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Nitrile growth pattern in Titan's atmosphere

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Abstract

This work presents the study of the gaseous products generated in a laboratory experiment simulating Titan atmospheric chemistry with a reactive plasma discharge.

The gas products from this simulation were analyzed, both *in situ* by mass spectrometry [1], and *ex situ* after cryogenic trapping with gas chromatography-mass spectrometry (GC-MS). This allowed the detection and identification of more than 30 products (mainly nitriles), in agreement with observational data obtained by the Cassini-Huygens mission as well as results from other laboratory setups.

Furthermore, a relative quantification of some nitriles has been done and it emphasizes a power-law dependence in their concentration as a function of their carbon content. This dependence is consistent with the Cassini-INMS data and Titan's photochemical models, and it can be directly used to predict the concentration of heavier nitriles in Titan's atmosphere.

1. Introduction

The atmosphere of Titan is mainly made of N_2 and CH_4. Chemical reactions, induced by solar irradiation and charged particles accelerated in Saturn's magnetosphere, lead to the production of an opaque layer of organic solid aerosols in the atmosphere. The composition and chemical production processes of these aerosols remain mainly unknown and provide a great challenge in planetary science. In order to better constrain the formation processes of these aerosols, we simulate the whole reaction chains with a laboratory RadioFrequency plasma discharge in a nitrogen and methane gas mixture. This leads to the creation of laboratory analogues of Titan’s aerosols, called Tholins [2].

In this study we were interested in understanding the gaseous processes leading to heavier but still gaseous organic products. These chemical species are indeed the gaseous key intermediates explaining the further production of solid aerosols.

2. Experimental Setup

The experimental device has been described in details in [3]. We give here the main characteristics of the experimental set up. The energy deposition is made by a radiofrequency plasma discharge in a reactive gas mixture of nitrogen containing from 0 to 10% of methane. The gas mixture is continuously flowed in the discharge to replenish the gas in reactive species. The pressure was kept constant at 1.7 mbar and the temperature was room temperature.

This setup allows the production of organic tholins [2], analogues of Titan's aerosols. With the aim to characterize the chemical pathway leading to their formation, we lead a study on the gas chemistry occurring in the plasma by different ways. The consumption of methane in the reactive mixture and the gas to solid conversion yields have been given in a previous study [4]. In this presentation, we focus on the identification and quantification of stable molecules produced in the plasma. In the present study we focused on the gas phase resulting from the tholins production process.

Gas products studied were condensed for 3 hours in a cold trap cooled by liquid nitrogen, downstream between the plasma reactor and the vacuum pump. Then, after heating the gas trap up to the room temperature, the condensed species were then analyzed using GC-MS (Thermofinigan equipped with a MXT-QPlot chromatographic column (Restek).

3. GC-MS analyses and Nitrile reactivity

The main peaks identified by GC-MS correspond to hydrogen cyanide (HCN) and acetonitrile (CH_3-CN), in agreement with the in situ MS measurements. More than 30 other molecules were also detected [3]. They are mainly nitriles species, but also hydrocarbons and aromatic species

The strong predominance of nitrogenous species tends to demonstrate the importance of these compounds in a reactive N_2-CH_4 mixture. This importance is retrieved in the solid phase produced since nitrogen was demonstrated to be a non negligible component of tholins and Titan's aerosols [5]. We also performed a quantification of some nitriles relative to HCN. Figure 2 shows the concentration of nitriles, relative to HCN (normalized to 100% for HCN), as a function of the number of carbon atoms in the molecule.

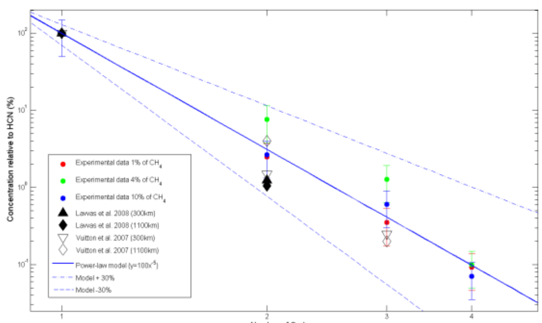

Figure 1: Concentration of nitriles as a function of number of the carbon atoms.

As one can see on Fig. 1, there is a power law dependence in the concentration of nitriles molecules. This dependence appeared to be found not only in our experimental data (dots) but also in models (full diamonds and triangles) and observational data (empty diamond and triangles).

This power law dependence can be turned into an empirical law which allows estimating the concentration of heavy nitriles in Titan's atmosphere knowing the concentration of the light ones (HCN, CH_3CN etc.). This empirical law is given in equation (1).

$$[C_xH_{2x-1}N] = 100x^{-5} \qquad (1)$$

where x is the number of carbon atoms in the molecule.

4. Summary and Conclusions

The results of our experiment are consistent with Titan's atmospheric composition. This tends to demonstrate that laboratory experiments can be used complementarily to observational data in order to predict both the presence of compounds which are not yet detected, and their possible concentrations.

Our results show the possible importance of nitrile chemistry in the Titan's atmosphere, which has also been recently observed with the CIRS instrument [6]. In addition, we have been able to relatively quantify some of the nitriles present in the gas phase. Using this relative quantification we propose a power-law model for the concentration of radically saturated mono-nitriles.

It will be important in the future to go further and to study the possible role of nitriles in Titan's atmospheric chemistry. Indeed, our study suggests that these compounds could have a key role in the formation of organic aerosols in the high atmosphere of Titan, and more generally in the organic chemistry which takes place on Titan. These molecules including nitrogen are interesting in exobiology as well since they are known for their reactivity and as precursor of amino acids.

References

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