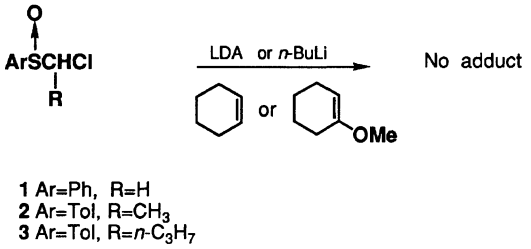
Generation of the α-Sulfinyl Carbenoid from α-Chloro Sulfoxides: A New Method for One-Carbon Homologation of Ketones to α-Sulfinyl Ketones

Tsuyoshi SATOH, Yasumasa HAYASHI, Yasuhiro MIZU, and Koji YAMAKAWA*
Faculty of Pharmaceutical Sciences, Science University of Tokyo, Ichigaya-funagawara-machi, Shinjuku-ku, Tokyo 162
(Received December 7, 1993)

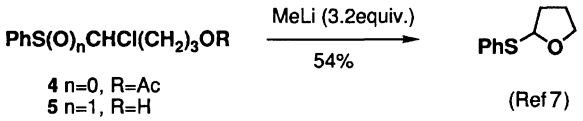
Treatment of 1-chloroalkyl phenyl sulfoxides with a base gave carbenoids rather than free carbenes. The carbenoids were successfully used in a new method for homologation of ketones to α-sulfinyl ketones. Treatment of the carbanion of chloromethyl phenyl sulfoxide with ketones gave the adducts, α-chloro β-hydroxy sulfoxides, in nearly quantitative yields. The adducts were treated with excess lithium diisopropylamide to give one-carbon homologated α-sulfinyl ketones via α-sulfinyl β-oxido carbenoids in moderate to good yields. This type of reaction was found not to occur with the corresponding sulfones.

Carbenes and carbenoids[1] have been known as highly reactive carbon species and are recognized as useful intermediates in organic synthesis.[2] Generation of carbenes and carbenoids has mainly been carried out in two ways: 1) photolysis, pyrolysis, and catalytic decomposition of diazo compounds, 2) base-induced α-elimination.[2b]

Recently, we have reported some new synthetic methods using aryl 1-haloalkyl sulfoxides (for example **1**—**3**) as carbon homologating agents.[3] In these studies, the lithium salt of carbanion from aryl 1-haloalkyl sulfoxides was generated with lithium diisopropylamide (LDA) in THF at below −40 °C. Above this temperature, the carbanion slowly decomposed to give a red-black complex mixture. We thought that the decomposition mainly took place through the α-sulfinyl carbenes or carbenoids which were generated via α-elimination of lithium chloride. In this paper we report the results for the treatment of several 1-haloalkyl phenyl sulfoxides with bases and a successful use of this reaction in the one-carbon homologation of ketones to α-sulfinyl ketones.[4]



Scheme 1.



Scheme 2.

Results and Discussion

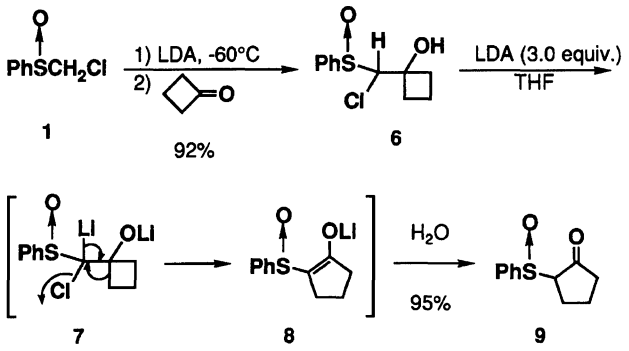
Trial for Generation of Sulfinyl Carbenes or Carbenoids by Treatment of Aryl 1-Haloalkyl Sulfoxides with Bases. In his pioneering work in the chemistry of chloromethyl phenyl sulfoxide **1**, Durst reported generation of carbanion of **1** at −78 °C.[5] This carbanion decomposed at above −20 °C, and it was mentioned that the decomposition gave (phenylsulfinyl)carbene[6] or chlorocarbene. Based on his report, we first investigated the properties of the carbanion of **1**—**3** at 0 °C in the presence of cyclohexene or 1-methoxycyclohexene (Scheme 1). The reaction was carried out with LDA or *n*-BuLi in THF in the presence of excess olefin from −78 to 0 °C. Though the reactions were performed under several experimental conditions, no trace of the expected cyclopropanes was found, but a complex mixture was obtained.

Harada and Oku reported an intramoleculer insertion reaction by (phenylthio)carbenes; for example, treatment of **4** with excess MeLi gave 2-(phenylthio)tetrahydrofuran via α-sulfenyl carbene[7] (Scheme 2). Similarly, 1-chloroalkyl phenyl sulfoxide **5**[8] was treated with excess LDA at −60 to −10 °C. This reaction again gave not the expected 2-(phenylsulfinyl)tetrahydrofuran but a complex mixture. The reaction species from the sulfoxides thus showed a somewhat different character compared with those from aryl 1-chloroalkyl silfides. We concluded that it was difficult to obtain the products expected from α-sulfinyl carbenes by treatment with aryl 1-chloroalkyl sulfoxides with bases.

One-Carbon Homologation of Ketones to α-Sulfinyl Ketones via β-Oxido Carbenoid Intermediates. We next turned our attention to β-oxido carbenoids.[9] Specifically, we noticed a ring expansion of cyclic ketones via α-sulfenyl β-oxido carbenoid, as reported by Cohen.[10]

First, the chloro alcohol **6** was synthesized from the carbanion of chloromethyl phenyl sulfoxide **1**[5,11] and cyclobutanone (Scheme 3). The adduct **6** was treated with three equivalents of LDA in THF at −60 to −50 °C for 1.5 h. Fortunately, the desired reaction took place quite smoothly and cleanly to afford 2-(phenylsulfinyl)cyclopentanone **9** in 95% yield as a mixture of two diastereomers.

This reaction was presumed to proceed as follows. Treatment of **6** with LDA gave the dianion **7**. Next, α-elimination and rearrangement took place simulta-



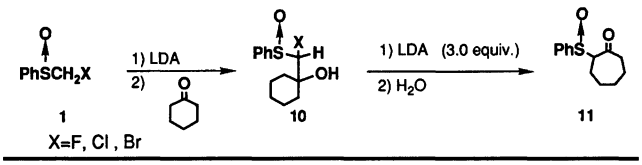
Scheme 3.

neously to afford the ring-expanded enolate **8**. In the elimination, both the phenylsulfinyl group and the chlorine atom are thought to be eliminated; however, it was seen from the result that the reactivity of the chlorine atom for the α-elimination is much higher.

Encouraged by this result, we next applied this reaction to cyclohexanone (Table 1). Chloro alcohol **10b**[11] was treated with three equivalents of LDA in THF. Compared with the result for the reaction of **6**, this reaction took much longer and gave many by-products and the desired **11** was obtained in 47% yield (Table 1, Entry 2). To overcome this problem, other halogenous compounds, fluoromethyl[12] and bromomethyl phenyl sulfoxide[13] were investigated (Entries 1, 3); however, as shown in Table 1, this trial was found to be fruitless.

Other results for the one-carbon ring-expansion of cyclic ketones to cyclic α-sulfinyl ketones through the adduct of cyclic ketones with chloromethyl phenyl sulfoxide **1** are summarized in Table 2. As shown in Scheme 3 and Tables 1 and 2, this procedure is useful in the one-carbon ring-expansion of 4- and 5-membered ring compounds (Entries 1, 6, and 7). This procedure was found to be also applicable to medium and large cyclic ketones; however, the yields are usually moderate. The conditions of the reaction are quite dependent on the cyclic ketones used. Usually, medium to large

Table 1. One-Carbon Ring-Expansion of Cyclohexanone to 2-(Phenylsulfinyl)cycloheptanone



Entry	X	**10** (Yield/%)[a]	Condn.[b]	**11** Yield/%[a]
1	F	**10a** (86)	A	33
2	Cl	**10b** (91)	B	47
3	Br	**10c** (69)	C	23

a) Isolated yield. b) All the reactions were carried out with 3 equiv of LDA in THF; Conditions: A, −70 to 0 °C (2 h), then 0 °C (1 h); B, −65 to 0 °C (2 h), then 0 °C (1 h); C, −78 to −30 °C (2 h).

ring compounds required higher reaction temperatures and longer reaction times.

When unsymmetrical cyclic ketones were used in this procedure, two regioisomers of the rearranged products were obtained (Entries 5 and 6). As known in this type of rearrangement,[14] the phenyl group migrated faster than the alkyl group. 2-Indanone gave 2-naphthol **25** (Entry 7); this product is thought to be produced by elimination of the sulfinyl group from the initial ring-expanded product, lithium enolate of 3-phenylsulfinyl-2-tetralone, under these strongly basic conditions.

We next applied this procedure to acyclic ketones. The results are summarized in Table 3. As shown in the table, addition of the carbanion of **1** to acyclic ketones gave nearly quantitative yield of chloro alcohols (87—99%). The rearrangement of β-oxido carbenoids was carried out in the same way as described for the cyclic chloro alcohols to afford 48—91% yield of α-sulfinyl ketones except in one example. Again, the reaction rate and the yields were found to be dependent on the ketones used. Use of HMPA as cosolvent was effective for dissolving the chloro alcohols **26** and **32** (Entries 1 and 7). Similar to the reaction of the cyclic chloro alcohols, unsymmetrical acyclic ones gave two products and all the main products are aryl-migrated α-aryl α-(phenylsulfinyl)ketones (Entries 2—5). The chloro alcohol derived from 2-acetylpyridine was unreactive under the conditions (Entry 6).

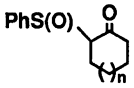
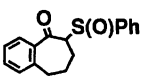
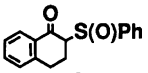
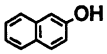
One-Pot Reaction. As described above, this one-carbon homologation of ketones to α-sulfinyl ketones was carried out as a two-step synthesis. Because the initially produced adducts are lithium alkoxide and the yields are usually excellent, this reaction may carried out as a one-pot reaction.

Thus, cyclopentanone was treated with the carbanion of **1** at −78 °C. After the reaction, three equivalents of LDA were added to the reaction mixture and the temperature was gradually allowed to warm to −45 °C. This one-pot reaction gave 2-(phenylsulfinyl)cyclohexanone **19** in 73% yield (Scheme 4). The yield of **19** in the two-step synthesis is calculated to be 66% (Table 2, Entry 1). Benzophenone gave **38** in 79% yield in the one-pot procedure (79% in the two-step synthesis; Table 3, Entry 7).

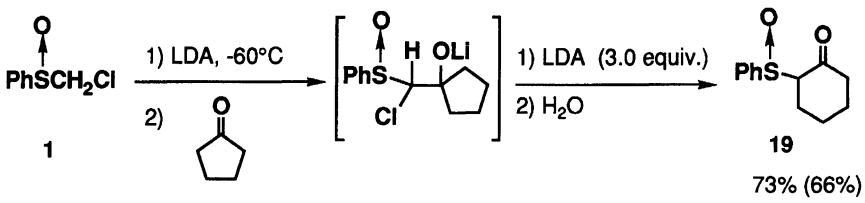
This one-pot procedure is effective when the yields of the β-oxido carbenoid rearrangement gave better than 80% yield. However, if the yields are much lower than 80%, the one-pot procedure gave a more complex mixture than in the two-step procedure, and isolation of the desired product became much more difficult.

Finally, we investigated whether treatment of α-chloro β-hydroxy sulfone **39** with a base gave ring-expanded α-sulfonyl ketone via α-sulfonyl β-oxido carbenoid. The sulfone **39**, derived from **12** by oxidation, was treated with three equivalents of LDA (Scheme 5). Compared with the corresponding sulfoxide **12** (Table 2, Entry 1), the sulfone was found to be quite unreactive and warm-

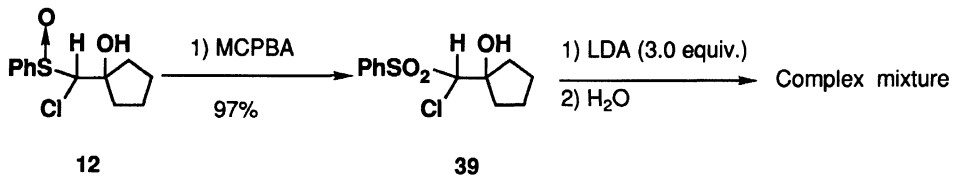
Table 2. One-Carbon Ring-Expansion of Cyclic Ketones to Cyclic α-Sulfinyl Ketones through Chloro Alcohols

Entry	Ketone	Chloro alcohol Yield/%[a]		Condn.[b]	α-Sulfinyl ketone Yield/%[a]	
1		**12** (n=1)	82	A		**19** (n=1) 81
2		**13** (n=3)	76	B		**20** (n=3) 38(47)[c]
3		**14** (n=6)	85	C		**21** (n=6) 52(73)[c]
4		**15** (n=8)	83	D		**22** (n=8) 51
5		**16**	99[d]	E	 **23a** 68	 **23b** 9
6		**17**	99[d]	F	 **24a** 50	 **24b** 21
7		**18**	88	G	 **25** 61	

a) Isolated yield. b) Unless otherwise noted, all the reactions were carried out with 3 equiv of LDA in THF. Conditions: A, −65 to −45 °C (2.5 h); B, −65 to 0 °C (2 h) then 0 °C (0.5 h); C, −60 to 10 °C (4 h); D, 4 equiv of LDA was used and HMPA (4 equiv) was added as cosolvent; E, −75 to −40 °C (1.5 h); F, −60 to −25 °C (1 h); G: 3 equiv of HMPA was used as cosolvent: −60 to −30 °C (2 h). c) The yield in parethesis was calculated based on the consumed starting material. d) An inseparable mixture of two diastereomers. All other chloro alcohols are single isomers.



Scheme 4.



Scheme 5.

ing the solution to 0 °C gave only a complex mixture without any desired ketone.

In conclusion, the characteristics of the procedure described above are as follows. 1) The starting material, chloromethyl phenyl sulfoxide **1** is easily obtainable from (methylthio)benzene in good yield in large quantity.[5,11] 2) The yields of the addition of the carbanion of **1** to various ketones are usually excellent, and the generation of β-oxido carbenoids is quite easily carried out. 3) The procedure is applicable to both cyclic and acyclic ketones. 4) The produced α-sulfinyl ketones are useful intermediates in organic synthesis.[15] For example, **22** and **38** were transformed to **40** and **41**, respectively, by thermal elimination of the sulfinyl group[16] and reduction of the sulfinyl group with Raney-Ni (Chart 1).[17]

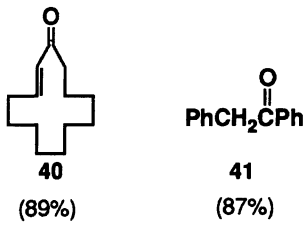
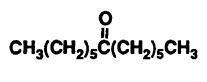
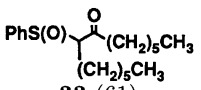
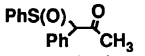
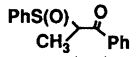
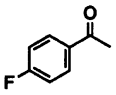
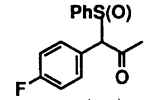
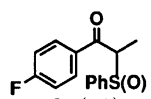
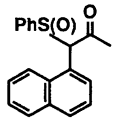
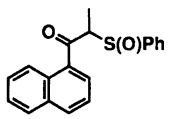
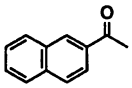
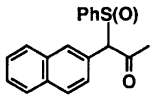
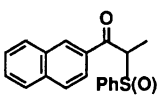
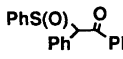


Chart 1.

Table 3. One-Carbon Homologation of Acyclic Ketones to α-Sulfinyl Ketones through Chloro Alcohols

Entry	Ketone	Chloro alcohol (Yield/%)[a]	Condn.[b]	α-Sulfinyl ketone (Yield/%)[a]
1		**26** (90)	H	 **33** (61)
2		**27** (88)	I	 **34a** (61)  **34b** (14)
3		**28** (89)	J	 **35a** (59)  **35b** (19)
4		**29** (99)	J	 **36a** (37)  **36b** (11)
5		**30** (99)	J	 **37a** (58)  **37b** (19)
6		**31** (99)	J	N.R.
7		**32** (87)	K	 **38** (91)

a) Isolated yield. b) All the reactions were carried out with 3 equiv of LDA in THF; Conditions: H, 3 equiv of HMPA was added as cosolvent: −78 to −30 °C (3 h); I, −65 to −15 °C (3 h); J, −60 to −5 °C (3 h); K, 3 equiv of HMPA was added as cosolvent: −78 to 0 °C (1.5 h) then 0 °C (0.5 h).

Experimental

All melting points are uncorrected. ^{1}H NMR spectra were measured in a $CDCl_3$ solution with a JEOL FX-100 spectrometer. Electron-impact mass spectra (MS) were obtained at 70 eV by direct insertion. Silica gel BW-127 ZH (Fuji-Devison) containing 2% fluorescence reagent 254 and a quartz column were used for column chromatography, and the products having UV absorption were detected by UV irradiation. In experiments requiring a dry solvent, THF was distilled from diphenylketyl; diisopropylamine, HMPA, benzene, and toluene were dried over CaH_2 and distilled.

1-[Chloro(phenylsulfinyl)methyl]cyclobutanol (6). A solution of chloromethyl phenyl sulfoxide **1** (524 mg; 3 mmol) in 3 ml of dry THF was added dropwise with stirring to a solution of LDA (3.6 mmol) in 5 ml of THF at −60 °C under Ar atmosphere. The solution was stirred for 10 min, then cyclobutanone (0.27 ml; 3.6 mmol) was added. The reaction mixture was stirred at −60 °C for 10 min, then the reaction was quenched with sat. aq NH_4Cl. The solution was extracted with ether–benzene, and the organic layer was washed with sat. aq NH_4Cl. The extract was dried over $MgSO_4$ and the solvent was evaporated. The product was purified by silica-gel column chromatography to afford **6** (673 mg; 92%) as colorless crystals. Mp 103—104 °C (AcOEt–hexane); IR (KBr) 3360 (OH), 1090, 1040 (SO) cm^{-1}; ^{1}H NMR δ=1.4—2.6 (6H, m); 3.49 (1H, s, OH), 4.53 (1H, s), 7.3—7.7 (5H, m); MS *m/z* (%) 244 (M^+, 0.4), 227 (3.5), 126 (100). Found: C, 53.98; H, 5.33; Cl, 14.24; S, 12.18%. Calcd for $C_{11}H_{13}ClO_2S$: C, 53.99; H, 5.35; Cl, 14.49; S, 13.10%.

2-(Phenylsulfinyl)cyclopentanone (9). A solution of the chloro alcohol **6** (122 mg; 0.5 mmol) in 2 ml of dry THF was added with stirring to a solution of LDA (1.5 mmol) in 3 ml of THF at −65 °C under Ar atmosphere. The reaction mixture was stirred at −65 to −50 °C for 1.5 h. The reaction was quenched with sat. aq NH_4Cl. The whole was extracted with ether–benzene and the combined organic layer was washed with sat. aq NH_4Cl. The product was purified by silica-gel column chromatography to give **9** (99 mg; 95%) as a colorless oil (4 : 1 diastereomeric mixture). IR (neat) 3480 (enol OH), 1740 (CO), 1090, 1040 (SO) cm^{-1}; ^{1}H NMR δ=1.4—2.7 (6H, m), 3.31 (0.8H, t, J=8 Hz), 3.77 (0.2H, t, J=7 Hz), 7.2—7.7 (5H, m); MS *m/z* (%) 208 (M^+, 54), 192 (3), 125 (100). Found: *m/z* 208.0556. Calcd for $C_{11}H_{12}O_2S$: M, 208.0557.

1-[Fluoro(phenylsulfinyl)methyl]cyclohexanol (10a) and 1-[Bromo(phenylsulfinyl)methyl]cyclohexanol (10c). These chloro alcohols were synthesized from fluoromethyl phenyl sulfoxide and bromomethyl phenyl sulfoxide

with cyclohexanone as described for the synthesis of **6**. **10a**: Mp 127—129 °C (AcOEt–hexane); IR (KBr) 3350 (OH), 1060, 1025 (SO) cm^{-1}; ^1H NMR δ=1.0—2.1 (10H, m), 4.59 (1H, d, J=47 Hz), 7.4—7.7 (5H, m); MS m/z (%) 256 (M^+, 0.2), 126 (100). Found: C, 61.00; H, 6.63; F, 7.46; S, 12.56%. Calcd for $C_{13}H_{17}FO_2S$: C, 60.91; H, 6.68; F, 7.41; S, 12.51%. **10c**: Mp 188—190 °C (AcOEt–hexane); IR (KBr) 3360 (OH), 1040 (SO) cm^{-1}; ^1H NMR δ=1.1—2.2 (10H, m), 4.51 (1H, s), 7.50 (5H, s); MS m/z (%) 318, 316 (M^+, trace), 203, 201 (3), 126 (100). Found: C, 49.17; H, 5.36; Br, 25.00; S, 10.08%. Calcd for $C_{13}H_{17}BrO_2S$: C, 49.22; H, 5.40; Br, 25.19; S, 10.11%.

2-(Phenylsulfinyl)cycloheptanone (11). Colorless oil (about 1:1 diastereomeric mixture); IR (neat) 1695 (CO), 1090, 1040 (SO) cm^{-1}; ^1H NMR δ=1.0—2.6 (10H, m), 3.50 (0.5H, dd, J=10, 5 Hz), 3.79 (0.5H, dd, J=11, 4 Hz), 7.3—7.7 (5H, m); MS m/z (%) 236 (M^+, 4), 126 (22), 111 (77), 55 (100). Found: m/z 236.0869. Calcd for $C_{13}H_{16}O_2S$: M, 236.0869.

1-[Chloro(phenylsulfinyl)methyl]cyclopentanol (12). Colorless crystals; mp 126—128 °C (AcOEt–hexane); IR (KBr) 3420, 3360 (OH), 1090, 1045 (SO) cm^{-1}; ^1H NMR δ=1.5—2.2 (8H, m), 2.93 (1H, s, OH), 4.42 (1H, s), 7.4—7.7 (5H, m); MS m/z (%) 258 (M^+, trace), 241 (0.4), 157 (2.5), 126 (100). Found: C, 55.48; H, 5.88; Cl, 13.89; S, 12.37%. Calcd for $C_{12}H_{15}ClO_2S$: C, 55.70; H, 5.84; Cl, 13.70; S, 12.39%.

1-[Chloro(phenylsulfinyl)methyl]cycloheptanol (13). Colorless crystals; mp 160—162 °C (AcOEt–hexane); IR (KBr) 3430 (OH), 1080, 1035 (SO) cm^{-1}; ^1H NMR δ=1.3—2.3 (12H, m), 2.50 (1H, s, OH), 4.31 (1H, s), 7.4—7.7 (5H, m); MS m/z (%) 286 (M^+, trace), 269 (0.5), 217 (1.7), 174 (2.8), 126 (100). Found: C, 58.70; H, 6.68; Cl, 12.19; S, 11.06%. Calcd for $C_{14}H_{19}ClO_2S$: C, 58.63; H, 6.68; Cl, 12.36; S, 11.18%.

1-[Chloro(phenylsulfinyl)methyl]cyclodecanol (14). Colorless crystals; mp 170—172 °C (AcOEt–hexane); IR (KBr) 3380 (OH), 1085, 1035 (SO) cm^{-1}; ^1H NMR δ=1.1—2.5 (18H, m); 4.29 (1H, s), 7.4—7.7 (5H, m), MS m/z (%) 328 (M^+, 0.2), 311 (1), 126 (100). Found: C, 62.06; H, 7.65; Cl, 10.77; S, 9.74%. Calcd for $C_{17}H_{25}ClO_2S$: C, 62.08; H, 7.66; Cl, 10.78; S, 9.75%.

1-[Chloro(phenylsulfinyl)methyl]cyclododecanol (15). Colorless crystals; mp 150—151 °C (AcOEt–hexane); IR (KBr) 3400 (OH), 1085, 1045 (SO) cm^{-1}; ^1H NMR δ=1.0—2.5 (22H, m), 4.29 (1H, s), 7.3—7.7 (5H, m); MS m/z (%) 356 (M^+, 0.3), 339 (1), 287 (10), 231 (21), 126 (100). Found: C, 64.06; H, 8.32; Cl, 10.02; S, 8.86%. Calcd for $C_{19}H_{29}ClO_2S$: C, 63.93; H, 8.19; Cl, 9.93; S, 8.98%.

1-[Chloro(phenylsulfinyl)methyl]-1-tetralol (16). Colorless crystals (about 3:2 diastereomeric mixture). IR (KBr) 3360 (OH), 1080, 1045 (SO) cm^{-1}; ^1H NMR δ=1.6—3.0 (6H, m); 4.70 (0.6H, s), 4.95 (0.4H, s), 7.0—7.6 (9H, m); MS m/z (%) 320 (M^+, 0.1), 303 (0.5), 159 (44), 131 (100). Found: m/z 320.0636. Calcd for $C_{17}H_{17}ClO_2S$: M, 320.0636.

1-[Chloro(phenylsulfinyl)methyl]-1-indanol (17). Colorless crystals (about 3:1 diastereomeric mixture). IR (KBr) 3360 (OH), 1085, 1035 (SO) cm^{-1}; ^1H NMR δ=1.0—1.6 (1H, m), 1.7—2.2 (3H, m), 4.60 (0.75H, s), 4.66 (0.25H, s) 7.2—7.6 (9H, m); MS m/z (%) 306 (M^+, trace), 289 (0.8), 180 (17), 145 (51), 126 (100). Found: m/z 306.0470. Calcd for $C_{16}H_{15}ClO_2S$: M, 306.0480. Main product was isolated by recrystallization; mp 168—170 °C (AcOEt–hexane). Found: C, 62.89; H, 4.97; Cl, 11.49; S, 10.43%. Calcd: C, 62.64; H, 4.93; Cl, 11.56; S, 10.45%.

2-[Chloro(phenylsulfinyl)methyl]-2-indanol (18). Colorless crystals; mp 209—211 °C (AcOEt–hexane); IR (KBr) 3430 (OH), 1090, 1050 (SO) cm^{-1}; ^1H NMR δ=3.39 (4H, quintet, J=16 Hz), 4.57 (1H, s), 7.0—7.4 (4H, m), 7.4—7.7 (5H, m); MS m/z (%) 306 (M^+, trace), 254 (1), 163 (74), 126 (100). Found: C, 62.51; H, 4.92; Cl, 11.67; S, 10.38%. Calcd for $C_{16}H_{15}ClO_2S$: C, 62.64; H, 4.93; Cl, 11.56; S, 10.45%.

2-(Phenylsulfinyl)cyclohexanone (19). Colorless crystals (diastereomeric mixture); mp 117—118 °C (AcOEt–hexane); IR (KBr) 1710 (CO), 1090, 1060, 1050 (SO) cm^{-1}; ^1H NMR δ=1.4—2.7 (8H, m), 3.2—3.7 (1H, m), 7.3—7.7 (5H, m); MS m/z (%) 222 (M^+, 32), 206 (12), 174 (3), 97 (95), 41 (100). Found: C, 64.86; H, 6.32; S, 14.11%. Calcd for $C_{12}H_{14}O_2S$: C, 64.84; H, 6.35; S, 14.42%.

2-(Phenylsulfinyl)cyclooctanone (20). Colorless oil (about 2:1 diastereomeric mixture); IR (neat) 1690 (CO), 1080, 1040 (SO) cm^{-1}; ^1H NMR δ=1.0—2.7 (12H, m), 3.64 (0.33H, dd, J=10, 4 Hz), 3.80 (0.66H, dd, J=12, 4 Hz), 7.3—7.7 (5H, m); MS m/z (%) 250 (M^+, 2), 125 (61), 55 (100). Found: m/z 250.1025. Calcd for $C_{14}H_{18}O_2S$: M, 250.1026.

2-(Phenylsulfinyl)cycloundecanone (21). Colorless oil; IR (neat) 1700 (CO), 1085, 1040 (SO) cm^{-1}; ^1H NMR δ=1.0—2.8 (18H, m), 3.68—3.88 (1H, m), 7.3—7.7 (5H, m); MS m/z (%) 292 (M^+, 0.2), 276 (0.3), 234 (3), 81 (100). Found: m/z 292.1504. Calcd for $C_{17}H_{24}O_2S$: M, 292.1495.

2-(Phenylsulfinyl)cyclotridecanone (22). Colorless oil; IR (neat) 1705 (CO), 1090, 1050 (SO) cm^{-1}; ^1H NMR δ=1.0—2.6 (22H, m), 3.62—3.84 (1H, m), 7.3—7.7 (5H, m); MS m/z (%) 320 (M^+, 3), 304 (4), 195 (87), 55 (100). Found: m/z 320.1807. Calcd for $C_{19}H_{28}O_2S$: M, 320.1808.

1-(Phenylsulfinyl)-2-benzosuberone (23a). Colorless oil (about 1:1 diastereomeric mixture); IR (neat) 1710 (CO), 1085, 1040 (SO) cm^{-1}; ^1H NMR δ=1.6—3.1 (4H, m), 4.32 (0.5H, s), 4.63 (0.5H, s), 7.0—7.6 (9H, m); MS m/z (%) 284 (M^+, 5), 159 (40), 131 (100). Found: m/z 284.0865. Calcd for $C_{17}H_{16}O_2S$: M, 284.0870.

2-(Phenylsulfinyl)-1-benzosuberone (23b). Colorless oil (about 1:1 diastereomeric mixture); IR (neat) 1670 (CO), 1085, 1045 (SO) cm^{-1}; ^1H NMR δ=1.5—2.4 (4H, m), 2.7—3.1 (2H, m), 3.84 (0.5H, dd, J=10, 6 Hz), 4.20 (0.5H, dd, J=12, 3 Hz), 7.0—7.7 (9H, m); MS m/z (%) 284 (M^+, 2), 236 (5), 159 (100), 131 (96). Found: m/z 284.0878. Calcd for $C_{17}H_{16}O_2S$: M, 284.0870.

1-(Phenylsulfinyl)-2-tetralone (24a). Colorless oil (about 2:1 diastereomeric mixture); IR (neat) 1700 (CO), 1085, 1050 (SO) cm^{-1}; ^1H NMR δ=2.2—3.5 (4H, m), 4.35 (0.33H, s), 4.76 (0.66H, s), 6.8—7.8 (9H, m); MS m/z (%) 270 (M^+, 4), 250 (9), 218 (18), 145 (76), 117 (100). Found: m/z 270.0744. Calcd for $C_{16}H_{14}O_2S$: M, 270.0714.

2-(Phenylsulfinyl)-1-tetralone (24b). Colorless oil (about 2:1 diastereomeric mixture); IR (neat) 1675 (CO), 1090, 1040 (SO) cm^{-1}; ^1H NMR δ=1.4—3.4 (4H, m), 3.62 (0.66H, dd, J=11, 5 Hz), 4.18 (0.33H, dd, J=11, 4 Hz), 7.0—8.1 (9H, m); MS m/z (%) 270 (M^+, 0.3), 252 (1), 222 (1.5), 144 (90), 115 (100). Found: m/z 270.0690. Calcd for $C_{16}H_{14}O_2S$: M, 270.0713.

The chloro alcohols in Table 3 (**26**—**32**) were synthesized from **1** and the corresponding acyclic ketones as described for the synthesis of **6**.

7-[Chloro(phenylsulfinyl)methyl]-7-tridecanol (26). Colorless oil; IR (neat) 3370 (OH), 1085, 1040 (SO) cm^{-1}; ^1H NMR δ=0.7—1.0 (6H, m), 1.0—2.1 (20H, m), 4.36 (1H, s), 7.4—7.7 (5H, m); MS *m/z* (%) 372 (M^+, trace), 355 (0.8), 303 (1), 126 (100). Found: *m/z* 372.1890. Calcd for $C_{20}H_{33}ClO_2S$: M, 372.1888.

1-[Chloro(phenylsulfinyl)methyl]-1-phenylethanol (27). Colorless oil (about 1 : 1 diastereomeric mixture); IR (neat) 3300 (OH), 1080, 1040 (SO) cm^{-1}; ^1H NMR δ=1.75, 2.01 (each 1.5H, s), 4.61, 4.66 (each 0.5H, s), 7.1—7.7 (10H, m); MS *m/z* (%) 294 (M^+, trace), 261 (2.5), 126 (100). Found: *m/z* 294.0468. Calcd for $C_{15}H_{15}ClO_2S$: M, 294.0480.

1-[Chloro(phenylsulfinyl)methyl]-1-(4-fluorophenyl)ethanol (28). Colorless crystals (about 1 : 1 diastereomeric mixture); IR (KBr) 3400 (OH), 1080, 1045 (SO) cm^{-1}; ^1H NMR δ=1.75, 2.02 (each 1.5H, s), 4.55, 4.60 (each 0.5H, s), 6.9—7.3 (2H, m), 7.3—7.7 (7H, m); MS *m/z* (%) 313 ($[M+H]^+$, 0.1), 294 (0.3), 279 (0.5), 126 (100). One of the isomers was separated by recrystallization (AcOEt–hexane); mp 146—148 °C. Found: C, 57.45; H, 4.50; Cl, 11.40; F, 6.23; S, 10.35%. Calcd for $C_{15}H_{14}ClFO_2S$: C, 57.60; H, 4.51; Cl, 11.33; F, 6.07; S, 10.25%.

1-[Chloro(phenylsulfinyl)methyl]-1-(1-naphthyl)ethanol (29). Colorless crystals (about 6 : 1 diastereomeric mixture); IR (KBr) 3320 (OH), 1090, 1040 (SO) cm^{-1}; ^1H NMR δ=1.06, (2.6H, s), 2.21 (0.4H, s), 5.41 (0.14H, s), 5.45 (0.86H, s), 6.9—8.2 (12H, m); MS *m/z* (%) 344 (M^+, 0.7), 218 (5), 183 (100). Main product was isolated by recrystallization (AcOEt–hexane); mp 174—176 °C. Found: C, 66.10; H, 4.93; Cl, 10.27; S, 9.36%. Calcd for $C_{18}H_{17}ClO_2S$: C, 66.17; H, 4.97; Cl, 10.28; S, 9.30%.

1-[Chloro(phenylsulfinyl)methyl]-1-(2-naphthyl)ethanol (30). Colorless crystals (about 1 : 1 diastereomeric mixture); IR (KBr) 3400 (OH), 1085, 1050 (SO) cm^{-1}; ^1H NMR δ=1.83, 2.21 (each 1.5H, s), 4.72, 4.78 (each 0.5H, s), 7.3—8.2 (12H, m); MS *m/z* (%) 344 (M^+, 2.6), 219 (30), 183 (100). Found: *m/z* 344.0627. Calcd for $C_{19}H_{17}ClO_2S$: M, 344.0636.

1-[Chloro(phenylsulfinyl)methyl]-1-(2-pyridyl)ethanol (31). Colorless oil (about 1 : 1 diastereometric mixture); IR (neat) 3330 (OH), 1085, 1050 (SO) cm^{-1}; ^1H NMR δ=1.89, 1.91 (each 1.5H, s), 4.78, 4.93 (each 0.5H, m); MS *m/z* (%) 295 (M^+, 0.3), 280 (0.1), 170 (100). Found: *m/z* (%) 295.0428. Calcd for $C_{14}H_{14}ClNO_2S$: M, 295.0432.

2-Chloro-1,1-diphenyl-2-(phenylsulfinyl)ethanol (32). Colorless crystals; mp 147—148 °C ($CHCl_3$–hexane); IR (KBr) 3450 (OH), 1085, 1065, 1035 (SO) cm^{-1}; ^1H NMR δ=5.35, (1H, s), 7.1—7.7 (15H, m). Found: C, 66.82; H, 4.68; Cl, 10.15; S, 8.87%. Calcd for $C_{20}H_{17}ClO_2S$: C, 67.31; H, 4.80; Cl, 9.93; S, 8.98%.

α-Sulfinyl ketones in Table 3 (**33**—**38**) were synthesized from the corresponding chloro alcohols in a way similar to that described for **9**.

8-(Phenylsulfinyl)-7-tetradecanone (33). Colorless oil (about 1 : 1 diastereometric mixture); IR (neat) 1710 (CO), 1090, 1050 (SO) cm^{-1}; ^1H NMR δ=0.84, 0.86 (each 3H, t, J=7 Hz), 1.0—2.6 (20H, m), 3.48—3.77 (1H, m), 7.50 (5H, m); MS *m/z* (%) 320 (M^+, 3), 319 (10), 211 (31), 113 (100). Found: *m/z* 320.2134. Calcd for $C_{20}H_{32}O_2S$: M, 320.3172.

1-Phenyl-1-(phenylsulfinyl)-2-propanone (34a) and 1-Phenyl-2-(phenylsulfinyl)-1-propanone (34b). **34a**: Colorless oil (about 1 : 1 diastereomeric mixture); IR (neat) 1710 (CO), 1090, 1050 (SO) cm^{-1}; ^1H NMR δ=2.03, 2.29 (each 1.5H, s), 4.61, 4.71 (each, 0.5H, s), 6.8—7.5 (10H, m); MS *m/z* (%) 258 (M^+, 8), 199 (3), 133 (91), 105 (100). Found: *m/z* 258.0715. Calcd for $C_{15}H_{14}O_2S$: M, 258.0714. **34b**: Colorless oil (about 3 : 2 diastereomeric mixture); IR (neat) 1680 (CO), 1090, 1050 (SO) cm^{-1}; ^1H NMR δ=1.32 (1.2H, d, J=7 Hz), 1.66 (1.8H, d, J=7 Hz), 4.59 (0.6H, q, J=7 Hz), 4.86 (0.4H, q, J=7 Hz), 7.1—8.0 (10H, m); MS *m/z* (%) 258 (M^+, 10), 133 (34), 105 (100). Found: *m/z* 258.0714. Calcd for $C_{15}H_{14}O_2S$: M, 258.0714.

1-(4-Fluorophenyl)-1-(phenylsulfinyl)-2-propanone (35a) and 1-(4-Fluorophenyl-2-(phenylsulfinyl)-1-propanone (35b). **35a**: Colorless solid (about 1 : 1 diastereomeric mixture); IR (KBr) 1705 (CO), 1080, 1045 (SO) cm^{-1}; ^1H NMR δ=2.06, 2.31 (each 1.5H, s), 4.57, 4.72 (each, 0.5H, s), 6.8—7.5 (9H, m); MS *m/z* (%) 276 (M^+, 4), 260 (10), 217 (34), 151 (94), 125 (100). Found: *m/z* 276.0622. Calcd for $C_{15}H_{13}FO_2S$: M, 276.0620. **35b**: Colorless oil (about 3 : 2 diastereomeric mixture); IR (neat) 1670 (CO), 1080, 1040 (SO) cm^{-1}; ^1H NMR δ=1.33 (12H, d, J=7 Hz), 1.65 (1.8H, d, J=7 Hz), 4.58 (0.6H, q, J=7 Hz), 4.79 (0.4H, q, J=7 Hz), 6.9—8.1 (9H, m); MS *m/z* (%) 276 (M^+, 11), 151 (38), 123 (100). Found: *m/z* 276.0625. Calcd for $C_{15}H_{13}FO_2S$: M, 276.0620.

1-(1-Naphthyl)-1-(phenylsulfinyl)-2-propanone (36a) and 1-(1-Naphthyl)-2-(phenylsulfinyl)-1-propanone (36b). **36a**: Colorless solid (about 3 : 1 diastereomeric mixture); IR (KBr) 1715 (CO), 1035 (SO) cm^{-1}; ^1H NMR δ=2.05 (0.75H, s), 2.25 (2.25H, s), 5.46 (1H, s), 6.8—8.0 (12H, m); MS *m/z* (%) 310 ($[M+2]^+$, 4), 308 (M^+, 2), 250 (3), 183 (75), 141 (100). **36b**: Colorless oil (about 1 : 1 diastereomeric mixture); IR (neat) 1670 (CO), 1080, 1040 (SO) cm^{-1}; ^1H NMR δ=1.42 (1.5H, d, J=7 Hz), 1.72 (1.5H, d, J=7 Hz), 4.61 (0.5H, q, J=7 Hz), 4.88 (0.5H, q, J=7 Hz), 7.0—8.4 (12H, m); MS *m/z* (%) 308 (M^+, 6), 292 (1), 182 (62), 155 (100). Found: *m/z* 308.0877. Calcd for $C_{19}H_{16}O_2S$: M, 308.0870.

1-(2-Naphthyl)-1-(phenylsulfinyl)-2-propanone (37a) and 1-(2-Naphthyl)-2-(phenylsulfinyl)-1-propanone (37b). **37a**: Colorless solid (about 1 : 1 diastereomeric mixture); IR (KBr) 1705 (CO), 1085, 1050 (SO) cm^{-1}; ^1H NMR δ=2.04 (1.5H, s), 2.32 (1.5H, s), 4.78 (0.5H, s), 4.86 (0.5H, s), 6.8—7.9 (12H, m); MS *m/z* (%) 308 (M^+, 1), 281 (0.5), 249 (3), 184 (55), 141 (100). Found: *m/z* 308.0877. Calcd for $C_{19}H_{16}O_2S$: M, 308.0870. **37b**: Colorless oil (about 3 : 2 diastereomeric mixture); IR (neat) 1660 (CO), 1090, 1040 (SO) cm^{-1}; ^1H NMR δ=1.38 (1.2H, d, J=7 Hz), 1.74 (1.8H, d, J=7 Hz), 4.76 (0.6H, q, J=7 Hz), 5.06 (0.4H, d, J=7 Hz), 7.1—8.1 (12H, m); MS *m/z* (%) 308 (M^+, 2), 182 (40), 155 (100). Found: *m/z* 308.0866. Calcd for $C_{19}H_{16}O_2S$: M, 308.0870.

1,2-Diphenyl-2-(phenylsulfinyl)ethanone (38). Colorless crystals (about 1 : 1 diastereomeric mixture); mp 147—150 °C (AcOEt–hexane); IR (KBr) 1680 (CO), 1040 (SO) cm^{-1}; ^1H NMR δ=5.41 (0.5H, s), 5.52 (0.5H, s), 6.9—8.0 (15H, m). Found: C, 74.83; H, 4.97; S, 9.91%. Calcd for $C_{20}H_{16}O_2S$: C, 74.97; H, 5.03; S, 10.01%.

Synthesis of 19 in One-Pot Reaction. A solution

of chloromethyl phenyl sulfoxide **1** (87 mg; 0.5 mmol) in 1 ml of dry THF was added with stirring to a solution of LDA (0.6 mmol) in 2 ml of THF at −70 °C. The reaction mixture was stirred for 10 min, then cyclopentanone (0.6 mmol) was added to the mixture through a syringe. The reaction mixture was stirred at −70 °C for 15 min and then a solution of LDA (1.5 mmol) in 3 ml of THF was added. The reaction mixture was stirred and allowed to warm to −20 °C for 1.75 h. The reaction was quenched by adding sat. aq NH_4Cl. The usual workup followed by silica-gel column chromatography gave 81 mg (73%) of **19**.

1-[Chloro(phenylsulfonyl)methyl]cyclopentanol (39). A solution of **12** (776 mg; 3 mmol) in 20 ml of CH_2Cl_2 at 0 °C was added *m*-chloroperbenzoic acid (MCPBA; 3.6 mmol). The reaction mixture was stirred at room temperature for 2 h. The reaction mixture was diluted with CH_2Cl_2 and the solution was washed successively with 10% NaOH and sat. aq NH_4Cl. The organic layer was dried over $MgSO_4$. The product was purified by silica-gel column chromatography to give **39** (795 mg; 97%) as a colorless oil. IR (neat) 3540 (OH), 1150 (SO_2) cm^{-1}; ^1H NMR δ=1.5—2.2 (8H, m), 4.79 (1H, s), 7.4—7.8 (3H, m), 7.8—8.0 (2H, m); MS *m/z* (%) 274 (M^+, 2), 232 (1), 221 (1), 190 (12), 85 (100). Found: *m/z* 274.0425. Calcd for $C_{12}H_{15}ClO_3S$: M, 274.0428.

(*E*)-2-Cyclotridecen-1-one (40). A solution of **22** (146 mg) in 2 ml of toluene was refluxed under Ar for 10 min. The solvent was evaporated under vacuum and the residue was purified by silica-gel column chromatography to afford 78 mg (89%) of **40** as a colorless oil. IR (neat) 1695, 1670 (CO), 1635 (C=C) cm^{-1}; ^1H NMR δ=0.9—1.9 (16H, m), 2.1—2.4 (2H, m), 2.4—2.6 (2H, m), 6.18 (1H, dt, *J*=16, 1 Hz), 6.83 (1H, dt, *J*=16, 7 Hz); MS *m/z* (%) 194 (M^+, 58), 151 (7), 123 (12), 109 (68), 81 (100). Found: *m/z* 194.1667. Calcd for $C_{13}H_{22}O$: M, 194.1669.

1,2-Diphenylethanone (41). A suspension of **38** (156 mg) and Raney-Ni (W-2; 2 ml)[16] in 3 ml of ethanol was stirred and refluxed for 30 min. The suspension was filtered and the filtrate was evaporated to give a residue, which was purified by silica-gel column chromatography to give 83 mg (87%) of **41** as a colorless amorphous. IR (KBr) 1695 (CO) cm^{-1}; ^1H NMR δ=4.25 (2H, s), 7.24 (5H, m), 7.3—7.6 (3H, m), 7.8—8.1 (2H, m); MS *m/z* (%) 196 (M^+, 5), 105 (100). Found: *m/z* 196.0887. Calcd for $C_{14}H_{12}O$: M, 196.0887.

This study was supported by Takeda Science Foundation and a Grant-in-Aid for Scientific Research No. 05671771 from the Ministry of Education, Science and Culture, which are gratefully acknowledged. We are grateful to Dr. Norio Takamura, Tanabe Seiyaku Co., Ltd., for elemental analyses, and to Noriko Sawabe and Fukiko Hasegawa of this laboratory for NMR and MS measurements.

References

1) In this paper, the term "carbenoid" is suggested for the description of intermediates which exhibit reactions qualitatively similar to those of free carbenes.

2) a) W. E. Parham and E. E. Schweizer, *Org. React.*, **13**, 55 (1963); b) W. Kirmse, "Carbene Chemistry," Academic Press, New York, (1971); c) P. J. Stang, *Chem. Rev.*, **78**, 383 (1978); d) S. D. Burke and P. Grieco, *Org. React.*, **26**, 361 (1979); e) H. F. Schaefer, III, *Acc. Chem. Res.*, **12**, 288 (1979); f) H. Wynberg and E. W. Meijer, *Org. React.*, **28**, 1 (1982); g) H. Nozaki, *Synlett*, **1990**, 441; h) A. Padwa and K. E. Krumpe, *Tetrahedron*, **48**, 5385 (1992).

3) T. Satoh, *Yakugaku Zasshi*, **111**, 205 (1991); T. Satoh and K. Yamakawa, "Reviews on Heteroatom Chemistry," ed by S. Oae, **6**, 218 (1992); T. Satoh and K. Yamakawa, *Synlett*, **1992**, 455.

4) A part of this study was reported as a communication: T. Satoh, Y. Hayashi, Y. Mizu, and K. Yamakawa, *Tetrahedron Lett.*, **33**, 7181 (1992).

5) T. Durst, *J. Am. Chem. Soc.*, **91**, 1034 (1969).

6) C. G. Venier, H. J. Barager, III, and M. A. Ward, *J. Am. Chem. Soc.*, **97**, 3238 (1975); M. F. Neumann and J-J. Lohmann, *Angew. Chem., Int. Ed. Engl.*, **16**, 323 (1977); C. G. Venier and H. Beckhaus, *Tetrahedron Lett.*, **1978**, 109.

7) T. Harada, E. Akiba, K. Tsujimoto, and A. Oku, *Tetrahedron Lett.*, **26**, 4483 (1985).

8) T. Satoh, K. Iwamoto, A. Sugimoto, and K. Yamakawa, *Bull. Chem. Soc. Jpn.*, **61**, 2109 (1988).

9) H. Taguchi, H. Yamamoto, and H. Nozaki, *J. Am. Chem. Soc.*, **96**, 6511 (1974); H. Taguchi, H. Yamamoto, and H. Nozaki, *Tetrahedron Lett.*, **1976**, 2617; H. Taguchi, H. Yamamoto, and H. Nozaki, *Bull. Chem. Soc. Jpn.*, **50**, 1592 (1977).

10) W. D. Abraham, M. Bhupathy, and T. Cohen, *Tetrahedron Lett.*, **28**, 2203 (1987).

11) T. Satoh, Y. Kaneko, T. Izawa, K. Sakata, and K. Yamakawa, *Bull. Chem. Soc. Jpn.*, **58**, 1983 (1985).

12) S. F. Wnuk and M. J. Robins, *J. Org. Chem.*, **55**, 4757 (1990).

13) S. Iriuchijima and G. Tsuchihashi, *Synthesis*, **1970**, 588.

14) B. H. Philip and J. Keating, *Tetrahedron Lett.*, **1961**, 523; B. H. Philip, M. K. Lowery, and J. Havel, *Tetrahedron Lett.*, **1967**, 5049.

15) B. M. Trost, *Chem. Rev.*, **78**, 363 (1978).

16) B. M. Trost, T. N. Salzmann, and K. Hiroi, *J. Am. Chem. Soc.*, **98**, 4887 (1976).

17) R. Mozingo, *Org. Synth.*, Coll. Vol. 3, 181 (1955).