Abundance of DCO^+ in Nearby Molecular Clouds

Harold M. Butner†
Space Science Division, NASA Ames Research Center, California 94035.

ABSTRACT. DCO^+ is one of the most common deuterated molecules in cold ($T_K \sim 10$ K) molecular cloud cores such as TMC-1. We report the results of a survey for DCO^+ and $H^{13}CO^+$ emission regions among a sample of low mass cloud cores. We compare the derived DCO^+/HCO^+ ratio (0.046±0.014) with current chemistry models for deuterium fractionation.

Deuterium Fractionation Chemistry

Watson (1977) pointed out that isotopic fractionation of molecules can be important for the conditions typically found in interstellar clouds. In particular, the abundance of DCO^+ can be enhanced significantly over that expected from the cosmic [D/H] ratio. The reason for this fractionation is the ancestral reaction

$$H_3^+ + HD \longleftrightarrow H_2D^+ + H_2 + \Delta E$$

to the formation of DCO^+. The energy difference, ΔE, causes the abundance of H_2D^+ to be temperature dependent. Estimates for ΔE lie between 180 K (Wootten *et al.* 1982) and 240 K (Herbst 1982), making the forward reaction dominant in the cold ($T_K \sim 10$ K) gas found in low mass dense cores. Since DCO^+ is produced primarily by

$$H_2D^+ + CO \longleftrightarrow DCO^+ + H_2,$$

the DCO^+ abundance is also temperature dependent. At low temperatures, the abundance of DCO^+ is significantly enhanced over the cosmic abundance of $[D/H] \sim 1.7 \times 10^{-5}$ (York and Rogerson 1976).

Additional reactions suggested by Dalgarno and Lepp (1984) and revised H_3^+ recombination rates (Smith and Adams 1984) have complicated the simple picture developed by Herbst (1982). In addition, our knowledge about possible reaction networks that could occur has increased dramatically in the past ten years. There has also been increased interest in the possible time-dependent variations of molecular abundances (Millar *et al.* 1988). However, there have been few attempts to incorporate deuterium chemistry in the new reaction models.

For this reason, Millar *et al.* (1989) have calculated the expected relative abundance for a number of deuterated molecules over a range of physical conditions, including those found in TMC 1 (cold, $T_K \sim 10$ K, dense, n $\sim 10^4$-10^5 cm^{-3}). They used a reaction network, based on the models of Millar, Leung and Herbst (1987) which describes the chemistry of dense molecular clouds using a pseudo-time-dependent model. In cores with similar physical conditions to TMC 1, Millar *et al.* (1989) find that the DCO^+/HCO^+ ratio should be between 0.02 and 0.05.

Observations

Based on the Myers and Benson (1983) NH_3 observations of low mass dense cores, the NH_3

†*NAS/NRC Resident Research Associate*

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cores identified in their survey should be an excellent laboratory to measure the amount of deuterium fractionation and thereby to constrain the chemical models better. The cores are all similar to TMC 1 in their density and temperature (n $\sim 10^4$-10^5 cm^{-3}, $T_K \sim$ 10-15 K based on NH_3 observations).

We observed the NH_3 cores using the DCO^+ and $H^{13}CO^+$ J=1→0 lines with the NRAO 12 meter and the DCO^+ J=2→1 line with the MWO 5 meter. We also observed the DCO^+ J=3→2 line with the NRAO 12 meter. $H^{13}CO^+$ was observed instead of the more abundant HCO^+ because the HCO^+ transitions are expected to be optically thick in most cases. Maps of 9 cores revealed that 2′ was the average DCO^+ J=1→0 emission region, which is similar to the NH_3 core size seen by Myers and Benson. All line intensities were corrected to T_R, where a source size of 2′ was assumed for η_c. We detected DCO^+ and $H^{13}CO^+$ in 24 out of 28 cores surveyed. We restrict our discussion to the 24 cores for which we have detections of both species.

The Deuterium Fractionation Ratio

To estimate the DCO^+/HCO^+ ratio, we used the column density derived from the DCO^+ and the $H^{13}CO^+$ J=1→0 observations with the assumption that $T_{ex} = T_K$. The $H^{13}CO^+$ abundance was converted to an HCO^+ abundance by assuming that the $HCO^+/H^{13}CO^+$ ratio is 75 (Wilson *et al.* 1981). Since the typical optical depth of the $H^{13}CO^+$ J=1→0 line is $\sim$ 0.2, the typical HCO^+ J=1→0 line will have optical depths in excess of 10, justifying our choice of $H^{13}CO^+$. There was no apparent difference in the DCO^+/HCO^+ ratio between cores with associated embedded infrared sources and cores without embedded sources. **The average $[DCO^+]/[HCO^+] = 0.046 \pm 0.014$ over all the cores is in excellent agreement with current models for cloud chemistry and deuterium fractionation in cold dense cores.**

The Physical Properties of the Cores: DCO^+ versus NH_3

From the DCO^+ J=1→0, J=2→1 and J=3→2 lines, it is possible to estimate the densities of the emission regions. Using an LVG model and assuming a gas kinetic temperature of 10 K, we derive an average density of 10^5 cm^{-3}. This is somewhat higher than the estimates derived form NH3, suggesting the DCO^+ is coming from a higher density region on average. The DCO^+ density estimates are in reasonable agreement with density estimates from other LVG studies using CS (Zhou *et al.* 1989) or C_3H_2 (Cox *et al.* 1989).

Another analomy compared to the NH_3 results of Myers and Benson is the observed DCO^+ linewidth. There are several potential explanations of the difference. However, the optical depth effects that have been proposed to explain large CS or $C^{18}O$ linewidths (see Zhou *et al.* 1989 and references therein) do not appear to work for the DCO^+ lines. The mechanisms require either line scattering by an envelope, producing a large observed core size relative to the NH_3 core size, or large line optical depths. Neither is seen in the case of the DCO^+ J=1→0 line.

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