

Anchimerically Assisted Redox Reactions. 7. A Comparison of the Effects of Neighboring Primary, Secondary, and Tertiary Amine Groups on the Kinetics and Mechanism of Thioether Oxidation by Aqueous Iodine¹

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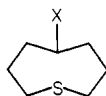
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Received November 9, 1982

Neighboring group participation between primary, secondary, and tertiary amine groups and a thioether during the aqueous oxidation of 5-amino-1-thiacyclooctane (1), 5-(methylamino)-1-thiacyclooctane (2), and 5-(dimethylamino)-1-thiacyclooctane (3) is indicated by anchimeric assistance. The following rate law is observed in the pH range 4-8: $d(\text{RSR})/dt = -k_{\text{ox}}[\text{RSR}][\text{I}_3^-][\text{I}^-]^{-1}[\text{H}^+]^{-1}$. The primary and secondary amine thioethers yield stable azasulfonium salt intermediates and oxidize at rates 30-50 times faster than the tertiary amine thioether. During the oxidation of 2 the unusually stable azasulfonium triiodide salt 4 precipitated out of the aqueous solution and was characterized by X-ray crystallography. As no other *N*-methyl azasulfonium salts have been reported, we present the results of the crystal structure determination here.

Intramolecular catalysis studies have shown that neighboring nucleophiles are capable of causing great acceleration of the rate of oxidation of thioethers by aqueous I₂. We have previously shown that in 5-methyl-1-thia-5-azacyclooctane,² the transannular tertiary amine group increases the oxidation rate on the order of 10⁵ relative to thiacyclooctane itself. Other neighboring groups with lone-pair electrons such as a carboxylic acid,³ pyridine, hydroxyl, or thioether⁴⁻⁶ group have been shown to interact with the thioether group. However, there have been no systematic studies on how the I₂ oxidation of thioethers would be affected by a primary, a secondary, and a tertiary amine group when these groups were located in identical positions relative to the sulfur atom. By studying such a series, some of the effects of substituents having different basicities and steric requirements might be evaluated. The effect of these amines could be compared with the effect of an hydroxyl group located in the same position.⁴

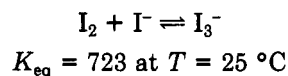
The formation and characterization of the *N*-methyl azasulfonium intermediate, 4 (see Figure 1 for a perspective drawing), by X-ray diffraction is added evidence of the stability of heteroatom-sulfonium intermediates. We had previously reported the structures of the corresponding intermediates from the I₂ oxidation of 1¹ and 5.⁶



- 1, X = NH₂
 2, X = NHCH₃
 3, X = N(CH₃)₂
 5, X = OH

Results and Discussion

Oxidation of Thioethers by Aqueous I₂. Thioethers are oxidized by iodine in solutions of aqueous KI. Triiodide is formed according to the following equilibrium:⁷



(1) For paper 6 in this series, see: Hirschon, A. S.; Olmstead, M. M.; Doi, J. Takahashi; Musker, W. K. *Tetrahedron Lett.* 1982, 23, 317.

(2) Doi, J. Takahashi; Musker, W. K. *J. Am. Chem. Soc.* 1981, 103, 1159.

(3) Tagaki, W.; Ochiai, M.; Oae, S. *Tetrahedron Lett.* 1968, 58, 6131.

(4) Hirschon, A. S.; Doi, J. Takahashi; Musker, W. K. *J. Am. Chem. Soc.* 1982, 104, 723.

(5) Doi, J. Takahashi; Musker, W. K.; deLeeuw, D. L.; Hirschon, A. S. *J. Org. Chem.* 1981, 46, 1239.

(6) Hirschon, A. S.; Beller, J. D.; Olmstead, M. M.; Doi, J. Takahashi; Musker, W. K. *Tetrahedron Lett.* 1981, 22, 1195.

Table I. Oxidation of Amine Thioethers by Aqueous I₂ at 26.0 °C

pH ^c	k, M ⁻¹ s ⁻¹		
	1	2	3
4.0 ^a	6.3 × 10 ⁻¹	6.4 × 10 ⁻¹	1.9 × 10 ⁻²
5.0 ^a	4.8	4.3	1.0 × 10 ⁻¹
6.0 ^a	3.9 × 10 ¹	2.4 × 10 ¹	7.7 × 10 ⁻¹
6.0 ^b	8.4 × 10 ¹	6.0 × 10 ¹	2.2
7.0 ^b	3.8 × 10 ²	3.2 × 10 ²	1.1 × 10 ¹
8.0 ^b			5.7 × 10 ¹

^a 0.225 M acetate buffer. ^b 0.225 M phosphate buffer.
^c [RSR] = 1.0 × 10⁻³ M, [KI] = 0.015 M, and [KCl] = 0.045 M.

Table II. Iodide Dependence of Amine Thioether Oxidations by Aqueous I₂ at 26.0 °C^a

[KI], M	[KCl], M	k, M ⁻¹ s ⁻¹		
		1	2	3
0.060	0.000	8.5	6.4	3.0 × 10 ¹
0.045	0.015	1.1 × 10 ¹	9.3	4.2 × 10 ¹
0.030	0.030	1.6 × 10 ¹	1.3 × 10 ¹	6.7 × 10 ¹
0.015	0.045	3.9 × 10 ¹	2.4 × 10 ¹	1.4 × 10 ²

^a [RSR] = 1.0 × 10⁻³ M. Compounds 1 and 2 were run at pH 6.0 (0.225 M phosphate buffer). Compound 3 was run at pH 8.2 (0.225 M phosphate buffer).

The rates of oxidation are followed spectrophotometrically by observing the decrease in absorbance of I₃⁻ at 353 nm as the oxidation progresses. Pseudo-first-order rate constants are obtained with excess thioether and conditions of invariant iodide concentration and pH. The pseudo-first-order rate constant is calculated from eq 1. The rate

$$d[\text{I}_3^-]/dt = -k_{\text{obsd}}[\text{I}_3^-] = d[\text{RSR}]/dt \quad (1)$$

constant k_{obsd} is divided by the thioether concentration to give second-order rate constants. Rate data for oxidation of thioethers at several values of pH are reported in Table I. An acetate buffer was used at pH of 4, 5, and 6 at a concentration of 0.225 M. Phosphate buffer was used at a pH of 6, 7, and 8 at a concentration of 0.225 M.

The iodide dependence of the rates is determined by measuring the oxidation rate for each compound with four concentrations of iodide. These second-order rate constants appear in Table II. The thioether dependence of the rate is determined by measuring the oxidation rate for each compound with four concentrations of thioether

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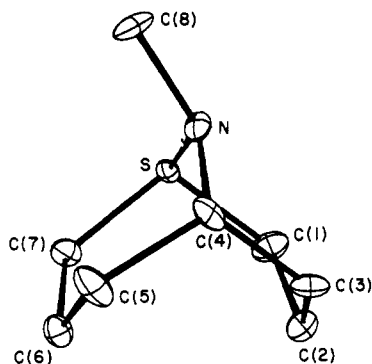


Figure 1. Perspective drawing of $\text{SNC}_6\text{H}_{16}^+$ (**4**) showing anisotropic thermal ellipsoids at the 50% probability level and the atom numbering scheme. Some important distances and angles are as follows: S–N, 1.650 (8) Å; N–C(4), 1.471 (15) Å; N–C(8), 1.486 (13) Å; S–C(7), 1.799 (12) Å; S–C(1), 1.823 (12) Å; N–S–C(7), 105.7 (5)°; S–N–C(4), 115.0 (7)°; N–S–C(1), 98.4 (5)°; C(1)–S–C(7), 106.1 (6)°; S–N–C(8), 112.5 (7)°; C(4)–N–C(8), 114.8 (9)°.

Table III. Thioether Dependence of Amine Thioether Oxidations by Aqueous I_2 at 26.0 °C^a

[RSR], M	k , s ⁻¹		
	1	2	3
2.0×10^{-3}	8.2×10^{-2}	4.2×10^{-2}	1.1×10^{-1}
1.0×10^{-3}	3.9×10^{-2}	2.4×10^{-2}	5.7×10^{-2}
5.0×10^{-4}	1.9×10^{-2}	1.1×10^{-2}	2.5×10^{-2}
2.5×10^{-4}	8.6×10^{-3}	6.4×10^{-3}	1.3×10^{-2}

^a [KI] = 0.015 M and [KCl] = 0.045 M. Compounds **1** and **2** were run at pH 6.0 (0.225 M phosphate buffer). Compound **3** was run at pH 8.0 (0.225 M phosphate buffer).

(Table III). No significant changes in oxidation rate are seen upon altering either the ionic strength of the solution or the concentration of the buffer.

Under a given set of conditions, compounds **1** and **2** oxidize at comparable rates, and compound **3** reacts about 30–50 times more slowly. All three compounds follow the same observed rate law. Plots of $\log k_{\text{obsd}}$ vs. pH are linear for compounds 1–3 with equal slopes of –0.9 and correlation coefficients of 0.9997, 0.996, and 0.994, respectively. Thus the rates are inversely proportional to $[\text{H}^+]$ over the range pH 4–8. Plots of $\log k_{\text{obsd}}$ vs. $\log [\text{I}^-]$ are linear for compounds 1–3, with slopes of –0.9, –1.1, and –0.9 and correlation coefficients of 0.996, 0.996, and 0.9997, respectively. Rates are inversely proportional to the iodide concentration, indicating a rate-determining step which occurs concurrently with or prior to loss of iodide from the thioether–iodine complex. Plots of $\log k_{\text{obsd}}$ vs. $\log [\text{RSR}]$ are linear for compounds 1–3, with slopes of 1.1, 0.9, and 1.0 and correlation coefficients of 0.9998, 0.997, and 0.9994, respectively. Rates are directly proportional to the thioether concentration.

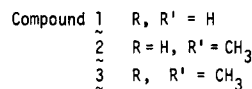
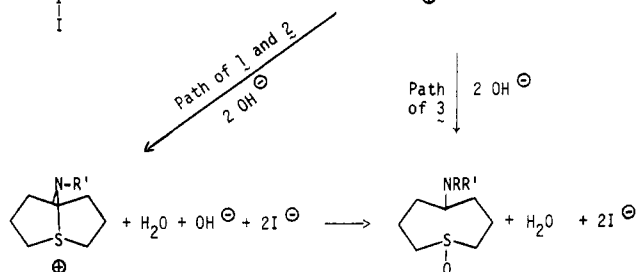
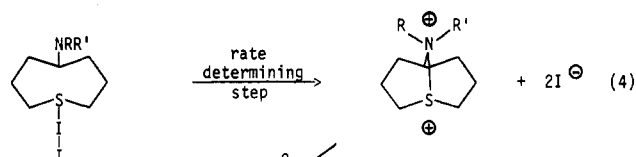
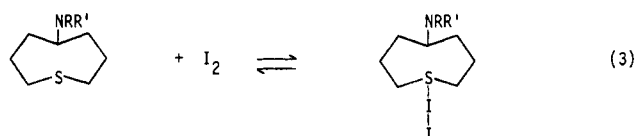
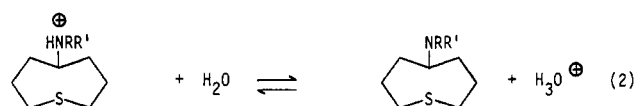
These data for all three compounds are consistent with the following rate law given in eq 2.

$$d[\text{RSR}]/dt = -k_{\text{ox}}[\text{RSR}][\text{I}_3^-][\text{I}^-]^{-1}[\text{H}^+]^{-1} \quad (2)$$

A mechanism consistent with the rate law is given in Scheme I.

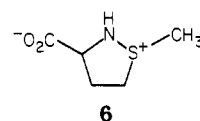
Attack of the thioether by I_2 leads to an iodine complex. The free amine bridges to the cationic sulfur, resulting in the loss of iodide ion. Step 4 in Scheme I shows dication formation, but an iodosulfurane cannot be ruled out.⁵ The intermediate in which the tertiary amine interacts with the sulfur reacts immediately with water to yield the sulfoxide. However, the intermediates resulting when primary and secondary amines interact with the sulfur are deprotonated

Scheme I



to form the azasulfonium ions which were isolated at pH 7 and characterized by X-ray crystallography. The intermediate azasulfonium iodide from compound **1** hydrolyzes rapidly (<10 min) in aqueous solutions when the pH of the solution is increased to 10 by adding KOH. At pH 10 azasulfonium iodide from compound **2** requires up to 2 h to hydrolyze. The products of the basic hydrolysis reactions are the corresponding sulfoxides.

The X-ray structure determination of $4\cdot\text{I}_3^-$ indicates a bicyclic structure with a short N–S bond similar to that of the azasulfonium salt resulting from oxidation of **1**.⁵ The crystallographic results for the azasulfonium salts can be compared with those found for dehydromethionine (**6**).^{8,9}



Dehydromethionine has N–S and C–N distances of 1.679 (3) and 1.475 (4) Å, respectively. Compound $4\cdot\text{I}_3^-$ has N–S and C–N distances of 1.650 (8) and 1.471 (15) Å, respectively. The azasulfonium salt of **1** has N–S and C–N distances of 1.67 (3) and 1.52 (4) Å, respectively. All three compounds have N–S distances shorter than the sum of the covalent radii of S and N (1.74 Å).⁹ Whether the bond shortening is due to partial double bond character or charge effects is not clear. The nitrogen atom in dehydromethionine is apparently sp³ hybridized, as the sum of

(8) Glass, R. S.; Duchek, J. R. *J. Am. Chem. Soc.* 1976, 98, 965.

(9) Lambeth, D. O.; Swank, D. W. *J. Org. Chem.* 1979, 44, 2632.

the nitrogen bond angles is 321.5° . For compound 4-I_3^- this sum is 342.3° . The expected values for sp^3 - and sp^2 -hybridized nitrogen are 328.5° and 360° , respectively. The bicyclononane ring systems of compound 4-I_3^- and 1-I_3^- both exhibit the chair-chair conformation. The shortest interionic contact is 3.589 (3) Å between S and I(3) at $1 + x, y, z$. This distance is well within the 4.00 Å obtained from the sum of the van der Waals radii.¹⁰ The shortest N...I distance is 3.858 (5) Å, which exceeds the sum of the van der Waals radii by 0.2 Å. From these observations it would appear that positive charge remains primarily on the sulfur atom.

The pK_a values for the amine thioethers are determined titrimetrically. Compounds 1–3 have pK_a 's of 10.6, 11.0, and 10.5, respectively. As is typical of many aliphatic amines, the secondary amine is the most basic. There is no direct correlation between this order of basicity and the rate of oxidation at a given pH.

The rates of oxidation of 1 and 2 are comparable to the rate of oxidation of methionine, $\text{CH}_3\text{S}(\text{CH}_2)_2\text{CH}(\text{CO}_2\text{H})\text{-NH}_2$.¹¹ All these compounds also give stable azasulfonium salt intermediates. The oxidation of the tertiary amine 3 and its acyclic analogue $(\text{CH}_3)_2\text{N}(\text{CH}_2)_3\text{SCH}_3$ is only slightly enhanced.⁵ The pH profile of the rate of the acyclic compound over pH 6–10 indicates an N–S interaction.⁵ Neither of the tertiary amines yielded isolable intermediates. The rate of oxidation of 3 is about the same as the oxidation rate of the hydroxyl analogue 5 from which the alkoxy sulfonium salt intermediate has also been isolated.⁶

Experimental Section

Materials. 5-Amino-1-thiacyclooctane (1) was synthesized according to the literature.⁶ The structure was confirmed by GC, TLC, ^1H NMR, IR, and mass spectroscopy.

5-(Methylamino)-1-thiacyclooctane (2). To 1.9 g (60 mmol) of methylamine in 25 mL of methanol were added 1.7 mL (20 mmol) of 12 N HCl/methanol, 1 g of 3A molecular sieves, 1.44 g (10.0 mmol) of 5-thiacyclooctanone, and 0.47 g (7.5 mmol) of NaBH_3CN . After the mixture was stirred at room temperature for 5 days, an additional 0.13 g of NaBH_3CN was added, and stirring was continued for another 24 h. The mixture was acidified with concentrated HCl to pH 2 and extracted with ether (six aliquots of 20 mL). Solid KOH was added to the aqueous layer to pH 10 before extraction with ether (three aliquots of 20 mL). Evaporation of the ether extracts provided 1.39 g of a pale yellow oil. The product contained 2% ketone by GLC. The impure product was dissolved in dilute HCl and extracted with CH_2Cl_2 (four aliquots of 20 mL).

The free amine was regenerated with solid KOH and extracted with CH_2Cl_2 (four aliquots of 15 mL) to provide 1.35 g (8.5 mmol, 85%) of 2 as a pale yellow oil containing no impurities by GLC. Pure, colorless 2 was obtained by short-path distillation: bp $51\text{--}52^\circ\text{C}$ (0.15 torr); 1.16 g (7.3 mmol, 73%). ^1H NMR (CDCl_3) δ 2.9–2.4 (m, 5), 2.41 (s, 3), 2.1–1.4 (m, 8), 1.03 (s, 1); mass spectrum (70 eV), m/z (relative intensity) 159 (9, $\text{C}_8\text{H}_{17}\text{NS}$), 144 (3, M – CH_3), 70 (74, $\text{C}_4\text{H}_8\text{N}$), 57 (100, $\text{CH}_3\text{NHCH}=\text{CH}_2$); IR (film) 3305 (w, NH) cm^{-1} . Anal. Calcd for $\text{C}_8\text{H}_{17}\text{NS}$: C, 60.31; H, 10.76; N, 8.79. Found: C, 60.07; H, 10.64; N, 8.69.

The picrate salt of 2 was obtained from aqueous solution as yellow crystals: mp $133.5\text{--}134.0^\circ\text{C}$; ^1H NMR (CDCl_3) δ 8.87 (s, 2), 4.1 (m, 1), 2.79 (s, 3), 2.6 (m, 4), 2.0 (m, 8).

5-(Dimethylamino)-1-thiacyclooctane (3). To 1.44 g (10 mmol) of 5-thiacyclooctanone, 4.10 g (50 mmol) of dimethylamine hydrochloride, 1 g of 3A molecular sieves, and 25 mL of methanol was added 0.44 g (7.0 mmol) of NaBH_3CN . The mixture was stirred at room temperature under nitrogen for 4 days, additional NaBH_3CN (0.10 g, 1.2 mmol) was added, and stirring was con-

tinued for an additional 24 h. Concentrated HCl was added to pH 1, and the methanol was removed at reduced pressure. The residue was dissolved in 15 mL of H_2O and extracted four times with 20-mL aliquots of CHCl_3 . Solid KOH was added to the aqueous layer to pH >10. The solution was saturated with solid NaCl and extracted with CHCl_3 (four aliquots of 20 mL). Concentration of the CHCl_3 extract provided the crude amine contaminated with 3% of the starting material by GLC. The ketone was removed by repeating the extraction procedure. The resulting oil was distilled under reduced pressure to give 3: bp $63\text{--}64^\circ\text{C}$ (0.25 torr); 0.80 g (4.6 mmol, 46%); ^1H NMR (CDCl_3) δ 2.9 (m, 1), 2.69 (t, 4), 2.22 (s, 6), 1.8 (m, 8); mass spectrum (70 eV), m/z (relative intensity) 173 (4, $\text{C}_9\text{H}_{19}\text{NS}$), 158 (1, M – CH_3), 129 (2, M – $(\text{CH}_3)_2\text{N}$), 98 (9, M – $\text{C}_3\text{H}_7\text{S}$), 87 (6, $\text{C}_4\text{H}_8\text{S}$), 84 (72, $(\text{CH}_3)_2\text{NCH}_2\text{CH}_2$), 71 (100, $(\text{CH}_3)_2\text{NCH}=\text{CH}_2$). Anal. Calcd for $\text{C}_9\text{H}_{19}\text{NS}$: C, 62.36; H, 11.05; N, 8.08. Found: C, 62.11; H, 10.93; N, 7.97.

The picrate salt of 3 was obtained as a yellow crystalline solid: mp $150.5\text{--}151.0^\circ\text{C}$; ^1H NMR (CDCl_3) δ 8.86 (s, 2), 4.4 (br, 1), 2.86 (s, 6), 2.7 (m, 4), 2.0 (m, 8). No N–H was observed.

9-Aza-9-methyl-1-thioniabicyclo[3.3.1]nonane Triiodide, (4-I_3^-). To 84.8 mg (0.532 mmol) of 2 in 2 mL of methanol and 2 mL of aqueous phosphate buffer (pH 6.95) was added dropwise 0.50 mmol of I_2 in 1.3 mL of methanol. Brown crystals admixed with a brown powder precipitated. Slow crystallization of the solids from methanol provided brown needles of 4-I_3^- (mp $68\text{--}69^\circ\text{C}$) suitable for X-ray structure determination.

Compound 4-I^- was formed by titrating 1.6 mmol of 2 with 1.0 equiv of I_2 in a 50% v/v MeOH/ H_2O solution maintained at pH 8 by addition of HCl or KOH solutions. Excess I_2 was destroyed by addition of solid $\text{Na}_2\text{S}_2\text{O}_3$. The solution was made basic (pH >10) by addition of KOH and then continuously extracted with CHCl_3 for 24 h. Evaporation of the extract provided 0.30 g (1.1 mmol, 69%) of the intermediate salt 4-I^- : mp $177\text{--}178^\circ\text{C}$ dec; ^1H NMR (CDCl_3) δ 4.1–3.8 (m, 3), 3.1 (s, 3), 2.7–1.7 (m, 10). Anal. Calcd for $\text{C}_8\text{H}_{16}\text{INS}$: C, 33.69; H, 5.65; N, 4.91. Found: C, 33.71; H, 5.57; N, 4.82.

Products. Reaction products are obtained by oxidizing the thioethers to sulfoxides in aqueous solution by titration with iodine at a constant pH of 8. Aqueous 0.5 M KOH or HCl is added to maintain the desired pH. The titration continues until a faint excess of iodine persists after several hours with stirring. Compounds 1–3 each consumed 1.0 equiv of iodine. At this point, the intermediate azasulfonium iodides from 1 and 2 are isolated as brown solids. The solution is made basic to litmus (pH >10) by addition of KOH. The basic amines are extracted with CH_2Cl_2 (four aliquots of 25 mL). Reaction products were determined to be the corresponding sulfoxides by NMR, IR, and TLC.

Kinetic Measurements. Procedures for the kinetic measurements have been described previously.^{2,4,5} The loss of I_2 in the presence of an amine had been monitored previously.⁵ However, the rate of this competing reaction was not considered significant within the range of experimental conditions employed.

Rates of oxidation of the amine thioethers were essentially first order in I_3^- over more than two half-lives. Twelve data points were equally spaced over two half-lives in determining rate constants. Mallinckrodt analytical reagent grade salts and acids were used to prepare buffer solutions. Solutions were bubbled with nitrogen for a minimum of 30 min before use.

X-ray Data Collection and Structure Solution. Dark needles of $\text{SNC}_8\text{H}_{16}\text{I}_3$ (fw 539.00) crystallize in the orthorhombic space group $P2_12_12_1$ (No. 19) with cell dimensions (at 140 K) of $a = 6.379$ (2), $b = 14.739$ (6) and $c = 15.149$ (4) Å, and with $Z = 4$, d_c (140 K) = 2.51 g cm^{-3} , and d_{ex} (298 K) = 2.49 g cm^{-3} . A crystal of dimensions $0.12 \times 0.20 \times 1.0$ mm was selected for data collection and mounted with the long axis parallel to ϕ . Data were collected at 140 K by using Mo $K\alpha$ radiation ($\lambda = 0.71069$ Å) on a Syntex $P2_1$ diffractometer to a $2\theta_{\text{max}}$ of 55° . A total of 1903 unique reflections was collected, of which 1838 with $F > 3\sigma(F)$ were retained for solution and refinement of the structure. An empirical absorption correction was applied ($\mu(\text{Mo } K\alpha) = 66.2$ cm^{-1} ; absorption correction factors of 3.31–9.09). All computations were carried out by using the SHELXTL (version 3, July 1981) crystallographic program library. The structure was solved by Patterson methods and refined to a final R value of 0.052. A routine for enantiomorph determination had shown the original choice

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(11) Gensch, K.-H.; Higuchi, T. *J. Pharm. Sci.* 1967, 57, 177.

of hand to be incorrect, and the x coordinate was inverted. Hydrogen atoms were not included. Maximum and minimum peaks of 1.50 and $-2.76 \text{ e } \text{Å}^{-3}$ were found on a final difference Fourier map. The majority of these features were in the vicinity of the iodine atoms. See the paragraph at the end of the paper about supplementary material.

Registry No. 1, 82200-91-7; 2, 85939-86-2; 2 picrate, 85939-87-3; 3, 85939-88-4; 3 picrate, 85939-89-5; 4-I⁻, 85939-90-8; 4-I₃⁻,

85939-92-0; NaBH₃CN, 25895-60-7; I₂, 7553-56-2; 9-aza-1-thioniabicyclo[3.3.1]nonane iodide, 85956-52-1; methylamine, 74-89-5; 5-thiacyclooctanone, 20701-80-8; dimethylamine hydrochloride, 506-59-2.

Supplementary Material Available: Tables of final atomic positional parameters, anisotropic thermal parameters, and bond distances and angles (2 pages). Ordering information is given on any current masthead page.

Proton and Carbon-13 Nuclear Magnetic Resonance Spectra of Methylenecyclopropane and Proton Nuclear Magnetic Resonance Spectra of Some Methyl-Substituted Methylenecyclopropanes. A Reinvestigation

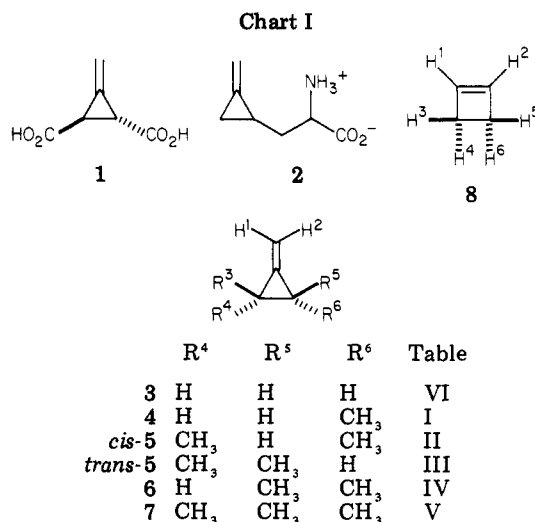
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Received November 15, 1982

The proton nuclear magnetic resonance spectra of some methyl-substituted methylenecyclopropanes and the parent compound have been reinvestigated at high resolution and 400-MHz spectrometer frequency. That of methylenecyclopropane has been analyzed with the help of the carbon-13 satellites and the proton-coupled carbon-13 spectrum. Pseudo-INDOR experiments uncovered an unexpected positive sign of the geminal coupling constants of the vinyl protons. The spectral parameters of all compounds, optimized via LAOCOON III and LAME analysis, and the deceptively simple appearance of the AA'A''XX' spectrum of both methylenecyclopropane and the isomeric cyclobutene are discussed.

One of the early applications of proton NMR spectroscopy to organic chemistry was the solution of the long-standing structural problem of Feist's acid (1,^{1,2} Chart I), the first known derivative of methylenecyclopropane. During the last decades, numerous methylenecyclopropanes have been reported, including natural products, e.g., the amino acid hypoglycin A (2)³ and the parent compound 3.^{4,5} The latter has been thoroughly investigated by microwave,⁶ infrared,⁷ carbon-13 NMR,⁸ and proton NMR spectroscopy in nematic phases.⁹ Although the proton NMR spectrum has been reported for the parent compound 3,⁵ a rigorous analysis of the spectra of simple alkyl-substituted methylenecyclopropanes is still lacking despite several papers devoted to the spectra of such compounds.¹⁰⁻¹² Only the allylic coupling constants for



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(2) For a review of Feist's acid see: Lloyd, D. "Topics in Carbocyclic Chemistry"; Logos Press: London, 1969; Vol. 1, p 249.

(3) For a review of the early work on hypoglycin A see: Vogel, E. *Angew. Chem.* 1960, 72, 4.

(4) Gragson, J. T.; Greenlee, K. W.; Derfer, J. M.; Boord, C. E. *J. Am. Chem. Soc.* 1953, 75, 3344.

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6, obtained by means of a more rigorous treatment, have been reported.¹³ In fact, most of the earlier spectra of alkyl-substituted methylenecyclopropanes have been determined at relatively low field and apparently sometimes with insufficient resolution. This resulted in an oversimplified (first order) interpretation which neglected small long-range couplings and therefore constituted an inadequate assignment of the spin system under investigation. For example, two different interpretations have been reported for the proton spectrum of 6,^{10,12} neither one being fully acceptable. In contrast, the proton spectra of several methylenecyclopropanes with two or three substituents

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