THE B BAND OF OXYGEN IN THE SPECTRUM OF MARS[1]

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ABSTRACT

Ten spectrograms of Mars covering the region of the B band of oxygen were obtained in the first order of the 9-foot grating spectrograph at the coudé focus of the 100-inch reflector during the autumn and winter of 1932–1933. During the interval covered by the observations, the radial velocity of the planet relative to the earth varied from −13.8 to +12.6 km/sec. The linear scale of the spectrograms was 5.6 A/mm.

Measures of the wave-lengths of about thirty oxygen lines on each of the ten spectrograms relative to lines of solar origin showed a mean displacement of but 0.0002 A from the position of the telluric oxygen lines. The contours of the oxygen lines were also investigated with the microphotometer and compared with the theoretical contours on the assumption of a ratio of 1:1000 in the relative abundance of molecules of free oxygen in the atmospheres of Mars and the earth. The final conclusion is that the amount of oxygen in the atmosphere of Mars is probably less than one-tenth of 1 per cent of that in the earth's atmosphere over equal areas of surface.

The detection of band lines arising from the presence of oxygen in the atmosphere of Mars is difficult on account of the strong overlying lines of telluric oxygen. Under suitable conditions, this difficulty may be overcome in two different ways.

First, the intensity of the oxygen band in the spectrum of Mars may be compared photometrically with the intensity of the band in a spectrum of the moon taken at the same altitude above the horizon. This was done in 1909 by F. W. Very, who used single-prism spectra of the B band taken by V. M. Slipher. Very concluded that the band was 24 per cent stronger in the spectrum of Mars than in that of the moon and attributed the difference to Martian oxygen.

The second method depends on the Doppler shift of Martian oxygen lines relative to the corresponding telluric lines when the planet is near quadrature. Percival Lowell suggested in 1905 that under these conditions each telluric oxygen line should be blended with a Martian oxygen line in its wing, with the result that its measured wave-length should differ slightly from the normal value. Slipher attempted to apply the method to the B band, but was unable to obtain a definite result. In 1910 W. W. Campbell and S. Albrecht,

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using higher dispersion on the α band, concluded that if oxygen were present in the atmosphere of Mars its amount must be small.

The α band in the spectrum of Mars was also photographed by Adams and St. John in 1926, with a dispersion of six prisms. The linear scale of the single spectrogram obtained was about 11 A to the millimeter and measures with a microphotometer pointed to a slight displacement of the oxygen lines. With allowance for the relative paths in the atmospheres of the two planets, the measurements indicated the presence of about 16 per cent as much oxygen above unit area on Mars as on the earth.

Recently Dr. Mees at the Research Laboratory of the Eastman Kodak Company has produced a photographic emulsion having a narrow band of sensitivity with a maximum near λ 6800. This emulsion has made it possible for us to photograph with high dispersion the strong B band of oxygen in the spectrum of Mars, which is much more favorable for an investigation of this character than the faint α band of shorter wave-length. The instrument used was a plane-grating spectrograph of 9-foot focal length, placed in a fixed position at the coudé focus of the 100-inch telescope. The linear scale of the spectrograms was 5.6 A per millimeter in the first order, and the definition was good. The average exposure time on the planet was three hours.

Ten spectrograms of the B band in Mars were obtained with this instrument: one in November, 1932; another in January, 1933; two in March; four in April; and two early in May. During this interval the radial velocity of the planet relative to the earth changed from −13.8 to +12.6 km/sec. In this region of the spectrum a velocity of 13.8 km/sec. would correspond to 0.32 A, or to a linear displacement on the spectrograms of 0.057 mm. Since this shift is about one-third of the average distance between the components of the conspicuous pairs in the tail of the band, the cores of lines due to oxygen in the atmosphere of Mars should be completely resolved. No trace of any such lines could be seen, however, and measurements of the telluric lines were undertaken to learn whether slight shifts due to the presence of possible very faint unresolved Martian components could be detected.

Since the arc spectrum of iron which is used for comparison purposes on spectrograms taken with the coudé instrument shows only a few faint lines in the region of the B band, solar lines were adopted as standards for the measurement of the oxygen lines. This method has the advantage of comparing absorption lines with absorption lines photographed simultaneously, and of utilizing the wave-lengths of the *Revised Rowland Table* throughout. Owing to the radial velocity of Mars, the lines of oxygen, if wholly terrestrial in origin, would be displaced by amounts corresponding exactly to the velocity of Mars,[2] but with reversed sign; but by smaller amounts, if any Martian oxygen is involved. Since the scale of the spectrograms is not strictly constant, owing principally to the color-curve of the lens in the spectrograph, the reduction of the measures requires the use of some form of interpolation formula. An equation of the Hartmann type involving three standard lines has been found satisfactory, the computed wave-lengths of the oxygen lines being corrected by means of a curve derived from other lines of known wave-length. Direct interpolation with a scale factor derived from short intervals along the spectrograms has also been used to some extent, and in general the wave-lengths thus obtained agree closely with those computed from the Hartmann formula. At best, the distribution of solar lines in this region of the spectrum is not good for comparison purposes, but we believe that the methods of reduction employed have reduced the errors from this source to small quantities. On the average, thirty oxygen lines in the B band have been measured on each spectrogram.

The final results, based in most cases upon measurements by two observers, are shown in the accompanying table. The calculated radial velocity of Mars, converted into fractions of an angstrom unit for direct comparison with the measured displacements of the oxygen lines, is given in the third column. The difference between the measured and the calculated values is in the last column. The method of reduction, which is based upon solar lines in the spectrum of

[2] This velocity is made up of the three components, Mars-earth, Mars-sun, and rotation of earth. Solar lines in the spectrum of Mars would be displaced by an amount corresponding to the algebraic sum of all three components, but oxygen lines in the spectrum of Mars by an amount corresponding to the sum of the first and third terms. The maximum velocity of Mars relative to the sun for any of the ten spectrograms here considered is +1.5 km/sec.

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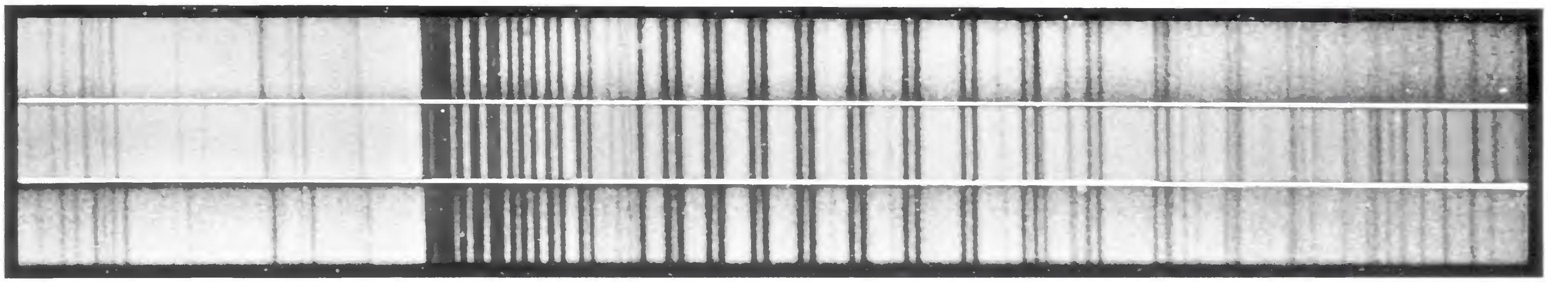
PLATE VII



SPECTRUM OF THE B BAND IN MARS AND THE SUN

a) Mars ($V = -13.75$ km/sec.)
b) Sun
c) Mars ($V = +12.42$ km/sec.)

Mars, is such that the presence of oxygen lines in Mars would in all cases give smaller numerical displacements for the oxygen lines measured on the spectrograms. Hence a persistent negative sign in these differences would point to the existence of Martian oxygen.

SUMMARY OF OXYGEN LINES IN MARS

Plate	Calc. V		Meas. V A	Diff. A
	Km/Sec.	A		
Coudé 579	−13.75	0.316	0.295	−0.021
594	−13.21	.304	.298	− .006
613	+ 3.55	.082	.077	− .005
618	+ 3.73	.086	.085	− .001
622	+10.30	.237	.232	− .005
627	+10.48	.241	.256	+ .015
632	+10.81	.248	.242	− .006
637	+10.86	.250	.252	+ .002
649	+12.42	.286	.298	+ .012
653	+12.60	0.290	0.303	+0.013
Mean difference				−0.0002 ±0.0024

If the lines measured on the spectrograms may be considered as blended lines consisting of two components, one due to telluric oxygen and the other to Martian oxygen displaced by an amount corresponding to the relative motion of Mars and the earth, the order of the intensity of the Martian component may be calculated from the measures. The mean difference shown by the ten spectrograms is −0.0002 A, which would indicate a Martian component considerably less than one-tenth of one per cent as strong as the telluric component. This quantity is far below the accidental error of measurement, the probable error of the mean being ±0.0024 A. A value of 0.0024 A, however, would indicate a Martian component only 0.8 of one per cent as strong as the telluric component, and the number of oxygen molecules producing the Martian line would be considerably less than 0.01 of one per cent as great as the number producing the telluric line.

Further, if oxygen is present in appreciable amount in the atmosphere of Mars, it should produce an asymmetry in the lines of the telluric B band due to Martian components, in the violet wings when the planet was approaching in November, 1932, and in the red wings when the planet was receding in May, 1933. A comparison of the contours of these lines on the plates taken at these times should bring out such an asymmetry. Plate VIII shows tracings obtained with the registering microphotometer of two spectrograms corresponding to the extreme range in radial velocity.

Since the components of each pair of lines in the tail of the B band are separated by only about 0.9 A, the wings overlap, and it is im-

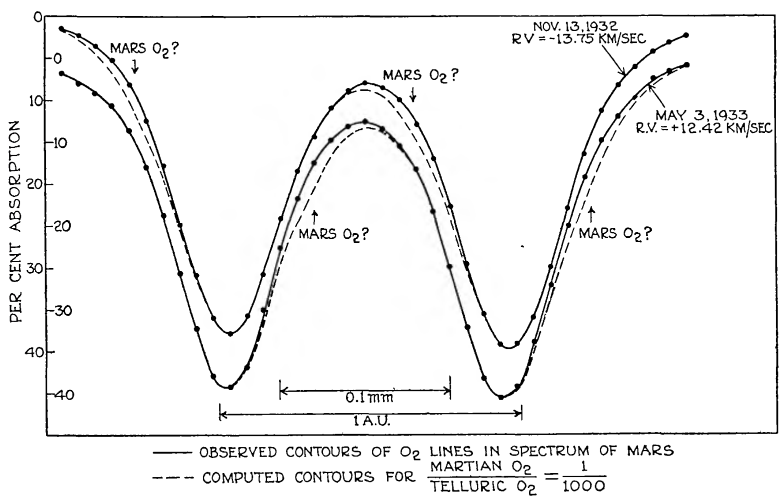
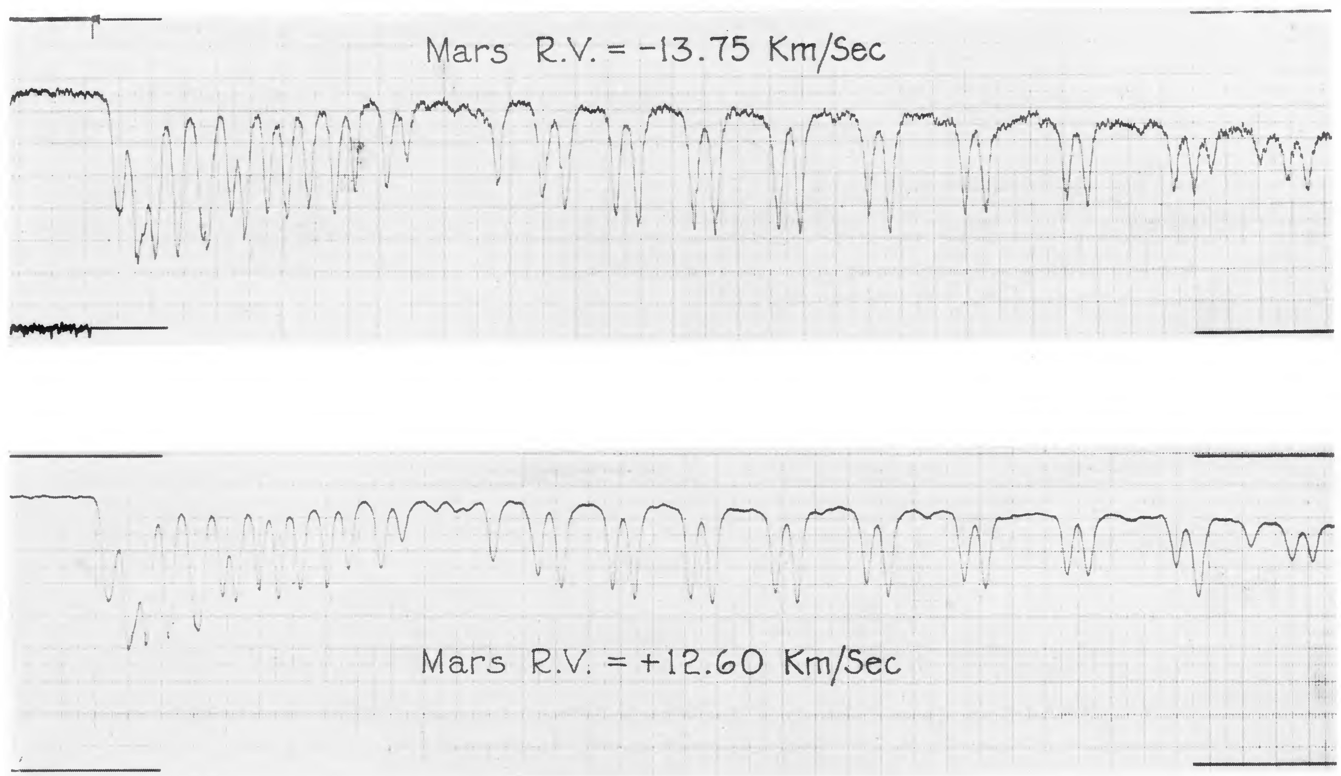


FIG. 1

possible to study the lines individually. They must therefore be studied in pairs. Accidental errors have been reduced by averaging the contours of six pairs of lines on each plate. Figure 1 shows the contours on November 13, 1932 ($V = -13.75$ km/sec.) and on May 3, 1933 ($V = +12.42$ km/sec.), the curves being displaced vertically for comparison. Before averaging the contours, the abscissae of individual pairs of lines were adjusted to take account of the slightly different separations of the components of different pairs. As the two plates were not taken at exactly the same zenith distance, the ordinates have been adjusted to make the total absorption equal in the two cases.

Since any asymmetry produced in these curves by Martian oxygen would affect the violet wings of one curve and the red wings of the other curve, a direct comparison of the curves should show a

PLATE VIII



MICROPHOTOMETER TRACINGS OF THE B BAND IN THE SPECTRUM OF MARS doubled effect. No such asymmetry is apparent from an inspection of Figure 1. In order to bring out differences that do exist in the shapes of the two curves, the differences in percentage absorption are plotted on an enlarged scale in Figure 2 for each 0.01 mm on the plate (0.056 A). The differences were taken after sliding one curve on the other longitudinally until the best fit possible was obtained.

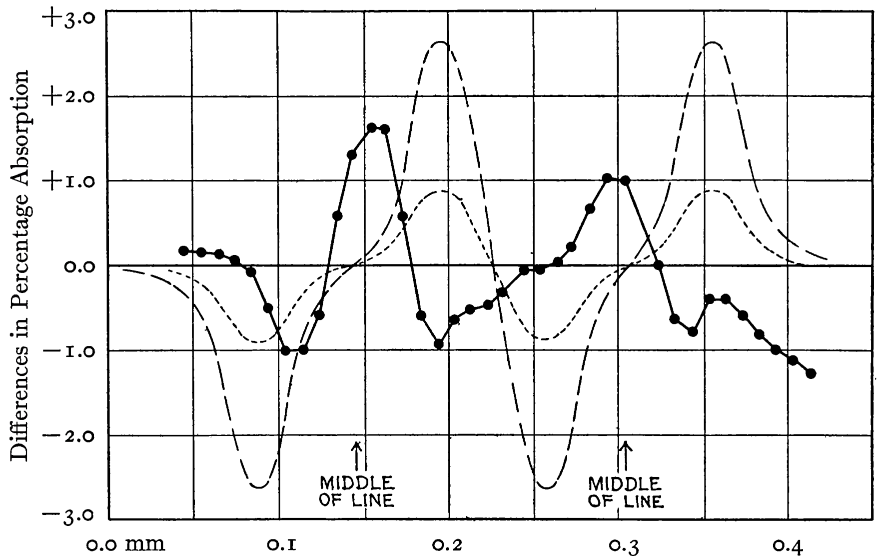


FIG. 2.—Differences in percentage absorption within pairs of oxygen lines shown in Figure 1, expressed as absorption: Mars receding (May 3, 1933, $V=+12.42$ km/sec.) *minus* Mars approaching (November 13, 1932, $V=-13.75$ km/sec.)

Full line: Observed differences in percentage absorption.

Dashed line: Theoretical differences for $\frac{\text{Martian } O_2}{\text{Telluric } O_2} = \frac{1}{1{,}000}$

Dotted line: Theoretical differences for $\frac{\text{Martian } O_2}{\text{Telluric } O_2} = \frac{1}{10{,}000}$

The observed differences between the two contours do not at any point exceed 1.5 per cent of the background intensity. There is no certain systematic agreement between the observed and theoretical curves, and hence no evidence for the existence of Martian oxygen.

An attempt has been made to estimate the contours these lines would have if the ratio of oxygen in the atmospheres of the two planets were 1:1000. Since the Martian path is approximately twice that of the telluric path, and since the total absorptions of spectral lines may be taken to vary as the square root of the number of molecules concerned, we should expect an integrated absorption equal to 4.5 per cent of that of the lines in the telluric band. The half-width of the monochromatic pattern of the spectrograph used is known to be about 0.33 A, and the displacement of the centers of the hypothetical Martian lines on the two dates in question is known from the computed velocity of the planet. The approximate contour for the blended oxygen lines can therefore be calculated. The computed contour for an abundance ratio of 1:1000 is shown in Figure 1 as a dotted line.

The differences in the ordinates of the two theoretical curves for Martian O_2: Telluric $O_2=1:1000$ are shown in Figure 2 by the dashed curve of larger amplitude. The dotted curve of smaller amplitude represents a ratio of 1:10,000 for the amounts of oxygen on the two planets. There is no indication of any significant similarity between the observed and the theoretical curves. The excursions of the observed curve nowhere represent differences in absorption between the two contours of more than 1.5 per cent, and are probably due to slight differences in focus of the spectrograph on the two dates in question. Judged by the magnitude of the observed fluctuations, it is highly probable that Martian oxygen amounting to 0.001 of the telluric oxygen could be detected with the present resolution, but that the detection of one-tenth of this amount would be uncertain.

It is of interest to estimate the displacement in wave-length to be expected from measures made by setting a wire on the apparent central wave-lengths of the oxygen lines for a ratio of Martian to telluric oxygen of 1:1000. In making settings on an asymmetrical line some observers are influenced more by the core and others more by the wings. For the present purpose we shall assume that the setting bisects the integrated absorption of the line. The differences in the abscissae of the two theoretical curves in Figure 1 indicate that for an oxygen ratio of 1:1000 and a radial velocity of 13.09 km/sec. (the mean of the two observations) we should expect a measured displacement of the line as a whole amounting to 0.010 A. This value is considerably greater than the probable error of the present measures, and the measures themselves give no indication of any such displacement.

The observed differences between the contours for November, 1932, and May, 1933, which are plotted in Figure 2 were obtained after sliding the curves horizontally to obtain the best fit. Under the assumed conditions, a displacement of the November curve in the direction of increasing wave-length amounting to twice the shift for each curve, or 0.020 A in all, might therefore have been expected. In order to include with certainty the correct match in wave-length, four observed difference-curves similar to Figure 2 were plotted, corresponding to the following relative positions of the November and May curves:

1. Best fit of the two curves
2. November curve displaced 0.020 A toward shorter wave-lengths
3. November curve displaced 0.040 A toward shorter wave-lengths
4. November curve displaced 0.020 A toward longer wave-lengths

In order to avoid confusion, only the first of these curves is reproduced in Figure 2. The others show, as is to be expected, a progressive change in shape, but none indicates any systematic agreement with the theoretical curves shown by dashed lines. We appear, therefore, to be justified in concluding that the observed shapes of the oxygen lines give no indication whatever of Martian oxygen, whereas an oxygen ratio of 1:1000 would cause a readily detectable asymmetry.

The A band of oxygen with its head near λ 7600 includes the strongest oxygen lines in the whole solar spectrum that can be studied photographically, and hence should be particularly favorable for investigation because of the increased intensity of possible Martian components. This band has the further advantage that in fully exposed solar spectra it shows the isotope lines of $O^{16}-O^{18}$, which are due to a definite number of absorbing molecules about 0.06 per cent as numerous as those producing the principal lines and which thus afford a basis for quantitative comparison of the intensity of Martian oxygen lines. The difficulties in obtaining high-dispersion spectrograms of sufficient density in this region of the spectrum on so faint an object as Mars are considerable. As yet we have but a single spectrogram, which was taken with the aid of a cylindrical lens placed close to the photographic plate to reduce the exposure time. This photograph agrees with those of the B band in showing no certain evidence of the presence of Martian components; but plates of greater density and higher contrast are required for a definite conclusion.

A few lines due to water vapor, lying to the red of the oxygen lines in the tail of the B band, appear on our spectrograms. The sensitivity of the plate falls off rapidly in this region and the focus of the spectrograph changes rapidly. The few measures made indicate displacements slightly smaller than those calculated from the velocity of the planet, as might be expected were Martian components present, but these measures are entitled to little weight. We hope to undertake further investigations of the water-vapor lines near λ 7200 and λ 8200, where much stronger lines are available.

The chief conclusion to be drawn from this study with high dispersion of the B band of oxygen in the spectrum of Mars is that the amount of free oxygen present in the atmosphere of the planet must be extremely small, certainly less than 1 per cent, and probably less than 0.1 per cent, of that present in the earth's atmosphere over equal areas of the surface.

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