Pergamon

Tetrahedron Vol. 50, No. 40, pp. 11569-11584, 1994

0040-4020/94 $7.00+0.00

0040-4020(94)00720-9

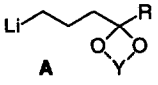
A General Preparative Method for Carbonyl-Protected γ-Lithioketones via Reductive Lithiation. Synthetic Uses of the Bishomoenolate Equivalents[1]

Theodore Cohen,* Birong Zhang, and John P. Cherkauskas

Department of Chemistry, University of Pittsburgh, Pittsburgh, PA 15260

Abstract: The mixed cuprates, generated by reductive lithiation of bis(phenylthio)acetals using lithium 4,4'-di-*tert*-butylbiphenylide (LDBB), followed by addition of cuprous bromide - dimethyl sulfide complex, undergo conjugate addition to enones in the presence of trimethylsilyl chloride to produce γ-(phenylthio)ketones. Protection of the ketone as its dioxolane, and reductive lithiation with LDBB provides carbonyl-protected γ-lithioketones. Primary, secondary, tertiary, and vinylic organolithiums have been prepared in this way and the protected ketone function can be in a ring. Previously, only primary straight chain γ-lithioketone equivalents were known . This method is the most versatile and general available for the production of such carbanions, which behave as bishomoenolate equivalents. The organometallics react with aldehydes to yield alcohols. The vinyllithiums react with *N,N*-dimethylformamide to produce an enal containing a protected ketone group. The mixed cuprates, formed upon treatment of the organolithiums with cuprous bromide - dimethyl sulfide complex, undergo allylation with allyl bromide, conjugate addition to enals and enones in the presence of trimethylsilyl chloride to produce monoprotected 1,7-dicarbonyl compounds, and acetylation to yield monoprotected 1,5-diketones. The monoprotected dicarbonyl compounds are readily deprotected and in a number of cases the resulting diketones can be induced to undergo base induced intramolecular aldol condensations to enones.

While a wide variety of β-lithioaldehyde and -ketone (homoenolate) equivalents are now available for synthetic purposes,[2] only a single type (**A**) of γ-lithioaldehyde and -ketone (bishomoenolate) equivalents is known.[3] The precursor of **A**, a 3-chloroaldehyde or -ketone, is prepared in several steps, protected by acetal formation, and submitted to reductive lithiation with lithium metal[3a] or lithium naphthalenide.[3b] The corresponding Grignard reagents have a longer history but are somewhat unstable, undergoing decomposition to a 4-member ring.[4] Despite the very limited number of bishomoenolate equivalents available, both **A**[3] and its Grignard analogues[4] have found rather extensive use in synthesis.



A

Y = CH_2CH_2 or $CH_2C(CH_3)_2CH_2$
R = H, CH_3, or Ph

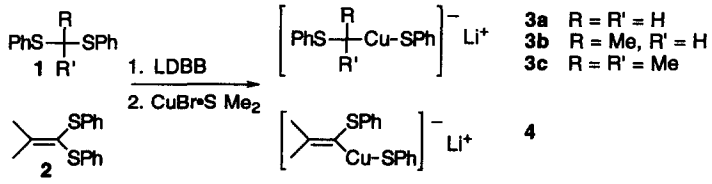
It thus seems clear that a general method to prepare carbonyl-protected γ-lithioaldehydes and -ketones would be very desirable from the point of view of synthetic chemists. We reported recently that reductive lithiation of the acetals of β-(phenylthio)ketones with aromatic radical anions is a very general method for the production of carbonyl-protected β-lithioketones.[2] The unprotected substrates are prepared readily either by conjugate addition of thiophenol to an enone or attack of a sulfur-stabilized carbocation on a silyl enol ether.

We now report that similar reductive lithiation of carbonyl-protected γ-(phenylthio)ketones is a simple method for the preparation of γ-lithioketone equivalents. The remarkable versatility of divalent sulfur allows the phenylthio group to be placed at a position γ to the aldehydes and -ketones by conjugate addition of the cuprates of readily available sulfur stabilized carbanions to enals and enones.

RESULTS AND DISCUSSION

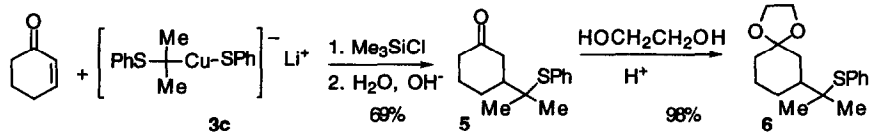
Preparation of γ-(Phenylthio)ketones

Sulfur-stabilized organolithium compounds are readily available by reductive lithiation of bis(phenylthio)acetals.[5] In the present work, all four of the phenylthio-substituted organocuprate reagents (presumably having the stoichiometry indicated in **3a-c** and **4**) used in the conjugate additions to produce γ-(phenylthio)ketones were generated by reductive lithiation of bis(phenylthio)acetals using lithium 4,4'-di-*tert*-butylbiphenylide (LDBB),[6] followed by addition of the cuprous bromide - dimethyl sulfide complex[7] (eq 1). The thioacetals **1** were either commercially available (bis(phenylthio)methane, Aldrich Chemical Co.) or were prepared from propionaldehyde or acetone.[8,9] Ketene thioacetal **2** was prepared in 94% yield by the reaction of isobutyric acid with aluminum thiophenoxide.[10,11] Because of the presence of lithium thiophenoxide in the solution, this procedure leads directly to the desired "mixed" cuprates bearing the phenylthio group and allows full stoichiometric utilization of the organolithium species.[12]

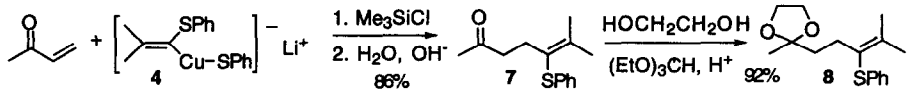


(1)

Conjugate addition of the mixed cuprates to enones in the presence of trimethylsilyl chloride[13] proceeded in satisfactory yield in most cases (e.g. eq 2 and 3). Of course, the yields for the conjugate additions in eq 2 and 3 include that for the reductive lithiation and transmetallation as well. The cuprate **4** adds well to terminally unsubstituted enones such as methyl vinyl ketone and 2-methylenecyclohexanone but it adds to cyclohex-2-en-1-one in only 29% yield. In Table 1, the combined yields of the reductive lithiation / conjugate additions and the carbonyl protection are given because in a number of cases the crude conjugate addition product was subjected directly to the acetalization reaction.[14] In another project in this laboratory, it has been found that the tertiary cuprate **3c** can also be added to acrolein in 65% yield[15] and it is thus likely that the product, after carbonyl protection, could be reductively lithiated successfully to provide a carbonyl-protected γ-lithioaldehyde.



(2)

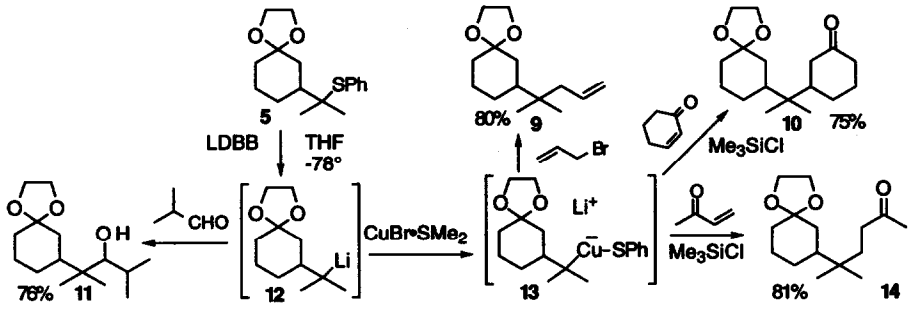


(3)

Reductive Lithiation of the Carbonyl-Protected γ-(Phenylthio)ketones

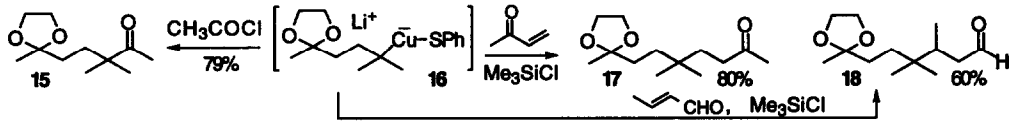
Reductive lithiation of the carbonyl-protected γ-(phenylthio)ketones with LDBB provides the carbonyl-protected γ-lithioketones. Scheme 1 outlines some of the exemplary reactions undergone by **12**, the reductive lithiation product of **6**. **12** is particularly interesting because it is a tertiary organolithium, a type of species that until the advent of reductive lithiation of phenylthio compounds was extremely rare in synthetic organic chemistry.[16] Reductive lithiation differs sharply from conventional methods of carbanion production, the removal of a proton or other electrophile with a strong base, in that the less stable the carbanion the more readily

it is produced, a consequence of the rate determining production of a radical intermediate.[5] As a result, very unstable tertiary carbanions are generated instantaneously at -78° and they can be captured by an electrophile before decomposition occurs. The addition of isobutyraldehyde to the tertiary organolithium **12** provides the acetal alcohol **11** in 76% yield (Scheme 1). The mixed cuprates (e.g. **13**) derived from carbonyl-protected γ-lithioketones are particularly useful synthetically. For example, allylation of **13** proceeded smoothly to produce the terminally unsaturated acetal **9** (Scheme 1) whereas it has been reported[3b] that **A** (R = CH_3; Y = CH_2CH_2) could not be allylated even in the presence of copper salts. As shown, conjugate addition of **13** to enones also occurs readily to yield monoprotected 1,7-diketones.



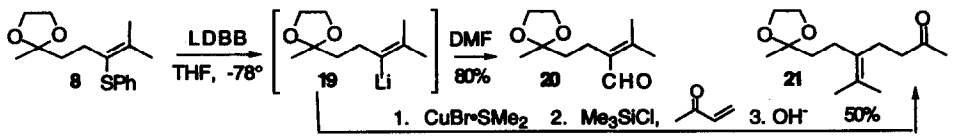
Scheme 1

Other aspects of the reactivity of such cuprates are demonstrated in Scheme 2 for **16**, derived from the reductive lithiation product of the carbonyl-protected adduct of **3c** with methyl vinyl ketone. Acetylation with acetyl chloride yields the monoprotected 1,5-diketone **15** in good yield. Furthermore, **16** not only undergoes conjugate addition to methyl vinyl ketone but even to crotonaldehyde to provide the keto-protected 1,7-ketoaldehyde **18**. The yields of electrophile capture of a number of bishomoenolate equivalents are shown in Table 1.



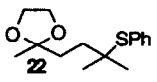
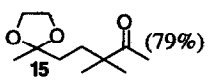
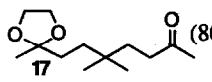
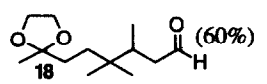
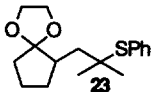
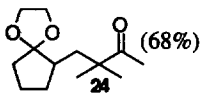
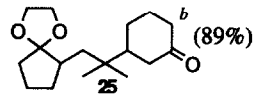
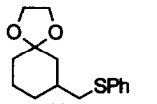
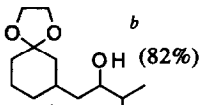
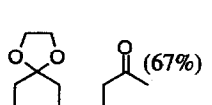
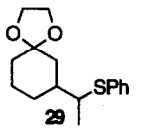
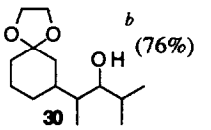
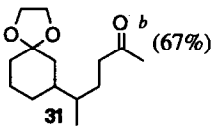
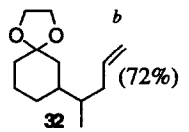
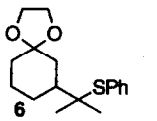
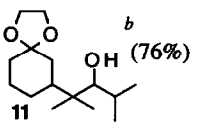
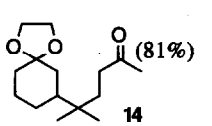
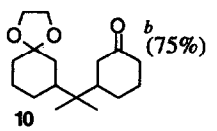
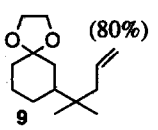
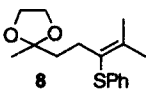
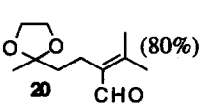
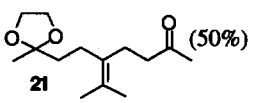
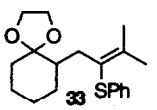
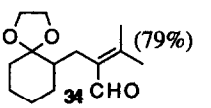
Scheme 2

Reductive lithiation of the carbonyl-protected unsaturated γ-(phenylthio)ketone **8** provides the unusual carbonyl-protected γ-lithioketone **19**. We have not been able to find other examples of vinyllithiums γ to an acetal function. As outlined in Scheme 3, such organolithiums can be formylated with N,N-dimethylformamide (DMF) to give a good yield of the keto-protected ketoenal **20** while the derived mixed cuprate from **19** undergoes conjugate addition to methyl vinyl ketone to provide **21** in modest yield. The yield of formylation product **34** of an analogue of **19** can be found in Table 1.



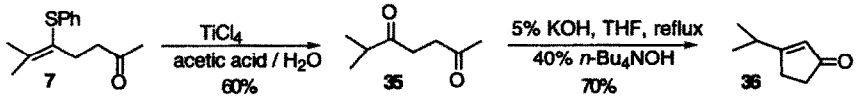
Scheme 3

Table I. Preparation of γ-(Phenylthio)acetals and Capture of Their Reductive Lithiation Products with Electrophiles

γ-(Phenylthio)-acetal	Yield[a]	Products of Reductive Lithiation and Electrophile Capture (Yield)
 **22**	74%	 (79%) **15**;  (80%) **17**;  (60%) **18**
 **23**	62%	 (68%) **24**;  *b* (89%) **25**
 **26**	65%	 *b* (82%) **27**;  (67%) **28**
 **29**	73%	 *b* (76%) **30**;  *b* (67%) **31**;  *b* (72%) **32**
 **6**	68%	 *b* (76%) **11**;  (81%) **14**;  *b* (75%) **10**;  (80%) **9**
 **8**	79%	 (80%) **20**;  (50%) **21**
 **33**	65%	 (79%) **34**

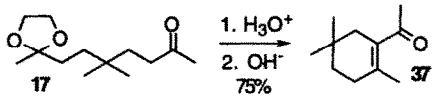
[a] Combined yield, reductive lithiation, addition, and protection. [b] Mixture of diastereomers.

Adducts such as **7** of sulfur-stabilized vinyl cuprates with enones are of interest not only because of the utility of their reductive lithiation products but because they are 1,4-diketones in which one of the carbonyl groups is masked. The free carbonyl group can be manipulated before the other is unmasked or the 1,4-diketone can be generated and induced to undergo an intramolecular aldol condensation. This latter process is shown in Scheme 4; Mukaiyama's hydrolysis method[17] proved far superior than the use of mercuric chloride.[18]

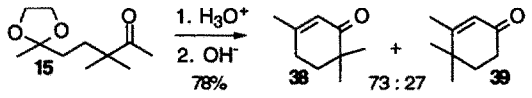


Scheme 4

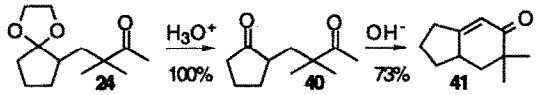
Monoprotected dicarbonyl compounds such as **10**,**14**, **15**, **17**, **18**, **20**, and **21** are particularly valuable since, in principle, the unprotected carbonyl group can be manipulated independently and then, after deprotection, the other carbonyl group can be made to undergo reaction. Alternatively, hydrolysis of the acetal group provides a dicarbonyl compound that is often capable of an intramolecular aldol reaction. Examples are given in eq 4-9.



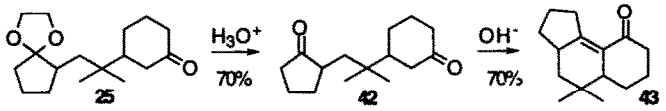
(4)



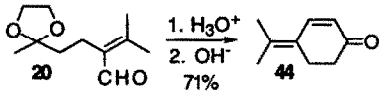
(5)



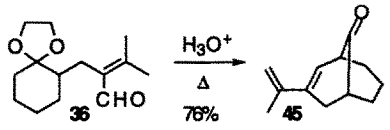
(6)



(7)



(8)



(9)

CONCLUSIONS

Previously, the only known carbonyl-protected γ-lithioaldehydes and -ketones were straight chain primary organolithiums of the type **A**. These and their Grignard analogues have been used as bishomoenolate equivalents in a number of natural product syntheses. It is shown in the present paper that a wide variety of carbonyl-protected γ-lithioketones can be generated by reductive lithiation of carbonyl-protected γ-(phenylthio)ketones which are readily available by conjugate addition of mixed, sulfur stabilized organocuprates to enones. Since in unpublished work[15] such conjugate additions to enals have also been successful, it is virtually certain that carbonyl-protected γ-lithioaldehydes would also be available by this methodology. Primary, secondary, tertiary, and vinylic organolithiums can been generated in this way and the protected ketone function can be in a ring. These organolithiums and the derived mixed cuprates are capable of reaction with a variety of electrophiles. This technology should find wide use in organic synthesis.

EXPERIMENTAL SECTION

All reactions were carried out in flame- or oven-dried glassware under an atmosphere of prepurified argon or nitrogen. All solvents were dried by using standard procedures and distilled. A dry ice / 2-propanol slush bath was used to obtain a temperature of -78 °C and an ice bath was used to obtain 0 °C. When temperatures of -78 °C were needed for extended periods of time, an FTS Systems, Inc Model TC-10 Flexi Cool cold probe was used. Infrared spectra were recorded using an IBM IR / 32 or Mattson Cygnus 100 FTIR spectrometer. ^1H (300 MHz) and ^{13}C (76 MHz) NMR spectra were recorded either on a Brucker WH-300 or a Brucker AF-300 spectrometer. High resolution mass spectra were recorded on a CH-5 double focusing Varian Mat mass spectrometer or on a VG 70-6 mass spectrometer. Gas liquid chromatographic mass spectral (GC/MS) analyses of reaction mixtures were performed on a Hewlett Packard 5890 Series II gas chromatograph equipped with a 5970 mass selective detector. Flash chromatography[19] was performed using 40-60 μm silica gel 60 (E. Merck). High pressure liquid chromatography was performed on a Rainin Rabbit dual pump instrument with a Dynamax-60A Si 83-121-C column. TLC was performed on glass supported 250 μm silica gel GF plates (Analtech). Visualization of TLC plates was performed using 7% phosphomolybdic acid in ethanol or 10% *p*-anisaldehyde in ethanol. Gas liquid chromatography was performed on a Hewlett Packard 5890 chromatograph equipped with a capillary column (Carbowax 20M) and a flame ionization detector. For the preparation of the 0.4 M solutions of LDBB used in this work, see footnote 17 of ref. 20

1,1-Bis(phenylthio)ethane (1b). To a solution of acetaldehyde (2.8 mL, 0.050 mol), thiophenol (10.3 mL, 0.100 mol) and chloroform (50 mL) was added trimethylsilyl chloride (9.5 mL, 0.075 mol) over a period of 30 min. The resulting mixture was stirred at room temperature for 1 h, and then washed with 5% NaOH (2 X 50 mL) to remove thiophenol. The organic layer was dried over $MgSO_4$ and the solvent was removed by rotary evaporation. The crude product was purified by flash chromatography (1% ethyl acetate / hexanes, R_f 0.20) to yield 8.5 g (69%) of product. ^1H NMR ($CDCl_3$) δ 7.50 - 7.44 (m, 4 H, phenyl H), 7.38 - 7.28 (m, 6 H, phenyl H), 4.55 (q, J = 6.0 Hz, 1 H, CH), 1.61 (d, J = 6.0 Hz, 3 H, CH_3).

2,2-Bis(phenylthio)propane (1c). The procedure was the same as for **1b** except that acetone was used instead of acetaldehyde. The crude product was purified by flash chromatography (5% ethyl acetate / hexanes, R_f 0.53) to yield 9.44 g (73%) of product. ^1H NMR ($CDCl_3$) δ 7.68 - 7.62 (m, 4 H, phenyl H), 7.41 - 7.32 (m, 6 H, phenyl H), 1.52 (s, 6 H, $(CH_3)_2$).

1,1-Bis(phenylthio)-2-methylpropene (4).[10] A solution of thiophenol (8.0 mL, 78 mmol) in 30 mL of xylene was added at ambient temperature in dropwise fashion to a xylene-hexane solution of $Al(CH_3)_3$ made by adding 13.7 mL of 2.0 M solution of $Al(CH_3)_3$ (27.4 mmol) to 100 mL of dry, deoxygenated xylene, and the mixture was heated at reflux for 18 h. During this period, a large amount of a porous white solid was formed. The mixture was allowed to cool to ambient temperature prior to the addition of isobutyric acid (1.2 mL, 13 mmol). The resulting mixture was heated at reflux for an additional 18 h and cooled to 0 °C, followed by the addition of 10% NaOH (150 mL). The aqueous layer was extracted with ether (3 X 50 mL), and the combined organic layer was washed with 10% NaOH until all of the thiophenol was removed. The organic layer was dried over $MgSO_4$ and the solvent was removed by rotary evaporation. The crude product was purified by flash chromatography (pure hexanes, R_f 0.13) to yield 3.32 g (94%) of product. ^1H NMR ($CDCl_3$) δ 7.26 - 7.13 (m, 10 H, phenyl H), 2.24 (s, 6 H, $(CH_3)_2$).

3-(1-Methyl-1-phenylthioethyl)cyclohexanone (5). To a solution of LDBB (40.5 mL, 16.2 mmol) at -78 °C, a solution of 2,2-bis(phenylthio)propane (**3c**; 1.86 g, 7.20 mmol) in 6 mL of THF was added dropwise. The reaction mixture, which changed from deep blue-green to red, was stirred for 30 min prior to the addition of $CuBr{\bullet}Me_2S$ (2.09 g, 10.1 mmol). After the mixture had been stirred for 3 h at -78 °C, a solution of

TMSCl (1.27 mL, 10.0 mmol) in 3 mL of THF was added followed by dropwise addition of a solution of 2-cyclohexen-1-one (0.89 mL, 9.2 mmol) in 3 mL of THF. The resulting mixture was stirred for 12 h at -78 °C, quenched with 5% NaOH (30 mL) and 40% aqueous *n*-Bu_4NOH (1 mL), filtered through celite, and extracted with ether (3 X 50 mL). The combined organic layer was dried over $MgSO_4$ and the solvent was removed by rotary evaporation. The crude product was purified by flash chromatography (10% ethyl acetate / hexanes, R_f 0.23) to yield 1.23 g (69%) of product. ^1H NMR ($CDCl_3$) δ 7.50 - 7.48 (m, 2 H, phenyl H), 7.39 - 7.29 (m, 3 H, phenyl H), 2.67 (m, 1 H), 2.40 - 2.11 (series of m, 5 H), 1.78 (m, 1 H), 1.62 - 1.44 (m, 2 H), 1.23 (s, 3 H, CH_3), 1.22 (s, 3 H, CH_3). IR (thin film) 3059 (m), 2963 (s), 2867 (s), 1711 (v), 1437 (m), 1125 (m), 752 (m), 695 (m) cm^{-1}. Exact mass cacld for $C_{15}H_{20}OS$ 248.1235, found 248.1244.

5-Methyl-5-phenylthio-2-hexanone. The reaction was performed using the same procedure as for **5** except that 9.5 mmol of methyl vinyl ketone was substituted for cyclohexenone. The crude product was purified by flash chromatography (5% ethyl acetate / hexanes, R_f 0.19) to yield 1.31 g (75%) of ketone. ^1H NMR ($CDCl_3$) δ 7.48 - 7.26 (m, 5 H, arom.), 2.71 (t, 2 H, J = 7.9 Hz, CH_2C=O), 2.16 (s, 3 H, CH_3C=O), 1.70 (t, 2 H, J = 7.9 Hz, CH_2CH_2C=O), 1.19 (s, 6 H, CH_3). MS m/e, exact mass calculated for $C_{13}H_{18}OS$ 222.1078, found 222.1074.

2-(2-Methyl-2-phenylthiopropyl)cyclopentanone. The reaction was performed using the same procedure as for **5** except that 10.0 mmol of 2-methylenecyclopentanone[21] was substituted for cyclohexenone. The crude product was purified by flash chromatography (10% ethyl acetate / hexanes, R_f 0.28) to yield 0.556 g (70%) of product. ^1H NMR ($CDCl_3$) δ 7.61 - 7.51 (m, 2 H, arom.), 7.38 - 7.28 (m, 3 H, arom.), 2.54 - 2.44 (m, 1 H), 2.40 - 2.26 (m, 2 H), 2.24 - 2.18 (m, 1 H), 2.13 - 1.97 (m, 2 H), 1.85 - 1.71 (m, 1 H), 1.60 - 1.46 (m, 1 H), 1.34 - 1.23 (m, 1 H), 1.26 (s, 3 H, CH_3), 1.22 (s, 3 H, CH_3). ^{13}C NMR ($CDCl_3$) δ 220.8 (C=O), 137.7, 131.7, 128.7, 128.5, 49.2, 47.0, 42.5, 37.2, 32.7, 29.7, 29.2, 20.7.

3-(1-Phenylthio)ethylcyclohexanone. The reaction was performed using 14.6 mmol of cyclohexenone and the same procedure as for **5** except that **1b** was substituted for **1c**. The crude product was purified by flash chromatography (10% ethyl acetate / hexanes, R_f 0.29) to yield 1.95 g (74%) of product. ^1H NMR ($CDCl_3$) δ 7.39 - 7.17 (m, 5 H, arom.), 3.18 (dq, J = 7.0 Hz, J = 4.2 Hz, 1 H, PhSCH), 2.46 (m, 1 H), 2.36 - 2.17 (m, 3 H), 2.09 - 1.91 (m, 3 H), 1.59 - 1.50 (m, 2 H), 1.27 - 1.25 (d, J = 7.0 Hz, 3 H, CH_3). ^{13}C NMR ($CDCl_3$) δ 210.9, 135.0, 131.9., 128.9, 126.9, 48.4, 45.1,43.6, 41.2, 27.5, 24.9, 17.8. MS m/e, exact mass calculated for $C_{14}H_{18}OS$ 234.1078, found 234.1059.

3-Phenylthiomethylcyclohexanone. The reaction was performed using 10.0 mmol of cyclohexenone and the same procedure as for **5** except that **3a** was substituted for **3c**. The crude product was purified by flash chromatography (10% ethyl acetate / hexanes, R_f 0.20) to yield the pure product as well as a mixture of the title compound and 2-cyclohexen-1-one. The mixture was subject to the protection step without further purification. Pure product: ^1H NMR ($CDCl_3$) δ 7.29 - 7.08 (m, 5 H, arom.), 2.86 - 2.84 (d, 2 H, J = 6.2 Hz, $PhSCH_2$), 2.53 - 2.46 (m, 1 H), 2.34 - 1.91 (m, 7 H), 1.65 - 1.33 (m, 2 H). MS m/e, exact mass calculated for $C_{13}H_{16}OS$ 220.0922, found 220.0932.

7-(1-Methyl-1-phenylthioethyl)-1,4-dioxaspiro[4,5]decane (6). To a flask equipped with a reflux condenser and a Dean-Stark trap was added 3-(1-methyl-1-phenylthioethyl)cyclohexanone **5** (1.03 g, 4.10 mmol), ethylene glycol (1.2 mL, 21 mmol), *p*-toluenesulfonic acid (0.079 g, 0.41 mmol) and anhydrous benzene (30 mL). The resulting mixture was heated at reflux for 16 h under argon. The mixture was allowed to cool to ambient temperature, washed with 5% $NaHCO_3$ (3 X 25 mL), and dried over $MgSO_4$. The solvent was removed by rotary evaporation and the product was purified by flash chromatography (10% ethyl acetate / hexanes, R_f 0.32) to yield 1.17 g (98%) of product. ^1H NMR ($CDCl_3$) δ 7.53 - 7.49 (m, 2 H, arom.), 3.99 -

3.91 (m, 4 H, OCH_2), 2.15 - 1.96 (m, 1 H), 1.80 - 1.66 (m, 3 H), 1.50 - 1.34 (m, 3 H), 1.18 (s, 3 H, CH_3), 1.17 (s, 3 H, CH_3), 1.09 (m, 1 H). ^{13}C NMR ($CDCl_3$) δ 137.7, 132.2, 128.6, 128.4, 109.8, 64.3, 64.1, 52.2, 44.4, 36.7, 34.8, 26.9, 26.6, 25.9, 23.2. IR (thin film) 3058 (w), 2946 (s), 2881 (s), 1481 (m), 1086 (s) cm^{-1}. MS m/e, exact mass calculated for $C_{17}H_{24}O_2S$ 292.1497, found 292.1493.

6-Methyl-5-phenylthiohept-5-en-2-one (7). To a solution of LDBB (42.2 mL, 16.9 mmol) at -78 °C, a solution of 1,1-bis(phenylthio)-2-methylpropene (**2**; 2.3 g, 8.5 mmol) in 6 mL of THF was added dropwise. The reaction mixture, which changed from deep blue-green to red, was stirred for 30 min prior to the addition of $CuBr{\bullet}Me_2S$ (1.97 g, 9.60 mmol). After the mixture had been stirred for 3 h at -78 °C, a solution of TMSCl (1.87 mL, 14.7 mmol) in 4 mL of THF was added followed by dropwise addition of a solution of methyl vinyl ketone (0.73 mL, 8.8 mmol) in 4 mL of THF. The resulting mixture was stirred for 12 h at -78 °C, quenched with 5% NaOH (40 mL) and 40% aqueous *n*-Bu_4NOH (1 mL), filtered through celite, and extracted with ether (3 X 60 mL). The combined organic layer was dried over $MgSO_4$ and the solvent was removed by rotary evaporation. The crude product was purified by flash chromatography (10% ethyl acetate / hexanes, R_f 0.23) to yield 1.71 g (86%) of product. ^1H NMR ($CDCl_3$) δ 7.24 - 7.05 (m, 5 H, arom.), 2.63 - 2.49 (m, 4 H), 2.02 (s, 3 H, CH_3CO), 2.00 (s, 3 H, CH_3), 1.91 (s, 3 H, CH_3). ^{13}C NMR ($CDCl_3$) δ 208.1 (C=O), 141.9, 136.5, 128.7, 127.3, 125.0, 123.9, 42.1, 29.7, 27.5, 23.4, 20.9. IR (thin film) 3059 (m), 2919 (s), 1717 (s), 1478 (s), 1439 (m), 741 (m), 692 (m) cm^{-1}. MS m/e, exact mass calculated for $C_{14}H_{18}OS$ 234,1044, found 234.1074.

2-(3-Methyl-2-phenylthiobuten-2-yl)cyclohexanone. The reaction was performed using the same procedure as for **7** except that 3.0 mmol of 2-methylenecyclohexanone[21] was substituted for methyl vinyl ketone. The crude product was purified by flash chromatography (10% ethyl acetate / hexanes, R_f 0.28) to yield 0.556 g (70%) of product. ^1H NMR ($CDCl_3$) δ 2.75 - 2.66 (m, 2 H), 2.37 - 2.20 (m, 3 H), 2.12 - 2.07 (m, 2 H), 2.05 (s, 3 H, CH_3), 1.94 (s, 3 H, CH_3), 1.84 (m, 1 H), 1.69 - 1.58 (m, 2 H), 1.30 (m, 1 H).

3-(2-Methyl-1-phenylthiopropen-1-yl)cyclohexan-1-one. The reaction was performed using the same procedure as for **7** except that 11.0 mmol of 2-cyclohexen-1-one was substituted for methyl vinyl ketone. The crude product was purified by flash chromatography (10% ethyl acetate / hexanes, R_f 0.36) to yield 0.39 g (29%) of product. ^1H NMR ($CDCl_3$) δ 7.24 - 7.04 (m, 5 H, arom.), 3.25 (m, 1 H), 2.65 (m, 1 H), 2.36 - 2.15 (m, 3 H), 2.02 (m, 1 H), 1.97 (s, 6 H, CH_3), 1.86 - 1.58 (m 3 H). IR (thin film) 2934 (s), 2860 (m), 1715 (s), 1581 (m), 1478 (s), 739 (s), 691 (s) cm^{-1}.

2-Methyl-2-(4-methyl-3-phenylthiopenten-3-yl)-1,3-dioxolane (8). A mixture of 6-methyl-5-phenylthio-5-hepten-2-one **7** (0.23 g, 1.0 mmol), ethylene glycol (0.39 mL, 7.0 mmol), triethyl orthoformate (0.50 mL, 3.1 mmol) and *p*-toluenesulfonic acid (0.019 g, 0.10 mmol) was stirred for 12 h at ambient temperature, and then added to ether (10 mL), washed with 5% $NaHCO_3$ (3 X 10 mL), dried over $MgSO_4$. The solvent was removed by rotary evaporation and the crude product was purified by flash chromatography (5% ethyl acetate / hexanes, R_f 0.19) to yield 0.225 g (92%) of product. ^1H NMR ($CDCl_3$) δ 7.24 - 7.08 (m, 5 H, arom.), 3.93 - 3.81 (m, 4 H, OCH_2), 2.37 - 2.31 (m, 2 H), 2.00 (s, 3 H, CH_3), 1.91 (s, 3 H, CH_3), 1.84 - 1.78 (m, 2 H), 1.25 (s, 3 H, CH_3). MS m/e, exact mass calculated for $C_{16}H_{22}O_2S$ 278.1341, found 278.1362.

7-(1,1-Dimethyl-3-buten-1-yl)-1,4-dioxaspiro[4,5]decane (9). A solution of 7-(1-methyl-1-phenylthioethyl)-1,4-dioxaspiro[4,5]decane (**5**; 0.18 g, 0.62 mmol) in 3 mL of THF was added dropwise to 1.4 mmol of 0.40 M LDBB solution. The reaction mixture, which changed from blue-green to yellow-red, was stirred for 30 min, $CuBr{\cdot}Me_2S$ (0.19 g, 0.93 mmol) was added, and the resulting solution was stirred for 3 h at -78 °C. A solution of allyl bromide (0.065 mL, 0.74 mmol) in 2 mL of THF was added dropwise. The

resulting mixture was stirred for 12 h, quenched at -78 °C with saturated NH_4Cl (10 mL), filtered through celite, and extracted with ether (4 X 75 mL). The organic layer was dried over $MgSO_4$ and the solvent removed by rotary evaporation. The crude product was purified by flash chromatography (5% ethyl acetate / hexanes R_f 0.28) yielding 0.11 g (80%) of product. ^1H NMR ($CDCl_3$) δ 5.89 - 5.75 (m, 1 H, C*H*=CH_2), 5.81 - 5.75 (bm, 2 H, CH=C*H*$_2$), 3.93 (s, 4 H, CH_2O), 2.00 (d, J = 7.4 Hz, 2 H, CH_2), 1.79 (m, 9 H, CH_2 and CH), 0.83 (s, 3 H, CH_3), 0.82 (s, 3 H, CH_3). ^{13}C NMR (77 MHz $CDCl_3$) δ 135.5, 116.6, 109.9, 64.2, 64.0, 44.8, 43.2, 35.9, 34.8, 25.6, 24.5, 24.3, 23.4, 23.2; IR (thin film) 3074 (w), 2958(s), 1637 (m), 1480 (m), 1081 (s) cm^{-1}. MS m/e, exact mass calculated for $C_{14}H_{24}O_2$ 224.1776, found 224.1776.

7-[1-Methyl-1-(3-oxocyclohexyl)ethyl]-1,4-dioxaspiro[4,5]decane (10). To a solution of LDBB (5.9 mL, 2.4 mmol) at -78 °C, a solution of **6** (0.20 g, 0.68 mmol) in 1 mL of THF was added dropwise. The reaction mixture, which changed from deep blue-green to red, was stirred for 30 min prior to the addition of CuBr•Me_2S (0.22 g, 1.1 mmol). After the mixture had been stirred for 3 h at -78 °C, a solution of TMSCl (0.18 mL, 1.4 mmol) in 1 mL of THF was added followed by dropwise addition of a solution of 2-cyclohexen-1-one (0.080 mL, 0.82 mmol) in 1 mL of THF. The resulting mixture was stirred for 12 h at -78 °C, quenched with 5% NaOH (15 mL) and 40% aqueous *n*-Bu_4NOH (10 drops), filtered through celite, and extracted with ether (3 X 20 mL). The combined organic layer was dried over $MgSO_4$ and the solvent was removed by rotary evaporation. The crude product was purified by flash chromatography (10% ethyl acetate / hexanes) to yield 0.066 g (35%) of less polar isomer (R_f 0.13) and 0.076 g (40%) of more polar isomer (R_f 0.11). Less polar isomer: ^1H NMR ($CDCl_3$) δ 4.00 - 3.93 (m, 4 H, OCH_2), 2.42 - 1.17 (series of m, 17 H), 0.93 (m, 1 H), 0.79 (s, 3 H, CH_3), 0.76 (s, 3 H, CH_3). MS m/e, exact mass calculated for $C_{11}H_{20}O_2$ (M^+ - C_6H_8O) 184.1463, found 184.1459. MS CI (isobutane) m/e (relative intensity) 281 (m + 1, 6). More polar isomer: ^1H NMR ($CDCl_3$) δ 3.95-3.87 (m, 4 H, OCH_2), 2.38-1.17 (series of m, 17 H), 0.87 (m, 1 H), 0.79 (s, 3 H, CH_3), 0.73 (s, 3 H, CH_3). MS CI (isobutane) m/e (relative intensity) 281 (m + 1, 5).

7-(2-Hydroxy-1,1,3-trimethylbutyl)1,4-dioxaspiro[4,5]decane (11). To a solution of LDBB (5.4 mL, 2.2 mmol) at -78 °C, a solution of **5** (0.18 g, 0.66 mmol) in 1 mL of THF was added dropwise. The reaction mixture, which changed from deep blue-green to red, was stirred for 30 min. A solution of isobutyraldehyde (0.64 g, 1.3 mmol) in 2 mL of THF was added dropwise. The resulting mixture was stirred for 30 min at -78 °C, quenched with water, extracted with ether (3 X 20 mL). The combined organic layer was dried over $MgSO_4$ and the solvent was removed by rotary evaporation. The crude product was purified by flash chromatography (10% ethyl acetate / hexanes, R_f 0.15) to yield 0.12 g (76%) of product (mixture of isomers). ^1H NMR ($CDCl_3$) δ 3.98 - 3.93 (m, 4 H, OCH_2), 3.34 - 3.32 (m, 1 H, HOC*H*), 2.00 - 1.90 (m, 1 H), 1.84 - 1.52 (m, 5 H), 1.48 - 1.22 (m, 5 H), 1.00 - 0.89 (d, 6 H, CH_3), 0.86 (s, 3 H, CH_3), 0.80 (s, 3 H, CH_3). ^{13}C NMR ($CDCl_3$) δ 109.8, 79.7, 65.6, 64.1, 63.9, 41.9, 41.8, 40.0, 36.3, 35.9, 34.9, 34.7, 27.9, 27.8, 26.0, 25.7, 23.8, 23.4, 23.3, 20.6, 20.3, 20.1, 16.6, 16.5, 15.1. MS m/e, exact mass calculated for $C_{15}H_{28}O_3$(M^+ - C_2H_5O) 213.1491, found 213.1535. MS CI (isobutane) m/e (relative intensity) 257 (m + 1).

7-(1,1-Dimethyl-4-oxopentyl)-1,4-dioxaspiro[4,5]decane (14). The reaction was performed using the same procedure as for **10** except that 0.68 mmol of methyl vinyl ketone was substituted for cyclohexenone. The crude product was purified by flash chromatography (20% ethyl acetate / hexanes R_f 0.17) yielding 0.12 g (81%) of product. ^1H NMR ($CDCl_3$) δ 3.97 (s, 4 H, CH_2O), 2.38 (t, J = 8.2 Hz, 2 H, CH_2O), 2.15 (s, 3 H, CH_3CO), 1.74 - 0.910 (m, 11 H, CH_2 and CH), 0.822 (s, 3 H, CH_3), 0.814 (s, 3 H, CH_3). ^{13}C NMR (77 MHz $CDCl_3$) δ 209.0 (C=O), 109.6 (OCO), 64.0, 63.8, 42.7, 38.1, 35.8, 34.5, 33.7, 33.4, 29.7, 25.4, 24.2, 24.1, 23.2; IR (thin film) 2950 (s), 2872 (m), 1717 (s), 1368 (m), 1086 (s) cm^{-1}. MS m/e, exact mass calculated for $C_{15}H_{26}O_3$ 254.1882, found 254.1880.

2-Methyl-2-(3,3-dimethyl-4-oxopentyl)-1,3-dioxolane (15). To a solution of LDBB (6.5 mL, 2.6 mmol) at -78 °C, a solution of 2-methyl-(3-methyl-3-phenylthiobutyl)-1,3-dioxolane **22** (0.29 g, 1.1 mmol) in 1 mL of THF was added dropwise. The reaction mixture, which changed from deep blue-green to red, was stirred for 30 min prior to the addition of $CuBr•Me_2S$ (0.27 g, 1.3 mmol). After the mixture had been stirred for 3 h at -78 °C, a solution of acetyl chloride (0.12 mL, 1.7 mmol) in 2 mL of THF was added dropwise. The resulting mixture was stirred for 12 h at -78 °C, quenched with saturated NH_4Cl (10 mL), filtered through celite, and extracted with ether (3 X 25 mL). The combined organic layer was dried over $MgSO_4$ and the solvent was removed by rotary evaporation. The crude product was purified by flash chromatography (10% ethyl acetate / hexanes, R_f 0.22) to yield 0.17 g (79%) of product. ^1H NMR ($CDCl_3$) δ 3.97 - 3.73 (m, 4 H, OCH_2), 2.13 (s, 3 H, $CH_3C=O$), 1.65 - 1.57 (m, 2 H), 1.53 - 1.45 (m, 2 H), 1.29 (s, 3 H, CH_3), 1.1 (s, 6 H, CH_3).

2-Methyl-2-(3,3-dimethyl-6-oxoheptyl)-1,3-dioxolane (17). The procedure, using 1.4 mmol of methyl vinyl ketone, was the same as for **14** except that 1.1 mmol of **22** was used instead of **6**. The crude product was purified by flash chromatography (10% ethyl acetate / hexanes, R_f 0.16) to yield 0.203 g (80%) of product. ^1H NMR ($CDCl_3$) δ 3.98 - 3.87 (m, 4 H, OCH_2), 2.40 - 2.34 (m, 2 H, CH_2CO), 2.15 (s, 3 H, CH_3CO), 1.63 - 1.54 (m, 2 H), 1.49 - 1.43 (m, 2 H), 1.30 (s, 3 H, CH_3), 1.28 - 1.23 (m, 2 H), 0.84 (s, 6 H, CH_3). ^{13}C NMR ($CDCl_3$) δ 216.2, 109.8, 64.2, 40.6, 38.8, 37.5, 36.2, 35.6, 33.8, 28.6, 24.8.

2-Methyl-2-(3,3,4-trimethyl-6-oxohexyl)-1,3-dioxolane (18). The procedure, using 0.73 mmol of **22**, was the same as for **17** except that 0.91 mmol of crotonaldehyde was used in place of MVK. The crude product was purified by flash chromatography (10% ethyl acetate / hexanes, R_f 0.17) to yield 0.10 g (60%) of product. ^1H NMR ($CDCl_3$) δ 9.74 (s, 1 H, CHO), 3.98 - 3.87 (m, 4 H, OCH_2), 2.53 (m, 1 H), 2.12 (m, 1 H), 1.96 (m, 1 H), 1.65 - 1.54 (m, 2 H), 1.38 (m, 1 H), 1.31 (s, 3 H, CH_3), 1.27 (m, 1 H), 0.87 (d, J = 6.5 Hz, 3 H, CH_3), 0.84 (s, 3 H, CH_3), 0.83 (s, 3 H, CH_3). ^{13}C NMR ($CDCl_3$) δ 210.0, 110.0, 63.4, 38.3, 37.4, 36.7, 34.4, 33.3, 29.9, 23.9 (two peaks), 14.5. MS CI (isobutane) m/e (relative intensity) 229 (m + 1).

2-Methyl-2-[3-(1-methyl)ethylidene-4-oxobutyl]-1,3-dioxolane (20). To a solution of LDBB (6.3 mL, 2.5 mmol) at -78 °C, a solution of 2-methyl-2-(4-methyl-3-phenylthiopenten-3-yl)-1,3-dioxolane (**8**; 0.29 g, 1.0 mmol) in 1 mL of THF was added dropwise. The reaction mixture, which changed from deep-green to red, was stirred for 30 min, and a solution of DMF (0.22 mL, 1.4 mmol) in 2 mL of THF was added dropwise. The mixture was stirred for 30 min at -78 °C, warmed to ambient temperature, stirred for an additional 1 h (the color of the mixture changed from red to light yellow), quenched with saturated NH_4Cl (20 mL), and extracted with ether (3 X 20 mL). The organic layer was dried over $MgSO_4$ and the solvent was removed by rotary evaporation. The crude product was purified by flash chromatography (15% ethyl acetate / hexanes, R_f 0.25) to yield 0.165 g (80%) of product. ^1H NMR ($CDCl_3$) δ 10.09 (s, 1 H, CHO), 3.94 - 3.93 (m, 4 H, OCH_2), 2.38 - 2.32 (m, 2 H), 2.17 (s, 3 H, CH_3), 1.98 (s, 3 H, CH_3), 1.61 - 1.55 (m, 2 H), 1.35 (s, 3 H, CH_3). ^{13}C NMR ($CDCl_3$) δ 190.4, 154.7, 136.4, 109.5, 64.5, 37.5, 23.4, 22.9, 19.9, 19.1. IR (thin film) 2982 (s), 2880 (s), 1665 (v), 1635 (m), 1053 (s) cm^{-1}. MS m/e, exact mass calculated for $C_{10}H_{15}O_3$ (M^+ - CH_3) 183.1021, found 183.1013.

6-(3-Methyl-2-phenylthiobutenyl)-1,4-dioxaspiro[4,5]decane (21). To a solution of LDBB (3.8 mL, 1.5 mmol) at -78 °C, a solution of **8** (0.15 g, 0.52 mmol) in 1 mL of THF was added dropwise. The reaction mixture, which changed from deep blue-green to red, was stirred for 30 min prior to the addition of $CuBr•Me_2S$ (0.16 g, 0.78 mmol). After the mixture had been stirred for 3 h at -78 °C, a solution of TMSCl (0.16 mL, 1.3 mmol) in 1 mL of THF was added followed by dropwise addition of a solution of methyl vinyl

ketone (0.065 mL, 0.78 mmol) in 1 mL of THF. The resulting mixture was stirred for 12 h at -78 °C, quenched with 5% NaOH (15 mL) and 40% aqueous *n*-Bu_4NOH (10 drops), filtered through celite, and extracted with ether (3 X 20 mL). The combined organic layer was dried over $MgSO_4$ and the solvent was removed by rotary evaporation. The crude product was purified by flash chromatography (10% ethyl acetate / hexanes, R_f 0.14) to yield 0.060 g (50%) of product. ^1H NMR ($CDCl_3$) δ 7.23 - 7.07 (m, 5 H, arom.), 3.92 - 3.47 (m, 4 H, OCH_2), 2.42-2.25 (m, 2 H), 2.02 (s, 3 H, CH_3), 1.93 (m, 1 H), 1.92 (s, 3 H, CH_3), 1.78 - 1.69 (m, 2 H), 1.63 - 1.58 (m, 2 H), 1.47 - 1.18 (m, 4 H). ^{13}C NMR ($CDCl_3$) δ 141.7, 137.2, 128.5, 127.6, 124.9, 124.7, 110.4, 64.4, 43.8, 34.5, 31.9, 28.7, 24.6, 23.8, 23.5, 21.4.

2-Methyl-(3-methyl-3-phenylthiobutyl)-1,3-dioxolane (22). The procedure is the same as that for the production of **6** from **5** except that 5.40 mmol of 5-methyl-5-phenylthio-2-hexanone was used as the ketone. The product was purified by flash chromatography (10% ethyl acetate / hexanes, R_f 0.30) to yield 1.44 g (99%) of product. ^1H NMR ($CDCl_3$) δ 7.54 - 7.28 (m, 5 H, arom.), 3.99 - 3.89 (m, 4 H, OCH_2), 1.91 - 1.85 (m, 2 H), 1.59 - 1.53 (m, 2 H), 1.32 (s, 3 H, CH_3), 1.22 (s, 6 H, CH_3). ^{13}C NMR ($CDCl_3$) δ 137.4, 132.0, 128.5, 128.3, 109.9, 64.5, 48.7, 35.8, 34.2, 28.7, 23.9. MS m/e, exact mass calculated for $C_{15}H_{22}O_2S$ 266.1341, found 266.1346.

6-(2-Methyl-2-pheylthiopropyl)-1,4-dioxaspiro[4,4]nonane (23). The procedure is the same as that for **22** except that 1.6 mmol of 2-(2-methyl-2-phenylthiopropyl)cyclopentanone was used as the ketone. The product was purified by flash chromatography (15% ethyl acetate / hexanes, R_f 0.31) to yield 0.43 g (93%) of **23**. ^1H NMR ($CDCl_3$) δ 7.59 - 7.51 (m, 2 H, arom.), 7.39 - 7.27 (m, 3 H, arom.), 3.94 - 3.85 (m, 4 H, OCH_2), 2.34 - 2.19 (m, 1 H), 2.16 - 1.98 (m, 1 H), 1.83 (dd, J = 14.4 Hz, J = 1.8 Hz, 2 H), 1.76 - 1.60 (m, 4 H), 1.49 - 1.34 (m, 2 H), 1.24 (s, 3 H, CH_3), 1.22 (s, 3 H, CH_3). ^{13}C NMR ($CDCl_3$) δ 137.7, 132.3, 128.2, 118.7, 64.7, 64.3, 49.3, 42.3, 41.3, 34.7, 31.5, 30.2, 28.8, 20.5. MS CI (isobutane) m/e (relative intensity) 293 (m + 1, 12).

6-(2,2-Dimethyl-3-oxobutyl)-1,4-dioxaspiro[4,4]nonane (24). The procedure was the same as that for **15** except that 3.2 mmol of **23** was used as substrate. The crude product was purified by flash chromatography (10% ethyl acetate / hexanes, R_f 0.17) to yield 0.142 g (70%) of product. ^1H NMR ($CDCl_3$) δ 3.87 - 3.74 (m, 4 H, OCH_2), 2.05 (s, 1 H, $CH_3C{=}O$), 1.83 - 1.37 (m, 8 H), 1.26 - 1.16 (m, 1 H), 1.02 (s, 6 H, CH_3). ^{13}C NMR ($CDCl_3$) δ 214.2, 64.5, 64.1, 347.4, 42.3, 38.7, 34.3, 30.3, 25.0, 24.9, 24.5, 20.2. IR (thin film) 2967, 2876, 1703, 1356, 1128, 1030 cm^{-1}. MS m/e, exact mass calculated for $C_{13}H_{22}O_3$ 226.1569, found 226.1529.

6-[2-Methyl-2-(3-oxocyclohexyl)propyl]-1,4-dioxaspiro[4,4]nonane (25). The procedure was the same as that for **17** except that 3.1 mmol of **23** was used as substrate and 3.7 mmol of 2-cyclohexen-1-one was the enone. The crude product was purified by flash chromatography (10% ethyl acetate / hexanes, R_f 0.10) to yield 0.77 g (89%) of product (mixture of isomers). ^1H NMR ($CDCl_3$) δ 3.98 - 3.84 (m, 4 H, OCH_2), 2.49 - 2.30 (m, 2 H), 2.28 - 2.16 (m, 1 H), 2.13 - 2.04 (m, 2 H), 2.00 - 1.85 (m, 3 H), 1.73 - 1.47 (m, 7 H), 1.45 - 1.26 (m, 2 H), 1.16 - 1.08 (m, 1 H), 0.85 (s, 6 H, CH_3). ^{13}C NMR ($CDCl_3$) δ 208.8, 109.3, 64.3, 64.1, 42.8, 41.6, 39.8, 39.2, 34.9, 34.6, 33.8, 33.6, 32.0, 31.8, 29.5, 29.0, 23.2, 22.8.

7-Phenylthiomethyl-1,4-dioxaspiro[4,5]decane (26). The procedure was the same as that for **6** except that the mixture obtained in the preparation of 3-phenylthiomethylcyclohexanone was used. The product was purified by flash chromatography (5% ethyl acetate / hexanes, R_f 0.16) to yield 0.823 g (67% for two steps) of the title compound. ^1H NMR ($CDCl_3$) δ 7.34 - 7.12 (m, 5 H, arom.), 3.98 - 3.89 (m, 4 H, OCH_2), 2.87 - 2.85 (d, J = 4.2 Hz, 2 H, $PhSCH_2$), 1.97 - 1.86 (m, 3 H), 1.79 (m, 2 H), 1.59 - 1.39 (m, 2 H), 1.28 -

1.23 (m, 1 H), 1.05 - 0.92 (m, 1 H). ^{13}C NMR ($CDCl_3$) δ 137.3, 128.7, 125.5, 118.8, 108.8, 64.2, 64.1, 40.7, 40.3, 35.4, 34.7, 31.2, 22.8. IR (thin film) 3050, 2938, 1584, 1480, 1439, 1368, 1354, 1304, 1171, 1142, 1080, 1026, 926, 739 cm^{-1}. MS m/e, exact mass calculated for $C_{15}H_{20}O_2S$ 264.1184, found 264.1156.

7-(2-Hydroxy-3-methylbutyl)-1,4-dioxaspiro[4,5]decane (27). The procedure was the same as that for **11** except that 1.10 mmol of **26** was used as substrate. The crude product was purified by flash chromatography (20% ethyl acetate / hexanes, R_f 0.15) to yield 0.147 g (82%) of product (mixture of isomers). ^1H NMR ($CDCl_3$) δ 3.98 - 3.90 (m, 4 H, OCH_2), 3.52 - 3.43 (m, 1 H, OCH), 1.89 - 1.07 (m, 12 H), 0.99 - 0.77 (m, 7 H). ^{13}C NMR ($CDCl_3$) δ 109.1, 73.5, 73.2, 64.1, 63.9, 42.3, 41.1, 40.9, 34.7, 34.6, 33.7, 33.6, 32.7, 32.1, 32.0, 31.0, 29.5, 23.0, 22.9, 18.6, 17.0, 16.9. IR (thin film) 3451, 2932, 1447, 1365, 1281, 1236, 1156, 1075, 1046, 949, 924 cm^{-1}. MS m/e, exact mass calculated for $C_{13}H_{24}O_3$ 228.1726, found 228.1737.

7-(4-Oxopentyl)-1,4-dioxaspiro[4,5]decane (28). The procedure was the same as that for **17** except that 1.10 mmol of **26** was used as substrate. The crude product was purified by flash chromatography (20% ethyl acetate / hexanes, R_f 0.25) to yield 0.127 g (67%) of product. ^1H NMR ($CDCl_3$) δ 3.85 - 3.77 (m, 4 H, OCH_2), 2.32 - 2.26 (t, J = 7.42 Hz, 2 H, CH_2CO), 2.01 (s, CH_3), 1.66 - 1.56 (m, 4 H), 1.52 - 1.22 (m, 5 H), 1.14 - 0.97 (m, 3 H), 0.98 - 0.64 (m, 1 H). ^{13}C NMR ($CDCl_3$) δ 208.7, 108.9, 64.0, 63.8, 43.6, 41.3, 36.1, 35.0, 34.6, 31.4, 29.6, 22.9, 20.8. IR (thin film) 2934, 1715, 1449, 1356, 1231, 1167, 1146, 1109, 1078, 932 cm^{-1}. MS m/e, exact mass calculated for $C_{13}H_{22}O_3$ 226.1569, found 226.1579.

7-(1-Phenylthioethyl)-1,4-dioxaspiro[4,5]decane (29). The procedure was the same as that for **6** except that 3-(1-phenylthio)ethylcyclohexanone was used. The product was purified by flash chromatography (5% ethyl acetate / hexanes, R_f 0.16) to yield 2.23 g (99%) of product (mixture of isomers). ^1H NMR ($CDCl_3$) δ 7.42 - 7.16 (m, 5 H, arom.), 3.98 - 3.85 (m, 4 H, OCH_2), 3.18 - 3.10 (m, 1 H, PhSCH), 1.98 - 1.70 (m, 5 H), 1.58 - 1.46 (m, 3 H), 1.30 - 1.22 (q, 3 H, CH_3), 1.20 - 1.10 (m, 1 H). ^{13}C NMR ($CDCl_3$) δ 135.9, 131.7, 131.5, 128.7, 126.4, 109.3, 109.2, 64.2, 64.1, 49.0, 48.8, 40.5, 40.4, 38.8, 34.8, 28.7, 28.0, 23.0, 22.9, 18.3. IR (thin film) 3085, 2942, 2874, 1584, 1480, 1447, 1439, 1167, 1088, 1040, 1024, 945, 926, 747, 693 cm^{-1}. MS m/e, exact mass calculated for $C_{16}H_{22}O_2S$ 278.1341, found 278.1321.

7-(2-Hydroxy-1,3-dimethylbutyl)-1,4-dioxaspiro[4,5]decane (30). The procedure was the same as that for **11** except 0.77 mmol of **29** was used as substrate . The crude product was purified by flash chromatography (20% ethyl acetate / hexanes, R_f 0.20) to yield 0.135 g (76%) of product (mixture of isomers). ^1H NMR ($CDCl_3$) δ 3.92 - 3.85 (m, 4 H, OCH_2), 3.25 - 3.12 (m, 1 H), 1.98 - 1.12 (m, 13 H), 0.98 - 0.65 (m, 8 H). MS m/e, exact mass calculated for $C_{14}H_{26}O_3$ (M^+ - C_3H_7O) 199.1334, found 199.1326. MS CI (isobutane) m/e (relative intensity) 243 (m + 1).

7-(1-Methyl-4-oxopentyl)-1,4-dioxaspiro[4,5]decane (31). The procedure was the same as that for **14** except that 0.46 mmol of **29** was used as substrate. The crude product was purified by flash chromatography (20% ethyl acetate / hexanes, R_f 0.28) to yield 0.073 g (67%) of product (mixture of isomers). ^1H NMR ($CDCl_3$) δ 3.93 - 3.73 (m, 4 H, OCH_2), 2.51 - 2.31 (m, 2 H, $COCH_2$), 2.13 (s, 3 H, CH_3CO), 1.74 - 1.19 (m, 11 H), 1.05 - 0.85 (m, 1 H), 0.83 - 0.80 (d, 3 H, CH_3). ^{13}C NMR ($CDCl_3$) δ 209.3, 109.7, 64.3, 64.1, 41.8, 39.8, 39.2, 37.3, 36.9, 34.9, 29.9, 29.0, 27.9, 27.7, 26.9, 23.3, 15.8. MS m/e, exact mass calculated for $C_{11}H_{19}O_2$ (M^+ - C_3H_5O) 183.1403, found 183.1383. MS CI (isobutane) m/e (relative intensity) 241 (m + 1).

7-(1-Methyl-3-buten-1-yl)-1,4-dioxaspiro[4,5]decane (32). The procedure was the same as that for **9** except that 0.77 mmol of **29** was used as substrate. The crude product was purified by flash chromatography (5% ethyl acetate / hexanes, R_f 0.32) to yield 0.111 g (72%) of product (mixture of isomers). ^{1}H NMR ($CDCl_3$) δ 5.84 - 5.69 (m, 1 H, C*H*=CH_2), 5.02 - 4.95 (m, 2 H, CH_2=CH), 3.98 - 3.87 (m, 4 H, OCH_2), 2.17 - 2.08 (m, 1 H), 1.91 - 1.82 (m, 1 H), 1.78 - 0.95 (m ,12 H), 0.83 (d, 3 H, CH_3). ^{13}C NMR ($CDCl_3$) δ 137.9, 115.5, 109.8, 64.3, 64.1, 39.7, 39.3, 38.8, 38.6, 37.4, 35.0, 29.1, 27.0, 23.3, 15.8, 15.7. MS CI (isobutane) m/e (relative intensity) 211 (m + 1).

6-(3-Methyl-2-phenylthiobutenyl)-1,4-dioxaspiro[4,5]decane (33). The procedure was the same as that for **8** except that 1.50 mmol of 2-(3-methyl-2-phenylthiobuten-2-yl)cyclohexanone was used as the ketone. The crude product was purified by flash chromatography (5% ethyl acetate / hexanes, R_f 0.28) to yield 0.451 g (93%) of product. ^{1}H NMR ($CDCl_3$) δ 7.23 - 7.07 (m, 5 H, arom.), 3.92 - 3.47 (m, 4 H, OCH_2), 2.42-2.25 (m, 2 H), 2.02 (s, 3 H, CH_3), 1.93 (m, 1 H), 1.92 (s, 3 H, CH_3), 1.78 - 1.69 (m, 2 H), 1.63 - 1.58 (m, 2 H), 1.47 - 1.18 (m, 4 H). ^{13}C NMR ($CDCl_3$) δ 141.7, 137.2, 128.5, 127.6, 124.9, 124.7, 110.4, 64.4, 43.8, 34.5, 31.9, 28.7, 24.6, 23.8, 23.5, 21.4.

6-[2-(1-methyl)ethylidene-3-oxopropyl]-1,4-dioxoaspiro[4,5]decane (34). The procedure was the same as that for **20** except that 1.30 mmol of **33** was used as the substrate. The crude product was purified by flash chromatography (15% ethyl acetate / hexanes, R_f 0.31) to yield 0.247 g (79%) of product. ^{1}H NMR ($CDCl_3$) δ 10.13 (s, 1 H, CHO), 4.00 - 3.91 (m, 4 H), 2.51 (m, 1 H), 2.24 (m, 1 H), 2.18 (s, 3 H, CH_3), 1.98 (s, 3 H, CH_3), 1.77(m, 1 H), 1.69 - 1.58 (m, 3 H), 1.48 - 1.41 (m, 2 H), 1.36 - 1.09 (m, 3 H). ^{13}C NMR ($CDCl_3$) δ 190.9, 155.2, 135.7, 110.3, 64.5, 64.4, 44.1, 34.3,28.6, 24.4, 23.6, 23.4, 19.1. MS m/e, exact mass calculated for $C_{14}H_{22}O_3$ 238.1569, found 238.1573.

6-Methylheptan-2,5-dione (35). A solution of 6-methyl-5-phenylthio-5-hepten-2-one **7** (0.47 g, 2.0 mol), $TiCl_4$ (0.44 mL, 4.0 mmol) and acetic acid (6 mL) was stirred for 0.5 h at ambient temperature prior to the addition of water (0.5 mL). The resulting mixture was then stirred overnight at ambient temperature. The acetic acid was removed under reduced pressure. The residue was added to ether (30 mL) and the solution was washed with 10% $NaHCO_3$ (3 X 20 mL) and brine (2 X 20 mL) and dried over $MgSO_4$. The solvent was removed by rotary evaporation and the crude product was purified by flash chromatography (5% ethyl acetate / hexanes, R_f 0.10) to yield 0.16 g (60%) of product. ^{1}H NMR ($CDCl_3$) δ 2.71 - 2.65 (m, 4 H), 2.60 (q, J = 6.9 Hz, 1 H, CH), 2.17 (s, 3 H, CH_3C=O), 1.09 (d, J = 6.9 Hz, 6 H, CH_3). ^{13}C NMR ($CDCl_3$) δ 213.3, 207.5, 40.8, 36.9, 33.8, 30.0, 18.3. MS m/e, exact mass calculated for $C_6H_{11}O$ (M^+ - C_2H_3O) 99.0446, found 99.0434.

3-Isopropylcyclopent-2-en-1-one (36). A biphasic mixture of 6-methyl-heptan-2,5-dione **35** (0.15 g, 1.1 mmol), THF (5 mL), 5% aqueous KOH (5 mL) and 40% aqueous *n*-Bu_4OH (10 drops) was stirred at ambient temperature for 12 h, poured into water, and extracted with ether (3 X 20 mL), washed with brine (2 X 20 mL), dried over $MgSO_4$, and the solvent was removed by rotary evaporation. The crude product was purified by flash chromatography (10% ethyl acetate / hexanes, R_f 0.30) to yield 0.090 g (71%) of product. ^{1}H NMR ($CDCl_3$) δ 5.90 (s, 1 H, C=CH), 2.65 - 2.56 (m, 3 H), 2.39 - 2.35 (m, 2 H), 1.15 (d, J = 6.8 Hz, 6 H, CH_3). The spectrum was identical to that reported previously.[22]

2-Acetyl-1,4,4-trimethyl-1-cyclohexene (37). A solution of 2-methyl-2-(3,3-dimethyl-6-oxoheptyl)-1,3-dioxolane **17** (0.15 g, 0.66 mmol), *p*-toluenesulfonic acid (0.075 g, 0.39 mmol), acetone (15 mL) and water (1 mL) was heated at reflux for 24 h. The reaction mixture was allowed to cool to ambient temperature and the acetone was removed under reduced pressure. To a solution of crude product in 25 mL of THF was added 5% aqueous KOH (25 mL) and 40% aqueous *n*-Bu_4NOH (10 drops). The resulting mixture

was heated at reflux for 72 h, poured into water, extracted with ether (3 X 20 mL). The combined organic layer was washed with brine (2 X 20 mL), dried over $MgSO_4$, and the solvent was removed by rotary evaporation. The crude product was purified by flash chromatography (10% ethyl acetate / hexanes, R_f 0.48) to yield 0.083 g (76%) of product. ^1H NMR ($CDCl_3$) δ 2.21 (s, 3 H, CH_3CO), 2.13 (t, J = 6.6 Hz, 2 H, $CH_2C{=}C$), 2.08 - 2.00 (m, 2 H, $C{=}CCH_2$), 1.34 (t, J = 6.6 Hz, 2 H, CH_2), 1.25 (s, 6 H, CH_3). MS m/e, exact mass calculated for $C_{11}H_{18}O$ 166.1217, found 166.1230.

3,6,6-Trimethyl-2-cyclohexen-1-one (38) and 3,4,4-Trimethyl-2-cyclohexen-1-one (39) by Unmasking of 15 and Subsequent Aldol Condensation. A solution of 2-methyl-2-(3,3-dimethyl-4-oxopentyl)-1,3-dioxolane (**15**; 0.23 g, 1.2 mmol), *p*-toluenesulfonic acid (0.12 g, 0.63 mmol), acetone (20 mL) and water (1 mL) was heated at reflux for 7 h. The reaction mixture was allowed to cool to ambient temperature and the acetone was removed under reduced pressure. To a solution of crude product in 25 mL of THF was added 5% aqueous KOH (10 mL) and 40% aqueous *n*-Bu_4NOH (12 drops). The resulting mixture was heated at reflux for 14 h, poured into water, extracted with ether (3 X 25 mL). The combined organic layer was washed with brine (2 X 25 mL), dried over $MgSO_4$, and the solvent was removed by rotary evaporation. The crude product was purified by flash chromatography to yield 0.090 g (57%) of more polar isomer **38** (10% ethyl acetate / hexanes, R_f 0.30) and 0.034 g (21%) of less polar isomer **39** (10% ethyl acetate / hexanes, R_f 0.18). **38**: ^1H NMR ($CDCl_3$) δ 5.8 (s, 1 H, C=CH), 2.29 (t, J = 6.7 Hz, 2 H, $C{=}CCH_2$,), 1.92 (s, 3 H, $CH_3C{=}C$), 1.79 (t, J = 6.7 Hz, 2 H, $C{=}CCH_2CH_2$,), 1.08 (s, 6 H, CH_3). **39**: ^1H NMR ($CDCl_3$) δ 5.8 (s, 1 H, C=CH), 2.44 (t, J = 6.8 Hz, 2 H, $COCH_2$,), 1.91 (s, 3 H, $CH_3C{=}C$), 1.85 (t, J = 6.8 Hz, 2 H, $COCH_2CH_2$,), 1.17 (s, 6 H, CH_3).

2-(2,2-Dimethyl-3-oxobutyl)cyclopentanone (40). A solution of 6-(2,2-dimethyl-3-oxobutyl)-1,4-dioxaspiro[4,4]nonane **24** (0.12 g, 0.53 mmol), *p*-toluenesulfonic acid (0.01 g, 0.05 mmol), acetone (15 mL) and water (0.5 mL) was stirred at ambient temperature for 10 min. The acetone was removed under reduced pressure. The residue was added to ether (30 mL) and the solution was washed with 5% $NaHCO_3$ (2 X 20 mL). The organic layer was dried over $MgSO_4$ and the solvent was removed by rotary evaporation to give the product in quantitative yield. ^1H NMR ($CDCl_3$) δ 2.34 - 2.20 (m, 2 H), 2.15 (s, 3 H, $CH_3C{=}O$), 2.11 - 1.61 (series of m, 5 H), 1.47 - 1.33 (m, 2 H), 1.14 (s, 6 H, $(CH_3)_2$). ^{13}C NMR ($CDCl_3$) δ 220.5, 213.8, 47.3, 46.5, 39.7, 37.1, 31.6, 25.1, 24.4, 20.5. IR (thin film) 2967, 2876, 1740, 1703, 1358, 1154, 1136 cm^{-1}.

6,6-Dimethyl-2,3,5,6,7,7a-hexahydro-1H-indene-5-one (41). A biphasic mixture of 2-(2,2-dimethyl-3-oxobutyl)cyclopentanone **40** (0.040 g, 0.22 mmol), THF (5 mL), 5% aqueous KOH (5 mL) and 40% aqueous *n*-Bu_4OH (10 drops) was stirred at ambient temperature for 10 min, poured into water, and extracted with ether (3 X 10 mL), dried over $MgSO_4$, and the solvent was removed by rotary evaporation. The crude product was purified by flash chromatography (10% ethyl acetate / hexanes, R_f 0.30) to yield 0.027 g (73%) of product. ^1H NMR ($CDCl_3$) δ 5.80 (s, 1 H, vinyl H), 2.69 - 2.59 (m, 2 H), 2.44 (m, 1 H), 2.05 (m, 1 H), 1.99 - 1.84 (m, 2 H), 1.71 (m, 1 H), 1.57 (m, 1 H), 1.23 (m, 1 H), 1.11 (s, 3 H, CH_3), 1.10 (s, 3 H, CH_3). ^{13}C NMR ($CDCl_3$) δ 204.5, 173.0, 120.8, 43.3, 40.8, 40.0, 33.0, 31.4, 25.9, 23.8, 23.5. Exact mass cacld for $C_{11}H_{16}O$ 164.1201, found 164.1217.

3-[1,1-Dimethyl-2-(2'-oxocyclopentyl)ethyl]cyclohexan-1-one (42). A solution of 6-[2-methyl-2-(3-oxocyclohexyl)]propyl-1,4-dioxaspiro[4,4]nonane **25** (0.60 g, 2.1 mmol), *p*-toluenesulfonic acid (0.30 g, 1.6 mmol), acetone (50 mL) and water (0.5 mL) was stirred at ambient temperature for 12 h. The acetone was removed under reduced pressure. The residue was added to ether (50 mL) and the mixture was washed with 5% $NaHCO_3$ (3 X 30 mL). The organic layer was dried over $MgSO_4$ and the solvent was

removed by rotary evaporation. The crude product was purified by flash chromatography (15% ethyl acetate / hexanes, R_f 0.13) to yield 0.352 g (70%) of product. ^1H NMR ($CDCl_3$) δ 2.47 - 2.18 (m, 5 H), 2.17 - 1.90 (m, 7 H), 1.79 - 1.65 (m, 1 H), 1.61 - 1.44 (m, 3 H), 1.42 - 1.32 (m, 1 H), 1.13 - 1.07 (m, 1 H), 0.89 (s, 3 H, CH_3), 0.88 (s, 3 H, CH_3). IR (thin film) 2961, 2868, 1738, 1711, 1451, 1153 cm^{-1}.

1,2,3,3a,4,5,5a,6,7,8-Decahydro-5,5-dimethyl-9H-benz[e]inden-9-one (43). A solution of **42** (0.34 g, 1.4 mmol), THF (15 mL), 5% aqueous KOH (15 mL) and 40% aqueous *n*-Bu_4NOH (30 drops) was stirred at ambient temperature for 7 h, poured into water, and the mixture was extracted with ether (3 X 20 mL). The organic extracts were combined and washed with brine (2 X 20 mL), dried over $MgSO_4$, and the solvent was removed by rotary evaporation. The residue was dissolved in 7 mL of anhydrous benzene containing *p*-toluenesulfonic acid (0.028 g, 0.15 mmol). The resulting mixture was heated at reflux for 1 h, using a Dean-Stark trap to azeotropically remove the water. The mixture was allowed to cool to ambient temperature, washed with 5% $NaHCO_3$ (2 X 10 mL), dried over $MgSO_4$, and the solvent was removed by rotary evaporation. The crude product was purified by flash chromatography (2.5% ethyl acetate / hexanes, R_f 0.16) to yield (0.22 g, 70%) of product. ^1H NMR ($CDCl_3$) δ 2.55 - 2.16 (series of m, 3 H,), 2.05 - 1.86 (m, 3 H), 1.84 - 1.71 (m, 3 H), 1.68 - 1.49 (m, 3 H), 1.35 - 1.20 (m, 2 H), 1.18 - 0.96 (m, 2 H), 0.92 (s, 3 H, CH_3), 0.89 (s, 3 H, CH_3). ^{13}C NMR ($CDCl_3$) δ 204.1, 156.3, 131.3, 46.4, 41.1, 40.3, 38.6, 33.1, 32.7, 31.6, 30.0, 28.7, 26.6, 24.0, 22.0. MS m/e, exact mass calculated for $C_{15}H_{22}O$ 218.1671, found 218.1671.

4-(1-Methylethylidene)cyclohex-2-en-1-one (44). A solution of 2-methyl-2-[3-(1-methyl)ethenylidene-4-oxobutyl]-1,3-dioxolane **20** (0.14 g, 0.71 mmol), *p*-toluenesulfonic acid (0.013 g, 0.071 mmol), acetone (15 mL) and water (1 mL) was heated at reflux for 5.5 h. The reaction mixture was allowed to cool to ambient temperature and the acetone was removed under reduced pressure. To a solution of crude product in 10 mL of THF was added 5% aqueous KOH (10 mL) and 40% aqueous *n*-Bu_4NOH (12 drops). The resulting mixture was heated at reflux for 6 h, poured into water and the mixture was extracted with ether (3 X 20 mL). The combined organic layer was washed with brine (2 X 20 mL), dried over $MgSO_4$, and the solvent was removed by rotary evaporation. The crude product was purified by flash chromatography (10% ethyl acetate / hexanes, R_f 0.21) to yield 0.068 g (71%) of product. ^1H NMR ($CDCl_3$) δ 7.47 (d, J = 10.2 Hz, 1 H, C*H*=CHCO), 5.83 (d, J = 10.2 Hz, 1 H, CH=C*H*CO), 2.71 (t, J = 7.2 Hz, 2 H, CH_2CO), 2.46 (t, J = 7.2 Hz, 2 H, CH_2CH_2CO), 1.93 (s, 3 H, CH_3), 1.89 (s, 3 H, CH_3). ^{13}C NMR ($CDCl_3$) δ 200.0, 143.8, 139.2, 126.2, 124.3, 36.9, 25.4, 21.6, 20.6. MS m/e, exact mass calculated for $C_9H_{12}O$ 136.0888, found 136.0892.

3-(1-Methyl)ethenylbicyclo[3.3.1]non-2-en-1-one (45). A solution of 6-[2-(1-methyl)ethenylidene-3-oxopropyl]-1,4-dioxaspiro[4,5]decane **36** (0.23 g, 0.97 mmol), *p*-toluenesulfonic acid (0.019 g, 0.10 mmol), acetone (20 mL) and water (0.5 mL) was stirred at ambient temperature for 20 h, and then heated at reflux for 48 h. The acetone was removed under reduced pressure. The residue was added to ether (25 mL) and washed with 5% $NaHCO_3$ (3 X 15 mL). The organic layer was dried over $MgSO_4$ and the solvent was removed by rotary evaporation. The crude product was purified by flash chromatography (5% ethyl acetate / hexanes, R_f 0.21) to yield 0.13 g (76%) of product. ^1H NMR ($CDCl_3$) δ 5.75 (d, J = 6.3 Hz, 1H, cyclic vinyl H), 4.99 (s, 1 H, vinyl H), 4.94 (s, 1 H, vinyl H), 2.92 - 2.73 (m, 2 H), 2.67 - 2.63 (m, 2 H), 1.92 - 1.86 (m, 8 H), 1.45 (m, 1 H). ^{13}C NMR ($CDCl_3$) δ 216.6, 141.3, 138.9, 124.8, 111.9, 47.2, 44.7, 36.8, 36.6, 33.6, 20.5, 16.9. MS m/e, exact mass calculated for $C_{12}H_{16}O$ 176.1201, found 176.1215.

ACKNOWLEDGMENTS. We thank the National Institutes of Health for financial support and Dr. Kasi Somayajula for recording the mass spectra.

REFERENCES AND NOTES

1. Taken from the M. S. Thesis of Birong Zhang and the Ph. D. Thesis of John P. Cherkauskas, University of Pittsburgh, 1993.
2. Cherkauskas, J. P.; Cohen, T. *J. Org. Chem.* **1992**, *57*, 6-8 and citations therein.
3. (a) Ryckman, D. M.; Stevens, R. V. *J. Amer. Chem. Soc.* **1987**, *109*, 4940-48. Ryckman, D. M.; Stevens, R. V. *J. Org. Chem.* **1987**, *52*, 4274-79. (b) Ramón, D. J.; Yus M. *J. Org. Chem.* **1991**, *56*, 3825-31. Yus, M; Ramón, D. J. *J. Org. Chem.* **1992**, *57*, 750-51.
4. Feugeas, C.; Normant, H. *Bull. Soc. Chim. Fr.* **1963**, 1441-43. Feugeas, C., Ibid. **1963**, 2568-79. van der Gen, A.; Wiedhaup, K.; Swoboda, J. J.; Dunathan, H. C.; Johnson, W. S. *J. Am. Chem. Soc.* **1973**, *95*, 2656-63. Johnson, W. S.; Wiedhaup, K.; Brady, S. F.; Olson, G. L. *J. Am. Chem. Soc.* **1974**, *96*, 3979-84. Bal, S. A.; Marfat, A.; Helquist, P. *J. Org. Chem.* **1982**, *47*, 5045-50. Joshi, N. N.; Mandapur, V. R.; Chadha, M. S. *J. Chem. Soc. Perkin Trans. I* **1983**, 2963-66.
5. Cohen, T.; Bhupathy, M. *Acc. Chem. Res.* **1989**, *22*, 152-161.
6. Freeman, P. K.; Hutchinson L. L. *J. Org. Chem.* **1980**, *45*, 1924-1930; **1984**, *48*, 4705-4713.
7. House, H. O.; Chu, C.-Y.; Wilkins, J. M. Umen, M. J. *J. Org. Chem.* **1975**, *40*, 1460-69.
8. Ong, B. S.; Chan, T. H. *Synth. Commun.* **1977**, *7*, 283-286.
9. For recent methods of preparation of thioacetals, see: Tani, H.; Masumoto, K.; Inamasu, T. *Tetrahedron Lett.* **1991**, *32*, 2039-2042 and citations therein.
10. Cohen, T.; Gapinski, R. E.; Hutchins, R. R. *J. Org. Chem.* **1979**, *44*, 3599-3601.
11. For preparative methods for ketene thioacetals, see Mikolajczyk, M.; Balczewski, P. *Tetrahedron* **1992**, *48*, 8697-8710 and citations therein.
12. Posner, G. H.; Whitten, C. E.; Sterling, J. J. *J. Am. Chem. Soc.* **1973**, *95*, 7788-7800.
13. Corey, E. J.; Boaz, N. W. *Tetrahedron Lett.* **1985**, *26*, 6015-18, 6019-22. Alexakis, A.; Berlan, J.; Besace, Y. *Tetrahedron Lett.* **1986**, *27*, 1047-1050.
14. Crimmins, M. T.; Deloach, J. A. *J. Am. Chem. Soc.* **1986**, *108*, 800-806. (b) Showler, A. J.; Darley. P. A. *Chem. Rev.* **1967**, *67*, 427-440. (c) Koreeda, M.; Brown, L. *J. Org. Chem.* **1983**, *48*, 2122-2124.
15. Unpublished work of F. P. Chen.
16. For other examples of tertiary organolithiums producted in this manner, see ref. 2 and Mudryk, B.; Cohen, T. *J. Am. Chem. Soc.* **1993**, *115*, 3855-65.
17. Mukaiyama, T.; Kamio, K.; Kobayashi, S.; Takei, H.; *Bull . Chem. Soc. Japan*, **1972**, *45*, 3723-.
18. Corey, E. J.; Shulman, J. I. *J. Org. Chem.* **1970**, *35*, 777-780.
19. Still, W. C.; Kahn, M.; Mitra, A. *J. Org. Chem.* **1978**, *43*, 2923-25.
20. Cohen T.; Doubleday, M. D. *J. Org. Chem.* **1990**, *55*, 4784-86.
21. Van Straten, J. W.; Van Norden, J. J.; Van Schaik, T. A. M.; Frake, G. F.; De Wolf, W. H.; Bickelhaupt, F. *Recl. Trav. Chim. Pays Bas.* **1978**, *97*, 105-106.
22. Ito, Y.; Aoyama, H.; Hirao, T.; Mochizuki, A.; Saegusa, T. *J. Am. Chem. Soc.* **1979**, *101*, 494-96.

(*Received in USA* 10 *July* 1994; *revised* 12 *August* 1994; *accepted* 16 *August* 1994)