

Investigation of the Carbon dioxide Production Process on Europa's Surface Based on Charged Particle Irradiation Experiments on Carbonates

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Jupiter's moon Europa has a subsurface ocean beneath an icy crust [Kivelson. 2000; Paranicas et al. 2001,2002] and likely has a potentially habitable environment [Chyba et al. 2001]. Carbon dioxide, which contains carbon, an essential element for life, was formally detected on the surface of Europa by Near Infrared Mapping Spectrometer (NIMS) onboard the Galileo spacecraft [McCord et al. 1998]. Recent observations from James Webb Space Telescope (JWST) showed spectral absorption features of carbon dioxide ice at $4.25\ \mu\text{m}$ and $4.27\ \mu\text{m}$, and a distribution of carbon dioxide concentrated within Tara Regio, a terrain recently resurfaced by the water plume that facilitates material transport from the subsurface ocean. This indicates that source of carbon on Europa's surface is the subsurface ocean [Trumbo SK et al. 2023; Villanueva GL et al. 2023]. The interaction between Jupiter's magnetosphere and Europa's surface generates carbon dioxide from materials originating in the subsurface ocean [Jones et al. 2014], however, further information on the endogenous source material is still unknown.

Here we investigate the production process of carbon dioxide through irradiation experiments on carbonate, a potential endogenous source of CO_2 . We irradiated carbonate samples (Na_2CO_3) with electrons at room temperature (300K). The production rate and yield were calculated from the partial gas pressure of carbon dioxide during irradiation. The near-infrared spectrum was measured after irradiation. The production rate of carbon dioxide at 10 keV, fluence $8.23 \times 10^{18}\ \text{e}^-/\text{cm}^2$, particle flux $1.52 \times 10^{15}/\text{cm}^2/\text{s}$ for 90 minutes of irradiation was found to be $6.7 \times 10^{-10}\ \text{mol/s}$, and the yield (# of sputter particles/ # of incident particle) was to be 1.2. Based on these results, the production rate on Europa's surface was estimated to be $2.16 \times 10^8\ \text{particles}/\text{cm}^2/\text{s}$. The laboratory CO_2 production rate increased to $2.57 \times 10^{-9}\ \text{mol/s}$ with lower fluence ($2.67 \times 10^{18}\ \text{e}^-/\text{cm}^2$) irradiation, and the apparent yield increased from 1.2 to 4.31. In the near-infrared spectrum, peaks in relative reflectance (after irradiation/before irradiation) were observed at $3.68\ \mu\text{m}$ and $4.42\ \mu\text{m}$ for carbon dioxide. The heights of the peaks increased with higher fluence and were approximately linearly proportional to the fluence. This indicates that the irradiation dissociates the carbonates, producing carbon dioxide, which then outgasses and decreases its abundance in the sample. We plan to conduct further experiments to compare the CO_2 production rate and sample surface spectral features under different conditions, including simultaneous irradiation of electrons and ions (O^+ , H^+) at low temperatures (80 K to 130 K). We reports the current status of our study in this presentation.

Keywords: Icy moons, Europa, Irradiation experiment