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Oxygenation of Thiophenes with Diisopropyl Peroxydicarbonate-Cupric Chloride[1]

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The reaction of thiophene and certain derivatives (2-methyl, 2-chloro, 2-bromo, 2-nitro, 2,5-dichloro, and 2,5-dibromo) with diisopropyl peroxydicarbonate in acetonitrile was investigated in the presence and absence of cupric chloride catalyst. In catalyzed reactions, thienyl isopropyl carbonates were formed in 41–74% yields in most cases, along with by-products. Without cupric chloride, different product distributions were generally observed. The mechanistic aspects are discussed. Dealkylation and decarboxylation of the esters gave hydroxythiophenes whose tautomeric nature was studied by nmr spectroscopy.

Oxygenated thiophenes[4,5] have been prepared by various methods which can be divided conveniently into two main categories: (1) ring closure of suitable open-chain compounds,[4] *e.g.*, synthesis of 5-methyl-2-hydroxythiophene from levulinic acid and phosphorus sulfides,[5b,6] and (2) replacement of a substituent on the thiophene nucleus.[7] The displacement reaction is illustrated by conversion of 2-iodothiophene to the corresponding methoxy derivative by treatment with sodium methoxide and cupric oxide.[8] Syntheses by way of organometallic compounds have proved useful,[9] as in the formation of 2-*tert*-butoxythiophene from 2-thienylmagnesium bromide and *tert*-butyl perbenzoate.[10] Another technique entails oxidation of thiopheneboronic acids.[11]

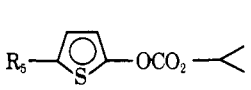
Direct oxygenation (replacement of nuclear hydrogen by an oxygen function) has been noted in a few systems.[12,13] The most pertinent prior literature describes peroxide decomposition in thiophene: 2-thenoyl peroxide gave 2-thienyl-2-thenoate (30%);[14a] 3-thenoyl peroxide produced 2-thienyl-3-thenoate (13%);[15] and benzoyl peroxide afforded 2-thienyl benzoate[14b] (15%).[14a]

The tautomeric nature of hydroxythiophenes is evidenced in part by their dual reactivity as phenols and active methylene compounds.[9a,16] Some authors made qualitative estimates of the position of equilibrium from ir data,[9d] but since about 1960 nmr has been used in a quantative approach.[9f-i,11,17]

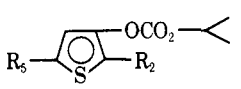
Recently it was shown that aromatic comounds can be oxygenated with diisopropyl peroxydicarbonate (IPP) and cupric chloride in acetonitrile.[18-20] The present work was undertaken to determine the applicability of this technique to compounds in the thiophene series. Principal attention was devoted to the mechanistic and synthetic features. Hydroxythiophenes were obtained from the ester products by dealkylation and decarboxylation.

Results and Discussion

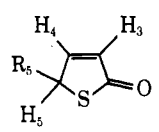
Oxygenation of Thiophenes. Thiophene. Catalytic oxygenation of thiophene with diisopropyl peroxydicarbonate (IPP) resulted in a 67% yield of 2-thienyl isopropyl carbonate (**1**) and 3% of the 3 isomer (**6**), along with small amounts of 5-chloro-2-thienyl isopropyl carbonate (**2**), 2,2′-bithienyl (**17**), 2,5-dihydroxythiophene bis(isopropyl carbonate) (**5**), and 2-isopropoxy-5-chlorothiophene (Table I). A thiophene:IPP:cupric chloride ratio of 10:1:0.3 in acetonitrile at 60° was found to give the best yield of major product (Table II). In general, similar results were observed when the temperature was reduced from 60° to 30°, but extended periods of time were required. A kinetic experiment revealed that reaction was substantially complete within the first 10 min at 60°, in agreement with the observation that essentially all gas evolution took place during that time. When the amount of solvent was halved, the yield of carbonate decreased to 55%, and to 50% when solvent was omitted. This is in sharp contrast to the behavior of toluene as the aromatic component, which gave only 7% of the corresponding ester in the neat system.[21] A possible explanation for the difference in behavior is that cupric chloride is 125 times more soluble in thiophene than in toluene at 60°. In view of the fact that benzene is cleanly oxygenated,[19] the number of by-products observed in the reaction with thiophene is noteworthy.



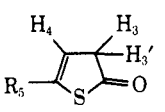
1, R_5 = H
2, R_5 = Cl
3, R_5 = Br
4, R_5 = CH_3
5, R_5 = $OCO_2CH(CH_3)_2$



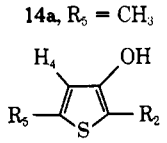
6, R_2 = R_5 = H
7, R_2 = CH_3; R_5 = H
8, R_2 = R_5 = Cl
9, R_2 = R_5 = Br
10, R_2 = Br; R_5 = Cl or R_2 = Cl; R_5 = Br



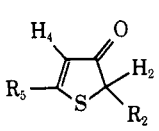
11a, R_5 = H
12a, R_5 = Cl
13a, R_5 = Br
14a, R_5 = CH_3



11b, R_5 = H
12b, R_5 = Cl
13b, R_5 = Br
14b, R_5 = CH_3



15a, R_2 = CH_3; R_5 = H
16a, R_2 = R_5 = Cl



15b, R_2 = CH_3; R_5 = H
16b, R_2 = R_5 = Cl

Table I
Catalyzed Oxygenations of Thiophenes

Substrate[a]	Major products[b]	Yield, % Glpc[c]	Yield, % Dist[d]	Recovery,[e] %	By-products
Thiophene	**1**	67	64[f]	*g*	*h*
2-Methylthiophene	**4**	47	27[f]	*g*	*i*
	7	25	11[f]		
2-Chlorothiophene	**2**	74			*j*
2-Bromothiophene	**3**	57			*k*
2,5-Dichlorothiophene	**2**	33	17[l]	88	*m*
	8	39	20[l]		
2,5-Dibromothiophene	**3**	21	10[n]	94	*o*
	9	20	17[n]		
2-Thienyl isopropyl carbonate	**2**	22			*j*
	5	33			
2-Nitrothiophene		<2			

[a] Aromatic substrate:peroxide:cupric chloride = 10:1:0.3, in acetonitrile, 60°, 2 hr. [b] See Table IV. [c] Glpc analysis, based on 1 mol of ester/mol of peroxide. [d] Distilled from larger scale reaction, greater than 98% pure by glpc. [e] Based on 9 mol of aromatic substrate. [f] Reaction time, 0.25 hr. [g] Appears to form azeotrope with acetonitrile, not easily recoverable by distillation. [h] **2**, 3%; **6**, 3%; **5**, trace; **17**, trace; 2-isopropoxy-5-chlorothiophene, 3%. [i] Three unidentified products of longer retention time, *ca.* 1, 2, and 1%. [j] None seen by glpc. [k] *Ca.* 5%, shorter retention time, unidentified. [l] Reaction time, 2.5 hr. [m] Less than 2% of a compound with slightly longer retention time than **8**. [n] Reaction time, 1 hr. [o] **10**, 3.5%.

Table II
Reaction Variables in Oxygenation of Thiophene with IPP–Cupric Chloride[a]

Thiophene:IPP:cupric chloride, molar ratio	Temp, °C	Time, hr	Thienyl isopropyl carbonates yield, %[b]
0.5:1:0.3	60	2	6
1:1:0.3	60	2	14
1:1:0.3	30	4.5	15
1:1:1	30	4.5	12
2:1:0.3	30	22	30
5:1:0.3	60	2	54
10:1:0.3	30	22	65
10:1:0.3	60	2	70
10:1:0.1	60	2	61
20:1:0.3	30	22	71
20:1:0.3	60	2	71
20:1:0.3[c]	60	2	55
20:1:0.3[d]	60	2	50

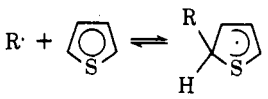
[a] Acetonitrile, 200 ml, and cupric chloride, 0.01 mol, unless otherwise noted. [b] Total yield of **1** and **6**, glpc. [c] 100 ml of acetonitrile. [d] No acetonitrile.

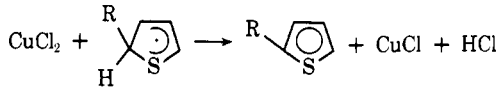
Decomposition of IPP in thiophene with acetonitrile solvent in the absence of oxidant gave **1** but no **6**, some diisopropyl carbonate, and significant amounts of the isomeric bithienyls: 2,2′ (**17**), 2,3′ (**18**), and 3,3′ (**19**) (Table III).

Properties of the isopropyl carbonate esters of hydroxythiophenes are summarized in Table IV.

The formation of the major product **1** and its isomer **6** can be envisioned as taking place according to the mechanism postulated for the oxygenation of benzenoid compounds.[19,21] Oxidation[19] of the σ complex radical might occur by H-atom abstraction, through an intermediate

$$IPP \longrightarrow 2R\cdot$$





$$CuCl + IPP \longrightarrow CuClR + R\cdot$$

$$CuClR + HCl \longrightarrow CuCl_2 + i\text{-}PrOH + CO_2$$

$$R = OCO_2CH(CH_3)_2$$

Table III
Uncatalyzed Reactions of IPP with Thiophenes[a]

Substrate	Products (%)[b]
Thiophene	**1** (17), **17** (9), **18** (6.5), **19** (0.7)[c]
2-Chlorothiophene	**1** (6), **2** (67)
2-Bromothiophene	**1** (3), **3** (62)
2,5-Dichlorothiophene	**2** (64), **8** (4)
2,5-Dibromothiophene	**3** (20), **9** (11)[d]
2-Bromo-5-chlorothiophene	**2** (33), **3** (3), **10** (12)

[a] Thiophene:IPP = 10:1 molar ratio, acetonitrile solvent, 60°, 63 hr. [b] Based on 1 mol of ester/mol of peroxide; glpc. [c] Diisopropyl carbonate, 4%. [d] One unidentified product, about 3%.

carbonium ion, or *via* either 5-chloro-2,5-dihydro-2-thienyl isopropyl carbonate (**22**) or 3-chloro-2,3-dihydro-2-thienyl isopropyl carbonate generated by ligand transfer. In the absence of added oxidant, loss of a hydrogen atom from the σ complex radical is less efficient.

Generation of **2** can be depicted in a number of ways. One route is through dehydrogenation of **22**. Another possibility entails chlorination of **1**, perhaps by ligand transfer between cupric chloride and the radical cation.[23] Some evidence for transformation of **1** to **2** is found in the observation that **2** is formed concomitantly in 22% yield during oxygenation of **1** to **5**.

Bithienyls could arise by attack on thiophene of a thienyl radical, which could conceivably be generated in a number of ways. One is abstraction of hydrogen by a radical [either an isopropoxy radical or $(CH_3)_2CHOCO_2\cdot$], as has been proposed in an analogous case with naphthalene[24a] (see DeTar and Long for an alternate explanation[24b]). Another possibility entails the mechanism advanced by Griffin and Martin for the formation of bithienyls, in the reaction of benzoyl peroxide with thiophene,[25] by way of a radical cation. A third hypothesis was suggested by the work of Mackay:[15] attack of an acyloxy radical on the aromatic ring to form a σ complex, removal of a proton by carboxylate anion, and then loss of carboxylate anion. Alternatively, evidence indicates that the σ complex radical can dimerize and then lose two molecules of benzoic acid.[14b] The isomer distributions of bithienyls from IPP–thiophene are set forth for comparison with those from related systems (Table V). A complicating feature in the interpretation of data in Table V is that decarboxylation of the thenoyloxy radical can give a thienyl radical, which

Table IV
Characterization of Isopropyl Carbonate Esters of Thiophenes[a]

Compd	Bp, °C (mm)	$n^{28}D$	Mol wt calcd	M+, m/e[b]	eV[c]	RT[d]	Uv, λ_{max}[e]	Log ε	Nmr, δ[f]	RI[g]	Type[h]	J, Hz[i]
1	64 (0.7)	1.4923[j]	186.2	*k*	*k*	1.50	232	3.89	6.47–6.69	3	m	*l*
2	122 (10)	1.5010	220.7	220, 222	15–70	3.33	234, 252[m]	3.89, 3.85	6.37, 6.57	2	A–B	4.2
3	93 (1.0)	1.5215	265.1	264, 266	13–70	5.17	249	3.86	6.38, 6.72	2	A–B	4.2
4	80 (1.0)	1.4875	200.3	200	14–70	2.56	235	3.81	6.35, 2.37[n]	2,3[n]	s, s	
5	125 (0.1)	1.4808[o]	288.3	*p*	*p*	33.6	245	3.79	6.26	2	s	
6	76 (1.0)	1.4898	186.2	186	20–70	1.50	232	3.69	6.66–7.06	3	m	*l*
7	72 (1.0)	1.4864	200.3	200	14–70	2.05	229	3.81	6.79, 6.91, 2.23[n]	2,3[n]	A–B, s	5.6
8	55 (0.02)	1.5108	255.1	254, 256	15–70	5.11	238, 255[m]	3.87, 3.81	6.89	1	s	
9		1.5482	344.0	342, 344, 346	6–70	10.65	239, 257[m]	4.00, 3.89	6.94	1	s	

[a] Microanalytical data were in satisfactory agreement with theory for carbon, hydrogen, sulfur, and halogen. [b] Mass, amu, of molecular ion. [c] Range of electron energies over which this ion is present in measurable amounts. [d] Retention time relative to 1,2,4-trichlorobenzene; see Experimental Section. [e] In mμ, in methanol solution; see Experimental Section. [f] Parts per million downfield from internal tetramethylsilane (TMS); isopropyl groups show expected nmr pattern, nearly unchanged, throughout this series. [g] Relative integrated intensity of absorption of aromatic protons, with the methine proton of the isopropyl group taken as 1. [h] Absorption pattern: m, multiplet; A–B, pattern produced by AB system; s, singlet; δ for A–B systems calculated according to ref 22. [i] Coupling constant for ring protons. [j] $n^{19.5}D$. [k] No molecular ion visible. [l] Not determined. [m] Shoulder. [n] Refers to proton resonance of nuclear CH_3 group. [o] $n^{28}D$. [p] Sample insufficiently volatile for mass spectral determination.

Table V
Product Distribution from Peroxides and Thiophene

Registry no.	R in $(RCO_2)_2$	Products, %[a] Bithienyls 2,2′	Bithienyls 2,3′	Bithienyls 3,3′	2-Thienyl-O_2CR	3-Thienyl-O_2CR	Others	Ref
30930-49-5	2-Thienyl	7	*b*	*b*	34	*b*	*c*	*d*
14596-82-8	3-Thienyl	8.9	6.7	<1	13.4	None	*e*	*f*
94-36-0	Phenyl	9.5	3	*b*	*b*	*b*	*g*	*h*
105-64-6	Isopropoxy	9.7	10.6	2.5	22	<0.1	*i*	*j*
	Isopropoxy[k]	9.3	6.5	0.7	16.7	<0.1	*i*	*j*
	Isopropoxy[k,l]	9.0	6.8	0.8	10.6	<0.1	*i*	*j*

[a] Based on 1 mol of products/mol of peroxide. [b] Not mentioned (not formed or not isolated?). [c] 2-Thenoic acid, 87%. [d] Reference 14a. [e] 3-Thenoic acid, 134%. [f] Reference 15. [g] 2-Phenylthiophene. [h] Reference 25. [i] Diisopropyl carbonate, 4%. [j] This work. [k] Acetonitrile solvent. [l] 2,5-Dideuteriothiophene substrate.

Table VI
Uncatalyzed Oxygenation of Thiophene–2,5-Dideuteriothiophene Mixtures with IPP

Substrate, d_2/d_0	Product ester,[a] d_0/d_1
1.00 ± 0.02[b]	1.54 ± 0.04
1.00	1.71
1.07	1.67
1.07	1.95

[a] Low precision may be due to traces of oxygen in the reaction mixture. [b] Errors are expressed as the average deviation of a measurement from the mean.

would tend to weight the isomer distribution in favor of compounds derived from attack of that radical on thiophene. The premise that 2- and 3-thienyl radicals give similar 2:3 isomer distributions with thiophene is supported by the results of studies on the photolysis of 2- and 3-iodothiophenes in aromatic solvents.[26,27]

An isotope effect, k_H/k_D = 1.73, was observed (Table VI) in the uncatalyzed, competitive oxygenation of thiophene–2,5-dideuteriothiophene mixtures with IPP.

The results from the competition experiments are in substantial agreement with the isotope effect, k_H/k_D = 1.57, indicated by comparison of ester yields from separate oxygenations of natural and 2,5-dideuteriothiophene (Table V). The situation is analogous to that for intramolecular cyclization of the 2-phenylbenzoyloxy radical to benzocoumarin[28a] (k_H/k_D = 1.32). Apparently, an isotope effect is observed since radical attack is reversible and dissociation competes favorably with oxidation of the σ complex radical.[28a] The isotope effect reported for phenylation of aromatic substrates apparently arises from nonreversibility of σ complex formation and slowness of the oxidation step.[28b]

The overall yield of bithienyls is essentially unchanged when the 2,5-dideuterated substrate was substituted for ordinary thiophene (Table V). This result should be considered in the context of the mechanisms which have been advanced for bithienyl formation (*vide supra*).

In relation to both ionic and free-radical substitution reactions in thiophene, the literature records indicate that, in most cases, there is predominant preference for the 2 position.[15,29]

2-Methylthiophene. Nuclear oxygenation was the major reaction, as in the case of toluene,[18] with no significant involvement of the methyl substituent. The isomer distribution was 5-methyl-2-thienyl isopropyl carbonate (4):2-methyl-3-thienyl isopropyl carbonate (7) = 65:35. Isomer distributions have been reported for several reactions of 2-methylthiophene. Phenylation[30] and nitration[31] gave 5:3 isomer ratios of 79:17 and 70:30, respectively, whereas acetylation,[29] chlorination (SO_2Cl_2),[32a] and bromination

Table VII
Yield and Characterization Data for Hydroxythiophenes–Thiolenones

Compd	Ref	Yield, %[a]	$n^{20}D$	Uv, λ_{max}	Log ϵ	λ_{max}	Log ϵ	λ_{max}	Log ϵ	Mol wt calcd	M^+ m/e	eV[b]
11a	This work	80	1.5551	215	3.83	262	3.31			100.1	100	20–70
	9a		1.5644[c]	220	3.9	320	2.0					
	9f		1.5613[c,d]	220	3.9	263	3.5					
12	This work	45[e]	1.5704[c,f]	219	3.85	273	3.21			134.6	134, 136	10–70
13	This work	53		216	3.92	290	3.20			179.0	*g*	
14	This work	57	1.5368	216	3.78	265	3.28			114.2	114	15–70
	17		1.5278[h]	220[i]	3.9[i]	268[i]	3.5[i]					
15	This work	26[j]	1.5552[c,k]	220[l]	3.52	268	3.22	317	3.25	114.2	114	15–70
16	This work	51[e]		233	3.73	271	3.58	316	3.19	169.0	168, 170	20–70

[a] Based on isopropyl carbonate ester. [b] Range of electron energies over which this ion is produced in measurable quantities. [c] $n^{20}D$. [d] Reference 10. [e] One-half scale dealkylation. [f] Reference 9i. [g] No M^+ ion observable. [h] $n^{20}D$. [i] Reference 9f. [j] Approximately 50% of the starting material was unchanged (glpc). [k] Reference 11c. [l] Shoulder.

(NBS)[32b] produced the 5 isomer almost exclusively.

2-Chlorothiophene. This compound generated 5-chloro-2-thienyl isopropyl carbonate (2) in 74% yield, the only product evident by glpc. Similar high specificities have been recorded for acetylation[29h,i] and chlorination.[29e] In contrast, the 5:3 isomer ratio for phenylation[30] was 60:34.[30] When cupric chloride was omitted from the reaction mixture, 1 was also formed (2:1 = *ca.* 11:1).

2-Bromothiophene. From 2-bromothiophene as substrate, 5-bromo-2-thienyl isopropyl carbonate (3) arose in 57% yield, along with a few products of shorter retention time, about 5% total, but not including 1. A ratio of 65:31 for the 5:3 isomers was reported for phenylation.[30] In the absence of cupric chloride, 3 and 1 were found in the ratio of 21:1.

2-Nitrothiophene. There was no appreciable substitution, analogous to the behavior of nitrobenzene.[20] No change was noted in the absence of cupric chloride.

2,5-Dichlorothiophene. Oxygenation gave mainly 2 and 2,5-dichloro-3-thienyl isopropyl carbonate (8) in the ratio of 11:13, in contrast to the 16:1 ratio in the absence of cupric chloride. In the case of acylation with aluminum chloride and acetyl chloride, apparently the 3 position is solely affected.[33] On the other hand, with orthophosphoric acid and acetic anhydride only 5-chloro-2-acetylthiophene was reported.[29h]

2,5-Dibromothiophene. The products generated were mainly 3 and 2,5-dibromo-3-thienyl isopropyl carbonate (9) (*ca.* 1:1 ratio). In the absence of cupric chloride the ratio was about 2:1. Both bromine replacement and 3 substitution arise from acetylation in the presence of aluminum chloride, with no information on the product ratio.[34]

2-Bromo-5-chlorothiophene. The reaction with IPP in the absence of cupric chloride gave three products, 2, 3, and 10 (11:1:4). Compound 10 is a bromochlorothienyl isopropyl carbonate of unknown orientation.

Comparison of Catalyzed and Uncatalyzed Systems. In reactions without cupric chloride, ease of replacement of α halogen increases as indicated: 2-bromo- < 2-chloro- < 2,5-dibromo- < 2-bromo-5-chloro- < 2,5-dichlorothiophene. This is also the order in which the total electronegative effect of the substituents increases. Upon addition of cupric chloride, α halogen is less readily replaced in all cases, or, to put it another way, hydrogen is replaced to a greater extent in catalyzed reactions. It is recognized that the ratio of products isolated or determined by glpc may not be exactly equal to the ratio of products initially formed, owing to selective further reaction. Nevertheless, the observed differences are such that this possibility would not nullify the conclusions. These observations can be correlated. It has been postulated[5d] that 2,5-dichlorothiophene acts more like an olefin than does thiophene owing to resonance participation by halogen, which gives rise to addition as well as substitution reactions, *i.e.*, the dichloro compound is less aromatic and the role of the sulfur atom is diminished. Furthermore, the halogenated compound would be expected to yield a more stable intermediate (or transition state) when attacked at the α position to give an allylic, d-orbital stabilized radical than when attacked at the β position to give a simple d-orbital stabilized radical. The foregoing reasoning does not apply to 2-methylthiophene because of the electronic nature of the substituent and its reluctance to undergo displacement.

The change in product ratios upon addition of cupric chloride can be ascribed to the difference between thermodynamic and kinetic control. In the absence of an efficient, added oxidant, the σ complex may form and dissociate many times before a radical (present in relatively low concentration) effects rearomatization. Hence, the more stable σ complexes, being longer lived, will account for a greater fraction of the product. With cupric chloride, an extremely effective oxidant present in relatively high concentration, the first-formed σ complex is more likely to be oxidized. The product distribution would then reflect the most favorable position for radical attack. Displacement of halogen from halobenzenes is known to occur with the 2- or 3-thenoyloxy radical.[14a,15] In the benzene–hexadeuteriobenzene system, a primary isotope effect was not observed in the cupric chloride catalyzed reaction with IPP,[19] and a similar result would be expected with thiophene.

Stability of Carbonate Esters. The carbonate esters 1, 4, 5, 6, and 7 proved stable to storage (remaining colorless to pale yellow for several months) at room temperature in brown bottles closed with polyethylene-lined screw caps. The halogenated compounds 2, 3, 8, 9, and 10 darkened rapidly when kept in the same manner. With 9 this decomposition was especially pronounced, as evidenced by evolution of an acrid gas, presumably hydrogen bromide. In a sealed tube in the dark, the halogenated esters could be kept for at least a few weeks without apparent decomposition.

Preparation and Tautomeric Equilibria of Hydroxythiophenes–Thiolenones. Formation of hydroxythiophenes–thiolenones from the carbonate esters was accomplished in good to fair yields (Table VII). The esters were

dealkylated with aluminum chloride in *m*-xylene, yielding the desired products, plus high-boiling hydrocarbons and carbon dioxide. With 2-hydroxythiophene (**11**), 5-methyl-2-hydroxythiophene (**14**), and 2-methyl-3-hydroxythiophene (**15**), simple extraction procedures gave pure material as determined by nmr. Distillation was not employed because of the small amount of material used. The halogenated products, however, when treated in like fashion, gave only tars. Fortunately, chromatography on silica gel yielded material whose nmr spectrum matched that reported, with no indication of extraneous peaks. The crude materials were dark in color, presumably from oxidation or other coupling reactions,[9i,35,36] giving rise to bands (orange to violet) in the fractions preceding the desired component (also colored, most likely by small amounts of impurities). Compounds obtained in this way were 5-chloro-3-thiolen-2-one (**12a**), 5-bromo-3-thiolen-2-one (**13a**), and 2,5-dichloro-3-hydroxythiophene–2,5-dichloro-4-thiolen-3-one (**16a:16b**) = 1:1. The product from dealkylation of **9** was obtained as an insoluble black solid.

Compounds **11**, **12**, **13**, **14**, and **15** formed from **1**, **2**, **3**, **4**, and **7**, respectively, have been prepared previously; our values for chemical shifts and coupling constants are in good agreement with reported values (**11**,[9d,17] **12**,[9i] **13**,[9i] **14**,[9f,17] and **15**[11d]). For those compounds which exist as tautomers, data obtained in this work for the position of equilibrium were identical (experimental error expected to be ±2%) with those reported, with the exception of **14a:14b**. Two values are recorded for this ratio, 85:15 for a neat sample with 10% cyclohexane added[17] and 80:20 in carbon tetrachloride.[9f] Most probably the discrepancy in our value (69:31) is due to lack of equilibration, since the material was kept at Dry Ice temperature after isolation. In 14 days pure **14b** standing in carbon tetrachloride at room temperature[9f] gave a ratio of 80:20 (acid catalysis hastened to attainment of equilibrium[11c]).

The ir spectrum of **16**, isolated by elution from the silica gel column and evaporation of the benzene eluent, showed a broad absorption centered at 2.95 μ (hydrogen-bonded OH) and a carbonyl absorption at 5.95 μ (liquid film). In carbon tetrachloride solution (about 15% v/v) an additional sharp absorption appeared at 2.82 μ (free OH). This compound, which has not been described, exists 50% as the phenol form (**16a**) and 50% as the keto form (**16b**) according to nmr spectroscopy. The nmr spectrum in carbon tetrachloride consisted of four absorptions at δ 6.55, 6.28, 5.80, and 5.49 (equal relative intensities). No coupling could be discerned. The peak at δ 5.80 was considerably broadened and on this basis was assigned to the hydroxylic proton of the phenol form. The peak at δ 6.55 is apparently due to the ring proton of the phenolic form by comparison with the peak at δ 6.89 in the corresponding carbonate ester **8** and at δ 6.70 in the *tert*-butyl ether. The other two peaks were assigned to the keto form. The peak at δ 6.28 was assigned to the proton H_4 on the following basis: proton H_3 in **11a**, **12a**, **13a**, and **14a** and H_4 in **15b** (vinylic, α to carbonyl, and β to sulfur) absorb at δ 6.31, 6.38, 6.34, 6.03, and 5.98, respectively. The peak at δ 5.49 was assigned to proton H_2 on the basis of the following comparison: H_5 of **14a** (bonded to sp^3 carbon, α to sulfur, geminal to methyl group) absorbs at δ 4.35. H_5 of **12a** (bonded to sp^3 carbon, α to sulfur, geminal to chlorine atom) absorbs at δ 6.31, a downfield shift of δ 1.98 due to substitution of a chlorine atom for a methyl group. In **15b**, H_2 (bonded to sp^3 carbon, α to sulfur, geminal to methyl group) absorbs at δ 3.49. Substitution of a chlorine atom for the methyl group might be expected to give a similar shift, to about δ 5.45, while **16b** shows the absorption at δ 5.49 An attempt to influence the ratio of **16a:16b** by acid catalysis[11c] resulted in decomposition, determined by nmr.

It is interesting to note that **16** could be recovered intact (ir spectrum) from gas chromatography (column 140°, injector 210°, detector 250°) while **12** did not elute and **13** gave solely **11**. Compounds **1**, **14**, and **15** could also be recovered largely unchanged under these conditions.

Synthetic Aspects. A consideration of the preparative features is appropriate. The oxygenation procedure is fast, requires neither special apparatus nor carefully controlled conditions, and generally gives a good yield based on peroxide. Drawbacks are the need for the thiophene substrate in excess and difficulties in shipping IPP. This is the method of choice for those esters, such as **1**, **2**, and **3**, which are essentially the sole products. Further substitution reactions can be carried out on the thienyl isopropyl carbonates, *e.g.*, chlorination and bromination. Since the isopropyl carbonate group does not exert a pronounced activating influence on the ring, polysubstitution is not a complicating feature.

Experimental Section

Materials. Thiophene, 2-chlorothiophene, 2-bromothiophene, 2,5-dibromothiophene, and 2,5-dichlorothiophene were commercial products of high purity, checked by glpc, and used without further purification. Commercial 2-methylthiophene was distilled to free it from thiophene (about 20% according to glpc). Acetonitrile was Mallinckrodt "Nanograde;" aluminum chloride and cupric chloride were Baker reagent grade. We are grateful to the Pittsburgh Plate Glass Co. for a generous sample of diisopropyl peroxydicarbonate.

Instruments. Infrared spectra were recorded on a Beckman IR-8 spectrophotometer with neat samples between sodium chloride plates unless otherwise noted. The polystyrene absorption at 6.243 μ was used for calibration. Ultraviolet spectra were obtained on a Cary 14 spectrophotometer with methanol solutions ($5-10 \times 10^{-4}$ M). Nuclear magnetic resonance spectra were recorded on a Varian Associates A-60, A-60A, or HA-100 nmr spectrometer with carbon disulfide solutions (about 15% v/v), except for the hydroxy compounds (carbon tetrachloride solutions, about 15% v/v). The hydroxy compounds were stored in Dry Ice. Chemical shifts (δ) are relative to internal tetramethylsilane (parts per million). Mass spectral data were derived from a Varian Associates M-66 mass spectrometer; a calibration with bromoform was run immediately after each group of determinations. Most quantitative glpc results were obtained on an Aerograph A-90-P gas chromatograph–thermal conductivity detector, 10 ft × 0.25 in. or 27 × 0.25 in. copper columns, 20% SF-96 on 30–60 mesh acid-washed Chromosorb P, He, 60–90 cc/min; column, 140–170°; inlet, 210°; detector, 250°; filament current, 150 mA. Bithienyl isomer distributions and isotope study results were obtained on a Varian Aerograph series 1200 instrument, flame ionization detector, N_2 at 40 psi, aluminum column, 12 ft × 0.125 in., 10% Carbowax 20M on 35–60 mesh acid-washed Chromosorb W column, 180–190°; detector, 280°; injector, 270°.

Melting points (Thomas-Hoover melting point apparatus) and boiling points are uncorrected. Refractive indices were determined on a Bausch and Lomb Abbe 3-L refractometer. Elemental analyses were done by Galbraith Laboratories, Knoxville, Tenn.

Catalyzed Reactions. General Procedure. The procedure represents a modification of that described previously.[18] Cupric chloride (1.35 g, 0.01 mol) was dissolved with heating and stirring in acetonitrile (160 ml). The solution was transferred to a 500-ml, three-necked flask equipped with stirrer, Friedrichs condenser, and Claisen adapter with thermometer and pressure-equalizing addition funnel, and immersed in an oil bath at 60°. A tube from the condenser outlet was placed in a test tube containing a few milliliters of acetone so that gas evolution could be observed. After the thiophene substrate was added, diisopropyl peroxydicarbonate (IPP, 6.8 g, 0.033 mol) dissolved in acetonitrile (40 ml) was introduced rapidly with stirring. The temperature fell to 55° and then rose to 60–67° after 5–15 min. The solution (homogeneous in all cases) was stirred for 2 hr, then poured over ice (150 g) and saturated ammonium chloride (100 ml). The organic layer was washed twice with 50% saturated ammonium chloride solution (100 ml) and three times with 10% saturated sodium chloride solution (100 ml). After the combined washing was extracted three times with ether (50 ml), the organic layers were combined, dried over sodium sulfate, and freed of solvent by rotary evaporation. An aliquot was taken, mixed 1:1 with a marker solution, and

subjected to glpc analysis (Table I). 1,2,4-Trichlorobenzene was used as a marker, except for 2,5-dibromothiophene (2,5-xylenyl benzoate). The products were isolated for analysis and characterization by preparative glpc and/or distillation *in vacuo*. Correction factors were determined by weighing out small samples of the pure carbonate esters, adding the same marker solution, and analyzing by glpc. Yields are based on peroxide with an assumed stoichiometry of 1 mol of ester/mol of peroxide. The peroxide (stored at −5°) was titrated by an iodometric method from time to time and found to contain 100% oxidizing power.[37]

Larger Scale. To obtain sufficient quantities of the carbonate esters for dealkylation, the amounts used in the general procedure were doubled or tripled, and the reaction was considered complete soon after gas evolution ceased. The peroxide solution must be added gradually with stirring in the larger scale reactions; otherwise gas evolution is too vigorous. After work-up, the remaining acetonitrile was removed through a 10-cm Vigreux column, followed directly by distillation of the starting material and products *in vacuo*. Products were collected from two or three runs and usually redistilled *in vacuo* with an 88-cm spinning-band column to separate the components. Thiophene products were distilled with the Vigreux column (Table I).

Rate of Product Formation. Aliquots (10 ml) were taken from the reaction mixture (see General Procedure) at times of 2, 4, 6, 8, 10, 15, 20, 25, 30, 45, 60, 75, 90, 105, and 120 min, and poured over ice (30 g) and saturated ammonium chloride solution (20 ml). The layers were separated, the aqueous layer was extracted once with ether (10 ml), and the organic layers were combined. After the marker was added, the solution was subjected to glpc analysis. Although a plot of product yield *vs.* time showed considerable scatter, it was evident that reaction was at least 95% complete after 10 min.

Uncatalyzed Reactions. The thiophene compound (0.05 mol) was treated with the peroxide (0.005 mol) in acetonitrile (35 ml) under nitrogen in an oil bath at 60° for 63 hr with occasional agitation. At the end of this time, the solution, which gave a negative peroxide test, was concentrated and subjected to glpc analysis. Results are summarized in Table III. The esters were isolated by preparative glpc and their ir spectra were compared with those of the previously characterized materials. The reaction with thiophene was run on a larger scale to obtain the products for identification. Compounds **1**, **17**, **18**, **19**, and diisopropyl carbonate were purified from distillation fractions by preparative glpc. As a comparison to previous work, the peroxide (0.005 mol) was decomposed in thiophene (35 ml) without solvent at 60° for 45 hr, at which time the solution was subjected to glpc analysis. The results are given in Table V, entry 4.

Isotope Effects. Thiophene and 2,5-dideuteriothiophene were subjected separately to the procedure in the preceding section (acetonitrile solvent, reaction time 50 hr). Results (Table V, entries 5 and 6) represent the average of two runs which were in good agreement.

A mixture of the two compounds was then investigated competitively. After 50 hr, the solvent was removed on the rotary evaporator and the 2-thienyl isopropyl carbonate was separated from the residue by preparative glpc. The starting mixture, recovered solvent, and collected ester were analyzed by mass spectroscopy. Results are reported in Table VI. An appropriate control experiment showed no evidence of exchange during glpc.

Characterization of the Carbonate Esters. These materials, purified by distillation or glpc collection, were identified (Table IV) by ir, nmr, uv, and mass spectrometry, glpc, refractometry, and elemental analysis. Structure determination was confirmed by synthesis in most cases.

Infrared Spectra. The compounds showed absorptions at 3.2 (aromatic CH, weak to medium), 3.34 (strong, 3.40 (weak), and 3.46 (very weak) (isopropyl group CH); 5.7 (strong, C=O); 6.4–6.5 (one absorption, medium); 6.7–6.9 (one absorption or very narrow doublet, medium); 7.0–7.5 (four absorptions, medium) (*gem*-dimethyl); 7.5–9.5 (strong to medium, position and arrangement somewhat variable, five or six absorptions, CO); 10.95–11.05 (strong); 11.75–11.9 (medium to weak, one absorption); and 12.8–12.95 μ (strong to medium, one absorption). One to three peaks occurred in the 13–16-μ range (variable).

Nuclear Magnetic Resonance Spectra. The nmr spectra showed a doublet, δ 1.28–1.36 (downfield from TMS), J = 6.3 Hz, integrated rel intensity 6; a heptet, δ 4.77–4.94, J = 6.3 Hz, rel intensity 1; and signals at δ 6.26–7.06 (Table IV). The positions of the signals varied over the indicated ranges from compound to compound. The doublet and heptet are assigned to the isopropyl group and the downfield resonances to the aromatic protons.

Ultraviolet Spectra. The uv spectra showed one or two absorptions in the region 229–257 mμ (log ϵ 3.69–4.00) (Table IV).

Mass Spectra. All of the esters showed M^+ peaks except **1** and **5** (**5** being insufficiently volatile to analyze in the usual manner). In most cases the ion of greatest relative intensity at 70 eV was $(M - 86)^+$, corresponding to the molecular weight of the hydroxy compound. Other peaks occurring in all spectra were *m/e* (rel intensity) 43 ($C_3H_7^+$ and $C_2H_3O^+$, 46–100), 41 ($C_3H_5^+$, 13–60), 27 ($C_2H_3^+$, 7–25), and M − 59 (ArO$^+$CO and ArO$^+$=CHCH$_3$, 3–16). Assignments are made by analogy to the spectrum of phenyl isopropyl carbonate.[38]

Synthesis of Thiophene Derivatives. 2-Nitrothiophene. Prepared in 80% yield, this compound melted at 43–45° [lit.[39] (75–85% yield) mp 44–45°].

2-Bromo-5-chlorothiophene. Bromination of 2-chlorothiophene in acetic acid gave the title compound (76% yield): bp 65° (14 mm); n^{21}D 1.5904 [lit.[40] bp 69.5–70° (18 mm); n^{25}D 1.5924]; nmr δ 6.6 and 6.8 (J = 4.0 Hz).

2,5-Dideuteriothiophene. This compound has been prepared by reduction of 2,5-dibromothiophene with zinc dust in D_2O-CH_3COOD.[41] Also, thiophene is known to undergo acid-induced isotope exchange readily and selectively in the 2 position.[42]

A literature report[43] mentions the preparation of 2,5-dilithiothiophene from thiophene and ethyllithium. To a 2-l. three-necked flask with stirrer, condenser, and addition funnel, containing 0.70 *N* *n*-butyllithium (830 ml), thiophene (23.0 g) was added dropwise over a period of 1 hr. The mixture was refluxed until butane was no longer evolved, whereupon deuterium oxide (20 ml) was added dropwise with cooling. After the mixture was stirred for 16 hr, it was poured over ice and dilute hydrochloric acid. The phases were separated, the aqueous portion was extracted three times with ether, and the ether layers were combined and washed once with dilute sodium hydroxide solution and then with water until the washings were neutral. Distillation gave product (16.9 g): bp 84–85°; $n^{26.5}$D 1.5224 (lit.[41] bp 83–84°; n^{20}D 1.5265); ir 4.31 (C-D), 12.2, and 13.3 μ; nmr δ 6.88 (s, H-D) (lit.[41] nmr δ 6.92). Mass spectrometry showed that about 99% of the desired conversion occurred.

2,5-Dichloro-3-iodothiophene. This compound was synthesized by the method of Hartough[5f] for tetraiodothiophene, with appropriate changes, giving a 37% yield: bp 79° (1.1 mm); n^{26}D 1.6552; nmr δ 6.70 (s); mass spectrum (70 eV) *m/e* (rel intensity) 278 (100), 279 (10), 280 (93), 281 (6), 282 (24).

Anal. Calcd for C_4HCl_2IS: C, 17.22; H, 0.36; Cl, 25.42; I, 45.50; S, 11.50; mol wt, 278.93. Found: C, 17.41; H, 0.40; Cl, 25.65; I, 45.78; S, 11.50.

Authentic Materials. Each of the carbonate esters identified from the oxygenation reaction was synthesized by an alternate route except **5** and **10**. In general, comparison was made by ir, nmr, and glpc retention time.

2-Thienyl Isopropyl Carbonate. 2-Hydroxythiophene, prepared by a literature procedure,[10] was allowed to react with isopropyl chloroformate in the presence of triethylamine in anhydrous ether.[44]

5-Chloro-2-thienyl Isopropyl Carbonate. After **1** was treated with chlorine in carbon tetrachloride, distillation of the product with a Vigreux column did not give pure fractions. Glpc on the recombined fractions showed unchanged **1** (23%), unidentified product (6%), and 5-chloro-2-thienyl isopropyl carbonate (60%).

5-Bromo-2-thienyl Isopropyl Carbonate. **1** (3.7 g) was brominated in acetic acid.[5c] Distillation *in vacuo* gave 5-bromo-2-thienyl isopropyl carbonate (62%).

5-Methyl-2-thienyl Isopropyl Carbonate. 2-*tert*-Butoxythiophene was prepared according to a literature procedure[10] (68% yield): bp 71° (16 mm); n^{28}D 1.4928 [lit.[10] 70% yield; bp 64–66° (13 mm); n^{20}D 1.4991]. *n*-Butyllithium was formed in anhydrous ether under nitrogen from lithium metal and a small excess of 1-chlorobutane,[45] and the normality was determined as reported.[46] 5-Methyl-2-*tert*-butoxythiophene, prepared according to a literature procedure[9f] (76% yield), bp 72° (6 mm), n^{28}D 1.4904 [lit.[9f] 87% yield, bp 77–78° (7 mm), n^{20}D 1.4970], was treated with toluenesulfonic acid as described.[9f] The undistilled product was cooled and esterified directly with isopropyl chloroformate.[44] Distillation gave 5-methyl-2-thienyl isopropyl carbonate (59%), bp 73–75° (1 mm).

2-Methyl-3-thienyl Isopropyl Carbonate. 2,3,5-Tribromothiophene was made by a modification of a literature procedure.[47] Thiophene (84 g, 1 mol) and glacial acetic acid (150 ml) were placed in an ice-cooled, 1-l., three-necked flask equipped with stirrer, addition funnel, and condenser. Bromine (157 ml, 480 g, 3 mol) was added dropwise with stirring. After the addition was

complete, the mixture was heated at reflux for 16 hr (hydrogen bromide was evolved), cooled, neutralized with concentrated sodium hydroxide solution, and extracted with ether. After the combined ether layer was freed of solvent, the residue was distilled under reduced pressure through a 51-cm column packed with glass helices. Yields follow: 2,5-dibromothiophene, 25%; 2,3,5-tribromothiophene, 196 g, 61% [bp 157–158° (40 mm); mp 27–28° [lit.[47] bp 120–122° (11 mm); mp 28–29°]]. 3-Bromothiophene was then prepared from this material according to Gronowitz[48] (84% yield): bp 158–160°; n^{28}D 1.5875 (lit.[48] 80% yld; bp 159–161°; n^{20}D 1.5919). 3-*tert*-Butoxythiophene was synthesized from the 3-bromothiophene[9e] (50% yield), bp 73–75° (14 mm). The distilled product showed two peaks on glpc, about 85:15 area ratio; major peak material gave n^{28}D 1.4925. The ir spectrum of the distilled material matched the published spectrum [lit.[9e] 70% yield; bp 74–76° (15 mm); n^{20}D 1.4996]. 2-Methyl-3-*tert*-butoxythiophene was formed from this material[9g] (40% yield): bp 81–83° (15 mm); n^{28}D 1.4872 [lit.[9g] 87% yield; bp 77–78° (10 mm); n^{20}D 1.4975]. It has been shown that 3-*tert*-butoxythiophene is metalated with *n*-butyllithium exclusively in the 2 position.[9e] 2-Methyl-3-thienyl isopropyl carbonate was formed from 2-methyl-3-*tert*-butoxythiophene (4 g) according to the procedure for 5-methyl-2-thienyl isopropyl carbonate, yielding 0.4 g (8.5%) from distillation.

2,5-Dichloro-3-thienyl Isopropyl Carbonate. The Grignard reagent from 2,5-dichloro-3-iodothiophene[5g] was treated with *tert*-butyl perbenzoate according to the procedure for 2-*tert*-butoxythiophene.[10] Glpc showed the presence of about 30% of the iodo compound. Distillation, bp 91–94° (5 mm), gave very poor separation. Treatment of the mixture (7 g) by the method for 5-methyl-2-thienyl isopropyl carbonate gave, after distillation, 1.2 g of the desired material.

2,5-Dibromo-3-thienyl Isopropyl Carbonate. 3-Thienyl isopropyl carbonate was prepared from 3-bromothiophene (24 g) by a modification of the procedure for 3-*tert*-butoxythiophene.[9e] The Grignard reagent (formed from the lithium reagent and magnesium bromide in anhydrous ether) was added dropwise to a solution of IPP in anhydrous ether. Distillation gave impure 3-thienyl isopropyl carbonate (1.2 g, 4.3%), bp 74–78° (1 mm). Collection of the major peak (about 80%) by glpc gave the purified material (see **6** in Table IV). The distilled product (0.5 g, 0.0027 mol), glacial acetic acid (20 ml), and sodium acetate (0.62 g, 0.0081 mol) were placed in a 50-ml, three-necked flask equipped with stirrer, addition funnel, and condenser and immersed in a cold-water bath. Bromine (0.86 g, 0.0054 mol) was added dropwise.[49] After 2 hr, the mixture was neutralized with sodium carbonate solution and extracted with ether. Evaporation gave a dark liquid (1 g). Glpc collection of the major peak (three minor peaks were present) provided the desired product.

2,2′-Bithienyl. This compound, synthesized by a previous method,[50] was purified by preparative glpc, mp 31–32° (lit.[50] mp 33°). A mixture melting point of the two products prepared in the study was undepressed.

3,3′-Bithienyl. Preparation was by a literature procedure,[51] mp 131–134° (lit.[51] mp 132–134°).

2,3′-Bithienyl. This compound was collected from the uncatalyzed decomposition of IPP in thiophene, mp 63–64°. The retention time was slightly longer than that of **17**, the nmr was similar to that of **17** (multiplet at similar position), and the ir was also similar to that of **17** (2–8 μ) (lit. mp 61.5–63°,[52] 65°,[53] 68–68.4°[54]).

Diisopropyl Carbonate. Material isolated from the uncatalyzed reaction of thiophene with IPP was identical with authentic diisopropyl carbonate.[21]

Other Products. Compound 10. A compound (n^{25}D 1.5306) arose in the uncatalyzed reaction of IPP with 2-bromo-5-chlorothiophene, and in the cupric chloride catalyzed oxygenation of 2,5-dibromothiophene, mass spectrum *m/e* 298, 300, 302 (calcd for $C_8H_8BrClO_3S$, mol wt 299.58), and fragmentation similar to that of other thienyl isopropyl carbonates. The nmr spectrum revealed an isopropyl carbonate group in the expected position and a singlet at δ 6.94 integrating to one proton. The ir spectrum was very similar to those of **8** and **9**. However, **8** had absorptions at 9.55 and 9.95 μ and **9** had absorptions at 10.2 and 9.95 μ, whereas **10** showed absorption at 9.55 and 10.2 but none at 9.95 μ.

5-Chloro-2-isopropoxythiophene. Arising in 3% yield in the cupric chloride catalyzed oxygenation of thiophene, this compound was identified (tentatively) as follows: retention time shorter than that of **1**; ir, similar to that of **2**, with much less absorption in the C–O region and no carbonyl absorption; nmr, isopropyl group (methine proton at δ 4.3 instead of δ 4.9 as with isopropyl carbonates) and aromatic protons (δ 5.95 and 6.5, J = 4.0 Hz); mass spectrum *m/e* 176 and 178 (calcd for C_7H_9ClOS, mol wt 176.67).

Dealkylative Decarboxylation of Carbonate Esters. Aluminum Chloride Catalyst.[55] The carbonate ester (0.01 mol) was added to *m*-xylene (20 ml) in a 125-ml erlenmeyer flask in an ice bath (magnetic stirrer). Aluminum chloride (3 g, 0.0225 mol) was added in one portion and the mixture was stirred for 15 min. The mixture was poured into ice-cold water (50 ml) and stirred until the phase separation was no longer visible. Upon standing the phases separated. The aqueous layer was extracted four times with ether (25 ml), and the organic layers were combined. For the methyl and unsubstituted compounds, the organic solution was extracted with 10% sodium hydroxide solution (100 ml) in three portions. The alkaline extracts were combined and neutralized with 10% hydrochloric acid, then extracted four times with ether (50 ml). Evaporation gave the hydroxy compounds.

For the halogen-substituted esters, the dealkylation procedure was the same, except that the ether–*m*-xylene solution was evaporated to about 20 ml and then chromatographed on a silica gel column prepared in hexane. Elution with hexane was continued until *m*-xylene was no longer found in the glpc of the eluted fractions. A mixture of hexane–benzene (1:1, v/v) was used to elute whatever starting ester was present, usually only a few per cent. These fractions contained very small amounts of intensely colored impurities. Then benzene was used to elute the hydroxy compound, which appeared dark red upon evaporation of the benzene. The hydroxy compounds were frozen in Dry Ice soon after isolation and stored at −70°. The compounds were subjected to glpc and ir, uv, nmr, and mass spectrometry.

Pyrolysis. Compound **1** (1 g) was vaporized from a 10-ml distilling flask and passed in a stream of nitrogen, flow rate about 1 cc/sec, through a vertical column (40 × 1 cm) of glass helices heated to 170° by means of an external nichrome spiral. A yellow oil (0.35 g), collected in the receiver, consisted of a 1:1 ratio of **11:1** (analysis by glpc and ir). The distilling flask contained 0.14 g of residue. The uncondensed gas from the reaction decolorized bromine in carbon tetrachloride.

Solubility of Cupric Chloride in Thiophene and Toluene. Cupric chloride (1 g) was mixed with the solvent (10 ml) in a 50-ml flask which was placed in an oil bath at 60° for 1 hr and agitated frequently. An aliquot of the clear supernatant liquid was removed and the solvent was evaporated. After concentrated hydrochloric acid (10 ml) and concentrated nitric acid (10 ml) were added, the mixture was boiled to dryness. Water (5 ml), concentrated hydrochloric acid (3 drops), and concentrated ammonium hydroxide solution (1 ml) were added, and the absorbance was measured at 620 mμ on a Beckman DB spectrophotomer. These values were compared with a standard curve (Beer's law plot) and the solubilities were found to be cupric chloride–thiophene, 0.25 g/l., and cupric chloride–toluene, 0.002 g/l.

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Registry No. **1**, 43225-39-4; **2**, 43225-40-7; **3**, 43225-41-8; **4**, 49562-65-4; **5**, 43225-42-9; **6**, 43225-43-0; **7**, 43225-44-1; **8**, 43225-45-2; **9**, 43225-46-3; **11a**, 3354-32-3; **12a**, 18468-89-8; **12b**, 19991-71-0; **13a**, 17019-33-9; **13b**, 43225-51-0; **14a**, 7210-64-2; **14b**, 930-64-3; **15a**, 3760-22-3; **15b**, 3760-25-6; **16a**, 43225-56-5; **16b**, 43225-57-6; thiophene, 110-02-1; 2-methylthiophene, 554-14-3; 2-chlorothiophene, 96-43-5; 2-bromothiophene, 1003-09-4; 2,5-dichlorothiophene, 3172-52-9; 2,5-dibromothiophene, 3141-27-3; 2-nitrothiophene, 609-40-5; 2-bromo-5-chlorothiophene, 2873-18-9; 2,5-dichloro-3-iodothiophene, 43225-59-8.

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Electrochemical Reduction of Carbon Disulfide in Dimethylformamide

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The electrolytic reduction of carbon disulfide in dimethylformamide followed by alkylation with methyl iodide gave 4,5-bis(methylthio)-1,3-dithiole-2-thione. This compound was identical with the product formed by the sodium amalgam reduction of carbon disulfide and erroneously reported as dimethyl tetrathiooxalate. The lower melting product in the latter work was found to be 4-methylthio-1,3-dithiole-2-thione. The structure proof for both compounds was based on spectral and polarographic data and chemical reaction with morpholine. 4,5-Bis(methylthio)-1,3-dithiole-2-thione was converted by alkaline hydrolysis and by electrolytic reduction followed by alkylation with methyl iodide into tetrakis(methylthio)ethylene.

The recent report[2] of the preparation of dialkyl oxalates and dialkyl carbonates by the electrochemical reduction of carbon dioxide in dimethylformamide followed by treatment with alkyl halides suggested the present study of the electrochemical reduction of carbon disulfide as a method for preparing dimethyl tetrathiooxalate. The results obtained were different from those expected and will be presented here.

Carbon disulfide gave two one-electron polarographic waves at −0.99 (Hg pool) (I_d = 2.34) and −2.21 V (Hg pool) (I_d = 2.04) in dimethylformamide containing 0.2 *M* tetrabutylammonium bromide. Electrolysis was carried out using a saturated calomel electrode as a reference electrode at a controlled potential of −1.40 and of −1.80 V, and at an uncontrolled potential, followed by alkylation with methyl iodide, and gave 4,5-bis(methylthio)-1,3-dithiole-2-thione (1) as the major product in yields varying from 12.5 to 41.5%.

Evidence for structure 1 was the spectral and polarographic data and its chemical reactions. The melting point of 101° was in agreement with that of the products obtained by the sodium amalgam reduction of carbon disulfide followed by alkylation with methyl chloride and formulated as dimethyl tetrathiooxalate. This reduction