in a chair conformation.[19]

Anal. Calcd for $C_{34}H_{28}OS$: C, 84.3; H, 5.8; S, 6.6. Found: C, 84.7; H, 6.0; S, 7.1.

A second crop of 350 mg of **12a** was obtained on concentrating the mother liquor (to ca. 20 mL) and seeding. The yield was 65% based on the crude **16**.

$\Delta^{4,4'}$-2,6-Diphenyl-4-(2',6'-diphenyl-4'*H*-dihydrothiopyranyl)-4*H*-pyran (12b). To the dark blue Wittig–Horner reagent prepared from 1 g (2.7 mmol) of the crude **16** and 1.3 mL of *n*-BuLi (2.4 M in hexane) in 30 mL of dry THF at −78 °C under argon was added dropwise a solution of 700 mg of 2,6-diphenyl-4*H*-dihydrothiopyran-4-one (**9b**)[17] in 10 mL of dry THF. The solution was slowly equilibrated to room temperature and kept overnight under argon. The mixture was poured into 300 mL of aqueous NH_4Cl and extracted with ether. The ether extracts were separated, dried ($MgSO_4$), and stripped on a Rotavap to give about 1 g of a dark reddish gum. This was recrystallized from a small amount of ethyl acetate (chilled in a freezer) to give 110 mg of pure **12b** as bright red needles: mp 224.9 °C; mass spectrum, *m/e* 482 (M^+); NMR δ 2.7–3.4 (m, 2, methylene), 4.35 (2 d, J = 12 Hz and J = 3 Hz, 1, sulfide benzylic), 6.53 (d, $J \simeq$ 2 Hz, 1, olefinic), 6.8 (d, $J \simeq$ 2 Hz, 1, olefinic), 7.13 (s, 1, olefinic), 7.15–7.85 (m, 20, Ar H).

Anal. Calcd for $C_{34}H_{26}OS$: C, 84.6; H, 5.4; S, 6.6. Found: C, 84.2; H, 5.3; S, 6.7.

A second crop of 50 mg of pure product was obtained from the mother liquor by rapid column chromatography[16] over silica gel, eluting with CH_2Cl_2/hexanes (1:3 v/v). The total yield was 12% based on the crude **16**.

$\Delta^{4,4'}$-2,6-Diphenyl-4-(2',6'-diphenyl-4'*H*-dihydrothiopyranyl)-4*H*-pyran (12b). To a solution of 360 mg (0.74 mmol) of **12a** and 58.7 mg (1 equiv) of dry pyridine in 10 mL of methylene chloride at room temperature was added 104 mg (1 equiv) of solid NCS. The reaction mixture was stirred overnight, poured into water, and extracted with methylene chloride. The extracts were dried ($MgSO_4$) and concentrated on a Rotavap to give a dark brown solid (350 mg) of which 210 mg was purified by preparative TLC (silica gel, 2 mm thick). The top orange band was removed, giving 170 mg of crude **12b** which contained ca. 38% of starting material **12a** (NMR). This material was purified further by recrystallization from a small amount of ethyl acetate (chilled), giving ca. 85 mg of **12b** as bright red needles. This crop, which contained less than 10% starting material **12a** (NMR), was suitable for use in the next reaction. Total yield of this material based on **12a** was ca. 40%.

$\Delta^{4,4'}$-2,6-Diphenyl-4-(2',6'-diphenyl-5'-*trans*-succinimidyl-4'*H*-dihydrothiopyranyl)-4*H*-pyran (17). To a solution of 50 mg (0.1 mmol) of the dihydro derivative **12b** and 8 mg (1 equiv) of dry pyridine in 10 mL of methylene chloride at ambient temperature was added 14 mg (1 equiv) of NCS. The mixture, which turned quickly from orange to dark green, was stirred overnight at room temperature. The reaction mixture, which changed back to a bright orange, homogeneous solution, was concentrated on a Rotavap. The residue was diluted with 200 mL of water, and the precipitated orange solid (35 mg, 60%) was essentially pure **17** (one major spot on TLC; silica gel, CH_2Cl_2). An analytical sample was obtained by recrystallization from 150 mL of chilled benzene and hexanes (1:30 v/v), affording ca. 20 mg of pure **17**: mp 245–247 °C (sintered and turned black at ca. 190 °C); mass spectrum, *m/e* 579 (M^+); NMR δ 2.51 (s, 4 H), 4.6 and 5.62 (AB q, J_{HH} = 7.5 Hz, 2 H), 6.31 and 6.85 (AB q, $J_{HH} \simeq$ 2 Hz, 2 H), 7.2–7.8 (m, 21 H).

Anal. Calcd for $C_{38}H_{29}NO_3S$: C, 78.7; H, 5.0; N, 2.4. Found: C, 78.6; H, 4.7; N, 2.4.

$\Delta^{4,4'}$-2,6-Diphenyl-4-(2',6'-diphenyl-4'*H*-thiopyranyl)-4*H*-pyran (18). A solution of 120 mg (0.21 mmol) of crude **17** in 25 mL of xylene (bp 138–140 °C) was refluxed for 18 h (or until a TLC assay showed the disappearance of **17** from the reaction mixture). The crystallized solid, which contained 1 equiv of succinimide, was collected and washed thoroughly with water (to remove the coprecipitated succinimide), giving ca. 60 mg (60%) of **18**: mp 280–281 °C; mass spectrum, *m/e* 480 (M^+ for $C_{34}H_{24}OS$), 240 (M^{2+}); NMR δ 6.62 (br s, 2, vinylic thiopyran), 6.88 (br s, 2, vinylic pyran), 7.1–7.8 (m, 20, Ar H); IR (KBr) 3080, 3060, 3025, 2920 (=CH), 1650 (s, C=C), 1596 (aromatic), 1575, 1491 (s, aromatic), 1445, 1335, 1275 (br), 1076, 930 (s), 841, 820, 760 (s), 748 (sh), 688 (s), 521 cm^{-1}.

Anal. Calcd for $C_{34}H_{24}OS$: C, 85.0; H, 5.0; S, 6.7. Found: C, 85.1; H, 4.9; S, 6.2.

This material is identical with an authentic sample prepared by an independent route.[18]

Acknowledgment. We thank Lauren B. Smith of the Special Projects Laboratory, Analytical Sciences Division of the Kodak Research Laboratories, for measuring the redox potentials by using cyclic voltammetry.

Registry No. *cis*-**9a**, 18456-44-5; **9b**, 60839-95-4; **9c**, 3528-17-4; **9d**, 492-22-8; *cis*-**12a**, 73454-70-3; **12b**, 73466-68-9; **12c**, 73466-69-0; **12d**, 73454-71-4; **14**, 3558-68-7; **16**, 73454-72-5; *trans*-**17**, 73454-73-6; **18**, 73453-50-6; sodium diethyl phosphonate, 2303-76-6; *N*-chlorosuccinimide, 128-09-6.

Synthesis and Reactions of (4*H*- and 2*H*-2,6-Diphenylthiopyran-4-yl)phosphonates[1a]

Chin H. Chen* and George A. Reynolds

Research Laboratories, Eastman Kodak Company, Rochester, New York 14650

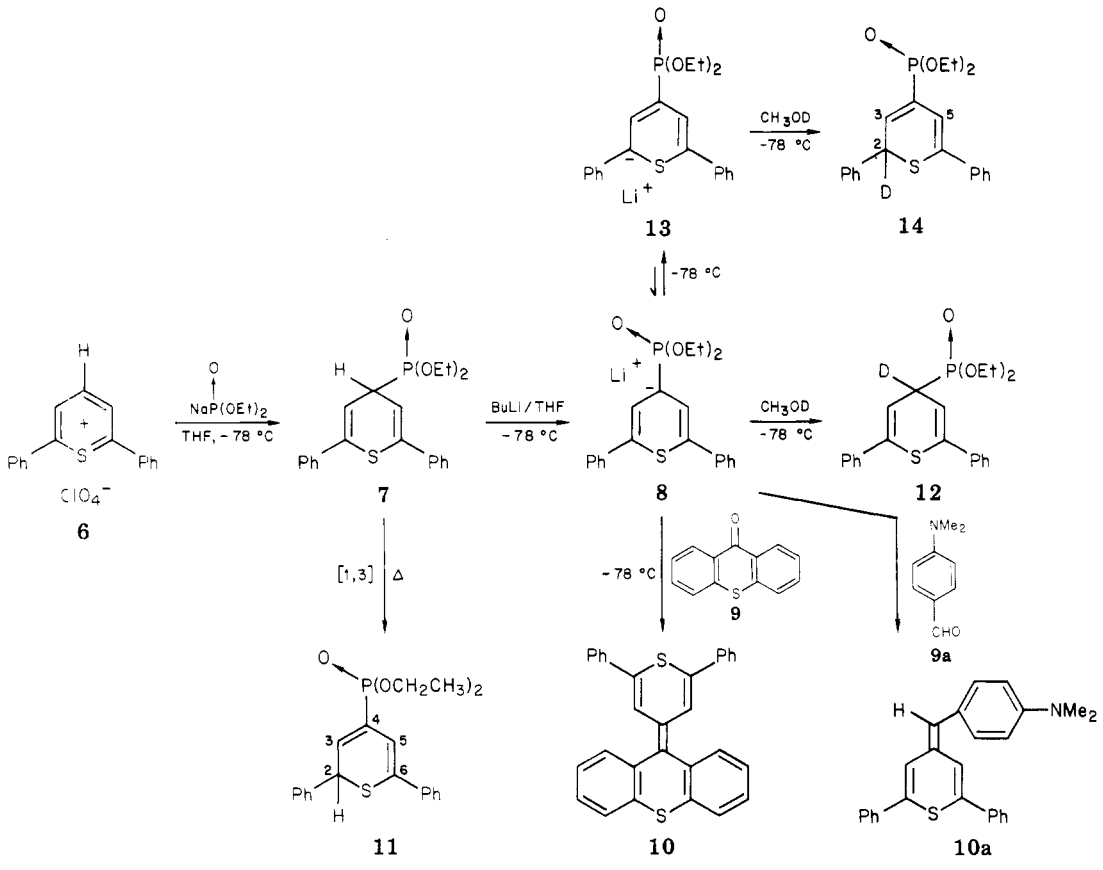
Received November 27, 1979

The umpolung of 2,6-diphenylthiopyrylium salts is achieved by the synthesis of the Wittig–Horner reagent of diethyl (2,6-diphenyl-4*H*-thiopyran-4-yl)phosphonate (**7**). This 4*H*-lithiated species is a kinetically controlled product which equilibrates to the more stable 2*H*-lithiated species at −78 °C. The 4*H* anion does react with thioxanthen-9-one (**9**) and *p*-(dimethylamino)benzaldehyde (**9a**) at low temperature to give the normal Wittig adducts in 43 and 67% yields, respectively. A facile synthesis of (2*H*-2,6-diphenylthiopyran-4-yl)phosphonates **11** and **25** from 2,6-diphenyl-4*H*-tetrahydrothiopyran-4-one (**20**) is described. Lithiation of **11** and **25** with lithium diisopropylamide in THF (−78 °C), however, produces only a small amount of the 4*H* anion from which, on addition of the carbonyl compounds **9** and **9a**, the corresponding Wittig adducts **10** and **10a** are obtained in 14 and 16% yields, respectively.

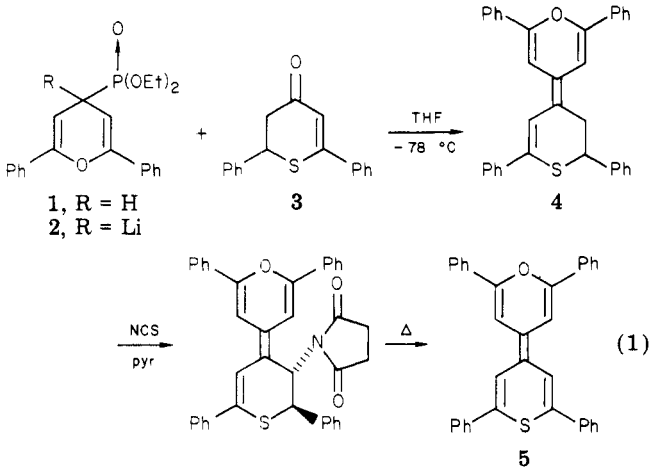
We have reported the synthesis of diethyl (2,6-diphenyl-4*H*-pyran-4-yl)phosphonate (**1**) and its lithiated anion **2**.[1b] This Wittig–Horner reagent, which is quite stable at low temperature (−78 to 5 °C), condenses with

0022-3263/80/1945-2453$01.00/0

Scheme I



a variety of ketones, including the somewhat deactivated 2,6-diphenyl-4*H*-dihydrothiopyran-4-one (**3**), to give the dihydrothiopyran **4** (eq 1). The latter, upon further oxidation with NCS–pyridine and thermolysis, gives the *unsymmetrical* $\Delta^{4,4'}$-2,2′,6,6′-tetraphenylthiobipyran **5** which is of interest in the study of new "organic metals".[2]



(1)

Since the substitution of heavier (or more polarizable) heteroatoms in donor molecules generally results in higher conductivities of their charge-transfer complexes,[2] it is desirable to have a synthon such as **1** in which the oxygen is replaced by sulfur. This paper describes the synthesis and reactions of such a reagent, diethyl (2,6-diphenyl-4*H*-thiopyran-4-yl)phosphonate (**7**), and its 2*H* isomer **11**.

The concept of "umpolung"[3] in thiopyrylium chemistry is demonstrated by the synthesis of the *unsymmetrical* diphenyl-substituted bithiopyran **10** and the *p*-(dimethylamino)phenyl-substituted 4*H*-thiopyranylidene **10a** from the (4*H*-thiopyran-4-yl)phosphonate **7**.

Although phosphonates have been prepared by the reaction of heteroaromatic cations such as 1,3-benzodithiolium, thioxanthylium, and thiochromenylium ions with trimethyl phosphite in the presence of sodium iodide,[4] the method was ineffective with 2,6-diphenylthiopyrylium perchlorate (**6**).[5]

The phosphonate **7** can be prepared by the direct coupling of sodium diethyl phosphonate and **6** in dry THF at low temperature (−78 °C) in 32% yield (Scheme I). The characteristic triplet at δ 5.9 ($J_{HH} \simeq J_{PH} \simeq 5$ Hz) for the two equivalent vinylic protons in the ^{1}H NMR spectrum of **7** is somewhat downfield from that of the oxygen analogue **1** [δ 5.46 (t, $J_{HH} \simeq J_{PH} \simeq 4.5$ Hz)].[1b] Similarly, the methine proton (α to the phosphonate) at ca. δ 4.0, which occurs as two sets of triplets owing to the coupling of phosphorus ($J \simeq 31$ Hz) and the two equivalent vinylic protons ($J \simeq 5$ Hz), is also more deshielded than that of **1**, suggesting that this proton is more acidic, owing to the greater electronegativity of the thiopyranyl system.

Pure **7** obtained by liquid chromatography and recrystallization is a colorless solid (mp 55.9 °C) which is not stable when kept for prolonged periods at ambient temperature. It slowly turns (in a few weeks) to a brown viscous oil whose TLC (silica gel, ethyl acetate) assay reveals the accumulation of a new compound with $R_f \sim 0.56$

(1) (a) Presented in part at the Wurtster Centennial Symposium at the 178th National Meeting of the American Chemical Society, Washington, DC, Sept 10–14, 1979. (b) Chen, C. H.; Reynolds, G. A. *J. Org. Chem.*, preceding paper in this issue.
(2) Perlstein, J. H. *Angew. Chem., Int. Ed. Engl.* **1977**, *16*, 519.
(3) Corey, E. J. *Pure Appl. Chem.* **1967**, *14*, 19. Lever, O. W., Jr. *Tetrahedron* **1976**, *32*, 1943.
(4) Akiba, K.-Y.; Ishikawa, K.; Inamoto, N. *Synthesis* **1977**, 862.
(5) Reynolds, G. A.; Chen, C. H.; Van Allan, J. A. *J. Org. Chem.* **1979**, *44*, 4456.

which is slightly less polar than 7 (R_f ~0.4). This new compound can be separated by preparative TLC as a brown oil and is assigned the isomeric 2H structure 11 on the basis of its mass [m/e 386 (M^+) for $C_{21}H_{23}O_3PS$] and ^1H NMR spectra: δ 1.3 (t, $J \approx 6$ Hz, 6, OCH_2CH_3), 4.1 (quintet, $J \simeq 12$ and 6 Hz, 4, OCH_2CH_3), 4.8 (2 d, J_{HH} = 6 Hz, $J_{PH} \simeq 3$ Hz, 1, C-2 benzylic proton), 6.59 (2 d, J_{HH} = 6 Hz, J_{PH} = 20 Hz, 1, C-3 vinylic), 6–7.4 (d, J_{PH} = 9 Hz, 1, C-5 vinylic), 7.2–8.0 (m, 10, Ar H). The structure of this material has been confirmed by an independent synthesis (vide infra).

The [1,3] sigmatropic rearrangement of 4H phosphonate 7 to the 2H isomer 11 presumably is a favorable process, owing to the formation of a cisoid diene configuration. This is supported experimentally by heating a solution of 7 in tetrachloroethylene (bp 120 °C, 24 h) to give a mixture (ca. 60:40) of 11 and 7 (NMR and TLC assay).

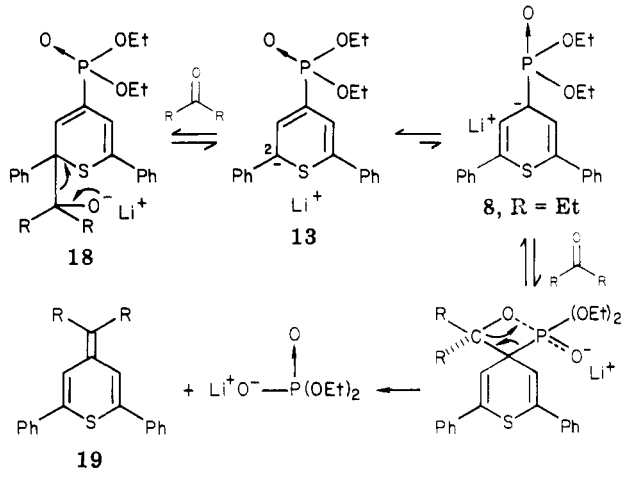
Compound 7 was lithiated by adding 1.2 equiv of n-butyllithium in dry THF at −78 °C under argon. A dark blue solution of 8 was immediately formed. Addition of thioxanthen-9-one (9) in THF at −78 °C and allowing the reaction mixture to equilibrate to room temperature produced the desired $\Delta^{4,9'}$-2,6-diphenyl-4-(9-thioxanthenyl)-4H-thiopyranylidene (10) in 43% yield. Similarly, addition of p-(dimethylamino)benzaldehyde (9a) gave 2,6-diphenyl-4-[p-(dimethylamino)benzylidenyl]-4H-thiopyranylidene (10a) in 67% yield.

The instantaneous formation of the Wittig–Horner reagent 8 under these conditions was confirmed by quenching with excess methanol-d immediately after the n-butyllithium addition. The ^1H NMR spectrum of this C-4 deuterated species 12 [m/e 387 (M^+) for $C_{21}H_{22}DO_3PS$] showed a doublet (J_{PCCH} = 5 Hz) for the two equivalent vinylic protons at δ 5.9. The identical phosphorus–hydrogen coupling constant and the chemical shift for these two vinylic protons are also obtained in the partly decoupled ^1H NMR spectrum of 7 when the methine proton (α to the phosphonate) at δ 3.84 (t) and 4.13 (t, hidden) is irradiated separately.

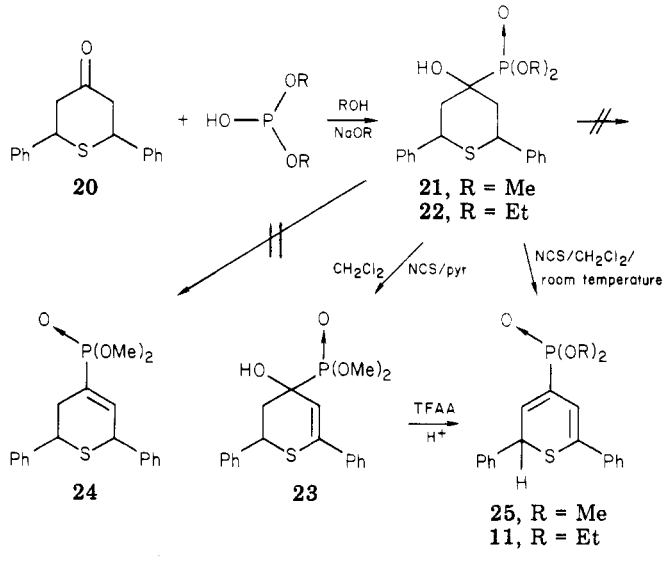
The Wittig–Horner reagent 8, in contrast to the oxygen analogue 2,[1] is extremely unstable even at −78 °C. This was shown by keeping the dark blue THF solution of 8 under argon at −78 °C for 10 min before quenching (CH_3OD). Analysis of the NMR spectrum of this mixture and a TLC assay revealed a new deuterium-substituted species which is present in an amount about equal to 12. This new compound, which had TLC behavior (R_f ~0.56, silica gel, ethyl acetate) identical with that of the 2H isomer 11 and an M^+ at m/e 387 ($C_{21}H_{22}DO_3PS$), is assigned the C-2-deuterated isomeric structure 14. This was confirmed by analyzing its ^1H NMR spectrum in the vinylic proton region. It shows two partially overlapped doublets due to the phosphorus coupling at δ 6.63 (J_{PH} = 19.5 Hz) for the C-3 proton and δ 6.8 (J_{PH} = 9 Hz) for the C-5 proton. The identical phosphorus–hydrogen coupling pattern and the chemical shifts for the C-3 and C-5 protons are also observed in the decoupled ^1H NMR spectrum of 11 when the C-2 benzylic proton at δ 4.8 (2 d) is irradiated. Since the ratio of 14 to 12 appears to increase (to ca. 4:1) with time, this suggests that 4-lithiated 8 is a kinetically controlled product which equilibrates to 13, which is a thermodynamically more stable anion by virtue of its cisoid diene conjugation.

Unfortunately, neither 8 nor the isomeric C-2-lithiated 13 is stable on being kept for prolonged periods under argon at −78 °C, and a true equilibrium ratio of 13 to 8 cannot be estimated. The use of lithium diisopropylamide and the presence of N,N,N′,N′-tetramethylethylenediamine (TMEDA) do not significantly affect the lithiation course or improve the stability of 8.

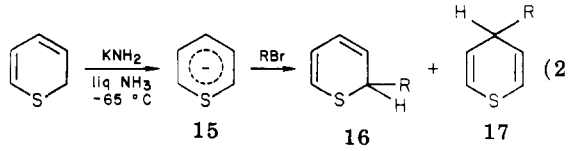
Scheme II



Scheme III



Recently, the equilibration of the parent 2H-thiopyran anion 15 in liquid ammonia at −65 °C was reported to give, on alkylation with cyclohexyl bromide, an 85:15 mixture of 2-cyclohexyl-2H-thiopyran (16, R = c-C_6H_{11}) and the 4H isomer 17 (R = c-C_6H_{11}) in 82% yield (eq 2).[6] These

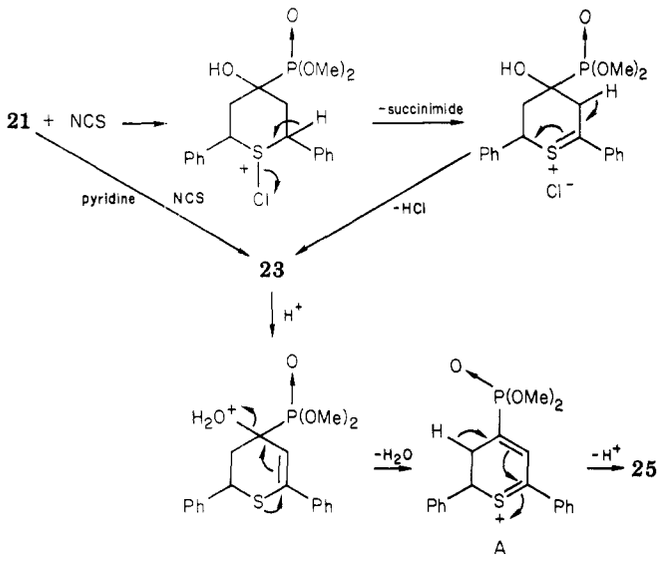


data combined with our deuterium-quenching results suggest that the C-2-lithiated anion 13, when generated independently, may be equilibrated (at least partly) to the 4H-lithiated isomer 8. Particularly, in our system, the steric hindrance at C-2 in 13 and the reversible nature of the Wittig–Horner adduct 18 are expected to favor the formation of only the 4H condensation product 19 (Scheme II).

Because of the preparation of 2,6-diphenylthiopyrylium perchlorate (6)[5] is somewhat laborious, we wanted an alternative synthesis of the 2H isomer, diethyl (2,6-di-

(6) Gräfing, R.; Verkruijsse, H. D.; Bransma, L. *J. Chem. Soc., Chem. Commun.* **1978**, 596.

Scheme IV



phenyl-2*H*-thiopyran-4-yl)phosphonate (**11**), as a potential synthon for the Wittig–Horner reagent **8**. Our approach is outlined in Scheme III.

The 1,2-addition of dimethyl phosphite to 2,6-diphenyl-4*H*-tetrahydrothiopyran-4-one (**20**) in the presence of 1 equiv of sodium methoxide gave **21** in 70% yield.[7] The corresponding ethyl ester **22** was similarly prepared in 80% yield. Direct dehydration of **21** to **24** under both acidic ($KHSO_4$/200–300 °C;[8] $FeCl_3$/alumina[9]) and basic ($POCl_3$/pyridine;[10] methanesulfonyl chloride/pyridine or Et_3N) conditions was unsuccessful.

Oxidative elimination with *N*-chlorosuccinimide/pyridine converted **21** to the dimethyl (2,6-diphenyl-4-hydroxy-4*H*-dihydrothiopyran-4-yl)phosphonate (**23**, mp 177 °C) in 30% yield. The colorless dihydro compound **23**, which is insoluble in most organic solvents (except Me_2SO and methanol), does not react readily with trifluoroacetic anhydride (heterogeneous). However, upon addition of 1 drop of trifluoroacetic acid (TFA), an intense yellow solution immediately resulted, and a new compound was formed. Its ^1H NMR spectrum for the thiopyran ring protons [δ 4.82 (2 d, J_{HH} = 6 Hz, J_{PH} = 3 Hz), 6.75 (2 d, J_{HH} = 6 Hz, J_{PH} = 19.5 Hz), 6.78 (d, J_{PH} = 9 Hz)] now displays a typical ABX splitting pattern (further coupled with phosphorus) consistent with the dehydrated structure **25**.

This facile acid-catalyzed dehydration, which is not observed in the tetrahydro derivative **21**, can be explained by invoking the vinylic sulfur-stabilized carbonium ion A as illustrated in Scheme IV. Since hydrogen chloride is evolved in the Pummerer oxidation of 2,6-diphenyl-4*H*-tetrahydrothiopyran-4-one (**20**) with NCS,[11] it is anticipated that the HCl eliminated would serve to self-catalyze the subsequent dehydration. Thus, a one-step synthesis of the desired 2*H* phosphonate **25** can be predicted by the mechanism proposed in Scheme IV. Indeed, when a suspension of the tetrahydro compound **21** or **22** in methylene chloride was treated with 1 equiv of NCS, a yellow solution slowly resulted. This gave, on aqueous workup, pure **25** (methyl ester) in 65% yield and **11** (ethyl ester) in 68% yield.

Treatment of **11** in dry THF under argon at −78 °C with 1.2 equiv of *n*-BuLi instantaneously produced a dark blue solution. This lithiated anion, when quenched immediately with methanol at −78 °C, did not regenerate a significant amount of the starting 2*H* phosphonate **11**, as shown by TLC assay and ^1H NMR. Instead, it gave a mixture of products, including only ~10% of the desired 4*H* isomer **7** [^1H NMR δ 5.9 (t, J_{PH} = 5 Hz)] and the 2*H* isomer **11** [^1H NMR δ 4.8 (2 d, J_{HH} = 6 Hz, J_{PH} = 3 Hz)].

One of the products isolated by column chromatography (silica gel, ethyl acetate/methylene chloride, 1:6 v/v) of the mixture shows a parent mass peak at *m/e* 444 (M^+) which is consistent with the product ($C_{25}H_{35}O_3PS$) resulting from the 1,4-addition of *n*-BuLi to the α,β-unsaturated 2*H* phosphonate **11**. This suggests that *n*-butyllithium is too nucleophilic to lithiate **11** exclusively at C-2 and that a nonnucleophilic base is required.

The effect of a nonnucleophilic base was examined by treating the 2*H* phosphonate **11** with 1.2 equiv of lithium diisopropylamide in THF at −78 °C under argon. The resulting dark blue lithiated solution was *immediately* treated with 1 equiv of *p*-(dimethylamino)benzaldehyde, and the reaction mixture was kept at −78 °C for at least 1 h before equilibrating to ambient temperature. We obtained, after the usual workup, the desired 4*H* Wittig adduct **10a** in 16% yield. The 9-thioxanthenyl adduct **10** was similarly prepared in ca. 14% yield from the 2*H* phosphonate **25** and thioxanthen-9-one (**9**). These yields, however, are still much lower than those obtained directly from the C-4-lithiated Wittig–Horner reagent **8**. Presumably, some lithiation of **11** or **25** can take place at the C-5 carbon, which is vinylic to the electronegative sulfur atom. This type of carbanion, which is very unstable in the dihydropyran system, undergoes β elimination at −90 °C to give the ring-opened acetylenic alcohol.[12]

Recently, regiospecific lithiation at C-2 and C-6 in the parent 2*H*-thiopyran system has been shown to depend on the nature of the base/solvent system.[13] In a polar medium, such as sodamide/liquid ammonia (−38 °C), exclusive C-2 lithiation is obtained. Unfortunately, this condition is inapplicable to our diphenyl-2*H*-thiopyranyl system, because the phosphonate ester function is rapidly aminolyzed in liquid ammonia.

Experimental Section

Melting points, obtained on a Mettler FPI instrument, are uncorrected. NMR spectra were recorded in $CDCl_3$ on a Varian EM-390 spectrometer using Me_4Si as internal standard. Mass spectra were obtained on an AEI MS-30 mass spectrometer. Elemental analyses were done by the Analytical Sciences Division, Kodak Research Laboratories. High-resolution mass spectra were obtained on an AEI MS-902 mass spectrometer.

Diethyl (2,6-Diphenyl-4*H*-thiopyran-4-yl)phosphonate (7). To a cooled (−78 °C) solution of 15 g (0.043 mol) of 2,6-diphenylthiopyrylium perchlorate[5] (**6**) in 200 mL of dry THF was added dropwise under nitrogen 27 mL of a solution of sodium diethyl phosphonate (1.7 mol) in benzene.[14] The reaction mixture was slowly equilibrated to ambient temperature overnight, and ether was added. The solution was washed with aqueous ammonium chloride and brine, dried ($MgSO_4$), and concentrated with a Rotavap to give 15 g of crude **7** as a viscous dark oil. Purification of 14 g of the crude material by liquid chromatography (Waters Associates LC/500 preparative unit) over silica gel with ethyl

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(10) Allen, W. S.; Bernstein, S. *J. Am. Chem. Soc.* **1955**, *77*, 1028.
(11) Chen, C. H.; Reynolds, G. A.; Van Allan, J. A. *J. Org. Chem.* **1977**, *42*, 2777.
(12) Ficini, J.; Kahn, P.; Falon, S.; Touzin, A. M. *Tetrahedron Lett.* **1979**, 67.
(13) Gräfing, R.; Bransma, L. *Synthesis* **1978**, 578; *Recl. Trav. Chim. Pays-Bas* **1978**, *97*, 208.
(14) Purchased from Organometallics, Inc., East Hampstead, NH.

acetate as solvent afforded 5 g (32%) of pure **7** as a colorless solid: mass spectrum, *m/e* 386 (M^+); ^1H NMR δ 1.36 (t, J = 7.5 Hz, 6), ca. 4.0 [d, t, $J_{PCH} \simeq 31$ Hz (obtained by partial decoupling), J_{HCCH} = 5 Hz, 1, methine], 4.1 (quintet, J = 7.5 Hz, 4), 5.9 (t, J_{PCCH} = 5 Hz, J_{HH} = 5 Hz, 2, olefinic), 7.2–7.7 (m, 10, Ar H). An analytical sample was obtained by recrystallization from hexanes (crystals grew slowly on keeping the mixture in a freezer for several days); mp 55.9 °C.

Anal. Calcd for $C_{21}H_{23}O_3PS$: C, 65.3; H, 6.0; P, 8.0; S, 8.3. Found: C, 65.1; H, 6.1; P, 8.2; S, 8.4.

$\Delta^{4,9'}$-2,6-Diphenyl-4-(9'-thioxanthenyl)-4H-thiopyran (10). To a solution (cooled to −78 °C) of 1 g (2.59 mmol) of **7** in 50 mL of dry THF under argon was added 1.2 mL of a hexane solution of butyllithium (2.4 mol) by syringe. A dark blue solution instantaneously resulted and was stirred at −78 °C for ca. 10 min before a solution of 550 mg (1 equiv) of thioxanthen-9-one in 40 mL of dry THF was added dropwise. The reaction mixture was slowly equilibrated to room temperature (3 h) as the color of the solution gradually turned to reddish brown. The solution was stirred at ambient temperature overnight and then poured into aqueous ammonium chloride (300 mL) from which the precipitated brown solid (0.95 g) was collected by filtration and washed with water. This solid was shown by TLC (silica gel, methylene chloride) to contain mostly the product and the unreacted thioxanthen-9-one.

The product was separated by boiling the crude material in ca. 250 mL of heptane to give 500 mg (43% based on the phosphonate **7**) of **10** as an insoluble yellow solid. The unreacted thioxanthen-9-one was recovered from the filtrate by removing the heptane and recrystallizing the residue from 15 mL of ethyl acetate to give 190 mg of pure thioxanthen-9-one as brown needles.

An analytical sample of **10** was obtained by recrystallization from 300 mL of ethyl acetate (not completely soluble), giving brown rhombic crystals: mp 256–257 °C; mass spectrum, *m/e* (relative intensity) 444 (M^+, 100) and 222 (M^{2+}, 10); ^1H NMR (Me_2SO-d_5) δ 6.8–7.9 (aromatic protons); IR (KBr) 1625 (C=C), 1600, 1500 (aromatic C=C) cm^{-1}.

Anal. Calcd for $C_{30}H_{20}S_2$: C, 81.0; H, 4.5; S, 14.4. Found: C, 79.8; H, 4.6; S, 13.9.

2,6-Diphenyl-4-[p-(dimethylamino)benzylidene]-4H-thiopyran (10a). The Wittig–Horner reagent was generated at −78 °C under argon from 1.5 g (3.88 mmol) of **7** and 1.2 equiv (1.9 mL) of *n*-BuLi (2.5 M in hexanes) in ca. 40 mL of dry THF. To this dark blue solution was immediately added dropwise a solution of 580 mg (1 equiv) of *p*-(dimethylamino)benzaldehyde (**9a**) in 10 mL of dry THF. The reaction mixture was kept at −78 °C for at least 1 h before being allowed to equilibrate to ambient temperature. After the reaction mixture was stirred at room temperature overnight under argon, the dark red solution was poured into water containing some NH_4Cl and extracted twice with ether. The combined ether extracts were dried ($MgSO_4$) and stripped of solvent on a Rotavap to give 1.5 g of a dark reddish gum which was recrystallized from 300 mL of ethanol, giving 800 mg of pure **10a**: mp 145–146 °C; mass spectrum, *m/e* 381 (M^+ for $C_{26}H_{23}NS$). A second crop of 200 mg of similar purity was also obtained from the concentrated mother liquor; total yield 67%.

Anal. Calcd for $C_{26}H_{23}NS$: C, 81.8; H, 6.1; N, 3.7. Found: C, 81.4; H, 5.8; N, 3.7.

Diethyl (2,6-Diphenyl-4-hydroxy-4H-tetrahydrothiopyran-4-yl)phosphonate (22). To a suspension of 4 g (0.0149 mmol) of 2,6-diphenyl-4*H*-tetrahydrothiopyran-4-one (**20**)[11] and 2.06 g (1 equiv) of diethyl hydrogen phosphite in ca. 200 mL of ethanol at ambient temperature was added 1 equiv of sodium ethylate (prepared from 0.35 g of sodium in 50 mL of ethanol). A yellow solution resulted, and a white solid soon precipitated. The milky suspension was stirred at room temperature for 3 h and poured into 400 mL of water containing some dilute HCl. The precipitated solid was collected, washed thoroughly with water, and recrystallized from 200 mL of ethanol to give 3.4 g of pure **22**, mp 234.4 °C. A second crop of 1.7 g was obtained from the mother liquors on addition of water; total yield 80%.

Anal. Calcd for $C_{21}H_{27}O_4PS$: C, 62.4; H, 6.2; P, 7.7; S, 7.9. Found: C, 62.0; H, 6.6; P, 8.0; S, 7.5.

Dimethyl (2,6-Diphenyl-4-hydroxy-4H-dihydrothiopyran-4-yl)phosphonate (23). To a suspension of 1 g (2.64 mmol) of dimethyl (2,6-diphenyl-4-hydroxy-4*H*-tetrahydrothiopyran-4-yl)phosphonate (**21**)[7] in 25 mL of methylene chloride containing 210 mg (1 equiv) of dry pyridine was added 371 mg (1 equiv) of solid *N*-chlorosuccinimide. The reaction mixture turned gradually into a yellow solution on stirring at ambient temperature. After 15 h, the solution was concentrated on a Rotavap, and the residue was diluted with ca. 50 mL of water. The precipitated solid was filtered, washed with water, and recrystallized from 50 mL of ethanol to give 300 mg (30%) of pure **23**: mp 177 °C; mass spectrum, *m/e* 376 (M^+), 358 ($M^+ - H_2O$); ^1H NMR (Me_2SO-d_6) δ 2.3 (m, 2, C-5 methylene), 3.71 (2 d, J = 10 Hz, 6, asymmetric methyl groups), 4.37 (m, 1, benzylic), 6.09 (d, J_{PH} = 5 Hz, olefinic), 6.17 (d, J_{PH} = 9 Hz, OH), 7.4 (s, 10, Ar H).

Anal. Calcd for $C_{19}H_{21}O_4PS$: C, 60.6; H, 5.6; P, 8.2. Found: C, 60.4; H, 6.0; P, 8.0.

This compound is insoluble in trifluoroacetic anhydride at room temperature. However, a yellow solution quickly resulted on addition of a catalytic amount of trifluoroacetic acid. The NMR and TLC (silica gel, ethyl acetate) of this yellow solution suggested that dehydration has been effected under these conditions (see below).

Dimethyl (2,6-Diphenyl-2H-thiopyran-4-yl)phosphonate (25). To a suspension of 3.8 g (0.01 mol) of dimethyl (2,6-diphenyl-4-hydroxy-4*H*-tetrahydrothiopyran-4-yl)phosphonate (**21**)[7] in 150 mL of methylene chloride cooled with ice (5–10 °C) was added slowly 1.5 g (1.1 equiv) of solid NCS. The reaction mixture slowly turned yellow and homogeneous upon stirring at ambient temperature. After 3 h at room temperature, the yellow solution was washed twice with 200 mL of water, dried ($MgSO_4$), and concentrated on a Rotavap to give 3.63 g of crude **25** as a brown oil. TLC (silica gel, ethyl acetate) of this material [*m/e* 358 (M^+), 249 [$M^+ - P(O)(OMe)_2$]] showed only one major spot with R_f ca. 0.5. An analytical sample of 1.5 g (65%) of **25** as a light brown viscous oil was obtained by rapid column chromatography[15] over silica gel (ethyl acetate) from 2 g of crude material: ^1H NMR δ 3.73 (d, J = 12 Hz, 6, OMe), 4.78 (2 d, J_{HH} = 6 Hz, J_{PH} = 3 Hz, 1, benzylic), 6.56 (2 d, J_{HH} = 6 Hz, J_{PH} = 19.5 Hz, 1, C-3 olefinic proton), 6.7 (d, J_{PH} = 9 Hz, 1, C-5 benzylic proton), 7.2–7.8 (m, 10, Ar H); mass spectrum, *m/e* 358.0796 (calcd for $C_{19}H_{19}O_3PS$, 358.0791 amu).

Anal. Calcd for $C_{19}H_{19}O_3PS$: C, 63.7; H, 5.3; P, 8.6; S, 8.9. Found: C, 63.3; H, 5.3; P, 8.3; S, 8.5.

Diethyl (2,6-Diphenyl-2H-thiopyran-4-yl)phosphonate (11). In a procedure similar to that described for the preparation of **25**, 2.7 g of crude **11** was prepared from 3 g (7.39 mmol) of the tetrahydro phosphonate **22** and 1 g (1 equiv) of NCS in ca. 200 mL of methylene chloride: ^1H NMR δ 1.3 (t, J = 6 Hz, 3, CH_3CH_2O), 4.1 (quintet, J_{PH} = 12 Hz, J_{HH} = 6 Hz, 2, CH_3CH_2O), 4.8 (2 d, J_{HH} = 6 Hz, $J_{PH} \simeq 3$ Hz, 1, benzylic), 6.59 (2 d, J_{PH} = 20 Hz, J_{HH} = 6 Hz, 1, C-5 olefinic), 6.74 (d, J_{PH} = 9 Hz, 1, C-3 olefinic), 7.2–7.7 (m, 10, Ar H). An analytical sample of 1.15 g (68% yield) of **11**, a light brown viscous oil, was obtained by rapid column chromatography[15] over silica gel (ethyl acetate) from 1.6 g of crude material: mass spectrum, *m/e* 386.1094 (calcd for $C_{21}H_{23}O_3PS$, 386.1104 amu).

Anal. Calcd for $C_{21}H_{23}O_3PS$: C, 65.3; H, 6.0; P, 8.0; S, 8.3. Found: C, 65.0; H, 6.1; P, 7.6; S, 7.9.

Synthesis of 2,6-Diphenyl-4-[p-(dimethylamino)benzylidene]-4H-thiopyran (10a) from Diethyl (2,6-Diphenyl-2H-thiopyran-4-yl)phosphonate (11). To a solution of 250 mg (0.65 mmol) of **11** in 50 mL of dry THF at −78 °C under argon was added dropwise 1.2 equiv of lithium diisopropylamide prepared at room temperature from 79 mg (0.78 mmol) of diisopropylamine and 0.32 mL of *n*-BuLi (2.4 M in hexanes). A solution of 100 mg of *p*-(dimethylamino)benzaldehyde (**9a**) in 10 mL of THF was *immediately* added to the resulting dark blue Wittig–Horner reagent, and the reaction mixture was kept at −78 °C for 2 h before being allowed to equilibrate slowly to room temperature (2 h). The reaction mixture was poured into aqueous NH_4Cl and extracted twice with ether. The combined ether extracts were dried ($MgSO_4$) and concentrated on a Rotavap to give a partly crystallized reddish brown gum. This was recrystallized from 25 mL of ethanol to give 40 mg (16%) of **10a**.

(15) Still, W. C.; Kahn, M.; Mitra, A. *J. Org. Chem.* **1978**, *43*, 2923.

This compound is identical with an authentic sample prepared from diethyl (2,6-diphenyl-4*H*-thiopyran-4-yl)phosphonate (**7**).

Synthesis of $\Delta^{4,9'}$-2,6-Diphenyl-4-(9'-thioxanthenyl]-4*H*-thiopyran (10) from Dimethyl (2,6-Diphenyl-2*H*-thiopyran-4-yl)phosphonate (25). To a solution of 450 mg (1.26 mmol) of **25** in 50 mL of dry THF at −78 °C under argon was added dropwise 1.2 equiv of LDA prepared at room temperature from 155 mg of diisopropylamine and 0.63 mL of *n*-BuLi (2.4 M in hexanes). A solution of 260 mg of thioxanthen-9-one (**9**) in 20 mL of dry THF was added immediately to this dark blue Wittig–Horner reagent, and the reaction mixture was kept at −78 °C for at least 1 h before being allowed to warm slowly to room temperature. After being stirred at ambient temperature overnight under argon, the reddish brown solution was worked up in the usual manner to give 600 mg of a reddish brown gum. This was purified by boiling with 120 mL of heptane, and the desired product, which is insoluble in hot heptane, was collected by filtration to give 80 mg (14%) of **10**.

This material is identical with an authentic sample prepared independently from diethyl (2,6-diphenyl-4*H*-thiopyran-4-yl)-phosphonate (**7**).

Acknowledgment. We thank Mr. Walter G. Dunn of the Kodak Industrial Laboratory for obtaining the high-resolution mass spectra.

Registry No. 6, 13586-29-3; **7**, 73453-36-8; **9**, 492-22-8; **9a**, 100-10-7; **10**, 73453-37-9; **10a**, 73453-38-0; **11**, 73453-39-1; **17** (R = c-C_6H_{11}), 68883-88-5; **20**, 37014-01-0; **21**, 62310-05-8; **22**, 62310-06-9; **23**, 73453-40-4; **25**, 73453-41-5; sodium diethyl phosphonate, 2303-76-6; diethyl hydrogen phosphite, 762-04-9.

Synthesis of Unsymmetrical $\Delta^{4,4'}$-Bi-4*H*-pyrans and -thiopyrans[1]

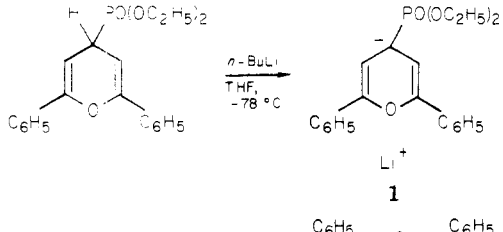
George A. Reynolds* and Chin H. Chen

Research Laboratories, Eastman Kodak Company, Rochester, New York 14650

Received November 27, 1979

Unsymmetrical $\Delta^{4,4'}$-bi-4*H*-pyrans and -thiopyrans are prepared from the Wittig reagent which is derived from (4*H*-pyran-4-yl)triphenylphosphonium salts or the thio analogues by allowing the reagent to react with a pyrylium or thiopyrylium salt with an unsubstituted 4-position.

We recently described the preparation of $\Delta^{4,4'}$-bi-4*H*-pyrans and thiopyrans which were unsymmetrically substituted about the exocyclic double bond by the reaction of the anion of a (4*H*-pyran-4-yl)phosphonate or the thio analogue with certain carbonyl compounds.[2,3] A typical example is given in eq 1. This reaction is limited in scope



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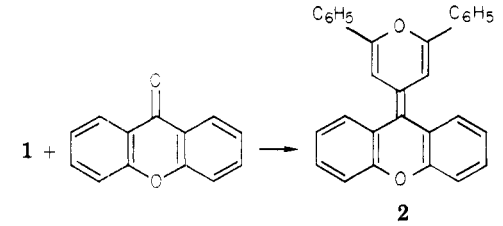
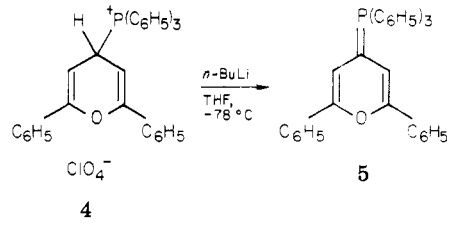


2 (1)

to certain reactive carbonyl compounds. For example, 2,6-diphenyl-4*H*-thiopyran-4-one does not react with **1**. Deactivated aldehydes, however, react with **1**; e.g., 4-(dimethylamino)benzaldehyde and **1** gave 4-[[4-(dimethylamino)phenyl]methylene]-2,6-diphenyl-4*H*-pyran (**3**) in 50% yield.

We now report a more general method for the preparation of unsymmetrically substituted bipyrans by use of triphenylphosphoranes as outlined in eq 2 for the preparation of **6**. Other examples that were prepared by this method with various phosphonium salts and pyrylium or thiopyrylium salts are collected in Table I. The phosphonate anion **1** did not react with 2,6-diphenylpyrylium or -thiopyrylium perchlorate to give bipyran derivatives.



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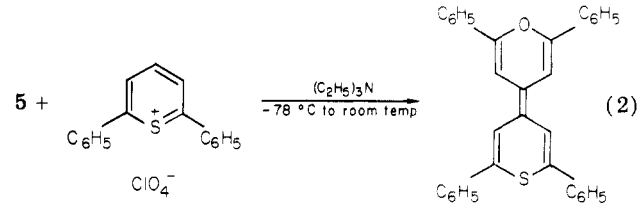

6 (2)

The yields of bipyrans prepared by the method shown in eq 2 are 30–40%. These low yields are due in part to the insolubility of the phosphonium salt and the pyrylium salt in tetrahydrofuran. We have unsuccessfully investi-

(1) Presented in part at the Wurster Centennial Symposium at the 178th National Meeting of the American Chemical Society, Washington, DC, Sept 10–14, 1979.

(2) Chen, C. H.; Reynolds, G. A. *J. Org. Chem.*, preceding two papers in this issue.

(3) In the course of this work the synthesis of unsymmetrical tetrathiofulvalenes by a similar procedure was published. Connella, N. C.; Cava, M. P. *J. Org. Chem.* **1978**, *43*, 369.

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