uct, m.p. 139°. Further concentration gave additional less pure product. The total yield was 7.3 g. (71%). A mixed melting point with 4-bromobenzothiophene 1-dioxide was depressed to 103–120°.

Anal. Calcd. for $C_8H_5BrO_2S$: C, 39.20; H, 2.06. Found: C, 39.24; H, 2.04.

6-Amino-2,3-dihydrobenzothiophene 1-Dioxide.—A suspension of 2.1 g. (0.01 mole) of 6-nitrobenzothiophene 1-dioxide in 50 ml. of ethanol was hydrogenated using 0.2 g. of 5% palladium-on-charcoal catalyst in a Parr low pressure hydrogenation apparatus. After one hour 0.04 mole of hydrogen was consumed. Concentration to 30 ml. gave 1.4 g. (78%) of yellow needles, m.p. 195–199°. One recrystallization from ethanol raised the melting point to 198–200°.

Anal. Calcd. for $C_8H_9NO_2S$: N, 7.65. Found: N, 7.87, 7.59.

6-Bromo-2,3-dihydrobenzothiophene 1-Dioxide.—A suspension of 2.45 g. (0.01 mole) of 6-bromobenzothiophene 1-dioxide in 50 ml. of ethanol was hydrogenated in a few minutes using 0.2 g. of 5% palladium-on-charcoal in a Parr low pressure hydrogenation apparatus. Concentration to 15 ml. gave 1.5 g. (61%) of white crystals, m.p. 136–139°. Recrystallization from ethanol gave 1.2 g. (49%), m.p. 142–144°. Further concentration of the original mother liquor gave an oil. The presence of hydrogen bromide in the liquor indicated some hydrogenolysis of the halide also occurred.

Anal. Calcd. for $C_8H_7BrO_2S$: C, 38.88; H, 2.86. Found: C, 38.61; H, 2.99.

This compound also was prepared by the diazotization of 0.50 g. (2.7 mmoles) of 6-amino-2,3-dihydrobenzothiophene 1-dioxide in 10 ml. of sulfuric acid (50% by volume) using 0.20 g. of sodium nitrite. The diazonium salt solution was added to 50 ml. of a boiling suspension of cuprous bromide.[18] Boiling was continued for 10 min. Extraction of the solids with acetone gave 0.45 g. (67%) of product, m.p. 133–140°. Three recrystallizations from ethanol raised the melting point to 142–143°. A mixed melting point of the product prepared by both methods was undepressed.

EVANSTON, ILLINOIS

[CONTRIBUTION FROM THE CHEMICAL LABORATORY OF IOWA STATE COLLEGE]

Studies in the Thianthrene System: Bromination and Reductive Bromination

BY HENRY GILMAN AND DHAIRYASHEEL R. SWAYAMPATI

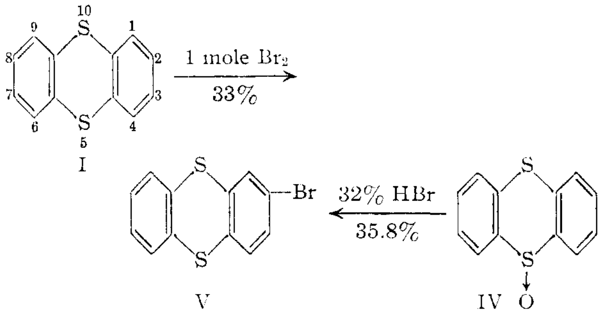
RECEIVED JUNE 13, 1955

One molar equivalent of bromine and thianthrene gave 2-bromothianthrene in fair yield, while two molar equivalents of bromine and thianthrene gave a mixture of 2,7- and 2,8-dibromothianthrene. The same isomeric mixture was obtained by the action of bromine on thianthrene-5-oxide, and of hydrobromic acid on thianthrene-5,10-dioxide. Bromine did not react with thianthrene-5-dioxide. Hydrobromic acid reacted with thianthrene-5-oxide to give 2-bromothianthrene in fair yield, and with thianthrene-5,5,10-trioxide to give a quantitative yield of thianthrene-5-dioxide. Reductive bromination of sulfoxides appears to proceed through the initial reduction of the sulfoxide to the sulfide with the liberation of bromine, which then attacks the heterocycle. Thianthrene-5-dioxide and thianthrene-5,5,10-trioxide were obtained by improved methods in excellent yields.

The bromination of dibenzothiophene (II),[1] and the dibromination of II[2] and its sulfoxide III[3] have been reported, but a bromination of thianthrene or its derivatives has not been reported where a derivative of known structure was obtained. We were able to show that the reported dibromothianthrene,[4,5] whose structure and physical characteristics were not given, is a mixture of 2,7- and 2,8-dibromothianthrene.

The purpose of this study has been to investigate the possibility of preparing bromo derivatives of thianthrene of known structure. Two methods seemed feasible: (1) the action of bromine on thianthrene, and (2) the action of hydrobromic acid on the sulfoxides of thianthrene. The reaction, termed reductive chlorination of sulfoxide,[6] has been successfully applied in the case of thianthrene-5-oxide (IV) to give 2-chlorothianthrene,[7] but a corresponding reaction with hydrobromic acid has not been reported.

We found that 2-bromothianthrene (V) can be obtained by the action of hydrobromic acid on thianthrene-5-oxide, as well as by the action of one molar equivalent of bromine on thianthrene in boiling acetic acid. At room temperature the action of hydrobromic acid on thianthrene-5-oxide did not proceed beyond reduction to thianthrene.



It was found that an approximately 32% solution of hydrobromic acid gave the best yield of the pure product. The yield was considerably decreased with 48 and 16% solutions of hydrobromic acid.

The action of two molar equivalents of bromine on thianthrene gave a product which was identical with the product obtained by the action of hydrobromic acid on thianthrene-5,10-dioxide (VI). The same product was also obtained by refluxing a solution of thianthrene-5-oxide and one molar equivalent of bromine in glacial acetic acid. Attempts to obtain a sharp-melting substance from it were unsuccessful. From its analysis, the examination of its infrared spectrum, and the comparison with the dibromination of dibenzothiophene, it is

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(1) N. M. Cullinane, C. G. Davis and G. I. Davis, *J. Chem. Soc.*, 1435 (1936).

(2) C. R. Neumoyer and E. D. Amstutz, THIS JOURNAL, **69**, 1920 (1947).

(3) H. Gilman and R. K. Ingham, *ibid.*, **73**, 4982 (1951).

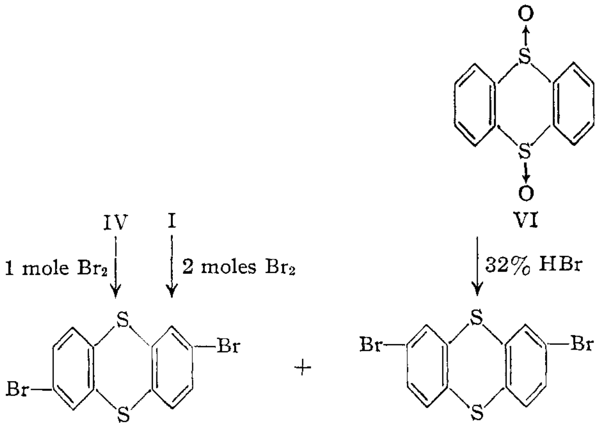
(4) Ciba Ltd., Swiss Patent 240,129, Apr. 1, 1946 [*C. A.*, **43**, 8691 (1949)].

(5) Ciba Ltd., Swiss Patent 243,008, Nov. 16, 1946 [*ibid.*, **43**, 5966 (1949)].

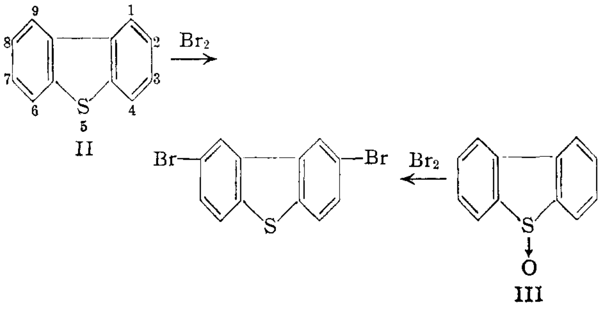
(6) H. J. Page and S. Smiles, *J. Chem. Soc.*, **97**, 1112 (1910).

(7) K. Fries and W. Vogt, *Ann.*, **381**, 312 (1911).

considered to be a mixture of 2,7- and 2,8-dibromothianthrene.

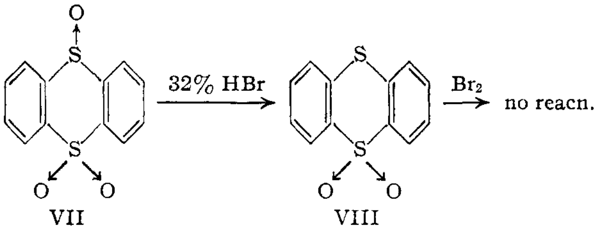


In the case of dibenzothiophene the sulfur atom has only one pair of *para* positions, therefore dibromination gives only one product, 2,8-dibromodibenzothiophene.[2,3] In the thianthrene molecule, on the other hand, positions 2 and 8 are *para* to the sulfur atom 5. At the same time positions 2 and 7 are *para* to the sulfur atoms 5 and 10, respectively. Thus, two products of dibromination, 2,7- and 2,8-dibromothianthrene, are possible with thianthrene. Attempts to separate the mixture into the two isomers through oxidation to the tetraoxides and subsequent recrystallizations were unsuccessful.



The reductive chlorination of 10-methylphenothiazine-5-oxide with hydrochloric acid to give 3-chloro-10-methylphenothiazine[6] recently has been investigated further by Schmalz and Burger.[8] These authors have suggested two mechanisms for this reaction. According to one mechanism, the chloride ion attacks the positively charged intermediate phenazothionium ion. The other mechanism involves the initial reduction of the sulfoxide to the sulfide. A mole of the free halogen, liberated in the process, subsequently attacks the heterocycle.

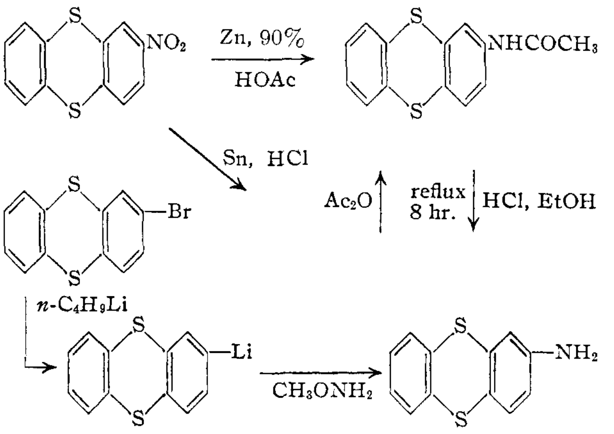
Experimental studies from this Laboratory favor the second mechanism.[9] Our studies in the thianthrene system also indicate that the second mechanism is more probable. With all of the three sulfoxides, IV, VI and thianthrene-5,5,10-trioxide (VII), hydrobromic acid first gave free bromine as evidenced by the color of the solution and of the vapor above the solution. The presence of a sulfone group, which would deactivate the benzene rings toward electrophilic attack, was expected to hinder bromination. Thianthrene-5-dioxide (VIII) was not brominated with bromine under our experimental conditions, while hydrobromic acid reduced VII quantitatively to VIII, but no bromination product was obtained from the reaction.



A method of preparing thianthrene-5-dioxide, involving the oxidation of thianthrene with moist chlorine, has been described by Fries and Vogt,[7] but later workers[10] could not repeat their experiments. We found that the action of chlorine on thianthrene in hot, aqueous acetic acid (method of Fries and Vogt) first results in the formation of thianthrene-5,10-dioxide, which on further treatment with chlorine gives thianthrene-5,5,10-trioxide in excellent yields. The subsequent reduction of the trioxide with zinc and acetic acid gave very high yields of VIII.

The structure of the monobromothianthrene was established by its conversion to the corresponding aminothianthrene through halogen–metal interconversion and subsequent treatment of the thianthrenyllithium with O-methylhydroxylamine. The aminothianthrene was identical with that obtained by Keats' method.[11]

Krishna[12] obtained a product from the reduction of 2-nitrothianthrene[12] with zinc and 90% acetic acid. The product which melted at 185° was reported by him as 2-aminothianthrene. Keats[11] found that this product was actually 2-acetamidothianthrene which could be hydrolyzed to the 2-aminothianthrene, m.p. 160°, by refluxing it with hydrochloric acid and ethanol for 8 hours. We were able to substantiate the finding of Keats. Treatment of 2-aminothianthrene with acetic anhydride gave a product which was identical with



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(8) A. C. Schmalz and A. Burger, THIS JOURNAL, **76**, 5455 (1954).

(9) H. Gilman and J. Eisch, *ibid.*, **77**, 3862 (1955).

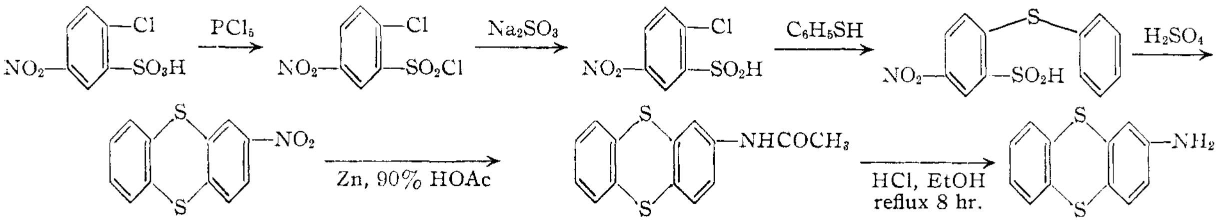
(10) J. Böeseken and A. T. H. Van der Meulen, *Rec. trav. chim.*, **55**, 925 (1936).

(11) G. H. Keats, *J. Chem. Soc.*, 1592 (1937).

(12) S. Krishna, *ibid.*, **123**, 156 (1923).

Krishna's product. 2-Nitrothianthrene could be reduced directly to the 2-aminothianthrene by treatment with tin and hydrochloric acid, while the reduction with zinc and 90% acetic acid gave 2-acetamidothianthrene. The different products were identified by the method of mixed melting point and the comparison of the infrared spectra.

Our method for the preparation of 2-aminothianthrene is shorter and more convenient than the previously described method[11,12] of obtaining that compound



Experimental[13]

Thianthrene-5,5,10-trioxide (VII).—Chlorine was bubbled at a rapid rate through a suspension of 129.6 g. (0.6 mole) of thianthrene in 1500 ml. of boiling 90% acetic acid. In a few minutes all of the thianthrene dissolved to give a pink solution. At this stage the solution was allowed to cool, while the addition of chlorine was continued. Heating was resumed as soon as white crystals began to separate. The pink color of the solution disappeared, and a clear, yellow solution resulted during a period of 1 hour. The solution was allowed to cool, and a small sample of the white needles which separated was taken out. It did not melt below 230°. This indicated that the product was thianthrene-5,10-dioxide, since both the α- and the β-forms of the disulfoxide[14] melt above the melting point of the trioxide (221.5–222.5°). The mixture was cooled to room temperature, and more chlorine was added for about 15 minutes. Upon heating a clear, yellow solution resulted. A white product separated in the form of small prisms as the solution cooled. Addition of chlorine was discontinued at this stage, and the mixture was diluted to three liters with cold water. The product which separated was filtered, washed successively with dilute sodium sulfite solution and water and dried to yield 145 g. (91.5%) of the crude product melting over the range 215–220°. Recrystallization from 90% acetic acid gave 132 g. (83.3%) of the pure VII, m.p. 221.5–222.5°. Fries and Vogt[7] have reported the melting point of this compound as 216°. The infrared spectrum showed bands at 8.63, 9.8 and 13.1 μ, characteristic of the sulfone group, the sulfoxide group and 1,2-substitution, respectively.

Anal. Calcd. for $C_{12}H_8O_3S_2$: S, 24.24. Found: S, 24.18, 24.15.

Thianthrene-5-dioxide (VIII).—To a solution of 105.6 g. (0.4 mole) of VII in 500 ml. of hot 90% acetic acid was added 60 g. of zinc dust, and the mixture was refluxed for 3 hours. The hot solution was decanted into 1.5 liters of cold water. The white product which separated was filtered, washed and dried to yield 94.0 g. (95%) of VIII melting at 167–168°. Recrystallization from acetic acid raised its melting point to 168–169°. The infrared spectrum showed bands at 8.65 and 13.2 μ, characteristic of the sulfone group and 1,2-substitution, respectively.

Anal. Calcd. for $C_{12}H_8O_2S_2$: S, 25.80. Found: S, 25.50, 25.52.

Fries and Vogt[7] have reported the melting point of this compound as 159°.

Thianthrene-5-dioxide and Bromine.—A solution of 2.48 g. (0.01 mole) of VIII and 1.6 g. (0.01 mole) of bromine in 10 ml. of glacial acetic acid was refluxed for 16 hours. A slight yellow color of the solution persisted. The mixture was cooled, filtered, washed and dried to give 2.28 g. (92%) of the unreacted VIII (mixed m.p.).

Thianthrene-5,5,10-trioxide and Hydrobromic Acid—A mixture of 7.92 g. (0.03 mole) of VII and 60 ml. of 32% hydrobromic acid was refluxed for 16 hours. Free bromine was liberated as soon as the mixture became warm, and the color of bromine slowly disappeared leaving a slight yellow color in the suspension at the end of the reaction period.

The mixture was cooled, filtered, washed and dried to yield 7.41 g. (99.6%) of VIII melting at 162–165°. Recrystallization from 90% acetic acid gave 6.87 g. (92%) of the pure VIII (mixed m.p.).

Thianthrene-5-oxide (IV) and Hydrogen Bromide.—A solution of 23.2 g. (0.1 mole) of IV[15] in 250 ml. of glacial acetic acid at room temperature was saturated with hydrogen bromide. The orange crystals which separated dissolved, upon heating, to give a red solution. A slight yellow color persisted at the end of a reflux period of 24 hours. The reaction mixture was allowed to cool and diluted with two liters of cold water. A white product which separated was filtered and recrystallized from methanol to give 17.6 g. of a white solid melting over the range 80–96°. Two recrystallizations of the product from methanol gave 3.2 g. (11%) of 2-bromothianthrene, m.p. 88–89°. The analytical sample melted at 89–90°. The product gave a qualitative test for bromine.

Anal. Calcd. for $C_{12}H_7BrS_2$: S, 21.69. Found: S, 21.89, 21.66.

The infrared spectrum showed absorption bands at 12.4 and 13.4 μ, characteristic of 1,2,4- and 1,2-substitution, respectively, and the spectrum was similar to that of 2-chlorothianthrene.[7]

If the reaction mixture in the above experiment was stirred at room temperature for 48 hours without any heating, the result was a 97.2% yield of the reduction product, thianthrene (mixed m.p.).

Thianthrene-5-oxide and Hydrobromic Acid. Run I.—A mixture of 11.6 g. (0.05 mole) of IV and 100 ml. of 48% hydrobromic acid was refluxed for 10 hours. Bromine was liberated as soon as the mixture became warm, and a red oil separated. At the end of the reaction period the contents of the flask were cooled and the mixture was extracted with ether. The ether extract was washed successively with dilute sodium hydroxide and water and dried over anhydrous sodium sulfate. The solvent was removed in a current of dry air, and the oily residue was crystallized from glacial acetic acid to give 2.9 g. (20%) of white crystals, melting over the range 84–87°. Recrystallization from the same solvent gave 2.5 g. (17%) of the pure 2-bromothianthrene, m.p. 89–90°.

Run II.—This experiment differed from run I in that a 32% solution of hydrobromic acid was used for the reaction. The yield of the almost pure 2-bromothianthrene (m.p. 86–88°) was 5.28 g. (35.8%).

The use of more dilute (16%) solution of hydrobromic acid gave only traces of 2-bromothianthrene, the main product of the reaction being thianthrene.

2-Bromothianthrene-5,10-tetraoxide.—To a hot solution of 2.06 g. (0.007 mole) of 2-bromothianthrene in 10 ml. of glacial acetic acid was added a solution of 6.3 g. (0.056 mole) of 30% hydrogen peroxide in 10 ml. of glacial acetic acid. Another 10 ml. of the solvent was added to effect a complete solution which was subsequently refluxed for 2 hours. A white, crystalline product which separated upon cooling was filtered and dried to give 2.20 g. (88%) of 2-bromothianthrene-5,10-tetraoxide, m.p. 226–227°. Recrystallization of the product from glacial acetic acid did not raise the melting point.

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[13] All melting points reported here are uncorrected. Reactions involving organometallic compounds were carried out in an atmosphere of dry, oxygen-free nitrogen.

[14] T. W. J. Taylor, *J. Chem. Soc.*, 625 (1935).

[15] H. Gilman and D. R. Swayampati, THIS JOURNAL, **77**, 3387 (1955).

The mother liquor, upon dilution, gave another 0.23 g. of the impure product melting over the range 200–213°. Two recrystallizations from glacial acetic acid gave 0.12 g. of the pure product melting at 226–227°. The total yield of the pure product was 2.32 g. (92.1%).

The infrared spectrum showed bands at 11.9, 13.1 and 8.65 μ, indicative of 1,2,4- and 1,2-substitution, and the sulfone group, respectively.

Anal. Calcd. for $C_{12}H_7BrO_4S_2$: S, 17.83. Found: S, 17.63.

Thianthrene (I) and Bromine. Run I.—To a hot solution of 21.6 g. (0.1 mole) of I[16] in 200 ml. of glacial acetic acid was added a solution of 17.6 g. (0.11 mole) of bromine in 50 ml. of glacial acetic acid, and the resulting red solution was refluxed for 7 hours, after which only a slight yellow color persisted. The mixture was allowed to cool and kept at room temperature for 24 hours, but no product separated during this period. Seeding was effected by the addition of a few crystals of 2-bromothianthrene. In a few minutes a white, crystalline product separated, which was filtered and dried to give 13.75 g. (47%) of crude 2-bromothianthrene melting over the range 80–84°. Recrystallization from glacial acetic acid gave 9.65 g. (33%) of the pure product melting at 88–89°. A mixed melting point with the 2-bromothianthrene, obtained from thianthrene-5-oxide and hydrobromic acid was not depressed.

The mother liquor from the reaction mixture was concentrated and allowed to cool. A white product separated, which after several recrystallizations from glacial acetic acid gave 0.9 g. (4.2%) of I (mixed m.p.).

Run II.—A mixture of 10.8 g. (0.05 mole) of I, 17.6 g. (0.11 mole) of bromine and 60 ml. of glacial acetic acid was refluxed for 16 hours after which a slight yellow color persisted in the solution. The mixture was allowed to cool, and the white product which separated was filtered and dried. The product, later shown to be a mixture of 2,7- and 2,8-dibromothianthrene, weighed 15.44 g. (82.6%), and melted over the range 115–130°. Attempts to obtain a sharp-melting product from this mixture were unsuccessful. Four recrystallizations from glacial acetic acid gave 7.3 g. of the white amorphous product melting over the range 140–149°.

Anal. Calcd. for $C_{12}H_6Br_2S_2$: S, 17.11; Br, 42.78. Found: S, 17.20, 16.74; Br, 42.71, 42.60.

The infrared spectrum showed an absorption band at 12.4 μ, characteristic of 1,2,4-substitution, but the band at 13.3 μ, characteristic of 1,2-substitution, which was present in 2-bromothianthrene, had disappeared in the spectrum, indicating that substitution had taken place in both rings. The spectrum did not show a band indicative of 1,2,3-substitution. It is considered from these data that the disubstitution had taken place in the 2,7- and/or 2,8-positions. Since neither the product itself, nor its tetraoxide could be obtained in sharp-melting forms, it is inferred that both of the 2,7- and 2,8-dibromothianthrene are present in the product.

The reported dibromothianthrene of unknown structure and physical constants[4,5] was prepared in essential accordance with the procedure described in the reference. The product, after several recrystallizations from glacial acetic acid, melted over the range 140–150°. Its infrared spectrum was identical with that of the dibromothianthrene obtained from our method. An admixture of the two products melted undepressed.

2,7- and 2,8-Dibromothianthrene-5,10-tetraoxide.—To a hot solution of 3.74 g. (0.01 mole) of the isomeric mixture of dibromothianthrene in 40 ml. of glacial acetic acid was added a solution of 9.0 g. (0.08 mole) of 30% hydrogen peroxide in 10 ml. of glacial acetic acid, and the resulting solution was refluxed for 2 hours. The mixture was cooled, and the white product which separated was filtered and dried to give 3.08 g. of the tetraoxide melting over the range 237–264°. From the mother liquor was obtained, upon dilution, another 1.17 g. of white product melting over the range 210–240°. Attempts to separate the mixture into sharp-melting products were unsuccessful. After several recrystallizations from glacial acetic acid the product melted over the range 246–280°. The total yield of the tetraoxide was 4.25 g. (96%).

Anal. Calcd. for $C_{12}H_6Br_2O_4S_2$: S, 14.61; Br, 36.53. Found: S, 14.64, 14.43; Br, 36.59, 36.44.

Thianthrene-5,10-dioxide (VI) and Hydrobromic Acid.—A mixture of 9.92 g. (0.04 mole) of VI[17] and 100 ml. of 32% hydrobromic acid was refluxed for 16 hours. Bromine was liberated as soon as the mixture became warm, and a red oil separated as a heavier layer. At the end of the reflux period the aqueous layer retained a slight yellow color. The mixture was cooled and extracted with ether. The ether extract was washed successively with dilute sodium hydroxide and water, treated with charcoal, filtered and dried over anhydrous sodium sulfate. Upon evaporation of the solvent a colorless oil was left as the residue which soon solidified. The dried product melted over the range 110–125°. Four recrystallizations from glacial acetic acid raised the melting range to 142–151°. The infrared spectrum of this product was identical with that of the isomeric mixture of 2,7- and 2,8-dibromothianthrene. An admixture of the product with the isomeric mixture melted undepressed. The yield of the crude product was 15.9 g. (85%).

Thianthrene-5-oxide and Bromine.—To a suspension of 11.6 g. (0.05 mole) of IV in 60 ml. of glacial acetic acid was added 8.8 g. (0.055 mole) of bromine. The sulfoxide dissolved immediately to give a red solution. The mixture was subsequently refluxed for 16 hours after which a supernatant, yellow acetic acid solution, and a heavier, yellow oil remained in the reaction flask. A white product which separated upon cooling was filtered and dried to give an amorphous powder melting over the range 110–125°. Four recrystallizations from glacial acetic acid raised the melting range to 139–149°. The infrared spectrum of this product was identical with that of the isomeric mixture of 2,7- and 2,8-dibromothianthrene. The yield of the crude product was 15.0 g. (80.2%).

2-Aminothianthrene. Method I.—The product obtained from the reduction of 2-nitrothianthrene[12] by Krishna's method showed absorption bands in the infrared spectrum at 6.05, 6.56, 12.2, and 13.5 μ, characteristic of the carbonyl group, a monosubstituted amide, 1,2,4- and 1,2-substitution, respectively. This shows that, in agreement with Keats' finding,[11] the product is not 2-aminothianthrene but 2-acetamidothianthrene.

Hydrolysis of the product in essential accordance with Keats' procedure gave a 69% yield of 2-aminothianthrene melting at 160.5–161°. Keats has reported the melting point of 2-aminothianthrene as 160°.

Method II.—In this method 2-nitrothianthrene was reduced directly to 2-aminothianthrene with tin and hydrochloric acid.

A mixture of 1.03 g. (0.005 mole) of 2-nitrothianthrene, 10 ml. of hydrochloric acid, 7.0 g. of tin and 3 ml. of ethanol was refluxed for 4 hours. The yellow color of the 2-nitrothianthrene disappeared in a few minutes and a white solid remained in the reaction flask. The mixture was cooled and filtered. The residue was warmed with 10% sodium hydroxide solution, filtered, washed and recrystallized from ethanol to give 0.6 g. (52%) of 2-aminothianthrene melting at 160°. A mixed melting point with the 2-aminothianthrene from method I was not depressed.

Method III.—To a stirred solution of 4.4 g. (0.015 mole) of the monobromothianthrene in 50 ml. of anhydrous ether was added 13 ml. (0.015 mole) of an ethereal solution of *n*-butyllithium[18] over a period of 5 minutes. The mixture was maintained at 0–5° during the addition of the *n*-butyllithium solution, and was subsequently allowed to warm up to room temperature. After a total reaction period of 20 minutes Color Test II[19] was found to be negative.

To the above stirred mixture was added a solution of 0.24 g.(0.005 mole) of O-methylhydroxylamine[20] in 20 ml. of anhydrous ether. After a stirring period of 15 minutes Color Test I[21] was found to be negative. The mixture was hydrolyzed with cold water, the layers were separated and the aqueous layer was extracted with ether. The combined extract was dried over anhydrous sodium sulfate. Hydrogen chloride was bubbled through the ether solution until no

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[16] K. Fleischer and J. Stemmer, *Ann.*, **422**, 265 (1921).

[17] K. Fries and W. Vogt, *Ber.*, **44**, 756 (1911).

[18] H. Gilman, J. A. Beel, C. G. Brannen, M. W. Bullock, G. E. Dunn and L. S. Miller, THIS JOURNAL, **71**, 1499 (1949).

[19] H. Gilman and J. Swiss, *ibid.*, **62**, 1847 (1940).

[20] The free base was obtained by the dropwise addition of a 50% sodium hydroxide solution to the hydrochloride. The reaction flask was immersed in a bath maintained at 60–70°, and the vapor was passed through potassium hydroxide pellets before being condensed.

[21] H. Gilman and F. Schulze, THIS JOURNAL, **47**, 2002 (1925).

more crystals separated. The product was filtered and dried to give 1.91 g. of the hydrochloride, which was subsequently warmed with 5% sodium hydroxide solution. The liberated free base was filtered, washed with water and recrystallized from 95% ethanol to give 0.72 g. (63%, based on O-methylhydroxylamine) of white crystals melting at 160°. The melting point of the product was not depressed when it was mixed with the 2-aminothianthrene obtained by method I. The identity was established further by the comparison of the infrared spectra, which showed absorption bands at 12.3 and 13.3 μ, characteristic of 1,2,4- and 1,2-substitution.

Anal. Calcd. for $C_{12}H_9NS_2$: S, 27.7. Found: S, 27.5, 27.3.

The mother liquor from the precipitation of the hydrochloride was evaporated in a current of dry air, and the yellowish residue was recrystallized from methanol to yield 1.64 g. (76%)[22] of thianthrene (mixed m.p.).

2-Acetamidothianthrene.—A solution of 0.23 g. (0.001 mole) of 2-aminothianthrene in 3 ml. of acetic anhydride was boiled for 5 minutes, diluted with water, cooled and filtered. The white residue was recrystallized from dilute ethanol to give 0.20 g. (73%) of white flakes melting at 182–183°. A mixed melting point with the product, obtained by reducing 2-nitrothianthrene according to Krishna's method, was not depressed, and the infrared spectra of the two products were identical.

Acknowledgment.—The authors wish to thank the Institute for Atomic Research, Iowa State College, for making available to us the Baird double beam infrared spectrophotometer used in the determination of the spectra of the compounds reported in this paper. We are grateful to Mr. Robert McCord for the actual determination of the spectra.

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[22] Yield based on the equation $3RLi + CH_3ONH_2 \rightarrow RNH_2 + = 2RH + LiOCH_3$.

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The Photosynthetic Cycle. CO_2 Dependent Transients[1]

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RECEIVED JUNE 20, 1955

Techniques have been developed and an apparatus has been designed and constructed to make possible quantitative experiments in photosynthesis. It is now possible to measure the amounts of the photosynthetic intermediates as a function of external variables such as partial pressure of CO_2 and O_2, light, temperature, *p*H, poisons, and various combinations of these. Use has been made of the above techniques to study the transient changes taking place when the carbon dioxide pressure is varied and these results have led to the development of the concept of fluctuating reservoir sizes. These data also have provided the first unequivocal evidence of the relation of phosphoglyceric acid and ribulose diphosphate to the carbon dioxide incorporation step. Ribulose diphosphate has been identified as being closely related to, if not actually, the carbon dioxide acceptor and phosphoglyceric acid as being the product of the carboxylation. The data show that ribulose monophosphate and triose phosphate are also in the cycle which regenerates the carbon dioxide acceptor, and provide us with the precursor–product relationships between the compounds in this cycle. The kinetics of free glycolic acid provide strong evidence of the presence of a transketolase enzyme system which transfers an unphosphorylated glycolyl fragment. Perhaps the most important result of this work is the insight it gives into the complicated, finely balanced system of interrelated chemical reactions we call life.

Many of the biological reaction cycles so far devised have been arranged by studying separated reactions and reaction pairs in cell-free systems and by making the assumption that this is the course of the reaction which takes place in the living intact cell. However, with the application of the techniques of paper chromatography as a method of separation, and C^{14} as a tracer, techniques were developed which made possible progress in the elucidation of the chemical changes taking place inside the living cell. In the course of a few short years these tracer experiments have led to the elucidation of many of the intermediates in the path of carbon in photosynthesis, and given a clear indication of the relationships between them. It also has become clear that in the study of photosynthesis one is dealing with a complicated network of reactions, the complete description of which would be difficult to achieve by qualitative means alone. Many quantitative studies of photosynthesis have been made, chiefly on the over-all reaction.[3-7] The main reason for this is that it has been impossible to obtain photosynthesis anywhere other than in the intact organisms or possibly in large highly organized fragments (chloroplasts) thereof and in these nothing less than the over-all reaction was accessible to measurement. The information obtained by such experiments is very difficult to interpret in terms of specific chemical reactions since any particular changes are modified as they pass through the complicated sequence of chemical transformations which finally result in externally observable fluorescence changes, quantum yields, or changes in the rate of uptake or evolution of CO_2 or O_2. More recently, quantitative studies involving the more intimate details of the chemical transformations of photosynthetic CO_2 reduction have been done. The use of isotopes (C^{14}, D, O^{18})[8] made possible, first, a

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[1] The work described in this paper was sponsored by the U. S. Atomic Energy Commission, and constitutes a part of the thesis of A. T. Wilson submitted in partial fulfillment of the requirements for the Ph.D. degree at the University of California, Berkeley, 1954.

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