Reaction of Methanesulfenyl Bromide with Silver 2,4,6-Trinitrobenzenesulfonate in Organic Solvents[1]

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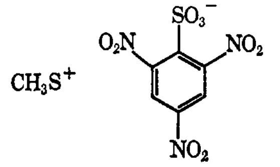
Abstract: Solutions of methanesulfenium 2,4,6-trinitrobenzenesulfonate in nitromethane, nitrobenzene, and acetonitrile have been prepared and studied by conductance and nmr techniques. The solutions show salt-like behavior, but conductometric and nmr data suggest specific bonding interactions between sulfenium ion and the solvent or the trinitrobenzenesulfonate anion. The results of this study show that these solvent systems behave as sulfenium ion transfer agents rather than as solutions of "free" methanesulfenium 2,4,6-trinitrobenzenesulfonate.

Solutions of alkanesulfenium 2,4,6-trinitrobenzenesulfonates (1) have been prepared and used *in situ* in our laboratory to prepare episulfonium salts.[3,4] However, no attempt was made to determine the nature of these solutions or to characterize the sulfenium intermediate.



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Other solutions believed to contain various sulfenium ions, RS^+, have been prepared. The cryoscopic data of Kharasch, *et al.*,[5] on sulfuric acid solutions containing 2,4-dinitrobenzenesulfenyl chloride indicate the presence of the 2,4-dinitrobenzenesulfenium ion. The ionic nature of sulfenium solutions has been demonstrated by conductance measurements on mixtures of sulfur dichloride and various Lewis acids in acetone solution,[6] and trichloromethanesulfenyl chloride has also shown salt-like behavior in acetic acid solution.[7]

Sulfenium ions have been postulated as intermediates in the polar additions of sulfenyl halides to olefins, acetylenes, and certain aromatic systems,[8-10] and in disulfide exchanges that occur both in acid solution and in biological systems.[8,11,12] Recently, we have presented evidence that benzenesulfenium 2,4,6-trinitrobenzenesulfonate or perchlorate reacts with molecular nitrogen at room temperature and atmospheric pressure.[13]

We wish now to report the results of conductance and nmr studies which indicate the nature of alkanesulfenium ions in several organic solvents that have been used previously in synthetic applications.

Results and Discussion

Conductance Measurements. Methanesulfenium 2,4-6-trinitrobenzenesulfonate was prepared by treating methanesulfenyl bromide with either of two silver 2,4,6-trinitrobenzenesulfonate salts.[3,4] The first salt contained three molecules of acetonitrile of crystallization, while the second was uncomplexed. The two salts were used in order to ascertain the effect of acetonitrile on the properties of the ion. The sulfenium compound was prepared at a concentration of 0.1 *M*

$$CH_3SBr + AgTNBS\ (or\ AgTNBS \cdot 3CH_3CN) \longrightarrow CH_3STNBS + AgBr$$

in a solution which consisted of equal volumes of dichloromethane and either nitromethane or acetonitrile. Our choice of solvent system was dictated by our use of solvents of approximately the same composition for research on synthetic applications of sulfenium salts.

Table I presents the results of our conductance measurements on methanesulfenium 2,4,6-trinitrobenzenesulfonate. From Table I, two trends are apparent. In runs I and II, in which acetonitrile was present, a

Table I. Specific Conductance of Methanesulfenium 2,4,6-Trinitrobenzenesulfonate Solutions

Run	Salt[a]	Solvent	Specific conduct,[b] ohm^{-1} cm^{-1}
I	$AgTNBS \cdot 3CH_3CN$	1:1 CH_2Cl_2–CH_3NO_2	$9,430 \times 10^{-6}$
	CH_3STNBS		$8,650 \times 10^{-6}$
II	$AgTNBS \cdot 3CH_3CN$	1:1 CH_2Cl_2–CH_3CN	$25,900 \times 10^{-6}$
	CH_3STNBS		$11,700 \times 10^{-6}$
III	AgTNBS	1:1 CH_2Cl_2–CH_3NO_2	$3,160 \times 10^{-6}$
	CH_3STNBS		513×10^{-6}
	CH_3STNBS	(after addn of 0.093 mol of CH_3CN)	$1,875 \times 10^{-6}$
	CH_3SBr	Pure CH_2Cl_2[c]	2×10^{-6}

[a] TNBS = 2,4,6-trinitrobenzenesulfonate. [b] Concentration 0.1 *M*. [c] The conductance of methanesulfenyl bromide in either of the two mixed solvents could not be obtained due to a reaction which rapidly produced HBr when either acetonitrile or nitromethane was present in great excess; concentration 0.2 *M*.

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[2] Institute for Environmental Sciences Trainee, 1966–1967.

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[9] N. Kharasch, S. J. Potempa, and H. L. Wehrmeister, *Chem. Rev.*, **39**, 269 (1946).

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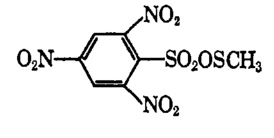
Table II. Chemical Shifts for Methanesulfenium 2,4,6-Trinitrobenzenesulfonate in Nitromethane and Nitrobenzene

Run	Silver salt[a]	Solvent	Chemical shift,[b] ppm (δ)		
			CH_3S	CH_3CN	TNBS
Ia	$AgTNBS \cdot 3CH_3CN$	CH_3NO_2	3.17	2.02 (broad)[c]	8.85
Ib, pyridine added			2.55	2.17 (sharp)[c]	
IIa	AgTNBS	CH_3NO_2	2.70	. . .	8.60
IIb, acetonitrile added			2.70	2.20 (sharp)[c]	8.60
IIc, pyridine added			2.53	. . .	
IIIa	$AgTNBS \cdot 3CH_3CN$	$C_6H_5NO_2$	3.13	1.83 (broad)[d]	8.82
IIIb, pyridine added			2.80	1.94 (sharp)[d]	
IVa	AgTNBS	$C_6H_5NO_2$	2.83	. . .	8.60
IVb, pyridine added			2.50	. . .	

[a] TNBS = 2,4,6-trinitrobenzenesulfonate. [b] Dichloromethane used as an internal standard. [c] Chemical shift for acetonitrile in pure nitromethane: 2.20 ppm. [d] Chemical shift for acetonitrile in pure nitrobenzene: 1.98 ppm.

definite salt-like behavior was observed for the sulfenium ion. However, in run III, in which no acetonitrile was present initially, the solution was only very weakly conducting. Addition of 0.093 mol of acetonitrile to the solution of run III caused the conductance to rise slowly to the final value of 1875×10^{-6} ohm^{-1} cm^{-1}. It therefore appears that there were two distinct species present in these three experiments. In the experiment in which no acetonitrile was present, a species which was only weakly conducting was formed. This species reacted slowly with acetonitrile to form a conducting solution. Thus a salt-like compound was formed when acetonitrile was present, indicating that the species in runs I and II was also of this type. The structure of the sulfenium trinitrobenzenesulfonate in III therefore must be that of a sulfenic–sulfonic anhydride of structure **2**. An intimate ion pair is ruled out by the slow reaction with acetonitrile that leads to increased conductivity.



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These results would seem to indicate that the weak conductance of trichloromethanesulfenyl chloride in acetic acid reported by Nabi and coworkers[7] may not be entirely attributable to the presence of trichloromethanesulfenium ion. Our data indicate that conductance measurements cannot differentiate between the following equilibria in their system.

$$CCl_3SCl + CH_3COOH \rightleftarrows CCl_3SOCOCH_3 + H^+ + Cl^-$$

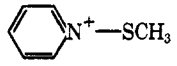
$$CCl_3SCl \rightleftarrows CCl_3S^+ + Cl^-$$

The nmr spectra of methanesulfenium 2,4,6-trinitrobenzenesulfonate in different solvents with and without acetonitrile also gave important indications of interactions between methanesulfenium ion and acetonitrile and trinitrobenzenesulfonate anion.

Proton Magnetic Resonance Measurements. If our solutions indeed contained a "free" alkanesulfenium ion, the nmr spectra of these solutions should give indications as to the electronic configuration of that ion. If it may be assumed that the sulfur atom in this ion is unhybridized, and Hund's rule is applicable to this system, a free alkanesulfenium ion would have an electronic configuration in which two 3p electrons are unpaired. The possibility of methanesulfenium ion having such an electronic configuration has interested us for some time, and therefore an nmr study of these sulfenium compounds was thought to be a good tool for gaining further understanding of the nature of the electronic configuration in these species. Thus, a paramagnetic substance in our solutions should give rise to considerable line broadening of both solvent and sulfenium ion signals.[14] An nmr study could also give data on the interactions of the methanesulfenium ion with other species present in our solutions.

We have obtained the nmr spectra of methanesulfenium 2,4,6-trinitrobenzenesulfonate (in both nitromethane and nitrobenzene solution) which show no broadening of solvent or S-methyl signals due to any paramagnetism inherent in this compound. Solutions containing what we believed to be methanesulfenium 2,4,6-trinitrobenzenesulfonate were prepared from methanesulfenyl bromide and the two silver trinitrobenzenesulfonate salts which were used for our conductivity measurements. The apparatus which was used for these experiments allowed the solutions to be filtered free of silver bromide in a nitrogen atmosphere. The nmr spectra of the resulting solution was then determined in nmr tubes which were flushed with dry nitrogen. Table II presents the results of these experiments.

In order to verify that a given signal corresponded to the S-methyl group of the sulfenium salt, pyridine was added to the solution. It was anticipated that pyridine would preferentially replace any other species which would be bonding to the sulfenium ion. This would leave the sulfur in the same terminal state in which direct comparisons of the S-methyl signals could be made. After formation of the methanesulfenylpyridinium ion (**3**) the spectrum was recorded again. These results are also presented in Table II.



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In runs I and III of Table II, acetonitrile was present in the system by virtue of our use of the acetonitrile-solvated silver trinitrobenzenesulfonate. The nmr spectra for these two runs show that a broad signal is found for the methyl group of acetonitrile 0.15–0.18 ppm upfield from the comparable signal for acetonitrile in the absence of sulfenium compound. For example, in nitromethane (run I) the signal for the methyl group of

(14) L. M. Jackman, "Applications of Nuclear Magnetic Resonance Spectroscopy in Organic Chemistry," Pergamon Press Inc., New York, N. Y., 1959, p 12.

acetonitrile was a broad singlet at δ 2.02. In pure nitromethane, the signal for this group was found to be a very sharp singlet at δ 2.20. Addition of pyridine to the solution of run I moved the acetonitrile signal downfield to δ 2.17, where it became a sharp singlet.

The results of runs I and III confirmed what was suspected from the conductivity data, namely, that methanesulfenium ion is involved in a specific bonding interaction with one or more molecules of acetonitrile. The nature of the acetonitrile signal also gives indications that there are two or more species involved in a mobile equilibrium at a rate which approximates the nmr time scale, for if no exchange were established, separate signals would be observed for each species, not the broad signal which we have noted. Thus, the sharp signal observed at 2.17 ppm in solution Ib must represent free acetonitrile in the solution.

Runs II and IV contained no acetonitrile to which the sulfenium ion can bond. The nmr spectra of these solutions showed the S-methyl signals 0.30–0.47 ppm upfield from the S-methyl signals of runs I and III. In Table III, the nmr data for a selected number of organic cations is presented. Neglecting solvent effects, it is readily apparent that the methyl protons of methanesulfenium 2,4,6-trinitrobenzenesulfonate are much more shielded than the protons α to a carbonium ion or a protonated sulfur atom in a thiol or thioether. The methyl protons of methanesulfenium trinitrobenzenesulfonate are even more shielded than the methyl protons of trimethylsulfonium trinitrobenzenesulfonate. These data indicate very little positive character to the sulfenium sulfur atom in the species formed in the absence of acetonitrile. The very low conductivity of these solutions indicates that the species which we have formulated as **2** is indeed the correct species in those cases in which acetonitrile is absent.

Table III. Chemical Shift Data for Protons α to a Cationic Center

Ion	Solvent	Chemical shift for α protons, ppm
$CH_3\overset{+}{S}H_2$	$HSO_3F–SbF_5–SO_2$	2.95[a]
$(CH_3)_2\overset{+}{S}H$	$HSO_3F–SbF_5–SO_2$	3.08[a]
$(CH_3)_3C^+$	$HSO_3F–SbF_5$	3.83[b]
$(C_6H_5)_2\overset{+}{C}CH_2CH_3$	$HSO_3F–SbF_5$	3.78[b]
$(CH_3)_3S^+ClO_4^-$	CF_3COOH	3.03[c]
$(CH_3)_3S^+TNBS^-$ [d]	CH_3NO_2	2.95[e]

[a] G. A. Olah, D. H. O'Brien, and C. U. Pittman, Jr., *J. Am. Chem. Soc.*, **89**, 2996 (1967). [b] G. A. Olah, M. B. Comisarow, C. A. Cupas, and C. U. Pittman, Jr., *ibid.*, **87**, 2997 (1965). [c] N. J. Leonard and C. R. Johnson, *ibid.*, **84**, 3701 (1962). [d] $TNBS^-$ = 2,4,6-trinitrobenzenesulfonate anion. [e] This spectrum was run in our own laboratories.

The data of run IIb also should be considered in reference to structure **2**. If 21 μl of acetonitrile is added to solution IIa, there is no detectable reaction after 10 min. The methyl protons of acetonitrile gave a sharp signal at δ 2.20. Thus, only if acetonitrile is in great excess, as in our conductance experiment III, does it react at a reasonable rate with **2** to give an acetonitrile "complexed" sulfenium ion.

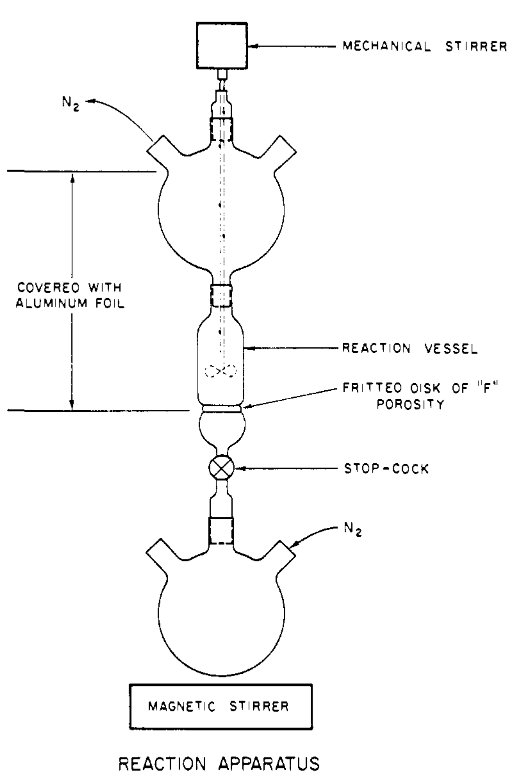

Figure 1. Schematic diagram of apparatus for generation o methanesulfenium 2,4,6-trinitrobenzenesulfonate.

Although the solutions of methanesulfenium 2,4,6-trinitrobenzenesulfonate which are in use in our laboratory exhibit the reactions of a free ion, our conductance and nmr data suggest that rather we are dealing with sulfenium ion transfer agents. The bonding interactions apparent in our data indicate that if an alkanesulfenium ion is formed in certain environments in which there are electrons available for bonding, it will form a compound with the molecule possessing those electrons. Thus, for example, dimethyl(methylthio)-sulfonium ion is generated in the presence of dimethyl sulfide.

$$CH_3SBr + AgTNBS + CH_3SCH_3 \longrightarrow \underset{50\%}{CH_3S\overset{+}{S}(CH_3)_2TNBS^-} + AgBr$$

Experimental Section

Materials. Bromine and dimethyl disulfide were reagent grade and were used without further purification. Acetonitrile and dichloromethane were dried and stored over Linde Type 4A Molecular Sieve. Nitromethane, spectral grade, was washed with concentrated sulfuric acid and water, dried over magnesium sulfate, and stored over Linde Type 4A Molecular Sieve. The silver 2,4,6-trinitrobenzenesulfonate salts were prepared as previously described.[3]

Conductance Measurements. Methanesulfenyl bromide (0.01 mol, prepared *in situ* from stoichiometric amounts of bromine and dimethyl disulfide) in 50 ml of dichloromethane was placed in a dip-type conductance cell (cell constant 1.58 cm^{-1}) which was fitted with a nitrogen inlet tube. Silver 2,4,6-trinitrobenzenesulfonate–acetonitrile complex (0.01 mol) in 50 ml of nitromethane or acetonitrile was added to the cell and stirred for about 10 min with a magnetic stirring bar placed in the cell. Measurements were then recorded on a "magic eye" type of conductance bridge constructed by the chemistry department at the University of California, Riverside.

Chemical Shift Measurements. On the porous disk of the apparatus depicted in Figure 1 was placed a solution of 0.01 mol of silver 2,4,6-trinitrobenzenesulfonate in nitromethane or nitrobenzene. Dry nitrogen was forced up through the disk so that the reaction was blanketed at all times by an inert atmosphere. Methanesulfenyl bromide (0.01 mol) was added to the silver salt solution from a dropping funnel. When reaction was complete, as indicated by the disappearance of the red color of the sulfenyl bromide, the direction of the nitrogen stream was reversed, and a partial vacuum was placed on the bottom flask. In this manner the solution of sulfenium ion was filtered free of silver bromide under nitrogen. The solution was then concentrated *in vacuo* in the same flask to a volume of about 10 ml. Samples were withdrawn under nitrogen with a syringe and injected into nitrogen-flushed nmr tubes through a small stopple. Spectra were recorded on a Varian Associates A-60 nmr spectrometer at 60 MHz. After the spectrum was recorded, 10 μl of pyridine or acetonitrile was introduced and the spectrum was recorded again.

Generation of Methanesulfenium Ion in the Presence of Dimethyl Sulfide. On the porous disk of Figure 1 was placed a solution of 2.0 g (0.031 mol) of dimethyl sulfide and 2.1 g (0.004 mol) of silver 2,4,6-trinitrobenzenesulfonate–acetonitrile complex in 10 ml of nitromethane. From the dropping funnel was added a solution of methanesulfenyl bromide (0.004 mol, prepared *in situ* from 0.002 mol of dimethyl disulfide and 0.002 mol of bromine) in 50 ml of dichloromethane. When the reaction was complete, the solution was filtered free from silver bromide as previously described. Precipitation of the product with anhydrous ether yielded 0.8 g (0.002 mol, 50%) of dimethyl(methylthio)sulfonium 2,4,6-trinitrobenzenesulfonate, mp 195–196°. The melting point, mixture melting point, and nmr and infrared spectra of this compound were identical with those of the compound prepared by the alkylation of dimethyl disulfide with trimethyloxonium 2,4,6-trinitrobenzenesulfonate.[3,4]

The Reaction of Hydroxamic Acids with Water-Soluble Carbodiimides. A Lossen Rearrangement

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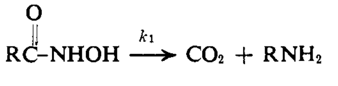
Abstract: A method for the conversion of hydroxamic acids to the amines under mild conditions has been developed. Treatment of the hydroxamic acid with a water-soluble carbodiimide at pH 5 and room temperature was found to give a quantitative conversion to the amine by means of a Lossen rearrangement. The mechanism of the reaction was established by kinetic data and product identifications. Since carboxylic acids can be readily converted to hydroxamic acids, the ready conversion of carboxylic acid groups to amino groups is possible by this method.

The conversion of carboxylic groups to amines can be effected in a number of ways.[2–5] Most of these methods, however, involve drastic conditions, such as strong alkali or highly reactive reagents. Since this reaction could be of great potential importance in biological investigations if it could be performed under mild conditions, a study of the conditions for such an interconversion was initiated. Hydroxamic acids exist in nature[6] and can be formed fairly readily from carboxylic acids.[7,8] Therefore, the first stage of our studies was to develop a method for the rearrangement of the hydroxamic acid at moderate pH's in aqueous solution at room temperature. The method which was found to be successful involves the treatment of the hydroxamic acid with a water-soluble carbodiimide to achieve a Lossen rearrangement (eq 1).



$$\mathrm{R}\overset{\overset{\displaystyle \mathrm{O}}{\|}}{\mathrm{C}}\text{-NHOH} \xrightarrow{k_1} \mathrm{CO_2} + \mathrm{RNH_2} \qquad (1)$$

In order to establish the mechanism of the reaction, the conditions to obtain quantitative yields, and the possibilities of side reactions, various kinetic measurements were made. These data together with a discussion of the advantages and limitations of the procedure are presented below.

Experimental Section

The authors are indebted to Dr. J. Kirsch for a sample of acetohydroxamic acid. The water-soluble reagent, 1-benzyl-3-dimethylaminopropylcarbodiimide (BDC), was prepared as its *p*-toluenesulfonate as described previously.[9] Glycylhydroxamic acid was made by the method of Cunningham,[10] mp 135° dec (lit.[10] value 137° dec).

All the reactions requiring titration or pH control were conducted in a Radiometer TTT1c pH-Stat with the ABU1b autoburet. A water-jacketed vessel was used, maintaining the temperature to better than ±0.1°.

Hydroxamic acids were assayed by a method based on the procedure of Goldenberg and Spoerri.[8] Aliquots of 0.5 ml at pH <4 were added to 2.5 ml of 0.10 *M* ferric chloride in 0.08 *M* HCl, and the absorbance (280 mμ, 1 cm) was measured; calibration indicated absorbance (280 mμ, 1 cm) = 0.321/μmol of acetohydroxamic acid. Control experiments indicated that O-acetylhydroxylamine yielded no hydroxamic acid under the assay conditions, even when the concentration of hydroxylamine hydrochloride in the assay solution was as high as 0.16 *M*. Diacetylhydroxylamine yielded 1 mol of hydroxamic acid per mol of diacetylhydroxylamine (*cf.* below).

Formaldehyde was estimated by a chromotropic acid procedure similar to that of Tompsett and Smith.[11] The sample (in 3 ml) was heated to 100° for 4 hr with 5.0 ml of chromotropic acid reagent (0.2 g of chromotropic acid in 2 ml of water plus 48 ml of 13 *M* H_2SO_4), cooled, and diluted with 2.0 ml of 9 *M* H_2SO_4. The formaldehyde was estimated from the absorbance (565 mμ, 1 cm). Calibration with hexamethylenetetramine gave absorbance (565 mμ, 1 cm) = 1.65/μmol of formaldehyde.

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