Emission of $\lambda$ 6300A in Martian atmosphere

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ABSTRACT. The paper deals with the emission of $\lambda$ 6300A of OI in the Martian atmosphere. Using the recently measured rate of coefficients of ion-atom interchange and other ionic reactions, the volume emission of this radiation is calculated out and found to be approximately 5 km.

1. Introduction

The atmosphere of the planet Mars has been studied by several investigators. Three models, namely, $F_2$, $F_1$, and $E$ models have been proposed by them for the Martian atmosphere. As in the earth's atmosphere, there is every possibility for the emission of $\lambda$ 6300A in the Martian atmosphere. The purpose of the present paper is to calculate the intensity of this radiation for all the three models of the Martian atmosphere.

2. Production and deactivation of O (1D) atoms

The O (1D) atoms may be produced by:

$$\text{CO}_2 + h\nu (1200 < \lambda < 1700 \text{ A}) \rightarrow \text{CO} + \text{O} (1D)$$


$$\text{O}_2^+ + h\nu (1350 < \lambda < 1750 \text{ A}) \rightarrow \text{O} (3P) + + \text{O} (1D)$$

(1)

(2)

(Ghosh and Sharma 1961) and

$$\text{NO}^+ + e \rightarrow \text{N} + \text{O} (1D)$$

(Chamberlain 1961)

For the reaction (3), the spin conservation rule does not hold good and so, this reaction has not been considered in the present calculations. CO$_2$ is dissociated by the solar ultraviolet radiations in the wavelength range 1700-1050 A (Chamberlain 1962) The photo-dissociation of CO$_2$ in the wavelength range 200-1700 may produce O(1D) atoms (Moll et al. 1963).

Probability of photo-dissociation of CO$_2$ at an altitude $z$ is given by

$$P_z = \gamma \sum n (h\nu)_\nu, \text{CO}_2$$

(5)

where, $n (h\nu)_\nu$ = photon flux corresponding to a frequency at an altitude $z$;

$\sigma_\nu \text{CO}_2$ = absorption cross-section of CO$_2$ for the frequency $\nu$ and

$\gamma$ = efficiency of the observed quantum for the dissociation of CO$_2$.

In the absence of the precise information, $\gamma$ is assumed to be unity. Utilising the values of absorption coefficients of CO$_2$ given by Nakata et al. (1965) and the photon flux data* given by Hinteregger et al. (1965), photon flux and dissociation probability at various altitudes are obtained. Rate of production ($R_z$) of O(1D) atoms is then obtained from the relation

$$R_z = n (\text{CO}_2)_z \cdot P_z$$

(6)

where, $n (\text{CO}_2)_z$ is the concentration of CO$_2$ at the altitude $z$.

Production of O(1D) atoms by the photo-dissociation of O$_2$ in the wavelength range 1350-1750A has been calculated (c.f. Agarwal p. 391). The absorption cross-section of O$_2$ has been taken from the data given by Hinteregger et al. (1965). The distribution of O$_2$ given by Chamberlain and McElroy (1966) has been utilized here.†

Let us now consider the deactivation of O(1D) atoms. The deactivation of O(1D) atoms has been considerably discussed in the literature. Bates and Dalgaro (1953) pointed out that O(1D) atoms should be very rapidly deactivated by the following reactions

$$\text{O}(1D) + \text{O}_2 (X^2 \Sigma_g^+ \nu = 0) \rightarrow \text{O}(3P) + + \text{O}_2 (b^2 \Sigma_g^+ \nu = 2)$$

(7)

The values are corrected for the the atmosphere of Mars by multiplying each by 0.44, the dilution factor.

†Its values have been extrapolated down to an altitude of 90 km.

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as this reaction is nearly in exact resonance. Deactivation by $N_2$, namely,

$$O^{(1D)} + N_2 \rightarrow O^{(3P)} + N_2 \rightarrow X^2 \Sigma^+_g \quad \text{(8)}$$

is disallowed by the spin conservation rule (S. K. Gupta, private communication, 1969). From an analysis of amount emission in the earth’s atmosphere, Wallace and Chamberlain (1959) concluded that $10^{-10} > k_7 > 5 \times 10^{-12} \text{ cm}^3 \text{ sec}^{-1}$. Dalgarino and Walker (1964) have shown that if $k_7 = 10^{-10} \text{ cm}^3 \text{ sec}^{-1}$ is assumed, the red line intensity in the day airglow of the earth’s atmosphere can be explained. DeMore and Raper (1962) have shown that $O_2$ is approximately 4-5 times faster than $N_2$ in deactivating $O^{(1D)}$ atoms.

While discussing the photochemistry of $O_3$ in the earth’s atmosphere, Hunt (1966a) concluded that in order to maintain the required concentration of $O^{(1D)}$ atoms in the ozonosphere, which effectively controls the $O_3$ abundance, the deactivation of $O^{(1D)}$ by $O_2$ and $N_2$ should be slow. He proposed that $k_7 = 2 \cdot 5 \times 10^{-14} \text{ cm}^3 \text{ sec}^{-1}$ and $k_8 = 5 \times 10^{-15} \text{ cm}^3 \text{ sec}^{-1}$. These rate coefficients can be discarded on the ground that the concentrations of $O^{(1D)}$ derived by them in the lower atmosphere of the earth would give an unacceptably large red line in the day airglow. However, in a modified photochemical theory of the ozonosphere (Hunt 1966b) for an oxygen-hydrogen atmosphere, he finds that if $k_7 = 5 \times 10^{-12} \text{ cm}^3 \text{ sec}^{-1}$ is accepted, the calculated $O_3$ abundance agrees with the observed value and that $O^{(1D)}$ concentration lies within the acceptable limits. Warneck and Sullivan (1966) obtained from a laboratory study that $k_7 = 4 \cdot 0 \times 10^{-15} \text{ cm}^3 \text{ sec}^{-1}$ which also be considered as being low. We have assumed its value as $10^{-10} \text{ cm}^3 \text{ sec}^{-1}$ as given by Dalgarino and Walker (1964).

Deactivation of $O^{(1D)}$ atoms with $CO_2$ also occurs with the formation of $CO_2$ molecules (Katlos and Taubes 1962; Warneck 1966; Young and Ung 1966; Raper and DeMore 1964; Young and Graham Black 1967; and Weissberger et al. 1967). Slanger (1966) on the assumption that the recombination of $O^{(1D)}$ and $O^{(3P)}$ atoms does not hold good, gave the following reaction scheme for the production and loss of metastable $CO_2$ molecules.

$$h\nu \rightarrow CO_2 \rightarrow CO + O^{(1D)} \quad \text{(9)}$$

$$O^{(1D)} + CO_2 \rightarrow CO + O^{(1D)} \quad \text{(10)}$$

$$CO_2 + CO_2 \rightarrow 2CO + O_2 \quad \text{(11)}$$

Young and Ung (1966) showed that $O^{(1D)}$ complexes with $CO_2$ with a rate coefficient greater than $10^{-12} \text{ cm}^3 \text{ sec}^{-1}$ and that $O^{(1D)}$ forms at least five times more rapidly than it is deactivated to $O^{(3P)}$ by $CO_2$. In the present calculations, I have taken $k_1 = 10^{-12} \text{ cm}^3 \text{ sec}^{-1}$.

The deactivation through superelastic collisions with electrons is negligible (Chamberlain 1961). Neglecting the reaction (8), the equilibrium concentrations of $O^{(1D)}$ at any altitude $z$ is given by—

$$n [O^{(1D)}] = \frac{q_1 (O^{(1D)}) + q_2 (O^{(1D)}) + k_3 (O^{(1D)})}{k_7 n (O_2) + k_10 n (CO_2)} + 0.0069$$

(12)

where, $q_1 (O^{(1D)})$ and $q_2 (O^{(1D)})$, are the production rates of $O^{(1D)}$ atoms by the photo-dissociation of $O_2$ and $CO_2$ respectively at the altitude $z$ and 0.0069 sec$^{-1}$ is the transition probability for 6300 A lines.

In practice, the first and the last terms in the numerator, and the first term in the denominator of Eq. (12) are negligible. Since $q_2 (O^{(1D)})$ is equal to $J_n n (CO_2)$, where $J_n$ is constant at high altitudes, there is an extended region with the same in all the three models, namely, $F_0, F_1, F_2$, and $E$ models of the Martian atmosphere. This maximum density extends from about 100 to 150 km in each model. Total emission from—

$$R_{6300} = n (O^{(1D)}) \times 0.0069$$

is thus about 15 kR. A more recent value of $k_10 = 3 \times 10^{-12}$ (Nixon 1970) reduces this to 5 kR.

3. Conclusions

(1) The maximum number density of $O^{(1D)}$ atoms extends from 100 to 150 km.

(2) Total emission of $\lambda$ 6300 A is about 5 kR.
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