Acknowledgment. We are grateful to the Natural Sciences and Engineering Research Council of Canada for financial support.

Supplementary Material Available: Tables of atomic coordinates, temperature factors, and bond lengths and angles for **1** and **2** (7 pages). Ordering information is given on any current masthead page.

Microwave Spectrum and Structure of the Trimethylamine–Sulfur Dioxide Charge-Transfer Complex[1]

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It has been pointed out by Tamres[2] and others[3] that trimethylamine–sulfur dioxide (TMA·SO_2) is the only charge-transfer complex for which the reaction thermodynamics are known in both solution and gas phase as well as the solvation and lattice energies necessary to complete the cycle.[3-5] Its dipole moment[6] and matrix IR spectrum[7] have been reported. Ab initio calculations gave N–S distances of 2.86[8] and 2.36 Å[9] compared with 2.06 Å by X-ray crystallography.[10] The SO_2 plane reportedly makes an angle with the TMA symmetry axis of 90–95° in the theoretical studies and 112° in the crystallographic study, with the sulfur atom close to the TMA axis. A 90° approach is not expected for a dipolar interaction but is favored when higher order electrostatic terms are considered.[11]

Such charge-transfer complexes have not been studied by conventional microwave spectroscopy due to the complexity of typical systems and their small equilibrium concentrations at low pressures. We have recently observed the rotational spectrum of TMA·SO_2 formed in a supersonic expansion using a Fourier-transform microwave (FTMW) spectrometer.[12,13] This has provided some insight on the structure of the complex.

A TMA·SO_2 sample[14] was held at 75–125 °C in a small chamber attached to a modified Bosch fuel injector pulsed valve. The equilibrium vapor above the sample (about 99% dissociated TMA·SO_2) was mixed with 1–2 atm of argon and pulsed through a 1-mm orifice into the resonant cavity of the FTMW spectrometer. Transitions were observed split by the ^{14}N quadrupole interaction. Components (64) from 18 μ_a and μ_c transitions involving J's between 1 and 4 were fit with an RMS deviation of 2.6 kHz. A weaker set of transitions were found in the regions expected for the ^{34}S species (4% abundance), and 31 components from 10 transitions were similarly fit. No evidence of internal rotation or inversion motions was seen. The spectral constants and selected inertial parameters are listed in Table I. The transition data are available as Supplementary Material.

Table I. Spectroscopic Constants for TMA·SO_2

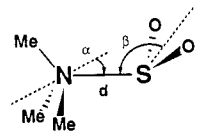
	TMA·$^{32}SO_2$[a]	TMA·$^{34}SO_2$	free TMA, SO_2[b]
A, MHz	3179.789 (6)	3172.628 (50)	
B, MHz	1720.319 (1)	1703.240 (3)	
C, MHz	1503.603 (1)	1492.122 (2)	
$I_a + I_c - I_b$, amu·Å^2	201.2752	201.2778	199.63
χ_{aa}, MHz	−3.52 (1)	−3.43 (3)	−5.47 (3)
χ_{bb}, MHz	1.96 (1)	1.88 (10)	2.74 (3)
χ_{cc}, MHz	1.57 (1)	1.55 (10)	2.74 (3)

[a] Centrifugal distortion constants (kHz): D_J = 0.84 (4), D_{JK} = −0.79 (7), D_K = 4 (1). [b] Data from ref 15 and 16.

Table II. Structural Parameters of TMA·SO_2

	I[a]	II[a]	III[a]	Kraitchman[b]
d(N–S), Å	2.25	2.25	2.29	
α, deg	17.2	17.5	20.3	
β, deg	90.9	90.8	90.9	
$\lvert a_s \rvert$, Å	1.168	1.164	1.156	1.147
$\lvert c_s \rvert$, Å	0.367	0.374	0.386	0.430
ΔI,[c] amu·Å^2	0.570	0.038	0.032	

[a] Least-square fitting of observed moments and assumptions described in text. [b] Kraitchman substitution coordinates.[17] [c] $\Delta I = (I_{obsd} - I_{calcd})$ rms.



The N–S distance and the tilt angles α and β relative to the N–S distance can be estimated from the inertial parameters; however, some ambiguities are encountered. The ab initio structures and the observed selection rules suggest an *ac* symmetry plane which passes through N, S, and one C atom. This is confirmed by the agreement in $I_a + I_c - I_b$ for the two isotopic species (Table I), which should be invariant for substitution in this plane. The observed value of $I_a + I_c - I_b$ is 1.65 amu·Å^2 larger than calculated from the undistorted structures of free TMA and SO_2,[15,16] suggesting either a distortion of one or both subunits or a large amplitude internal motion.

There are other indications that a change in subunit(s) geometry should be considered, unlike hydrogen-bonded or van der Waals dimers in which the component structures remain virtually unchanged. The decrease in the quadrupole coupling constants from TMA seem too large to arise entirely from a large amplitude motion; for example, the change in χ_{bb} would imply an average out-of-plane bending amplitude of nearly 26°. These sizeable changes might imply an electronic redistribution which could affect the subunit geometries. The appreciable shifts in SO_2 vibrational frequencies[7] and the large dipole moment of the complex (4.60 D[6]) also suggest possible geometric changes in the subunits.

To estimate the N–S distance and the tilt angles α and β we adopt three strategies. (1) The TMA and SO_2 structures are fixed at the free molecule geometries, and their orientations adjusted in a least-squares fit to the moments of inertia of both species. This gives a poor fit since $I_a + I_c - I_b$ cannot match the experimental value (see above). (2) The S–O bonds are lengthened by 0.012 Å to match the observed $I_a + I_c - I_b$, repeating the least-squares fit. (3) The C–N–C angles in TMA are increased by 1.5° to match $I_a + I_c - I_b$ (SO_2 unchanged), and the least-squares fit is repeated. The results are listed in Table II along with a com-

(1) Dedicated to Prof. Milton Tamres upon appointment to Professor Emeritus status.
(2) Tamres, M. *Molecular Complexes*; Foster, R.; Ed.; Crane, Russak: New York, NY, 1973; Vol. 1, pp 49–116.
(3) Grundnes, J.; Christian, S. D.; Cheam, V.; Farnham, S. B. *J. Am. Chem. Soc.* **1971**, *93*, 20.
(4) Christian, S. D.; Grundnes, J. *Nature (London)* **1967**, *214*, 1111.
(5) Grundnes, J.; Christian, S. D. *J. Am. Chem. Soc.* **1968**, *90*, 2239.
(6) Moede, J. A.; Curran, C. *J. Am. Chem. Soc.* **1949**, *71*, 852.
(7) Sass, C. S.; Ault, B. S. *J. Phys. Chem.* **1984**, *88*, 432.
(8) Lucchese, R. R.; Haber, K.; Schaefer III, H. F. *J. Am. Chem. Soc.* **1976**, *98*, 7617.
(9) Douglas, J. E.; Kollman, P. A. *J. Am. Chem. Soc.* **1978**, *100*, 5226.
(10) Van der Helm, D.; Childs, J. D.; Christian, S. D. *Chem. Commun.* **1969**, 887.
(11) (a) Kollman, P. A. *Acc. Chem. Res.* **1977**, *10*, 365. (b) Singh, U. C.; Kollman, P. A. *J. Chem. Phys.* **1984**, *80*, 353.
(12) Hillig II, K. W.; Matos, J.; Scioly, A.; Kuczkowski, R. L. *Chem. Phys. Lett.* **1987**, *133*, 359.
(13) Balle, T. J.; Flygare, W. H. *Rev. Sci. Instr.* **1981**, *52*, 33.
(14) Burg, A. B. *J. Am. Chem. Soc.* **1943**, *65*, 1629.
(15) Harmony, M. D.; Laurie, V. W.; Kuczkowski, R. L.; Schwendeman, R. H.; Ramsay, D. A.; Lovas, F. J.; Lafferty, W. J.; Maki, A. G. *J. Phys. Chem. Ref. Data* **1979**, *8*, 619.
(16) Lide, D. R.; Mann, D. E. *J. Chem. Phys.* **1958**, *28*, 572.

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parison of the sulfur *a* and *c* coordinates calculated from Kraitchman's equations.[17]

The fits show the sensitivity to the model assumptions. These and other calculations indicate that d(NS) is between 2.25 and 2.30 Å while α is 19° ± 5° and β is 91° ± 2°. The inertial data cannot distinguish whether the TMA staggers or eclipses the S–O bonds. It appears worthwhile to examine this question and to ascertain the extent of any structural changes in TMA and SO_2 by obtaining additional isotopic data. This work is in progress as well as a reevaluation of the structure of crystalline TMA·SO_2.

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Supplementary Material Available: Tables S1–S3 listing hyperfine fitting of transition frequencies and centrifugal distortion fitting of the unsplit frequencies (6 pages). Ordering information is given on any current masthead page.

(17) Kraitchman, J. *Am. J. Phys.* **1953**, *21*, 17.

Novel Approaches to Functionalized Nucleosides via Palladium-Catalyzed Cross Coupling with Organostannanes

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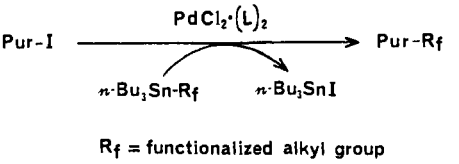
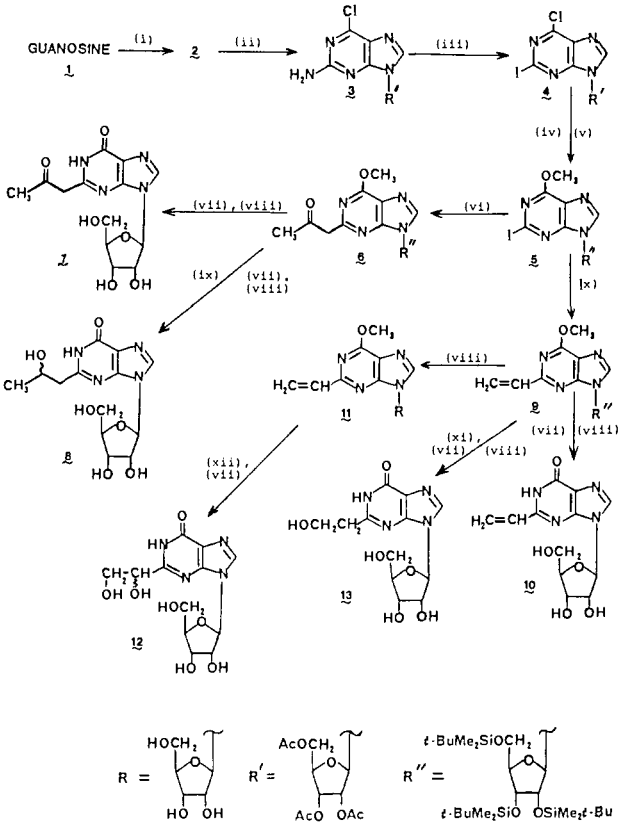
Purine nucleosides and related systems are currently receiving a considerable amount of renewed interest because of the remarkable biological activity of some of these compounds as antiviral agents.[1-4] Although a wide variety of C-6 substituted purine nucleosides bearing functionalized alkyl groups are known, the same cannot be said for the C-2 position.[5] While a number of simple C-2 alkylated compounds have been synthesized,[6-9] very few functionalized alkyl derivatives have been reported.[10] The single general method known for obtaining 2-alkylated purine nucleosides involves ring closure from the appropriately substituted ribofuranosyl imidazole.[6-8] A few other methods are known but are of limited scope.[11,12] Functionalized C-2 alkylated inosine analogues are not only of considerable potential interest as antiviral agents[4] but also there is enzymological interest in these novel compounds as potential inhibitors of a key purine metabolizing enzyme, inosine monophosphate dehydrogenase.[13] This communication reports on the development and application of a general methodology (Scheme I) for the introduction of functionalized carbon–carbon bonding at the 2-position of the hypoxanthine ring.

Scheme I



R_f = functionalized alkyl group

Scheme II



[a] (i) Ac_2O, $(C_2H_5)_3N$, *N,N*-(dimethylamino)pyridine; (ii) $POCl_3$, *N,N*-diethylaniline, Δ; (iii) n-$C_5H_{11}ONO$, CH_2I_2, CH_3CN; (iv) $NaOCH_3$, MeOH; (v) t-Bu$(CH_3)_2SiCl$, imidazole, DMF; (vi) $Pd(OAc)_2$, (o-Tolyl)$_3$P, n-Bu_3SnOMe, $CH_2{=}C(CH_3)OAc$, toluene, Δ; (vii) $(CH_3)_3SiI$, CH_3CN; (viii) Et_4NF, CH_3CN; (ix) $NaBH_4$, THF; (x) n-$Bu_3SnCH{=}CH_2$, $PdCl_2(CH_3CN)_2$, toluene, Δ; (xi) 9-BBN, THF, Δ; (xii) OsO_4, pyridine.

A logical approach to the synthesis of these rare nucleosides would be through the corresponding 2-halogenated precursor. Thus, protected 2-iodo-6-methoxypurine **5** was the key precursor for all of the target molecules described in this communication. This precursor can be prepared from the 6-chloro-2-aminopurine **3**[14,15] in three steps. The first step (i.e., **3** → **4**) involved a radical deamination–halogenation procedure developed and previously reported by us.[16,17] Nucleophilic displacement of the 6-chloro group in **4** with methoxide was accompanied by the desired deprotection of the acetate groups (96% yield). Subsequent protection of the carbohydrate moiety with *tert*-butyldimethylsilyl chloride and imidazole in DMF[18] gave **5** in 96% yield. The key step in the synthesis of the target molecule **7** was the conversion of **5** to **6** in 70% yield by a palladium-catalyzed cross-coupling reaction (Schemes I and II). This conversion presumably involves

(1) De Clercq, E. *J. Med. Chem.* **1986**, *29*, 1561.
(2) Robins, R. K. *Chem. Eng. News* **1986** (Jan. 27, 28).
(3) Mitsuya, H.; Broder, S. *Proc. Natl. Acad. Sci. U.S.A.* **1986**, *83*, 1911.
(4) *Targets for the Design of Antiviral Agents*, De Clercq, E., Walker, R. T., Eds.; Plenum Press: New York, 1984.
(5) (a) Nair, V.; Chamberlain, S. D. *J. Am. Chem. Soc.* **1985**, *107*, 2183. (b) Nair, V.; Chamberlain, S. D. *J. Org. Chem.* **1985**, *50*, 5069.
(6) Yamazaki, A.; Kumashiro, I.; Takenishi, T. *J. Org. Chem.* **1967**, *32*, 3258.
(7) Imai, K.; Marumoto, R.; Kobayashi, K.; Yoshioka, Y.; Toda, J. *Chem. Pharm. Bull.* **1971**, *19*, 576.
(8) Marumoto, R.; Yoshioka, Y.; Miyashita, O.; Shima, S.; Imai, K.; Kawazoe, K.; Honjo, M. *Chem. Pharm. Bull.* **1975**, *23*, 759.
(9) *Chem. Abstr.* **1983**, *99*, P120680n.
(10) Matsuda, A.; Nomato, Y.; Ueda, T. *Chem. Pharm. Bull.* **1979**, *27*, 183.
(11) Matsuda, A.; Satoh, K.; Miyasaka, T.; Ueda, T. *Chem. Pharm. Bull.* **1984**, *32*, 2048.
(12) Matsuda, A.; Shinozaki, M.; Miyasaka, T.; Machida, H.; Abiru, T. *Chem. Pharm. Bull.* **1985**, *33*, 1766.
(13) Wong, C. G.; Meyer, R. B., Jr. *J. Med. Chem.* **1984**, *27*, 429.
(14) Gerster, J. F.; Jones, J. W.; Robins, R. K. *J. Org. Chem.* **1963**, *28*, 945.
(15) Nair, V.; Young, D. A.; DeSilvia, R., Jr. *J. Org. Chem.* **1987**, *52*, 1344.
(16) Nair, V.; Richardson, S. G. *J. Org. Chem.* **1980**, *45*, 3969.
(17) Nair, V.; Richardson, S. G. *Synthesis* **1982**, 670.
(18) Ogilvie, K. K.; Beaucage, S. L.; Shifman, A. L.; Theriault, N. Y.; Sadana, K. L. *Can. J. Chem.* **1978**, *56*, 2768.

0002-7863/87/1509-7223$01.50/0