Rotationally cold (>99 % $J = 0$) OH^- molecular ions in a cryogenic storage ring

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Synopsis We store beams of 10 keV OH^- ions in an electrostatic storage ring at a temperature of 13 K and a residual-gas density of the order of only 10^4 molecules per cm^3. We monitor the rotational-level distribution of the stored ions as a function of time after injection by a laser-photodetachment technique. We find that the ions come close to thermal equilibrium with the surroundings after ten minutes of storage. Furthermore, by selectively depleting rotationally excited molecular ions, we form a >99% pure $J = 0$ beam with a storage lifetime in excess of six minutes.

When an ensemble of molecular ions only interacts with a black-body radiation field, characterized by a temperature T, thermal equilibrium at this temperature will be reached eventually. In such an idealized situation, the population of quantum levels will be given by the relevant Boltzmann factors. In a real environment the challenge is to approach this situation by minimizing any other possible sources of excitation. For ions stored with keV kinetic energies in a storage ring, the particular challenges are to maintain a very high vacuum to avoid excitations in collisions and to eliminate all sources of external radiation from warmer regions. We present an experiment in the cryogenic electrostatic ion-storage ring, DESIREE [1, 2], where we have stored OH^- ions at 10 keV with 10 minute 1/e lifetime and probed the distribution over rotational levels by investigating the effective cross section for photodetachment in the threshold region as a function of storage time. We find that after about ten minutes of storage the rotational distribution is well characterized by a thermal distribution with a temperature close to that of the surroundings [3].

We have adopted the method from Ref. [4] where OH^- was stored and cooled by buffer gas collisions in a radio-frequency trap and the rotational temperature probed by means of laser photo-detachment. Recently a similar technique based on laser *photodissociation* was applied to study the rotational distribution of CH^+ ions stored in the cryogenic storage ring CSR in Heidelberg [5].

In the present work, we did not only reach lower degree of excitation than in other similar studies. We, further, applied a second (cw) laser beam to actively remove rotationally excited molecular ions. With the depletion laser on we reached a situation where more than 99 % of the stored ions were in the $J = 0$, OH^- ground state. In fig. 1 we show measured $J \geq 1$ fractional populations as function of time after injection in the storage ring. For this data set, the depletion laser was switched on at $t = 110$ s and switched off at $t = 380$ s. In the time interval 250 s < t < 380 s we clearly see that the fraction of rotationally excited OH^- ions is less than 1%. The increase in $J \geq 1$ population when the depletion laser is switched off is due to 'heating up' by the 13 K Planck radiation!

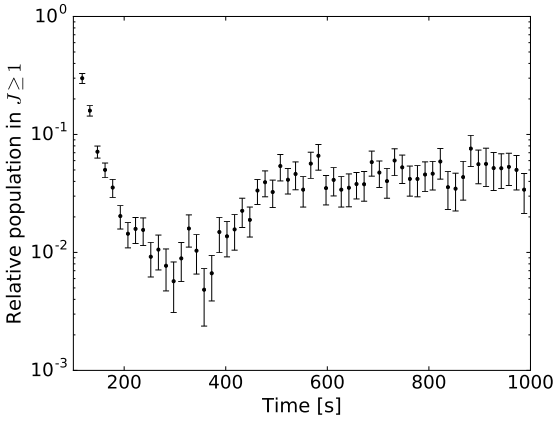

Figure 1. Measurement of the $J \geq 1$ fraction as functions of time, t, after the ion-beam injection. A merged cw depletion laser beam, detaching ions with $J \geq 1$, is applied for the time interval 110 s < t < 380 s.

References

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