Indian J. Met. Geophys. (1972), **23**, 1, 23-28

551.521.326 : 551.594.5

Day airglow emissions of 5577A and 6300 OI lines in Martian atmosphere

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(*Received 27 July 1971*)

ABSTRACT. In this paper emissions of 5577A and 6300 A lines of OI in Martian atmosphere have been investigated. It has been found that for the 5577A line there are two peaks at 90 and 120 km and its total intensity is about 3·5 kR. For the 6300A line, since the rate of quenching by CO_2 molecules is not known, its emission profile is obtained for two values of quenching coefficient, namely, 1×10^{-13} cm^3 sec^{-1} and 1×10^{-12} cm^{-3} sec^{-1}. It has been found to have a broad peak at 100-140 km. Its intensity has been found to be 3 and 1 kR for the two values of rate coefficient.

1. Introduction

As in the earth's atmosphere, solar radiations are expected to produce day airglow in the Martian atmosphere. The emissions of 5577A & 6300A line in the day airglow give information of metastable oxygen atoms which is important in many respects. For example, in the polar region, the sun remains below the horizon for several months and therefore cannot replenish excited oxygen atoms lost by radiative transitions or by mass movement of air. From the concentration of excited oxygen atoms the speed of this movement can be determined.

Emissions of 5577A and 6300A lines in the earth's atmosphere have been extensively studied (Wallace and McElroy 1966, Silverman and Bellew 1966, Zipf 1966, Shapiro 1969, Broadfoot and Kendall 1968, Dandekar 1969). In this paper these line emission in the day airglow of the Martian atmosphere are investigated.

2. Production of $O(^1S)$ atoms in the Martian atmosphere

$O(^1S)$ atoms may be produced by the following reactions:

$$CO_2 + h\nu \rightarrow CO + O\,(^1S) \tag{1}$$

$$O + O + O \xrightarrow{k_1} O_2 + O\,(^1S) \tag{2}$$

$$O + O + N \xrightarrow{k_2} NO + O\,(^1S) \tag{3}$$

$$O + N + N \xrightarrow{k_3} N_2 + O(^1S) \tag{4}$$

Wilkinson and Johnston (1950) studied the absorption spectra of CO_2 in the region 1440-1670A. They reported an absorption continuum with a maximum at 1495A. Watanabe *et al.* (1953) extended the region of observation (1050-1750A) by using helium and argon sources with a 1P21 photomultiplier tube coated with sodium salicylate. They observed three absorption continua with peaks at 1475, 1332 and 1121A. Another continuum was observed around 860 A which was attributed to the ionization of CO_2 (Sun and Weissler 1955). Vacuum monochromator used by them had a resolution of about 1A. The entire region was reinvestigated and the absorption coefficients were measured by Nakata *et al.* (1965) at a resolution of 0·2A, obtaining more quantitative K-value at band centres. The K-values obtained by Nakata *et al.* agree well with the earlier values given by Watanabe *et al.* (1953). From energy considerations, the three absorption continua have been interpreted as given in Table 1.

Thus $O(^1S)$ atoms are produced by photodissociation in the wavelength range 1175-1050A. The rate of production of these atoms is given by

$$P_1 = \sum_{\nu} n\,(h\nu)_z\, \delta\nu,\ CO_2 \tag{5}$$

TABLE 1

Absorption spectrum of CO_2 in the region 1750-1050A

Wavelength range (A)	Wavelength for peak absorption (A)	Photodissociated products
1750-1400	1475	$CO(^1\Sigma)+O(^3P)$
1480-1250	1332	$CO(^1\Sigma)+O(^1D)$
1175-1050	1121	$CO(^1\Sigma)+O(^1S)$

TABLE 2

Photon flux at the top of Martian atmosphere

Wavelength range (A)	Photon flux (Photons $cm^{-2}sec^{-1}$	Wavelength range (A)	Photon flux (Photons $cm^{-2}sec^{-1}$)
1750-1725	$2\cdot24\times10^{11}$	1260-1250	$2\cdot00\times10^{9}$
1725-1700	$1\cdot48\times10^{11}$	1250-1230	$3\cdot99\times10^{9}$
1700-1675	$1\cdot48\times10^{11}$	1230-1220	$2\cdot00\times10^{9}$
1675-1650	$8\cdot86\times10^{10}$	1215·7	$1\cdot14\times10^{11}$
1650-1625	$8\cdot86\times10^{10}$	1206·5	$1\cdot82\times10^{9}$
1625-1600	$5\cdot48\times10^{10}$	1220-1200	$3\cdot12\times10^{9}$
1600-1575	$5\cdot48\times10^{10}$	1200-1180	$2\cdot32\times10^{9}$
1575-1550	$2\cdot81\times10^{10}$	1175·5	$1\cdot05\times10^{8}$
1550-1525	$2\cdot81\times10^{10}$	1180-1170	$4\cdot90\times10^{8}$
1525-1500	$1\cdot54\times10^{10}$	1170-1158	$5\cdot87\times10^{9}$
1500-1475	$1\cdot54\times10^{10}$	1158-1130	$1\cdot37\times10^{9}$
1475-1425	$1\cdot56\times10^{10}$	1130-1108	$1\cdot02\times10^{9}$
1425-1375	$7\cdot59\times10^{9}$	1108-1090	$8\cdot35\times10^{8}$
1375-1350	$3\cdot80\times10^{9}$	1085·7	$2\cdot02\times10^{8}$
1350-1325	$3\cdot80\times10^{9}$	1090-1088·5	$5\cdot31\times10^{7}$
1325-1290	$3\cdot48\times10^{9}$	1088·5-1086·5	$7\cdot07\times10^{7}$
1290-1260	$2\cdot99\times10^{9}$	1086·5-1065	$7\cdot62\times10^{8}$

where $n(h\nu)_z$ is the photon flux corresponding to a frequency ν at an altitude z and $\delta\nu$, CO_2 is the absorption cross-section for CO_2 at a frequency ν.

Photon fluxes at the top of the Martian atmosphere are derived from those for the earth's atmosphere obtained by Hinteregger *et al.* (1964) and are shown in Table 2.

Photon fluxes at various altitudes are then calculated assuming absorption cross-sections and concentrations obtained respectively by Nakata *et al.* (1965) and Donahue (1966). Calculated rate of production of $O(^1S)$ due to photo-dissociation of CO_2 is shown in Fig. 1.

Reactions (2), (3) and (4) were studied by Young and Black (1966) and their rate coefficients are $1\cdot5\times10^{-34}$ cm^6 sec^{-1}, 3×10^{-33} cm^6 sec^{-1} and 1×10^{-33} cm^6 sec^{-1} respectively. Since the nitrogen content of the Martian atmosphere is small (Barth *et al.* 1969), contributions of reactions (3) and (4) are negligible. It can be seen that K_1 n(O) ^{3} is at least four orders less than the photo-dissociation rate and hence reaction (2) is neglected.

Now the rate of emission of the green lines is given by 'O'—

$$R_{5577} = \frac{Q\,O\,(^1S)\ A_{5577}}{A_{5577} + Kn(M)} \qquad (6)$$

where $QO(^1S)$ is total rate of production of $O(^1S)$ atoms, A_{5577} is the transition probability, K is the quenching cross-section and $n(M)$ is the concentration of the quenching species.

$O\,(^1S)$ atoms are deactivated by CO_2, O_2 and O atoms. These deactivation reactions have been studied by Young and Black (1966). Quenching cross-sections for these species have been found to be $2\cdot5\times10^{-14}$, $1\cdot0\times10^{-13}$ and $1\cdot8\times10^{-13}$ cm^3 molecule^{-1} sec^{-1} respectively. In the emitting layer (80-160 km), concentrations of O_2 and O atoms are small and hence the quenching of $O(^1S)$ takes place mainly due to CO_2 molecules. $O(^1S)$ may also be removed by resonant absorption of solar 1215·7A radiations (Walher 1965). It has been found that the probability of resonant deactivation of $O(^1S)$ is negligible (7×10^{-4} sec^{-1}) compared to the probability of emission of 5577A. The rate of emission of 5577A is shown in Fig. 2.

3. Production of $O(^1D)$ atoms in the Martian atmosphere

$O(^1D)$ atoms are produced by photodissociation of CO_2 in the wavelength range 1480-1250A (Table 1) as follows:—

$$CO_2 + h\nu\ (1480 > \lambda > 1250A) \rightarrow CO + O\,(^1D) \quad (7)$$

As in the earth's atmosphere (Dalgarno and Walker 1964), these atoms may also be produced by photodissociation of O_2 in the wavelength range ($1750 > \lambda > 1350$A). Thus

$$O_2 + h\nu\ \ (1750 > \lambda > 1350\ A) \rightarrow O\ (^1D)\ + O(^3P) \qquad (8)$$

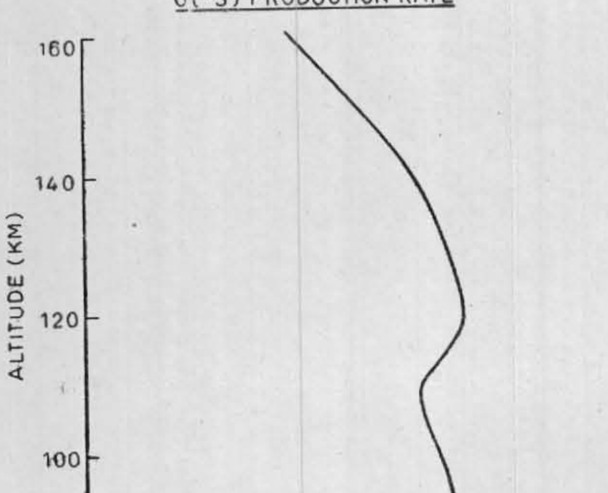

Fig. 1

Production rate of O (^{1}S) atoms in Martian atmosphere

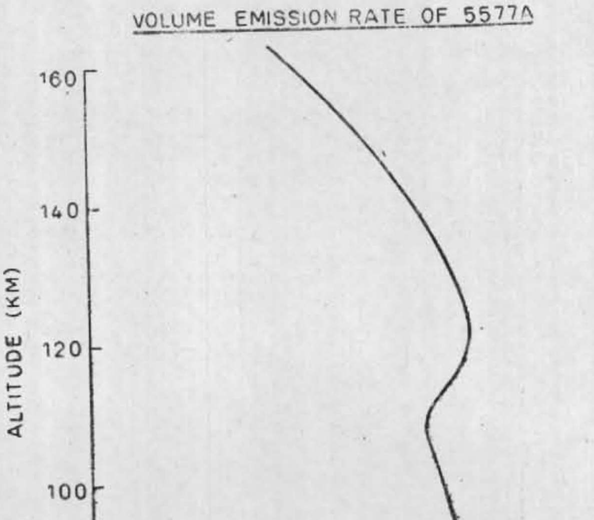

Fig. 2

Volume emission rate of 5577A in Martian atmosphere

Note that there are two peaks, one at 90 km and the other at 120 km

Young and Black (1966) showed that O(^{1}D) atoms are produced by quenching of O(^{1}S) by O(^{3}P) as follows—

$$O(^1S) + O(^3P) \xrightarrow{k_4} O(^1D) + O(^1D) \tag{9}$$

Finally, these atoms are produced by the radiative transition—

$$O(^1S) \rightarrow O(^1D) + h\nu \text{ (5577 A)} \tag{10}$$

The rates of production of O(^{1}D) due to the above reactions are given by—

$$Q_7 = PCO_2 \, n \, (CO_2) \tag{11}$$

$$Q_8 = PO_2 \, n \, (O_2) \tag{12}$$

$$Q_9 = k_4 \, n \, (O^1S) \, n \, (O^3P) \tag{13}$$

$$Q_{10} = A_{\,5577} \, n \, (O^1S) \tag{14}$$

where suffix refers to the particular reaction.

By substituting the values of various quantities, it can be seen that Q_8 and Q_9 are comparatively small and hence they can be neglected.

Rates of production are obtained from equations (11) and (14) and are shown in Fig. 3. From the figure, it is seen that in the region 90 125 km O(^{1}D) atoms are produced by photodissociation of CO_2 molecules while in the region 120-160 km, they are also produced by the radiative transition.

It was proposed by Bates and Dalgarno (1959) that O (^{1}D) can be deactivated efficiently by O_2. From the analysis of auroral emissions from the earth's atmosphere, Wallace and Chamberlain (1959) concluded that its quenching cross-section lies between 1×10^{-10} and 5×10^{-12} cm^3 sec^{-1}. Again, Dalgarno and Walker (1964) showed that in order to explain the red line intensity in the day airglow from the earth's atmosphere, the quenching cross-section should be 1×10^{-10} cm^3 sec^{-1}. While considering distribution of O(^{1}D) in the ozonosphere, Hunt (1966) obtained on entirely different value, namely ($2{\cdot}5\times10^{-14}$ cm^3 sec^{-1}).

In addition to the deactivation reactions, O(^{1}D) is removed by reactions with CO (Clerc and Barat 1967) and CO_2 (Weissberger *et al.* 1967). For the first reaction, the rate coefficient

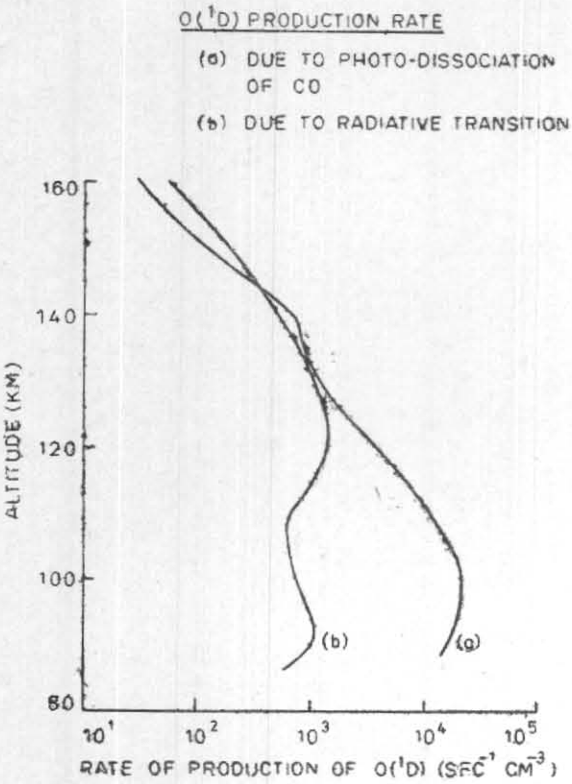

Fig. 3

Production rate of O(^{1}D) atoms in the Martian atmosphere

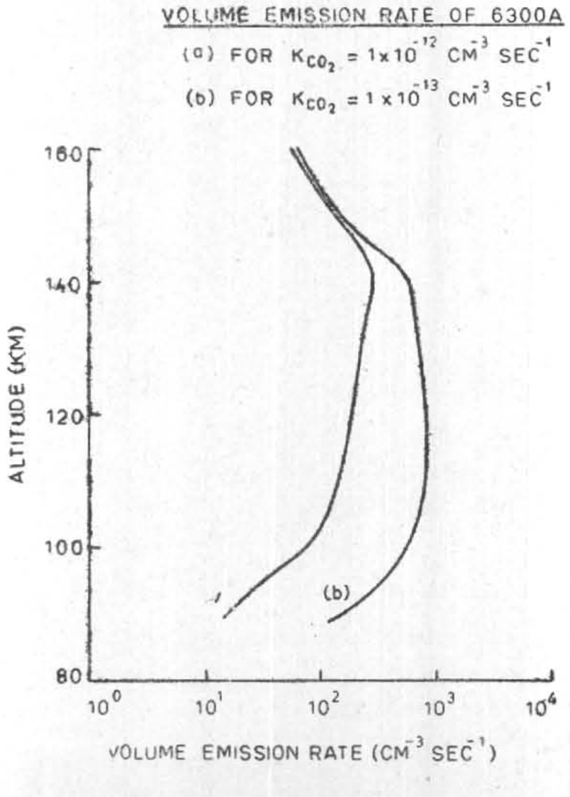

Fig. 4

Volume emission rate of 6300A in Martian atmosphere

TABLE 3

Comparison of the characteristic features of $O(^1S)$ and $O(^1D)$ atoms in the terrestrial and Martian atmospheres

		Terrestrial atmosphere	Martian atmosphere
1. Production process for—			
$O(^1S)$		(i) $O(^3P) + e \rightarrow O(^1S) + e$	$CO_2 + h\nu\ (1175 > \lambda > 1050A) \rightarrow CO + O(^1S)$
		(ii) $O + O + O \rightarrow O_2 + O(^1S)$	
		(iii) $\overset{+}{O}_2 + e \rightarrow O + O(^1S)$	
$O(^1D)$		(i) $O_2 + h\nu\ (1750 > \lambda > 1350A) \rightarrow O(^1D) + O(^3P)$	(i) $CO_2 + h\nu\ (1480 > \lambda > 1250A) \rightarrow CO + O(^1D)$
		(ii) $O(^3P) + e \rightarrow O(^1D) + e$	(ii) $O(^1S) \rightarrow O(^1D) + h\nu\ (5577A)$
		(iii) $\overset{+}{O}_2 + e \rightarrow O + O(^1D)$	
2. Quenching species for—			
$O(^1S)$		O_2 and N_2	CO_2, O_2
$O(^1D)$		O_2 and N_2	CO_2, CO and O_2
3. Intensity of—			
5577A		1 kR	3·5 kR
6300A		5 kR	1-3 kR
4. Height of maximum emission of—			
5577A		95 and 250 km	90 and 120 km
6300A		220 km	100-140 km
5. Intensity profile of—			
5577A		There are two peaks and emission layer is wide (80-300 km)	There are two peaks and emission layer is wide (85r160 km)
6300A		Emission layer is wide (100-300 km) and its peak is not well defined	Emission layer is wide (90-160 km) and its peak is not sharp

is $3 \cdot 3 \times 10^{-12}$ cm^3 molecule^{-1} sec^{-1} and for the second reaction no data is available.

The rate of emission of the oxygen red line is given by—

$$R_{6300} = \frac{Q\,O(^1D)\,A_{6300}}{A_{6300} + k_{O_2} n(O_2) + k_{CO} n(CO) + k_{CO_2} n(CO_2)} \tag{15}$$

where k_x is the quenching rate due to the molecule x, $QO(^1D)$ is the total rate of production of $O(^1D)$ atmos and A_{6300} is the transition probability.

Rates of emission are obtained from equation (15) for following two sets of values of k_{CO_2} namely, 1×10^{-13} cm^3 sec^{-1} and 1×10^{-12} cm^3 sec^{-1}.

Calculated emission rates are shown in Fig. 4. The height of maximum emission is about 100 km and its intensity is about 3 kR for the two values of the quenching coefficient.

Table 3 gives a comparison of the characteristic features of $O(^1S)$ and $O(^1D)$ atoms in the terrestrial and Martian atmospheres.

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