IR 3420 (NH), 3150-2460 (OH), 1680 (CO), 1220 (CF) cm^{-1}. Anal. Calcd for $C_{14}H_7NO_4F_{14}$: C, 32.37; H, 1.35. Found: C, 32.46; H, 1.37.

2,5-Diiodo-3,4-bis(1*H*,1*H*-heptafluorobut-1-yl)pyrrole (6). Precautions against direct illumination should be taken during all the following operations. A solution of I_2 (3.0 g) and NaI (3.2 g) in water (14 mL) was added to a flask wrapped in aluminum foil and charged with **5** (1.0 g, 1.93 mmol) and $NaHCO_3$ (1.5 g) in water (40 mL) and $ClCH_2CH_2Cl$ (40 mL). The two-phase mixture was stirred under a nitrogen atmosphere at 25 °C for 48 h. $NaHSO_3$ was added slowly until the red color dissipated, and the solution was extracted with CH_2Cl_2. The combined organic fractions were dried over anhydrous Na_2SO_4 and concentrated on a rotatary evaporator, yielding 1.27 g (97%) of **6** as a slightly red solid. This product appeared quite pure by NMR and TCL and was used directly in the preparation of **7** and **4a**. An analytical sample was obtained by recrystallization from petroleum ether (30-60 °C) at -10 °C: mp 78-82 °C dec; ^1H NMR δ 3.28 (4 H, t, J = 19.0 Hz), 8.25 (1 H, br s); ^{13}C NMR δ 29.13 (t, J = 23.1 Hz), 72.29, 109.14 (tqm, J = 264.2, 38.9, ~2 Hz), 116.90 (tt, J = 253.4, 30.5 Hz), 118.07 (qt, J = 290.8, 34.2 Hz), 119.02; mass spectrum, m/e (relative intensity) 683 (58, M^+), 514 (78), 345 (23), 268 (51), 114 (34), 69 (100); IR 3470 (NH), 1230 (CF) cm^{-1}. Anal. Calcd for $C_{12}H_5NF_{14}I_2$: C, 21.08; H, 0.73. Found: C, 21.45; H, 0.80.

3,4-Bis(1*H*,1*H*-heptafluorobut-1-yl)pyrrole (7). A suspension of **6** (1.60 g, 2.34 mmol), zinc dust (1.00 g), NH_4Cl (1.60 g), and 95% EtOH (40 mL) was stirred under a nitrogen atmosphere at 75 °C for 15 h. The excess zinc was filtered and washed with CH_2Cl_2 (20 mL). The filtrate was diluted with water (100 mL) and extracted with CH_2Cl_2. The combined organic fractions were dried over anhydrous Na_2SO_4 and concentrated, yielding 0.98 g (98%) of **7** as a pale yellow oil. This product appeared quite pure by NMR and TLC and was used directly in the prepartion of **4a**: ^1H NMR δ 3.24 (4 H, t, J = 19.5 Hz), 6.77 (2 H, d, J = 2.75 Hz), 8.22 (1 H, br s); ^{13}C NMR δ 27.22 (t, J = 23.8 Hz), 109.62 (tqm, J = 263.6, 37.9, ~2 Hz), 110.76, 116.78 (tt, J = 252.5, 30.5 Hz), 118.37 (qt, J = 287.6, 34.2 Hz), 119.53; mass spectrum, m/e (relative intensity) 431 (14, M^+), 412 (8), 262 (100), 142 (15), 93 (31), 69 (39); IR (neat) 3500 (NH), 1220 (CF) cm^{-1}.

Octakis(1*H*,1*H*-heptafluorobut-1-yl)porphyrin (4a) Prepared from 6. A solution of **6** (1.19 g, 1.74 mmol), 37% formaldehyde (8.0 mL), and 48% HBr (2.5 mL) in 1-propanol (70 mL) was heated at 100 °C for 35 h. The mixture was cooled and suction filtered. Recrystallization from acetone gave 0.238 g (31%) of **4a**. The filtrate was allowed to stand in a large open beaker for 14 days. Filtration and recrystallization from acetone gave another 0.030 g (4%) of **4a**.

Octakis(1*H*,1*H*-heptafluorobut-1-yl)porphyrin (4a) Prepared from 7. A solution of **7** (0.78 g, 1.80 mmol), 37% formaldehyde (7.0 mL), and 48% HBr (1.6 mL) in 1-propanol (60 mL) was heated 100 °C for 48 h. The mixture was allowed to stand in a large open beaker for 21 days. Filtration of the reaction mixlture and recrystallization from acetone gave 0.240 g (30%) of **4a**.

Registry No. **1**, 625-84-3; **2a**, 83650-62-8; **2b**, 83664-26-0; **3a**, 83650-63-9; **3b**, 83650-70-8; **3c**, 83650-71-9; **3d**, 83650-72-0; **3e**, 83650-64-0; **4a**, 83650-65-1; **4b**, 83650-66-2; **5a**, 83650-67-3; **6**, 83650-68-4; **7**, 83650-69-5; heptafluorobutyraldehyde, 375-02-0; trifluoroacetaldehyde, 75-90-1; formaldehyde, 50-00-0.

Cycloaddition Reactions of 3-(Phenylthio)-3-buten-2-one: Synthesis of Functionalized Dihydropyran Derivatives and Their Ring-Opening Reactions

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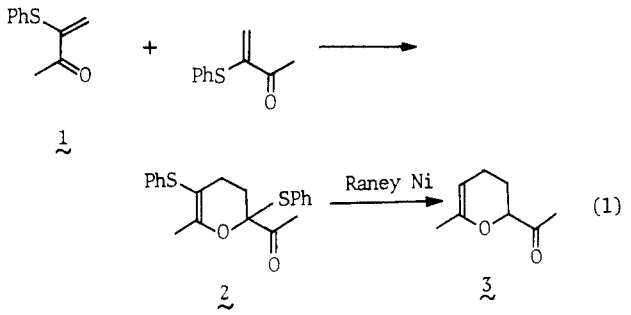
3-(Phenylthio)-3-buten-2-one (**1**) reacted with nucleophilic olefins such as vinyl ethers, vinyl sulfide, and enamine to give 1,4-cycloaddition products and/or Michael adducts **7-17** in fairly good yields. Treatment of 2-acetyl-2,5-bis(phenylthio)-3,4-dihydro-6-methyl-2*H*-pyran (**2**) with various acids or mercury(II) chloride gave the cyclopentanone **19**. In addition, the dimer **2** was converted into 3-(phenylthio)-7-octene-2,6-dione (**23**) by the three steps.

1,4-Cycloaddition reactions of hetero dienes have attracted considerable attention from both synthetic and mechanistic standpoints. Particularly, α,β-unsaturated carbonyl compounds have been utilized in the synthesis of dihydropyrans.[1] However, little is known about reactivities of the enones substituted with functional groups in spite of the likely versatility of the expected adducts. In the course of our studies on annelation reactions,[2] we found that 3-(phenylthio)-3-buten-2-one (**1**) could be quantitatively dimerized and desulfurized to give 2-acetyl-3,4-dihydro-6-methyl-2*H*-pyran (**3**, eq 1). These results prompted us to examine the reactivities of the butenone **1** as a hetero diene with the intent to prepare



(1)

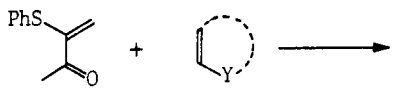
dihydropyrans **5** and/or γ,δ-unsaturated ketones **6** (eq 2). We report here the reaction of 3-(phenylthio)-3-buten-2-one (**1**) with olefinic compounds **4** and the ring opening reactions of the adducts, especially the dimer **2**.

The butenone **1** was treated with ethyl vinyl ether in an autoclave to give 3,4-dihydro-2-ethoxy-6-methyl-5-(phe-

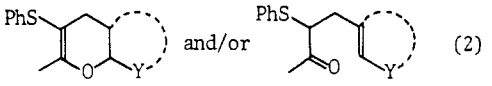
(1) For a review, see: Desimoni, G.; Tacconi, G. *Chem. Rev.* **1975**, *75*, 651.

(2) Takaki, K.; Okada, M.; Yamada, M.; Negoro, K. *J. Org. Chem.* **1982**, *47*, 1200.

0022-3263/82/1947-5246$01.25/0



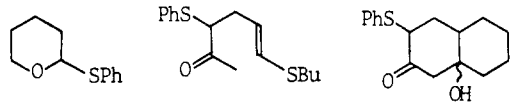
1 4 Y=O,S,N



5 6 (2)

nylthio)-2*H*-pyran (**7**) in 95% yield (Table I). Similarly, the tetrahydrofuro[2,3-*b*]pyran **8** was obtained in the reaction with dihydrofuran as a mixture of trans and cis isomers in a ratio of 1:1.4 (entry 2). The NMR spectrum of **8** shows two signals of the acetal methine proton at 5.13 and 5.46 ppm, assignable to trans and cis isomers, respectively, on the basis of their coupling constants.[3]

The reaction with dihydropyran was complicated and gave unstable products **9** and **10**, depending on the reaction conditions (entries 3 and 4). The products **9** and **10** readily decomposed to give finally 2-(phenylthio)tetrahydropyran (**11**), which was obtained exclusively in the same reaction



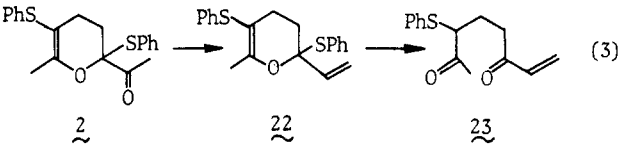
11 13 16

at higher temperature.[4] The butenone **1** reacted with butyl vinyl sulfide to give the expected dihydropyran **12** in 81% crude yield (entry 5); however, pure samples were not obtained because elimination to unsaturated ketone **13** occurred in the course of preparative GLC. While the IR spectrum of **12** displays vinyl ether absorptions at 1640 and 1070 cm^{-1}, that of **13** shows a carbonyl at 1710 cm^{-1} and a vinyl sulfide at 1600 cm^{-1}.

The reaction of **1** with 1-(*N*-morpholino)-1-cyclohexene at room temperature gave the primary adduct, dihydropyran **14** (entry 6), which was readily changed to diketone **15** (a mixture of diastereomers) and ketol **16** (trans/cis, 2:1) in 48% and 10% yields, respectively, by gentle heating.[5] The diketone **15** was also obtained predominantly in the same reaction at 60 °C (entry 7). Furthermore, Michael adduct **17** was formed in 94% yield in the reaction with pyrrole (entry 8). In contrast to the nucleophilic olefins described above, any effort to react **1** with methyl acrylate was unsuccessful, providing only the dimer **2** and diphenyl disulfide.

The adducts from **1** have potentialities as synthetic building blocks; in particular, the dimer **2** can be considered as a masked triketone system, and we have examined the ring-opening reaction of **2** to test this possibility. When the dimer **2** was treated with various acids with the hope that 6-(phenylthio)octane-2,3,7-trione (**18**) would be formed, 3-acetyl-2-hydroxy-2-methyl-3-(phenylthio)cyclopentanone (**19**) was obtained as a mixture of cis and trans isomers instead of **18** (Scheme I); **19** was also formed by treatment with mercury(II) chloride. These results are summarized in Table II. The structure of **19** was determined by spectral data and elemental analyses. Furthermore, treatment of **19** with Raney Ni afforded 3-acetyl-2-methyl-2-cyclopentenone (**20**) in 89% yield. Oxidation of **19** with *m*-chloroperbenzoic acid and subsequent elimination of the sulfinyl group gave 3-acetyl-2-hydroxy-2-methyl-3-cyclopentenone (**21**) in 65% yield. It was not settled with certainty which isomer is cis or trans since recrystallization of the mixture gave the major isomer but analytically pure minor product was not obtained. The cyclopentanone **19** could be derived from the triketone **18** generated by hydrolysis of **2**. The alternative cyclization of **18** to give a cyclohexanone was not found, probably owing to the phenylsulfenyl group.[6]

It is well-known that 7-octene-2,6-dione derivatives are fundamental units for bisannelation reactions, and some useful synthons have been developed.[7] The results mentioned above suggested that if the dimer **2** was converted into vinylpyran **22**, its ring-opening reaction would afford 7-octene-2,6-dione derivative **23** (eq 3). Reduction



2 22 23 (3)

of **2** with lithium aluminum hydride and subsequent treatment with *p*-toluenesulfonyl chloride gave the tosylate **25a** in 81% yield (Scheme II). The vinylpyran **22**, however, was not obtained by the treatment with potassium *tert*-butoxide under standard conditions,[8] affording diphenyl disulfide and unknown product. Degradation of the tosylhydrazone of **2** was also unsuccessful.[9]

Bromination of **24** with phosphorus tribromide in the presence of pyridine gave 3,4-dihydro-2-hydroxy-6-methyl-5-(phenylthio)-2-[1-(phenylthio)ethyl]-2*H*-pyran (**26**) and 3,7-bis(phenylthio)octane-2,6-dione (**27**) in 47% and 41% yields, respectively; no brominated product was detected. The mass spectra of **26** and **27** exhibit the parent peaks at *m/e* 358. The IR spectrum of **26** shows a vinyl ether absorption at 1640 cm^{-1}, and that of **27** shows two carbonyls at 1705 and 1695 cm^{-1}. Of course, the pyran **26** was readily hydrolyzed to give the diketone **27**. The unexpected products **26** and **27** are apparently formed by the migration of the phenylsulfenyl group at C-2 via an episulfonium ion intermediate.[10]

Oxidation of the diketone **27** with 2 equiv of *m*-chloroperbenzoic acid and subsequent elimination of the sulfinyl groups resulted in the formation of diphenyl disulfide and polymeric tar under various conditions.[11] In contrast, similar treatment with an equimolar amount of the oxidant afforded the desired enone **23** in 54% yield, and formation of other isomers was not observed by GLC and ^1H NMR.

In summary, 3-(phenylthio)-3-buten-2-one (**1**) is applicable as a hetero diene to the reaction with nucleophilic olefins, affording functionalized dihydropyrans and γ,δ-unsaturated ketones in fairly good yields. Of the adducts, the dimer of the enone **1** is a useful precursor for 3-

(3) Formation of the mixture would be accounted for by a two-step mechanism most likely via a zwitterionic intermediate or by a concerted mechanism involving an asymmetrical transition state: Desimoni, G.; Cellerino, G.; Minoli, G.; Tacconi, G. *Tetrahedron* **1972**, *28*, 4003.

(4) The mechanism of the formation of **11** is now ambiguous.

(5) The compounds **15** and **16** should be formed by hydrolysis of **14** probably during the workup.

(6) Formation of cyclopentanones has been observed in the cyclization of the 2,3,7-triketone system: Danishefsky, S.; Zamboni, R.; Kahn, M.; Etheredge, S. J. *J. Am. Chem. Soc.* **1980**, *102*, 2097.

(7) (a) Tsuji, J.; Shimizu, I.; Suzuki, H.; Naito, Y. *J. Am. Chem. Soc.* **1979**, *101*, 5070. (b) Danishefsky, S.; Cain, P.; Nagel, A. *Ibid.* **1975**, *97*, 380.

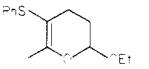
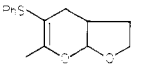
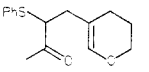
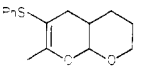
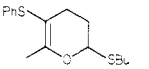
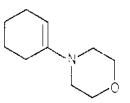
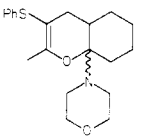
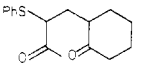
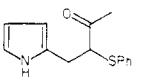
(8) Malherbe, R.; Bellus, A. *Helv. Chim. Acta* **1978**, *61*, 3096.

(9) Kolonko, K. J.; Shapiro, R. H. *J. Org. Chem.* **1978**, *43*, 1404.

(10) Warren, S. *Acc. Chem. Res.* **1978**, *11*, 401.

(11) Even if in the presence of *N*-morpholino-1-cyclohexene, only 2-(phenylthio)cyclohexanone was detected.

Table I. Reactions of 3-(Phenylthio)-3-buten-2-one (1) with Olefins

entry	olefin	temp, °C	time, h	product	yield,[a] %
1		180	3	 **7**	95
2		180	19.5	 **8**[b]	68
3		155	15	 **9**	80
4		180	20.5	**9** +  **10**	50 + 40
5		160	8	 **12**	81
6		*d*	24	 **14**	>58[c]
7		60	23	 **15**	94
8		*d*	2	 **17**	94

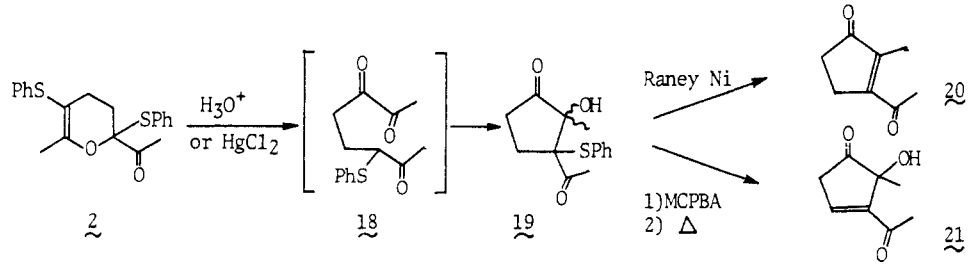
[a] Yields were determined by GLC. [b] A mixture of trans and cis (1:1.4). [c] Yield was based on the rearranged products. [d] Room temperature.

Table II. Synthesis of the Cyclopentanone 19 from the Dihydropyran 2

catalyst	eq. mol	solvent	temp, °C	time, h	yield,[a] %	ratio of isomers[b]
HCl	0.03	EtOH	room temp	0.5	*c*	
HCl	1.0	EtOH	reflux	6.5	64	1:3
PTS	1.0	EtOH	reflux	26	*d*	
CF_3CO_2H	3.0	C_6H_6	50	2.5	80	1:6
$HgCl_2$	2.0	CH_3CN-H_2O	reflux	16	46	1:1

[a] Yields of isolated product. [b] Determined by GLC. [c] The dihydropyran **2** was recovered in 96% yield. [d] Diphenyl disulfide and polymeric tar were obtained.

Scheme I



2 18 19 20 21

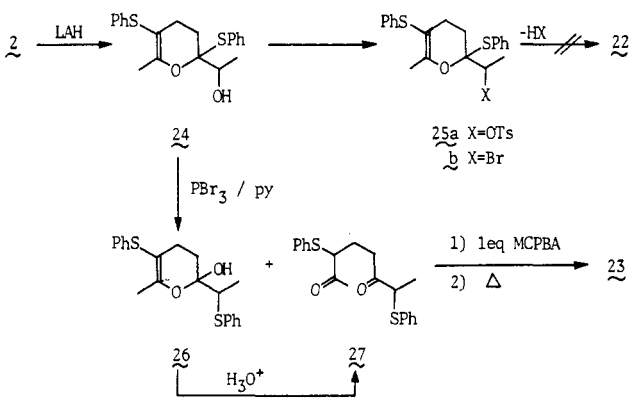
acetylcyclopentanone and 7-octene-2,6-dione derivatives.

Experimental Section

Melting points were measured with a Yanagimoto micro melting point apparatus and uncorrected. IR spectra were recorded with a Hitachi 215 spectrophotometer. ^1H NMR spectra were obtained from a JEOL PMX-60, and chemical shifts are reported in parts per million on the δ scale from internal tetramethylsilane. Mass spectra were taken with a Hitachi RMU-6D mass spectrometer. Microanalyses were determined on a Yanagimoto CHN-Corder, Type II. GLC analyses were performed on a KOR-70 equipped with an FID and on a G-80 with a TCD by using a 2 m × 3 mm i.d. column of 10% OV-17 and 10% SE-30 on Chromosorb W. Column chromatography was carried out on Wakogel C-300 (silica gel).

Reaction of 3-(Phenylthio)-3-buten-2-one (1) with Olefins. General Procedure. A solution of the enone 1[2] (1.12 g, 6.3 mmol) in dry THF (12 mL) was added to the olefin (31.5 mmol) under N_2 with cooling in an ice bath. Then, the resulting mixture was transferred to an autoclave by syringe and heated to the tem-

Scheme II



perature indicated in Table I. After the mixture cooled, evaporation of the solvent and excess olefin gave an oily residue which was chromatographed on silica gel with hexane and hexane–benzene. The eluted products were purified, if necessary, on the preparative GLC.

3,4-Dihydro-2-ethoxy-6-methyl-5-(phenylthio)-2*H*-pyran (7): bp 200 °C (4 mm; bath temperature); IR (neat) 1640, 1055 cm^{-1}; ^1H NMR ($CDCl_3$) δ 1.27 (t, J = 7.0 Hz, 3 H), 2.10 (s, 3 H), 1.63–2.53 (m, 4 H), 3.75 (q, J = 7.0 Hz, 2 H), 5.07 (t, J = 3.0 Hz, 1 H), 6.89–7.49 (m, 5 H); mass spectrum (70 eV), m/e 250 (M^+). Anal. Calcd for $C_{14}H_{18}O_2S$: C, 67.18; H, 7.25. Found: C, 67.37; H, 7.57.

3,4-Dihydro-6-methyl-5-(phenylthio)-2*H*-tetrahydrofuro-[2,3-*b*]pyran (8): bp 150 °C (3 mm; Kugelrohr); IR (neat) 1640, 1070 cm^{-1}; ^1H NMR ($CDCl_3$) δ 1.60–2.80 (m, 5 H), 2.33 (s, 3 H), 3.53–4.36 (m, 2 H), 5.13 (m, 0.42 H), 5.46 (d, J = 3.5 Hz, 0.58 H), 7.10–7.63 (m, 5 H); mass spectrum (70 eV), m/e 248 (M^+).

Reaction of 1 with Dihydropyran. When this reaction was carried out at 155 °C for 15 h, 3,4-dihydro-5-[3-oxo-2-(phenylthio)butyl]-2*H*-pyran (**9**) was obtained in 80% yield: IR (neat) 1720, 1060, 1020 cm^{-1}; ^1H NMR ($CDCl_3$) δ 1.35–2.50 (m, 6 H), 2.21 (s, 3 H), 3.70–4.03 (m, 2 H), 3.78 (t, J = 7.2 Hz, 1 H), 6.27 (br, 1 H), 7.03–7.56 (m, 5 H); mass spectrum (70 eV), m/e 262 (M^+). Anal. Calcd for $C_{15}H_{18}O_2S$: C, 68.68; H, 6.92. Found: C, 68.71; H, 6.88.

Heating neat **9** at 185 °C for 25 h gave 2-(phenylthio)tetrahydropyran (**11**), diphenyl disulfide, and recovered materials in 52%, 33%, and 15% yields, respectively. The reaction of **1** with dihydropyran at 180 °C for 20.5 h afforded the pyran **9** and 3,4-dihydro-6-methyl-5-(phenylthio)-2*H*-tetrahydropyrano[2,3-*b*]pyran [**10**; IR (neat) 1640, 1060 cm^{-1}] in 50% and 40% yields, respectively. The pyran **10** was also changed into **11** on heating at 200 °C for 3 h. The compound **11** was exclusively obtained in the same reaction at 185 °C for 36 h in 90% yield: IR (neat) 1580, 1070, 1030 cm^{-1}; ^1H NMR ($CDCl_3$) δ 1.33–2.38 (m, 6 H), 3.23–4.47 (m, 2 H), 5.09–5.38 (m, 1 H), 7.06–7.68 (m, 5 H); mass spectrum (70 eV), m/e 194 (M^+), 109 (SPh^+), 85 (M^+ – SPh).

6-(Butylthio)-3-(phenylthio)-5-hexen-2-one (13). The reaction of **1** with butyl vinyl sulfide gave primarily 2-(butylthio)-3,4-dihydro-6-methyl-5-(phenylthio)-2*H*-pyran (**12**) in 81% yield [IR (neat) 1640, 1070 cm^{-1}], however, preparative GLC at 275 °C caused it to change to the hexenone **13** quantitatively: IR (neat) 1710, 1600 cm^{-1}; ^1H NMR ($CDCl_3$) δ 0.73–1.81 (m, 7 H), 2.26 (s, 3 H), 2.41–2.92 (m, 4 H), 3.45–3.96 (m, 1 H), 5.35–5.83 (m, 1 H), 6.06 (d, J = 14.0 Hz, 1 H), 7.16–7.63 (m, 5 H); mass spectrum (70 eV), m/e 294 (M^+). Anal. Calcd for $C_{16}H_{22}OS_2$: C, 65.29; H, 7.53. Found: C, 65.53; H, 7.31.

4a,5,6,7,8,8a-Hexahydro-2-methyl-8a-(*N*-morpholino)-3-(phenylthio)-4*H*-chromene (14). The reaction of **1** with 1-(*N*-morpholino)-1-cyclohexene at room temperature gave crystalline product **14** [IR (Nujol) 1640, 1115 cm^{-1}], but recrystallization of the crude product resulted in the formation of 2-[3-oxo-2-(phenylthio)butyl]cyclohexanone (**15**) and 8a-hydroxy-3-(phenylthio)-2-decalone (**16**) in 48% and 10% yields, respectively. For cyclohexanone **15**: IR (neat) 1700 cm^{-1}; ^1H NMR ($CDCl_3$) δ 1.12–2.06 (m, 8 H), 2.27 and 2.30 (2 s, total 3 H), 2.06–2.85 (m, 3 H), 3.73–4.07 (m, 1 H), 7.14–7.57 (m, 5 H); mass spectrum (70 eV), m/e 276 (M^+). Anal. Calcd for $C_{16}H_{20}O_2S$: C, 69.54; H, 7.30. Found: C, 69.38; H, 7.18. The cyclohexanone **15** was also obtained in the same reaction at 60 °C in 94% yield. For the decalone **16**: mp 165–167 °C (benzene–hexane); IR (Nujol) 3420, 1700 cm^{-1}; ^1H NMR ($CDCl_3$) δ 1.16–2.35 (m, 12 H), 2.50 (s, 0.67 H, OH), 2.68 (s, 0.33 H, OH), 3.24 (d, J = 14.0 Hz, 1 H), 3.60–4.06 (m, 1 H), 7.14–7.55 (m, 5 H); mass spectrum (70 eV), m/e 276 (M^+). Anal. Calcd for $C_{16}H_{20}O_2S$: C, 69.54; H, 7.30. Found: C, 69.57; H, 7.15.

2-[3-Oxo-2-(phenylthio)butyl]pyrrole (17): IR (neat) 3500–3300, 1710 cm^{-1}; ^1H NMR ($CDCl_3$) δ 2.26 (s, 3 H), 3.18 (d, J = 7.0 Hz, 2 H), 3.85 (t, J = 7.0 Hz, 1 H), 5.85–6.42 (m, 2 H), 6.55–6.74 (m, 1 H), 7.05–7.54 (m, 5 H), 8.16 (br, 1 H, NH); mass spectrum (70 eV), m/e 245 (M^+).

Synthesis of 3-Acetyl-2-hydroxy-2-methyl-3-(phenylthio)cyclopentanone (19). A solution of the dimer **2** (7.50 g, 21 mmol), 33% HCl (2.33 mL), and H_2O (2.33 mL) in ethanol (170 mL) was refluxed for 6.5 h. After cooling, the mixture was neutralized with 10% aqueous NaOH solution, and the solvent was evaporated. The residue was extracted with ether, washed with brine, dried over sodium sulfate, and concentrated in vacuo to give a yellow oil containing crystals. The crystals were filtered, and the filtrate was chromatographed on silica gel with benzene and benzene–ether. GLC analyses of the combined crude crystals (3.56 g, 64%) showed two close peaks which were considered as *cis* and *trans* isomers; however, recrystallization gave only a major isomer (longer retention time). The pentanone **19** was also obtained in a similar treatment with other acids or $HgCl_2$. For the pentanone (**19**): mp 139–140.5 °C (benzene–hexane); IR (Nujol) 3450, 1740, 1690 cm^{-1}; ^1H NMR ($CDCl_3$) δ 1.22 (s, 3 H), 1.42–2.38 (m, 4 H), 2.56 (s, 3 H), 3.33 (br s, 1 H, OH), 7.18–7.56 (m, 5 H); mass spectrum (70 eV), m/e 264 (M^+). Anal. Calcd for $C_{14}H_{16}O_3S$: C, 63.62; H, 6.10. Found: C, 63.80; H, 6.22.

A solution of **19** (1.03 g, 3.90 mmol) in ethanol (50 mL) was treated with Raney Ni (reflux, 12 h) to afford 0.48 g (89%) of 3-acetyl-2-methyl-2-cyclopentenone (**20**): bp 65–68 °C (4 mm; bath temperature); IR (neat) 1680, 1605 cm^{-1}; ^1H NMR ($CDCl_3$) δ 2.00 (s, 3 H), 2.45 (s, 3 H), 2.17–2.93 (m, 4 H); mass spectrum (70 eV), m/e 138 (M^+), 123 ($M^+ - CH_3$), 95 ($M^+ - COCH_3$).

To a stirred solution of **19** (0.73 g, 2.77 mmol) in CH_2Cl_2 (10 mL) was added *m*-chloroperbenzoic acid (80%, 0.66 g, 3.0 mmol) in CH_2Cl_2 (30 mL) with cooling in an ice bath, and stirring was continued for 3 h at room temperature. After addition of 10% aqueous sodium sulfite solution, the water layer was extracted with CH_2Cl_2. The combined organic layers were washed with 10% aqueous sodium bicarbonate solution and brine, dried over sodium sulfate, and concentrated in vacuo to give 0.65 g of residue. A solution of the residue in benzene (20 mL) was refluxed for 4 h in the presence of calcium carbonate. The mixture was filtered, and the filtrate was concentrated to give oily residue. Short-path distillation of the residue afforded 0.28 g (65%) of 3-acetyl-2-hydroxy-2-methyl-3-cyclopentenone (**21**): bp 150–155 °C (2 mm; bath temperature); IR (neat) 3400, 1760, 1670, 1580 cm^{-1}; ^1H NMR ($CDCl_3$) δ 1.47 (s, 3 H), 2.40 (s, 3 H), 3.30–3.33 (m, 3 H, CH_2 and OH), 6.25 (m, 1 H); mass spectrum (70 eV), m/e 154 (M^+).

2,5-Bis(phenylthio)-3,4-dihydro-2-(1-hydroxyethyl)-6-methyl-2*H*-pyran (24). Lithium aluminum hydride (1.16 g, 30.6 mmol) was added to a cooled solution of **2** (28.46 g, 79.9 mmol) in dry ether (250 mL) with stirring under N_2, and stirring was continued for 2 h at room temperature. The mixture was diluted with ether (50 mL) and cooled in an ice bath. Water (50 mL) and then 10% sulfuric acid (20 mL) was added cautiously to the mixture, and the organic layer was extracted with ether, washed with brine, and dried over sodium sulfate. Evaporation of the solvent gave 27.76 g (97%) of **24**: mp 70–72 °C (hexane); IR (Nujol) 3400, 1640 cm^{-1}; ^1H NMR ($CDCl_3$) δ 1.36 (d, J = 6.8 Hz, 3 H), 1.95–2.66 (m, 8 H), 3.86 (q, J = 6.8 Hz, 1 H), 7.00–7.75 (m, 10 H); mass spectrum (70 eV), m/e 358 (M^+). Anal. Calcd for $C_{20}H_{22}O_2S_2$: C, 67.02; H, 6.19. Found: C, 67.24; H, 6.11.

2,5-Bis(phenylthio)-3,4-dihydro-6-methyl-2-[1-(tosyloxy)ethyl]-2*H*-pyran (25a). Triethylamine (0.69 g, 6.83 mmol) was added to a stirred solution of **24** (0.96 g, 2.68 mmol) and tosyl chloride (0.56 g, 2.94 mmol) in benzene (10 mL), and the mixture was stirred for 4.5 h at room temperature and then for 4.5 h at reflux temperature. After filtration of precipitate, the filtrate was washed with 10% aqueous sodium carbonate solution and brine, dried over sodium sulfate, and concentrated to give 1.14 g (83%) of **25a**: IR (neat) 1640, 1255, 810 cm^{-1}; ^1H NMR ($CDCl_3$)

δ 1.40 (d, J = 6.8 Hz, 3 H), 2.15 (s, 3 H), 2.43 (s, 3 H), 2.17–2.53 (m, 4 H), 3.90 (q, J = 6.8 Hz, 1 H), 7.15–7.96 (m, 14 H).

Reaction of the Pyran 24 with Phosphorus Tribromide. Phosphorus tribromide (1.36 g, 5.02 mmol) in dry ether (10 mL) was added to a stirred solution of the pyran **24** (4.50 g, 12.57 mmol) and pyridine (0.26 g, 3.29 mmol) in dry ether (25 mL) with cooling in an ice bath, and stirring was continued for 4.5 h at 0 °C and for 1.5 h at room temperature. After cooling, the mixture was quenched with water (40 mL), extracted with ether, and dried over sodium sulfate. Evaporation of the solvent afforded a mixture of **26** and **27** which were separated by column chromatography with hexane and hexane–benzene to give 2.11 g (47%) of **26** and 1.85 g (41%) of **27**.

3,4-Dihydro-2-hydroxy-6-methyl-5-(phenylthio)-2-[1-(phenylthio)ethyl]-2*H*-pyran (26): bp 180 °C (2.5 mm; bath temperature); IR (neat) 1640 cm^{-1}; ^1H NMR ($CDCl_3$) δ 1.33 (d, J = 7.0 Hz, 3 H), 1.47–2.30 (m, 7 H), 3.00–3.30 (m, 1 H, OH), 3.63–3.97 (m, 1 H), 7.06–7.83 (m, 10 H); mass spectrum (70 eV), m/e 358 (M^+).

Treatment of **26** with hydrochloric acid gave **27** quantitatively.

3,7-Bis(phenylthio)octane-2,6-dione (27): bp 230 °C (2.5 mm; bath temperature); IR (neat) 1705, 1695 cm^{-1}; ^1H NMR ($CDCl_3$) δ 1.40 (d, J = 7.6 Hz, 3 H), 1.73–2.13 (m, 2 H), 2.25 (s, 3 H), 2.67–3.06 (m, 2 H), 3.50–3.97 (m, 2 H), 7.20–7.46 (m, 10 H); mass spectrum (70 eV), m/e 358 (M^+). Anal. Calcd for $C_{20}H_{22}O_2S_2$: C, 67.02; H, 6.19. Found: C, 66.72; H, 6.11.

3-(Phenylthio)-7-octene-2,6-dione (23). *m*-Chloroperbenzoic acid (80%, 0.54 g, 2.51 mmol) in CH_2Cl_2 (30 mL) was added to a stirred solution of octanedione **27** (0.90 g, 2.5 mmol) in CH_2Cl_2 (40 mL) at 0 °C, and stirring was continued for 3 h at 0 °C and then for 2.5 h at room temperature. The mixture was treated with 10% aqueous sodium sulfite solution, and the water layer was extracted with CH_2Cl_2. The combined organic layers were washed with 10% aqueous sodium carbonate solution and then brine, dried over sodium sulfate, and concentrated to give 0.67 g of the residue: IR (neat) 1710, 1080, 1045 cm^{-1}; ^1H NMR ($CDCl_3$) δ 1.20–1.56 (m, 3 H), 1.70–2.16 (m, 2 H), 2.33 (s, 3 H), 2.56–2.93 (m, 2 H), 3.50–4.03 (m, 2 H), 7.23–7.66 (m, 10 H). The residue (0.50 g) was dissolved in benzene (30 mL) and allowed to reflux for 7.5 h in the presence of calcium carbonate (0.15 g). After filtration, the mixture was concentrated and chromatographed on silica gel with hexane and hexane–benzene to give 0.25 g (54%) of **23**: IR (neat) 1710, 1680, 1615 cm^{-1}; ^1H NMR ($CDCl_3$) δ 1.77–2.33 (m, 2 H), 2.27 (s, 3 H), 2.77 (t, J = 6.8 Hz, 2 H), 3.72 (t, J = 7.0 Hz, 1 H), 5.60–6.37 (m, 3 H), 7.12–7.87 (m, 5 H); mass spectrum (70 eV), m/e 248 (M^+).

Registry No. 1, 13522-48-0; **2**, 19718-58-2; **7**, 83666-42-6; *cis*-**8**, 83666-43-7; *trans*-**8**, 83666-44-8; **9**, 83666-45-9; **10**, 83666-46-0; **11**, 20965-36-0; **12**, 83666-47-1; **13**, 83666-48-2; **14**, 83666-49-3; **15**, 83666-50-6; **16**, 77202-22-3; **17**, 83666-51-7; *cis*-**19**, 83666-52-8; *trans*-**19**, 83666-53-9; **20**, 83220-31-9; **21**, 83666-54-0; **23**, 83666-55-1; **24**, 19718-59-3; **25a**, 83666-56-2; **26**, 83666-57-3; **27**, 83666-58-4; ethyl vinyl ether, 109-92-2; 2,3-dihydrofuran, 1191-99-7; 3,4-dihydro-2*H*-pyran, 110-87-2; butyl vinyl sulfide, 4789-70-2; 1-morpholino-1-cyclohexene, 670-80-4; pyrrole, 109-97-7.

Synthesis of Adamantane Derivatives. 60.[1] Stereospecific Synthesis of 2,4 Amino Alcohol Derivatives of Noradamantane, Protoadamantane, and Adamantane via Bicycloalkenylnitrones

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The intramolecular 1,3-dipolar cycloadditions of *C*-bicycloalkenylnitrones **3**, **9**, and **17** generated in situ from the aldehydes **1**, **8**, and **16** and hydroxylamines proceeded smoothly at 25–80 °C, affording 2,4-(epoxyimino)-noradamantane (**4**), 2,4-(epoxyimino)protoadamantane (**10**), and 4,2-(epoxyimino)protoadamantane (**18**) and 2,4-(epoxyimino)adamantane (**19**), respectively, in good yields. These adducts were reductively cleaved to give the corresponding amino alcohol derivatives **5**, **6**, **11**, **13**, **15**, **20**, and **21**. Novel thermal cleavage of **19a** and **19b** and hydrogen abstractions from the solvent yielded also directly amino alcohols **20a** and **20b**. The regiochemistry of cycloaddition of **17** was discussed on the basis of N-substituent effects and solvent effects on the product ratios.

The use of intramolecular 1,3-dipolar cycloadditions in organic synthesis has developed quite rapidly in recent years.[2] In particular, the use of nitrones has been explored extensively for regio- and stereoselective synthesis of functionalized carbo- and heterocycles as well as natural products such as alkaloids since the pioneering work of LeBel and co-workers on acyclic and monocyclic alkenylnitrones.[3-6] In this paper, we report a convenient stereospecific synthesis of 2,4-disubstituted noradamantane, protoadamantane, and adamantane derivatives based on *C*-bicycloalkenylnitrones.[7,8]

Results and Discussions

2-*endo*-Hydroxy-4-*endo*-(benzylamino)noradamantane (5) and Related Derivatives from *C*-*endo*-Bicyclo[3.2.1]oct-6-en-3-ylnitrone (3). The nitrone **3**, containing a symmetrical olefin, was generated in situ by stirring *endo*-bicyclo[3.2.1]oct-6-ene-3-carbox-

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