

## A novel principle to separate and identify groups of solid particles in general using a facile magnetic circuit

\*Chiaki Uyeda<sup>1</sup>

1. Institute of earth and Space Science Graduate School of Science Osaka University

Magnetic separation was recently realized for an ensemble of solid particles composed of different materials that exist in outer space, namely, diamond, enstatite, graphite, ice Ih, magnesia, solid CO<sub>2</sub> and olivine [1]. These materials are categorized as diamagnetic or paramagnetic substances, which do not exhibit saturated magnetization; they are generally believed to be magnetically inert. The separation was driven by a field gradient force, which was caused by a pair of small Nd magnetic plate in a microgravity condition. Furthermore, if an unidentified particle is included in the ensemble, its material can be directly identified from the value of magnetic susceptibility  $\chi$  which is determined from the velocity of the translating particle. The identification is possible because an intrinsic  $\chi$  value (per unit volume) is assigned to a solid material which originates from the electronic state of the material. It is expected from the above results that the histogram of material abundance is speedily obtained for an ensemble of particle that is collected at individual sites of a remote sensing mission in outer space.

The separation proceeds by a recently proposed mechanism [1]. An external field  $\mathbf{B}$  induces a small magnetization in a diamagnetic particle which is proportional to three parameters, namely  $\chi$ ,  $B$  and mass of particle  $m$ . The particle will translate in the direction of monotonically decreasing field by a field gradient force, because magnetization is induced in a opposite direction with respect to  $\mathbf{B}$ . Considering an energy conservation rule, the variance of terminal velocity  $v_T$  observed between the particle outside the field is uniquely determined by intrinsic  $\chi$  value of material [2]; here particles are released at the same position. Accordingly, the released particles will be separated into different groups of materials as they translate in the direction of decreasing field [1]. In a preliminary experiment, the Nd circuit was enclosed in a transparent vacuum chamber with the heterogeneous particles. The image of the translating particle was observed by a hi-vision camera that was set outside the chamber;  $\chi$  value of individual particle was determined from  $v_T$  that was obtained from the images. The short microgravity condition was produced inside a small box (inner area: 550 x 430 x 300 mm), which was used in a shaft having a height of 180 cm (duration < 0.5 s) [2]; it is possible to reduce the effective size of the apparatus

Using a conventional mass spectrometer, it is difficult to identify the material of a solid particle without consuming the sample. In the case of an infrared optical analysis, material composition of the particle interior is difficult to detect when its diameter is larger than 100 microns. The proposed method of magnetic separation can overcome the above-mentioned limitations of the conventional methods. Hence the method may serve as a supplemental tool of material analysis in the future. The prototype apparatus developed in the present study has a rigid and compact structure, and operated by a simple principle that can be easily examined; its power consumption is small, and finally, analysis is completed without consuming sample. So far, the spec of the machine seems to be suitable for a remote sensing mission. In the present report, the validity of the proposed method is examined based on the numerical data obtained in the extending experiments, where magnitude of field gradient is considerably enhanced. In order to put the system to a practical use, it is necessary to improve the resolution in separating two different materials that have small variance of  $\chi$  values.

References [1] Hisayoshi, Uyeda Terada (2016) Sci Reps, 6, 38431; YouTube "Magnetic separation of general solid particles realised by a permanent magnet"

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