Absorption Coefficients of 0_2 at the Lyman-alpha Line and its Vicinity

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ABSTRACT

Using a 3-m vacuum spectrometer, absorption coefficients of 0_2 at the Lyman-alpha line and its vicinity have been remeasured between 1214.8 and 1217.8 A. Coefficients at the wavelengths of the apparent doublet peaks of the Lyman-alpha line, caused by self-absorption and separated by 0.09 A, are pressure independent at relatively low pressure ($p \leq 6.3$ torr). The absorption coefficient at the shorter wavelength peak is 0.304 ± 0.002 cm^{-1} and that at the longer wavelength peak 0.278 ± 0.002 cm^{-1}. The minimum of the transmission window is located at about 1216.0 A and its value is 0.254 cm^{-1}.

1. INTRODUCTION

Absorption coefficients of 0_2 at the Lyman-alpha line, Ly-α, and its vicinity are of considerable importance in the study of the upper atmosphere, because the Ly-α line is located in one of the deepest transmission windows of 0_2 and because the observed width of the solar Ly-α line at half-maximum is very large, of the order of 1.0 A (Purcell et al., 1960). The coefficients in this region have been studied by many investigators (Preston, 1940; Watanabe et al., 1953; Ditchburn et al., 1954; Lee, 1955; Watanabe et al., 1958; Metzger et al., 1964; Shardanand, 1967). Although the coefficients at the Ly-α line reported in the literatures agree to within ± 14%, the coefficients measured by a photoelectric method showed a linear pressure dependence. On the other hand, the coefficients measured by photographic methods did not show such a pressure effect. All previous photoelectric measurements were carried out at relatively high pressures of 0_2 ($p \geq 10$ torr) by using relatively low resolution equipment (less than 0.1 A) with the Ly-α line or the hydrogen many line spectrum as a background.

In the present work, the absorption coefficients of 0_2 at the Ly-α line and its vicinity have been reinvestigated by using a high resolution spectrometer, relatively low pressures of 0_2 ($p \leq 6.3$ torr), with the Ly-α line and separately an argon continuum as background.

2. EXPERIMENTAL PROCEDURES

A 3-m vacuum monochromator equipped with a grating of 1200 lines/mm blazed at 2950 A was used. Reciprocal linear dispersions were 1.42 A/mm in the second order and 0.95 A/mm in the third order spectrum.

The discharge tube was an ordinary water cooled π-shaped tube with a LiF window. For an argon continuum source, argon gas was continuously flowed through the tube and was excited by a neon sign transformer, 900 W, 15 KV, in combination with a 500 μμF capacitor and 3-mm air-blown spark gap. The argon pressure was maintained at 18 torr. For the Ly-α line source, a trace of H_2 gas was introduced into argon at about 4 torr. In this way, we were able to obtain a very clean Ly-α line both in the second and third order spectra without any spectral interference. An enlargement of the Ly-α line in the third order spectrum is shown in Fig. 1. As seen in this figure, the line shows the apparent doublet due to self-absorption, and these components were separated by 0.09 A. This separation could be changed by the mixing ratio of H_2+ Ar and the discharge condition, but a separation of 0.09 A was adopted throughout the present experiments.

For the measurement of the absorption coefficients at the Ly-α line, an additional absorption tube, 15 cm long, was inserted between the entrance slit and the light source. By flowing O_2 at 1.2 torr through this tube, it was used as a filter in order to minimize the dissociation of O_2 along the absorption path within the spectrometer between the entrance and exit slits and thus suppress the formation of O_3 as a secondary process. This filter action is, of course, due to the fact that O_2 has very high absorption coefficients in the vacuum UV region, except for a few transmission windows, and thus filters out among other wavelengths any residual light from the source in the Schuman-Runge region.

The spectrometer itself was used as an absorption cell whose path length was 618 cm. Extra-dry oxygen gas, obtained from the Matheson Co., was introduced into the spectrometer, and its pressure was measured by a diaphragm type pressure gauge (CVC, GHD-100) and an oil manometer. Maximum pressures were 6.3 torr and 4.75

torr for the measurements with the Ly-α line and the argon continuum, respectively.

The transmitted light was measured behind the exit slit by a photomultiplier tube, type EMI 9514S, attached behind a LiF window with sodium salicylate on its back surface. Current from the tube was amplified by an electrometer and monitored by a 10 mV strip-chart recorder.

For the Ly-α line, the widths of both entrance and exit slits were adjusted to 21μ which corresponded to a band width of 0.03 A in the second order and 0.02 A in the third order. For the argon continuum, both slits were adjusted to 50μ which corresponded to a 0.07 A band width in the second order.

Absorption coefficients, k, are defined by the relation $\ln(I_o/I) = kx$, where I_o and I are light intensities before and after absorption in a path length x reduced to the standard conditions of 0^oC and 760 torr. The reduced path is given by $x = lpT_o/Tp_o$, where l is the actual cell length and the subscript o refers to standard conditions. In the pressure range of the present experiment, the absorption coefficient followed Beer's low within experimental error. Therefore, the coefficients were obtained from the slope of a straight line in a plot of $\ln(I_o/I)$ vs p.

3. RESULTS AND DISCUSSIONS

As seen in Fig 1 (b), the intensity of the shorter wavelength peak of the apparent doublet of the Ly-α line is stronger than the other component. However, in Fig. 1 (a), the intensity of the shorter wavelength component decreases more rapidly than the other as 0_2 pressure increases. The measured coefficients at the peaks in the second and third order agreed within the experimental errors. The values obtained are $0.304 \pm 0.002\ cm^{-1}$ and $0.278 \pm 0.002\ cm^{-1}$ at the shorter and longer wavelength peaks, respectively.

The coefficients of the transmission window from 1214.8 to 1217.8 A region are listed in Table 1 at 0.2 A intervals and are shown in Fig. 2 together with those at the Ly-α line. In the last column of the table, the absorption cross sections calculated from $\sigma = k/n_o$ are also listed, where n_o is Loschmidt's number (2.687×10^{19} molecules/cm^3). Wavelengths of the apparent doublet of the Ly-α line listed in the table were calculated by $\lambda = \lambda_o \pm \frac{1}{2}\Delta\lambda$, where $\lambda_o = 1215.671$ A and $\Delta\lambda = 0.09$ A, the separation of the apparent doublet components.

As shown in Fig. 2, the shape of the transmission window is very smooth, the shorter wavelength side is steeper than the other, and its minimum value is $0.254\ cm^{-1}$ at around 1216.0 A. For comparison with the present results, the coefficients obtained by Lee (1955) and Watanabe et al. (1958) are also plotted in the same figure. Present values at the shorter wavelength side are larger and those at the longer wavelength side are smaller than the previous ones.

The center of the Ly-α line is located about 0.33 A below the minimum of the transmission window, and the coefficient of the shorter wavelength peak is about 10% higher than that of the other peak, even though their separation is only 0.09 A. Therefore, the apparent coefficient at the Ly-α line may change with the resolution of the apparatus and with the width of the Ly-α source line, if the resolution is not high enough to separate the apparent doublet components.

The measured absorption coefficients of O_2 at the Ly-α line are summarized in Table 2, which includes the method of measurement and the pressure range of O_2 used. In this table, (P) indicates that the coefficient was pressure dependent. However, as also seen in the table, the pressure dependent measurements were carried out at relatively high pressures compared with those which were pressure independent. The coefficients measured by Watanabe et al. (1958), or more recently by Shardanand (1967), increased at a rate of 5.0×10^{-4} cm^{-1}/torr or 4.5×10^{-4} cm^{-1}/torr, respectively. Therefore, the pressure dependence is too small to be detected at low pressures and the results shown in the table are consistent in regard to the observation of pressure effect.

Preston (1940) suggested that the pressure broadening of the rotational lines of the O_2 absorption bands may account for the pressure dependence of the absorption coefficient. Recently, the pressure dependence has been ascribed by Shardanand (1967) to the formation of the O_4 molecule. We are not in a position to discuss the origin of the pressure dependence. However, we can give the position of the rotational lines of the O_2 absorption band in the transmission window in question. Very recently, Alberti et al. (1968) and independently we have analyzed the rotational structure of the Tanaka progression (II), the forbidden transition $\alpha^1\Sigma_u^+ - X^3\Sigma_g^-$, whose 3-0 band is located in this transmission window. Alberti et al. observed the rotational lines of the ^sR-branch up to N=15 and we observed them up to N=29. The observed and the calculated wavelengths of the rotational lines of the ^sR-branch which are located in the region of the present experiment, are the following: $(N=33)_{calc}$ 1215.61 A, $(N=31)_{calc}$ 1216.16A, $(N=29)_{obs}$ 1216.69 A, $(N=27)_{obs}$ 1217.20A, $(N=25)_{obs}$ 1217.70 A, $(N=23)_{obs}$ 1218.20A. The position of these lines is indicated by their N-numbers in Fig. 2. These lines are quite sharp on the photographic plate (Kodak SWR), but they are not in evidence on the strip-chart trace in the present experiment with a band width of 0.07 A.

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TABLES and FIGURES

Fig. 1. The Ly-α line spectrum in the third order.

(a) Pressures of 0_2 are 0, 7, and 14 torr from the top. Exposure times are 90 seconds.

(b) Exposure times are 60, 10, and 2 seconds from the top. Pressure of 0_2 is zero torr.

Fig. 2. Absorption coefficients of 0_2 in the range of 1214. 8-1217. 8A Present work, o; Watanabe, Mottl, and Sakai, x; Lee

TABLE 1. Absorption Coefficients of 0_2 at the Lyman-alpha Line and its Vicinity

TABLE 2. Absorption Coefficients of 0_2 at the Lyman-alpha Line

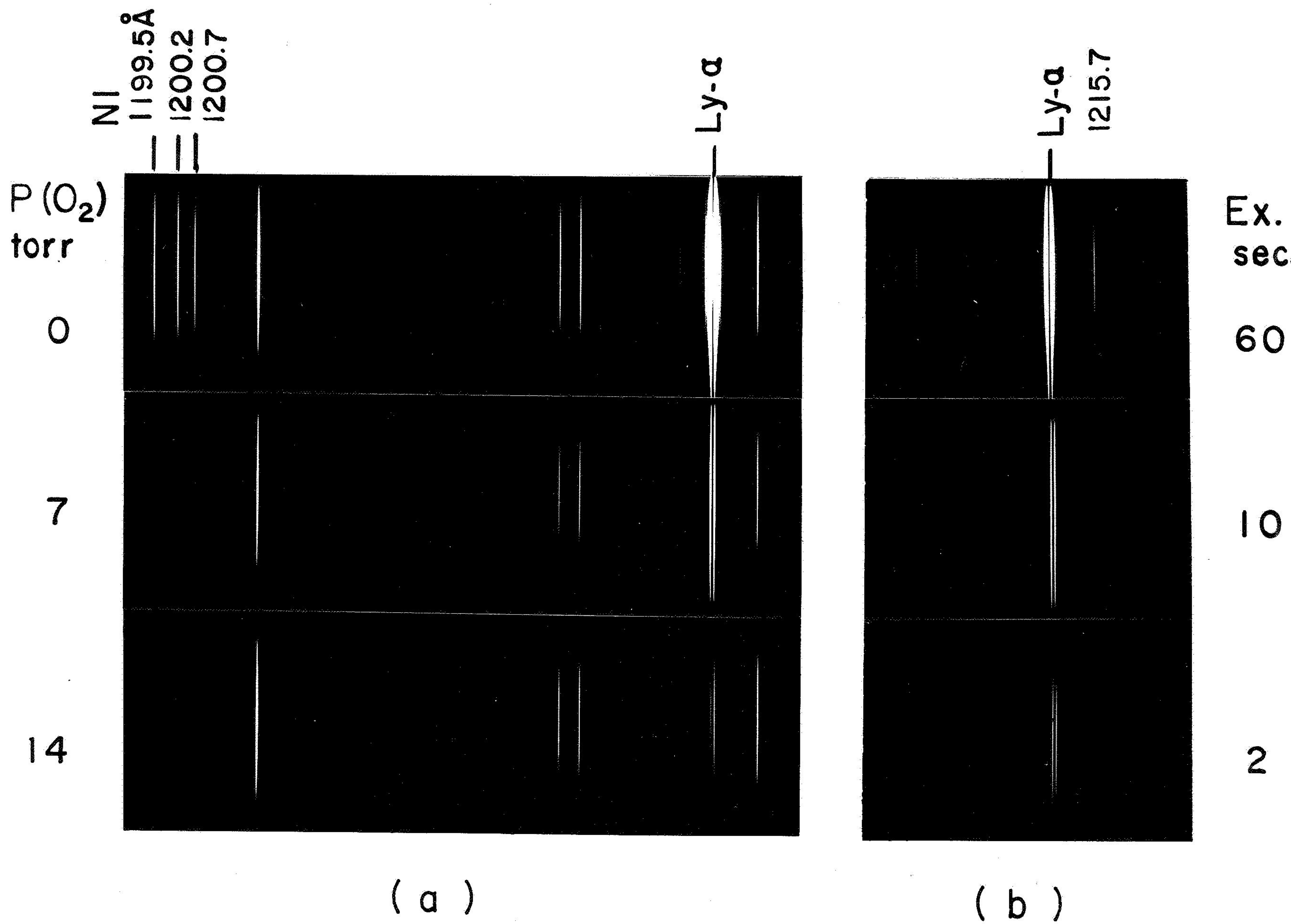
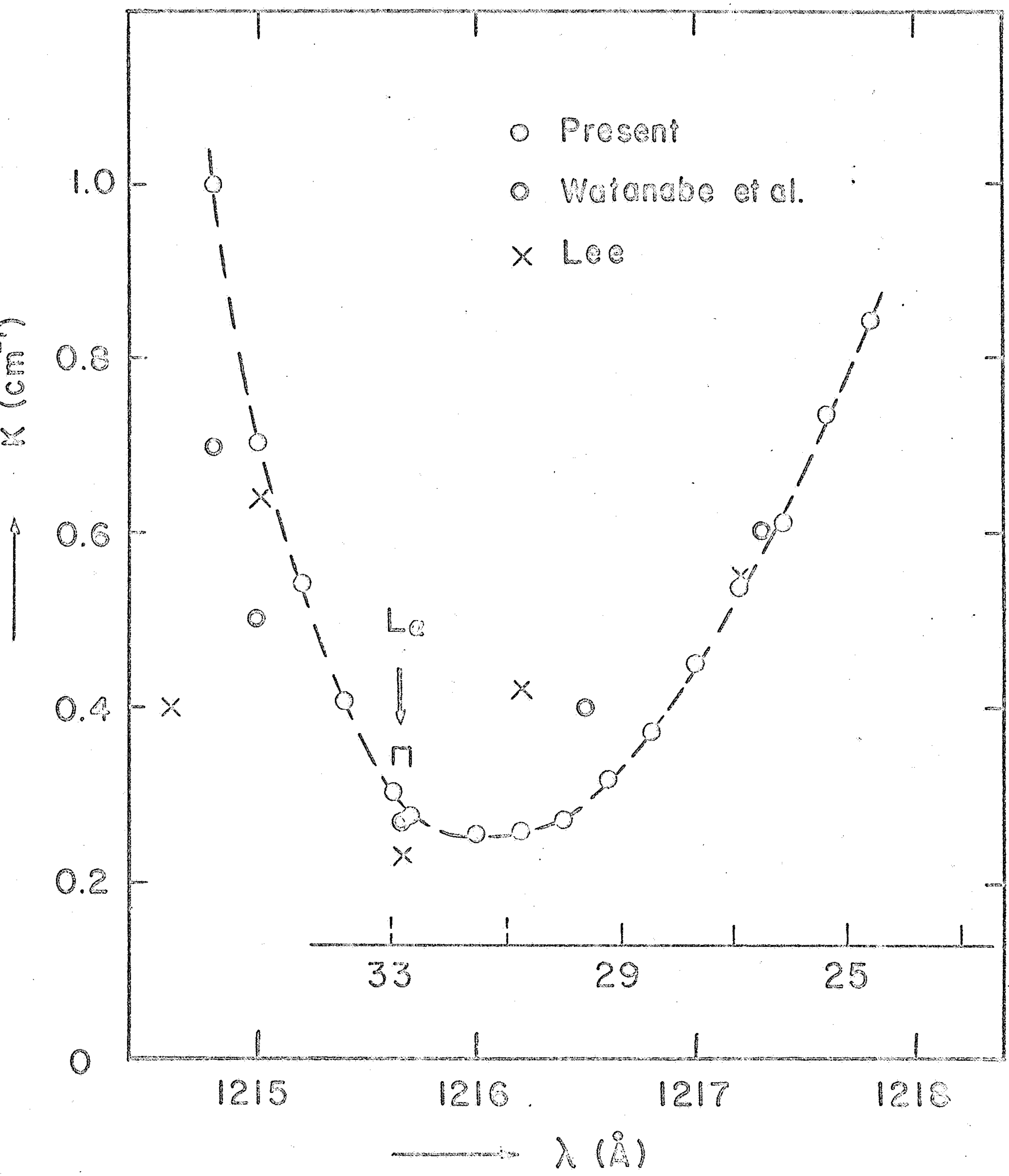

NI
1199.5Å
1200.2
1200.7
Ly-α
Ly-α
1215.7
P(O2) torr
0
7
14
Ex. sec.
60
10
2
(a)
(b)

Fig. 1



Present
Watanabe et al.
Lee
1.0
0.8
0.6
0.4
0.2
0
K (cm⁻¹)
Lα
33
29
25
1215
1216
1217
1218
λ (Å)

Fig. 2

TABLE 1. Absorption Coefficients of O_2 at the Lyman-alpha and its Vicinity

λ(A)	$k(cm^{-1})$	$\sigma(10^{-20} cm^2)$
1217.8	0.840	3.12
1217.6	0.732	2.72
1217.4	0.610	2.27
1217.2	0.537	2.00
1217.0	0.450	1.67
1216.8	0.370	1.38
1216.6	0.317	1.18
1216.4	0.271	1.01
1216.2	0.259	0.963
1216.0	0.254	0.945
1215.72*	0.278	1.03
1215.63*	0.304	1.13
1215.4	0.409	1.52
1215.2	0.542	2.02
1215.0	0.704	2.62
1214.8	1.000	3.72

* The Lyman-alpha line

TABLE 2. Absorption Coefficients of 0_2 at the Lyman-alpha Line

Investigator	k (cm^{-1})	σ $(10^{-20} cm^2)$	pressure (torr)	method
Preston (1940)	0.28(P)[a]	1.04	30-290	photoelectric, poly.[b]
Watanabe et al. (1953)	0.27(P)	1.00	70-490	photoelectric, mono.[b]
Ditchburn et al. (1954)	0.226	0.84	-20	photographic, poly.
Lee (1955)	0.23	0.85	-23	photographic, poly.
Watanabe et al. (1958)	0.27(P)	1.00	18-500	photoelectric, mono.
Metzger et al. (1964)	0.28(P)	1.04	---	photoelectric, mono.
Shardanand (1967)	0.29(P)	1.08	25-400	photoelectric, mono.
Present Work	{0.278 0.304	1.03 1.13	1.2-6.3	{ photoelectric, poly. with 0_2 filter

a; (P) refers to observed pressure dependence. b; mono. and poly. indicate "monochromatic" or "polychromatic" light passing through the absorption cell.