

Experimental study toward the measurements of rotational state dependence of interstellar ion-polar molecule reactions at low temperatures

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Recent astronomical observations have revealed the details of chemical composition in star-forming regions and molecular clouds. However, the chemical processes in those regions have not been fully understood using the existing chemical models with available data on relevant reaction rate constants [1]. This is because the temperature dependence of the gas-phase ion-molecule reactions in the range of low to intermediate temperatures (10 - 200 K) and their reaction branching ratio remain unknown. Thus, we have been developing a new experimental apparatus to measure the reaction temperature dependence of ion-polar molecule reactions at low temperatures [2, 3].

We report on an experimental study of the rotational cooling effect on the reaction rate constant of $\text{Ca}^+ + \text{CH}_3\text{F} \rightarrow \text{CaF}^+ + \text{CH}_3$ at low translational temperatures as a performance test of a new experimental apparatus. Combining a cold helium buffer gas cell with a wavy Stark velocity filter provides us with rotationally and translationally cooled polar molecules, we could compare the reaction rate constants measured at two different gas cell temperatures, namely the room temperature and about 30 K. The translational temperatures of the velocity-selected molecules were set in the range of approximately 10 to 40 K. The rotational level distribution of the velocity-selected CH_3F molecules was determined by numerical simulations of the velocity filtering and was used to calculate the rotationally-averaged capture rate constants with the Perturbed Rotational State (PRS) theory [2]. Comparing to the results obtained under the condition of room temperature gas cell, we observed a notable increase in the reaction rate constant at low buffer-gas temperatures. This clearly shows a strong rotational state dependence of the rate constant at low translational temperatures.

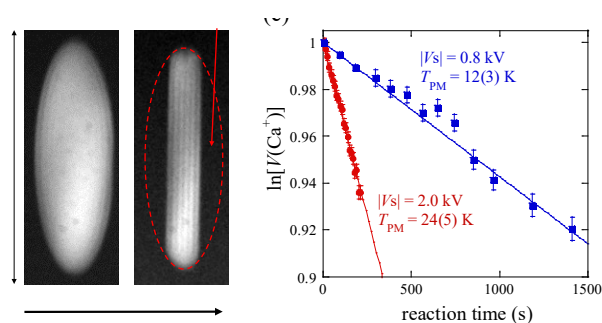


Figure 1 Fluorescence images of Ca^+ Coulomb crystals before (a) and after (b) the $\text{Ca}^+ + \text{CH}_3\text{F} \rightarrow \text{CaF}^+ + \text{CH}_3$ reactions. (c) A decay curve of the relative number of Ca^+ ions due to the reactions between Ca^+ and the velocity-selected CH_3F measured at two different translational temperatures of CH_3F extracted from the helium buffer gas cell at about 30 K (He pressure 80 Pa, UV laser detuning -40 MHz).

References

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- [2] K. Okada, K. Sakimoto, Y. Takada, and H. A. Schuessler, 2020, *J. Chem. Phys.* 153, 124305.
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