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PRECISE LABORATORY MEASUREMENT OF THE 4830-MHz FORMALDEHYDE ROTATIONAL TRANSITION

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ABSTRACT

The frequencies of the hyperfine components of the $1_{10} \rightarrow 1_{11}$ rotational transition of H_2CO have been measured with a molecular-beam maser to an absolute precision of about 1 part in 10^8.

Radial velocities of interstellar H_2CO derived from radio observation of its 4830-MHz line (Zuckerman *et al.* 1970) have to date been based on a laboratory measurement of the transition hyperfine frequencies made by Shigenari (1967). We have recently begun a systematic measurement to high precision of a number of lines of H_2CO and its isotopic species that are of interest to radio astronomy. On remeasurement of the line of the normal isotopic species studied by Shigenari, we have found absolute hyperfine frequencies that are systematically 10 kHz greater than his values, for which an uncertainty of 0.5 kHz is quoted. Our hyperfine splittings, however, are in good agreement with his. Ten kilohertz at 4830 MHz corresponds to a velocity of 0.6 km sec^{-1} and is comparable to the width of the 4830-MHz absorption lines observed in many dark clouds.

Our spectrometer is a beam maser with a cylindrical resonant cavity 30 cm long operating in the TM_{010} mode. The cavity is wrapped in a thin sheet of μ-metal to cancel out the terrestrial magnetic field, which causes Zeeman shifts of the 4830-MHz hyperfine components that amount to an appreciable fraction of 1 kHz. This arrangement yields line widths of only 1.3 kHz when the H_2CO molecular beam is produced by a crinkly-foil effuser of the type used in the first ammonia maser (Gordon, Zeiger, and Townes 1955).

To observe the molecular resonances, we used as a microwave source the extremely stable and spectrally pure tenth harmonic of a Hewlett-Packard 5105 A frequency synthesizer, whose frequency was known to better than 1 part in 10^9 by continuous reference to station WWVB, and to three parts in 10^9 from occasional measurement in this laboratory of the hfs, of ^{85}Rb (W. Stern, private communication). By employing beam chopping at 37 Hz and phase-sensitive detection following the spectrometer's superheterodyne receiver, it was possible to attain a signal-to-noise ratio of $\sim$1000:1 for the most intense H_2CO lines in 1 sec of integration. Even stronger signals (but somewhat poorer line widths), leading to simultaneous maser oscillation at the $F = 2 \rightarrow 2$, $1 \rightarrow 2$, and $1 \rightarrow 1$ hyperfine components, were achieved when the beam was produced by hydrodynamic flow through a single small ($\frac{1}{64}$-inch diameter) hole.

The measured values of the $1_{10} \rightarrow 1_{11}$ hyperfine components are listed in Table 1. The quoted uncertainties represent in each case the standard deviation of a total of eight measurements. It would be possible to determine the transition frequencies to even higher precision from a study of the maser oscillations in a well-stabilized cavity, but since the uncertainty of 0.050 kHz in the frequencies of the emission lines given in Table 1 corresponds to a velocity of only 300 cm sec^{-1}, we have been content to show that the frequencies determined from the emission lines and from the maser oscillations are in good agreement.

Finally, it should be noted that, after the discovery of interstellar H_2CO, an attempt was made to deduce the precise rest frequency of the 4830-MHz transition in terms of the known frequencies of OH by assuming that H_2CO and OH lines in various clouds are formed at identical radial velocities (Snyder *et al.* 1969). Under conditions of thermal excitation, the central frequency of the unresolved transition will be very nearly that of the most intense $F = 2 \rightarrow 2$ hyperfine component. From the lines in Cas A and NGC 2024, the rest frequency was determined to be 4829659 ± 10 kHz, which is in precise agreement with our measurement of the $F = 2 \rightarrow 2$ hyperfine transition, but also not

TABLE 1

MEASURED HYPERFINE COMPONENTS OF THE $1_{10} \rightarrow 1_{11}$ H_2CO TRANSITION

$F \rightarrow F'$ Transition*	Relative Intensity (Theoretical)	Frequency (kHz)
2→2.........	15	4829 659.61±0.05
1→1.........	3	4829 671.04±0.05
2→1.........	5	4829 664.01±0.05
1→2.........	5	4829 666.44±0.05
1→0.........	4	4829 641.43±0.06
0→1.........	4	4829 658.61±0.12†

* F refers to the upper rotational level and F' to the lower rotational level of the transition.

† This line cannot be resolved from the 2 → 2 transition. Since the hyperfine structure is overdetermined, this value is calculated from the other frequencies.

inconsistent with Shigenari's value of 4829649 kHz. Subsequent analysis in this way of a number of formaldehyde sources (Zuckerman *et al.* 1970) has led to a rest frequency that is apparently in good agreement with Shigenari's value but disagrees with ours. The origin of this discrepancy is unclear.

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