  Bull. Chem. Soc. Jpn., 60, 1457—1464 (1987)

Selective 1,4-Chiral Induction in the Reaction of Enolates Generated from *t*-Butyl δ-Hydroxy Carboxylates

Koichi NARASAKA,* Yutaka UKAJI, and Kazutoshi WATANABE
Department of Chemistry, Faculty of Science, The University of Tokyo, Hongo, Bunkyo-ku, Tokyo 113
(Received October 20, 1986)

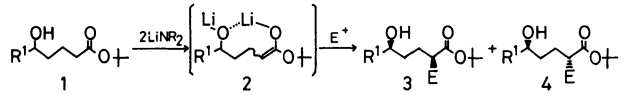
Lithium enolates generated from *t*-butyl esters of δ-hydroxy carboxylic acids with lithium dialkylamides in THF-HMPA were alkylated stereoselectively to give the corresponding *syn*-α-alkylated δ-hydroxy esters. The generation of the enolates was accelerated by the addition of lithium trifluoromethanesulfonate, and the successive aldol and hydroxylation reactions of the enolates also proceeded in a stereoselective manner.

In recent years a number of efforts have been devoted on the exploration of stereoselective reactions in acyclic precursors, and various excellent methods have been developed toward the diastereoselection between adjacent carbon atoms (1,2-relationships).[1] However, general approaches to the construction of remote chiral relationships in acyclic systems are rare, and such a control of the diastereoselectivity between remote carbons has still been a challenging problem in organic synthesis.

Concerning 1,3-chiral induction[1b,2] we have reported the stereoselective preparations of *syn*-1,3-diols and *syn*-β-amino alcohols from β-hydroxy ketones.[3] In this paper, we describe the rusults of a study on 1,4-chiral induction[2b,4] directed by a hydroxyl group in the reaction of lithium enolates derived from δ-hydroxy esters.[5]

Results and Discussion

The formation of 6-membered chelate is known to well regulate the 1,2-chiral induction in the reaction of dilithio derivatives generated from β-hydroxy esters.[6] It was considered that the lithium enolate dianion **2** prepared from δ-hydroxy esters would also form even a strained 8-membered chelate by the strong interaction between lithium and the oxygen of the alkoxide group. Hence the successive reaction of **2** with electrophiles would proceed in a stereoselective manner.



By the above hypothesis, the alkylation reaction of ester enolates generated from **1** was firstly examined. *t*-Butyl 5-hydroxyhexanoate (**1A**) was treated with 2 molar amounts of lithium diisopropylamide (LDA) in THF at −78 °C and the resulting enolate was alkylated with methyl iodide, however, a ca. 1 : 1 mixture of **5a** and **6a** was obtained. When the formation of the enolate from **1A** and the successive alkylation were carried out using hexamethylphosphoric triamide (HMPA) as a co-solvent with THF, the remarkable stereoselectivity was observed to give a *syn*[7]-α-alkylated product **5a** and an *anti*-product **6a** in a ratio of 86 : 14. It was also observed that the enolization of *t*-butyl 5-hydroxynonanoate (**1B**) with LDA in THF or in THF-HMPA at −78 °C was followed by the addition of butyl iodide to furnish **5b** and **6b** in a ratio of 52 : 48 or 88 : 12, respectively.

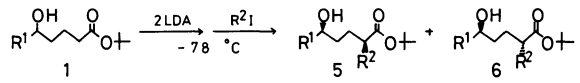
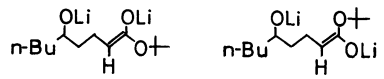


Table 1. Alkylation Reaction of **1** (2 equiv LDA, −78 °C)

	R^1	R^2	Solvent	**5**:**6**[a]
a	Me	Me	THF	56:44
			THF-HMPA	86:14
b	*n*-Bu	*n*-Bu	THF	52:48
			THF-HMPA	88:12

a) The ratios were determined by capillary gas chromatography (PEG-HT).

The geometry of the enolates generated from **1B** in THF and THF-HMPA was studied by trapping the enolates with *t*-butyldimethylsilyl chloride according to the Ireland's procedure,[8] and in each case, the silyl enol ether of the different configuration was formed predominantly. Based on the Ireland's study, lithiation in THF and THF-HMPA was considered to mainly afford the *trans*[9]-enolate *trans*-**2B** and the *cis*-enolate *cis*-**2B**, respectively. Furthermore, the observation that the vinylic proton of the silyl enol ether of the enolate generated in THF-HMPA appears at 0.03 ppm lower field than the corresponding resonance for that generated in THF supported the above stereochemical assignment.[8]



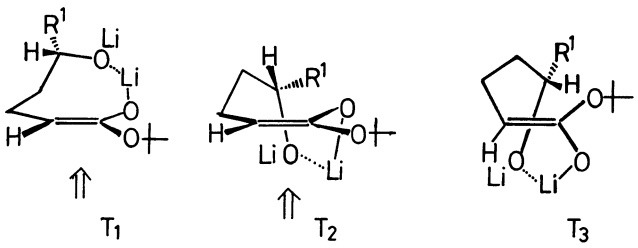
We supposed that the enhanced selectivity by the addition of HMPA may be due to the formation of an 8-membered chelate of a *cis*-enolate. In the 8-membered chelate of the *cis*-enolate, the attack of an electrophile would be expected to proceed from the less hindered side in the preferable conformations such as T_1 (no-symmetry) or T_2 (twist chair)[10a] to result in the formation of the *syn*-alkylated product **5**. On the con-

Table 2. Effect of Lithium Dialkylamides on the Methylation Reaction of **1A**

$LiNR_2$	Temp of enolization/°C	MeX	**5a**:**6a**
LDA	−78	MeI	86:14[a]
	−100→−78	MeI	87:13
	−100→−78	Me_2SO_4	90:10
LTMP	−100→−78	Me_2SO_4	90:10
$LiNEt_2$	−100→−78	Me_2SO_4	92: 8
	−100	Me_2SO_4	95: 5
$LiNMe_2$	−100	Me_2SO_4	94: 6
LiN⟨⟩	−100	Me_2SO_4	95: 5

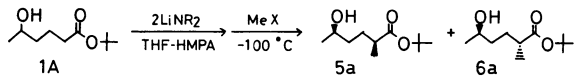
a) The alkylation reaction was performed at −78°C.

trary, the formation of a chelate T_3 should be difficult for the *trans*-enolate because of the severe steric strain,[10] therefore any stereoselection was not observed in the alkylation reaction.

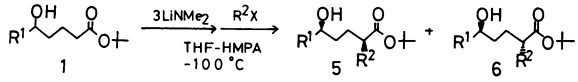


Our initial report that the *syn*-stereoselection is controlled by the addition of HMPA without regard to the configuration of the generating lithium enolate was noted to be incorrect. By the experiments of the reproducibility, it was found that the addition of HMPA after the generation of the enolate (in THF at −78 °C) little changed the selectivity of the successive alkylation.

In order to improve the selectivity toward *syn*-alkylated products, the enolate formation was examined using various lithium amides. It is noteworthy that the treatment of the *t*-butyl ester **1A** with less hindered lithium amides such as lithium diethylamide, lithium dimethylamide, or lithium pyrrolidinide in THF-HMPA at lower temperature (−100 °C) realized the significant stereoselectivity (Table 2).



Based on these preliminary investigations, the lithium enolates generated from δ-hydroxy esters (**1A** and **1B**) with 3 molar amounts of lithium dimethylamide in THF-HMPA at −100 °C were treated with alkylating reagents. The corresponding *syn*-α-alkylated δ-hydroxy esters **5** were found to be obtained in excellent stereoselectivity (Table 3).



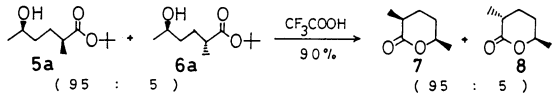
The stereochemistry of **5a** and **5b** was confirmed by the following results. Acid treatment of the *syn*-

Table 3. Stereoselective Alkylation Reaction of **1**

	R^1	R^2X	**5**:**6**[a]	Total yield/%
a	Me	Me_2SO_4	94:6	87
			95:5	81[b]
			95:5	50[c]
b	*n*-Bu	*n*-BuI[d]	94:6	84
c	Me	*n*-BuI[d]	92:8	82
d	*n*-Bu	Me_2SO_4	94:6	92

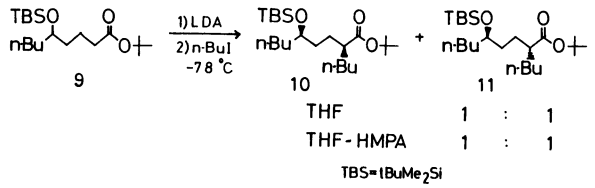
a) The ratios were determined by capillary gas chromatography (PEG-HT). b) Instead of lithium dimethylamide, lithium pyrrolidinide was used. c) Instead of lithium dimethylamide, lithium diethylamide was used. d) After the addition of *n*-BuI, the reaction mixture was stirred for 1 h at −100 °C and gradually warmed to −78 °C.

alkylated ester **5a** readily afforded the sex pheromone of the carpenter bee, (±)-*cis*-2-methyl-5-hexanolide (**7**).[11,12]



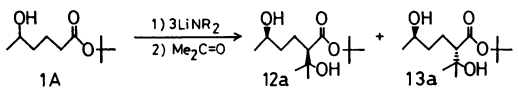
The *syn*-alkylated ester **5b** was also transformed to *cis*-2-butyl-5-nonanolide, which was identical with the authentic *cis*-lactone derived from *cis*-2,5-dibutylcyclopentanone by the Bayer-Villiger reaction.

To confirm the influence of a hydroxyl group on the stereoselection, we examined the alkylation of *t*-butyl 5-hydroxynonanoate (**1B**) after the protection of the hydroxyl group as a *t*-butyldimethylsilyl ether. Although the alkylation reaction of the silyl ether **9** proceeded smoothly, the ratio of the products **10** and **11** was almost 1:1 even when a mixture of THF-HMPA was employed as a solvent. Accordingly, the transformation of a hydroxyl group to lithium alkoxide should be indispensable for the present chiral 1,4-induction.

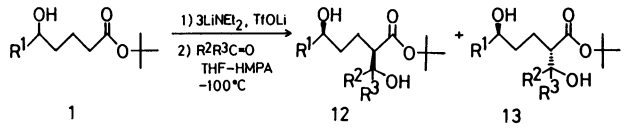


Due to the demonstrated efficiency for the stereoselection in the alkylation of δ-hydroxy carboxylic acid esters, we next investigated the 1,4-chiral induction in the aldol reaction of δ-hydroxy esters with acetone and cyclohexanone.

Hydroxy ester **1A** was lithiated under the same reaction conditions as the alkylation reaction (3 molar amounts of lithium pyrrolidinide, −100 °C), and the successive treatment with acetone was firstly examined. The aldol adducts **12a** and **13a** were obtained in a moderate (81 : 19) ratio, however, the total yield of the products was only 33%. When 3 molar amounts of lithium diethylamide was employed in the above reaction, the yield of the aldol products was not also sufficient (53%). On the other hand, as can be seen in Table 3, the alkylation reaction proceeded smoothly in over 80% yield in the same reaction conditions. By comparison of these results, it was noted that the enolization of δ-hydroxy esters **1** was not sufficient in the first lithiation stage (at −100 °C for 1 h) and that the enolization proceeds furthermore after the addition of an alkylating reagent. The presence of an alkylating reagent or a lithium salt genarated during alkylation reaction would be considered to accelerate the lithiation of δ-hydroxy esters, and the lithiation of **1** was examined in the presence of various lithium salts. Finally lithium trifluoromethanesulfonate (LiOTf) or lithium iodide was found to enhance the lithiation.[13] Thus the hydroxy ester **1A** was smoothly converted to the enolate **2A** with 3 molar amounts of lithium diethylamide in the presence of 3 molar amounts of LiOTf even at −100 °C in THF-HMPA, and the reaction with acetone gave the aldol adducts **12a** and **13a** in 92% yield (Table 4). Furthermore, the high stereoselectivity toward the *syn*-aldol product was also achieved by the addition of LiOTf (**12a** : **13a**=91 : 9). When LiOTf and then acetone were added succesively after the enolate formation at −100 °C, the yield of the aldol products was lower (74%). These observations suggested that LiOTf is not effective to promote the aldol reaction, but accelerates the enolization.



The aldol reaction of **1A** and **1B** with acetone and cyclohexanone was conducted by the combined use of LiOTf and lithium diethylamide with the results shown in Table 5. In all cases, the *syn*-aldol products **12** were obtained in high yield with high stereoselectivity.



The confirmation of the relative stereochemistry of **12a** was carried out by the transformation of **12a** to **17**,

Table 4. Aldol Reaction of **1A** with Acetone in the Presence of Lithium Halides

$LiNR_2$	Additive[a]	**12a**:**13a**[b]	Total yield/%
$LiNMe_2$		c	24
LiN⟨⟩		81:19	33
	LiI	86:14	64
	LiOTf	89:11	66
$LiNEt_2$		86:14	53
		82:18	78[d]
	LiI	88:12	79
	LiOTf	91: 9	92
	LiOTf[e]	85:15	74
	LiOTf	87:13	82[f]

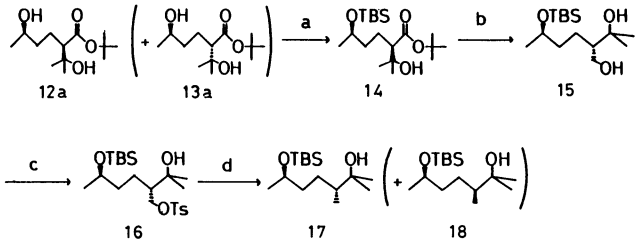
a) 3 molar amounts of additive were used. b) The ratios were determined by ^{13}C NMR spectra. c) The ratio was not determined. d) Lithiation was performed at −100 °C for 1 h, then warmed to −78 °C. e) 1 molar amount of LiOTf was used. f) 2.2 molar amounts of lithium diethylamide were used.

Table 5. Stereoselective Aldol Reaction of **1** in the Presence of LiOTf

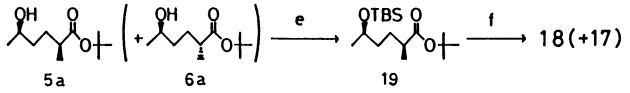
	R^1	R^2 R^3	**12**:**13**[a]	Total yield/%
a	Me	Me Me	91: 9	92
b	Me	$-(CH_2)_5-$	86:14	99
c	*n*-Bu	Me Me	91: 9	99
d	*n*-Bu	$-(CH_2)_5-$	93: 7	97

a) The ratios were determined by ^{13}C NMR spectra.

which was compared with the authentic **17** derived from **6a**. That is, a ca. 4 : 1 mixture of **12a** and **13a** was converted to **17** and **18** as shown in Scheme 1. The authentic samples **18** and **17** were obtained from a ca. 4 : 1 mixture of **5a** and **6a** (Scheme 2). The ^{13}C NMR spectra of the main product **17** obtained from a mixture of **12a** and **13a** and the minor product **17** derived from a mixture of **5a** and **6a** were identical with each other. The ^{13}C NMR spectrum of the minor product **18** produced from a mixture of **12a** and **13a** also agreed with that of the major product **18** from a mixture of **14** and **15**. Furthermore, in ^{13}C NMR spectra, all the chemical shifts of α-carbons (-CH(COO^{t}Bu)-) and δ-



Scheme 1. (a): TBSCl, Et_3N; 90% (b): $LiAlH_4$; 76%, (c): *p*-TsCl, pyridine; 94%, (d): $LiAlH_4$; 69%.



Scheme 2. (e): TBSCl, Et_3N; 90%, (f): MeLi; 89%.

Table 6. Hydroxylation of **1**

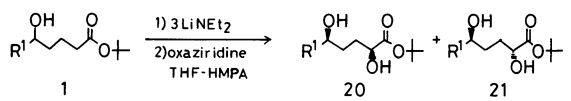
	R^1	Temp of lithiation/°C	Oxaziridines	**20**:**21**[a]	Total yield/%
a	Me	−100→−78	**22**	92: 8	40
		−78	**23**	89:11	48[b]
		−78	**24**	88:12	34
		−100→−78	**25**	90:10	70
		−100	**25**	92: 8	83[c]
b	*n*-Bu	−100	**25**	92: 8	82[c,d]

a) The ratios of **20a** to **21a** were determined by capillary gas chromatography (OV-101) and the ratio of **20b** to **21b** was measured by ^{13}C NMR spectrum of the corresponding acetates. b) Instead of lithium diethylamide, LDA was used. c) 3 molar amounts of LiOTf were present during the reaction. d) Diols were isolated as the corresponding diacetates.

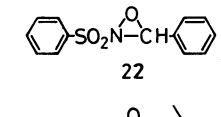
carbons (-CH(OH)-) of the *syn*-isomers **12** appear at lower fields about 0.4—0.7 ppm and 0.5—1.0 ppm than those of the *anti*-isomers **13**, respectively.

As the significant effect for the acceleration of the enolate formation was observed by the addition of LiOTf, the alkylation reaction was reexamined in the presence of LiOTf. The enolate formation of **1A** (3 $LiNEt_2$, 3LiOTf in THF-HMPA, −100 °C, 2 h) and the successive alkylation with dimethyl sulfate was carried out at −100 °C. The alkylated products **5a** and **6a** were however obtained in low yield (20%). This result means that LiOTf accelerates the formation of the ester enolate but disturbs the reaction with alkylation reagents.

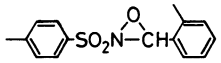
Next, we have used the lithium enolates of δ-hydroxy esters **1** in the stereoselective preparation of *syn*-1,4-diols by the direct oxidation of the enolates. And it has been found that the α-hydroxylation reaction of this system proceeded with an oxidant, oxaziridine.[14,15] The δ-hydroxy ester **1A** was transformed into the lithium enolate (3 equiv $LiNEt_2$, THF-HMPA, −100→−78 °C) and treated with an excess amount of the oxaziridine **22**. After an immediate reaction, the *syn*-α,δ-dihydroxy ester **20a** and the *anti*-isomer **21a** were obtained in high selectivity (**20a**:**21a**=92:8). It was evident that the sense of chiral induction in this hydroxylation paralleled the observation made in the alkylation and aldol reactions. However, the yield of the diols was modest. As a reaction of the enolate with the generated sulfonylimine was considered to be accompanied, we modified the hydroxylation reaction by means of an employment of more sterically hindered oxaziridines. When a newly synthesized oxaziridine **25** was utilized to the hydroxylation, the yield of diols consequently improved up to 70%. Moreover, the enolate formation at −100 °C in the presence of LiOTf and the treatment of the resulting enolates with **25** afforded the corresponding diols **20** and **21** in superior yield and stereoselectivity (Table 6).



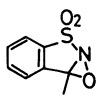
1 20 21



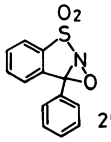
22



23

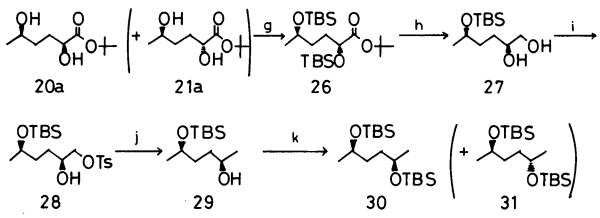


24



25

The relative stereochemistry of diols was determined by transformation of **21a** and **22a** to silyl ethers **30** and **31** (Scheme 3), which were identified by comparing the ^{13}C NMR spectra with the spectrum of the authentic silyl ether derived from *dl*-2,5-hexanediol.[16]



20a 21a 26 27

28 29 30 31

Scheme 3. (g): TBSCl, Et_3N; 99%, (h): $LiAlH_4$; 78%, (i): *p*-TsCl, pyridine, (j): 1) NaOMe, 2) $LiAlH_4$; 50% from **27**, k) TBSCl, Et_3N; 93%.

Experimental

All the boiling points and the melting points are uncorrected. The IR spectra were determined on a Hitachi Model 260-30 spectrometer. The ^1H NMR spectra were recorded with a Hitachi R-24B, a Varian EM-390, and a JEOL GX-400 spectrometers, and ^{13}C NMR spectra were measured with a JEOL FX-90Q spectrometer with tetramethylsilane as an internal standard. Tetrahydrofuran (THF) and diethyl ether were freshly distilled from sodium benzophenone ketyl. Dichloromethane, hexamethylphosphoric triamide (HMPA) and pyridine were distilled from CaH_2 and stored over Molecular Sieves. Purification of products was performed by column chromatography on silica gel (Wakogel C-200 or C-300), preparative TLC on silica gel (Wakogel B-5F).

Preparation of *t*-Butyl 5-Hydroxyhexanoate (1A). 5-Oxohexanoic acid[17] (6.09 g, 47 mmol) was treated with an excess amount of 2-methylpropene and three drops of concd H_2SO_4 in autoclave and was stirred at room temperature overnight.[18] The reaction mixture was quenched with triethylamine and was extracted with CH_2Cl_2. The combined extracts were washed with brine, dried over Na_2SO_4,

and condensed under reduced pressure. Purification by column chromatography (hexane : ethyl acetate=2 : 1, v/v) gave *t*-butyl 5-oxohexanoate (8.72 g, 74%). IR (neat) 1720 cm^{-1}. ^1H NMR ($CDCl_3$) δ=1.43 (9H, s), 1.73—2.29 (4H, m), 2.13 (3H, s), 2.29—2.67 (2H, m). Next, to a solution of *t*-butyl 5-oxohexanoate (2.15 g, 11.5 mmol) in CH_2Cl_2 (50 mL) and methanol (10 mL) was added sodium borohydride (1.31 g, 34.6 mmol) at 0 °C, and stirred for 15 min at room temperature. The mixture was quenched with sat. aqueous NH_4Cl and extracted with CH_2Cl_2. The separated organic layer was dried over Na_2SO_4 and was condensed under reduced pressure. Purification by column chromatography on silica gel (hexane : ethyl acetate=3 : 1, v/v) gave *t*-butyl 5-hydroxyhexanoate (**1A**) (2.09 g, 96%). Bp 80 °C/0.15 mmHg (1 mmHg=133.322 Pa). IR (neat) 3430, 1720 cm^{-1}. ^1H NMR ($CDCl_3$) δ=1.13 (3H, d, J=6.0 Hz), 1.45 (9H, s), 1.23—1.90 (4H, m), 1.90—2.53 (2H, m), 3.36—3.98 (2H, m). Found: C, 63.51; H, 10.98%. Calcd for $C_{10}H_{20}O_3$: C, 63.79; H, 10.71%.

Preparation of *t*-Butyl 5-Hydroxynonanoate (1B). To a CH_2Cl_2 (20 mL) solution of 5-oxononanoic acid[19] (5.61 g, 33 mmol) was added concd H_2SO_4 (2 mL). Into the resulting mixture was bubbled 2-methylpropene for 1 h.[20] The reaction was quenched with water and extracted with CH_2Cl_2, then washed with water and brine. The organic layer was dried over Na_2SO_4 and condensed in vacuo. The residue was purified by column chromatography on silica gel (hexane: ethyl acetate=9 : 1, v/v) to give *t*-butyl 5-oxononanoate (5.10 g, 69%). IR (neat) 1720 cm^{-1}. ^1H NMR (CCl_4) δ=0.62—2.43 (15H, m), 1.29 (9H, s). Reduction of *t*-butyl 5-oxononanoate with $NaBH_4$ as described for **1A** gave *t*-butyl 5-hydroxynonanoate (**1B**) in 92% yield. Bp 135 °C (bath temp)/4 mmHg. IR (neat) 3440, 1735 cm^{-1}. ^1H NMR ($CDCl_3$) δ=0.55—1.83 (14H, m), 1.35 (9H, s), 1.97—2.28 (2H, m), 3.07—3.62 (1H, m). Found: C, 67.65; H, 11.61%. Calcd for $C_{13}H_{26}O_3$: C, 67.78; H, 11.38%.

Stereoselective Alkylation Reaction of 1A with Dimethyl Sulfate. To a THF (7 mL) solution of lithium dimethylamide (2.37 mmol), which was prepared from an excess amount of dimethylamine (ca. 0.5 mL) and butyllithium (2.37 mmol), was added a THF (1 mL) solution of HMPA (0.83 mL, 4.77 mmol) at −78 °C under an argon atmosphere, and cooled to −100 °C. A THF (2 mL) solution of *t*-butyl 5-hydroxyhexanoate (**1A**) (149 mg, 0.79 mmol) was added to the mixture and stirred for 1 h at that temperature. Then a THF (2 mL) solution of dimethyl sulfate (316 mg, 2.51 mmol) was added to the mixture. After being stirred for 1 h at −100 °C, the reaction was quenched with sat. aqueous NH_4Cl and extracted with ether. The combined ether extracts were washed with water and brine, dried over Na_2SO_4, and condensed under reduced pressure. Purification by column chromatography (hexane: ethyl acetate=8 : 1, v/v) gave *t*-butyl *syn*-5-hydroxy-2-methylhexanoate (**5a**) and the *anti*-isomer **6a** (total 140 mg, 87%) in the ratio of 94 : 6, respectively.

The stereoselective preparations of **5b—d** were carried out by the same procedure. All the alkylated products were obtained as a mixture of *syn*- and *anti*-isomers **5** and **6**, which were not able to be separated by column chromatography or TLC. Each pair of isomers was indistinguishable by ^1H NMR (90 MHz) spectra, and the following spectral and analytical data were for a mixture of *syn*- and *anti*-isomers (90 : 10—95 : 5), respectively.

t-Butyl *syn*-5-hydroxy-2-methylhexanoate (**5a**) and the *anti* isomer **6a**: IR (neat) 3425, 1725 cm^{-1}. ^1H NMR ($CDCl_3$) δ=1.00 (3H, d, J=5.6 Hz), 1.06 (3H, d, J=6.4 Hz), 1.20—1.80 (4H, m), 1.31 (9H, s), 1.92—2.42 (1H, m), 2.67 (1H, br s), 3.38—3.92 (1H, m). Found: C, 65.19; H, 11.25%. Calcd for $C_{11}H_{22}O_3$: C, 65.31; H, 10.96%.

t-Butyl *syn*-2-butyl-5-hydroxynonanoate (**5b**) and the *anti* isomer **6b**: IR (neat) 3450, 1725 cm^{-1}. ^1H NMR ($CDCl_3$) δ= 0.53—2.39 (24H, m), 1.32 (9H, s), 3.17—3.59 (1H, m). Found: C, 71.55; H, 12.18%. Calcd for $C_{17}H_{34}O_3$: C, 71.28; H, 11.96%.

t-Butyl *syn*-2-butyl-5-hydroxyhexanoate (**5c**) and the *anti* isomer **6c**: IR (neat) 3430, 1725 cm^{-1}. ^1H NMR (CCl_4) δ= 0.53—2.24 (14H, m), 0.98 (3H, d, J=5.8 Hz), 1.31 (9H, s), 2.90 (1H, br s), 3.23—3.79 (1H, m). Found: C, 68.60; H, 11.84%. Calcd for $C_{14}H_{28}O_3$: C, 68.81; H, 11.55%.

t-Butyl *syn*-5-hydroxy-2-methylnonanoate (**5d**) and the *anti* isomer **6d**: IR (neat) 3430, 1730 cm^{-1}. ^1H NMR (CCl_4) δ=0.63—1.87 (14H, m), 1.07 (3H, d, J=6.8 Hz), 1.42 (9H, s), 1.90—2.47 (1H, m), 3.18—3.63 (1H, m). Found: C, 68.58; H, 11.49%. Calcd for $C_{14}H_{28}O_3$: C, 68.81; H, 11.55%.

Transformation of a Mixture of 5a and 6a to the Lactones. A 95 : 5 mixture of **5a** and **6a** (total 140 mg, 0.69 mmol) was dissolved in trifluoroacetic acid (2mL), and stirred for 2 h. After evaporation of the excess trifluoroacetic acid in vacuo, the residue was purified by preparative TLC on silica gel (hexane : ethyl acetate=1 : 1, v/v) to afford *cis*-2-methyl-5-hexanolide (**7**) and the *trans*-isomer **8** (total 80 mg, 90%) in the ratio of 95 : 5, respectively. Isomeric ratio was determined by capillary gas chromatography (OV-101, 95 °C).

cis-2-Methyl-5-hexanolide (**7**) and the *trans* isomer **8**: IR (neat) 1720 cm^{-1}. ^1H NMR (400 MHz) ($CDCl_3$) δ=1.23 (2.85H, d, J=6.8 Hz, *cis*), 1.31 (0.15H, d, J=6.4 Hz, *trans*), 1.36 (2.85H, d, J=6.4 Hz, *cis*), 1.37 (0.15H, d, J=6.4 Hz, *trans*), 1.50—1.68 (2H, m), 1.90—2.13 (2H, m), 2.41—2.48 (0.05H, m, *trans*), 2.55—2.64 (0.95H, m, *cis*), 4.43—4.51 (1H, m).

cis-2-Butyl-5-nonanolide. A solution of *cis*-2,5-dibutylcyclopentanone[21] (126 mg, 0.64 mmol) in acetic acid (3 mL) was mixed with 30% hydrogen peroxide (1 mL) and stirred at 50 °C for 3 d.[22] The reaction mixture was poured into water, extracted with ether and washed with aqueous $NaHCO_3$ and brine, dried over Na_2SO_4, and condensed in vacuo. Purification by preparative TLC on silica gel (hexane : ethyl acetate=6 : 1, v/v) to give *cis*-2-butyl-5-nonanolide (41 mg, 30%). IR (neat) 1740 cm^{-1}. ^1H NMR ($CDCl_3$) δ=0.53—2.59 (23H, m), 3.83—4.42 (1H, m). Found: C, 73.55; H, 11.59%. Calcd for $C_{13}H_{24}O_2$: C, 73.53; H, 11.39%.

By capillary gas chromatography (OV-101, 135 °C), the authentic lactone was identical with the major isomer of the lactones derived from **5b** and **6b**.

Stereoselective Aldol Reaction of 1A with Acetone. To a THF (5 mL) solution of LiOTf (323 mg, 2.07 mmol) was added a THF (5 mL) solution of diethylamine (179 mg, 2.44 mmol) under an argon atmosphere, and cooled to −78 °C. Butyllithium (1.25 mL of a 1.54 M solution in hexane (1 M=1 mol dm^{-3})) was added and the solution was stirred at that temperature for 15 min followed by the addition of a THF (1 mL) solution of HMPA (0.66 mL, 3.79 mmol) and then cooled to −100 °C. A THF (4 mL) solution of **1A** (119 mg, 0.63 mmol) was added to the mixture and stirred for 2 h at that temperature, and then a THF (4 mL) solution of acetone (91 mg, 1.57 mmol) was added. After being stirred for 30 min at −100 °C, the reaction was quenched with sat. aqueous NH_4Cl and extracted with ether. The ethereal

extracts were washed with water and brine, dried over Na_2SO_4, and condensed in vacuo. Purification by preparative TLC on silica gel (hexane : ethyl acetate=1 : 2, v/v) to give *t*-butyl *syn*-5-hydroxy-2-(1-hydroxy-1-methylethyl)-hexanoate (**12a**) and the *anti*-isomer **13a** (total 142 mg, 92%) in a ratio of 91 : 9, respectively.

Stereoselective syntheses of **12b—d** were carried out by the same procedure. All the *syn*- and *anti*-isomers of the aldol products **12** and **13** were not separable by column or thin-layer chromatography. In the ^1H NMR spectra (90 MHz), each isomer was not distinguished.

t-Butyl *syn*-5-hydroxy-2-(1-hydroxy-1-methylethyl)-hexanoate (**12a**) and the *anti* isomer **13a**: IR (neat) 3400, 1725 cm^{-1}. ^1H NMR ($CDCl_3$) δ=1.18 (3H, d, J=6.0 Hz), 1.22 (6H, s), 1.33—1.97 (4H, m), 1.45 (9H, s), 2.10—2.41 (1H, m), 3.03 (2H, br s), 3.37—3.97 (1H, m). ^{13}C NMR ($CDCl_3$) δ=56.20 (Cα, *anti*), 56.66 (Cα, *syn*), 66.90 (Cδ, *anti*), 67.63 (Cδ, *syn*). Analytical data for the corresponding 5-*O*-acetate; Found: C, 62.22; H, 10.13%. Calcd for $C_{15}H_{28}O_5$: C, 62.47; H, 9.79%.

t-Butyl *syn*-5-hydroxy-2-(1-hydroxycylohexyl)hexanoate (**12b**) and the *anti* isomer **13b**: Mp 90.1—90.2 °C (hexane). IR (KBr) 3400, 1715 cm^{-1}. ^1H NMR ($CDCl_3$) δ=1.17 (3H, d, J=5.4 Hz), 1.28—1.97 (14H, m), 1.47 (9H, s), 2.10—2.57 (1H, m), 2.94 (1H, br s), 3.10 (1H, br s), 3.47—4.17 (1H, m). ^{13}C NMR ($CDCl_3$) δ=55.01 (Cα, *anti*), 55.42 (Cα, *syn*), 67.39 (Cδ, *anti*), 67.93 (Cδ, *syn*). Found: C, 67.17; H, 10.84%. Calcd for $C_{16}H_{30}O_4$: C, 67.09; H, 10.56%.

t-Butyl *syn*-5-hydroxy-2-(1-hydroxy-1-methylethyl)-nonanoate (**12c**) and the *anti* isomer **13a**: IR (neat) 3390, 1725 cm^{-1}. ^1H NMR ($CDCl_3$) δ=0.60—1.88 (13H, m), 1.08 (3H, s), 1.12 (3H, s), 1.35 (9H, s), 1.97—2.27 (1H, m), 2.53 (2H, br s), 3.20—3.63 (1H, m). ^{13}C NMR ($CDCl_3$) δ=56.34 (Cα, *anti*), 57.01 (Cα, *syn*), 70.91 (Cδ, *anti*), 71.86 (Cδ, *syn*). Analytical data for the corresponding 5-*O*-acetate; Found: C, 65.45; H, 10.56%. Calcd for $C_{18}H_{34}O_5$: C, 65.42; H, 10.37%.

t-Butyl *syn*-5-hydroxy-2-(1-hydroxycyclohexyl)nonanoate (**12d**) and the *anti* isomer **13d**: Mp 58.0—60.5 °C (2-propanol-H_2O). IR (KBr) 3480, 1695 cm^{-1}. ^1H NMR ($CDCl_3$) δ=0.68—2.70 (25H, m), 1.48 (9H, s), 2.84—3.19 (1H, m), 3.30—3.77 (1H, m). ^{13}C NMR ($CDCl_3$) δ=54.88 (Cα, *anti*), 55.47 (Cα, *syn*), 71.02 (Cδ, *anti*), 71.89 (Cδ, *syn*). Found: C, 69.19; H, 11.33%. Calcd for $C_{19}H_{36}O_4$: C, 69.47; H, 11.05%.

Transformation of 12a and 13a to 17 and 18. a) *t*-Butyl 5-*t*-butyldimethylsilyloxy-2-(1-hydroxy-1-methylethyl)-hexanoate (**14**). A 4 : 1 mixture of **12a** and **13a** (total 531 mg, 2.15 mmol), *t*-butyldimethylsilyl chloride (395 mg, 2.63 mmol), triethylamine (328 mg, 3.24 mmol), and a catalytic amount of 4-dimethylaminopyridine in DMF (6 mL) was stirred for 15 h at room temperature under an argon atmosphere.[23] Then the reaction was quenched with ice and the mixture was extracted with ether. The ether extracts were washed with water and brine and dried over Na_2SO_4. The ether solution was concentrated and the residue was purified by column chromatography on silica gel (hexane: ethyl acetate=10 : 1, v/v) to give the silylated ester **14** (698 mg, 90%). IR (neat) 3450, 1725 cm^{-1}. ^1H NMR (CCl_4) δ=0.03 (6H, s), 0.81 (9H, s), 1.01 (6H, s), 1.01 (3H, d, J=6.0 Hz), 1.25—2.25 (6H, m), 1.40 (9H, s), 2.55 (1H, br s), 3.50—4.00 (1H, m). b) 3-hydroxymethyl-2-methyl-6-*t*-butyldimethylsilyloxy-2-heptanol (**15**). To an ether (5 mL) solution of **14** (698 mg, 1.94 mmol) was added an ether (2.5 mL) solution of lithium aluminum hydride (3.88 mmol) at 0 °C under an argon atmosphere, and stirred for 16 h at that temperature. The mixture was quenched with sat. aqueous Na_2SO_4 (1.8 mL) and the resulting precipitate was filtered off. The condensed filtrate was purified by column chromatography on silica gel (hexane: ethyl acetate=4 : 1, v/v) to furnish the diol **15** (430 mg, 76%). IR (neat) 3340 cm^{-1}. ^1H NMR ($CDCl_3$) δ=0.06 (6H, s), 0.90 (9H, s), 1.11 (3H, d, J=6.0 Hz), 1.18 (3H, s), 1.29 (3H, s), 3.33—4.04 (3H, m), 3.73 (2H, d, J=5.0 Hz). c) 6-(*t*-Butyldimethylsilyloxy)-2-methyl-3-(*p*-tolylsulfonyloxymethyl)-2-heptanol (**16**). A mixture of **15** (430 mg, 1.48 mmol), *p*-toluenesulfonyl chloride (427 mg, 2.24 mmol), and a catalytic amount of 4-dimethylaminopyridine in pyridine (2 mL) was stirred for 2 h at room temperature under an argon atmosphere. After evaporation of the excess pyridine in vacuo, the residue was purified by column chromatography on silica gel (hexane : ethyl acetate=4 : 1, v/v) to afford the corresponding tosylate **16** (621 mg, 94%). IR (neat) 3550, 1365 cm^{-1}. ^1H NMR ($CDCl_3$) δ=0.06 (6H, s), 0.72 (9H, s), 0.91 (3H, d, J=6.0 Hz), 0.92—1.81 (5H, m), 1.00 (3H, s), 1.04 (3H, s), 3.20—3.80 (1H, m), 3.27 (3H, s), 3.98 (2H, d, J=5.4 Hz), 7.13—7.71 (4H, m). d) 6-*O*-(*t*-Butyldimethylsilyl)-2,3-dimethyl-2,6-heptanediol **17** and **18**. Under an argon atmosphere, an ether (1.83 mL) solution of lithium aluminum hydride (2.82 mmol) was added to an ether (20 mL) solution of **16** (621 mg, 1.41 mmol) at room temperature, and stirred for 30 min. The mixture was quenched with sat. aqueous Na_2SO_4 (0.8 mL) and the resulting precipitate was filtered off. The condensed filtrate was purifued by column chromatography on silica gel (hexane : ethyl acetate=4 : 1, v/v) to give **17** and **18** (268 mg, 69%). IR (neat) 3375 cm^{-1}. ^1H NMR (CCl_4) δ=0.02 (6H, s), 0.53—0.88 (3H, m), 0.75 (9H, s), 0.88—1.86 (5H, m), 0.95 (3H, d, J=6.0 Hz), 0.96 (6H, s), 3.28—3.80 (1H, m). ^{13}C NMR ($CDCl_3$) δ=0.81, 14.29, 17.90, 23.53 (**17**), 23.72 (**18**), 25.75 (**17**), 26.21 (**18**), 26.43 (**17**), 26.65 (**17**), 26.81 (**18**), 27.51 (**18**), 38.46, 44.33, 68.79, 73.07.

Transformation of 5a and 6a to 18 and 17. e) *t*-Butyl 5-(*t*-butyldimethylsilyloxy)-2-methylhexanoate (**19**). A 4 : 1 mixture of α-methylated ester **5a** and **6a** (total 299 mg, 1.48 mmol) and triethylamine (222 mg, 2.19 mmol), *t*-butyldimethylsilyl chloride (275 mg, 1.83 mmol), and a catalytic amount of 4-dimethylaminopyridine in DMF (6 mL) was stirred for 18 h at room temperature under an argon atmosphere. The reaction was quenched with ice, and the mixture was extracted with ether. The ether extracts were washed with water and brine and dried over Na_2SO_4. The ether solution was condensed and the residue was purified by column chromatography on silica gel (hexane : ethyl acetate=15 : 1, v/v) to give the silylated ester **19** (419 mg, 90%). IR (neat) 1725 cm^{-1}. ^1H NMR (CCl_4) δ=0.03 (6H, s), 0.87 (9H, s), 1.02 (3H, d, J=6.6 Hz), 1.05 (3H, d, J=6.0 Hz), 1.22—1.76 (4H, m), 1.40 (9H, s), 1.80—2.57 (1H, m), 3.43—4.00 (1H, m). f) 6-*O*-(*t*-Butyldimethylsilyl)-2,3-dimethyl-2,6-heptanediol **18** and **17**. To an ether (5 mL) solution of **19** (92 mg, 0.92 mmol) was added methyllithium (0.49 mL of a 1.29 M solution in ether) at 0 °C under an argon atmosphere, and stirred for 30 min at that temperature. To the mixture was added sat. aqueous NH_4Cl and the organic layer was extracted with CH_2Cl_2. The separated organic layer was dried over Na_2SO_4 and was condensed under reduced pressure. Purification by preparative TLC (hexane: ethyl acetate=5 : 1, v/v) to give **18** and **17** (total 71 mg, 89%).

7*b*-Phenyl-7*bH*-oxazirino[2,3-*b*][1,2]benzisothiazole 3,3-dioxide (**25**). A mixture of 3-phenyl-1,2-benzisothiazole 1,1-

dioxide[24] (1.00 g, 4.1 mmol) in $CHCl_3$ (16 mL) and $NaHCO_3$ (1.05 g, 13 mmol) in water (12 mL) was cooled to 0 °C and rapidly stirred and *m*-chloroperbonzoic acid (2.20 g, 13 mmol) in $CHCl_3$ (30 mL) was added dropwise.[14] After the addition was complete, the solution was stirred overnight and the $CHCl_3$ solution was washed with 10% Na_2SO_3 and 10% $NaHCO_3$. After the solution was dried over K_2CO_3 at 0 °C, the solvent was removed. The residue was dissolved in a small amount of ethyl acetate and precipitated by slow addition of pentane with stirring to give the oxaziridine **25** (0.95 g, 89%). Mp 123 °C. IR (KBr) 1325 cm^{-1}. ^1H NMR ($CDCl_3$) δ=7.42 (5H, s), 7.53—7.68 (4H, m). Found: C, 59.94; H, 3.38; N, 5.26; S, 12.14%. Calcd for $C_{13}H_9NO_3S$: C, 60.22; H, 3.50; N, 5.40; S, 12.37%.

Stereoselective Preparation of 1,4-Diols 20a. To a THF (5 mL) solution of LiOTf (303 mg, 1.94 mmol) was added a THF (4 mL) solution of diethylamine (134 mg, 1.83 mmol) under an argon atmosphere, and cooled to −78 °C. Butyllithium (1.16 mL of a 1.54 M solution in hexane) was added and the solution was stirred at that temperature for 15 min followed by the addition of a THF (1 mL) solution of HMPA (0.62 mL, 3.56 mmol) and then cooled to −100 °C. A THF (4 mL) solution of **1A** (112 mg, 0.59 mmol) was added to the mixture and stirred for 2 h at that temperature, and then a THF (5 mL) solution of the oxaziridine **25** (465 mg, 1.79 mmol) was added. After being stirred for 30 min at −100 °C, the reaction was quenched with sat. NH_4Cl and extracted with ether. The combined extracts were washed with water and brine, dried over Na_2SO_4, and condensed under reduced pressure. Purification by column chromatography on silica gel (hexane: ethyl acetate=4 : 1, v/v) to give *t*-butyl *syn*-2,5-dihydroxyhexanoate (**20a**) and the *anti*-isomer **21a** (total 101 mg, 83%) in a ratio 92 : 8, respectively. The *syn*-and *anti*-isomers **20a** and **21a** could not be separated, and in ^1H NMR (90 MHz) spectrum, two isomers were indistinguishable. IR (neat) 3380, 1725 cm^{-1}. ^1H NMR ($CDCl_3$) δ=1.18 (3H, d, J=6.0 Hz), 1.35—1.99 (4H, m), 1.47 (9H, s), 2.16—2.68 (2H, m), 3.62—4.03 (1H, m), 4.21—4.41 (1H, m). Analytical data for the corresponding diacetate; Found: C, 58.07; H, 8.36%. Calcd for $C_{14}H_{24}O_6$: C, 58.31; H, 8.39%.

Stereoselective preparation of **20b** was carried out by the same procedure. The resulting diols **20b** and **21b** were isolated as corresponding diacetates by the treatment with acetic anhydride, pyridine and a catalytic amount of 4-dimethylaminopyridine because the diols **20b** and **21b** were not separable from generated sulfonyl imine.

t-Butyl *syn*-2,5-diacetoxyhexanoate and *anti*-isomer: IR (neat) 1735 cm^{-1}. ^1H NMR ($CDCl_3$) δ=0.63—2.32 (13H, m), 1.47 (9H, s), 2.02 (3H, s), 2.09 (3H, s), 4.64—5.06 (2H, m). ^{13}C NMR ($CDCl_3$) δ=13.90, 20.53, 21.02, 22.56, 27.06, 27.52, 28.06, 29.63, 33.83, 72.51, 73.51 (*syn*), 73.70 (*anti*), 82.02, 169.02, 170.13, 170.48. Found: C, 61.65; H, 9.21%. Calcd for $C_{17}H_{30}O_6$: C, 61.79; H, 9.15%.

Conversion of 20a and 21a to 30 and 31. g) *t*-Butyl 2,5-bis(*t*-butyldimethylsilyloxy)hexanoate (**26**). A 3 : 1 mixture of dihydroxy esters **20a** and **21a** (total 291 mg, 1.42 mmol), triethylamine (446 mg, 4.41 mmol), *t*-butyldimethylsilyl chloride (572 mg, 3.80 mmol), and a catalytic amount of 4-dimethylaminopyridine in DMF (10 mL) was stirred for 2 d at room temperature under an argon atmosphere. The reaction was quenched with ice, and extracted with ether. The ethereal extracts were washed with water and brine, dried over Na_2SO_4, and condensed in vacuo. Purification by column chromatography on silica gel (hexane: ethyl acetate=15 : 1, v/v) afforded **26** (613 mg, 99%). IR (neat) 1745 cm^{-1}. ^1H NMR ($CDCl_3$) δ=0.01 (3H, s), 0.04 (6H, s), 0.07 (3H, s), 0.88 (9H, s), 0.89 (9H, s), 1.08 (3H, d, J=6.0 Hz), 1.26—1.96 (4H, m), 1.43 (9H, s), 3.48—4.14 (2H, m). h) 5-*t*-Butyldimethylsilyloxy-1,2-hexanediol (**27**). To a THF (10 mL) solution of **26** (613 mg, 1.42 mmol) was added lithium aluminum hydride (125 mg, 3.30 mmol) under an argon atmosphere, and stirred overnight. The mixture was quenched with sat. aqueous Na_2SO_4 (3 mL) and the resulting precipitate was filtered off. The condensed filtrate was purified by TLC on silica gel (ethyl acetate) to give the monosilylated **27** (274 mg, 78%). IR (neat) 3350 cm^{-1}. ^1H NMR ($CDCl_3$) δ=0.07 (6H, s), 0.88 (9H, s), 1.12 (3H, d, J=6.0 Hz), 1.27—1.60 (4H, m), 3.13—4.03 (4H, m), 3.37 (2H, br s). i,j) 5-*O*-(*t*-Butyldimethylsilyl)-2,6-hexanediol (**29**). A mixture of **27** (55 mg, 0.22 mmol) and *p*-toluenesulfonyl chloride (67 mg, 0.36 mmol) in pyridine (3 mL) was stirred at −10 °C for 6 h, then 0 °C overnight under an argon atmosphere. The reaction mixture was quenched with ice, extracted with CH_2Cl_2, dried over Na_2SO_4, and condensed under reduced pressure. Purification by preparative TLC on silica gel (hexane: ethyl acetate=3 : 1, v/v) gave **28** (51 mg). Then to a MeOH (3 mL) solution of **28** was added sodium methoxide (1.15 mL of a 0.12 M solution in MeOH) under an argon atmosphere, and was stirred at room temperature overnight. After the addition of sat. aqueous NH_4Cl the mixture was extracted with CH_2Cl_2, dried over Na_2SO_4, and condensed in vacuo to give a crude epoxide. Next, the crude epoxide was dissolved in THF (5 mL) and cooled to 0 °C. To the solution was added lithium aluminum hydride (0.25 mL of a 1.54 M solution in ether), and stirred at room temperature overnight. After the addition of sat. aqueous Na_2SO_4 (0.1 mL), the resulting precipitate was filtered off and the filtrate was condensed. Purification by preparative TLC on silica gel (hexane: ethyl acetate=4 : 1, v/v) furnished **29** (26 mg, 50% from **27**). IR (neat) 3350 cm^{-1}. ^1H NMR (CCl_4) δ=0.03 (6H, s), 0.87 (9H, s), 1.10 (3H, d, J=6.4 Hz), 1.28—1.65 (4H, m), 1.83—2.28 (1H, m), 3.35—3.98 (1H, m). k) *O*-Bis(*t*-butyldimethylsilyl)-2,5-hexanediol (**30** and **31**). **29** (25 mg, 0.11 mmol) was silylated as described above to give bis(silyl) ether **30** and **31** (35 mg, 93%). ^1H NMR ($CDCl_3$) δ=0.05 (12H, s), 0.88 (18H, s), 1.08 (6H, d, J=6.0 Hz), 1.16—1.52 (4H, m), 3.30—3.90 (2H, m). ^{13}C NMR ($CDCl_3$) δ=−4.65, −4.32, 18.23, 23.86, 25.98, 35.80 (**30**), 35.89 (**31**), 68.68 (**30**), 68.99 (**31**). The ^{13}C NMR spectrum of the major isomer **30** was agreed with that of the authentic sample derived from *dl*-2,5-hexanediol.[16]

The authors are grateful to Professor Teruaki Mukaiyama for valuable discussion during this work.

References

1) a) P. A. Bartlett, *Tetrahedron*, **36**, 2 (1980); b) M. T. Reetz, *Angew. Chem., Int. Ed. Engl.*, **23**, 556 (1984); c) "Asymmetric Synthesis," ed by J. D. Morrison, Academic Press, Inc., New York (1984), Vol. 3.

2) a) P. A. Bartlett and K. K. Jernstedt, *J. Am. Chem. Soc.*, **99**, 4829 (1977); b) T. Fukuyama, B. Vranesic, D. P. Negri, and Y. Kishi, *Tetrahderon Lett.*, **1978**, 2741; c) D. A. Evans, J. Bartroli, and T. Godel, *ibid.*, **23**, 4577 (1982); d) M. Hirama and M. Uer, *ibid.*, **23**, 5307 (1982); e) Y. F. Wang, T. Izawa, S. Kobayashi, and M. Ohno, *J. Am. Chem. Soc.*, **104**,

6465 (1982); f) Y. Matsumura, J. Fujiwara, K. Maruoka, and H. Yamamoto, *ibid.*, **105**, 6312 (1983); g) M. Hirama, T. Shigemoto, Y. Yamazaki, and S. Ito, *ibid.*, **107**, 1797 (1985); h) Y. Yamamoto, T. Komatsu, and K. Maruyama, *J. Chem. Soc., Chem. Commun.*, **1985**, 814.

3) K. Narasaka and F. C. Pai, *Tetrahedron*, **40**, 2233 (1984); K. Narasaka, Y. Ukaji, and S. Yamazaki, *Bull. Chem. Soc. Jpn.*, **59**, 525 (1986).

4) M. T. Reetz, K. Kesseler, S. Schmidtberger, B. Wenderoth, and R. Steinbach, *Angew. Chem., Int. Ed. Engl.*, **22**, 989 (1983); S. R. Wilson and M. F. Price, *Tetrahedron Lett.*, **24**, 569 (1983); J. E. Bäckball, J. E. Nyström, and R. E. Nordberg, *J. Am. Chem. Soc.*, **107**, 3676 (1985) and the references cited therein.

5) Preliminary work of the stereoselective alkylation reaction and aldol reaction of δ-hydroxy esters has been briefly reported as communications; K. Narasaka and Y. Ukaji, Chem. Lett., **1986**, 81: K. Narasaka, Y. Ukaji, and K. Watanabe, *ibid.*, **1986**, 1755.

6) G. Fráter, U. Muller, and W. Gunter, *Tetrahedron*, **40**, 1269 (1984) and the references cited therein; D. Seebach, H. F. Chow, R. F. W. Jackson, K. Lawson, M. A. Sutter, S. Thaisrivongs, and J. Zimmermann, *J. Am. Chem. Soc.*, **107**, 5292 (1985).

7) The relative stereochemistry of δ-hydroxy-α-substituted esters is presented according to the Masamune's nomenclature using *syn* and *anti* terms; S. Masamune, S. A. Ali, D. L. Snitman, and D. S. Garvey, *Angew. Chem., Int. Ed. Engl.*, **19**, 557 (1980).

8) R. E. Ireland, R. H. Mueller, and A. K. Willard, *J. Am. Chem. Soc.*, **98**, 2868 (1976).

9) The geometry of the ester enolates is referred using *cis* and *trans* terms; C. H. Heathcock, C. T. Buse, W. A. Kleschick, M. C. Pirrung, J. E. Sohn, and J. Lampe, *J. Org. Chem.*, **45**, 1066 (1980).

10) a) G. Favini, C. Rubino, and R. Todeschini, *J. Mol. Struct.*, **41**, 305 (1977); b) N. L. Allinger and J. T. Sprague, *J. Am. Chem. Soc.*, **94**, 5734 (1972).

11) Alkylation reaction of 5-hexanolide with methyl iodide gave 1:1 mixture of *cis*- and *trans*-2-methyl-5-hexanolide, see: W. H. Pirkle and P. E. Adams, *J. Org. Chem.*, **44**, 2169 (1979).

12) Recent stereoselective syntheses of *cis*-2-methyl-5-hexanolide, see: K. Mori and S. Senda, *Tetrahedron*, **41**, 541 (1985); J. E. Bäckvall, S. E. Byström, and J. E. Nystrom, *ibid.*, **41**, 5761 (1985).

13) Recently Masamune, Roush, and Rathke reported that lithium halides are effective for the generation of carbanions in Horner-Wadsworth-Emmons reaction using weak bases such as amines; M. A. Blanchette, W. Choy, J. T. Davis, A. P. Essenfeld, S. Masamune, W. R. Roush, and T. Sakai, *Tetrahedron Lett.*, **25**, 2183 (1984); M. W. Rathke and M. Nowak, *J. Org. Chem.*, **50**, 2624 (1985).

14) F. A. Davis, J. Lamendola, Jr., U. Nadir, E. W. Kluger, T. C. Sedergran, T. W. Panunto, R. Billmers, R. Jenkins, Jr., I. J. Turchi, W. H. Watson, J. S. Chen, and M. Kimura, *J. Am. Chem. Soc.*, **102**, 2000 (1980).

15) In contrast to oxaziridines, we found MoOPH to be none stereoselective, and O_2 to be far less reactive.

16) R. M. Dodson and V. C. Nelson, *J. Org. Chem.*, **33**, 3966 (1968).

17) R. Chong and P. S. Clezy, *Aust. J. Chem.*, **20**, 123 (1967).

18) A. L. McCloskey, G. S. Fonken, R. W. Kluiber, and W. S. Johnson, *Org. Synth.*, Coll. Vol. IV, 261 (1963).

19) H. Stetter and W. Dieirchs, *Chem. Ber.*, **85**, 61 (1952).

20) B. Anilin and S. Fabrik, *Chem. Abstr.*, **54**, 16387b (1960).

21) Two isomers of 2,5-dibutylcyclopentanone were separated by column chromatography and the geometry was determined by Irvine's procedure; J. L. Irvine, I. H. Hall, G. L. Carlson, and C. Piantadosi, *J. Org. Chem.*, **37**, 2033 (1972).

22) G. Mehta and P. N. Pandey, *Synthesis*, **1975**, 404.

23) S. K. Chaudhary and O. Hernandez, *Tetrahedron Lett.*, **1979**, 99.

24) R. A. Abramovitch, E. M. Smith, M. Humber, B. Purtschert, P. C. Srinivasan, and G. M. Singer., *J. Chem. Soc., Perkin Trans., 1*, **1974**, 2589.