FORMATION OF ORGANIC MOLECULES BY FORMALDEHYDE REACTIONS IN ASTROPHYSICAL ICES AT VERY LOW TEMPERATURES

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ABSTRACT. Warm-up of astrophysical ice analogues containing formaldehyde produced organic residues in large abundances. It is argued that formaldehyde reactions at very low temperatures could be an important source of interstellar and cometary organic molecules.

1. Introduction

The higly reactive molecule formaldehyde (H_2CO) is present at the level of a few percent in cometary and probably also in interstellar ices, making it one of the more abundant constituents after water (Mumma and Reuter 1989). This paper reports the results of experiments on analogues of astrophysical ice mixtures (H_2O, H_2CO, NH_3, CH_3OH) that were performed to investigate the possible role that formaldehyde may have in the formation of cometary and interstellar organic molecules.

2. Experimental Results

Ice mixtures containing water (H_2O), ammonia (NH_3) and H_2CO in various concentrations were prepared at 10 K. Upon warm-up, reactions involving formaldehyde took place between 40 - 180 K, producing organic residues in high yields. Remarkably, these residues seem to consist of only 3 products. The first product can be obtained from H_2CO ice with traces of NH_3. Its IR spectrum identifies it as polyoxymethylene (POM; $[-CH_2-O-CH_2-O]_n$), a well known H_2CO polymerization product. The second product, designated X, is produced by reactions between H_2CO and NH_3. Its IR spectrum reveals C-H, C-O, $-NH_2$ and possibly O-H groups. It evaporates below 230 K, implying a small structure with $<\approx$ 2 C atoms. The third product, designated Y, is obtained from reactions between H_2CO and H_2O. It contains O-H, C-H, and C-O groups and seems to have ether- as well as alcohol-type properties. Evaporating below 260 K, it should contain at most ~ 2 C atoms.

Figure 1 shows the yields of POM, X, and Y, i.e., the fraction of the carbon initially deposited as formaldehyde that ends up in these products, as well as the total residue yield as a function of the initial $[NH_3/H_2CO]$ ratio at $[H_2CO/H_2O] = 0.05$. It can be seen that traces of ammonia ($[NH_3/H_2CO] >\approx 0.005$) are required to initialize reactions involving H_2CO and the production of an organic residue. For $[NH_3/H_2CO] >\approx 0.4$, the conversion of formaldehyde to organic molecules is almost 100 %. The produced relative

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amounts of POM, X and Y depend sensitively on the initial ice composition.

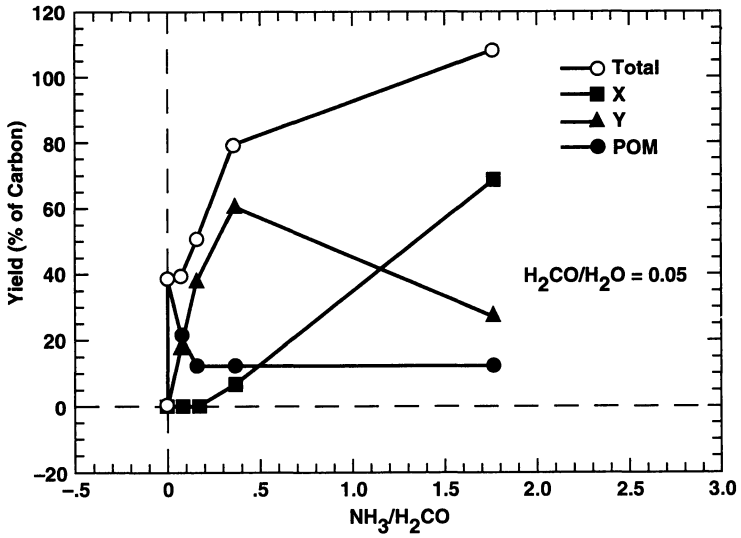

Figure 1. Yields of POM, X and Y obtained upon warm-up of ices with initial ratio [H_2CO/H_2O] = 0.05, as a function of NH_3 concentration.

Introduction of 1 - 10 % of methanol (CH_3OH) in water-rich ices ([H_2CO/H_2O] ≈ 0.05) with [NH_3/H_2CO] <≈ 0.01 decreases the total yield of residue from 40 % to 10 - 20 %. Furthermore, the yield of POM drops to less than 3 % and the residue is dominated by new alcohol-type compounds. For water-rich ices with [NH_3/H_2CO] >≈ 0.25, adding CH_3OH does not significantly change the organic residues.

3. Astrophysical Implications

Our experimental results have a number of astrophysical implications. Low temperature formaldehyde reactions in astrophysical ices are probably an important source of interstellar and cometary organic compounds and may account for 1 - 10 % of the organic molecules detected in Comet Halley. Only a small number of compounds are produced (4 - 6). For astrophysically relevant ices the major products are small (<≈ 2 C atoms), highly O-rich (O/C ≈ 1) and have alcohol-, amine-, and ether-like properties, while POM is a minor product. The kind of molecules that are produced and their relative abundances trace the initial ice composition and concentrations.

References

Mumma, M. J., and Reuter, D. C. (1989) 'On the Identification of Formaldehyde in Halley's Comet', ApJ 344, 940-948.