

Cold ion chemistry using the ion trap technique

K. Okada,¹ T. Furukawa,¹ M. Ichikawa,¹ K. Yasuda,¹ M. Wada² and H. A. Schuessler³

¹*Department of Materials and Life Sciences, Sophia University, Japan*

²*Nishina Center for Accelerator-Based Science, RIKEN, Japan*

³*Department of Physics, Texas A & M University USA*

The cold ion-molecule reactions play important roles in synthesis of interstellar molecules, and their reaction-rate constants are important information for studying the chemical evolution of interstellar clouds [1]. Therefore, the databases of the rate constants were developed for astrochemistry and some reaction network models were proposed to understand the synthetic mechanisms of interstellar molecules [2, 3]. Recently, the present state of knowledge concerning the reaction-rate constants and their uncertainties for the major gas-phase chemical processes was reviewed [4]. It was pointed out that most of the measurements of ion-neutral reactions were only at room temperature or at a restricted range of temperatures near room temperature, even though the reactions occur actually at very low temperatures in interstellar clouds. Especially, the cold ion-polar molecule reactions have not been studied extensively in the laboratory, owing to some experimental difficulties, such as condensation of polar gases at relatively high temperatures. For that reason, we planned to measure the reaction rates of cold ion- molecule reactions using the ion trap technique. The main purpose of the present study is the contribution to the astronomical databases.

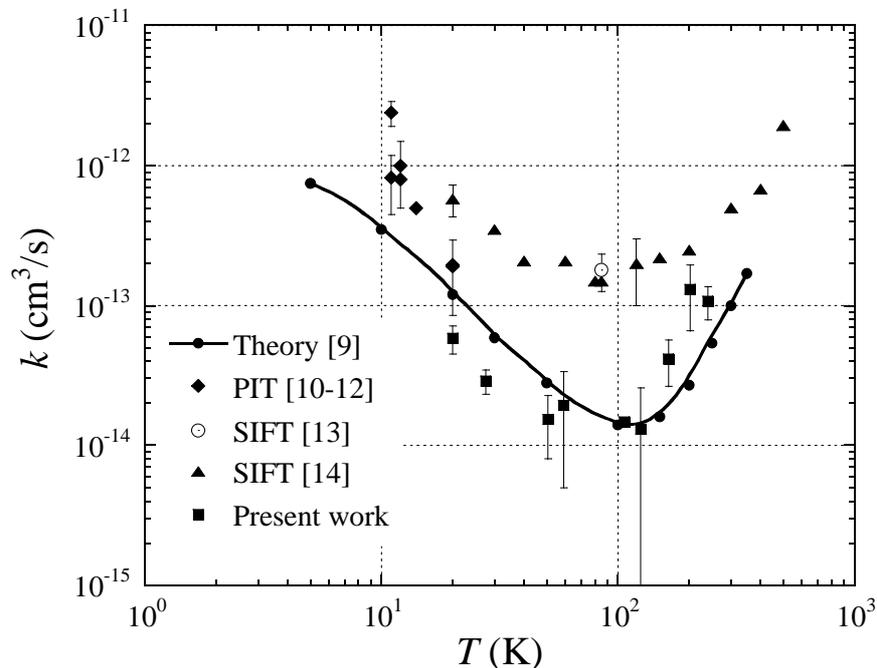


Figure 1: A summary of the temperature dependence of the reaction-rate constant in the $\text{NH}_3^+ + \text{H}_2 \rightarrow \text{NH}_4^+ + \text{H}$ reaction. PIT: Penning ion trap, SIFT: Selected Ion Flow Tube.

We report two experimental approaches by the ion trap technique: one is a conventional method to measure the ion-molecule reactions by combining a cryogenic linear multipole rf ion trap with the cold buffer-gas cooling method [5], and the other is a new method to measure cold ion-polar molecule reactions using a Stark velocity filter and the laser cooling

technique [6]. The latter method can be extended to the reaction-rate measurements between sympathetically cooled molecular ions and slow polar molecules.

In the experiment using the cryogenic linear octupole rf ion trap, we have measured the temperature dependence in the reaction-rate constant of $\text{NH}_3^+ + \text{H}_2 \rightarrow \text{NH}_4^+ + \text{H}$ [7], which is known as a bottleneck of the gas-phase ammonia synthesis in interstellar clouds [8]. The summary of the present measurement is shown in Fig.1. We also plot the data taken from Refs. [9-14]. The present result well agree with the theoretical values [9]. The experimental method and the measurement procedure will be described. We will also report recent experimental development for studying cold ion-polar molecule reactions [15-17]. We actually performed the reaction-rate measurement between sympathetically cooled molecular ions (N_2^+ , N_2H^+) and slow CH_3CN molecules, which were produced by a Stark velocity filter [18]. The sequential fluorescence images of the Ca^+ Coulomb crystal including N_2^+ ions during the cold $\text{CH}_3\text{CN} + \text{N}_2^+ \rightarrow \text{products}$ reaction are shown in Fig.2. The shadowed area progressively decreases with increasing the reaction time. Since the number of N_2^+ ions in each image can be determined from the structure of the images, the reaction rate can also be determined. Preliminary results and the discussions will be presented.

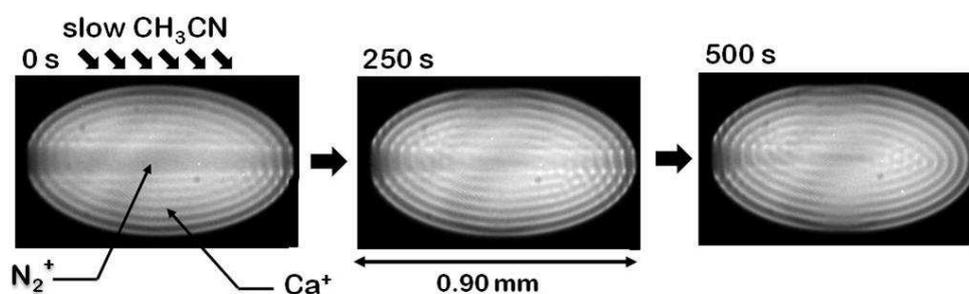


Figure 2: Sequential fluorescence images of the Ca^+ Coulomb crystal (bright) including N_2^+ ions (shadowed) during the cold $\text{CH}_3\text{CN} + \text{N}_2^+ \rightarrow \text{products}$ reaction. The number of Ca^+ was roughly estimated to be 1.8×10^3 .

References

- [1] E. Herbst and T. J. Millar, *Low temperature and cold molecules*, Chap. 1, 2008, Imperial College Press
- [2] J. Woodall *et al.*, *A & A* **466**, 1197 (2007).
- [3] D. Quan and E. Herbst, *A & A* **474**, 521 (2007)
- [4] V. Wakelam *et al.*, *Space Sci. Rev.* **156**, 13 (2010).
- [5] D. Gerlich and S. Horning, *Chem. Rev.* **92**, 1509 (1992).
- [6] S. Willitsch *et al.*, *Phys. Rev. Lett.* **100**, 043203 (2008).
- [7] K. Okada, K. Yasuda, T. Takayanagi, *Low Temperature Science* **66**, 1 (2007) (*in Japanese*).
- [8] E. Herbst and W. Klemperer, *ApJ* **185**, 505 (1973).
- [9] E. Herbst, D. J. DeFrees, D. Talbi, F. Pauzat, W. Koch, A. D. McLean, *J. Chem. Phys.* **94**, 7842 (1991).
- [10] S. E. Barlow, G. H. Dunn, M. Schauer, *Phys. Rev. Lett.* **52**, 902 (1984).
- [11] J. A. Luine, G. H. Dunn, *ApJ*. **299**, L67 (1985).
- [12] S. E. Barlow, J. H. Luine, G. H. Dunn, *Int. J. Mass Spectrom. Ion Proc.* **74**, 97 (1986).
- [13] N. G. Adams and D. Smith, *ApJ*. **317**, L 25 (1987).
- [14] H. Böhrringer, *Chem. Phys. Lett.* **122**, 185 (1985).
- [15] K. Okada *et al.*, *Phys. Rev. A* **81**, 013420 (2010).
- [16] N. Kimura *et al.*, *Phys. Rev. A* **83**, 033422 (2011).
- [17] K. Okada *et al.*, to be published in the *Journal of Physics: Conference Series* 2012.
- [18] S. A. Rangwala *et al.*, *Phys. Rev. A* **67**, 043406 (2003).