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Astronomy, Physics, and Chemistry of H_3^+

Takeshi Oka
Department of Astronomy and Astrophysics, and Department of Chemistry, The Enrico Fermi Institute, The University of Chicago

Abstract. This is a report of a Discussion Meeting titled "Astronomy, Physics, and Chemistry of H_3^+" which was held on February 9 and 10, 2000 at the Royal Society in London.

1. Introduction

H_3^+ is the simplest polyatomic system and is the most abundantly produced ion in molecular hydrogen dominated plasmas. It plays a pivotal role as the universal proton donor in the cosmic ray driven ion-neutral reaction scheme for the formation of interstellar molecules. The recent observations of the infrared spectrum of H_3^+ in dense molecular clouds (Geballe and Oka 1996; McCall et al. 1999) as well as in the diffuse interstellar medium (McCall et al. 1998; Geballe et al. 1999) have demonstrated the ubiquity of this fundamental molecular ion in interstellar space. The abundance of H_3^+ in molecular clouds had been anticipated but its abundance in the diffuse medium was surprising.

The spectrum has also been observed in outer planets as strong and pure emission and has become a powerful probe for monitoring morphology of plasma activities in planetary ionospheres, providing means for studying their magnetospheres from ground based observatories (Connerney and Satoh 2000).

These astronomical observations and their analysis have introduced novel questions whose solution require participation of researchers in different fields. In particular, the observed unexpectedly large column densities of H_3^+ ($4–2 \times 10^{14}$ cm^{-2}) in diffuse clouds toward Cygnus OB2 No. 12 and 5 have revealed a major problem involving the dissociative recombination rate of H_3^+. In both clouds H_3^+ is produced by cosmic ray ionization of H_2 followed by the ion-neutral reaction $H_2+H_2^+ \rightarrow H_3^+ + H$. But the destruction of H_3^+ in diffuse clouds (due to electron recombination) is supposed to be faster than that in dense clouds (due to proton hop reaction to CO) by 2 to 3 orders of magnitude. In order to explain the comparable H_3^+ column densities observed in dense and diffuse clouds, we need to assume extraordinarily large diffuse clouds.

The Royal Society Discussion Meeting titled "Astronomy, Physics, and Chemistry of H_3^+" was organized by E. Herbst, S. Miller, T. Oka, and J. K. G. Watson on February 9 and 10, 2000 in London where chemists, physicists, and astronomers discussed a variety of general and specific problems on H_3^+ from different perspectives. The fundamental nature of the molecular ion made such interdisciplinary discussions possible and fruitful.

2. Program

The topics and discussion leaders (in parentheses) and the speakers and titles of talks are given below. The whole program including a poster session can be viewed on webpage, `http://h3plus.uchicago.edu`.

1. Spectroscopy (W. Klemperer, A. Carrington)

J. K. G. Watson, An introduction to the Spectroscopy of H_3^+

B. J. McCall, Laboratory Spectroscopy of H_3^+

I. R. McNab, The near dissociation spectrum of H_3^+

J. Tennyson, The theory of H_3^+ near its dissociation

2. Dynamics (D. Smith, D. Clary)

M. Larsson, Experimental studies of the dissociative recombination of H_3^+

A. Suzor-Weiner, Dissociative recombination of H_3^+: progress in theory

T. Amano, Infrared absorption spectroscopy of D_3: an investigation into the mechanism of triatomic hydrogen species

3. Planetary (R. Prangé)

J. E. P. Connerney, The H_3^+ ion: a remote diagnostics of the jovian magnetosphere

S. Miller, The role of H_3^+ in planetary atmosphere

4. Interstellar H_3^+ (E. F. van Dishoeck, D. A. Williams)

T. R. Geballe, H_3^+ between the stars

J. H. Black, The abundance and excitation of interstellar H_3^+

E. Herbst, The astrochemistry of H_3^+

T. J. Millar, The role of H_2D^+ in the deuteration of interstellar molecules

E. Roueff, H_3^+ recombination and bistability in the interstellar medium

The Discussion Meeting was accompanied by two related meetings at University College London, "Molecules and Dust in Region of High Extinction" on February 8 and "H_3^+, Further Discussions and Future Perspectives" on February 11. In the latter meeting findings obtained after the programming of the main meeting and some more speculative thoughts on various aspects of H_3^+ were presented. The speakers and titles of the meeting were as follows.

C. Cecchi-Pestellini, H_3^+ in diffuse interstellar clouds

(R. Stark), Detection of interstellar H_2D^+ and its unique role in the chemistry of star formation

(M. Mumma), H_3^+ emission from exoplanets

R. Jaquet, Investigation of H_3^+ based on explicitly correlated wavefunctions

R. Johnsen, Review of the experimental work on the recombination of H_3^+

D. Gerlich, Experimental studies of ion molecule reactions at low energies: fast and slow reactive ways from H^+ and H_2^+ to H_3^+

A. Bandrauk, H_3^+ in intense laser fields-enhanced ionization, Coulomb explosion and harmonic generation

M. Cordonnier, Selection rules for ortho- and para-H_3^+ in ion-neutral reactions.

3. Summary

The laboratory spectroscopy is approaching high vibrational states near the top of the barrier to linearity (McCall 2000). A hyperspherical coordinate formalism

is being developed to cope with the singularity at such point (Watson 2000). The highly congested H_3^+ spectrum near the dissociation limit (Kemp et al. 2000) presents a great challenge to theory (Tennyson et al. 2000).

Despite many experimental efforts, consensus has not been reached on the recombination rate of H_3^+ (Larsson 2000). The theoretical value differs from the experimental by more than orders of magnitude (Orel et al. 2000). This is a crucial problem for the analysis of interstellar H_3^+. Spectroscopy of D_3 provides insight for the formation of triatomic hydrogen (Amano & Chan 2000).

Jovian magnetosphere has been studied by H_3^+ spectrum (Connerney and Satoh 2000). It was proposed (Miller et al. 2000) that H_3^+ also plays a major role in energy budget and dynamics of planetary atmospheres. It was speculated that H_3^+ emission might just be detectable from exoplanets using current technology.

The H_3^+ infrared absorption observed in molecular clouds provides a unique means to determine the basic parameters of the cloud. Observation of H_3^+ in diffuse clouds have been a surprise and its true implication is yet to be understood (Geballe 2000). Some models have been proposed (Black 2000; Cecchi-Pestellini and Dalgarno 2000). H_3^+ plays the central role in molecular formation (Herbst 2000), the high deuterium fractionation (Millar et al. 2000) and the bistability in model calculation (Pineau des Forêts and Roueff 2000).

The proceedings of the meeting has been published in the Philosophical Transactions of the Royal Society of London A358 (2000) and as a book.

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