IONIZATION BY keV ELECTRON PRECIPITATION IN THE AURORAL ZONE

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***Abstract*:** The electron fluxes precipitating into the aurora zone were observed by the electron spectrometers (ESM) onboard the Japanese Antarctic sounding rockets S-310JA-5 and -6 at Syowa Station in 1978. The ESM measured successfully the electron fluxes in the energy range of 1 to 10 keV at small and near 90° pitch angles. The detailed description of the ESM instrument and the results of the observations were presented elsewhere (KAYA *et al.*, 1981). The density of secondary electrons ionized by the precipitating electrons was estimated and compared with the data obtained by the impedance probe onboard the same rockets. The method of the calculation was based on KAMIYAMA (1966). The electron densities estimated by the calculation are 5 times more on the average than those measured by the impedance probe. However, there is a close resemblance in the fine structures of the altitude profiles of the electron density.

1. Introduction

A number of papers are concerned with the interactions of the precipitating energetic fluxes in the atmosphere. REES (1963) developed the first widely used model of the auroral electron penetration, and calculated the atmospheric ionization rate as a function of altitude for incident electron energies greater than 400 eV and for arbitrary pitch angles. MAEDA (1965) calculated energy dissipation of auroral electrons by the Monte Carlo method. KAMIYAMA (1966) paid special attention to the energy range below 400 eV, and discussed excitations of auroral lines and electron density produced by the incident electron fluxes. Another approach to the problem of the auroral electrons was taken by WALT *et al.* (1969), who used a Fokker-Planck diffusion equation to describe electron energy dissipation and angular scattering through atmospheric particles.

In this paper, we estimate the electron density produced by the precipitating electron fluexes using the method adopted by KAMIYAMA. The calculation was carried out with the data of electron fluxes measured by the electron spectrometers (ESM) onboard the Japanese Antarctic sounding rockets S-310JA-5 and -6 at Syowa Station in 1978. The calculated electron density was compared with the data measured by the impedance probe onboard the same rockets.

2. Estimation of the Density of Secondary Electrons

The electrons precipitating into the atmosphere lose their energy through inelastic collisions with neutral particles and ionize the neutral particles. The density of the produced ions and electrons reaches an equilibrium through recombinations and ion-atom interchange processes.

The ion production rate $q(E, x, \alpha)$ due to the electron fluxes $i(E, x, \alpha)\mathrm{d}E$ is given by the following equation, assuming one ion pair is produced by the loss of energy of 32 eV on the average due to the precipitating electrons.

$$q(E, x, \alpha)=\frac{\cos\alpha}{32\varepsilon}i(E, x, \alpha)\mathrm{d}E\left(-\frac{\mathrm{d}E}{\mathrm{d}x}\right), \tag{1}$$

where E denotes the kinetic energy of an electron in ergs, x the distance along the magnetic field line, and α the pitch angle. $\mathrm{d}E/\mathrm{d}x$ is an energy-loss rate through inelastic collisions, which is expressed by the following equation obtained from the Thomas-Fermi model with the Born approximation.

$$-\left(\frac{\mathrm{d}E}{\mathrm{d}x}\right)=NZ\phi_0\frac{3\mu^2}{4E}\left[\ln\frac{E}{IZ\sqrt{2}}+\frac{1}{2}\right]\Big/\cos\alpha\ , \tag{2}$$

where N denotes the number of atmospheric particles per cm^3, Z the atomic number, ϕ_0 the cross section for Thomson scattering, μ the rest energy of electron, and I is the average ionization energy of an atmospheric particle.

The electron fluxes $i(E, x, \alpha)$ were given by the data obtained by the ESM. The measured electron fluxes showed a Gaussian energy spectrum in the S-310JA-5 rocket experiment (shown in Fig. 1), and an exponential distribution in the S-310JA-6 experiment (Fig. 2). The energy spectra are consistent with types of the observed auroras into which the rockets penetrated, namely a discrete aurora for the S-310JA-5 and an intense one for the S-310JA-6, respectively. Since the measurable energy range of the

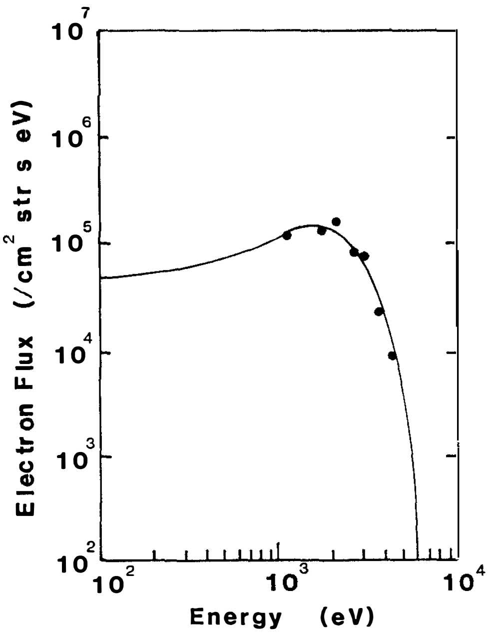

Fig. 1. One of the energy spectra from the S-310JA-5 rocket experiment.

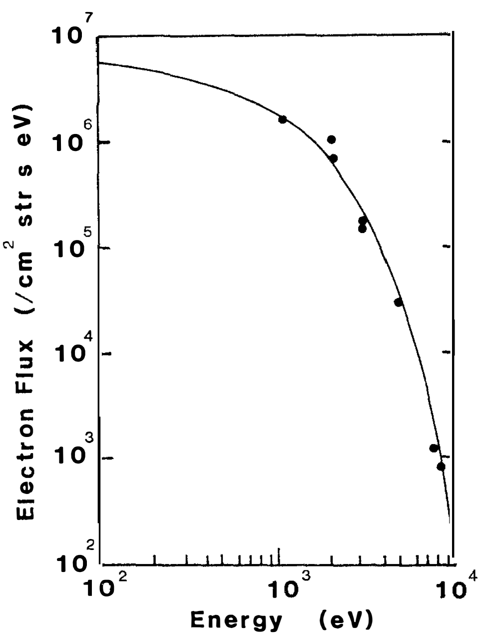

Fig. 2. One of the energy spectra from the S-310JA-6 rocket experiment.

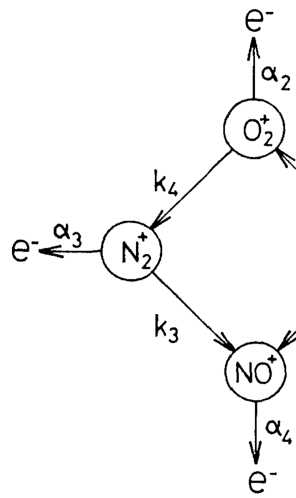

Fig. 3. Chemical processes considered in the calculation.

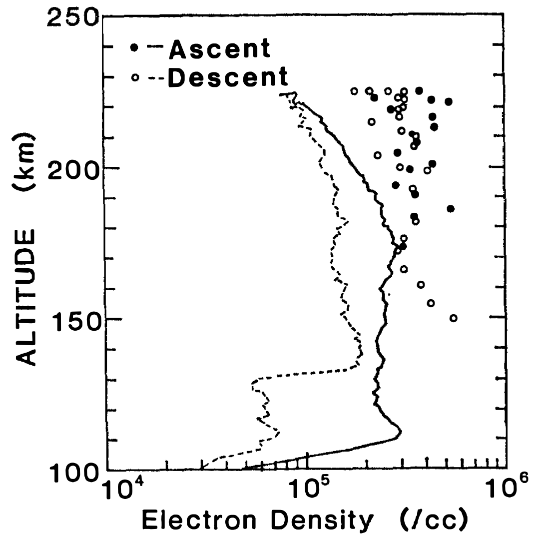

Fig. 4. The calculated (circles) and observed (curves, after T. TAKAHASHI) electron density as a function of altitude in the S-310JA-5 rocket experiment.

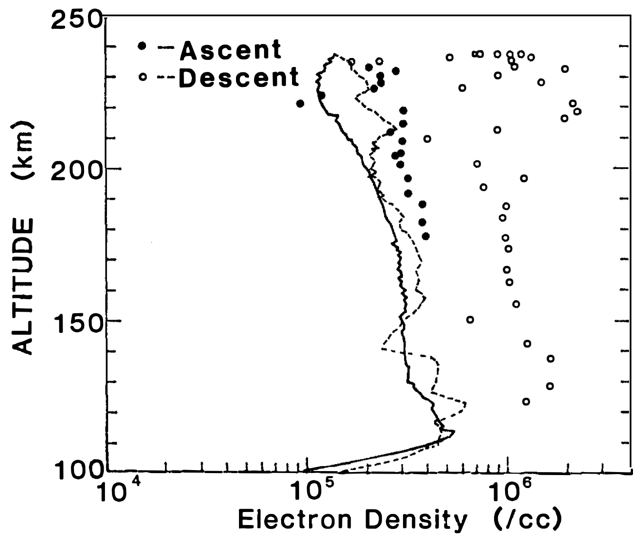

Fig. 5. The calculated (circles) and observed (curves, after T. TAKAHASHI) electron density as a function of altitude in the S-310JA-6 rocket experiment.

ESM is from 1 keV to 10 keV, the energy spectra below 1 keV are calculated by an extrapolation of the measured electron fluxes in the range of 1 to 10 keV. The pitch angle distributions are isotropic for the downward fluxes.

The CIRA model is used as a model atmosphere. The exospheric temperature T_∞ in the CIRA model is calculated from the Kp value and 10.7 cm solar flux of the day. The calculated T_∞ are 1035 K in the S-310JA-5 rocket experiment and 1001 K in the S-310JA-6, respectively.

Produced ions and electrons are recombined through chemical processes. Though many chemical processes take place in the ionosphere, the most active seven processes, shown in Fig. 3, are selected for the calculation. The coefficients for the radiative recombinations and the rate coefficients for the ion-atom interchange processes are taken from KAMIYAMA (1966).

In Figs. 4 and 5 the electron densities computed by the calculations are compared with those measured by the impedance probe.

3. Discussion

The results of the calculation show that the electron densities calculated by the measured electron fluxes are 5 times more than those measured by the impedance probe in both experiments. The following four items should be examined in order to solve the discrepancy between the calculations from the energetic electron fluxes and direct measurements of the ionospheric electron density: 1) The accuracy of the measurements of the electron fluxes and the electron density. 2) The theory of the ionization. 3) The atmospheric model. 4) The loss processes of the ions produced by the precipitating electron fluxes.

The accuracy of the electron density measurement by the impedance probe has been confirmed by many rocket experiments (TAKAHASHI *et al.*, 1981). On the other hand, the ESM has been newly developed for the Antarctic sounding rockets and was calibrated in the vaccum chamber prior to the launch. The calibrations of the geometrical factor of the ESM and the efficiency of the channel electron multiplier (CEM) are generally difficult and need a very accurate gimbal and an electron beam source which is homogeneous in time, in space and in energy, as well as a precise measurement of extremely low current ($<10^{-14}$ A). However, the error involved in the calibration of the geometrical factor is less than a factor of 2. The efficiency of the handmade CEM was determined to 20% from the experiment. It is not more than 40% at the outside. If it is less than 20%, the calculated electron density becomes larger than those shown in Figs. 4 and 5, and the discrepancy becomes larger. Therefore, we need to seek other factors as a cause of the discrepancy.

The energy spectra in the range below 1 keV were extrapolated from the spectra in the range between 1 keV and 10 keV. The theory used in this paper can be applied only to the electron fluxes in the energy range above 400 eV. Electron fluxes in the energy range below 400 eV are thus ignored in this estimation. The contribution to the ionization of the fluxes is of the same order as those above 1 keV. Therefore, even if an extremely low flux below 1 keV is assumed instead of the present extrapolation scheme, there still remains a 2.5 factor discrepancy. However, such extreme energy spectra have rarely been observed.

We do not know whether or not the CIRA model used in the calculation is reasonable for the atmosphere in the polar region as there have been very few or no observations that the authers are aware of.

The coefficients of the recombinations and the ion-atom interchange processes are based on the data obtained from laboratory experiments. The conditions of the laboratory experiments, however, are generally different from those of the space experiments. If the rate coefficient of the ion-atom interchange from O^+ to $O_2^+(k_1)$ is one order larger than the value used, and the recombination coefficient for $NO^+(\alpha_4)$

is one order of the magnitude larger, the calculated electron density agrees well with the direct measurement. However, the time necessary for the chemical processes to reach an equilibrium must be examined. The estimated longest time is 300 s for NO^+. According to the data of the all-sky camera, the auroras are steady for more than 300 s, indicating that all chemical processes are well in equilibrium during the experiments.

Though the discussions given above could not point to the causes of the discrepancy between the calculations and the observations, the most plausible interpretation may be the difference of the coefficients for the most dominant chemical processes in space from those measured by laboratory experiments. In order to confirm this point, however, electron fluxes in the energy range from 100 eV to 20 keV at all pitch angles, must be observed by well calibrated particle detectors together with simultaneous measurements of densities of electrons, ions and neutral particles.

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