

# Alkali in Europa's exosphere: an endogenous scenario

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## Abstract

An endogenous scenario is developed that follows the alkali metals from their washing out of the rocky kernel of Europa by the internal ocean in the early times of the satellite formation. During the cooling period, the ice crust formed at the surface of the ocean and trapped the alkali allowing them to migrate to the surface and be ejected in the exosphere. This scenario is supported by “first principle” numerical simulations showing the trapping and progressive neutralization of the initial ions in the ice matrix.

## 1. Introduction

Because Europa is believed to hide a deep ocean beneath its icy shell, the question that it could have seen the development of an early form of life is actually of real concern. The detection of sodium and potassium in the exosphere [1] might be a hint of the emergence of primitive cells because these alkali metals are well-known to be associated with the opening and closing of the activation gates of the Na<sup>+</sup>, K<sup>+</sup>, ionic channels through cellular membranes [2-4].

It has been proposed that these metals could have either exogenous or endogenous origin:

- exogenous, if inherited from contamination from the intense volcanism of Io nearby and/or the implantation of these elements due to meteoritic bombardment. However, these scenarios do not account for the Na/K ratio of ~25 measured in Europa's exosphere,
- endogenous, if produced by a chemical scenario starting deep in the core of this Jovian moon, and delivered to the surface via the upwelling of ices formed in contact with the hidden ocean.

## 2. Computational background

The approach used is based on periodic DFT whose implementation relying on plane waves expansions removes the artifacts created by limited clusters and finite basis sets. The PBE+D2 functional is employed (including Grimme correction [5]) for a better description of long-range interactions. The Vienna Ab-initio Simulation Package (VASP) is used in all calculations [6]. How the electronic charge of Na and K vary in relation with the ice environment have been addressed by means of a topological analysis of the electron localization function recently extended to periodic systems [7].

## 3. The way out to the exosphere

In a preceding study of the origin of neutral Na in cometary tails [8], it was shown that, whatever the disk temperature of the protosolar nebula, all the sodium is contained in refractory materials below 800K (here we assume this to be true also for potassium).

The formation of an internal ocean following a progressive cooling created the conditions favorable to the washing of the rocky kernel that resulted in the transfer of Na and K to the surrounding water in the form of positive ions in abundances related to their relative solubility.

Due to the lack of in-situ data, we turned to plausible similar situations on Earth, namely those that can be found in geothermal fields. Extensive studies have been carried out in Iceland to determine the hardness of water as a function of temperature in view of possible exploitation of the Bakki geothermal field [9]. These investigations show that the molalities (mole/l) present very little changes for water/rock ratios between 10<sup>3</sup> and 10<sup>6</sup>. No saturation being implied, we took the molalities of 0.750 and 0.025

mole/l obtained for a water/rock ratio of  $10^6$  at 393K for Na and K, respectively.

Following Europa’s cooling, an ice shield formed on the ocean surface whose thickness increased with time imprisoning sodium and potassium (together with other solutes). The migration of the metals from deep inside to the top ice layers can then proceed via convection/diapirism [10].

The crucial point at this stage is the metal ability to stabilize,  $E_{Stab}$ , within the icy structure. It is define as:

$$E_{Stab} = (E_{Ice} + E_{Metal}) - E$$

where  $E_{Metal}$  is the energy of the metal,  $E_{Ice}$  is the energy of the pristine ice bulk and  $E$  the total energy of the [Ice bulk+ Metal] system in which all entities are optimized in isolation.

Typical situations in the migration of the metal toward the surface are quantified in Table 1.

Table 1: Stabilization energies (eV) and atomic charges (electron unit)

Environment	Na	K
	$E_{stab}$ (q)	$E_{stab}$ (q)
Inclusion in the bulk	0.1 (0.9)	0.2 (0.9)
Substitution: 1 H <sub>2</sub> O hole	1.0 (0.8)	0.9 (0.8)
Substitution: 4 H <sub>2</sub> O hole	1.4 (0.6)	1.6 (0.8)
Adsorption (surface)	0.1 (0.2)	0.2 (0.1)

The inclusion in the bulk means that Na, K, would stay ionic trying to force their way in the ice lattice, which appears difficult in view of the poor energy stabilization. In holes (substitution) corresponding to the removal/destruction of 2 or 4 H<sub>2</sub>O molecules, the alkali metals lose part of their positive charge and are stabilized by an energy that increases with the size of the cavity in which they are trapped (porous ice). In the end they reach the ice surface where they are neutral (q~0.2 e) and weakly adsorbed (0.1-0.2 eV), ready to be ejected in the exosphere by any external energy (irradiation or collisional sputtering).

## 4. Summary and Conclusions

In a purely chemical scenario we show that Na and K can be washed out of the solid core of Europa, transferred into the internal ocean, possibly embedded in the ice shell and pushed up to the surface by solid convection where they remain as neutral atoms until they are ejected in the exosphere. Since there is no noticeable difference between the stabilities of Na and K in the ice, the initial relative

abundances in the ocean water should be the discriminating factor and not the cosmic abundances. It lets anticipate an abundance of Na released in the gas phase greater than that of K by more than an order of magnitude. The ratio of the molalities being ~30, gives an estimation close to that found in the observations.

A similar scenario may be anticipated for other volatiles provided they can be trapped inside cavities in the forming ice of porous nature.

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