LICK OBSERVATORY BULLETIN

NUMBER 180

ON THE SPECTRUM OF MARS AS PHOTOGRAPHED WITH HIGH DISPERSION.

INTRODUCTION.

Let us recall that the solar spectrum, as viewed by terrestrial observers, is composite. Photospheric light, in passing out through the gases and vapors of the Sun's atmosphere, is selectively absorbed, with the result that many thousands of absorption lines are introduced into the spectrum. The transmitted light passes down through the Earth's atmosphere to the observer, and the absorption by water vapor and oxygen in the terrestrial atmosphere introduces many hundreds of additional lines, at definite points in the yellow, orange and red regions. The observed spectrum of the Sun is in reality the spectrum of the Sun plus the spectrum of the Earth. The spectrum of the Moon, so far as our present problem is concerned, is simply this Sun-Earth spectrum.

The light from *Mars* is photospheric light, which passes out through the Sun's atmosphere, thence down through the atmosphere of *Mars* to the planet's crust, where a certain proportion is reflected out through the Martian atmosphere, and thence down through the Earth's atmosphere to the observer. The so-called spectrum of *Mars* is in reality the Sun's spectrum plus *Mars*' spectrum plus the Earth's spectrum.¹ Any water vapor and oxygen in the Martian atmosphere should introduce the same absorption lines which are introduced by the Earth's atmosphere into the Sun-Earth spectrum.

If the distance between *Mars* and the Earth is not changing rapidly, the water vapor and oxygen lines from *Mars* and the lines from the Earth will coincide. When this condition of coincidence exists, it is clearly a difficult problem to detect moderate quantities of water vapor and oxygen in the Martian atmosphere, for the evidence of Martian absorption will be over-

whelmed by the absorption of the richly laden terrestrial atmosphere, especially if the observer be near sea level. To hope for success, the observations should be made from a high-altitude station, at times when the overlying air strata carry a minimum of water vapor, and when the planet is as near the zenith as practicable; observing the lunar spectrum, under identical conditions, for comparison.

Because of the faintness of the Martian and lunar spectra, it has been found that we are limited to low dispersion in visual observations; and that, when the distance between the two planets is constant, or nearly so, low dispersion offers a more sensitive method than high dispersion, even when photography is employed.

Complying with the conditions in the two preceding paragraphs, the writers photographed the spectra of *Mars* and the Moon last September, from the summit of Mt. Whitney. The conclusion drawn from that investigation was, in brief, that the quantity of any water vapor then existing in the equatorial atmosphere of *Mars* was too small to be detected by the spectrographic methods available. This does not mean that the Martian atmosphere was carrying no water vapor, but only that the quantity must have been very small.

At times other than those when *Mars* is near opposition, the Earth and *Mars* are relatively approaching or receding from one another. Their relative velocity at quadrature may amount to 20 km., more or less, per second, depending upon the concurrence of favorable circumstances.

¹ A little of the light would be reflected from the atmospheric strata of various heights without passing down to the planet's surface. On the other hand, the rays did not pass through the planet's atmosphere at right angles to the strata, in the observations described in this paper, but the average angle of incidence and reflection was about 20°.

When Mr. Campbell was photographing the spectrum of *Mars*, in December, 1896, with a Rowland grating, fourth order,² 568 lines per mm. (14438 per inch), he realized that the Doppler-Fizeau principle offers great advantages, in theory at least, for solving the problem of the Martian atmosphere; for on photographs of the spectrum, made near quadrature, with sufficiently high dispersion, the Martian absorption lines and the terrestrial absorption lines should be separated. At that time (thirteen years ago) the method could not succeed, for all the prominent water vapor and oxygen lines are in the region on the red side of $\lambda 5875$, and the photographic dry plates then available were not sufficiently sensitive to record this region. Even in the fairly sensitive region $\lambda 5700$ - $\lambda 5800$ the grating spectrograms of *Mars* were underexposed. The successes of recent years in sensitizing dry plates to yellow, orange and red light have encouraged the present effort to apply the method.

Early in 1909 Mr. Campbell designed the optical parts and the general features of the mounting of a spectrograph adapted to the requirements of this problem. A Michelson 5-inch plane grating and a Brashear collimator lens were purchased with William H. Crocker funds; a Brashear slit with funds granted by the Rumford Committee of the American Academy of Arts and Sciences for another purpose; and a Brashear camera lens with Observatory funds. Messrs. Campbell, Albrecht and Young designed the details of the mounting; Mr. Wright designed the support for the grating, along the lines of Ritchey's mirror supporting system; Mr. Reynold Young made the working drawings; and the instrument was constructed by the carpenter and the instrument maker of the Observatory. Mr. Albrecht made all the adjustments of the instrument, all the photographic exposures (with Mr. Kristian Lows assisting), and all the measurements and reductions of the photographic plates.

INSTRUMENTS AND METHODS.

1. 36-inch (91 cm.) refractor, focal length for D rays, 57 feet 10 inches (1763 cm.).
2. Reflecting slit, with guiding telescope.
3. Collimator lens: Brashear, aperture 82 mm. ($3\frac{1}{4}$ inches); focus $1524 \pm$ mm. (60 inches); corrected for D.
4. Grating: Michelson, 5-inch plane; ruled surface 98×68 mm. (3.86×2.68 inches); 591 lines per mm. (15,000 per inch); definition described by Michelson as "perfect"; brilliant in 1st order on one side and in 2nd order on the other side.

² *Astrophysical Journal*, 5, 236, 1897.

5. Camera lens: Brashear, aperture 82 mm. ($3\frac{1}{4}$ inches); focus 610 mm. (24 inches); triple, corrected for D.

The spectrograph, designed at all points to resist flexure, was supported and connected with the telescope by means of two steel tubes 76 mm. (3-inch) in diameter, very much as in the case of the original visual spectroscope of the Lick Observatory (see illustration, Frost's Scheiner's Astronomical Spectroscopy, p. 74), save that the bearing near the slit was of ring-form and free to rotate. No provision was made for maintaining constant temperature. We have no evidences of differential flexure or of changes in the position of the grating during exposures.

The angle between the collimator and camera axes was fixed at 30° . The second order spectrum was employed throughout the investigation. With the D region central in the camera, the linear dispersion was 11.6 A. U. = 1 mm.; and with the alpha region ($\lambda 6280$) central, 11.4 A. U. = 1 mm.

It was planned to secure observations of *Mars* and the Moon on or near January 17, 1910, as the planet was in quadrature at that time. The spectrographic velocity of *Mars* with reference to the Earth was then 18.8 km. per second, recession. Unfavorable weather delayed somewhat the carrying out of the program, but fortunately the velocity remained nearly constant for several weeks, until satisfactory observations were secured.

The plates employed were Cramer's Crown, selected for the purpose by Mr. R. James Wallace, Director of the Research Laboratory, and the formulae used were Mr. Wallace's, as published in *L. O. Bulletin*, 5, 151, 1909.

OBSERVATIONS.

The absorption in the water vapor lines in all the spectrograms was very incomplete. It is stronger for those taken on January 26th under poor atmospheric conditions than on those of February 2nd made under excellent conditions. Four exposures on the spectrum of *Mars* were made on the evening of January 28, at zenith distances 38° , 54° , 64° , and 76° , respectively. The humidity of our atmosphere was high for Mt. Hamilton, about 80 per cent. at air temperature $+5^\circ$ C., and the spectrograms have not been measured on that account. They show clearly the increase of water vapor absorption with increasing zenith distance.

The absorption for the oxygen lines in the alpha region was perceptibly more complete than for the water vapor lines referred to above.

No provision was made for removing the under-

lying spectrum of the third order. The region $\lambda 3930$ of the third spectrum of *Mars* did not seem to influence appreciably the second order spectrograms in the D region, no doubt because of the well known weakness of the Martian spectrum in the blue and violet. The region $\lambda 4185$ in the third order, somewhat out of focus, probably combined appreciably with the second order alpha region to strengthen the continuous spectrum background. The definition on the lunar spectrograms, in both the D and alpha regions, is much poorer than in the corresponding Martian spectrograms, no doubt in part at least because the third order lunar spectrum in the violet is sufficiently strong to influence the continuous spec-

trum background, slightly in the second order D region, and more strongly in the second order alpha region. It would be a simple matter to use appropriate screens in front of the slit, for cutting out the third order violet spectrum, but these we did not employ on account of a desire to avoid increasing the exposure times.

The image of the planet was allowed to travel along the slit, in order to widen the spectrum. In all cases the slit was placed on the east and west diameter of the planet.

Table I contains the records of the observations and the principal results of the investigation.

TABLE I.
SPECTROGRAMS OF MARS.

D REGION.											
Date of Mid-exposure Gr.M.T. 1910	Duration of Exposure	Slit- Width mm.	Measured Displacements		No. of Lines Used	Zenith- Distance Of Mars	Atmospheric Conditions				Clouds
			Of Water Vapor Lines km.	Of Oxygen Lines km.			Air Temperature	Relative Humidity	Grams Per Cubic Meter		
Jan. 26.74	1h 45m	0.08	19.7	Wt. 1	11	57°	+1.7 C.	70%	3.9	0	
Jan. 27.69	1 46	.05	21.6	1	10	44	+6.4	47	3.5	0	
Jan. 27.76	1 46	.05	18.8	1	17	64	+6.4	58	4.4	0	
Feb. 2.72	2 20	.08	18.3	3	22	55	+0.0	33	1.9	0	
a REGION.											
Feb. 3.67	2 00	.08			7	41	+0.3	42			thin
Feb. 3.77	2 15	.08			6	68	+0.3	42			thin
Mean observed velocities			19.2	18.1							
Computed velocity of Mars			19.1	19.1							

TABLE II.
MARS.—D REGION.

Displacements from Dispersion Curve.
(1 A. U. = 50.7 km. per second.)

Gr. M.T. 1910 λ Rowland		Jan. 26.735			Jan. 27.686			Jan. 27.761	Feb. 2.722		
		1st Meas.	2nd Meas.	Mean	1st Meas.	2nd Meas.	Mean		1st Meas.	2nd Meas.	Mean
		A.U.	A.U.	A.U.	A.U.	A.U.	A.U.	A.U.	A.U.	A.U.	A.U.
5816.601	Fe 5	.000	.000	.000	-.076	-.026	-.051	-.032	.000	.000	.000
57.674 } .756	Ca 8	+.010	-.009	.000	+.009	+.014	+.012	-.003	-.002	-.026	-.014
.976 }	Ni 3										
59.809	Fe 5	+.006	-.014	-.004	-.012	+.052	+.020	-.010	.000	-.003	-.002
62.585	Fe 6	+.004	+.009	+.006	-.003	+.013	+.005	+.018	+.012	+.043	+.028
79.820 } .882	w v 1	-.439	-.400	-.420	.....	.....	.....	.....	-.390	-.389	-.390
.945 }	w v 1										
80.948 }	w v 0										
81.147 }	w v 1								-.265	-.244	-.254
.320 }	w v 0										
82.084 }	w v 1										
.203 }	w v 0							-.557		-.423	-.423
83.025	w v 0							-.184		-.121	-.121
86.193	w v 5							-.383	-.298	-.344	-.321
87.445 } .608	w v 5				-.440	-.389	-.414	{ -.276	-.526	-.522	-.524
.880 }	w v 3							{ -.215			
88.920	w v 2				-.420	-.413	-.416	-.476	-.488	-.483	-.486

TABLE II—(Continued).

Gr.M.T. 1910 λ Rowland		Jan. 26.735			Jan. 27.686			Jan. 27.761	Feb. 2.722		
		1st Meas. A.U.	2nd Meas. A.U.	Mean A.U.	1st Meas. A.U.	2nd Meas. A.U.	Mean A.U.	A.U.	1st Meas. A.U.	2nd Meas. A.U.	Mean A.U.
89.855	.953	w v 3	—	—	—	—	—	—	—	—	—
90.100		w v 2	—	—	—	—	—	—	—	—	—
90.186		Na 30 D ₂	—	—	.000	—	—	—	.000	—	.000
91.398	.782	w v —, 1	—	—	—	—	—	—	—	—	—
.878		w v 4	—	—	—	—	—	—	—	—	—
92.608		w v 3	—	—	—	—	—	—	—	—	—
93.097		Ni 4	—	—	—	—	—	—	—	—	—
95.162	.261	w v 0	—	—	—	—	—	—	—	—	—
.360		w v 0	—	—	—	—	—	—	—	—	—
96.155		Na 20 D ₁	+	+	+	+	+	+	+	+	+
98.378		w v 4	—	—	—	—	—	—	—	—	—
5900.135	.218	w v 2	—	—	—	—	—	—	—	—	—
.260		w v 4	—	—	—	—	—	—	—	—	—
01.682		w v 6	—	—	—	—	—	—	—	—	—
05.505		w v 0	—	—	+	—	—	+	+	+	+
.895		Fe 4	—	—	—	—	—	—	—	—	—
15.650	.745	w v 1	—	—	—	—	—	—	—	—	—
.840		w v 1	—	—	—	—	—	—	—	—	—
16.475		Fe 3	+	—	—	—	—	—	+	+	+
19.860		w v 7	—	—	—	—	—	—	—	—	—
20.776		w v 1	—	—	—	—	—	—	—	—	—
22.334		Ti 0	—	—	—	—	—	—	—	—	—
.578		w v 0	—	—	—	—	—	—	—	—	—
.735		w v 2	—	—	—	—	—	—	—	—	—
.930		w v 0	—	—	—	—	—	—	—	—	—
28.013		Fe 2	—	—	—	—	—	—	—	—	—
29.898		Fe 2	+	+	+	+	+	+	+	+	+
30.406		Fe 6	+	+	+	+	+	+	—	—	—
32.306		w v 5	—	—	—	—	—	—	—	—	—
32.998		w v 2	—	—	—	—	—	—	—	—	—
34.881		Fe 5	+	+	+	+	+	+	—	—	—
41.290	.449	w v 5	—	—	—	—	—	—	—	—	—
.845		w v 2	—	—	—	—	—	—	—	—	—
48.765		Si 6	+	+	+	+	+	+	+	+	+
52.943	.032	Fe 4	—	—	—	—	—	—	+	+	+
53.386		Ti 1	—	—	—	—	—	—	+	+	+
56.573		w v 0	—	—	—	—	—	—	—	—	—
56.923		Fe 4	—	—	—	—	—	—	—	—	—
58.098	.466	w v 1	—	—	—	—	—	—	—	—	—
.460		w v 1	—	—	—	—	—	—	—	—	—
.840		w v 1	—	—	—	—	—	—	—	—	—
66.055		Ti A? 2	—	—	—	—	—	—	+	+	+
68.058	.276	w v 2	—	—	—	—	—	—	—	—	—
.495		w v 2	—	—	—	—	—	—	—	—	—
69.260		w v 0	—	—	—	—	—	—	—	—	—
70.280		w v 0	—	—	—	—	—	—	—	—	—
71.557		w v 1	—	—	—	—	—	—	—	—	—
75.330		w v 1	—	—	—	—	—	+	—	+	—
.575		Fe 3	—	—	—	—	—	—	—	—	—
83.908		Fe 5	—	—	—	—	—	—	+	+	+
85.040		Fe 6	—	+	—	—	—	+	+	+	+
.435		w v 0	—	—	—	—	—	—	—	—	—
98.002		Fe 2	—	—	—	—	—	—	+	—	+
6003.239		Fe 6	+	+	+	+	+	+	—	—	—
Means in A. U.		—	—	—	—	—	—	—	—	—	—
Number of lines		—	—	11	—	—	10	17	—	—	22
Corresponding velocity		—	—	18.5 km.	—	—	20.4 km.	17.6 km.	—	—	17.1 km.
Correction from spectrograms of Moon		—	—	1.2	—	—	1.2	1.2	—	—	1.2
Corrected velocity		—	—	19.7	—	—	21.6	18.8	—	—	18.3

TABLE III.

MOON.—D REGION.

Displacements of Water Vapor Lines.

Gr.M.T., 1910	Jan. 27.86	Jan. 28.89	March 30.98	March 30.98
Mean displacement	+ .036 A. U.	+ .029 A. U.	+ .043 A. U.	+ .015 A. U.
Number of lines	16	10	10	9
Observed velocity	—1.83 km.	—1.47 km.	—2.18 km.	—0.76 km.
Computed velocity of Moon	—0.45 km.	—0.51 km.	—0.38 km.	—0.38 km.
O—C	—1.38 km.	—0.96 km.	—1.80 km.	—0.38 km.
Weight	2	1	1	1
Mean correction	+1.18 km.			

TABLE IV.

MARS.— α REGION.

Displacements from Dispersion Curve.

(1 A. U. = 47.8 km. per second.)

Rowland's Wave-lengths			1910, Feb. 3.67		Feb. 3.77
			1st Meas.	2nd Meas.	
			A.U.	A.U.	A.U.
6276.815	A (0) 2d	.884	— .506	— .496	— .501
.021	A (0)				— .408
77.513	A (0) 2	.641	— .599	— .573	— .586
.639	" 1				
.701	" 1				
.837	" 1				
77.303	" 4d		— .490	— .496	— .493
79.084	" 2	.218	— .367	— .329	— .348
.308	" 3				— .324
79.108	" 2		— .278	— .300	— .289
80.598	" 2		.....	—.338	— .338
80.833	Fe 3d	}	.....	.....	.....
81.387	A (0) 1		.....	.....	.....
6282.164	A (0) 2		— .180	— .225	— .202
					— .321
Means			.....	.....	—.394
Corresponding velocity			.....	.....	18.8 km. 17.4 km.

Table II contains the observed displacements of the solar and water vapor lines for the D region spectrograms of *Mars*. The displacements printed in ordinary type refer to the solar lines, which were used as a basis for constructing the dispersion curves. The displacements printed in bold-face type are for the water vapor lines. The first column contains Rowland's wave-lengths of all the lines employed, together with his estimates of the intensities of these lines, as observed under conditions prevailing at Baltimore, where the water vapor content of the atmosphere is usually high.

The fraction $\frac{1}{2}$ following an observed displacement indicates that weight $\frac{1}{2}$ has been ascribed to this displacement, in accordance with Mr. Albrecht's judgment as to the relative excellence of the water vapor lines measured. However, the final results would have been substantially the same if weights unity had been used throughout.

Lunar spectrograms were obtained as listed in Table III, the two on March 30th having been made simultaneously, utilizing different sections of the slit.

Using the observed water vapor lines as reference spectrum, the observed velocities of the Moon were as contained in the table. The computed velocities of the Moon indicate that a mean correction of +1.18 km. should be applied to the observed velocities. This correction has been applied to the observed velocities of *Mars*. It was evident from the measures that some water vapor lines and blends require corrections to the Rowland values. Lines giving large or small values for the displacements on the *Mars* plates gave correspondingly small or large displacements on the Moon spectrograms. For example, lines $\lambda 5883.0$ and $\lambda 5895.3$ would be improved by applying corrections of —.121 and —.075 A. U., respectively, as obtained from the lunar spectrograms. We considered it advisable, however, to leave all the measures on the Rowland system. The application of such corrections would have changed the final results inappreciably.

With the spectrograph adjusted for the orange region, which is rich in water vapor absorption lines, spectrograms of *Mars* for measurement were secured, as indicated in Table I, on January 26th and 27th under poor atmospheric conditions, and on February 2nd under excellent conditions, our atmosphere on this night being exceedingly dry.³ Measures of the available water vapor lines on these spectrograms, 10 to 22 in number, establish that they were displaced with reference to the lines of solar origin in the observed Martian spectrum, by amounts on the three dates corresponding to velocities in the line of sight of 19.7, 20.2, and 18.3 km. per second; weighted mean value, 19.2 km. The relative velocities of *Mars*, computed from our knowledge of the orbits of the Earth and *Mars*, amounted to 19.1 km. per second. The dispersion and slit-width employed were such that the water vapor lines originating in our atmosphere and any originating in *Mars*' atmosphere should have appeared side by side, though not clearly separated. If the absorptions by the two planets were equal, the two sets of lines of equal intensities should, in effect,

³ Settled and dry weather conditions prevailed from the morning of February 1 to noon of February 6; average humidity about 40 per cent, average air temperature about —0°5 C.

have appeared as broad lines of double width, and the measured velocities should have been but half the computed velocities,—in the present case, $10\frac{1}{2}$ km. per second. The facts are that the terrestrial lines were not bordered nor increased in width by companion lines. When the micrometer wire was set successively in the positions which Martian absorption lines would occupy, no traces of absorption were found in these positions. In effect, Martian absorption did not exist to such an extent as to be visible in the spectrum, or to influence the measurements referred to.

With the spectrograph adjusted to the so-called “alpha” region at $\lambda 6280$, which includes a large number of oxygen absorption lines, two spectrograms were obtained on 1910 February 3.67 and February 3.77. The observable oxygen lines, seven and six in number, were displaced with reference to the lines of solar origin, as recorded in Table IV, by amounts corresponding to velocities in the line of sight of 18.8 and 17.4 km. per second. The velocity computed from the elements of the orbits of Earth and *Mars* amounted to 19.1 km. The discrepancy of 1.0 km. is within the unavoidable error of measurement. Here again the terrestrial oxygen lines were not bordered nor doubled in width by Martian lines. No

corrections to the zero positions of the oxygen lines were obtained by means of lunar spectrograms.

CONCLUSIONS.

We draw the following conclusions from this investigation.

The quantity of water vapor existing above unit area in the equatorial atmosphere of *Mars* was certainly less than one-fifth that existing above Mt. Hamilton under the excellent conditions prevailing on February 2nd. On that date the air temperature was 0° Centigrade; the relative humidity was 33 per cent.; the absolute humidity was 1.9 grams per cubic meter; and the zenith distance at mid-exposure was 55° .

Likewise the quantity of oxygen above unit area on *Mars* must be small in comparison with that in the Earth’s atmosphere.

It should be repeated that the rays of light utilized had passed in effect at least twice through the Martian atmosphere.

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1910 April 20.