Transacetalization of Diethyl Tartrate with Acetals of α-Dicarbonyl Compounds: A Simple Access to a New Class of C_2-Symmetric Auxiliaries and Ligands

Ulrich Berens,*,† Dieter Leckel,‡ and Susanne C. Oepen§

Max-Planck-Gesellschaft AG "Asymmetrische Katalyse" an der Universität Rostock, Buchbinderstrasse 5-6, 18055 Rostock, Germany, and Institut für Organische Chemie der Rheinisch Westfälischen Technischen Hochschule, Professor-Pirlet-Strasse 1, 52076 Aachen, Germany

Received May 22, 1995®

A simple access to a new class of C_2-symmetric auxiliaries and ligands is based on the transacetalization of diethyl tartrate (**1**) with monoacetals of butane-2,3-dione in the key step. Acid-catalyzed reaction of **1** with 2 equiv of 3,3-diethoxybutan-2-one (**2**) gives the C_2-symmetric 1,4-dioxane **7** in 88% yield. Reduction of **7** with $LiAlH_4$ affords the crystalline diol **9**. The structure of **7** was established from the X-ray structure of **9**. Dioxane **7** was converted by standard methodology into the diphosphine **24** and the TARTROL **22**. Reaction of **1** with 3,3-dimethoxybutan-2-one (**3**) in the presence of BF_3–etherate gives in analogy to the formation of **7** the 1,4-dioxane **8**. This compound was transformed into the diphosphine **25** and the TARTROL **23**. The trans-diaxial relationship of the methoxy groups present in **8** could be deduced without X-ray analysis from the ^{1}H-NMR spectrum of **23**.

As part of the search for new ways to obtain bicyclic acetals of the type found in 6,8-dioxabicyclo[3.2.1]octane, which are of interest as bark beetle pheromones,[1] we wanted to prepare the 1,3-dioxolane **4** and perform the intramolecular ester condensation of **4** to form the bicyclic β-diketone **5** as a key step in a new synthesis of (−)-exo-brevicomin (**6**).

We intended to prepare **4** following closely the route to prepare the structurally similar 1,3-dioxolane **15**,[2] which was obtained by transacetalization of the diol **11** with the acyloin acetal **12** into the 1,3-dioxolane **14** and subsequent Swern oxidation of the hydroxy group (Scheme 1). Since the only method to prepare **13**[3] published at the time appeared unsatisfactory, and also to bypass the oxidation step, diethyl tartrate **1** was reacted directly with the acetal **2**.[4]

Instead of the intended dioxolane **4**, we obtained the hitherto unknown 1,4-dioxane **7**. A 1:2 stoichiometric ratio of the educts **1** and **2** is required, but in practice, the use of a 10% excess of **2** proved advantageous, as unreacted **1** is difficult to separate from **7** by distillation. Only one set of signals is observed in the ^{1}H- and ^{13}C-NMR spectra of **7**, and as a result the C_1-symmetric **16** can be excluded from the group of possible diastereomers **7**, **16**, and **17**.

On the other hand, it was not possible to differentiate between the two alternatives **7** and **17** using NMR methods. The correct structure was elucidated after reduction of **7** to the diol **9**, which was shown by means of single crystal X-ray analysis to have the ethoxy groups in a 1,2-trans-diaxial relationship.[5]

While this configuration is favored due to double anomeric stabilization, testing the purity of the obtained **7** using GC revealed a further diastereomer which makes up 4% of the mixture and shows the same MS spectrum as **7**. Although we did not succeed in obtaining a pure sample of this diastereomer for the purpose of structural characterization, we believe it to be **16**. This assumption is based on the fact that the closely related derivatives of hexahydro[1,4]dioxino[2,3-*b*]dioxane **18** all exhibit a cis-connection of the two 1,4-dioxane rings.[6] In this class of compounds a trans diaxial ring annelation is not possible due to steric strain, while a trans diequatorial ring linkage, energetically more favorable in comparable decalins, becomes destabilized by the anomeric effect. Thus, acetals like **16** should be partially stabilized by the anomeric effect and form in favor of acetals like **17** (Chart 1).

Baldwin's rules offer a possible explanation for the sole formation of the 1,4-dioxane **7** instead of the 1,3-dioxolane **4**. According to the rules, a 5-*endo-trig* cyclization, which in the present system would yield **4**, is highly unfavored as compared to a 6-*exo-trig* cyclization leading to **7**.[7,8] The formation of **19** in the reaction of glyoxal with *N*-methyl-(*R*)-phenylglycinol was also explained by using Baldwin's rules.[9]

While the transacetalization of diethyl tartrate (**1**) with **2** did not cause problems, it was not possible to react **1** with 3,3-dimethoxybutan-2-one (**3**) in an analogous manner due to the low boiling point of **3**. The reaction of **1**

* To whom correspondence should be addressed. New address: Chiroscience Ltd., Cambridge Science Park, Milton Road, Cambridge CB4 4WE, England.
† Max-Planck-Gesellschaft AG "Asymmetrische Katalyse".
‡ Current address: Sastech, Sasolburg South Africa.
§ Current address: Institut für Anorganische Chemie der RWTH Aachen.

® Abstract published in *Advance ACS Abstracts*, November 15, 1995.

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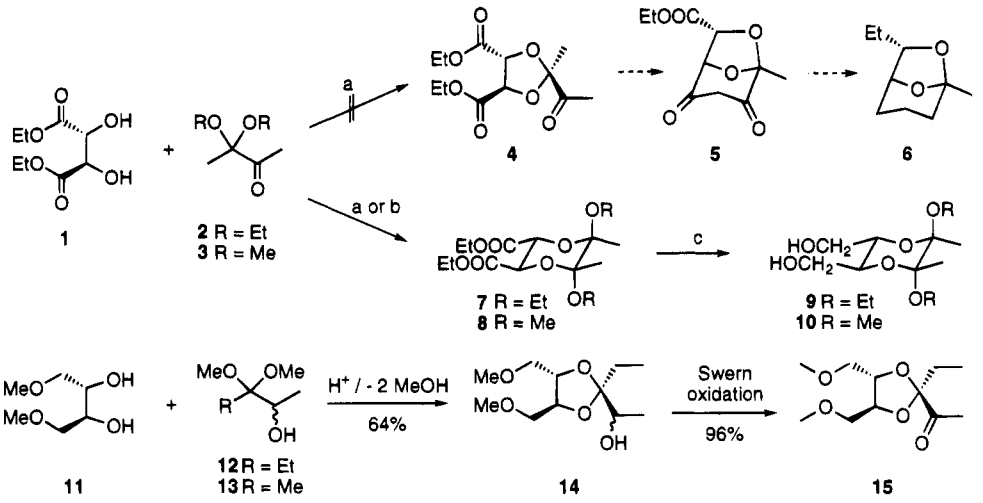
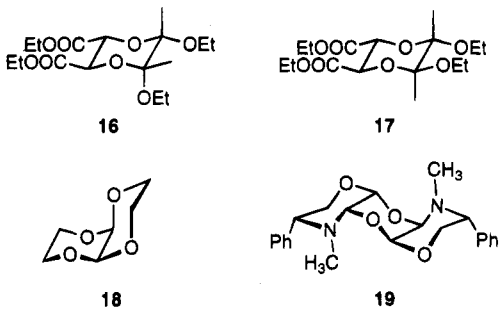
Scheme 1[a]



[a] Key: (a) 1 equiv of **1** + 2.2 equiv of **2**, *p*-TsOH, 60 °C, 88%; (b) 1 equiv **1** + 1.1 equiv **3** + 1.1 equiv $BF_3 \cdot Et_2O$ in EtOAc, 65%; (c) $LiAlH_4$.

Chart 1



with 1 equiv of **3** in the presence of BF_3-etherate[10a] afforded a mixture of diastereomeric 1,4-dioxanes in a ratio of ca. 80:15:5. The structural assignment of the main diastereomer **8** is based on its ^{1}H-NMR, which reveals a C_2-symmetry and from the chemical shift of the methoxy groups in the derivative **21** (vide infra). Obviously, transacetalizations of **1** with **2** or **3** are closely related to the formation of acetals from 1,2-diols and the "Dispoke"[11] or "CDA"[12] protecting group developed by Ley and his group. It seems probable that **2** and **3** may play an important role as protective groups for *trans*-1,2-diols in carbohydrate chemistry in the future. While **7** and **8** are not suitable for the formerly intended synthesis of brevicomin **6**, they nevertheless constitute an interesting starting material for the synthesis of new C_2-symmetric ligands and auxiliaries.

So far, the diols **22** and **23** as well as the diphosphines **24** and **25** have been prepared from **7** or **8** (Scheme 2). The diphosphines resemble the DIOP ligand (**27**) introduced by Kagan,[13] which has acquired great importance in the field of homogenous catalysis using transition metals.[14] The low yield obtained in the tosylation step probably is caused by an intramolecular reaction with formation of a tetrahydrofuran derivative.[15]

On the other hand, the diols **22** and **23** are structurally closely related to the TADDOLs **26** which have been introduced by Seebach and his group. Diols of this type have been used as auxiliaries in various methods to produce enantiomerically pure compounds.[10] The signals for the methylene protons either of the axially ethoxy group in **22** or the protons of the methoxy group present in **23** are significantly shifted to higher field as compared with the starting materials **7** and **8**. From this effect caused by the anisotropic shielding of the aryl groups,[16] it can be concluded that the methoxy groups of **8** are in the same trans-diaxial relationship as the ethoxy groups of **7**.

On account of their similarity to the TADDOLs and their synthesis from tartaric acid we propose to call diols such as **22** and **23** TARTROLs to allow them to be distinguished from Seebach's TADDOLs. Like the TADDOLs, the TARTROLs tend to form selectively inclusion compounds, and thus **22** forms a well-crystallizing 1:1 adduct with acetone, while **23** forms a 1:1 adduct with CCl_4 or ether. This property opens up a number of possibilities regarding the use of TARTROLs as chemical sensors[17] or in the separation of enantiomers.[18] Currently, we are investigating the extent to which the principle of transacetalization of diethyl tartrate with acetals of α-dicarbonyl compounds might provide a basis for a new class of auxiliaries. Results on the asymmetric hydrogenation of enamides with cationic Rh(I) chelates derived from **24** and **25** will be reported soon.

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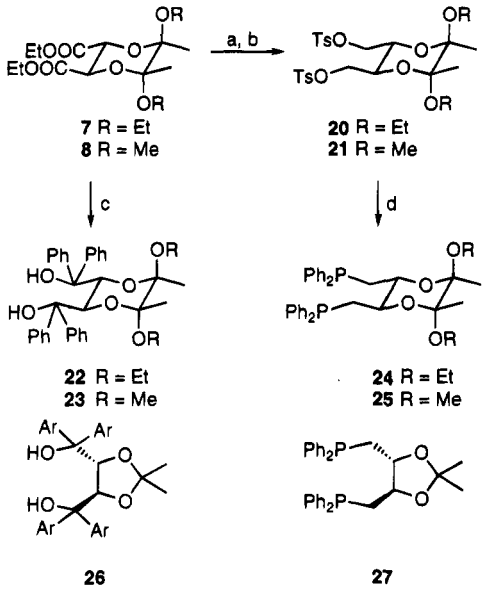
Scheme 2[a]



[a] Key: (a) $LiAlH_4$, 80%; (b) TsCl/Py, 54%; (c) excess PhMgBr, ca. 30%; (d) $KP(Ph)_2$, 50%.

Experimental Section

THF was dried by the sodium–benzophenone method, all the other solvents were used as purchased without further pretreatment. Microanalyses were performed at the microanalytical laboratories of the RWTH Aachen and the Institut für Organische Katalyse e. V. in Rostock. The spinning band distillation column was a Normag SAA-08101 model.

3,3-Diethoxybutan-2-one (2).[4] A 1 L flask was charged with 258 g of 2,3-butanedione (3 mol), 489 g of triethyl orthoformate (3.3 mol), and 1 g of *p*-toluenesulfonic acid. After mixing, the flask was allowed to stand for 18 h at ambient temperature. The reddish brown reaction mixture was then neutralized by addition of 5 g of potassium carbonate and stirred for 1 h. The obtained mixture was distilled rapidly at a pressure of 27 mb over a 30 cm Vigreux column. The column was required since the mixture tended to foam. To avoid loss of product an efficient condenser and cooling of the recipient by an ice bath were required. The fraction boiling from 55 to 65 °C was collected and distilled again at a pressure of 50 mb over a spinning band column. The fraction boiling from 80 to 81 °C was collected to give 285 g of **2**. Yield 59.5% based on 2,3-butanedione. ^{1}H-NMR (300 MHz, $CDCl_3$): δ 1.22 (tr, 6, ^3J = 7.1 Hz), 1.39 (s, 3), 2.22 (s, 3), 3.42, 3.53 (ddq, 2 H, $|^2J|$ = 9.1 Hz). ^{13}C-NMR (75 MHz, $CDCl_3$): δ 15.36, 20.59, 25.89, 57.61, 102.20, 207.66. Anal. Calcd: C, 59.98 (found 59.73); H, 10.07 (found 10.33). In the presence of small quantities of acid 2-ethoxybut-1-en-3-one is formed which is probably identical with a byproduct mentioned in ref 4. ^{1}H-NMR (300 MHz, $CDCl_3$): δ 1.38 (tr, 3, ^3J = 7.1 Hz), 2.30 (s, 3), 3.81 (q, 2), 4.45, 5.17 (2 d, 1 each, $|^2J|$ = 2.3 Hz). ^{13}C-NMR (75 MHz): δ 14.32, 25.87, 63.81, 91.09, 157.83, 195.81.

3,3-Dimethoxybutan-2-one (3). This compound was prepared in analogy to the preparation of **2** from 472.5 g of 2,3-butanedione (5.5 mol) and 583 g of trimethyl orthoformate (5.5 mol). After addition of 1.4 g of *p*-toluenesulfonic acid, the mixture was allowed to stand for 4 h. Then, an additional 58.3 g of trimethyl orthoformate (0.55 mol) and 0.55 g of *p*-toluenesulfonic acid were added. After standing for 2 h, the crude product was distilled off in the same manner as described for the preparation of **2** at a pressure of 100 mmHg and then refractionated at a pressure of 200 mbar over a spinning band column. Bp: 90 °C. Yield: 533 g (73% based on 2,3-butanedione). ^{1}H-NMR (300 MHz, $CDCl_3$): δ 1.38 (s, 3), 2.23 (s, 3), 3.25 (s, 6). ^{13}C-NMR (75 MHz, $CDCl_3$): δ 19.59, 25.84, 49.69, 102.49, 207.03. Anal. Calcd: C 54.53 (found 54.82); H, 9.15 (found 9.25).

(2*R*,3*R*,5*R*,6*R*)-5,6-Diethoxy-5,6-dimethyl[1,4]dioxane-2,3-dicarboxylic Acid Diethyl Ester (7). A 250 mL flask was fitted with a thermometer, a pressure-equalized dropping funnel, and a gas outlet leading to a condensing trap which was cooled to −78 °C. The flask was charged with 103 g of L-(+)-diethyl tartrate (**1**) (0.5 mol) and 2 g of *p*-toluenesulfonic acid. After being heated to 60 °C, the condensing trap was connected to a water aspirator and the pressure in the flask was adjusted to 40 mmHg. Then, 168 g of **2** (1.05 mol) was added to the reaction mixture within 2 h. The mass of the obtained condensate (ethanol and 2,3-butanedione) was almost equal to the theoretical amount (89 g). After addition of 8 g of K_2CO_3, the reddish brown reaction mixture was stirred for another hour, filtered, and carefully distilled over a 30 cm Vigreux column. The fraction boiling at 115 °C/0.01 mbar was collected. Yield 153.3 g (88% of theory based on **2**). $[\alpha]^{20}_D$: −78.8 (neat). ^{1}H-NMR ($CDCl_3$, 500 MHz): δ 1.25 (tr, 6, ^3J = 7.1 Hz), 1.29 (tr, 6, ^3J = 7.1 Hz), 1.37 (s, 6), 3.58, 3.61 (ddq, 4, $|^2J|$ = 9.4 Hz), 4.20, 4.22 (ddq, 4, $|^2J|$ = 10.8 Hz), 4.50 (s, 2). ^{13}C-NMR: δ 14.01, 15.46, 18.19, 56.45, 61.45 (tr), 68.89 (d), 99.10 (q), 169.07. Anal. Calcd: C, 55.16 (found 54.95); H, 8.10 (found 8.07).

(2*R*,3*R*,5*R*,6*R*)-5,6-Dimethoxy-5,6-dimethyl[1,4]dioxane-2,3-dicarboxylic Acid Diethyl Ester (8). A 2 L flask with a magnetic stirrer was charged with 103 g of L-(+)-diethyl tartrate (**1**) (0.5 mol), 72.6 g of 3,3-dimethoxybutan-2-one (**3**) (0.55 mol), and 300 mL of ethyl acetate. Under efficient stirring, a solution of 78 g of BF_3–etherate (0.55 mol) in 300 mL of ethyl acetate was added to the obtained mixture via a dropping funnel within 6 h. After the reaction mixture was stirred overnight, 300 mL of water was added, and with stirring solid $NaHCO_3$ was added carefully until the aqueous layer exhibited a pH of 8. After separation of the organic layer and drying (Na_2SO_4), the solvent was removed on a rotavapor. To improve the yield, the aqueous layer was extracted twice with the recovered solvent (and treated as described above). The obtained yellow residue was fractionated in vacuum over a 30 cm Vigreux column. The fraction boiling at 105 °C/5 × 10^{-3} mb contained the product and some diethyl tartrate (**1**). To remove the latter, 10.8 g of trimethylchlorosilane (0.1 mol) and 16.1 g of hexamethyldisilazane (0.1 mol) were added, and the mixture was stirred overnight. Then the precipitated NH_4Cl was filtered off, and the filtrate was fractionated again over a 30 cm vigreux column. After a small forerun consisting of diethyl 2,3-bis(trimethylsilyl)tartrate, the product was collected at 105 °C/5 × 10^{-3} mb. Yield: 101.2 g (63.1% based on **1**). $[\alpha]^{20}_D$: −130.2 (*c* = 5, $CHCl_3$). ^{1}H-NMR ($CDCl_3$, 300 MHz): δ 1.29 (tr, 6, ^3J = 7.1 Hz), 1.36 (s, 6), 3.33 (s, 6), 4.22 (q, 4, ^3J = 7.1 Hz), 4.49 (s, 2). ^{13}C-NMR ($CDCl_3$): δ 14.02, 17.35, 48.37 (OCH_3), 61.51 (tr), 68.81 (d), 99.15 (s), 167.99. Anal. Calcd: C, 52.49 (found 52.72); H, 7.55 (found 7.41).

(2*R*,3*R*,5*S*,6*S*)-2,3-Diethoxy-5,6-bis(hydroxymethyl)-2,3-dimethyl[1,4]dioxane (9). A dry 2 L round-bottom flask with paddle agitator, pressure-equalized addition funnel, and efficient reflux condenser was charged with 30 g of $LiAlH_4$ (0.79 mol) and flushed with nitrogen, and 700 mL of dry ether was added by the dropping funnel. To the obtained $LiAlH_4$ slurry a solution of 226.5 g of **7** (0.665 mol) in 100 mL of ether was added within 2 h. After the addition of **7** was complete, the reaction mixture which had become viscous was heated to reflux for 3 more h. After hydrolysis of the excess $LiAlH_4$ by careful addition of 30 mL of water, the reaction mixture was extracted for 3 days with ether in a continuous extraction apparatus. After drying ($MgSO_4$), the extract was filtered through a 15 cm silica pad and the solvent was removed on a rotavapor. The crude product was redissolved in a minimum of ether, and petroleum ether (bp 30–50 °C) was added until the solution became turbid. This solution was kept first at 4 °C until no further product crystallized and then kept 1 night at −24 °C to complete the crystallization. The crystals were filtered off and washed with cold (−24 °C) petroleum ether to give 140.0 g of colorless needles (81.5% based on **7**). Mp: 121 °C. $[\alpha]^{20}_D$: −133.6 (*c* = 4.89, $CHCl_3$). ^{1}H-NMR ($CDCl_3$, 300 MHz): δ 1.21 (tr, 6, ^3J = 7.1 Hz), 1.33 (s, 6), 2.76 (br s, 2, OH), 3.52 (dq, 4, OCH_2), 3.66 (br q, 4, CH_2OH), 3.82 (br s, 2, H-5, H-6). ^{13}C-NMR: δ 15.48, 18.36, 55.89 (OEt), 62.32 (tr),

69.32 (d,), 98.70 (s). Anal. Calcd: C, 54.53 (found 54.53); H, 9.15 (found 9.31).

(2*S*,3*S*,5*R*,6*R*)-2,3-Bis(hydroxymethyl)-5,6-dimethoxy-5,6-dimethyl[1,4]dioxane (10). This compound was prepared in analogy to the preparation of **9** from 31.5 g of $LiAlH_4$ (0.83 mol) and 224.2 g of **8** (0.7 mol) in 700 mL of THF. After hydrolysis, the reaction mixture was extracted for 5 days in a 2 L continuous extraction apparatus. After drying ($MgSO_4$), the extract was filtered over a 15 cm silica pad, the solvent was removed on a rotavapor, and the residue was then redissolved in a minimum of ether. After addition of petroleum ether the solution became turbid, and on standing in the refrigerator at −24 °C the product crystallized to give 85 g of **10** (51.4% based on **8**) as colorless crystals. Mp: 121 °C. $[\alpha]^{20}_D$: −170.2 (c = 10.00 in $CHCl_3$). ^{1}H-NMR ($CDCl_3$, 300 MHz): δ 1.31 (s, 6), 2.80 ("tr", 2, H-2, H-3), 3.26 (s, 6), 3.61 (m, 4, CH_2OH), 3.79 (br s, 2, OH). ^{13}C-NMR ($CDCl_3$): δ 17.45, 47.98, 62.27 (CH_2OH), 69.47 (d), 98.83 (s). Anal. Calcd: C, 50.84 (found 50.93); H, 8.53 (found 8.42).

(2*R*,3*R*,5*S*,6*S*)-2,3-Diethoxy-2,3-dimethyl-5,6-bis((toluene-4-sulfonyl)oxy)methyl)[1,4]dioxane (20). In a 1 L flask with paddle agitator 216.8 g of tosyl chloride (1.135 mol) and 3 g of 4-(dimethylamino)pyridine were dissolved in 400 g of dry pyridine. After this solution was cooled to −5 °C by an ice/NaCl bath, a solution of 100 g of **9** (0.378 mol) in 250 mL of dry pyridine was added in such a way that the temperature did not exceed 5 °C. After the addition of **9** was completed, the reaction mixture was stirred for 30 min at 5 °C, and then the cooling bath was removed and the reaction mixture was stirred for another 2 h. After the mixture was recooled to 5 °C, the excess TsCl was hydrolyzed by slow addition of 30 mL of water and stirred for 2 more h. A solid, which had formed during the addition of **9**, dissolved again. The obtained mixture was poured on 1 kg ice, neutralized by careful addition of 3 N H_2SO_4, and extracted four times with 300 mL of CH_2Cl_2. The combined organic layers were dried ($MgSO_4$), and the solvent was removed on a rotavapor. After removal of the last traces of CH_2Cl_2 by high vacuum, the remaining oil was redissolved in about 600 mL of MeOH. After the solution was seeded and stored in a refrigerator at 4 °C, the product crystallized within several days to give 114.9 g of **20** (53% of theory based on **9**) as colorless crystals. Mp: 64 °C. $[\alpha]^{20}_D$: −74.0 (c = 20.00, THF). ^{1}H-NMR ($CDCl_3$, 300 MHz): δ 1.12 (tr, 6, ^3J = 7.1 Hz), 1.18 (s, 6), 2.45 (s, 6), 3.34, 3.42 (ddq, 2, $|^2J|$ = 9.4 Hz), 3.82 (m, 2), 4.06 (m, 4), 7.34 (m, 4), 7.79 (m, 4). ^{13}C-NMR: δ 15.38, 18.03, 21.65, 55.94 (OCH_2), 66.85 (d), 68.85 (tr), 98.81 (s), 128.04, 129.85, 132.77, 144.91. Anal. Calcd: C, 54.53 (found 54.53); H, 6.34 (found 6.39).

(2*R*,3*R*,5*S*,6*S*)-2,3-Dimethoxy-2,3-dimethyl-5,6-bis(((toluene-4-sulfonyl)oxy)methyl)[1,4]dioxane (21). This compound was prepared in analogy to the preparation of **20** from 160.5 g of *p*-tosyl chloride (0.84 mol) in 300 g of dry pyridine and 66.6 g of **10** (0.28 mol). The crude product was dissolved in about 500 mL of MeOH. After seeding, the crystallization started at room temperature and was complete within 1 day on standing in the refrigerator at 4 °C. Yield: 115.2 g of colorless crystals (76% based on **10**). Mp: 126 °C. $[\alpha]^{20}_D$: −93.8 (c = 10.02 in THF). ^{1}H-NMR ($CDCl_3$, 300 MHz): δ 1.17 (s, 6), 2.45 (s, 6), 3.13 (s, 6), 3.71 (m, 2), 4.03−4.06 (m, 4), 7.35, 7.79 (2 m, 8). ^{13}C-NMR ($CDCl_3$): δ 17.23, 21.66, 48.03, 66.94, 68.72, 98.97, 128.07, 129.91, 132.68, 145.01. Anal. Calcd: C, 52.93 (found 52.88); H, 5.92 (found 5.74).

(2*R*,3*R*,5*R*,6*R*)-5,6-Bis((diphenylphosphanyl)methyl)-2,3-diethoxy-2,3-dimethyl[1,4]dioxane (24). A 1 L flask was flushed with argon. Then, 6 g of potassium (154 mmol) from which the crusts had been thoroughly removed and ca. 200 mL of absolute THF were placed in the flask. After the solution was heated to reflux, the molten potassium was finely dispersed by rapid stirring. A solution of 17.15 g of chlorodiphenylphosphine (77 mmol) in ca. 100 mL of absolute THF was added via a dropping funnel within 20 min to the obtained potassium emulsion. After the complete addition of the chlorodiphenylphosphine, the reaction was stirred until all potassium had been consumed. The obtained solution was cooled to ambient temperature, and 20.0 g of **20** (34.9 mmol) dissolved in ca. 50 mL of absolute THF was added within 20 min. After the reaction mixture was stirred for 1 h, 30 mL of methanol was carefully added to decompose the last traces of potassium. Most of the solvents were then removed on a rotavapor, and after addition of 200 mL of water the mixture was extracted three times with 150 mL of petroleum ether (bp 30−50 °C). After the combined organic layers ($MgSO_4$) were dried, the solvent was removed on a rotavapor and the residue filtered over a silica pad (30 cm × 3 cm diameter). After elution with petroleum ether (ca. 3 L) ca. 1 g of a colorless oil was obtained. This material was discarded, and the elution was continued with a mixture of petroleum ether and ether (95:5 v:v) until no further material could be eluted (ca. 1.5 L of eluent was required). After removal of the solvents, 12.0 g of crude **24** was obtained as a semisolid mass which was recrystallized from 100 mL of ethanol to give 10.2 g of **24** (50% based on **20**). Mp: 99 °C. $[\alpha]^{20}_D$: −98.0 (c = 5.00, $CHCl_3$). ^{1}H-NMR (500 MHz, $CDCl_3$): δ 0.94 (tr, 6, ^3J = 7.1 Hz), 1.21 (s, 6), 2.11, 2.28 (2 m, 2 each, CH_2P), 3.23−3.34 (2dq, 1 each, $|^2J|$ = 9.1 Hz, CH_2CH_3), 3.69 (m, 2 H-5, H-6), 7.23−7.37 (m, 16), 7.44−7.48 (m, 4). ^{13}C-NMR (125 MHz, $CDCl_3$): δ 15.38, 18.28, 30.74 (d, $|^1J|_{P,C}$ = 15.2 Hz, CH_2P), 55.91, 70.32 (dd, $|^2J|_{P,C}$ ≈ 9.8 Hz, $|^3J|_{P,C}$ ≈ 9.8 Hz, C-5, C-6), 98.85 (s), 128.09, 128.14, 128.18, 128.23, 128.47, 128.52, 128.58, 129.00, 132.20, 132.32, 132.45, 133.40, 133.53, 133.67, 138.04, 138.24, 139.56, 139.76. ^{31}P-NMR: δ −21.42. Anal. Calcd; C, 71.99 (found 71.91); H, 7.05 (found 7.07).

(2*R*,3*R*,5*R*,6*R*)-5,6-Bis((diphenylphosphanyl)methyl)-2,3-dimethoxy-2,3-dimethyl[1,4]dioxane (25). This compound was prepared in analogy to the preparation of **24** from 15.0 g of **21** (27.6 mmol) and potassium diphenylphosphide, which was prepared by the reaction of 4.3 g of potassium (110 mmol) with 12.2 g of chlorodiphenylphosphine (55.1 mmol) in 200 mL of THF. After filtration over a silica pad (20 cm × 3cm diameter), the crude product was recrystallized from 80 mL of ethanol to give 8.5 g of **25** (54% based on **21**) as colorless needles. Mp: 73 °C. $[\alpha]^{20}_D$: −125.6 (c = 5, THF). ^{1}H-NMR (250 MHz, $CDCl_3$): δ 1.16 (s, 6), 2.05−2.17, 2.18−2.28 (2 m, 2 each, CH_2P), 3.04 (s, 6), 3.69 (m, 2), 7.25−7.48 (m, 20). ^{13}C-NMR ($CDCl_3$): δ 17.44, 30.84 (d, $|^1J|_{P,C}$ = 13.4 Hz, CH_2P), 48.08, 70.58 (m, C-5, C-6), 98.99 (s), 128.17, 128.20, 128.28, 128.49, 128.61, 129.00, 132.49, 133.45 (2 d, $|^2J|_{P,C}$ ≈ 19.5 Hz, Ph *o*-C), 138.39, 139.46 (2 d, $|^1J|_{P,C}$ = 14.3 Hz, Phipso-C). ^{31}P-NMR ($CDCl_3$): δ = −19.71. Anal. Calcd: 71.32 (found 71.07); H, 6.69 (found 6.49).

(2*R*,3*R*,5*R*,6*R*)-5,6-Diethoxy-2,3-bis(hydroxydiphenylmethyl)-5,6-dimethyl[1,4]dioxane (22). A solution of phenylmagnesium bromide in 200 mL of THF was prepared from 6.0 g of Mg turnings (0.25 mol) and 39.3 g of bromobenzene (0.25 mol). Under cooling with ice, this solution was added to a solution of 17.4 g of **7** (50 mmol) in 100 mL of THF in such a way that a temperature of 20 °C was not exceeded. After being stirred for 1 h the reaction was quenched by careful addition of a saturated NH_4Cl solution. A precipitate was formed intermediately, which redissolved later. The organic layer was separated, and the aqueous layer was extracted twice with ether (200 mL in each portion). After the combined organic layers ($MgSO_4$) were dried, the solvent was removed on a rotavapor. The red residue was redissolved in acetone and water was added dropwise, until the solution became turbid. The product crystallized after standing overnight at −24 °C as a 1:1 clathrate with acetone. Yield: 10.1 g (32% based on **7**). Mp: 208 °C. $[\alpha]^{20}_D$: 54.7 (c = 10.04, $CHCl_3$). ^{1}H-NMR ($CDCl_3$, 300 MHz): δ 1.03 (tr, 6, ^3J = 7.1 Hz), 1.04 (s, 6), 2.34, 2.93 (2dq, 4, $|^2J|$ = 8.8 Hz), 3.8−4.0 (br. s, 2, OH), 4.47 (s, 2), 7.00−7.45 (m, 20). ^{13}C-NMR: 15.18, 17.91, 55.23, 76.08, 126.82, 127.03, 127.17, 127.73, 128.82, 142.84 (s), 146.43 (s). Anal. Calcd: C ($C_{39}H_{46}O_7$), 74.73 (found 74.26); H, 7.40 (found 7.53).

(2*R*,3*R*,5*R*,6*R*)-2,3-Bis(hydroxydiphenylmethyl)-5,6-dimethoxy-5,6-dimethyl[1,4]dioxane (23). In a 2 L three-necked flask a THF solution of phenylmagnesium bromide was prepared from 251 g of bromobenzene (1.6 mol) and 40.8 g of Mg turnings (1.7 mol) in 600 mL of THF. Under efficient cooling with an ice bath, to the Grignard solution a solution of 64 g of **8** (0.2 mol) was added in such a way that the temperature did not exceed 15 °C. When the addition of **8**

was complete, the mixture was heated to reflux for 2 h. Then the mixture was hydrolyzed by careful addition of a saturated NH_4Cl solution. A precipitate formed during the hydrolysis, but redissolved later. The orange organic layer was separated, and the aqueous layer was extracted twice with 200 mL of ethyl acetate. After the combined organic layers ($MgSO_4$) were dried, the solvents were removed on a rotavapor to give 129 g of a viscous residue. The residue was heated under vacuum (0.01 mb), finally up to a temperature of 220 °C. The residue, a brown glass (65 g) was dissolved in 100 mL of ether and filtered with ether over a silica pad (20 cm × 3 cm diameter). From the filtrate the ether was removed on a rotavapor, and the residue was redissolved in 80 mL of ether. After standing for 7 days at −24 °C, 20.4 g of a 1:1 clathrate of **23** with ether had separated in large crystals. Mp: 99 °C. $[\alpha]^{20}_D$: 47.2 (c = 1 in $CHCl_3$). Addition of CCl_4 (50 mL) to the mother liquor and standing overnight at −24 °C gave a further crop of a 1:1 clathrate of **23** with CCl_4 (15.7 g) as fine needles. Yield: 27.9% based on **8**. ^{1}H-NMR ($CDCl_3$, 300 MHz): δ 1.15 (s, 6), 2.58 (s, 6), 4.40 (s, 2, OH), 7.02−7.15 (m, 10), 7.33−7.47 (m, 6), 7.95−8.02 (m, 4). ^{13}C-NMR ($CDCl_3$): δ 17.17, 47.67, 75.99 (C-2, C-3), 79.44 (s), 98.51 (s), 126.83, 127.12, 127.15, 127.29, 127.71, 128.02, 142.85 (s), 146.07 (s). Anal. Calcd: C ($C_{38}H_{46}O_7$), 74.23 (found 74.48); H, 7.54 (found 7.62).

Acknowledgment. This work was started in the group of Prof. Dr. H.-D. Scharf at the Institut für Organische Chemie of the Rheinisch-Westfälische Technische Hochschule Aachen and finished in the Max-Planck Arbeitsgruppe "Asymmetrische Katalyse" an der Universität Rostock. U.B. is indebted to Prof. Dr. H.-D. Scharf and Prof. Dr. R. Selke for their interest in this work and for helpful discussions and to the Max-Planck-Gesellschaft for a postdoctoral stipend. The authors are grateful to Dr. J. Runsink for recording the NMR spectra.

Supporting Information Available: Ortep plot of compound **9** (1 page). This material is contained in libraries on microfiche, immediately follows this article in the microfilm version of the journal, and can be ordered from the ACS; see any current masthead page for ordering information.

JO950932Z