CH^+ in Shocks, Cloud-Intercloud Interfaces, and Dense Photodissociation Regions

W W DULEY
Physics Department, University of Waterloo, Waterloo, Ontario, Canada N2L 3G1
T W HARTQUIST
Max Planck Institute for Physics and Astrophysics, Institute for Extraterrestrial Physics, 8046 Garching, Germany
A STERNBERG
Department of Astronomy, Tel Aviv University, Tel Aviv, Israel
and
R WAGENBLAST and D A WILLIAMS
Department of Mathematics, UMIST, PO Box 88, Manchester M60 1QD, UK

September 5, 1991

1. Introduction

Substantial CH^+ abundances are found in at least three types of environment (Lambert and Danks, 1985): atomic regions with little H_2, $N(CH^+) \sim 10^{12}$ cm^{-2}; diffuse clouds such as that toward ζ Oph, $N(CH^+) \sim 10^{13}$ cm^{-2}; reddened ($2 \lesssim A_v \lesssim 4$) lines of sight to bright stars $N(CH^+) \sim 10^{14}$ cm^{-2}. We explore the view that several different mechanisms operate.

2. CH^+ in atomic gas

Chemistries based on H_2 are inoperative. We propose that CH^+ is the major erosion product of amorphous carbon grains (Jones, Duley and Williams, 1990) in shocked atomic gas. The outer layers of such grains are primarily alkane chains. Laboratory studies of such carbons show that small alkanes are released thermally and in sputtering. Alkanes in the interstellar medium are subjected to a variety of reactions, and ions tend to appear in the processing, and the final stage before dissociation to atoms is often CH^+.

The column density of CH^+ may be calculated and may be shown to have values comparable with those observed on lines of sight where H_2 is low in abundance.

3. CH^+ in warm interfaces of diffuse clouds

In diffuse clouds such as that towards ζ Oph H_2 is abundant. Shock models (Pineau des Forêts et al., 1986) have been developed in which CH^+ is formed

P. D. Singh (ed.), Astrochemistry of Cosmic Phenomena, 309–310.

in the warm post-shock gas via the endothermic reaction $C^+(H_2,H)CH^+$. It is unclear whether MHD shock models meet the observational constraints ($H_2(J)$, OH, and velocity shifts: Lambert et al., 1990). We explore the possibility that CH^+ is formed in a warm interface between the diffuse cloud and the ambient hot gas. We have examined a large number of such models. Models in least conflict with observations are warm (2000-4000 K) and of low intensity (radiation parameter $\chi \sim 3$). A model that meets all constraints is $\chi = 3$, T = 4000, nT = 10000 with k_1 twice the canonical value. Warm interfaces ~ 10% of cloud diameter are required to produce the observed CH^+. Turbulent boundary layers generally have this extent, and their temperatures are elevated (Hartquist and Dyson, 1988).

4. CH^+ in highly reddened regions

$N(CH^+) \sim 10^{14}\ cm^{-2}$ could be achieved in a single exceptionally large interface, or by contributions from several interfaces. Alternatively, the background stars are very luminous; if the cloud is close to the star a photodissociation region (PDR) will develop (Sternberg and Dalgarno, 1991) and large values of $N(CH^+)$ arise at high number densities and with intense radiation fields. We find that $N(CH^+)$ achieves values $\sim 10^{14}\ cm^{-2}$ only when conditions are similar to those associated with OH masers (Hartquist and Sternberg, 1989).

5. Conclusions

When H_2 is absent, CH^+ must arise from grains. Models of CH^+ production satisfying other observational constraints are viable, and consistent with the expected warm boundary layers expected around diffuse clouds. Very high CH^+ column densities in highly reddened regions may arise in boundary layers. Alternatively, PDRs can be locations where CH^+ is abundant.

References

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