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New Methods for Synthesis of α,β-Unsaturated Carboxylic Esters from Carbonyl Compounds Using Monoanions of Dithiocarbonates, and Dianions of Ethyl Mercaptoacetate and Ethyl 2-Mercaptopropionate

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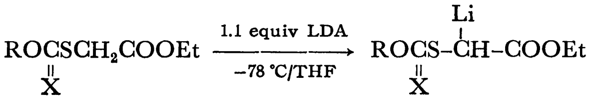
The lithium enolates of *O*-alkyl *S*-alkoxycarbonylmethyl dithiocarbonates and monothiocarbonates were found to be efficient reagents for the synthesis of α,β-unsaturated esters from carbonyl compounds by single-step procedure. The dianions of ethyl mercaptoacetate and ethyl 2-mercaptopropionate were successfully generated by treatment with 2.2 equivalents of lithium diisopropylamide (LDA) in the presence of *N*,*N*,*N*′,*N*′-tetramethylethylenediamine (TMEDA) at −78 °C in THF. The dianions so formed are highly reactive toward various electrophiles. The procedure leads to a novel one-pot synthesis of α,β-unsaturated carboxylic esters from carbonyl compounds.

Synthetic routes to α,β-unsaturated carboxylic esters have attracted considerable attention recently because of their importance as useful synthetic intermediates and the increase in the number of naturally occurring substances such as insect pheromones and pigments.[1,2] Ethoxycarbonylmethylenetriphenylphosphorane, an efficient reagent for the direct synthesis of α,β-unsaturated esters from carbonyl compounds, was introduced by Wittig and Haag in 1955.[3] Since then considerable efforts have been made to utilize the reagent.[2] Wadswarth and Emmons found that sodium enolate of diethyl ethoxycarbonylmethylphosphonate reacted with carbonyl compounds to give α,β-unsaturated esters in good yields.[4] Hartzell *et al.*[5] and Shimoji *et al.*[6] found a new method for the conversion of aldehydes or ketones into α,β-unsaturated esters utilizing lithium enolate of (trimethylsilyl)acetate.

We wish to report a novel and general method for the one-pot synthesis of α,β-unsaturated carboxylic esters using sulfur-stabilized carbanions and dianions.[7]

Results and Discussion

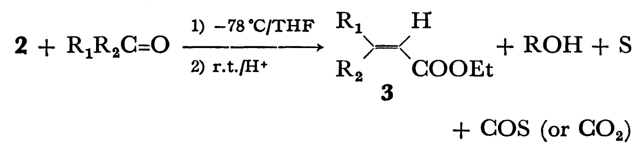
Lithium Enolates of Dithiocarbonates and Monothiocarbonates. A yellow solution of the carbanion **2a** is obtained by treatment of *O*-ethyl *S*-ethoxycarbonylmethyl dithiocarbonate (**1a**) with LDA at −78 °C in THF. It is stable at this temperature for several hours.



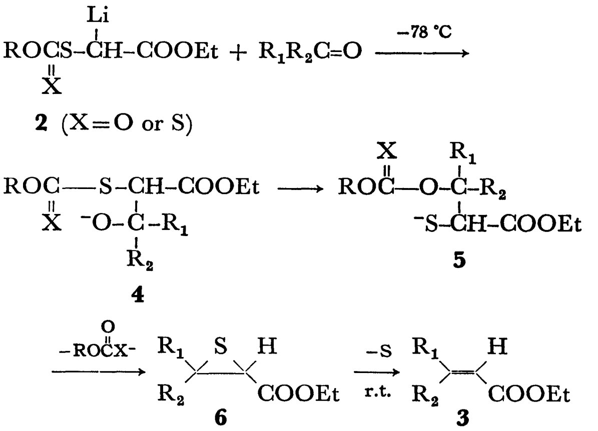
$$\underset{\underset{\textstyle X}{\|}}{\text{ROC}}\text{SCH}_2\text{COOEt} \xrightarrow[-78\,^\circ\text{C/THF}]{1.1 \text{ equiv LDA}} \underset{\underset{\textstyle X}{\|}}{\text{ROC}}\text{S-}\overset{\text{Li}}{\text{CH}}\text{-COOEt}$$

1a: R=Et; X=S	**2a**: R=Et; X=S
1b: R=Et; X=O	**2b**: R=Et; X=O
1c: R=*i*-Pr; X=S	**2c**: R=*i*-Pr; X=S

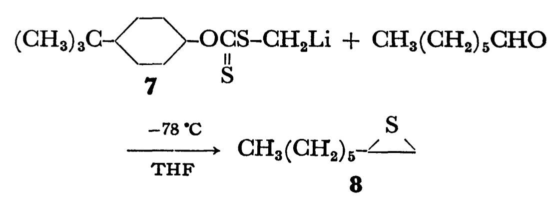
When the lithium enolate (**2a**) was allowed to react with a variety of carbonyl compounds, α,β-unsaturated esters (**3**) were obtained in good yields (Table 1). Since the starting materials are readily prepared from inexpensive commercial reagents, the sequence constitutes a useful one-pot synthesis of **3** from carbonyl compounds.



The structure of **3** was confirmed by its elemental analysis and spectral (IR, NMR) properties (see Experimental). No isomerized β,γ-unsaturated esters were detected by NMR analysis. The *E*/*Z* ratio of **3** was determined by GLC and NMR analysis; *e.g.*, the ratio of *E*-isomer to *Z*-isomer of ethyl 3-phenyl-2-butenoate (**3e**) determined by integration of the olefinic proton at δ 6.04 and δ 5.78, respectively, is 42:58. Analysis of this material by GLC indicates a 43:57 mixture of *E*-**3e** and *Z*-**3e**. The mechanism of this reaction consists of the intramolecular cyclization to thiirane **6** as an intermediate, followed by spontaneous extrusion of sulfur to **3** (Scheme 1). Actually, an intermediate such as **6** could be isolated. Thus, treatment of lithium salt of *O*-*trans*-(4-*t*-butylcyclohexyl) *S*-methyl dithiocarbonate (**7**) with heptanal as described before gave 2-hexylthiirane (**8**) in 71% yield.[8]



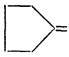
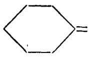
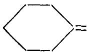
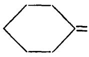
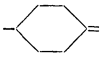
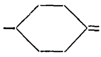
Scheme 1.



Thiiranes containing strongly electron-attracting substituents such as alkoxycarbonyl or cyano groups readily extrude sulfur to afford olefins.[9]

When α-alkyl-substituted dithiocarbonates **1d** and **1e**

TABLE 1. SYNTHESIS OF α,β-UNSATURATED ESTERS (**3**) FROM CARBONYL COMPOUNDS AND CARBONATES (**1a**—**1c**)

Carbonate (**1**)[a] R	X	Carbonyl compound	Solvent	Product[b] (**3**)	Yield %	E/Z[c] ratio
Et	S (**1a**)	Propanal	THF	$EtCH{=}CHCOOEt$(**3a**)	52	*E* only
Et	S (**1a**)	Acetone	THF	$Me_2C{=}CHCOOEt$(**3b**)	85	
Et	S (**1a**)	2-Butanone	THF	Me(Et)C=CHCOOEt(**3c**)	74	39/61
Et	O (**1b**)	2-Butanone	THF	Me(Et)C=CHCOOEt(**3c**)	71	47/53
i-Pr	S (**1c**)	2-Butanone	THF	Me(Et)C=CHCOOEt(**3c**)	67	
Et	S (**1a**)	3-Pentanone	THF	Et(Et)C=CHCOOEt(**3d**)	69	
Et	S (**1a**)	Acetophenone	THF-HMPA (8: 1 v/v)	Ph(Me)C=CHCOOEt(**3e**)	76	43/57
Et	S (**1a**)	Cyclopentanone	THF	=CHCOOEt(**3f**)	88	
Et	S (**1a**)	Cyclohexanone	THF	=CHCOOEt(**3g**)	78	
Et	O (**1b**)	Cyclohexanone	THF	=CHCOOEt(**3g**)	61	
i-Pr	S (**1c**)	Cyclohexanone	THF	=CHCOOEt(**3g**)	81	
Et	S (**1a**)	4-Methylcyclohexanone	THF	=CHCOOEt(**3h**)	69	
Et	S (**1a**)	4-Methylcyclohexanone	THF-HMPA (8: 1 v/v)	=CHCOOEt(**3h**)	87	

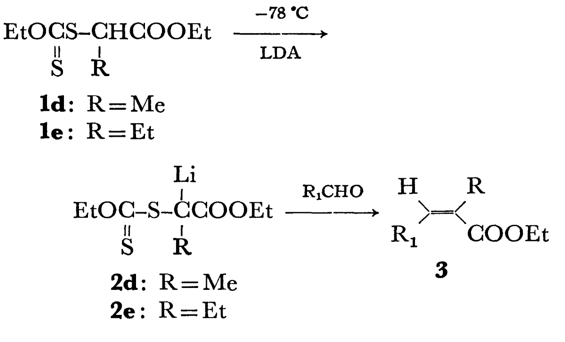
a) All reactions carried out at −78 °C on a 20 mmol scale using LDA as a base. b) Isolated yields. c) Determined by ^{1}H-NMR and GLC.

TABLE 2. SYNTHESIS OF α,β-UNSATURATED ESTERS (**3**) FROM CARBONYL COMPOUNDS AND DITHIOCARBONATES (**1d**—**1e**)

Dithiocarbonate (**1**)[a] R	Carbonyl compound	Solvent	Product[b] (**3**)	Yield %	E/Z[c] ratio
Me (**1d**)	Benzaldehyde	THF	PhCH=(Me)COOEt (**3i**)	82	21/79
Et (**1e**)	Benzaldehyde	THF	PhCH=(Et)COOEt (**3j**)	82	37/63
Me (**1d**)	2-Methylpropanal	THF	*i*-PrCH=C(Me)COOEt (**3k**)	78	59/41
Me (**1d**)	2-Methylpropanal	THF-HMPA (8: 1 v/v)	*i*-PrCH=C(Me)COOEt (**3k**)	84	11/89
Et (**1e**)	2-Methylpropanal	THF	*i*-PrCH=C(Et)COOEt (**3l**)	82	42/58
Et (**1e**)	2-Methylpropanal	THF-HMPA (8: 1 v/v)	*i*-PrCH=C(Et)COOEt (**3l**)	91	46/54

a) All reactions carried out at −78 °C using LDA as a base on a 20 mmol scale. b) Isolated yields. c) Determined by ^{1}H-NMR and GLC.

were allowed to react with LDA at −78 °C in THF, lithium enolates **2d** and **2e** were readily formed. These reagents also react with various aldehydes to produce **3** (Table 2).



$$\underset{\overset{\|}{S}}{EtOC}S\text{-}\underset{\overset{|}{R}}{C}HCOOEt \xrightarrow[LDA]{-78\,^\circ C}$$

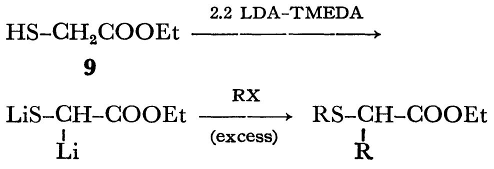
1d: R=Me
1e: R=Et

$$\underset{\overset{\|}{S}}{EtOC}\text{-}S\text{-}\underset{\overset{|}{R}}{\overset{\overset{Li}{|}}{C}}COOEt \xrightarrow{R_1CHO} \mathbf{3}$$

2d: R=Me
2e: R=Et

The enolates **2d** and **2e** do not react with ketones, presumably due to steric hindrance or enolization of ketones.

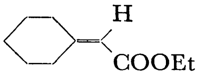
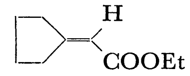
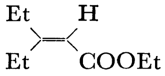
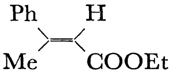
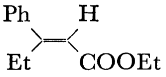
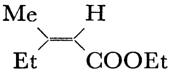
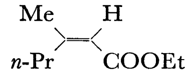
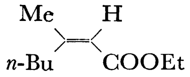
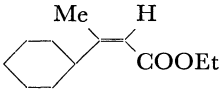
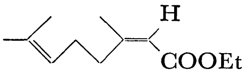
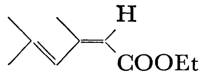
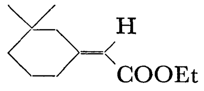
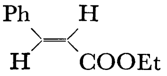
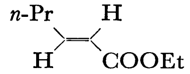
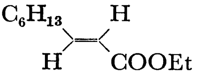
Formation of Dianions and Their Synthetic Applications. We have found that the hitherto unknown dianion **10** derived from ethyl mercaptoacetate (**9**) can be generated, undergoing regioselective alkylation depending on electrophiles used. Treatment of **9** with 2.2 equiv of LDA in the presence of 2.2 equiv of TMEDA in THF at −78 °C gave soluble dianion **10**, stable at −78 °C for at least several hours. When a solution of **10** in THF was treated with an excess of alkylating agent, a facile reaction occurred both at carbon and at sulfur.



$$\underset{\mathbf{9}}{HS\text{-}CH_2COOEt} \xrightarrow{2.2\ LDA\text{-}TMEDA} \underset{\mathbf{10}}{LiS\text{-}\underset{\overset{|}{Li}}{C}H\text{-}COOEt} \xrightarrow[(excess)]{RX} RS\text{-}\underset{\overset{|}{R}}{C}H\text{-}COOEt$$

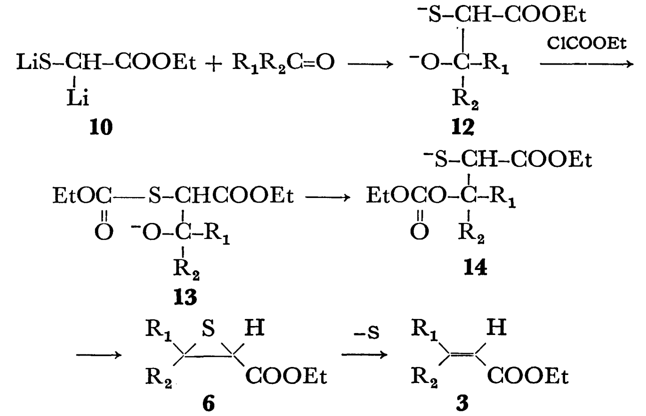
RX=MeI; 86%(**11a**)
RX=EtI; 66%(**11b**)
RX=$CH_2{=}CHCH_2Br$; 64%(**11c**)

TABLE 3. SYNTHESIS OF α,β-UNSATURATED ESTERS (**3**) FROM CARBONYL COMPOUNDS AND DIANION (**10**)

Carbonyl compound	Product[a] (**3**)	Yield[b] %	E/Z[c] ratio
Cyclohexanone	 (**3g**)	60	
Cyclopentanone	 (**3f**)	74	
3-Pentanone	 (**3d**)	61	
Acetophenone	 (**3e**)	58	97/3
Propiophenone	 (**3m**)	51	100/0
2-Butanone	 (**3c**)	64	43/57
2-Pentanone	 (**3n**)	62	45/55
2-Hexanone	 (**3o**)	67	38/62
Methylcyclohexyl ketone	 (**3p**)	53	41/59
6-Methyl-5-hepten-2-one	 (**3q**)	70	38/62
4-Methyl-3-penten-2-one	 (**3r**)	64	66/34
3,3-Dimethylcyclohexanone	 (**3s**)	32[d]	44/56
Benzaldehyde	 (**3t**)	57	100/0
Butanal	 (**3u**)	34	100/0
Heptanal	 (**3v**)	19	95/5

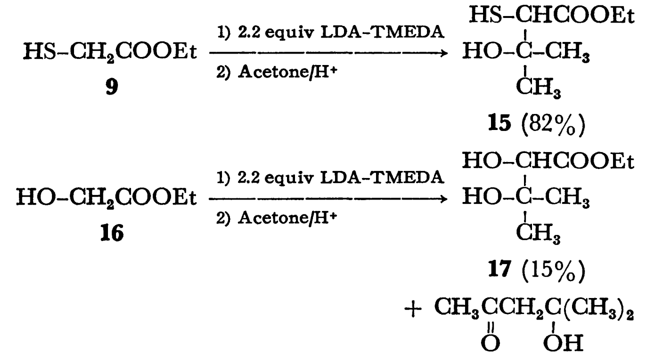
a) All reactions carried out at −78 °C on a 20 mmol scale. b) Isolated yields. c) Determined by ^{1}H-NMR and GLC. d) A mixture of THF and HMPA (8: 1 v/v) was used as a solvent.

Dianion **10** undergoes aldol-type reaction with carbonyl compounds. Thus, reaction of **10** with a variety of carbonyl compounds gave the adduct **12**, which, upon treatment with ethyl chloroformate at −78 °C, afforded **3** as the sole product in good yields after the usual work-up. Generality of this new methodology is apparent from the results summarized in Table 3. The use of ethyl chloroformate is important since no α,β-unsaturated esters can be isolated from the reaction of **10** and carbonyl compounds with *diethyl carbonate*. The low yields of monosubstituted propenoates, *i.e.*, **3u** and **3v**, are ascribed to the polymerization at the stage of thiirane formation.[10] The initial step of this reaction might be the formation of adduct **12** as shown in Scheme 2.



Scheme 2.

The adduct **12** should react with ethyl chloroformate to afford *S*-ethoxycarbonylated intermediate **13**, since a thiolate anion is a more powerful nucleophile than an alcoholate anion. Another intermediate such as **12** could be trapped when the reaction mixture of **10** and acetone was quenched with aqueous NH_4Cl solution at −78 °C.



$$\underset{\textbf{9}}{HS\text{-}CH_2COOEt} \xrightarrow[\text{2) Acetone/H}^+]{\text{1) 2.2 equiv LDA-TMEDA}} \underset{CH_3}{\overset{HS\text{-}CHCOOEt}{HO\text{-}C\text{-}CH_3}}$$

15 (82%)

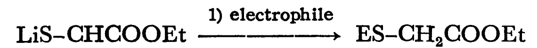
$$\underset{\textbf{16}}{HO\text{-}CH_2COOEt} \xrightarrow[\text{2) Acetone/H}^+]{\text{1) 2.2 equiv LDA-TMEDA}} \underset{CH_3}{\overset{HO\text{-}CHCOOEt}{HO\text{-}C\text{-}CH_3}}$$

17 (15%)

$$+\ CH_3\underset{O}{\overset{}{C}}CH_2\underset{OH}{C}(CH_3)_2$$

18

In contrast, no such selective reaction of **10** was observed for oxygen analogue. The reaction of ethyl glycolate (**16**) with a base gives the addition product only in 15% yield along with the condensation product of acetone and some other unidentified products. The intermediacy of **13** in Scheme 2 is in line with the fact that lithium enolate of dithiocarbonate **2b** gives **4** (=**13**) on treatment with carbonyl compound. The regioselectivity of **10** depends upon the electrophiles used. Thus, the reaction of **10** with 1 equiv of alkyl halides afforded *S*-alkylated products in good yields, whereas **10** reacted with carbonyl compounds on α-carbon of dianion as described before.



$$\underset{Li}{LiS\text{-}CHCOOEt} \xrightarrow[\text{2) H}^+]{\text{1) electrophile}} ES\text{-}CH_2COOEt$$

19

10

Electrophile	E	Yield of **19**
MeI	Me	89% (**19a**)
EtBr	Et	81% (**19b**)
Propylene oxide	$MeCHCH_2$– OH	49% (**19c**)

In order to clarify the mechanism, we have investigated the effects of reaction time, temperature, and solvents in the case of 6-methyl-5-hepten-2-one. The results (Tables 4, 5, and 6) indicate that the reaction of dianion **10** is kinetically controlled process since there is no obvious effect on the *E*/*Z* ratio of **3q**. Dianion is highly reactive toward carbonyl compounds since even the α-methylsubstituted dianion **21** reacts with various ketones (Table 7), in contrast to monoanion **2d**.

Table 4. Effect of reaction time on the *E*/*Z* ratio of **3q**

Reaction time/h	Yield of **3q** %	*E*/*Z* ratio of **3q**
0.5	61	43/57
2.0	70	38/52
16.0	65	42/58

All reactions carried out at −78 °C in THF.

Table 5. Effect of solvent on the *E*/*Z* ratio of **3q**

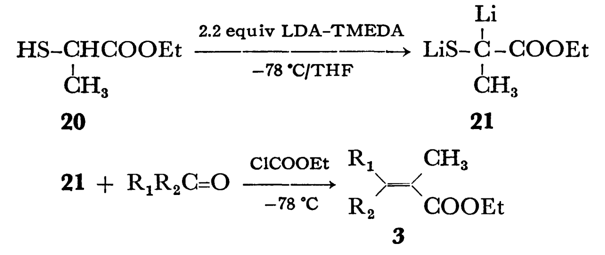
Solvent	Yield of **3q** %	*E*/*Z* ratio of **3q**
THF[a]	70	38/62
DME[b]	62	45/55
Diethyl ether[a]	62	51/49
Hexane[a]	55	51/49

a) At −78 °C. b) At −65 °C.

Table 6. Effect of reaction temperature on the *E*/*Z* ratio of **3q**

Reaction temp/°C[a]	Yield of **3q** %	*E*/*Z* ratio of **3q**
−78	70	38/62
−100	64	40/60

a) Reaction carried out in THF.

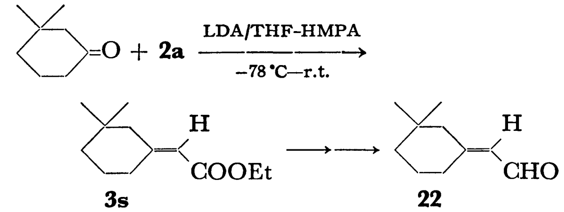


$$\underset{CH_3}{HS\text{-}CHCOOEt} \xrightarrow[-78\,^\circ C/THF]{\text{2.2 equiv LDA-TMEDA}} \underset{CH_3}{\overset{Li}{LiS\text{-}C\text{-}COOEt}}$$

20 **21**

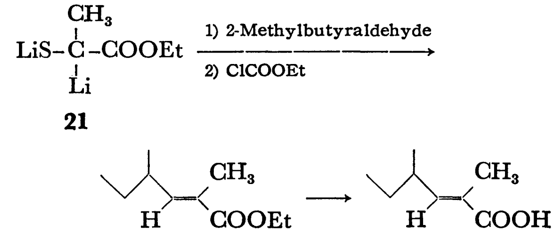
3

The methodology employed here is particularly useful synthetically since the conversion of ketones into trisubstituted propenoates is difficult.[11] In order to demonstrate the utility of our novel reactions, we have carried out the synthesis of the key intermediates for insect pheromones such as boll weevil sex pheromone (**22**), and a component of ant mandibular gland secretions (**23**).



3s **22**

Treatment of 3,3-dimethylcyclohexanone with **2a** at −78 °C gave the key intermediate for sex pheromones in 84% yield. Separation of *Z*-**3s** and *E*-**3s**, and conversion into the target pheromones have been established.[12] Utilizing the dianion **21**, α,β-unsaturated ester **3B** was isolated in 67% yield. The *E*- and *Z*-isomers of **3B** were separated by GLC in 98% and 95%

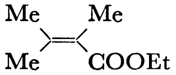
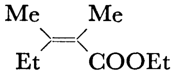
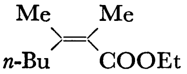
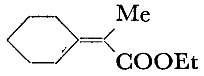
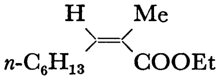
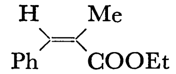


21

3B **23**

E/*Z*=55/45

Table 7. Synthesis of α,β-unsaturated esters (**3**) from carbonyl compounds and dianion (**21**)

Carbonyl compound	Product[a] (**3**)	Yield[b] / %	E/Z[c] ratio
Acetone	 (**3w**)	57	
2-Butanone	 (**3x**)	59	23/77
2-Hexanone	 (**3y**)	51	24/76
Cyclohexanone	 (**3z**)	43	
Heptanal	 (**3A**)	55	58/42
Benzaldehyde	 (**3i**)	45	53/47

a) All reactions carried out at −78 °C on a 20 mmol scale. b) Isolated yields. c) E/Z ratio determined by ^{1}H-NMR and GLC.

purity, respectively, exhibiting NMR and IR spectra identical to the reported data.[13] Hydrolysis of E-**3B** to the desired ant mandibular gland secretion has been reported.[13]

Experimental

General. Infrared spectra were determined on a Hitachi Model-215 spectrophotometer. Nuclear magnetic resonance spectra were determined on a JEOLCO PS-100 spectrometer. Chemical shifts are given in δ units, parts per million relative to tetramethylsilane as an internal standard. Gas chromatograms were obtained using a Varian Aerograph Model 920 instrument with a 0.15 cm × 120 cm glass column (20% Silicone DC-550 on Celite 545). Tetrahydrofuran (THF) was dried by distillation calcium hydride and by subsequent distillation from lithium aluminum hydride. Hexamethylphosphoric triamide (HMPA), diisopropylamine, and N,N,N',N'-tetramethylethylenediamine (TMEDA) were distilled from calcium hydride and stored over molecular sieves. All reactions were performed under a nitrogen atmosphere.

General Procedure. *Reaction of Carbanion **2a** with Carbonyl Compounds*: A solution of 20 mmol of **1a** in 3 ml of THF was added to a stirred solution of 22 mmol of LDA in 40 ml of THF at −78 °C. After the yellow solution had been stirred at −78 °C for 30 min, 24 mmol of carbonyl compound in 2 ml of THF was added over a 5 min period. Stirring was continued at −78 °C for 1 h and at room temperature for 1 h before it was quenched with aqueous NH_4Cl (10 ml). The mixture was poured into dilute HCl and extracted four times with ether, the combined organic layer being washed twice with brine, dried (anhydrous Na_2SO_4), and concentrated under reduced pressure. Distillation gave α,β-unsaturated esters (**3**).

*Reaction of Dianion **10** with Carbonyl Compounds.* To a mixture of LDA (44 mmol) and TMEDA (44 mmol) in 40 ml of THF was added a solution of 2.4 g (20 mmol) of ethyl mercaptoacetate (**9**) in 7 ml of THF at −78 °C. After being stirred for 1 h, a solution of 22 mmol of carbonyl compounds in 5 ml of THF was added and the reaction mixture was stirred at −78 °C for 2 h. Ethyl chloroformate (20 mmol) in 5 ml of THF was then added portionwise to the above solution with stirring and the mixture was kept at −78 °C for 30 min and at room temperature for 1 h before it was quenched with aqueous NH_4Cl (10 ml). The reaction mixture was poured into dilute HCl and extracted four times with ether, the combined organic layer being washed twice with brine, dried (anhydrous Na_2SO_4), and concentrated under reduced pressure. Distillation of the resulting oil gave **3**. The following α,β-unsaturated esters were prepared in a similar manner.

Physical Properties. *Ethyl 2-Pentenoate (**3a**)*: Bp 86—87 °C/70 Torr. ^{1}H-NMR (CCl_4); δ 6.86 (m, 1H, CH=C), 5.68 (m, 1H, CH=C), 4.08 (q, J=7 Hz, 3H, CH_2), 2.22 (m 2H, CH_2), 1.24 (t, J=7 Hz, 3H, CH_3), 1.10 (t, J=7 Hz, 3H, CH_3). IR (neat); 1650 cm^{-1} (C=C).

*Ethyl 3-Methyl-2-butenoate (**3b**)*: Bp 90—92 °C/100 Torr. ^{1}H-NMR (CCl_4); δ 5.52 (m, 1H, CH=C), 4.00 (q, J=7 Hz, 2H, CH_2), 2.08 (s, 1H, CH_3), 1.78 (s, 1H, CH_3), 1.16 (t, J=7 Hz, 3H, CH_3). IR (neat); 1675 cm^{-1} (C=C). Spectral data were identical with those of an authentic sample prepared from 3-methyl-2-butenoic acid and ethyl bromide in the presence of DBU in benzene.[14]

*Ethyl 3-Methyl-2-pentenoate (**3c**)*: Bp 93—97 °C/60 Torr. ^{1}H-NMR (CCl_4); δ 5.50 (m, CH=C), 4.04 (q, J=7 Hz, 2H, CH_2), 2.60 (q, J=8 Hz, CH_2 for Z-isomer), 2.14 (q, J=8 Hz, CH_2 for E-isomer), 2.06 (m, CH_3 for E-isomer), 1.84 (m, CH_3 for Z-isomer), 1.24 (t, J=7 Hz, 3H, CH_3), 1.04 (t, J=8 Hz, 3H, CH_3). IR (neat); 1640 cm^{-1} (C=C). Found: C, 67.40; H, 10.15%. Calcd for $C_8H_{14}O_2$: C, 67.57; H, 9.92%.

*Ethyl 3-Ethyl-2-pentenoate (**3d**)*: Bp 84 °C/22 Torr. ^{1}H-NMR (CCl_4); δ 5.58 (bs, 1H, CH=C), 4.03 (q, J=7 Hz, 2H, CH_2), 2.56 (q, J=8 Hz, 2H, CH_2), 2.14 (q, J=8 Hz, 2H, CH_2), 0.9—1.3 (m, 9H, $3CH_3$). IR (neat); 1640 cm^{-1} (C=C). Found: C, 68.91; H, 10.50%. Calcd for $C_9H_{16}O_2$: C, 69.20; H, 10.32%.

*Ethyl 3-Phenyl-2-butenoate (**3e**)*: Bp 132 °C/12 Torr. ^{1}H-NMR (CCl_4); δ 7.24 (m, 5H, aromatic), 6.04 (m, CH=C for E-isomer), 5.78 (m, CH=C for Z-isomer), 4.10 (q, J=7 Hz, CH_2 for E-isomer), 3.88 (q, J=7 Hz, CH_2 for Z-isomer), 2.50 (brs, CH_3 for E-isomer), 2.05 (brs, CH_3 for Z-isomer), 1.24 (brs, CH_3 for E-isomer), 1.00 (brs, CH_3 for Z-isomer). IR (neat); 1625 cm^{-1} (C=C). Found: C, 75.76; H, 7.42%. Calcd for $C_{12}H_{14}O_2$: C, 75.76; H, 7.52%.

Ethyl Cyclopentylideneacetate (3f): Bp 93—96 °C/20 Torr. ^{1}H-NMR (CCl$_4$); δ 5.70 (m, 1H, CH=C), 4.04 (q, *J*=7 Hz, 2H, CH$_2$), 2.74 (m, 2H, CH$_2$), 2.40 (m, 2H, CH$_2$), 1.68 (m, 4H, 2CH$_2$), 1.24 (t, *J*=7 Hz, 3H, CH$_3$). IR (neat); 1645 cm^{-1} (C=C). Found: C, 70.33; H, 9.23%. Calcd for $C_9H_{14}O_2$: C, 70.10; H, 9.15%.

Ethyl Cyclohexylideneacetate (3g): Bp 110—112 °C/20 Torr. ^{1}H-NMR (CCl$_4$); δ 5.50 (brs, 1H, CH=C), 4.05 (q, *J*=7 Hz, 2H, CH$_2$), 2.84 (m, 2H, CH$_2$), 1.62 (m, 6H, 3CH$_2$), 1.24 (t, *J*=7 Hz, 3H, CH$_3$). IR (neat); 1620 cm^{-1} (C=C). Found: C, 71.61; H, 9.44%. Calcd for $C_{10}H_{16}O_2$: C, 71.39; H, 9.59%.

Ethyl 4-Methylcyclohexylideneacetate (3h): Bp 123—125 °C/23 Torr. ^{1}H-NMR (CCl$_4$); δ 5.54 (brs, 1H, CH=C), 4.05 (q, *J*=7 Hz, 2H, CH$_2$), 3.80 (m, 1H, CH), 0.8—2.4 (m, 8H, 4CH$_2$), 1.25 (t, *J*=7 Hz, 3H, CH$_3$), 0.94 (d, *J*=6 Hz, 3H, CH$_3$). IR (neat); 1645 cm^{-1} (C=C). Found: C, 72.76; H, 10.13%. Calcd for $C_{11}H_{18}O_2$: C, 72.49; H, 9.95%.

Ethyl 2-Methyl-3-phenyl-2-propenoate (3i): Bp 115—117 °C/12 Torr. ^{1}H-NMR (CCl$_4$); δ 7.62 (brs, CH=C for *E*-isomer), 7.26 (m, 5H, aromatic), 6.60 (brs, CH=C for *Z*-isomer), 4.18 (q, *J*=7 Hz, CH$_2$ for *E*-isomer), 4.00 (q, *J*=7 Hz, CH$_2$ for *Z*-isomer), 2.04 (s, 3H, CH$_3$), 1.28 (t, *J*=7 Hz, CH$_3$ for *E*-isomer), 1.02 (t, *J*=7 Hz, CH$_3$ for *Z*-isomer). IR (neat); 1635 cm^{-1} (C=C). Found: C, 75.95; H, 7.54%. Calcd for $C_{12}H_{14}O_2$: C, 75.76; H, 7.42%.

Ethyl 2-Ethyl-3-phenyl-2-propenoate (3j): Bp 135—137 °C/11 Torr. ^{1}H-NMR (CCl$_4$); δ 7.52 (s, CH=C for *E*-isomer), 7.15 (m, 5H, aromatic), 6.48 (brs, CH=C for *Z*-isomer), 4.16 (q, *J*=7 Hz, CH$_2$ for *E*-isomer), 4.00 (q, *J*=7 Hz, CH$_2$ for *Z*-isomer), 2.40 (m, 2H, CH$_2$), 1.10 (m, 6H, 2CH$_3$). IR (neat); 1640 cm^{-1} (C=C). Found: C, 76.28; H, 7.90%. Calcd for $C_{13}H_{16}O_2$: C, 76.44; H, 7.90%.

Ethyl 2,4-Dimethyl-2-pentenoate (3k):[15] Bp 90—97 °C/55 Torr. ^{1}H-NMR (CCl$_4$); δ 6.45 (dq, CH=C for *E*-isomer), 5.60 (dq, CH=C for *Z*-isomer), 4.10 (m, 2H, CH$_2$), 3.24 (m, CH for *Z*-isomer), 2.60 (m, CH for *E*-isomer), 1.80 (m, 3H, CH$_3$), 1.28 (t, *J*=7 Hz, 3H, CH$_3$), 1.00 (t, *J*=7 Hz, 6H, 2CH$_3$).

Ethyl 2-Ethyl-4-methyl-2-pentenoate (3l): Bp 94—100 °C/63 Torr. ^{1}H-NMR (CCl$_4$); δ 6.44 (m, CH=C for *E*-isomer), 5.54 (m, CH=C for *Z*-isomer), 4.14 (m, 2H, CH$_2$), 3.12 (m, CH for *Z*-isomer), 2.64 (m, CH for *E*-isomer), 2.24 (m, 2H, CH$_2$), 1.28 (t, *J*=7 Hz, 3H, CH$_3$), 1.00 (m, 9H, 3CH$_3$). IR (neat); 1620 cm^{-1} (C=C). Found: C, 70.51; H, 10.58%. Calcd for $C_{10}H_{18}O_2$: C, 70.55; H, 10.65%.

Ethyl 3-Phenyl-2-pentenoate (3m): Bp 98 °C/1.5 Torr. ^{1}H-NMR (CCl$_4$); δ 7.2—7.5 (m, 5H, aromatic), 5.96 (s, 1H, CH=C), 4.15 (q, *J*=7 Hz, 2H, CH$_2$), 3.11 (q, *J*=7 Hz, 2H, CH$_2$), 1.30 (t, *J*=7 Hz, 3H, CH$_3$), 1.08 (t, *J*=7 Hz, 3H, CH$_2$). IR (neat); 1620 cm^{-1} (C=C).

Ethyl 3-Methyl-2-hexenoate (3n): Bp 75—76 °C/17 Torr. ^{1}H-NMR (CCl$_4$); δ 5.61 (brs, 1H, CH=C), 4.09 (q, *J*=7 Hz, 2H, CH$_2$), 1.88—2.62 (m, 5H, CH$_2$ and CH$_3$), 1.3—1.7 (m, 2H, CH$_2$), 1.25 (t, *J*=7 Hz, 3H, CH$_3$), 0.96 (m, 3H, CH$_3$). IR (neat); 1640 cm^{-1} (C=C). Found: C, 69.04; H, 10.32%. Calcd for $C_9H_{16}O_2$: C, 69.20; H, 10.32%.

Ethyl 3-Methyl-2-heptenoate (3o): Bp 97—98 °C/13 Torr. ^{1}H-NMR (CCl$_4$); δ 5.40 (brs, 1H, CH=C), 3.95 (q, *J*=7 Hz, 2H, CH$_2$), 1.03—2.32 (m, 5H, CH$_2$ and CH$_3$), 1.2—1.6 (m, 4H, 2CH$_2$), 1.22 (t, *J*=7 Hz, 3H, CH$_3$), 0.92 (m, 3H, CH$_3$). IR (neat); 1640 cm^{-1} (C=C). Found: C, 70.66; H, 10.68%. Calcd for $C_{10}H_{18}O_2$: C, 70.54; H, 10.66%.

Ethyl 3-Cyclohexyl-2-butenoate (3p): Bp 121—123 °C/18 Torr. ^{1}H-NMR (CCl$_4$); δ 5.54 (m, 1H, CH=C), 4.06 (q, *J*=7 Hz, 2H, CH$_2$), 3.4—3.7 (m, 1H, CH), 1.0—2.1 (m, 13H, CH$_2$ and CH$_3$), 1.24 (t, *J*=7 Hz, 3H, CH$_3$). IR (neat); 1640 cm^{-1} (C=C).

Ethyl 3,7-Dimethyl-2,6-octadienoate (3q): Bp 75—80 °C/2.3 Torr. ^{1}H-NMR (CCl$_4$); δ 5.52 (m, 1H, CH=C), 4.9—5.2 (m, 1H, CH=C), 4.03 (q, *J*=7 Hz, 2H, CH$_2$), 1.86—2.58 (m, 7H, 2CH$_2$ and CH$_3$), 1.68 (s, 3H, CH$_3$), 1.61 (s, 3H, CH$_3$), 1.24 (t, *J*=7 Hz, 3H, CH$_3$). IR (neat); 1640 cm^{-1} (C=C). Found: C, 73.43; H, 10.11%. Calcd for $C_{12}H_{20}O_2$: C, 73.43; H, 10.27%.

Ethyl 3,5-Dimethyl-2,4-hexadienoate (3r): Bp 90 °C/23 Torr. *E*-isomer: ^{1}H-NMR (CCl$_4$); δ 5.64 (m, 1H, CH=C), 5.52 (m, 1H, CH=C), 4.07 (q, *J*=7 Hz, 2H, CH$_2$), 2.19 (s, 3H, CH$_3$), 1.83 (m, 6H, 2CH$_3$), 1.25 (t, *J*=7 Hz, 3H, CH$_3$). IR (neat); 1625 cm^{-1} (C=C). *Z*-isomer: ^{1}H-NMR (CCl$_4$); δ 6.42 (brs, 1H, CH=C), 5.52 (brs, 1H, CH=C), 4.02 (q, *J*=7 Hz, 2H, CH$_2$), 2.00 (s, 3H, CH$_3$), 1.85 (s, 3H, CH$_3$), 1.73 (s, 3H, CH$_3$), 1.22 (t, *J*=7 Hz, 3H, CH$_3$). IR (neat); 1630 cm^{-1} (C=C).

Ethyl 3,3-Dimethylcyclohexylideneacetate (3s): A solution of LDA (22 mmol) in a mixture of 40 ml of THF and 5 ml of HMPA was stirred under nitrogen at −78 °C and 20 mmol of *O*-ethyl *S*-ethoxycarbonylmethyl dithiocarbonate (**1a**) in 3 ml of THF was added dropwise. After the yellow solution had been stirred for 30 min, 2.78 g (20 mmol) of 3,3-dimethylcyclohexanone in 2 ml of THF was added over a 5 min period. The mixture was stirred at −78 °C for 1 h and at room temperature for 1 h. The usual work-up and distillation gave **3s** in 84% yield. Bp 113 °C/23 Torr. ^{1}H-NMR (CCl$_4$); δ 5.52 (m, 1H, CH=C), 4.06 (q, *J*=7 Hz, 2H, CH$_2$), 1.2—2.8 (m, 8H, 4CH$_2$), 1.24 (t, *J*=7 Hz, 3H, CH$_3$), 0.92 (m, 6H, 2CH$_3$). MS (20 eV) *m/e* 196 (M$^+$). IR (neat); 1645 cm^{-1} (C=C).

Ethyl (E)-3-Phenyl-2-propenoate (3t): Bp 86 °C/0.7 Torr. ^{1}H-NMR (CCl$_4$); δ 7.64 (d, *J*=16 Hz, 1H, CH=C), 7.2—7.6 (m, 5H, aromatic), 6.36 (d, *J*=16 Hz, 1H, CH=C), 4.20 (q, *J*=7 Hz, 2H, CH$_2$), 1.32 (t, *J*=7 Hz, 3H, CH$_3$). IR (neat); 1630 cm^{-1} (C=C). Found: C, 74.86; H, 7.03%. Calcd for $C_{11}H_{12}O_2$: C, 74.98; H, 6.86%.

Ethyl (E)-2-Hexenoate (3u): Bp 61 °C/17 Torr. ^{1}H-NMR (CCl$_4$); δ 6.80 (dt, *J*=7 Hz, 16 Hz, 1H, CH=C), 5.72 (d, *J*=16 Hz, 1H, CH=C), 4.11 (q, *J*=7 Hz, 2H, CH$_2$), 2.20 (m, 2H, CH$_2$), 1.4—1.8 (m, 2H, CH$_2$), 1.28 (t, *J*=7 Hz, 3H, CH$_3$), 0.98 (t, *J*=7 Hz, CH$_3$). IR (neat); 1650 cm^{-1} (C=C).

Ethyl 2-Nonenoate (3v): Bp 50 °C/1 Torr. ^{1}H-NMR (CCl$_4$); δ 6.88 (dt, *J*=7 Hz, 16 Hz, CH=C), 5.72 (d, *J*=16 Hz, 1H, CH=C), 4.12 (q, *J*=7 Hz, 2H, CH$_2$), 2.0—2.2 (m, 2H, CH$_2$), 1.1—1.8 (m, 8H, 4CH$_2$), 0.9 (m, 3H, CH$_3$). IR (neat); 1645 cm^{-1} (C=C).

Ethyl 2,3-Dimethyl-2-butenoate (3w): Bp 105—106 °C/100 Torr. ^{1}H-NMR (CCl$_4$); δ 4.10 (q, *J*=7 Hz, 2H, CH$_2$), 1.8—2.0 (m, 9H, 3CH$_3$), 1.28 (t, *J*=7 Hz, 3H, CH$_3$). IR (neat); 1635 cm^{-1} (C=C).

Ethyl 2,3-Dimethyl-2-pentenoate (3x): Bp 67—72 °C/14 Torr. ^{1}H-NMR (CCl$_4$); δ 4.15 (q, *J*=7 Hz, 2H, CH$_2$), 2.28 (m, 2H, CH$_2$), 1.93 (m, 6H, 2CH$_3$), 1.28 (t, *J*=7 Hz, 3H, CH$_3$), 1.04 (t, *J*=7 Hz, 3H, CH$_3$). IR (neat); 1630 cm^{-1} (C=C).

Ethyl 2,3-Dimethyl-2-heptenoate (3y): Bp 90—94 °C/13 Torr. *E*-isomer: ^{1}H-NMR (CCl$_4$); δ 4.02 (q, *J*=7 Hz, 2H, CH$_2$), 2.09 (m, 2H, CH$_2$), 1.93 (m, 3H, CH$_3$), 1.80 (m, 3H, CH$_3$), 1.2—1.6 (m, 4H, 2CH$_2$), 1.26 (t, *J*=7 Hz, 3H, CH$_3$), 0.93 (m, 3H, CH$_3$). IR (neat); 1630 cm^{-1} (C=C). *Z*-isomer: ^{1}H-NMR (CCl$_4$); δ 4.03 (q, *J*=7 Hz, 2H, CH$_2$), 2.30 (m, 2H, CH$_2$), 1.74 (m, 6H, 2CH$_3$), 1.2—1.6 (m, 4H, 2CH$_2$), 1.25 (t, *J*=7 Hz, 3H, CH$_3$), 0.91 (m, 3H, CH$_3$). IR (neat); 1630 cm^{-1} (C=C). Found: C, 71.72; H, 11.00%. Calcd for $C_{11}H_{20}O_2$: C, 71.70; H, 10.94%.

Ethyl 2-Cyclohexylidenepropionate (3z): Bp 104—107 °C/10 Torr. ^{1}H-NMR (CCl_4); δ 4.10 (q, 2H, CH_2), 2.0—2.6 (m, 4H, $2CH_2$), 1.80 (s, 3H, CH_3), 1.58 (m, 6H, $3CH_2$), 1.26 (t, J=7 Hz, 3H, CH_3). IR (neat); 1625 cm^{-1} (C=C).

Ethyl 2-Methyl-2-nonenoate (3A): Bp 109—114 °C/14 Torr. IR (neat); 1650 cm^{-1} (C=C). *E*-isomer: ^{1}H-NMR (CCl_4); δ 6.64 (m, 1H, CH=C), 4.10 (q, J=7 Hz, 2H, CH_2), 2.16 (m, 2H, CH_2), 1.98 (s, 3H, CH_3), 1.1—1.6 (m, 11H, CH_2 and CH_3), 0.89 (m, 3H, CH_3). *Z*-isomer: ^{1}H-NMR (CCl_4); δ 5.83 (m, 1H, CH=C), 4.12 (q, J=7 Hz, 2H, CH_2), 2.42 (m, 2H, CH_2), 1.86 (s, 3H, CH_3), 1.0—1.6 (m, 11H, CH_2 and CH_3), 0.90 (m, 3H, CH_3).

Ethyl 2,4-Dimethyl-2-hexanoate (3B): A solution of ethyl 2-mercaptopropionate (**20**) (20 mmol) in 3 ml of THF was added dropwise to a magnetically stirred solution of LDA (44 mmol) and TMEDA (44 mmol) at −78 °C. After the mixture had been stirred at this temperature for 1 h, a solution of 2-methylbutyraldehyde (24 mmol) in 3 ml of THF was added and the resulting pale yellow mixture was maintained at −78 °C for 2 h. After the addition of a solution of ethyl chloroformate (20 mmol) in 5 ml of THF was complete, the reaction mixture was stirred at −78 °C for 30 min and then at room temperature for 1 h. Work-up and distillation gave a mixture of *E*- and *Z*-isomers of **3B** in 67% yield, which was readily separated by GLC. Bp 110—115 °C/68 Torr. IR (neat); 1645 cm^{-1} (C=C). *E*-isomer: ^{1}H-NMR (CCl_4); δ 6.36 (m, 1H, CH=C), 4.08 (q, J=7 Hz, 2H, CH_2), 2.37 (m, 1H, CH), 1.76 (s, 3H, CH_3), 1.25 (m, 5H, CH_2 and CH_3), 0.98 (d, J=7 Hz, 3H, CH_3), 0.86 (t, 3H, CH_3). *Z*-isomer: ^{1}H-NMR (CCl_4); δ 5.52 (m, 2H, CH_2), 4.10 (q, 2H, CH_2), 3.00 (m, 1H, CH), 1.86 (s, 3H, CH_3), 1.29 (m, 5H, CH_2 and CH_3), 0.7—1.0 (m, 6H, $2CH_3$). Found: C, 70.42; H, 10.79%. Calcd for $C_{10}H_{18}O_2$: C, 70.55; H, 10.65%.

Alkylation of Dianion. A solution of alkyl halide (80 mmol for dialkylation; 20 mmol for monoalkylation) was added dropwise to a solution of dianion (20 mmol) generated at −78 °C in THF in the same way as described above. After the solution had been stirred at −78 °C for 30 min and at room temperature for 1 h, the mixture was quenched with 10 ml of aqueous solution of NH_4Cl. The product was purified by distillation.

Ethyl 2-Methylthiopropionate (11a): Bp 66—68 °C/15 Torr. ^{1}H-NMR (CCl_4); δ 4.12 (q, J=7 Hz, 2H, CH_2), 3.18 (q, J=7 Hz, 1H, CH), 2.10 (s, 3H, CH_3), 1.2—1.4 (m, 6H, $2CH_3$). IR (neat); 1725 cm^{-1} (COO). Found: C, 48.70; H, 8.36; S, 21.61%. Calcd for $C_6H_{12}O_2S$: C, 48.62; H, 8.16; S, 21.63%.

Ethyl 2-Ethylthiobutanoate (11b): Bp 91—92.5 °C/14 Torr. ^{1}H-NMR (CCl_4); δ 4.09 (q, J=7 Hz, 2H, CH_2), 3.00 (t, J=7 Hz, 1H, CH), 2.55 (q, J=7 Hz, 2H, CH_2), 1.6—2.0 (m, 2H, CH_2), 1.1—1.4 (m, 6H, $2CH_3$), 0.97 (t, J=7 Hz, 3H, CH_3). IR (neat); 1720 cm^{-1} (COO).

Ethyl 2-Allylthio-4-pentenoate (11c): Bp 115 °C/16 Torr. ^{1}H-NMR (CCl_4); δ 5.40—5.90 (m, 2H, CH=C), 5.05 (m, 4H, $2CH_2$=C), 4.09 (q, 2H, CH_2), 3.00—3.30 (m, 3H, CH_2 and CH), 2.2—2.8 (m, 2H, CH_2), 1.27 (t, J=7 Hz, 3H, CH_3). IR (neat); 1720 (COO), 1635 cm^{-1} (C=C).

Ethyl 3-Hydroxy-2-mercapto-3-methylbutanoate (15): Bp 115 °C/27 Torr. ^{1}H-NMR (CCl_4); δ 4.22 (q, J=7 Hz, 2H, CH_2), 3.00—3.20 (m, 2H, OH and CH), 2.22 (d, J=9 Hz, 1H, SH), 1.0—1.4 (m, 9H, $3CH_3$). Found: C, 47.36; H, 8.01; S, 17.76%. Calcd for $C_7H_{14}O_3S$: C, 47.17; H, 7.91; S, 17.99%. IR (neat); 3500 (OH), 2550 (SH), 1710 cm^{-1} (COO).

Ethyl 2,3-Dihydroxy-3-methylbutanoate (17): ^{1}H-NMR (CCl_4); δ 4.26 (q, J=7 Hz, 2H, CH_2), 3.83 (s, 1H, CH), 3.0—3.3 (m, 2H, 2OH), 1.34 (t, J=7 Hz, 3H, CH_3), 1.24 (s, 3H, CH_3), 1.16 (s, 3H, CH_3). IR (neat); 3400 (OH), 1720 cm^{-1} (COO).

Ethyl (Methylthio)acetate (19a): Bp 111 °C/20 Torr. ^{1}H-NMR (CCl_4); δ 4.10 (q, J=7 Hz, 2H, CH_2), 3.06 (s, 2H, CH_2), 2.19 (s, 3H, SCH_3), 1.29 (t, J=7 Hz, 3H, CH_3). IR (neat); 1730 cm^{-1} (COO).

Ethyl (Ethylthio)acetate (19b): Bp 81 °C/15 Torr. ^{1}H-NMR (CCl_4); δ 4.02 (q, J=7 Hz, 2H, CH_2), 3.02 (s, 2H, CH_2), 2.55 (q, J=7 Hz, 2H, CH_2), 1.22 (t, J=7 Hz, 6H, $2CH_3$). IR (neat); 1730 cm^{-1} (COO).

Ethyl (2-Hydroxypropylthio)acetate (19c): Bp 112 °C/10 Torr. ^{1}H-NMR (CCl_4); δ 4.16 (q, J=7 Hz, 2H, CH_2), 3.85 (m, 1H, CH), 3.48 (m, 1H, OH), 3.22 (s, 2H, SCH_2), 2.46 (m, 2H, CH_2), 1.1—1.4 (m, 6H, $2CH_3$). IR (neat); 3450 (OH), 1720 cm^{-1} (COO).

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