SHOCK VAPORIZATION OF WATER ICE IN AN OPEN SYSTEM INVESTIGATED USING A TWO-STAGE LIGHT-GAS GUN.
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Introduction: Hypervelocity collisions between two icy bodies are thought to be one of the most fundamental processes in the early-outer Solar System. If impact velocity is sufficiently high, icy materials vaporize due to irreversible shock heating, resulting in intense chemical reactions in a mixture of water ice, silicates, and organics. Impact-driven chemistry may play important roles in a chemical evolution on icy bodies.

Recently, the equations of state (EOS) for water ice, which is main constituent of icy planetary bodies, has been developed [1]. Then, the physical behavior after impacts on water ice has been studied extensively [e.g., 2-4]. Subsequent chemical reactions between water vapor and other constituents, including silicates and organics, however, have not been investigated well.

A direct measurement of impact-generated gases in an open system is essential to understand phase changes and post-impact chemistry [e.g., 5, 6]. In the previous study, we developed an experimental system to investigate degassing processes of calcite targets using a two-stage light-gas gun and a quadruple mass spectrometer (QMS) without a chemical contamination from an acceleration gas [6]. We newly added a cooling stage into the experimental system at the Planetary Exploration Research Center of Chiba Institute of Technology (PERC/Chitech) [7] to apply the method to icy materials. In this study, we conducted impact experiments using a pure-water ice target as the first step of research development. The objective of this study is to detect an impact-generated water vapor.

Experiments: We summarized the experimental condition and procedure as follows. Two successful shots were obtained in this study.

Experimental conditions. An Al_2O_3 sphere with the diameter of 2 mm was used as a projectile. A nylon-slit sabot [8] was used to accelerate the projectile. The impact velocities for the 2 shots were 2.4 km/s and 4.9 km/s. A distilled water was frozen at 250 K to produce an ice target with a shape of cylinder (~5 cm in diameter and ~5 cm in thickness). A cooling stage at ~200 K was used to avoid sublimation of comminuted and fallen ice on the stage after impacts. The water ice target was placed on a plastic block on the cooling stage to prevent generation of thermal cracks in the ice due to the large temperature gradient between the ice and the stage. A QMS (Pfeiffer vacuum, Prisma plus QMG220) was used for the in-situ analysis of an impact-generated water vapor. Although the original procedure for chemical analysis in an open system [6] used an Ar gas to avoid intrusion of the contaminant gas from the gun into the experimental chamber, the Ar gas was not used in this study to minimize the time for the transport of the water vapor from the chamber to the QMS, leading to minimize the amount of adsorbed water into the chamber wall. Thus, the total pressure in the chamber prior to the shot was <10 Pa in this study. A rotary pump was used to produce a gas flow to introduce the water vapor into the QMS efficiently. A plastic diaphragm and an automatic gate valve were used to minimize the intrusion of the contaminant gas and the escape amount of the water vapor in the same way employed in the previous study [6]. Figure 1 shows a schematic diagram of the experimental system.

Experimental procedure. A water ice target and a plastic diaphragm were positioned in the experimental chamber. Next, the experimental system was evacuated. We used liquid nitrogen to cool down the stage to ~200 K at this time. Then, a variable leak valve connected between the chamber and the QMS was opened, and the QMS was operated. An Al_2O_3 projectile was then shot onto the target. The automatic gate valve was operated by the signal from a laser-cut sensor placed on the projectile trajectory in our system. The impact-generated water vapor was carried into the QMS by a pressure gradient produced by the rotary pump.

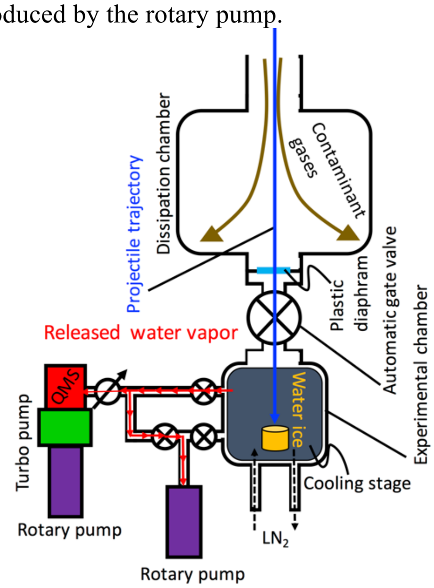

Figure 1. A schematic diagram of the experimental system. The path of impact-generated gases toward the QMS is indicated as the red arrows.

Results: Figure 2 shows the time variation of ion currents for major gas species. The gas species were identified based on the mass number (*M/Z*) and the cracking pattern of each species. The ion current of water (*M/Z*=18) drastically increased to the >10-fold ion current for both shots. The ion current of OH^+ (*M/Z*=17), which is expected to be produced by the cracking of the water vapor due to the ionization in the QMS, increased simultaneously with the same trend, strongly suggesting that we detected an impact-generated water vapor in the open system. We also detected an increase in the ion current of H_2, which is the main component of the contaminant gas from the gun, because the experiments were conducted under the vacuum condition as mentioned in the previous section. The ratio of the ion currents of H_2O to that of H_2, however, always exceeded five. The degree of chemical contamination from the gun is minor under our experimental system. Sudden decrease in the ion currents for the species related to contaminant air, including N_2, O_2, ^{40}Ar, were also detected. This would be caused by the interference between ions in the QMS. Thus, we could not quantify the total production of water vapor in these measurements.

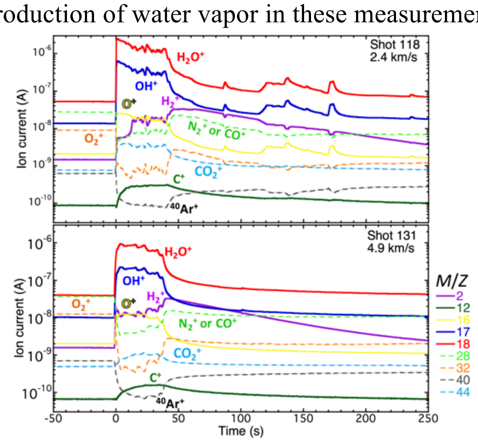

Figure 2. The time variation of ion currents for major gas species. The identified gas species and the impact velocity of each shot are indicated in the figure.

Future plan and Conclusions: We constructed the new experimental system and procedure to investigate shock vaporization of water ice in an open system at PERC/Chitech. Although there is a problem in the quantification of total vapor production at this time as mentioned above, it would be resolved by using the Ar gas in the same way performed in our previous study [6]. We are planning to do a next series of experiments to quantify the total production of water vapor as a function of impact velocity and to compare the results with theoretical predictions based on the EOS for water ice [1]. Since the pressure distribution in shocked water ice is necessary to calculate the total vapor production, we have performed a numerical calculation using the iSALE shock physics code [9-11]. An example of calculation results is shown in Figure 3. The calculation condition almost corresponds to Shot# 131. We adopted the Tillotson EOS [12] for Al_2O_3 and the ANEOS [13] for water ice. Lagrangian tracer particles were used to obtain the peak pressure as a function of their initial positions. We will be able to model the total vapor production as a function of impact velocity based on a relation between the shocked mass and shock pressure as shown in Figure 3b at a given impact velocity.

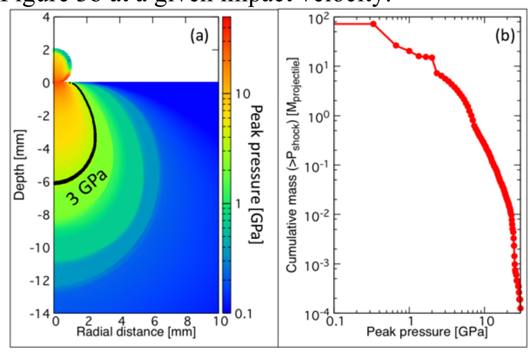

Figure 3. An example of the iSALE calculation. (a) The peak pressure distribution as a function of the initial positions. The black line indicates an isobaric line at 3 GPa. This value is an approximated value of the required shock pressure for incipient vaporization of water ice at 270 K [e.g., 2]. (b) The cumulative mass experienced the pressure higher than a given value as a function of peak pressure.

Following that, we will apply the experimental method to an analog of comets, which is a mixture of water-silicates-organics to investigate post-impact chemistry on icy bodies.

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