ISOTOPIC ABUNDANCE RATIOS FROM MICROWAVE OBSERVATIONS OF FORMALDEHYDE

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This report is a summary of the determination of the ratio of the column density of $H_2{}^{12}C^{16}O$ (hereafter H_2CO) or $H_2{}^{12}C^{18}O$ (hereafter $H_2C^{18}O$) to that of $H_2{}^{13}C^{16}O$ (hereafter $H_2{}^{13}CO$). With one exception, all of the published ratios have been determined from measurements of the $1_{10}-1_{11}$ lines. The exception is the Orion Molecular Cloud (see discussion of Kutner et al. 1976). The most complete surveys of $H_2{}^{13}CO$ are those of Wilson et al. (1976) and Gardner and Whiteoak (1979). The ratios obtained from $1_{10}-1_{11}$ data are lower limits because of the effect of photon trapping in H_2CO (see the discussion by Henkel et al. 1979b). From measurements of the $1_{10}-1_{11}$ and $2_{11}-2_{12}$ lines and model calculations, Henkel et al. estimate that the corrections for 10 clouds outside the Galactic center region is $1.6{\pm}0.7$. This correction gives an average ($H_2CO/H_2{}^{13}CO$) ratio of $64{\pm}17$. The models of Henkel et al. also predict the optical depth of the $3_{12}-3_{13}$ line and the brightness temperature of the $2_{12}-1_{11}$ line. Preliminary measurements of Wilson et al. (1979) show that the $3_{12}-3_{13}$ results are consistent with the predictions; but more sensitive measurements are required to test the model fully. Unpublished $2_{12}-1_{11}$ emission-line spectra are weaker than predicted by the model, but this might be caused by beam dilution, since the observations were made so as to cover a 1.5' uniformly weighted aperture. The lineshapes of the $1_{10}-1_{11}$ and $2_{11}-2_{12}$ absorption lines agree poorly with the $2_{12}-1_{11}$ emission lines, indicating either that self-absorption in the millimeter lines of H_2CO is important, or that there are H_2CO clouds behind the continuum sources. Because of their position relative to the continuum sources these clouds would contribute to the millimeter emission lines but not to the centimeter absorption lines.

In a few sources such as the molecular clouds toward the high brightness HII regions W33, W51, Sgr B_2 and Sgr A it is possible to determine the ratio of $H_2C^{18}O$ to $H_2{}^{13}CO$. Because both of these rare isotopes are optically thin, no trapping corrections are required. The average ratios obtained by Tucker et al. (1979) and Henkel et al. (1979a) are about twice the ratio of the column density of $^{12}C^{18}O$ to $^{13}C^{16}O$ measured by Wannier et al. (1976) for 14 molecular clouds. The difference in these double ratios is an indication that ^{13}CO is enhanced by a fractionation

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process (see discussion by Watson and R.W. Wilson et al., in this volume). The Sgr B_2 molecular cloud was not analyzed by Henkel et al. (1979b) because of the large optical depth in the $1_{10}-1_{11}$ line. However, measurements of the $3_{12}-3_{13}$ line, and model calculations indicate that the correction for photon trapping is about a factor of 2. From this factor and measurements of the $1_{10}-1_{11}$ line, the ($H_2CO/H_2{}^{13}CO$) ratio is about 25. Combining this result with the ($H_2{}^{12}C^{18}O/H_2{}^{13}C^{16}O$) average ratio from Tucker et al. (1979) and Henkel et al. (1979a), we find ($^{16}O/^{18}O$) = 160, which is significantly below the terrestrial value of 489 (Heath 1976).

A partial map of the Orion Molecular Cloud in the $3_{12}-3_{13}$ line with a ∿30" angular resolution shows that structure on the order of 20" exists in the source. This measurement is consistent with the model of Evans et al. (1979) which predicts an H_2 density of $\sim 10^6$ cm^{-3}. From the analysis of the Sgr B_2 cloud, the density is $\sim 10^{4.2}$ cm^{-3}; and for the 10 clouds studied by Henkel et al. (1979b) the density is $\sim 10^5$ cm^{-3}. These densities are 10-100 times those obtained from measurements of CO by Plambeck and Williams (1979) but agree roughly with the CS results of Linke and Goldsmith (1979). It is possible that different molecules are located mainly in different regions of the clouds, where different H_2 densities are present.

REFERENCES

Evans, N.J., Plambeck, R.L., Davis, J.H.: 1979, Astrophys. J. Lett. 227, L25
Gardner, F.F., Whiteoak, J.B.: 1979, Monthly Notices Roy. Astron. Soc. 188, 331
Heath, R.L.: 1976 in "Handbook of Chemistry and Physics", 57th Edition, ed. R.C. Weast, CRC Press, Cleveland, p. B-270
Henkel, C., Wilson, T.L., Downes, D.: 1979a, Astron. Astrophys. 73, L13
Henkel, C., Walmsley, C.M., Wilson, T.L.: 1979b, Astron. Astrophys., in press
Kutner, M.L., Evans, N.J., Tucker, K.D.: 1976, Astrophys. J. 209, 452
Linke, R.A., Goldsmith, P.: 1979, this volume
Plambeck, R.L., Williams, D.R.W.: 1979, Astrophys. J. 227, L43
Tucker, K.D., Kutner, M.L., Massano, W.: 1979, Astrophys. J. Lett. 227, L143
Wannier, P.G., Penzias, A.A., Linke, R.A., Wilson, R.W.: 1976, Astrophys. J. 204, 26
Wilson, T.L., Bieging, J., Downes, D., Gardner, F.F.: 1976, Astron. Astrophys. 51, 303
Wilson, T.L., Walmsley, C.M., Henkel, C., Pauls, T., Mattes, H.: 1979, Astron. Astrophys., in press

DISCUSSION FOLLOWING WILSON

Field: The density you derive for H_2 depends on the rotational-excitation rate-coefficients. The cross-sections given by Sheldon Green are for He-HCHO collisions and may be rather different for H_2-HCHO collisions. Even if H_2 is in the J=0 state, the anisotropy of the potential may be significantly different from that of He. A further point is that very recent calculations by Gerratt and Wilson in Bristol (U.K.) show that cross-sections for rotational excitation are sharply resonant with kinetic energy of He in collisions with HCHO. With a knowledge of the temperatures at which these resonances occur we may be able in the future to characterize cloud temperatures by anomalously high populations of excited rotational states.

Wilson: There are still problems in that we are always making line-of-sight averages in astronomy and in that the density of H_2 is a free parameter. Our density estimates depend on the collisional cross-sections, so estimates of the effect of substituting H_2 for He as a collision partner would be valuable.

Guélin: There is evidence that a cold, low density (10^2-$10^3 cm^{-3}$) foreground cloud lies in the line of sight to the Sgr B2 source at $V \sim 62$ km/s (e.g. the HCO^+ data of Guélin and Thaddeus, 1979). How will the presence of this low density cloud affect your results?

Wilson: The line shapes of the 1_{10}-1_{11} lines of $H_2^{12}C^{18}O$ and $H_2^{12}C^{16}O$ agree, yet $H_2^{12}C^{18}O$ is optically thin, while $H_2^{12}C^{16}O$ has a measured optical depth of 1.3-1.8. Hence we do not believe that self-absorption affects our 1_{10}-1_{11} line. It may be that the H_2CO is in some way related to the low density foreground cloud that you observe. However, the absorption is associated with the region in front of the compact continuum sources, a fact which may explain our higher density ($n(H_2) \sim 10^{4.2} cm^{-3}$) and kinetic temperature ($T_K \sim 60K$). Similar parameters for $n(H_2)$ and T_K were obtained by Winnewisser, Walmsley and Churchwell (1978) from NH_3 absorption toward Sgr B2.

Greenberg: I know that density alone is not the best way to distinguish the clouds you considered, but did you find any significant difference in the carbon isotopic ratio as a function of density? It appeared to me that Sgr B2, which has the lowest density, also had the lowest $^{13}C/^{12}C$ ratio.

Wilson: Unfortunately, the Sgr B2 cloud is the only one in our sample in which the density and the ($^{12}C/^{13}C$) ratio are low. The ($^{12}C/^{13}C$) ratios of the other 10 sources are scattered, whereas $n(H_2)$ is, in all cases, close to $10^5 cm^{-3}$.

de Jong: Should your results be interpreted to mean that H_2CO can only form in high density regions or do they mean only that high densities are required to excite the H_2CO molecules sufficiently?

Wilson: Because we make use of measurements of the 1_{10}-1_{11} line, which is the lowest K-doublet in the K_a=1 ladder, the excitation should not be dependent on high densities. The H_2CO is located mainly in regions where $n(H_2) \simeq 10^5 cm^{-3}$, though you should note that we assume that clouds are spheres or slabs of uniform density and uniform temperature.

Evans: I have to disagree with your conclusion that H_2CO exists only in dense regions. We find that the H_2CO abundance actually decreases in dense regions.

Wilson: "Dense" is a vague term. Our results show that the H_2CO occurs where $n(H_2){\sim}10^5 cm^{-3}$. Plambeck and Williams (1979) derive $n(H_2){\sim}10^2$-$10^3 cm^{-3}$ from a similar study of CO. The H_2CO is located in a denser region than that. We know that regions where $n(H_2){\sim}10^6 cm^{-3}$ (e.g. Orion) exist, but we obtain (except for Orion) no such high density. So in this sense we agree. Finally our results apply to molecular clouds near HII regions, and you are comparing them to results obtained for dark dust clouds.

Evans: Your result in OMC 1 agrees with our model, which requires the presence of small dense clumps, and results in a $H_2^{12}CO/H_2^{13}CO$ ratio higher than 100.

Wilson: Our map of Orion in the 3_{12}-3_{13} line of H_2CO should give us a direct check of your angular size predictions.