Electron elastic collision by H_2O originating from Enceladus: Test-particle simulation

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1 Introduction

In this study, we focus on the collisional loss process with neutrals. The observations of injected electrons and ions in the inner magnetosphere suggested that these particles do not survive very long time due to the neutral cloud originated from Enceladus [e.g., Paranicas et al., 2007; 2008]. These neutrals in the inner magnetosphere play the dominant role in a loss process of energetic electrons and ions [e.g., *Paranicas et al.,* 2007; *Sittler et al.,* 2008]. However, little has been reported on a quantitative study of the electron loss process due to electron-neutral collisions. Especially, a quantitative study of variation of an electron pitch angle distribution due to electron-neutral elastic collisions has not been clarified. This study aims at revealing the variation of energetic electron pitch angle distribution and the loss rate of electrons into the loss cone through pitch angle scattering due to electron elastic collisions with the neutral H_2O molecules along Saturn's magnetic field line around Enceladus when the electron flux tube passes the region of the dense H_2O molecules in the vicinity of Enceladus (~6.4 minutes). We focus on 1 keV electron in this study.

2 Simulation model

We focus on 1 keV as a typical kinetic energy of the electrons in the present study. We conduct one dimensional test-particle simulation for monoenergetic electron along Saturn's dipole magnetic field line around Enceladus (L=3.95). The number of electron used in this simulation is 500,000. We assume that the boundary condition is in the magnetic latitude range of -10 – 10 degrees and the loss cone angle at the equator is 7.3 degrees. A trajectory trace is terminated when a pitch angel of each article at the boundary is smaller than the loss cone angle. We assume that the electrons precipitate into the atmosphere since the collisional frequency at the boundary is smaller than the bounce frequency. Trajectories of the electrons are computed by considering under a dipole magnetic field.

$$m\,dv/dt = q\left(\vec{E} + v\times\vec{B}\right),$$

where B is the magnetic field. We assume that the electric field (E) is zero in this study. To examine the variation of pitch angle distribution we assume that the initial pitch angle distribution is isotropic distribution.

With regard to the elastic collision process, if the collision occurs, then we conduct a calculation of scattering angle based on the differential cross sections. The collision is solved by the Monte-Carlo method. The collisional frequency, f_{col}, between an electron and H_2O molecule can be given by

$$f_{col} = n\sigma v,$$

where n is the neutral H_2O density, σ is the cross section, and v is the relative velocity between an electron and neutral H_2O. We assume that the relative velocity is the electron velocity since the electron velocity is much greater than the neutral H_2O velocity. The total and differential cross sections for elastic collisions based on the experimental data are given by *Katase et. al.* [1986]. We use the total cross section (5.48×10^{-17} cm^2) at 1 keV electron and the differential cross sections in the scattering angle range from 0 – 180 degrees. We assume that the probability of the collision happening, P, is given by

$$P = n\sigma_{tot}v\Delta t$$

where the Δt is the time step (1/25 of the gyro-period at 1 keV electron) in this simulation and σ_{tot} is the total cross section.

We assume that the neutral H_2O density is set to background parameter. We model the H_2O density profile, n, as following equation

$$n = n_{max}(1 + |x|)^{\alpha},$$

where n_{max} is the peak of H_2O density at Encelaus, x is the radial distance from Enceladus, and α is the parameter. We assume that n_{max} and α are 2×10^8 (7×10^5) cm^3 and -1.8 (-0.7) in the southern hemisphere (northern hemisphere) of Saturn. Note that $z < 0$ ($z > 0$) shows the northern (southern) hemisphere of Enceladus.

3 Result

The top and bottom panels of Figures 1 show the time variation of equatorial electron pitch angle distribution at 1keV through pitch angle scattering due to elastic collisions with the H_2O molecules. It is found that the normalized electron pitch angle distribution near the loss cone (<20 degrees and >160 degrees) decreases with time through pitch angle scattering due to elastic collision. In contrast, the pitch angle distribution in the range from 20 – 160 degrees does not show significant variation. Note that the range of normalized number of electrons in the top panel is different form that in the top panel. Figure 2 shows the time variations of the loss rate of electron into the loss cone. The red line indicates the amount of electrons into the loss cone, N_{lc}, to the total number of equatorial electrons at the initial condition, N_{0eq}. The electrons of ~11.4% to N_{0eq} are lost in ~380 seconds. The blue line indicates the percentage of small equatorial pitch angle electrons (<20 and >160 degrees) at the initial condition into the loss cone, N_{slc}, to N_{lc}. It is found that the percentage of the electrons decreases with time.

To examine the calculated loss rate quantitatively, we compare the loss rate with the strong diffusion through wave-particle interactions [e.g., *Kennel and Petschek,* 1966; *Tomás et al.,* 2004]. Here, we assume that the strong diffusion is loss cone filling with electrons within the time scale of electron moving from the equator to the pole (i.e., 0.25 bounce period). The loss rate is computed by S_{lc}/S, where S_{lc} is the surface area of a sphere in the loss cone angle at the equator and S is the total surface area of a sphere. We estimated S_{lc} to be ~0.22% by using 5.4 degrees of the loss cone angle at the equator. Since the bounce period of an electron for 1 keV under a dipole magnetic field is estimated to be ~62.8 seconds, we assume that the loss rate under the strong diffusion is 0.22 % over 0.25 bounce period (~15.7 seconds). As shown in the red line of Figure 4, the calculated loss rate is 0.22 % for ~7.3 seconds (380 sec × 0.22 % / 11.4 %). This calculated loss time (7.3 seconds) is about twice faster than the loss time (15.7 seconds) under the strong diffusion.

4 Summary

Conducting one dimensional test-particle simulation code along a dipole magnetic field at Enceladus (~3.95 Rs) when the electron flux tube passes the region of the dense H_2O molecules in the vicinity of Enceladus (~6.4 minutes), we have examined the time variations of equatorial pitch angle distribution and electrons within loss cone (7.3 degrees) through electron (1 keV) pitch angle scattering due to electron-H_2O elastic collisions. The result showed that the electrons of 11.4 % are lost in ~380 sec. To examine the calculated loss rate quantitatively, we compared the loss rate with the loss rate of strong diffusion due to wave-particle interactions. We found that the calculated loss time is about twice faster than the loss time under the strong diffusion. For our future study, the calculation of electrons with > keV and other L shell in the inner magnetosphere to compare observational parameters.

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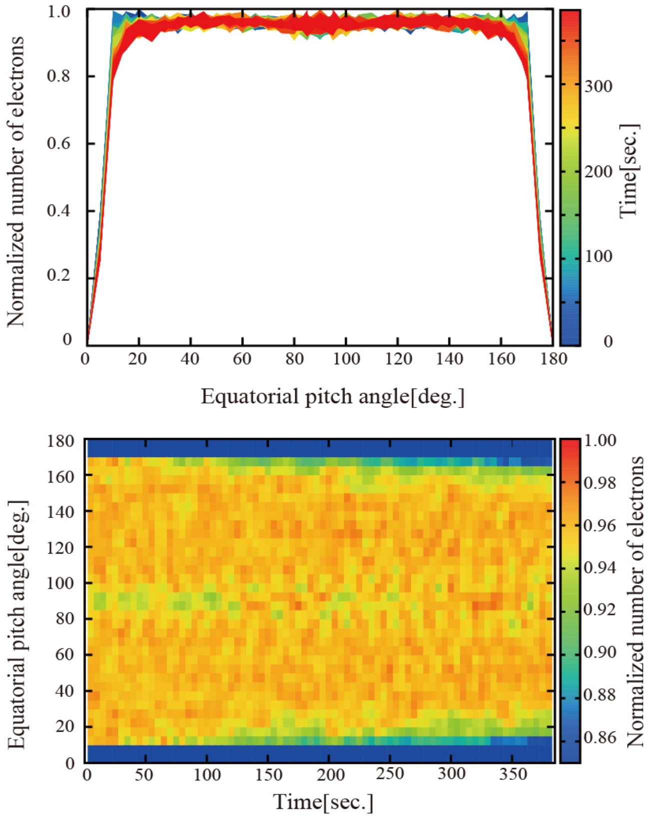

Figure 1. Time variation of the equatorial pitch angle distribution of electron at 1 keV. Note that the axes in the top and bottom panels is different [*Tadokoro and Katoh*, 2014].

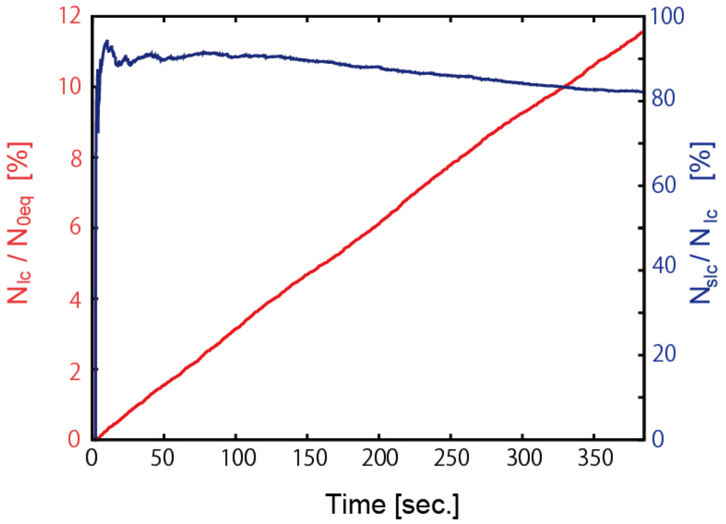

Figure 2. N_{lc} is the number of electrons into the loss cone. N_{0eq} is the total number of equatorial electrons at the initial condition. N_{slc} is the small equatorial pitch angle electrons (<20 and >160 degrees) at the initial condition into the loss cone. The red (blue) line shows the percentage of N_{lc}/N_{0eq} (N_{slc}/N_{lc}) as a function of time [*Tadokoro and Katoh*, 2014].