ABUNDANCE OF CH^+ IN TRANSLUCENT MOLECULAR CLOUDS: PROBLEMS FOR SHOCK MODELS?

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1. Introduction

The large abundance of CH^+ in diffuse clouds has been a mystery for more than 50 years (Dalgarno 1976). Many different explanations have been proposed, but only (shock) models with a substantial column of warm gas appear capable of approaching the observed column densities (Elitzur and Watson 1978). In these models, CH^+ is formed in the warm postshock gas through the reaction $C^+ + H_2 \rightarrow CH^+ + H$, which is endoergic by 4650 K. Although the most sophisticated MHD shock models are consistent with various observational aspects of CH^+, they require substantial "fine–tuning" of the parameters (Draine and Katz 1986; Hartquist et al. 1990). In addition, they predict a shift in velocity between CH^+ and other molecules found in the cold quiescent gas, which is not observed in recent data (e.g. Crawford 1989). In order to test further the shock models, we have searched for CH^+ in a number of translucent clouds ($A_V \approx$1–5 mag), which have H_2 column densities that are up to an order of magnitude larger than the clouds studied so far (cf. Souza 1979). Observations of the chemically related molecules CH, C_2, CN and CO have been obtained as well.

2. Observations and Analysis

Spectra of CH^+, CH, CN and C_2 at $\lambda/\Delta\lambda$=60,000–100,000 were observed with the ESO 1.4m Coudé Auxiliary Telescope equipped with the Coudé Echelle Spectrometer and CCD detector. For CH^+, we obtained spectra of both the A–X (0,0) and (1,0) bands. For the other molecules, we generally also measured at least two different transitions (Gredel et al. 1991). Millimeter emission lines of ^{12}CO and ^{13}CO 1–0 were observed with the SEST.
Most of the optical absorption lines are saturated, so that the Doppler parameter b along the line of sight needs to be accurately known in order to derive column densities. For CH^+, b can be determined from the ratio of the strengths of the A–X (0,0) and (1,0) bands. For lines of sight with high enough S/N, this suggests $b = 2 - 3$ km s^{-1}. We assume that similar b–values apply to the CH^+ observations for other lines of sight. For CN, the saturation corrections have been determined from comparison of the violet B–X and red A–X systems, resulting in accurate b values of 0.4–1.0 km s^{-1} which agree well with those derived from the widths of ^{13}CO millimeter lines. For CH, we assume b–values in the range (1.0–1.4)$\times b$(CN).

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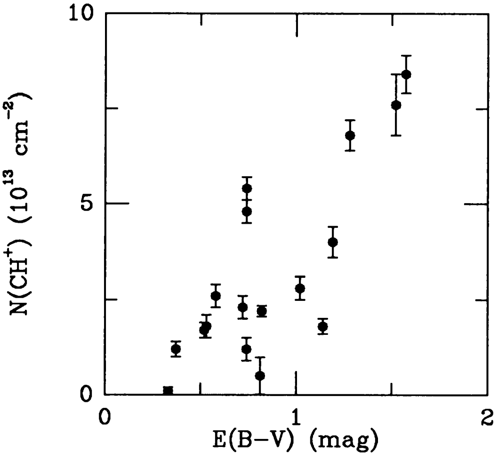

Figure 1. Observed CH$^+$ column densities as functions of reddening $E(B-V)$.

3. Results and Discussion

Figure 1 shows the CH$^+$ column densities obtained in this work as functions of $E(B-V)$. The most significant result is that they continue to increase with reddening. Moreover, the CH$^+$ velocities agree with those of CH, CN and C_2 within the errors. The largest CH$^+$ column densities are found for lines of sight for which the CO emission profiles are broader or more complex. The C_2 and CN column densities are strongly correlated with that of CH, which is probably a good tracer of the H_2 column density. CH$^+$ shows a larger scatter with CH, but still an overall increase. Finally, there is a tendency for the column density of CH$^+$ to decrease with increasing density n as derived from the C_2 excitation. In contrast, those of CN and C_2 increase strongly with n.

The fact that the CH$^+$ column density continues to increase with total column density is difficult to reconcile with the shock models, unless the number of shocks also increases. The absence of significant velocity shifts between CH$^+$ and other species further argues against the shock models. However, the larger b–values inferred for CH$^+$ together with the inverse correlation with density and possible association with more complex CO line profiles suggest that some energetic mechanism is responsible for the formation of the ion. Possibilities include translationally "hot" C$^+$ ions or H_2 molecules, since only a fraction 10^{-4} is needed to explain the observed CH$^+$ abundances. The warm turbulent interfaces of the clouds or clumps are a possible formation site (Duley et al. 1991), but quantitative calculations must await a physical description of turbulence.

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