at −2° for 24 hr. The crystalline material present in the reddish brown reaction mixture was collected by filtration, and while still moist with solvent was dissolved in absolute ethanol and precipitated with ether. Minute traces of pyridine caused the product to have a slight brown color. Analytically pure pyridinium salt was obtained by crystallization from hot absolute ethanol; yield 0.25 g. (40%), m.p. 189.5–190.5.

Anal. Calcd. for $C_{13}H_{15}NO_8S_2$: C, 41.37; H, 4.01; N, 3.71; S, 16.99. Found: C, 41.93; H, 4.26; N, 3.60; S, 17.20.

Reaction products from other pyridine quaternization reactions with 2-chloromethyl- and 2-bromomethyl-4H-pyran-4-ones are listed, with melting points and analytical data, in Table I. Procedure for their preparation is as immediately above, except that in some cases products were transferred to a vacuum desiccator immediately upon isolation, dried over concentrated sulfuric acid, and then recrystallized from absolute ethanol or absolute ethanol–benzene.

2-Bromomethyl-5-mesyloxy-1,4-pyrone (2-Bromomethyl-5-methanesulfonyloxy-4H-pyran-4-one) (XIII). A. From Kojic Acid Dimethanesulfonate.—To 4 g. of kojic acid dimethanesulfonate was added 160 ml. of 48% hydrobromic acid. The reaction mixture was allowed to stand at room temperature undisturbed for 1 month, and then was neutralized with solid sodium bicarbonate. The mixture was extracted exhaustively with chloroform and solvent removed from the dried combined extracts to give a light brown residue, m.p. 102–103°; yield, 3.5 g. (92.5%). Mixture melting point with starting material, m.p. 110°, gave a depression to 86°. Recrystallization of 2-bromomethyl-5-mesyloxy-1,4-pyrone from 95% ethanol gave 2.9 g. of colorless, crystalline compound, m.p. 102–103°.

Anal. Calcd. for $C_7H_7BrO_6S$: C, 29.70; H, 2.49; Br, 28.23; S, 11.32. Found: C, 29.68; H, 2.37; Br, 27.79; S, 11.17.

B. From 2-Chloromethyl-5-mesyloxy-1,4-pyrone.—To 2 g. of 2-chloromethyl-5-mesyloxy-1,4-pyrone was added 80 ml. of 48% hydrobromic acid. The reaction mixture was permitted to stand at room temperature for 10 days, and then was neutralized with solid sodium bicarbonate. The mixture was extracted exhaustively with chloroform. Solvent removal from the dried combined extracts gave 2.1 g. (86%) of product, m.p. 101–102.5°. Recrystallization from 95% ethanol gave 1.7 g. of colorless 2-bromomethyl-4-mesyloxy-1,4-pyrone, m.p. and mixture m.p. 102–103°. Mixture melting point with starting material was 78°.

When 1 g. of 2-bromomethyl-5-mesyloxy-1,4-pyrone reacted with 50 ml. of concentrated hydrochloric acid for 5 days, and the product was isolated as immediately above, 0.8 g. (97%) of 2-chloromethyl-5-mesyloxy-1,4-pyrone, m.p. and mixture m.p. 82–83°, was obtained.

To 1 g. of 2-bromomethyl-5-mesyloxy-1,4-pyrone was added 10 ml. of glacial acetic acid. One gram of zinc dust, previously treated with dilute sulfuric acid and washed with water, was added slowly and the mixture allowed to stand on the steam bath 7 hr. The mixture was filtered and the filtrate neutralized with solid sodium bicarbonate. Extraction with chloroform and solvent removal gave 0.37 g. (51.4%) of colorless tablets, m.p. 99.5–100.5°. Mixture melting point with starting material, m.p. 102–103°, was 77–78°. Recrystallization from chloroform gave colorless tablets of allomaltol methanesulfonate, m.p. and mixture m.p. 100–101°.

2-Chloromethyl-5-methoxy-4H-pyran-4-one (XIV).—This substance was prepared by the method of Yabuta.[5]

2-Bromomethyl-5-methoxy-4H-pyran-4-one (XV).—2-Chloromethyl-5-methoxy-4H-pyran-4-one (17.5 g.) was dissolved in 275 ml. of 48% hydrobromic acid. The solution stood for 10 days at room temperature, and then was carefully neutralized with solid sodium bicarbonate. After the resulting mixture stood in a refrigerator overnight, the white solid present was collected by filtration, washed with cold water, and air-dried; yield, 19 g. (85%). Recrystallization was effected with hot water to give cream-colored crystals of 2-bromomethyl-5-methoxy-4H-pyran-4-one, m.p. 135–136°.

Anal. Calcd. for $C_7H_7BrO_3$: C, 38.53; H, 3.21; Br, 36.24. Found: C, 38.46; H, 3.37; Br, 36.67.

Acknowledgment.—The advice and counsel of Dr. F. H. Stodola, who made a sample of authentic maltol available to us, are gratefully acknowledged. We are indebted to the Corn Products Sales Company for a generous gift of kojic acid, and to the New York Quinine and Chemical Works, Inc., for supplying us with a 100-g. sample of meconic acid.

Sulfenic Acids and Their Derivatives. XLI. Sulfenyl Nitrates and Sulfinyl Radicals[1]

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Sulfenyl nitrates, $RSONO_2$, represent a novel class of sulfenyl compounds. The preparation of the first examples is described and some of their properties are recorded. The near-quantitative conversion of sulfenyl nitrates to thiolsulfonate esters ($2RSONO_2 \rightarrow RSO_2SR + 2NO_2$) is demonstrated and interpreted as a dimerization reaction of sulfinyl radicals.

In seeking routes to substances capable of generating sulfinyl radicals, RSO·, a series of sulfenyl nitrates, $RSONO_2$, a new class of sulfenyl derivatives of both theoretical and practical interest has been prepared. It was reasoned that the loss of NO_2 radicals from the sulfenyl nitrates could provide an advantageous source of the little known sulfinyl radicals, and that the chemistry of these radicals and of the sulfenyl nitrates would offer a new field of study.

For small-scale synthesis, the preparation of sulfenyl nitrates by reactions of equivalent quantities of the sulfenyl chlorides and silver nitrate in

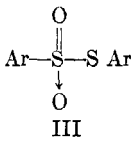
(1) This study was carried out under contract AF-49-(638)-718, with the Office of Scientific Research, Air Research and Development Command, and with partial support of a grant from the Stauffer Chemical Company. For a preliminary communication concerning this study, see R. M. Topping and N. Kharasch, *Chem. Ind.* (London), 178 (1961).

dry acetonitrile solutions (equation 1) proved effective.

$$\underset{\text{I}}{\text{ArSCl}} + \text{AgNO}_3 \xrightarrow{\text{low temperatures}} \underset{\text{II}}{\text{ArSONO}_2} + \text{AgCl} \quad (1)$$

Silver chloride precipitated quantitatively and the sulfenyl nitrate remained dissolved.

The stability of the sulfenyl nitrates depended greatly on the nature of the aryl group. 2,4-Dinitrobenzenesulfenyl nitrate (II, Ar = 2,4-dinitrophenyl) was the most stable, while *p*-chlorobenzenesulfenyl nitrate was least stable. The former was readily isolatable from the acetonitrile solution as an excellently crystalline solid, while *p*-chlorobenzenesulfenyl nitrate decomposed spontaneously during preparation. Decomposition was indicated by continuous evolution of nitrogen dioxide when isolation of the nitrate was attempted by removal of acetonitrile in partial vacuum, at room temperature. The only product isolated from such attempts was the thiolsulfonate ester (III. Ar = *p*-chlorophenyl).



III

4-Chloro-2-nitrobenzenesulfenyl nitrate and 2-nitrobenzenesulfenyl nitrate showed intermediate stabilities; the nitrate isolated from the reaction mixtures in these cases were contaminated with the corresponding thiosulfonate esters.

The decomposition of the nitrates in the solid state was accelerated by crushing the product finely and keeping it for extended periods under pressures of about 0.5 mm. Under these conditions, the infrared absorption bands at 8.05 μ and 8.25 μ, which we have tentatively assigned to the covalent nitrate structure, diminished in intensity, while an absorption at 8.7 μ, characteristic of the thiolsulfonate structure appeared. Two medium intensity bands, which appear to be typical only of 2,4-dinitrobenzenesulfenyl nitrate, at 10.25 μ and 10.65 μ, also disappeared during decomposition of the latter compound. At room temperature, however, the decomposition of 2,4-dinitrobenzenesulfenyl nitrate was still incomplete after one week.

Ultraviolet irradiation of solutions of 2,4-dinitrobenzenesulfenyl nitrate in acetonitrile caused considerable decomposition, but no distinct products were identified. X-Ray irradiation of 2-nitro-4-chlorobenzenesulfenyl nitrate also caused its decomposition, giving a product with an identical X-ray pattern to that of a similarly irradiated sample of the corresponding thiolsulfonate ester (III. Ar = 2-nitro-4-chlorophenyl). It is probable, therefore, in these experiments also, that decomposition of the nitrate proceeds *via* the thiolsulfonate ester.

Treatment of the sulfenyl nitrates with certain solvents, such as ethanol, ethylene chloride, methylene chloride and water causes a remarkably facile conversion to the pure thiolsulfonate esters. Thus, upon adding such a solvent to 2,4-dinitro-, 2-nitro- or 2-nitro-4-chlorobenzenesulfenyl nitrate, ArSONO_2, conversion to the corresponding pure thiolsulfonate ester, ArSO_2SAr, is practically instantaneous. The infrared spectra of the product revealed no absorptions at 8.05 μ or 8.25 μ, indicating the complete loss of the covalent nitrate function. Furthermore, using known amounts of 2,4-dinitrobenzenesulfenyl nitrate, a 95% yield of thiolsulfonate ester was recovered using distilled water as wash solvent and 91% recovery was found with 100% ethanol as solvent. Acetonitrile and nitromethane were much less effective in promoting the conversion, while carbon tetrachloride and benzene were completely ineffective. The structural diversity of the effective solvents suggests that they may function by trapping the low equilibrium concentration of nitrogen dioxide radical either by furnishing a hydrogen atom to the radical or, in the case of water, by hydrolysis of the nitrogen dioxide. In support of this conclusion it was found that the aqueous washings of the nitrates responded strongly to tests for nitrous acid—*e.g.*, diazotization of sulfanilic acid and formation of a red dyestuff—by coupling with α-naphthylamine. This test was also given by a solution of nitrogen dioxide in water but not by a dilute solution of nitric acid. The presence of nitrous acid was also indicated by diazotization of benzidine. Similarly, the addition of a crystal of a sulfenyl nitrate to a few drops of a solution of diphenylamine in concentrated sulfuric acid produced an intense blue color, indicating the presence of a strong oxidizing agent (nitric or nitrous acid).

On the basis of (*a*) the nature of the products of decomposition (nitrogen dioxide and thiolsulfonate ester only), (*b*) the observation that decomposition may occur spontaneously, and (*c*) the effect of storage under vacuum, we propose a mechanism for the decomposition of sulfenyl nitrate in which the primary homolytic cleavage of the sulfenyl nitrate (equation 2) leads to quantitative production of thiolsulfonate ester by coupling of the arenesulfinyl radicals, *via* intermediate IV and its subsequent rearrangement (equation 3).

$$\text{ArSONO}_2 \longrightarrow \text{ArSO}\cdot + \text{NO}_2 \quad (2)$$

$$2\text{ArSO}\cdot \longrightarrow \underset{\text{IV}}{\left[\text{ArS}(=\text{O})\text{—O—SAR}\right]} \longrightarrow \text{ArSO}_2\text{—S—Ar} \quad (3)$$

The possibility that $\text{ArSO}\cdot$ interacts with ArSONO_2, giving $\text{ArSO}_2\text{SAr} + \text{NO}_2\cdot$, has of course not been ruled out. Hence the above dimerization of $\text{ArSO}\cdot$ is schematic only.

An analogous first step has also been proposed for the thermal decomposition of ethyl nitrate

$$C_2H_5ONO_2 \longrightarrow C_2H_5O\cdot + NO_2\cdot \quad (4)$$

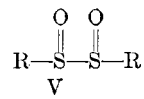
(equation 4)[2] but this occurs at 200° in contrast to the ease of scission of $ArSONO_2$.

The implied instability of intermediate IV, leading to its rearrangement to the thiolsulfonate ester is supported by the work of Stirling[3] who has shown that thiolsulfonate esters are produced by the reaction of sulfenyl chlorides with sulfinic acids.

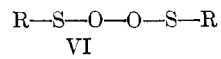
A possible decomposition process occurring by a chain mechanism could involve a propagation step in which the nitrogen dioxide radical attacked the sulfenyl nitrate to produce a free sulfinyl radical. This was shown to be unlikely, since 2,4-dinitrobenzenesulfenyl nitrate was recovered unchanged from a solution in acetonitrile through which a stream of nitrogen dioxide had been passed.

The coupling of sulfinyl radicals to form thiolsulfonate ester has also recently been suggested[4] to be the common mechanism responsible for the identical distribution of activity in thiosulfonate and disulfide formed from a specifically labelled thiolsulfinate (*a*) in the initial stages of oxidation, (*b*) by spontaneous disproportionation in vacuum, and (*c*) by sulfinyl radical-induced decomposition.

The question as to whether RSO· radicals might couple at low temperatures to yield intermediates as disulfoxides (V) or sulfenyl peroxides (VI) is of interest.



V



VI

As the generation of sulfinyl radicals at low temperatures has not been previously feasible, the methods outlined in this paper for the production of sulfinyl radicals at low temperatures from selected sulfenyl nitrates may prove of value in such work. In connection with these possible structures and their relations to thiolsulfonate esters, the earlier papers of Cymerman and Willis[5a] and of D. Barnard[5b] are pertinent.

Reaction of 2,4-dinitrobenzenesulfenyl chloride with silver nitrite yielded a solid, VII, analysis of which showed values between those calculated for the nitrite and for the corresponding thiolsulfonate ester. Treatment of VII with water or ethanol caused it to be *fully* converted to the thiolsulfonate ester (III. Ar = 2,4-dinitrophenyl). The infrared spectrum of the solid VII, however, closely resembled that of a mixture of the corresponding nitrate and thiolsulfonate ester, suggesting that the initially formed sulfenyl nitrite may be readily oxidizable.

The synthetic technique for the preparation of sulfenyl nitrates is being extended (*a*) to the possible synthesis of nitrates from other active chlorides [such as $Ar(SCl)_2$, $ArS(O)Cl$, $Ar_2P(O)Cl$ and $ArSO_2Cl$] and (*b*) to the preparations of new classes of sulfenyl compounds by the interactions of sulfenyl halides with various silver salts (such as $AgNO_2$, AgOCN, Ag_2CrO_4, and $AgClO_4$). The reaction with silver perchlorate and 2,4-dinitrobenzenesulfenyl chloride, in ethylene chloride, has been recorded previously.[6] Preliminary studies with ArSeCl and ArSOCl are suggestive of distinct differences in chloride reactivity and product stabilities, in contrast to the sulfenyl nitrates.

Experimental

Reagents.—2,4-Dinitro[7]- 2-nitro-, and 2-nitro-4-chlorobenzenesulfenyl chlorides were obtained from the corresponding disulfides by cleavage with sulfuryl chloride, using pyridine as catalyst in carbon tetrachloride solvent. 4-Chlorobenzenesulfenyl chloride was obtained as a freshly distilled sample. Silver nitrate, finely powdered, was dried in a stream of dry air at 150–180°. Acetonitrile was dried by refluxing over calcium hydride, followed by distillation. All melting points are uncorrected.

Preparation of 2,4-Dinitrobenzenesulfenyl Nitrate (VIII) and Other Nitrates.—To a solution of 2,4-dinitrobenzenesulfenyl chloride (15 g.; 0.064 mole) in dry acetonitrile (300 ml.) was slowly added, with continuous stirring, a solution of silver nitrate (10.87 g.; 0.064 mole) in dry acetonitrile (300 ml.), the mixture being cooled in an acetone bath containing solid carbon dioxide. An immediate precipitate of silver chloride and a change in the color of the reaction mixture from yellow to green was noted. After the addition was completed the precipitate was allowed to coagulate before removal by filtration through sintered glass. Removal of solvent from the filtrate under a stream of dry air yielded VIII as a pale yellow crystalline solid (m.p. 117°).

Anal. Calcd. for $C_6H_3O_7N_3S$: C, 27.59; H, 1.16; S, 12.28. Found: C, 27.00; H, 1.41; S, 11.70.

Similar procedures were used for the preparations of 2-nitrobenzenesulfenyl nitrate (IX) (m.p. 110–114°) and 2-nitro-4-chlorobenzenesulfenyl nitrate (X) (m.p. 125–132°). In these cases, however, elemental analyses suggested them to be mixtures of the nitrate and of the corresponding thiolsulfonate ester. In all cases the precipitation of silver chloride was quantitative.

In the attempted preparation of 4-chlorobenzenesulfenyl nitrate a continuous evolution of nitrogen dioxide was observed during removal of solvent. The thiolsulfonate ester was the single product formed.

Treatment of the Sulfenyl Nitrates with Various Solvents.—VIII (257 mg.), after thorough mixing with 100% ethanol (5 ml.), followed by filtration through sintered glass, was converted to a pale yellow crystalline solid (191 mg.; 91% of theoretical yield of thiolsulfonate ester); m.p. 126.5–127° [lit.,[6] m.p. of III (Ar = 2,4-dinitrophenyl) = 126–126.5°].

Anal. Calcd. for $C_{12}H_6O_{10}N_4S_2$: C, 33.49; H, 1.41; S, 14.8. Found: C, 33.14; H, 1.40; S, 14.69.

Similar treatment using distilled water in place of 100% ethanol gave 94% recovery of thiolsulfonate ester. Qualitative experiments using ethylene dichloride, methylene dichloride, and acetone as wash liquids all effected the conversion of sulfenyl nitrate to thiolsulfonate ester, the identity

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of the products being checked by melting point and mixture melting points.

IX (contaminated with the corresponding thiolsulfonate ester) (m.p. 110–114°) was suspended in dry carbon tetrachloride and boiled for 30 min. The material was recovered unchanged. Treatment of IX with 100% ethanol gave an immediate precipitate of a very pale yellow, highly crystalline solid (m.p. 145–146°) [lit. m.p. of III (Ar = 2-nitrophenyl) = 143°]. Treatment of IX with distilled water yielded a residue of m.p. 143–144° which showed no mixture melting point depression with the corresponding product from ethanol.

X (contaminated with the corresponding thiolsulfonate ester) (m.p. 125–132°) yielded a pale yellow crystalline solid (m.p. 144–145°) upon treatment with 100% ethanol [lit. m.p. of III (Ar = 2-nitro-4-chlorobenzene) = 145°]. The same product resulted from treatment of this nitrate with distilled water.

The ultraviolet spectrum of 2,4-dinitrobenzenesulfenyl nitrate was determined in acetonitrile solvent using a Cary recording spectrophotometer (model 14): λ_{max} = 245 mμ (ϵ_{max} 11,540).

Infrared spectra were determined using a Perkin–Elmer Infracord spectrophotometer. It was noted that even Nujol promoted decomposition of the nitrates and thus all infrared spectra were made using potassium bromide disks. The detailed spectra of $ArSONO_2$, ArSCl, and $ArSO_2SAr$ (Ar = 2,4-dinitrophenyl) have been deposited in the collection of the Instrumentation Research Center, Los Angeles, California,[8] from whom copies may be obtained at minimal cost. The spectral patterns clearly differentiate the three products.

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(8) Intra-Science Research Foundation, Instrumentation Research Center, 2404 Wilshire Boulevard, Los Angeles 57, Calif.

A Convenient Stereospecific Synthesis of Axial Amines in Some Steroidal, Decalyl, and Cyclohexyl Systems[1]

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It has been shown that ammonolysis of a variety of equatorial sulfonate esters in steroidal, decalyl, and cyclohexyl systems furnishes axial amines free of structural and stereochemical isomers. The simplicity, the exceedingly high stereospecificity, and the nonreductive nature of the reaction makes this the preferred method for the synthesis of axial amines.

In connection with studies on substitution reactions in rigid systems, we have sought to develop a simple method for the stereospecific synthesis of cycloalkyl axial amines. Two popular routes to axial amines have been platinum-catalyzed hydrogenation in acetic acid solution[2–5] or lithium aluminum hydride reduction of the appropriate oxime.[4,6–9] Although the first of these methods is widely used, it suffers from several disadvantages. The alcohol, which is the usual starting material in these reactions, must be oxidized to the ketone and the latter converted to oxime. The oxime is sometimes a mixture of *syn* and *anti* isomers[10,11] and is thus difficult to purify. Often the hydrogenation is not reproducible and it frequently gives poor yields,[8,12] an important side product being secondary amine.[12,13] Furthermore, the axial amine obtained is usually contaminated with varying amounts of the equatorial isomer and in one case, that of coprostanone oxime, the equatorial amine appears to be formed exclusively.[4] Another factor that limits the utility of this method is its reductive nature which precludes the preparation of axial amines bearing reducible groups. Reduction of the oxime with lithium aluminum hydride furnishes mixtures, containing both equatorial and axial amines, which are usually difficult to separate. Although separation of the epimeric amines *via* their amide derivatives is sometimes possible, the very hindered axial amides are difficult to cleave.[2,12]

The Hofmann and Curtius reactions have also been used in some instances, but the preparation of the requisite axial carboxylic acid involves a multistep sequence entailing severe losses.[14,15] Occasionally, reductive amination of the appropriate cyclic ketone with ammonium formate has been

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