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Roles of Electron and Photon Induced Desorption in the Formation of Mercury's Exosphere

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Abstract

Mercury is surrounded by an exosphere whose properties are determined primarily by its interaction with the surface and the space environment seen by both ground- and space-based observation.[1, 4, 6] The primary processes thought to be governing the ejection of materials into the exosphere are high energy ion sputtering, thermal desorption, micrometeorite impact and non-thermal desorption. When photons or electrons are involved, these non-thermal processes are usually referred to as photon stimulated desorption (PSD) or electron-stimulated desorption (ESD), respectively.[2, 3] These radiolytic and space weathering processes (i.e., ion sputtering, PSD and ESD) are of general importance, not only for Mercury but for other airless bodies, such as moons and asteroids, that interact with solar wind and magnetospheric plasmas. Laboratory measurements are being performed to determine the efficiency of these non-thermal processes in removing ionic and neutral species from minerals likely to be present on Mercury's surface.

1. Introduction

Recent results from the MErcury Surface, Space ENvironment, GEochem., and Ranging (MESSENGER spacecraft) preinsertion flybys confirm previous space- and ground-based observations that an exosphere surrounds Mercury. This exosphere contains ions and neutrals that originate from the solar wind interacting with the space environment and Mercury's surface.[7] Furthermore, results from the second and third flybys show optical emission from excited alkali (Na) and alkaline earth (Ca and Mg) atoms and Ca^+ ions in the exosphere. Specifically, observations by the Mercury Atmospheric and Surface Composition Spectrometer (MACS) revealed the presence of neutral Mg in the anti-sunward region as well as differing spatial distributions of Mg, Ca and Na atoms in both the tail and night side near planet exosphere. These dissimilar distributions are a good indication that different desorption processes are occurring.

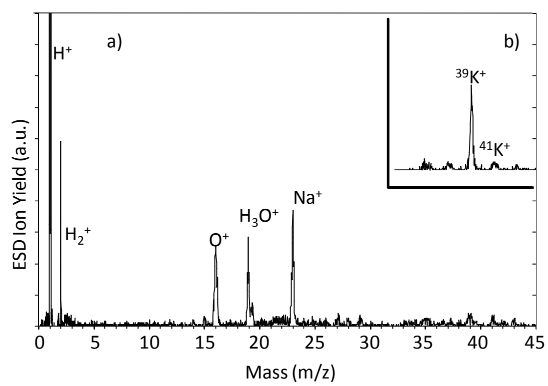

Figure 1: 200 eV ESD time-of-flight (ToF) mass spectrum obtained from a glassy silicate containing (a) Na and (b) K.

PSD with solar photons is an important low energy process but lacks sufficient energy to release alkaline earth ions from minerals. Since impinging electron energies are generally > 10 eV, ESD typically involves higher energy processes that are capable of causing direct desorption of ions and the breaking of multiple bonds, see Figure 1. PSD, ESD and ion-sputtering are therefore likely to be among the dominant source terms for populating the exosphere; particularly with alkaline earth species. In order to directly examine the primary processes supplying alkaline earth atoms to the exosphere, we have performed experiments to compare PSD and ESD processes. Since our experimental approach monitors gas-phase emission from suitable mineral analogs, these results could provide direct links between observed spatial atmospheric compositions and the nature of the material present on the planet surface. These experimental data are necessary for the complete understanding of the chemical composition and dynamics of Mercury's exosphere. It is also crucial for understanding the roles of stimulated desorption in the formation of exospheres around other airless bodies.

2. Electron Precipitation

The intensity, energy and location of electron precipitation fluxes, and thus the relative importance of ESD with respect to the formation of the exosphere depend on the solar wind interplanetary magnetic field (IMF) orientation. Solar wind electrons can enter Mercury's magnetosphere at locations where magnetic reconnection occurs between the IMF and Mercury's intrinsic magnetic field, with entry locations dependent on the direction of the IMF. A simulation study has been carried out for the approximate solar wind conditions corresponding to the first two MESSENGER flybys and electron precipitation fluxes and energies have been calculated.[5] Electron fluxes as large as 10^{10} $cm^{-2}s^{-1}$ are calculated at some locations, with average energies up to 0.5 keV. We predict that under conditions where the impinging electron energy exceeds ~20 eV, direct ejection of ions is occurring from Mercury's surface. We suggest here that ESD removal of neutral and ionic molecules provides a plausible explanation for some of the ions observed by FIPS and the MACS instrument. [7] Note that the Coulomb explosion resulting from Auger cascading events typically ejects the ions with kinetic energies between 3 - 10 eV. This is the energy necessary to prevent recapture by the surface and may enable the direct ejection of ions from Mercury into the exosphere. The calculations by Shriver et al.[5] suggest that the majority of the ejected ions may stay trapped near the planet in a region coinciding with large portions of the neutral exosphere. This pertains to all of the ions observed in our ESD study.

Summary and Conclusions

Mercury has a tenuous atmosphere which is supplied by material escaping from its surface. Several energetic phenomena which originate from the sun and solar wind's interaction are responsible for removing both neutral and ionic chemical species from Mercury's surface. Laboratory experiments are being performed to determine the role of these phenomena which include: ESD, PSD, proton-induced sputtering, and thermal desorption processes on comparable Mercury regolith. These experiments utilize several mass spectrometric techniques which are performed in custom-built ultrahigh vacuum chambers. Determining the contributions from these interactions are important in understanding the fundamental processes involved with space weathering and the formation of exospheres.

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