

## FAR-INFRARED AND MICROWAVE SPECTROSCOPY OF HCOOCH<sub>3</sub> II.

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The known interstellar molecule, methyl formate (HCOOCH<sub>3</sub>) has been studied by microwave spectroscopy since 1959<sup>a</sup>. The laboratory spectra of methyl formate exhibit many unassigned transitions and are due to rotational transitions in the low-lying vibrational excited states. The first torsional excited state was reported in 2003<sup>b</sup>, and up to the second torsional excited state was identified in laboratory and in space.<sup>c d</sup>

Our laboratory microwave spectra include a series of unknown  $K_a=0,1$  transitions. Based on relative intensities, we estimate that these transitions arise from an excited state about 300 cm<sup>-1</sup> above the ground state. To facilitate identification, we have taken spectra of methyl formate in the 260-370 cm<sup>-1</sup> range at Far-Infrared Beamline of the Canadian Light Source synchrotron. The resolution was instrument-limited to 0.00096 cm<sup>-1</sup>. The spectra were very dense, and included the overlapping  $\nu_{12}$  (C-O-C deformation) and  $\nu_{17}$  (C-O torsion) modes. Conventional assignment proved very difficult, so we calculated a-type  $K_a=0, 1$  rotation-vibration spectra based on the unknown and ground-state microwave data, and gave them arbitrary origins near 300 cm<sup>-1</sup>. By correlating them with the far-infrared spectrum, we were able to determine that the new series correspond to  $\nu_{12}$  near 312 cm<sup>-1</sup>.<sup>e</sup> We will report on our assignment technique and results, as well as any further developments we have made in extending the assignments of both the microwave and far-infrared spectra.

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<sup>a</sup>R. F. Curl, *J. Chem. Phys.* **30**, 1529 (1959).

<sup>b</sup>H. Odashima, K. Ogata, K. Takagi, & S. Tsunekawa, *Molecules* **8**, 139 (2003).

<sup>c</sup>S. Takano, Y. Sakai, S. Kakimoto, M. Sasaki, & K. Kobayashi, *Publ. Astron. Soc. Jpn.* **64**, 89 (20012).

<sup>d</sup>K. Kobayashi, K. Takamura, Y. Sakai, S. Tsunekawa, H. Odashima, & N. Ohashi, *Astrophys. J. Suppl. Ser.* **205**, 9 (2013) and references therein.

<sup>e</sup>K. Kobayashi, Y. Sakai, M. Fujitake, D. W. Tokaryk, B. E. Billinghurst & N. Ohashi, *Submitted to Can. J. Phys.*