Using stable isotope geochemistry to investigate the source(s) of volatiles in the lunar regolith

Conference or Workshop Item

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Version: Version of Record
1: Introduction:

- Previous laboratory analyses of lunar soil samples have documented a range of volatile species present within the regolith that
- Thermolysis release studies (heating soil samples at rates of 4 °C/min up to temperatures just exceeding their initial melting points) released solid gases, C₂H₂, CO, CO₂, H₂, H₂O, and sulfur-bearing species (S₂, SO₂, SO₃) (2). The temperatures at which these gases are released can be used to tentatively identify their sources, for example, solar-wind derived hydrogens and hydroxyls are released between 150-200 °C (2).
- Acid and deuterium solubility studies (heating lunar soil samples with H₂O and D₂) released several gaseous "buffer" molecules (H₂S, H₂O, and CH₄) and reaction-produced CO₂, most likely from hydrocarbon degradation (9). It is also suggested that some of these gas species may form during the heating process itself (9).
- Isotopic studies have also been conducted. Isotopic values are expressed using the delta notation, where:
  \[ \delta ^{13}C = \frac{\left( \frac{^{13}C}{^{12}C} \right)_{\text{sample}} - \left( \frac{^{13}C}{^{12}C} \right)_{\text{standard}}}{\left( \frac{^{13}C}{^{12}C} \right)_{\text{standard}}} \times 1000 \]

These studies have yielded data on the isotopic compositions of the released gases, and the isotopic compositions of the gaseous species (e.g. CH₄, CO₂) have been measured using mass spectrometry (9). The isotopic compositions of the gases released from the soil samples have been used to infer the origin of the gases, and to determine the isotopic composition of the precursor materials (9).

2: IonCam 2020 Gas Analysis Mass Spectrometer

- The IonCam 2020 mass spectrometer was purchased from Opal (Athens, GA) in the autumn of 2012.
- It is a sensitive, "portable" mass spectrometer, allowing for simultaneous detection of all masses present in a gas sample.
- The Van der Graaf (charge coupled device) vision within the device is as pressure independent, and highly linear, suggesting that it should function well with small amounts of gas (ideal for lunar soil samples). The ion mass range of the machine should be proportional to pressure required.
- It is a capable of performing full analyses of samples, which allows process monitoring to be measured and monitored in real-time.

3: Detection Limit

- To make reliable, precise isotope measurements, the response seen on the detector needs to be set at 10 times the noise over the measurement period of 10 minutes.
- Given that 8% values from previous studies of lunar soils range from -30‰ to +30‰, the detection limit for 10% CH₄ would be about 10 ‰.
- To avoid the variation in the measurements, the IonCam makes data collected at the detection limit at 10% CH₄, and then performs a least squares fit on the data, as well as a linear regression of the data points, and then calculates the average ratio of each isotope mass.
- The average value for each isotope mass is then calculated for all the samples, and then compared to the average ratio of the following samples of 100 frames, as a "zero-referenced" calculation.

4: Stability

- In order to make reliable, precise isotope measurements, the response seen on the detector needs to be set at 10 times the noise over the measurement period of 10 minutes.
- Given that 8% values from previous studies of lunar soils range from -30‰ to +30‰, the detection limit for 10% CH₄ would be about 10 ‰.
- The relative standard deviation of each isotope mass is calculated for all the samples, and then compared to the average ratio of the following samples of 100 frames, as a "zero-referenced" calculation.

5: Suitability

- Using these results to make rough calculations, based on the expected yield of volatiles contained between 10% and 100% of the mass of the samples, the IonCam would only need around 10 times more mass than the sample in the region of hundreds of micrometers per measurement to make one isotopic measurement that would have high precision established mass spectrometry provided in the open literature. However, the amount of sample gas needed to build up to a pressure of 10 Torr, which is enough for isotopic measurement to be taken into account, is taken at 0.001 Torr, or 100 times more than the sample in the region of hundreds of micrometers per measurement.
- Further, the detector is capable of making isotope measurements with a variation of 10 ‰. Knowing that the whole range of values for possible solar system sources of carbon is only ±30 ‰, it would be impossible to distinguish between different sources for the carbon found in lunar soils, using the IonCam as it is currently performing.
- It is also a number of other losses, such as those that occur from gas phase measurements, and for this reason the IonCam is not a good gas phase measurement instrument, and is unlikely to be a good gas phase measurement instrument. However, this may require further investigation.

6: Other Instrumentation

- There are several well-established instruments at the Open University that are capable of making highly precise isotopic measurements on small sample sizes, such as the next possibilities to explore.
- The first of these is a "Rosen", a custom-built instrument that incorporates a series of pumps and compressors with three dedicated static mass spectrometers to simultaneously collect data for a variety of species, and a series of high-purity mass spectrometers, and a series of high-purity mass spectrometers with the same mass spectrometer at different pressures. Initial tests (using CH₄ and CH₃OH) have shown that the sensitivity of this machine is about 10⁻⁸‰ using a sample size of just 500 mg. Further measurement will be carried out in the coming months to test its precision using 10% CH₄ to be confirmed as a standard reference gas.

7: References