H, unresolved multiplets, aryl H's and vinyl H), 4.91 (2 H, d, J = 2 Hz, CH_2O), 4.20-(2 H, q, $COOCH_2$), 1.30 (3 H, t, $COOCH_2CH_3$); HRMS 204.0771 (34, M^+ calcd for $C_{12}H_{12}O_3$: 204.0788), 175 (100), 131 (89), 77 (28). Anal. Calcd for $C_{12}H_{12}O_3$: C, 70.58; H, 5.92. Found: C, 70.26; H, 5.94.

9-Ethoxycarbonyl-7-oxabicyclo[4.3.0]-1(9)-nonene (14). To a suspension of 144 mg (3.00 mmol) of a 50% oil dispersion of NaH, washed free of oil with dry pentane, in 5 mL of dry THF at 0 °C is added 432 mg (3.78 mmol) of freshly distilled 2-hydroxycyclohexanone dropwise over a 3-min period. After 1 h, 709 mg (3.00 mmol) of compound 1 is added dropwise over a 20-min period by means of a syringe pump. The reaction solution is refluxed for 24 NH_4Cl, diluted with water, and extracted and dried over Na_2SO_4, evaporated, and chromatographed on silica gel, eluting with ethyl acetate/hexane (2:6, v/v), to afford 230 mg (39%) of **14** (R_f 0.40 eluting with 40% EtOAc/hexane) as a clear liquid: IR (thin film) 1710 cm^{-1}; ^{1}H-NMR (CCl_4) δ 4.63 (2 H, broad, CH_2O), 4.13 (2 H, q, $COOCH_2$), 3.7–3.3 (1 H, unresolved multiplet, CHO), 2.4–1.0 (8 H, unresolved multiplets, cyclohexyl H's), 1.28 (3 H, t, $COOCH_2CH_3$); HRMS 196.1057 (35, M^+ calcd for $C_{11}H_{16}O_3$: 196.1099), 194 (41), 151 (53), 150 (71), 123 (100), 122 (41). Anal. Calcd for $C_{11}H_{16}O_3$: C, 67.32; H, 8.22. Found: C, 66.83; H, 8.17.

Acknowledgments. Support for this research was provided by funds from the National Science Foundation (Grant No. GP-31321X) and the National Institutes of Health (Grant No. CA-12617). We thank Professor Martin Semmelhack for informing us of his similar research with compound 1 prior to publication [see accompanying note].

Registry No.—**1**, 20345-61-3; **2**, 64739-80-6; **3**, 64739-81-7; **8**, 64739-82-8; **9**, 64739-83-9; **13**, 57543-58-5; **14**, 64739-84-0; ethyl 2-diethylphosphonopropeionate, 3699-66-9; phenylselenyl bromide, 34837-55-3; cyclohexanone, 108-94-1; salicylaldehyde, 90-02-8; 2-hydroxycyclohexanone, 533-60-8; i, 64739-85-1.

References and Notes

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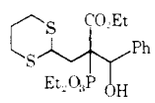
(7) The unknown compound was not distinguishable by TLC from **12** and was not detectable by GLC. From the fact that the ^{1}H-NMR spectrum of the product after Kugelrohr distillation contained an additional aromatic singlet and absorptions characteristic of the methylene protons of a diethylphosphonate functional group, and that the IR spectrum showed a weak OH stretching absorption, the unknown compound was postulated to have structure i.



i

Preparation of 2-(Alkylthiomethyl)acrylates

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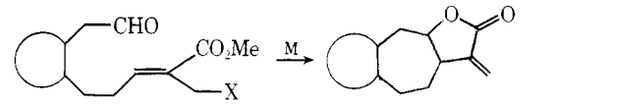
The synthesis of trisubstituted alkenes has been an active area of study in recent years; many general strategies are now available.[1] We are pursuing a plan for synthesis of the sesquiterpene α-methylene-γ-lactones which utilizes intramolecular Reformatsky-type reaction[2] and necessitates the preparation of the 2-substituted acrylate unit as in **1**. Previously developed stereospecific methods were applied to simple systems related to **1** with some success but required



1, X = Br, OH, SR + MeO—M—X

M = metal

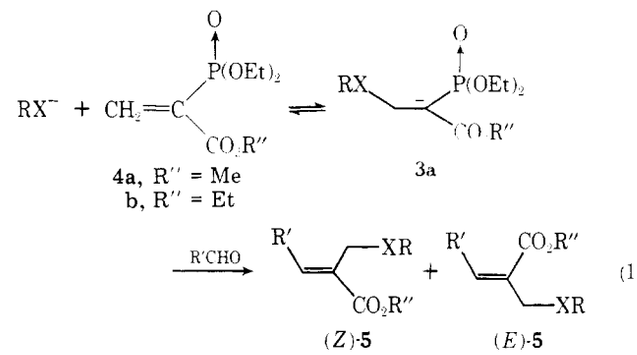
several steps, some involving vigorous reaction conditions.[2] Here we report a method for preparation of the desired acrylate unit under mild conditions and with high efficiency. The method is based on Wittig reagents of the sort represented by **2** and **3**. A general technique for preparation of phosphorus reagents such as **2b** is due to Corey[3] and to Schlosser,[4] but we have failed in our attempts to apply that method in preparation of **2a** (X = OH) or **3a** (X = OH). Apparently, reaction of

2a, R = CO_2Me; X = OH
b, R = alkyl; X = OH

3a, R = CO_2Me; X = OH
b, R = alkyl; X = OH

2a or **3a** with an aldehyde is slower than elimination of Ph_3PO (from **2a**) and $HOP(O)(OMe)_2$ (from **3a**). With other heteroatom units X in **2a** and **3a** (e.g., X = acetate), elimination of X^- is invariably too rapid.

Nevertheless, we expected that the elimination of X^- could be reversible, still providing useful concentrations of **2a** and **3a**. After a series of unsuccessful experiments with oxygen anions (in eq 1), the thiolate anion (X = S) was found to lead



4a, R'' = Me
b, R'' = Et

3a

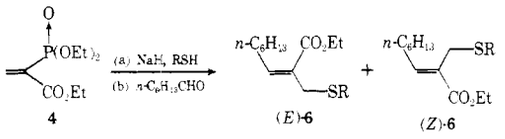
(Z)-5 (E)-5 (1)

to the desired conversion. The requisite methyl 2-(diethylphosphono)acrylate **4** was prepared according to the procedure of Pudovik,[5] which is presented in detail in the Experimental Section. The yield of **4** was only moderate, but the procedure is direct, and the reagent can be prepared on large scale, distilled, and stored for later use. Then addition of **4** to a suspension of sodium hydride and the thiol in tetrahydrofuran, followed by an aldehyde (stirring for 2.0 h at 25 °C), affords the 2-(alkylthiomethyl)acrylate (**5**) in high yield.

Table I displays the results of experiments designed to test the effects of solvent polarity, cation type, and structure of the organic unit in the thiolate anion on the efficiency and the stereochemical outcome of the reaction. In this case n-heptanal, phosphonoacrylate **4b**, and a thiolate anion were allowed to react under a variety of conditions. The yield of combined E and Z isomers was high in every case.[6]

The data in Table I demonstrate that the ratio of isomers depends upon counterion, solvent, and the nature of the thiolate anion, although no useful correlation is evident. The

Table I. Effects of Reaction Conditions on Isomer Distribution



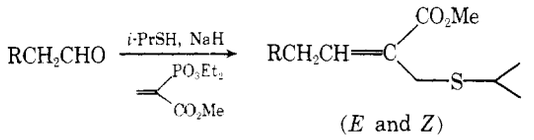
4 (E)-6 (Z)-6

Thiol R	Solvent	Base	E/Z
Isopropyl	THF	*n*-BuLi[a]	46/54
Isopropyl	THF	*n*-BuLi[b]	10/90
Isopropyl	THF	NaH[c]	45/55
Isopropyl	THF	KH[c]	10/90
Isopropyl	THF	Triton B[c]	30/70
Isopropyl	DMF	NaH[c]	10/90
tert-Butyl	THF	NaH[a]	45/55
tert-Butyl	DMF	NaH[a]	10/90
Benzyl	THF	NaH[c]	36/64
Phenyl	THF	NaH[a]	18/82

[a] The reaction time was 1 h. [b] The reaction time was 144 h. [c] The reaction time was 12 h.

ratio of isomers also depends upon whether equilibrium between the isomers is established; addition of 0.1 mol equiv of sodium isopropylthiolate effected rearrangement of pure (*E*)-**6** into an 18:80 mixture of (*E*)-**6**/(*Z*)-**6** in less than 5 min at 25 °C in DMF.[6] A parallel experiment in THF gave the same result, but only after 24 h. Presumably, equilibration of the *E* and *Z* isomers occurs by conjugate addition/elimination of the thiolate. Under conditions designed to minimize the rate of equilibration (nonpolar solvent, deficiency of RS^-), the ratio of isomers is generally about 1:1. After equilibration, the *Z* isomer usually predominates by a factor of 8:1 or 9:1. Chromatographic separation provides samples of the pure isomers with good efficiency.

A number of difunctional aldehydes have been converted to 2-(alkylthiomethyl)acrylates; examples such as **7** and **8** are obtained in high yields. A more demanding example is the preparation of the 4-chlorocrotonate derivatives, **9**, from chloroacetaldehyde under the usual conditions. The yield of (*E*)-**9** and (*Z*)-**9** is 98%, with an isomer ratio of 1:2.8.

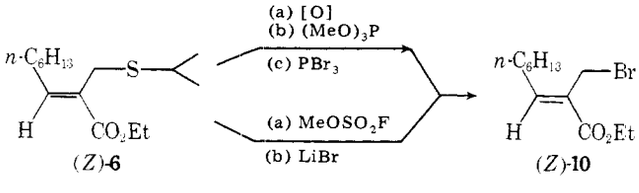


(*E* and *Z*)

7, R = $(CH_2)_4CH(OMe)_2$
8, R = $C(CH_3)_2CH_2CH(OMe)_2$
9, R = Cl

Our planned application of the 2-(alkylthiomethyl)acrylates requires conversion of the allylic thioether to an allylic halide. Preliminary studies provided the desired conversion in low overall yield using the three-step procedure based on the work of Evans:[8] oxidation of the thioether (**6**) to the sulfoxide using *m*-chloroperbenzoic acid, cleavage of the sulfinate ester (from [2.3]sigmatropic rearrangement), and bromination (with allylic rearrangement) of the allylic alcohol. The bromide (**10**) was obtained in 20–25% overall yield as a single isomer (*Z*) starting from either (*Z*)-**6** or (*E*)-**6**.

In an effort to convert (*E*)-**6** or (*Z*)-**6** to the corresponding allylic halides more efficiently and without isomerization of the olefin geometry, direct displacement of sulfur was studied. Methylation of the sulfur in (*Z*)-**6** with methyl fluorosulfonate (to give the sulfonium ion) followed by treatment with excess lithium bromide produced (*Z*)-**10** in high purity (93% yield). Parallel reactions with (*E*)-**6** also gave (*Z*)-**10** exclusively, although by monitoring the reaction by ^1H NMR, the transient formation of (*E*)-**10** was demonstrated.



(*Z*)-**6** (*Z*)-**10**

Finally, it should be mentioned that parallel techniques utilizing addition of carbanions to phosphonoacrylates (**4** and substituted analogues) are under development by C. Heathcock and co-workers at the University of California, Berkeley.[9]

Experimental Section

Preparation of Methyl 2-(Diethylphosphono)acrylate (4a). According to the general procedure of Pudovik,[5] a mixture of paraformaldehyde (19.95 g, 0.665 mol), methyl alcohol (470 mL), and piperidine (5.7 g, 6.63 mL, 0.067 mol) under argon in a 1-L flask equipped with a reflux condenser, magnetic stirrer, and inlet was heated at reflux for 1.5 h. During this time, the paraformaldehyde dissolved to give a colorless solution. To this mixture at 25 °C was added methyl (diethylphosphono)acetate[10] (105 g, 0.50 mol) and the mixture was heated at reflux for an additional 8 h. The solution was cooled and concentrated by rotary evaporation, benzene was added, and the mixture was concentrated again by rotary evaporation. After repeating this procedure, the residual oil was transferred to a 250-mL flask and phosphoric acid (5 mL, 85%) was added all at once. Distillation through an 18-in. vigreux column afforded a middle fraction of bp 95–98 °C (0.15 Torr) (lit.[5] bp 100–101 °C (1.0 Torr)), 31.32 g (28% yield): ^1H NMR (CCl_4) δ 1.33 (6 H, t, *J* = 7 Hz, OCH_2CH_3), 3.81 (3 H, s, OCH_3), 3.73–4.33 (4 H, m, OCH_2CH_3), 6.48 (1 H, dd, *J* = 2 and 2 Hz), 7.01 (1 H, dd, *J* = 2 and 25 Hz). An additional 8.5 g (8% yield) of less pure product was obtained as forerun and tailings.

A parallel preparation using triethyl phosphonoacetate (112 g, 0.50 mol) produced ethyl 2-(diethylphosphono)acrylate (**4b**) with bp 98.5–99.5 °C (0.13 Torr) (lit.[5] bp 101–102 °C (1.0 Torr)), 48.3 g (41% yield): ^1H NMR (CCl_4) δ 1.35 (9 H, t, *J* = 7 Hz, OCH_2CH_3), 3.84–4.45 (6, H, m, OCH_2CH_3), 6.47 (1 H, dd, *J* = 2 and 2 Hz), 7.00 (1 H, dd, *J* = 2 and 25 Hz). An additional 1.36 g (11.5% yield) of less pure material was also obtained.

Preparation of (*E*)-6 and (*Z*)-6 (R = 2-Propyl), 1-(2-Propylthio)-2-ethoxycarbonyl-2-nonene. Typical Procedure. Into a 50-mL three-neck flask equipped with an argon/vacuum inlet, serum cap, and magnetic stirrer was placed sodium hydride (0.084 g as a 57% slurry with mineral oil, 2.0 mmol). The flask was alternately evacuated and filled with argon three times. THF (15 mL, freshly distilled from benzophenone ketyl) was added and the stirred suspension was cooled to 0 °C. Then 2-propanethiol (0.152 g, 0.186 mL, 2.0 mmol) was added dropwise via syringe over 1 min (no apparent gas evolution). Ethyl phosphonoacrylate **4b** (0.47 g, 0.42 mL, 2.0 mmol) was added over several min (gas evolution). After the mixture was stirred for 5 min at 0 °C, heptanal (0.23 g, 0.27 mL, 2.0 mmol) was added over 1 min and the mixture was maintained at 0 °C for 2 h; a gummy precipitate formed. The mixture was partitioned between water and ether, the ether solution was set aside, and the aqueous layer was washed with ether. The combined ether solutions were dried over magnesium sulfate and concentrated by rotary evaporation to afford a colorless oil. Short-path distillation (85°/0.005 torr) gave 0.48 g (89% yield) of a mixture of (*E*)-**6**/(*Z*)-**6** in a ratio of about 1:1 (^1H NMR and GLC analysis).

Separation of the isomers was achieved by preparative GLC (6-ft × 0.375-in. column packed with 3% OV-225 on chromosorb W) and by open column chromatography (60–200 mesh silica gel, increasing proportion of benzene in hexane as eluant). The *E* isomer appeared first.

Compound (*E*)-**6** (R = 2-propyl), (*E*)-1-(2-propylthio)-2-ethoxycarbonyl-2-nonene, showed the following spectral data: IR (neat) 3.40, 3.43, 3.51 (s, CH), 5.83 (s, C=O), 6.10 (w, C=C), 6.85 (m), 7.28 (m), 8.12, 8.34 μm; ^1H NMR (CCl_4) δ 0.77–1.58 (w, 11 H), 0.87 (m, 3 H, OCH_2CH_3), 1.23 (d, 6 H, *J* = 7.5 Hz, $CH(CH_3)_2$), 2.07–3.0 (m, 3 H, CH_2CH=C and $SCH(CH_3)_2$), 3.27 (br s, 2H, CH_2S), 4.17 (q, 2 H, *J* = 7 Hz, OCH_2CH_3), 5.85 (t, 1 H, *J* = 7 Hz, $—CH_2CH$=); mass spectral molecular weight: calcd for $C_{15}H_{28}O_2S$, 272, and found, 272 (electron impact).

Anal. Calcd for $C_{15}H_{28}O_2S$: C, 66.13; H, 10.36; S, 11.77. Found: C, 65.94; H, 10.09; S, 11.93.

Compound (*Z*)-**6** (R = 2-propyl), (*Z*)-1-(2-propylthio)-2-ethoxy-

carbonyl-2-nonene, showed the following spectral data: IR (neat) 3.39, 3.42, 3.50 (s, CH), 5.84 (s, C=O), 6.09 (w, C=C), 6.83 (m), 7.30 (m), 7.80, 8.45 (m, CO), 9.50 μm; ^{1}H NMR (CCl_4) δ 0.68–1.62 (m, 11 H), 0.89 (m, 3 H, OCH_2CH_3), 1.27 (d, 6 H, J = 7Hz, $CH(CH_3)_2$), 1.98–2.45 (m, 2 H, —CH_2CH=), 2.87 (sept, 1 H, J = 7 Hz, $SCHC(CH_3)_2$), 3.41 (br s, 2 H, CH_2S), 4.17 (q, 2 H, J = 7 Hz, OCH_2CH_3), 6.72 (t, 1 H, J = 7.5 Hz, —CH_2CH=); mass spectral molecular weight: calcd for $C_{15}H_{28}O_2S$, 272 and found, 272 (electron impact).

Anal. Calcd for $C_{15}H_{28}O_2S$: C, 66.13; H, 10.36; S, 11.77. Found: C, 66.08; H, 10.13; S, 11.89.

In the same way, the following mixtures were prepared.

(*E*)- and (*Z*)-1-[2-(2-Methylpropyl)thio]-2-ethoxycarbonyl-2-nonene. (6, R = *tert*-Butyl). The yield of the mixture after short-path distillation (120 °C (0.03 Torr)) was 80%. Characteristic ^{1}H NMR signals at: δ 3.30 (br s, 2 H, $-CH_2S-$ in *E* isomer), 3.37 (br s, 2 H, $-CH_2S-$ in *Z* isomer), 5.93 (t, 1 H, J = 7 Hz, CH_2CH= in *E* isomer[6]), 6.62 (t, 1 H, J = 7 Hz, CH_2CH= in *Z* isomer).

Anal. Calcd for $C_{16}H_{30}O_2S$: C, 67.08; H, 10.56; S, 11.19. Found (mixture of *E* and *Z*): C, 67.23; H, 10.61; S, 11.38.

(*E*)- and (*Z*)-1-(Benzylthio)-2-ethoxycarbonyl-2-nonene (6, R = Benzyl). The yield of the mixture after short-path distillation (120 °C (0.03 Torr)) was 85%. Characteristic ^{1}H NMR signals at: δ 3.15 (br s, 2 H, CH_2S in *E* isomer), 3.50 (br s, 2 H, CH_2S in *Z* isomer), 3.59 (s, 2 H, SCH_2Ph in *E* isomer), 3.67 (s, SCH_2Ph in *Z* isomer), 4.19 (q, J = 7 Hz, OCH_2CH_3 in *E* isomer), 4.15 (q, 2 H, OcH_2CH_3 in *Z* isomer), 5.77 (t, 1 H, J = 7 Hz, CH_2CH= in *E* isomer), 6.72 (t, 1 H, J = 7 Hz, CH_2CH= in *Z* isomer).[6] The mixture was separable by GLC on a 6-ft × 0.375-in. column packed with 3% OV-225. Mass spectrometry showed no parent ion (electron impact).

Anal. Calcd for $C_{19}H_{28}O_2S$: C, 71.20; H, 8.81; S, 10.00. Found: C, 71.09; H, 8.82; S, 9.90.

(*E*)- and (*Z*)-1-(Phenylthio)-2-ethoxycarbonyl-2-nonene (6, R = phenyl). The yield of the mixture after short-path distillation (110 °C (0.05 Torr)) was 89%. Characteristic ^{1}H NMR signals at: δ 3.59 (br s, 2 H, $-CH_2S-$ in *E* isomer), 3.71 (br s, 2 H, $-CH_2S-$ in *Z* isomer), 4.13 and 4.15 (q, J = 7 Hz, 2 H each, OCH_2CH_3), 5.67 (t, 1 H, J = 7 Hz, —CH_2CH= in *E* isomer), 6.66 (t, 1 H, J = 7 Hz, —CH_2CH= in *Z* isomer).[6]

Anal. Calcd for $C_{18}H_{26}O_2S$: C, 70.54; H, 8.55; S, 10.46. Found: C, 70.76; H, 8.46; S, 10.45.

(*E*)- and (*Z*)-1-(2-Propylthio)-2-methoxycarbonyl-8,8-dimethoxy-2-octene ((*E*)-7 and (*Z*)-7). On a 10-mmol scale according to the typical procedure, the yield of the mixture before separation of *E*/*Z* isomers was 95%. Column chromatography on 300 g of silica gel (2.5-cm i.d. column, elution with 25% v/v ether in hexane) allowed partial separation of isomers.

Pure (*E*)-7 eluted first: 0.53 g; ^{1}H NMR (CCl_4) δ 1.08–1.66 (m, 6 H), 1.20 [d, 6 H, J = 7 Hz, $CH(CH_3)_2$], 2.12–3.08 [m, 3 H, $CH(CH_3)_2$ and —CH_2CH_2C=], 3.21 [s, 6 H, $CH(OCH_3)_2$], 3.29 (s, 2 H, $-CH_2S-$), 3.70 (s, 3 H, CO_2CH_3), 4.26 (distorted t, 1 H, CH_2CH), and 5.91 (t, 1 H, J = 7 Hz, —CH_2CH=).

Anal. Calcd for $C_{15}H_{28}O_4S$: C, 59.18; H, 9.27; S, 10.53. Found: C, 59.43; H, 9.39; S, 10.34.

Pure (*Z*)-7 eluted last: 0.50 g; ^{1}H NMR (CCl_4) δ 1.09–1.67 (m, 6 H), 1.23 [d, 6 H, J = 7 Hz, $CH(CH_3)_2$], 2.01–2.43 (m, 2 H, $-CH_2CH_2CH$=), 2.86 [sept, 1 H, J = 7 Hz, $CH(CH_3)_2$], 3.31 [s, 6 H, $CH(OCH_3)_2$], 3.37 (s, 2 H, CH_2S), 3.70 (s, 3 H, CO_2CH_3), 4.26 (distorted t, 1 H, CH_2CH), and 6.69 (t, 1 H, J = 7 Hz, —CH_2CH=).

An intermediate fraction was a mixture of *E* and *Z* isomers, 1.60 g. The combined yield of both isomers was 2.63 g (86%).

(*E*)- and (*Z*)-1-(2-Propylthio)-2-methoxycarbonyl-5,5-dimethyl-7,7-dimethoxy-2-heptene ((*Z*)-8 and (*E*)-8). According to the typical procedure (above), 3,3-dimethyl-5,5-dimethoxypentanal[11] (0.880 g, 5.05 mmol) was converted to a mixture of (*E*)-8 and (*Z*)-8. The yield of the crude material was 1.55 g (97%); ^{1}H NMR analysis suggested high purity. Column chromatography (silica gel, eluting with 12% ether in hexane) produced 1.23 g (77% yield) of a mixture of *E*/*Z* isomers, 43/57 [integration of ^{1}H NMR signals centered at δ 5.99 (*E* vinyl H) and at 6.80 (*Z* vinyl H)]. The mixture was not further purified. ^{1}H NMR (CCl_4) δ 0.94 [s, 6 H, $C(CH_3)_2$, *E*], 0.98 [s, 6 H, $C(CH_3)$, *Z*], 1.22 [d, 6 H, J = 7 Hz, $SCH(CH_3)_2$, *E*], 1.25 [d, 6 H, J = 7 Hz, $SCH(CH_3)_3$, *Z*], 1.48 (d, 2 H, J = 6 Hz, CH_2CH, *E*), 1.51 (d, 2 H, J = 6, CH_2CH, *Z*), 2.19 (d, 2 H, J = 7 Hz, CH_2C=C, *Z*), 2.40 (d, 2 H, J = 7 Hz, CH_2C=C, *E*), 2.85 (septet, 2 H, J = 7 Hz, $SCH(CH_3)_2$ *E* and *Z*), 3.21 (s, 6 H, $CHOCH_3$, *E* and *Z*), 3.33 (s, 2 H, C=C=CCH_2S, *E*), 3.36 (s, 2 H, C=CCH_2S, *Z*), 3.72 (s, 6 H, CO_2CH_3, *E* and *Z*), 4.40 [t, 2 H, J = 6 Hz, $CH(OCH_3)_2$, *E* and *Z*], 5.99 (t, 1 H, J = 7 Hz, vinyl H in *E*), 6.80 (t, 1 H, J = 7 Hz, vinyl H in *Z*); IR (CCl_4) 3.39, 3.53, 5.80 (C=O), 6.09 (C=C), 7.24, 8.9, 9.5, 10.4 (C=CH) μm.

Anal. Calcd for $C_{16}H_{30}O_4S$: C, 60.34; H, 9.50; S, 10.07. Found: C, 60.37; H, 9.48; S, 9.99.

Methyl (*E*)- and (*Z*)-29[(2-propyl)thiomethyl]-4-chloro-2-butenoates ((*E*)-9 and (*Z*)-9). According to the typical procedure, chloroacetaldehyde[12] (0.385 mg, 4.9 mmol, 32% excess), sodium hydride (0.155 g, 3.8 mmol), 2-propanethiol (0.292 g, 3.8 mmol), and phosphonoacrylate **4a** (0.825 g, 3.7 mmol) were converted at −78 °C to a mixture of (*E*)-9 and (*Z*)-9, 0.850 g (98% yield), which showed only two components by TLC analysis and no significant spurious signals in the ^{1}H NMR spectrum of the mixture. Integration of the ^{1}H NMR signals δ 4.5 (d, CH_2Cl in (*E*)-9) and 4.2 (d, CH_2Cl in (*Z*)-9) were in the ratio of 1:2.8.

Medium pressure preparative LC of the mixture (15:1 hexane/ether at 10 psi, 100 × 2.5-cm column, silica gel) afforded 0.221 g (27%) of (*E*)-9 (fraction 1), 0.085 g of a mixture of (*E*)-9 and (*Z*)-9, and 0.310 g (38%) of (*Z*)-9 (fraction 3). Compound (*Z*)-9 began to decompose slowly upon removal of solvent at 25 °C.

Short-path distillation of fraction 1 (50–65 °C (0.001 Torr)) afforded 0.186 g (23%) of (*E*)-9 as a colorless liquid. IR (neat) 5.81 (s) and 6.10 (m) μm; ^{1}H NMR ($CDCl_3$) δ 1.21 [d, 6 H, J = 7 Hz, $CH(CH_3)_2$], 2.84 [sept, 1 H, J = 7 Hz, $CH(CH_3)_2$], 3.37 (s, 2 H, CH_2S), 3.78 (s, 3 H, CO_2CH_3), 4.46 (d, 2 H, J = 7 Hz, $ClCH_2$), 6.13 (t, 1 H, J = 7 Hz, C=CH). Attempted combustion analysis was not successful, presumably due to significant decomposition during several days at 25 °C (also indicated in the ^{1}H NMR spectrum).

Short-path distillation of fraction 3 (50–65 °C (0.001 Torr)) afforded 0.127 g (16%) of (*Z*)-9 as a colorless liquid which began to turn yellow within minutes at 25 °C. Working quickly the following spectral data were obtained: IR (neat) 5.82 (s) and 6.10 (m) μm; ^{1}H NMR ($CDCl_3$) δ 1.28 [d, 6 H, J = 7 Hz, $CH(CH_3)_2$], 2.94 [sept, 1 H, J = 7 Hz, $CH(CH_3)_2$], 3.50 (s, 2 H, CH_2S), 3.81 (s, 3 H, CO_2CH_3), 4.25 (d, 2 H, J = 7 Hz, CH_2Cl), 6.88 (t, 1 H, J = 7 Hz, C=CH), with detectable and increasing signals at δ 3.9 and 1.8 (impurities and/or decomposition products).

Preparation of (Z)-1-Bromo-2-ethoxycarbonyl-2-nonene (10). In a 50 mL three-neck flask equipped with an argon/vacuum inlet, serum cap, and magnetic stirrer was placed 0.20 g (0.74 mmol) of (*Z*)-1-(2-propylthio)-2-ethoxycarbonyl-2-nonene. The flask was alternately evacuated and filled with argon (3×). Methylene chloride (10 mL) was added and the mixture was cooled in an ice bath. Methyl fluorosulfonate (0.086 g, 0.061 mL, 0.75 mmol) was added all at once via syringe. After 0.5 h at 0 °C, the mixture was stirred at 20 °C for an additional 2.5 h and then cooled again to 0 °C. Lithium bromide (anhydrous, 0.35 g, 4.0 mmol) was added all at once. The suspension was stirred at 2 °C for 40 h, then methylene chloride was added and the mixture was filtered. Concentration by rotary evaporation provided 0.19 g (93%) of the allylic bromide (>90% pure by ^{1}H NMR analysis). Preparative layer chromatography afforded pure (*Z*)-10: 0.13 g (55% yield). ^{1}NMR (CCl_4) δ 0.68–1.73 (m, 14 H), 2.04–2.52 (m, 2 H, —CH_2CH_2CH=), 4.14 (s, 2 H, $BrCH_2C$=), 4.20 (q, J = 7 Hz, 2 H, OCH_2CH_3), 6.85 (t, J = 7 Hz, 1 H, —CH_2CH=); mass spectral molecular weight calcd for $C_{12}H_{21}BrO_2$, 276 and 278, and found, 276 and 278 (chemical ionization).

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Registry No.—**4a,** 993-88-4; **4b,** 20345-61-3; (*Z*)-**6** (R = *i*-Pr), 64600-31-3; (*E*)-**6** (R = *i*-Pr), 64600-32-4; (*Z*)-**6** (R = *t*-Bu), 64600-33-5; (*E*)-**6** (R = *t*-Bu), 64600-34-6; (*Z*)-**6** (R = CH_2-Ph), 64600-35-7; (*E*)-**6** (R = CH_2-Ph), 64600-36-8; (*Z*)-**6** (R = Ph), 64600-37-9; (*E*)-**6** (R = Ph), 64600-38-0; (*Z*)-**7,** 64626-93-3; (*E*)-**7,** 64600-39-1; (*Z*)-**8,** 64600-40-4; (*E*)-**8,** 64600-41-5; (*Z*)-**9,** 64600-42-6; (*E*)-**9,** 64600-43-7; (*Z*)-**10,** 64600-44-8; methyl diethyl phosphonoacetate, 1067-74-9; paraformaldehyde, 30525-89-4; triethyl phosphonoacetate, 867-13-0; 2-propanethiol, 75-33-2; *tert*-butylthiol, 75-66-1; benzylthiol, 100-53-8; phenylthiol, 108-98-5; 7,7-dimethoxyheptanal, 55489-11-7; 3,3-dimethyl-5,5-dimethoxypentanal, 64600-45-9; chloroacetaldehyde, 107-20-0.

References and Notes

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(3) Cf. E. J. Corey and H. Yamamoto, *J. Am. Chem. Soc.,* **92,** 226 (1970).
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(6) Determination of the ratio of *E* and *Z* isomers was based on relative areas of the ^{1}H NMR signals due to the vinyl protons. A vinyl proton cis to a car-

boalkoxy unit appears ca. 0.9 ppm downfield (ca. δ 5.8) relative to the vinyl proton (ca. δ 6.7) arranged trans to a carbomethoxy group.[7] Isomerization of α,β-unsaturated esters through reversible Michael addition of thiols has been noted: R. E. Ireland, M. I. Dawson, C. J. Kowalski, C. A. Lipinski, D. R. Marshall, J. W. Tilley, J. Bordner, and B. L. Trus, *J. Org. Chem.*, **40**, 1 (1975).

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(8) D. A. Evans and G. C. Andrews, *Acc. Chem. Res.*, **7**, 147 (1974).
(9) (a) Personal communication, August, 1975; (b) Abstract ORGN 85, American Chemical Society National Meeting, New Orleans, La., March, 1977; (c) see preceding note in this issue.
(10) This compound is now available commercially, for example, from Aldrich Chemical Co.
(11) Prepared from 3,3-dimethylglutaric anhydride by conventional techniques.
(12) Cf. H. O. House, V. K. Jones, and G. A. Frank, *J. Org. Chem.*, **29**, 3327 (1969).

Allylic Trifluoroacetylation Proceeding via an Additive Pummerer Rearranged Intermediate

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The rearrangement of sulfoxides to give α-substituted derivatives of the corresponding sulfides is well-known as the Pummerer reaction.[1,2] Recently, several instances of an interesting variation on this reaction, the so-called additive Pummerer rearrangement, have been reported.[3,4,5] In these examples the rearrangement of vinylogous sulfoxides yielded α,β-disubstituted derivatives of the corresponding sulfides. Evidence for a vinylogous Pummerer rearrangement involving an allylic methylene position has also been presented[6] and we have recently demonstrated a transannular-type Pummerer rearrangement with a para-substituted phenol sulfoxide.[7] In both the aforementioned cases the preferential abstraction of a distant hydrogen atom was thought responsible for the substitution pattern. We now report the first example of a reaction sequence involving the functionalization of an allylic methyl group proceeding via an additive Pummerer rearranged intermediate. This novel reaction provides ready access to a number of previously unavailable 2-oxymethyl analogues of the highly active and widely used systemic fungicide carboxin[8] (5,6-dihydro-2-methyl-1,4-oxathiin-3-carboxanilide).

Results and Discussion

Carboxin sulfoxide (**1**, Scheme I) on treatment with trifluoroacetic anhydride in benzene at room temperature rapidly underwent an additive Pummerer rearrangement to yield the spectroscopically homogeneous bis(trifluoroacetoxy)-1,4-oxathiane **2**. The proposed mechanism for the additive Pummerer reaction[4] would predict the possible formation of two diastereomers. However, in the present case, steric considerations appear to favor the trans-substitution pattern only. This would result in production of just the one stereoisomer presently observed. A somewhat analogous result has been reported previously.[5] A related reaction sequence demonstrated that the N–H moiety does not participate in the reaction with trifluoroacetic anhydride; i.e., the *N*-methyl analogue of carboxin sulfoxide yielded the similar bis(trifluoroacetate) **10**. The structure of compound **2** was further elucidated by methanolysis to the dimethoxy analogue **3**.

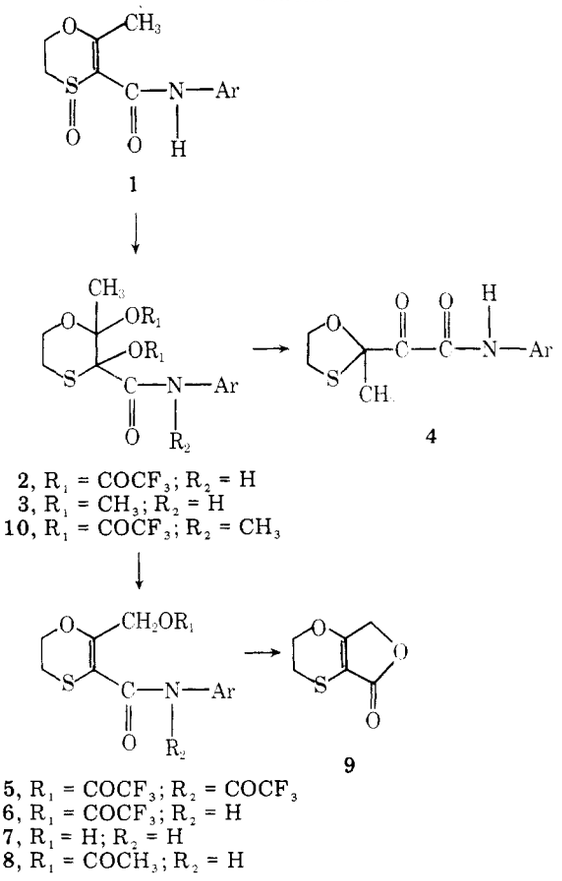
When subjected to mild hydrolytic conditions (i.e., aqueous dimethylformamide), **2** was converted to a 1,3-oxathiolane (**4**). In addition to having the requisite NMR and IR properties, mass spectral data of **4** showed a parent ion of *m/e* 251 and a prominent fragment ion of *m/e* 103, corresponding to the 2-methyl-1,3-oxathiolane moiety. An analogous rearrangement of 2,3-diacetoxy-1,4-dithane has been reported[9] and is similar to the well-known rearrangement of β-halo sulfides.[10]

When a benzene solution of compound **2** (with or without trifluoroacetic anhydride present) was refluxed for 1 h or alternately left to stand at room temperature overnight, it was converted to another compound which was assigned structure **5** on the basis of its spectroscopic properties. Infrared data showed strong absorption at 1795 and 1745 cm^{-1}, indicative of O- and N-trifluoroacetylated groups, respectively, and the NMR spectrum indicated loss of the C-2 methyl signal and the appearance of a two-proton singlet at δ 5.17.

Selective removal of the *N*-trifluoroacetyl group from compound **5** with saturated $NaHCO_3$ solution was shown by loss of the IR absorption band at 1745 cm^{-1} and reappearance of the N–H proton signal at δ 8.02 in the spectral data of the monotrifluoroacetate **6**. Mild treatment of **6** with pyridine hydrolyzed the remaining trifluoroacetyl group. A substantial shift upfield (δ 1.09) in the methylenic proton signal of the resultant alcohol **7** confirmed the postulated site of the trifluoroacetyl group prior to its removal. Acetylation of **7** with acetic anhydride–pyridine afforded the acetate analogue **8**. Prolonged hydrolysis of compounds **5**, **6**, and **7** resulted in quantitative degradation to the α,β-unsaturated-γ-lactone **9**.

Investigations regarding the mode of conversion from compound **2** to **5** suggest a concerted reaction involving participation of the anilide group; i.e., TLC and NMR studies of the reaction mixture failed to detect the presence of any stable intermediates such as the monotrifluoroacetate **6**, and the *N*-methylbis(trifluoroacetyl) analogue **10** once formed did not undergo a similar rearrangement.

Scheme I



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