Modeling of $O^+(^2P)$ dayglow emission .

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Abstract

$O^+(^2P)$ emission can be used to infer the thermospheric atomic oxygen density hence modeling this emission has a good potential reason. The accuracy of the emission rate of 732.0 nm depends mainly on the production and loss rates of $O^+(^2P)$ in the thermosphere. However the quenching rate coefficient of $O^+(^2P)$ by O and N_2 given by various studies shows a large variation and hence leads in erroneous determination of O concentration and further in validating the airglow model. The Volume emission rate (VER) of 732.0 nm dayglow emission is calculated using glow model with two different solar EUV flux coupled with the three different estimates of the quenching rate coefficients. However there is a dire need of observation to validate the obtained VER, which will ultimately lead to determine the correct quenching rate coefficient value of $O^+(^2P)$ by O and N_2.

1. Introduction

The $O^+(^2P)$ emission at 732.0 nm is used for observing and modeling F-region ionospheric dynamics and has the potential to be an important diagnostic of the thermospheric oxygen density [1-4]. A number of workers [5-7] have given the quenching rate coefficients of $O^+(^2P)$ by O and N_2 using various approaches in the thermosphere. The very first analysis of quenching rate coefficient was given by Rusch et al., [5] using aeronomic data. Chang et al., [6] have further calculated these coefficients using Atmosphere Explorer C measurements of the 7320/7330 Å doublet emission. Chang et al., [6] calculated the O and N_2 reaction rates for $O^+(^2P)$ using updated photoionization cross-sections and refined solar and photoelectron fluxes. The value obtained by Chang et al., [6] for N_2 reaction rate is close to the value obtained by Rusch et al., [5]. Recently Stephan et al., [7] have obtained quenching rate coefficients of $O^+(^2P)$ by O and N_2 by modelling rocket and satellite limb measurements of thermospheric middle ultraviolet (MUV) airglow at 247.0 nm. So there is a need to find the efficacy of these given values.

In the thermosphere, the major source of the $O^+(^2P)$ ion is the direct photoionization excitation of atomic oxygen caused by absorption of solar extreme ultraviolet photons with wavelengths less than 66.6 nm

$$O + h\nu\ (\lambda < 66.6\ \text{nm}) \dashrightarrow O^+(^2P) + e \qquad (1)$$

A secondary source is photoelectron impact ionization excitation of ground state oxygen atoms,

$$O + e_{ph} \dashrightarrow O^+(^2P) + 2e \qquad (2)$$

Where e_{ph} is a photoelectron. The production rates due to processes 1 and 2 are obtained using the following expressions.

$$R_1(z, \alpha) = [O] \sum I_z(\lambda, \alpha)\, \sigma_{O^+(2P)}(\lambda) \qquad (3)$$

$\lambda < 66.6$ nm

$$R_2(z, \alpha) = [O] \int_{E_{th}}^{\infty} \phi(E, z, \alpha) * \sigma_e(E) dE \qquad (4)$$

Where I_z (λ, α) is the solar flux at wavelength λ and solar zenith angle α at height z, [O] is the atomic oxygen density $\sigma_{O^+(2P)}$ (λ) is the photoionization cross-section of $O^+(^2P)$ state, σ_e (E) is the total excitation cross section of $O^+(^2P)$ due to photoelectron of energy E and Φ (E , Z , α) is the photoelectron flux with energy E. E_{th} is the threshold energy.

The total production rate of $O^+(^2P)$ is therefore

$$R(z, \alpha) = R_1(z, \alpha) + R_2(z, \alpha) \qquad (5)$$

The $O^+(^2P)$ ions produced by photoionization and photoelectron ionization are lost through the following processes.

Radiative decay:

$$O^+(^2P) \xrightarrow{A_6} O^+(^2D\ ,\ ^4S) + h\nu\ (\ 732.0 \text{ nm}\ ,\ 733.0 \text{ nm},\ 247.0 \text{ nm}) \qquad (6)$$

Quenching:

$$O^+(^2P)\ + e_{th} \xrightarrow{k_7} O^+(\ ^4S) + e \qquad (7)$$

$$O^+(^2P)\ + O \xrightarrow{k_8} O^+(\ ^4S) + O \qquad (8)$$

$$O^+(^2P)\ + N2 \xrightarrow{k_9} O^+(\ ^4S) + N_2 \qquad (9)$$

The complete quenching factor 'Q' is given by

$$Q_{O^+(2P)} = \frac{A_6}{A_6 + k_7[e] + K_8[O] + k_9[N_2]} \qquad (10)$$

Where [e], [O] and $[N_2]$ are the densities of thermal electrons, atomic oxygen and molecular nitrogen respectively. The reactions and the rate coefficients are given in

Table 1. The volume emission rate is therefore given by,

$$V\ (O^+(^2P))\ = Q_{O^+(^2P)}\ * R(z, \alpha) \qquad (11)$$

Table 1. Reactions and Rate Coefficients.

Reaction	Rate coefficient($cm^3\ s^{-1}$)	Reference
$O^+(^2P)\ +\ e_{th} \xrightarrow{k_7} O^+(\ ^4S) + e$	$k_7 = 1.89 \times 10^{-7}(300/T_e)^{0.5}$	Chang et al., [6]
$O^+(^2P)\ +\ O \xrightarrow{k_8} O^+(\ ^4S) + O$	$k_8 = 0.52 \times 10^{-10}$	Rusch et al.,[5]
	$k_8 = 4.0 \times 10^{-10}$	Chang et al.,[6]
	$k_8 = 0.5 \times 10^{-10}$	Stephan et al.,[7]
$O^+(^2P)\ +\ N_2 \xrightarrow{k_9} O^+(\ ^4S) + N_2$	$k_9 = 4.8 \times 10^{-10}$	Rusch et al.,[5]
	$k_9 = 3.4 \times 10^{-10}$	Chang et al.,[6]

$k_9 = 1.8 \times 10^{-10}$ Stephan et al.,[7]

$O^+(^2P) \xrightarrow{A_6} O^+(^2D, ^4S) + h\nu$ (732.0 nm) $A_6 = 0.1712\ s^{-1}$ Link [8]

The Hinteregger et al.,[9] and the Tobiska [10] are the two respective models which provide the solar EUV fluxes under different solar activity conditions. Though these models take into account the variation of solar activity but have different scaling techniques. These Solar EUV flux models are discussed in detail Upadhayaya & Singh[11]

In this paper the variation in volume emission rates of 732.0 nm emission is presented which is obtained by using the glow model. The volume emission rate is obtained using the quenching rate coefficients of $O^+(^2P)$ for O and N2 as given by Rusch et al., [5], Chang et al., [6]) and Stephan et al., [7] with the two possible solar flux models. The VER is calculated using these two solar flux model as these are the two model that are reliably used to study dayglow emissions.

Results and Discussion

The accuracy of the derived thermospheric concentration would depend how accurately the production and loss of $O^+(^2P)$ are calculated in the thermosphere.It is quite clear from Table 1that the value obtained by Chang et al.,[6] for N_2 reaction rate is close to the value obtained by Rusch et al.[5] However in case of O the value of reaction rate obtained by Chang et al., [6] is 8 times larger than the value obtained by Rusch et al., [5]. The values of quenching rate coefficients obtained by Stephan et al.,[7] for N_2 are about 2.5 times smaller than the values obtained by Rusch et al., [5] and about 2 times smaller than the values obtained by Chang et al., [6]. However, the value of quenching rate coefficient obtained by Stephan et al., [6] for O is more or the less same as obtained by Rush et al., [5]. It means that the values obtained by Stephan et al., [7] and Rusch et al., [5] for O are about 8 times smaller than the value obtained by Chang et [6].These large variations in the quenching rate coefficients have created a lot of problems in the modeling of 732.0 nm emission. Figure 1a and b shows the volume emission rate profiles obtained using the various quenching rate coefficients for $O^+(^2P)$ given by Rush et al., [5], Chang et al., [6] and Stephan et al., [7] with the Hinteregger et al., [9] and Tobiska [10] solar EUV flux model. The case for 44S latitude on April 1,1994 UT 1.4hrs has been taken to depict the results. However the same results has been obtained with different latatitude and local times. These variations in VER are clearly due to the large variation in quenching rate coefficient of $O^+(^2P)$ by O and N_2 as given by various workers. The efficacy and validation of these VER are constrained due to unavailability of observation.

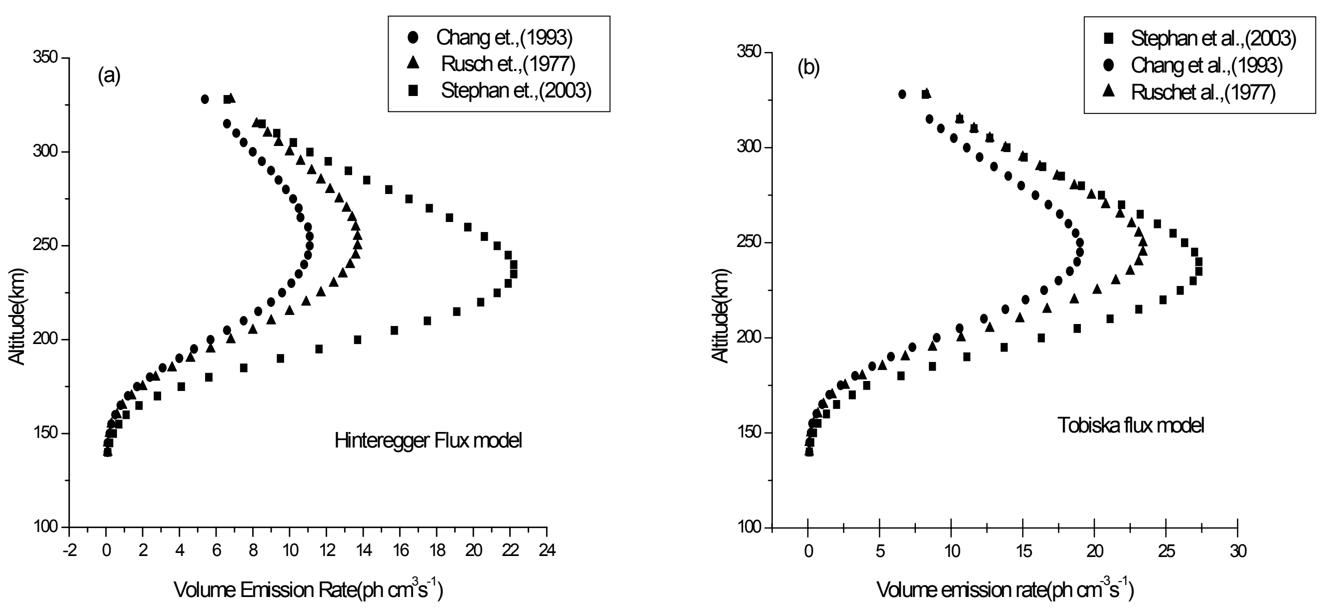

Fig 1 Comparison of modeled Volume emission rate obtained using quenching coefficient of Rusch

et.,(1977), Chang et al., (193) and Stephan et al.,(2003) using (a) Hinteregger Solar flux model (b) Tobiska Solar Flux model.

Conclusions

The quenching rate coefficients of $O^+(^2P)$ by O and N_2 as given by Rusch et al., [5], Chang et al., [6] and Stephan et al. [7] have been examined for 732.0 nm dayglow emission. The volume emission rates have been obtained using the glow model of Solomon 1991 for the Hinteregger et al. [9] and Tobiska [10] solar EUV flux models with the various quenching rate coefficients. The present study indicates that the volume emission rates obtained using these quenching rate coefficients vary to a great extent due to large variation in quenching rates values and there is a need of observation to validate the results.

Acknowledgement

AKU thanks Prof. Vir Singh and R.S Dabas for helpful discussions.

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