Radiolysis of water in the cores of ocean worlds: a potential steady source of H_2 to sustain habitability

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Introduction: The radiolysis of water produces, among other chemical species, molecular hydrogen [1]. Liquid water surrounded by rocks containing natural abundances of long-lived radionuclides ^{40}K, ^{232}Th, ^{235}U, and ^{238}U can be enriched in H_2 by this process. The H_2 provides a source of chemical energy that helps to sustain intraterrestrial microbial communities on Earth [2, 3, 4]. Such production of H_2 can be envisioned in the rocky cores of icy bodies hosting a liquid water ocean, or even in differentiated bodies that lack an ocean. While serpentinization (the aqueous alteration of ultramafic rocks) is the most often considered source of H_2 in such settings (e.g., [5]), it requires continuous exposure of unaltered rocks to water and appropriate temperature conditions. Here, we investigate the potential for H_2 production by radiolysis and its relative importance compared to serpentinization.

Model: We used a geochemical model of radiolysis developed for Earth sediments [4], which calculates the amount of energy from α and β particles and rays that is deposited into water. The H_2 production rate is then computed from published yields (G values; [6]). The model assumes that the energy deposition into water vs. rock depends on the volume ratio and stopping powers of these materials. The abundances of radionuclides are assumed to be consistent with measurements of ordinary chondrites [7]. The porosity of the rock (assuming the interstices are all filled with liquid water) plays a determining role in the production rate of H_2 (Figure 1).

Application to icy bodies: We performed calculations of H_2 production for several known or suspected ocean worlds: Europa, Ceres, Titania, Oberon, Pluto, and Charon. We assumed water from the ocean percolates deeper into the core as time passes in response to thermal cracking due to cooling [5,8]. We calculated the production of H_2 by radiolysis in the volume accessible to ocean water and compared it to the published estimates of production from serpentinization [5].

With a porosity of 2.5%, consistent with studies of serpentinite from earthly seafloors [9], yields a cumulated (over the age of the solar system) production of H_2 by radiolysis equivalent to 5 to 10 % of production by serpentinization.

Radiolysis can therefore provide a non-negligible steady flux of H_2 to this day. Figure 1 shows a higher value of porosity can drastically augment the production; for a porosity of 25 %, the production would be higher by an order of magnitude; bringing radiolysis to the level of serpentinization for Europa and Ceres. Such high porosities are very unlikely at the scale of the whole core due to compaction [10] but possible close to the seafloor [11].

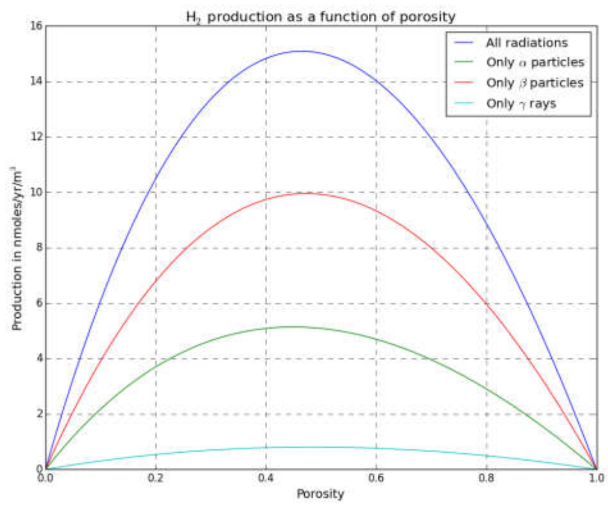

Figure 1: Present-day production of H_2 in 1 m^3 of chondritic sediment, depending on porosity.

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