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New analytical methods and a system for noble-gas measurements of extraterrestrial materials

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Noble gas isotopes in extraterrestrial materials, meteorites, cosmic dust (micrometeorites), and spacecraft-return samples, are one of the most useful tools of cosmochemistry. Radiogenic (e.g., ^{40}Ar, ^{129}Xe, and ^{136}Xe) and cosmogenic (^{21}Ne, ^{81}Kr, ^{83}Kr, and ^{128}Xe) isotopes are used for dating when gases have begun to be accumulated in the relevant minerals or phases. Primordial or trapped (neither radiogenic nor cosmogenic) isotopes are informative to infer the origin of the materials. Conditions of physical processes, such as evaporation and condensation, will be discussed based on elemental/isotopic fractionation effects.

The mass spectrometry system at Kyushu Univ. consists of a conventional mass spectrometer (MS) and a resonance ionization MS, called RING (Resonance Ionization Noble Gas mass spectrometer). The conventional MS is mainly used to measure light noble gases (He, Ne, and Ar) in micro- or submicro-gram samples enriched in solar-wind noble gases, such as mineral separates from regolith breccia meteorites, Antarctic micrometeorites [1], lunar soils, and the Itokawa dust particles returned by the Hayabusa spacecraft [2]. Extraction of noble gases is performed using infrared radiation lumps for 50-200 ℃ and a resistant furnace (called Pot-pie furnace) for 200-2000 ℃. In addition, the MS system is equipped with a Nd:YAG laser that produces energy of 200 mJ/pulse (with a 10 nsec width) at 1064 nm and a spot with ~50 μm in diameter. In the ablation of samples, plasma lights are emitted due to the high energy density of the laser pulse, and have wavelengths depending on the chemical composition of the fused area. The plasma emission spectra are measured using a LIBS (Laser-induced Breakdown Spectroscopy, e.g., [3]) system prepared for the laser extraction system. Combination of the conventional MS and LIBS enables to determine K-Ar radiometric ages for the specific areas (e.g., shock-melt veins or feldspathic phases) of polished sections. Experimental analyses using terrestrial rocks containing K-rich phases (e.g., K-feldspar) and equilibrated ordinary chondrite samples are now on going.

The RING mass spectrometer is designed to measure extremely small amounts of Kr and Xe ($>$100 atoms), as modeled after RELAX (Refrigerator Enhanced Laser Analyzer for Xenon) developed by the Manchester group (e.g., [4] and [5]). In our system, a dye laser equipped generates 3.5 mJ/pulse at ~216 and ~256 nm of wavelengths that ionize resonantly Kr and Xe, respectively. At this moment, we have got mass spectrum of Xe isotopes but not those of Kr yet.

In addition to the improvements and developments of instruments for noble-gas mass spectrometry, sample preparation methods have also been developed for combinational (multidiscipline) analyses for individual samples with micro- and submicro-gram masses. For example, we have performed TEM and noble gas analyses for individual micrometeorites [1] and the Itokawa dust particles [2].

References: [1] Okazaki et al. (2015) submitted to Earth Planet. Space. [2] Noguchi et al. (2015) this issue. [3] Loree and Radziemsky (1981) Plasma Chem. Plasma Process. 1, 271-279. [4] Gilmour et al. (1994) Rev. Sci. Instrum. 65, 617-625. [5] Strashnov et al. (2011) J. Anal. At. Spectrom. 26, 1763-1772.

Keywords: noble gas, extraterrestrial material, resonance ionization mass spectrometry, laser-induced breakdown spectroscopy, K-Ar dating