Formation of CO_2 and H_2CO_3 through non-energetic surface reactions at low temperatures.

Y. Oba,[1] N. Watanabe,[1] A. Kouchi,[1] T. Hama,[1] and V. Pirronello[2]

[1]*Institute of Low Temperature Science, Hokkaido University, Japan*
[2] *DMFCI, Università di Catania, Italy*

INTRODUCTION

Carbon dioxide (CO_2) is one of the most abundant solid components in icy grain mantles of dense molecular clouds. It is well known that CO_2 can be synthesized from pure carbon monoxide (CO) or CO-containing ices through energetic processes such as UV irradiation, ion irradiation, and electron irradiation [e.g. 1]. However, recent detections of abundant CO_2 in dense clouds observed toward background stars, in which the UV field is relatively weak, suggest that some reactions without UV irradiation may also contribute to the CO_2 formation in these environments [2]

In contrast to CO_2, carbonic acid (H_2CO_3) has never been detected either in the gas phase or solid phase in molecular clouds. However, it is considered that H_2CO_3 may have a role in acid-base chemistry, such as in reactions with NH_3 to yield NH_4^+, in astrophysical environments [3]. Therefore, elucidating the formation pathways of H_2CO_3 and its astrophysical significance is necessary for understanding chemical reaction networks related to the presence of CO in molecular clouds.

In the present study, we demonstrate formation of CO_2 and H_2CO_3 through surface reactions of CO with non-energetic OH radicals at low temperatures.

EXPERIMENTAL

Experiments were performed using the Apparatus for SUrface Reaction in Astrophysics (ASURA) system. ASURA consists of a main chamber, an atomic source, and a Fourier transform infrared (FTIR) spectrometer. Hydroxyl (OH) radicals, produced by dissociating water molecules in microwave-induced plasma, were cooled down to 100 K prior to react with CO. OH and CO were codeposited onto an Al substrate (10–40 K) and the reaction products were monitored *in-situ* by infrared reflection-absorption spectroscopy.

RESULTS

When CO molecules were simultaneously introduced together with OH radicals onto the substrate, formation of CO_2 was clearly identified in the reaction product even at 40 K. In addition to CO_2, several peaks were observed in the IR spectrum. It has been theoretically demonstrated that gas phase synthesis of CO_2 by CO + OH proceeds through the following pathways: CO + OH → *trans*-HOCO → *cis*-HOCO → CO_2 + H [4]. Detection of both HOCO radicals in the reaction product at 10 K further supports an assumption that CO_2 formed through the above reaction pathways in the present experiment.

After the sample was warmed up to 220 K, some peaks were still observed in the IR spectrum, which were attributable to carbonic acid (H_2CO_3). Formation of H_2CO_3 was also demonstrated by the temperature-programmed desorption spectra of the reaction product. It is likely that H_2CO_3 formed through reactions of *trans*- and *cis*-HOCO radicals with OH.

The present study demonstrated that CO_2 and H_2CO_3 can form inside dense molecular clouds without external energy inputs from UV, ions, and electrons.

References

[1] N. Watanabe, & A. Kouchi, 2002, ApJ, 567, 851.
[2] E. A. Bergin et al., 2005, ApJ, 627, L33.
[3] W. A. Schutte & R. K. Khanna, 2003, A&A, 398, 1049.
[4] H.-G. Yu, J. T. Muckerman, and T. J. Sears, 2001, Chem. Phys. Lett., 349, 547.