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Scientific Report

IONOSPHERIC CHARACTERISTICS FROM ALTITUDE VARIATIONS OF POSITIVE ION DENSITIES AT NIGHT

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Abstract

Altitude variations of different types of positive ions in the ionosphere at night obtained from rocket-borne experiments, have been utilized to obtain ionospheric characteristics. Major nighttime ionic processes and rate coefficients of certain reactions involving positive ion - neutral atoms or molecules are obtained. Lifetimes and effective recombination coefficients of positive ions at night are also obtained. It was further shown that at night the ionosphere is not in equilibrium. Only at localized regions, there is equilibrium between the production and loss rates.

1. Introduction

In a previous report (Ghosh, 1967), the ionospheric characteristics from altitude variations of positive ion densities during daytime obtained from rocket-borne experiments, have been obtained. At night also, the altitude distributions of ion densities were obtained. Although ion densities decrease to a great extent at night, and that the number of nocturnal rocket firings are comparatively few, certain ionospheric characteristics can be drawn from the ion distributions at night. These are presented in this report.

2. Altitude Distributions of Positive Ions at Different Times of the Day.

Noon and nighttime altitude distributions of ionic densities, as obtained from rocket-borne mass spectrometers during period of solar minimum activity (Holmes *et al.*, 1965), are given in Fig. 1. Dashed curves are extrapolated. Important features of such distributions are given in Table 1.

Table 1. Characteristics of Positive Ion Distributions for 100-280 Km at Different Times of the Day.

Noon	Night	Morning
1. At lower altitudes (around 140 km), the concentrations of NO^+ and O_2^+, which are the major ions, are nearly equal.	1. O^+ is the predominant ion at higher altitudes and then rapidly falls with the decreasing altitude, so much so, that at 200 km, its density becomes very small.	1. Percentagewise, different types of ions in the morning are the same as at noontime except that O_2^+ density is small at lower altitudes. At these altitudes, NO^+ is the predominant ion.
2. Above 180 km, O^+ becomes the predominant ion.	2. Around 240 km, O_2^+ and NO^+ densities become equal and same as for daytime. There is no diurnal density variations of these ions at these altitudes.	2. N_2^+ and N^+ concentrations hardly become greater than 1% of the total ion content.
3. During daytime, the concentrations of N_2^+ and N^+ hardly become greater than 1% of the total ion content, although N_2^+ production rate is high. (Istomin, 1963).	3. O_2^+ percentage is small at lower altitudes.	
	4. N_2^+ and N^+ concentrations hardly become greater than 1% of the total ion content.	

3. Nighttime Ionic Processes

In Figs. 2-6, the production and loss rates of O^+, O_2^+, N_2^+, NO^+ and N^+ ions at night for the altitude range 100-280 km are drawn. Due to the non-availability of data, these rates for N_2^+ and O^+ ions are calculated only for a small altitude range. It is desirable to calculate the loss and production rates of different species of ions for the whole altitude range as the importance of reactions vary with altitude. To calculate these rates at night, ion densities as obtained from rocket-borne mass spectrometers given in Fig. 1 are utilized. O, O_2 and N_2 densities are obtained from CIRA 1965 for the mean solar condition, N and NO densities are obtained by Ghosh (1968). The rate coefficients and their temperature variations are the same as given in (Ghosh, 1967).

Assuming the equilibrium of N^+ ion at night by the following reactions

$$N_2^+ + N \rightarrow N^+ + N_2$$

$$N^+ + O_2 \begin{cases} \rightarrow O_2^+ + N \\ \rightarrow NO^+ + O \end{cases},$$

N^+ ion densities are obtained.

It is seen from Figs. 2-6 that at night, the ionosphere is not in equilibrium. Only at localized regions, there is equilibrium between the production and loss rates. For O^+, the equilibrium is around 220 km, for O_2^+ around 240 km, for NO^+ at 120 km. For N_2^+, there is no production mechanism at night. For the greater part of the above altitude range, O_2^+ loss rates are higher than the production rate and vice versa for NO^+.

Major nighttime ionic processes and certain characteristics of nighttime processes between 100-280 km are shown in Table 2.

Table 2

NIGHT TIME IONIC PROCESSES FOR 100-280 Km

Ion	Major Production Process	Major Loss Process	Remarks
O^+	$N_2^+ + O \rightarrow O^+ + N_2$	(1) $O^+ + N_2 \rightarrow NO^+ + N$ (2) $O^+ + NO \rightarrow O_2^+ + N$ (3) $O^+ + O_2 \rightarrow O_2^+ + O$ (arranged in order of importance)	Due to the high loss rates of these reactions, O^+ density falls rapidly with decreasing altitudes. Around 220 km, the total loss and production rates become equal.
O_2^+	$O^+ + NO \rightarrow O_2^+ + N$ $O^+ + O_2 \rightarrow O_2^+ + O$ (rapidly falling rate from 230 to 200 km)	(1) $O_2^+ + N \rightarrow NO^+ + O$ (2) $O_2^+ + N_2 \rightarrow NO^+ + NO$ (3) $O_2^+ + NO \rightarrow NO^+ + O_2$	Around 240 km, the total loss and production rates of O_2^+ become equal. At other altitudes loss rates are higher and hence O_2^+ ions form a small proportion of the total ion content at night.
N_2^+	nil	(1) $N_2^+ + O \rightarrow NO^+ + N$; $N_2^+ + O \rightarrow O^+ + N_2$	Since there is no production mechanism and the loss rate being high, $[N_2^+]$ at night at 220 km is about two orders lower than that during daytime.
NO^+	$O_2^+ + N_2 \rightarrow NO^+ + NO$ $O_2^+ + NO \rightarrow NO^+ + O_2$ $O_2^+ + N \rightarrow NO^+ + O$ $N_2^+ + O \rightarrow NO^+ + N$ $O^+ + N_2 \rightarrow NO^+ + N$ (important for 280-220 km)	$NO^+ + e \rightarrow N + O$	Large production rate compared to the loss rate. Only one loss process. This accounts for the comparatively large NO^+ concentration at night.
N^+	$N_2^+ + N \rightarrow N^+ + N_2$	$N^+ + O_2 \rightarrow O_2^+ + N$; $N^+ + O_2 \rightarrow NO^+ + O$	N^+ density is calculated from the equilibrium between these reactions. The rates for both these reactions are small.

4. Calculated Rate Codfficients of Ionospheric Reactions

The calculated rate coefficients of certain reactions between ions and neutral particles in the ionosphere as obtained from the altitude distributions of positive ions are given below. Comparison with the available data shows that there is a fair agreement between calculated and observed rate coefficients except for the reaction $O^+ + NO \rightarrow O_2^+ + N$

Reaction	Altitude	Assumption made	Calculated rate coeff. ($cm^3 sec^{-1}$)	Observed rate coeff. ($cm^3 sec^{-1}$)
$N_2^+ + O \rightarrow O^+ + N_2$	130 Km	Equilibrium of O^+, by this reaction and losses by the three major loss processes given in Sec. 3.	$2.2x10^{-11}$ *	$6x10^{-12}$ for daytime ionosphere (Donahue, 1966)
(1)$O^+ + NO \rightarrow O_2^+ + N$ (2)$O^+ + O_2 \rightarrow O_2^+ + O$	130 Km	Equilibrium of O_2^+ by these processes (assuming the rate of the second process is half of that of the first process) and major loss processes given in Sec. 3.	(1)$1.4x10^{-9}$ ** (2)$3.6x10^{-11}$ **	(1)$2.4x10^{-11}$ (Goldan et al, 1966) (2) { $2.6x10^{-11}$ at thermal energy (Warneck, 1967); $4x10^{-11}$ for daytime ionosphere at 130 Km (Donahue, 1966) }
(1)$O_2^+ + N \rightarrow NO^+ + O$ (2)$O_2^+ + NO \rightarrow NO^+ + O_2$ (3)$O_2^+ + N_2 \rightarrow NO^+ + NO$	130 Km	Equilibrium of NO^+ by these production processes (assuming their rates are equal) and the only loss process, $NO^+ + e \rightarrow N + O$.	(1)$2.1x10^{-10}$ (2)$1x10^{-9}$ (3)$6.6x10^{-14}$	(1)$1.8x10^{-10}$ at thermal energy (Warneck, 1967) (2)$8x10^{-10}$ at thermal energy (Warneck, 1967) (3) { $<2x10^{-15}$ at thermal energy (Warneck, 1967); $<4x10^{-14}$ for daytime ionosphere at 130 Km (Donahue, 1966) }

* obtained from equilibrium at 220 Km

** calculated from equilibrium at 240 Km

Table 3

Effective Recombination Coefficients and Lifetimes of Positive Ions at Night

Alt. (Km)	α^{i}_{eff} $(cm^3 sec^{-1})$					τ(sec)				
	O^+	O_2^+	N^+	N_2^+	NO^+	O^+	O_2^+	N^+	N_2^+	NO^+
130		2.7×10^{-5}			2.1×10^{-7}		1.0×10^{1}			1.3×10^{3}
140		9.1×10^{-5}			1.7×10^{-7}		4.6			2.5×10^{3}
150		3.5×10^{-4}			1.5×10^{-7}		3.6			8.5×10^{3}
160		5.6×10^{-4}			1.4×10^{-7}		3.4			1.4×10^{4}
170		5.6×10^{-4}			1.3×10^{-7}		3.4			1.5×10^{4}
180		5.1×10^{-4}			1.3×10^{-7}		3.6			1.5×10^{4}
190		3.7×10^{-4}			1.2×10^{-7}		3.8			1.2×10^{4}
200	1.7×10^{-5}	1.9×10^{-4}			1.2×10^{-7}	4.7×10^{1}	4.3			6.7×10^{3}
210	5.9×10^{-6}	6.2×10^{-5}	1.1×10^{-4}	3.9×10^{-4}	1.2×10^{-7}	6.7×10^{1}	6.3	3.7	1.0	3.4×10^{3}
220	2.4×10^{-6}	2.4×10^{-5}	4.0×10^{-5}	2.2×10^{-4}	1.1×10^{-7}	9.3×10^{1}	9.2	5.5	1.0	2.0×10^{3}
230	7.8×10^{-7}	8.4×10^{-6}	1.2×10^{-5}	1.0×10^{-4}	1.1×10^{-7}	1.3×10^{1}	1.1×10^{1}	1.7	1.0	9.0×10^{3}

5. Lifetimes and Effective Recombination Coefficients of Positive Ions at Night

The effective recombination coefficients (α^i_{eff}) and lifetimes (τ) of different species of positive ions at night at different altitudes are given in Table 3. They are claculated from the formula [1]

$$\alpha^i_{eff} = \frac{\text{Loss rate of positive ions of the ith species}}{n_i^+ n_e}$$

and

$$\tau = \frac{1}{\alpha^i_{eff} n_e}$$

where

n_i^+ - density of positive ions of the ith type

n_e - electron density, which is taken to be equal to the total positive ion density

It will be seen from the above table that NO^+ has the highest lifetime, 10^4 - 10^3 sec, and that of N_2 the least, about 1 sec. The effective recombination coefficients of positive ions vary between 10^{-4} and 10^{-7} cm^3/sec.

6. Conclusions

The analysis of altitude distributions of positive ion density at different times of the day for the altitude range 100-280 km shows the following:

1. At lower altitudes, O^+, O_2^+ and N_2^+ are produced mainly by photo-ionization and hence their densities have large diurnal variations. (Because of the high I. P., N_2^+ can be produced only by photoionization).
2. NO^+ is produced at low altitudes mainly by charge exchange processes and hence its density has small diurnal variations.

3. At high altitudes, N_2^+ and O^+ mostly, are produced by solar rays. NO^+ and O_2^+ to a large extent, are created by charge exchange processes. The densities of latter ions have small diurnal variations. In fact, at 220 km at night, their densities become equal and same as those for daytime.

4. N_2^+ ion rapidly decays by undergoing ion-atom interchange with O and O_2 producing mainly NO^+ ions.

$$N_2^+ + \begin{cases} O \rightarrow NO^+ + N \\ O_2 \rightarrow NO^+ + NO \end{cases}$$

This accounts for the low percentage of N_2^+ which, during the whole day, seldom becomes greater than 1% of the total ion content.

5. O^+ rapidly exchanges charge with N_2, NO and O_2 producing NO^+ either directly or through the intermediate production of O_2^+.

$$O^+ \begin{cases} N_2 \rightarrow NO^+ + N \\ NO \rightarrow O_2^+ + N \rightarrow NO^+ + O \\ O_2 \rightarrow O_2^+ + O \\ \qquad\quad +N_2 \rightarrow NO^+ + NO \\ \qquad\quad +NO \rightarrow NO^+ + O_2 \; . \end{cases}$$

At night O^+ loss rate by these processes is not balanced by the rate of the single important production process involving N_2^+ and O atoms. This accounts for the rapid O^+ density fall at night.

6. In the low altitude range, O_2^+ loss rates are greater than the production rates and explain its large density fall at night.

7. The final removal of charge from the ionosphere takes place mainly through the dissociative recombination of NO^+ ions and electrons.

8. Calculations show that although the concentration of neutral NO molecules is small, the rates of ion-atom reaction involving it is of the same order as those involving major atmospheric constituents, N_2 and O_2.

9. It was shown by Ghosh (1967) that at daytime at each level in the altitude range 100-280 km, the total rate of production of all positive ions is approximately equal to their total loss rate. The equality does not hold at night indicating that the ionosphere is not balanced.

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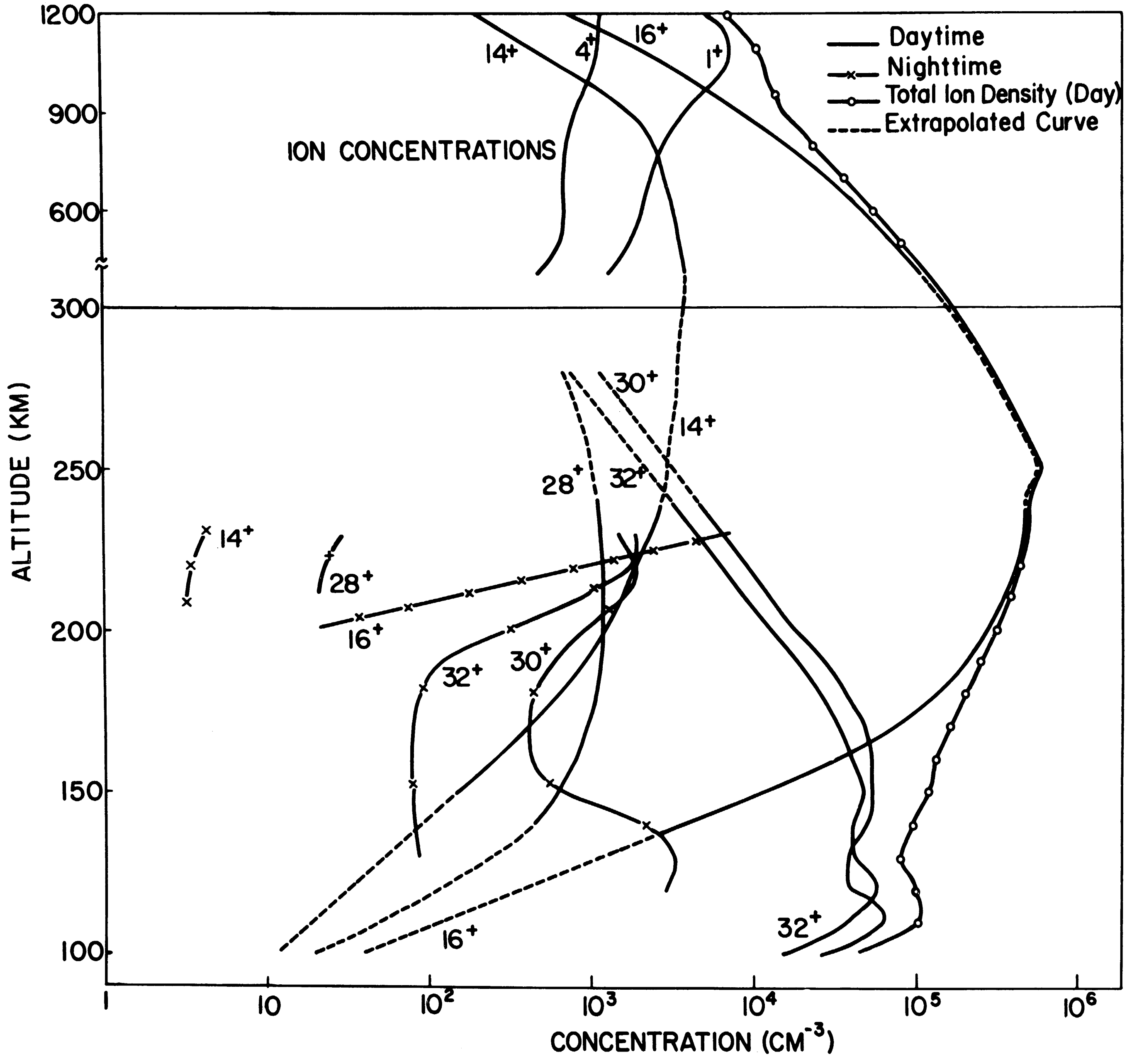

Fig. 1. Day and nighttime altitude variations of positive ions during the last solar minimum activity period averaged from observations made by different investigators.

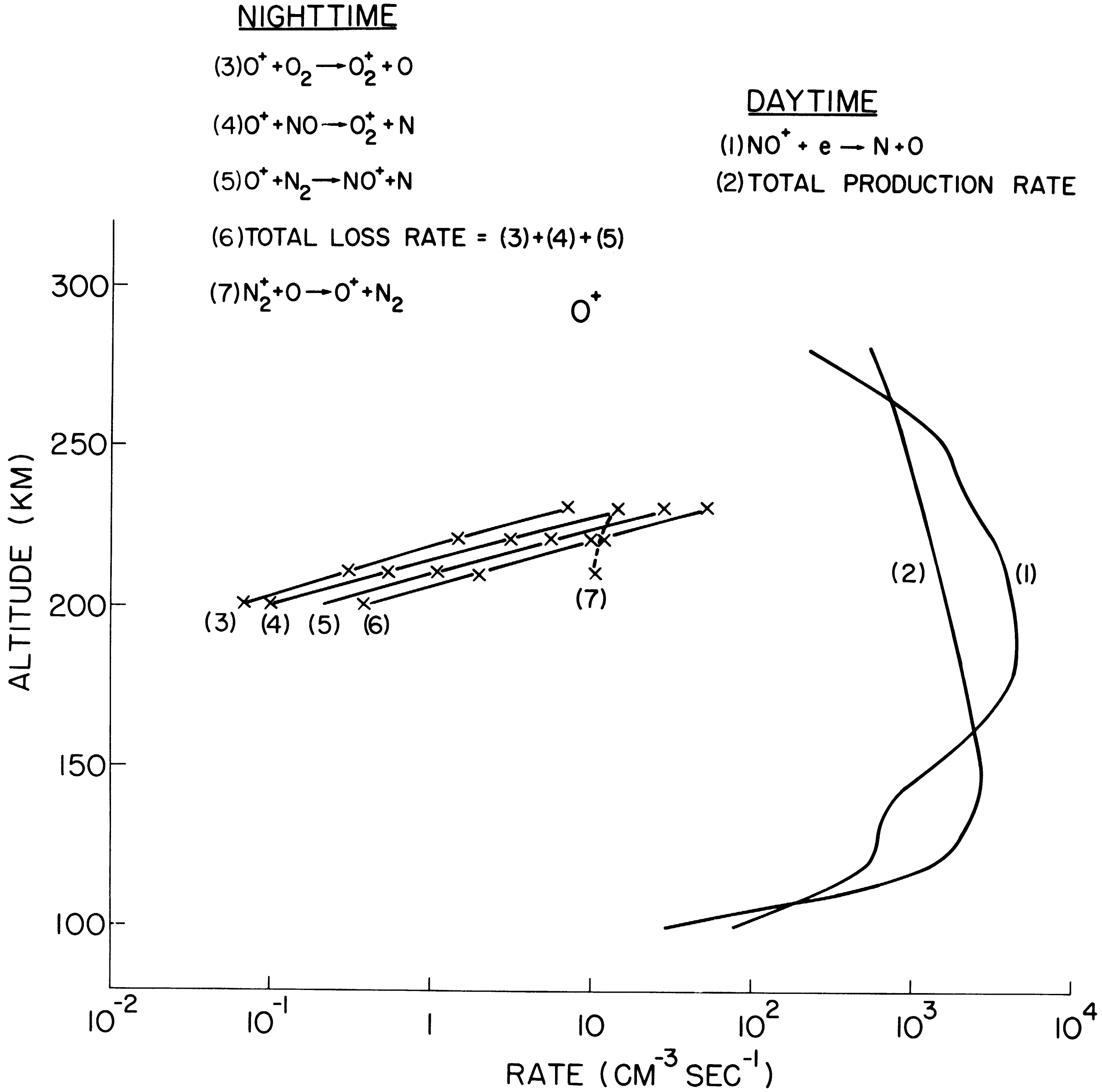

Fig. 2. Production and loss rates of O^+ ions at night. For comparison the total production and loss rates of O^+ during daytime are drawn.

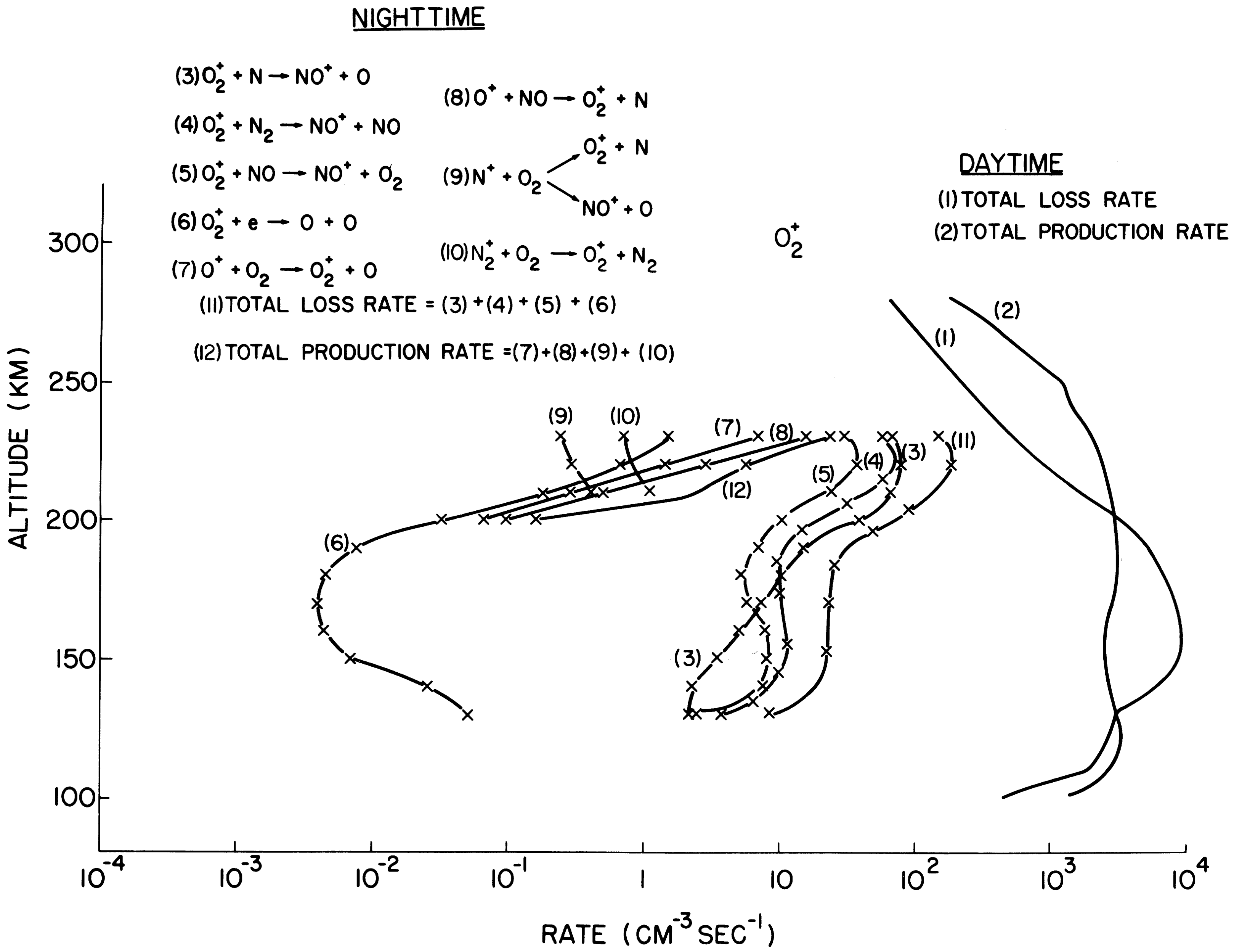

Fig. 3. Production and loss rates of O_2^+ ions at night. The total production and loss rates of O_2^+ during daytime are also drawn.

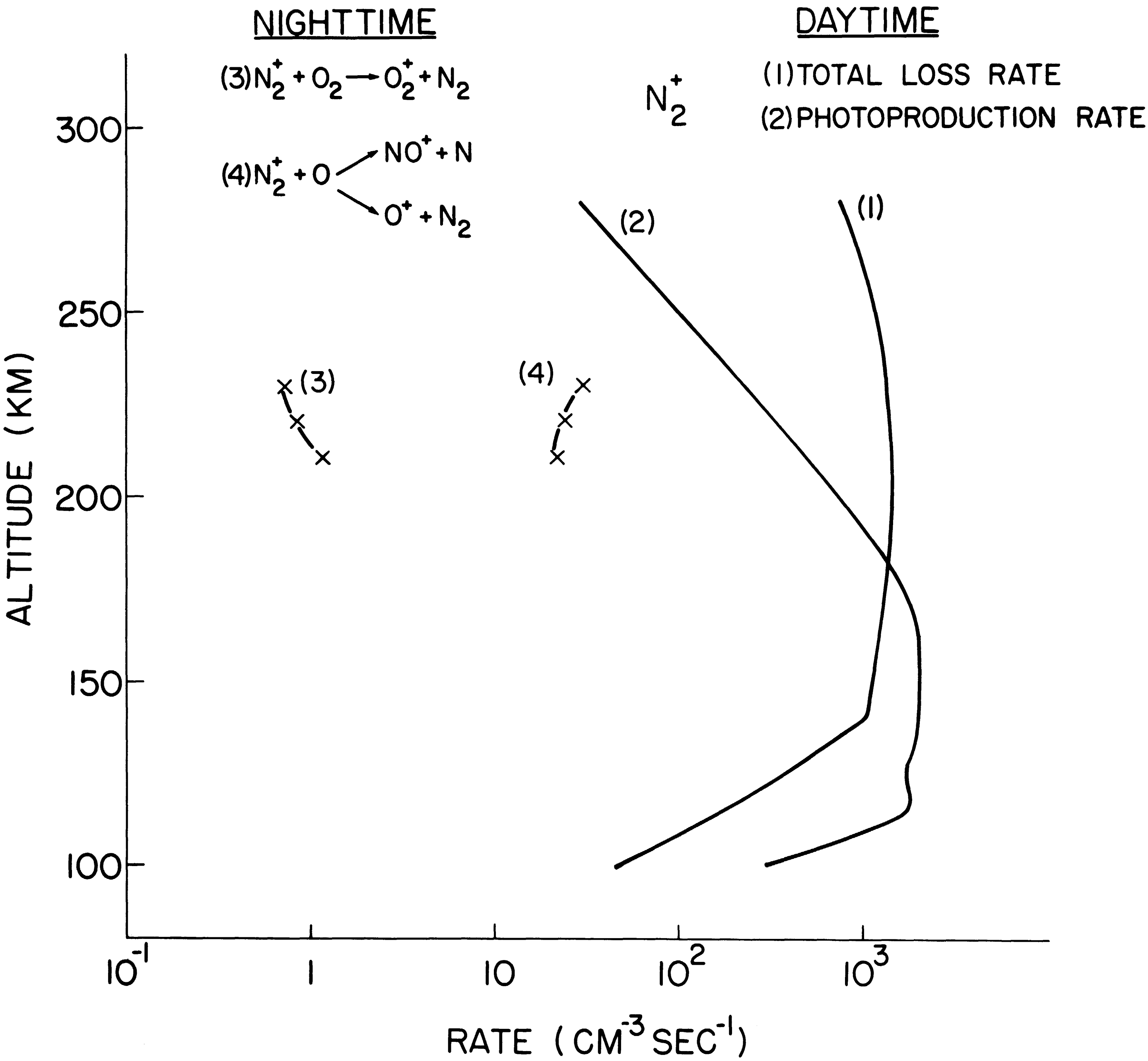

Fig. 4. Loss rates of N_2^+ ions at night. For comparison the total production and loss rates of N_2^+ during daytime are drawn.

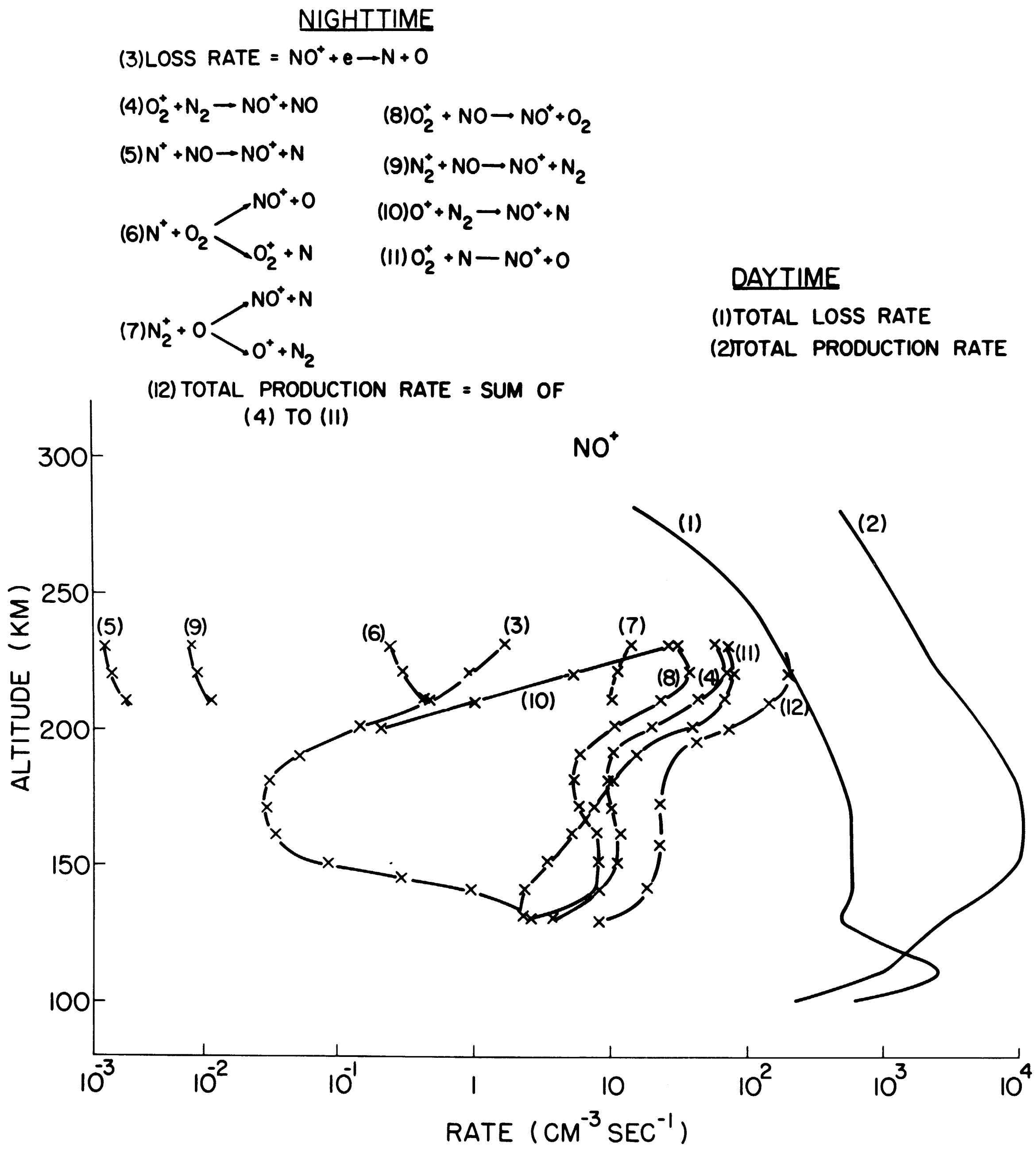

Fig. 5. Production and loss rates of NO^+ ions at night. The total production and loss rates of NO^+ during daytime are also drawn.

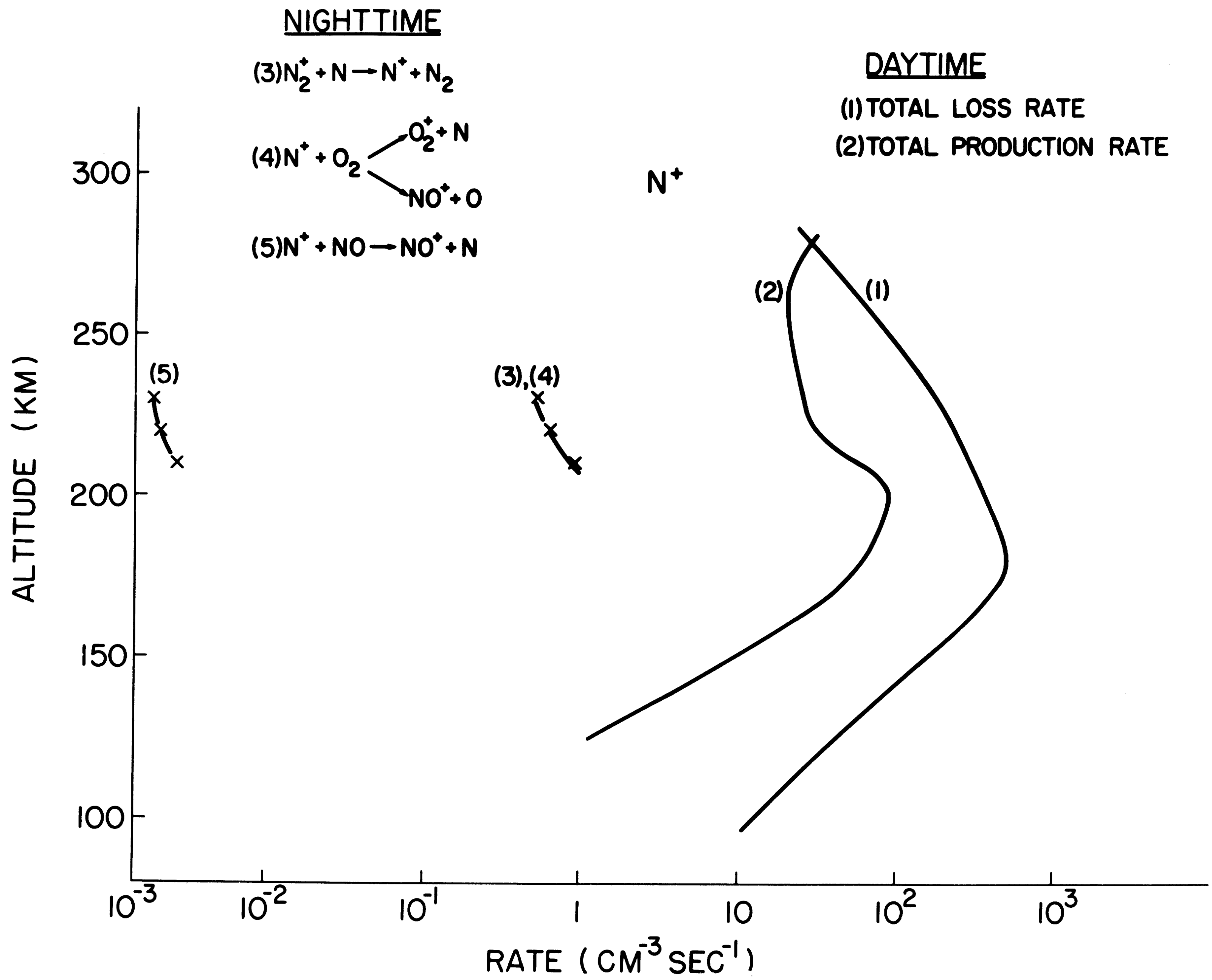

Fig. 6. Production and loss rates of N^+ ions at night. For comparison the total production and loss rates of N^+ during daytime are drawn.