in the case of the trimethylbiphenylylsilanes. As in this paper, these workers observed absorption at 6.47 μ resulting probably from *para*-substitution in unhindered biphenyls. This conclusion is supported by the data of Cannon and Sutherland¹⁴ and others.25

Although Young and co-workers²¹ noted a symmetrical splitting of the 8.95 μ band upon diphenyl substitution in polysiloxane chains, there is no such comparable branching in the spectra of diphenylsilanes of the present paper or in 1,1-diphenylalkanes.26

Absorption at 9.91 μ is characteristic of certain biphenyl compounds and seems to be due to stretching vibration in the ring-to-ring C-C bond. It ap-

(25) R. B. Barnes, R. C. Gore, R. W. Stafford and V. Z. Williams, Anal. Chem., 20, 402 (1948).

(26) K. T. Serijan, I. A. Goodman and W. J. Yankauskas, National Advisory Committee for Aeronautics, Technical Note 2557, November. 1951.

pears at this wave length in ortho- or para-substituted biphenyl.14,24

The characteristic 10.05μ band probably arises from benzene ring C-C stretching, although this mode is infrared inactive in more symmetrical compounds such as benzene itself. The same band has been reported as a characteristic phenyl frequency in trimethylphenylsilane. $^{\rm 27}$

The bands at about 13.5–13.6 and 14.3 μ appear to be due to C-H out-of-plane deformations associated with monosubstituted benzenes, whereas such vibrations cause absorption at 12.0 μ in p-disubstituted benzenes.14,28,29

(27) C. C. Cerato, J. L. Lauer and H. C. Beachell, J. Chem. Phys., 22, 5 (1954),

(28) D. H. Whiffen and H. W. Thompson, J. Chem. Soc., 268 (1945). (29) H. W. Thompson and P. Torkington, Trans. Faraday Soc., 41, 246 (1945).

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[CONTRIBUTION FROM THE RESEARCH AND DEVELOPMENT DIVISION OF LEVER BROTHERS CO.]

The Synthesis of Mercaptoalkanesulfonic Acids

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2-Mercaptoethane-, 3-mercaptopropane- and 4-mercaptobutanesulfonic acids and several salts of these acids have been synthesized. A series of new betaine-type compounds has been prepared and these products have been found to undergo a novel cleavage reaction with ammonium hydroxide.

The chemical literature describes the preparation of the gold-sodium salt,¹ Au(SCH₂CH₂SO₃Na)₂, of 2-mercaptoethanesulfonic acid and an impure sample of the sodium salt,² HSCH₂CH₂SO₃Na. The use of the sodium salt as a chemical intermediate has been mentioned in two patents.³ However, there are no published data relative to the preparation of pure ω -mercaptoalkanesulfonic acids or their salts. This paper describes the first practical synthesis4 of these compounds which were prepared by the following reactions, using the ethane derivative as an example

$$\begin{array}{c} \text{BrCH}_{2}\text{CH}_{2}\text{SO}_{3}\text{Na} + (\text{NH}_{2})_{2}\text{CS} &\longrightarrow \overset{\text{H}_{2}\text{N}^{+}}_{\text{H}_{2}\text{N}} \text{CSCH}_{2}\text{CH}_{2}\text{SO}_{3}^{-} \\ \xrightarrow{\text{aq. NH}_{3}} \text{HSCH}_{2}\text{CH}_{2}\text{SO}_{3}^{-} \overset{\text{inn}}{\text{NH}_{2}} = C(\text{NH}_{2})_{2} &\xrightarrow{\text{ion}}_{\text{exchange}} \\ & \text{II} \\ & \text{HSCH}_{2}\text{CH}_{2}\text{SO}_{2}\text{H} \\ & \text{III} \end{array}$$

Sodium 2-bromoethanesulfonate⁵ was allowed to react under carefully controlled conditions with thiourea to yield the internal salt, 2-S-thiuronium ethanesulfonate (I). The thiuronium compound was

(1) A. Lumiere and F. Perrin, 14me Congr. Chim. Ind. Paris, (October, 1934); C. A., 29, 5990 (1935).

(2) I. M. Lipovich, J. Applied Chem. (U.S.S.R.), 18, 718 (1945).

(3) Henkel and Cie, German Patent 619,299 (1935); C. A., 30, 1386 (1936); A. Kirstahler and W. J. Kaiser, German Patent 644,275 (1937); C. A., 31, 5383 (1937).

(4) U. S. Patent 2,695,310, Nov. 23, 1954.
(5) C. S. Marvel and M. S. Sparberg in "Organic Syntheses," Coll. Vol. 11, John Wiley and Sons, Inc., New York, N. Y., 1943, p. 558.

recrystallized from water from which it was obtained as a hard, white crystalline solid. It was insoluble in organic solvents and did not possess a sharp melting point but decomposed slowly upon heating to 265°. These characteristically ionic features helped to verify the above assigned structure of this compound. It appears that this is the first time that compounds of this type have been prepared.

Thiuronium compounds are readily converted into mercaptans by treatment with sodium hydroxide.6

$$RSC \xrightarrow{NH_2X^-} \xrightarrow{NaOH} RSH + 1/2(NH_2CN)_2 + NaX$$

Although the betaine-type compounds, the thiuronium alkanesulfonates, can be cleaved readily by this method, a pure product is not obtained since the dicyandiamide (or a product derived therefrom) cannot be removed readily from the reaction mixture. Substituted guanidine compounds have been prepared by the reaction of N-alkyl isothioureas with ammonia,⁷ *i.e.*

$$RSC \begin{pmatrix} NHR \\ + \\ NHRX^{-} \end{pmatrix} \xrightarrow{NH_{\delta}} \begin{pmatrix} RNH \\ RNH \end{pmatrix} C = NH + RSH$$

However, as far as it is known, it seems that this reaction has never been used in the synthesis of mercaptans, nor is there any published record of re-

(6) G. G. Urquhart, J. W. Gates and R. Connoc. Org. Syntheses, 21, 36 (1941).

(7) B. Rathke, Ber., 14, 1774 (1881); 17, 297 (1884); G. Noah ibid., 23, 2195 (1890); H. Lecher and F. Graf, ibid., 56, 1326 (1923) action of internal salts such as I with ammonia. When 2-S-thiuronium ethanesulfonate was treated with warm aqueous ammonia, facile cleavage of the salt took place which resulted in the formation of a single chemical entity, namely, guanidinium 2-mercaptoethanesulfonate (II), in virtually quantitative vield.8 Guanidinium 2-mercaptoethanesulfonate was readily converted into 2-mercaptoethanesulfonic acid (III) by processing it in aqueous medium through a polystyrene-sulfonate ion exchange resin (Amberlite IR-120, Dowex-50). Concentration of the aqueous effluent solution yielded the pure, highly viscous, 2-mercaptoethanesulfonic acid. The acid proved to be a fairly unstable compound as evidenced by the hydrogen sulfide odor which developed when samples of the sulfonic acid were stored at room temperature.

Although the reaction of 2-S-thiuroniumethanesulfonate with ammonia gives an almost quantitative yield of guanidinium 2-mercaptoethanesulfonate, aqueous solutions of 2-mercaptoethanesulfonic acid preparations at times deposited small amounts of a white crystalline solid. The formula $C_4H_9N_{3}$ - O_4S_2 is most compatible with the analytical results obtained for this material. Its physical and chemical properties resembled those of the thiuronium salt. On this basis, it is possible to postulate structures A or B for this compound.

$$\begin{array}{c} O & & \overrightarrow{NH_2} \\ H_2NCNH & & & \\ H_2NCNH \\ H_2N & & \\ H_2N & A & \\ \end{array}$$

To distinguish between these is rather difficult. Additional evidence in support of the structures A and B was obtained when the solid was subjected to the ammoniacal cleavage reaction. From this there was obtained a compound with a mercaptan titration and elemental analyses that fitted the formula

$$\begin{array}{c} & \operatorname{NH}_2 & \operatorname{NH}_2 \\ & & & | & | \\ \operatorname{HSCH}_2\operatorname{CH}_2\operatorname{SO}_3^- & \operatorname{H}_2^+ & \operatorname{CNHC} = 0 \end{array}$$

which is the guanylurea salt of 2-mercaptoethanesulfonic acid. This product is analogous to guanidinium 2-mercaptoethane-sulfonate and it can be formed from either A or B.⁹

(8) As far as the mechanism of the ammoniacal cleavage reaction is concerned, this can involve attack by either ammonia or amide ion, NH2-

on the thiuronium salt. A mechanism which proceeds via hydroxyl ion attack, formation of cyanamide and reaction with ammonia is probably ruled out since the hydroxyl ion-catalyzed hydrolysis of the thiuronium salt seems to proceed at a slower rate than the ammonolysis reaction. The compound I can be cleaved with aqueous sodium hydroxide under somewhat more vigorous conditions, and sodium 2mercaptoethanesulfonate has been obtained from this reaction.

(9) The precursor of A or B is probably the guanyl derivative of the thiuronium salt

In the original experiments in this synthesis, the product of the first reaction, sodium 2-bromoethanesulfonate, was isolated from the reaction mixture and recrystallized before conversion to 2-S-thiuronium ethanesulfonate. Subsequent work on this step made it possible to effect this conversion without preliminary separation of the bromosulfonate salt. This was accomplished by concentrating the solution obtained in the sulfonate conversion to the proper volume, adding the right amount of thiourea, and heating. Upon cooling, the thiuronium salt crystallized from the reaction mixture in a purity of over 99%. Only a trace of bromide was found in this material.

The same general synthesis was used in the preparation of the 3-mercaptopropane- and 4-mercapto-butanesulfonic acids. The respective starting ma-terials were 1-bromo-3-chloropropane and 1,4-dichlorobutane. The thiuronium intermediates were readily obtained in both cases.

Experimental

Sodium 2-Bromoethanesulfonate .-- This compound was prepared by essentially the same method as described by Marvel and Sparberg.⁶ It was found that all of the sulfite could be added to the reaction at the outset without adversely affecting the yield. In later syntheses, sodium 2bromoethanesulfonate was not isolated from the reaction mixture. The following modification was used: A mixture of 246 g. (1.31 moles) of ethylene dibromide, 500 cc. of 95% ethanol, 50 g. (0.4 mole) of sodium sulfite and 360 cc. of water was refluxed until a clear solution was obtained. This required approximately four hours. The reaction mixture was concentrated to 250 cc. by distillation at atmospheric pressure, which resulted in the removal of the excess dibromide, alcohol and a portion of the water. The concentrated solution containing the sodium 2-bromoethanesulfonate (78.6% yield by organic halogen analysis) and sodium bromide was used directly in the thiuronium conversion.

2-S-Thiuronium Ethanesulfonate .-- Twenty-four grams (0.31 mole) of thiourea was added to the concentrated solution obtained in the above preparation, the mixture was stirred and heated to 95°. When the thiourea was all dissolved, the solution was allowed to cool slowly to room temperature. 2-S-Thiuronium ethanesulfonate separated as a hard, white, crystalline solid. This material was isolated by filtration and washed twice with water. The yield was 39 g. (68%), sodium bromide content, 0.04%, m.p., decom-posed slowly on heating to 265°. The product was re-crystallized once from water and analyzed.

Anal. Calcd. for $C_3H_8N_2O_3S_2$: C, 19.55; H, 4.37; N, 15.21; S, 34.80. Found: C, 19.61; H, 4.50; N, 15.41; S, 34.67.

Guanidinium 2-Mercaptoethanesulfonate.---A mixture of 200 g. of 2-S-thiuronium ethanesulfonate and 220 cc. of concentrated ammonium hydroxide was slowly heated on the steam-bath. A vigorous reaction ensued within a short time and the thiuronium salt dissolved. The heating was

which is produced by the reaction of the thiuronium compound with cyanamide

(

$$\begin{array}{c} \begin{pmatrix} N \\ \parallel \\ NH_2C \end{pmatrix} \xrightarrow{ NH_2 } CSCH_2CH_2SO_3^- \longrightarrow C \text{ or } D \\ \xrightarrow{ + \\ NH_2C } \end{array}$$

or by the attack of one molecule of the salt on another molecule.

$$\begin{array}{ccc} & & & & & & & & \\ & \parallel & & & \parallel & & \\ H_2N - CSCH_2CH_2SO_3^- \longrightarrow & H_2N - C - SCH_2CH_2SO_3^- \longrightarrow \\ & & C \text{ or } D + HSCH_2CH_2SO_3H \end{array}$$

The conversion of C (or D) to A (or B) occurs during or after the ion exchange step where the prevailing acid conditions effect hydrolysis of the protonated imino group.

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controlled to give a final temperature of $60-65^{\circ}$. The flask was swirled gently during the course of the reaction. After standing for two hours at room temperature, vacuum was applied and the solution was concentrated to dryness. The white guanidinium 2-mercaptoethanesulfonate was obtained in 98% (214 g.) yield. The product after recrystallization from ethyl alcohol melted at 169-172°.

Anal. Calcd. for $C_3H_{11}N_3O_3S_2$: C, 17.91; H, 5.51; N, 20.89; S, 31.88. Found: C, 18.33; H, 5.67; N, 20.89; S, 31.58.

Pure guanidinium 2-mercaptoethanesulfonate is moderately stable to air oxidation. It can be recrystallized readily and it is possible to obtain a 99% SH value (iodine titration) for material so handled. The presence of guanidinium ion was verified by the precipitation of guanidinium nitrate from solutions of the mercaptoethanesulfonate when nitrate ion was added. A mixed melting point determination with an authentic sample of guanidinium nitrate showed no depression.

2-Mercaptoethanesulfonic Acid.—One hundred grams of guanidinium 2-mercaptoethanesulfonate (as a 2 M solution) was processed through a column of polystytene-sulfonate ion exchange resin (Amberlite IR-120) operating in its acid cycle. Vacuum concentration of the aqueous effluate gave 68 g. (96% yield) of the highly viscous 2mercaptoethanesulfonic acid. This acid proved to be a rather unstable entity and its decomposition was evidenced by the development of a hydrogen sulfide odor on standing. The purity of the material was checked by both acid and mercaptan titrations. Neutralization with guanidinium carbonate reconverted the acid to the guanidinium salt. Other salts (sodium, ammonium, etc.) were readily made by neutralization with the proper base.

N-Carbamyl 2-S-Thiuronium Ethanesulfonate.—This compound was isolated from acidic solutions (1-2 M) of 2-mercaptoethanesulfonic acid from which it was deposited in 1-4 days. It was recrystallized from water in which it was found to be more insoluble than the thiuronium salt. The compound melted with decomposition at $268-269^\circ$.

Anal. Calcd. for $C_4H_9N_3O_4S_2$: C, 21.14; H, 3.99; N, 18.49; S, 28.22. Found: C, 21.33; H, 4.30; N, 18.29; S, 27.85.

Guanylurea Salt of 2-Mercaptoethanesulfonic Acid.— Ten grams of N-carbamyl 2-S-thiuroniumethanesulfonate was heated with 50 cc. of ammonium hydroxide for four hours at 70°. Another 50 cc. of ammonia was added and heating was continued for two hours more. Concentration of the aqueous solution afforded 11 g. of the guanylurea salt which was recrystallized from ethyl alcohol, m.p. 146–148°.

Anal. Calcd. for $C_4H_{12}N_4O_4S_2;$ C, 19.67; H, 4.95; N, 22.94; S, 26.25. Found: C, 19.88; H, 5.18; N, 23.22; S, 26.00.

3-S-Thiuronium Propanesulfonate.—One hundred fiftyfive grams (0.98 mole) of 1-bromo-3-chloropropane was stirred and refluxed for 1.5 hours with 100 g. (0.79 mole) of sodium sulfite in 1200 cc. of 50% (H₂O) ethyl alcohol. The solution was then concentrated to 300 cc. and used directly in the next reaction. To this concentrate there was added 49 g. (0.64 mole) of thiourea and the mixture was refluxed for 0.5 hour. Upon cooling, 74 g. of crystals was obtained. The mother liquors were allowed to stand overnight and this yielded an additional 40 g. of crystals. These were recrystallized from water and combined with the first crop. Recrystallization from water afforded 64 g. (41% yield based on sodium sulfite) of the halogen-free thiuronium salt, m.p. 254-257°.

Anal. Calcd. for $C_4H_{10}O_3S_2N_2$: C, 24.23; H, 5.08; N, 14.13. Found: C, 24.34; H, 5.15; N, 14.10.

Guanidinium 3-Mercaptopropanesulfonate.—This compound was prepared from 3-S-thiuroniumpropanesulfonate by the same method as used for the ethane compound; melting point after recrystallization from chloroform-npropyl alcohol, 112-114°.

Anal. Calcd. for C₄H₁₃O₅S₂N₃: C, 22.31; H, 6.09; N, 19.52. Found: C, 22.47; H, 5.84; N, 19.21.

Potassium 4-Chlorobutanesulfonate.—A mixture of 254 g. (2.0 moles) of 1,4-dichlorobutane and 109 g. (0.69 mole) of potassium sulfite in 2.5 liters of ethyl alcohol and 1.4 liters of water was refluxed and stirred for 12.5 hours. The solution was concentrated in vacuum until it weighed 260 g. The precipitate which formed was removed by filtration. The residual solution now weighed 217 g.; yield of potassium 4-chlorobutanesulfonate by organic halogen analysis, 50%.

4.S-Thiuronium Butanesulfonate.—Thirty grams (0.39 mole) of thiourea was added to the solution described in the preceding paragraph. The reaction mixture was heated to boiling and the water which distilled was collected (*ca.* 60 cc.). When the solution was cooled, 96 g. of crystals were obtained and these were recrystallized from 90 cc. of water to yield 53 g. of product containing 2.4% potassium chloride; yield 35% based on potassium sulfite, m.p. after three recrystallizations 268-269°.

Anal. Calcd. for $C_{5}H_{12}O_{5}S_{2}N_{2}$: C, 28.29; H, 5.70; N, 13.20. Found: C, 28.46; H, 5.89; N, 13.32.

Guanidinium 4-Mercaptobutanesulfonate.—4-S-Thiuronium butanesulfonate was converted into guanidinium 4-mercaptobutanesulfonate according to the procedure used for the ethane salt. The compound could be recrystallized from ethylene chloride—n-propyl alcohol mixtures but it did not have a sharp melting point.

Anal. Calcd. for $C_5H_{15}O_3S_2N_2$: C, 26.19; H, 6.59; N, 18.32. Found: C, 26.70; H, 6.57; N, 17.98.

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