

## Development of an Instrument for In Situ Measurement of Ne Isotope on Mars: experiments and considerations on the design of vacuum system with a Ne and Ar separating membrane

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The Martian atmosphere contains noble gases important to understand evolution of planetary atmospheres as they are chemically inert and trace the physical process well (e.g., Lammer et al. 2020). Among noble gases, Ne is more susceptible to atmospheric escape for its light mass; the timescale of Ne loss from Mars is  $0.6-1.0 \times 10^8$  years estimated from MAVEN observation. Thus, the current Ne of Martian atmosphere is likely to reflect the Ne isotope ratio of Martian mantle through recent volcanic degassing (Kurokawa et al. 2021), and constrain the origin of it. However, accurate in-situ measurement of Ne isotope in the Martian atmosphere has not been possible because  $^{40}\text{Ar}^{++}$  produced from Ar, more abundant than Ne, interferes with  $^{20}\text{Ne}^+$ , making the accurate measurement by mass spectrometry difficult. In lab experiments, one could use extremely high-resolution mass spectrometers or cold trapping to remove Ar, but these methods are not practical for planetary exploration. Thus, a mass spectrometric method using a membrane separating Ne and Ar has been proposed (Miura et al. 2020). Their study showed that this membrane can selectively permeate Ne from the Martian atmosphere and increase the Ne/Ar ratio measured in a mass spectrometer.

The membranes' resistance to vibration, shock, low temperature, and radiation has been investigated by Cho et al. (2024). However, the types of vacuum pumps and valves that are suitable for spacecraft missions and the vacuum levels achievable in the vacuum system using them have not been investigated yet. In this study, we measure the pressure the space-grade vacuum pump and valves can achieve, and estimate the attainable vacuum level of the entire system when they are combined.

First, we calculated the residual gas pressure inside the vacuum system, which is required to measure the Ne isotope ratio. Specifically, the  $^{40}\text{Ar}$  background of the instrument should be less than the amount of permeated  $^{20}\text{Ne}$  (0.04 pmol), assuming a double charge ratio of  $^{40}\text{Ar}$  ( $^{40}\text{Ar}^{++}/^{40}\text{Ar}^+$ ) is 0.1. As a result, we found that it is necessary to evacuate the Martian atmosphere that could be filled in the system to the order of  $10^{-4}$  Pa.

Next, we investigated the feasibility of achieving this pressure when using space-oriented components. First, a turbo-molecular pump (Wide Range Pump, WRP, Sorensen et al., 2014), developed by Creare and NASA Goddard Space Flight Center, was used to measure the achievable vacuum pressure. The pump, which is on board the Mars rover Curiosity, is a small, lightweight pump made for space use with a pumping speed of 5 L/s. We found that the pressure directly above the pump was  $1.27 \times 10^{-5}$  Pa. For the valves, an electric valve (HVOL-2-N1F, with a tube of approximately 20 cm in length) from Takasago Electric Industry and one (Microvalve, with a tube of approximately 10 cm in length) from Mindrum Precision, were connected to a commercially available turbo-molecular pump. Then, the pressure changes at both ends of the valves were measured. The results showed that the pressures upstream and downstream of the valve differed by an order of magnitude at 3 h from the start of the measurement, yielding the conductances of  $1.7 \pm 0.5 \times 10^{-2}$  L/s and  $1.8 \pm 0.5 \times 10^{-2}$  L/s, respectively.

Finally, these results were used to calculate the achievable pressure of this instrument, assuming a gas analyser with a 1/4 inch outer diameter and 90 cm-long pipe from the pump to the air inlet, using the WRP and the HVOL-2-N1F valve. By assuming an outgassing rate after a bakeout, the reachable vacuum pressure was calculated to be  $0.9-1.0 \times 10^{-4}$  Pa, which satisfies the pressure required for the in situ Ne measurements. These experiments and calculations suggest a design solution for a Ne measurement instrument that combines space-oriented vacuum pump, valves and pipes, while meeting the vacuum pressure required for measuring Ne isotope ratios on Mars. We thus plan to proceed with assembling the device and conducting demonstration experiments.

Keywords: Mars, Ne, Isotope, Planetary exploration