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Toward laser spectroscopy of rotationally cooled CaH^+ ions trapped in a cryogenic linear Paul trap

Kunihiro Okada[1] and Masatoshi Kajita

* Department of Physics, Sophia University, 7-1 Kioicho, Chiyoda, Tokyo 102-8554, Japan
National Institute of Information and Communications Technology, Koganei, Tokyo 184-8795, Japan

Synopsis We have generated rotationally cooled CaH^+ ions with a cryogenic linear Paul trap toward laser spectroscopy. The direct observation of cold CaH^+ ions via laser Raman spectroscopy is now undergoing.

The study of possible time variations in fundamental constants plays an important role for the development of a ground unification theory (GUT) [1]. In addition to the fine structure constant α, the proton-to-electron mass ratio ($\beta = m_p/m_e$) is also one of important parameters for GUT, since β is related to $\dot{\alpha}/\alpha$ [1]. The ratio between a molecular vibrational transition frequency and an optical atomic transition yields the information of β. However, compared with the atomic transitions, precision measurements of the molecular transitions have not been progressed almost. In connection with this context, Kajita *et al*. proposed to detect possible time variation of β using a vibrational transition frequency of a single cold CaH^+ ion in a linear Paul trap (LPT) [2]. Then CaH^+ ions have been successfully produced by laser-induced reactions of $Ca^+(^2P_{1/2}) + H_2 \rightarrow CaH^+ + H$ in a LPT [3].

In this work we have developed a cryogenic LPT (Fig.1 (a)) in order to generate rotationally cooled CaH^+ ions. As shown in Fig.1 (b), the temperature at the LPT is cooled down to 13 K. Figure 1 (c) shows laser-induced fluorescence (LIF) images of Ca^+ Coulomb crystals in the cryogenic LPT before and after the laser-induced reactions. Since the mass of CaH^+ is a little larger than that of Ca^+, CaH^+ ions are distributed at the outside of the ion crystal. In this example, the number of CaH^+ ions is on the order of 10^3. In order to evaluate the rotational state distribution in $1^1\Sigma$ ($v = 0$), we have performed the rate-equation analysis including up to $J = 18$ rotational levels. The transition dipole moments and the rotational state constants were taken from the theoretical values [4] in order to include the transitions by black body radiations and spontaneous emissions. Figure 1 (d) shows plots of the time-dependence of the populations in $J = 0-3$ at 13 K, where we assume that the initial populations are the same as those at room temperature. The rotational state population of $1^1\Sigma$ ($v = 0$, $J = 0$) is evaluated to be 55% after 16 minutes.

We have been working on the laser Raman spectroscopy by $1^1\Sigma \rightarrow 2^1\Sigma$ ($\lambda = 405$ nm) excitations of rotationally cooled CaH^+ ions [4]. By inserting a half mirror in the detection optics, the Raman photons ranging from 430－750 nm [5] and the LIF from Ca^+ are simultaneously detected by a photomultiplier tube and a cooled CCD camera, respectively. At present we are searching for the resonance wavelengths of the rovibrational transitions in $1^1\Sigma \rightarrow 2^1\Sigma$, which are still unknown experimentally. The status of the experiment will be presented at the conference.

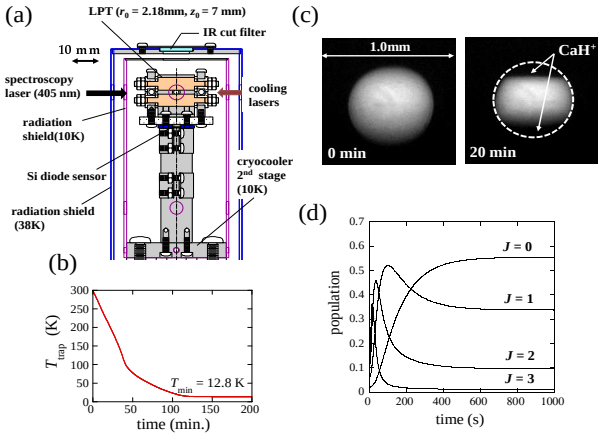

Figure 1 (a) Schematic drawing of the cryogenic LPT. (b) A plot of the wall temperature enclosing the LPT after turning on the cryocooler. (c) LIF images of Ca^+ ion crystals before and after the laser-induced reactions. (d) Simulation results of the rotational state populations of CaH^+ $1^1\Sigma$ ($v = 0$, J) as a function of time at 13 K.

References

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E-mail: okada-k@sophia.ac.jp