

# Energetic electron collisions with water molecules: elastic collision and ionization in the magnetosphere at the orbit of Enceladus

Hiroyasu Tadokoro<sup>1</sup> and Yuto Katoh<sup>2</sup>

<sup>1</sup> Chiba Keizai University, Chiba, Japan

E-mail: h-tadokoro@cku.ac.jp

<sup>2</sup> Tohoku University, Miyagi, Japan

## 1 Introduction

Saturn's inner magnetosphere is rich in water group neutrals (H<sub>2</sub>O, OH, and O) originated from Enceladus (~3.95 Rs). It has been suggested that these neutrals play the dominant role in loss of plasmas [e.g., Paranicas et al., 2007; 2008, Sittler et al., 2008]. Little has been reported on a quantitative study of the electron loss process due to electron-neutral collisions. Tadokoro and Katoh [2014] performed one dimensional test-particle simulation regarding 1keV electrons to examine the time variations of equatorial pitch angle distribution and electrons within loss cone through pitch angle scattering due to electron-H<sub>2</sub>O elastic collisions around Enceladus. Chemical reactions in plasmas depend on electron energy. At energies above several hundred eV, ionization is the dominant chemical reaction rather than elastic collision. In this study, we report on the current state of development of the simulation code regarding ionization and show a result of estimation of auroral brightness by electron precipitation due to elastic collision.

## 2 Simulation model

Following the method of Tadokoro and Katoh [2014], we use one dimensional test-particle simulation code for monoenergetic electron along Saturn's dipole magnetic field line around Enceladus. Trajectories of the electrons are computed by considering under a dipole magnetic field.

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

where B is the magnetic field. We assume that the electric field (E) is zero in this study. In this study, we assume that the initial pitch angle distribution is isotropic distribution. The number of electrons used in this simulation is 500,000. A trajectory trace is terminated when a calculation time is over ~380s. The end of calculation time corresponds to the time scale of the co-rotating flux tube passing through the region of the dense H<sub>2</sub>O around Enceladus.

The collision is solved by a Monte-Carlo procedure. The collisional frequency,  $f_{col}$ ,

between an electron and H<sub>2</sub>O molecule can be given by

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

where  $n$  is the neutral H<sub>2</sub>O density,  $\sigma$  is the cross section, and  $v$  is the relative velocity between an electron and neutral H<sub>2</sub>O. The H<sub>2</sub>O density model used in this simulation is the same as the model based on observations used in *Tadokoro and Katoh* [2014].

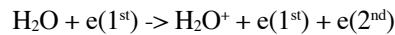
### 3 Auroral brightness due to elastic collision

If the elastic collision occurs, then we conduct a calculation of scattering angle based on the differential cross sections. The total and differential cross sections for elastic collisions based on the experimental data are given by *Katase et. al.* [1986].

Using the calculated electron loss rate (elastic collision) in  $\sim 380$  sec as a function of electron energy in the range from 500 eV to 50 keV and the modeled electron flux base on observations [*Cravens et al.*, 2011], we derive auroral brightness. As a result, the auroral brightness through pitch angle scattering due to elastic collisions is estimated to be  $\sim 2.6[R]$ .

### 4 Simulation code development regarding ionization

In this study, we assume that the product ion after ionization is H<sub>2</sub>O<sup>+</sup> as



where  $e(1^{\text{st}})$  shows the incident electron,  $e(2^{\text{nd}})$  shows the secondary electron. We trace the trajectory of the incident electron. The ionization cross section based on the experimental data is given by *Itikawa and Mason* [2005]. If the ionization occurs, then we conduct a calculation of electron energy loss. We assume that the incident electron energy after ionization impact decreases by 12.6eV (ionization energy) and secondary electron energy. The secondary electron energy is solved by a Monte-Carlo procedure using singly differential cross section [*Itikawa and Mason*, 2005]. In actual ionization, the energy of the incident electron decreases with each ionization. It is necessary to use ionization cross sections of secondary electrons considered the energy decrease. We found that the method using linear interpolation is significantly different from the experimental cross section. The fitting using interpolation method is a subject for future works.

## References

- Cravens, T. E., N. Ozak, M. S. Richard, M. E. Campbell, I. P. Robertson, M. Perry, and A. M. Rymer (2011), Electron energetics in the Enceladustorus, *J. Geophys. Res.*, 116, A09205, doi:10.1029/2011JA016498.
- Itikawa Y., and N. Mason, Cross sections for electron collisions with water molecules (2005), *J. Phys. Chem. Ref. Data*, 34, 1, 1–22.
- Katase, A., K. Ishibashi, Y. Matsumoto, T. Sakae, S. Maezono, E. Murakami, K. Watanabe, and H. Maki, Elastic scattering of electrons by water molecules over the range 100-1000 eV (1986), *J. Phys. B: At. Mol. Phys.*, 19, 2,715–2,734.
- Paranicas, C., D. G. Mitchell, E. C. Roelof, B. H. Mauk, S. M. Krimigis, P. C. Brandt, M. Kusterer, F. S. Turner, J. Vandegriff, and N. Krupp, Energetic electrons injected into Saturn's neutral gas cloud, *Geophys. Res. Lett.*, 34, L02109, doi:10.1029/2006GL028676, 2007.
- Paranicas, C., D. G. Mitchell, S. M. Krimigis, D. C. Hamilton, E. Roussos, N. Krupp, G. H. Jones, R. E. Johnson, J. F. Cooper, and T. P. Armstrong (2008), Sources and losses of energetic protons in Saturn's magnetosphere, *Icarus*, 197, 519-525.
- Sittler Jr., E. C., N. André, M. Blanc, M. Burger, R. E. Johnson, A. Coates, A. Rymer, D. Reisenfeld, M. F. Thomsen, A. Persoon, M. Dougherty, H. T. Smith, R. A. Baragiola, R. E. Hartle, D. Choray, M. D. Shappirio, D. Simpson, D. J. McComas, and D. T. Young (2008), Ion and neutral sources and sinks within Saturn's inner magnetosphere: Cassini results, *Planet. Space Sci.*, 56, 3–18.
- Tadokoro, H., and Y. Katoh (2014), Test-particle simulation of energetic electron-H<sub>2</sub>O elastic collision along Saturn's magnetic field line around Enceladus, *J. Geophys. Res.*, 119, doi:10.1002/2014JA019855.