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Cryogenic micro-calorimeters for mass spectrometry of keV neutral atoms and molecules

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Synopsis We demonstrate the capability of micro-calorimeters to detect and mass-resolve neutral atoms and molecules at ∼ keV energies, reaching single H-atom resolution.

Mass spectrometric identification of fragmentation products is one of the most important tools for molecular collision physics. Most molecular mass-spectrometry methods employ electromagnetic fields to determine the mass-to-charge ratio of ionized particles. Two major limitations arise from this approach. First, the ratios may be ambiguous, e.g., singly charged monomers are indistinguishable from doubly charged dimers. Second, neutral fragments cannot be directly analyzed and either a "neutral loss" must be accepted or an additional ionization stage must be used, which results in additional ambiguities.

As an alternative method, the mass of a neutral particle can be deduced from its kinetic energy if the particle velocity is known. This calorimetric approach has been successfully used in high-energy physics experiments by employing, for example, surface barrier detectors [1]. These detectors, however, are very restricted in their use at the ∼ keV energies relevant for low-energy collision experiments, as their energy resolution becomes poor and they often are insensitive to the low-energy incident particles.

A promising approach to solve the needs for low kinetic energy measurements is the use of cryo-detectors, such as micro-calorimeters. With these detectors the particle kinetic energy is transformed into heat and sensitive temperature monitoring then provides the measure of the kinetic energy deposited. The operation at ∼ 10 mK limits the thermal noise and thus enables resolving low measured energies.

We have systematically investigated the energy resolution of magnetic micro-calorimeters (MMC) [2] for atomic and molecular projectiles at impact energies ranging from $E \approx 13$ keV to 150 keV. For atoms we obtained relative energy resolutions down to $\Delta E/E \approx 10^{-3}$ and absolute energy resolutions down to $\Delta E \approx 120$ eV. We also studied in detail the MMC response function for molecular projectiles of masses up to 56 amu. We have demonstrated the capability of identifying neutral fragmentation products of these molecules by calorimetric mass spectrometry (see Figure 1) with single H-atom resolution. We have modeled the MMC response function for molecular projectiles and concluded that backscattering is the dominant source of the observed energy spread at the impact energies studied. Furthermore, we have successfully demonstrated the use of a detector absorber coating to minimize such spreads.

Our findings [3] are of general interest for mass spectrometric techniques with special advantage for neutral-particle mass measurements.

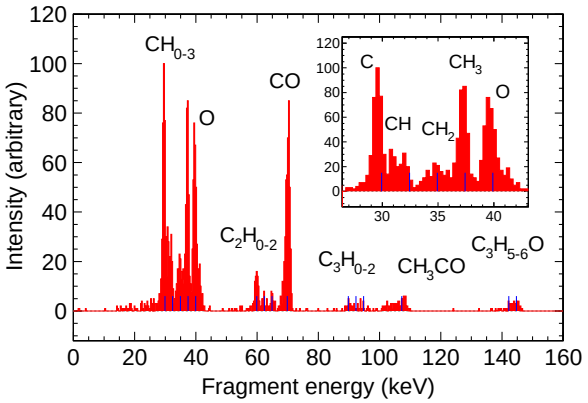

Figure 1. MMC energy spectrum of neutral products arising from collisions of 150 keV acetone radicals ($C_3H_6O^+$, 56 amu) with residual gas.

References

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