Observation of a hot-gas plume produced after impact in nitrogen gas using a gas gun and analysis of synthesized amino acids

窒素ガス中高速飛翔体衝突により発生する高温ガスプルームの観察と合成アミノ酸の分析

Grad. School Science & Technol., Shizuoka Univ.   Tetsu Mieno

(静岡大学・創造科学技術大学院　三重野 哲, mieno.tetsu@shizuoka.ac.jp)

Dept. Physics, Shizuoka Univ.,   Shunsuke Sekiguchi, Satoshi Nakamura（静岡大学・理学部　関口 俊介、中村 悟之）

Osaka Univ., Hiromi Shibata（大阪大学　柴田 裕実）

ISAS/JAXA, Sunao Hasegawa（JAXA宇宙研・長谷川 直）

Grad. School & Fac. Eng., Yokohama National Univ., Hitomi Abe, Yoko Kebukawa, Kensei Kobayashi

（横浜国立大学・大学院工学研究科　阿部 仁美、 癸生川 陽子、小林 憲正）

Abstract　To investigate synthesis of amino acids by asteroid's impact onto Titan and other satellites / planets, simulation experiment has been carried out using a 2-stage light gas gun. A small polycarbonate projectile with about 7 km/s is injected into a pressurized target chamber filled with 1 atm of nitrogen gas, to impact onto a target. After the impact, a hot gas plume is generated and expands in the chamber, which is recorded by a high-speed camera and measured by a Langmuir-probe array. After extinction of the plume, carbon-particles deposit on the inner wall of the chamber, which is collected, hydrolyzed and analyzed by the HPLC method. As a result, many kinds of amino acids (glycine, alanine *etc*.) are detected.

1. Introduction

Huge amount of carbonaceous molecules and particles have been produced in space. A part of them have been stored on the surface of planets and satellites. When evolution of the surface took place, carbons on the surface could have reacted to make complex organic molecules. [1 - 3] Here, we are interested in evolution of carbons on Titan surface, where huge methane and carbonaceous molecules have been stored. [4, 5] And, a lot of asteroids have hit the surface for long years, which would make impact reactions in nitrogen atmosphere, and produced many kinds of organic materials including amino acids. The products were stored on the dark and cold surface, while a part of them were diffused into space. A model explaining this process is shown in Fig. 1. To make clear the production process of amino acids by asteroid's impacts, simulation experiment using a 2 staged-gas-gun has been carried out. [6, 7] Produced carbonaceous black soot is carefully collected and analyzed using the hydrolyzed method, the dabsylization method and the high-performance liquid chromatograph (HPLC) method. [8]

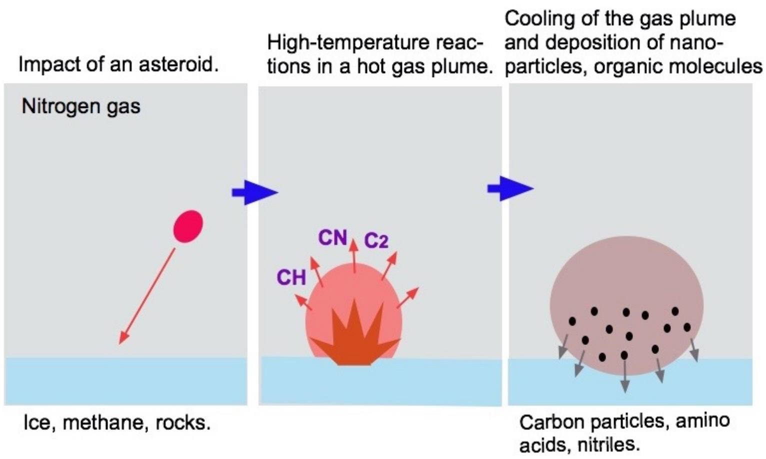

Fig.1. Model figures explaining the impact reactions on Titan.

2. Experimental

The experiment is carried out using a 2-stage light-gas gun at ISAS/ JAXA, Sagamihara. [9] This gas gun can accelerate a polycarbonate projectile 7.1 mmϕ (or a stainless steel projectile 3.2 mmϕ) to about 7 km/s under a vacuum of 0.1 Pa. [8, 10] The bullet collides with an ice + iron target (an iron target, or an ice + hexane + iron target) in a pressurized chamber. A schematic of the pressurized cylindrical chamber is shown in Fig. 2, which is 255 mm in diameter and 250 mm long, and made of stainless steel. At the end of the target chamber, the pressurized chamber is set. To collect the produced soot, inside wall of the chamber is covered with clean aluminum sheets. The pressurized chamber is at first evacuated by a rotary pump, and then 100 kPa of nitrogen gas is filled. A projectile penetrates the aperture of the chamber, 65 mm in diameter covered with a 0.05 mm thick aluminum film, and hits an iron target 76 mm in diameter and 25 mm thick. The target can be cooled down to about −50 °C by thermal conduction of a copper rod, which is cooled by liquid nitrogen. On the iron target, thin ice (ice + hexane) layer about 2 mm thick can be set by covered with a thin aluminum-film.

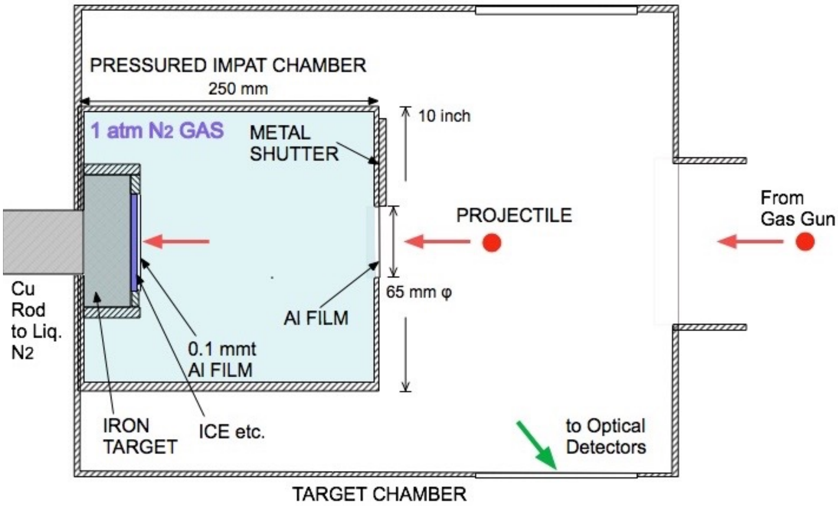

Fig. 2. Schematic of the pressurized chamber in the target chamber.

The produced hot gas plume is recorded by a high-speed camera (Shimadzu, HPV-X) and the evolution of the plume is analyzed. The hot gas erupting from the orifice into the target chamber is also recorded by this camera. Generation of plasma in the plume is measured by a 16-channel Langmuir-probe-array, which was developed here and is shown in Fig. 3. In a plate (10x12 mm), 16 column-electrodes (0.9 mm in diameter, 2 mm long) are set. The probes are biased by solid batteries, and time-variations of the probe currents are recored by data loggers (Graphtec, GL900).

Fig. 3. A photograph of the 16-ch Langmuir probe array, which is set in the pressurized chamber.

After the impact, produced soot is carefully collected under protection from any contamination, and stored in 2-propanol. A part of the soot is refluxed in pure water at 100 °C. Then, the sample is filtered using a 0.2 μm membrane filter and condensed. The sample is reacted with dabsyl chloride to make dabsyl-amino acids at 70 °C [10]. The prepared samples are analyzed by a HPLC with a UV/VIS detector (Jasco, Gulliver System, λ= 465 nm) to detect amino acids. Another part of soot is hydrolyzed using hydrochloric acid at 110 °C for 24 H. After removing hydrochloric acid, the sample is dabsylized and measured using the HPLC.

3. Experimental Results

The ejection of the hot gas plume is recorded by the high-speed camera. There are 3 profile images in front of the entrance of the pressurized chamber. After the impact, there is a strong ejection of the hot gas, which strongly emits light (emissions from molecules) (b), and then we can record outflow of cloud of carbon particles with speed of about 1

(a) (b) (c)

Fig. 4. Profile images in front of the entrance orifice. The right end is the entrance surface. (a) The projectile is coming at speed of 7 km/s. (b) Strong emission from the gas plume. (c) The cloud of carbon particles coming out with speed of about 1 km/s.

km/s, which is not a parallel flow, but tends to concentrates to one point (c). A part of the produced carbon particles flow out from the orifice with the hot gas.

We can expect generation of plasma in the gas plume as its gas temperature is about 5000 K, which would generate for about 100 μs. To obtain the electron density and the electron temperature, the 16-ch Langmuir probe-array was utilized, and time variation of the electron currents could be recorded. From the 16-ch signals, the V-I characteristics are obtained. Figure 4 shows a typical result when the gas plume flows over the array. In this result, electron density: ~10^{14} m^{-3}, electron temperature, ~7000 K are obtained, and the plasma is detected for about 30 μs. In this case, as the gas pressure is very high and it is collisional, and there are many negative ions, the plasma state would not so simple.

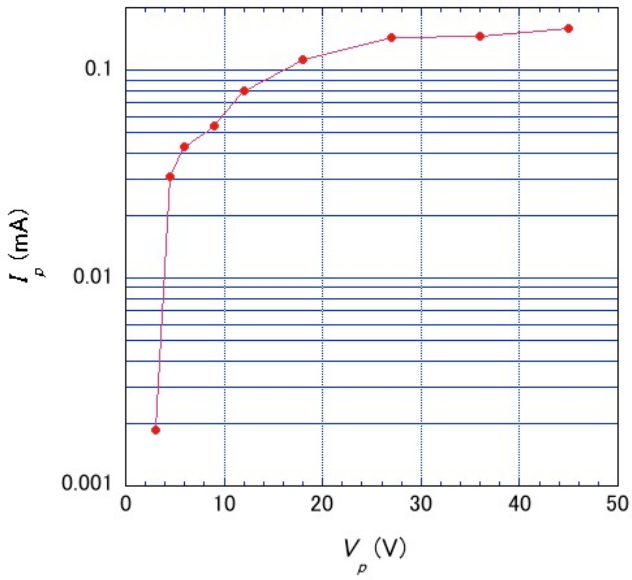

Fig. 5. A typical I-V characteristic of the probe measurement when the gas plume flows over the probe.

As amino-acid molecules tend to make coagulation, we utilize the hydrolysis method. The treated samples are measured by HPLC. Figure 5 shows a typical result (HPLC chart). We can detect amino acids like serine, glycine, alanine, leucine etc. By the hydrolysis method, 13 amino acids could be detected. To make clear the synthesis of enantiomers of amino acids, the 2-D HPLC method is utilized. As a result, enantiomers, L-alanine and D-alanine are detected in case (a polycarbonate projectile hits an ice + iron target).. The D/L ratio of alanine is about 0.4. Another D-amino acids are also detected. In this case, the chemical synthesis of enantiomers should have equal probability, and the D/L ratio should be 1. Now, this discrepancy can not be explained. [11] We conjecture fluctuation of the reaction, but are afraid of inclusion of contamination. We will repeat careful experiments to check the D/L ratio.

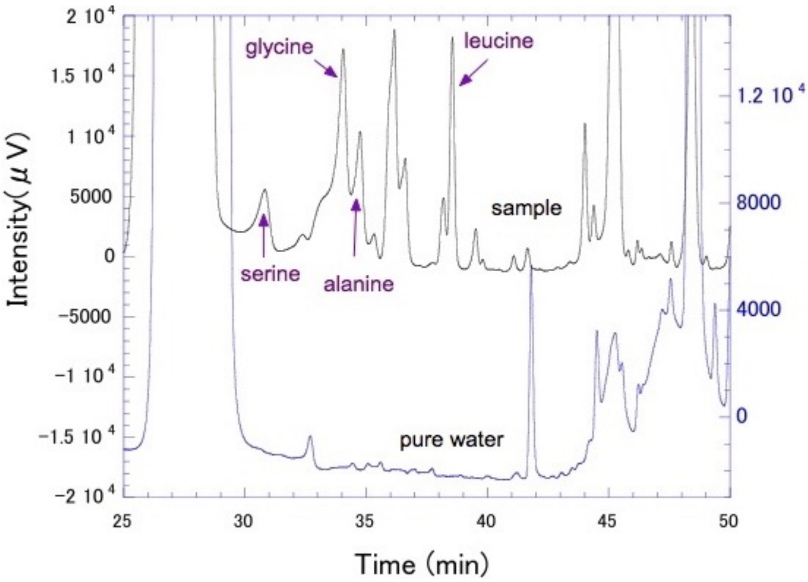

Fig. 6. A HPLC chart for the hydrolyzed sample (a polycarbonate projectile impacts on an ice + hexane + iron target) . A chart for pure water is also shown for comparison.

5. Conclusions

To investigate production of the gas plume and synthesis of amino acids by impact reactions on Titan, the simulation experiment is carried out using a 2-stage light-gas gun. We could observe evolution of the hot gas plume after the impact, flow of carbon particles, and measure the electron density and the temperature of the plume. After the impact, the soot is collected and hydrolyzed. The HPLC analysis shows peaks of many amino acids. The D/L ratio of alanine was about 0.4, which is not an expected value.

Acknowledgments

This study was supported by a Grant-in-Aid for scientific research (C) from MEXT, Japan. This work was also supported by ISAS/JAXA as a collaborative program of the Space Plasma Experiment.

References:

[1] C. Chyba, C. Segan, “Endogenous production, erogenous delivery and impact-shock synthesis of organic molecules: an inventory for the origins of life”, Nature **355** (1992)125.

[2] D. Goldsmith, T. Owen, “The search for life in the universe”, Benjamin/Cummings Publishing, 1980.

[3] Kvenvolden K, Lawless J, Pering K, Peterson E, Flores J, Ponnamperuma C, Kaplan IR, Moore C, “Evidence for extraterrestrial amino acids and hydrocarbon in the Murchison meteorite”, Nature **228** (1970) 923–926.

[4] Eds. R. H Btown, J-P. Lebreton, J. H. Waite, “Titan from Cassini-Huygens”, Springer. 2009.

[5] Eds. I. Muller-Woodard, C. A. Griffith, E. Lellouch T. E. Cravens, “Titan”, Cambridge Univ. Press, 2014.

[6] T. Mieno, S. Hasegawa, “Production of carbon clusters by impact reaction using light-gas gun in experiment modeling asteroid collision”, Appl. Phys. Express **1** (2008) 067006-1-3.

[7] T. Mieno, K. Okochi, K, Kondo, S. Hasegawa, K. Kuroasawa, “Production of carbonaceous molecules by the impact reaction in nitrogen gas by use of a gas-gun”, Advanced Materias Res. **1117** (2015) 31-34.

[8] K. Okochi, T. Mieno, K. Kondo, S. Hasegawa, K. Kurosawa, “Possibility of Production of Amino Acids by Impact reaction Using a Light-Gas Gun as a Simulation of Asteroid Impacts”, Orig. Life Evol. Biosph. **45** (2015) 195-205.

[9] N. Kawai, K. Tourui, H. asegawa, E. Sato, “Single microparticle launching method using two-stage light-gas gun for simulating hypervelocity impacts of micrometeoroids and space debris”, Rev. Sci. Instrum. **81** (2010) 115105.

[10] T. Mieno, K. Okochi, S. Hasegawa *et al*., “Analysis of amino acids synthesized by impact reactions in nitrogen gas using a light-gas-gun“, Proc. 2016 Space Science Sympo. ISAS/JAXA, Sagamihara, Feb. 2016.

[11] M. H. Engel, B. Nagy, “Distribution and enantiomeric composition of amino acids in the Murchison meteorite”, Nature **296** (1982) 837.

.