ROCKET SPECTROGRAPHIC OBSERVATIONS OF α VIRGINIS

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ABSTRACT

Two spectrograms of α Vir (B1 V) in the wavelength interval $928 < \lambda < 1350$ Å and with 0.8 Å resolution were successfully recorded on a rocket flight June 1, 1967. The data revealed hydrogen Lyman absorption lines through Ly-ζ and, in addition, evidence for 128 absorption lines arising from the ground and low-lying states in ions of C, N, Si, S, Cl, Ti, V, Cr, and Fe. The results imply that strong line blanketing occurs at $\lambda < 1350$ Å. No interstellar absorption lines due to H_2 were observed; an upper limit for the mean number density of this molecule between the Earth and α Vir is 3.1×10^{-4} cm^{-3}.

I. INTRODUCTION

Rocket and satellite measurements of stellar fluxes have clearly shown a large flux deficiency in the far-ultraviolet spectral region of main-sequence B-type stars when compared with model atmospheres in which line absorption has been excluded. The photometric measurements of Chubb and Byram (1963), Smith (1967), and Stecher (1967) have illustrated this fact quantitatively. The spectrographic experiments of Morton and Spitzer (1966), Morton (1967), Carruthers (1968), and Morton, Jenkins, and Bohlin (1968) indicate strong ultraviolet line absorption, and through the efforts of these workers and others many identifications of the more important lines have been made. The spectrographic results have so far extended down to 1050 Å, and in this paper they will be extended further to include the Lyman-ζ line near 930 Å.

Gaustad and Spitzer (1961) have pointed out and discussed theoretically the many strong absorption lines which can be expected in this wavelength region. Accordingly, models in radiative equilibrium have been constructed for a B1.5 V atmosphere (Mihalas and Morton 1965) and a B4 V atmosphere (Adams and Morton 1968) including the effects of ninety-eight ultraviolet absorption lines in the opacity. A similar model for a B0 V star has been constructed (Hickok and Morton 1968) using 104 ultraviolet lines. The results indicate a generally depressed flux level at $\lambda \leq 1300$ Å for stars of this type. However, the predicted deficiencies do not yet seem to be as large as the observed deficiencies, and in particular it is not clear that sufficient account has been taken of the many weaker absorption lines which can be expected to contribute to the opacity.

This paper presents the results obtained from two spectrograms of α Vir (B1 V) recorded in the range $928 \leq \lambda \leq 1344$ Å. Again, large absorption is observed at these wavelengths, and the purpose of the paper is to identify at least some of the absorbing agents, to suggest the presence of others, and to estimate their total effect.

In the absence of any observed H_2 it is also possible to derive an upper limit to the amount of this molecule between Earth and α Vir.

II. THE EXPERIMENT

The instrumental package consisted of a one-element, "stigmatic-mounting" grating spectrograph, a pointing control system, and telemetry instrumentation required to monitor the payload status. The spectrograph, which is described elsewhere (Hochgraf 1966; Mostrom 1966), is shown diagrammatically in Figure 1. Starlight fell upon a platinum-coated concave grating ruled at 1200 lines mm^{-1}. The grating itself defined the

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instrumental aperture to be 14 cm². A stigmatic image was formed on the grating normal at the focal plane for $\lambda \approx 1216$ Å, but on either side of the grating normal the diffracted image became astigmatic, thereby decreasing the speed of the system. A modest sacrifice in speed was found desirable, however, since the intentional introduction of some astigmatism provided better grain statistics as well as better resolution. The instrument was adjusted to give about $\frac{1}{4}$ Å resolution at 1134 Å, and a nearly linear dispersion of 33.4 Å mm⁻¹ throughout the entire recorded spectrum. A mechanical collimator located in front of the grating limited the field of view in the plane of dispersion to $\pm \frac{1}{2}°$ at the
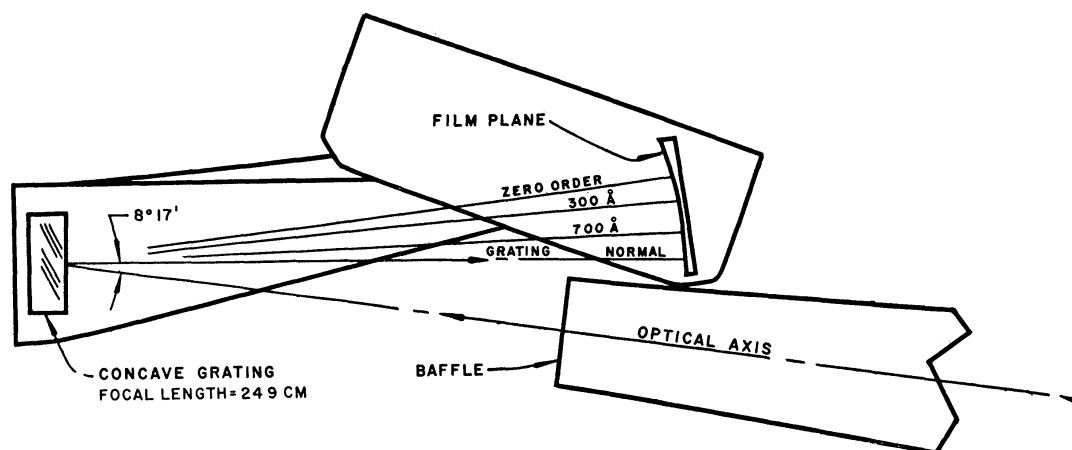

Fig. 1.—Simplified diagram of the rocket spectrograph. Essentially a Wadsworth mounting, a stigmatic image is formed on the grating normal near 1216 Å. A slot near the focal plane defines a field of view normal to the dispersion plane of $\pm 1°$. Effective grating area, i.e., instrumental aperture, is 14 cm² and is ruled at 1200 lines mm⁻¹. Grating is platinum coated.
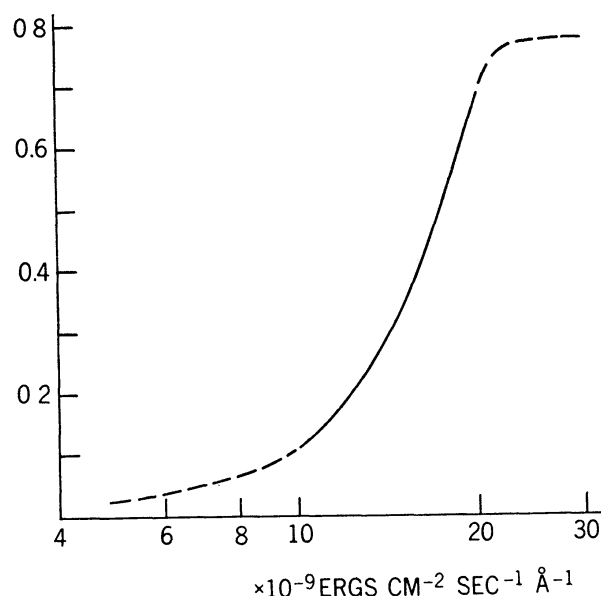

Fig. 2.—A calibration function of the entire rocket spectrograph system at 1216 Å. Curve represents an average of three calibrations corresponding to a 150-sec exposure using three samples of Kodak Pathé SC5 flight film. Ordinate values represent film densities averaged over area of densitometer slit.

half-power transmission points. Similarly, a slot close to the focal plane defined the field of view normal to the dispersion plane to be $\pm 1°$.

The film used in the experiment was Kodak Pathé SC5 which in combination with the instrument exhibits a sensitivity curve as shown in Figure 2. The calibration was carried out at Lyman α and, except for the absolute value of the abscissa, represents a characteristic curve for this type of film. Three calibrations using different strips of flight film were made in which the diffracted image of the slit source was shifted in 1-Å increments over a small area of each strip. Under the assumption that there was no reciprocity failure (Fowler, Rense, and Simmons 1965) the exposure time was varied with each position, and the source intensity was kept constant. Figure 2 shows the averaged results corresponding to an exposure of 150 sec. The development procedure used throughout the experiment included slight agitation of the exposed film for 2 minutes in D19B at 68° F. The dashed portions of the curve indicate regions where the data are unreliable. The solid portion, derived from relatively reliable data, defines a very small dynamic range of a factor of 2. Relative flux values falling outside this range are extremely uncertain; consequently it is difficult to estimate the threshold sensitivity. There is evidence, however, that some sensitivity exists for flux levels a factor of 10 below that necessary to produce half-maximum density in the film. In addition to the difficulty of a small dynamic range it has been observed that flux levels corresponding to half-maximum density vary by as much as a factor of 2 for samples of film from the same batch; however, for a given sample this same flux level was observed to vary less than 10 per cent in the wavelength range recorded, i.e., $928 < \lambda < 1343$ Å.

The experiment package was launched at White Sands, New Mexico, at 2130 hours (M.S.T.) on June 1, 1967, by an Aerobee 150 rocket. Based on the data of Struve *et al.* (1958) the relative radial velocity between the components of this binary system at the time of launch was 67 km sec^{-1}. Consequently, the wavelength difference between identical lines associated with each component is less than 0.3 Å for all wavelengths in the present experiment. These same authors further suggest that the secondary component is type B7 in terms of its mass but exhibits a spectrum of a B2 or B3 star because of its non-synchronous rotation and consequential heating of its entire surface by the primary component. In view of these facts no spectrographic discrimination between the two components was expected. During most of the flight when spectrograms were being recorded the spectrograph pointed at the star to within $\pm 10''$, this being achieved by the "STRAP II" pointing control system developed at the Goddard Space Flight Center. Two exposures were taken, one at a mean altitude of 164 km for 150 sec, and the other at 127 km for 54 sec. The payload was recovered, and the film subsequently developed according to the calibration procedures. The wavelength scale was determined by fitting the easily identified features of Lyman α, Lyman δ, and N II λ1085.1 to a quadratic function of the distance measured on the film along the spectrum from an arbitrary starting point. The scale is believed to be accurate to within 0.3 Å. The resolution was approximately 0.8 Å limited mainly by the rocket motion.

III. THE RESULTS

Figure 3 (Plate 1) is an enlarged reproduction of both spectrograms with the strongest lines identified. Figure 4 presents in three wavelength sections microdensitometer traces which have been smoothed in a computer by using a triangular weighting function 0.62 Å full width at half-maximum. The lower and upper traces in each section correspond to the long and short exposures, respectively. Vertical lines corresponding to laboratory-measured transitions indicate various spectral features which are definitely or possibly present. The horizontal lines connect members of the same multiplet, but for purposes of clarity all such members are not necessarily shown.

The fluctuations within the resolution element of 0.8 Å are commensurate with the
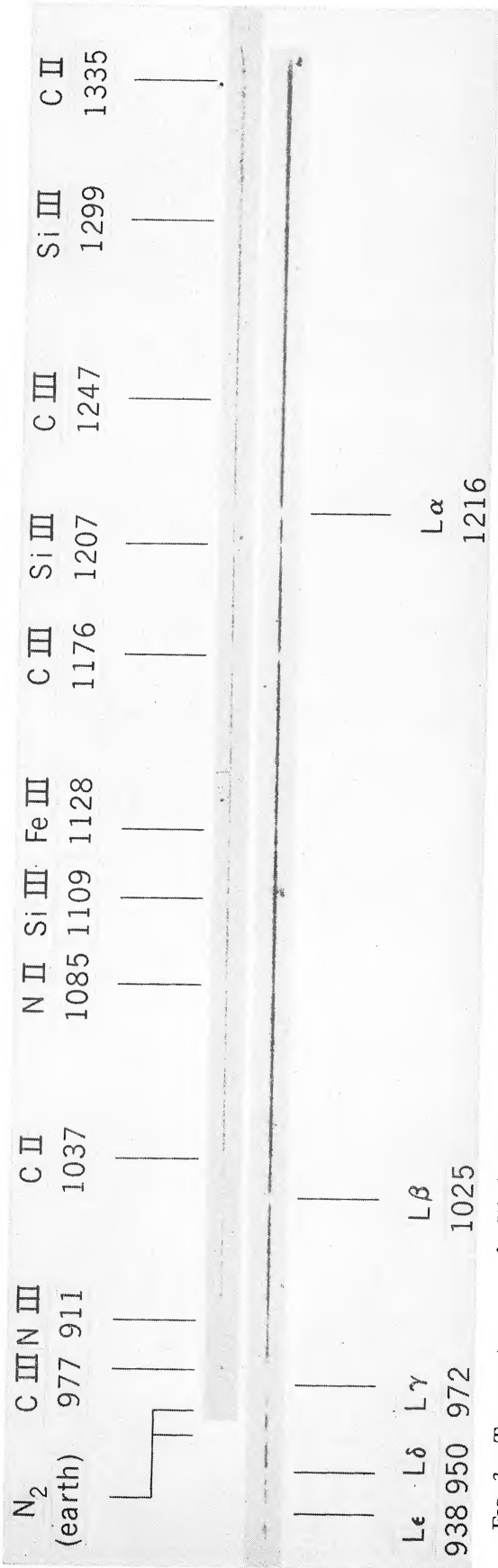
PLATE 1

FIG. 3.—Two spectrograms of α Vir (B1 V) secured with stigmatic-mounting rocket spectrograph. Exposure times of top and bottom spectrograms were 54 sec and 150 sec, respectively. Some identifications of stronger features are shown in which numbers represent an approximate average of wavelengths in Ångstrom units at which known ionic transitions occur.

SMITH (*see* page 95)
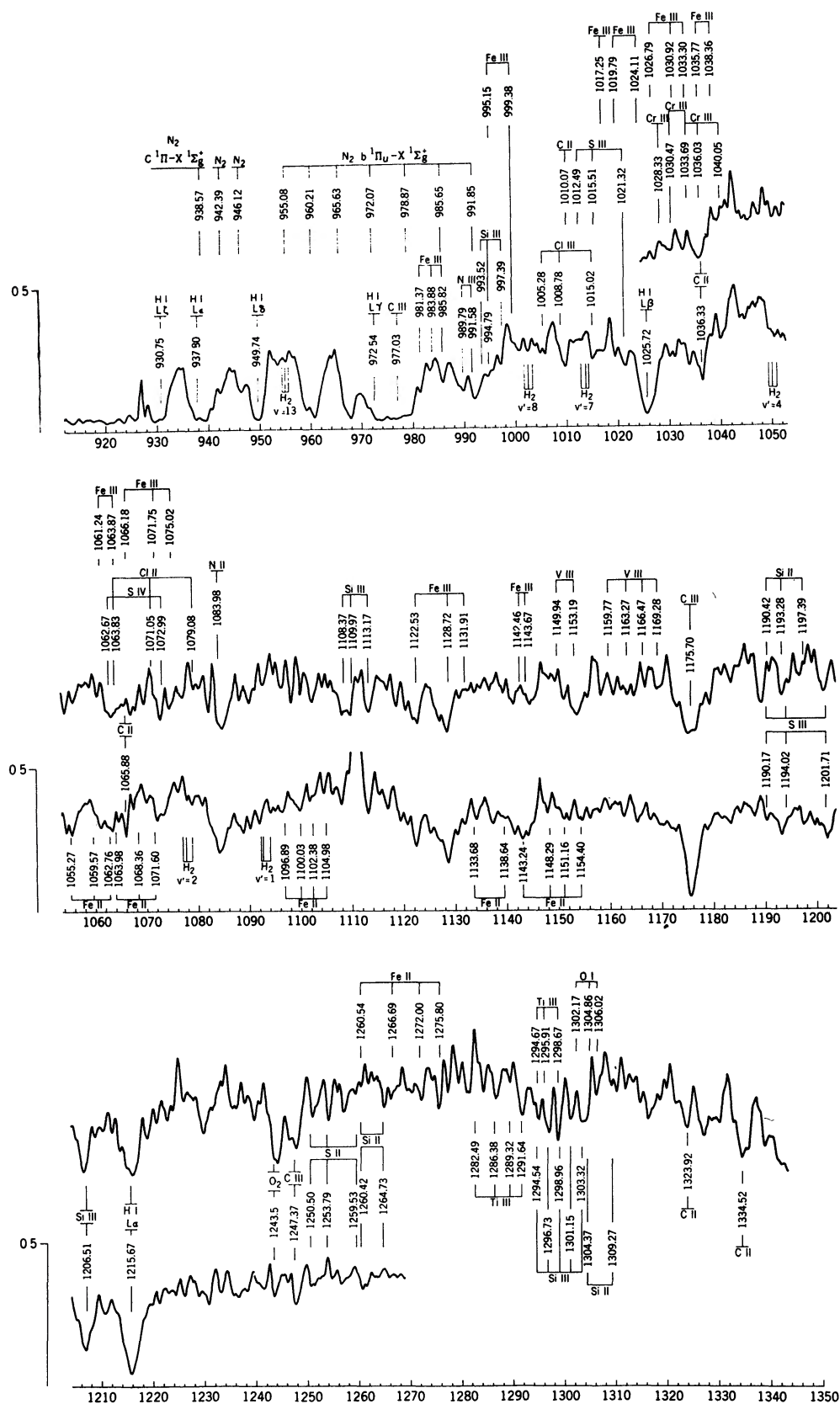
FIG. 4.—Microdensitometer traces of the α Vir (B1 V) spectrograms. Horizontal scale is in Ångstrom units, and ordinates represent densities of long (150-sec) exposure only. Top and bottom tracings were made from short and long exposures, respectively, with an effective densitometer-slit width of 0.62 Å. Vertical lines indicate various spectral features which are definitely or possibly present; horizontal lines connect members of the same multiplet.

expected photon statistics. Examination of the flight film, however, indicates that grain noise must also contribute to the fluctuations and that the data quality could have been improved by elongating the image normal to the dispersion plane without a significant loss in sensitivity.

Both spectrograms exhibit strong telluric line absorption. Features due to N_2 at 960.2 and 965.6 Å are the most obvious while absorption at 972.1 Å is expected to be even greater on the basis of laboratory data (Watanabe 1961). This latter transition occurs in the same region where strong stellar absorption due to C III and H I is expected, irrevocably confusing the observations at these wavelengths. The positions of other N_2 transitions are shown, and are perhaps reflected in the data; note for example, features at 942.4 and 946.1 Å.

The only obvious evidence for telluric O_2 is on the short exposure (mean altitude of 127 km) at 1244 Å. A weak feature corresponding to this wavelength can also be seen on the long exposure. As determined from the Cospar International Reference Atmosphere (1965) and the cross-section measurements of Watanabe (1961) transitions at 966, 972, and 983 Å can be expected to be about the same strength or less. Transitions at 939, 948, and 956 Å may be as much as 6% stronger, but absorption by N_2 probably predominates at these wavelengths. A transition in O_2 at 1205 Å is suggested in both traces, but it has small effect indeed on the strong Si III blend at 1206.5 Å. Except in the absorption bands noted, the N_2 and O_2 molecules above these rocket altitudes should have negligible effect on the stellar spectrum.

On the short exposure, O I may produce a weak feature at 1306 Å, and probably contributes to the width of the Si III lines observed at 1301.2 and 1303.3 Å. The O I absorption is considered telluric, particularly in view of the fact that no interstellar lines can be definitely identified in these spectra.

No emission features have been detected. The peak near 1110 Å on the long exposure is a film blemish and can be located on the corresponding spectrum reproduction in Figure 3.

Morton (1965) has listed twenty-four multiplets with lines expected to be wider than 2 Å in stars of this type and in the wavelength range $928 < \lambda < 1350$ Å. Lines in all of these multiplets have been identified with the exception of an Ar II transition at 932.05 Å. The latter is probably blended with the Lyman-ζ line to such a degree that it cannot be detected. Apart from the strong expected lines a number of tentative identifications have been attempted. For example, as expected the C II doublets near 1335 and 1037 Å which include resonance transitions are clearly seen. There is also, however, evidence for transitions in this ion starting from the 5.31- and 9.25-eV levels corresponding to features near 1010 Å in the first case and both 1066 and 1324 Å in the second.

Si II appears to be a stronger absorber at 1193 Å than S III. If this is the case one might expect to see the effects of Si II at longer wavelengths. There is indeed weak evidence on the short exposure for Si II multiplets near 1265 and 1309 Å.

It may be noted here that none of the sulfur lines appear to be strong when compared, for example, with resonant absorption from Fe III at 1122 Å. The strongest absorption feature due to sulfur is apparently a blend of S III lines near 1201 Å. There also seems to be weak evidence for S II at 1259.5, 1253.8, and 1250.5 Å which are resonant transitions of this ion.

Cl III appears as expected at 1015, 1009, and 1005 Å but the Cl II lines at 1071, 1072, 1063, and 1079 Å are difficult to distinguish since they are blended with other features and particularly with the S IV lines at 1074, 1073, and 1063 Å.

Two Fe III multiplets are indicated here also. The lower levels in these transitions are near 3.1 eV, and the presence of their lines in the spectrum is uncertain. Perhaps the strongest evidence for absorption due to Fe III ions of low excitation may be found where two multiplets are noted, one at 1017 Å, and another at 985.8, 983.9, and 981.4 Å. If this identification is accepted as plausible one might expect to find other features due

to excited Fe III ions. Accordingly, such transitions have been noted throughout the range from 980 to 1150 Å where they could possibly account for some of the observed structure. Attention is called to the region around the C II lines at 1037 Å where some of the features have been attributed to transitions from the ground-state term of Cr III. Excited Fe III ions may also contribute to absorption in this region.

The spectrum possesses features probably arising in transitions from the ground state of the Fe II ion. The multiplet noted in the vicinity of 1100 Å indicates evidence to this effect. Again other Fe II ground-state transitions which possibly are associated with spectral features are noted. Thus, the contour of the spectrum from 1133 to 1155 Å may be principally influenced by the Fe II ion. Also there is some evidence on the short exposure that Fe II accounts for some of the features near 1270 Å.

In the category of possible low-abundance elements the Cr III identification is the most certain. Three multiplets in the interval from 1027 to 1042 Å provide the only observable transitions in the sensitivity range of the experiment, and it is considered quite likely that the features in this region are due in part to the Cr III ion.

Not so certain is the identification of ground-state transitions in Ti III near 1290 Å. Some lines would be masked by those of the more abundant Si III ions; others may be associated with weak spectral features particularly at 1286.4 and 1291.6 Å.

Finally, an attempt was made to identify ground-state transitions of V III with structure observed near 1165 Å. The correlation, however, is weak. Another multiplet of V III which might contribute to absorption is located near 1152 Å and, if significant, would combine its effect with that of Fe II. The strong absorption associated with the ground state of Fe III would completely predominate at 1123 Å where another V III ground-state multiplet is found.

There is much structure in the spectrograms which is not accounted for. An absorption feature at 1230 Å is revealed on the short exposure which may be telluric, in view of the fact that it is not well reproduced in the long exposure. Absorption lines near 1327, 1316, 1211, 1183, and 1117 Å seem real but unidentifiable. A line near 1137 Å may be an unclassified line of Cr III at 1136.67 Å. There is a depression on either side of the C III line at 1175.1 Å, which extends for several Ångstroms, and a general decrease in density with decreasing wavelength in a region just above the N II lines at 1085 Å. No agents accountable for these effects could be identified. The same may be said for the region near 1053 Å where the λ1055.27 line of Fe II is considered only a possible identification, and the line at 1054.4 Å does not correspond well to any produced by H_2.

Table 1 contains a list of all multiplets in which at least one transition has been identified in the tracings. The ion species appear in the first column, the laboratory and observed transition wavelengths in the second and third columns, respectively, and the multiplet number in the fourth column. All the information contained in the first, second, and fourth columns is taken from *An Ultraviolet Multiplet Table* of Moore (1950) except in the case of silicon, where her *Selected Tables of Atomic Spectra* (1965) was used. Listed in the fifth column are *gf*-values as compiled by Morton (1965), Wiese, Smith, and Glennon (1966), or Garstang and Shamey (1967). In the sixth column are comments which include crude estimates of the observed stellar line intensities ranging from very strong to very weak in five steps. For a weak or very weak classification the certainty of the identification is also given as either probable or possible. Blends of lines in the same multiplet are indicated where applicable.

IV. DISCUSSION

The data indicate that not only are the strong lines employed by Mihalas and Morton in their B1.5 V model present in the atmosphere of α Vir, but that many other weaker lines appear as well. These arise in transitions from low-lying levels in both abundant ions, e.g., Fe III, and less abundant ions, e.g., Si II, Fe II, Cr III, Ti III, and V III. Only for the ions of Fe II and Fe III have transitions been noted which originate from levels not

Table 1
INDICATED TRANSITIONS IN THE ULTRAVIOLET SPECTRUM OF α VIR

Ion	λ (Å) (Laboratory)	λ (Å) (Measured)	Multiplet No.	gf	Remarks
H I	1215.67	1215.8	UV(1)	0.8324	Very strong;
	1025.72	1025.7	UV(2)	0.1582	Lyman lines
	972.54	---	UV(3)	0.05798	
	949.74	949.5	UV(4)	0.02788	
	937.80	937.6	UV(5)	0.01560	
	930.75	930.2	UV(6)	0.009628	
C II	1335.71 } 1335.68	1335.7	UV(1)	1.60 0.11	Strong; blended
	1334.52	1334.4		0.52	
C II	1323.92	1323.9	UV(11)	2.30	Weak; probable iden.
C II	1066.12 } 1065.88	1066.0	UV(12)	0.28 0.49	Weak; probable iden; blended
C II	1037.02 } 1036.33	1036.6	UV(2)	0.24 0.12	Moderate; blended
C II	1010.37		UV(7)	1.02	Weak; probable
	1010.07	1010.0		0.68	iden; blended
	1009.85			0.34	
C III	1247.37	1247.8	UV(9)	0.27	Moderate
C III	1176.35		UV(4)	0.32	Very strong;
	1175.97			0.26	blended
	1175.70	1175.7		1.00	
	1175.57			0.20	
	1175.25			0.26	
	1174.92			0.33	
C III	977.03	~ 997	UV(1)	0.81	Very strong
N II	1085.70		UV(1)	0.70	Very strong;
	1085.54			0.12	blended
	1084.57	1084.5		0.39	
	1084.57			0.13	
	1083.98			0.17	
N III	991.58 } 991.51	991.8	UV(1)	0.64 0.072	Strong; λ991.58 and 991.51Å are
	989.79	989.8		0.36	blended, λ989.79 is partially blended
Si II	1309.27	1309.1	UV(3)	0.57	Weak; possible
	1304.37	1304.2		0.21	iden.
Si II	1265.02 } 1264.73	1265.0	UV(4)	0.62 6.2	Weak; possible iden.
	1260.42	---		3.6	

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Table 1 (Cont'd.)

Ion	λ (Å) (Laboratory)	λ (Å) (Measured)	Multiplet No.	gf	Remarks
Si II	1197.39	1197.5	UV(5)	1.03	Weak; probable
	1194.50	---		5.1	iden.
	1193.28	1193.3		2.0	
	1190.42	---		0.92	
Si III	1303.32	---	UV(4)	0.50	Moderate
	1301.15	1301.2		0.40	
	1298.96 } 1298.89	1298.8		1.80	
	1296.73	1296.9			
	1294.54	---			
Si III	1206.51	1206.6	UV(2)	1.68	Very strong
Si III	1113.23 } 1113.20 } 1113.17	1113.1	UV(5)	2.00	Moderate; λ1109.94 and 1108.37Å are blended
	1109.97 } 1109.94	1109.8		1.20	
	1108.37	1108.0		0.40	
Si III	997.39	997.3	UV(6)	1.00	Moderate
	994.79	994.7		0.64	
	993.52	---		0.20	
Si II	1259.53	1259.5	UV(1)	1.34	Weak; possible
	1253.79	1254.2		0.89	iden.
	1250.50	---		0.45	
S III	1202.10 } 1201.71 } 1200.97	1202.0	UV(1)	0.021 0.32 1.77	Weak; probable iden; λ1202.10, 1201.71 and 1200.97Å are
	1194.40 } 1194.02	1194.1		0.32 0.94	blended; λ1194.40 and 1194.02Å
	1190.17	1190.2		0.42	are blended
S III	1021.32 } 1021.10	1021.3	UV(2)	1.12 0.38	Weak; probable iden; λ1021.32
	1015.76 } 1015.51	1015.7		0.38 0.52	and 1021.10Å are blended; λ1015.76
	1012.49	1012.3		0.30	and 1015.51Å are blended
S IV	1073.52 } 1072.99	1073.1	UV(1)	1.69 0.19	Weak; probable iden; λ1073.52
	1062.67	1062.6		0.94	and 1072.99Å are blended

Table 1 (Cont'd.)

Ion	λ (Å) (Laboratory)	λ (Å) (Measured)	Multiplet No.	gf	Remarks
Cl II	1079.08	1078.8	UV(1)	0.94	Very weak; possible
	1071.76⎫	1072.0		0.56	iden;λ1071.76 and
	1071.05⎭			2.82	1071.05Å are
	1063.83	1063.5		0.94	blended
Cl III	1015.02	1014.8	UV(1)	1.66	Weak; probable
	1008.78	1009.0		1.10	iden.
	1005.28	---		0.56	
Ti III	1298.67	---	UV(1)	---	Very weak;
	1298.95	---		---	possible iden.
	1295.91	---		---	
	1294.67	1293.7		---	
Ti III	1294.67	1293.7	UV(2)	---	Very weak;
	1293.26	---		---	possible iden.
	1291.64	1291.8		---	
	1289.32	1289.4		---	
	1286.38	---		---	
	1282.49	---		---	
V III	1169.28	1169.4	UV(1)	---	Very weak;
	1166.58⎫	1166.2		---	possible iden.
	1166.47⎭			---	
	1163.27	1162.7		---	
	1159.77	1159.8		---	
Cr III	1041.34	1040.9	UV(1)	---	Weak; probable
	1040.17⎫	1040.1		---	iden; λ1040.17
	1040.05⎭			---	and λ1040.05Å
	1037.80	1037.6		---	are blended
	1036.03	---		---	
	1035.93	---		---	
	1033.69	1033.8		---	
Cr III	1035.77	---	UV(2)	---	Weak; probable
	1035.57	---		---	iden; λ1033.99,
	1035.29	---		---	1033.69, 1033.45
	1033.99	---		---	and 1033.23Å are
	1033.69⎫	1033.8		---	are blended
	1033.45⎬			---	
	1033.23⎭			---	
	1030.89	---		---	
	1030.47	1030.2		---	
Cr III	1030.10⎫	1030.2	UV(3)	---	Weak; probable
	1029.57⎭			---	iden; λ1030.10
	1028.33	1028.4		---	and 1029.57Å are
	1027.46	---		---	blended

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Table 1 (Cont'd.)

Ion	λ (Å) (Laboratory)	λ (Å) (Measured)	Multiplet No.	gf	Remarks
Fe II	1275.80 } 1275.15 }	1275.6	UV(9)	--- ---	Very weak; possible iden.
	1272.64 } 1272.00 } 1271.24 }	1272.0		--- --- ---	
	1267.44 } 1266.69 }	1266.8		--- ---	
	1260.54	---		---	
Fe II	1154.40 } 1153.96 }	1154.3	UV(10)	--- ---	Very weak; possible iden.
	1153.28	---		---	
	1152.88	---		---	
	1152.44	---		---	
	1151.16	1151.1		---	
	1150.69	---		---	
	1150.29	---		---	
	1148.30 } 1147.41 } 1146.96 }	1147.6		--- --- ---	
	1144.95	---		---	
	1143.24	---		---	
	1142.33	---		---	
Fe II	1142.33	---	UV(11)	---	Very weak; possible iden.
	1138.64	1138.6		---	
	1133.68	---		---	
Fe II	1104.98	1104.4	UV(18)	---	Very weak; possible iden.
	1102.38 } 1101.54 }	1102.3		--- ---	
	1100.52 } 1100.03 }	1099.9		--- ---	
	1099.12	1098.8		---	
	1096.89 } 1096.79 } 1096.62 }	1096.4		--- --- ---	
Fe II	1062.76	---	UV(21)	---	Very weak; possible iden.
	1059.57	---		---	
	1055.27	1055.5		---	
Fe III	1131.91	1131.9	UV(1)	0.17	Moderate
	1131.19 } 1130.40 }	1130.7		0.38 0.50	
	1129.19 } 1128.72 } 1128.02 }	1128.8		1.12 1.46 1.17	
	1126.72	1127.0		0.88	
	1124.88	1125.3		2.32	
	1122.53	1122.5		4.50	

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Table 1 (Cont'd.)

Ion	λ (Å) (Laboratory)	λ (Å) (Measured)	Multiplet No.	gf	Remarks
Fe III	1075.02	1074.9	UV(26)	---	Very weak;
	1071.75	---		---	possible iden.
	1066.18	---		---	
Fe III	1063.87	---	UV(40)	---	Very weak;
	1061.71	1061.2		---	possible iden.
	1061.24			---	
Fe III	1038.36	1038.4	UV(20)	---	Very weak;
	1035.77	---		---	possible iden.
	1032.12	1032.3		---	
Fe III	1033.30	---	UV(28)	---	Very weak;
	1030.92	1031.2		---	possible iden.
	1026.79	---		---	
Fe III	1024.11	---	UV(41)	---	Very weak;
	1021.56	---		---	possible iden.
	1019.79	1019.4		---	
Fe III	1018.29	---	UV(12)	---	Very weak;
	1017.74	1017.8		---	possible iden.
	1017.25	1017.2		---	
Fe III	999.38	999.4	UV(21)	---	Very weak;
	997.60	---		---	possible iden.
	995.15	---		---	
Fe III	985.82	985.8	UV(13)	---	Very weak;
	983.88	983.3		---	possible iden.
	981.37	981.4		---	

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included in the ground-state configurations. It is not unreasonable to expect, however, that similar transitions will occur in the other observed metallic ions and perhaps in some which remain unobserved, such as Mn III or Mn II within the experimental wavelength range. Thus, in the atmosphere of α Vir the line blanketing due to weak but numerous lines is indeed significant and may be comparable in strength to the opacity of continuous absorption sources.

If such a situation prevails, the wings of the hydrogen Lyman lines will be unobservable and, therefore, the measured line profiles will not provide a suitable comparison with Stark broadened lines derived theoretically. The cores of the Lyman lines remain of course, but since these are formed high in the stellar atmosphere the theory is inadequate for comparison with the data. In any event it would be difficult to correct the profiles for the effect of interstellar hydrogen without a reliable independent measurement of the interstellar hydrogen abundance. If it is assumed, for example, that the mean number density of atomic hydrogen between the Earth and α Vir is 0.1 cm^{-3} then the width of the observed Lyman-α line at half-minimum is widened by a factor of about 1.14.

TABLE 2

VIBRATIONAL OSCILLATOR STRENGTHS AND WAVELENGTHS
FOR THE LYMAN BANDS OF H_2

$v-v'$	Vibrational Factor f_v	$R(0)$	Wavelength (Å) $R(1)$	$P(1)$
0– 1	0 0294	1092 196	1092 734	1094 053
0– 2	0685	1077 140	1077 700	1078 927
0– 4	143	1049 386	1049 960	1051 034
0– 7	117	1012 814	1013 814	1014 328
0– 8	0877	1001 824	1002 452	1003 297
0–13	0 0527	954 414	955 065	955 710

Spitzer, Dressler, and Upson (1964) have listed a number of lines in the Lyman bands of H_2 corresponding to transitions from $v = 0$ of (X) $^1\Sigma_g{}^+$ to $v' = 0, 1, \ldots, 13$ of (B) $^1\Sigma_u{}^+$ with $J = 0$ and 1. Some of their data for lines which could possibly be detected among the observed stellar lines of α Vir are reproduced in Table 2.

The left and right sides of the first column contain the vibrational quantum numbers of the lower and upper states, the second column the Franck-Condon factors, and the third, fourth, and fifth columns contain the only possible lines for transitions from the $J = 0$ and 1 rotational levels of the ground state. The positions of these lines are indicated in Figure 4 and are referenced by the vibrational quantum numbers v'. For the strongest vibration transition ($v' = 4$) the spectrogram contains no convincing evidence for any of the possible lines. Some features are observed near the lines for which $v' = 1$, 2, 8, and 13, but with the exception of the $v' = 1$ transition the correlation between the apparent absorption features and the actual line positions is weak. Furthermore, these vibrational transitions are relatively weak and would not be expected if the $v' = 4$ transition were not observed. The average equivalent width of all the small apparent absorption features for each v' listed is 0.053 Å. The rms equivalent width of clear plate noise is 0.040 Å which represents an optimistic limit of detectability. The absence of lines near 1050 Å together with the small average equivalent width, when compared with clear plate noise, of features at wavelengths corresponding to the listed vibrational transitions argues against the detection of H_2 in this experiment.

A somewhat arbitrary condition for an identification of H_2 is that there should be correlation between the lines of the 0–2, 0–4, 0–7, and 0–8 vibrational transitions and

observed features with equivalent widths greater than about 0.08 Å. For the $R(0)$ line in the 0–4 vibrational transition this figure corresponds to an upper limit of 6.5×10^{16} H_2 molecules cm^{-2} in the line of sight according to the calculations of Spitzer *et al.* (1964). The equivalent mean number density of 3.1×10^{-4} H_2 molecules cm^{-3} may be compared with the value estimated by Stecher and Williams (1967) for the general interstellar medium of $\sim 10^{-7}$ cm^{-3}.

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