Dihydrothiophenes. II. Preparation and Properties of Some Alkylated 2,5-Dihydrothiophenes[1a]

John M. McIntosh,* H. Bruce Goodbrand,[1b] and Gary M. Masse[1c]

Department of Chemistry, University of Windsor, Windsor, Ontario, Canada N9B 3P4

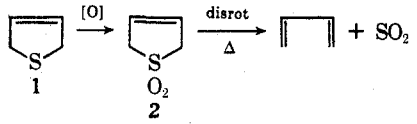
Received August 10, 1973

A new general preparation of alkylated 2,5-dihydrothiophenes 1 is reported. Reaction of α-mercapto ketones with vinylphosphonium salts leads to compounds of type 1 in excellent yield. The preparation of substituted vinylphosphonium salts is also described. The synthetic utility of 1 in the preparation of dienes has been demonstrated by the formation of **29** and **33** from **18** and **15**.

The wide applicability of the Diels–Alder reaction to the synthesis of complex molecules is well known.[2] While the common dienophiles can be obtained in a variety of ways, in many cases the preparation of the required diene is not so straightforward. Isomerically and stereoisomerically pure materials are required if the stereochemical integrity of the reaction is to be maximally utilized.

The formation of conjugated dienes can be effected in a number of diverse ways. In addition to the classical methods,[3] newer methods, including the addition of vinyl organometallic reagents to acetylenic bonds[4a] and those related to the Wittig reaction,[4b] have recently been developed. While some of these reactions are completely or partially stereospecific, the stereochemistry of the newly formed double bond is in many cases quite difficult to predict.[5] Another difficulty encountered is the lack of stability of many functional groups to the reaction conditions. Furthermore, one of the chief drawbacks to the use of the Wittig reaction is the low yield frequently obtained in the preparation of tri- and tetrasubstituted double bonds,[2,3b,6,7] although Wittig's method for "directed aldol condensations"[6] has provided a useful alternative. Therefore, the development of a new method for the regiospecific and stereospecific formation of conjugated double bonds under mild reaction conditions would be desirable.

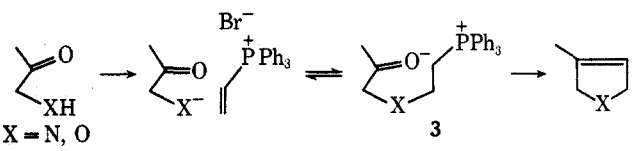
The thermal decomposition of 2,5-dihydrothiophene sulfones (2) to sulfur dioxide and dienes has frequently



been used as the final step in the purification of diene mixtures.[8] This reaction invariably proceeds at an easily accessible temperature and in a completely regiospecific and stereospecific disrotatory manner.[9] While the most common preparation of compounds of type 2 involves the cycloaddition of sulfur dioxide to conjugated dienes,[8] a method which clearly does not fit our requirements, an alternate approach involves the oxidation of 2,5-dihydrothiophenes (1).[10] Thus a general synthesis of compounds of type 1 would constitute a method for the preparation of dienes and our attention was focused on this problem.

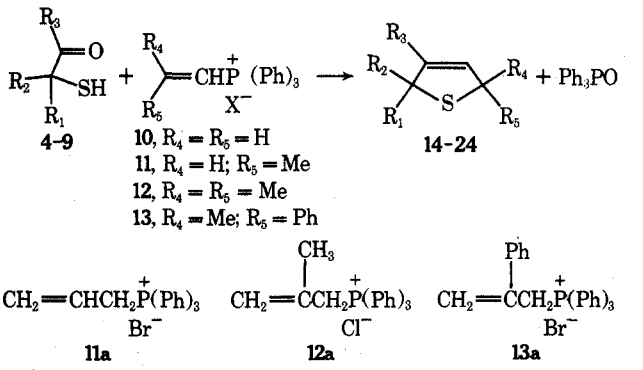
Results and Discussion

Vinyltriphenylphosphonium bromide[11a] **(10)** has been used extensively by Schweizer in the preparation of a large variety of carbocyclic, heterocyclic, and acyclic molecules.[11] In particular the preparations of 2,5-dihydropyrroles[12] and furans[13] have been reported. Initial addition of a nucleophile to the vinyl salt affords an intermediate ylide (3) which undergoes an intramolecular or intermolecular Wittig reaction leading to the desired product with



the concomitant loss of triphenylphosphine oxide. As we have reported,[14] the use of **10** and α-mercapto ketones as the nucleophilic species leads to the required 2,5-dihydrothiophenes (Scheme I, Table I).

Scheme I



It should be noted that several groups have commented[15,16] on the lack of addition of alcohols and amines to β-substituted vinylphosphonium salts. We were aware of these reports, but one publication[15b] indicated that the more nucleophilic mercaptans would add to salt **11** in the presence of a catalytic amount of base. Based on this, we proceeded to investigate the preparation of dihydrothiophenes utilizing substituted vinyl salts.

Schweizer has reported preparation[17] and reactions[11,17] of a number of α-substituted vinylphosphonium salts. The interference of an alkyl group attached to phosphorus in the usual reaction has been noted.[11] Also, previous investigations[15] of the base-catalyzed isomerization of allylic phosphonium salts to their vinyl isomers showed that the presence of aromatic groups attached to phosphorus facilitated the reaction.[15a] Since we wished to prepare the substituted vinyl salts **11**, **12**, and **13** by isomerization of the appropriate allyl salts, we decided to restrict our present investigation to the salts derived from triphenylphosphine which bore no substituents in the α position.

We have verified the isomerization by nmr. While pyridine solutions of the allyl salts **11a**, **12a**, and **13a** were stable at room temperature, addition of a catalytic amount of triethylamine caused complete and rapid disappearance of the methylene absorption at δ 5–6. We have used this solvent system to prepare vinyl salts **11**, **12**, and **13** in high yields. In cases where the reaction medium used for the formation of the dihydrothiophenes contained

Table I
Products and Yields of 2,5-Dihydrothiophenes[a]

Ketone	Salt	Product	R_1	R_2	R_3	R_4	R_5	Time, hr	Yield, %
4[b]	**10**	**14**[c]	H	H	Me	H	H	24	60
5[d]	**10**	**15**	Me	Me	Me	H	H	30	95
5	**11**	**16**	Me	Me	Me	Me	H	20	80
5	**12**	**17**	Me	Me	Me	Me	Me	30	30
6[e]	**10**	**18**	H	$-(CH_2)_4-$		H	H	18	74
6	**11**	**19**	H	$-(CH_2)_4-$		Me	H	18	91
6	**12**	**20**	H	$-(CH_2)_4-$		Me	Me	55	61
7[d]	**10**	**21**	H	$-(CH_2)_3-$		H	H	18	76
8[f]	**10**	**22**	H	Ph	Me	H	H	168	65[g]
9[h]	**10**	**23**	Me	Me	*i*-Pr	H	H	48	20
9	**11**	**24**	Me	Me	*i*-Pr	Me	H	72	6

[a] Satisfactory analytical data were recorded for all new compounds in the table. [b] L. Field, W. S. Hanley, and I. McVeigh, *J. Org. Chem.*, **36**, 2731 (1971). [c] S. F. Birch and D. T. McAllan, *J. Chem. Soc.*, 3411 (1951). [d] F. Ansinger, M. Thiel, and G. Esser, *Justus Liebigs Ann. Chem.*, **610**, 33 (1953). [e] G. Gieseler and F. Stache, *Chem. Ber.*, **94**, 337 (1961). [f] A. von Wacek, K. Kratzl, and A. von Bezard, *ibid.*, **75**, 1348 (1942). [g] By-product of phenylacetone also present. [h] F. Ansinger, M. Thiel, and V. Tesar, *Justus Liebigs Ann. Chem.*, **619**, 169 (1958).

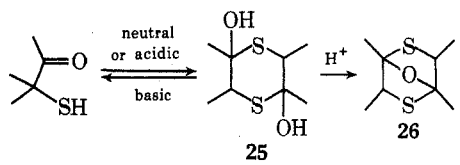
triethylamine (*vide post*), the allyl salts **11a**, **12a**, and **13a** could be substituted with no decrease in yield.

Investigations by other workers of the reactions of allyl salts have led to the formation of materials which could be envisaged as proceeding by initial isomerization followed by the same Michael addition–Wittig cyclization, but which, on closer scrutiny, proved to proceed by initial Wittig reaction followed by cyclization.[12a,16] Although we have no direct evidence for either mechanism, we favor the former sequence because the decreased basicity of the mercaptide ion relative to the alkoxide ion should inhibit the proton exchange leading to the phosphorane and thus to the initial Wittig reaction.

We were intrigued by the report[18] of the isolation of the vinyl salt **11** (X^- = Cl) when allyl chloride and triphenylphosphine were heated together in benzene, while the use of allyl bromide led to the expected allyl salt **11a**. We have found that the same situation obtains when methallyl chloride is treated under the same conditions. The vinyl salt **12** obtained has the same physical properties as those reported[19] for the expected allyl salt **12a**, and clearly the earlier reports are in error. In analogy with the previous report,[18] when a large excess of methallyl chloride is heated in the presence of the phosphine in the absence of added solvent, a 5:1 mixture (nmr) of **12a** and **12** is obtained. The suggestion has been made that the increased nucleophilicity of chloride relative to bromide ion was responsible for this result.[18] We have found that refluxing a benzene slurry of bromide salt **11a** with lithium chloride effects complete isomerization (nmr) into vinyl salt **11**, but we attribute this result to the difference in basicity of the two halide ions. Other workers have reported the isolation of vinyl salts from reactions of allylic halides.[20]

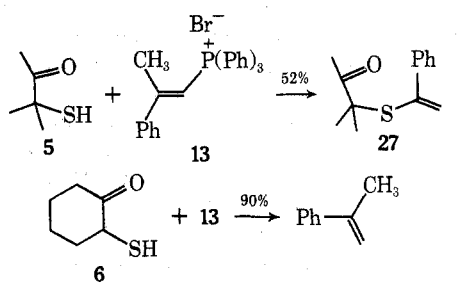
In order to attain generality for the synthesis, a reliable preparation of the α-mercapto ketones or the α-halocarbonyl precursors is required. The regiospecific halogenation of carbonyl compounds has been reviewed[21] and a recent method[22] appears to offer a completely regiospecific synthesis. The replacement of halogen by the sulfhydryl group is a facile reaction. It is worthy of note that the stereochemistry of halogenation is unimportant as the eventual fate of the carbon atom being substituted is sp^2 hybridization and thus any stereochemistry is destroyed.

The α-mercaptocarbonyl compounds typically exist as dimeric dihydroxy-1,4-dithianes,[23,24] (**25**), many of which are highly insoluble in the usual organic solvents and which are easily dehydrated to transannular ethers **26** by traces if acid,[23a] In basic medium, an equilibrium is established between monomer and dimer and the material



becomes much more soluble.[24] However, under these conditions, protonic solvents readily add to the vinyl salts, forming β-substituted compounds which are inactive in the desired reaction. The ability of pyridine to dissolve both reactants, serve as the base, and provide a solvent which could easily be removed by acid extraction suggested its use. While some reactions did indeed proceed satisfactorily under these conditions, the addition of some triethylamine to the reaction system speeded the reaction and allowed the use of either the vinyl or allyl salt as the starting material. Simple chromatography eliminated all phosphorus-containing and colored impurities and afforded the dihydrothiophenes listed in Table I in the generally excellent yields shown.

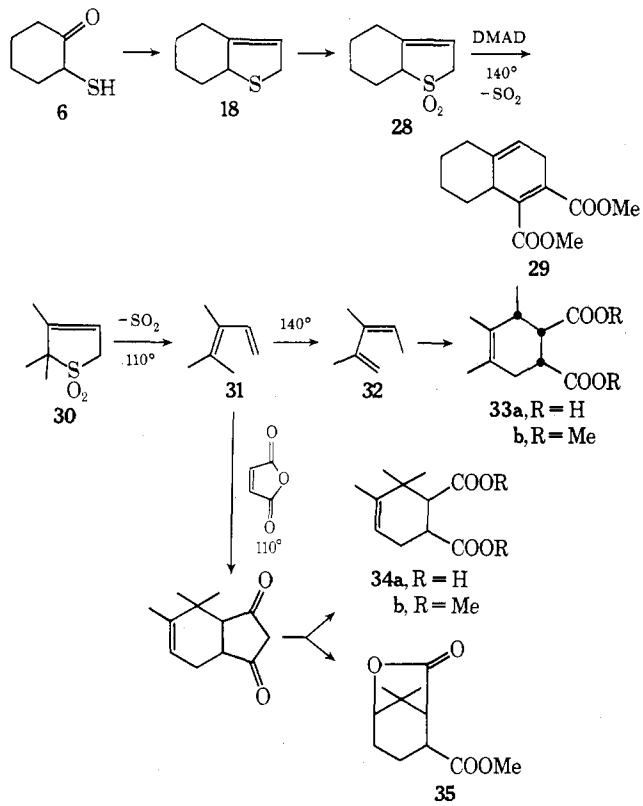
Anomalous results were obtained using salt **13** and ketones **5** and **6**. In the first case, the product (**27**) formed was derived by attack of the sulfur nucleophile on the equilibrium concentration of the allylic isomer of the salt.



The increased steric hindrance to attack at the carbon atom β to phosphorus must preclude the reaction of the nucleophile at this point. Substitution, with or without allylic rearrangement, will lead to the observed product.

The product isolated in high yield from the reaction between **13** and **6** was identified as α-methylstyrene. This may be formed by attack of sulfur at phosphorus, but we have no further information on this reaction at the present time. Finally, when mercapto ketone **8** was used, an additional peak in the glc appeared which was identified as phenylacetone, a product of desulfurization of **8**. Desulfurization of aromatic mercapto ketones under basic conditions also has been observed by other workers.[25]

Scheme II



The synthetic utility of the overall scheme is illustrated by the oxidation-cycloelimination-cycloaddition sequences outlined in Scheme II. Oxidation of **18** with *m*-chloroperbenzoic acid afforded the known[26] sulfone **28** in quantitative yield. Refluxing a xylene solution of this material in the presence of 1 equiv of dimethyl acetylenedicarboxylate led to **29**[27] in an isolated yield of 78%. Thus the overall conversion of **6** to **29** occurs in 58% yield in three simple steps. Similarly, the oxidation of **15** under the same reaction conditions afforded sulfone **30**, again in quantitative yield. In refluxing xylene solution in the presence of maleic anhydride, a rapid evolution of sulfur dioxide occurred, but the product isolated in 58% yield after hydrolysis was the diacid **33a**[28] derived from rearranged diene **32**. Reducing the reaction temperature to 110° reduced the rate of reaction drastically, but, after prolonged reaction, a quantitative yield of three products was obtained. Hydrolysis and esterification of these materials led to the isolation of rearranged adduct **33b** (11%), unrearranged diester **34b**,[28,29] and the known lactone ester **35**[28] derived from diacid **34a**. The unambiguous synthesis of diene **31** from ketone **5** thus proceeds in 74% overall yield in three steps. The only previous synthesis of this diene involved a multistep reaction sequence starting from a complex starting material and proceeding in 8% overall yield.[29]

We are currently engaged in an investigation of the stereochemistry of formation of the dihydrothiophenes by this method, in its extension to functionalized reactants and intermolecular examples. Work is also in progress on other reactions of compounds of type **1** and the results of these investigations will be reported at a later date.

Experimental Section

Unless otherwise noted, infrared spectra were recorded on a Beckman IR-20A spectrometer in carbon tetrachloride solution and nmr spectra were obtained on a JEOLCO C60HL spectrometer in deuteriochloroform and are reported in parts per million from TMS as internal standard. Glc analyses were carried out on an F & M Model 720 gas chromatograph utilizing an 8 ft × 0.375 in. 20% SE-30 on Chromosorb W column. The flow rate of the helium carrier gas was 1 ml/sec. Mass spectra were obtained on a Varian MAT CH5-DF instrument. Unless otherwise noted, the drying agent used was anhydrous sodium sulfate and solvents were removed on a rotary evaporator at reduced pressure. Chromatography was performed using Fisher acidic alumina, 80–200 mesh, Brockman activity grade I. Microanalyses were performed by A. B. Gygli, Microanalysis Laboratory, Toronto, Ontario, Canada.

Preparation of Salts 10, 11, 12, 13, and 13a. Vinyltriphenylphosphonium bromide[11a] (**10**) was purchased from the Aldrich Chemical Co.

2-Methylvinyltriphenylphosphonium bromide[15a] (**11**) was prepared by stirring a solution of 5 g of salt **11a** in 40 ml of dry pyridine containing 6 drops of triethylamine at room temperature for 18 hr. After removal of solvent, purification was effected by adding 50 ml of boiling benzene, adding enough methylene chloride to effect solution, cooling to room temperature, and precipitating the salt with 20 ml of ethyl acetate. The yield was 96%, mp 210–212° (lit.[15a] mp 213–214°).

2,2-Dimethylvinyltriphenylphosphonium chloride (**12**) was prepared by refluxing equimolar amounts of triphenylphosphine and methallyl chloride in benzene solution, removing the solvent, and recrystallizing the residue in the same manner as for **11**: mp 211–213° (lit.[19a] mp 214–216° reported as **12a**); nmr δ 7.80–7.38 (m, 15), 6.48 (d, 1, J = 20 Hz), 2.42 (br s, 3), 1.76 (d, 3, J = 2 Hz). An alternate procedure whereby a large excess of methallyl chloride was used as the reaction solvent afforded a crude product whose nmr spectrum showed it to be a 5:1 mixture of salts **12a** and **12**.

Bromination of α-Methylstryene. α-Methylstryene (94.4 g, 0.8 mol) and 90 g (0.5 mol) of *N*-bromosuccinimide were mixed under a nitrogen atmosphere in a 1000-ml flask fitted with a magnetic stirrer, a reflux condenser, and an addition funnel containing 400 ml of carbon tetrachloride. The stirrer was started and the flask was heated with a Meker burner until the solid started to melt. An exothermic reaction started and the flask was cooled in an ice bath to moderate the reaction. After the reaction had subsided, the mixture was stirred for 2 hr, the carbon tetrachloride was added, and the insoluble material was removed by filtration. The residue was washed with solvent and the filtrate was evaporated to afford 95 g of a dark oily lachrymator[30] which was used without further purification.

2-Phenyl-1-propen-3-yltriphenylphosphonium Bromide (**13a**). Crude α-bromomethylstryene (80 g, 0.4 mol) was dissolved in 50 ml of methylene chloride, and 107 g (0.41 mol) of triphenylphosphine was added. The solution was heated at reflux for 24 hr. The cooled solution was filtered, and the filtrate was diluted with 50 ml of ethyl acetate and refiltered. The combined residues were washed with ethyl acetate and dried to yield 59 g of salt **13a**: mp 224–226°; nmr δ 8.0–6.8 (m, 20), 5.5–5.1 (m, 4).

Anal. Calcd for $C_{27}H_{24}PBr$: C, 70.57; H, 5.27. Found: C, 70.71; H, 5.40.

2-Phenyl-2-methylvinyltriphenylphosphonium Bromide (**13**). Salt **13a** (60 mg) was dissolved in pyridine-d_5 in an nmr tube and 2 drops of triethylamine was added. After 30 min, the absorption at δ 5–6 had completely disappeared. Repeating the procedure on a preparative scale led to the isolation of salt **13a** and an oil which could not be crystallized, but whose nmr spectrum was consistent with structure **13**, nmr δ 7.9–7.35 (m, 20), 7.1–6.3 (m, 1), 2.20 (d, 3, J = 3.5 Hz). This salt was normally prepared *in situ* from **13a**.

Preparation of Dihydrothiophenes. All the dihydrothiophenes listed in Table I were prepared by the following procedure.

The appropriate phosphonium salt (0.01 mol) was dissolved in 50 ml of dry pyridine in a 100-ml flask fitted with magnetic stirring, a reflux condenser, and a nitrogen inlet. Triethylamine was added (0.015 mol) and the mixture was stirred at room temperature for 30 min. The appropriate mercapto ketone (0.01 mol) was added, the system was purged with nitrogen, and the solution was heated at reflux for the time indicated in Table I. The cooled solution was poured into 600 ml of water and extracted twice with 100 ml of ether and twice with 100 ml of pentane. The combined organic layers were washed with two 100-ml portions of 10% hydrochloric acid and dried. The solution was reduced in volume to *ca.* 10 ml and chromatographed on alumina using pentane as the eluent. This removed all phosphorus-containing and colored materials. The solvent was removed to yield the dihydrothiophene, which glc analysis showed to be greater than 95% pure. Analyti-

Table II
Indices of Refraction and Nmr Spectra

Compd	$n^{25}D$	Nmr spectral data[a]
14	1.5192	5.40 (s, 1), 3.57 (s, 4), 1.81 (s, 3)
15	1.4912	5.32 (m, 1), 3.60 (t, 2, J = 2 Hz), 1.72 (d, 3, J = 1.5 Hz), 1.51 (s, 2)
16	1.4860	5.22 (m, 1), 4.02 (m, 1), 1.69 (t, 3, J = 1.8 Hz), 1.50 (s, 3), 1.47 (s, 3), 1.35 (d, 3, J = 6 Hz)
17	1.4701	5.15 (d, 1, J = 1 Hz), 1.67 (d, 3, J = 1 Hz), 1.50 (s, 12)
18	1.5476	5.35 (m, 1), 3.70 (m, 3), 2.80–1.01 (m, 8)
19	1.5272	5.26 (d, 1, J = 2 Hz), 4.48–3.70 (m, 2), 2.72–1.10 (m, 8), 1.40 (d, 3, J = 6.5 Hz)
20	1.5129	5.10 (t, 1, J = 1.5 Hz), 3.70 (m, 1), 2.65–1.10 (m, 8), 1.48 (s, 3), 1.44 (s, 3)
21	1.5408	5.35 (br s, 1), 4.26 (m, 1), 4.00 (m, 2), 2.5–1.2 (m, 6)
22	1.5186	7.12 (s, 5), 5.50 (m, 1), 4.85 (m, 1), 3.71 (m, 2), 1.51 (m, 3)
23	1.4732	5.40 (t, 1, J = 2 Hz), 3.53 (d, 2, J = 2 Hz), 2.22 (m, 1), 1.45 (s, 3), 1.12 (d, 6, J = 7 Hz)
24	*b*	5.23 (d, 1, J = 2 Hz), 3.99 (m, 1), 2.13 (m, 1), 1.45 (s, 3), 1.41 (s, 3), 1.27 (d, 3, J = 7 Hz), 1.07 (d, 6, J = 7 Hz)

[a] Tabulation follows the order chemical shift (δ), multiplicity, number of protons, coupling constant. Spectra run in $CDCl_3$. [b] Insufficient sample available.

cal samples were collected by glc. Indices of refraction and nmr spectra are shown in Table II. Except for the lack of carbonyl absorption, the infrared spectra were uninformative.

Keto Sulfide 27. When salt **13** and mercapto ketone **5** were allowed to react under the conditions given for the preparation of the dihydrothiophenes, elution of the chromatography column with pentane afforded a 52% yield of **27** as a pale yellow oil: nmr δ 7.20 (s, 5), 5.28 (d, 1, J = 1 Hz), 5.15 (m, 1), 3.32 (d, 2, J = 1 Hz), 2.10 (s, 3), 1.37 (s, 6); ir 1720 cm^{-1}.

2,4,5,6,7,7a-Hexahydrobenzo[*b*]thiophene 1,1-Dioxide (28).[26] The reaction was carried out in the same manner as for **30** using 1.4 g (0.01 mol) of **18** and 3.96 g (0.022 mol) of *m*-chloroperbenzoic acid. Evaporation of the dried solution afforded 1.67 g (98%) of a colorless liquid: nmr δ 5.57 (t, 1, J = 2 Hz), 3.8–3.3 (m, 3), 2.7–1.1 (m, 8).

Dimethyl 3,5,6,7,8,8a-Hexahydronaphthalene-1,2-dicarboxylate (29).[27] Sulfone **28** (1 g, 0.0058 mol) was dissolved in 5 ml of xylene and 0.28 g of dimethyl acetylenedicarboxylate and a small amount of hydroquinone were added. The solution was heated at reflux for 6 hr and the xylene was removed by distillation at atmospheric pressure. Glc analysis of the residue showed only one peak which was collected and proved to be **29**. The yield was calculated to be 78%: nmr δ 5.35 (br s, 1), 3.80 (s, 3), 3.75 (s, 3), 2.97 (br s, 3), 2.32–1.10 (m, 8); ir 1730, 1660 cm^{-1}.

2,2,3-Trimethyl-2,5-dihydrothiophene 1,1-Dioxide (30). To a cold solution of 2 g (0.0156 mol) of **15** in methylene chloride was added 6.18 g (2.15 equiv) of *m*-chloroperbenzoic acid in two equal portions. The exothermic reaction was moderated by use of an ice bath. The solution was stirred at 0° for 3 hr and at room temperature for 1 hr. The precipitate was removed by filtration and the filtrate was washed with two 75-ml portions of saturated sodium carbonate solution, dried, and evaporated. The residue solidified to give 2.5 g (100%) of a white solid: mp 64–65° which was not raised by recrystallization from benzene–pentane; nmr δ 5.70 (m, 1), 3.71 (m, 2), 1.81 (m, 3), 1.44 (s, 6); ir 3030, 2990, 2940, 1310, 1140; 1110 cm^{-1}.

Anal. Calcd for $C_7H_{12}O_{12}S$: C, 52.46; H, 7.51; S, 20.00. Found: C, 52.62; H, 7.72; S, 19.86.

3,4,5-Trimethyl-4-cyclohexene-1,2-dicarboxylic Acid (33).[28] Sulfone **30** (0.5 g, 3.12 mmol) and 0.31 g (3.13 mmol) of maleic anhydride were dissolved in 5 ml of xylene and a small amount of hydroquinone was added. The solution was refluxed for 6 hr, cooled, and evaporated to afford 0.5 g of a solid which was immediately hydrolyzed in boiling water for 1.5 hr. Evaporation and crystallization of the residue from water afforded 0.45 g (58%) of **30**, mp 173–174° (lit.[28] mp 173–174°).

Reaction of 30 with Maleic Anhydride in Toluene. The reaction was run as before except that toluene was used as solvent. The evolution of sulfur dioxide was much slower and the reaction was monitored by nmr. After 165 hr reflux, the reaction was worked up as before and a mixture of acids was obtained from which 65 mg of **33a** could be isolated by crystallization from water. Esterification of the evaporated mother liquors using diazomethane gave a mixture of three esters which were separated by glc. These proved to be diester **33b**, 3,3,4-trimethyl-4-cyclohexene 1,2-dicarboxylate (**34b**), and 2-carbomethoxy-5-hydroxy-5,6,6-trimethylcyclohexanecarboxylic acid lactone (**35**).[28]

Acknowledgment. The financial support of the National Research Council of Canada is most gratefully acknowledged.

Registry No. **4**, 24653-75-6; **5**, 42855-44-7; **6**, 42904-05-2; **7**, 42855-45-8; **8**, 42855-46-9; **9**, 42855-47-0; **10**, 5044-52-0; **11**, 7301-94-2; **12**, 42855-48-1; **13**, 42904-06-3; **13a**, 42855-49-2; **14**, 42855-50-5; **15**, 42855-51-6; **16**, 42855-52-7; **17**, 42855-53-8; **18**, 42855-54-9; **19**, 42855-55-0; **20**, 42854-41-1; **21**, 42854-42-2; **22**, 42854-43-3; **23**, 42854-44-4; **24**, 42854-45-5; **27**, 42854-46-6; **28**, 42854-47-7; **29**, 42854-48-8; **30**, 42854-49-9; triphenylphosphine, 603-35-0; 2-methallyl chloride, 563-47-3; α-bromomethylstyrene, 3360-54-1.

References and Notes

(1) (a) Presented in part at the annual meeting, Chemical Institute of Canada, Montreal, June 1973; (b) National Research Council of Canada Predoctoral Fellow, 1969–1973; (c) NRCC Predoctoral Fellow, 1973.
(2) (a) For a comprehensive reference list, see H. O. House, "Modern Synthetic Reactions," 2nd ed, W. A. Benjamin, New York, N. Y., 1972, p 817.
(3) M. Cais in "The Chemistry of Alkenes," S. Patai, Ed., Wiley, New York, N. Y., 1964, p 955; (b) A. Maercker in "Organic Reactions," Vol. 14, Wiley, New York, N. Y., 1965, p 270; (c) D. V. Banthorpe, "Elimination Reactions," Elsevier, New York, N. Y., 1963; (d) G. Kobrich, *Angew. Chem., Int. Ed. Engl.*, **4**, 49 (1965).
(4) (a) E. J. Corey, C. U. Kim, R. H. K. Chen, and M. Takeda, *J. Amer. Chem. Soc.*, **94**, 4395 (1972); E. J. Corey and R. H. K. Chen, *Tetrahedron Lett.*, 1611 (1973); (b) E. J. Corey and G. T. Kwiatkowsky, *J. Amer. Chem. Soc.*, **90**, 6816 (1968); E. J. Corey and T. Durst, *ibid.*, **90**, 5548 (1968).
(5) (a) The effect of solvent polarity, dissolved lithium salts, and other reaction variables on the stereochemistry of the Wittig reaction are not yet totally predictable; see ref 2, p 682; (b) Ref 3b.
(6) G. Wittig and H. Reiff, *Angew. Chem., Int. Ed. Engl.*, **7**, 7 (1968).
(7) The main utility of the Wittig reaction has been in the preparation of disubstituted olefins and exocyclic methylene compounds. The limitations in the formation of more highly substituted olefins do not seem to have been widely recognized. Specific examples can be found in the tables of ref 3b.
(8) S. D. Turk and R. L. Cobb in "1-4-Cycloaddition Reactions," J. Hamer, Ed., Academic Press, New York, N. Y., 1967, p 13.
(9) (a) W. Mock, *J. Amer. Chem. Soc.*, **88**, 2857 (1966); (b) S. D. McGregor and D. M. Lemal, *ibid.*, **88**, 2858 (1966); (c) P. Chao and D. M. Lemal, *ibid.*, **95**, 920 (1973).
(10) R. C. Krug and D. E. Boswell, *J. Heterocycl. Chem.*, **4**, 309 (1967).
(11) (a) E. E. Schweizer and R. D. Bach, *J. Org. Chem.*, **29**, 1746 (1964); (b) E. E. Schweizer, A. T. Wehman, and D. M. Nycz, *J. Org. Chem.*, **38**, 1583 (1973), and previous papers in the series.
(12) (a) E. E. Schweizer and K. K. Light, *J. Org. Chem.*, **31**, 2912 (1966); (b) E. E. Schweizer and C. M. Kopay, *ibid.*, **37**, 1561 (1972).
(13) E. E. Schweizer and J. G. Liehr, *J. Org. Chem.*, **33**, 583 (1968).
(14) J. M. McIntosh and H. B. Goodbrand, *Tetrahedron Lett.*, 3157 (1973).
(15) (a) P. T. Keough and M. Grayson, *J. Org. Chem.*, **29**, 631 (1964); (b) J. M. Swan and S. H. B. Wright, *Aust. J. Chem.*, **24**, 477 (1971).
(16) E. E. Schweizer, E. T. Schaffer, C. T. Hughes, and C. J. Berninger, *J. Org. Chem.*, **31**, 2907 (1966).
(17) E. E. Schweizer and A. T. Wehman, *J. Chem. Soc. C*, 343 (1971).
(18) G. Buchi and H. Wuest, *Helv. Chim. Acta*, **54**, 1767 (1971).
(19) (a) J. Wolinsky, B. Chollar, and M. D. Baird, *J. Amer. Chem. Soc.*, **84**, 2775 (1962); (b) H. Plieninger, M. Hobel, and V. Liede, *Chem. Ber.*, **96**, 1618 (1963).
(20) M. Grayson and P. T. Keough, *J. Amer. Chem. Soc.*, **82**, 3919 (1960).
(21) Reference 2, p 459.
(22) J. Hooz and J. N. Bridon, *Can. J. Chem.*, **50**, 2387 (1972).
(23) (a) F. Asinger, M. Thiel, and H. Kaltwasser, *Justus Liebigs Ann. Chem.*, **606**, 67 (1957); (b) W. E. Parham, H. Wynberg, and F. L. Ramp, *J. Amer. Chem. Soc.*, **75**, 2065 (1953); (c) G. Gieseler and F. Stache, *Chem. Ber.*, **94**, 337 (1961).

(24) A. Kirrmann, J. Cantacuzene, and L. Vio, *Rev. Chim. Acad. Repub. Pop. Roum.*, **7**, 1011 (1962); *Chem. Abstr.*, **61**, 8180a (1962).
(25) R. G. Hiskey, J. A. Kepler, and B. D. Thomas, *J. Org. Chem.*, **29**, 3684 (1964).
(26) S. F. Birch, R. A. Dean, N. J. Hunter, and E. V. Whitehead, *J. Org. Chem.*, **30**, 1178 (1965).
(27) V. F. Kucherov, N. Y. Grigor'eva, T. M. Fadeeva, and G. A. Kogan, *Izv. Akad. Nauk SSSR, Otd. Khim. Nauk*, 2196 (1962); *Chem. Abstr.*, **58**, 11235d (1962).
(28) I. Ichikizaki and A. Arai, *Bull. Chem. Soc. Jap.*, **37**, 432 (1964).
(29) N. L. Goldman, *Chem. Ind. (London)*, 1036 (1963).
(30) S. F. Reed, *J. Org. Chem.*, **30**, 3258 (1965).

A Photochemical Route to the Thieno[*c*]cyclobutene System

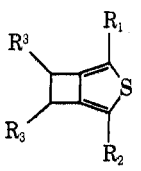
M. P. Cava,* M. V. Lakshmikantham, and M. Behforouz

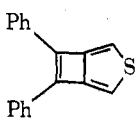
Department of Chemistry, University of Pennsylvania, Philadelphia, Pennsylvania 19174

Received August 23, 1973

Photolysis of either of the cis or trans dihydrothienothiophene sulfones **15** and **16** affords primarily the thienocyclobutene **6**; similarly, the methoxy sulfone isomers **18** yield the methoxythienocyclobutene **19**. Both **6** and **19** undergo ready thermolysis to naphtho[*c*]thiophene derivatives. Evidence is presented which indicates that the thermolysis of **6** does not proceed *via* a tetravalent sulfur quinodimethane-type intermediate.

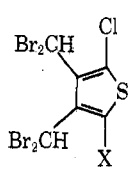
The first thieno[*c*]cyclobutenes have been reported only recently. These include the parent heterocycle **1**[1] and the tetrahalo derivatives **2** and **3**,[2] as well as the stable thienocyclobutadiene **4**.[3] Compounds **1** and **4** were prepared by constructing the thiophene nucleus by a Wittig synthesis; compounds **2** and **3** were prepared by a Finkelstein-type dehalogenation of an appropriate halo thiophene (**5**).





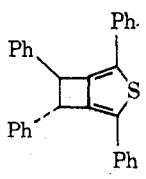
1, $R_1 = R_2 = R_3 = H$
2, $R_1 = R_2 = Cl$; $R_3 = Br$ (cis and trans)
3, $R_1 = Cl$; $R_2 = R_3 = Br$ (cis and trans)

4

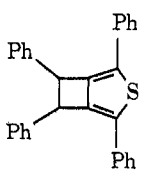


5

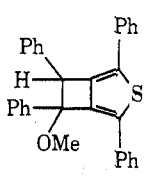
We now report the synthesis and properties of several 3,4-diphenylthieno[*c*]cyclobutenes (**6**, **7** and **8**), employing the photochemical decomposition of a sulfone precursor as the key synthetic step.



6



7

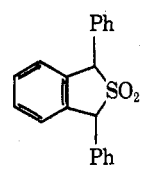


8

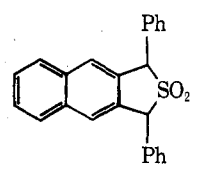
Results

The photochemical decomposition of the cyclic benzylic sulfones **9** and **10** affords a direct synthesis of the condensed cyclobutane aromatic hydrocarbons **11** and **12**.[4] Consequently, we decided to investigate the applicability of this type of reaction in the thiophene series. Thus, peracid oxidation of the known dihydrothienothiophenes **13** and **14**[5] gave the corresponding sulfone isomers **15** and **16**.

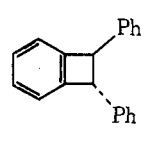
Both **15** and **16** lost sulfur dioxide cleanly upon irradiation in benzene–methanol in the presence of barium oxide



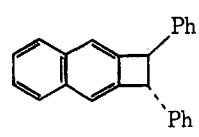
9



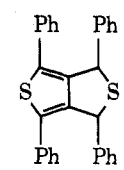
10



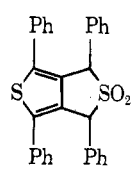
11



12



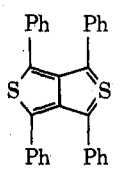
13, cis isomer
14, trans isomer



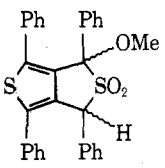
15, cis isomer
16, trans isomer

to give, in good yield, the crystalline trans thienocyclobutene **6**. Careful chromatography of the photolysis residues afforded a very small amount of the corresponding cis isomer **7**. The nmr spectra of **6** and **7** showed benzylic singlets at δ 4.47 and 5.20, respectively; the corresponding reported values for *trans*-1,2-diphenylbenzocyclobutene (**11**) and its cis isomer are δ 4.42 and 5.20, respectively.[6]

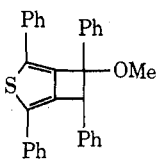
A two-step conversion of tetraphenylthieno[3,4-*c*]thiophene (**17**) to the methoxy sulfone **18** has been reported.[5] We have now found that sulfone **18** can be separated into two stereoisomers, A and B (mp 234° dec and 210° dec, respectively), both of which lose sulfur dioxide upon irradiation to give the same methoxycyclobutene **19**. The nmr spectrum of **19**, which is probably the trans isomer, shows a single benzylic hydrogen at δ 4.72 as well as a methoxyl signal at δ 3.00.



17



18



19

The thienocyclobutene **6** is quite stable in solution at temperatures up to about 60°. At 75°, however, an nmr study showed that it rearranged completely in hexachlorobutadiene solution within 45 min. The product, which was isomeric with **6** and which showed a one-proton singlet at δ 5.42 and a two-proton singlet at δ 3.98, was assigned structure **20**. Compound **20** was also obtained directly by the pyrolysis of sulfones **15** and **16** at their melt-