BULLETIN OF THE CHEMICAL SOCIETY OF JAPAN VOL. 43 488—491 (1970)

The Double Cycloaddition of Disulfene and Its Related Reactions

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(Received July 14, 1969)

The reactions of methanedisulfonyl chloride (II) with ketene diethylacetal (III), 1-morpholinocyclohexene (IV), and 1-piperidinopropene (V) in the presence of triethylamine were studied. The products obtained were the double cycloadduct, spiro bithietane tetroxide (VI), and the substitution products (X and XV). These findings suggest that triethylamine dehydrochlorinates methanedisulfonyl chloride to produce disulfene. However, as yet we cannot say whether the formation of disulfene is the one-step dechydrochlorination mechanism ($ClSO_2CH_2SO_2Cl \rightarrow SO_2{=}C{=}OS_2$) or the two-step one ($ClSO_2CH_2SO_2Cl \rightarrow ClSO_2CH{=}SO_2 \rightarrow SO_2{=}\underset{|}{C}{-}\underset{|}{SO_2}$).

In the presence of triethylamine, various alkanesulfonyl chlorides react with compounds containing electron-rich and polarizable double bonds, such as enamines and ketene acetals, to afford four-membered cyclic sulfones (thietane dioxide) or isomeric acyclic compounds, depending on the nature of reactants and the reaction media. These reactions have been formulated as involving the reactive intermediacy of sulfene ($RCH{=}SO_2$).[1-3] However, it has only recently been reported that 1,3-propanedisulfonyl chloride reacts with 1-morpholinocyclohexene or ketene diethylacetal in the presence of triethylamine to yield the corresponding bithietane tetroxide (Fig. 1).[4] These reactions are regarded as proceeding through the intermediacy of disulfene.

In view of these facts, we were prompted to study the possibility of preparing a new disulfene $O_2S{=}C{=}SO_2$ (I) as an analogy to carbon suboxide $OC{=}C{=}CO$. In this paper we now wish to report some of the information obtained from the reactions of methanedisulfonyl chloride (II) with ketene diethylacetal (III), 1-morpholinocyclohexene (IV), and 1-piperidinopropene (V) in the presence of triethylamine. The reaction of II with III and

$$ClSO_2CH_2SO_2Cl + 2\,CH_2{=}C(OEt)_2 \xrightarrow[-5°C\ 10\ hr]{4\text{ or }2\ Et_3N} \underset{(VI)}{\text{spiro bithietane tetroxide}}$$

(II) (III)

triethylamine in benzene at −5°C for 10 hr gave a crystalline substance, which was formulated as spiro bithietane tetroxide (VI), in a 45% yield. The formation of VI is conceived of as proceeding through the intermediacy of disulfene, which then undergoes a double cycloaddition reaction with III.

When VI was dissolved in cold ethanol and set aside at −10——50°C for more than 30 hr, a ring cleavage and proton transfer occurred to give the product, VII, quantitatively. This reaction is

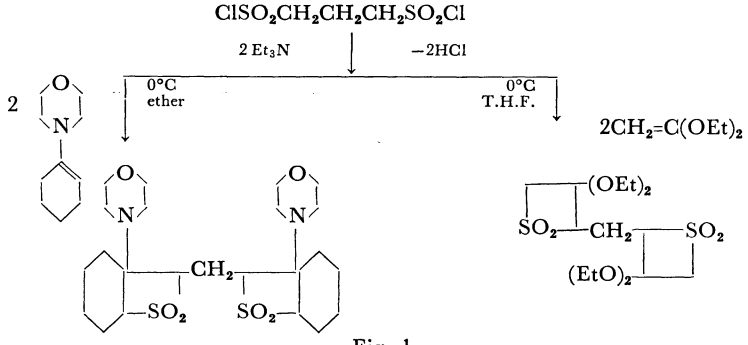
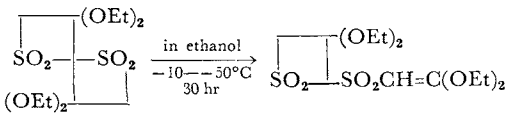


Fig. 1

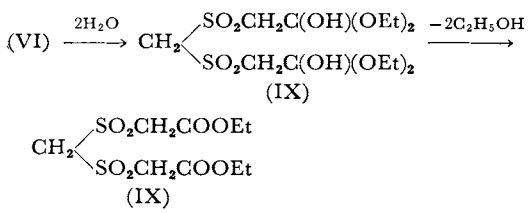
1) W. E. Truce and J. R. Norell, *J. Amer. Chem. Soc.*, **85**, 3231 (1963).
2) G. Stork and I. J. Borowitz, *ibid.*, **84**, 313 (1962).
3) a) G. Opitz, *Angew. Chem.*, **79**, 161 (1967). b) G. Opitz and H. R. Mohl, *ibid.*, **81**, 36 (1969).
4) T. Nagai, H. Namikoshi and N. Tokura, *Tetrahedron Lett.*, **1968**, 4329.

considered to be due to the strain inherent in VI.



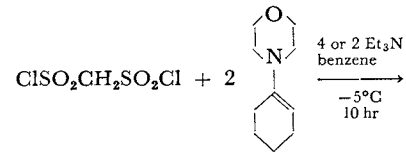
(VI) (VII)

On the other hand, when pure VI was dissolved in ether or ethanol containing a trace of water at 30°C, the diester (IX) was immediately formed quantitatively. Presumably, IX may have arisen from the β-elimination of ethanols from the intermediate diol (VIII), which was produced by the two ring cleavages of VI and the addition of water. The compound VII is found to be stable and does not change to IX under similar or even more vigorous (reflux in ethanol) conditions.

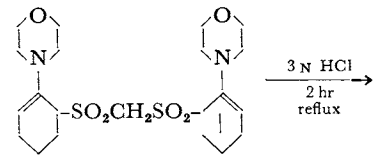


Although the IR and NMR spectra of VI have not yet been obtained because of its instability, the structure VI is adequate judging from elemental analysis and the conversion to VII and IX. The IR spectrum of VII shows strong bands at 1340 and 1130 ($-SO_2-$) and at 1585 cm^{-1}, the latter being attributed to the olefinic double bond; it also shows weak band at 3100 cm^{-1} (CH=). The NMR spectrum is also in harmony with the structure VII. The appearance of the ring methine proton at τ 4.5 as a quartet leads us to attribute the splitting to a 1,3-transannular interaction with the two nonequivalent ring methylene protons (ABX system). A singlet at τ 5.21 was assigned to an olefinic proton, and the abnormal up-field shift of the olefinic proton is considered to be due to the polarization of the double bond by the two electron-donating ethoxyl groups. A double triplet at τ 8.75 accounts for the methyl protons of the ketal moiety. This is regarded as a result of the fact that the two ethoxyl groups of the ketal moiety become unequivalent. Similarly, the methyl protons of the vinyl ether moiety appeared as a double triplet at τ 8.63. The IR spectrum of IX had absorptions at 1740 cm^{-1} (C=O of the ester).

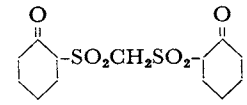
A similar reaction of II with IV in the presence of triethylamine led to the formation of sulfonylenamine (X) in a 34% yield. The acid-catalyzed hydrolysis of X gave the expected corresponding ketosulfone (XI) almost quantitatively. The IR spectrum of X shows an olefin band at 1658 cm^{-1}. A broad triplet at τ 4.55 was assigned to the two olefinic protons, and a multiplet at τ 5.4 was attributed to the two methine protons. This reaction has the possibility of generating different products, for example, the less substituted sulfonylenamine (X) and the more substituted one (XIII) by proton transfer from the 2 and 6 positions of the ring respectively, or a compound like XIV by a double cycloaddition. In this reaction several factors may contribute to the preferred formation of one of the possible isomers. The determining factors may be the particular structure and conformation of the zwitterionic intermediate (XIIa, XIIb) and the nature of the reactants (II, IV, base). For instance, when the intermediate (XIIa, XIIb) bears bulky groups at the electrophilic center, only the less substituted sulfonylenamine (X) is formed.



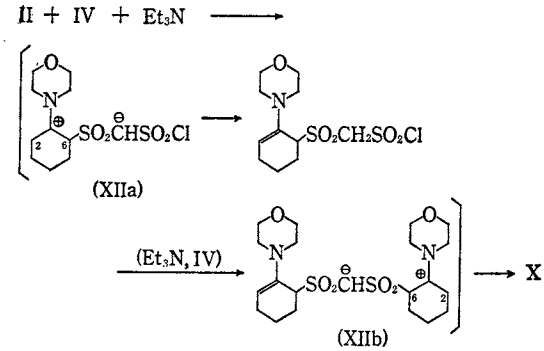
(II) (IV)



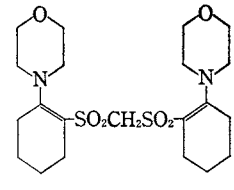
(X)



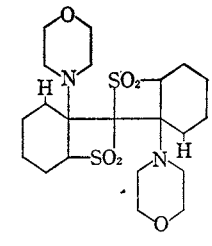
(XI)



Although the two-step dehydrochlorination mechanism seems to be preferable to the one-step one, more definitive experiments are needed.



(XIII)

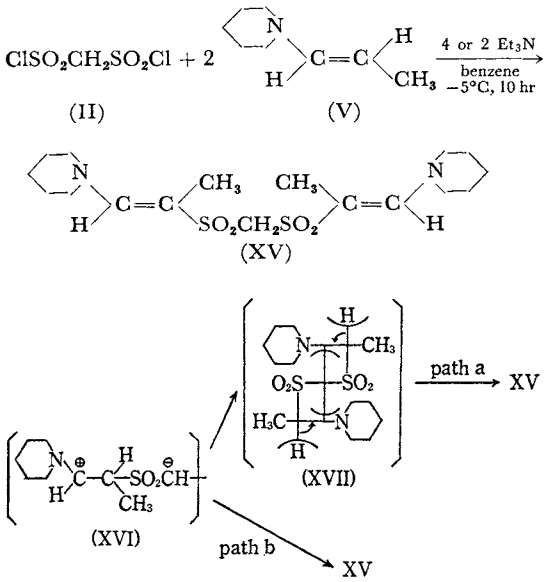


(XIV)

When the reaction time was 1—2 hr, the yields of VI and X were lowered to 2—4% and a white precipitate formed during the reaction immediately decomposed to methanedisulfonic acid, triethylamine hydrochloride, and an intractable dark brown oil on exposure to air. After 10 hr, however, the products obtained did not include this precipitate, but VI (45%) or X (34%) and triethylamine hydrochloride. From these results, it is apparent that these reactions are not complete within 1—2 hr and that this precipitate is the unstable intermediate, from which VI and X result. Methanedisulfonic acid was characterized by its conversion to the dianilide.

In like fashion, the interaction of II, triethylamine, and V under the same conditions led to the formation of XV in a 16% yield. The IR spectrum of XV shows the presence of the olefinic double bond at 1638 cm^{-1}.

The path of this reaction cannot be stated with certainty, but a postulated mechanism is shown below. In this case again, if the steric interference exists, the compound XV would arise from substitution instead of cyclization *via* a zwitterionic intermediate such as XVI (path b), but presumably XV may have arisen from ring cleavages of the intermediacy of spirane (XVII), as is shown in path a, in view of recent articles[5,6] about the reactions of sulfenes and such enamines as V and our own finding regarding ketene diethylacetal, which is not greatly different with regard to its steric circumstances.



5) G. Opitz and H. Adolph, *Angew. Chem.*, **74**, 77 (1962).

6) G. Opitz and K. Rieth, *Tetrahedron Lett.*, **1965**, 3977.

Experimental

Materials. The methanedisulfonyl chloride,[7] ketene diethylacetal,[8] 1-morpholinocyclohexene,[9] and 1-piperidinopropene[10] were prepared by methods described in the literature.

Reaction of Methanedisulfonyl Chloride with Ketene Diethylacetal. A solution of 5.3 g (0.025 mol) of methanedisulfonyl chloride in 50 m*l* of benzene was stirred, drop by drop, into a solution of 5.8 g (0.05 mol) of ketene diethylacetal and 11.0 g (0.1 mol) of triethylamine in 200 m*l* of benzene at −5°C over a 10-hr period. The amine hydrochloride was then removed by filtration, and the benzene solution was evaporated under reduced pressure to afford 4.15 g (45%) of crude VI, which was then washed with cold petroleum ether - ether and recrystallized from cold ethanol, the temperature being kept below 0°C.

Found: C, 41.70; H, 6.20; S, 17.25%. Calcd for $C_{13}H_{24}O_8S_2$: C, 41.92; H, 6.49; S, 17.21%.

Compound VI (2.0 g) was dissolved in cold ethanol (20 m*l*) and then set aside at −10——50°C for more than 30 hr. The subsequent removal of the ethanol under reduced pressure and recrystallization from ethanol gave 2.0 g of VII. Colorless needles, mp 135.5—136.5°C. IR: 3100 (ν CH=), 1585 (ν C=C), 1340, 1130 cm^{-1} (ν SO_2). NMR ($CDCl_3$): τ 4.5(1H, quartet, SO_2CHSO_2), 5.21 (1H, singlet, $=CHSO_2$), 5.6—6.1 (2H, octet, CH_2SO_2), 5.76 (4H, quartet, CH_2O-C=), 6.35 (4H, quartet, CH_2O-C–), 8.63 (6H, double triplet, CH_3CH_2O-C=), 8.75 (6H, double triplet, CH_3CH_2O-C–).

Found: C, 41.75; H, 6.55; S, 17.02%. Calcd for $C_{13}H_{24}O_8S_2$: C, 41.92; H, 6.49; S, 17.21%.

The mass spectrum gave a parent peak at 372 *m/e* and other major peaks at 357, 317, 271, 179, 151, 123, 116, 105, 79, 78, 77, 73, 60, 55, 46, 44, and 43 *m/e*.

When VI (2.0 g) was dissolved in ether or ethanol containing a trace of water at 30°C, 1.7 g of IX were immediately formed; the IX was then recrystallized form ethanol. Colorless needles; mp 73.5°C.

IR: 1740 (ν C=O), 1320, 1100 cm^{-1} (ν SO_2). NMR ($CDCl_3$): τ 4.7 (2H, singlet, $SO_2CH_2SO_2$), 5.6 (4H, singlet, SO_2CH_2CO), 5.7 (4H, quartet, OCH_2CH_3), 8.67 (6H, triplet, OCH_2CH_3).

Found: C, 34.14; H, 5.03%. Calcd for $C_9H_{16}O_8S_2$: C, 34.18; H, 5.09%.

The mass spectrum gave a parent peak at 316 *m/e* and other major peaks at 289, 271, 243, 225, 166, 137, 88, 45, 43, and 42 *m/e*.

Reaction of Methanedisulfonyl Chloride with 1-Morpholinocyclohexene. A solution of 5.3 g (0.025 mol) of methanedisulfonyl chloride in 50 m*l* of benzene was stirred, drop by drop, into a solution of 8.4 g (0.05 mol) of 1-morpholinocyclohexene and 11.0 g (0.1 mol) of triethylamine in 200 m*l* of benzene at −5°C over a 10-hr period. The amine hydrochloride was removed by filtration, and the benzene solution was evaporated under reduced pressure to afford 4.0 g

7) H. Goldwhite and M. S. Gibson, *Tetrahedron*, **21**, 2743 (1965).

8) S. M. McElvain, "Organic Syntheses," Coll. Vol. III, p. 506, (1955).

9) S. Hünig, "Organic Syntheses," **41**, 65 (1961).

10) C. Mannich and H. Davidsen, *Ber.*, **69**, 2107 (1936).

(34%) of crude X, which was then washed with ether and recrystallized from methanol. Colorless needles, mp 202°C (dec). IR: 1658 (ν C=C), 1310, 1120 cm^{-1} (νSO_2). NMR($CDCl_3$): τ4.0 (2H, singlet, $SO_2CH_2SO_2$), 4.55 (2H, broad triplet, =CH), 5.4 (2H, multiplet, $CHSO_2$), 6.2 (8H, triplet, O-CH_2), 6.6—7.1 (4H, multiplet, allylic proton), 7.1—8.5 (16H, multiplet, N-CH_2 and other CH_2 groups of the cyclohexene ring).

Found: C, 53.30; H, 7.26; N, 5.74%; mol wt, 474. Calcd for $C_{21}H_{34}N_2O_6S_2$: C, 53.14; H, 7.22; N, 5.90%; mol wt, 474.

Hydrolysis of Sulfonylenamine (X). Compound X was suspended in 200 m*l* of 3 N hydrochloric acid and heated at a gentle reflux for 2 hr, during which time dissolution was completed. The solution was then extracted with benzene, and the bezene layer was washed with water, dried, and concentrated. The solid residue was washed with petroleum ether and recrystallized from ethanol to give 1.35 g (95%) of XI. Colorless plates; mp 158.5°C. IR: 1720 (νC=O), 1320, 1120 cm^{-1} (νSO_2). NMR ($CDCl_3$): τ 4.67 (2H, singlet, $SO_2CH_2SO_2$), 5.5 (2H, multiplet, $CHSO_2$), 7.28—8.4 (16H, multiplet, CH_2 groups of the cyclohexane ring).

Found: C, 46.18; H, 6.21%. Calcd for $C_{13}H_{20}O_6S_2$: C, 46.31; H, 6.00%.

The mass spectrum gave a parent peak at 336 *m/e* and other major peaks at 241, 223, 176, 175, 174, 98, 97, 96, 81, 69, 68, 67, 55, and 41 *m/e*.

Reaction of Methanedisulfonyl Chloride with 1-Piperidinopropene. A solution of 5.3 g (0.025 mol) of methanedisulfonyl cholride in 50 *ml* of benzene was stirred, drop by drop, into a solution of 6.2 g (0.05 mol) of 1-piperidinopropene and 11.0 g (0.1 mol) of triethylamine in 200 m*l* of benzene at −5°C over a 10-hr period. The amine hydrochloride was then removed by filtration, and the benzene solution was evaporated under reduced pressure. The residue was chromatographed on activated alumina. Elution with chloroform gave 1.45 g (16%) of XV, which was then washed with ether and recrystallized from ether. Colorless needles; mp 99—100°C. IR: 1638 (ν C=C), 1300, 1150 cm^{-1} (νSO_2). NMR ($CDCl_3$): τ 3.0 (2H, singlet, =CH), 5.7 (2H, singlet, $SO_2CH_2SO_2$), 6.6 (8H, broad singlet, N-CH_2), 7.9 (6H, singlet, CH_3), 8.35 (12H, broad singlet, other CH_2 groups of the piperidine ring).

Found: C, 52.21; H, 7.76; N, 7.28%. Calcd for $C_{17}H_{30}O_4S_2N_2$: C, 52.27; H, 7.74; N, 7.17%.

The mass spectrum gave a parent peak at 390 *m/e* and other major peaks at 248, 188, 150, 138, 125, 124, 123, 122, 110, 96, 81, 68, 55, and 41 *m/e*.