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LOSS RATES OF EUROPA'S EXOSPHERE

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Abstract

Reactions in Europa's exosphere are dominated by plasma interactions with neutrals. The cross-sections for these processes are energy dependent and therefore the respective loss rates of the exospheric species depend on the speed distribution of the charged particles relative to the neutrals, as well as the densities of each reactant. In this work we perform a detailed estimation of the H_2O, O_2, and H_2 loss rates due to plasma-neutral interactions with the aim of calculating the total mass loss from the moon. We also investigate the role of the interactions between the planetary ions and the neutral populations in the loss of exospheric species. For completeness, in our estimations we also include photoreactions for both cases of quiet and active Sun.

Introduction

The exosphere of Jupiter's moon Europa includes mainly the following populations: H_2O, released through ion sputtering caused by the energetic ions of Jupiter's magnetosphere that impact the moon's surface ([1], [2], [3], [4]); O_2, and H_2, both species produced through chemical reactions among different products of H_2O radiolytic decomposition ([5], [6], [7], [2], [3], [8]); and some minor species like Na and K ([9], [10], [11], [12]) and H, O, HO_2, and H_2O_2 [13]. The understanding of the evolution of Europa's exosphere and the estimation of its total mass loss has as a mandatory prerequisite the understanding of the interactions between Jupiter's magnetospheric plasma and the satellite's neutral environment.

1. Loss processes

The interactions between the Jupiter's magnetospheric plasma (and the UV radiation) with Europa's neutral environment lead in general to ionization and/or dissociation of the exosphere constituents. As a result, a population of fresh ions can be produced and supply the plasma, contributing, in this way, to the further ionization of the neutral environment; moreover, the freshly dissociated molecules modify the composition of the exosphere creating inhomogeneities in the nominal neutral distribution around the moon.

1.1 Electron impact reactions

The thermal (20 eV) electron density at Europa's orbit varies significantly with magnetic latitude having a value of 38 cm^{-3} near a magnetic latitude of 10° as measured by the Voyager spacecraft [14] and a much larger value of 120 cm^{-3} as modeled for this Voyager epoch data in the centrifugal equatorial plane by [15]. The suprathermal electron density at Europa's orbit is 2 cm^{-3}. The dissociation and ionization rates for electrons impact processes are computed by [16]:

$$\nu = k(T_e)n_e$$

where n_e is the electron density and κ is the rate coefficient in cm^{-3} s^{-1} as a function of electron temperature T_e. The rate coefficient is determined by $\kappa = \int f(v)\sigma(v)dv$, where f(v) is the Maxwellian distribution of the measure electron temperature, and σ the experimentally cross section.

Electron impact reaction	Rate ($10^{-6}s^{-1}$)	Note
$H_2O + e \rightarrow OH + H + e$	1.17 - 3	[1,2]
$H_2O + e \rightarrow H_2O^+ + 2e$	0.68 - 1.71	[2]
$H_2O + e \rightarrow OH^+ + H + 2e$	0.087 - 0.123	[2]
$H_2O + e \rightarrow OH + H^+ + 2e$	0.07 - 0.08	[2]
$H_2O + e \rightarrow H_2 + O^+ 2e$	0.013 - 0.014	[3]
$O_2 + e \rightarrow O + O + e$	0.68 - 2	[4]
$O_2 + e \rightarrow O_2^+ + 2e$	0.57 - 1.2	[5]
$O_2 + e \rightarrow O^+ + O + 2e$	0.2 - 0.25	[5]
$H_2 + e \rightarrow H + H + e$	0.01 - 0.03	[6]
$H_2 + e \rightarrow H_2^+ + e$	0.44 - 1.1	[5]
$H_2 + e \rightarrow H^+ + H + 2e$	0.016 - 0.028	[5]

[1]Harb et al. (2001);[2]Itikawa & Mason (2005);
[3]Shirai et al. (2001);[4]Cosby (1993);
[5]Straub et al. (1996);[6]De La Haye (2005).

Table 1 *Electron impact rates. The range of electron impact rates are for the assumed plasma properties: low (high) core electron density = 38 cm^{-3} (120 cm^{-3}), core electron temperature = 20 eV, suprathermal electron density = 2 cm^{-3}, suprathermal electron temperature = 250 eV.*

1.2 Photoreactions

Photoreaction rates are given at 1 AU by [17]. These rates are inversely proportional to the square distance to the Sun. In Table 2 are reported the rates for quiet and active Sun at Europa's orbit (5.2 AU) for the H_2O, O_2, and H_2 Photo-Reactions.

Photo-Reaction	$\nu(10^{-6}s^{-1})$
$H_2O + h\nu \rightarrow H + OH$	$0.38 - 0.65$
$H_2O + h\nu \rightarrow H_2 + O(^1D)$	$0.022 - 0.055$
$H_2O + h\nu \rightarrow H + H + O$	$0.028 - 0.71$
$H_2O + h\nu \rightarrow H_2O^+ + e$	$0.012 - 0.031$
$H_2O + h\nu \rightarrow OH^+ + H + e$	$0.0021 - 0.0056$
$H_2O + h\nu \rightarrow OH + H^+ + e$	$0.00048 - 0.0015$
$H_2O + h\nu \rightarrow H_2 + O^+ + e$	$0.00022 - 0.00082$
$O_2 + h\nu \rightarrow O(^3P) + O(^3P)$	$0.0052 - 0.0082$
$O_2 + h\nu \rightarrow O(^3P) + O(^1D)$	$0.15 - 0.24$
$O_2 + h\nu \rightarrow O(^1S) + O(^1S)$	$0.0015 - 0.0035$
$O_2 + h\nu \rightarrow O_2^+ + e$	$0.017 - 0.044$
$O_2 + h\nu \rightarrow O + O^+ + e$	$0.004 - 0.013$
$H_2 + h\nu \rightarrow H(^1S) + H(^1S)$	$0.0018 - 0.004$
$H_2 + h\nu \rightarrow H(^1S) + H(2s, 2p)$	$0.0013 - 0.003$
$H_2 + h\nu \rightarrow H_2^+ + e$	$0.002 - 0.004$
$H_2 + h\nu \rightarrow H + H^+ + e$	$0.00035 - 0.0011$

Table 2. *Photoreactions rates*

1.3 Charge-exchange reactions

Ion-neutral reaction rates and rate coefficients are also determined by the same equations reported for electron impact reactions, but since ions are more massive than electrons, the relative bulk motion between the ions and neutrals is significant. The rate coefficient reduces to

$$\nu = n_i v_{flow} \sigma(v_{flow})$$

where n_i is the ion density, v_{flow} is the bulk flow velocity of the ions relative to the neutral gas. If the plasma is corotating with the magnetic field and neutrals are in the satellite exospheres or bound neutral tori, then the relative velocities are well approximated by the difference between the magnetic field corotational velocity and the Keplerian orbital velocity (about 100 km/s).

In addition, charge-exchange reactions between planetary ions and the neutral populations are considered. For example, dissociative ionization of H_2O and direct ionization of O_2 produced by the impact of magnetospheric electrons is primarily responsible for the formation of O_2^+ ions from the dominant O_2 atmosphere. The O_2^+ source creates a large density of ionospheric ions (10^2 – 10^4 cm^{-3}) with a characteristic flow speed of 20 km/s through the atmosphere [18].

Charge-exchange reaction	Rate $(10^{-6}s^{-1})$	Note
$O_2^+ + O_2 \rightarrow O_2 + O_2^+$	0.2 - 20	[1]

[1]Benyoucef & Yousfi (2014)

Table 3. *Charge-exchange rates between* O_2^+ *and* O_2*. The rate values correspond to a range density of* $10^2 – 10^4$ cm^{-3}

Discussion and Conclusions

Dissociative and direct ionization electron impact reactions rates seems to dominate the relative photodissociation rates by an order of magnitude. On the night side the photoreaction are negligible, but on the day side, depending on the position of Europa and on the plasma sheet, photoreactions can be a strong contribution. Charge-exchange reactions between the heavy-ion corotating plasma (O^+, O^{2+}, S^+, S^{2+}, S^{3+}, S^{4+}) and Europa's neutral environment must be studied in more detail to understand better their contribution. The loss rates calculations are very important for the estimation of the neutral environment of Europa's tenuous atmosphere. The variation of these values defines a local anisotropy of the neutral populations defining a specific morphology of Europa's atmosphere. These loss rates must be taken into account inside exosphere's models to better constrain observation emission measurements (e.g. VIS, UV,IR) and must also be taken into account in the modeling of Europa's plasma interaction with the Jovian magnetosphere.

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