Laboratory Measurements for Deuterated Astrochemistry

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Synopsis We have carried out a series of laboratory measurements of neutral atomic C reacting with H_2^+ and D_2^+. These provide important guidance for converting current astrochemical reaction databases for hydrogen-bearing species into ones than includes partially and fully deuterated species.

Deuterated molecules are powerful probes of the cold interstellar medium (ISM), such as dark clouds, pre-stellar cores, material surrounding low- and high-mass protostars, and protoplanetary disks. Observations of D-bearing molecules are used to infer the chemistry of the ISM and to trace out physical conditions such as density, ionization fraction, and thermal history. However, the information gained hinges on an accurate understanding of the underlying deuterated astrochemistry.

The chemistry of the ISM results from a complicated interplay between gas-phase processes, reactions on dust grain surfaces, and chemistry occurring both in and on the icy mantles of dust grains. Our focus here is on an improved understanding of the relevant deuterated gas-phase chemistry. At the low temperatures and densities typical of the cold ISM, much of this chemistry is driven by binary ion-neutral reactions, which are typically barrierless and exoergic (as compared to neutral-neutral reactions which often have significant activation energies).

One of the biggest challenges in generating a reliable deuterated gas-phase astrochemical network is the uncertainty of the necessary rate coefficients. The vast majority of available chemical data are for reactions involving H-bearing molecular species. For reactions involving D-bearing molecular species, where no laboratory data are available, two approaches have been adopted for converting the data for H-bearing data into that needed for partially and fully deuterated species. The first approach is simply to "clone" the H-bearing reactions into D-bearing reactions and assume that the rate coefficients are the same; for partially deuterated species, a statistical branching ratio is assumed for the final position of the D atom [1]. The second approach uses a simple mass scaling relationship based on the Langevin formalism [2].

We have initiated a series of laboratory measurements aimed at resolving this issue. For this we use our novel dual-source, merged fast-beams apparatus, which enables us to study reactions of neutral atoms and charged molecules [3, 4]. Using co-propagating beams enables us to achieve collision energies corresponding to temperatures as low as 25 K, limited only by the divergences of the two beams. Recently we have measured the reaction $C + H_2^+$ forming $CH^+ + H$ and $C + D_2^+$ forming $CD^+ + D$. We are now studying $D + H_3^+$ forming $H_2D^+ + H$ and $D + D_2H^+$ forming $D_3^+ + H$. Here we report on these results and discuss their astrochemical implications.

References

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