Stable Isotope Chemistry in Titan Haze Aerosol

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Introduction and Motivation

Why study Titan?
- Titan is the largest satellite of Saturn and has atmosphere composed of nitrogen and a few percent methane (CH₄).
- The atmosphere is believed to be similar to that of early Earth.
- The haze layer of Titan is rich in organic chemistry and can give new insights into prebiotic chemistry and planetary habitability.

Why study isotopes on Titan?
- The measurements of stable isotope ratios give information on the history and evolution of the atmosphere.
- Measurements from Titan indicate that the ¹³C/¹²C ratio in CH₄ is similar to the protosolar ratio, which suggests that the CH₄ is relatively young.¹
- The ¹⁵N/¹⁴N is similar to the protosolar value of NH₃ based on comet measurements.¹,²

Are aerosols a sink for stable isotopes?
- Current models of the observed isotope ratios on Titan do not incorporate isotopic fractionation resulting from organic aerosol formation and subsequent deposition onto the surface of Titan (Figure 2).
- Initial studies have shown that fractionation direction and magnitude are dependent on the initial bulk composition of the gas mixture (Figure 3).

Why study aromatic compounds?
- Cassini-borne instruments have detected benzene in Titan’s atmosphere.
- Aromatics, such as benzene (below, left), has been shown to be an important pathway in aerosol formation.
- Far-IR spectral feature of Titan’s haze layer is similar to that of aerosols produced from aromatic compounds.³,⁴ (Figure 4)
- Though not observed in situ, pyridine (N-containing aromatic, below) is a likely product of Titan chemistry and produces laboratory aerosol with a strong far-IR feature.

Materials and Methods

Aerosol Production
- Titan aerosol analogs are produced in the laboratory to study their fractionation.
- Gas mixtures used are trace gases (CH₄, benzene (C₆H₆), and pyridine (C₅H₅N) with nitrogen (N₂)) in mixing chamber as shown in Figure 6.
- The gas mixture is irradiated with far-UV light (115-400 nm) that leads to aerosol production. a quartz filter (Figure 7).
- Aerosol samples are collected in an inert, ex situ environment (Ar, N₂, or vacuum) and processed for Isotope Ratio Mass Spectrometry (IRMS) Analysis

Isotope Ratio Mass Spectrometry (IRMS)
- IRMS is used to measure the relative abundance of isotopes in a given sample.
- The sample is combusted and is converted into CO₂ and N₂.
- Carbon and nitrogen stable isotope values are reported in standard δ notation in permil (%) as defined by:
  \[ \delta(X) = \frac{R_{sample} - R_{standard}}{R_{standard}} \times 1000 \]
  where \( R_{sample} \) is the ratio of the heavy to light isotope (¹³C/¹²C or ¹⁵N/¹⁴N) and \( R_{standard} \) is the isotopic ratio of the standard.
- To determine the isotopic fractionation induced by the aerosol production, the isotopic ratios of the products and reactants are compared using the equation:
  \[ \Delta^{12}C = \delta^{12}C_{products} - \delta^{12}C_{reactants} \]
  or
  \[ \Delta^{15}N = \delta^{15}N_{products} - \delta^{15}N_{reactants} \]

Results
- Significant differences in the isotopic ratios between the aerosols generated by the two different aromatic compounds (benzene and pyridine).
- The addition of methane to the mixture significantly increases the aerosol production time.
- The uncertainties of the data are still being assessed.

Conclusions
- The aerosols produced in the laboratory setting demonstrate a change in isotopic ratio for ¹³C and ¹⁵N from the starting products.
- The addition of methane to a gas mixture appears to partially inhibit aerosol formation and increase collection time.
- Further work will need to be done to assess the effects of temperature and pressure on aerosol formation and isotopic ratio for ¹³C/¹²C, ¹⁵N/¹⁴N and D/H.

References

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