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A LOW DENSITY MOLECULAR CLOUD IN THE VICINITY OF THE PLEIADES

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ABSTRACT

The central region of a small, low density molecular cloud, which lies to the south of the Pleiades cluster, has been studied through the use of molecular line observations. Column densities for CH, OH, ^{12}CO, and ^{13}CO are derived from the radio data. The CH and OH data yield a visual extinction through the center of the cloud of about 3 mag. The ratio of the antenna temperatures for the OH main lines is consistent with optically thin emission; therefore, the OH results are a good indication of the total extinction through the cloud. The analysis of the carbon monoxide data produces a relatively high kinetic temperature of at least 20 K, a low total gas density of ~ 300–500 cm^{-3}, and a column density of $\sim 4 \times 10^{17}$ cm^{-2} for ^{12}CO. Thus this small molecular cloud is not typical of the molecular material generally studied in Taurus.

Subject headings: clusters: open — interstellar molecules

I. INTRODUCTION

The chemistry of the carbon monoxide, CO, molecule has been studied in the direction of diffuse clouds by means of ultraviolet absorption line measurements (Federman *et al.* 1980) and toward dark clouds using millimeter wavelength transitions (see, e.g., Dickman 1978; Myers, Linke, and Benson 1983). These observations typically indicate column densities of $N(\text{CO}) \leq 10^{15}$ cm^{-2} in diffuse clouds and $N(\text{CO}) \sim 10^{18}$ cm^{-2} in dark clouds. Most investigations of CO in interstellar clouds have focused on the more opaque clouds, largely because of the relative ease of detecting millimeter wavelength lines from these denser regions. However, few measurements have been made to study CO in the transition in density from diffuse clouds to dark clouds. Combes *et al.* (1980) have obtained limiting values for $N(\text{CO})$ of ≥ 3–5×10^{17} cm^{-2} in several clouds seen in the direction of extragalactic radio sources. A small cloud in the vicinity of the Pleiades, first observed by Cohen (private communication), offers the opportunity to study CO in an intermediate density cloud.

In this paper we present radio wavelength observations of CH, OH, and $J = 2$–1 ^{12}CO and ^{13}CO in the direction of this small molecular cloud. The cloud was mapped by Cohen (private communication) in the $J = 1$–0 transition of ^{12}CO and was found to have an angular size of $\sim 30'$ by $60'$. The reflection nebulae within the Pleiades cluster are probably due to the effects of the radiation field of the stars interacting with the surrounding gas (Arny 1977; Jura 1977; Federman 1982*a*; White 1983*a*, *b*). Because of its close proximity to the Pleiades, the molecular cloud also provides the opportunity to study the chemistry of molecular gas which is interacting with the stars. In § II we present our observations of CH, OH, and CO toward the region, and in § III we use the CH and OH data to infer the column densities $N(\text{CH})$ and $N(\text{OH})$. In addition to studying the chemistry of CH and OH, the observations of these two molecules yield constraints on the analysis that determines $N(\text{CO})$ because CH and OH have been correlated with optical obscuration in both diffuse clouds and dark clouds (Rydbeck *et al.* 1976, and Lang and Willson 1978 for CH; Crutcher 1979 for OH). The carbon monoxide results are given in § IV from which we calculate the ^{12}CO column density, the ^{13}CO abundance, and the molecular hydrogen density. These parameters are determined from two independent methods: the optically thin approximation for ^{13}CO emission and the ^{13}CO data together with a large velocity gradient model for the radiative transfer. Finally in § V we discuss our basic results.

II. OBSERVATIONS

Observations of the $F = 1$–1 $^2\Pi_{1/2} J = \frac{1}{2}$ Λ doublet transition of CH at 3335.481 MHz were made in 1982 July using the 43.5 m antenna of the National Radio Astronomy Observatory.[1] At this frequency, the half-power beamwidth of the antenna is $9'$. Two 512 channel autocorrelators were operated in parallel with 1.25 MHz bandwidths and individual channel resolutions of 0.22 km s^{-1}. Observations were made on a grid of positions whose center [$\alpha = 3^h43^m00^s$(1950.0), $\delta = +23°30'00''$(1950.0)] coincides with the peak of the $J = 1$–0 ^{12}CO emission (Cohen, private communication). The spectra were obtained by frequency switching at ± 0.625 MHz within the band. The spectra from both autocorrelators were averaged, shifted, and Hanning smoothed to yield an effective resolution of ~ 0.4 km s^{-1}. Each resulting profile was fitted by a least-squares iteration with a linear baseline and a Gaussian function to obtain the peak antenna temperature, T_L, the full-width at half-maximum, ΔV, and the radial velocity with respect to the local standard of rest, V_{LSR}. The results of this analysis are given in Table 1. In Figure 1*b* a Hanning-smoothed spectrum of CH observed at the ^{12}CO $J = 1$–0 peak of the cloud is shown.

Observations of the $F = 1$–1 and $F = 2$–2 transitions of the $^2\Pi_{3/2}$ $J = 3/2$ doublet transition of OH at 1665.402 MHz and 1667.359 MHz were made in 1983 March using the same antenna. At these frequencies, the half-power beamwidth of the antenna is $18'$. For the OH observations, the autocorrelator was also divided into two 512 channel spectrometers with

[1] The National Radio Astronomy Observatory is operated by the Associated Universities, Inc. under contract with the National Science Foundation.

TABLE 1

CH MEASUREMENTS

Position[a]	T_L (K)	V_{LSR} (km s^{-1})	ΔV (km s^{-1})	N(CH) (cm^{-2})
(0, 0)	0.058 ± 0.011	10.37 ± 0.08	1.61 ± 0.18	4.8(13)[b]
(0, −4.5)	0.037 ± 0.008	10.04 ± 0.07	1.05 ± 0.16	2.0(13)
(0, 4.5)	0.042 ± 0.010	10.38 ± 0.10	1.56 ± 0.23	3.4(13)
(0, −9)	0.017 ± 0.008	10.09 ± 0.16	1.16 ± 0.38	1.0(13)
(0, 9)	0.036 ± 0.008	10.57 ± 0.08	1.17 ± 0.18	2.2(13)
(0, 13.5)	≲0.015	...	...	≲7.8(12)[c]
(4.5, −4.5)	0.032 ± 0.008	9.97 ± 0.10	1.47 ± 0.23	2.4(13)
(4.5, 0)	0.050 ± 0.006	10.23 ± 0.05	1.45 ± 0.12	3.8(13)
(4.5, 4.5)	0.047 ± 0.010	10.41 ± 0.06	1.10 ± 0.15	2.7(13)
(4.5, 9.0)	0.019 ± 0.009	10.85 ± 0.14	1.19 ± 0.33	1.2(13)
(9, −9)	0.025 ± 0.008	10.16 ± 0.08	0.95 ± 0.19	1.2(13)
(9, −4.5)	0.026 ± 0.007	10.22 ± 0.10	1.52 ± 0.22	2.0(13)
(9, 0)	0.040 ± 0.008	9.95 ± 0.08	1.57 ± 0.20	3.3(13)
(9, 4.5)	0.019 ± 0.008	10.25 ± 0.12	1.13 ± 0.29	1.1(13)
(13.5, 0)	0.028 ± 0.007	9.59 ± 0.09	1.05 ± 0.20	1.5(13)
(18, 0)	≲0.015	...	...	≲7.8(12)[c]
(−4.5, −4.5)	0.023 ± 0.009	9.92 ± 0.15	1.36 ± 0.34	1.6(13)
(−4.5, 0)	0.039 ± 0.009	10.39 ± 0.08	1.09 ± 0.19	2.2(13)
(−4.5, 4.5)	0.046 ± 0.009	10.57 ± 0.06	0.93 ± 0.14	2.2(13)
(−4.5, 9)	0.034 ± 0.009	10.42 ± 0.10	1.40 ± 0.23	2.5(13)
(−9, 0)	≲0.016	...	...	≲8.3(12)[c]
(−9, 9)	0.030 ± 0.007	10.49 ± 0.09	1.27 ± 0.21	2.0(13)
(−9, 13.5)	0.015 ± 0.007	10.73 ± 0.17	1.16 ± 0.40	9.0(12)
(−13.5, 9)	0.026 ± 0.008	10.47 ± 0.09	0.91 ± 0.22	1.2(13)
(−18, 0)	≲0.015	...	...	≲7.8(12)[c]

[a] ($\Delta\alpha$, $\Delta\delta$) offset in arcmin relative to $\alpha(1950) = 3^h43^m00^s$ and $\delta(1950) = +23°30'00''$.

[b] $4.8(13) = 4.8 \times 10^{13}$.

[c] Used $\Delta V = 1$ km s^{-1} in equation (1).

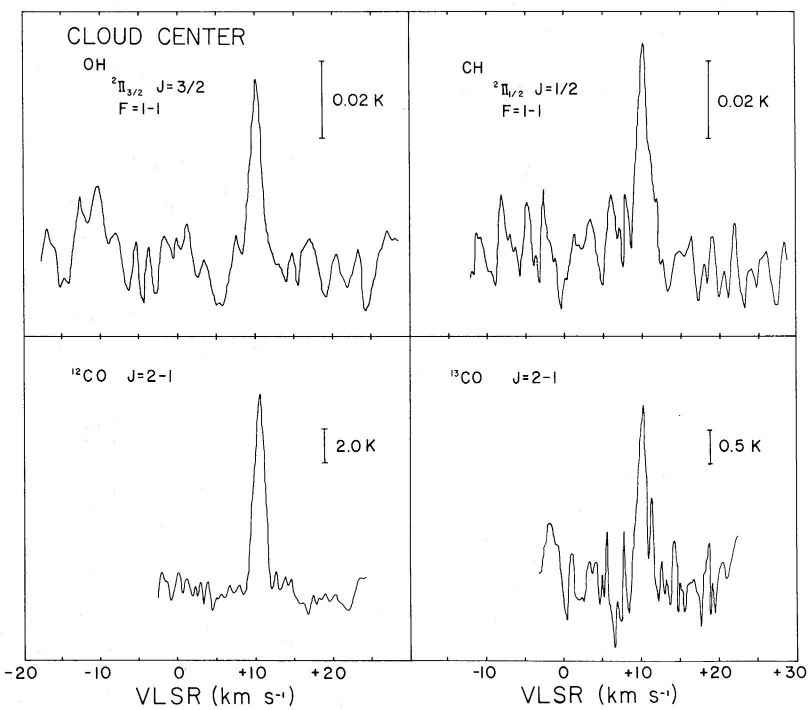

FIG. 1.—Sample spectra from the central position of the cloud. (*a*) OH emission at 1667 MHz in terms of T_L; (*b*) CH emission (T_L); (*c*) CO J = 2–1 emission (T_R); and (*d*) ^{13}CO J = 2–1 emission (T_R).

TABLE 2

OH MEASUREMENTS

Position[a]	1667 MHz T_L (K)	1667 MHz V_{LSR} (km s^{-1})	1667 MHz ΔV (km s^{-1})	1667 MHz N(OH) (cm^{-2})	1665 MHz T_L (K)	1665 MHz V_{LSR} (km s^{-1})	1665 MHz ΔV (km s^{-1})
(0, 0)	0.047 ± 0.006	10.05 ± 0.11	1.80 ± 0.30	2.8(14)	0.029 ± 0.005	9.90 ± 0.12	1.60 ± 0.30
(0, −18)	$\lesssim 0.020$	...	...	$\lesssim 6.6(13)^b$			
(0, −9)	0.043 ± 0.005	10.09 ± 0.10	1.60 ± 0.20	2.3(14)			
(0, 9)	0.038 ± 0.006	10.09 ± 0.08	1.00 ± 0.20	1.2(14)			
(0, 36)	$\lesssim 0.012$	...	...	$\lesssim 3.9(13)^b$			
(9, −9)	$\lesssim 0.013$	...	...	$\lesssim 4.3(13)^b$			
(9, 0)	0.033 ± 0.006	10.77 ± 0.11	1.30 ± 0.30	1.4(14)			
(9, 9)	$\lesssim 0.012$	...	...	$\lesssim 3.9(13)^b$			
(18, 0)	0.028 ± 0.007	9.44 ± 0.14	1.14 ± 0.20	1.0(14)			
(−9, −18)	$\lesssim 0.016$	...	...	$\lesssim 5.3(13)^b$			
(−9, −9)	0.036 ± 0.005	9.58 ± 0.10	1.40 ± 0.20	1.6(14)			
(−9, 0)	$\lesssim 0.014$	...	...	$\lesssim 4.6(13)^b$	$\lesssim 0.014$		
(−9, 9)	$\lesssim 0.011$	...	...	$\lesssim 3.6(13)^b$			
(−18, −18)	$\lesssim 0.010$	...	...	$\lesssim 3.3(13)^b$			
(−18, −9)	$\lesssim 0.018$	...	...	$\lesssim 5.9(13)^b$			

[a] ($\Delta\alpha$, $\Delta\delta$) are the same as in Table 1.
[b] $\Delta V = 1$ km s^{-1} used.

0.625 MHz bandwidths and individual channel resolutions of ~ 0.2 km s^{-1}. Frequency switching at ± 0.312 MHz was also employed, with each bandwidth centered on the rest frequency of one of the OH transitions. The spectra were then processed identically to the CH spectra. The OH line parameters are given in Table 2, and in Figure 1*a* we show the 1667 MHz OH spectrum obtained at the center of the cloud.

The carbon monoxide data were obtained using the 4.9 m antenna of the Millimeter Wave Observatory[2] near Fort Davis, Texas. Observations of the $J = 2$–1 rotational transition of ^{12}CO (hereafter CO) at 230.538001 GHz were made in 1980 April and those of ^{13}CO at 220.398714 GHz were made in 1983 April. The beam is approximately 1′.3 at these frequencies. A Schottky diode mixer, developed at the University of Massachusetts (Erickson 1981), was used for these observations. A typical value for the single sideband temperature, including atmospheric effects and antenna loss, was 1500 K. For the CO observations, 128 channel filter banks of 62.5 kHz and 250 kHz per channel (~ 0.1 km s^{-1} and ~ 0.3 km s^{-1}) were used, while only the 250 kHz (~ 0.3 km s^{-1}) filter bank was used during the ^{13}CO observations. The spectra were obtained by position-switching 30′ north and 30′ east of the cloud whose center is given above. Figures 1*c* and 1*d* show the CO and ^{13}CO spectra at the position of the peak.

III. CH AND OH RESULTS

In Figure 2 we show contour maps of CO in the $J = 1$–0 line of Cohen relative to the CH intensity (Fig. 2*a*) and relative to the OH intensity (Fig. 2*b*). The peak of the $J = 1$–0 CO emission lies approximately 10′ south of the star 23 Tau (Cohen, private communication). The angular extent of the CO cloud at the 2 K level is about 30′ × 60′; the region of enhanced emission covers an area of about 15′ × 15′ and has a peak radiation temperature, T_R, of ~ 15 K. Recent observations of CO and ^{13}CO confirm the results of Cohen (Bally, private communication). Our measurements of CH and OH indicate that the emission from these two molecules is detected only from the region of enhanced CO emission, as shown in Figures 2*a* and 2*b*. Furthermore, the contours of CH intensity follow the CO contours quite closely, but the large beamwidth of the OH measurements prevents us from making a detailed analysis of the correspondence between OH and CO.

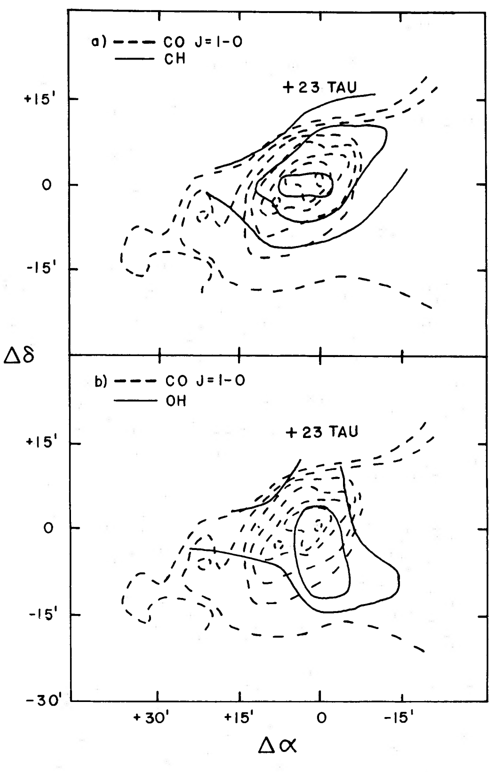

FIG. 2.—Contour maps indicating the intensity of molecular emission. (*a*) comparison between CO emission in the $J = 1$–0 line (Cohen, unpublished) and CH emission. The CO contours of radiation temperature are in steps of 2 K with the outermost contour being 2 K. The CH contours of T_L are in steps of 0.015 K; (*b*) comparison between the CO emission and OH emission at 1667 MHz. The CO contours are the same as those in (*a*); the OH contours of T_L are in steps of 0.020 K. The beam sizes for the three maps are 2′.6 for CO, 9′ for CH, and 18′ for OH.

[2] The Millimeter Wave Observatory is operated by the Electrical Engineering Research Laboratory of the University of Texas at Austin, with support from the National Science Foundation and McDonald Observatory.

For CH, the peak antenna temperature is 0.058 K, significantly greater than the upper limits of ~0.015 K several beamwidths away. The column density of CH can be calculated using the expression (Rydbeck *et al.* 1976):

$$N(\mathrm{CH}) = \frac{2.9 \times 10^{14} T_x(\mathrm{CH}) T_L \Delta V}{\eta_m\{[T_x(\mathrm{CH})\Omega_c/\Omega_A] - T_B\}} \ \mathrm{cm}^{-2} . \quad (1)$$

Here, T_x(CH) is the CH excitation temperature, T_B (=2.8 K) is the brightness temperature of the microwave background, η_m is the main beam efficiency (0.6), and Ω_c and Ω_A are the solid angles subtended by the cloud and the main beam of the antenna. Using the data given in Table 1, and equation (1), CH column densities that range from 4.8×10^{13} cm^{-2} at the peak to $\leq 7.8 \times 10^{12}$ cm^{-2} in the outer region of the cloud are inferred. In deriving these estimates, we assumed that $\Omega_A = \Omega_c$, i.e., the CH was not clumped on angular scales smaller than the antenna beam, and that the excitation temperature, T_x(CH), was equal to 40 K, the approximate kinetic temperature (see below). A smaller excitation temperature would yield a somewhat larger value for the column density. A velocity width of 1 km s^{-1} was also assumed for those positions where no line was detected. The sharp decrease in column density north of the peak is consistent with the upper limit of $N(\mathrm{CH}) \leq 3.3 \times 10^{12}$ cm^{-2} obtained by Federman (1982*a*) from optical measurements toward the star 23 Tau. Although no satellite transitions of CH were measured, masing, which could affect the values for N(CH), is not likely to be significant in regions without strong sources of radio continuum (cf. Genzel *et al.* 1979).

Because of the larger beamwidth of the antenna at the frequency of the OH transition, fewer points were measured. OH emission from the stronger 1667 MHz transition was detected at only six positions, including the peak of CH and CO. The antenna temperature at the peak is 0.047 K, and typical upper limits are again 0.015 K. The column density of OH was determined using a relationship similar to that for CH with the appropriate molecular constants. The optical depth, τ, and excitation temperature, T_{ex}(OH), can be found using the expressions:

$$T_L = \eta_m[T_{ex}(\mathrm{OH}) - T_B][1 - \exp(-\tau)] \ \mathrm{K}$$

and

$$\frac{T_L(1665)}{T_L(1667)} = \frac{[1 - \exp(-5\tau/9)]}{[1 - \exp(-\tau)]} . \quad (2)$$

The results for the cloud peak yield a ratio for the main-line temperatures, $T_L(1665)/T_L(1667)$, of 0.62, and thus τ is about 0.5, indicating emission that is slightly optically thick. The excitation temperature derived using the above equations is 3.03 K. With a beam efficiency of 0.6, the column density for OH is 2.8×10^{14} cm^{-2} at the cloud peak and is less than 4.9×10^{13} cm^{-2} in the outer regions of the cloud where no line was detected.

We also note that, within the uncertainties in measurement, the ratio of main-line antenna temperatures is consistent with the optically thin value of 0.55. [When the errors in T_L are considered, τ is less than 1.5 and T_{ex}(OH) is at least 2.9 K. Since T_{ex}(OH) may be as large as T_x(CH), an uncertainty of a factor of about 3 in N(OH) arises.] Thus, because the emission is optically thin, the OH observations sample the gas through the entire cloud. The CH observations probably also sample the gas through the whole cloud as indicated by the similar velocities and line widths for CH and OH emission at the cloud peak.

IV. CARBON MONOXIDE RESULTS AND ANALYSIS

a) Results

Both CO and ^{13}CO were observed in the $J = 2$–1 transition so that a comparison with measurements of the $J = 1$–0 transition could be made. With a main beam efficiency of 0.65 at the frequencies of the $J = 2$–1 CO line (Mundy, private communication), our observations indicate a radiation temperature of $T_R \sim 15$ K at the cloud center. T_R includes the effects of atmospheric and antenna losses, as well as the efficiency of the antenna at 230 GHz. Since observations at the Millimeter Wave Observatory of the $J = 1$–0 transition also indicate a radiation temperature of ~15 K (Cohen, private communication), we infer that the cloud is optically thick in CO. The ^{13}CO $J = 2$–1 line, however, has a radiation temperature of only ~3 K compared with a T_R of 5 K for the $J = 1$–0 transition (from measurements at Bell Labs by Bally, private communication), indicating that this transition is not saturated. These conditions regarding the optical depth are reinforced when an analysis using a large velocity gradient (LVG) model (Goldsmith, Young, and Langer 1983) is applied to the ^{13}CO data.

b) Optically Thin Approximation

The column density of CO cannot be obtained directly because the emission is optically thick, but must instead be inferred from the ^{13}CO data. Since the ^{13}CO lines are optically thin, the determination of $N(^{13}\mathrm{CO})$ is straightforward. The excitation temperature of the ^{13}CO transitions is assumed to be the same as that for CO which has a value of ~20 K when the contribution from the universal background is included. In order to derive the ^{13}CO column density, it is necessary to know the quantities F_1 and F_2, which represent, respectively, the relative population of the $J = 1$ and $J = 2$ rotational levels. The results for the $J = 1$–0 lines are consistent with the $J = 2$–1 results only when values for F_1 and F_2, appropriate at low densities are used; $F_1 \sim 0.5$ and $F_2 \sim 0.1$. Densities of $n \approx 300$ cm^{-3} are required for consistency, indicating that in addition to being optically thin, the ^{13}CO emission is subthermal. Under these conditions we derive a column density of $N(^{13}\mathrm{CO}) \sim 7.5 \times 10^{15}$ cm^{-2}. Because the excitation temperature is not especially low, the effect of subthermal emission on the determination of $N(^{13}\mathrm{CO})$ is minimal. This value for $N(^{13}\mathrm{CO})$ incorporates a factor that takes account of the moderately large optical depth of the $J = 1$–0 line ($\tau \sim 0.4$). Finally, under the assumption that the isotopic ratio $^{12}\mathrm{CO}/^{13}\mathrm{CO}$ is equal to 60 (cf. Wannier 1980), we find $N(\mathrm{CO}) = 4.5 \times 10^{17}$ cm^{-2}.

c) Large Velocity Gradient Model

The density of the gas and the abundance of ^{13}CO can be obtained from an analysis of the ^{13}CO data using the LVG model of Goldsmith, Young, and Langer (1983). These quantities are determined for a specific kinetic temperature with the LVG model by comparing the radiation measured in both the $J = 1$–0 and $J = 2$–1 lines for the molecule of interest. For the model of Goldsmith *et al.* the ratio of the emission in the lines and the radiation temperature of the $J = 1$–0 transition are needed. At the center of the cloud, the ratio $T_R(2\text{–}1)/T_R(1\text{–}0)$ for ^{13}CO is approximately 0.6. A kinetic temperature that is higher than the excitation temperature of ~20 K is possible because the low density inferred above indicates subthermal emission, and because the nearby cluster probably heats the gas. In

TABLE 3

LVG Model Results

T (K)	n (cm^{-3})	$x(^{13}CO)$
20..........	1000	2.2×10^{-6}
40..........	500	3.5×10^{-6}
60..........	350	4.4×10^{-6}

Table 3 we show the results of the LVG model for kinetic temperatures of 20 K, 40 K, and 60 K. A velocity gradient of 1 km s^{-1} pc^{-1} is assumed in the determination of $x(^{13}CO)$. The results for higher temperatures are similar to those for 60 K. Our results show that the derived values for the density, n, and abundance, $x(^{13}CO)$, do not change significantly with temperature. Typical values are $n \sim 500$ cm^{-3} and $x(^{13}CO) \sim 3.5 \times 10^{-6}$.

In order to derive $N(^{13}CO)$ and thus N(CO), it is necessary to estimate the column density of molecular hydrogen, $N(H_2)$. We can obtain an estimate of $N(H_2)$ by first using a relationship between the CH and OH column densities and the optical extinction, A_V (Sandell *et al.* 1981; Crutcher 1979), and with a value of 3.1 for the selective extinction then using a general relationship between $E(B-V)$ and $N(H_2)$ (Bohlin, Savage, and Drake 1977). This method assumes that all of the gas is in molecular form; thus we obtain an upper limit for $N(H_2)$ and hence N(CO).

The column density of H_2 required to convert $x(^{13}CO)$ into $N(^{13}CO)$, and then N(CO) will be derived from the CH data; OH measurements are used as a check. With $N(CH)/A_V = 2 \times 10^{13}$ cm^{-2} mag^{-1} (Sandell *et al.* 1981; Federman 1982*b*) and with $N(CH) = 4.8 \times 10^{13}$ cm^{-2} at the cloud center, we find $A_V = 2.4$ mag and $E(B-V) = 0.77$ mag. The column density of hydrogen, $2N(H_2)$, is then found from the results of Bohlin, Savage, and Drake (1977), namely $N(H)/E(B-V) = 5.8 \times 10^{21}$ cm^{-2} mag^{-1}. This relationship predicts $N(H_2) = 2.2 \times 10^{21}$ cm^{-2} and ^{13}CO and CO column densities of 7.7×10^{15} cm^{-2} and 4.6×10^{17} cm^{-2}, respectively. We note that these values are in excellent agreement with the values deduced from the optically thin line approximation.

d) Consistency of A_V Determination

The estimate for $N(H_2)$ that was obtained from the CH measurements can also be compared with estimates derived from the OH emission, the optically thin approximation for ^{13}CO emission, and directly from extinction measurements of a star, HD 23512, that lies behind the cloud and in the direction of the cloud center. The visual extinction is obtained from the relations $N(OH)/A_V$ and $N(^{13}CO)/A_V$ found, respectively, by Crutcher (1979) and by Dickman (1978). These relations are $N(OH)/A_V = 8 \times 10^{13}$ cm^{-2} mag^{-1} and $N(^{13}CO)/A_V = 2.5 \times 10^{15}$ cm^{-2} mag^{-1} from which we derive $A_V = 3.5$ mag and 3.0 mag, respectively. Furthermore, $uvby\beta$ photometry of the star HD 23512 (Crawford and Perry 1976; McNamara 1976), *which lies a few arcminutes away from the molecular peak*, indicates a reddening of $E(B-V) = 0.36 \pm 0.01$, and a visual extinction of 1.1 mag. Thus the extinction estimates that were derived using the molecular line and photometric data all give consistent results. The consistent results among the molecular data also indicate that the abundances of CH, OH, and CO are similar in dark clouds and the intermediate density cloud studied here.

V. DISCUSSION

Two comments regarding our analysis are necessary. First, the column density of CO could not be obtained directly from the LVG model because the data fall toward the upper right-hand portion of the plots of Goldsmith *et al.*, an indication that the lines are saturated. In this portion of the plots, the curves only produce limiting values for the gas density and the abundance of CO. Second, the column density of CO from the analysis of the ^{13}CO data may be an upper limit. Since the thermal energy probably is similar to the zero point energy difference between CO and ^{13}CO, and since the nearby Pleiades cluster may be a source of ultraviolet radiation so that sufficient ionized carbon is available, fractionation may be present. That is, an isotopic ratio $^{12}CO/^{13}CO$ of less than 60 may be more appropriate (Langer 1977; Liszt 1978). For 2–3 magnitudes of extinction, the theoretical results indicate that a ratio of 25 or 30 may be more likely. The selective photodestruction of ^{13}CO over CO may take place, however, because if photodestruction of carbon monoxide occurs through the absorption of line radiation, the rarer isotope would have less optical depth in the absorption lines (Bally and Langer 1982; Chu and Watson 1983). Selective photodestruction may thus compensate for any fractionation present.

There is some evidence for fractionation in the Pleiades cloud. If $N(^{13}CO)/A_V$ for the warm ρ Oph cloud (Frerking, Langer, and Wilson 1982) is used in place of the relationship of Dickman (1978), a significantly larger value for A_V is obtained ($A_V \sim 10$ mag). Because a single CH beam lies within the CO contours with the highest radiation temperatures, beam dilution should not be a severe (factor of 4) problem. Most of the factor of 4 difference can be eliminated if fractionation is considered (see above); the remaining differences are well within observational uncertainties.

The column density of $\sim 4.5 \times 10^{17}$ cm^{-2} is larger than the values measured in diffuse clouds, but is lower than those measured toward centers of dark clouds. Even though Federman and Willson (1982) argued that diffuse clouds with large molecular contents are probably the outer regions of the more opaque, dark clouds, our results for the molecular cloud near the Pleiades are *not* an indication that we are observing the intermediate zone between diffuse clouds and dark clouds. This cloud is instead a much less opaque cloud than is generally investigated in the Taurus complex. Our observations sampled the densest, most opaque portion of the cloud, but both the CO column density and the hydrogen density are significantly lower for the cloud in our study when compared to the densities derived for other clouds in Taurus. The cloud is still predominantly molecular because for the diffuse gas like that toward ζ Oph ($A_V \sim 1$ mag), at least 30% of the gas is in molecular form (Savage *et al.* 1977). It appears reasonable to suggest that a cloud with N(CO) a factor of 100 larger than the ζ Oph cloud (Morton 1975; Liszt 1979) should be nearly all molecular.

In Taurus, the molecular clouds are generally small and filamentary, as is the cloud that we have studied. Because of the presence of reflection nebulae, the large number of H_2 molecules in excited rotational states and the large amount of CH^+ seen toward several members of the cluster, Arny (1977), Jura (1977), Federman (1982*a*), and White (1983*a*, *b*) have suggested that the cloud may be interacting with the radiation field of the stars. It appears that the cluster is moving into the cloud at a velocity of approximately 10 km s^{-1} and may be in the process of generating a shock. The shock may be necessary in order to explain the large amount of CH^+ and possibly the populations of excited H_2 rotational levels (Federman 1982*a*). There is, however, no evidence for the presence of a shock from the molecular emission, such as broadened lines in the vicinity of the cluster, although a velocity gradient of about 0.5 km s^{-1} pc^{-1} in the northwest–southwest direction may indicate fluid motion. There is no apparent correspondence between the small velocity gradient and the location of cluster stars. The sharp drop in intensity of the CO emission between the center of the cloud and the star 23 Tau suggests that photodestruction has taken place, but a molecular dissociation front need not lead to a shock (see, e.g., Hill and Hollenbach 1978). Moreover, there is still evidence for a substantial amount of CO in front of the cluster stars, since Federman *et al.* (1980) determined a lower limit of 3×10^{13} cm^{-2} for N(CO) in the direction of 20 Tau. Because a 1 K line observed in the $J = 1$–0 transition of CO corresponds to a column density of $\sim 10^{15}$ cm^{-2} (cf. Liszt 1979), emission is therefore unlikely to be observable in the direction of the stars in the cluster.

White (1983*a*, *b*) recently suggested that a dissociation front is taking place near the bright members of the Pleiades. In his analysis, H_2 is destroyed by the stellar UV radiation, thereby also populating the excited rotational levels through optical pumping (see also Jura 1977), and CH^+ is formed from the intense photoelectric heating of grains at the front. It should be noted that his model requires densities of ~ 300 cm^{-3}.

In conclusion, we have deduced from our observations of CH, OH, and CO the presence of a low density ($n \sim 300$–500 cm^{-3}), thin ($A_V \sim 3$ mag) molecular cloud in the vicinity of the Pleiades. The various methods of analyzing the molecular data lead to similar values of n and A_V, thereby strengthening the reliability of each of the techniques. Line emission was detected from all three molecules at the core of the cloud, whose position is approximately 10′ south of the star 23 Tau. The cloud is currently interacting with the cluster; optical data indicate the presence of mass motion in the form of a shock (Federman 1982*a*) or a dissociation front (Jura 1977; White 1983*a*, *b*), but no definitive evidence is seen in the molecular line data for such fluid motion.

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