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Using Stable Isotope Geochemistry to Investigate the Source(s) of Volatiles in the Lunar Regolith

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1: Introduction:

- Previous laboratory analyses of lunar soil samples have documented a range of volatile species present within the regolith that blankets the lunar surface.
- Thermal gas release studies (heating soil samples at rates of 4 °C/min up to temperatures just exceeding their initial melting points) revealed solid gases, CO₂, CO, δ-D₂O, δ-D₂O, and sulphur-bearing species, (S₂) and (SO₂). 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 300–700 °C.[2]
- Acid and deuterated acid dissolution studies (heating lunar soil samples with H₂SO₄, and HDO) released several gases of "lower" methane (Δ13C) and reaction produced CO₂, which is likely from hydrocarbon (C₄) and carbon species, such as C₃H₆, and CO respectively. The variation in isotopic compositions was considered to be related to the difference in the microstructure of the lunar regolith (low temperature formation of methanol and CO is evident).[3,4]
- Isotopic studies have also been conducted. Isotope values are expressed using the delta notation, where:

\[
\delta = \frac{R_{\text{sample}} - R_{\text{standard}}}{R_{\text{standard}}} \times 1000
\]

For the purposes of making an isotope measurement, the detection limit of the machine is taken to be the amount of gas needed to generate a stable, measureable peak. The machine's detection limit for most of the volatile gases is typically less than 10 nmol (10⁻⁹ moles). For example, in the case of CO₂, the detection limit is 10 nmol at 10 Torr (1 Torr = 133.32 Pa), corresponding to a mass of 44 amu.[6]

2: IonCam 2020 Gas Analysis Mass Spectrometer

- The IonCam 2020 mass spectrometer was purchased from QI Analytical (Alabama, USA) in the autumn of 2012 and it is a multi-purpose machine, allowing for the simultaneous detection of a wide range of volatile gases. The machine is a linear quadrupole mass spectrometer with a single channel detector (charge magnification (IonCam) or faraday cup detector (IonCam's up detector)).
- The machine's detection limit of 10 nmol at 10 Torr (1 Torr = 133.32 Pa) is achievable using a mass peak of 20 pixels wide and centered on specific pixels. The mass peaks are the result of a linear response of gas flow (measured as gas intensity at the detector) to the mass of all masses present in a gas sample.
- The mass of a gas is approximately divided in half by a quadrupole mass spectrometer, and the machine's detection limit of 10 nmol at 10 Torr (1 Torr = 133.32 Pa) can be achieved in 5 minutes (5 minutes). Because this data was collected right at the detection limit of the machine, occasionally, the signal-to-noise ratio was so low that the machine's detection limit of 10 nmol at 10 Torr (1 Torr = 133.32 Pa) was not achieved. In the case of CO₂, the detection limit is 10 nmol at 10 Torr (1 Torr = 133.32 Pa), corresponding to a mass of 44 amu.[6]

3: Detection Limit

- In this study, we are investigating the detection limit of the machine. The detection limit of the machine can be achieved by measuring the signal-to-noise ratio of a gas sample at the detection limit of 10 nmol at 10 Torr (1 Torr = 133.32 Pa).
- The gas sample is a mixture of CO₂, CH₄, and δ-D₂O, and the detection limit of the machine is 10 nmol at 10 Torr (1 Torr = 133.32 Pa). For example, in the case of CO₂, the detection limit is 10 nmol at 10 Torr (1 Torr = 133.32 Pa), corresponding to a mass of 44 amu.[6]

4: Stability

- In order to make reliable, precise isotope measurements, the more stable the detector is, the more stable the measurement. The detector should be able to distinguish between different potential sources of carbon, in a variation over measurement time of ± 1 %. It is necessary to have an excellent detector to make the measurement.
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5: Suitability

- In order to make reliable, precise isotope measurements, the detector needs to be as stable as possible over the time taken to make a measurement (in this case, over 5 minutes).
- The detector needs to be as stable as possible over the time taken to make a measurement (in this case, over 5 minutes).

6: Other Instrumentation

- There are several well-established instruments at the Open University that are capable of making highly precise isotope measurements on small sample sizes, which will be the next possibilities to explore.
- The first of these is "Kaiser", a custom-built machine that incorporates a 5-channel liquid chromatograph (GC) with a 5-channel liquid chromatographic mass spectrometer. This is the Open University's in-house GCMS (Gas Chromatography-Mass Spectrometry).
- The GCMS is used to separate the components of the sample into their constituent parts, and to determine the isotopic composition of each part. This is achieved by injecting a small amount of the sample into the GCMS, where it is separated into its component parts, and the isotopic composition of each part is determined by measuring the relative abundances of the isotopes in each part. This is repeated for each part until the complete isotopic composition of the sample is known.

7: References