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TRANSLUCENT MOLECULAR CLOUDS: THEORY AND OBSERVATIONS

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The study of interstellar clouds has traditionally been concerned with two different classes of clouds. Diffuse clouds, which have a total visual extinction $A_V \leq 2$ mag, have been observed through absorption lines of atoms and molecules at optical and ultraviolet wavelengths in the spectra of background stars. Photoprocesses, such as photodissociation and photoionization of the molecules and atoms, play an important role in the structure and chemistry of these clouds, and the fractional ionization is consequently high. Molecular clouds, which typically have $A_V > 10$ mag and much larger molecular column densities, have been studied by emission lines of molecules at centimeter and millimeter wavelengths. Because of the large extinction, photoprocesses are generally thought to be negligible inside molecular clouds, and the inferred electron abundances are much lower. Only few studies exist of clouds with $A_V \simeq 2$–10 mag, which bridge the gap between the diffuse and molecular clouds (Crutcher 1985). With the improved sensitivity of detectors in the red part of the spectrum, these clouds are amenable to study not only by radio techniques, but also through optical absorption line observations, provided that a suitable background star can be found. We will denote these clouds as "translucent molecular clouds".

On the observational side, few suitable stars behind molecular clouds have been identified. We have therefore performed a limited survey of interstellar lines toward highly-reddened stars ($V \simeq 5 - 10$ mag) in the southern sky, using the ESO 1.4 m CAT telescope with a Reticon detector, and the Cerro Tololo 4 m telescope equipped with a GEC CCD detector. Because of the reduced extinction at longer wavelengths, we searched primarily for molecules with transitions in the red part of the spectrum such as C_2 and CN. For some lines-of-sight for which C_2 was detected, the 4300 Å line of CH was also observed. Absorption lines of interstellar C_2 around 8750 Å were detected in the spectra of about one-fourth of the 36 observed stars. The inferred C_2 column densities range between 10^{13} and 10^{14} cm^{-2}, and are up to an order of magnitude larger than those found for diffuse clouds. The observed column densities of CH correlate very well with those of C_2 over this range. In contrast, the measured column densities of CN vary by orders of magnitude between the various regions, and they do not correlate with those of C_2 and CH. The observed rotational population distribution of C_2 also provides information about the physical conditions in the clouds (van Dishoeck and Black 1982). Densities n_H varying between 500 and 1500 cm^{-3}, and temperatures T ranging between 15 and 60 K were inferred.

Models of translucent molecular clouds have been constructed along the lines described by van Dishoeck and Black (1986) for diffuse clouds. The models compute accurately the fractions of atomic and molecular hydrogen as functions of depth into the clouds, as well as the excitation of H_2 by ultraviolet pumping. They also incorporate a detailed treatment of the photodissociation processes of the molecules (cf. van Dishoeck 1986), which play an important role in the chemistry up to depths of about 3 mag. In particular, the models include an accurate calculation of the depth dependence of the CO photodissociation, by using the most recent experimental

TABLE 1

Calculated column densities (in cm^{-2}) of various atoms and molecules in models with increasing total visual extinction[a]

Nr.	A_V^{tot}	T (K)	n_H (cm^{-3})	I_{UV}^b	H_2	H	CO	C	C^+	CH	C_2	CN	OH	HD
1 ...	0.8	40	500	2	5.0(20)	2.6(20)	3(14)	3(15)	2(17)	3(13)	2(13)	3(12)	4(13)	1(15)
2 ...	1.5	20	500	2	1.0(21)	3.1(20)	3(15)	2(16)	4(17)	8(13)	5(13)	1(13)	1(14)	9(15)
3 ...	2.2	20	500	2	1.5(21)	6.3(20)	4(16)	7(16)	6(17)	2(14)	2(14)	5(13)	3(14)	3(16)
4 ...	3.0	15	700	1	2.2(21)	3.2(20)	2(17)	3(16)	2(17)	2(14)	1(14)	1(14)	2(15)	6(16)
5 ...	3.0	50	1500	12	2.0(21)	8.3(20)	1(16)	5(16)	4(17)	1(14)	1(14)	2(13)	2(14)	3(16)

[a] All models have oxygen and nitrogen depletion factors $\delta_O = \delta_N$=0.5. Models 1–3 have a carbon depletion factor δ_C=0.4, whereas Models 4–5 have δ_C=0.2. A cosmic ray ionization rate $\zeta_0 = 5 \times 10^{-17}$ s^{-1} is employed throughout.

[b] Scaling factor for the strength of the ultraviolet interstellar radiation field relative to the average radiation field given by Draine (1978).

information on the predissociating lines of CO. Table 1 shows the results of the calculations for a series of cloud models with increasing total H_2 column density and extinction. The first model is representative of a typical diffuse cloud such as the cloud toward ζ Per. Model 4 has the physical conditions that are thought to prevail in the cloud in front of the star HD 29647, whereas Model 5 may be appropriate to describe the HD 147889 cloud. Table 1 clearly demonstrates the large increase (by several orders of magnitude) of the CO and C column densities relative to that of C^+ in the thicker clouds. The computed CH and C_2 column densities agree well with the observed values. The processes leading to the formation of the CN molecule are still not well understood. Further observations of translucent molecular clouds through ultraviolet absorption line observations and radio emission line measurements will be very fruitful.

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