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Oxygen Sources on Europa

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Abstract

Europa, one of the Galilean satellites, has a tenuous, oxygen-dominated atmosphere that is usually referred to as a collision-less exosphere. It's generally understood that the primary source of oxygen is the sputtering of Europa's surface ice by energetic particles coming from the Jovian magnetosphere, particularly the positive ions such as H^+, O^+, and S^+. These ions penetrate only a few hundred microns to a couple of mm deep into the ice. However, high-energy (hundreds of keV to tens of MeV) electrons in the Jovian magnetosphere are able to dissociate water molecules when bombarded on Europa's surface ice and produce oxygen atoms inside the ice at centimeters depths, which can diffuse radially inward and outward. Oxygen diffusing outwards can be regarded as an oxygen source that contributes to the atmosphere. Molecular oxygen in the form of a dimer $(O_2)_2$ is detected at the surface of Europa in the ice, indicating significant amount of molecular oxygen presence. Observations have also revealed the presence of a tenuous ionosphere on Europa in contact with the surface and coupled to the neutral atmosphere. Such an ionosphere is thought to be produced by solar photoionization and electron-impact ionization of the oxygen in the atmosphere. However, a recent study showed that the maximum ionosphere coincides with intermittent water plume on Europa, suggesting that water plays an important role in the formation of the ionosphere. Therefore, there may be another oxygen source initiated by water photolysis and photoionization. Here, we use a 1D chemical-transport model KINETICS to simulate the photochemical and electron-impact reactions in Europa's atmosphere. These two oxygen sources together will provide a better understanding of the different processes that are happening in both Europa's atmosphere and surface ice. The study also has implications for the chemical composition of Europa's subsurface ocean, and may give us insight into Europa's habitability and suggestions for future measurements.

1. Introduction

The atmosphere of Europa was first detected by Hall et al. [1] using Hubble Space Telescope observations. Based on observations of oxygen's electronic excitation emission, the dominant composition of the atmosphere is proposed to be molecular oxygen [1], which has been confirmed by several studies [2, 3, 4, 5, 6]. Atomic oxygen has also been proposed to be present in Europa's atmosphere with a column density of 4.7×10^{12} cm^{-2}, which is two orders of magnitude lower than the O_2 dominated model [7]. Europa's oxygen-dominated atmosphere is thought to be a major reservoir for oxygen, despite the fact that it is tenuous and referred to as an exosphere or a surface boundary-layer atmosphere [8], with a surface pressure of 10^{-6} μbar [9]. It's generally understood that the primary source of the oxygen in the atmosphere is ion sputtering of Europa's surface ice [5, 10, 11, 12], as Europa is embedded within Jupiter's magnetosphere and experiencing an intense flux of low-energy heavy ions (O^+, S^+). During the ion sputtering process, H_2O and H_2O products (H_2, H, O_2, O, etc.) are sputtered out of the surface ice. Among the products, only oxygen, which is heavy and less likely to be adsorbed by the surface, remains in Europa's atmosphere. Besides the slow heavy ions, energetic ions, electrons, secondary electrons and photons produced by the incoming electrons [13] can penetrate into the surface ice, dissociate water molecules and produce oxygen inside the ice [14]. This oxygen produced inside the ice, which can diffuse out of the ice and go into the atmosphere at kinetic energies closer to the thermal sublimation energy at the surface, provides an alternative source for the oxygen in the atmosphere. Intermittent water plumes on Europa, detected by Roth et al. [15], Sparks et al. [16], and Jia et al [17], are found to be coincident with the maximum ionosphere on Europa [18], which implies that the water molecule plays an important role in the formation of Europa's ionosphere through multiple processes: photoionization, electron impact ionization, charge transfer and a sequence of chemical reactions. Since the water column density is estimated to be as high as 1.8×10^{17} cm^{-2} [19], the atmosphere near plumes becomes continuous, which would also result in an efficient photochemical production of oxygen. Due to the lack of studies on the photolysis and photoionization of water molecules from plumes and their influence on the formation of atmosphere and ionosphere, these processes are not yet fully understood.

2. Figures

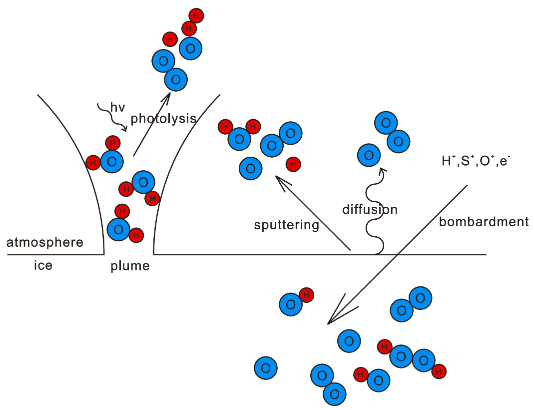

Figure 1. Schematic picture of the oxygen sources on Europa.

3. Summary and Conclusions

The three important oxygen sources on Europa include direct sputtering, radiolysis and outgassing, and photolysis of the water plumes (shown in Figure 1). In this study, we build a model to describe the water dissociation, combination and diffusion processes inside the ice to evaluate the oxygen production below the surface. We also use a photochemical model to investigate the photoionization and photolysis processes of water molecules from the plumes, estimate its influence on the formation of atmosphere and ionosphere, and construct profiles of neutral and ionized species.

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References

[1] Hall, D. T., Strobel, D. F., Feldman, P. D., McGrath, M. A., & Weaver, H. A. 1995, Nature, 373, 677

[2] Hall, D. T., Feldman, P. D., McGrath, M. A., & Strobel, D. F. 1998, ApJ, 499, 475

[3] Saur, J., Strobel, D. F., & Neubauer, F. M. 1998, J. Geophys. Res., 103, 19947

[4] Hansen, C. J., Shemansky, D. E., & Hendrix, A. R. 2005, Icarus, 176, 305

[5] Smyth, W. H., & Marconi, M. L. 2006, Icarus, 181, 510

[6] Roth, L., Saur, J., Retherford, K. D., et al. 2016, Journal of Geophysical Research (Space Physics), 121, 2143

[7] Shemansky, D. E., Yung, Y. L., Liu, X., et al. 2014, ApJ, 797, 84

[8] Johnson, R. E., Leblanc, F., Yakshinskiy, B. V., & Madey, T. E. 2002, Icarus, 156, 136

[9] McGrath, M. A., Hansen, C. J., & Hendrix, A. R. 2009, Europa, p.485. Edited by Robert T. Pappalardo, William B. McKinnon, Krishan K. Khurana, with the assistance of Ren´e Dotson with 85 collaborating authors. University of Arizona Press, Tucson

[10] Brown, W. L., Augustyniak, W. M., Marcantonio, K. J., Simmons, E. H., Boring, J. W., Johnson, R. E., & Reimann, C. T. 1984, Nuclear Instruments and Methods in Physics Research Section B: Beam Interactions with Materials and Atoms, 1(2-3), 307-314.

[11] Ip, W.-H. 1996, Icarus, 120, 317

[12] Ip, W.-H., Williams, D. J., McEntire, R. W., & Mauk, B. H. 1998, GeoRL, 35, 829

[13] Gudipati, M., Henderson, B., & Bateman, F. 2017, AAS/Division for Planetary Sciences Meeting Abstracts #49, 49, 203.10

[14] Teolis, B. D., Plainaki, C., Cassidy, T. A., & Raut, U. 2017, Journal of Geophysical Research: Planets, 122(10), 1996-2012.

[15] Roth, L., Saur, J., Retherford, K. D., et al. 2014, Science, 343, 171

[16] Sparks, W. B., Hand, K. P., McGrath, M. A., et al. 2016, ApJ, 829, 121

[17] Jia, X., Kivelson, M. G., Khurana, K. K., & Kurth, W. S. 2018, Nature Astronomy, 1

[18] McGrath, M. A., and Sparks, W. B. 2017, Res. Notes AAS, 1, 14

[19] Sparks, W. B., Schmidt, B. E., McGrath, M. A., et al. 2017, ApJ, 839, L18