(12) G. A. Baramki, G. Derdall, and J. T. Edward, *Can. J. Spectrosc.*, **18**, 160 (1973).
(13) K. Kakemi, H. Sezaki, M. Nakano, K. Ohsuga, and T. Mitsunaga, *Chem. Pharm. Bull.*, **17**, 901 (1969).
(14) T. C. Bruice and J. M. Sturtevant, *J. Am. Chem. Soc.*, **81**, 2860 (1959).
(15) T. Okuyama and G. L. Schmir, *J. Am. Chem. Soc.*, **94**, 8805 (1972).
(16) M. L. Bender and R. D. Ginger, *J. Am. Chem. Soc.*, **77**, 348 (1955).
(17) The value of k_{obsd} for hydrolysis of benzamide in 1 M HCl has also been reported as 9.55×10^{-6} s^{-1} at 59.6 °C; B. S. Rabinowitch and C. A. Winkler, *Can. J. Res., Sect. B*, **20**, 73 (1942).
(18) The pK_a of benzamide has been reported as −2.16 in aqueous H_2SO_4; J. T. Edward, H. S. Chang, K. Yates, and J. R. Stewart, *Can. J. Chem.*, **38**, 1518 (1960).
(19) E. M. Arnett, *Prog. Phys. Org. Chem.*, 1, 223 (1963).
(20) The small difference in the rate constants (threefold) could result from the transition from rate-determining breakdown to formation of a tetrahedral intermediate in the pH range 8.0–7.0, with the consequence that the observed rate constants in that pH range and the assumed value of k_2 could be less than theoretically expected from eq 2.
(21) M. Eigen, *Angew. Chem., Int. Ed. Engl.*, **3**, 1 (1964).
(22) T. H. Fife and B. M. Benjamin, *J. Chem. Soc., Chem. Commun.*, 525 (1974).
(23) D. G. Oakenfull and W. P. Jencks, *J. Am. Chem. Soc.*, **93**, 178 (1971).
(24) D. G. Oakenfull, K. Salvesen, and W. P. Jencks, *J. Am. Chem. Soc.*, **93**, 188 (1971).
(25) A. C. Satterthwait and W. P. Jencks, *J. Am. Chem. Soc.*, **96**, 7018 (1974).
(26) W. P. Jencks and M. Gilchrist, *J. Am. Chem. Soc.*, **86**, 5616 (1964).

Lithiation of Cyclopropyl and 2-Methylcyclopropyl Phenyl Sulfides. Addition to Carbonyl Partners

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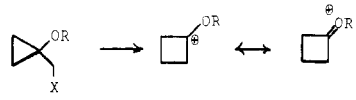
Abstract: Cyclopropyl phenyl sulfide undergoes complete metalation with *n*-butyllithium at 0 °C in about 1 h. The corresponding anion shows no inversion on the NMR time scale. It adds to the carbonyl group of saturated and α,β-unsaturated aldehydes and ketones. The stereochemistry, regiochemistry, and chemoselectivity of the addition is discussed. The effect of a β-methyl group on the metalation and carbonyl additions is examined. The question of nonclassical stabilization of the cyclopropyl anion is raised.

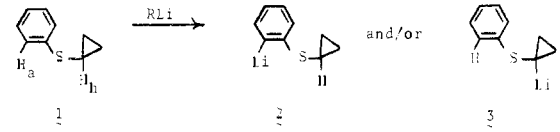
The generation of quaternary carbon atoms with stereochemical control is an important problem in organic synthesis. The replacement of the two carbon–oxygen bonds of a carbonyl group with two carbon–carbon bonds as a direct geminal alkylation has promise for organic synthesis.[1] The ability to incorporate these two bonds into a cyclobutyl ring has the virtue that the strain energy of the product can provide a driving force for further skeletal reorganization and the generation of a myriad of useful carbon frameworks.[2,3]

Wagner–Meerwein rearrangements of cyclopropyl systems offer a potential for accomplishment of such an overall process provided that the reaction can be made unidirectional for formation of the four-membered ring system.[4] Several reports in the literature suggested the ability to achieve this goal by placing an oxygen substituent on the cyclopropyl carbon atom.[5]

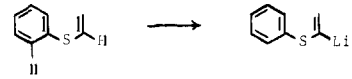


In ours[2,3] and other related work[6] this type of substitution was achieved by the formation of oxaspiropentane intermediates. Their accessibility directly from ketones via diphenylsulfonium cyclopropylide has offered a host of potential new approaches to the elaboration of organic molecules of theoretical and biological significance. Three limitations suggested the need for an alternative. (1) The ylide undergoes conjugate addition rather than carbonyl addition with α,β-unsaturated carbonyl compounds. (2) Very sterically hindered ketones react very sluggishly. (3) Silver salts are required in the preparation of the precursor sulfonium salt.

Cyclopropyl phenyl sulfides offered a potential for overcoming these limitations. Three questions that must be resolved are: (1) the ability to metalate directly; (2) the nucleophilicity of the resultant organometallic; and (3) the ability of sulfur



to direct the carbonium ion rearrangement. Metalation on carbon adjacent to sulfur had been reported for thioanisole[7] and allyl phenyl sulfide,[8] although rather drastic conditions had been employed for the latter case. On the other hand, thiophenetole had been reported not to metalate on the ethyl group.[9] In the case of thioanisole metalation occurs initially on the aromatic ring and subsequent rearrangements lead to the side chain metalation. The ability of oxygen to activate ortho positions in aryl ethers toward metalation further reinforced the idea that abstraction of Ha in **1** might be a very favorable process. On the other hand, it is reasonable to anticipate that the ability of sulfur to stabilize α-carbanions might overcome the unfavorable differences in hybridization of the C–Li bond between **2** and **3** to favor the formation of **3** at least in a thermodynamic, if not a kinetic, process. At the time this work was begun, the metalation of phenyl vinyl sulfide had not been reported. We found that metalation does proceed with

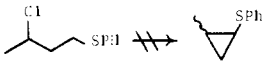


sec-butyllithium at the α-vinyl position.[10] Recently this metalation has also been accomplished with *n*-butyllithium–potassium *tert*-butoxide[11] and a related metalation of 1-ethoxy-2-phenylthioethene has been reported.[12] It is interesting to note that phenyl vinyl ether does metalate in the aromatic ring, which subsequently rearranges to the product of side

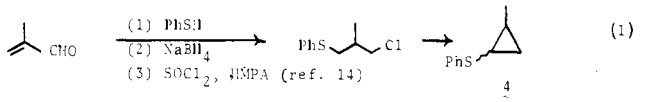
chain metalation.[11] Once formed, the ability of this rather bulky organometallic to add to carbonyl groups, especially of hindered ketones and α,β-unsaturated systems, had to be established. In this paper, we wish to report on the metalation of **1**, the effect of a β-alkyl substituent on this reaction, and the addition of these anions to carbonyl groups. In the accompanying manuscript, we deal with the question of the ability of sulfur to direct the carbonium ion rearrangement.

Results and Discussion

Preparation of Cyclopropyl Phenyl Sulfides. Cyclopropyl phenyl sulfide was prepared by the method of Truce et al.[13] A dramatic increase in the concentration for the ring closure step in liquid ammonia has had no deleterious effect. Interestingly, attempts to prepare 2-methylcyclopropyl phenyl sulfide (**4**) from 1-bromo-3-chlorobutane by an analogous route failed in



the cyclization step. Alternatively, 1-chloro-2-phenylthiopropane, available from methacrolein (eq 1), did cyclize smoothly.

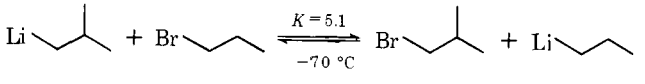


(1)

Metalation and Structure. Treatment of **1** with *n*-butyllithium in THF at 0 °C for 2 h followed by quenching with acetic acid-*O*-*d* in deuterium oxide led to 96% recovery of material. NMR revealed the complete disappearance of the signal at δ 2.05 due to the hydrogen α to sulfur. On the other hand, metalation of **4** under similar conditions led to only about 30% deuterium incorporation. To obtain more quantitative comparison in order to determine the effect of the methyl substituent, **1**, *cis*-**4**, and *trans*-**4** were treated with *n*-butyllithium at 0 °C and aliquots quenched in $DOAc/D_2O$ after various time intervals. Table I summarizes the approximate rate constants available from this study.

It is significant that the difference in $t_{1/2}$ between *cis*-**4** and *trans*-**4** of about 2 is considerably smaller than the difference in rate between **1** and *cis*-**4** of about 5. This observation implies that the slower rate of metalation of **4** relative to **1** is mainly electronic rather than steric in origin. It can be speculated that interaction between the carbanion orbital with the C(2)–C(3)

bond, as represented by the extreme resonance structure **5**, may help stabilize the anion.[15a] Since such interaction increases electron density at the carbon bearing the alkyl substituent, inductive destabilization of the anion ensues. In order to evaluate this point, the inductive effect of β-alkyl substitution on the stability of organometallics must be estimated. Unfortunately the available data do not allow one to evaluate this point. From the known equilibrium constants for the process represented by eq 2,[15b] it appears that a substantial part of the



(2)

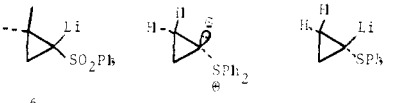
difference between **1** and **4** may arise from the simple inductive effect. Some credence that the unusual delocalization suggested above may play some role comes in comparing the metalation of phenyl vinyl sulfide and phenyl propenyl sulfide.[11] While any interpretation is complicated due to competing metalation at the methyl group in the latter case, in

Table I. Rates of Metalation

Compd	$t_{1/2}$, s	R_2, L mol^{-1} s^{-1}
1	1 080	3.8×10^{-3}
cis-**4**	5 700	7.3×10^{-4}
trans-**4**	11 100	3.7×10^{-4}

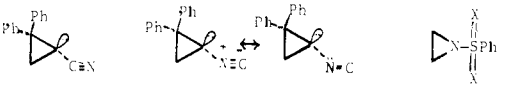
similar time periods, both metalated to about the same extent. A rate deceleration of the kind seen here is not apparent from the published data, indicating a small inductive effect of the β-methyl group. In any event, we were unable to see greater than 70% metalation in THF at 0 °C even after 24 h. It is apparent that β-alkyl substitution greatly inhibits the rate of metalation and makes anything but the parent reagent impractical by the direct metalation route.[16]

The question of the structure of the anion is of some interest. In the sulfur series, the sulfone **6** shows rapid inversion on the



NMR time scale,[17] but the ylide **7**, which should not be complicated by metal ion effects, shows inversion to be slow relative to the NMR time scale.[18] The NMR spectrum of **3** shows an AA′BB′ pattern at δ 0.60 and 0.91 with no temperature dependence between −78 °C and ambient probe temperature for the cyclopropyl protons. While inversion is slow on the NMR time scale, the cyclopropyl sulfide recovered from quenching of the organolithium from either pure *cis*-**4** or pure *trans*-**4** shows an 80:20 mixture of *trans*- and *cis*-1-deuterio-2-methylcyclopropyl phenyl sulfide. From this data, the activation energy for inversion is in the range of 15–25 kcal/mol.[19] The higher barrier to inversion compared to the sulfone may be attributed to lone pair–lone pair repulsions that destabilize flattening of the carbon atom in **3** (as well as **7**) and to the decreased ability of the sulfide to "delocalize" the negative charge compared to sulfone.

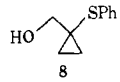
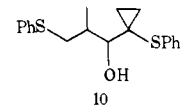
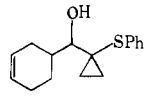
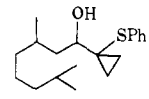
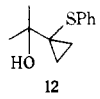
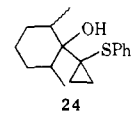
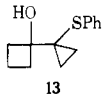
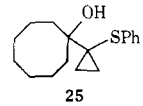
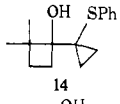
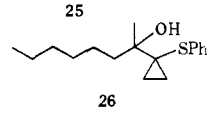
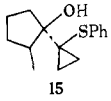
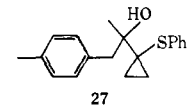
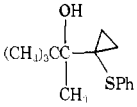
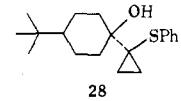
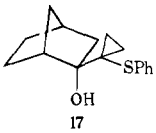
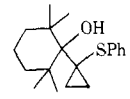
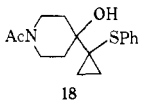
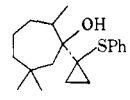
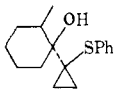
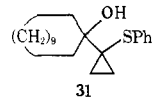
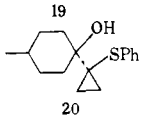
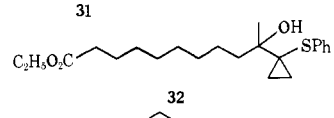
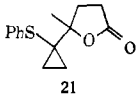
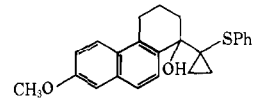
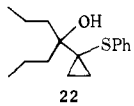
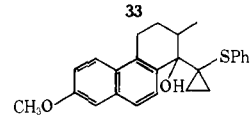
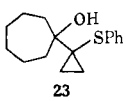
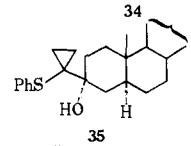
A similar trend was observed in the case of cyclopropyl nitriles and isonitriles.[20] Whereas the nitrile anion loses its configuration in aprotic solvents rapidly at low temperature, the isonitrile anion maintains it. The case of *N*-benzenesulfenyl- and *N*-phenylsulfonylaziridines parallels the behavior



seen here.[21] The various factors affecting inversion rates in this case have been thoroughly discussed.[21,22]

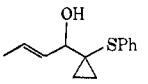
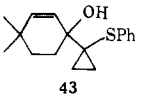
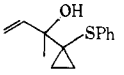
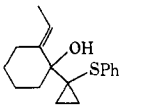
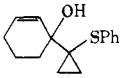
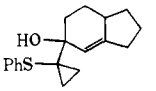
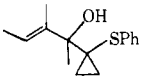
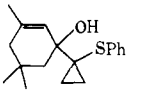
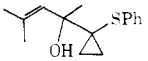
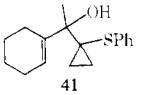
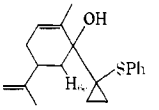
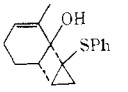
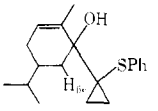
Carbonyl Additions. The addition of the organolithium species **3** to carbonyl groups of saturated aldehydes and ketones is a general reaction. In the reaction of aldehydes, excellent yields of the adducts were obtained at 0 or at −78 °C (see Table II). An interesting temperature dependence was observed in the case of 2-methyl-3-phenylthiopropanal. At 0 °C, elimination to α-methacrolein predominated, but was virtually stopped at −78 °C. While enolization of aldehydes generally presented little difficulty, enolization of ketones is more troublesome. Enolization decreases in the order cyclic ketones > acyclic ketones > hindered ketones. Thus, with six-, seven-, and eight-membered ring ketones yields generally were in the range of 60–70% with the remainder being recovered ketones. If the yield is based upon recovered starting material, it normally exceeded 90%. Cyclopentanones gave the lowest yields, since enolization was most troublesome. On the other hand, cyclobutanones presented no difficulties. Presumably, the

Table II. Additions of 1-Lithiocyclopropyl Phenyl Sulfide to Saturated Carbonyl Partners

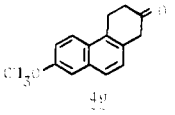
Entry	Carbonyl compd	Adduct	% yield	Entry	Carbonyl Compd	Adduct	% yield
				A. Aldehydes			
1	Formaldehyde	 8	83	3	2-Methyl-3-phenylthiopropanal	 10	93
2	Cyclohex-3-en-1-carboxaldehyde	 9	93	4	3,7-Dimethyloctanal	 11	91
				B. Ketones			
1	Acetone	 12	56	13	2,6-Dimethylcyclohexanone	 24	92
2	Cyclobutanone	 13	93	14	Cyclooctanone	 25	67
3	2,2-Dimethylcyclobutanone	 14	97	15	2-Octanone	 26	87
4	2-Methylcyclopentanone	 15	41	16	*p*-Tolylacetone	 27	93
5	Pinacolone	 16	92	17	4-*tert*-Butylcyclohexanone	 28	95
6	Norbornanone	 17	93	18	2,2,6,6-Tetramethylcyclohexanone	 29	98
7	*N*-Acetyl-4-piperidone	 18	25	19	Tetrahydroeucarvone	 30	62
8	2-Methylcyclohexanone	 19	93	20	Cyclododecanone	 31	94
9	4-Methylcyclohexanone	 20	52	21	Ethyl 10-oxoundecanoate	 32	87
10	Ethyl levullinate	 21	46	22	7-Methoxy-1-oxo-1,2,3,4-tetrahydrophenanthrene	 33	87
11	4-Heptanone	 22	87	23	7-Methoxy-2-methyl-1-oxo-1,2,3,4-tetrahydrophenanthrene	 34	96
12	Cycloheptanone	 23	51	24	Cholestanone	 35	93

enhanced reactivity of the carbonyl group overcomes the generally facile enolization, leading to a high yield of addition product. We have been unsuccessful in adding this anion to a β-tetralone type such as **49**—presumably because of enolization. On the other hand, an acyclic arylacetone (Table IIB, entry 16) adds nicely. Most delightfully, sterically congested ketones add **3** exceedingly well. The chemospecificity was examined in two cases, Table IIB, entires 10 and 21. In both cases, selective ketone addition occurred when **3** was added to the keto ester at −78 °C (i.e., inverse addition). In the case of

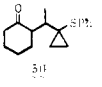
Table III. Addition of 1-Lithiocyclopropyl Phenyl Sulfide to α,β-Unsaturated Carbonyl Partners

Entry	Carbonyl compd	Adduct	% yield	Entry	Carbonyl compd	Adduct	% yield
1	Crotonaldehyde	 **36**	92	8	4,4-Dimethylcyclohexenone	 **43**	86
2	3-Buten-2-one	 **37**	83	9	2-Ethylidenecyclohexanone	 **44**	85
3	Cyclohex-2-en-1-one	 **38**	85	10	Bicyclo[4.3.0]non-1-en-3-one	 **45**	84
4	3-Methyl-(*E*)-3-penten-2-one	 **39**	96	11	3,5,5-Trimethyl-cyclohex-2-en-1-one	 **46**	43
5	Mesityl oxide	 **40**	89				
6	1-Acetylcyclohexene	 **41**	91	12	Carvone	 **47**	98
7	2,6-Dimethyl-cyclohex-2-en-1-one	 **42**	88	13	2-Methyl-5-isopropyl-cyclohex-2-en-1-one	 **48**	72

ethyl levullinate, it is not surprising that the alkoxide cyclized to give the lactone as the direct product of the addition.

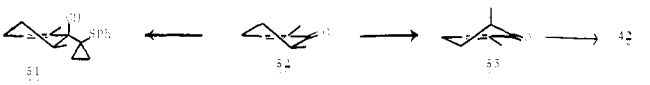


One of the major goals in developing this approach envisions the extension of the cyclobutanation of carbonyl groups to enals and enones. Diphenylsulfonium cyclopropylide undergoes conjugate addition in preference to carbonyl addition in such cases.[23] As illustrated in Table III, α,β-unsaturated aldehydes and ketones add **3** exclusively at the carbonyl group. Such is the case even for enones held rigidly in a cisoid conformation (Table II, entry 9). In one run, a second product was isolated and was tentatively assigned the structure of the product expected from conjugate addition (**50**). However, this result was not reproducible.

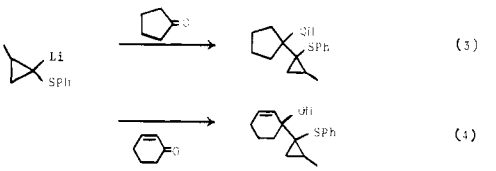


The stereochemistry of the addition was examined by NMR spectroscopy and absorption chromatography (TLC, LLC) in a few cases. In the 2-methylcycloalkanones, Table IIB, entries 4, 8, 19, and 23, the methyl group appeared as a sharp doublet at δ 0.93, 0.80, 0.82, and 0.95 for adducts **15, 19, 30,** and **34,** respectively. Assuming that, as with any bulky organometallic, steric hindrance to attack is controlling, the stereochemistry possessing the methyl group trans to the cyclopropyl unit is assigned.[24] The homogeneity of adduct **28** was established by LLC, which showed a major peak and a very minor peak (~3%) at somewhat longer retention volumes. Again, by analogy to the additions of other organometallics to this ketone, the major isomer is assigned as depicted.[25] The cholestanone adduct (**35**) was a sharp melting solid whose NMR spectra showed clean angular methyl groups—again these observations imply stereohomogeneity.

The cases of the enones follow similar trends. In the adducts to several cyclohexenones (Table III, entires 7, 12, and 13) a one-proton signal appears at somewhat lower fields (.δ 2.43, 2.40, and 2.42). In the cases of **47***E* and **48** it appears as a doublet of doublets (**47,** J = 13 and 3 Hz, and **48,** J = 16 and 2 Hz), indicating it is H(6e). The downfield shift may result from deshielding of this proton due to its being situated above the plane of the cyclopropane ring, the latter somewhat immobilized due to interactions with the methyl group. Due to virtual coupling, complete analysis of the coupling constants for this proton in **42** is not possible. Analogy to **47** and **48,** however, suggests that the proton at C(6) is equatorial and therefore the methyl group axial. Analysis of the eclipsing interactions in the alternative isomer **51** suggests that severe steric hindrance is encountered for equatorial approach of **3** to conformer **52,** but less so for equatorial approach to **53.**[26]



The difficulties in getting the metalation of **4** to go to completion as well as subsequent difficulties in utilizing the adducts in synthesis led us to explore the reactions of 2-methyl-1-lithiocyclopropyl phenyl sulfide only cursorily. Its addition to ketones like cyclopentanone (eq 3) or cyclohex-2-en-1-one (eq 4) was hampered by enolization problems to a somewhat



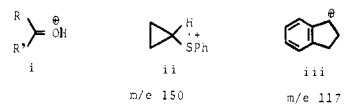
(3)

(4)

greater extent, producing the adducts in approximately 30% yield with the majority being recovered starting material.

The adducts were characterized by their spectral properties

as well as subsequent chemical transformations. In the infrared spectra, in addition to the normal absorptions for the hydroxyl and phenyl groups, two bands at 1075 ± 15 and 1025 ± 15 cm^{-1} appear consistently and can be assigned to the cyclopropyl ring.[27] In the NMR spectra, the cyclopropyl ring normally appears as an AA'BB' pattern in the region δ 0.6–1.2. It is interesting to note the somewhat high field position for the HO-C*H*- in the aldehyde adducts, which suggests a net shielding by the cyclopropyl phenyl sulfide unit. The mass spectra are characterized by ions i–iii with frequent appearance of ions corresponding to thiophenol or $C_6H_5S^+$.



i ii iii

m/e 150 m/e 117

These adducts are the springboard for a number of synthetic uses. In particular, the strain of the cyclopropyl ring and the versatility of the sulfur atom provide the basis for their utility in synthesis.[2,3,28,29] One major application is their utility in cyclobutane, cyclobutene, and cyclobutanone synthesis, which is the subject of the accompanying manuscript.

Experimental Section

General. Melting points were taken on a Thomas-Hoover melting point apparatus. All melting and boiling points are uncorrected. Unless otherwise stated, infrared spectra were determined in carbon tetrachloride or chloroform-d_1 solution on a Beckman IR-8 or Perkin-Elmer 267 spectrophotometer. NMR spectra were determined in carbon tetrachloride solution on a Varian A60A or Jeolco MH-100 spectrometer; chemical shifts are given in δ with Me_4Si as the internal standard. Splitting patterns are designated as s, singlet; d, doublet; t, triplet; q, quartet; br s, broad singlet; m, multiplet. Coupling constants are given in hertz. Mass spectra were taken on an AEI MS-902 high resolution mass spectrometer at an ionizing voltage of 70 eV and an ionizing current of 98 mA. All exact mass determinations were obtained on the MS-902 instrument. Elemental analyses were determined by the Spang Microanalytical Laboratory, Ann Arbor, Michigan.

All experiments were carried out under an atmosphere of dry nitrogen. In experiments requiring dry solvents, ether, tetrahydrofuran, and dimethoxyethane were distilled from sodium-benzophenone. Methylene chloride was distilled from calcium hydride. Apparatus for experiments requiring dry conditions was dried by flaming in a nitrogen stream.

During workup of the reactions, general drying of the solvent was performed over anhydrous magnesium sulfate or anhydrous sodium sulfate as indicated.

Thin layer or preparative thick layer plates were made of E. Merck AG Darmstadt silica gel PF-254 activated by drying for 2 h at 140 °C. Removal of material from the silica gel was accomplished by successive washings with ether.

Preparation of Cyclopropyl Phenyl Sulfide. Following the procedure of Truce et al.[13] 196.35 g (1.79 mol) of thiophenol, 281.25 g (1.79 mol) of 1-bromo-3-chloropropane, and 100.2 g (1.79 mol) of potassium hydroxide in 300 mL of water produced 315.3 g (95%) of 3-chloropropyl phenyl sulfide, bp 92–94 °C (0.15 mm) (lit. bp 110–111 °C (1.7 mm)). Cyclization of 339 g (1.82 mol) of this sulfide in 350 mL of anhydrous ether with potassium amide generated from 142 g (3.64 g-atom) of potassium in 1.5 L of liquid ammonia (catalyzed by 0.75 g of ferric nitrate nonahydrate) gave 205 g (75%) of cyclopropyl phenyl sulfide, bp 51–52 °C (0.10 mm) (lit. bp 62–63 °C (1.0 mm)): IR (CCl_4) 1570, 1475, 1208, 1095, 1023, 880, 696, 687 cm^{-1}; NMR ($CDCl_3$) δ 7.0–7.4 (m, 5 H), 1.9–2.2 (m, 1 H), 0.80–1.0 (m, 2 H), 0.5–0.8 (m, 2 H).

Generation of 1-Lithiocyclopropyl Phenyl Sulfide and Quench with Deuterium Oxide–Acetic Acid-d_1. To a solution of 1.5 g (10.0 mmol) of cyclopropyl phenyl sulfide in 20 mL of freshly distilled tetrahydrofuran cooled to 0 °C was added 9.0 mL (12 mmol) of *n*-butyllithium in hexane solution via syringe. After stirring at 0 °C for 2.5 h, 2.8 mL of deuterium oxide–acetic acid-*O*-d_1 solution was added via syringe all at once. After stirring for 10 min, hexane (100 mL) was added, and the layers separated. The hexane layer was washed once with saturated aqueous sodium bicarbonate solution (20 mL). The hexane layer was dried ($MgSO_4$) and the solvents removed in vacuo. The residue (1.43 g, 96% yield) lacked the absorption at δ 2.05 due to the hydrogen α to the sulfur: IR (CCl_4) 3080, 3000, 2250, 1580, 1475, 1435 cm^{-1}; NMR ($CDCl_3$) δ 7.0–7.4 (m, 5 H), 0.95 (br t, J = 4 Hz, 2 H), 0.65 (br t, J = 4 Hz, 2 H).

NMR Study of 1-Lithiocyclopropyl Phenyl Sulfide. The solvent was removed from 1.0 mL (1.68 mmol) of methyllithium in ether on a vacuum pump (0.10 mm) at room temperature for 2 h. Tetrahydrofuran-d_8 (0.5 mL) was added and then removed under vacuum (0.10 mm). Tetrahydrofuran-d_8 (1.0 mL) was added and this solution cooled to 0 °C under nitrogen. Cyclopropyl phenyl sulfide (75 mg, 0.5 mmol) was added via syringe to a flame-dried NMR tube and cooled to 0 °C. The solution of methyllithium in tetrahydrofuran-d_8 was added via syringe to the cyclopropyl phenyl sulfide in the NMR tube. After 2 h at 0 °C, the mixture was cooled to −78 °C. NMR spectra were recorded at −66, −26, 0 °C, and ambient probe temperature. No coalescence of the multiplets at δ 0.60 and 0.91 could be seen at any of the above temperatures. This NMR sample was quenched with deuterium oxide, dried ($MgSO_4$), and concentrated in vacuo. NMR ($CDCl_3$) showed greater than 95% uptake of deuterium (absence of multiplet at δ 2.05).

Preparation of 2-Methyl-3-phenylthiopropanal. Thiophenol (15.4 g, 0.14 mol) was added dropwise to methacrolein (10.0 g, 0.14 mol) cooled to 0 °C. When the addition was complete, 5 drops of triethylamine was added. Stirring was continued for 15 min at 0 °C and then for 1 h at room temperature. Ether (50 mL) was added and this solution was washed with three 50-mL portions of 10% aqueous hydrochloric acid. The organic layer was dried ($MgSO_4$) and the solvents removed in vacuo. The residue was distilled to give 20 g (80%) of 2-methyl-3-phenylthiopropanal, bp 130–135 °C (3 mm): IR ($CHCl_3$) 3000, 2920, 2810, 2710, 1560 cm^{-1}; NMR (CCl_4) δ 9.6 (s, 1 H), 7.1–7.4 (m, 5 H), 3.2 (d of d, J = 12 and 6 Hz, 1 H), 2.8 (d of d, J = 12 and 7 Hz, 1 H), 2.5 (d of d of q, J = 6, 7, and 7 Hz, 1 H), 1.15 (d, J = 7 Hz, 3 H); MS *m/e* (%) 180 (17), 110 (100), 66 (13), 41 (20), 40 (28). Calcd for $C_{10}H_{12}OS$: 180.0609. Found: 180.0618.

Preparation of 2-Methyl-3-phenylthiopropan-1-ol. To a cold (0 °C) solution of 15 g (0.083 mol) of 2-methyl-3-phenylthiopropanal in 75 mL of absolute ethanol was added 0.95 g (0.025 mol) of solid sodium borohydride over a 45-min period. After stirring at 0 °C for 25 min and room temperature for 20 min, the mixture was poured into a two-phase system consisting of 150 mL of ether and 50 mL of 10% aqueous hydrochloric acid solution. The ether phase was separated and washed with 50 mL of saturated aqueous sodium carbonate solution. After drying ($MgSO_4$) and evaporation in vacuo, the residue was distilled at 107–116 °C (0.5 mm) to give 13.5 g (90%) of colorless oil: IR ($CHCl_3$) 3430, 1560 cm^{-1}; NMR (CCl_4) δ 7.19 (m, 5 H), 3.8 (s, 1 H), 3.42 (d, J = 3 Hz, 2 H), 2.8 (m, 2 H), 1.8 (m, 1 H), 0.9 (d, J = 4 Hz, 3 H); MS *m/e* (rel %) 182 (50), 123 (32), 111 (4), 110 (100), 109 (15), 72 (17), 57 (15). Calcd for $C_{10}H_{14}OS$: 182.0765. Found: 182.0764.

Preparation of 1-Chloro-2-methyl-3-phenylthiopropane.[14] To a solution of 8 g (0.044 mol) of 2-methyl-3-phenylthiopropan-1-ol in 15 mL of dry HMPA at −10 °C was added 5.3 g (0.044 mol) of freshly distilled (over triphenyl phosphite) thionyl chloride over a 1.5-h period. Upon completion of the addition, the reaction was warmed to 25 °C, stirred 4 h, poured onto ice, and extracted with pentane. After drying ($MgSO_4$) and evaporation in vacuo the residue distilled at 112–115 °C (1 mm) to provide 7.5 g (86%) of product: IR (CCl_4) 1560 cm^{-1}; NMR (CCl_4) δ 7.08 (m, 5 H), 3.45 (dd, J = 3 and 0.5 Hz, 2 H), 2.8 (m, 2 H), 1.9 (m, 1 H), 1.0 (d, J = 4 Hz, 3 H); MS *m/e* (rel %) 202 (15), 200 (43), 123 (100), 110 (55), 109 (11), 77 (9), 65 (10), 55 (11), 45 (26). Calcd for $C_{10}H_{13}ClS$: 200.0427. Found: 200.0441.

Preparation of 2-Methylcyclopropyl Phenyl Sulfide. Potassium (2.54 g, 0.065 g-atom) was added in small pieces over 30 min to 75 mL of anhydrous liquid ammonia containing 121 mg (0.3 mmol) of ferric nitrate nonahydrate. A solution of 6.5 g (32.5 mmol) of 1-chloro-2-methyl-3-phenylthiopropane in 40 mL of dry ether was added dropwise over 2.5 h. A green-black mixture resulted. The liquid ammonia was allowed to evaporate and the remaining brown ether solution refluxed for 4 h. After quenching with 100 mL of distilled water, the ether layer was separated and washed with 50 mL of saturated aqueous sodium chloride solution. After drying ($MgSO_4$) and removal of the solvent in vacuo, the remaining light yellow oil was distilled at 71–74 °C (0.8 mm) to give 4.4 g (82%) of a colorless liquid. VPC analysis indicates a 5:1 mixture of *E* (retention time 10.5 min) and

Table IV. Deuteration of Cyclopropyl Phenyl Sulfides

Sulfide	0.25 h	0.5 h	1 h	1.5 h	2 h	3 h	4 h	5 h
1[a]	45	55	73	100				
1[a]	49	60	73	95				
4[b]			24		36	51		
4[b]			28		33	44		61
trans-**4**[b]			29		42	49	57	63
trans-**4**[b]			23		35	48	60	60
cis-**4**[b]			46		61			
cis-**4**[b]			38		51			

[a] Determined by NMR integration of signal at δ 1.9-2.2 compared to either aryl or CH_2CH_2 signals. [b] Determined by mass spectroscopy.

Z (retention time 14.5 min) isomers: IR (CCl_4) 3080, 1580 cm^{-1}; NMR (CCl_4) δ 0.6-1.1 (m, 3 H), 1.18 (d, J = 3 Hz, 3 H), 1.8 (dt, J = 8 and 4 Hz, 0.8 H), 2.16 (m, 0.2 H), 7.05 (m, 5 H); MS *m/e* (rel %) 166 (5), 165 (11), 164 (100), 149 (29), 135 (13), 131 (14), 116 (19), 110 (79), 91 (13), 77 (11), 66 (15), 65 (10). Calcd for $C_{10}H_{12}S$: 164.0660. Found: 164.0660.

Rate of Anion Generation from Cyclopropyl Phenyl Sulfides. Anion generation was performed for the 5:1 *E* and *Z* mixture, the pure *E*, and pure *Z* isomers of 2-methylcyclopropyl phenyl sulfide and cyclopropyl phenyl sulfide in duplicate. The pure *E* and pure *Z* were obtained by collection from VPC. A typical procedure is detailed. To a solution of 549 mg (3.61 mmol) of 2-methylcyclopropyl phenyl sulfide in 15.0 mL of dry THF maintained at 0 °C was added 2.65 mL (3.98 mmol) of a solution of *n*-butyllithium in hexane. At 1, 2, 3, 4, and 5 h a 1-mL aliquot was rapidly quenched into 1 mL of acetic acid-*O*-*d* (>98% deuterium). The quench was diluted with ether and the solution washed with two 20-mL portions of saturated aqueous sodium chloride solution, dried, and evaporated. The product was examined by VPC to determine isomer ratios and by NMR or MS to determine deuterium incorporation. Table IV summarizes the specific data.

Addition of 3 to Carbonyl Compounds: Method A (Normal Addition): Preparation of 2,2-Dimethyl-1-(1′-phenylthiocycloprop-1′-yl)cyclobutan-1-ol (14). To a solution of cyclopropyl phenyl sulfide (3.3 g, 22.0 mmol) in 75 mL of tetrahydrofuran at 0 ° was added *n*-butyllithium (15.1 mL, 22.0 mmol) in hexane via syringe. After stirring at 0 °C for 90 min, 2,2-dimethylcyclobutanone was added via syringe. After an additional 30 min at 0 °C, water (5 mL) was added, followed by ether (100 mL). The organic layer was washed with saturated aqueous sodium chloride solution (10 mL), dried ($MgSO_4$), and concentrated in vacuo. The residue was chromatographed on 200 g of silica gel using hexane to give recovered cyclopropyl phenyl sulfide and then 5% ether in hexane to give 2,2-dimethyl-1-(1′-phenylthiocycloprop-1′-yl)cyclobutan-1-ol (4.78 g, 96.5%): IR (CCl_4) 3710, 3590, 3080, 2890, 1585, 1460, 1070, 1030 cm^{-1}; NMR (CCl_4) δ 1.15 (s, 3 H), 1.2 (s, 3 H), 0.6-2.0 (m, 8 H), 2.4 (s, 1 H), 7-7.5 (m, 5 H); MS *m/e* (%) 248 (21), 192 (59), 159 (30), 117 (35), 58 (47), 55 (44), 41 (100). Calcd for $C_{15}H_{20}OS$: 248.1234. Found: 248.1236.

Method B (Normal Addition, Low Temperature): Preparation of 2-Methyl-3-phenylthio-1-(1′-phenylthiocycloprop-1′-yl)propan-1-ol (10). To a solution of 2.25 g (15.0 mmol) of cyclopropyl phenyl sulfide in 50 mL of tetrahydrofuran at 0 °C was added 10.79 mL (15.0 mmol) of *n*-butyllithium in hexane via syringe. After stirring at 0 °C for 2 h, the reaction mixture was cooled to −78 °C and 2.0 g (11.1 mmol) of 2-methyl-3-phenylthiopropanal was added via syringe. After stirring for 45 min at −78 °C, water (5 mL) was added and the reaction mixture allowed to warm to room temperature. Hexane (100 mL) was added and the layers separated. The organic layer was washed with saturated aqueous sodium chloride solution (10 mL), dried ($MgSO_4$), and the solvents were removed in vacuo. The resulting oil was chromatographed on 150 g of silica gel using hexane to elute recovered cyclopropyl phenyl sulfide and then 10% chloroform in hexane to give 2-methyl-3-phenylthio-1-(1′-phenylthiocycloprop-1′-yl)propan-1-ol (3.39 g, 92.5%): IR ($CHCl_3$) 3580, 3470, 3070, 2970, 2940, 2880, 1588, 1480, 1090, 1030 cm^{-1}; NMR (CCl_4) δ 7.0-7.5 (m, 10 H), 3.2-3.8 (m, 1 H), 2.2-3.2 (m, 2 H), 0.8-1.8 (m, 6 H), 1.0 (d, J = 6 Hz, 3 H); MS *m/e* (%) 330 (8), 255 (12), 220 (36), 158 (21), 110 (57), 78 (13). Calcd for $C_{19}H_{22}OS_2$: 330.1112. Found: 330.1111.

Method C (Inverse Addition): Preparation of Ethyl 10-Hydroxy-10-(1′-phenylthiocycloprop-1′-yl)undecanoate (31). To a solution of cyclopropyl phenyl sulfide (1.5 g, 10.0 mmol) in 50 mL of tetrahydrofuran at 0 °C was added via syringe *n*-butyllithium (14.5 mL, 10.0 mmol) in hexane. After stirring at 0 °C for 2 h, this mixture was added to 2.05 g (9.65 mmol) of ethyl 10-ketoundecanoate in 50 mL of tetrahydrofuran at −78 °C via a cannula. After stirring at room temperature for 30 min, water (5 mL) was added, followed by ether (100 mL). The organic layer was washed with saturated aqueous sodium chloride solution (10 mL), dried ($MgSO_4$), and concentrated in vacuo. The residue was chromatographed on 200 g of silica gel using hexane to give recovered cyclopropyl phenyl sulfide and ethyl 10-hydroxy-10-(1′-phenylthiocycloprop-1′-yl)undecanoate (**31**) (3.33 g, 95%): IR (CCl_4) 3610, 3095, 2980, 2900, 1730, 1490, 1470, 690 cm^{-1}; NMR (CCl_4) δ 0.85-2.5 (m, 27 H), 7.1-7.6 (m, 5 H), 4.1 (q, J = 0 Hz, 2 H), 2.25 (tm, J = 7 Hz, 2 H), 2.08 (br s, 1 H), 0.8-1.9 (m, 24 H). Calcd for $C_{22}H_{34}O_3S$: 378.2228. Found: 378.2228.

The remaining examples are summarized in Table V.

Spectral Properties of Selected Additional Adducts. Listed below are the characterization data for a few additional adducts. In the appendix can be found the data for the remaining examples.[30]

15: IR ($CHCl_3$) 3700, 3640, 3550, 3080, 3025, 2895, 1585, 1480, 1069, 1031 cm^{-1}; NMR ($CDCl_3$) δ 7.0-7.5 (m, 5 H), 0.9-2.5 (m, 12 H) with 1.0 (d, J = 6 Hz, 3 H) superimposed; MS *m/e* (rel %) 248 (9), 150 (13), 149 (11), 127 (34), 117 (25), 113 (41), 99 (64), 85 (34), 83 (27), 69 (48), 55 (93), 43 (100). Calcd for $C_{15}H_{20}OS$: 248.1235. Found: 248.1234.

18: mp 135-136.5 °C; IR ($CHCl_3$) 3680, 3550, 3430, 3110, 3090, 1625, 1583, 1485, 1059, 1010 cm^{-1}; NMR ($CDCl_3$) δ 7.1-7.6 (m, 5 H), 4.58 (dm, J = 15 Hz, 1 H), 3.64 (m, 2 H), 2.92 (m, 1 H), 2.3 (br s, 1 H), 2.11 (s, 3 H), 1.5-1.8 (m, 4 H), AA′BB′ with AA′ at 1.2 and BB′ at 1.0. Anal. ($C_{16}H_{21}NO_2S$): C, H, N, S.

19: IR (CCl_4) 3630, 3070, 3050, 1585, 1483, 1082, 1025 cm^{-1}; NMR (CCl_4) δ 7.3-7.5 (m, 2 H), 7.0-7.3 (m, 3 H), 0.6-2.4 (m, 14 H) with (d, J = 7 Hz, 3 H) superimposed at 0.78; UV $\lambda_{max}^{ethanol}$ nm (ϵ) 253 (6700); MS *m/e* (rel %) 262 (3), 150 (10), 113 (100), 95 (43), 81 (24), 69 (23), 68 (28), 55 (27). Calcd for $C_{16}H_{22}OS$: 262.1391. Found: 262.1397.

21: IR (CCl_4) 3080, 2970, 2870, 1762, 1600, 1488, 1080, 1025 cm^{-1}; UV $\lambda_{max}^{ethanol}$ nm (ϵ) 248 (8000); NMR (CCl_4) δ 7.0-7.5 (m, 5 H); MS *m/e* (rel %) 248 (11), 149 (12), 99 (100). Calcd for $C_{14}H_{16}O_2S$: 248.0875. Found: 248.0871.

28: IR (CCl_4) 3630, 3550, 3080, 1590, 1478, 1084, 1022 cm^{-1}; NMR (CCl_4) δ 7.0-7.5 (m, 5 H), 1.78 (s, 1 H), 1.0-1.7 (m, 11 H), 0.7-1.0 (m, with s superimposed at 0.84); MS *m/e* (rel %) 304 (23), 286 (19), 155 (26), 150 (94), 149 (32), 135 (28), 117 (100), 91 (43), 83 (21), 81 (39), 57 (94), 55 (32). Calcd for $C_{19}H_{28}OS$: 304.1861. Found: 304.1865.

30: IR ($CHCl_3$) 3630, 3080, 1590, 1470, 1070, 1028 cm^{-1}; UV $\lambda_{max}^{ethanol}$ nm (ϵ) 285 sh (1660), 257 (2440); NMR (CCl_4) δ 7.3-7.5 (m, 2 H), 7.0-7.3 (m, 3 H), 2.1-2.5 (m, 2 H), 1.1-2.0 (m, 10 H), 0.6-1.1 (m, 11 H); MS *m/e* (rel %) 304 (10), 180 (47), 162 (22), 155 (27), 150 (100), 147 (49), 137 (36), 135 (27), 134 (38), 119 (72), 117 (76), 110 (43), 109 (31), 107 (44), 105 (69), 95 (39), 93 (57), 83 (37), 82 (27), 81 (67), 79 (56), 77 (64), 69 (66), 55 (100). Calcd for $C_{19}H_{28}OS$: 304.1861. Found: 304.1855.

46: mp 63.5-65.0 °C (pentane); IR ($CHCl_3$) 3600, 3550, 3070, 1673, 1587, 1480, 1079, 1052, 1028 cm^{-1}; NMR ($CDCl_3$) δ 7.0-7.6 (m, 5 H), 5.2 (br s, 1 H), 1.73 and 1.60 (two br s, 8 H), 1.0 (s, 6 H), superimposed on 0.7-1.3 (m, 4 H). Anal ($C_{18}H_{24}OS$): C, H, S.

Table V. Reaction Details for Addition of **3** to Carbonyl Partners

Carbonyl compd (wt, g; mmol)	Cyclopropyl phenyl sulfide (wt, g; mmol)	THF, mL	n-C_4H_9Li, mmol	Procedure	Product wt, g (% yield)	Isolation	Chromatographic solvent[a]
Paraformaldehyde (1.5, 50)	8.9, 60	90	60	A	**8:** 8.9 (83)	bp 90–93 °C (0.3 mm)	
Cyclohex-3-ene-1-carboxaldehyde (1.06, 9.65)	1.50, 10	50	10	A	**9:** 2.31 (93)	col (150 g)[b]	A
2-Methyl-3-phenylthiopropanal	See text						
3,7-Dimethyloctanal (1.90, 12.2)	2.0, 13.4	30	13.4	B	**11:** 3.41 (91)	col (130 g)[b]	B
Acetone (9.6, 160)	27.3, 182	300	182	A	**12:** 18.7 (56)	col (1 kg)[b]	C
Cyclobutanone (0.91, 13)	2.4, 16	25	16	A	**13:** 2.67 (93)	TLC[c]	B
2,2-Dimethylcyclobutanone	See text						
2-Methylcyclopentanone (4.4, 45)	7.0, 46.6	150	46.6	B	**15:** 4.58 (41)	bp 135–140 °C (0.1 mm)	
Pinacolone (1.0, 10)	3.0, 20	25	20	A	**16:** 2.3 (92)	col (150 g)[b]	B
Norbornanone (5.0, 45.5)	7.48, 49.9	53	49.9	A	**17:** 10.9 (93)	col (500 g)[b]	B
N-Acetyl-4-piperidone	1.8, 12.0	200	12	A	**18:** 0.453 (24)[f]	Recrystallization	
2-Methylcyclohexanone	17.8, 119	200	120	B	**19:** 24.7 (93)	col	C
4-Methylcyclohexanone	4.45, 29.6	50	30	B	**20:** 3.4 (52)	col	C
Ethyl levullinate (14.4, 100)	15.0, 100	100	100	C	**21:** 11.4 (46)	col (500 g)	D
4-Heptanone (5.7, 50)	8.0, 53.3	150	53.3	B	**22:** 11.5 (87)	bp 131–134 °C (0.1 mm)	
Cycloheptanone (0.37, 3.3)	1.25, 8.3	20	1.0	B	**23:** 0.3 (51)	TLC	E
2,6-Dimethylcyclohexanone (2.76, 10)	1.80, 12	25	12	A	**24:** 2.29 (92)	col (99 g) bp 100 °C (0.05 mm)	B
Cyclooctanone (0.420, 3.3)	0.60, 4.0	22	3.7	A	**25:** 0.831 (67)	TLC	B
2-Octanone (1.38,10.8)	1.73, 11.5	50	11.5	A	**26:** 2.61 (87)	col (200 g)	B
p-Tolylacetone (0.60, 4.1)	0.675, 4.5	50	4.5	A	**27:** 1.12 (93)	col (100 g)	F
4-*tert*-Butylcyclohexanone (1.0, 6.5)	1.2, 8.0	28	8.0	A	**28:** 1.96 (95)	TLC	B
2,2,6,6-Tetramethylcyclohexanone (1.08, 7.0)	2.34, 15.6	25	15.6	A	**29:** 1.75 (98)	bp 133–135 °C (0.1 mm)	
Tetrahydroeucarvone (18.5, 120)	24.0, 160	200	160	A	**30:** 22.6 (62)	col	G
Cyclododecanone (5.0, 27.4)	4.5, 30	110	30	B	**31:** 8.58 (94)	bp 145–150 °C (0.1 mm)	
Ethyl 10-oxoundecanoate	See text						
7-Methoxy-1-oxo-1,2,3,4-tetrahydrophenanthrene (0.540, 2.39)	0.375, 2.5	15	2.5	A	**33:** 0.638 (87)	TLC	B
7-Methoxy-2-methyl-1-oxo-1,2,3,4-tetrahydrophenanthrene (2.32, 9.65)	1.5, 10	50	10	A	**34:** 3.60 (95)	col (200 g)	B
Cholestanone (0.450, 1.16)	0.180, 1.20	10	1.20	A	**35:** 0.578 (93)	TLC	B
Crotonaldehyde (1.61, 23.0)	4.20, 28.0	100	28	A	**36:** 4.59 (92)	col (200 g)	B
3-Buten-2-one (0.56, 8.0)	2.34, 15.6	25	15.6	A	**37:** 1.41 (83)	TLC	B
Cyclohex-2-en-1-one(1.15, 12.0)	2.70, 18.0	25	18.0	A	**38:** 2.56 (85)	TLC	B
3-Methyl-(*E*)-3-penten-2-one (2.25, 23.0)	4.20, 28.0	25	28.0	A	**39:** 5.53 (96)	col (250 g)	B
Mesityl oxide (0.98, 10.0)	3.00, 20.0	20	20.0	A	**40:** 2.20 (89)	col	A
1-Acetylcyclohexene (1.80, 14.5)	2.40, 16.0	50	16.0	A	**41:** 3.64 (91)	col (200 g)	F
2,6-Dimethylcyclohex-2-en-1-one (11.08, 89.0)	15.47, 103	250	103	A	**42:** 13.99 (88)	col (200 g) bp 80 °C (0.02 mm)	B
4,4-Dimethylcyclohexenone (5.0, 40.3)	6.35, 42.3	50	42.3	B	**43:** 9.5 (86)	col (200 g)	H
2-Ethylidenecyclohexanone (1.5, 12.1)	2.25, 15.0	25	15.0	A	**44:** 2.80 (85)	TLC	B
Bicyclo[4.3.0]non-1-en-3-one (1.36, 10.0)	3.00, 20	25	20	A	**45:** 2.40 (84)	col	B
Isophorone (2.64, 19.1)	3.15, 21.0	45	21.0	A or B	**46:** 4.82 (43)[d]	col (730 g)[e]	I
Carvone (1.50, 10.0)	3.00, 20.0	20	20.0	A	**47:** 2.94 (98)	col	B
2-Methyl-5-isopropyl cyclohex-2-en-1-one (3.0, 19.7)	3.25, 21.7	50	21.7	A	**48:** 4.28 (72)	col (200 g)	J

[a] Solvent systems for chromatography: A, 5% ether in hexane; B, 10% ether in hexane; C, 1:1 v/v hexane in chloroform; D, 2.5% acetone in benzene; E, 1:1 v/v hexane in ether; F, 2% ether in hexane; G, chloroform; H, hexane; I, 8% chloroform in hexane; J, 25% chloroform in hexane. [b] Col ≡ column chromatography on W. R. Grace silica gel (wt of column support). [c] Preparative thick layer (~2 mm) chromatography. [d] The crude material from two identical runs was combined for purification. Thus, the yield is calculated on the basis of twice the amount of starting material. [e] Fisher alumina employed for this chromatography. [f] The yield in this reaction, performed by procedure A, would improve if performed by procedure B.

47, *E* isomer (cyclopropyl and isopropenyl substituents cis, major): IR (CCl_4) 3559, 1639, 1585, 1475, 1082, 1059; 1029 cm^{-1}; NMR (CCl_4) δ 7.0–7.5 (m, 5 H), 5.48 (m, 1 H), 4.65 (m, 1 H), 2.6 (br s, 1 H), 2.40 (dd, J = 13 and 3 Hz, 1 H), 1.6–2.2 (m, 4 H), 1.7 (s, 3 H), 1.6 (d, J = 1 Hz, 3 H), 0.7–1.3 (m, 4 H); MS *m/e* (rel %) 300 (1), 282 (100), 267 (43), 205 (28), 173 (90), 157 (47), 131 (98), 117 (55), 110 (55), 91 (87). Calcd for $C_{19}H_{24}OS$: 300.1548. Found: 300.1557.

47, *Z* isomer (cyclopropyl and isopropenyl groups trans, minor): IR (CCl_4), 3636, 3497, 3097, 1642, 1585, 1475, 1084, 1050, 1032 cm^{-1}; NMR (CCl_4) δ 7.0–7.5 (m, 5 H), 5.53 (br s, 1 H), 4.58 (br s, 2 H), 1.3–2.3 (m, 6 H), 1.68 (d, J = 1.5 Hz, 3 H), 1.60 (s, 3 H), 0.7–1.3 (m, 4 H); MS *m/e* (rel %) 300 (18), 282 (15), 151 (27), 150 (100), 131 (27), 117 (76), 110 (39), 109 (61), 91 (61). Calcd for $C_{19}H_{24}OS$: 300.1548. Found: 300.1549.

48: IR (CCl_4) 3600, 3500, 3073, 1587, 1477, 1086, 1071, 1028 cm^{-1}; NMR (CCl_4) δ 7.3–7.5 (m, 2 H), 7.0–7.3 (m, 3 H), 5.43 (br s, 1 H), 2.41 (d, J = 12 Hz, 1 H), 1.66 (s, 3 H), 1.5–2.2 (m, 5 H), 0.89 (d, J = 7 Hz, 6 H), 0.6–1.5 (m, 6 H).

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Supplementary Material Available: a listing of the spectral properties for the remaining adducts appears as an Appendix (7 pages). Ordering information is given on any current masthead page.

References and Notes

(1) For some approaches other than cyclobutyl spiroannelation see V. V. Kane, *Synth. Commun.*, **6**, 237 (1976); H. Wolf *Chem. Ber.*, **109**, 41 (1976); S. F. Campbell, *Synth. Commun.*, **5**, 353 (1975); S. F. Martin and R. Gompper, *J. Org. Chem.*, **39**, 2814 (1974); D. A. Evans and C. L. Sims, *Tetrahedron Lett.*, 4691 (1973); G. H. Posner and D. J. Brunelle, *J. Org. Chem.*, **38**, 2747 (1973); D. Seebach, M. Kolb, and B. T. Gröbel, *Angew. Chem., Int. Ed. Engl.*, **12**, 69 (1973); D. Seebach, B. T. Gröbel, A. K. Beck, M. Brown, and K. H. Geiss, *ibid.*, 11, 443 (1972); F. E. Ziegler and P. A. Wender, *J. Am. Chem. Soc.*, **93**, 4318 (1971); E. J. Corey and J. I. Shulman, *ibid.*, **92**, 5522 (1970). For a review with further references, see A. P. Krapcho, *Synthesis*, 383 (1974).

(2) (a) B. M. Trost and M. J. Bogdanowicz, *J. Am. Chem. Soc.*, **93**, 3773 (1971); (b) *ibid.*, **95**, 2038 (1973); (c) *ibid.*, **95**, 5321 (1973); (d) B. M. Trost and M. Preckel, *ibid.*, **95**, 7862 (1973); (e) B. M. Trost, M. J. Bogdanowicz, and J. Kern, *ibid.*, **97**, 2218 (1975); (f) B. M. Trost, M. Preckel, and L. M. Leichter, *ibid.*, **97**, 2224 (1975).

(3) B. M. Trost, D. E. Keeley, and M. J. Bogdanowicz, *J. Am. Chem. Soc.*, **93**, 3773 (1971); B. M. Trost and D. E. Keeley, *ibid.*, **96**, 1252 (1974).

(4) For a few pertinent studies see M. C. Caserio, W. A. Graham, and J. D. Roberts, *Tetrahedron*, 11, 171 (1960); M. Julia, S. Julia, and R. Guegan, *Bull. Soc. Chim. Fr.*, 1072 (1960); M. Julia, S. Julia, T. S. Yu, and C. Newville, *ibid.*, 1381 (1960); M. Julia, S. Julia, and Y. Noël, *ibid.*, 1708 (1960); M. Julia, S. Julia, and S. Y. Tschen, *ibid.*, 1849 (1961); S. F. Brady, M. A. Ilton, and W. S. Johnson, *J. Am. Chem., Soc.*, **90**, 2882 (1968).

(5) For a review, see J. M. Conia and M. J. Robson, *Angew. Chem., Int. Ed. Engl.*, **14**, 473 (1975).

(6) K. K. Crandall and D. R. Paulson, *J. Org. Chem.*, **33**, 991, 3291 (1968); J. R. Wiseman and H. F. Chan, *J. Am. Chem. Soc.*, **92**, 4749 (1970); J. R. Salun and J. M. Conia, *Chem. Commun.*, 1579 (1971); M. Braun, R. Dammann, and D. Seebach, *Chem. Ber.*, **108**, 2368 (1975).

(7) E. J. Corey and D. Seebach, *J. Org. Chem.*, **31**, 4097 (1966).

(8) (a) J. F. Bieilmann and J. B. Ducep, *Tetrahedron*, **27**, 5861 (1971); (b) J. Hartmann, R. Muthukrishnan, and M. Schlosser, *Helv. Chim. Acta*, **57**, 2261 (1974).

(9) P. A. Shirley and B. J. Reeves, *J. Organomet. Chem.*, **16**, 1 (1969).

(10) B. M. Trost and W. C. Vladuchick, unpublished observations.

(11) R. Muthukrishnan and M. Schlosser, *Helv. Chim. Acta*, **59**, 13 (1976).

(12) F. Vlattas, L. D. Vecchia, and A. O. Lee, *J. Am. Chem. Soc.*, **98**, 2008 (1976).

(13) W. E. Truce, K. R. Hollister, L. B. Lindy, and J. E. Parr, *J. Org. Chem.*, **33**, 43 (1968). For a carbene approach to substituted derivatives see G. Boche and D. R. Schneider, *Tetrahedron Lett.*, 4247 (1975).

(14) S. F. Normant and H. Deshayes, *Bull. Soc. Chim. Fr.*, 2858 (1972).

(15) (a) Ring opening of cyclopropyl anions stabilized by electron withdrawing groups are known: see G. Boche, D. Martens, and H. V. Wagner, *J. Am. Chem. Soc.*, **98**, 2668 (1976); M. Newcomb and W. T. Ford, *ibid.*, **95**, 7186 (1973); *ibid.*, **96**, 2968 (1974); (b) D. E. Applequist and D. F. O'Brien, *ibid.*, **85**, 743 (1963).

(16) *tert*- and *sec*-butyllithium do metalate **4** more completely (~70%) in shorter times, but still not satisfactorily. For preparative runs, *sec*-butyllithium may be recommended.

(17) A. Ratajczak, F. A. L. Anet, and D. J. Cram, *J. Am. Chem. Soc.*, **89**, 2072 (1967).

(18) B. M. Trost in "Organic Sulfur Chemistry, Structure, Mechanism, and Synthesis", C. J. M. Stirling, Ed., Butterworths, London, 1975, pp 237–263.

(19) A. Allerhand, H. S. Gutowsky, J. Jonas, and R. A. Weinzer, *J. Am. Chem. Soc.*, **88**, 3185 (1966).

(20) H. M. Walborsky and F. M. Hornyak, *J. Am. Chem. Soc.*, **77**, 6026 (1955); H. M. Walborsky and M. P. Periasamy, *ibid.*, **96**, 3711 (1974); **97**, 5930 (1975).

(21) F. A. L. Anet, R. D. Trepka, and D. J. Cram, *J. Am. Chem. Soc.*, **89**, 357 (1967).

(22) J. B. Lambert, *Top. Stereochem.*, **6**, 19 (1971).

(23) B. M. Trost and M. J. Bogdanowicz, *J. Am. Chem. Soc.*, **95**, 5307 (1973).

(24) J. Battioni and W. Chodkiewicz, *Bull. Soc. Chim. Fr.*, 1824 (1971); J. Laemmle, E. C. Ashby, and P. V. Roling, *J. Org. Chem.*, **38**, 2526 (1973).

(25) M. Chastrette and R. Amouroux, *Bull. Soc. Chim. Fr.*, 1555 (1974); E. C. Ashby, S. H. Yu, and P. V. Roling, *J. Org. Chem.*, **37**, 1918 (1972).

(26) M. Chérest and H. Felkin, *Tetrahedron Lett.*, 2205 (1968); 383 (1971); M. Chérest, H. Felkin, and C. Frajerman, *ibid.*, 379 (1971).

(27) J. M. Derfer, E. E. Pickett, and C. E. Boord, *J. Am. Chem. Soc.*, **71**, 2482 (1949).

(28) For reviews, see ref 18 and B. M. Trost, *Fortschr. Chem. Forsch.*, **41**, 1 (1973); *Acc. Chem. Res.*, **7**, 85 (1974).

(29) B. M. Trost and D. E. Keeley, *J. Am. Chem. Soc.*, **98**, 248 (1976).

(30) See paragraph at end of paper regarding supplementary material.