with stirring. After 3 h at 20 °C, water (1 mL) was added. The precipitate was filtered off and washed with toluene. The organic solution was dried ($MgSO_4$) and evaporated to dryness under vacuum. The residue was purified by column chromatography on silica gel (25 g, AcOEt). The yield was 0.235 g (37%) of **10** after recrystallization from hexane/CH_2Cl_2 (3:1) as colorless crystals: mp 85–86 °C (there was less than 5% of the trienes **3**, **6**, and **7** isolated by chromatography); UV (EtOH 95%) 243 (8000), UV (isooctane) 243 (8000); IR ($CHCl_3$) 3580 (w), 3460 (w), 3080 (m), 2980 (s), 2950 (s), 2920 (m), 2880 (w), 1800 (w), 1710 (w), 1640 (m), 1620 (m), 1450 (m), 1390 (s), 1370 (s), 1295 (m), 1260 (s), 1230 (m), 1105 (s), 1095 (s), 1035 (m), 1005 (w), 985 (w), 950 (s), 900 (s), 860 (s), 845 (s); ^1H NMR ($CDCl_3$) δ 5.44, 5.43, 4.99, 4.94, 4.88 and 4.81 (s, H_2C=C(3′, 5′, 6′)), 3.45 (dd, J = 4.0, 4.5 Hz, H(4′)), 3.33 (m, H(7′, 8′)), 3.22 (q, J = 6.5 Hz, H–C(OH)Me), 2.63 (dd, J = 4.0, 4.5 Hz, H(1′)), 2.02 (br s, OH), 1.20 (s, CH_3), 1.07 (d, J = 6.5 Hz, CH_3); ^{13}C NMR ($CDCl_3$ [relative slope of the induced chemical shift by added $Yb(dpm)_3$]) δ 153.1 (s, C(3′) [36.2]), 142.6 (s, C(6′) [21.9]), 141.8 (s, C(5′) [19.3]), 108.8 (t, $^1J_{CH}$ = 158 Hz, CH_2=C(3′) [28.7]), 108.33 (t, $^1J_{CH}$ = 158 Hz, CH_2=C(5′) [10.3]), 108.28 (t, $^1J_{CH}$ = 158 Hz, CH_2=C(6′) [12.9]), 69.8 (d, $^1J_{CH}$ = 146 Hz, C(OH) [100]), 53.1 (d, $^1J_{CH}$ = 188 Hz, C(7′) [36.7]), 52.7 (d, $^1J_{CH}$ = 188 Hz, C(8′) [23.8]), 52.5 (d, $^1J_{CH}$ = 139 Hz, C(1′) [39.1]), 49.0 (d, $^1J_{CH}$ = 139 Hz, C(4′) [30.7]), 45.6 (s, C(2′) [48.9]), 16.1 (q, $^1J_{CH}$ = 128 Hz, CH_3C(2′) [35.9]), 15.6 (q, $^1J_{CH}$ = 126 Hz, CH_3 [55.3]); MS (70 eV) 174 (38 [M^+ – 44]), 159 (46) 145 (100), 131 (67), 130 (42), 129 (46), 128 (42), 117 (25), 116 (23), 115 (56), 105 (41), 91 (75). Anal. Calcd for $C_{14}H_{18}O_2$ (218.3): C, 77.03; H, 8.31. Found: C, 76.79; H, 8.47%.

***p*-Bromobenzoate of Alcohol 10 (11).** A mixture of **10** (0.15 g, 0.68 mmol), *p*-bromobenzoyl chloride (0.17 g, 0.77 mmol), and anhydrous pyridine (2.5 mL) was heated until complete dissolution. After stirring at 20 °C for 5 h, the reaction mixture was poured onto ice (25 g) and $NaHCO_3$ (1 g). The mixture was extracted with CH_2Cl_2 (25 mL, 3×) and dried ($MgSO_4$). The solvent was evaporated under vacuum and the residue recrystallized from CH_2Cl_2/hexane (1:2) with a yield of 0.215 g (78%): mp 187–189 °C; UV (EtOH 95%) 245 (7800); IR (KBr) 2990, 1710, 1590, 1480, 1450, 1395, 1370, 1340, 1300, 1270, 1250, 1170, 1115; ^1H NMR (CD_3COCD_3) δ 7.95, 7.71 (4 H, aromatic), 5.62, 5.55, 5.08, 5.02, 4.70, 4.69 (s, H_2C=C(3′, 5′, 6′)), 4.78 (q, J = 6.5 Hz, H–C(OAr)), 3.46 (d, J = 4–5 Hz, H(4′)), 3.35 (t, J = 4–5 Hz, H(7′)), 3.31 (t, J = 4–5 Hz, H(8′)), 2.85 (d, J = 4–5 Hz, H(1′)), 1.45 (s, CH_3), 1.25 (d, J = 6.5 Hz, CH_3); MS (70 eV) 402 (1), 400 (1), 358 (13), 356 (13), 343 (10), 341 (10), 330 (23), 329 (23), 328 (23), 327 (23), 315 (10), 313 (15), 312 (15), 310 (12), 229 (15), 227 (17), 221 (18), 200 (82), 157 (100), 155 (85). Anal. Calcd for $C_{21}H_{21}O_3Br$ (401.3): C, 62.85; H, 5.27. Found: C, 62.78; H, 5.32%.

Acknowledgment. We thank Hoffmann-La Roche & Co (Basel), the Swiss National Science Foundation, and the Fonds Herbette (Lausanne) for generous financial support. We are grateful to F. Berchier and C. Debonneville for the technical assistance and to Dr. R. Hunston for correcting the manuscript.

Registry No. 1, 75073-80-2; 3, 82149-54-0; 3 tetracyanoethylene adduct, 82134-65-4; 4, 82134-61-0; 5, 82149-56-2; 6, 82189-06-8; 7, 82134-62-1; 8, 82134-63-2; 9, 82188-44-1; 10, 82149-55-1; 11, 82134-64-3; acetaldehyde, 75-07-0; acetyl chloride, 75-36-5; vitride, 22722-98-1; tetracyanoethylene, 670-54-2.

Supplementary Material Available: Crystal structure of $C_{21}H_{21}O_3Br$ (11) with a summary of the crystal data and refinement information (Table I), interatomic distances (Table 2), bond angles (Table 3), torsion angles and information on least-squares planes (Table 4), shortest intermolecular contacts (Table 5), atomic parameters and anisotropic temperature factors (Table 6), and an ORTEP drawing (Figure 2) (7 pages). Ordering information is given on any current masthead page.

Synthesis of Sulfides and Mercaptans from Thioketals

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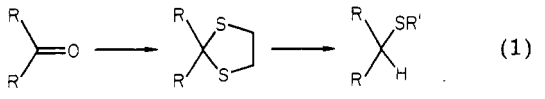
The treatment of ketone thioketals with excess *n*-butyllithium in ether at 25 °C leads to fragmentation to intermediate thioketones, which in most cases are further reduced to mercaptans via β-hydrogen transfer from *n*-butyllithium. Mercaptide anions formed in the reaction can be quenched with electrophiles to produce sulfides. Mercaptans, methyl sulfides, and allyl sulfides have been prepared from adamantanone, menthone, and cyclooctanone by using this approach. Camphor thioketal, however, cleaves to give thiocamphor which because of steric hindrance enolizes with *n*-butyllithium rather than reduces. Thiocamphor is isolated after quenching in 62% yield.

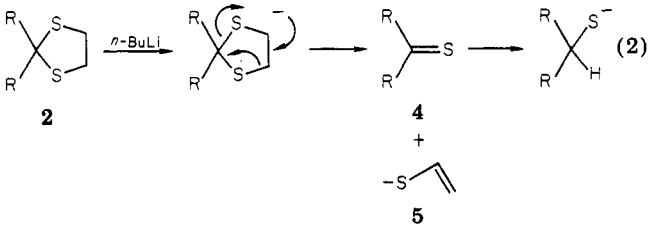
A recent publication from this laboratory[1] described a new method for the synthesis of secondary mercaptans and sulfides from 1,3-dithiolanes (eq 1). A fragmentation



(1)

1 2 3

mechanism involving a thiocarbonyl intermediate has been proposed to account for the products. The following describes the synthesis of various sulfides and mercaptans and provides specific evidence for the proposed thiocarbonyl intermediate. Our mechanism for the cleavage/reduction process we proposed is shown in eq 2.



(2)

2 4 + 5

While our original paper put forward no direct evidence for the intermediate thioketone 4 and thioacetaldehyde

(1) Wilson, S. R.; Georgiadis, G. M.; Khatri, H. N.; Bartmess, J. E. *J. Am. Chem. Soc.* **1980**, *102*, 3577–3583.

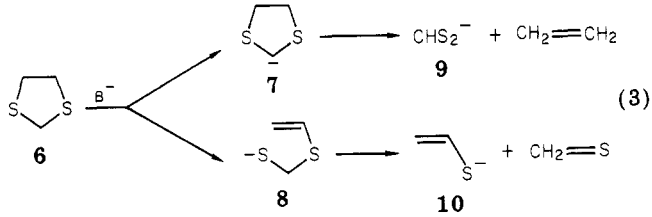
0022-3263/82/1947-3319$01.25/0 © 1982 American Chemical Society

Table I. Sulfides and Mercaptans from Thioketals (Eq 1)

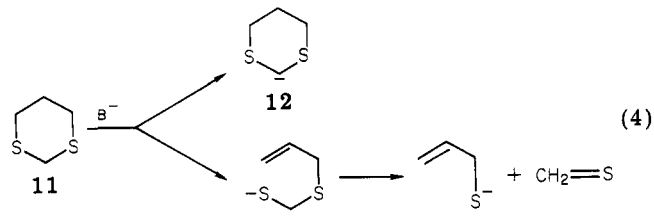
entry	starting matl	% yield thiol	% yield methyl sulfide	% yield allyl sulfide
1	adamantanone thioketal	85[a]	96[a]	66
2	menthone thioketal	81	85	81
3	cyclooctanone thioketal	74	97	69
4	camphor thioketal	38[b]		

[a] Reference 1. [b] The major product is thiocamphor (62%).

enolate **5**, a study of the reactivity of dithiolane **6** (eq 3) and dithiane **11** (eq 1) in the gas phase[2] was enlightening.



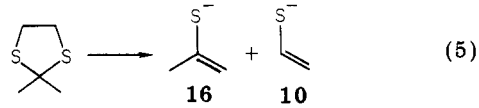
6 **7** **8** **9** **10** (3)



11 **12** **13** **14** (4)

In both cases the relative proportion of deprotonation at C-2 (yielding ions **7** or **12**) relative to the E2-type elimination (ions **8** or **13**) could be controlled by the base strength. Weaker bases induced E2-type elimination. Ion **7** *when it is formed* is not stable to [2 + 4] cycloreversion and therefore gives **9** plus ethylene.

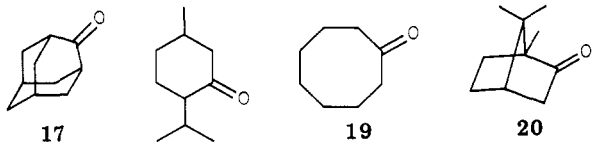
Direct evidence for most of the ionic intermediates was available from this study; however, confirmation of the thioketone product was still elusive. It was interesting to note, however, that 2,2-dimethyl-1,3-dithiolane **15** reacted with NH_2^- in the gas phase to give ion **16** (eq 5), in addition



15 **16** **10** (5)

to the expected **10**. We proposed that proton transfer occurred between thioacetone and **10** before the cluster complex breaks up.

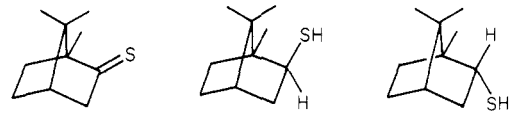
In a continuing study of this reaction in solution, ketones [2-adamantanone (**17**), methone (**18**), cyclooctanone (**19**), 2-*d*-camphor (**20**)] were studied because of their availability



17 **18** **19** **20**

and structural characteristics (unhindered vs. hindered). All four ketones formed the thioketals with 1,2-ethanedithiol (72–90%) in the presence of either BF_3–Et_2O or *p*-toluenesulfonic acid. Mercaptan synthesis[3] (eq 1) from the corresponding 1,2-ethylene dithioketal (Table I) was accomplished by treatment of the thioketal with 2.5 equiv of *n*-butyllithium (2.4 M in *n*-hexane). After the mixture was stirred for 6–8 h, a fine, white precipitate formed, and the light yellow solution was slowly quenched with water to yield the desired product (74–85%). After distillation of the oils, the pure fraction was light pink and gradually turned colorless (24–48 h). This characteristic pink color is believed to be traces of the thiocarbonyl compound which slowly decomposes.[4]

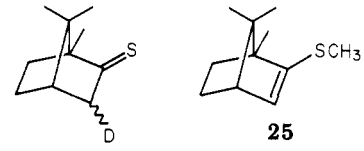
The reaction of camphor thioketal (entry 4, Table I) with 2.5 equiv of *n*-butyllithium in ether at room temperature gave as the major product, bright orange crystals of thiocamphor (**21**). This was the first instance in which we



21 **22** **23**

were able to isolate the thioketone intermediate. Although thiols **22** and **23** could not be separated from thiocamphor (**21**) by GC or TLC initially, its presence was inferred by the mass spectrum as compared to that of an authentic sample of **21**.[5] Quantitation proved extremely difficult until it was found that a good separation could be achieved on a 10 ft × 2 mm glass column of 2% Carbowax 20M. Under these conditions it was shown that the reaction gave 62% **21**, 23% **22** (exo), and 15% **23** (endo).[6]

These results are further confirmed by the treatment of pure **22** with *n*-butyllithium, which under the same conditions returned starting material. The reaction also showed revealing color changes. When *n*-BuLi was added to the orange ether solution of **21**, decolorization occurred (over about 10 min) with consumption of *n*-BuLi to give a clear, pale yellow solution. When H_2O was added, the solution immediately turned orange. This color change also characterized the cleavage reaction. We therefore conclude that *enolization* of the thioketone rather than reduction predominates for thiocamphor, most likely for steric reasons. This was established by quenching the mixture with either D_2O or CH_3I to produce **24** and **25**, respectively, as established by GC/MS. These observa-



24 **25**

tions are entirely in accord with a study of the reaction of thiocamphor with Grignard reagents[4] which gave either thioenolation or reduction depending on the conditions.[8]

(2) Bartmess, J. E.; Hays, R. L.; Khatri, H. N.; Misra, R. N.; Wilson, S. R. *J. Am. Chem. Soc.* **1981**, *103*, 4746–4751.

(3) Wilson, S. R.; Georgiadis, G. M. *Org. Synth.*, in press.

(4) Dagonneau, M.; Paquer, D.; Vialle, J. *Bull. Soc. Chem. Fr.* **1973**, 1699.

(5) Sen, D. C. *J. Indian Chem. Soc.* **1935**, *12*, 647–652.

(6) We thank Dr. Brian J. Willis (Fritzsche, Didge and Olcott, Inc., New York) for GC analyses.

(7) Rangathan, S.; Raman, H.; Srinivasan, C. V. *Tetrahedron* **1978**, *34*, 3129–3132, footnote 15.

(8) We have also observed slow cleavage of the thioketal of camphor to thiocamphor with $KOC(CH_3)_3$ in THF. In a recent report, the cleavage/hydrolysis of thioketals via thioketones to ketones with NaOH has been observed: Carson, J. R. 183rd National Meeting of the American Chemical Society, Los Vegas, NV, March 28–April 2, 1982. American Chemical Society: Washington, DC, 1982; ORGN 70.

Experimental Section

All reactions were carried out under a nitrogen atmosphere. Melting points were obtained on a Thomas capillary melting point apparatus and are uncorrected. Boiling points are uncorrected.

Infrared (IR) spectra were obtained by using a Perkin-Elmer Infracord Model 137 spectrometer. Proton nuclear magnetic resonance (NMR) spectra were obtained by using a Varian T-60A spectrometer. All chemical shifts were measured relative to an internal standard, tetramethylsilane. Mass spectral analyses were obtained on a Hewlett-Packard 5992-A GC/MS.

Analytical TLC analyses were determined by using J. T. Baker-flex (silica gel 1B-F) sheets. Vapor-phase chromatography (VPC) analyses were performed on a Varian Model 3700 gas chromatograph with an FID (5 ft × $^1/_8$ in. column, 5% OV-101 on Chromasorb G).

All chemicals used were commercial samples unless reference is given to their purification or preparation. The ether used was distilled from LAH.

All entries refer to Table I.

General Procedure for the Synthesis of Mercaptans from Ethylene Thioketals. To a solution of ethylene thioketal at 0 °C was added 2.5 equiv of *n*-butyllithium, and this mixture was allowed to warm to room temperature and was stirred for 6–8 h. The reaction mixture was then slowly quenched with water and shaken in a separatory funnel, and the organic layer was dried ($MgSO_4$) and concentrated.

Menthyl Mercaptan. From 8.06 g (35 mmol) of the thioketal of menthone (entry 2) was recovered 4.86 g (81.0%) of a clear oil after distillation: bp 58.0 °C (1.0 mm); IR (neat) 3.40, 6.88, 7.20, 7.30, 7.69, 7.79, 12.60-13.20 (br) μm; NMR (CCl_4) δ 0.90 (d, 3 H), 0.91 (d, 3 H), 0.95 (d, 3 H), 1.20–2.07 (m, 10 H), 3.13–3.47 (br, 1 H); mass spectrum, *m/e* (relative intensity) 172 (17), 138 (33), 123 (31), 95 (100), 83 (35), 82 (27), 81 (69), 69 (28), 67 (45), 55 (58), 43 (30), 41 (88).

Cyclooctyl Mercaptan. From 7.0 g (34.6 mmol) of the thioketal of cyclooctanone (entry 3) was recovered 3.69 g (74.0%) of a clear oil after distillation: bp 55.0–57.0 °C (1.0 mm); IR (neat) 3.43, 6.22, 6.75, 6.90, 7.30, 8.00, 8.45, 9.52, 12.70, 13.94 μm; NMR (CCl_4) δ 1.16–2.10 (m, 15 H), 2.80–3.20 (br, 1 H); mass spectrum, *m/e* (relative intensity) 144 (57), 111 (37), 110 (44), 95 (22), 82 (79), 81 (43), 69 (100), 68 (20), 67 (66), 60 (17), 55 (56), 54 (30), 53 (17), 41 (89).

General Procedure for Synthesis of Alkyl Sulfides from Ethylene Thioketals. To a solution of ethylene thioketal at 0 °C was added 2.5 equiv of *n*-butyllithium, and this mixture was allowed to warm to room temperature and was stirred for 6–8 h. The reaction mixture was then recooled to 0 °C, 2.5 equiv of the alkyl halide and 2.5 equiv of HMPA were added, and the mixture was warmed to room temperature and stirred from 20–160 min. The solution was then poured into water, extracted with pentane, dried ($MgSO_4$), and concentrated.

2-Adamantyl Allyl Sulfide. From 5.80 g (25.7 mmol) of the thioketal of 2-adamantanone (entry 1) was recovered 3.54 g (66%) of a clear oil after distillation: bp 94.0 °C (1.00 mm); IR (neat) 3.40, 3.72, 6.12, 6.84, 6.94 (s), 7.04, 7.14, 7.42, 7.80, 8.22, 9.14, 9.42, 9.62, 10.14 (s), 10.40, 11.00, 11.54, 12.22, 12.74 (br) μm; NMR (CCl_4) δ 1.30–2.37 (br m, 14 H), 2.58 (d, 1 H), 2.80–3.23 (m, 2 H), 4.80–5.20 (m, 2 H), 5.43–6.13 (m, 1 H); mass spectrum, *m/e* (relative intensity) 208 (16), 166 (59), 135 (100), 107 (21), 93 (46), 91 (35), 79 (53), 77 (24), 67 (54), 41 (72).

Menthyl Methyl Sulfide. From 5.47 g (24.0 mmol) of the thioketal of menthone (entry 2) was recovered 3.83 g (85%) of a clear oil after distillation: bp 74.0 °C (1.0 mm); IR (neat) 3.42, 6.92, 7.38, 7.48, 7.65, 7.75, 8.10 μm; NMR (CCl_4) δ 0.90 (d, 3 H), 0.91 (d, 3 H), 0.95 (d, 3 H), 1.20–1.93 (m, 9 H), 2.03 (d, 3 H), 2.87–3.10 (br, 1 H); mass spectrum, *m/e* (relative intensity) 186 (22), 138 (31), 95 (77), 83 (40), 81 (42), 69 (29), 67 (45), 55 (58), 43 (45), 45 (100).

Menthyl Allyl Sulfide. From 5.70 g (25.0 mmol) of the thioketal of menthone (entry 2) was recovered 4.30 g (81%) of a clear oil after distillation: bp 8.40–880 °C (1.0 mm); IR (neat) 3.45, 3.80, 6.15, 6.51, 6.91, 7.30, 7.40, 7.60, 8.20, 10.20, 10.40, 11.00, 11.20, 11.50, 11.65, 12.00, 12.80, 13.0–13.20 (br), 13.95 μm; NMR (CCl_4) δ 0.90 (d, 3 H), 0.91 (d, 3 H), 0.95 (d, 3 H), 1.46–2.50 (m, 9 H), 3.03 (d, 2 H), 3.26 (m, 1 H), 4.83–5.23 (m, 2 H), 5.4–6.0 (m, 1 H); mass spectrum, *m/e* (relative intensity) 212 (4), 95 (49), 83 (34), 81 (33), 69 (29), 67 (23), 57 (20), 55 (56), 45 (20), 43 (32), 41 (100).

Cyclooctyl Methyl Sulfide. From 137.0 mg (0.60 mmol) of the thioketal of cyclooctanone (entry 3) was recovered 92.0 mg (86%) of a clear oil after distillation: bp 58.0 °C (1.0 mm); IR (neat) 3.35, 6.20–6.30 (br), 6.75, 6.95, 7.05, 7.22, 7.32, 7.70, 7.85, 8.05, 8.25, 8.90, 9.05, 9.25, 9.65, 10.25, 10.40, 11.70, 12.50, 13.32 μm; NMR (CCl_4) δ 0.93–1.93 (7, 14 H), 2.00 (d, 3 H), 2.47–2.87 (br, 1 H); mass spectrum, *m/e* (relative intensity) 158 (22), 110 (26), 82 (51), 81 (26), 69 (76), 67 (50), 55 (61), 54 (26), 41 (100).

Cyclooctyl Allyl Sulfide. From 790.0 mg (3.9 mmol) of the thioketal of cyclooctanone (entry 3) was recovered 493.0 mg (69%) of a clear oil after distillation: bp 57.0–67.0 °C (1.0 mm); IR (neat) 3.21, 3.42, 6.15, 6.82, 6.92, 7.35 (br), 8.20, 8.90, 9.60, 10.15, 11.00 (s), 11.60, 13.44 μm; NMR (CCl_4) δ 1.84 (m, 14 H), 2.33–2.93 (br, 1 H), 3.11 (d, 2 H), 4.80–5.30 (m, 2 H), 5.47–6.17 (m, 1 H); mass spectrum, *m/e* (relative intensity) 184 (53), 143 (23), 82 (27), 74 (22), 69 (46), 67 (36), 55 (46), 45 (23), 41 (100).

Cleavage of Camphor Thioketal. The ketal[7] (500 mg, 2.2 mmol entry 4) was treated in the usual way with *n*-butyllithium (2.5 equiv). After 16 h GC analysis showed that most of the starting material had been consumed and showed a new peak at a shorter retention time. When 10 mL of distilled water was added to the colorless or light yellow mixture, the solution turned a deep orange. The organic layer was washed twice with water, dried, and concentrated to yield bright orange crystals of thiocamphor (**21**), mp 134–136 °C. The crude product was a mixture of thiocamphor (**21**, mol wt 168) and bornanethiols **22** and **23** (mol wt 170) as evidenced by the mass spectrum: *m/e* (relative intensity) 170 (20), 168 (55), 153 (21), 126 (23), 125 (54), 124 (13), 121 (16), 113 (42), 112 (35), 111 (24), 110 (21), 107 (14), 95 (100), 91 (29), 85 (36), 81 (16), 79 (30), 77 (21), 69 (22), 67 (25), 55 (21), 53 (22), 45 (21), 41 (80).

Separation of **21–23** was achieved on a 10 ft × 2 mm i.d. glass column packed with 2% Carbowax 20M on Chromosorb G (HP, 100/120) programmed at 90–225 °C at 5 °C/min. The crude reaction mixture showed three main peaks: *endo*-bornanethiol **23** at 8.66 min (relative area 15), *exo*-bornanethiol **22** at 9.12 min (relative area 23), and thiocamphor (**21**) at 10.38 min (relative area 62). Each peak was compared to that for the authentic material.

Thiocamphor showed the following: NMR ($CDCl_3$) δ 0.75 (3 H, s), 0.97 (3 H, s), 1.03 (3 H, s); NMR (CCl_4) δ 0.80 (3 H, s), 1.03 (3 H, s), 1.06 (3 H, s); ^{13}CNMR ($CHCl_3$) δ 271.6, 69.4, 55.7, 49.1, 45.3, 34.1, 27.4, 20.0, 19.9, 13.4.

If the reaction above was quenched with D_2O, monodeuteriothiocamphor **24** was isolated (*m/e* 169). If the reaction mixture was quenched with methyl iodide, an easily separable mixture of **25** and **26** (2:1) was formed.

Compound **25**: mass spectrum, *m/e* (relative intensity) 182 (64), 167 (65), 154 (100), 139 (59), 138 (16), 125 (22), 119 (27), 107 (29), 106 (51), 105 (22), 93 (18), 91 (52), 79 (19), 77 (21), 41 (39).

Compound **26**: mass spectrum, *m/e* (relative intensity) 184 (50), 169 (19), 137 (23), 136 (37), 121 (36), 95 (100), 93 (33), 81 (42), 79 (17), 74 (58), 69 (15), 67 (24), 55 (15), 41 (51).

Treatment of **21** with *n*-BuLi under the same conditions returned only starting material.

Registry No. 21, 53402-10-1; **22**, 6704-56-9; **23**, 34942-24-0; **25**, 40920-05-6; menthone thioketal, 65448-02-4; menthyl mercaptan, 52636-53-0; cyclooctanone thioketal, 183-04-0; cyclooctyl mercaptan, 20628-54-0; 2-adamantanone thioketal, 19557-70-1; 2-adamantyl allyl sulfide, 65566-48-5; menthyl methyl sulfide, 52636-52-9; menthyl allyl sulfide, 81831-70-1; cyclooctyl methyl sulfide, 71284-78-1; cyclooctyl allyl sulfide, 71284-79-2; camphor thioketal, 6787-91-3.