Soc. Am. and Rev. Sci. Inst., **9**, p. 611; 1924.

[7] J. Sci. Inst., **3**, pp. 97 and 129; 1926.

[8] Publ. Allegheny Observatory, **6**, p. 126; 1927.

[9] B. S. Sci. Paper No. 329, **14**, p. 765; 1918.

[10] Astrophys. J., **66**, p. 256; 1927.

from the Ag films required correction for dispersion of phase change which was determined by the method of short and long etalons as described by Meggers.[11] The phase change curve is illustrated in Figure 1. No phase change correction was apparent for the results obtained with the Pt films in the region under investigation. However, when the means of the wave lengths obtained with the Pt films were compared with the means of all the observations, it was found that they were systematically higher by 0.001 A from 5150 to 4850 A by 0.002 A from 4850 to 4070 A; and by 0.003 A from 4070 to 3650 A. Accordingly, the wave lengths in Table 1 which were derived only from the Pt films have been corrected by the above amounts, the correction 0.003 A being extrapolated to apply to all the lines shorter than 3650 A. The justification for this procedure is given below in the discussion on the calculation of wave lengths from spectral terms.

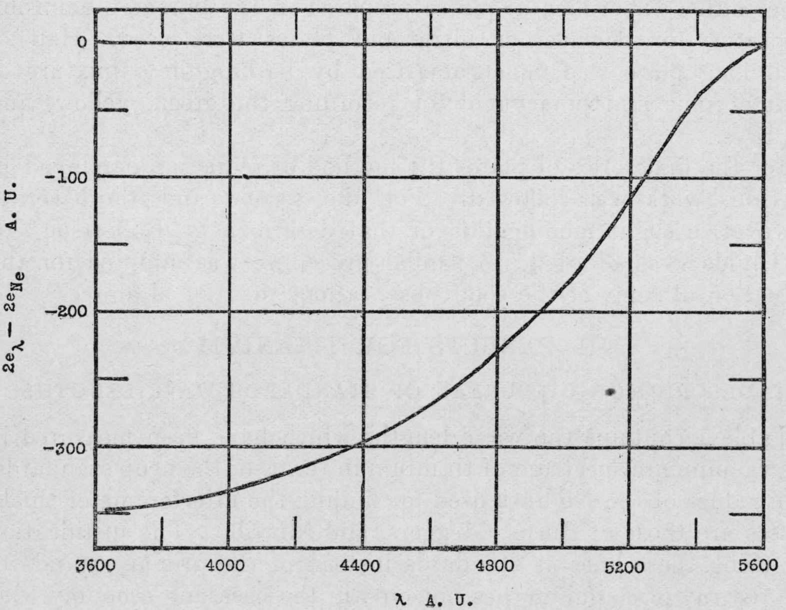

FIG. 1.—*Dispersion of phase change at reflection from silver films*

In columns 2 and 3 of Table 1 are entered the number of observations from which the mean values of the wave lengths were derived, and letters indicating the probable errors of the determinations. The probable errors are expressed in parts per million; thus the letter A denotes a p. e. of 1 part in 6,000,000; B, 1 part in 4,500,000; C, 1 part in 3,000,000; and D, probable errors greater than 1 in 3,000,000. The fourth column of the table contains the intensities and temperature classes of the lines as determined by King.[12] Lines emitted

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[11] B. S. Sci. Papers No. 251, **12**, p. 199; 1915.

[12] Astrophys. J., **39**, p. 139; 1914; **59**, p. 155; 1924.

by the ionized Ti atom are designated in this column by the symbol Ti II. The remaining three columns of the table contain data the significance of which is discussed below.

TABLE 1.—*Vacuum arc wave lengths of titanium*

λ I. A.	Number of observations	Weight	Intensity and temperature class	ν (Vac)	Term combination	(O−C) λ
6743. 124	6	A	10 III*A*	14825. 836	$aD'-aD$	
6556. 066	17	A	25 III	15248. 847	$b^3F_4-d^3F'_4$	000
6554. 226	16	A	30 III	15253. 126	$b^3F_3-d^3F'_3$	000
6546. 276	12	A	20 III	15271. 650	$b^3F_2-d^3F'_2$	000
6366. 354	6	C	8 III	15703. 246	$b^3F_4-c^3D_3$	+004
6336. 104	2	D	8 III	15778. 216	$b^3F_3-c^3D_2$	000
6312. 240	6	C	10 III	15837. 866	$b^3F_4-b^3G_4$	+003
6303. 754	6	C	10 III	15859. 188	$b^3F_3-b^3G_3$	+010
6261. 101	26	A	35 II	15967. 225	$b^3F_2-b^3G_3$	−001
6258. 706	23	A	50 II	15973. 336	$b^3F_4-b^3G_5$	000
6258. 103	24	A	40 II	15974. 875	$b^3F_3-b^3G_4$	000
6126. 217	16	A	20 II	16318. 780	$a^3P_2-a^3S_1$	
6091. 175	16	B	20 III	16412. 662	$bG'-bG$	
6085. 228	16	A	20 II	16428. 700	$a^3P_1-a^3S_1$	
6064. 631	3	B	9 II*A*	16484. 496	$a^3P_0-a^3S_1$	
5999. 668	1	D	8 III	16662. 984	a^3H_4-bG	
5978. 543	20	A	25 II	16721. 863	$a^3G'_3-a^3H'_4$	000
5965. 828	24	A	30 II	16757. 501	$a^3G'_4-a^3H'_5$	000
5953. 162	22	A	30 II	16793. 155	$a^3G'_5-a^3H'_6$	000
5941. 755	7	B	12 II*A*	16825. 395	$a^3P_1-b^3D_1$	+005
5937. 806	1	D	6 II*A*	16836. 584	$a^3P_2-b^3D_2$	−002
5922. 112	7	C	18 II	16881. 201	$a^3P_0-b^3D_1$	+004
5918. 548	2	D	10 II	16891. 367	$a^3P_2-a^3P'_2$	
5903. 317	1	D	5 III*A*	16934. 947	$a^3P_2-a^3P'_1$	
5899. 295	22	A	25 II	16946. 493	$a^3P_1-b^3D_2$	000
5866. 453	31	A	35 II	17041. 364	$a^3P_2-b^3D_3$	+004
5804. 265	8	C	5*n* IV	17223. 947	$b^5G_6-c^5H_7$	
5785. 979	3	B	5*n* IV	17278. 379	$b^5G_5-c^5H_6$	
5774. 037	6	C	5*n* IV	17314. 116	$b^5G_4-c^5H_5$	
5766. 330	3	D	4*n* IV	17337. 257	$b^5G_3-c^5H_4$	
5739. 464	5	B	9 III	17418. 410	$a^3H_5-b^3H'_5$	000
5715. 123	3	D	9 III	17492. 594	$a^3H_6-b^3H'_6$	000
5689. 465	7	B	10 III	17571. 481	$a^5D_2-b^5F_3$	
5675. 413	10	B	9 III*A*	17614. 987	$a^5D_3-b^5F_4$	
5662. 154	10	A	12 III	17656. 237	$a^5D_4-b^5F_5$	
5648. 570	4	D	5 IV	17698. 695	$a^3D_3-c^3F_4$	+003
5644. 137	13	A	18 III	17712. 595	$bG'-cG$	
5565. 476	11	A	9 III	17962. 941	a^3H_4-cG	
5512. 529	17	A	25 II	18135. 471	$b^3F_4-e^3D_3$	+001
5503. 897	8	B	8 III	18163. 912	$aH-dG$	
5490. 151	10	B	12 II	18209. 391	$b^3F_4-b^5D_3$	
5488. 210	2	D	5 III	18215. 829	$a^3F'_2-c^3F_2$	000
5481. 426	3	D	6 III	18238. 374	$a^3F'_2-c^3F_3$	000
5477. 695	11	B	8 III	18250. 796	$a^3F'_4-c^3F_4$	000
5429. 139	5	D	6 III	18414. 022	$c^3P_2-d^3P'_2$	
5409. 609	8	C	6 II	18480. 500	$a^3G'_5-e^3F'_4$	−001
5397. 093	5	D	4 III	18523. 359	$a^3G'_4-e^3F'_3$	000
5389. 996	2	D	3 III	18547. 745	$a^3G'_3-e^3F'_2$	000
5369. 635	3	D	4 III	18618. 077		
5298. 429	2	D	4 III	18868. 284	$bD'-cP'$	
5297. 236	3	D	6 III	18872. 532	$a^3G'_3-f^3F'_2$	000
5295. 781	2	D	4 III	18877. 720	$a^3P_2-c^3D_3$	+002
5283. 441	4	D	8 III	18921. 809	$a^3G'_4-f^3F'_3$	000
5265. 967	6	C	10 III	18984. 597	$a^3G'_5-f^3F'_4$	+002
5224. 928	3	D	8 III	19133. 706	$a^5F'-b^5F_4$	

TABLE 1.—*Vacuum arc wave lengths of titanium*—Continued

λ I. A.	Number of observations	Weight	Intensity and temperature class	ν (Vac)	Term combination	(O−C) λ
5224. 301	3	D	15 III	19136. 006	$a^5F'_5-b^5F_5$	
5210. 386	29	A	40 I	19187. 107	$a^3F_4-a^3F'_4$	000
5192. 971	26	A	35 I	19251. 453	$a^3F_3-a^3F'_3$	−001
5173. 742	27	A	30 I	19323. 003	$a^3F_2-a^3F'_2$	000
5147. 483	12	A	10 I*A*	19421. 575	$a^3F_2-a^3F'_3$	+001
5145. 465	13	A	12 II	19429. 194	$b^3F_4-f^3D_3$	000
5120. 420	10	A	12 III	19524. 222		
5113. 448	8	C	10 III	19550. 843	$b^3F_3-f^3D_2$	000
5087. 055	3	D	8 III	19652. 277	$b^3F_2-f^3D_1$	000
5064. 654	26	A	25 I	19739. 198	$a^3F_4-a^3D_3$	000
5062. 112	2	D	7 III	19749. 111	$a^3D'_2-d^3P'_1$	000
5052. 879	2	D	8 IV	19785. 196	$a^3D'_3-d^3P'_2$	000
5039. 959	22	A	22 I	19835. 917	$a^3F_3-a^3D_2$	000
5038. 400	15	A	25 II	19842. 053	$b^3F_2-d^3G_3$	−001
5036. 468	10	B	25 II	19849. 667	$b^3F_3-d^3G_4$	000
5035. 908	11	B	25 II	19851. 873	$b^3F_4-d^3G_5$	+001
5025. 570	9	C	18 III	19892. 711	$a^5G_6-b^5F_5$	
5024. 842	12	C	20 II	19895. 592	$a^5F_2-b^5G_2$	
5022. 871	22	A	25 II	19903. 397	$a^5F_3-b^5G_3$	
5020. 028	22	A	25 II	19914. 670	$a^5F_4-b^5G_4$	
5016. 162	19	A	20 II	19930. 026	$a^5F_5-b^5G_5$	
5014. 277	28	A	25 I	19937. 512	$a^5F_1-b^5G_2$	
5014. 185	3	D	25 I	19937. 878	$a^3F_2-a^3D_1$	000
5009. 652	1	D	7 I*A*	19955. 917	$a^3F_3-a^3D_3$	+006
5007. 209	28	A	40 II	19965. 651	$a^5F_2-b^5G_3$	
4999. 504	30	A	45 II	19996. 425	$a^5F_3-b^5G_4$	
4997. 099	2	D	8 I*A*	20006. 046	$a^3F_2-a^3D_2$	+001
4991. 067	30	A	50 II	20030. 226	$a^5F_4-b^5G_5$	
4981. 732	30	A	60 II	20067. 757	$a^5F_5-b^5G_6$	
4978. 191	8	C	10 III	20082. 031	$a^5G_2-b^5F_1$	
4975. 344	10	C	10 III	20093. 523	$bD'-dF'$	
4938. 283	9	D	8 IV	20244. 321	$aH-fG$	
4928. 342	13	A	12 III	20285. 152	$a^3D'_1-g^3F'_2$	000
4921. 768	13	B	12 III	20312. 248	$a^3D'_3-g^3F'_4$	000
4919. 867	11	B	10 III	20320. 098	$a^3D'_2-g^3F'_3$	000
4913. 616	20	A	20 III	20345. 946	$a^3G'_3-b^3H'_4$	000
4899. 910	24	A	20 III	20402. 859	$a^3G'_4-b^3H'_5$	000
4885. 082	25	A	20 II	20464. 788	$a^3G'_5-b^3H'_6$	000
4870. 129	15	A	20 III	20527. 621	$a^3H_5-a^3I_6$	
4868. 264	15	A	18 III	20535. 483	$a^3H_4-a^3I_5$	
4856. 012	19	A	20 III	20587. 298	$a^3H_6-a^3I_7$	
4840. 874	25	A	25 I	20651. 676	$aD'-bD$	
4820. 410	14	A	20 II	20739. 345	$aG'-bF'$	
4805. 416	13	B	12 III	20804. 051	$c^3P_2-i^3D_3$	
4799. 797	14	B	12 III	20828. 412	$bG'-c^3H'_4$	
4792. 482	13	A	10 III	20860. 203	$c^3P_1-i^3D_2$	
4778. 259	9	B	10 III	20922. 292	a^3H_4-dG	
4759. 272	21	A	25 III	21005. 760	$a^3H_6-c^3H'_6$	
4758. 120	18	A	25 III	21010. 849	$a^3H_5-c^3H'_5$	
4742. 791	18	A	20 III	21078. 756	$a^3H_4-c^3H'_4$	
4731. 172	7	A	9 III	21130. 521	$a^3D'_3-h^3F'_4$	
4715. 295	4	D	4 II*A*	21201. 668	$a^3F_4-a^3G_4$	−005
4710. 186	15	A	18 III	21224. 663	$a^3P_0-e^3D_1$ $a^3D'_3-h^3D_3$	
4698. 766	21	A	20 II	21276. 247	$a^3P_1-e^3D_2$	000
4691. 336	24	A	20 II	21309. 944	$a^3P_2-e^3D_3$	−001
4681. 908	30	A	30 I	21352. 857	$a^3F_4-a^3G_5$	+003
4675. 118	9	C	10 III	21383. 870	$a^3P_2-b^5D_3$	
4667. 585	30	A	25 I	21418. 381	$a^3F_3-a^3G_4$	+002
4656. 468	30	A	25 I	21469. 515	$a^3F_2-a^3G_3$	+005
4645. 193	12	C	12 III	21521. 626	$a^5P_1-c^5D_0$	
4629. 336	24	A	15 III	21595. 343	$a^5P_1-c^5D_2$	
4623. 098	26	A	25 III	21624. 478	$a^5P_2-c^5D_3$	
4617. 269	29	A	30 II	21651. 780	$a^5P_3-c^5D_4$	
4599. 226	9	A	5 IV	21736. 720		

TABLE 1.—*Vacuum arc wave lengths of titanium*—Continued

λ I. A.	Number of observations	Weight	Intensity and temperature class	ν (Vac)	Term combination	(O−C) λ
4571. 971	23	A	15 V*E*, Ti II	21866. 297	$a^2H_5-a^2G_4$	
4563. 761	16	A	15 V*E*, Ti II	21905. 632	$a^2P_1-a^2D_2$	
4559. 920	7	B	6 III	21924. 083	$b^3F_4-e^3F'_4$	−001
4555. 486	30	A	30 II	21945. 422	$a^5F_5-b^5F'_4$	
4552. 453	30	A	35 II	21960. 044	$a^5F_4-b^5F'_3$	
4549. 622	10	C	25 V*E*, Ti II	21973. 709	$a^2H_6-a^2G_5$	
4548. 764	29	A	35 II	21977. 853	$a^5F_3-b^5F'_2$	
4544. 688	29	A	30 II	21997. 564	$a^5F_2-b^5F'_1$	
4533. 238	21	B	80 II	22053. 109	$a^5F_5-b^5F'_5$	
4527. 305	30	A	35 II	22082. 026	$a^5F_1-b^5F'_2$	
4522. 798	30	A	40 II	22104. 030	$a^5F_2-b^5F'_3$	
4518. 022	30	A	50 II	22127. 394	$a^5F_3-b^5F'_4$	
4512. 734	30	A	40 II	22153. 325	$a^5F_4-b^5F'_5$	
4503. 762	2	D	4*n* IV	22197. 454		
4501. 270	23	A	25 V*E*, Ti II	22209. 745	$a^2G'_4-a^2F'_3$	
4496. 146	25	A	20 III	22235. 054	$a^5P_3-a^5P'_2$	
4489. 089	25	A	20 III	22270. 009	$a^5P_2-a^5P'_1$	
4482. 688	2	D	10 III	22301. 809	$b^3F_4-f^3F'_3$	−003
4481. 261	26	A	30 III	22308. 910	$a^5P_3-a^5P'_3$	
4474. 852	11	A	8 III	22340. 862	$b^3F_3-f^3F'_2$	+001
4471. 238	25	B	20 III	22358. 920	$a^5P_1-a^5P'_2$	
4468. 493	25	A	25 V*E*, Ti II	22372. 651	$a^2G'_5-a^2F'_4$	
4465. 807	25	A	20 III	22386. 108	$a^5P_2-a^5P'_3$	
4457. 428	29	A	40 II	22428. 187	$b^3F_4-f^3F'_4$	−002
4455. 321	28	A	30 II	22438. 796	$b^3F_3-f^3F'_3$	−001
4453. 708	2	D	20 III	22446. 921	$a^3G'_3-e^3G_3$	
4453. 312	17	C	30 II	22448. 916	$b^3F_2-f^3F'_2$	−009
4450. 896	29	C	25 III	22461. 104	$a^3G'_4-e^3G_4$	
4449. 143	30	A	30 III	22469. 951	$a^3G'_5-e^3G_5$	
4443. 802	21	A	25 V*E*, Ti II	22496. 960	$a^2D'_2-a^2F'_3$	
4440. 345	20	A	10 III	22514. 475	$a^3G'_3-cF'$	
4436. 586	5	C	4 III	22533. 551	$a^3G'_4-e^3G_5$	
4434. 003	14	C	15 III *A*	22546. 674	{ $b^3F_2-f^3F'_3$ $a^3G'_3-g^3F'_2$ }	
4430. 366	12	C	7 III *A*	22565. 183	$b^3F_3-f^3F'_4$	−001
4427. 098	30	A	40 III	22581. 841	$aG'-bG$	
4426. 054	11	C	10 II	22587. 166	$a^3G'_4-g^3F'_3$	
4422. 823	17	A	10 II	22603. 667	$a^3P_2-f^3D_3$	−001
4421. 754	9	C	6 III	22609. 135	$b^3P_1-j^3D_2$	
4417. 274	13	B	15 III	22632. 064	$a^3G'_5-g^3F'_4$	
4399. 767	6	B	6 V*E*, Ti II	22722. 119	$a^2P_2-a^4D_3$	
4395. 031	26	A	25 V*E*, Ti II	22746. 602	$a^2D'_3-a^2F'_4$	
4393. 925	15	B	8 III	22752. 326	$bG'-fG$	
4372. 383	2	D	3 IV	22864. 423		
4369. 682	10	C	5*n* IV	22878. 552	$aH-gG$	
4360. 487	11	B	4 III	22926. 798	$a^3D'_3-e^3P'_2$	
4346. 104	11	A	5 IV	23002. 667	a^3H_4-fG	
4337. 916	19	A	10 V*E*, Ti II	23046. 089	$a^2D'_2-a^2D_2$	
4325. 134	6	A	9*n* III	23114. 194	$a^3H^5-f^3G_4$	
4321. 655	20	A	8*n* III	23132. 801	$a^3H_4-f^3G_3$	
4318. 631	25	A	10*n* III	23149. 000	$a^3H_6-f^3G_5$	
4314. 801	30	A	25 II	23169. 542	{ $a^5F_4-e^3D_3$ $a^5F_2-e^3D_2$ }	
4312. 861	7	C	7 V*E*, Ti II	23179. 966	$a^4P_3-a^4D_3$	
4307. 900	21	B	12 V*E*, Ti II	23206. 664	$a^4P_2-a^4D_2$	
4305. 910	26	A	60 II	23217. 386	$a^5F_5-b^5D_4$	
4298. 664	29	A	40 II	23256. 522	$a^5F_2-b^5D_1$	
4295. 751	29	A	22 II	23272. 294	$a^5F_1-b^5D_0$	
4294. 101	11	C	8 V*E*, Ti II	23281. 234	$a^2D'_3-a^2D_3$	
4289. 068	27	A	25 II	23308. 551	$a^5F_2-b^5D_2$	
4287. 405	26	A	22 II	23317. 595	$a^5F_4-b^5D_4$	
4286. 006	30	A	25 II	23325. 204	$a^5F_3-b^5D_3$	
4282. 702	23	A	12 III	23343. 199	$a^3G'_3-h^3F'_2$	
4281. 371	11	C	10 III	23350. 459	$a^5F_1-b^5D_2$	
4274. 584	13	B	15 III	23387. 529	{ $a^3G'_4-h^3F'_3$ $a^5F_2-b^5D_3$ }	

TABLE 1.—*Vacuum arc wave lengths of titanium*—Continued

λ I. A.	Number of observations	Weight	Intensity and temperature class	ν (Vac)	Term combination	(O−C) λ
4263.134	25	A	15 III	23450.343	$a^3G'_5-h^3F'_4$	
4258.523	3	D	4*n* IV	23475.738	$a^5D_1-b^5D'_2$	
4256.025	10	B	8*n* III	23489.513	$a^5D_4-b^5D'_4$	
4249.114	5	D	5*n* III	23527.718	$a^5D_2-b^5D'_3$	
4237.889	10	A	7 III	23590.035	$bD'-dD$	
4186.119	25	A	25 III	23881.766	$aG'-cG$	
4171.897	8	C	5 V*E*, Ti II	23963.179	$b^2F_3-c^2D_2$	
4163.644	8	C	8 V*E*, Ti II	24010.682	$b^2F_4-c^2D_3$	
4159.634	11	A	9 III	24033.828	$a^3D'_2-i^3F'_3$	
4150.963	8	C	10 III	24084.030	$a^3D'_3-i^3F'_4$	
4137.284	10	B	10*n* III	24163.654	$a^5D_4-b^5P_3$	
4127.531	12	B	15 III	24220.752	$a^3G_5-b^3H_6$	
4122.143	7	C	10 III	24252.407	$a^3G_3-b^3H_4$	
4112.708	25	A	20 II	24308.047	a^3F_4-aG	
4099.166	8	B	8 III	24388.346	$a^3D'_3-f^3P'_2$	
4082.456	24	A	20 III	24488.173	$a^3P_2-c^3P'_1$	
4078.471	26	A	30 III	24512.099	$a^3P_2-c^3P'_2$	
4065.094	8	B	15 III	24592.756	$a^3P_1-c^3P'_0$	
4060.263	23	A	20 III	24622.015	$a^3P_1-c^3P'_2$	
4058.139	6	D	7 IV	24634.904		
4055.011	22	A	20 III	24653.908	$a^3P_0-c^3P'_1$	
4035.828	1	D	10 III	24771.090	$a^3D'_3-k^3D_3$	
4030.512	15	A	25*n* III	24803.759	$a^5F'_5-b^5G'_6$	
4026.539	10	B	25*n* III	24828.232	$a^5F'_4-b^5G'_5$	
4024.573	29	B	35 II	24840.363	$a^3F_4-b^3F'_3$	000
4017.771	10	B	15*n* III	24882.418	$a^5F'_2-b^5G'_3$	
4015.377	8	B	12*n* III	24897.249	$a^5F'_1-b^5G'_2$	
4013.587	8	B	12*n* III	24908.356	$a^5F'_5-b^5H_6$	
4008.926	28	A	35 II	24937.314	$a^3F_3-b^3F'_2$	+001
3998.635	25	A	100*R* II	25001.494	$a^3F_4-b^3F'_4$	−003
3989.758	25	A	80*R* II	25057.118	$a^3F_3-b^3F'_3$	−002
3981.761	26	A	70*R* II	25107.441	$a^3F_2-b^3F'_2$	+001
3964.269	23	B	35 II	25218.220	$a^3F_3-b^3F'_4$	−001
3962.851	23	A	35 II	25227.247	$a^3F_2-b^3F'_3$	−001
3958.206	25	B	80 II	25256.850	$a^3F_4-b^3D_3$	+001
3956.336	28	A	60 II	25268.790	$a^3F_3-b^3D_2$	+002
3948.670	26	B	60 II	25317.847	$a^3F_2-b^3D_1$	+004
3947.770	25	B	40 II	25323.617	$a^3F_3-a^3P'_2$	
3929.875	25	B	40 II	25438.923	$a^3F_2-b^3D_2$	+001
3924.527	28	A	50 II	25473.592	$a^3F_3-b^3D_3$	000
3921.423	16	B	30 II	25493.757	$a^3F_2-a^3P'_2$	
3914.334	20	B	35 II	25539.920	$a^3F_4-c^3F'_4$	
3913.464	11	B	40 V*E*, Ti II	25545.603	$a^2G'_4-a^2G_4$	
3904.785	26	A	40*n* II	25602.379	$aD'-bF'$	
3900.546	7	D	50 V*E*, Ti II	25630.202	$a^2G'_5-a^2G_5$	
3895.243	6	C	30*n* III	25665.092	$a^5G_6-b^5H_6$	
3875.262	14	C	20*n* III	25797.424	$\left\{\begin{array}{c} a^3F_2-c^3F_3 \\ a^5G_4-b^5G'_5 \end{array}\right\}$	
3866.446	2	D	15*n* IV	25856.242	$a^5G_5-b^5H_6$	
3798.276	3	D	6 IV	26320.291	$b^3F_2-g^3D_1$	
3786.043	23	C	20 II	26405.331	$aD'-aP'$	
3771.652	24	A	25 I	26506.075	$a^3F_4-d^3F'_3$	000
3761.320	24	B	40 IV *Er*, Ti II	26578.885	$a^2F_3-a^2F'_3$	
3759.291	23	B	40 IV *Er*, Ti II	26593.234	$a^2F_4-a^2F'_4$	
3752.860	24	B	80*r* I	26638.799	$a^3F_4-d^3F'_4$	−001
3741.059	25	B	60*r* I	26722.827	$a^3F_3-d^3F'_3$	−002
3729.806	25	A	50*r* I	26803.450	$a^3F_2-d^3F'_2$	+001
3725.155	5	C	20 III	26836.920	$a^3P_2-b^3S_1$	
3724.570	7	C	20 III	26841.134	$a\,G'-d\,G$	
3722.568	14	B	15 II	26855.565	$a^3F_3-d^3F'_4$	−004
3717.393	14	A	20 I	26892.955	$a^3F_2-d^3F'_3$	−001
3694.445	9	C	10 III	27059.989	$b^3F_3-h^3D_2$	
3689.916	14	A	15 I	27093.208	$a^3F_4-c^3D_3$	+001
3685.192	17	B	40 IV *Er*, Ti II	27127.936		
3671.672	14	A	20 I	27227.821	$a^3F_4-b^3G_4$	000

TABLE 1.—*Vacuum arc wave lengths of titanium*—Continued

λ I. A.	Number of observations	Weight	Intensity and temperature class	ν (Vac)	Term combination	(O−C) λ
3668. 965	14	B	15 I	27247. 912	$a^3F_3-c^3D_2$	−001
3660. 631	12	A	12 I	27309. 943	$a^3F_3-c^3D_3$	000
3658. 097	12	B	20 I	27328. 863	$a^3F_3-b^3G_3$	+005
3654. 592	10	B	15 I	27355. 073	$a^3F_2-c^3D_1$	−001
3653. 497	15	C	100*r* I	27363. 270	$a^3F_4-b^3G_5$	+002
3646. 198	9	A	12 I	27418. 045	$a^3F_2-c^3D_2$	−001
3642. 675	14	B	80*r* I	27444. 563	$a^3F_3-b^3G_4$	000
3641. 330	6	B	10 V*E*, Ti II	27454. 697	$a^2P_2-a^2S_1$	
3635. 462	12	B	80*r* I	27499. 014	$a^3F_2-b^3G_3$	+003
3624. 826	10	B	8 V*E*, Ti II	27579. 694	$a^2P_1-a^2S_1$	
3610. 154	9	B	12 III	27691. 779	$a\ D'-b\ P'$	
3598. 714	12	A	15 III	27779. 807	$a\ D'-c\ D$	
3596. 048	9	B	10 V*E*, Ti II	27800. 404	$a^2F_4-a^4D_3$	
3547. 029	5	B	15 IV	28184. 583	$a\ G'-d\ F'$	
3535. 408	9	A	10 V*E*, Ti II	28277. 224	$b^2P_2-c^2D_3$	
3510. 840	12	B	10 V*Er*, Ti II	28475. 101	$b^2G'_4-b^2G_4$	
3504. 890	12	A	8 V*Er*, Ti II	28523. 436	$b^2G'_5-b^2G_5$	
3491. 053	3	D	8 III*Eru*, Ti II	28636. 491	$b^4F_2-a^4G_3$	
3480. 525	5	D	12 II	28723. 103	$a^3P_2-d^3P'_2$	
3477. 181	9	C	15 III*Eru*, Ti II	28750. 726	$b^4F_3-a^4G_4$	
3461. 496	12	A	20 III*Eru*, Ti II	28881. 000	$b^4F_4-a^4G_5$	
3444. 306	12	C	15 III*Eru*, Ti II	29025. 141	$b^4F_5-a^4G_6$	
3394. 574	12	B	15 III*Eru*, Ti II	29450. 353	$a^4F_3-a^4G_3$	
3387. 834	12	B	15 III*Eru*, Ti II	29508. 944	$a^4F_4-a^4G_4$	
3385. 944	12	B	40*r* II	29525. 411	$a^3F_4-e^3D_3$	000
3383. 761	10	A	40 III*Eru*, Ti II	29544. 463	$a^4F_2-a^4G_3$	
3380. 278	12	A	15 III*Eru*, Ti II	29574. 905	$a^4F_5-a^4G_5$	
3377. 577	9	C	30*r* I	29598. 557	$a^3F_3-e^3D_2$	+001
3371. 447	4	D	80*R* II	29652. 367	$a^3F_4-c^3G_5$	+001
3370. 436	6	C	40*r* II	29661. 260	$a^3F_2-e^3D_1$	+001
3361. 213	11	B	40 III*Er*, Ti II	29742. 652	$a^4F_4-a^4G_5$	
3358. 271	5	C	10 I	29768. 709	$a^3F_2-e^3D_2$	−002
3354. 634	11	B	60*r* II	29800. 975	$a^3F_3-c^3G_4$	000
3349. 399	11	C	40 II*Er*, Ti II	29847. 557	$a^4F_5-a^4G_6$	
3341. 875	11	B	50*r* II	29914. 755	$a^3F_2-c^3G_3$	+003
3340. 344	10	C	15 III*Eru*, Ti II	29928. 462	$b^4F_2-a^4F'_2$	
3335. 192	12	B	20 III*Eru*, Ti II	29974. 689	$b^4F_3-a^4F'_3$	
3332. 111	8	B	8 V*Er*, Ti II	30002. 406	$b^4P_3-a^4S_2$	
3329. 455	9	B	20 III*Eru*, Ti II	30026. 342	$b^4F_4-a^4F'_4$	
3326. 762	2	D	5 III*Eru*, Ti II	30050. 641	$b^4F_2-a^4F'_3$	
3322. 936	11	A	20 III*Eru*, Ti II	30085. 241	$b^4F_5-a^4F'_5$	
3318. 024	7	A	8 III*Eru*, Ti II	30129. 784	$b^4F_3-a^4F'_4$	
3314. 422	10	B	10 I	30162. 528	$a^3P_2-h^3D_3$	
3292. 078	10	B	20 I	30367. 234	$aD'-cF'$	
3287. 657	10	B	10 V*Er*, Ti II	30408. 067	$b^2G'_4-a^2H'_5$	
3261. 596	8	B	25 V*Er*, Ti II	30651. 031	$b^2G'_5-a^2H'_6$ $b^4P_2-b^4D_3$	
3241. 984	10	A	40 III*Er*, Ti II	30836. 445	$a^4F_2-a^4F'_2$	
3239. 037	10	C	40 III*Er*, Ti II	30864. 588	$a^4F_3-a^4F'_3$	
3236. 573	10	B	50 III*Er*, Ti II	30888. 089	$a^4F_4-a^4F'_4$	
3234. 517	10	B	60 III*Er*, Ti II	30907. 726	$a^4F_5-a^4F'_5$	
3229. 397	4	D	10 V*Eru*, Ti II	30956. 623	$a^2G'_4-b^2F'_4$	
3222. 843	9	A	15 III*Er*, Ti II	31019. 583	$a^4F_3-a^4F'_4$	
3217. 056	9	A	15 III*Er*, Ti II	31075. 376	$a^4F_4-a^4F'_5$	
3214. 240	8	C	12 I	31102. 603	$a^3F_4-d^3G_4$	+002
3202. 535	9	A	12 V*Er*, Ti II	31216. 276	$a^2D'_2-b^2F'_3$	
3199. 915	10	B	100*R* II	31241. 828	$a^3F_4-d^3G_5$	000
3191. 994	9	A	80*R* II	31319. 353	$a^3F_3-d^3G_4$	000
3190. 801	4	D	20 IV*Er*, Ti II	31331. 070	$a^2D'_3-b^2F'_4$	
3186. 451	10	A	60*r* II	31373. 839	$a^3F_2-d^3G_3$	+002
3168. 519	10	A	30 III*Eru*, Ti II	31551. 385	$b^4F_5-a^4D_4$	
3161. 755	6	D	20 III*Eru*, Ti II	31618. 884	$b^4F^3-a^4D_2$	
3148. 033	2	D	12 IV*E*, Ti II	31756. 698	$a^4F_2-a^2D_2$	
3130. 804	3	D	15 IV, Ti II	31931. 457	$a^4F_3-a^2D_3$	
3088. 027	10	A	60 III*Er*, Ti II	32373. 764	$a^4F_5-a^4D_4$	
3078. 645	10	A	45 III*Er*, Ti II	32472. 424	$a^4F_4-a^4D_3$	
3075. 225	10	C	40 III*Er*, Ti II	32508. 527	$a^4F_3-a^4D_2$	
2956. 133	7	C	70*R* II	33818. 127	$a^3F_4-f^3F'_4$	000
2948. 255	8	A	60*r* II	33908. 489	$a^3F_3-f^3F'_3$	000
2941. 995	7	C	60*r* II	33980. 630	$a^3F_2-f^3F'_2$	+004

2. COMPARISON WITH OTHER OBSERVATIONS

Two other observers have measured wave lengths in the vacuum arc spectrum of titanium. In 1922 Brown [13] published a list of more than 100 wave lengths between 4263 and 6261 A determined by interference methods in terms of the primary standard—the red ray of cadmium. This was followed two years later by a more extensive list by Crew,[14] who observed the region from 3653 to 6366 A with a plane grating giving high dispersion. There is most excellent agreement between the Bureau of Standards wave lengths and those of Brown in the interval from 4262 to 5200 A. Most of the differences, Bureau of Standards *minus* Brown, are less than 0.003 A and exhibit no systematic shift between the two sets of results, the mean of the differences being +0.0001 A. Between 5200 and 5800 A Brown's list contains 13 Ti lines, of which 11 may be compared with the Bureau of Standards determinations. Of these, there are two positive differences, three zeros, and six negative differences, the mean value of Bureau of Standards *minus* Brown being −0.001 A. From 5800 to the end of Brown's list, his wave lengths are systematically longer than the Bureau of Standards values, the difference increasing from −0.001 A at 5800 A to −0.004 A at 5260 A.

The comparison of the Bureau of Standards wave lengths with Crew's is limited to the region 3653 to 4263 A, his wave lengths longer than 4263 A being based on those of Brown described above. The differences, Bureau of Standards *minus* Crew, change linearly from −0.005 A at 3653 to +0.002 A at 3800 A, being zero at 3750 A. From 3800 to 4000 A the difference is practically constant, amounting to +0.002 A. At 4000 A there is an abrupt increase in the difference to +0.010 A from which it decreases linearly to −0.010 A at 4263 A, being zero in the vicinity of 4130 A.

3. COMPUTATION OF WAVE LENGTHS FROM SPECTRAL TERMS

Classification of the lines of a spectrum as the difference of two spectral terms permits a calculation of the wave lengths of the lines if the term values are known. In recent years rapid progress has been made in the extension of our knowledge of the structure of spectra not only of neutral atoms which emit arc spectra, but also of ionized atoms which emit the various stages or orders of spark spectra. Such analyses of the spectrum of titanium have been made by Kiess and Kiess [15] and by Russell.[16] From the work of these

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[13] Astrophys. J., **56**, p. 53; 1922.

[14] Astrophys. J., **60**, p. 108; 1924.

[15] J. Opt. Soc. Am. and Rev. Sci. Inst., **8**, p. 607; 1924.

[16] Astrophys. J. **66**, pp. 283 and 347; 1927.

investigators have been taken the term combinations or series classifications of the lines given in column 6 of Table 1. The numerical values of the term combinations are the wave numbers in vacuum of the lines as entered in column 5.

If the terms involved in the production of the spectrum can be determined solely from lines measured in the yellow and red—that is, in the vicinity of the neon standards—then it is possible to calculate from them the wave lengths of lines in the blue and violet and thereby check the accuracy of observations remote from the standards. Such an ideal procedure, however, is not entirely possible in the case of titanium owing to the low intensities and consequent paucity of the longer Ti lines in the vacuum arc. An alternative procedure for testing the scale of a wave-length interval by means of cyclical term combinations, such as carried out by Meggers[17] for the iron spectrum, was likewise not feasible for Ti because of the small number of cycles which could be formed from the wave lengths of Table 1. It was, therefore, decided to set up a system of terms based not only on the longer wave lengths of the table, but also on the relative term separations as given by observations throughout the measured wave-length interval. The degree of the constancy of these term separations is exhibited in Table 2, wherein are collected various differences used in calculating the relative values of the low terms.

TABLE 2.—*Constancy of term differences throughout the spectrum*

$a^3\mathrm{F}_4-a^3\mathrm{F}_3$	$a^3\mathrm{F}_3-a^3\mathrm{F}_2$	$a^3\mathrm{F}_4-b^3\mathrm{F}_4$	$a^3\mathrm{F}_3-b^3\mathrm{F}_2$	$a^3\mathrm{F}_2-b^3\mathrm{F}_2$	$a^3\mathrm{F}_4-a^3\mathrm{P}_2$	$a^3\mathrm{F}_3-a^3\mathrm{P}_1$	$a^3\mathrm{F}_2-a^3\mathrm{P}_0$
216.722	170.122	11389.934	11469.688	11531.789	8215.486	8322.307	8436.646
.726	.129	.960	.672	.786	.488	.310	.597
.755	.129	.955	.686	.800	.467		
.752	.127	.952	.701				
.744	.106	.940	.693				
.742	.133	.947	.688				
.741	.150	.940					
.749	.133						
.735	.151						
	.140						
216.741	170.132	11389.947	11469.688	11531.792	8215.480	8322.308	8436.622

The mean values of the term differences of Table 2 were used in deriving the values of the terms $a^3\mathrm{F}$, $b^3\mathrm{F}$, and $a^3\mathrm{P}$ of Table 3. From these the remainder of Table 3 was calculated by the joint use of wave numbers shorter than 21,300.000 from Table 1 and relative term separations similar to those of Table 2. Although many of the well-observed lines of Table 1 belong to the singlet and quintet systems of Ti I, yet it was not possible to derive good term values for these systems by adhering to the limitations set for the derivation of the triplet system terms. The wave numbers calculated from

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[17] Astrophys. J., **60**, p. 60 1924.

these terms were converted into wave lengths which were compared with the observed values of Table 1. The results of the comparison are shown in the last column of Table 1, where the residuals O − C are entered. The algebraic sum of the differences O − C for the interval 4700–2941 A is practically zero, although negative residuals predominate in the region 4700–3700 A, and positive residuals in the region 3700–2941 A. However, since the wave lengths would require, in each of these regions, a mean correction of less than 0.001 A to reduce the sums of the residuals to zero, the representation of the wave lengths by means of the terms of Table 3 is regarded as satisfactory and is interpreted as indicating that the blue and violet lines have been measured to the same scale as those longer than 4700 A. For lines longer than 4700 A the majority of the residuals are necessarily zero, since the lines were used directly in the computation of the terms. With one exception the residuals greater than 0.002 A in this region refer to lines observed only a few times.

TABLE 3.—*Terms in the triplet system of titanium*

a^3F_4	386.873	a^3D_3	20126.072	$a^3F'_4$	19573.980	a^3G_5	21739.743	$a^3H'_6$	32013.555
	216.741		*120.023*		*152.400*		*151.223*		*99.251*
a^3F_3	170.132	a^3D_2	20006.049	$a^3F'_3$	19421.580	a^3G^4	21588.520	$a^3H'_5$	31914.304
	170.132		*68.171*		*98.577*		*118.986*		*84.288*
a^3F_2	0.000	a^3D_1	19937.878	$a^3F'_2$	19323.003	a^3G_3	21469.534	$a^3H'_3$	31830.016
b^3F_4	11776.820	b^3D_3	25643.724	$b^3F'_4$	25388.345	b^3G_5	27750.156	$b^3H'_6$	35685.188
	137.000		*204.794*		*161.109*		*135.463*		*125.526*
b^3F_3	11639.820	b^3D_2	25438.930	$b^3F'_3$	25227.236	b^3G_4	27614.693	$b^3H'_5$	35559.662
	108.008		*121.088*		*119.783*		*115.660*		*105.563*
b^3F_2	11531.812	b^3D_1	25317.842	$b^3F'_2$	25107.453	b^3G_3	27499.033	$b^3H'_4$	35454.099
a^3P_2	8602.353	c^3D_3	27480.077	$d^3F'_4$	27025.667	c^3G_5	30039.246		
	109.916		*62.040*		*132.721*		*68.140*		
a^3P_1	8492.437	c^3D_2	27418.037	$d^3F'_3$	26892.946	c^3G_4	29971.106		
	55.807		*62.972*		*89.484*		*56.333*		
a^3P_0	8436.630	c^3D_1	27355.065	$d^3F'_2$	26803.462	c^3G_3	29914.773		
$a^3G'_5$	15220.400	c^3D_3	29912.292	e^3F_4	33700.897	d^3G_5	31628.698		
	63.597		*143.606*		*20.735*		*139.212*		
$a^3G'_4$	15156.803	e^3D_2	29768.686	$e^3F'_3$	33680.162	d^3G_4	31489.486		
	48.650		*107.414*		*24.264*		*115.624*		
$a^3G'_3$	15108.153	e^3D_1	29661.272	$e^3F'_2$	33655.898	d^3G_3	31373.862		
a^3H_6	18192.594	f^3D_3	31206.014	f^3F_4	34205.001				
	51.342		*15.351*		*126.389*				
a^3H_5	18141.252	f^3D_2	31190.663	$f^3F'_3$	34078.612				
			6.574		*97.927*				
a^3H_4		f^3D_1	31184.089	$f^3F'_2$	33980.685				

IV. RESULTS FOR OTHER ELEMENTS

In Tables 4, 5, and 6 which follow are given the vacuum arc wave lengths of a few lines of elements which appeared as impurities in the titanium or were especially observed to supply additional data for the solar work. The most abundant impurity in the titanium was iron; in lesser amounts were calcium, aluminum, chromium, vanadium, and sodium. The elements especially observed for wave lengths in the yellow and red were calcium, barium, manganese, and nickel, the observations being made at the same time as the first series of titanium. Owing to the fact that a copper rod was used nearly always for the negative electrode, 26 lines of this element were also measured on the spectrograms of all three series and are given below.

TABLE 4.—*Vacuum arc wave lengths of iron*

λI.A	Number of observations	Weight	Intensity, temperature, and pressure classes	Bureau of Standards *minus* Babcock
5371. 488	5	D	50 I*B* *a*	−005
5328. 044	10	A	50 I*B* *a*	+002
5269. 539	13	A	60 I*B* *a*	−002
4415. 123	6	A	20 II *b*	−002
4383. 545	25	A	45*r* II *b*	−003
4271. 762	22	A	35 II *b*	−002
4260. 476	12	B	35 III *d*	−004
4250. 789	9	A	25 II *b*	−001
4235. 937	6	D	25 II *d*	−005
4202. 030	10	A	30 II *b*	−002
4143. 869	7	B	15 III *b*	−002
4132. 060	11	B	25 II *b*	−001
4071. 740	22	A	40 II *b*	−001
4045. 813	27	A	60*r* II *b*	−001
4005. 244	4	C	25 II *b*	000
3930. 294	2	C	25*R* I*B* *a*	−004
3927. 919	14	A	30*R* I*B* *a*	−002
3922. 914	5	C	25*R* I*B* *a*	+001
3920. 261	5	D	20*r* I*B* *a*	+002
3899. 712	3	D	30*R* I*B* *a*	+004
3886. 281	24	B	40*R* I*B* *a*	−003
3859. 905	8	C	300*R* I	
3856. 377	2	C	50*r* I*A*	+004
3834. 221	12	A	100*r* II *b*	−003
3827. 821	2	C	75*r* II *b*	−003
3825. 881	4	B	200*R* II *b*	−003
3824. 447	3	C	50*r* I*A*	+002
3820. 428	20	A	250*R* II	000
3815. 844	21	A	100*r* II *b*	+002
3806. 711	2	D	10 III	+013
3799. 554	4	C	50 II	+005
3795. 005	6	C	60 II *b*	+001
3767. 193	14	A	80*r* II *b*	000
3763. 791	14	A	100*r* II *b*	000
3758. 237	7	C	150*R* II *b*	+003
3749. 488	8	C	200*R* II *b*	+001
3748. 264	8	B	60*R* I*A* *a*	000
3745. 560	14	A	100*R* I	
3737. 132	13	B	150*R* I *a*	−002
3734. 865	17	B	300*R* II	
3733. 320	11	B	40*r* I*A* *a*	+002
3727. 621	10	B	50*r* II *b*	000
3719. 934	13	B	250*R* I *a*	−003
3709. 256	8	C	75*r* II *b*	+008
3705. 566	13	A	100*r* I *a*	−001
3687. 454	12	B	40*r* I *b*	−005
3679. 915	14	A	40*r* I*A* *a*	000
3647. 844	14	A	100*R* I *b*	+001
3631. 465	14	A	125*R* I *b*	000
3618. 769	14	A	125*R* I *b*	000
3608. 861	8	B	100*r* I	−001
3581. 194	12	A	250*R* I	−002
3570. 099	11	B	100*R* I	
3565. 380	12	B	60*r* II	
3558. 517	11	B	30 II	−001
3497. 844	4	C	40 I	+001
3465. 862	11	B	60*r* I	000
3440. 990	12	C	75*R* I	
3020. 635	6	D	200*R* I	

TABLE 5.—*Vacuum arc wave lengths of copper*

λ I. A.	Number of observations	Weight	Intensities	Bureau of Standards *minus* Wolfsohn	
				Vacuum	Air
5782. 132*	31	A	8*r*	−004	
5700. 239*	23	A	8*r*		
5292. 519	9	C	6		
5220. 070*	13	A	6	−040	−008
5218. 202	27	A	10	−031	000
5153. 237*	27	A	8	−035	+004
5105. 542	23	A	7	−017	−009
4704. 593	6	D	4		
4651. 124	14	B	8	−025	
4530. 786*	11	A	6	−009	
4509. 374	10	B	6	−015	−013
4480. 360*	6	C	7	−004	
4062. 639	8	C	10		
4022. 627	11	A	10		
3530. 382	9	B	7		
3337. 845	10	A	8		
3279. 815	10	B	5	−017	−005
3273. 956*	7	A	10*R*	−018	−005
3247. 540*	8	B	10*R*	−016	−002
3208. 230	8	B	6	−020	−010
3194. 096	8	B	8	−018	
3063. 411	10	A	7	−015	−008
3036. 101	10	B	8	−013	−006
3010. 838	10	A	7	−013	−007
2961. 164	4	D	9	−015	−009
2824. 369	4	B	10	−013	

TABLE 6.—*Vacuum arc wave lengths of Na, Al, Ca, V, Cr, Mn, Ni, and Ba*

λ I. A.	Number of observations	Weight	Intensity	Temperature class
SODIUM				
5895. 927	5	A	8*R*	
5889. 954	8	A	10*R*	
ALUMINUM				
3961. 527	6	B	10*R*	
3944. 009	6	B	10*R*	
CALCIUM				
6499. 651	3	C	30	II
6493. 780	8	A	80	II
6471. 661	4	B	40	II
6462. 565	7	A	125	II
6449. 809	7	A	50	II
6439. 073	7	A	150	II
6169. 554	3	B	40	III
6169. 048	4	C	25	III
6162. 173	7	A	150	II
6122. 217	8	A	100	II
6102. 720	7	A	80	II
5857. 451	6	A	100	III
4226. 728	3	C	500*R*	I
3968. 469	12	A	350*R*	II
3933. 669	4	C	400*R*	II
VANADIUM				
4379. 234	7	B	150*r*	II
CHROMIUM				
4254. 337	19	A	500*R*	II
3593. 488	12	B	160*R*	II
3578. 687	11	B	200*R*	II
MANGANESE				
6021. 798	12	A	50	III
6016. 639	9	A	40	III
6013. 490	4	B	30	III
NICKEL				
6767. 778	10	A	20	I
6643. 641	10	A	20	I
6314. 666	10	A	15	II
6256. 365	10	A	15	I
6176. 813	6	A	12	V
6108. 121	6	A	8	II
5892. 878	6	A	12	II
BARIUM				
6595. 328	4	A	200	I
6527. 314	5	A	250	I
6498. 762	6	A	300*r*	II
6496. 901	6	A	600*r*	III
6482. 912	3	B	200	II
6450. 854	3	A	125	I
6341. 683	3	A	150	I
6141. 716	5	A	600*r*	III
6110. 785	5	A	300*r*	II
6063. 118	3	A	200	II
6019. 474	2	C	100	II
5997. 091	3	A	100	II
5971. 701	3	A	100	II
5853. 679	4	A	200	III

1. IRON

The iron lines whose wave lengths are given in the first column of Table 4 all originate in the lowest or the low metastable states of the iron atom. They are, accordingly, easily excited and appear with great intensity. In arcs in air most of them are reversed. The character of the lines in arcs in air and their behavior in the vacuum furnace are described in columns 4 and 5, the data for which are taken from King.[18] In the vacuum arc, however, these lines become narrow and give sharp interference fringes with high orders, a phenomenon pointed out long ago by Fabry and Buisson.[19] With two exceptions these lines belong to pressure classes *a* and *b* which means that they experience the least displacement with increasing pressure. We should, therefore, expect to find very little difference between their wave lengths in vacuum and in air, the amount of the displacement increasing with wave length. Such, indeed, is the case. Quite

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[18] Astrophys. J., **37**, p. 239; 1913; **56**, p. 318; 1922.

[19] J. de Physique (IV), **9**, p. 947; 1910.

recently Babcock[20] has published interferometer measurements of iron wave lengths emitted by arcs in air. The comparison of the Bureau of Standards values with his is shown in the last column of Table 4. In the ultra-violet—that is, the region of wave lengths shorter than 3922 A—the residuals, Bureau of Standards *minus* Babcock, are about equally distributed among positive and negative values, being in the mean +0.0007 A. But for all lines longer than 3922 A the residuals, Bureau of Standards *minus* Babcock, are negative, with one exception, the mean being −0.002 A.

2. COPPER

The copper lines which were measured are listed in Table 5. Of these, the pair at 5700 and 5782 A in the yellow, and the *raies ultimes*, 3247 and 3274 A, always appeared reversed. The intensities assigned to the lines are taken from Kayser's *Tabelle der Hauptlinien.* Four pairs of lines in this table, marked with an asterisk (*), involve the term $^2P_{1,2}$ as may be seen by reference to Shenstone's[21] classification of the Cu arc spectrum. They may, therefore, be used to determine the separation of the components of this term, and thereby check the relative accuracy of the measurements. The four values of $^2P_2 - {}^2P_1$ are: 248.392, 248.377, 248.335, and 248.364. The low value of the third is accounted for by the fact that the wave length 4480.360 A which enters into its determination is affected by the Ti line at 4480.60. A correction of −0.009 A applied to the tabulated wave length would give a value of $^2P_2 - {}^2P_1$ equal to the mean of the other three determinations.

The vacuum arc spectrum of Cu has been measured recently by Wolfsohn[22] who photographed it in juxtaposition with the spectrum of the arc in air, using the high dispersion afforded by the grating spectrograph at Bonn. His vacuum values are systematically larger than his air values which he interprets as a pressure shift toward the violet for lines emitted by the arc in air. A comparison of the Bureau of Standards wave lengths with Wolfsohn's is given in the last two columns of Table 5, which shows that his conclusions concerning the pressure shift toward the violet are not verified. In fact, assuming the correctness of his arc-in-air measurements the residuals, Bureau of Standards *minus* Wolfsohn, indicate for copper the same type of pressure shift as has been found for all other spectra which have been investigated.

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[20] Astrophys. J. **66**, p. 256; 1927.

[21] Phys. Rev., **28**, p. 449; 1926.

[22] Annalen der Physik (IV), **80**, p. 415; 1926.

3. Na, Al, Ca, V, Cr, Mn, Ni, Ba

In Table 6 are listed some wave lengths of Na, Al, Ca, V, Cr, Mn, Ni, and Ba. Some of these elements, as stated above, occurred as impurities in the electrodes. Ca, Mn, Ni, and Ba were especially investigated to furnish additional standards in the red for comparison with the solar wave lengths. The intensities and temperature classes given for each line are those assigned by King, except for Na, and Al, for which the estimates given by Kayser [23] are quoted. The impurity lines are in all cases either the *raies ultimes* or persistent lines of the corresponding elements, and all appear among the Fraunhofer lines of the sun's spectrum.

V. ACKNOWLEDGMENTS

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WASHINGTON, December 19, 1927.

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[23] Kayser, Tabelle der Hauptlinien. Julius Springer, Berlin, 1926.

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