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Laboratory studies into the cosmic origins of organic chemistry

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Synopsis We have constructed a novel merged-beams apparatus to study the cosmic origins of organic chemistry. Here we report rate coefficients measurements for reactions of atomic C with H_3^+. These data are important for astrochemical models.

The chain of chemical reactions leading towards life is thought to begin in molecular clouds when atomic carbon is fixed into molecules, initiating the synthesis of complex organic species. Spectroscopic observations, combined with sophisticated astrochemical models to interpret the collected spectra, provide much of our knowledge of this process [1]. However, uncertainties in the underlying chemical data in these models limit our understanding of the molecular universe [2].

Theory provides little insight as fully quantum mechanical calculations for reactions with four or more atoms are too complex for current capabilities. On the other hand, measurements of cross sections and rate coefficients for reactions of C with molecular ions are extremely challenging. This is due to the difficulty in producing a sufficiently intense and well characterized beam of neutral carbon atoms [3].

We have developed a novel merged beam apparatus to study reactions of neutral atomic C with molecular ions. A C^- beam is generated in a cesium ion sputter source and accelerated to 28 keV. A series of apertures and electrostatic optics create a well defined, collimated beam. Using an 808 nm (1.53 eV) laser beam, ∼4% of the C^- beam is neutralized via photodetachment. We produce a pure ground term neutral C beam by electrostatically removing the remaining C^-. The beam is then merged with a velocity matched, co-propagating H_3^+ beam at 7.05 keV, created with a duoplasmatron source.

The merged beams method allows us to use fast beams (keV in the lab frame), which are easy to handle and monitor, while being able to achieve relative collision energies down to some tens of meV. An electrostatic energy analyzer separates and detects the charged end products of the different reaction channels. The reactions rate coefficients are determined by measuring all the relevant currents, beam shapes, energies, signal counts and background rates.

We have measured the absolute rate coefficients for

$$C + H_3^+ \rightarrow CH^+ + H_2 \quad (1)$$
$$\rightarrow CH_2^+ + H. \quad (2)$$

As H_3^+ is ubiquitous in molecular clouds [4], these reactions are some of the first steps in the gas phase chemistry leading to the formation of complex organic molecules within such clouds [1]. Our reaction studies will help to provide a better basis for astrochemical models and benchmarks for future theoretical development.

References

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