A.7.3. Ion-Trap Studies of Negative Ions and Vibrationally Cold Molecular Ions--*I. Ben-Itzhak*

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Studies involving molecular ions are often hard to interpret because the initial distribution of the rotational and vibrational states is not known. Many processes in nature depend strongly on the *v,l* state of the molecule in addition to its electronic state. Heavy ion storage rings have been used to store a molecular ion beam long enough to allow complete relaxation of the energy initially stored in the vibrational degrees of freedom (see for example [1,2]). The typical time scale, for dipole-allowed transitions, is milliseconds to seconds for vibrational relaxation, and seconds to minutes for rotational relaxation. Instead of storing ions at MeV energies, where ionization and capture cross sections are small, we store them at keV energies, where ionization is negligible and capture is much smaller than the peak value at matching velocity. The ion trap consists of two electrostatic mirrors and einzel lenses, which trap the ion beam along the cylindrical axis of the device [3,4]. At a pressure of about 10^{-10} Torr the storage time of Ar^+ is about a second.

This ion trap was used to measure the mean lifetimes of a few metastable states of He^-, the 1*s*2*s*2*p*, $^4P_{5/2}$ level, as well as the average of the $^4P_{3/2}$ and $^4P_{1/2}$ levels [Publication #110]. The use of pure electrostatic fields avoids the complication of magnetic-field-induced mixing effects, which can interfere with the measurement of the spontaneous decay [5].

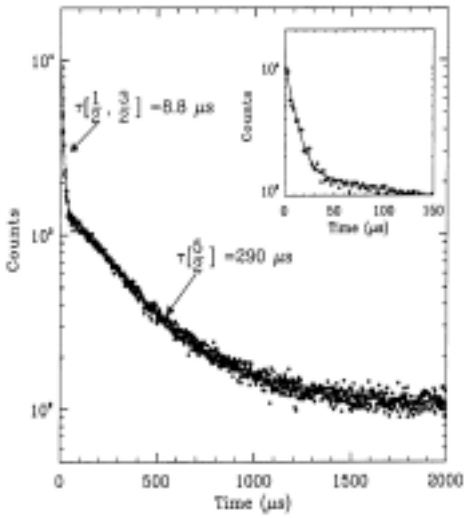

Figure 1. Neutral He signal from the channel plate detector as a function of time. The solid line is the fit to the data as described in the text. The two lifetimes $\tau_{<1/2,3/2>}$ and $\tau_{5/2}$ are not corrected for blackbody radiation induced decay. **Inset:** expanded scale for short times.

The measured lifetime for the $^4P_{5/2}$ state was determined to be 343±10 μs from the decay curve shown in Fig. 1 after correction for decay induced by blackbody radiation. This value is consistent with previous experiments [5-10], and in excellent agreement with the most recent theoretical calculations [11], which predict a value of 345±10 μs. The average lifetime of the $^4P_{3/2}$ and $^4P_{1/2}$ was measured to be 8.9±0.2 μs, an improvement of about an order of magnitude over previous measurements [5-10]. This improvement is mainly due to the faster stabilization of the stored beam in this ion trap as compared to the high-energy storage rings. The measured value is also about 20% lower than the weighted theoretical value [12].

Studies of collisions between molecular ions and atomic or molecular targets are usually hard to interpret, because many processes depend strongly on the initial vibrational state of the molecular ions, which are typically produced in highly excited vibrational states. Storing the molecular ions and cooling them to the vibrational ground state resolves this problem [1,2]. We have extracted a beam of vibrationally cold HeH^+ molecular ions from the ion trap and studied their dissociation following electron capture from He. We used 3D momentum imaging of the dissociating fragments to probe the dependence of the capture process on the orientation of the molecular axis relative to the beam direction. These measurements were compared to collisions with "hot" HeH^+ molecular ions extracted directly from the ion source. Preliminary results indicate significant differences in the capture cross section between cold and "hot" molecular ions. Recently, Wu *et al*. [13] reported orientation dependence in dissociative charge transfer of HeH^+ colliding with He. They have used recoil ion momentum imaging techniques (COLTRIMS) to identify the final state of the transient HeH molecule formed by electron capture. The interpretation of their data, however, was limited by the large spread of initial vibrational states. We have installed a recoil ion spectrometer, designed and tested at JRML, at the Weizmann Institute of Science, in order to measure the recoil He^+ in coincidence with both neutral fragments of the molecule, which was previously vibrationally cooled in the ion trap, to accomplish the same goal in our studies. Using vibrationally cold molecular ions, however, will hopefully allow state specific studies of angular dependencies in electron capture, as well as other collision induced processes (see proposal A.3.5).

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