Nuclear Spin Dependence of Hydrogenic Plasmas in the Laboratory and the Diffuse Interstellar Medium

Kyle N. Crabtree, *Department of Chemistry, University of Illinois, Urbana, IL 61801*; Nick Indriolo, *Department of Astronomy, University of Illinois, Urbana, IL 61801*; Holger Kreckel, Carrie A. Kauffman, Brian A. Tom, Eftalda Beçka, Brett A. McGuire, *Department of Chemistry, University of Illinois, Urbana, IL 61801*; Benjamin J. McCall, *Departments of Chemistry, Astronomy, and Physics, University of Illinois, Urbana, IL, 61801.*

Observations of diffuse molecular clouds have shown that the excitation temperature $T(H_3^+)$ derived from the (J, K) = $(1, 0)$ (*ortho*) and $(1, 1)$ (*para*) rotational levels of H_3^+ does not necessarily agree with the kinetic temperature (T_{01}) inferred from UV measurements of H_2. In four of the five diffuse molecular cloud sight lines for which both H_3^+ and H_2 observations are available, $T(H_3^+)$ is lower than T_{01} by 30 K. The reaction $H_3^+ + H_2 \rightarrow H_2 + H_3^+$ is expected to thermalize the H_3^+ nuclear spin distribution, but the interplay of nuclear spin selection rules and energetic restrictions at the low temperatures of the diffuse interstellar medium may prevent full thermalization at steady state. Alternatively, the nonthermal distribution could arise if H_3^+ does not experience a sufficient number of thermalizing collisions with H_2 during its lifetime.

We have studied the nuclear spin dependence of the reaction of H_3^+ with H_2 in the laboratory by measuring the *ortho*:*para* ratio of H_3^+ formed in plasmas of varying *ortho*:*para* H_2 ratios. This study was performed in a hollow cathode cell which enabled the first measurements of this reaction at low temperature (130 K). From these measurements, we derived the ratio of the "proton hop" and "hydrogen exchange" rate coefficients as a function of temperature. The ratio, α, was found to decrease with temperature, already reaching the statistical limit of 0.5 at a temperature of 130 K.

Knowledge of α enables modeling of the *ortho*:*para* ratio of H_3^+ in diffuse molecular clouds. We have modeled the nuclear spin dependence of the formation, thermalization, and destruction processes of H_3^+, and found that the nonthermal distribution is not caused by nuclear spin selection rules or energetic restrictions in the $H_3^+ + H_2$ reaction. Rather, it is likely caused by incomplete thermalization prior to H_3^+ destruction via electron dissociative recombination.