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# Ion irradiation of ammonia/carbon dioxide mixtures

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## Abstract

We present new experimental results on the thermal and ion irradiation processing of ammonia/carbon dioxide frozen mixtures. Mixtures deposited at low T (16 K) have then been warmed up to 160 K. During warm up complex chemical reactions occur leading to the formation of new molecules and, in particular, of ammonium carbamate. Other samples have been irradiated with 144 keV $S^{9+}$ ions. Also in this case new chemical species are formed among which CO and $OCN^-$. The results are discussed in the light of their relevance to understand the effects of different processes going on in the variegated superficial and sub-superficial layers of Enceladus.

## 1. Introduction

Frozen ammonia and carbon dioxide have been detected or inferred to be present on many objects in the Solar System (for a review see e.g. [1]). In particular on Enceladus, $CO_2$ has been detected in the solid phase and ammonia in the plume ejects (see [2] and references therein). On Enceladus thermal annealing is responsible for the cycling of matter from the (liquid?) interior to the surface. In addition energetic processing by electron and ion bombardment is an additional mechanism of chemico-physical alteration of the original material (for a review of effects induced by ion bombardment of icy moons see [3]). Results relative to electron bombardment have been recently presented [4].
As a contribution to the field, here we present the results of new experiments in which ammonia and carbon dioxide frozen mixtures are deposited at low T and then annealed to 160 K and/or bombarded with 144 keV $S^{9+}$ ions.

## 2. Experimental apparatus

The experiments are being performed at ARIBE, a facility of GANIL (Grand Accélérateur National d'Ions Lourds, Caen, France) where multiply charged ions at different energies can be obtained.

Vapor mixtures (1:1) of ammonia and carbon dioxide are prepared in a glass bulb and deposited at low T (16 K) onto IR transparent substrates (CsI) in an high-vacuum chamber (P~$2\times10^{-8}$ mbar). The chamber is faced through IR-transparent windows, to a FTIR spectrophotometer (Nicolet Magna 500), the sample-cryostat system can be rotated and is fixed at three different positions to allow: (a) gas deposition, (b) FTIR measurement and (c) ion irradiation (for details see [5]).

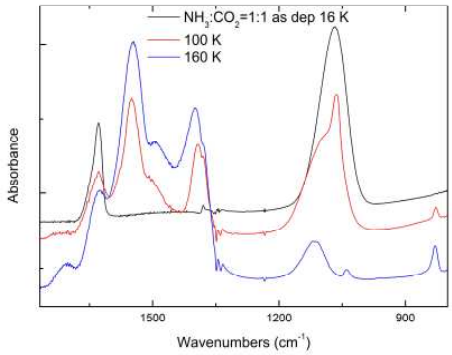


Figure 1: IR spectra of an ammonia and carbon dioxide mixture (1:1) as deposited at 16 K and after warming up at 100 and 160 K.

## 3. Results

In Fig. 1 we show the IR spectra of an ammonia and carbon dioxide mixture (1:1) as deposited at 16 K and after warming up at 100 and 160 K. It is evident the thermally induced reactions leading to the formation of new chemical species exhibiting many intense bands in the shown spectral range that are listed in Table 1. In Fig. 2 we show the IR spectra of the same mixture as deposited at 16 K and after irradiation with $7\times10^{14}$ 144 keV $S^{9+}/cm^2$ ions. Also in

this case "hot" chemistry induces the formation of new chemical as detailed in Table 1.

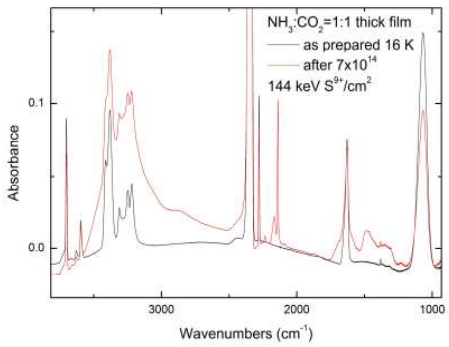


Figure 2: IR spectra of an ammonia and carbon dioxide mixture as deposited at 16 K and after irradiation with $7\times10^{14}$ 144 keV $S^{9+}/cm^2$.

Table 1 Peak position of the main bands observed in the IR spectra of $NH_3$:$CO_2$ frozen mixture as deposited at 16 K, after annealing at 160 K, or after ion irradiation ($7\times10^{14}$ 144 keV $S^{9+}$ /$cm^2$).

| Peak position ($cm^{-1}$) | species |
|---|---|
| **As deposited at 16 K** | |
| 2340 | $CO_2$ |
| 1630 | $NH_3$ |
| 1067 | $NH_3$ |
| 659 | $CO_2$ |
| **After annealing at 160 K** | |
| 1700 | ν (C=O) $(NH_2COOH)_2$ |
| 1630 | ν $(NH_2)$ $[NH_2COO^-][NH_4^+]$ |
| 1548 | $\nu_{as}$ $(COO^-)$ $[NH_2COO^-][NH_4^+]$ |
| 1490 | $\delta_s$ $(NH_4^+)$ $[NH_2COO^-][NH_4^+]$ |
| 1399 | $\nu_s$ $(COO^-)$ $[NH_2COO^-][NH_4^+]$ |
| 1118 | $\nu_s$ (C-N) $[NH_2COO^-][NH_4^+]$ |
| 1040 | $\rho_s$ $(NH_2)$ $[NH_2COO^-][NH_4^+]$ |
| 830 | ω $(COO^-)$ $[NH_2COO^-][NH_4^+]$ |
| **After irradiation at 16 K** | |
| 2235 | $N_2O$ |
| 2167 | $OCN^-$ |
| 2139 | CO |
| 1694 | ν (C=O) $(NH_2COOH)_2$ |
| 1590 | ν $(NH_2)$ $[HCOO^-][NH_4^+]$ |
| 1480 | $\delta_s$ $(NH_4^+)$ $[HCOO^-][NH_4^+]$ |
| 1383 | $\delta_s$ (CH) $[HCOO^-][NH_4^+]$ |
| 1354 | $\nu_s$ $(COO^-)$ $[HCOO^-][NH_4^+]$ |
| 1230 | ? |
| 1120 | $\nu_s$ (C-N) $(NH_2COOH)_2$ |

# 4. Discussion

The results obtained so far suggest that the thermal and/or energetic processing of ammonia/carbon dioxide mixtures induce a complex chemistry that could be of great relevance for the formation of complex molecules of potential astrobiological relevance on the surface of Enceladus. Surface species can be easily transported to sub-superficial layers supporting chemical cycles.

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