tilled to give an oil **9**: 10.2 g (78%); bp 150° (0.18 mm); ir (CCl_4) 3070 (s), 2900 (s), 1600 (m), 1480 (s), and 1430 cm^{-1} (s); nmr δ 1.95 (quintet, 2, J = 7.0 Hz), 2.27 (s, 3), 2.75 (t, 4, J = 7.0 Hz), 7.07 (s, 4), 7.15 (s, 5); mass spectrum (70 eV) m/e (rel intensity) 242 (33), 137 (10), 124 (91), 91 (100), and 77 (18).

Anal. Calcd for $C_{16}H_{18}S$: C, 79.31; H, 7.49; S, 13.20. Found: C, 79.38; H, 7.56; S, 12.81.

Phenyl 4-Toluenethiolacetate (10).—To an ethereal solution of 7.04 g (0.05 mol) of **7** and 5.8 g of Et_3N at 0° was added 8.81 g (0.057 mol) of phenylacetyl chloride to give 10.4 g (80%) of **10**: mp 60–62° (lit.[23] mp 59–61°); ir (CCl_4) 3030 (s), 2920 (m), 1700 (s), 1600 (m), 1480 (s), and 1460 cm^{-1} (s); nmr (CCl_4) δ 2.43 (s, 3), 3.85 (s, 2), 7.25 (s, 4), and 7.35 (s, 5); mass spectrum (70 eV) m/e (rel intensity) 242 (7), 124 (42), 118 (100), and 91 (93).

Photolysis of 10.—A deoxygenated solution of 0.142 g (0.59 mmol) of **10** in 15 ml of cyclohexane was irradiated for 3 hr and then evaporated, and the residue was analyzed in glpc with triphenylmethane was internal standard. The mixture contained **12** (28%), **13** (13%), and **2a** (35%). The compounds were identified by mass spectrometry: **12**, mass spectrum (70 eV) m/e (rel intensity) 182 (53), 91 (100), and 77 (17); **13**, mp 65–66° (lit.[24] mp 64–66°), mass spectrum (70 eV) m/e (rel intensity) 200 (19), 109 (6), and 91 (100).

4'-Tolyl Benzenethiolacetate (11).—The ester **11** was prepared by a similar procedure as reported for **10**. We obtained 3.3 g (20%) of **11**: mp 35–37° (lit.[23] mp 36–37°); ir (CCl_4) 3050 (m), 2950 (s), 1710 (s), 1475 (s), and 1415 cm^{-1} (s); nmr (CCl_4) δ 2.43 (s, 3), 3.85 (s, 2), 7.17 (s, 5), and 7.37 (s, 4); mass spectrum (70 eV) m/e (rel intensity) 242 (3), 133 (9), 110 (5), 109 (9), 105 (100), and 77 (13).

Photolysis of 11.—A deoxygenated solution of 0.151 g (0.62 mmol) of **11** in 15 ml of cyclohexane was irradiated for 3 hr and evaporated to give a residue which was analyzed by glpc with triphenylmethane as standard. The residue contained **14** (18%), **15**[24] (3%), **16** (25%), **17** (8%), **18** (11%), and **19**[25] (7%). The products were identified by mass spectrometry. **14** had mass spectrum (70 eV) m/e (rel intensity) 210 (16), 105 (100), 79 (10), and 77 (12); **15** had mass spectrum (70 eV) m/e (rel intensity) 214 (15), 109 (5), 105 (100), and 77 (12); **16** had mass spectrum (70 eV) m/e (rel intensity) 218 (77), 109 (100), and 77 (25); **17** had mass spectrum (70 eV) m/e (rel intensity) 106 (48), 105 (25), 91 (100) and 77 (14); **18** had mass spectrum (70 eV) m/e (rel intensity) 110 (100), 109 (31), 84 (23), and 77 (21); **19** had mass spectrum (70 eV) m/e (rel intensity) 208 (100), 178 (61), and 91 (17).

Photolysis of 10 and 11.—A solution of 0.076 g (0.31 mmol) of **10** and **11** in 15 ml of cyclohexane was irradiated for 3 hr and evaporated to give a residue which was analyzed on glpc. The mixture contained **12** (6%), **14** (3%), **22** (2%), **13** (5%), **15** (2%), **20**[26] (6%), **21**[24] (11%), **16** (16%), **3a** (40%), and **23**[27] (5%). The products were identified by mass spectrometry. **20** had mass spectrum (70 eV) m/e (rel intensity) 200 (19), 109 (6), 91 (100), and 77 (4); **21** had mass spectrum (70 eV) m/e (rel intensity) 228 (65), 123 (17), 105 (100), 91 (21), 79 (51), and 77 (56).

Photolysis of 18 and 1a.—A deoxygenated solution of 0.14 g (1.3 mmol) of **18** and 0.22 g (1.3 mmol) of **1a** in 15 ml of cyclohexane was irradiated for 3 hr, evaporated, and analyzed using glpc with p-xylene as standard. The mixture contained **7** (5%), **18** (4%), **3a** (1%), **25** (5%), **1a** (9%), **24** (3%), **16** (32%), **2a** (14%), **23** (16%), **26** (2%), and **27** (1%). The products were identified by mass spectrometry. **26**[28] had mass spectrum (70 eV) m/e (rel intensity) 192 (23), 110 (100), 109 (16), and 83 (14); and **27**[28] had mass spectrum (70 eV) m/e (rel intensity) 206 (20), 124 (100), and 91 (56).

Photolysis of 7 and 24.—A solution of 0.19 g (1.5 mmol) of **7** and 0.22 g (1.5 mmol) of **24** was photolyzed and analyzed in the same way as **18** and **1a**. The mixture contained **7** (6%), **18** (8%), **1a** (11%), **24** (28%), **16** (4%), **2a** (22%), **23** (9%), **26** (1%), and **27** (2%).

Phenyl Thiolacetate (24).—The ester **24** was prepared by a method similar to that for **1c**. We obtained 8.6 g (57%): bp 110–111° (11 mm) [lit.[13] bp 91° (7 mm)]; mass spectrum (80 eV) m/e (rel intensity) 152 (33), 110 (91), 109 (53), 77 (16), and 43 (100). Other spectral data are the same as reported by others.[3,13]

Registry No.—**1a**, 10436-83-6; **1b**, 14297-63-3; **1c**, 15119-62-7; **2a**, 103-19-5; **2b**, 5397-29-5; **3a**, 623-13-2; **3b**, 2388-51-4; **4**, 38644-96-1; **7**, 106-45-6; **9**, 38644-97-2; **10**, 38644-98-3; **11**, 18241-65-1; **18**, 108-98-5; **14**, 934-87-2; 4-phenylbutyryl chloride, 18496-54-3; 3-bromopropylbenzene, 637-59-2.

(23) J. Morgenstern and R. Mayer, *Z. Chem.*, **8**, 146 (1968).
(24) R. F. Brooks, N. G. Clark, J. E. Cranshaw, D. Greenwood, J. R. Marshall, and H. A. Stevenson, *J. Sci. Food Agr.*, **9**, 111 (1958).
(25) R. N. Sieber, *Justus Liebigs Ann. Chem.*, **730**, 31 (1969).
(26) E. A. Lehto and D. A. Shirley, *J. Org. Chem.*, **22**, 989 (1957).
(27) A. B. Sullivan and K. Boustany, *Int. J. Sulfur Chem., Part A*, **1**, 121 (1971).
(28) J. I. Cuneen, *J. Chem. Soc.*, 36 (1947).

Synthesis of Octahydrothiopyrano[3,2-*b*]thiopyran and Certain Derivatives[1]

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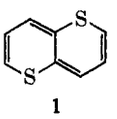
Octahydrothiopyrano[3,2-*b*]thiopyran (**10a**) has been prepared by a multistep synthesis in which the enamine, 3-pyrrolidinothiacyclohex-2-ene (**6**), served as a key intermediate. The title compound (**10a**), isolated from a liquid mixture of isomeric materials, was obtained as a pure crystalline isomer (mp 68.5–70°) and assigned the trans configuration on the basis of nmr spectral parameters. Sodium metaperiodate oxidation of **10a** yielded a well-defined monosulfoxide (**11**) which underwent a Pummerer dehydration in acetic anhydride to afford a mixture of two isomeric hexahydrothiopyrano[3,2-*b*]thiopyrans (**12a** and **12b**).

The synergistic interaction of theoretical[3] and synthetic investigations during the past several years has led to an unusual variety of new heterocyclic sulfur compounds, of which cyclopenta[*c*]thiopyran,[4] 1-phenyl-1-thianaphthalene,[5] and thienothiapyrylium cations[6,7] have been of particular interest as nonclassical 10-π-electron systems. Among other novel thia heterocycles, whose syntheses have not yet been realized, thiopyrano[3,2-*b*]thiopyran (**1**) appeared to be an especially attractive goal for synthesis, since this



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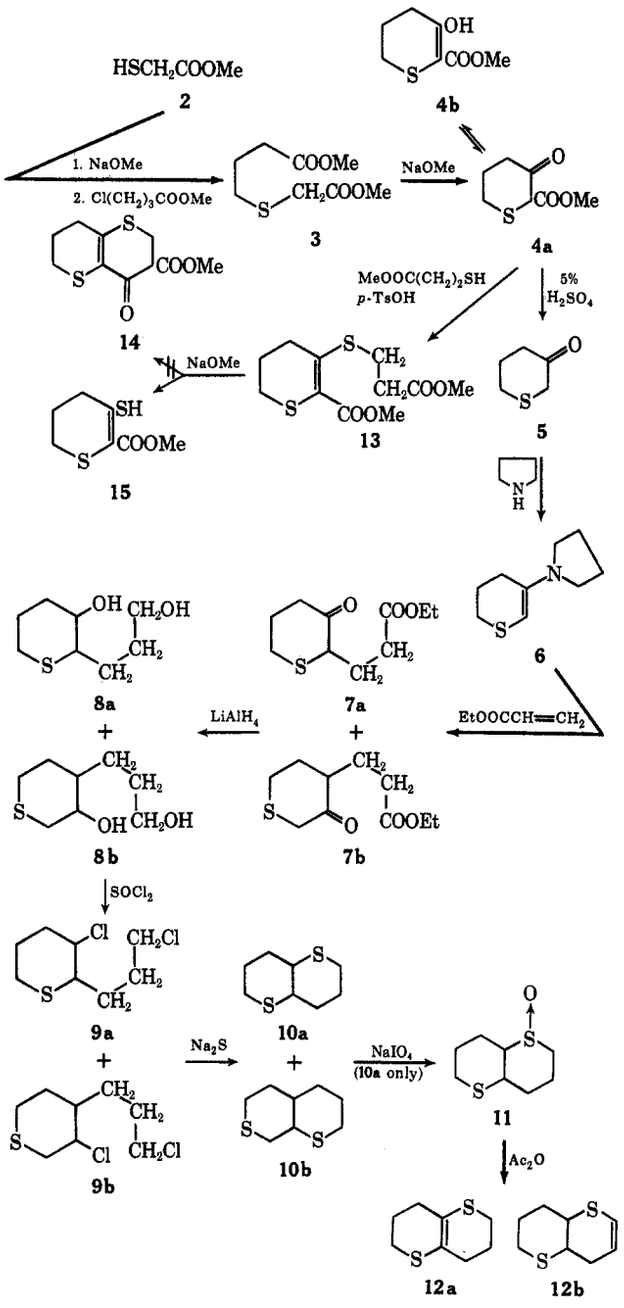
(2) National Defense Education Act Fellow, 1966–1969; Research Assistant, 1969–1971.
(3) R. Zharadnik, *Advan. Heterocycl. Chem.*, **5**, 1 (1965).
(4) A. G. Anderson, Jr., W. F. Harrison, and R. G. Anderson, *J. Amer. Chem. Soc.*, **85**, 3488 (1963).
(5) C. C. Price, M. Hori, T. Parasaran, and M. Polk, *ibid.*, **85**, 2278 (1963).
(6) I. Degani, R. Fochi, and G. Spunta, *Ann. Chim. (Rome)*, **58**, 263 (1968).
(7) T. E. Young and C. R. Hamel, *J. Org. Chem.*, **35**, 821 (1970).

structure, although formally iso-π-electronic with the somewhat elusive and unstable heptalene,[8] is expected to have a weakly bonding HOMO and a delocalization energy of 2.26 β.[3,9] When a literature search revealed that not even the skeletal structure of **1** was known, we undertook exploratory syntheses of this bicyclic system, and report here a multistep preparation of octahydrothiopyrano[3,2-*b*]thiopyran (**10a**), along with some preliminary attempts to dehydrogenate **10a** to **1**. The synthetic sequences investigated are illustrated in Scheme I.

SCHEME I



An initial alkylation of methyl thioglycolate (**2**) with methyl 4-chlorobutyrate gave an 84% yield of methyl 4-(carbomethoxymethylmercapto)butyrate (**3**), which underwent Dieckmann cyclization with sodium methoxide to afford a 57% yield of 2-carbomethoxythiacyclohexan-3-one (**4**).[10-12] The nmr spectrum of this keto ester (**4**) clearly defined its structure and further revealed an enolic proton (OH of **4b**) and a methinyl proton (2-H of **4a**) in a 60:40 ratio, an enol:keto ratio which remained virtually unchanged on prolonged storage of the compound.

The keto ester **4** reacted with methyl 3-mercaptopropionate in the presence of *p*-toluenesulfonic acid with azeotropic separation of water (refluxing benzene) to give a 42% yield of 2-carbomethoxy-3-(2-carbomethoxyethylmercapto)thiacyclohex-2-ene (**13**), which exhibited infrared and nmr spectra consistent with the assigned structure. In particular, the nmr spectrum was devoid of vinyl proton signals, indicating absence of the isomeric 3-ene.

The diester **13** was then treated with sodium methoxide in an attempted Dieckmann cyclization to the bicyclic keto ester **14**, which would have functionality suitable for introduction of further ring unsaturation. However, no detectable cyclization occurred. The sole sulfur-containing product isolated was a liquid, bp 98° (0.13 mm), exhibiting an nmr spectrum [CCl_4, δ 9.48 (s, 1, SH), 3.78 (s, 3, Me), 2.90 (m, 2, CH_2), 2.58 (m, 2, CH_2), and 2.08 ppm (m, 2, CH_2), the various methylene groups not being uniquely assignable] and an infrared spectrum [neat, 2520 (SH) and 1730 cm^{-1} (C=O)] consistent with the mercapto ester structure **15**. This product, apparently resulting from a retro-Michael reaction of **13**, could not be obtained in satisfactory analytical purity even after repeated distillation, hence was of no further immediate interest. We therefore turned our attention to the following sequence.

2-Carbomethoxythiacyclohexan-3-one (**4**) was hydrolyzed and decarboxylated with 5% sulfuric acid solution to give a 73% yield of the previously known thiacyclohexan-3-one (**5**).[11] This ketone, on refluxing with excess pyrrolidine in benzene under a water separator, was converted to 3-pyrrolidinothiacyclohex-2-ene (**6**) in 88% yield. Enamine **6** showed a single olefinic absorption in the infrared and an nmr spectrum in which a lone vinyl proton appeared as a singlet at δ 4.39 ppm, thus characterizing the material as a pure isomer (**6**), uncontaminated by the isomeric 3-ene, which would have shown its vinyl proton (H-4) as a triplet.

Despite the singular structure of this enamine **6**, its alkylation with ethyl acrylate in dioxane solution afforded a 53% yield of mixed keto esters **7a** and **7b**. The dominance of the expected isomer, 2-(2-carbethoxyethyl)thiacyclohexan-3-one (**7a**), was clearly confirmed by the nmr spectrum, which showed the 2-methinyl proton of **7a** as an isolated triplet (J = 7.0 Hz) centered at δ 3.55 ppm and integrating for *ca.* 0.8 proton. The only hint of isomeric impurity was a singlet (integration 0.2 proton) at δ 3.35 ppm, assignable to H-2 of **7b**. Glpc analysis confirmed the presence

(8) H. J. Dauben, Jr., and D. J. Bertelli, *J. Amer. Chem. Soc.*, **83**, 4658 (1961).

(9) R. Zharadník and C. Párkányi, *Collect. Czech. Chem. Commun.*, **30**, 3016 (1965).

(10) The methyl esters **3** and **4**, quite surprisingly, have not been previously reported (although the corresponding ethyl esters are known[11]) and were used here because of the availability of high-quality commercial sodium methoxide and also to simplify the nmr spectra of certain compounds encountered in this series.

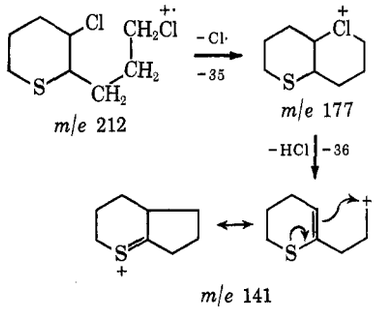
(11) E. A. Fehnel, *J. Amer. Chem. Soc.*, **74**, 1569 (1952).

(12) The thiacyclohexane nomenclature preferred here for **4** and several ensuing derivatives seems less cumbersome than names based on the alternative tetrahydrothiopyran.

of the two compounds in a ratio of 79:21. Since further fractional distillation did not improve the ratio significantly, the remaining synthetic steps were carried out from the mixture with the hope that the predominant isomer **7a** would ultimately lead to a purifiable end product.

Reduction of keto esters **7** with lithium aluminum hydride gave a 70% yield of the corresponding diols (**8a,b**) as an exceptionally viscous oil which could not be provoked to crystallize.[13] Although such a reduction of either cyclic ketone **7a** or **7b** would be expected to yield the more stable trans isomer if unhindered or alternately the cis isomer if the side chain carbethoxyethyl group exerts significant hindrance,[14] the steric effect cannot be evaluated *a priori;* hence cis and trans isomers of both **8a** and **8b** would be expected. Indeed, glpc of the exhaustively silylated diol mixture (*cf.* Experimental Section) showed the presence of four components. Surprisingly, however, the two major components comprised 74 and 17% of the mixture, suggesting that the reduction had been highly stereoselective. The nmr spectrum of the diol mixture was not clearly interpretable, hence the stereochemistry of the major product could not be directly defined.[15]

Reaction of the diols **8** with excess thionyl chloride in refluxing chloroform yielded a black reaction mixture which on distillation gave a 67% yield of the corresponding dichlorides **9**, as a somewhat unstable liquid, which even on storage at room temperature was transformed into a black, solid material. Repeated distillation of the dichlorides afforded analytically pure material as a mobile, nearly colorless liquid, whose mass spectrum showed a parent peak for the molecular ion at *m/e* 212 (calcd 212) and P + 2 and P + 4 peaks having intensities of 61 and 13%, respectively, of the parent, as expected[16] for a dichloride. The primary fragmentation pattern, a portion of which is illustrated below for **9a**, was also in accord with the behavior of other known primary and secondary halides.[16] Glpc analysis of the chloride mixture was prohibited by decomposition of the material at required column temperatures; however, the dominance of isomer **9a** is logically consistent with the glpc results for the precursor diols.



The mixture of isomeric dichlorides reacted smoothly with an equimolar amount of sodium sulfide in refluxing ethanol to give a 43% yield of a mixture of isomeric octahydrothiopyranothiopyrans as a liquid that partially solidified on standing. The colorless, crystalline fraction (18% yield), after recrystallization from hexane and sublimation at 55° (0.05 mm), had mp 68.5–70°, was homogeneous by glpc, and showed a molecular ion parent peak at *m/e* 174 (calcd 174) in the mass spectrum. This pure compound also comprised 27% of the residual liquid sample, which additionally contained three other closely related components (by glpc) that could not be identified, but which were ostensibly isomeric materials. While the preponderance of the crystalline compound suggests its derivation from the a series precursors, confirmation of its structure as octahydrothiopyrano[3,2-*b*]thiopyran (**10a**) was based on its 100-MHz nmr spectrum.[17]

The 100-MHz nmr spectrum of the crystalline isomer (**10a** in CCl_4) showed three groups of multiplets centered at δ 3.05, 2.45, and 1.95 ppm, integrating in the ratio 1:2:4, and clearly assignable to the bridgehead methinyl protons (H-4a and -8a), the α-methylenes (2-CH_2 and 6-CH_2), and the remaining β- and γ-methylene groups (3, 4, 7, and 8-CH_2), respectively, of structure **10a**.[18] These chemical shifts are sequentially comparable with those observed (in $CDCl_3$) for 1,4-dithiane (δ 2.90 ppm),[19] the α-CH_2 of thiane (δ 2.57 ppm), and the β- and γ-methylene groups of thiane (δ 1.5–1.9 ppm).[20] The bridgehead methinyl absorption was especially revealing and appeared essentially as a doublet ($J_{4,4a} = J_{8,8a} = 8$ Hz) with fine splitting of 3 Hz as expected for a rigid[21] *trans*-decalin-like structure in which an axial bridgehead proton (in *trans*-**10a**) would experience one axial–axial coupling and one axial–equatorial coupling from the adjacent methylene protons (*e.g.*, C-4). The observed magnitudes of $J_{\text{axial-axial}}$ and $J_{\text{axial-equatorial}}$ (8 and 3 Hz, respectively) are comparable with those of other six-membered systems existing primarily in chair conformation,[22] and the ratio ($R = J_{\text{trans}}/J_{\text{cis}} = 8/3 = 2.67$) is comparable with that of thiane ($R = 8.51/3.26 = 2.61$), which is known to exhibit a preference for the chair conformation.[23,24] Finally, it

(13) C. Ganter and J. F. Moser, *Helv. Chim. Acta*, **51**, 300 (1968), obtained 54 mg of the cis isomer of diol **8a** (reported mp 74–75°) by lithium aluminum hydride reduction of *cis*-3-acetoxy-2-(2-carbomethoxyethyl)thiacyclohexane, obtained in turn *via* photolysis of 2-oxo-6-acetoxy-9-thiabicyclo[3.3.1]-nonane.

(14) N. G. Gaylord, "Reduction with Complex Metal Hydrides," Interscience, New York, N. Y., 1956, p 150.

(15) In attempts to characterize the stereochemistry of the major diol component, similar reductions of the keto esters **7** were carried out with lithium aluminum hydride–aluminum chloride followed by post-reaction equilibration with acetone or excess ketone. E. L. Eliel and M. N. Rerick [*J. Amer. Chem. Soc.*, **82**, 1367 (1960)] have reported that this method reduces simple substituted cyclohexanones with thermodynamic control of products and preponderant formation of trans alcohols. However, in the present application none of the diols **8** were obtained at all, but a whole new set of nonhydroxylic products which are currently under further investigation.

(16) H. Budzikiewicz, C. Djerassi, and D. H. Williams, "Mass Spectrometry of Organic Compounds," Holden-Day, San Francisco, Calif., 1967, Chapter 12.

(17) The 60-MHz nmr spectrum was not sufficiently resolved for detailed interpretation, and the introduction of 76 mg/ml of Eu(fod)$_3$-d_{27} caused insignificant downfield shifts. For comparison, the singlet resonance of 1,4-dithiane, with the same concentration of shift reagent, showed a downfield shift of only 0.08 ppm.

(18) On the basis of a similar analysis, structure **10b** is excluded, since it should show three analogous groups of protons integrating in a ratio of 3:4:7.

(19) The 1,4-dithiane was analyzed reagent grade material from the Aldrich Chemical Co.

(20) N. S. Bhacca, L. F. Johnson, and J. N. Shoolery, "NMR Spectra Catalog," Vol. I, Varian Associates, Palo Alto, Calif., 1962, spectrum 118.

(21) E. L. Eliel, "Stereochemistry of Carbon Compounds," McGraw-Hill, New York, N. Y., 1962, pp 279–281.

(22) L. M. Jackman and S. Sternell, "Applications of Nuclear Magnetic Resonance Spectroscopy in Organic Chemistry," 2nd ed, Pergamon Press, Elmsford, N. Y., 1969, p 288.

(23) J. B. Lambert, R. G. Keske, and Donnas K. Weary, *J. Amer. Chem. Soc.*, **89**, 5921 (1967).

(24) C. H. Bushweller, "Mechanisms of Reactions of Organic Sulfur Compounds," Vol. 5, Intrascience Research Foundation, Santa Monica, Calif., 1970, p 76.

should be noted that the cis configuration of **10a** (again assuming chair–chair preference) can exist in two conformations, one having both sulfur atoms equatorial and one having both sulfur atoms axial. Examination of Dreiding models suggests that the bridgehead methinyl splitting pattern in the cis case would be considerably more complex than that observed in the present instance, in which the nmr evidence favors assignment of the structure of crystalline **10a** (mp 68.5–70°) as *trans*-octahydrothiopyrano[3,2-*b*]thiopyran.

Attempts to dehydrogenate the octahydro compound **10a** directly to the fully conjugated system **1** with high potential quinones such as *p*-chloranil or dichlorodicyanoquinone yielded only complex, intractable products, while treatment of **10a** with palladium on charcoal at 200° afforded recovered starting material. As an alternate means of introducing ring unsaturation, the octahydro compound **10a** was converted by Leonard's sodium metaperiodate method[25] to octahydrothiopyrano[3,2-*b*]thiopyran 1-oxide (**11**) in 46% yield. This monosulfoxide underwent a Pummerer dehydration[26] by reaction with acetic anhydride at 100° to yield a mixture of the monoenes **12a** and **12b** as a liquid which exhibited a strong olefinic absorption at 1620 cm^{-1} in the infrared and an nmr spectrum (CCl_4) in which the vinyl protons of **12b** (*i.e.*, SCH=CH) appeared respectively as a doublet (δ 5.93 ppm) and a multiplet (δ 5.55 ppm) of equal intensity. The integrated intensities also indicated an approximate ratio of **12a**:**12b** of *ca.* 3:1.

Paucity of this last material **12** prohibited further experiments leading to the fully unsaturated system **1** *via* this lengthy pathway. Consequently, shorter alternative routes to the theoretically interesting thiopyrano[3,2-*b*]thiopyran (**1**) are currently under investigation. The octahydro compound (*trans*-**10a**) herein defined will serve as a suitable reference compound for structural definition of other related derivatives of this bicyclic system.

Experimental Section[27]

Methyl 4-(Carbomethoxymethylmercapto)butyrate (3).—To 1.5 l. of anhydrous methanol cooled to ice-bath temperature was added 210 g (3.75 mol) of commercial sodium methoxide during 30 min. Then 400 g (3.78 mol) of methyl mercaptoacetate was added over a period of 30 min followed by 500 g (3.66 mol) of methyl 4-chlorobutyrate over 30 min. The ice bath was removed, a thermometer was inserted in place of the dropping funnel, and stirring was continued under ambient conditions. After the temperature had risen to its maximum (41°) the solution was stirred for another 2 hr and then allowed to stand overnight. The precipitated sodium chloride was filtered off and washed with anhydrous methanol. The combined filtrates were concentrated by rotary evaporation and the viscous residue (containing more precipitated NaCl) was taken up in 1.5 l. of a 1:1 ether–water mixture. The ether layer was separated, washed with water, dried ($MgSO_4$), and filtered. The solvent was removed by rotary evaporation and the residual oil was distilled through a Vigreux column to give a small forerun, bp 40–107° (0.15 mm), followed by 634 g (84%) of water white methyl 4-(carbomethoxymethylmercapto)butyrate (**3**), bp 108–115° (0.1 mm). Redistillation gave an analytical sample: bp 118° (0.15 mm); ir (neat) 3000–2850, 1740 broad (C=O), 1440, 1370, 1300–1120, 1010 cm^{-1}.

Anal. Calcd for $C_8H_{14}O_4S$: C, 46.58; H, 6.84; S, 15.55. Found: C, 46.81; H, 7.11; S, 15.66.

2-Carbomethoxythiacyclohexan-3-one (4).—To a mechanically stirred, ice-cooled suspension of 54 g (1.0 mol) of commercial grade sodium methoxide in 500 ml of anhydrous ether was added 103 g (0.500 mol) of methyl 4-(carbomethoxymethylmercapto)-butyrate (**3**) during 10 min. The reaction mixture partially coagulated when approximately half of the diester had been added but gradually turned to a fine suspension by the end of the addition period. After the addition was complete, the mixture was stirred for 1 hr at ice-bath temperature followed by 2 hr at room temperature. Then the mixture was hydrolyzed with 200 ml of water containing 60 ml of glacial acetic acid. The ether layer was separated, washed with sodium bicabonate solution, dried ($MgSO_4$), and filtered, and the solvent was removed on a rotary evaporator. The residual oil was distilled through a Vigreux column to give 49.7 g (57%) of water-white 2-carbomethoxythiacyclohexan-3-one (**4**), bp 80–84° (0.15 mm). Redistillation gave an analytical sample: bp 84° (0.15 mm); ir (neat) 2940, 1745 (ester C=O), 1715 (ketone C=O), 1645 (chelated C=O), 1600 (C=C), 1435, 1370, 1330, 1295, 1280, 1220, 1175, 1075 cm^{-1}; nmr (neat) δ 12.13 (s, 0.6, OH), 4.20 (s, 0.4, H-2), 3.80 (two closely spaced singlets, 3, $COOCH_3$ of keto and enol forms), 2.80 (m, 2, CH_2), 2.30 ppm (m, 4, CH_2's).

Anal. Calcd for $C_7H_{10}O_3S$: C, 48.26; H, 5.79; S, 18.41. Found: C, 48.21; H, 5.96; S, 18.24.

Thiacyclohexan-3-one (5).—A mechnically stirred mixture of 156 g (0.895 mol) of 2-carbomethoxythiacyclohexan-3-one (**4**) and 500 ml of 5% H_2SO_4 solution was refluxed for 10 hr, cooled, and then adjusted to pH 6 with 10% sodium hydroxide. This mixture was extracted with several portions of ether and the combined extracts were washed with water. The ether solution was then dried ($MgSO_4$) and filtered, and the solvent was removed on a rotary evaporator. The residual oil was distilled through a Vigreux column to give 76.1 g (73%) of thiacyclohexan-3-one (**5**), bp 55–60° (0.10 mm) [lit.[11] bp 101–102° (18 mm). The infrared spectrum (neat), 2920, 1720–1710 (C=O), 1440, 1410, 1325, and 1235 cm^{-1}, was identical with that of an authentic sample; nmr (CCl_4) δ 3.17 (s, 2, 2-CH_2), 2.80 (m, 2, CH_2), 2.43 ppm (m, 4, CH_2's) [lit.[28] nmr δ 3.09 (s, 2), 2.73 (m, 2) 2.40 (s, 2), and 2.38 ppm (m, 2)].

3-Pyrrolidinothiacyclohex-2-ene (6).—A mixture of 11.6 g (0.10 mol) of thiacyclohexan-3-one (**5**) and 8.5 g (0.12 mol) of pyrrolidine in 150 ml of benzene was refluxed for 2 hr, during which time 2.5 ml of water was collected in a Dean–Stark trap. The solvent was removed on a rotary evaporator and the residual oil was distilled through a Vigreux column to give 13.92 g (88%) of 3-pyrrolidinothiacyclohex-2-ene (**6**), bp 98–103° (0.10 mm). Redistillation gave an analytical sample: bp 100° (0.10 mm); ir (neat) 2960–2800, 1600 (C=C), 1385, 1350, 1265 cm^{-1}; nmr (neat) δ 4.39 (s, 1, H-2), 2.95 (t, 4, CH_2's), 2.63 (m, 2, CH_2), 2.17 (m, 4, CH_2's), 1.80 ppm (m, 4, CH_2's).

Anal. Calcd for $C_9H_{15}NS$: C, 63.85; H, 8.93; N, 8.28; S, 18.94. Found: C, 63.62; H, 8.91; N, 8.25; S, 19.04.

2- and 4-(Carbethoxyethyl)thiacyclohexan-3-one (7a and 7b).—To a stirred solution of 57.0 g (0.337 mol) of 3-pyrrolidinothiacyclohex-2-ene (**6**) in 300 ml of *p*-dioxane at room temperature was added dropwise 37.0 g (0.370 mol) of ethyl acrylate during 20 min. The solution was refluxed for 10 hr and cooled, and 150 ml of water was added. Stirring was continued for 0.5 hr and then another 150 ml of water was added, at which point an oil separated. The mixture was extracted with two 200-ml portions of benzene, and the benzene extracts were washed with water, dried ($MgSO_4$), and filtered. The solvent was evaporated and the residual oil was distilled through a Vigreux column to give the

(25) N. J. Leonard and C. R. Johnson, *J. Org. Chem.*, **27**, 282 (1962).

(26) W. E. Parham and M. D. Bhavsar, *ibid.*, **28**, 2686 (1963).

(27) Melting points were determined on a Mel-Temp apparatus (Laboratory Devices, Cambridge, Mass.) which was calibrated with a standard series of compounds of known corrected melting point. The microanalyses were performed by the late Dr. V. B. Fish (Lehigh University), Galbraith Microanalytical Laboratories, Knoxville, Tenn., and by Dr. G. I. Robertson, Florham Park, N. J. Infrared spectra were recorded on a Perkin-Elmer Model 257 instrument. Nmr spectra were determined on a Varian A-60 or a Perkin-Elmer R20A spectrometer using tetramethylsilane as internal standard. The 100-MHz spectrum was run by Sadtler Laboratories, Philadelphia, Pa. Data are presented in the order δ (multiplicity, number of protons, assignment). The mass spectra were run by Dr. J. E. Sturm (Lehigh University) on a Hitachi RMU-6E high-resolution instrument equipped with double-focusing sector. Glpc analyses were performed on an F & M (Hewlett-Packard) Model 5750 research chromatograph equipped with a TC detector and an 8 ft × 0.125 in. column containing ethylene glycol succinate packing (LP-71). Helium flow rates were 25 ml/min and column temperature was generally at 210° except where otherwise noted.

(28) K. Sato, S. Inoue, and K. Kondo, *J. Org. Chem.*, **36**, 2077 (1971).

following: a, 14.34 g of forerun, bp up to 61° (0.30 mm); b, 1.00 g of liquid, bp 61–131° (0.30 mm); c, 38.73 g (53% yield) of product **7**, bp 131–133° (0.30 mm); and d, 9.55 g of viscous amber residue; combined wt 62.62 g. Fraction c was redistilled with 91% recovery to give analytically pure **7**: bp 117–117.5° (0.13 mm); ir (neat) 2975, 2950, 2930 (CH), 1735 (ester C=O), 1710 (C=O), 1448, 1422, 1372, 1260, 1185, 1095, and 1030 cm^{-1}; nmr (CCl_4) δ 4.27 (q, J = 7.0 Hz, 2, CH_2CH_3), 3.55 (t, J = 7.0 Hz, 0.8, H-2 methinyl), 3.35 (s, 0.2), 3.1–1.6 (complex m, 10), and 1.22 ppm (t, J = 7.0 Hz, 3, CH_2CH_3).

Anal. Calcd for $C_{10}H_{16}O_3S$: C, 55.53; H, 7.46; S, 14.83. Found: C, 55.62; H, 7.44; S, 14.76.

Glpc analysis of pure material at 210° showed two peaks: retention time, min (%) 43.6 (79) and 49.5 (21), which on the basis of the nmr spectrum (*cf.* especially the δ 3.55 ppm triplet) must be assigned to **7a** and **7b**, respectively.

2- and 4-(3-Hydroxypropyl)thiacyclohexan-3-ol (8a and 8b).—To a mechanically stirred slurry of 4.00 g (0.105 mol) of lithium aluminum hydride in 500 ml of anhydrous ether was added dropwise 21.6 g (0.100 mol) of the foregoing keto ester mixture (**7a,b**) over a period of 30 min. The mixture was refluxed for 0.75 hr and cooled, and 15 ml of ethyl acetate was added dropwise to destroy the excess hydride. Just enough water was then added to coagulate the solids. The mixture was filtered and the solids were extracted thoroughly with ether. The combined ether extracts were dried ($MgSO_4$) and filtered, and the solvent was removed on a rotary evaporator. The residual oil (14.65 g) was distilled to give about 1 ml of forerun, bp up to 135° (0.30 mm), then the diols **8**, 12.21 g (70%), as a very viscous oil, bp 140–143° (0.10 mm), leaving a semisolid residue (1.12 g.) Redistillation of the diols gave an analytical sample: bp 150° (0.25 mm); ir (neat) 3370 broad (H-bonded hydroxyl), 2930–2860, 1950–1150, 1050, 940, and 900 cm^{-1}; nmr ($CDCl_3$) δ 3.92 (m, 1, CHOH), 3.68 (s + m, 4, two OH and CH_2OH), 2.85 (m, 1, SCH), 2.53 (m, 2, CH_2S), 1.70 ppm (m, 8, remaining four CH_2's).

Anal. Calcd for $C_8H_{16}O_2S$: C, 54.51; H, 9.15; S, 18.19. Found: C, 54.31; H, 8.94; S, 18.15.

This diol mixture was exhaustively silylated with hexamethyldisilazane and trimethylchlorosilane in pyridine;[29] the resulting bistrimethylsilyl derivatives were analyzed by glpc (140°). Four peaks were observed, retention time, min (%), 7.2 (74), 8.9 (17), 9.4 (6), and 10.2 (3), of which the first, preponderant peak must be derived from 2-(3-hydroxypropyl)thiacyclohexan-3-ol (**8a**), whose structure accounts for the principal features of the nmr spectrum.

3-Chloro-2- and -4-(3-chloropropyl)thiacyclohexane (9a and 9b).—To a mechanically stirred solution of 59 g (0.50 mol) of thionyl chloride in 250 ml of chloroform was added dropwsie 39.3 g (0.223 mol) of the above diols **8** in 50 ml of chloroform over a period of 0.5 hr. The resulting mixture was refluxed for 5.5 hr, cooled, and left to stand overnight. The solution was poured into 1 l. of ice water and stirred for 20 min. The layers were separated; the chloroform layer was dried ($MgSO_4$) and filtered and the solvent stripped on the rotary evaporator. Distillation of the residual oil gave 32.0 g (67%) of the dichlorides **9**, bp 108–112° (0.35 mm). Several redistillations were required to give analytical material: bp 96–97° (0.07 mm); ir (neat) 2950, 2860, 1450, 1285, 790, 740, and 650 cm^{-1}; nmr (CCl_4) δ 3.58 (m, 3, CHCl and CH_2Cl), 2.70 (m, 3), 1.95 ppm (m, 8).

Anal. Calcd for $C_8H_{14}Cl_2S$: C, 45.08; H, 6.62; Cl, 33.26; S, 15.04. Found: C, 45.29; H, 6.65; Cl, 33.00; S, 15.35.

Octahydrothiopyrano[3,2-*b*]thiopyran (10a).—A stirred solution of 34.7 g (0.163 mol) of the dichlorides **9** and 39.0 g (0.163 mol) of sodium sulfide nonahydrate in 300 ml of 95% ethanol was refluxed for 19 hr, cooled, and diluted with an equal volume of water. This mixture was extracted with four 100-ml portions of benzene, the benzene extracts were washed with saturated sodium chloride solution and then with water, and the solution was dried ($MgSO_4$) and filtered. The solvent was removed on a rotary evaporator and the residual oil (28.4 g) was distilled through a Vigreux column. The combined fractions, bp 75–79° (0.05 mm), weighed 13.1 g (46% crude yield) and solidified to a great extent after overnight refrigeration or on standing several days at room temperature. Only a few drops of higher boiling distillate had been collected, bp 131–154° (0.25 mm), when the pot residue, comprising about half of the original charge, began to decompose extensively with loss of vacuum. Recrystallization of the solid fraction from hexane gave 5.0 g (18%) of octahydrothiopyrano-[3.2-*b*]thiopyran (**10a**), mp 60–66°. Sublimation at 55° (0.05 mm) and further recrystallization gave an analytical sample: mp 68.5–70°; ir (KBr) 2930, 2850, 1440, 1100, 1065, and 725 cm^{-1}; nmr (CCl_4) δ 3.05 (q, 2), 2.45 (m, 4), and 1.95 ppm (m, 8); mass spectrum m/e 174 (M^+) (calcd 174).

Anal. Calcd for $C_8H_{14}S_2$: C, 55.12; H, 8.10; S, 36.79. Found: C, 54.91; H, 7.92; S, 36.56.

The pure crystalline compound was homogeneous by glpc and had a retention time of 12.1 min at 210°. The residual oil, after separation of the solid fraction, weighed 6.86 g and on glpc at 210° showed four well-defined peaks, retention time, min (%), 8.6 (34), 9.9 (6), 12.1 (27), and 13.8 (33). The peak at 12.1 min was identical with that of pure crystalline **10a** on the basis of both retention time and peak enhancement. Although no further separation was achieved by either fractional distillation or chromatography on silica gel, this four-component mixture showed an ir spectrum similar to that of the crystalline product.

Octahydrothiopyrano[3,2-*b*]thiopyran 1-Oxide (11).—A solution of 2.00 g (0.0115 mol) of octahydrothiopyrano[3,2-*b*]-thiopyran (**10a**) in 50 ml of *p*-dioxane was added to 2.45 g (0.0115 mol) of sodium metaperiodate in 50 ml of water. The resulting mixture became immediately cloudy and a white, fluffy solid precipitated. The mixture was stirred at room temperature for 24 hr, the solid was removed by filtration, and the filtrate was diluted with 150 ml of water. This solution was extracted with chloroform and the chloroform extracts were dried ($MgSO_4$) and filtered. Removal of the solvent on the rotary evaporator gave 1.8 g of an orange solid which was recrystallized from petroleum ether (bp 30–60°) to give 1.0 g (46%) of octahydrothiopyrano-[3,2-*b*]thiopyran 1-oxide (**11**), mp 100–106°. Three more recrystallizations gave an analytical sample: mp 112–114°; ir (KBr) 2920, 1430, 1060, 1030 (S→O), 1000, 930 cm^{-1}.

Anal. Calcd for $C_8H_{14}OS_2$: C, 50.49; H, 7.41; S, 33.69. Found: C, 50.64; H, 7.47; S, 33.45.

2,3,4,6,7,8-Hexahydrothiopyrano[3,2-*b*]thiopyran (12a) and 4,4a,6,7,8,8a-Hexahydrothiopyrano[3,2-*b*]thiopyran (12b).—A mixture of 4.85 g (0.0255 mol) of octahydrothiopyrano[3,2-*b*]-thiopyran 1-oxide (**11**) and 20 ml of acetic anhydride was heated at 100° for 66 hr. The solvent was then removed on a rotary evaporator and the residual oil was distilled on a short-path apparatus to give 3.40 g (77%) of crude product, bp 68–75° (0.05 mm). Redistillation afforded an oil, bp 68–70° (0.03 mm), whose spectra were consistent with the products **12a** and **12b**: ir (neat) 2930, 2840, 1620 (C=O), 1440, 1295, 1255, 1185, 940, 780, 690, 670 cm^{-1}; nmr (CCl_4) δ 5.93 (d, 0.25, SC**H**=CH), 5.55 (m, 0.25, SCH=C**H**), 2.70 (m, 5), 2.08 ppm (m, 7); mass spectrum m/e 172 (M^+).

Anal. Calcd for $C_8H_{12}S_2$: C, 55.76; H, 7.02; S, 37.22. Found: C, 56.03; H, 7.30; S, 36.97.

2-Carbomethoxy-3-(2-carbomethoxyethylmercapto)thiacyclohex-2-ene (13).—A solution of 20.0 g (0.115 mol) of 2-carbomethoxythiacyclohexan-3-one (**4**), 17.5 g (0.115 mol) of methyl β-mercaptopropionate, and 1 g of *p*-toluenesulfonic acid monohydrate in 150 ml of benzene was refluxed under a Dean–Stark trap for 9 hr, during which time 2.3 ml of water was collected. The benzene solution was cooled, then washed successively with water, 5% sodium bicarbonate, and again with water, and dried over $MgSO_4$. Benzene was removed on a rotary evaporator and the residual oil was distilled to give 14.64 g (46%) of crude product, bp 165–175° (0.40 mm). Redistillation gave analytically pure **13**: bp 153–154° (0.10 mm); ir (neat) 2985, 2940, 2920 sh, 2830, 1735 (C=O), 1430, 1355, 1240, 1050 cm^{-1}; nmr (CCl_4) δ 3.73 (s, 3) and 3.66 (s, 3), both CH_3's of ester groups, 3.0–2.0 ppm (m, 10, various methylenes).

Anal. Calcd for $C_{11}H_{16}O_4S_2$: 47.80; H, 5.84; S, 23.21. Found: C, 47.73; H, 5.99; S, 23.16.

Registry No.—**3,** 38555-40-7; **4,** 38555-41-8; **5,** 19090-03-0; **6,** 38555-43-0; **7a,** 38555-44-1; **7b,** 38555-45-2; **8a,** 38555-46-3; **8b,** 38555-47-4; **9a,** 38555-48-5; **9b,** 38555-49-6; **10a,** 36910-78-8; **11,** 38555-51-0; **12a,** 38555-52-1; **12b,** 38555-53-2; **13,** 38555-54-3; methyl mercaptoacetate, 2365-48-2; methyl 4-chlorobutyrate, 3153-37-5; methyl β-mercaptopropionate, 2935-90-2.

(29) C. C. Sweeley, R. Bentley, M. Makita, and W. W. Wells, *J. Amer. Chem. Soc.*, **85**, 2497 (1963), developed optimal conditions for the use of these reagents for carbohydrate analysis.