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Use of 1,3-Dioxin-4-ones and Related Compounds in Synthesis. XLIV.1) Asymmetric Aldol Reaction of 4-Trimethylsiloxy-6-methylene-1,3-dioxines: Use of Tartaric Acid-Derived (Acyloxy)borane Complex as the Catalyst

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A novel enantioselective synthesis of 1,3-dioxin-4-ones having a 2-hydroxylated alkyl group at the 6-position has been accomplished by chiral tartaric acid-derived acylborane-mediated aldol condensation of the silyl enol ether derived from 6-methyl-derivatives of 1,3-dioxin-4-one with achiral aldehydes.

Keywords Mukaiyama aldol reaction; asymmetric aldol reaction; 6-methyl-1,3-dioxin-4-one; chiral (acyloxy)borane complex; monoacylated tartaric acid–borane complex; goniothalamin

Previously, we have accomplished the enantioselective synthesis of 1,3-dioxin-4-ones having a 2,3-dihydroxylated alkyl group at the 6-position from the silyl enol ethers (**2**)2) derived from the 6-alkylated dioxinones (*e.g.* **1**) by utilizing titanium tetrachloride-mediated aldol condensation with chiral α-alkoxy aldehydes.3) Due to ready manipulation of the dioxinone ring to a variety of three-carbon units,4) we have utilized 1,3-dioxin-4-ones having a hydroxylated alkyl group at the non-acetal carbon as intermediates for a variety of EPC (enantiomerically pure compounds) syntheses.5) Though chiral Lewis acid-mediated reactions have been recognized as useful tools for the enantioselective formation of carbon–carbon bonds, few examples of aldol reaction of silyl ketene acetals with aldehydes by the use of chiral catalysts had been known before 1989.6) Since 1990, however, this has become an active field for synthetic chemists. Thus, many researchers have reported the synthesis of new chiral Lewis acids and applied them to promote asymmetric aldol and related reactions.7−9) One obvious advantage to the use of chiral catalysts for EPC synthesis compared to other methods is the ability to create chiral compounds without consuming any chiral material. Furthermore, it is better than a chiral pool approach, because both enantiomers of the target molecule could be synthesized by using both enantiomers as the ligands for the catalysts. Among the catalysts so far reported, chiral borane complexes are the most promising. This paper describes asymmetric aldol condensation reactions of the silyl enol ethers (**2** and **2′**) of 2,2,6-trimethyl-1,3-dioxin-4-one (**1**) and the corresponding 2,2-spiro-linked pentamethylene derivative (**1′**) with achiral aldehydes utilizing chiral tartaric acid-derived (acyloxy)borane complexes, originally reported by Yamamoto *et al.*10)

The reasons for this choice are as follows: 1) both tartaric acids (natural and non-natural) are readily available and 2) though in some silyl enol ethers high enantiomeric excess's (ee's) were realized, the details of mechanism have not yet been clarified and there is some possibility that the silyl atom may participate in the reaction.7b,11) In our case, however, the reaction site is a C-3 unit apart from the silyl group, whereas in the simple silyl enol ethers the departure is only a C-1 unit away and hence, the results of the former reactions may afford some extra information for clarification of the mechanism of the latter reactions.

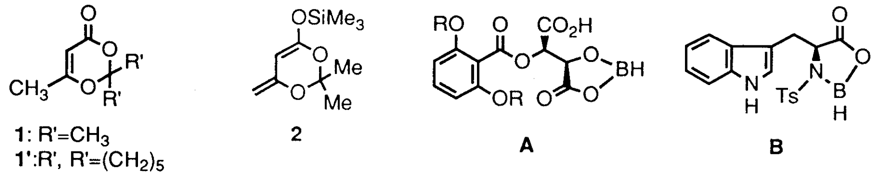
Results and Discussion

Asymmetric Aldol Reaction Using Monoacylated Tartaric Acid–Borane Complex as the Catalyst At first, the aldol reaction of **2′** with *trans*-cinnamaldehyde was carried out by using chiral borane complex catalysts derived either from monoacylated tartaric acid (**A**)10) or from tryptophan (**B**)7a) as the catalysts.

Though the chemical yields of the expected aldol condensation product were satisfactory in both cases, only the former catalyst gave satisfactory ee's and the best ee attained by use of the latter catalyst was only 29%.

In order to find the best condition for the chiral (acyloxy)borane complex derived from natural tartaric acid as the catalyst [throughout this paper, the complexes (**6**) are abbreviated as CAB complexes], we carried out the reaction between **2** and benzaldehyde under various conditions. First, the substituent effect of various ligands in the CAB complexes (**6**) was examined. The amount of the catalyst was 50 mol% and dichloromethane was used as the solvent. The ee's of the products were determined by HPLC analysis using a chiral column (chiralcel OD). The result of this study as well as experiments in other solvents are summarized in Table I.

The extent of asymmetric induction largely depended



1: R′=CH_3
1′:R′, R′=$(CH_2)_5$
2
A
B

Chart 1

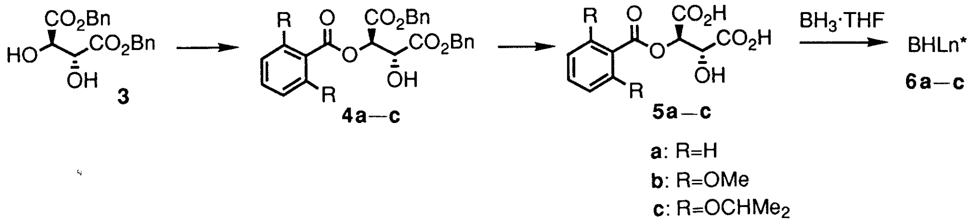
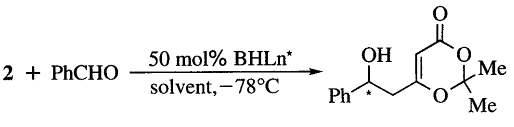


Chart 2

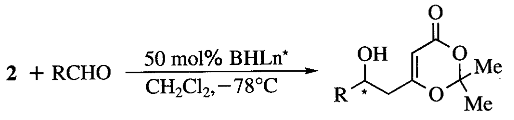
Table I. The CAB-Catalyzed Asymmetric Aldol Reaction of **2** with Benzaldehyde



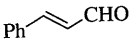
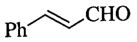
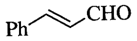
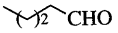
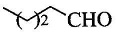
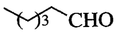
(+)-**7**

Entry	BHLn*	Solvent	Yield (%)	ee (%)
1	**6a**	CH_2Cl_2	79	46
2	**6b**	CH_2Cl_2	69	67
3	**6b**	C_2H_5CN	68	44
4	**6b**	Toluene–CH_2Cl_2	50	61
5	**6c**	CH_2Cl_2	74	52

Table II. The CAB-Catalyzed Asymmetric Aldol Reaction of **2** with a Variety of Aldehydes in Dichloromethane



8: R=PhCH=CH
9: R=$CH_3(CH_2)_3$
10: R=$CH_3(CH_2)_4$

Entry	Aldehyde	BHLn*	Yield (%)	ee (%)[a]
6		**6b**	84	62
7		**6b**	56	73[b]
8		**6c**	63	38
9		**6b**	52	70
10		**6c**	45	64
11		**6b**	44	73[b]

a) Determined by HPLC analysis using a chiral column (Chiralcel OD). *b*) Slow addition of **2** and the aldehyde to the CAB complex solution.

on the acyl moiety of tartaric acid derivatives, and **6b** revealed the highest asymmetric induction among the tartaric acid derivatives tested so far. Also, the enantioselectivities of these reactions showed solvent dependency. Thus, as shown in entry 3, use of propionitrile as the solvent resulted in lowering of the ee to 44%.

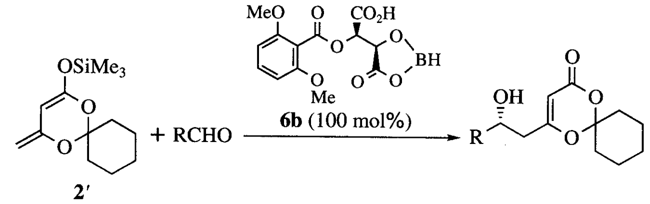
These trends apparently relate to the structure of the transition state of the reaction and much effort has been made to clarify the mechanism. For example, Yamamoto recently reported that the boron atom might form a five-membered ring structure with the α-hydroxy acid moiety of tartaric acid and the remaining carboxyl group might not be bonded to the boron atom (*cf.* **A**).[10b] However, the mechanism of the reaction seems to be not completely elucidated.

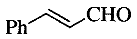
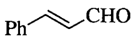
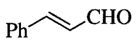
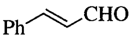
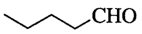
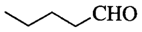
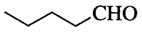
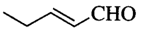
The same reactions were then carried out in dichloromethane using *trans*-cinnamaldehyde, *n*-valeraldehyde, and hexanal. The ee (determined by HPLC analysis) was nearly 70% in every case, when the tartaric acid derivative (**5b**) was used as the ligand (Table II). It should be noted that slow addition[9] of **2** and the aldehyde simultaneously to the CAB complex resulted in an increase in the enantioselectivity from 62 to 73% ee (entry 7).

Next, the aldol reaction of **2′** with a variety of aldehydes using the CAB catalyst (**6b**) was examined. As shown in Table III, the chemical and optical yields were very similar to those obtained by the use of **2**.

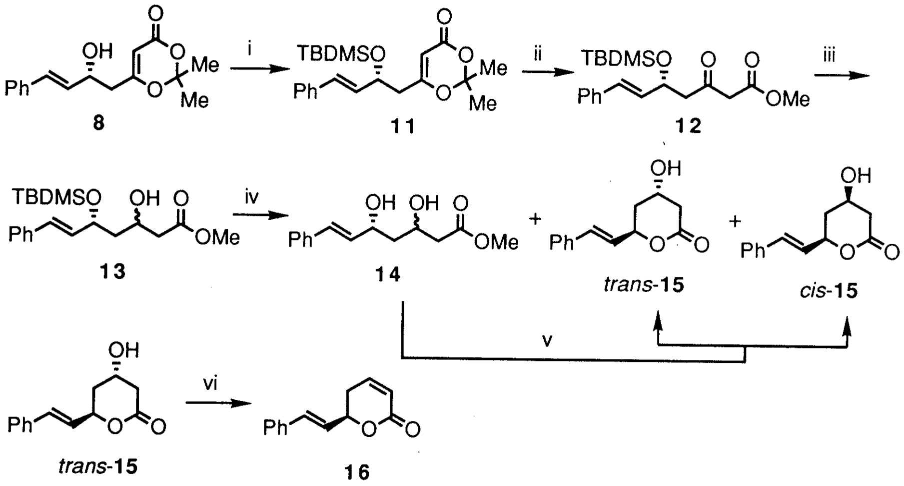
Finally, the effect of the amounts of the CAB catalyst (**6b**) on this reaction was investigated using *trans*-cinnamaldehyde as the substrate. It was found that the

Table III. The CAB-Catalyzed Aldol Reaction of **2′** with a Variety of Aldehydes



Entry	Aldehyde	Solvent	Temp. (°C)	Yield (%)	ee (%)[a]
12		CH_2Cl_2	−78	72	72
13		CH_2Cl_2	−98	93	76
14		CH_2Cl_2–Et_2O	−78	59	73
15		THF	−78	60	67
16		CH_2Cl_2	−78	53	69
17		CH_2Cl_2	−98	39	64
18		CH_2Cl_2	−40	19	57
19		CH_2Cl_2	−78	57	50
20	PhCHO	CH_2Cl_2	−78	61	73
21	PhCHO	CH_2Cl_2	−98	91	73

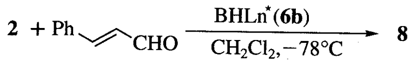
[a] Determined by HPLC analysis using a chiral columns (Chiralcel OD, OJ).



i) TBDMSCl, imidazole, DMF; ii) MeOH, toluene, Δ; iii) $NaBH_4$, MeOH; iv) aq. AcOH, THF; v) AcOH, 50 °C; vi) MsCl, Et_3N, CH_2Cl_2, -35 °C

Chart 3

Table IV. Effect of Amount of the CAB Catalyst (**6b**)[a]



Entry	BHLn* (mol%)	Yield (%)	ee (%)
22	20	25	73
23	30	42	73
24	50	56	73
25	100	87	73

[a] Slow addition of **2** and the aldehyde to the CAB complex solution.

use of increased amounts of the catalyst resulted only in an enhancement of the chemical yield, but not in an improvement of the ee (Table IV).

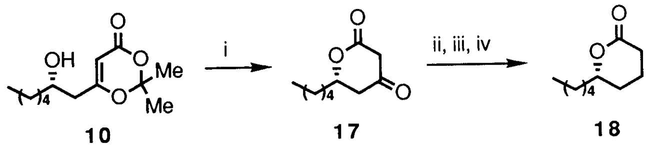
Fortunately, the optically pure compound **8** was obtained when the crude aldol adduct was recrystallized from ether.

Determination of the Absolute Structures of the Products and their Use for the Synthesis of Natural Products Goniothalamin[12] was isolated from *Cryptocarya caloneura*. We wished to utilize the aldol condensation product obtained in the above work for the EPC synthesis of this natural product, goniothalamin (**16**). Thus, the optically pure alcohol (**8**) was protected with a silyl group and the silyl ether (**11**) was converted into the β-keto ester (**12**) by heating in toluene containing methanol. Reduction of the carbonyl group of **12** followed by treatment with aqueous acetic acid gave **14** (a mixture of the two diastereomers) and **15** (a mixture of *trans* and *cis* isomers) in 82% and

16% yields, respectively. The lactones (*trans*- and *cis*-**15**)[13] were also obtained in 48% and 24% yields, respectively, when **14** was heated in acetic acid. Treatment of *trans*-**15** with mesyl chloride in the presence of triethylamine gave natural (*R*)-goniothalamin (**16**), whose absolute configuration was determined by comparison of the specific rotation with that of an authentic specimen.[13,14] Thus, the newly formed chiral center of the aldol condensation product should have *R*-configuration.

The absolute configuration of the alcohol **10** obtained from **2** in the same manner was determined by the following experiments. Thus **10** was subjected to the one-pot lactonization to give the δ-lactone (**17**). The optically pure lactone (**17**) obtained by recrystallization of the crude product from ether was treated with acetyl chloride and the product was then subjected to catalytic hydrogenation to give the (*S*)-lactone (**18**). The absolute configuration of the lactone was determined as assigned by comparison of the specific rotation with that of an authentic specimen.[15,16]

The absolute structures of some of the aldol condensation products derived from **2′** were also determined as shown in Chart 5. Thus, the product **8′** was converted to **12** in the same manner as in the conversion of **8** to **12**. The product **19′** was hydrogenated to give the dihydro derivative (**9′**), and methoxide-mediated dioxinone cleavage reaction[5a] then gave **20**. The stereostructure of **20** as well as that of the corresponding α-pyrone (**21**) were determined by comparison of their optical rotation values with those of authentic specimens.[16] Finally, the product (**22′**) was silylated in the usual manner and the silyl ether thus obtained was heated in the presence of water to give **24**. Clearly, this product was generated *via* initial formation of **23** followed by spontaneous decarboxylation. Deprotection of the silyl group in **24** gave **25**, whose optical rotation was positive, indicating *R*-configuration at the chiral center.[17]



i) K_2CO_3, MeOH; ii) recrystallization; iii) AcCl, pyridine, CH_2Cl_2; iv) H_2/Pd-C, AcOEt

Chart 4

Conclusion

From the absolute configurations of **8**, **8′**, **10**, **19′**, and **22′** thus determined, it seems reasonable to assume that the CAB catalyst (derived from natural tartaric acid) may cover the *si* face of the carbonyl group in the substrate and, hence, the nucleophile approaches the opposite (*re*) face.[10a] Although the absolute configuration of some of the products has not been determined, it seems likely that the absolute stereochemistry of the other products should be as indicated.

On the basis of the above result, the transition-state assembly (**C**) has emerged as the most likely representation for these reactions. The donor–acceptor interaction between the CAB catalyst and the aldehyde favors the positioning of the formyl carbon above the benzoyl π-cloud with parallel π-stacking and the carbonyl bond lying above the center of the phenyl ring. In addition to their electron-donating effect, the dimethoxyl groups are necessary to keep the carboxyl group and the phenyl ring in a perpendicular conformation and the orientation of the aldehyde as suggested may be caused by attractive dipole-dipole interaction between the aldehyde (+→) and the heterocyclic 5-membered ring (←+). A quite similar transition-state assembly (**D**) was proposed by Corey *et al.*[7a] for the aldol reaction catalyzed by the (*S*)-tryptophan-derived oxazaborolidine (**B**).

The CAB catalysts (monoacylated tartaric acids-borane complexes) used in this study exhibited the following characteristic features. 1) In general, good yields and moderate enantioselectivity were obtained with the predominating enantiomer being that corresponding to *re* face attack of the aldehydes (*cf.* **C**). 2) The enantioselectivity of the reactions showed solvent dependency and the use of CH_2Cl_2 as the solvent gave the best result. 3) The extent of asymmetric induction is largely dependent on the structure of the benzoyl portion in the catalyst. Introduction of two methoxy groups at the *ortho*-positions

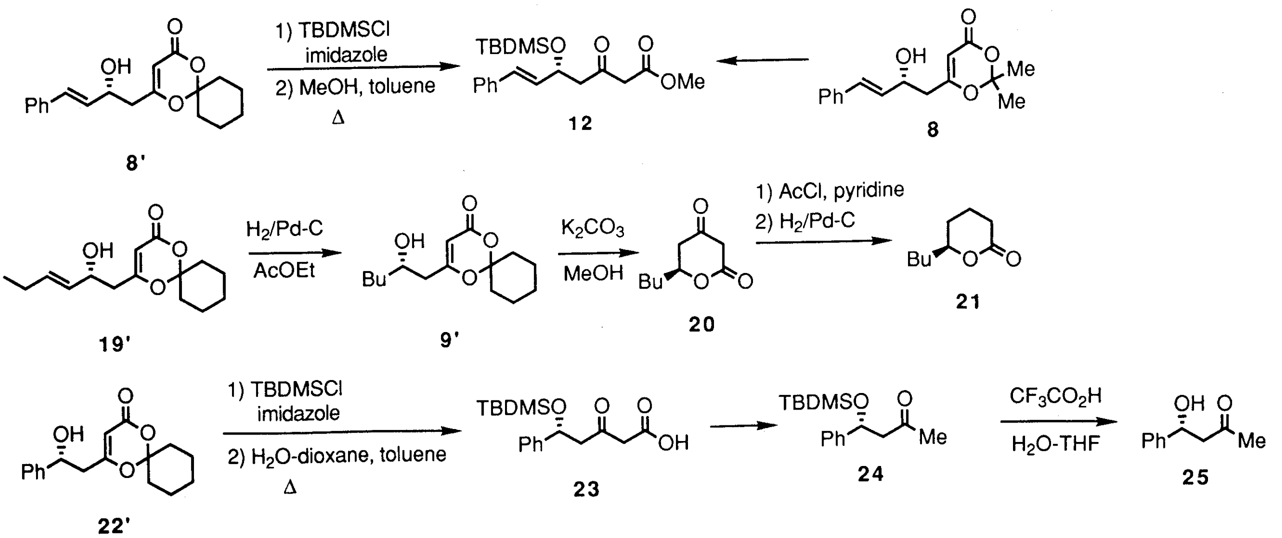
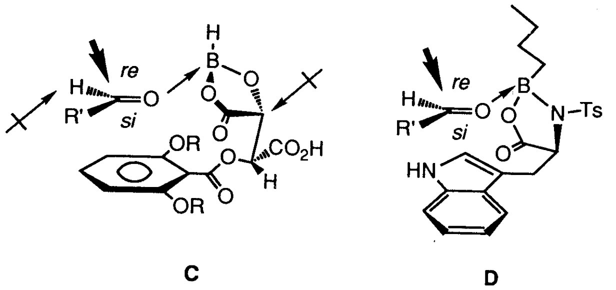


Chart 5



C

D

Chart 6

of the benzoyl group enhanced the enantioselectivity. On the contrary, two isopropoxy groups had no effect on the selectivity. 4) The chiral source (tartaric acids) is easily obtainable in both enantiomeric forms at low cost, and is recoverable after the reaction. 5) The use of an unnatural form of tartaric acid as a chiral source may be applicable to the preparation of the antipodal compounds of the dioxinones [(+)-**7** and **8**—**11**] derived from the natural tartaric acid.

Experimental

All melting points were determined on a Yanagimoto micro-hot stage and are uncorrected. Optical rotations were measured with a JASCO DIP-340 digital polarimeter. IR spectra were measured on a JASCO A-102 spectrophotometer and ^{1}H-NMR spectra were recorded on a JEOL JNM-PMX 60 SI or JEOL JNM-GX 500 spectrometer with tetramethylsilane as an internal standard; the abbreviations of signal patterns are as follows: s, singlet; d, doublet; t, triplet; q, quartet; m, multiplet; br, broad. High-resolution mass spectra were recorded on a JEOL JMS-DX-303 or JMS-AX-500 spectrometer. High-performance liquid chromatography (HPLC) was carried out on a Waters Associates instrument (M 6000 pump; U6K injector) using a 254 nm UV or RI detector. Wakogel (C-200) and Merck Kieselgel 60 F254 were employed for silica gel column and preparative thin layer chromatographies (PTLC), respectively. The ratios of solvent mixtures for chromatography are shown as volume/volume.

Benzyl (2*R*,3*R*)-3-Hydroxy-2-[(2,6-dimethoxybenzoyl)-oxy]butanedioate (4b) Dibenzyl tartrate [**3**, prepared from L-(+)-tartaric acid (1.0 eq) and benzyl bromide (2.0 eq) in the presence of DBU (3.0 eq) in DMF (10 g, 30.3 mmol)], DMAP (1.22 g, 10 mmol) and DCC (8.24 g, 40 mmol) were added to a solution of 2,6-dimethoxybenzoic acid (7.28 g, 40 mmol) in CH$_2$Cl$_2$ (180 ml) at 0 °C. The whole was stirred for 48 h at room temperature. The precipitated urea derivative was then filtered off and the filtrate was washed with 10% HCl and with saturated NaHCO$_3$ solution. The organic layer was dried over MgSO$_4$ and the solvent was evaporated *in vacuo*. The residue was purified by silica gel column chromatography [hexane–AcOEt (4 : 1)] to give **4b** (12.8 g, 86%) as a colorless oil. $[\alpha]_D^{22}$ $-59.8°$ ($c=0.92$, CHCl$_3$). High-resolution MS *m*/*z* Calcd for C$_{27}$H$_{26}$O$_9$ (M$^+$): 494.1575. Found: 494.1590. IR (CHCl$_3$): 3550, 1745 cm^{-1}. ^{1}H-NMR (CDCl$_3$) δ: 3.30 (1H, br s, OH), 3.73 (6H, s, OMe × 2), 4.80—5.10 (1H, m, CH), 5.17 (2H, d, $J=16.0$ Hz, PhC$\underline{H}$ × 2), 5.37 (2H, d, $J=16.0$ Hz, PhC$\underline{H}$ × 2), 6.00 (1H, d, $J=2.0$ Hz, CH), 6.53 (2H, d, $J=8.0$ Hz, Ar), 7.20—7.60 (11H, m, Ar).

Benzyl (2*R*,3*R*)-2-(Benzoyloxy)-3-hydroxybutanedioate (4a) Following the procedure given for preparation of **4b**, **3** and benzoic acid afforded **4a** in 70% yield as colorless needles of mp 122—123 °C (from CH$_2$Cl$_2$–hexane). $[\alpha]_D^{20}$ $+36.8°$ ($c=1.51$, CHCl$_3$). High-resolution MS *m*/*z* Calcd for C$_{25}$H$_{23}$O$_7$ (M$^+$+1): 435.1442. Found: 435.1485. IR (CHCl$_3$): 3560, 1742 cm^{-1}. ^{1}H-NMR (CDCl$_3$) δ: 3.20—3.70 (1H, br s, OH), 4.92 (1H, d, $J=2.5$ Hz, CH), 5.10—5.45 (4H, m, PhC$\underline{H}_2$ × 2), 5.72 (1H, d, $J=2.5$ Hz, CH), 7.00—8.10 (15H, m, Ph).

Benzyl (2*R*,3*R*)-3-Hydroxy-2-[(2,6-diisopropoxybenzoyl)oxy]-butanedioate (4c) Following the procedure given for preparation of **4b**, **3** and 2,6-diisopropoxybenzoic acid$^{17)}$ afforded **4c** in 74% yield as a colorless oil. $[\alpha]_D^{24}$ $-29.1°$ ($c=1.51$, CHCl$_3$). High-resolution MS *m*/*z* Calcd for C$_{31}$H$_{34}$O$_9$ (M$^+$): 550.2201. Found: 550.2215. IR (CHCl$_3$): 3560, 1745 cm^{-1}. ^{1}H-NMR (CDCl$_3$) δ: 1.27 (12H, d, $J=6.0$ Hz, Me × 4), 3.16 (1H, br s, OH), 4.53 (2H, septet, $J=6.0$ Hz, C$\underline{H}$Me$_2$ × 2), 4.80—5.00 (1H, m, OCH), 4.95—5.50 (4H, m, PhC$\underline{H}_2$ × 2), 5.83 (1H, d, $J=2.5$ Hz, OCH), 6.52 (2H, d, $J=8.5$ Hz, Ar), 7.26 (1H, t, $J=8.5$ Hz, Ar), 7.35 (10H, s, Ph × 2).

(2*R*,3*R*)-3-Hydroxy-2-[(2,6-dimethoxybenzoyl)oxy]butanedioic Acid (5b) A mixture of **4b** (3.0 g, 6.07 mmol), 10% Pd–C (500 mg) and AcOEt (40 ml) was shaken in hydrogen under atmospheric pressure for 40 min at room temperature. After filtration to remove the catalyst, the filtrate was concentrated. The residue was recrystallized from AcOEt to give **5b** (1.9 g, quant.) as colorless prisms of mp 187—188 °C. $[\alpha]_D^{26}$ $-69.2°$ ($c=1.71$, MeOH). Anal. Calcd for C$_{13}$H$_{14}$O$_9$: C, 49.68; H, 4.49. Found: C, 49.61; H, 4.61. IR (Nujol): 3300, 1740, 1720 cm^{-1}. ^{1}H-NMR (CDCl$_3$–CD$_3$OD, *ca.* 10 : 1) δ: 3.82 (6H, s, OMe × 2), 4.82 (1H, d, $J=2.0$ Hz, CH), 5.82 (1H, d, $J=2.0$ Hz, CH), 6.57 (2H, d, $J=9.0$ Hz, Ar), 7.37 (1H, t, $J=9.0$ Hz, Ar).

(2*R*,3*R*)-2-(Benzoyloxy)-3-hydroxybutanedioic Acid (5a) Following the procedure given for preparation of **5b**, **5a** was obtained from **4a** in a quantative yield as colorless powder of mp 211—212 °C (from AcOEt). $[\alpha]_D^{24}$ $-5.76°$ ($c=1.11$, MeOH). *Anal.* Calcd for C$_{11}$H$_{10}$O$_7$: C, 51.97; H, 3.97. Found: C, 51.96; H, 3.97. IR (Nujol): 3330, 1760, 1710 cm^{-1}. ^{1}H-NMR (CDCl$_3$–CD$_3$OD, *ca.* 10 : 1) δ: 4.88 (1H, d, $J=2.0$ Hz, CH), 5.73 (1H, d, $J=2.0$ Hz, CH), 7.20—7.70 (3H, m, Ar), 8.00—8.20 (2H, m, Ar).

(2*R*,3*R*)-3-Hydroxy-2-[(2,6-diisopropoxybenzoyl)oxy]butanedioic Acid (5c) Following the procedure given for preparation of **5b**, **5c** was obtained from **4c** in a quantative yield as a colorless oil. $[\alpha]_D^{25}$ $-23.6°$ ($c=1.46$, MeOH). High-resolution MS *m*/*z* Calcd for C$_{17}$H$_{22}$O$_9$ (M$^+$): 370.1262. Found: 370.1277. IR (CHCl$_3$): 3400, 1740 cm^{-1}. ^{1}H-NMR (CDCl$_3$–CD$_3$OD, *ca.* 10 : 1) δ: 1.31 (12H, d, $J=6.0$ Hz, Me × 4), 1.57 (2H, septet, $J=6.0$ Hz, C$\underline{H}$Me$_2$ × 2), 4.80 (1H, d, $J=2.0$ Hz, CH), 5.73 (1H, d, $J=2.0$ Hz, CH), 6.58 (2H, d, $J=8.5$ Hz, Ar), 7.15—7.45 (1H, m, Ar).

General Procedure for the CAB-Catalyzed Asymmetric Aldol Reaction of the Enol Silane (2) with Aldehydes Procedure A: BH$_3$·THF [1.0 M solution in THF (tetrahydrofuran), 0.5 ml, 0.5 mmol] was added to a mixture of monoacylated tartaric acid (**5b**) (157 mg, 0.5 mmol) and CH$_2$Cl$_2$ (2 ml) at 0 °C under an Ar atmosphere. The reaction mixture was stirred for 1 h at that temperature, during which period the evolution of hydrogen gas ceased, and then the solution was cooled to -78 °C. An aldehyde (1.0 mmol) was added to this solution and the whole was stirred for 20 min. Compound **2**$^{2)}$ (257 mg, 1.2 mmol) was added *via* a syringe over a 1 h period. Stirring was continued for 3 h, then the whole was poured into diluted HCl. After vigorous stirring for 1 h at room temperature, the product was extracted with CH$_2$Cl$_2$. The organic layer was dried over MgSO$_4$ and the solvent was evaporated *in vacuo*. The residue was purified by silica gel column chromatography to give the product. The aqueous layer was extracted with AcOEt–MeOH (97 : 3) and the organic layer was dried over MgSO$_4$. The crude **5b** (*ca.* 70—80%) was recovered after evaporation of the solvent *in vacuo*.

Procedure B: Compound **2** (257 mg, 1.2 mmol) and the aldehyde (1.0 mmol) were added simultaneously to a solution of the CAB complex (**6b**, 0.5 mmol) in CH$_2$Cl$_2$ (2 ml) over a 3 h period at -78 °C under an Ar atmosphere. Stirring was continued for 2 h at the same temperature, then the mixture was poured into diluted HCl. After vigorous stirring for 1 h at room temperature, the product was extracted with CH$_2$Cl$_2$. The organic layer was evaporated *in vacuo* and the residue was purified by silica gel column chromatography.

(+)-6-(2-Hydroxy-2-phenylethyl)-2,2-dimethyl-1,3-dioxin-4-one [(+)-7] Following procedure A, **2** (257 mg, 1.2 mmol) and benzaldehyde (106 mg, 1.0 mmol) afforded (+)-**7** (171 mg, 69%) as a solid. $[\alpha]_D^{20}$ $+26.6°$ ($c=1.96$, CHCl$_3$). The ee was 67% by HPLC analysis (Chiralcel OD; eluent, hexane : iso-PrOH = 7 : 3; flow rate, 0.7 ml/min). The IR and ^{1}H-NMR data were identical with those reported.$^{4a)}$

(*R*)-6-[(*E*)-2-Hydroxy-4-phenylbut-3-enyl]-2,2-dimethyl-1,3-dioxin-4-one (8) Following procedure B, **2** (257 mg, 1.2 mmol) and *trans*-cinnamaldehyde (132 mg, 1.0 mmol) afforded **8** (153 mg, 56%) as a solid with 73% ee. The solid was recrystallized twice from ether to give enantiomerically pure **8** as colorless needles of mp 88—88.5 °C. $[\alpha]_D^{24}$ $+7.2°$ ($c=1.38$, CHCl$_3$). The ee was >99% by HPLC analysis (Chiralcel OD; eluent, hexane : iso-PrOH = 7 : 3; flow rate, 0.8 ml/min). *Anal.* Calcd for C$_{16}$H$_{18}$O$_4$: C, 70.05; H, 6.61. Found: C, 70.05; H, 6.70. IR (CHCl$_3$): 3500, 1720 cm^{-1}. ^{1}H-NMR (CDCl$_3$) δ: 1.72 (6H, s, Me$_2$), 2.20 (1H, br s, OH), 2.53 (2H, d, $J=6.5$ Hz, C$_{1'}$-H), 4.58 (1H, q, $J=6.0$ Hz, C$_{2'}$-H), 5.36 (1H, s, C$_5$-H), 6.17 (1H, dd, $J=15.5$, 6.0 Hz, C$_{3'}$-H), 6.67 (1H, d,

J=15.5 Hz, $C_{4'}$-H), 7.33 (5H, s, Ph).

(+)-6-(2-Hydroxyhexyl)-2,2-dimethyl-1,3-dioxin-4-one (9) Following procedure A, **2** (257 mg, 1.2 mmol) and *n*-valeraldehyde (86 mg, 1.0 mmol) afforded **9** (119 mg, 52%) as a colorless oil. $[\alpha]_D^{25}$ +15.7° (c=2.14, $CHCl_3$). The ee was 70% by HPLC analysis (Chiralcel OD; eluent, hexane: iso-PrOH=96:4; flow rate, 0.6 ml/min). High-resolution MS *m/z* Calcd for $C_{12}H_{21}O_4$ (M^++1): 229.1439. Found: 229.1436. IR ($CHCl_3$): 3460, 1720 cm^{-1}. ^{1}H-NMR ($CDCl_3$) δ: 0.70—1.10 (3H, m, Me), 1.10—1.60 (6H, m, CH_2 × 3), 1.70 (6H, s, C_2-Me_2), 2.27 (1H, br s, OH), 2.37 (2H, d, J=6.0 Hz, $C_{1'}$-H), 3.60—4.10 (1H, m, $C_{2'}$-H), 5.32 (1H, s, C_5-H).

(*S*)-6-(2-Hydroxyheptyl)-2,2-dimethyl-1,3-dioxin-4-one (10) Following procedure B, **2** (257 mg, 1.2 mmol) and hexanal (100 mg, 1.0 mmol) afforded **9** (106 mg, 44%) as a colorless oil. $[\alpha]_D^{22}$ +14.5° (c=1.24, $CHCl_3$). The ee was 73% by HPLC analysis (Chralcel OD; eluent, hexane: iso-PrOH=96:4; flow rate, 0.6 ml/min). High-resolution MS *m/z* Calcd for $C_{13}H_{23}O_4$ (M^++1): 243.1595. Found: 243.1624. IR ($CHCl_3$): 3440, 1720 cm^{-1}. ^{1}H-NMR ($CDCl_3$) δ: 0.70—1.20 (3H, m, Me), 1.00—1.60 (8H, m, CH_2 × 4), 1.70 (6H, s, Me_2), 1.90 (1H, br s, OH), 2.37 (2H, d, J=5.8 Hz, $C_{1'}$-H), 3.60—4.10 (1H, m, $C_{2'}$-H), 5.32 (1H, s, C_5-H).

2-Methylene-4-trimethylsiloxy-1,5-dioxaspiro[5.5]undec-3-ene (2′) A solution of *n*-butyl lithium (1.6 M THF solution, 37.5 ml, 60 mmol) was added to a solution of diisopropylamine (6.2 g, 60 mmol) in dry THF (50 ml) and the mixture was stirred at −30 °C for 30 min. Compound **1** (5.50 g, 30 mmol) was added to the above solution at −78 °C with stirring. After 45 min, trimethylchlorosilane (11.5 ml, 90 mmol) was added over 30 min. The whole was stirred for 2 h at −78 °C and then allowed to warm to room tempereture. After evaporation of the solvent, the residue was distilled under reduced pressure to give **2′** as an oil of bp 77 °C (0.1 Torr). Yield, 4.9 g (64%). High-resolution MS *m/z* Calcd for $C_{13}H_{22}O_3Si$ (M^+): 254.1338. Found: 254.1314. IR ($CHCl_3$): 1668, 1636 cm^{-1}. ^{1}H-NMR ($CDCl_3$) δ: 0.26 (9H, s, $SiMe_3$), 1.76—1.87 [10H, m, –$(CH_2)_5$–], 3.66, 3.86 (each 1H, s, =CH_2), 4.39 (1H, s, C_3-H).

General Procedure for the CAB-Catalyzed Asymmetric Aldol Reaction of the Enol Silane (2′) with Aldehydes A solution of BH_3·THF (1.0 M solution in THF, 0.5 ml, 0.5 mmol) was added to a mixture of **5b** (157 mg, 0.5 mmol) and CH_2Cl_2 (2 ml) at 0 °C under an Ar atmosphere. The mixture was stirred for 1 h at 0 °C and then cooled to −78 °C. The aldehyde (0.5 mmol) was added to the solution and the whole was stirred at −78 °C for 30 min. Compound **2′** (143 mg, 0.6 mmol) was added, and the reaction mixture was stirred at −78 °C for 1 h. Then 10% HCl (2 ml) was added. The whole was stirred for 1 h at room temperature, and the product was extracted with CH_2Cl_2. The organic layer was dried over $MgSO_4$ and evaporated *in vacuo*. The residue was purified by silica gel chromatography to give the product.

(*S*)-2-(2-Hydroxy-2-Phenylethyl)-4-oxo-1,5-dioxaspiro[5.5]undec-2-ene (7′) The reaction of **2′** with benzaldehyde at −98 °C gave **7′**, 131 mg (91%), as a solid. $[\alpha]_D^{20}$ +22.8° (c=1.16, $CHCl_3$). The ee was 73% based on HPLC analysis (Chiralcel OD, eluent, hexane: iso-PrOH=7:3. *Anal.* Calcd for $C_{17}H_{20}O_4$: C, 70.81; H, 6.99. Found: C, 70.53; H, 7.09. IR ($CHCl_3$): 1720, 1641 cm^{-1}. ^{1}H-NMR ($CDCl_3$) δ: 1.42—2.05 (10H, m, –$(CH_2)_5$–), 2.73 (2H, d, J=7 Hz, $C_{1'}$-H_2), 2.73—3.23 (1H, br s, OH), 5.07 (1H, t, J=7 Hz, $C_{2'}$-H), 5.33 (1H, s, C_3-H), 7.10 (5H, s, Ph).

(*S*)-2-(2-Hydroxy-4-Phenyl-3-butenyl)-4-oxo-1,5-dioxaspiro[5.5]-undec-2-ene (8′) The reaction of **2′** with (*E*)-cinnamaldehyde at −98 °C gave **8′**, 128 mg (72%), as a solid. The ee was 73% based on HPLC analysis (Chiralcel OD, eluent, hexane: iso-PrOH=7:3). Recrystallization of this sample from a mixture of hexane and ether gave enantiomerically pure **8′** as needles of 83—84 °C. $[\alpha]_D^{22}$ +4.09° (c=0.83, $CHCl_3$). High-resolution MS *m/z* Calcd for $C_{19}H_{22}O_4$ (M^+): 314.1518. Found: 314.1520. IR ($CHCl_3$): 1722, 1634 cm^{-1}. ^{1}H-NMR ($CDCl_3$) δ: 1.04—2.14 (10H, m, –(CH_2)5–), 2.42 (2H, d, J=14.5 Hz, C_1'-H_2), 2.39—3.04 (1H, br s, OH), 4.49 (1H, t, J=14 Hz, $C_{2'}$-H), 5.23 (1H, s, C_3-H), 6.07 (1H, dd, J=16, 5 Hz, $C_{3'}$-H), 6.57 (1H, d, J=16 Hz, $C_{4'}$-H), 7.23 (5H, s, Ph).

(*R*)-2-(2-Hydroxy-3-hexenyl)-4-oxo-1,5-dioxaspiro[5.5]undec-2-ene (9′) The reaction of **2′** with pentanal at −78 °C gave **9′** as an oil. Yield, 71 mg (53%). The ee was 69% based on HPLC analysis (Chiralcel OJ, eluent, hexane: iso-PrOH=98:2). $[\alpha]_D^{20}$ +12.60° (c=1.19, $CHCl_3$). High-resolution MS *m/z* Calcd for $C_{15}H_{24}O_4$ (M^+): 268.1675. Found: 268.1699. IR ($CHCl_3$): 1730, 1643 cm^{-1}. ^{1}H-NMR ($CDCl_3$) δ: 1.00 (3H, t, CH_3), 1.16—2.30 (12H, m, –$(CH_2)_5$–, $C_{5'}$-CH_2), 3.48 (1H, s, OH), 4.42 (1H, q, J=6.6 Hz, $C_{2'}$-H), 5.31 (1H, s, C_3-H), 5.43—6.13 (2H, m, $C_{3'}$-H, $C_{4'}$-H).

(*R*)-2-(2-Hydroxy-3-hexenyl)-4-oxo-1,5-dioxaspiro[5.5]undec-2-ene (19′) The reaction of **2′** with (*E*)-2-hexenal gave the product as an oil. Yield, 76 mg (57%). Catalytic hydrogenation of this compound with 10% Pd–C (20 mg) in ethyl acetate gave compound **9′**, whose ee was 50% based on HPLC analysis.

(*R*)-6-[(3*E*)-2-(*tert*-Butyldimethylsilyloxy)-4-phenylbut-3-enyl]-2,2-dimethyl-1,3-dioxin-4-one (11) *tert*-Butyldimethylchlorosilane (426 mg, 2.84 mmol) and imidazole (290 mg, 4.27 mmol) were added to a solution of **8** (390 mg, 1.42 mmol) in DMF (3 ml) under ice-cooling. Stirring was continued for 2 h at room temperature, ice-water was added to the mixture and the whole was extracted with ether. The organic layer was dried over $MgSO_4$ and the solvent was evaporated *in vacuo*. The residue was purified by silica gel column chromatography [hexane–AcOEt (20:1)] to give **11** (545 mg, 99%) as a colorless oil. $[\alpha]_D^{24}$ +57.2° (c=1.83, $CHCl_3$). High-resolution MS *m/z* Calcd for $C_{19}H_{26}O_3Si$ (M^+ − Me_2CO): 330.1650. Found: 330.1632. IR ($CHCl_3$): 1720 cm^{-1}. ^{1}H-NMR ($CDCl_3$) δ: 0.09 (6H, s, $SiMe_2$), 0.92 (9H, s, *tert*-Bu), 1.67 (6H, s, Me_2), 2.48 (2H, d, J=6.0 Hz, CH_2), 4.58 (1H, q, J=6.0 Hz, $C_{2'}$-H), 5.30 (1H, s, C_5-H), 6.10 (1H, dd, J=15.5, 6.0 Hz, $C_{3'}$-H), 6.58 (1H, d, J=15.5 Hz, $C_{4'}$-H), 7.32 (5H, s, Ph).

Methyl (*R*,*E*)-5-(*tert*-Butyldimethylsilyloxy)-3-oxo-7-phenylhept-6-enoate (12) A solution of **11** (530 mg, 1.37 mmol) and absolute MeOH (96 mg, 3.0 mmol) in toluene (20 ml) was refluxed for 2.5 h. The solvent was evaporated *in vacuo*, and the residue was purified by silica gel column chromatography [hexane–AcOEt (30:1)] to give **12** (484 mg, 98%) as a colorless oil. $[\alpha]_D^{24}$ +70.6° (c=1.49, $CHCl_3$). High-resolution MS *m/z* Calcd for $C_{16}H_{21}O_4Si$ (M^+ − *tert*-Bu): 305.1208. Found: 305.1191. IR ($CHCl_3$): 1745, 1720 cm^{-1}. ^{1}H-NMR ($CDCl_3$, keto: enol form = *ca.* 6:1) δ: 0.06 (6H, s, $SiMe_2$), 0.90 (9H, s, *tert*-Bu), 2.30—2.90 (2H, m, CH_2), 3.50 (2H × 6/7, s, $COCH_2CO$), 3.71 (3H, s, OMe), 4.78 (1H, q, J=6.0 Hz, C_5-H), 5.03 (1H × 1/7, s, enol C_2-H), 6.10 (1H, dd, J=16.0, 6.0 Hz, C_6-H), 6.58 (1H, d, J=16.0 Hz, C_7-H), 7.31 (5H, s, Ph), 12.03 (1H × 1/7, s, OH).

Methyl (5*R*,*E*)-5-(*tert*-Butyldimethylsilyloxy)-3-hydroxy-7-phenylhept-6-enoate (13) Finely powdered $NaBH_4$ (28 mg, 0.74 mmol) was added to a solution of **12** (486 mg, 1.34 mmol) in MeOH (20 ml) under ice-cooling. The mixture was stirred for 5 min, the solvent was evaporated *in vacuo* and the residue was neutralized by the addition of diluted HCl and extracted with AcOEt. The organic layer was dried over $MgSO_4$ and the solvent was evaporated *in vacuo*. The residue was purified by silica gel column chromatography [hexane–AcOEt (10:1)] to give **13** (477 mg, 98%) as a colorless oil. $[\alpha]_D^{25}$ +51.2° (c=1.76, $CHCl_3$). High-resolution MS *m/z* Calcd for $C_{16}H_{23}O_4Si$ (M^+ − *tert*-Bu): 307.1364. Found: 307.1344. IR ($CHCl_3$): 3500, 1730 cm^{-1}. ^{1}H-NMR ($CDCl_3$) δ: 0.08 (6H, s, $SiMe_2$), 0.93 (9H, s, *tert*-Bu), 1.50—1.98 (2H, m, CH_2), 2.48 (2H, d, J=6.0 Hz, C_2-H), 3.50 (1H, br s, OH), 3.69 (3H, s, OMe), 4.00—4.50 (1H, m, C_3-H), 4.58 (1H, q, J=6.0 Hz, C_5-H), 5.93—6.40 (1H, m, C_6-H), 6.43—6.75 (1H, m, C_7-H), 7.34 (5H, s, Ph).

Methyl (5*R*,*E*)-3,5-Dihydroxy-7-phenylhept-6-enoate (14) A solution of **13** (467 mg, 1.28 mmol) in AcOH–THF–H_2O (2:1:1, 10 ml) was stirred for 24 h at room temperature. The solvent was evaporated *in vacuo*, and the residue was purified by silica gel column chromatography [hexane–AcOEt (3:1)] to give **14** (265 mg, 82%) as a colorless oil. Further elution with hexane–AcOEt (1:1) gave **15** (a mixture of *trans*- and *cis*-isomers, 46 mg, 16%) as a colorless oil. **14**: $[\alpha]_D^{24}$ +4.6° (c=1.58, $CHCl_3$). High-resolution MS *m/z* Calcd for $C_{14}H_{18}O_4$ (M^+): 250.1204. Found: 250.1193. IR ($CHCl_3$): 3480, 1730 cm^{-1}. ^{1}H-NMR ($CDCl_3$) δ: 1.60—1.90 (2H, m, CH_2), 2.53 (2H, d, J=6.5 Hz, CH_2CO), 3.10—3.90 (2H, m, OH × 2), 3.72 (3H, s, OMe), 4.00—4.80 (2H, m, CH × 2), 6.00—6.40 (1H, m, C_6-H), 6.67 (1H, d, J=16.0 Hz, C_7-H), 7.20—5.50 (5H, m, Ph).

(4*S*,6*R*,*E* and 4*R*,6*R*,*E*)-4-Hydroxy-6-(2-phenylethenyl)-tetrahydropyran-2-one (*trans*- and *cis*-15) A solution of **14** (170 mg, 0.68 mmol) in AcOH (6 ml) was stirred for 20 h at 50 °C. The solvent was evaporated *in vacuo*, and the residue was purified by silica gel column chromatography (ether) to give *trans*-**15** (71.2 mg, 48%) and *cis*-**15** (35 mg, 24%).

trans-**15**: mp 112—113 °C (from ether). $[\alpha]_D^{24}$ −8.5° (c=1.08, $CHCl_3$). *Anal.* Calcd for $C_{13}H_{14}O_3$: C, 71.54; H, 6.47. Found: C, 71.59; H, 6.54. IR ($CHCl_3$): 3450, 1730 cm^{-1}. ^{1}H-NMR ($CDCl_3$) δ: 1.62 (1H, br s, OH), 1.97 (1H, ddd, J=15.0, 11.0, 3.8 Hz, C_5-H), 2.10—2.16 (1H, m, C_5-H), 2.69 (1H, ddd, J=19.0, 4.0, 2.0 Hz, C_3-H), 2.81 (1H, dd, J=19.0, 5.0 Hz, C_3-H), 4.45 (1H, br quintet, J=4.0 Hz, C_4-H), 5.38 (1H, dddd, J=11.0, 6.5, 3.5, 1.5 Hz, C_6-H), 6.22 (1H, dd, J=16.5, 6.5 Hz, $C_{1'}$-H), 6.71 (1H, d, J=16.5 Hz, $C_{2'}$-H), 7.26—7.41 (5H, m, Ph). *cis*-**15**: mp 89—91 °C (from AcOEt–hexane). $[\alpha]_D^{26}$ $-10.2°$ ($c=1.22$, THF). *Anal.* Calcd for $C_{13}H_{14}O_3$: C, 71.54; H, 6.47. Found: C, 71.44; H, 6.50. IR ($CHCl_3$): 3450, 1730 cm^{-1}. ^{1}H-NMR ($CDCl_3$) δ: 1.63 (1H, br s, OH), 1.78—1.86 (1H, m, C_5-H), 2.38—2.44 (1H, m, C_5-H), 2.54 (1H, dd, $J=18.0$, 8.2 Hz, C_3-H), 2.98 (1H, dd, $J=18.0$, 6.2 Hz, C_3-H), 4.31—4.38 (1H, m, C_4-H), 4.85—4.91 (1H, m, C_6-H), 6.22 (1H, dd, $J=16.5$, 7.0 Hz, $C_{1'}$-H), 6.70 (1H, d, $J=16.5$ Hz, $C_{2'}$-H), 7.25—7.42 (5H, m, Ph).

(*R*)-(+)-Goniothalamin (16) MsCl (52.5 mg, 0.46 mmol) was added to a solution of *trans*-**15** (50 mg, 0.23 mmol) and Et_3N (93 mg, 0.92 mmol) in CH_2Cl_2 (2 ml) at -35 °C. Stirring was continued for 4 h, the whole was washed with brine, and the organic layer was dried over $MgSO_4$. The solvent was evaporated *in vacuo* and the residue was purified by silica gel column chromatography [hexane–AcOEt (1 : 1)] to give **16** (42 mg, 91%) as colorless needles of mp 76—77 °C (from ether–hexane). $[a]_D^{22}$ $+173.6°$ ($c=1.18$, $CHCl_3$) [lit.[14] $[\alpha]_D^{22}$ $+179°$ ($c=2$, $CHCl_3$)]. ^{1}H-NMR ($CDCl_3$) δ: 2.53—2.57 (2H, m, C_5-H), 5.08—5.14 (1H, m, C_6-H), 6.10 (1H, dt, $J=10.0$, 2.0Hz, C_3-H), 6.28 (1H, dd, $J=16.5$, 6.5 Hz, $C_{1'}$-H), 6.74 (1H, d, $J=16.5$ Hz, $C_{2'}$-H), 6.93 (1H, dt, $J=10.0$, 4.2 Hz, C_4-H), 7.27—7.42 (5H, m, Ph).

(*S*)-6-Pentyl-5,6-dihydropyran-2(3*H*),4-dione (17) A solution of **10** (484 mg, 2.0 mmol) and potassium carbonate (828 mg, 6.0 mmol) was stirred at room temperature overnight. The solvent was evaporated *in vacuo* and the residue was neutralized by the addition of diluted HCl and extracted with AcOEt. The organic layer was dried over $MgSO_4$ and the solvent was evaporated *in vacuo*. The residue was purified by silica gel column chromatography [hexane–AcOEt (3 : 1)] to give **17** (364 mg, 99%) as colorless needles of mp 86—88 °C (from ether). $[\alpha]_D^{24}$ $+69.7°$ ($c=1.22$, $CHCl_3$). The ee was >99% by HPLC analysis (Chiralcel OD). *Anal.* Calcd for $C_{10}H_{16}O_3$: C, 65.19; H, 8.75. Found: C, 65.10; H, 8.85. IR ($CHCl_3$): 1765, 1732 cm^{-1}. ^{1}H-NMR ($CDCl_3$) δ: 0.70—1.20 (3H, m, Me), 1.00—1.90 (8H, m, $CH_2 \times 4$), 2.30—2.76 (2H, m, C_5-H), 3.30 (1H, d, $J=19.0$ Hz, C_3-H), 3.70 (1H, d, $J=19.0$ Hz, C_3-H), 4.30—4.90 (1H, m, C_6-H).

(*S*)-6-Pentyltetrahydropyran-2-one (18) AcCl (69 mg, 0.88 mmol) was added to a solution of **17** (80 mg, 0.44 mmol) and pyridine (104 mg, 1.32 mmol) in CH_2Cl_2 (5 ml) under ice-cooling. The reaction mixture was stirred for 1 h at room temperature and the whole was washed with 10% HCl and then with brine. The organic layer was dried over $MgSO_4$ and the solvent was evaporated *in vacuo*. The residue was dissolved in AcOEt (3 ml) and the solution was shaken in the presence of 10% Pd–C (20 mg) in hydrogen under atmospheric pressure at room temperature for 30 min. After filtration to remove the catalyst, the filtrate was concentrated *in vacuo*. The residue was purified by silica gel column chromatography [hexane–AcOEt (10 : 1)] to give **18** (55.5 mg, 75%) as a colorless oil. $[\alpha]_D^{26}$ $-53.6°$ ($c=1.74$, MeOH) [the enantiomer of **18**: lit.[15] $[\alpha]_D$ $+55.6°$ (MeOH)].

Conversion of 8′ to 12 Following the procedure given for preparation of **12** from **8**, enantiomerically pure **8′** was treated with *tert*-butyldimethylchlorosilane to give the silyl ether derivative as an oil (yield, 100%). This product was refluxed in toluene (1 ml) and methanol (1 drop) for 1 h. After evaporation of the solvent, the residue was purified by PTLC to give **12** as an oil. $[\alpha]_D^{19}$ $+59.8°$ ($c=0.67$, $CHCl_3$).

(*S*)-6-Butyl-5,6-dihydropyran-2(3*H*),4-dione (20) A mixture of **9′** (52 mg, 0.2 mmol; obtained by the reaction of **2′** with *n*-pentanal), K_2CO_3 (55 mg), and methanol (1 ml) was stirred at room temperature for 12 h. The solvent was evaporated and the residue was acidified with 10% HCl. The mixture was extracted with CH_2Cl_2. The organic layer was dried over $MgSO_4$ and evaporated. Purification of the residue by PTLC gave **20** as an oil. Yield, 49 mg (100%). $[\alpha]_D^{20}$ $+34.28°$ ($c=0.49$, $CHCl_3$). High-resolution MS *m/z* Calcd for $C_9H_{14}O_3$ (M^+): 170.0943. Found: 170.0943. IR ($CHCl_3$): 1762, 1735 cm^{-1}. ^{1}H-NMR ($CDCl_3$) δ: 0.938 (3H, t, $J=7.0$ Hz, CH_3), 1.310—1.910 (6H, m, $C_{1'}$-H, $C_{2'}$-H, $C_{3'}$-H), 2.451 (1H, dd, $J=18.7$, 11.3 Hz, C_5-H), 2.696 (1H, dd, $J=18.7$, 2.93 Hz, C_5-H), 3.427 (1H, d, $J=19$ Hz, C_3-H), 3.580 (1H, d, $J=9$ Hz, C_3-H), 4.573—4.687 (1H, m, C_6-H).

(*S*)-6-Butyltetrahydropyran-2-one (21) Following the procedure given for conversion of **17** to **18**, compound **20** (49 mg, 0.29 mmol) was first treated with acetyl chloride to give the enol acetate (oil), which was hydrogenated with 10% Pd–C. Purification of the oily product by PTLC gave **21** (5.6 mg, 16% from **20**) as an oil. $[\alpha]_D^{20}$ $-23.57°$ ($c=0.56$, $CHCl_3$) [the enantiomer of **21**: lit.[16] $[\alpha]_D^{22}$ $+53.9°$ ($c=0.65$, $CHCl_3$)]. The IR and ^{1}H-NMR data were identical with the reported values.

(*R*)-4-(*tert*-Butyldimethylsiloxy)-4-phenyl-2-butanone (24) Following the procedure given for preparation of compound **12**, compound **7′** (28.8 mg, 0.1 mmol) was treated with *tert*-butyldimethylchlorosilane and the product was purified by PTLC to give the silyl ether [oil, 39.8 mg (100%)]. This product was refluxed for 1 h in a mixture of water (0.1 ml), dioxane (0.1 ml), and toluene. After evaporation of the solvent, the residue was purified by PTLC to give **24** as an oil. $[\alpha]_D^{18}$ $+49.12°$ ($c=1.77$, $CHCl_3$). High-resolution MS *m/z* Calcd for $C_{12}H_{17}O_2Si$ ($M^+ -$ *tert*-butyl): 221.0998. Found: 221.1009. IR ($CHCl_3$): 1718 cm^{-1}. ^{1}H-NMR ($CDCl_3$) δ: 0.17 (6H, s, $Si(CH_3)_2$), 1.03 (9H, s, *tert*-butyl), 2.30 (3H, s, CH_3), 2.70 (1H, dd, $J=15$, 4.6 Hz, C_3-H), 3.15 (1H, dd, $J=15$, 8 Hz, C_3-H), 5.33 (1H, dd, $J=8.0$, 4.6 Hz, C_4-H), 7.47 (5H, s, Ph).

(*R*)-4-Hydroxy-4-phenyl-2-butanone (25) A solution of **24** (27.8 mg, 0.1 mmol) in trifluoroacetic acid (1 ml), water (5 ml), and THF was stirred at room temperature for 1 h. The mixture was extracted with CH_2Cl_2. The organic layer was washed with saturated $NaHCO_3$ solution and then with brine. Evaporation of the solvent gave an oil, which was purified by PTLC to give **25** as an oil. Yield, 8.9 mg (54%). $[\alpha]_D^{19}$ $+44.71°$ ($c=0.89$, $CHCl_3$) [the enantiomer of **25**: lit.[17] $[\alpha]_D^{20}$ $+40.9°$ ($c=10.3$, $CHCl_3$)].

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