Synthesis, Chemical Properties, and Structure of a Sterically Hindered Ketone, 2,2,5,5-Tetramethyl-4,4-diphenyl-3-thiolanone

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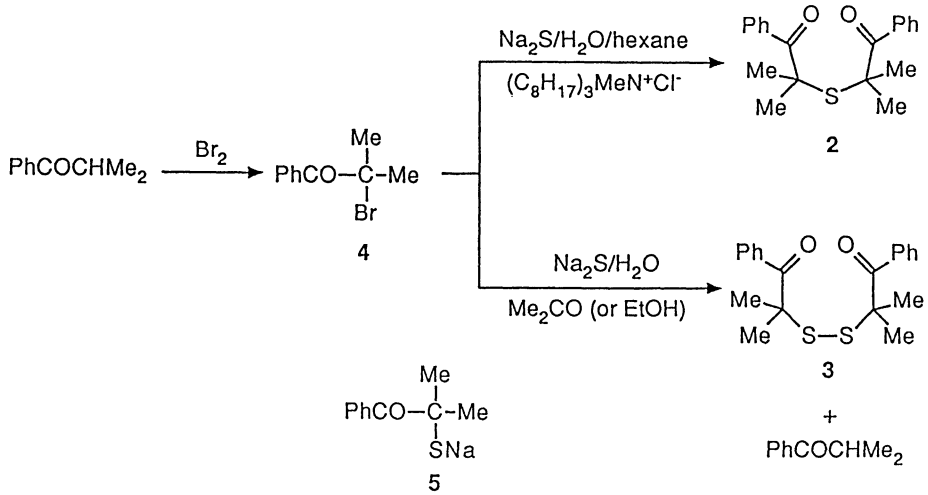
A sterically hindered ketone, 2,2,5,5-tetramethyl-4,4-diphenyl-3-thiolanone (**1**), was synthesized in two steps starting from 2,2,4,4-tetramethyl-1,5-diphenyl-3-thiapentane-1,5-dione. The carbonyl group of **1** is unreactive toward a series of nucleophiles which are bulkier than hydride or its equivalents. The observed unreactivity is ascribed to the steric hindrance enhanced by the two methyl groups on C-5 ("buttressing" effect). The result of an X-ray single crystal structure analysis of **1** is also described.

We have been investigating the synthesis using 3-thiapentane-1,5-diones and related compounds as starting materials.[1] In this connection we have synthesized a sterically hindered ketone, 2,2,5,5-tetramethyl-4,4-diphenyl-3-thiolanone (**1**), in two steps starting from 2,2,4,4-tetramethyl-1,5-diphenyl-3-thiapentane-1,5-dione (**2**). We report here the synthesis, chemical properties, and X-ray single crystal structure analysis of **1**.

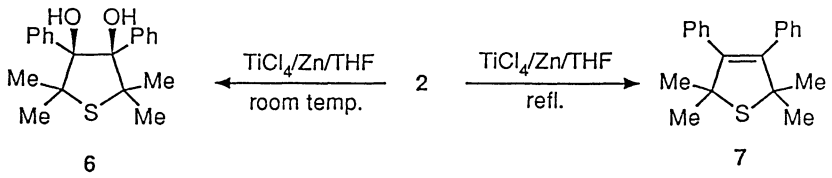
Results and Discussion

Preparation of 1 and Related Compounds. Isobutyrophenone was brominated by molecular bromine in ether and the resulting crude bromide **4** was allowed to react with sodium sulfide in two ways. A two-phase mixture of sodium sulfide and **4** in water–hexane was stirred in the presence of methyltrioctylammonium chloride (a phase transfer catalyst) at room temperature. Usual work-up of the mixture afforded the expected sulfide **2** in 60% yield (based on isobutyrophenone). When an aqueous solution of sodium sulfide was added to a stirred and ice-cooled solution of **4** in acetone or ethanol, however, the disulfide **3** was obtained unexpectedly in 45% yield along with isobutyrophenone. The initial process of this reaction also must involve a nucleophilic substitution leading to **5**. In this case, however, **5** preferentially reacts with sodium sulfide, but not with **4**, to give the enolate of isobutryophenone and sodium disulfide. The reaction of sodium disulfide with **4** should give rise to the final product **3**. Supporting evidence for this mechanism comes from the finding that treatment of α-chlorodeoxybenzoin with one equiv of sodium methanethiolate at 0 °C in ethanol affords α-methylthiodeoxybenzoin, which in turn gives deoxybenzoin and dimethyl disulfide by further treatment with sodium methanethiolate.[2] We have also experienced that α-halodeoxybenzoins and related compounds are reduced to the corresponding dehalogenated products by sodium sulfide even when the reaction was carried out under phase transfer conditions in the presene of methyltrioctylammonium chloride.[1]

We have previously shown that intramolecular reductive coupling of a series of 3-thiapentane-1,5-diones with a low valent titanium reagent, prepared from titanium(IV) chloride and zinc in tetrahydrofuran (THF),[4] around 0 °C affords 3,4-thiolanediols in good yields,[1c,e–g,k] while the reduction in refluxing THF gives 2,5-dihydrothiophenes.[1b,d,f] Thus, treatment of **2** with



Scheme 1.



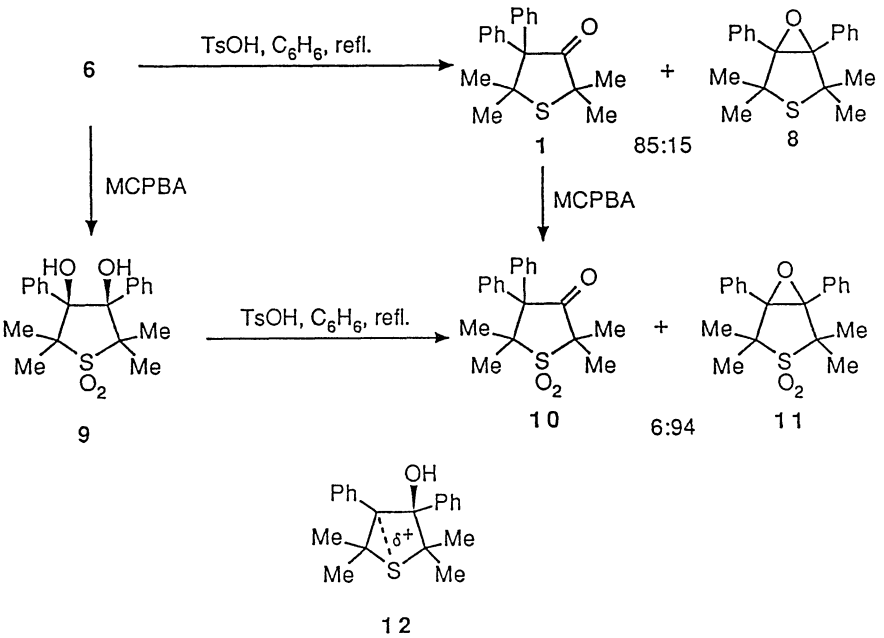
Scheme 2.

the low valent titanium reagent at room temperature affords the diol **6** in 45% yield, while the reduction in refluxing THF gives the dihydrothiophene **7** in 43% yield. Two hydroxyl groups of a number of thiolanediols prepared by the present method have a *cis*-configuration without any exception,[1e,g] and hence two hydroxyl groups of **6** must have a *cis*-configuration.

It is well documented that cyclic *cis*-1,2-diols undergo pinacol rearrangement more smoothly than the corresponding *trans*-1,2-diols do.[5] Thus, heating the diol **6** with a catalytic amount of *p*-toluenesulfonic acid (TsOH) in refluxing benzene for 2 h brings about a smooth pinacol rearrangement to give the expected ketone **1** (84%) in addition to the epoxide **8** (15%). Prolonged heating does not change the ratio of **1** to **8**, revealing that no rearrangement of **8** to **1** occurs under the applied conditions. Oxidation of **6** with 2.3 equiv of *m*-chloroperbenzoic acid (MCPBA) in dichloromethane at room temperature gives the sulfone **9** nearly quantitatively. The pinacol rearrangement of **9** is sluggish; heating **9** with TsOH in refluxing benzene for 5 h affords the ketone **10** only in 3% yield with 50% recovery of **9**, the main product being the epoxide **11** (38%). Oxidation of the ketone **1** with 2.2 equiv of MCPBA at room temperature gives the corresponding sulfoxide (24%) and the sulfone **10** (68%). No clear explanation for the difference of the ratio of ketones to epoxides produced from **6** and **9** is available. More smooth pinacol rearrangement of **6** may be ascribed to the difference of the conformation between **6** and **9** or the stabilization of the carbonium ion intermediate by the neighboring group participation of sulfur such as **12**.

Chemical Properties of 1. Reactivities toward nitrogen nucleophiles were first examined. Many sterically hindered ketones react with hydrazine in refluxing diethylene glycol to give the corresponding hydrazones in good yields.[6] However, **1** does not react with excess hydrazine under the above conditions (refl., 97 h), **1** being recovered nearly quantitatively. Heating **1** with *p*-toluenesulfonohydrazide in the presence of a catalytic amount of hydrochloric acid in refluxing ethanol for 54 h also did not bring about hydrazone formation, but unexpectedly afforded di-*p*-tolyl disulfide (4%) and *S*-*p*-tolyl *p*-toluenethiosulfonate (80%) with quantitative recovery of **1**. A separate experiment showed that heating the hydrazide alone under the above conditions gives the disulfide (32%) and thiosulfonate (48%). Although the mechanism of the reaction is not clear, this type of reaction seems unprecedented.

The ketone **1** is also inert to sulfur nucleophiles.



Scheme 3.

Heating **1** with excess Lawesson's reagent [2,4-bis(4-methoxyphenyl)1,3-dithia-2,4-diphosphetane-2,4-disulfide] in refluxing toluene for 12 h resulted in the quantitative revovery of **1** without formation of the corresponding thioketone. Treatment of **1** with 1,2-ethanedithiol in the presence of $BF_3 \cdot Et_2O$ in refluxing dichloromethane does not bring about dithioacetal formation.

Attempted reduction of **1** with sodium borohydride in refluxing THF resulted in the quantitative recovery of **1**. Lithium aluminum hydride reduced **1** to the corresponding alcohol **13** in 87% yield in THF at room temperature. This is the only example that a soomth reaction occurred at the carbonyl moiety.

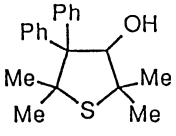
Reaction of **1** with excess butyllithium in THF at room temperature for 24 h affords the alcohol **13** in 28% yield with 52% recovery of **1**. The formation of **13** may best be explained by assuming a cyclic transition state mechanism **14**. Such mechanim is often encountered in reactions of sterically hindered nonenolizable ketones with Grignard reagents or organolithium reagents.[7] Thus, methylmagnesium bromide which does not carry a β hydrogen and hence cannot react with **1** by the above mechanism is inactive toward **1** in refluxing THF. The reaction of **1** with excess butylmagnesium bromide in refluxing THF for 27 h affords the dihydrothiophene **7** in 54% yield with 43% recovery of **1**. The most straightforward explanation for the above result involves the initial formation of **13**; dehydration of **13** accompanied by migration of phenyl should lead to **7**. However, neither action of butylmagnesium bromide on **13** nor heating **19** with TsOH in refluxing THF affords **7**. An alternative mechanism producing **7** may, therefore, be operative.

Metallation of α-alkyl substituent of nonenolizable ketones with lithium 2,2,6,6-tetramethylpiperidide (LTMP) was recently reported.[8] Treatment of **1** with excess LTMP afforded a complex mixture containing unreacted **1** (65%), no evidence for metallation of the methyl or phenyl being obtained.

Oxidation of **1** with excess MCPBA at room temperature affords a mixture of the corresponding sulfoxide and sulfone **10** as already described. Oxidation of **1** with a large excess of MCPBA catalyzed by TsOH in refluxing dichloromethane afforded **10** quantitatively; no product due to the Baeyer–Villiger oxidation was formed.

We therefore conclude that the carbonyl of **1** is inactive toward nucleophiles which are bulkier than hydride or its equivalent (butyllithium and probably butylmagnesium bromide). The observed inactivity must be ascribed to steric hindrance. Thus, two methyls on C-2 and two phenyls on C-4 interfere the approach of nucleophiles to the carbonyl carbon. At least, in the present system, phenyl behaves as a bulkier substituent than methyl because the ketone **15** and related ones are able to react with hydrazine,[6b–d] whereas **1** is not.[9] The steric hindrance must be further enhanced by the presence of two methyls on C-5; interaction between two phenyls and these two methyls makes the former substituents conformationally more rigid and inelastic ("buttressing" effect).[10] Incidentally the spacial interaction between carbonyl carbon and sulfur such as **16** is not appreciable and thus is not the cause of the inactivity. In ^{13}C NMR the carbonyl carbon of **1** occurs at δ=215 and that of **10** at δ=205. The observed difference is not the one expected from the presence of spacial interaction. In the IR spectrum the carbonyl stretching of **1** appears at 1728 cm^{-1}, the normal position as a five-membered ketone.[11]

X-Ray Single Crystal Structure Analysis of 1. Figure 1 shows an ORTEP drawing of the compounds **1**. The



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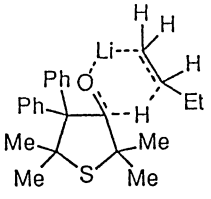

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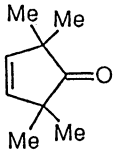

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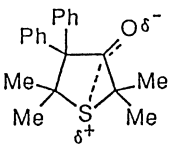

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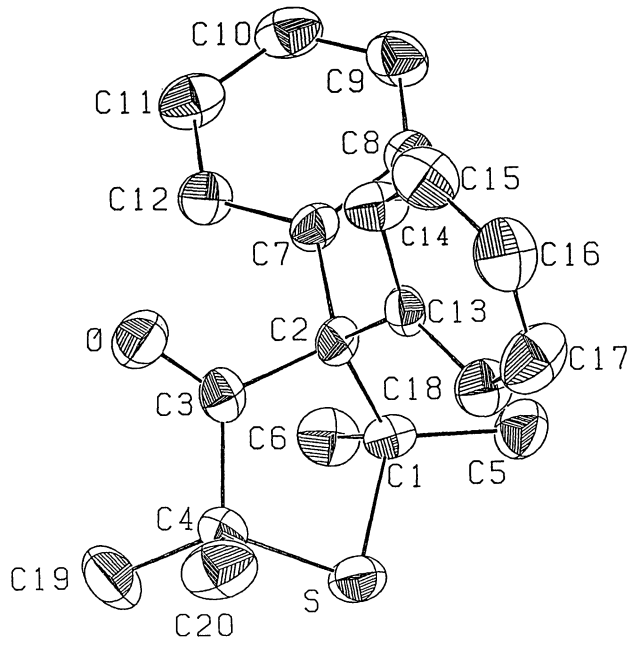

Fig. 1. An ORTEP drawing (Johnson) of compound **1**, showing the numbering scheme of the atoms (50% probability thermal ellipsoids).

Table 1. Final Atomic Coordinates ($\times 10^4$) and Equivalent Isotropic Thermal Parameters ($Å^2 \times 10^2$) with Estimated Standard Deviations in Parentheses

Atom	x	y	z	B_{eq} [a)]
S	3202(1)	314(1)	8376(1)	319(6)
O	2813(5)	−712(3)	5127(4)	401(23)
C1	2556(6)	−751(3)	8433(5)	257(25)
C2	3049(5)	−1202(3)	7305(5)	227(23)
C3	2949(6)	−554(3)	6232(6)	254(26)
C4	3128(6)	348(3)	6692(6)	277(25)
C5	3073(8)	−1113(4)	9741(6)	385(33)
C6	961(7)	−717(4)	8266(7)	345(30)
C7	2113(6)	−1964(3)	6933(5)	259(26)
C8	2336(7)	−2673(4)	7657(6)	295(28)
C9	1446(8)	−3343(4)	7469(7)	369(33)
C10	309(8)	−3315(4)	6511(7)	387(34)
C11	84(7)	−2629(4)	5741(7)	366(33)
C12	978(6)	−1958(4)	5961(6)	303(28)
C13	4600(6)	−1456(3)	7450(5)	238(24)
C14	4971(7)	−2036(4)	6602(7)	344(31)
C15	6344(8)	−2243(4)	6599(7)	411(36)
C16	7378(7)	−1874(5)	7456(8)	456(40)
C17	7036(8)	−1294(5)	8288(8)	476(40)
C18	5667(7)	−1078(4)	8281(6)	349(31)
C19	1857(9)	848(4)	6023(7)	482(39)
C20	4449(9)	717(5)	6352(7)	473(39)

a) $B_{eq}=1/3\sum_i\sum_j B_{ij}d_i^*d_j^*\boldsymbol{a}_i\cdot\boldsymbol{a}_j$.

Table 2. Bond Lengths and Angles with Estimated Standard Deviations in Parentheses

(a) Bond lengths (l/Å)			
S–C1	1.840(6)	C5–C1–C6	106.7(5)
S–C4	1.801(6)	C1–C2–C3	105.9(4)
O–C3	1.201(7)	C1–C2–C7	109.0(4)
C1–C2	1.562(8)	C1–C2–C13	118.2(4)
C1–C5	1.527(10)	C3–C2–C7	112.9(4)
C1–C6	1.538(9)	C3–C2–C13	100.8(4)
C2–C3	1.549(8)	C7–C2–C13	109.8(4)
C2–C7	1.545(8)	O–C3–C2	125.1(5)
C2–C13	1.550(8)	O–C3–C4	120.4(5)
C3–C4	1.543(8)	C2–C3–C4	114.4(4)
C4–C19	1.549(10)	S–C4–C3	106.0(4)
C4–C20	1.523(10)	S–C4–C19	111.8(4)
C7–C8	1.382(9)	S–C4–C20	111.5(4)
C7–C12	1.384(9)	C3–C4–C19	108.0(5)
C8–C9	1.382(10)	C3–C4–C20	110.4(5)
C9–C10	1.377(11)	C19–C4–C20	109.1(6)
C10–C11	1.380(10)	C2–C7–C8	119.2(5)
C11–C12	1.387(9)	C2–C7–C12	123.4(5)
C13–C14	1.401(9)	C8–C7–C12	117.3(5)
C13–C18	1.391(9)	C7–C8–C9	122.3(6)
C14–C15	1.382(10)	C8–C9–C10	119.3(7)
C15–C16	1.379(11)	C9–C10–C11	119.9(7)
C16–C17	1.377(12)	C10–C11–C12	119.8(6)
C17–C18	1.381(11)	C7–C12–C11	121.4(6)
		C2–C13–C14	118.1(5)
(b) Bond angles (ϕ/°)		C2–C13–C18	124.0(5)
C1–S–C4	96.2(2)	C14–C13–C18	117.6(5)
S–C1–C2	105.0(4)	C13–C14–C15	121.7(6)
S–C1–C5	109.2(4)	C14–C15–C16	119.4(7)
S–C1–C6	108.0(4)	C15–C16–C17	119.8(7)
C2–C1–C5	116.1(5)	C16–C17–C18	120.9(7)
C2–C1–C6	111.7(5)	C13–C18–C17	120.6(6)

numbering given in Fig. 1 is arbitrary and is not consistent with that of the IUPAC nomenclature. Final atomic coordinates and equivalent thermal parameters are summarized in Table 1. Bond lengths and bond angles are listed in Table 2. These results show that the five-membered ring of **1** is in a half-chair conformation. The longer bond length (1.562 Å) of the C1–C2 bond compared to usual sp^3–sp^3 carbon bonds reveals the presence of large nonbonded repulsion between two methyls on C1 and two phenyls on C2; length of the corresponding bond of the parent thiolane is 1.536 Å.[12] The bond angle C2–C3–O is as large as 125.1°, while the bond angle C4–C3–O is reduced to 120.4°. This indicates that the nonbonded repulsion mentioned above thrusts the phenyls to the carbonyl side, which in turn results in the repulsion between the phenyls and the carbonyl oxygen and thus expands the bond angle C2–C3–O. The repulsion between the carbonyl oxygen and the two methyls on C4 is avoidable by placing these groups in a noneclipsed conformation. This may agree with the fact that the C3–C4 bond (1.543 Å) is slightly shorter than the C2–C3 bond (1.549 Å). Also interesting is the fact that the S–C1 bond (1.840 Å) is longer than the S–C4 bond (1.801 Å). This probably means that the nonbonded repulsion between the phenyls on C2 and methyls on C1 thrusts the latters to the sulfur side, thus in turn making the nonbonded repulsion between the methyls and lone pair electrons on the sulfur large enough to lengthen the S–C1 bond. The C=O bond length (1.201 Å) seems to correspond to those of usual carbonyl compounds.[13] The C1–S–C4 bond angle (96.2°) is larger than the corresponding bond angle (93.4°) of the parent thiolane.[12] The distances between S and C3 and between S and O are 2.675(6) and 3.828(6) Å, respectively. The former value shows that the spacial interaction beween the sulfur and C3 is weak, if present.

Experimental

General. Melting points were measured on a MEL-TEMP capillary tube melting point apparatus and are uncorrected. IR spectra were taken on a Hitachi 270-50 spectrometer. ^{1}H NMR spectra were recorded on a JEOL PMX-60 or a JEOL FX-90Q spectrometer. ^{13}C NMR spectra were determined on a JEOL FX-90Q spectrometer. Chemical shifts are reported as δ values in parts per million relative to tetramethylsilane. Mass spectra (MS) were determined on a Shimadzu QP 1000 spectrometer. Column chromatography was conducted using E. Merck silica gel 60 (70—230 mesh). Tetrahydrofuran (THF) containing no stabilizer from a freshly opened bottle was dried over molecular sieves under nitrogen. Other materials were used as purchased unless otherwise noted. Elemetnal analyses of all new compounds were performed by the chemical analysis center of Saitama University and are consistent with the calculated values within ±0.30%.

2,2,4,4-Tetramethyl-1,5-diphenyl-3-thiapentane-1,5-dione (2). To a stirred and ice-cooled mixture of 25.1 g (0.17 mol)

of isobutyrophenone and a catalytic amount of aluminum chloride (ca. 0.3 g) in 170 ml of ether was added 27.1 g (0.17 mol) of bromine over a period of 1.5 h. After stirring for 0.5 h at room temperature the reaction was quenched by adding 300 ml of ice-water. The organic layer was separated, washed with water, dried over anhydrous magnesium sulfate, and evaporated to give 38.0 g of the crude bromide **4**.

The bromide thus obtained was dissolved in 170 ml of hexane and then mixed with a solution of 93.0 g (0.38 mmol) of sodium sulfide nonahydrate in 170 ml of water. The addition of 2 ml of methyltrioctylammonium chloride under stirring to the above two-phase mixture brought about a mildly exothermic reaction. After stirring for 6 h at room temperature the white crystals deposited were collected by filtration, washed with 20 ml of hexane and then with 20 ml of water, and dried to give 14.6 g of **2**, mp 98.5—99 °C. The filtrate and washings were combined and then the organic layer was separated, washed with water, dried, and evaporated. The residue was recrystallized from methanol to give 2.1 g of **2**, mp 99 °C (combined yield 60%, based on isobutyrophenone). **2**: ^{1}H NMR ($CDDCl_3$) δ=1.55 (12H, s, Me), 7.1—7.7 (6H, m, phenyl), 7.9—8.4 (4H, m, phenyl); MS m/z 326 (M^+). Anal. ($C_{20}H_{22}O_2S$) C, H.

2,2,5,5-Tetramethyl-1,6-diphenyl-3,4-dithiahexane-1,6-dione (3). The crude bromide **4** (22.7g, 0.1 mmol) obtained as above was dissolved in 130 ml of ethanol. To this ice-cooled and stirred solution was added a solution of 12.3 g (51 mmol) of sodium sulfide nonahydrate in 25 ml of water over a period of 0.5 h. The mixture was warmed to room temperature and stirred for 3 h. The resulting crystalline precipitate was collected by filtration, washed with water and then with 10 ml of methanol, and dried to give 7.4 g (41%) of **3**. Analyses of the filtrate by TLC and ^{1}H NMR revealed the formation of isobutyrophenone in a considerable amount. Analytically pure **3** was obtained by recrystallization from methanol: mp 59.5—60 °C; ^{1}H NMR ($CDCl_3$) δ=1.50 (12H, s, Me), 7.1—7.5 (6H, m, phenyl), 7.8—8.1 (4H, m, phenyl); MS m/z 358 (M^+), 179 (base peak). Anal. ($C_{20}H_{22}O_2S_2$)C,H.

2,2,5,5-Tetramethyl-3,4-diphenylthiolanethiolane-3,4-diol (6). To a stirred and ice-cooled suspension of 6.0 g (92 mmol) of zinc powder in 100 ml of THF was added 5 ml (46 mmol) of titanium(IV) chloride during 0.5 h. Alter stirring for 0.5 h at that temperature, a solution of 3.27 g (10 mmol) of the sulfide **2** in 70 ml of THF was added over a period of 0.5 h. The mixture was slowly warmed to room temperature and stirred for 12 h. The reaction was quenched by adding a sufficient amount of ice and a 10% aqueous sodium carbonate solution (100 ml). Dichloromethane (200 ml) was added and the mixture was stirred for 15 min and filtered through a pad of celite. The organic layer was separated, washed with water repeatedly, dried over anhydrous magnesium sulfate, and evaporated. The residue was recrystallized from hexane to afford 0.76 g of **6**, mp 128—129 °C. Purification of the mother liquor of recrystallization by silica-gel column chromatography gave a further amount (0.74 g) of **6**. Total yield, 45% (1.50 g). **6**: IR (KBr) 3556, 3512 cm^{-1} (OH); ^{1}H NMR ($CDCl_3$) δ=1.27 (6H, s, Me), 1.73 (6H, s, Me), 3.41 (2H, s, OH), 6.9—7.6 (10H, m, phenyl). Anal. ($C_{20}H_{24}O_2S$) C, H.

2,2,5,5-Tetramethyl-3,4-dipheyl-2,5-dihydrothiophene (7). A low valent titanium reagent was prepared from 10 ml (92 mmol) of titanium(IV) chloride and 12 g (184 mmol) of zinc powder in 150 ml of THF. A solution of 6.53 g (20 mmol) of **2** in 60 ml of THF was added dropwise to the above reagent which was stirred and cooled by an ice-salt bath. The mixture was slowly warmed to room temperature and then refluxed for 2 h. Treatment of the mixture in a manner silmilar to that described above gave 2.52 g (40%) of **7**: Mp 163—164 °C (from methanol); ^{1}H NMR ($CDCl_3$) δ=1.56 (12H, s, Me), 7.03 (10H, broad s, phenyl). Anal. ($C_{20}H_{22}S$) C, H.

Pinacol Rearrangment of 6. A mixture of 328 mg (1 mmol) of **6** and 30 mg of *p*-toluenesulfonic acid monohydrate in 30 ml of benzene was refluxed for 2 h. The mixture was evaporated and the residue was chromatographed on a column of silica gel. Elution with carbon tetrachloride gave 261 mg (84%) of 2,2,5,5-tetramethyl-4,4-diphenyl-3-thiolanone (**1**), 47 mg (15%) of 3,4-epoxy-2,2,5,5-tetramethyl-3,4-diphenylthiolane (**8**), and a trace amount of **6** in this order. Prolonged heating (reflux for 6.5 h) also afforded **1** and **8** in 85 and 14.5% yields, respectively, indicating that no rearrangement of **8** to **1** occurs under the applied conditions.

1: Mp 154 °C (from methanol); IR (KBr) 1728 cm^{-1} (C=O); ^{1}H NMR ($CDCl_3$) δ=1.36 (12H, s, Me), 7.13—7.34 (6H, m, phenyl), 7.39—7.59 (4H, m, phenyl); ^{13}C NMR ($CDCl_3$) δ= 29.5, 31.6, 49.5, 54.6, 71.6, 126.8, 127.4, 131.6, 140.9, 214.5 (C=O). Anal. ($C_{20}H_{22}OS$) C, H.

8: Mp 178—179 °C (from ethanol); ^{1}H NMR ($CDCl_3$) δ=1.37 (6H, s, Me), 1.64 (6H, s, Me), 6.96—7.47 (10H, m, phenyl). Anal. ($C_{20}H_{22}OS$)C, H.

Preparation of 9 and Its Acid-Catalyzed Rearrangement. A mixture of 658 mg (2 mmol) of the diol **6** and 781 mg (4.5 mmol) of MCPBA (Tokyo Kasei) in 20 ml of dichloromethane was stirred at room temperature for 4 h. The mixture was diluted with 50 ml of dichloromethane, washed with a 10% aqueous solution of sodium hydrogensulfite, a 10% aqueous solution of sodium carbonate, and water, dried over magnesium sulfate, and evaporated. Purification of the resulting crystalline residue with a short column of silica gel using dichloromethane as the eluent gave 703 mg (98%) of 3,4-dihydroxy-2,2,5,5-tetramethyl-3,4-diphenylthiolane 1,1-dioxide (**9**): Mp 169—171 °C (from cyclohexane); IR (KBr) 3404 (OH), 1268, 1102 cm^{-1} (SO_2); ^{1}H NMR ($CDCl_3$) δ=1.42 (6H, s, Me), 1.64 (6H, s, Me), 3.98 (2H, s, OH), 6.95—7.35 (10H, m, phenyl). Anal. ($C_{20}H_{24}O_4S$) C, H.

A mixture of 360 mg (1 mmol) of **9** and 30 mg of *p*-toluenesulfonic acid monohydrate in 30 ml of benzene was heated under reflux for 5 h. The mixture was evaporated and the residue was chromatographed on a column of silica gel. Elution with dichloromethane gave 8.6 mg (2.5%) of 2,2,5,5-tetramethyl-4,4-diphenyl-3-thiolanone 1,1-dioxide (**10**), 131 mg (38%) of 3,4-epoxy-2,2,5,5-tetramethyl-4,4-diphenylthiolane 1,1-dioxide (**11**), and 182 mg (50%) of **9** in this order.

10: Mp 191—192 °C (from cyclohexane); IR (KBr) 1738 (C=O), 1296, 1108 cm^{-1} (SO_2); ^{1}H NMR ($CDCl_3$) δ=1.41 (6H, s, Me), 1.48 (6H, s, Me), 7.1—7.7 (10H, m, phenyl); ^{13}C NMR ($CDCl_3$) δ=22.6, 22.9, 23.9, 24.3, 62.0, 66.7, 71.6, 126.1, 129.2, 132.3, 139.4, 207.5 (C=O). Anal. ($C_{20}H_{22}O_3S$) C, H.

11: Mp 259—260 °C (from EtOH); IR (KBr) 1298, 1108 cm^{-1} (SO_2); ^{1}H NMR ($CDCl_3$) δ=1.42 (6H, s, Me), 1.61 (6H, s, Me), 7.0—7.4 (10H, m, phenyl); ^{13}C NMR ($CDCl_3$) δ=18.0, 23.3, 62.9, 74.9, 127.6, 128.4, 128.6, 131.1. Anal. ($C_{20}H_{22}O_3S$) C, H.

Oxiation of 1 with MCPBA. To a stirred solution of 162 mg (0.52 mmol) of **1** in 10 ml of dichloromethene was added 197 mg (1.15 mmol) of MCPBA in small portions. After stirring at room temperature for 21 h, the mixture was washed

with a 10% aqueous sodium hydrogensulfite solution, a 10% aqueous sodium carbonate solution, and water, dried over magnesium sulfate, and evaporated. The residue was chromatographed on a column of silica gel. Elution with dichloromethane gave 122 mg (68%) of the sulfone **10**, which is identical with that obtained by the acid-catalyzed rearrangement of **9** in every respect. Further elution with the same solvent gave 41 mg (24%) of 2,2,5,5-tetramethyl-4,4-diphenyl-3-thiolanone 1-oxide: Mp 167 °C (from hexane); ^{1}H NMR ($CDCl_3$) δ=1.06 (3H, s, Me), 1.10 (3H, s, Me), 1.40 (3H, s, Me), 1.62 (3H, s, Me), 7.05—7.62 (10H, m, phenyl). Anal. ($C_{20}H_{22}O_2S$) C, H.

A mixture of 156 mg (0.5 mmol) of **1**, 363 mg (2 mmol) of MCPBA, and 10 mg of *p*-toluenesulfonic acid monohydrate in 20 ml of dichloromethane was stirred for several hours at room temperature and then refluxed for 32 h. Workup of the mixture gave the sulfone **10** quantitatively; no product arising from Baeyer–Villiger oxidation was detected.

Attempted Reactions of 1 with Nitrogen Nucleophiles. a) With Hydrazine. A mixture of 621 mg (2 mmol) of **1** and 1.25 ml (25.7 mmol) of hydrazine monohydrate in 10 ml of diethylene glycol was heated under reflux for 97 h. Usual workup of the resulting dark brown mixture afforded **1** in 97% yield.

b) *p*-Toluenesulfonohydrazide. A mixture of 546 mg (1.76 mmol) of **1**, 376 mg (2 mmol) of *p*-toluenesulfonohydrazide, and three drops of concentrated hydrochloric acid in 15 ml of 95% ethanol was refluxed for 54 h. The mixture was cooled and the resulting crystalline precipitate was collected by filtration to give 76% recovery of **1**. The filtrate was evaporated under reduced pressure and the residue was chromatographed on a column of silica gel. Elution with carbon tetrachloride gave 9 mg (3.7%) of di-*p*-tolyl disulfide, mp 44—45 °C, 101 mg (18.5%) of **1**, and 224 mg (80%) of *S*-*p*-tolyl *p*-toluenethiosulfonate, mp 74 °C (lit,[14] mp 76 °C), in this order.

In a separate experiment a mixture of 374 mg (2 mmol) of *p*-toluenesulfonohydrazide and three drops of concentrated hydrochloric acid in 15 ml of 95% ethanol was refluxed for 54 h. Chromatographic workup of the mixture gave the disulfide and thiosulfonate in 32 and 48% yields, respectively.

Attempted Reactions of 1 with Sulfur Nucleophiles. a) With Lawesson's Reagent. A mixture of 155 mg (0.5 mmol) of **1** and 1.03 g (2.5 mmol) of freshly prepared Lawesson's reagent in 10 ml of anhydrous toluene was refluxed for 12 h under nitrogen. Workup of the mixture gave **1** quantitatively.

b) With 1,2-Ethanedithiol. A mixture of 155 mg (0.5 mmol) of **1**, 377 mg (4 mmol) of 1,2-ethanedithiol, and 0.2 ml of boron trifluoride etherate in 5 ml of dichloromethane was refluxed for 12 h. Chromatographic workup of the mixture gave **1** quantitatively.

Hydride Reduction of 1. a) With Sodium Borohydride. To a stirred and ice-cooled solution of 226 mg (0.73 mmol) of **1** in 5 ml of THF was added 100 mg (2.7 mmol) of sodium borohydride. The mixture was warmed to room temperature and then refluxed for 8 h. Usual workup of the mixture gave **1** quantitatively.

b) With Lithium Aluminum Hydride. To a stirred and ice-cooled solution of 155 mg (0.5 mmol) of **1** in 5 ml of anhydrous THF was added 100 mg (2.6 mmol) of lithium aluminum hydride. The mixture was stirred for 0.5 h at that temperature, warmed to room temperature, and stirred for 3.5 h. The reaction was quenched by addition of wet THF and then water. The mixture was extracted with ether. The extract was washed with water, dried over anhydrous magnesium sulfate, and evaporated. The residue was chromatographed on a column of silica gel. Elution with benzene gave 5.4 mg of an unidentified product and then 135 mg (87%) of 2,2,5,5-tetramethyl-4,4-diphenyl-3-thiolanol (**13**):Mp 124 °C (from hexane); IR (KBr) 3560 cm^{-1} (OH); ^{1}H NMR ($CDCl_3$) δ=0.83 (3H, s, Me), 1.09 (3H, s, Me), 1.61 (3H, s, Me), 1.67 (3H, s, Me), 1.45 (1H, d, *J*=13Hz, OH), 5.14 (1H, d, *J*=13Hz, methine), 7.06—7.54 (8H, m, phenyl), 7.54—8.01 (2H, m, pheyl); ^{13}C NMR ($CDCl_3$) δ=23.6, 24.1, 35.8, 36.1, 49.6, 51.9, 66.4, 81.9, 126.6, 127.1, 127.8, 128.8, 133.8, 134.0, 139.8, 145.0. Anal. ($C_{20}H_{24}OS$) C, H.

Reactions of 1 with Organometallic Reagents. a) With Butyllithium. To a stirred and ice-cooled solution of 311 mg (1 mmol) of **1** in 5 ml of anhydrous THF was added 1.26 ml (2 mmol) of 1.59 M (1M=1 mol dm^{-3}) solution of butyllithium in hexane under nitrogen. The mixture was slowly warmed to room temperature and stirred for 24 h. The reaction was quenched by addition of wet THF and then water. The mixture was extracted with water, dried over anhydrous magnesium sulfate, and evaporated. Silica-gel column chromatography of the residue with carbon tetrachloride as the eluent gave **1** (52%), 88 mg (28%) of **13**, and three unidentified compounds in small amounts.

b) With Methylmagnesium Bromide. To a solution of 311 mg (1 mmol) of **1** in 5 ml of anhydrous THF was added 0.67 ml (2 mmol) of 3 M solution of methylmagnesium bromide in ether under nitrogen. The mixture was stirred for 2 h at room temperature and then refluxed for 15 h. Usual workup of the mixture gave **1** in 99% yield.

c) With Butylmagnesium Bromide. To a stirred and ice-cooled butylmagnesium bromide solution, prepared from 766 mg (5.6 mmol) of butyl bromide and 122 mg (5 mmol) of magnesium in 3 ml of THF, was added a solution of 303 mg (0.98 mmol) of **1** in 2 ml of THF under nitrogen. The mixture was slowly warmed to room temperature and then refluxed for 27 h. The reaction was quenched by addition of wet THF and then water. The mixture was extracted with ether. The extract was washed with water, dried over anhydrous magnesium sulfate, and evaporated. The residue was chromatographed on a column of silica gel. Elution with carbon tetrachloride afforded 126 mg (44%) of **7**, 109 mg of a mixture of **7** and **1** in the ratio 1 : 2.6, and 50 mg of **1**. The compound **7** obtained above is identical with that prepared by reductive coupling of **2** in every respect.

Neither action of excess butymagnesium bromide on **13** in refluxing THF for 27 h nor heating **13** with *p*-toluenesulfonic aicd monohydrate in refluxing THF for 11 h gave any **7**, **13** being recovered quantitatively.

d) With Lithium 2,2,6,6-Tetramethylpiperidide. The reagent was prepared by addition of 1.6 ml (2.54 mmol) of 1.59 M solution of butyllithium in hexane to a stirred and ice-cooled solution of 2.5 mmol of 2,2,6,6-tetramethylpiperidine in 12 ml of hexane under nitrogen.[15] To this reagent was added 155 mg (0.5 mmol) of **1** all at once. The mixture was slowly warmed to room temperature and heated under reflux for 24 h. Column chromatographic workup of the mixture allowed the isolation of several unidetified products in minute amounts and **1** in 65% yield.

X-Ray Crystal Structure Analysis of 1. A colorless crystal of **1** with dimensions of ca. 0.2×0.2×0.1 mm^3 was mounted on a Rigaku AFC-6 automated diffractometer. Systematic

absences were consistent with the space group $P\,2_1/c$. The intensity data were measured by means of ω-2θ of 60° by using graphite-monochromated Mo $K\alpha$ radiation (λ=0.7107 Å). Usual corrections were made for Lorentz and polarization effects, but no absorption correction was applied. Independent reflections with $|F_o|>4\sigma(F_o)$, 1901 reflections, were used for the structural determination.

Crystal Data: $C_{20}H_{22}OS$, F.W.=310.5, monoclinic, $P2_1/c$, a=9.764(3), b=16.174(9), c=10.755(6) Å, β=100.04(3)°, V=1672 Å^3, Z=4, D_x=1.233 g cm^{-3}, μ(Mo $K\alpha$)=1.84 cm^{-1}. The structure was solved by the direct method (MULTAN 78).[16] Positions of H atoms were fixed at calculated positions (with C-H=1.08 Å) with fixed isotropic temperature factors (B=5.0. Å^2). The structure was refined anisotropically for non-H atoms and isotropically for H atoms by full-matrix least squares method. The final discrepancy factors were R=0.090 and R_w=0.052 [w=$(\sigma^2(F_o)+0.14722|F_o|-0.0015|F_o|^2)^{-1}$], and $(\Delta/\sigma)_{max}$ in the final refinement cycle was 0.01. The scattering factors were taken from Ref 17. The calculations were carried out on a HITAC M-680H computer at the computer room of The National Defense Academy, using UNICS-Nagoya.[18,19]

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