CO ABUNDANCE AND ISOTOPIC FRACTIONATION IN DARK CLOUDS

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In order to determine molecular fractional abundances, both the molecular density and hydrogen density must be known. In this study we have determined these parameters by fitting the observed intensities of $J=2\rightarrow1$ and $J=1\rightarrow0$ ^{13}CO and $C^{18}O$ transitions using a spherical cloud LVG radiative transfer model. The kinetic temperature is determined by observations of ^{12}CO and is found to be between 9 K and 13 K for our sources. The fractional abundance of CO is expected to rise rapidly between regions of low extinction and those with $Av \geq 4$ mag, due primarily to the decrease in photodestruction rates (Langer 1976). The $C^{18}O$ fractional abundance data plotted as function of Av support a nonlinear relationship between $X(C^{18}O)$ and Av for $Av \leq 4$ mag, with an indication of an asymptotoic value $X(C^{18}O) = 2.2 \times 10(-7)$ in highly obscured regions. For $^{16}O/^{18}O$ ratios of 250 (suggested by our data although possible uncorrected saturation of ^{13}CO makes this a lower limit) and 700 (A. Penzias, private communication) the fractions of carbon in CO in well-shielded regions are .08 and .23, respectively.

SOURCE	$n(H_2)$	A_V	$^{13}CO/C^{18}O$	$C^{18}O/^{13}C^{18}O$	$C^{18}O/C^{17}O$
B5	3150	>7.6	4.1	50	3.0
B335	3150	>5.2	2.5	49	2.2
L1262	3150	>4.3	5.3	44	3.3
B5(-8,0)	2150	1.5	17.9		
B5(0,-14)	2150	3.0	25.8		
B5(0,-16)	3150	3.0	29.1		
B335 (-4,2)	2150	1.0	33.1		
L1262(12,0)	1450	1.5	36.0		
L1262(0,-6)	700	3.0	29.4		

The transition region in which the $C^{18}O$ fractional abundance is rising is characterized by an elevated $^{13}CO/C^{18}O$ abundance ratio, which reaches a value 3 to 7 times greater than in the cloud cores. This effect is consistent with the presence of the isotopic exchange reaction discussed by Watson, Anicich, and Huntress 1976 taking place in the

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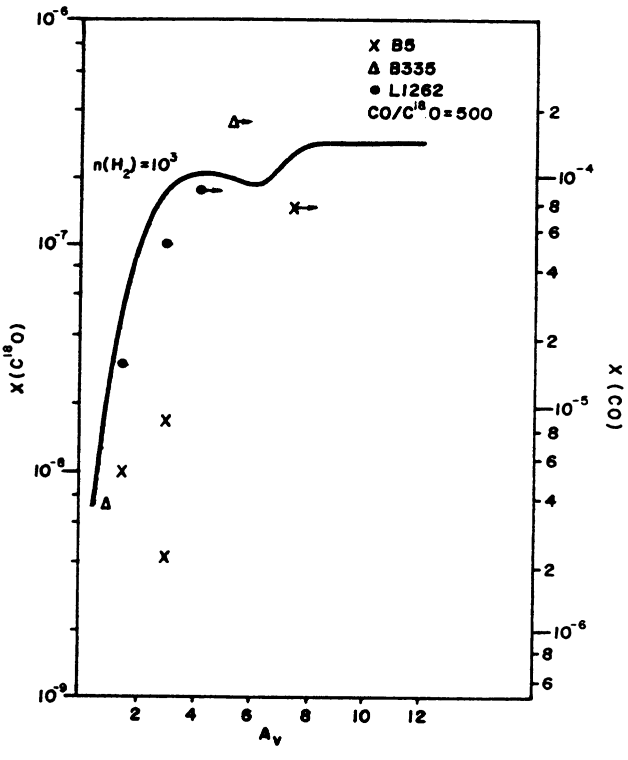
partially shielded cloud edges (Langer 1977). These results are discussed more fully by Langer *et al.* (1980).



Measured $C^{18}O$ fractional abundance as a function of A_v with corresponding CO abundances for $^{16}O/^{18}O = 500$. The theoretical curve is from Langer 1976.

REFERENCES

Langer, W. D. 1976, Ap. J., 206, 699.
Langer, W. D. 1977, Ap. J., 212, L39.
Langer, W. D., Goldsmith, P. F., Carlson, E. R., and Wilson, R. W. 1980, Ap. J. (Letters), in press.
Watson, W. D., Anicich, V. G., and Huntress, W. T., Jr. 1976, Ap. J., 205, L165.

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DISCUSSION FOLLOWING GOLDSMITH

Dickinson: Your last slide shows the varying abundance ratio for the two isotopically substituted CO species. The errors are clearly bad in the wings of the line; over how great a velocity range do you consider the ratio reliable?

Goldsmith: The double ratio (of $^{13}C^{16}O/^{12}C^{18}O$ antenna temperatures) increases from $\sim$4 at line centers to a value of 12-20 where the signal to noise prevents further analysis. This occurs at velocities differing from the central velocity by 1 km s^{-1}, with our present sensitivity. If large scale mass motions of the form $V(r)=r^{\alpha}, \alpha>0$ dominate line formation, then as we look further in the wings we are seeing material further removed from the cloud centers, and the high ratios confirm that the chemical isotopic fractionation process is indeed occurring there.

Plambeck: The large-velocity-gradient model gives you the CO fractional abundance divided by the velocity gradient, not the fractional abundance directly. How did you determine the velocity gradients, and what uncertainty does this introduce into your fractional abundances?

Goldsmith: A good point! We have mapped the clouds, and used the linewidth divided by the linear size for the velocity gradient. This procedure introduces a formal error of approximately 50%, but a bigger uncertainty is in knowing how well this radiative transfer model applies.

de Jong: Your derived CO abundance of $X(CO) \simeq 10^{-4}$ seems to be inconsistent with the upper limit derived from the observed DCO^+/HCO^+ ratios in dark clouds. It probably means that the largest contribution to the CO signal comes from the outer parts of the cloud ($A \lesssim 4$), where the CO abundance may indeed be of the order of magnitude that you mentioned.

Goldsmith: More recent observations of the DCO^+/HCO^+ ratio by Langer and collaborators show that, due to severe self-absorption of HCO^+ (indicated by the study of $H^{13}CO^+$ and other isotopes), the deuterium fractionation is not as large as previously thought. This relaxes the upper limit on X(CO) so that it is now consistent with our derived value.

Kutner: Regarding the so-called "Dickman" ratio, two points should be made:

(1) A point that is often missed is that Dickman's result is essentially an observational prescription for converting apparent ^{13}CO column density into H_2 column density. As such, the details of how that result comes about do not necessarily affect its validity.

(2) If the relation does break down, the effect on derived cloud mass depends on how that ratio is used, so you can get an overestimate or an underestimate.

Goldsmith: Our data are more restricted than Dickman's but have the advantage of higher signal-to-noise ratio, better velocity resolution, and the J=2-1 lines. I feel that our analysis is probably somewhat more accurate, but our results do NOT differ violently from Dickman's: although $X(C^{18}O)$ drops radically at low extinctions, the isotopic fractionation enhances the relative abundance of ^{13}CO, tending

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to give a more linear relationship between column density and A_V for this molecule.

Bok: Dickman's formula for going from ^{13}CO numbers to H_2 numbers referred originally (thesis) only to very dense globules for which the zone with A_V<5 mag. was too thin to be significant for mass estimates.

Goldsmith: An accurate determination of cloud mass from CO observations requires a knowledge both of the fraction of the mass corresponding to regions of various extinctions and of the variation of the fractional abundance of CO with extinction.