Indian Journal of Radio & Space Physics
Vol. 38, April 2009, pp. 71-73

Effect of temperature dependent rate coefficient of reaction $N_2(A^3\Sigma_u^+)$ + O on proton heating efficiency in auroral region

Vir Singh[†,*] & M V Sunil Krishna
Department of Physics, Indian Institute of Technology Roorkee, Roorkee 247 667, Uttrakhand, India
†Email: virphfph@iitr.ernet.in

Received 9 June 2008; accepted 24 October 2008

The proton heating efficiency in polar thermosphere is revisited in the light of new findings of the temperature dependence of rate coefficient of the reaction $N_2(A^3\Sigma_u^+)$ + O. This reaction is considered as one of the most significant source of proton heating in auroral region. The present results show that the heating rate due to this reaction above 110 km is 1.4 to 2.3 times higher than the earlier results. The proton heating efficiency is found eight to ten percent higher than the earlier results in the peak energy deposition region (110-130 km). These results would be very useful in the study of heat budget in the polar thermosphere particularly during solar proton events.

Keywords: Proton heating efficiency, Auroral region, Rate coefficient, Heat budget, Polar thermosphere

PACS No.: 92.60.*hb*

1 Introduction

The heating of polar thermosphere due to precipitation of charged particles (electrons and protons) is one of the significant source along with Joule heating. The heating influences the convection processes in the auroral region[1]. Rees[2], Singh & Gerard[3] and Rees *et al.*[4] have studied the auroral heating due to precipitating electrons. The electron heating is a quite normal process and is always present in the polar thermosphere. However, the proton precipitation would also be a source of polar thermosphere heating particularly during solar proton events. In a solar proton event, highly energetic protons precipitating over the polar atmosphere deposit their energy as low as to the mesospheric level. Consequently, these highly energetic protons would contribute quite significantly to the heating of polar thermosphere. The first study of polar heating due to precipitating protons has been carried out by Srivastava & Singh[5]. In this study, Srivastava & Singh[5] have included all possible sources of heating. Their study shows that exothermic chemical reactions are the main sources of heating. This study has included a set of 35 chemical reactions in the calculation of proton heating efficiency. Amongst these 35 chemical reactions, the reaction $O(^1D)+N_2$ and $N_2(A^3\Sigma_u^+)$ + O are major contributors of heating rate in the peak energy deposition altitude region. The heating rate depends very strongly on the reaction rate coefficient. Consequently, any change in the value of rate coefficient would have strong bearing on the results of heating rate. The reaction rate coefficient used by Srivastava & Singh[5] for $O(^1D)+N_2$ is consistent and is still being used in the modeling of auroral and airglow emissions. The reaction rate coefficient of $N_2(A^3\Sigma_u^+)$ + O used by Srivastava & Singh[5] was adopted from the work of Piper *et al.*[6] and it was independent of neutral temperature. It may be noted that the model study[7] of greenline dayglow emission has been unable to explain the measurements of this dayglow emission with the rate coefficient of Piper *et al.*[6]. This study of greenline dayglow emission suggests that the rate coefficient given by Piper *et al.*[6] is not consistent with the dayglow measurements. Hill *et al.*[8] have re-examined the rate coefficient of reaction $N_2(A^3\Sigma_u^+)$ + O and have found that rate coefficient depends on the neutral temperature. Subsequently, the inclusion of temperature dependent rate coefficient in greenline dayglow study[9] gives better agreement with the measurements. Consequently, in the light of revised temperature dependent rate coefficient of reaction $N_2(A^3\Sigma_u^+)$ + O, one should re-examine the proton heating efficiency results of Srivastava & Singh[5]. In this paper, the revised results of proton heating efficiency are presented by taking into account the temperature dependent rate coefficient of reaction $N_2(A^3\Sigma_u^+)$ + O.

2 Heating efficiency

The heating efficiency is obtained by dividing total heat production rate by rate of energy deposition at each altitude. In the present calculations, only the contribution of reaction $N_2(A^3\Sigma_u^+)$ + O to the heating rate has been studied. The contributions of other sources of heating rate and cooling rate are the same as given by Srivastava & Singh[5] and are not reproduced in this paper. The following Maxwellian distribution of protons outside earth's atmosphere is used.

$$\frac{d\phi}{dE} = F_O \frac{E}{\alpha^2} \exp\left(-\frac{E}{\alpha}\right) \text{protons cm}^{-2}\ \text{s}^{-1}\ \text{KeV}^{-1} \qquad \ldots(1)$$

where, E, is proton energy; F_O, total proton flux; and α, determines the hardness of spectrum. Proton flux with α=50 KeV and total enery input 10 ergs cm^{-2} sec^{-1} have been used in the present calculations. For a moderate proton event, these values are realistic. The reaction of $N_2(A^3\Sigma_u^+)$ + O proceeds as follows:

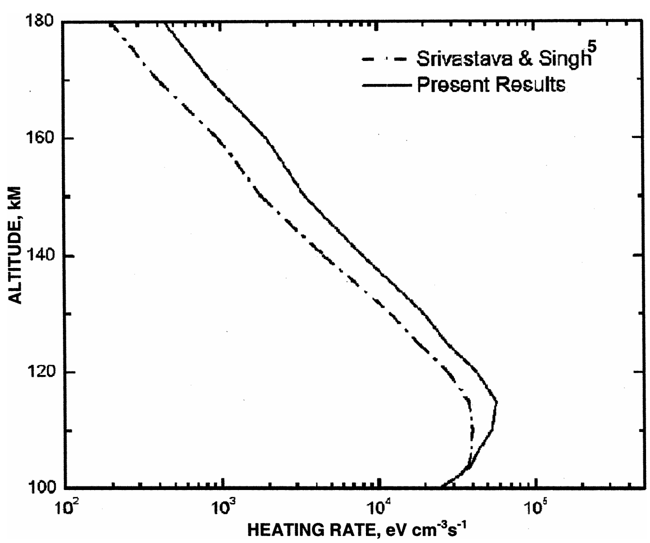

Fig. 1—Variation of proton heating rate as a function of altitude for the reaction $N_2(A^3\Sigma_u^+)$ + O. Solid line curve shows present results and broken line shows results of Srivastava & Singh[5]

$$N_2(A^3\Sigma_u^+) + O \longrightarrow N_2 + O(^1S) + 1.98\text{eV} \qquad \ldots(2)$$

In the present calculations, same parameters as used by Srivastava & Singh[5] are used with the exception that temperature dependence of rate coefficient of the reaction $N_2(A^3\Sigma_u^+)$ + O proposed by Hill *et al.*[7] is now included. The new rate coefficient is 3.4×10^{-11} $(T/298)^{0.5}$ in place of 2.8×10^{-11} (Piper *et al.*[6]). Here, T, is the altitude dependent neutral temperature which has been taken from MSIS-90 (ref. 10).

3 Results and discussion

Figure 1 shows the variation of proton heating rate as a function of altitude for the reaction $N_2(A^3\Sigma_u^+)$ + O. A comparison is made between the present results and those given by Srivastava & Singh[5]. It is noticed from Fig. 1 that present results are higher than the results of Srivastava & Singh[5] by a factor ranging between 1.4 and 2.3. This is due to the effect of temperature dependence of the rate coefficient. The effect is more on higher altitudes because neutral temperature increases as altitude increases in the thermosphere. The reaction $N_2(A^3\Sigma_u^+)$ + O is one of the major contributors to the heating rate below 130 km. Above 130 km, the production rate of $N_2(A^3\Sigma_u^+)$ decreases rapidly and then this reaction is not the major source of heating. Consequently, the results given by Srivastava &

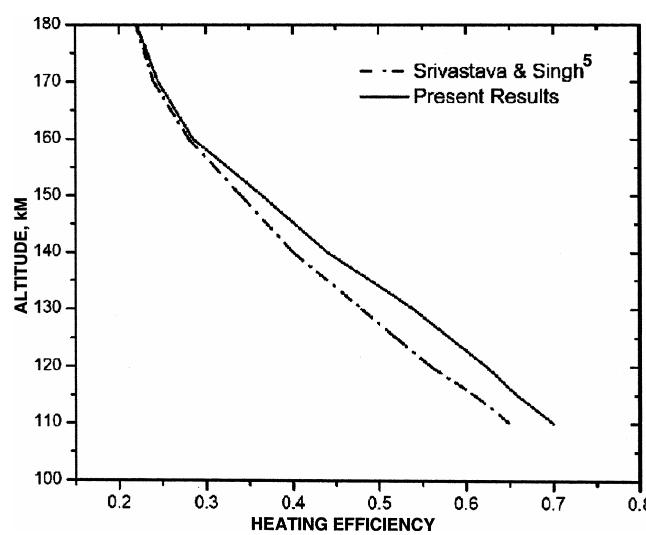

Fig. 2—Variation of proton heating efficiency as a function of altitude. Solid line curve shows present results and broken line shows results of Srivastava & Singh[5]

Singh[5] above 140 km would be unaffected by the inclusion of temperature dependent rate coefficient. In Fig. 2, a comparison is made between present results and those given by Srivastava & Singh[5] for the proton heating efficiency. It is clear from Fig. 2 that the present results and those given by Srivastava & Singh[5] are more or less same above 140 km. However, the present results of proton heating efficiency are about 8 to 10 percent higher than the results of Srivastava & Singh[5] below 130 km. The protons mainly deposit maximum energy in the altitude between 110 and 130 km and this altitude region is affected during solar proton events. In this altitude region, which is very close to the mesopause, there is vertical transport of heat. Thus the present proton heating efficiency results would be very useful in the study of heat transport in this altitude region.

4 Conclusions

The present study shows that the temperature dependent rate coefficient of the reaction $N_2(A^3\Sigma_u^+)$ + O affects the proton heating efficiency between 110 and 130 km. The present proton heating efficiency is about 8 to 10 percent higher than earlier results of Srivastava & Singh[5]. These new results would be very useful in the study of heat budget in the polar thermosphere particularly during solar proton events.

Acknowledgements

One of the authors M V Sunil Krishna is thankful to Ministry of Human Resource Development, New Delhi for providing the financial support to carry out the research work.

References

1 Thorp K, Lockwood M, Lanchester B S, Morley S K & Frey H U, Modeling the observed proton aurora and ionospheric convection responses to changes in the IMF clock angle: 1. Persistence of CUSP proton aurora, *J Geophys Res (USA),* 110 (2005) A12311.

2 Rees M H, Magnetospheric substorm energy dissipation in the atmosphere, *Planet Space Sci (UK),* 23 (1975) 1589.

3 Singh Vir & Gerard J C, The thermospheric heating under electron precipitation condition, *Planet Space Sci (UK),* 30 (1982) 1983.

4 Rees M H, Emery B A, Roble R G & Stamnes S K, Neutral and ion gas heating by auroral electron precipitation, *J Geophys Res (USA),* 88 (1983) 6289.

5 Srivastava V & Singh Vir, Thermospheric heating under proton precipitation, *J Geophys Res (USA),* 93 (1988) 5845.

6 Piper L G, Caledonia G E & Kennealy J P, Rate constants for deactivation of N_2 $(A^3\Sigma_u^+)$, v=0,1, *J Chem Phys (USA),* 75 (1981) 2847.

7 Singh Vir, McDade I C, Sheppherd G G, Solheim B H & Ward W E, The $O(^1S)$ dayglow emission as observed by the WIND Imaging interferometer on the UARS, *Ann Geophys (France),* 14 (1986) 637.

8 Hill S M, Solomon S C, Cleary D D &. Broadfoot A L, Temperature dependence of the reaction N_2 $(A^3\Sigma_u^+)$ + O in the terrestrial thermosphere, *J Geophys Res (USA),* 105 (2000) 10615.

9 Singh V & Upadhyaya Arun K, Greenline dayglow emission under equinox conditions, *J Geophys Res (USA),* 109 (2004) A01308.

10 Hedin A E, Extension of the MSIS thermosphere Model into the middle and lower atmosphere, *J Geophys Res (USA),* 96 (1991) 1159.