Enzymatic Transformation and Liquid-Chromatographic Separation as Methods for the Preparation of the (*R*)- and (*S*)-Enantiomers of the Centrochiral Hydridogermanes *p*-$XC_6H_4(H)Ge(CH_2OAc)CH_2OH$ (X = H, F)

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The arylbis(hydroxymethyl)germanes $Ph(H)Ge(CH_2OH)_2$ (**5**) and *p*-$FC_6H_4(H)Ge(CH_2OH)_2$ (**6**) as well as the bis(acetoxymethyl)arylgermanes $Ph(H)Ge(CH_2OAc)_2$ (**9**) and *p*-$FC_6H_4(H)Ge(CH_2OAc)_2$ (**10**) were synthesized, starting from dichlorobis(chloromethyl)germane [$Cl_2Ge(CH_2Cl)_2$ → $Aryl(Cl)Ge(CH_2Cl)_2$ → $Aryl(AcO)Ge(CH_2OAc)_2$ → $Aryl(H)Ge(CH_2OH)_2$ → $Aryl(H)Ge(CH_2OAc)_2$; Aryl = Ph, *p*-FC_6H_4]. Reaction of the diols **5** and **6** with Ac_2O and NEt_3 (molar ratio 1:1:1) yielded the (acetoxymethyl)aryl(hydroxymethyl)germanes *rac*-$Ph(H)Ge(CH_2OH)CH_2OAc$ (*rac*-**1**) and *rac*-*p*-$FC_6H_4(H)Ge(CH_2OH)CH_2OAc$ (*rac*-**2**), respectively. The (*R*)- and (*S*)-enantiomers of **1** and **2** were prepared on a preparative scale by enzymatic conversions. (*R*)-**1** and (*R*)-**2** were obtained by enantioselective transesterifications of the prochiral diols **5** and **6**, respectively, with ethyl acetate (acyl donor) using porcine pancreas lipase (PPL, E.C.3.1.1.3) as the biocatalyst (reaction medium, ethyl acetate). The corresponding antipodes (*S*)-**1** and (*S*)-**2** were prepared by PPL-catalyzed enantioselective hydrolyses of the prochiral diacetates **9** and **10**, respectively [reaction medium, Sörensen phosphate buffer (pH 7)/tetrahydrofuran (25:1, v/v)]. The yields and enantiomeric purities of the optically active germanes were as follows: (*R*)-**1**, 76%, 93% ee; (*S*)-**1**, 48%, 84% ee; (*R*)-**2**, 77%, 86/87% ee; (*S*)-**2**, 62%, 94% ee. Alternatively, (*R*)-**2** and (*S*)-**2** were obtained by preparative liquid-chromatographic resolution of *rac*-**2** using cellulose tribenzoate as the chiral stationary phase (yield 80%; enantiomeric purities 97% ee). For reasons of comparison, the (*R*)- and (*S*)-enantiomers of $Ph(H)C(CH_2OH)CH_2OAc$ (**3**) and *p*-$FC_6H_4(H)C(CH_2OH)CH_2OAc$ (**4**) (carbon analogues of the germanes **1** and **2**) were prepared using the same preparative methods [PPL-catalyzed transesterifications of $Ph(H)C(CH_2OH)_2$ (**7**) and *p*-$FC_6H_4(H)C(CH_2OH)_2$ (**8**) with vinyl acetate and ethyl acetate, respectively (→ (*R*)-**3**, (*R*)-**4**); PPL-catalyzed hydrolyses of $Ph(H)C(CH_2OAc)_2$ (**11**) and *p*-$FC_6H_4(H)C(CH_2OAc)_2$ (**12**) (→ (*S*)-**3**, (*S*)-**4**); chromatographic resolution of *rac*-*p*-$FC_6H_4(H)C(CH_2OH)CH_2OAc$ (*rac*-**4**) (→ (*R*)-**4**, (*S*)-**4**)]. The preparative results were similar to those obtained for the germanium compounds. In contrast to the configurationally stable antipodes of the carbon compounds **3** and **4**, the (*R*)- and (*S*)-enantiomers of the corresponding germanium analogues **1** and **2** undergo a slow racemization upon heating (neat compounds). The chiroptical properties of the Ge/C analogues (*R*)-**1**/(*R*)-**3**, (*S*)-**1**/(*S*)-**3**, (*R*)-**2**/(*R*)-**4**, and (*S*)-**2**/(*S*)-**4** (dissolved in acetone) differ significantly from one another (opposite signs of optical rotation at various wavelengths). In contrast, the respective optically active Ge/C analogues (*R*)- and (*S*)-$Ph(H)El(CH_2OAc)CH_2OSiPh_2tBu$ [(*R*)- and (*S*)-**21**, El = Ge; (*R*)- and (*S*)-**23**, El = C], (*R*)- and (*S*)-*p*-$FC_6H_4(H)El(CH_2OAc)CH_2OSiPh_2tBu$ [(*R*)- and (*S*)-**22**, El = Ge; (*R*)- and (*S*)-**24**, El = C], $Ph(H)El(CH_2OH)CH_2OSiPh_2tBu$ [(*R*)- and (*S*)-**25**, El = Ge; (*R*)- and (*S*)-**27**, El = C], and (*R*)- and (*S*)-*p*-$FC_6H_4(H)El(CH_2OH)CH_2OSiPh_2tBu$ [(*R*)- and (*S*)-**26**, El = Ge; (*R*)- and (*S*)-**28**, El = C] display similar chiroptical properties when having the same absolute configuration. The antipodes of **21**−**24** were prepared by silylation of the corresponding (*R*)- and (*S*)-enantiomers of **1**−**4** with $Ph_2tBuSiCl$; the antipodes of **25**−**28** were obtained by transesterification of the (*R*)- and (*S*)-enantiomers of **21**−**24** with methanol (all reactions with retention of absolute configuration).

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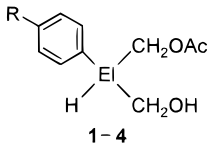
Introduction

In contrast to the extensive research activities in the field of centrochiral optically active silicon compounds of the formula type $R^1R^2SiR^3R^4$,[1−3] the chemistry of related optically active germanium compounds is rather unexplored.[4] Very recently, it has been demonstrated by pharmacological studies that biological systems can discriminate between enantiomeric germanes.[4m]

The methods used for the preparation of the (*R*)- and (*S*)-enantiomers of centrochiral germanes of the formula type $R^1R^2GeR^3R^4$ are mainly based on (i) classical resolution of the respective racemic mixtures via fractional crystallization of appropriate diastereomeric derivatives and (ii) stereoselective chemical transformation of the optically active compounds obtained by the aforementioned method. Recently, biotransformation has also been demonstrated to be a useful preparative method for the synthesis of optically active centrochiral germanes.[4l,n]

Here we report on the synthesis of the (*R*)- and (*S*)-enantiomers of the centrochiral hydridogermanes **1** and **2** using enantioselective enzymatic transformations. In



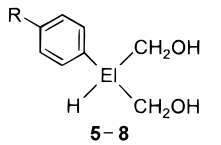
1−**4**

	El	R
1	Ge	H
2	Ge	F
3	C	H
4	C	F

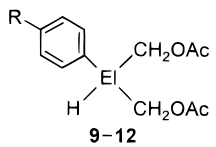
addition, the preparation of (*R*)-**2** and (*S*)-**2** by liquid-chromatographic resolution of *rac*-**2** is reported. For reasons of comparison, the corresponding carbon analogues (*R*)-**3**, (*S*)-**3**, (*R*)-**4**, and (*S*)-**4** were also prepared using the same methods. The main goal of the studies presented here was the development of efficient synthetic and chromatographic methods for the preparation of centrochiral hydridogermanes with high enantiomeric purity. The investigations concerning the enzymatic conversions were carried out with a special emphasis on the aspect "Ge/C bioisosterism".

Results and Discussion

Enzymatic Syntheses of the Antipodes of 1−4. General Aspects. Numerous prochiral organic diesters and diols have been successfully subjected to lipase-catalyzed enantioselective transesterifications and hydrolyses, respectively.[5] A typical example for this is the enzymatic synthesis of the (*R*)- and (*S*)-enantiomers of the monoester 3-hydroxy-2-phenylpropyl acetate (**3**).[6] Compound (*R*)-**3** was prepared by an enantioselective transesterification of the diol **7** using immobilized porcine pancreas lipase (PPL) as the biocatalyst and methyl acetate as the acylation agent and solvent. The antipode (*S*)-**3** was obtained by an enantioselective hydrolysis of the corresponding diester **11** in a phosphate buffer system (pH 7) using immobilized PPL as the biocatalyst. We could demonstrate that these synthetic methods can also be applied to prepare the antipodes of the related centrochiral hydridogermanes (acetoxymethyl)(hydroxymethyl)phenylgermane (**1**) and (acetoxymethyl)(4-fluorophenyl)(hydroxymethyl)germane (**2**). Compounds (*R*)-**1** and (*R*)-**2** were prepared by a PPL-catalyzed transesterification of the diols **5** and **6**, respectively, whereas the corresponding antipodes (*S*)-**1** and (*S*)-**2** were obtained by a PPL-catalyzed hydrolysis of the diesters **9** and **10**. For reasons of comparison, we also studied the analogous enzymatic conversions of the corresponding carbon



5−**8**



9−**12**

	El	R
5, 9	Ge	H
6, 10	Ge	F
7, 11	C	H
8, 12	C	F

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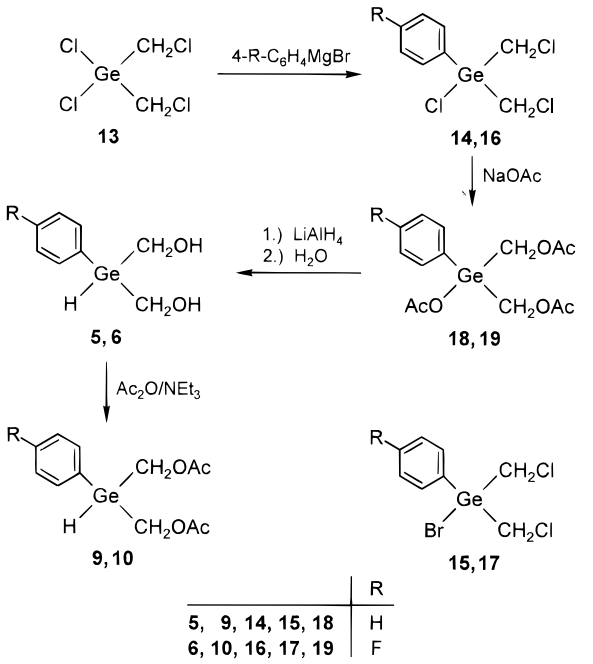
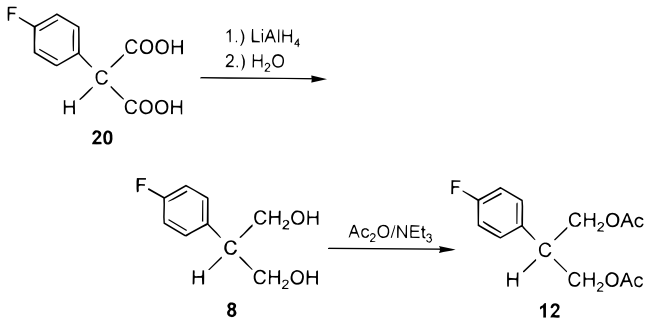
Scheme 1

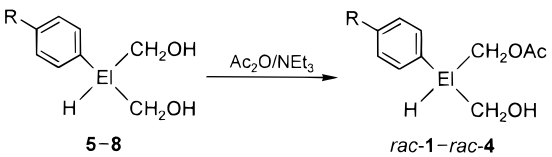


	R
5, 9, 14, 15, 18	H
6, 10, 16, 17, 19	F

Scheme 2



Scheme 3



	El	R
rac-**1**, **5**	Ge	H
rac-**2**, **6**	Ge	F
rac-**3**, **7**	C	H
rac-**4**, **8**	C	F

analogues **7** [→ (*R*)-**3**)], **8** [→ (*R*)-**4**], **11** [→ (*S*)-**3**], and **12** [→ (*S*)-**4**].

Syntheses of the Starting Materials for the Enzymatic Transformations, Compounds 5−12. Bis(hydroxymethyl)phenylgermane (**5**), (4-fluorophenyl)-bis(hydroxymethyl)germane (**6**), bis(acetoxymethyl)-phenylgermane (**9**), and bis(acetoxymethyl)(4-fluorophenyl)germane (**10**) were synthesized according to Scheme 1, starting from dichlorobis(chloromethyl)-germane[4l] (**13**).

In the first step, chlorobis(chloromethyl)phenylgermane (**14**) and chlorobis(chloromethyl)(4-fluorophenyl)germane (**16**) were synthesized by reaction of the germane **13** with phenylmagnesium bromide and (4-fluorophenyl)magnesium bromide, respectively, in diethyl ether. The corresponding bromogermanes **15** and **17** (formed by a chlorine/bromine exchange) were obtained as byproducts. The respective mixtures **14**/**15** and **16**/**17** were treated in the next step with sodium acetate in dimethylformamide to give acetoxybis(acetoxymethyl)phenylgermane (**18**) and acetoxybis(acetoxymethyl)-(4-fluorophenyl)germane (**19**), respectively (yields related to **13**: **18**, 65%; **19**, 65%). Subsequent reaction of the germanes **18** and **19** with lithium aluminum hydride in diethyl ether, followed by working up with water, gave compounds **5** (yield 74%) and **6** (yield 74%). Treatment of **5** and **6** with an excess of acetic anhydride and triethylamine in diethyl ether finally yielded compounds **9** (yield 94%) and **10** (yield 91%).

2-Phenyl-1,3-propanediol[7] (**7**) and 2-phenyl-1,3-propanediyl diacetate[8] (**11**) were prepared according to the literature. The corresponding *p*-fluoro derivatives 2-(4-fluorophenyl)-1,3-propanediol (**8**) and 2-(4-fluorophenyl)-1,3-propanediyl diacetate (**12**) were synthesized according to Scheme 2, starting from (4-fluorophenyl)malonic acid[9] (**20**). In the first step, compound **20** was treated with lithium aluminum hydride, followed by working up with water, to give the diol **8** (yield 79%). Subsequent reaction with an excess of acetic anhydride and triethylamine in diethyl ether yielded the corresponding diacetate **12** (yield 95%).

Syntheses of *rac*-1−*rac*-4. Compounds *rac*-**1**−*rac*-**4** were used as references to monitor the kinetics of the enzymatic transformations by gas chromatography and to determine the enantiomeric purities of the biotransformation products by various analytical methods. In addition, compounds *rac*-**2** and *rac*-**4** served as starting materials for their preparative liquid-chromatographic resolution. The monoacetates *rac*-**1**−*rac*-**4** were synthesized by reaction of the corresponding diols **5**−**8** with acetic anhydride and triethylamine in diethyl ether and isolated by column chromatography on silica gel (yields: *rac*-**1**, 50%; *rac*-**2**, 47%; *rac*-**3**, 59%; *rac*-**4**, 49%) (Scheme 3).

Enzymatic Transesterifications of 5−8. The prochiral bis(hydroxymethyl)germanes **5** and **6** and the corresponding carbon analogues **7** and **8** were transformed enantioselectively into the (*R*)-enantiomers of **1**−**4** using a PPL-catalyzed (E.C.3.1.1.3) transesterification with ethyl acetate (for **5**, **6**, and **8**) or vinyl acetate (for **7**) (Scheme 4). Ethyl acetate and vinyl acetate served as acylation agents and solvents. The enzymatic transformations were carried out on a preparative scale (substrate, 1 mmol; EtOAc (ViOAc), 25 mL; PPL, 1 g; *T*, 30 °C; for further details, see the Experimental Section). The reactions were monitored by gas-chromatographic analyses (see the Experimental Section) and stopped when the formation of the corresponding diacetates was detected. The products (*R*)-**1**−(*R*)-**4** were

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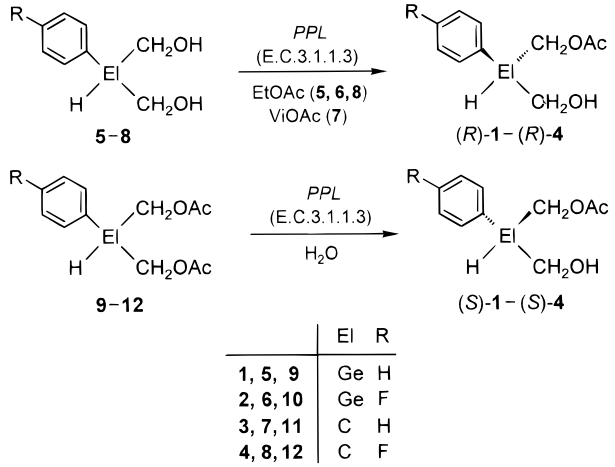
Scheme 4



	El	R
1, 5, 9	Ge	H
2, 6, 10	Ge	F
3, 7, 11	C	H
4, 8, 12	C	F

Table 1. Experimental Data[a] for the PPL-Catalyzed Transesterifications of 5−8 [Formation of (*R*)-1−(*R*)-4]

compd	reaction time (min)	yield (%)	ee value (%) ^{1}H[b]	ee value (%) ^{19}F[c]	$[\alpha]_{366}^{20}$ [d]
(*R*)-**1**[e]	150	76	93	93	+6.4
(*R*)-**2**[e]	75	77	87	86	+5.9
(*R*)-**3**[f]	50	76	89	89	−17.5
(*R*)-**4**[e]	240	76	89	90	−19.0

[a] The data (mean values) given are based on three single enzymatic transformations (for the experimental conditions, see the Experimental Section). [b] Data obtained by ^{1}H NMR studies (see text). [c] Data obtained by ^{19}F NMR studies (see text). [d] Specific optical rotation determined in acetone (*c*, 2.5). [e] Ethyl acetate as acyl donor. [f] Vinyl acetate as acyl donor.

isolated and subsequently purified by preparative layer chromatography on silica gel. Their enantiomeric purities were determined by NMR-spectroscopic investigations (see below). Alternatively, the ee values were established by liquid-chromatographic [(*R*)-**1**−(*R*)-**4**] and gas-chromatographic [(*R*)-**2**, (*R*)-**4**)] studies (see below). Selected experimental data (mean values for three single experiments) for the enzymatic transesterifications of **5**−**8** are summarized in Table 1.

The conversion rates of the transesterifications of the bis(hydroxymethyl)germanes **5** and **6** with ethyl acetate were found to be higher than those of the corresponding carbon analogues **7** and **8**. As the conversion rate of **7** was particularly low (ca. 50% conversion after 48 h), vinyl acetate was used as the acyl donor for the synthesis of (*R*)-**3**. The products (*R*)-**1**−(*R*)-**4** were isolated in reasonable yields with high enantiomeric purities. The ee values determined by NMR-spectroscopic studies (see Table 1) were in good agreement with those obtained by the liquid-chromatographic and gas-chromatographic investigations (data not given). Further attempts to optimize the enzymatic transesterifications of **5**−**8** were not made.

Enzymatic Hydrolyses of 9−12. The prochiral bis(acetoxymethyl)germanes **9** and **10** and the corresponding carbon analogues **11** and **12** were transformed enantioselectively into the (*S*)-enantiomers of **1**−**4** using a PPL-catalyzed (E.C.3.1.1.3) hydrolysis in a phosphate buffer/tetrahydrofuran system (25:1, v/v) (Scheme 4). The enzymatic transformations were carried out on a preparative scale [substrate, 1 mmol; Sörensen phosphate buffer (pH 7), 25 mL; tetrahydrofuran, 1 mL; PPL, 80 mg; *T*, 30 °C]. The reactions were monitored by gas-chromatographic analyses (see the Experimental Section) and stopped when the formation of the corresponding diols was detected. The products (*S*)-**1**−(*S*)-**4** were isolated and subsequently purified by preparative layer chromatography on silica gel. Their enantiomeric purities were determined by NMR-spectroscopic investigations. Alternatively, the ee values were established by liquid-chromatographic [(*S*)-**1**−(*S*)-**4**] and gas-chromatographic [(*S*)-**2**, (*S*)-**4**] studies (see below). Selected experimental data (mean values for three single experiments) for the enzymatic hydrolyses of **9**−**12** are summarized in Table 2.

Table 2. Experimental Data[a] for the PPL-Catalyzed Hydrolyses of 9−12 [Formation of (*S*)-1−(*S*)-4]

compd	reaction time (min)	yield (%)	ee value (%) ^{1}H[b]	ee value (%) ^{19}F[c]	$[\alpha]_{366}^{20}$ [d]
(*S*)-**1**	375	48	84	84	−5.8
(*S*)-**2**	315	62	94	94	−6.4
(*S*)-**3**	420	63	81	81	+15.7
(*S*)-**4**	240	63	88	86	+18.3

[a] The data (mean values) given are based on three single enzymatic transformations (for the experimental conditions, see the Experimental Section). [b] Data obtained by ^{1}H NMR studies (see text). [c] Data obtained by ^{19}F NMR studies (see text). [d] Specific optical rotation determined in acetone (*c*, 2.5).

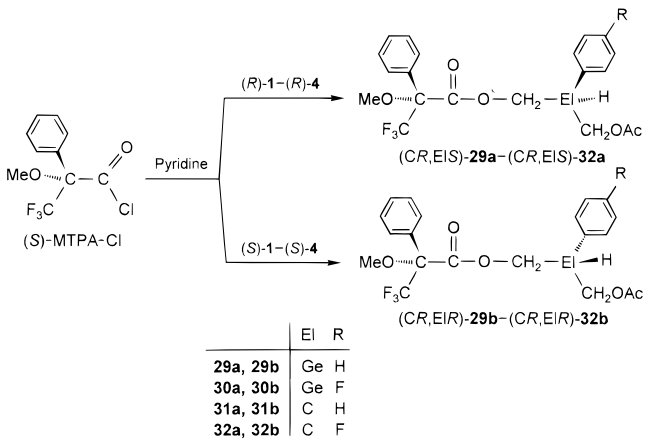
The conversion rates of the hydrolyses of the bis(acetoxymethyl)germanes **9** and **10** were found to be similar to those of the corresponding carbon analogues **11** and **12**. The products (*S*)-**1**−(*S*)-**4** were isolated in reasonable yields with high enantiomeric purities. The ee values determined by NMR-spectroscopic studies (see Table 2) were in good agreement with those obtained by the liquid-chromatographic and gas-chromatographic investigations (data not given). Further attempts to optimize the enzymatic hydrolyses of **9**−**12** were not made.

Configurational Stability of the Antipodes of 1−4. In contrast to the configurationally stable antipodes of **3** and **4**, the corresponding germanes (*R*)-**1**, (*S*)-**1**, (*R*)-**2**, and (*S*)-**2** were found to undergo a partial racemization (up to ca. 5%) upon heating (Kugelrohr distillation, 120 °C, 0.01 Torr). However, storage of the purified antipodes of the germanes **1** and **2** at −20 °C for 6 months did not lead to a significant degree of racemization.

Preparative Liquid-Chromatographic Resolution of *rac*-2 and *rac*-4. The germanium/carbon analogues *rac*-**2** and *rac*-**4** were resolved by preparative liquid chromatography on cellulose tribenzoate using the solvent system *n*-hexane/diisopropyl ether (50:50, v/v) and *n*-hexane/*tert*-butyl methyl ether (50:50, v/v), respectively. The yields were 80% (enantiomers of **2**; eight runs each on a 500-mg scale) and 97% (enantiomers of **4**; three runs each on an 850-mg scale). The enantiomeric purities of the resolved antipodes were as follows: (*R*)-**2**, 97% ee; (*S*)-**2**, 97% ee; (*R*)-**4**, >99% ee; (*S*)-**4**, >98% ee (ee values determined by liquid chromatography). To the best of our knowledge, the resolution of *rac*-**2** is the first example of a preparative liquid-chromatographic separation of the antipodes of a centrochiral germane.

The yields and enantiomeric purities of the germanes (*R*)-**2** and (*S*)-**2** were lower than those obtained for their

Scheme 5



carbon analogues (*R*)-**4** and (*S*)-**4**. This observation can be explained in terms of a decomposition of the germanes. The nature of this process (which even proceeded after the chromatographic separation was finished) is unknown.[10] Interestingly, this particular type of decomposition was not observed for the samples obtained by the enzymatic transformations. However, by analogy with the behavior of the products prepared by biotransformation, the samples obtained by liquid chromatography were also found to undergo a partial racemization (up to ca. 5%) upon heating (Kugelrohr distillation, 120 °C, 0.01 Torr).

Determination of the Enantiomeric Purities of the Antipodes of 1−4 by ^{1}H and ^{19}F NMR Spectroscopy. The enantiomeric purities of the antipodes of **1**−**4** were determined, after derivatization with (*S*)-α-methoxy-α-(trifluoromethyl)phenylacetyl chloride [(*S*)-MTPA-Cl] (Scheme 5), by ^{1}H and ^{19}F NMR studies of the corresponding diastereomeric (*R*)-MTPA esters **29a**−**32a** and **29b**−**32b** (quantification of the diastereomers by integration of characteristic resonance signals). Generally, both NMR-spectroscopic methods gave almost the same results. In addition, these results were in good agreement with those obtained by the liquid-chromatographic and gas-chromatographic studies.

Determination of the Enantiomeric Purities of the Antipodes of 1−4 by Liquid Chromatography. Compounds *rac*-**1**−*rac*-**4** were resolved by analytical liquid chromatography (HPLC) using cellulose tribenzoate as the chiral stationary phase. The retention times of the (*R*)- and (*S*)-enantiomers of **1**−**4** are listed in Table 3. This liquid-chromatographic method was used to determine the enantiomeric purities of the antipodes of **1**−**4** obtained by enzymatic transformations and liquid-chromatographic resolutions.

Determination of the Enantiomeric Purities of the Antipodes of 2 and 4 by Capillary Gas Chromatography. Compounds *rac*-**2** and *rac*-**4** were additionally resolved, after conversion into the corresponding trifluoroacetates, by analytical capillary gas chromatography using a chemically modified cyclodextrin column. The retention times of the (*R*)- and (*S*)-enantiomers of **2** and **4** are listed in Table 4. This gas-chromatographic method was used to determine the enantiomeric purities of the antipodes of **2** and **4** obtained by enzymatic transformations. To the best of our knowledge, the resolution of *rac*-**2** is the first example of an analytical gas-chromatographic separation of the enantiomers of a centrochiral germane.

Table 3. Retention Times[a] for the Analytical Liquid-Chromatographic (HPLC) Separation of the (*R*)- and (*S*)-Enantiomers of 1−4

compd	retention time (min)	compd	retention time (min)
(*R*)-**1**	116	(*R*)-**3**	48
(*S*)-**1**	105	(*S*)-**3**	39
(*R*)-**2**	90	(*R*)-**4**	24
(*S*)-**2**	71	(*S*)-**4**	54

[a] Determined for the racemic mixtures; for experimental conditions, see the Experimental Section.

Table 4. Retention Times[a] for the Analytical Gas-Chromatographic Separations of the Trifluoroacetates of the (*R*)- and (*S*)-Enantiomers of 2 and 4

compd	retention time (min)	compd	retention time (min)
(*R*)-**2**	29.50	(*R*)-**4**	29.20
(*S*)-**2**	29.70	(*S*)-**4**	29.50

[a] Determined for the racemic mixtures; for experimental conditions, see the Experimental Section.

Absolute Configuration of the Antipodes of 1−4. The stereochemical course of the PPL-catalyzed transesterification of the prochiral diol **7** with methyl acetate [formation of (*R*)-**3**] has already been reported in the literature.[6] We observed the same stereochemistry when using ethyl acetate instead of methyl acetate as the acyl donor. This result is in agreement with the stereochemical course of a series of PPL-catalyzed transesterifications with related 2-organyl-1,3-propanediols.[5,6] Thus, it is likely to assume that the transesterifications of the diols **5**, **6**, and **8** proceed with the same stereochemistry [formation of (*R*)-**1**, (*R*)-**2**, and (*R*)-**4**]. On the basis of analogous considerations, the (*S*)-configuration can be assumed for the products obtained by the PPL-catalyzed hydrolysis of the prochiral diacetates **9**−**12** [formation of (*S*)-**1**−(*S*)-**4**] (in this context, see also refs 5 and 6). In the case of the (*R*)- and (*S*)-enantiomers of **3** and **4**, assignment of the absolute configurations by this particular biochemical correlation is strongly supported by chiroptical correlations. As expected, the chiroptical properties (specific optical rotations at 366, 436, 546, 578, and 589 nm; acetone, $c = 2.5$) of the levorotatory enantiomers (*R*)-**3** and (*R*)-**4** [dextrorotatory enantiomers (*S*)-**3** and (*S*)-**4**] were found to be very similar. In contrast, the chiroptical properties of the (*R*)- and (*S*)-enantiomers of the germanes **1** and **2** differ significantly from those determined for the antipodes of their corresponding carbon analogues **3** and **4**. Compounds (*R*)-**1** and (*R*)-**2** [(*S*)-**1** and (*S*)-**2**] are the dextrorotatory (levorotatory) enantiomers, whereas the carbon analogues (*R*)-**3** and (*R*)-**4** [(*S*)-**3** and (*S*)-**4**] show the opposite sign of optical rotation (Figure 1). However, this surprising observation does not contradict the absolute configurations of the germanes (*R*)-**1**, (*S*)-**1**, (*R*)-**2**, and (*S*)-**2** assigned on the basis of the biochemical correlation. Additional experimental studies have shown that removal of the

(10) This decomposition is probably supported by trace components arising from the stationary phase and/or the eluents. This process can be stopped by an additional purification by layer chromatography on silica gel and/or distillation (Kugelrohr distillation, 120 °C, 0.01 Torr). However, the distillation leads to a decrease in enantiomeric purity.

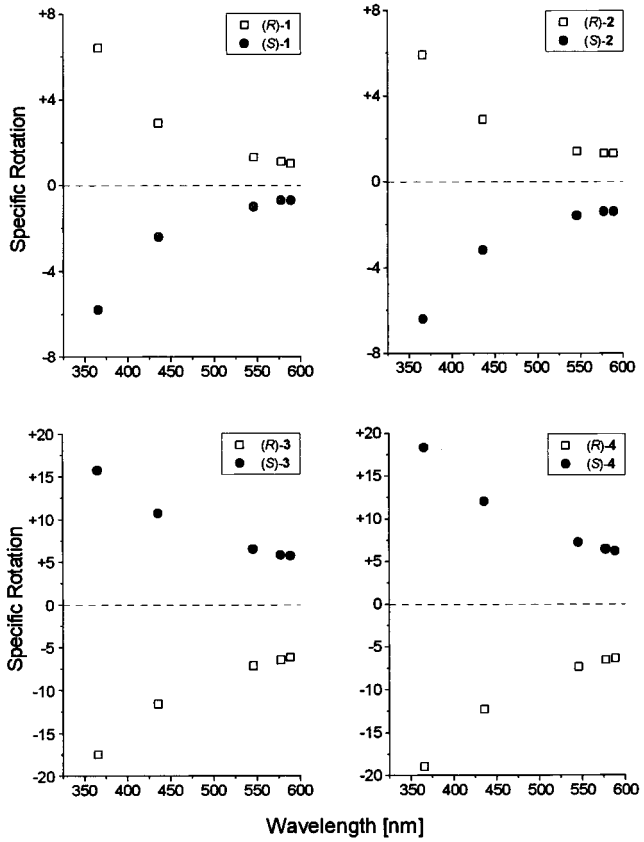
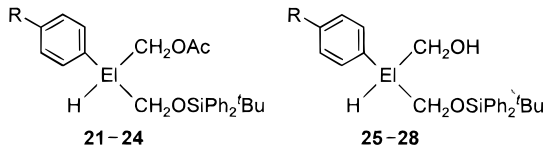


Figure 1. Specific optical rotations of the antipodes of the germanes **1** and **2** (above) and the antipodes of their carbon analogues **3** and **4** (below) determined at 366, 436, 546, 578, and 589 nm in acetone (*c*, 2.5; *T*, 20 °C). The (*R*)-enantiomers were prepared by enzymatic transesterifications, the (*S*)-enantiomers by enzymatic hydrolyses (see text).

alcohol or ester functionality of the biotransformation products (*R*)-**1**−(*R*)-**4** and (*S*)-**1**−(*S*)-**4** by derivatization (see next section) leads to similar chiroptical properties of the (*R*)- and (*S*)-enantiomers of the respective Ge/C analogues (Figure 2). Thus, the respective dextrorotatory Ge/C pairs (*S*)-**21**/(*S*)-**23**, (*S*)-**22**/(*S*)-**24**, (*S*)-**25**/(*S*)-



	El	R
21, 25	Ge	H
22, 26	Ge	F
23, 27	C	H
24, 28	C	F

27, and (*S*)-**26**/(*S*)-**28** display similar chiroptical properties. The same holds true for the corresponding levorotatory Ge/C pairs (*R*)-**21**/(*R*)-**23**, (*R*)-**22**/(*R*)-**24**, (*R*)-**25**/(*R*)-**27**, and (*R*)-**26**/(*R*)-**28**. These results additionally support the assignment of the absolute configurations of the germanes (*R*)-**1**, (*S*)-**1**, (*R*)-**2**, and (*S*)-**2**. The differences in the chiroptical properties observed for the Ge/C analogues (*R*)-**1**/(*R*)-**3**, (*S*)-**1**/(*S*)-**3**, (*R*)-**2**/(*R*)-**4**, and (*S*)-**2**/(*S*)-**4** cannot yet be explained.[11]

Derivatization of the Antipodes of 1−4. The biotransformation products (*R*)-**1**, (*S*)-**1**, (*R*)-**2**, and (*S*)-**2**

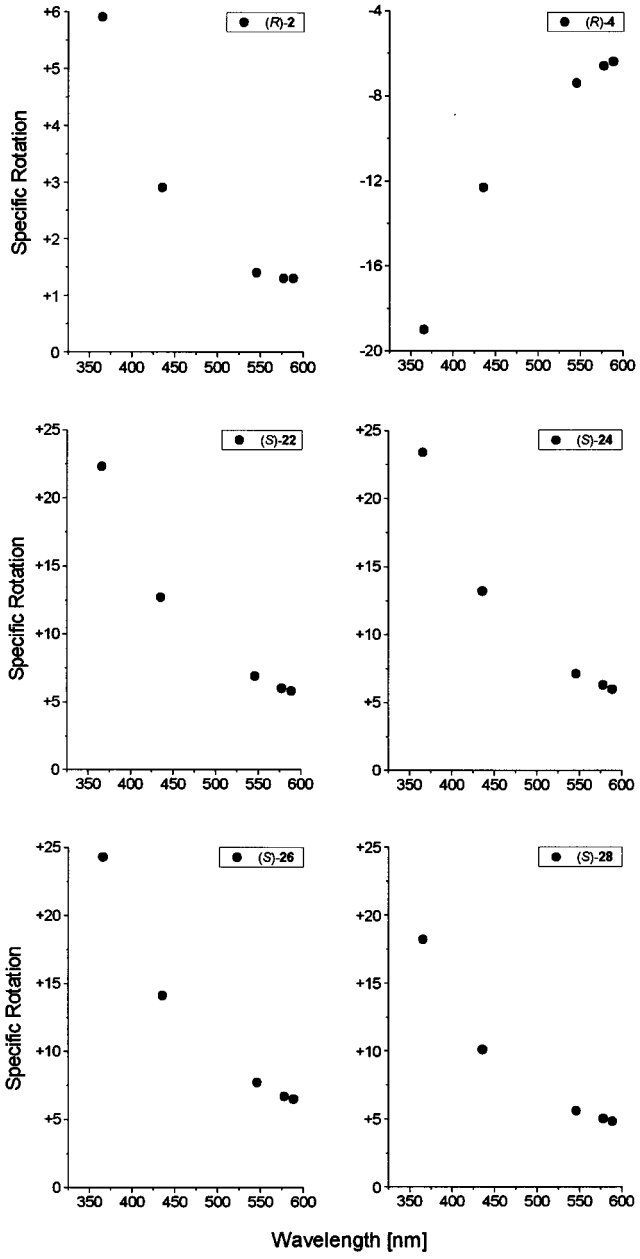
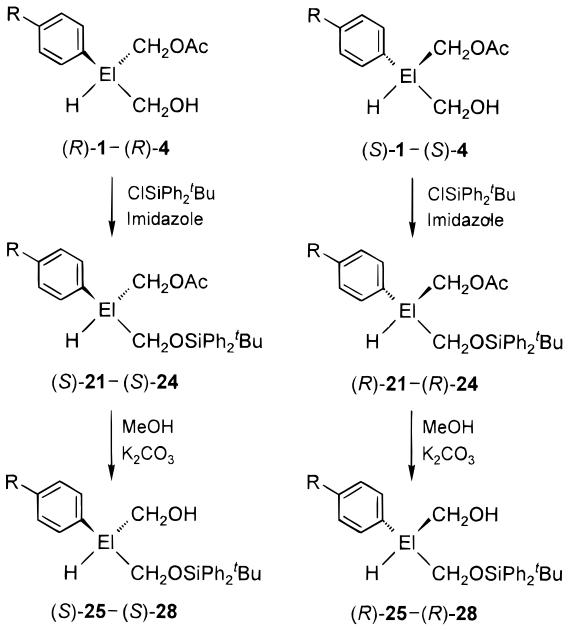


Figure 2. Specific optical rotations of the Ge/C analogues (*R*)-**2**/(*R*)-**4** (above), (*S*)-**22**/(*S*)-**24** (middle), and (*S*)-**26**/(*S*)-**28** (below) determined at 366, 436, 546, 578, and 589 nm in acetone (*c*, 2.5; *T*, 20 °C). Compounds (*R*)-**2** and (*R*)-**4** were prepared by enzymatic transesterifications; compounds (*S*)-**22**, (*S*)-**24**, (*S*)-**26**, and (*S*)-**28** were synthesized from the corresponding biotransformation products (see text).

are trifunctional compounds containing a GeH moiety, an alcoholic OH group, and an ester function [ROC(O)-Me]. To demonstrate that these compounds can be used as starting materials for the synthesis of further optically active hydridogermanes, reactions at their alcoholic OH groups and ester moieties were carried out. For reasons of comparison, the corresponding carbon analogues (*R*)-**3**, (*S*)-**3**, (*R*)-**4**, and (*S*)-**4** were included

(11) One may speculate about different conformations of the corresponding Ge/C analogues caused by different O−H···O interactions between their OH and OAc groups (the different covalent radii of germanium and carbon may affect this hydrogen bonding system). Removal of one of the two functionalities should lead to more similar conformations of the Ge/C analogues.

Scheme 6



	El	R
1, 21, 25	Ge	H
2, 22, 26	Ge	F
3, 23, 27	C	H
4, 24, 28	C	F

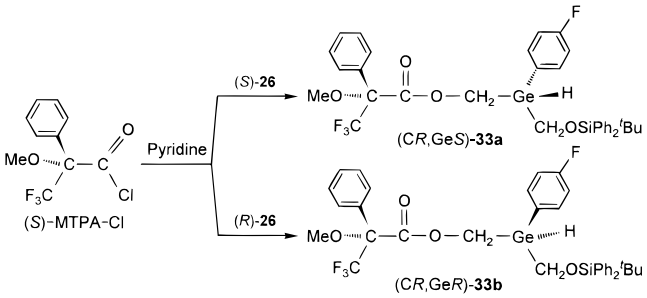
in these studies. As shown in Scheme 6, the biotransformation products (*R*)-**1**−(*R*)-**4** and (*S*)-**1**−(*S*)-**4** were converted into the derivatives (*S*)-**21**−(*S*)-**28** and (*R*)-**21**−(*R*)-**28**, respectively. Reaction of (*R*)-**1**−(*R*)-**4** with *tert*-butylchlorodiphenylsilane and imidazole in dimethylformamide yielded the corresponding *O*-silyl derivatives (*S*)-**21**−(*S*)-**24** (yields 79−82%). The antipodes (*R*)-**21**−(*R*)-**24** were obtained analogously, starting from (*S*)-**1**−(*S*)-**4** (yields 78−85%). Subsequent reaction of the esters (*S*)-**21**−(*S*)-**24** and (*R*)-**21**−(*R*)-**24** with methanol, in the presence of potassium carbonate, yielded the corresponding alcohols (*S*)-**25**−(*S*)-**28** and (*R*)-**25**−(*R*)-**28**, respectively (yields 76−87%). As the center of chirality (central germanium or carbon atom) is not involved in these chemical transformations, retention of absolute configuration can be assumed for the reaction sequences **1**−**4** → **21**−**24** → **25**−**28**.

As investigated exemplarily for the reactions (*R*)-**2** → (*S*)-**22** → (*S*)-**26** and (*S*)-**2** → (*R*)-**22** → (*R*)-**26**, the enantiomeric purities of the germanes were not affected by these chemical transformations. This was demonstrated, after derivatization of (*S*)-**26** and (*R*)-**26** with (*S*)-α-methoxy-α-(trifluoromethyl)phenylacetyl chloride [(*S*)-MTPA-Cl] (Scheme 7), by ^{1}H and ^{19}F NMR studies of the corresponding (*R*)-MTPA ester **33a**/**33b**. The enantiomeric purities of the derivatives (*S*)-**26** and (*R*)-**26** were found to be almost the same as those determined for the biotransformation products (*R*)-**2** and (*S*)-**2**, respectively.

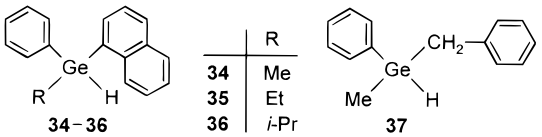
Conclusion

When the investigations described in this paper were started, only a few optically active hydridotriorganyl-

Scheme 7



germanes R^{1}R^{2}R^{3}GeH were known. To the best of our knowledge, the antipodes of **34**,[4b] **35**,[4d,e] and **36**[4g] as well



	R
34	Me
35	Et
36	*i*-Pr

as (+)-**37**[4i] are the only examples of this particular type of compound. Their syntheses are based on the resolution of chiral Ge-functional precursors R^{1}R^{2}R^{3}GeX via fractional crystallization of appropriate diastereomeric derivatives and subsequent chemical transformation of the resolved germanes (R^{1}R^{2}R^{3}GeX → R^{1}R^{2}R^{3}GeH). The enantiomeric purities of these optically active compounds have not been reported.

We have now succeeded for the first time in preparing the (*R*)- and (*S*)-enantiomers of centrochiral hydridotriorganylgermanes by enantioselective enzymatic transformations [synthesis of (*R*)-**1**, (*S*)-**1**, (*R*)-**2**, and (*S*)-**2**] and by preparative liquid-chromatographic resolution on a chiral stationary phase [preparation of (*R*)-**2** and (*S*)-**2**]. In addition, we have demonstrated that the antipodes of the trifunctional compounds **1** and **2** (GeH, COH, and COAc functionalities) can be used as starting materials for the preparation of further optically active hydridotriorganylgermanes [syntheses of the (*R*)- and (*S*)-enantiomers of **20**, **21**, **25**, and **26** by reaction at the COH and COAc groups]. As optically active hydridogermanes have been shown to be useful synthons for the preparation of further optically active derivatives (R^{1}R^{2}R^{3}GeH → R^{1}R^{2}R^{3}GeX),[4c,e−i] the antipodes of **1**, **2**, **20**, **21**, **25**, and **26** can also be regarded as potential starting materials for the synthesis of a variety of optically active centrochiral germanes. Reactions at the organic functional groups and at the GeH moiety as well offer a wide range of synthetic possibilities.

Generally, biocatalysis and liquid-chromatographic resolution on chiral stationary phases offer interesting fields of application for preparative organometallic chemistry. Both methods are characterized by relatively mild conditions, which is very advantageous for the preparation of compounds with limited chemical and thermal stability.

Experimental Section

General Procedures. All reactions were carried out under dry nitrogen unless otherwise indicated. The organic solvents used for the nonenzymatic syntheses were dried and purified according to standard procedures and stored under nitrogen. ^{1}H and ^{13}C NMR spectra were recorded at room temperature on a Bruker AMX-400 (^{1}H, 400.1 MHz; ^{13}C, 100.6 MHz), Bruker

DRX-300 (^{1}H, 300.1 MHz; ^{13}C, 75.5 MHz), or Bruker AC-250 NMR spectrometer (^{1}H, 250.1 MHz; ^{13}C, 62.9 MHz). ^{19}F NMR spectra were recorded at room temperature on a Bruker AMX-400 NMR spectrometer (^{19}F, 376.4 MHz). C_6D_6 was used as solvent. Chemical shifts (ppm) were determined relative to internal C_6D_5H (^{1}H, δ 7.28), C_6D_6 (^{13}C, δ 128.0), and $CFCl_3$ (^{19}F, δ 0). Assignment of the ^{13}C NMR data was supported by DEPT experiments. Analysis and assignment of the ^{1}H NMR data was partially supported by simulations using the WINDAISY software package (version 4.0, Bruker). Mass spectra were obtained with a Varian MAT-711 (EI MS, 70 eV; FI MS, 11 kV), Finnigan MAT-8430 (EI MS, 70 eV; CI MS, isobutane as reactant gas), or Finnigan MAT-8200 mass spectrometer (EI MS, 70 eV). The selected *m*/*z* values given refer to the isotopes ^{1}H, ^{12}C, ^{16}O, ^{19}F, ^{28}Si, ^{35}Cl, and ^{74}Ge. Optical rotations were measured with a POL S-2-5 polarimeter (L.O.T.-Oriel) using freshly prepared solutions; acetone (Uvasol; Merck, 100022) served as solvent. Preparative layer chromatography was performed with silica gel TLC plates (stationary phase, silica gel 60 F_{254}; layer thickness, 2 mm; Merck, 5717). Preparative column chromatography [column: 40 mm i.d. × 250 mm (*rac*-**1**, *rac*-**2**); 25 mm i.d. × 300 mm (*rac*-**3**); 60 mm i.d. × 200 mm (*rac*-**4**)] was performed using silica gel as stationary phase (silica gel 60, 0.063−0.200 mm; Merck, 15111).

Preparation of (*R*)-1−(*R*)-4 by Enzymatic Transesterification (General Procedure). Porcine pancreas lipase (E.C.3.1.1.3; Fluka, 62300; 2.55 U/mg) (1 g) was added to a solution of the respective diol **5**−**8** (1 mmol) in ethyl acetate (25 mL) (LiChrosolv; Merck, 100868) (**5**, **6**, **8**) or vinyl acetate (25 mL) (Aldrich, V150-3) (**7**). The suspension was shaken at the air in a water bath (30 °C, 145 rpm) and the enzymatic transformation monitored by gas chromatography (see below). After the formation of the respective diacetates **9**−**12** was detected, the biotransformation was stopped by centrifugation. The solvent was removed under reduced pressure (rotary evaporator) and the residue purified by preparative layer chromatography on silica gel [diethyl ether/*n*-hexane (2:1, v/v)]. Experimental data for the enzymatic transesterifications are listed in Table 1. The NMR-spectroscopic and mass-spectrometric data of (*R*)-**1**−(*R*)-**4** were identical with those obtained for the corresponding racemic mixtures *rac*-**1**−*rac*-**4** (see below). Anal. Calcd for (*R*)-**1** ($C_{10}H_{14}GeO_3$): C, 47.13; H, 5.54. Found: C, 46.8; H, 5.8. Calcd for (*R*)-**2** ($C_{10}H_{13}FGeO_3$): C, 44.03; H, 4.80. Found: C, 43.8; H, 4.8. Calcd for (*R*)-**3** ($C_{11}H_{14}O_3$): C, 68.02; H, 7.27. Found: C, 67.7; H, 7.2. Calcd for (*R*)-**4** ($C_{11}H_{13}FO_3$): C, 62.26; H, 6.17. Found: C, 61.7; H, 6.0.

Preparation of (*S*)-1−(*S*)-4 by Enzymatic Hydrolysis (General Procedure). Porcine pancreas lipase (E.C.3.1.1.3; Fluka, 62300; 2.55 U/mg) (80 mg) was added to a mixture of the respective diacetate **9**−**12** (1 mmol) in tetrahydrofuran (1 mL) and Sörensen phosphate buffer (pH 7) (25 mL). The suspension was shaken at the air in a water bath (30 °C, 145 rpm) and the enzymatic transformation monitored by gas chromatography (see below). After the formation of the respective diols **5**−**8** was detected, the biotransformation was stopped by centrifugation. The aqueous solution was extracted with diethyl ether (3 × 20 mL) and the combined organic layers dried over anhydrous Na_2SO_4. The solvent was removed under reduced pressure (rotary evaporator) and the residue purified by preparative layer chromatography on silica gel [diethyl ether/*n*-hexane (2:1, v/v)]. Experimental data for the enzymatic hydrolyses are listed in Table 2. The NMR-spectroscopic and mass-spectrometric data of (*S*)-**1**−(*S*)-**4** were identical with those obtained for the corresponding racemic mixtures *rac*-**1**−*rac*-**4** (see below). Anal. Calcd for (*S*)-**1** ($C_{10}H_{14}GeO_3$): C, 47.13; H, 5.54. Found: C, 46.8; H, 5.8. Calcd for (*S*)-**2** ($C_{10}H_{13}FGeO_3$): C, 44.03; H, 4.80. Found: C, 43.8; H, 4.7. Calcd for (*S*)-**3** ($C_{11}H_{14}O_3$): C, 68.02; H, 7.27. Found: C, 67.6; H, 7.4. Calcd for (*S*)-**4** ($C_{11}H_{13}FO_3$): C, 62.26; H, 6.17. Found: C, 62.0; H, 5.9.

Monitoring of the Time Course of the Enzymatic Transformations by Capillary Gas Chromatography. For monitoring the enzymatic conversions, 1-mL samples of the reaction mixtures were taken after various periods of time and analyzed by capillary gas chromatography. For this purpose, the samples taken from the enzymatic transesterifications were diluted with ethyl acetate (1 mL) and 1 μL of the resulting solution was injected into the gas chromatograph [gas chromatograph, Shimadzu GC-14A; capillary column, SE-30 CB (Ziemer, 6232.028), 10 m; carrier gas, nitrogen; temperature program, 80 °C (2 min) to 280 °C (20 min) with 10 °C/min; injector temperature, 200 °C; split, 1:50; detector, FID; detector temperature, 320 °C]. In the case of the enzymatic hydrolyses, the aqueous samples were extracted with diethyl ether (1 mL) and 1 μL of the organic extract was injected into the gas chromatograph. The retention times (min) were as follows: **1**, 9.1; **5**, 8.3; **9**, 10.2. −**2**, 9.0; **6**, 8.4; **10**, 10.0. −**3**, 7.9; **7**, 6.7; **11**, 9.1. −**4**, 8.1; **8,** 6.9; **12**, 9.2.

Preparative Liquid-Chromatographic Resolution of *rac*-2 and *rac*-4. The (*R*)- and (*S*)-enantiomers of **2** and **4** were obtained by liquid-chromatographic separation of *rac*-**2** and *rac*-**4**, respectively, on cellulose tribenzoate (10−20 μm; Riedel-deHaën, 39852). The experimental conditions were as follows: LC pump, Shimadzu LC8-A; detector, Knauer VW monitor; integrator, Shimadzu C−R3A; column (100 mm i.d. × 130 mm), Merck Superformance; eluent, *n*-hexane/diisopropyl ether (50:50, v/v) for *rac*-**2** and *n*-hexane/*tert*-butyl methyl ether (50:50, v/v) for *rac*-**4** (HPLC-grade solvents purchased from Merck); detection, 215 nm; *T*, ambient temperature; injection volume, 15 mL (500 mg of the sample material in 15 mL of 2-propanol) for *rac*-**2** and 20 mL (850 mg of the sample material in 20 mL of 2-propanol) for *rac*-**4**. Eight runs each on a 500-mg scale (*rac*-**2**) and three runs each on a 850-mg scale (*rac*-**4**), respectively, were performed. The solvents of the respective fractions obtained [(*R*)-**2**, second fraction; (*S*)-**2**, first fraction; (*R*)-**4**, first fraction; (*S*)-**4**, second fraction] were removed immediately after the chromatographic separation (rotary evaporator, 30 °C, 150 Torr), and the respective residues were combined and then stored at −18 °C. The yields and enantiomeric purities of the separated enantiomers (colorless liquids) were as follows: (*R*)-**2**, 80%, 97% ee; (*S*)-**2**, 80%, 97% ee; (*R*)-**4**, 97%, >99% ee; (*S*)-**4**, 97%, >98% ee (ee values determined by analytical liquid chromatography). Anal. Calcd for (*R*)-**2** ($C_{10}H_{13}FGeO_3$): C, 44.03; H, 4.80. Found: C, 43.6; H, 4.7. Calcd for (*S*)-**2** ($C_{10}H_{13}FGeO_3$): C, 44.03; H, 4.80. Found: C, 43.5; H, 4.8. Calcd for (*R*)-**4** ($C_{11}H_{13}FO_3$): C, 62.26; H, 6.17. Found: C, 61.5; H, 6.3. Calcd for (*S*)-**4** ($C_{11}H_{13}FO_3$): C, 62.26; H, 6.17. Found: C, 61.5; H, 6.1.

***rac*-(Acetoxymethyl)(hydroxymethyl)phenylgermane (*rac*-1).** Acetic anhydride (960 mg, 9.40 mmol) and triethylamine (951 mg, 9.40 mmol) were added to a solution of **5** (2.00 g, 9.40 mmol) in diethyl ether (100 mL). After the mixture was heated under reflux for 8 h and stirred at room temperature for 12 h, the organic layer was extracted with water (3 × 30 mL) and then dried over anhydrous Na_2SO_4. The solvent was removed under reduced pressure (rotary evaporator) and the product isolated and purified by column chromatography on silica gel [eluent diethyl ether/*n*-hexane (1:1, v/v); R_f(**9**) > R_f(*rac*-**1**) > R_f(**5**)] to give *rac*-**1** in 50% yield as a colorless liquid (1.20 g, 4.71 mmol). [In addition, the diol **5** (200 mg, 940 μmol; yield 10%) and the diacetate **9** (640 mg, 2.16 mmol; yield 23%) were isolated as colorless liquids.] ^{1}H NMR (400.1 MHz, C_6D_6): δ 1.66 (s, 3 H, CCH_3), 2.2 (br s, 1 H, OH), 4.02 ($\delta_{A(A')}$), 4.31 (δ_K), 4.34 (δ_L), and 4.89 (δ_X) [Ge($CH_AH_{A'}$-OH)(CH_KH_LOAc)H_X, $^3J_{AX} + {}^3J_{A'X} = 4.4$ Hz, $^2J_{KL} = -12.3$ Hz, $^3J_{KX} = 1.6$ Hz, $^3J_{LX} = 3.0$ Hz], 7.23−7.28 and 7.55−7.61 (m, 5 H, GeC_6H_5). ^{13}C NMR (62.9 MHz, C_6D_6): δ 20.1 (CCH_3), 53.0 ($GeCH_2O$), 55.0 ($GeCH_2O$), 128.3 (C-3/C-5, GeC_6H_5), 129.4 (C-4, GeC_6H_5), 134.5 (C-1, GeC_6H_5), 135.9 (C-2/C-6, GeC_6H_5),

171.6 (C=O). EI MS: *m*/*z* 256 [<1%, M^+], 225 [100%, $M^+ - CH_2OH$]. Anal. Calcd for $C_{10}H_{14}GeO_3$: C, 47.13; H, 5.54. Found: C, 47.3; H, 5.5.

***rac*-(Acetoxymethyl)(4-fluorophenyl)(hydroxymethyl)-germane (*rac*-2).** This compound was prepared analogously to the synthesis of *rac*-**1** by addition of acetic anhydride (995 mg, 9.75 mmol) and triethylamine (987 mg, 9.75 mmol) to a solution of **6** (2.25 g, 9.75 mmol) in diethyl ether (125 mL). After column-chromatographic separation on silica gel [eluent diethyl ether/*n*-hexane (1:1, v/v; **6** was eluated with ethyl acetate); R_f(**10**) > R_f(*rac*-**2**) > R_f(**6**)], *rac*-**2** was isolated in 47% yield as a colorless liquid (1.24 g, 4.55 mmol). [In addition, the diol **6** (231 mg, 1.00 mmol; yield 10%) was isolated as a white solid and the diacetate **10** (601 mg, 1.91 mmol; yield 20%) as a colorless liquid.] ^{1}H NMR (400.1 MHz, C_6D_6): δ 1.65 (s, 3 H, CCH_3), 1.9 (br s, 1 H, OH), 3.93 ($\delta_{A(A')}$), 4.22 (δ_K), 4.26 (δ_L), and 4.78 (δ_X) [$Ge(CH_AH_{A'}OH)(CH_KH_LOAc)H_X$, $^3J_{AX} + {}^3J_{A'X} = 3.8$ Hz, $^2J_{KL} = -12.3$ Hz, $^3J_{KX} = 1.6$ Hz, $^3J_{LX} = 3.0$ Hz], 6.90−6.98 and 7.34−7.40 (m, 4 H, GeC_6H_4F). ^{13}C NMR (62.9 MHz, C_6D_6): δ 20.1 (CCH_3), 53.1 ($GeCH_2O$), 55.0 ($GeCH_2O$), 115.7 (d, $^2J_{CF} = 19.5$ Hz, C-3/C-5, GeC_6H_4F), 129.8 (d, $^4J_{CF} = 4.3$ Hz, C-1, GeC_6H_4F), 136.9 (d, $^3J_{CF} = 7.3$ Hz, C-2/C-6, GeC_6H_4F), 164.2 (d, $^1J_{CF} = 247.8$ Hz, C-4, GeC_6H_4F), 171.7 (C=O). EI MS: *m*/*z* 274 [<1%, M^+], 243 [100%, $M^+ - CH_2OH$]. Anal. Calcd for $C_{10}H_{13}FGeO_3$: C, 44.03; H, 4.80. Found: C, 43.8; H, 4.8.

***rac*-3-Hydroxy-2-phenylpropyl Acetate (*rac*-3).** This compound was prepared analogously to the synthesis of *rac*-**1** by addition of acetic anhydride (671 mg, 6.57 mmol) and triethylamine (665 mg, 6.57 mmol) to a solution of **7** (1.00 g, 6.57 mmol) in diethyl ether (50 mL). After column-chromatographic separation on silica gel [eluent diethyl ether/*n*-hexane (1:1, v/v); R_f(**11**) > R_f(*rac*-**3**) > R_f(**7**)], *rac*-**3** was isolated in 59% yield as a colorless liquid (750 mg, 3.86 mmol). [In addition, the diol **7** (180 mg, 1.18 mmol; yield 18%) was isolated as a white solid and the diacetate **11** (330 mg, 1.40 mmol; yield 22%) as a colorless liquid.] ^{1}H NMR (300.1 MHz, C_6D_6): δ 1.36 (δ_Z), 3.02 (δ_X), 3.65 ($\delta_{A(A')}$), 4.42 (δ_K), and 4.44 (δ_L) [$C(CH_AH_{A'}OH_Z)(CH_KH_LOAc)H_X$, $^3J_{AX} + {}^3J_{A'X} = 12.2$ Hz, $^3J_{AZ} + {}^3J_{A'Z} = 11.4$ Hz, $^2J_{KL} = -11.0$ Hz, $^3J_{KX} = 6.6$ Hz, $^3J_{LX} = 6.9$ Hz], 1.67 (s, 3 H, CCH_3), 7.10−7.30 (m, 5 H, CC_6H_5). ^{13}C NMR (75.5 MHz, C_6D_6): δ 20.3 (CCH_3), 47.7 (CH), 63.9 (CCH_2O), 65.1 (CCH_2O), 127.2 (C-4, CC_6H_5), 128.4 (C-2/C-6, CC_6H_5), 128.8 (C-3/C-5, CC_6H_5), 139.9 (C-1, CC_6H_5), 170.7 (C=O). EI MS: *m*/*z* 134 [27%, $M^+ - CH_3COOH$], 104 [100%, $M^+ - CH_3COOH - CH_2O$]. Anal. Calcd for $C_{11}H_{14}O_3$: C, 68.02; H, 7.27. Found: C, 68.3; H, 7.3.

***rac*-2-(4-Fluorophenyl)-3-hydroxypropyl Acetate (*rac*-4).** This compound was prepared analogously to the synthesis of *rac*-**1** by addition of acetic anhydride (2.40 g, 23.5 mmol) and triethylamine (2.38 g, 23.5 mmol) to a solution of **8** (4.00 g, 23.5 mmol) in diethyl ether (250 mL). After column-chromatographic separation on silica gel [eluent diethyl ether/*n*-hexane (1:1, v/v); R_f(**12**) > R_f(*rac*-**4**) > R_f(**8**)], *rac*-**4** was isolated in 49% yield as a colorless liquid (2.44 g, 11.5 mmol). [In addition, the diol **8** (408 mg, 2.40 mmol; yield 10%) was isolated as a white solid and the diacetate **12** (1.24 g, 4.88 mmol; yield 21%) as a colorless liquid.] ^{1}H NMR (400.1 MHz, C_6D_6): δ 1.61 (δ_Z), 2.93 (δ_X), 3.58 ($\delta_{A(A')}$), 4.31 (δ_K), and 4.37 (δ_L) [$C(CH_AH_{A'}OH_Z)(CH_KH_LOAc)H_X$, $^3J_{AX} + {}^3J_{A'X} = 12.0$ Hz, $^3J_{AZ} + {}^3J_{A'Z} = 11.6$ Hz, $^2J_{KL} = -11.2$ Hz, $^3J_{KX} = 6.7$ Hz, $^3J_{LX} = 6.8$ Hz], 1.69 (s, 3 H, CCH_3), 6.85−6.97 (m, 4 H, CC_6H_4F). ^{13}C NMR (100.6 MHz, C_6D_6): δ 20.3 (CCH_3), 46.8 (CH), 63.7 (CCH_2O), 65.0 (CCH_2O), 115.8 (d, $^2J_{CF} = 21.1$ Hz, C-3/C-5, CC_6H_4F), 130.2 (d, $^3J_{CF} = 7.0$ Hz, C-2/C-6, CC_6H_4F), 135.8 (d, $^4J_{CF} = 3.0$ Hz, C-1, CC_6H_4F), 162.3 (d, $^1J_{CF} = 244.5$ Hz, C-4, CC_6H_4F), 170.5 (C=O). EI MS: *m*/*z* 212 [<1%, M^+], 152 [33%, $M^+ - CH_3COOH$], 122 [100%, $M^+ - CH_3COOH - CH_2O$]. Anal. Calcd for $C_{11}H_{13}FO_3$: C, 62.26; H, 6.17. Found: C, 61.7; H, 6.1.

Bis(hydroxymethyl)phenylgermane (5). A solution of **18** (14.0 g, 39.4 mmol) in diethyl ether (50 mL) was added dropwise at 0 °C over 1 h to a stirred suspension of lithium aluminum hydride (3.12 g, 82.2 mmol) in diethyl ether (250 mL). The reaction mixture was heated under reflux for 6 h and then stirred for a further 16 h at room temperature. After the mixture was cooled to 0 °C, a saturated aqueous solution of sodium sulfate was added cautiously in 10-mL portions until a white coagulum was formed. The organic layer was decanted and the coagulum extracted with diethyl ether (6 × 50 mL). The combined organic extracts were dried over anhydrous Na_2SO_4, and the solvent was removed under reduced pressure (rotary evaporator). The crude product was purified by distillation in vacuo (Vigreux column) to give **5** in 74% yield as a colorless liquid (6.20 g, 29.1 mmol); bp 130 °C/ 0.01 Torr. ^{1}H NMR (400.1 MHz, C_6D_6): δ 2.1 (br s, 2 H, OH), 3.97−4.08 [m, 4 H, $Ge(CH_AH_BO)(CH_{A'}H_{B'}O)$], 4.81 [m, center, 1 H, GeH), 7.24−7.30 and 7.59−7.65 (m, 5 H, GeC_6H_5). ^{13}C NMR (62.9 MHz, C_6D_6): δ 53.6 ($GeCH_2O$), 128.5 (C-3/C-5, GeC_6H_5), 129.3 (C-4, GeC_6H_5), 135.0 (C-2/C-6, GeC_6H_5), 135.3 (C-1, GeC_6H_5). EI MS: *m*/*z* 213 [2%, $M^+ - H$], 183 [70%, $M^+ - CH_2OH$], 91 [100%, $C_7H_7^+$]. Anal. Calcd for $C_8H_{12}GeO_2$: C, 45.16; H, 5.68. Found: C, 45.1; H, 5.6.

(4-Fluorophenyl)bis(hydroxymethyl)germane (6). This compound was prepared analogously to the synthesis of **5** by addition of a solution of **19** (5.30 g, 14.2 mmol) in diethyl ether (20 mL) to a suspension of lithium aluminum hydride (1.62 g, 42.7 mmol) in diethyl ether (100 mL). The crude product was distilled in vacuo (Vigreux column) to give **6** in 74% yield as a colorless liquid (crystallization on cooling to room temperature) (2.44 g, 10.6 mmol); bp 130 °C/0.01 Torr. ^{1}H NMR (400.1 MHz, C_6D_6): δ 2.3 (br s, 2 H, OH), 3.90−4.05 [m, 4 H, $Ge(CH_AH_BO)(CH_{A'}H_{B'}O)$], 4.73 [m, center, 1 H, GeH), 6.93−7.02 and 7.37−7.46 (m, 4 H, GeC_6H_4F). ^{13}C NMR (62.9 MHz, C_6D_6): δ 53.6 ($GeCH_2O$), 115.8 (d, $^2J_{CF} = 20.1$ Hz, C-3/C-5, GeC_6H_4F), 130.4 (d, $^4J_{CF} = 4.3$ Hz, C-1, GeC_6H_4F), 136.9 (d, $^3J_{CF} = 6.2$ Hz, C-2/C-6, GeC_6H_4F), 164.2 (d, $^1J_{CF} = 247.8$ Hz, C-4, GeC_6H_4F). EI MS: *m*/*z* 201 [78%, $M^+ - CH_2OH$], 109 [100%, $C_7H_6F^+$]. Anal. Calcd for $C_8H_{11}FGeO_2$: C, 41.64; H, 4.80. Found: C, 41.3; H, 4.8.

2-Phenyl-1,3-propanediol (7). Synthesis was according to ref 7.

2-(4-Fluorophenyl)-1,3-propanediol (8). A solution of **20** (7.46 g, 37.6 mmol) in diethyl ether (50 mL) was added dropwise at 0 °C over 1 h to a stirred suspension of lithium aluminum hydride (3.57 g, 94.1 mmol) in diethyl ether (250 mL). The reaction mixture was heated under reflux for 6 h and then stirred for a further 16 h at room temperature. After the mixture was cooled to 0 °C, a saturated aqueous solution of sodium sulfate was added cautiously in 10-mL portions until a white coagulum was formed. The organic layer was decanted and the coagulum extracted with diethyl ether (6 × 50 mL). The combined organic extracts were dried over anhydrous Na_2SO_4, and the solvent was removed under reduced pressure (rotary evaporator). The crude product was purified by distillation in vacuo (Vigreux column) to give **8** in 79% yield as a colorless liquid (crystallization on cooling to room temperature) (5.06 g, 29.7 mmol); bp 130 °C/0.01 Torr. ^{1}H NMR (400.1 MHz, C_6D_6): δ 2.99 (m, center, 1 H, CH), 3.78−3.94 [m, 4 H, $C(CH_AH_BO)(CH_{A'}H_{B'}O)$], 4.03 (s, 2 H, OH), 6.93−7.10 (m, 4 H, CC_6H_4F). ^{13}C NMR (100.6 MHz, C_6D_6): δ 49.1 (CH), 65.8 (CCH_2O), 115.5 (d, $^2J_{CF} = 21.1$ Hz, C-3/C-5, CC_6H_4F), 129.8 (d, $^3J_{CF} = 8.1$ Hz, C-2/C-6, CC_6H_4F), 136.1 (d, $^4J_{CF} = 3.6$ Hz, C-1, CC_6H_4F), 162.2 (d, $^1J_{CF} = 244.1$ Hz, C-4, CC_6H_4F). EI MS: *m*/*z* 170 [2%, M^+], 122 [100%, $M^+ - CH_2OH - OH$]. Anal. Calcd for $C_9H_{11}FO_2$: C, 63.52; H, 6.51. Found: C, 63.1; H, 6.4.

Bis(acetoxymethyl)phenylgermane (9). Acetic anhydride (3.57 g, 35.0 mmol) and triethylamine (3.54 g, 35.0 mmol) were added to a solution of **5** (3.20 g, 15.0 mmol) in diethyl ether (150 mL). The mixture was heated under reflux for 8 h

and then stirred for a further 12 h at room temperature. After the organic layer was extracted with water (3 × 30 mL) and dried over anhydrous Na_2SO_4, the solvent was removed under reduced pressure (rotary evaporator) and the residue distilled in vacuo (Vigreux column) to give **9** in 94% yield as a colorless liquid (4.20 g, 14.1 mmol); bp 110 °C/0.01 Torr. ^{1}H NMR (250.1 MHz, C_6D_6): δ 1.71 (s, 6 H, CCH_3), 4.40 (d, $^3J_{HH}$ = 2.4 Hz, 4 H, $GeCH_2O$), 5.04 (q, $^3J_{HH}$ = 2.4 Hz, 1 H, GeH), 7.20−7.60 (m, 5 H, GeC_6H_5). ^{13}C NMR (62.9 MHz, C_6D_6): δ 20.0 (CCH_3), 55.1 ($GeCH_2O$), 128.5 (C-3/C-5, GeC_6H_5), 129.5 (C-4, GeC_6H_5), 133.9 (C-1, GeC_6H_5), 135.0 (C-2/C-6, GeC_6H_5), 176.7 (C=O). EI MS: *m/z* 297 [1%, $M^+ - H$], 225 [100%, $M^+ - CH_2OC(O)CH_3$]. Anal. Calcd for $C_{12}H_{16}GeO_4$: C, 48.55; H, 5.43. Found: C, 48.1; H, 5.4.

Bis(acetoxymethyl)(4-fluorophenyl)germane (10). This compound was prepared analogously to the synthesis of **9** by addition of acetic anhydride (2.99 g, 29.3 mmol) and triethylamine (2.96 g, 29.3 mmol) to a solution of **6** (2.91 g, 12.6 mmol) in diethyl ether (100 mL). The crude product was purified by distillation in vacuo (Vigreux column) to give **10** in 91% yield as a colorless liquid (3.60 g, 11.4 mmol); bp 113 °C/0.01 Torr. ^{1}H NMR (250.1 MHz, C_6D_6): δ 1.69 (s, 6 H, CCH_3), 4.31 (d, $^3J_{HH}$ = 2.4 Hz, 4 H, $GeCH_2O$), 4.96 (q, $^3J_{HH}$ = 2.4 Hz, 1 H, GeH), 6.85−7.00 and 7.30−7.43 (m, 4 H, GeC_6H_4F). ^{13}C NMR (62.9 MHz, C_6D_6): δ 20.0 (CCH_3), 55.2 ($GeCH_2O$), 115.7 (d, $^2J_{CF}$ = 20.1 Hz, C-3/C-5, GeC_6H_4F), 129.3 (d, $^4J_{CF}$ = 4.3 Hz, C-1, GeC_6H_4F), 136.9 (d, $^3J_{CF}$ = 8.2 Hz, C-2/C-6, GeC_6H_4F), 164.3 (d, $^1J_{CF}$ = 248.4 Hz, C-4, GeC_6H_4F), 170.8 (C=O). EI MS: *m/z* 315 [3%, $M^+ - H$], 243 [100%, $M^+ - CH_2OC(O)CH_3$]. Anal. Calcd for $C_{12}H_{15}FGeO_4$: C, 45.78; H, 4.80. Found: C, 45.8; H, 4.8.

2-Phenyl-1,3-propanediyl Diacetate (11). Synthesis was according to ref 8.

2-(4-Fluorophenyl)-1,3-propanediyl Diacetate (12). This compound was prepared analogously to the synthesis of **9** by addition of acetic anhydride (4.91 g, 48.1 mmol) and triethylamine (4.86 g, 48.0 mmol) to a solution of **8** (3.51 g, 20.6 mmol) in diethyl ether (175 mL). The crude product was purified by distillation in vacuo (Vigreux column) to give **12** in 95% yield as a colorless liquid (5.00 g, 19.7 mmol); bp 110 °C/0.01 Torr. ^{1}H NMR (400.1 MHz, C_6D_6): δ 1.70 (s, 6 H, CCH_3), 3.15 (q, $^3J_{HH}$ = 6.6 Hz, 1 H, CH), 4.25 (d, $^3J_{HH}$ = 6.6 Hz, 4 H, CCH_2O), 6.88 ($\delta_{A(A')}$) [$CC_6(H_AH_{A'})_2F_X$, $^3J_{AX} + {}^4J_{A'X}$ = 14.4 Hz]. ^{13}C NMR (100.6 MHz, C_6D_6): δ 20.2 (CCH_3), 43.5 (CH), 64.7 (CCH_2O), 115.6 (d, $^2J_{CF}$ = 21.1 Hz, C-3/C-5, CC_6H_4F), 129.8 (d, $^3J_{CF}$ = 8.1 Hz, C-2/C-6, CC_6H_4F), 134.6 (d, $^4J_{CF}$ = 3.0 Hz, C-1, CC_6H_4F), 162.4 (d, $^1J_{CF}$ = 244.1 Hz, C-4, CC_6H_4F), 169.9 (C=O). EI MS: *m/z* 194 [25%, $M^+ - CH_3COOH$], 43 [100%, $C(O)CH_3^+$]. Anal. Calcd for $C_{13}H_{15}FO_4$: C, 61.41; H, 5.95. Found: C, 61.1; H, 5.8.

Dichlorobis(chloromethyl)germane (13). Synthesis was according to ref 4j.

Chlorobis(chloromethyl)phenylgermane/Bromobis(chloromethyl)phenylgermane (14/15). A 2.1 M solution of phenylmagnesium bromide in diethyl ether (43.2 mL, 90.7 mmol C_6H_5MgBr) was added dropwise at 0 °C over 2 h to a stirred solution of **13** (22.0 g, 90.7 mmol) in diethyl ether (350 mL). After the reaction mixture was stirred at room temperature for 4 h and heated under reflux for 4 h, the precipitate was filtered off and the solvent of the filtrate removed under reduced pressure. *n*-Pentane (100 mL) was added to the residue and the resulting precipitate filtered off. The filtrate was concentrated under reduced pressure and the residue distilled in vacuo (Vigreux column) to give a mixture of **14** and **15** as a colorless liquid (22.8 g); bp 103−113 °C/0.01 Torr. This mixture was used for the synthesis of **18** (see below).

Chlorobis(chloromethyl)(4-fluorophenyl)germane/Bromobis(chloromethyl)(4-fluorophenyl)germane (16/17). This mixture was prepared analogously to the synthesis of **14/15** by addition of a 1.54 M solution of (4-fluorophenyl)magnesium bromide in diethyl ether (61.3 mL, 94.4 mmol *p*-FC_6H_4MgBr) to a solution of **13** (22.9 g, 94.4 mmol) in diethyl ether (350 mL). The mixture of **16** and **17** was isolated by distillation as a colorless liquid (22.8 g); bp 103−117 °C/0.01 Torr. This mixture was used for the synthesis of **19** (see below).

Acetoxybis(acetoxymethyl)phenylgermane (18). A mixture of **14** and **15** (22.8 g; see above) and sodium acetate (20.0 g, 244 mmol) in dimethylformamide (250 mL) was stirred at 80 °C for 8 h. The mixture was allowed to cool to room temperature and the precipitate filtered off. The solvent of the filtrate was removed under reduced pressure at room temperature and diethyl ether (100 mL) added to the residue. The resulting precipitate was filtered off and the solvent of the filtrate removed under reduced pressure. The crude product was purified by Kugelrohr distillation (oven temperature 170 °C, 0.01 Torr) to give **18** in 65% yield (referred to **13**) as a colorless liquid (21.0 g, 59.2 mmol). ^{1}H NMR (250.1 MHz, C_6D_6): δ 1.65 [s, 6 H, $COC(O)CH_3$], 1.98 [s, 3 H, $GeOC(O)CH_3$], 4.61 (δ_A) and 4.69 (δ_B) [$Ge(CH_AH_BO)_2$, $^2J_{AB}$ = −12.8 Hz], 7.2−8.0 (m, 5 H, GeC_6H_5). ^{13}C NMR (62.9 MHz, C_6D_6): δ 19.7 [$COC(O)CH_3$], 21.8 [$GeOC(O)CH_3$], 58.2 ($GeCH_2O$), 128.4 (C-3/C-5, GeC_6H_5), 130.1 (C-4, GeC_6H_5), 134.2 (C-2/C-6, GeC_6H_5), 135.5 (C-1, GeC_6H_5), 172.4 [$GeOC(O)CH_3$], 174.2 [$COC(O)CH_3$]. EI MS: *m/z* 356 [1%, M^+], 283 [100%, $M^+ - CH_2OC(O)CH_3$]. Anal. Calcd for $C_{14}H_{18}GeO_6$: C, 47.38; H, 5.11. Found: C, 47.1; H, 5.0.

Acetoxybis(acetoxymethyl)(4-fluorophenyl)germane (19). This compound was prepared analogously to the synthesis of **18** by treating a mixture of **16** and **17** (22.8 g; see above) with sodium acetate (20.0 g, 244 mmol) in dimethylformamide (250 mL). The crude product was purified by Kugelrohr distillation (oven temperature 170 °C, 0.01 Torr) to give **19** in 65% yield (referred to **13**) as a colorless liquid (22.9 g, 61.4 mmol). ^{1}H NMR (250.1 MHz, C_6D_6): δ 1.63 [s, 6 H, $COC(O)CH_3$], 1.96 [s, 3 H, $GeOC(O)CH_3$], 4.51 (δ_A) and 4.65 (δ_B) [$Ge(CH_AH_BO)_2$, $^2J_{AB}$ = −12.5 Hz], 6.90−7.10 and 7.77−7.90 (m, 4 H, GeC_6H_4F). ^{13}C NMR (62.9 MHz, C_6D_6): δ 19.6 [$COC(O)CH_3$], 21.8 [$GeOC(O)CH_3$], 58.2 ($GeCH_2O$), 115.6 (d, $^2J_{CF}$ = 20.1 Hz, C-3/C-5, GeC_6H_4F), 130.9 (d, $^4J_{CF}$ = 4.3 Hz, C-1, GeC_6H_4F), 136.3 (d, $^3J_{CF}$ = 7.3 Hz, C-2/C-6, GeC_6H_4F), 164.5 (d, $^1J_{CF}$ = 249.0 Hz, C-4, GeC_6H_4F), 172.6 [$COC(O)CH_3$], 174.3 [$GeOC(O)CH_3$]. FI MS: *m/z* 374 [5%, M^+], 301 [100%, $M^+ - CH_2OC(O)CH_3$]. Anal. Calcd for $C_{14}H_{17}FGeO_6$: C, 45.10; H, 4.60. Found: C, 44.6; H, 4.7.

(4-Fluorophenyl)malonic Acid (20). Synthesis was according to ref 9.

(*S*)-(Acetoxymethyl)[((*tert*-butyldiphenylsilyl)oxy)methyl]phenylgermane [(*S*)-21]. *tert*-Butylchlorodiphenylsilane (129 mg, 469 μmol) was added to a solution of (*R*)-**1** (100 mg, 392 μmol; obtained by enzymatic transformation) and imidazole (59 mg, 867 μmol) in dimethylformamide (4 mL), and the reaction mixture was stirred at room temperature for 1 h. After the solvent was removed under reduced pressure, diethyl ether (40 mL) was added. The mixture was extracted with water (3 × 20 mL) and then dried over anhydrous Na_2SO_4. The solvent was removed under reduced pressure and the residue purified by preparative layer chromatography on silica gel [diethyl ether/*n*-hexane (1:3, v/v)] to give (*S*)-**21** in 79% yield as a colorless liquid (153 mg, 310 μmol). ^{1}H NMR (400.1 MHz, C_6D_6): δ 1.24 [s, 9 H, $C(CH_3)_3$], 1.70 [s, $C(O)CH_3$], 4.16 ($\delta_{A(A')}$), 4.47 (δ_K), 4.48 (δ_L), and 5.03 (δ_X) [$Ge(CH_AH_{A'}O)(CH_KH_LO)H_X$, $^3J_{AX} + {}^3J_{A'X}$ = 4.6 Hz, $^2J_{KL}$ = −12.5 Hz, $^3J_{KX}$ = 2.4 Hz, $^3J_{LX}$ = 2.8 Hz], 7.24−7.38, 7.60−7.67, and 7.81−7.90 (m, 15 H, GeC_6H_5, SiC_6H_5). ^{13}C NMR (100.6 MHz, C_6D_6): δ 19.4 [$C(CH_3)_3$], 20.2 [$C(O)CH_3$], 27.0 [$C(CH_3)_3$], 54.5 ($GeCH_2O$), 55.1 ($GeCH_2O$), 128.1 (C-3/C-5, SiC_6H_5), 128.5 (C-3/C-5, GeC_6H_5), 129.4 (C-4, GeC_6H_5), 129.98 (C-4, SiC_6H_5), 130.00 (C-4, SiC_6H_5), 133.56 (C-1, SiC_6H_5), 133.59 (C-1, SiC_6H_5), 134.7 (C-1, GeC_6H_5), 135.2 (C-2/C-6, GeC_6H_5), 136.1 (C-2/C-6, SiC_6H_5), 170.6 (C=O). EI MS: *m/z* 493 [1%, $M^+ - H$], 317 [100%, $M^+ - C_6H_5 -$

$C(CH_3)_3 - C(O)CH_3$]. Anal. Calcd for $C_{26}H_{32}GeO_3Si$: C, 63.31; H, 6.54. Found: C, 62.9; H, 6.5. $[\alpha]_{366}^{20} = +25$ (acetone, c = 2.5).

(*R*)-(Acetoxymethyl)[((*tert*-butyldiphenylsilyl)oxy)-methyl]phenylgermane [(*R*)-21]. This compound was prepared analogously to the synthesis of (*S*)-**21** by addition of *tert*-butylchlorodiphenylsilane (137 mg, 498 μmol) to a solution of (*S*)-**1** (106 mg, 416 μmol; obtained by enzymatic transformation) and imidazole (63 mg, 925 μmol) in dimethylformamide (4 mL). After preparative layer chromatography on silica gel [diethyl ether/*n*-hexane (1:3, v/v)], (*R*)-**21** was isolated in 81% yield as a colorless liquid (167 mg, 339 μmol). The NMR and MS data of the product were identical with those obtained for (*S*)-**21**. $[\alpha]_{366}^{20} = -23$ (acetone, c = 2.5).

(*S*)-(Acetoxymethyl)[((*tert*-butyldiphenylsilyl)oxy)-methyl](4-fluorophenyl)germane [(*S*)-22]. This compound was prepared analogously to the synthesis of (*S*)-**21** by addition of *tert*-butylchlorodiphenylsilane (121 mg, 440 μmol) to a solution of (*R*)-**2** (100 mg, 367 μmol; obtained by enzymatic transformation) and imidazole (55 mg, 808 μmol) in dimethylformamide (4 mL). After preparative layer chromatography on silica gel [diethyl ether/*n*-hexane (1:3, v/v)], (*S*)-**22** was isolated in 82% yield as a colorless liquid (154 mg, 301 μmol). ^{1}H NMR (400.1 MHz, C_6D_6): δ 1.23 [s, 9 H, $C(CH_3)_3$] 1.70 [s, 3 H, $C(O)CH_3$], 4.10 (δ_A), 4.11 (δ_B), 4.38 (δ_K), 4.40 (δ_L), and 4.95 (δ_X) [$Ge(CH_AH_B O)(CH_KH_L O)H_X$, $^2J_{AB} = -11.7$ Hz, $^3J_{AX} = 2.1$ Hz, $^3J_{BX} = 2.5$ Hz, $^2J_{KL} = -12.3$ Hz, $^3J_{KX} = 2.4$ Hz, $^3J_{LX} = 2.7$ Hz], 6.90−7.00, 7.30−7.46, and 7.78−7.87 (m, 14 H, GeC_6H_4F, SiC_6H_5). ^{13}C NMR (100.6 MHz, C_6D_6): δ 19.4 [$C(CH_3)_3$], 20.1 [$C(O)CH_3$], 27.0 [$C(CH_3)_3$], 54.4 ($GeCH_2O$), 55.0 ($GeCH_2O$), 115.6 (d, $^2J_{CF} = 19.6$ Hz, C-3/C-5, GeC_6H_4F), 128.1 (C-3/C-5, SiC_6H_5), 129.9 (d, $^4J_{CF} = 3.6$ Hz, C-1, GeC_6H_4F), 130.1 (C-4, SiC_6H_5), 133.46 (C-1, SiC_6H_5), 133.48 (C-1, SiC_6H_5), 136.03 (C-2/C-6, SiC_6H_5), 136.05 (C-2/C-6, SiC_6H_5), 137.1 (d, $^3J_{CF} = 7.3$ Hz, C-2/C-6, GeC_6H_4F), 162.8 (d, $^1J_{CF} = 247.5$ Hz, C-4, GeC_6H_4F), 170.6 (C=O). CI MS (positive ions): m/z 511 [40%, $(M - H)^+$], 417 [100%, $(M - C_6H_4F)^+$]. Anal. Calcd for $C_{26}H_{31}FGeO_3Si$: C, 61.09; H, 6.11. Found: C, 61.3; H, 6.4. $[\alpha]_{366}^{20} = +22$ (acetone, c = 2.5).

(*R*)-(Acetoxymethyl)[((*tert*-butyldiphenylsilyl)oxy)-methyl](4-fluorophenyl)germane [(*R*)-22]. This compound was prepared analogously to the synthesis of (*S*)-**21** by addition of *tert*-butylchlorodiphenylsilane (121 mg, 440 μmol) to a solution of (*S*)-**2** (100 mg, 367 μmol; obtained by enzymatic transformation) and imidazole (55 mg, 808 μmol) in dimethylformamide (4 mL). After preparative layer chromatography on silica gel [diethyl ether/*n*-hexane (1:3, v/v)], (*R*)-**22** was isolated in 78% yield as a colorless liquid (146 mg, 286 μmol). The NMR and MS data of the product were identical with those obtained for (*S*)-**22**. $[\alpha]_{366}^{20} = -24$ (acetone, c = 2.5).

(*S*)-1-Acetoxy-3-((*tert*-butyldiphenylsilyl)oxy)-2-phenylpropane [(*S*)-23]. This compound was prepared analogously to the synthesis of (*S*)-**21** by addition of *tert*-butylchlorodiphenylsilane (170 mg, 618 μmol) to a solution of (*R*)-**3** (100 mg, 515 μmol; obtained by enzymatic transformation) and imidazole (78 mg, 1.15 mmol) in dimethylformamide (4 mL). After preparative layer chromatography on silica gel [diethyl ether/*n*-hexane (1:3, v/v)], (*S*)-**23** was isolated in 81% yield as a colorless liquid (180 mg, 416 μmol). ^{1}H NMR (400.1 MHz, C_6D_6): δ 1.24 [s, 9 H, $C(CH_3)_3$], 1.68 [s, 3 H, $C(O)CH_3$], 3.25 (δ_X), 3.97 ($\delta_{A(A')}$), 4.60 (δ_K), and 4.67 (δ_L) [$C(CH_AH_{A'}O)(CH_KH_L O)H_X$, $^3J_{AX} + {}^3J_{A'X} = 11.6$ Hz, $^2J_{KL} = -10.9$ Hz, $^3J_{KX} = 7.4$ Hz, $^3J_{LX} = 6.6$ Hz], 7.14−7.37 and 7.70−7.82 (m, 15 H, CC_6H_5, SiC_6H_5). ^{13}C NMR (100.6 MHz, C_6D_6): δ 19.4 [$C(CH_3)_3$], 20.4 [$C(O)CH_3$], 27.0 [$C(CH_3)_3$], 47.5 (CH), 64.7 (CCH_2O), 65.5 (CCH_2O), 127.1 (C-4, CC_6H_5), 128.1 (C-3/C-5, SiC_6H_5), 128.6 (C-2/C-6, CC_6H_5), 129.9 (C-4, SiC_6H_5), 130.0 (C-3/C-5, CC_6H_5), 133.8 (C-1, SiC_6H_5), 135.94 (C-2/C-6, SiC_6H_5), 136.0 (C-2/C-6, SiC_6H_5), 140.2 (C-1, CC_6H_5), 170.0 (C=O). CI MS (positive ions): m/z 433 [100%, $(M + H)^+$]. Anal. Calcd for $C_{27}H_{32}O_3Si$: C, 74.96; H, 7.46. Found: C, 74.8; H, 7.6. $[\alpha]_{366}^{20} = +28$ (acetone, c = 2.5).

(*R*)-1-Acetoxy-3-((*tert*-butyldiphenylsilyl)oxy)-2-phenylpropane [(*R*)-23]. This compound was prepared analogously to the synthesis of (*S*)-**21** by addition of *tert*-butylchlorodiphenylsilane (177 mg, 644 μmol) to a solution of (*S*)-**3** (104 mg, 535 μmol; obtained by enzymatic transformation) and imidazole (80 mg, 1.18 mmol) in dimethylformamide (4 mL). After preparative layer chromatography on silica gel [diethyl ether/*n*-hexane (1:3, v/v)], (*R*)-**23** was isolated in 81% yield as a colorless liquid (188 mg, 435 mmol). The NMR and MS data of the product were identical with those obtained for (*S*)-**23**. $[\alpha]_{366}^{20} = -25$ (acetone, c = 2.5).

(*S*)-1-Acetoxy-3-((*tert*-butyldiphenylsilyl)oxy)-2-(4-fluorophenyl)propane [(*S*)-24]. This compound was prepared analogously to the synthesis of (*S*)-**21** by addition of *tert*-butylchlorodiphenylsilane (156 mg, 568 μmol) to a solution of (*R*)-**4** (100 mg, 471 μmol; obtained by enzymatic transformation) and imidazole (70 mg, 1.03 mmol) in dimethylformamide (4 mL). After preparative layer chromatography on silica gel [diethyl ether/*n*-hexane (1:3, v/v)], (*S*)-**24** was isolated in 81% yield as a colorless liquid (172 mg, 382 μmol). ^{1}H NMR (400.1 MHz, C_6D_6): δ 1.21 [s, 9 H, $C(CH_3)_3$], 1.70 [s, 3 H, $C(O)CH_3$], 3.13 (δ_X), 3.88 ($\delta_{A(A')}$), 4.48 (δ_K), and 4.56 (δ_L) [$C(CH_AH_{A'}O)(CH_KH_L O)H_X$, $^3J_{AX} + {}^3J_{A'X} = 11.6$ Hz, $^2J_{KL} = -11.0$ Hz, $^3J_{KX} = 7.0$ Hz, $^3J_{LX} = 6.7$ Hz], 6.85−7.00, 7.28−7.36, and 7.70−7.89 (m, 14 H, CC_6H_4F, SiC_6H_5). ^{13}C NMR (100.6 MHz, C_6D_6): δ 19.4 [$C(CH_3)_3$], 20.3 [$C(O)CH_3$], 27.0 [$C(CH_3)_3$)], 46.6 (CH), 64.6 (CCH_2O), 65.3 (CCH_2O), 115.3 (d, $^2J_{CF} = 20.8$ Hz, C-3/C-5, CC_6H_4F), 128.1 (C-3/C-5, SiC_6H_5), 130.0 (C-4, SiC_6H_5), 130.1 (d, $^3J_{CF} = 5.5$ Hz, C-2/C-6, CC_6H_4F), 133.6 (C-1, SiC_6H_5), 135.3 (C-1, CC_6H_4F), 135.87 (C-2/C-6, SiC_6H_5), 135.96 (C-2/C-6, SiC_6H_5), 162.3 (d, $^1J_{CF} = 244.8$ Hz, C-4, CC_6H_4F), 170.0 (C=O). CI MS (positive ions): m/z 451 [100%, $(M + H)^+$]. Anal. Calcd for $C_{27}H_{31}FO_3Si$: C, 71.97; H, 6.93. Found: C, 72.7; H, 7.1. $[\alpha]_{366}^{20} = +23$ (acetone, c = 2.5).

(*R*)-1-Acetoxy-3-((*tert*-butyldiphenylsilyl)oxy)-2-(4-fluorophenyl)propane [(*R*)-24]. This compound was prepared analogously to the synthesis of (*S*)-**21** by addition of *tert*-butylchlorodiphenylsilane (156 mg, 568 μmol) to a solution of (*S*)-**4** (100 mg, 471 μmol; obtained by enzymatic transformation) and imidazole (70 mg, 1.03 mmol) in dimethylformamide (4 mL). After preparative layer chromatography on silica gel [diethyl ether/*n*-hexane (1:3, v/v)], (*R*)-**24** was isolated in 85% yield as a colorless liquid (180 mg, 399 μmol). The NMR and MS data of the product were identical with those obtained for (*S*)-**24**. $[\alpha]_{366}^{20} = -22$ (acetone, c = 2.5).

(*S*)-[((*tert*-Butyldiphenylsilyl)oxy)methyl](hydroxymethyl)phenylgermane [(*S*)-25]. Potassium carbonate (109 mg, 789 μmol) was added to a solution of (*S*)-**21** (97 mg, 197 μmol; for synthesis, see above) in methanol (3 mL). After the reaction mixture was stirred at room temperature for 1 h, diethyl ether (40 mL) was added and the organic layer was extracted with water (3 × 20 mL) and then dried over anhydrous Na_2SO_4. The solvent was removed under reduced pressure (rotary evaporator) and the residue purified by preparative layer chromatography on silica gel [diethyl ether/*n*-hexane (1:3, v/v)] to give (*S*)-**25** in 85% yield as a colorless liquid (75 mg, 166 μmol). ^{1}H NMR (400.1 MHz, C_6D_6): δ 1.24 [s, 9 H, $C(CH_3)_3$], 1.5 (br s, 1 H, OH), 4.11 ($\delta_{A(A')}$), 4.16 (δ_B), 4.19 (δ_C), and 4.89 (δ_X) [$Ge(CH_AH_{A'}O)(CH_BH_C O)H_X$, $^3J_{AX} + {}^3J_{A'X} = 5.2$ Hz, $^2J_{BC} = -11.6$ Hz, $^3J_{BX} = 3.1$ Hz, $^3J_{CX} = 1.6$ Hz], 7.22−7.40, 7.60−7.67, and 7.80−7.90 (m, 15 H, GeC_6H_5, SiC_6H_5). ^{13}C NMR (100.6 MHz, C_6D_6): δ 19.4 [$C(CH_3)_3$], 27.0 [$C(CH_3)_3$], 53.4 ($GeCH_2O$), 56.6 ($GeCH_2O$), 128.09 (C-3/C-5, SiC_6H_5), 128.12 (C-3/C-5, SiC_6H_5), 128.5 (C-3/C-5, GeC_6H_5), 129.3 (C-4, GeC_6H_5), 130.01 (C-4, SiC_6H_5), 130.05 (C-4, SiC_6H_5), 133.35 (C-1, SiC_6H_5), 133.37 (C-1, SiC_6H_5), 135.2 (C-2/C-6, GeC_6H_5), 135.5 (C-1, GeC_6H_5), 136.06 (C-2/C-6, SiC_6H_5), 136.07 (C-2/C-6, SiC_6H_5). CI MS (positive ions): m/z 453 [5%, $(M + H)^+$],

297 [100%]. Anal. Calcd for $C_{24}H_{30}GeO_2Si$: C, 63.89; H, 6.70. Found: C, 64.2; H, 6.7. $[\alpha]_{366}^{20} = +28$ (acetone, $c = 2.5$).

(*R*)-[((*tert*-Butyldiphenylsilyl)oxy)methyl](hydroxymethyl)phenylgermane [(*R*)-25]. This compound was prepared analogously to the synthesis of (*S*)-**25** by addition of potassium carbonate (134 mg, 970 μmol) to a solution of (*R*)-**21** (120 mg, 243 μmol; for synthesis, see above) in methanol (3 mL). After preparative layer chromatography on silica gel [diethyl ether/*n*-hexane (1:3, v/v)], (*R*)-**25** was isolated in 87% yield as a colorless liquid (95 mg, 211 μmol). The NMR and MS data of the product were identical with those obtained for (*S*)-**25**. $[\alpha]_{366}^{20} = -25$ (acetone, $c = 2.5$).

(*S*)-[((*tert*-Butyldiphenylsilyl)oxy)methyl](4-fluorophenyl)(hydroxymethyl)germane [(*S*)-26]. This compound was prepared analogously to the synthesis of (*S*)-**25** by addition of potassium carbonate (108 mg, 781 μmol) to a solution of (*S*)-**22** (100 mg, 196 μmol; for synthesis, see above) in methanol (3 mL). After preparative layer chromatography on silica gel [diethyl ether/*n*-hexane (1:3, v/v)], (*S*)-**26** was isolated in 84% yield as a colorless liquid (77 mg, 164 μmol). ^{1}H NMR (400.1 MHz, C_6D_6): δ 1.23 [s, 9 H, $C(CH_3)_3$], 1.5 (br s, 1 H, OH), 4.01 (δ_A), 4.05 (δ_B), 4.09 (δ_C), 4.13 (δ_D), and 4.81 (δ_X) [$Ge(CH_AH_BO)(CH_CH_DO)H_X$, $^2J_{AB} = -12.1$ Hz, $^3J_{AX} = 2.5$ Hz, $^3J_{BX} = 1.8$ Hz, $^2J_{CD} = -11.8$ Hz, $^3J_{CX} = 2.8$ Hz, $^3J_{DX} = 1.7$ Hz], 6.90−7.00, 7.28−7.45, and 7.77−7.89 (m, 14 H, GeC_6H_4F, SiC_6H_5). ^{13}C NMR (100.6 MHz, C_6D_6): δ 19.4 [*C*$(CH_3)_3$], 27.0 [C(*C*$H_3)_3$], 53.3 ($GeCH_2O$), 55.5 ($GeCH_2O$), 115.6 (d, $^2J_{CF} = 19.6$ Hz, C-3/C-5, GeC_6H_4F), 128.11 (C-3/C-5, SiC_6H_5), 128.13 (C-3/C-5, SiC_6H_5), 130.09 (C-4, SiC_6H_5), 130.12 (C-4, SiC_6H_5), 130.7 (d, $^4J_{CF} = 3.6$ Hz, C-1, GeC_6H_4F), 133.28 (C-1, SiC_6H_5), 133.31 (C-1, SiC_6H_5), 136.02 (C-2/C-6, SiC_6H_5), 136.05 (C-2/C-6, SiC_6H_5), 137.0 (d, $^3J_{CF} = 7.3$ Hz, C-2/C-6, GeC_6H_4F), 164.2 (d, $^1J_{CF} = 247.1$ Hz, C-4, GeC_6H_4F). EI MS: *m*/*z* 439 [18%, $M^+ - CH_2OH$], 317 [100%, $C_{14}H_{15}GeO_2Si^+$]. Anal. Calcd for $C_{24}H_{29}FGeO_2Si$: C, 61.44; H, 6.23. Found: C, 61.2; H, 6.3. $[\alpha]_{366}^{20} = +24$ (acetone, $c = 2.5$).

(*R*)-[((*tert*-Butyldiphenylsilyl)oxy)methyl](4-fluorophenyl)(hydroxymethyl)germane [(*R*)-26]. This compound was prepared analogously to the synthesis of (*S*)-**25** by addition of potassium carbonate (130 mg, 941 μmol) to a solution of (*R*)-**22** (120 mg, 235 μmol; for synthesis, see above) in methanol (3 mL). After preparative layer chromatography on silica gel [diethyl ether/*n*-hexane (1:3, v/v)], (*R*)-**26** was isolated in 84% yield as a colorless liquid (92 mg, 196 μmol). The NMR and MS data of the product were identical with those obtained for (*S*)-**26**. $[\alpha]_{366}^{20} = -26$ (acetone, $c = 2.5$).

(*S*)-3-((*tert*-Butyldiphenylsilyl)oxy)-2-phenyl-1-propanol [(*S*)-27]. This compound was prepared analogously to the synthesis of (*S*)-**25** by addition of potassium carbonate (140 mg, 1.01 mmol) to a solution of (*S*)-**23** (110 mg, 254 μmol; for synthesis, see above) in methanol (3 mL). After preparative layer chromatography on silica gel [diethyl ether/*n*-hexane (1:3, v/v)], (*S*)-**27** was isolated in 83% yield as a colorless liquid (82 mg, 210 μmol). ^{1}H NMR (400.1 MHz, C_6D_6): δ 1.24 [s, 9 H, $C(CH_3)_3$], 1.7 (br s, 1 H, OH), 3.10 (δ_X), 3.94 (δ_A), 4.03 (δ_C), 4.04 (δ_B), and 4.10 (δ_D) [$C(CH_AH_BO)(CH_CH_DO)H_X$, $^2J_{AB} = -10.7$ Hz, $^3J_{AX} = 5.8$ Hz, $^3J_{BX} = 6.8$ Hz, $^2J_{CD} = -10.0$ Hz, $^3J_{CX} = 5.5$ Hz, $^3J_{DX} = 7.4$ Hz], 7.10−7.24, 7.28−7.35, and 7.76−7.83 (m, 15 H, CC_6H_5, SiC_6H_5). ^{13}C NMR (100.6 MHz, C_6D_6): δ 19.4 [*C*$(CH_3)_3$], 27.0 [C(*C*$H_3)_3$] 50.7 (CH), 64.8 (CCH_2O), 66.7 (CCH_2O), 127.0 (C-4, CC_6H_5), 128.1 (C-3/C-5, SiC_6H_5), 128.6 (C-2/C-6, CC_6H_5), 129.98 (C-4, SiC_6H_5), 130.0 (C-3/C-5, CC_6H_5), 133.7 (C-1, SiC_6H_5), 133.8 (C-1, SiC_6H_5), 135.96 (C-2/C-6, SiC_6H_5), 135.99 (C-2/C-6, SiC_6H_5), 140.7 (C-1, CC_6H_5). CI MS (positive ions): *m*/*z* 391 [100%, $(M + H)^+$]. Anal. Calcd for $C_{25}H_{30}O_2Si$: C, 76.88; H, 7.74. Found: C, 77.0; H, 7.7. $[\alpha]_{366}^{20} = +15$ (acetone, $c = 2.5$).

(*R*)-3-((*tert*-Butyldiphenylsilyl)oxy)-2-phenyl-1-propanol [(*R*)-27]. This compound was prepared analogously to the synthesis of (*S*)-**25** by addition of potassium carbonate (142 mg, 1.03 mmol) to a solution of (*R*)-**23** (111 mg, 257 μmol; for synthesis, see above) in methanol (3 mL). After preparative layer chromatography on silica gel [diethyl ether/*n*-hexane (1:3, v/v)], (*R*)-**27** was isolated in 85% yield as a colorless liquid (85 mg, 218 μmol). The NMR and MS data of the product were identical with those obtained for (*S*)-**27**. $[\alpha]_{366}^{20} = -14$ (acetone, $c = 2.5$).

(*S*)-3-((*tert*-Butyldiphenylsilyl)oxy)-2-(4-fluorophenyl)-1-propanol [(*S*)-28]. This compound was prepared analogously to the synthesis of (*S*)-**25** by addition of potassium carbonate (158 mg, 1.14 mmol) to a solution of (*S*)-**24** (129 mg, 286 μmol; for synthesis, see above) in methanol (3 mL). After preparative layer chromatography on silica gel [diethyl ether/*n*-hexane (1:3, v/v)], (*S*)-**28** was isolated in 79% yield as a colorless liquid (92 mg, 225 μmol). ^{1}H NMR (400.1 MHz, C_6D_6): δ 1.23 [s, 9 H, $C(CH_3)_3$], 1.76 (s, 1 H, OH), 2.99 (δ_X), 3.83 (δ_A), 3.93 (δ_B), 3.94 (δ_C), and 4.01 (δ_D) [$C(CH_AH_BO)(CH_CH_DO)H_X$, $^2J_{AB} = -10.7$ Hz, $^3J_{AX} = 5.8$ Hz, $^3J_{BX} = 6.7$ Hz, $^2J_{CD} = -10.0$ Hz, $^3J_{CX} = 5.5$ Hz, $^3J_{DX} = 7.1$ Hz], 6.80−7.00, 7.28−7.37, and 7.75−7.81 (m, 14 H, CC_6H_4F, SiC_6H_5). ^{13}C NMR (100.6 MHz, C_6D_6): δ 19.3 [*C*$(CH_3)_3$], 27.0 [C(*C*$H_3)_3$], 49.7 (CH), 64.5 (CCH_2O), 66.4 (CCH_2O), 115.3 (d, $^2J_{CF} = 21.5$ Hz, C-3/C-5, CC_6H_4F), 128.1 (C-3/C-5, SiC_6H_5), 130.0 (C-4, SiC_6H_5), 130.1 (d, $^3J_{CF} = 4.9$ Hz, C-2/C-6, CC_6H_4F), 133.60 (C-1, SiC_6H_5), 133.65 (C-1, SiC_6H_5), 135.91 (C-2/C-6, SiC_6H_5), 135.95 (C-2/C-6, SiC_6H_5), 136.4 (d, $^4J_{CF} = 3.5$ Hz, C-1, CC_6H_4F), 162.2 (d, $^1J_{CF} = 244.1$ Hz, C-4, CC_6H_4F). CI MS (positive ions): *m*/*z* 409 [100%, $(M + H)^+$]. Anal. Calcd for $C_{25}H_{29}FO_2Si$: C, 73.49; H, 7.15. Found: C, 73.7; H, 7.3. $[\alpha]_{366}^{20} = +18$ (acetone, $c = 2.5$).

(*R*)-3-((*tert*-Butyldiphenylsilyl)oxy)-2-(4-fluorophenyl)-1-propanol [(*R*)-28]. This compound was prepared analogously to the synthesis of (*S*)-**25** by addition of potassium carbonate (211 mg, 1.53 mmol) to a solution of (*R*)-**24** (172 mg, 382 μmol; for synthesis, see above) in methanol (4 mL). After preparative layer chromatography on silica gel [diethyl ether/*n*-hexane (1:3, v/v)], (*R*)-**28** was isolated in 76% yield as a colorless liquid (119 mg, 291 μmol). The NMR and MS data of the product were identical with those obtained for (*S*)-**28**. $[\alpha]_{366}^{20} = -17$ (acetone, $c = 2.5$).

Preparation of the MTPA Esters 29a/29b−32a/32b (General Procedure). (*S*)-α-Methoxy-α-(trifluoromethyl)-phenylacetyl chloride [(*S*)-MTPA-Cl; prepared from (*R*)-α-methoxy-α-(trifluoromethyl)phenylacetic acid (Fluka, 65364) as described in ref 12] (56 μL) was added at room temperature to a stirred solution of the respective monohydroxy compounds **1**−**4** (140 μmol) in toluene/pyridine (2:1, v/v) (1.2 mL). After the mixture was stirred at room temperature for 12 h [complete conversion as monitored by TLC; silica gel plates (Merck, 5554), *n*-hexane/diethyl ether (2:1, v/v), UV detection], 3-(dimethylamino)-1-propylamine (60 μL) was added and the mixture stirred for 10 min. After addition of diethyl ether (15 mL) and 2 M hydrochloric acid (10 mL), the organic layer was separated and shaken first with a saturated aqueous Na_2CO_3 solution (10 mL) and then with a saturated aqueous NaCl solution (10 mL). The organic layer was dried over $MgSO_4$, the solvent removed under reduced pressure (rotary evaporator), and the residue dissolved in C_6D_6 (0.5 mL). To remove traces of diethyl ether, the solvent was again evaporated and the residue dissolved in C_6D_6. The sample obtained by this procedure was used for the NMR-spectroscopic studies (determination of the ee values of the enantiomers of **1**−**4** by integration of characteristic resonance signals of the respective diastereomeric MTPA esters). For NMR data, see the Supporting Information.

Preparation of the MTPA Esters 33a/33b. The MTPA esters **33a**/**33b** were prepared analogously to the synthesis of the MTPA esters **29a/29b**−**32a/32b**. For NMR data, see the Supporting Information.

(12) Dale, J. A.; Dull, D. L.; Mosher, H. S. *J. Org. Chem.* **1969**, *34*, 2543−2549.

Determination of the Enantiomeric Purities of the Antipodes of 1−4 by Liquid Chromatography. The (*R*)- and (*S*)-enantiomers of **1**−**4** were separated by liquid chromatography on cellulose tribenzoate (10−20 μm; Riedel-deHaën, 39852). The experimental conditions were as follows: HPLC pump, Shimadzu LC6-A; detector, Soma S-3702 UV−VIS; integrator, Shimadzu C-R3A; column (10 mm i.d. × 150 mm), Merck Superformance; eluent, *n*-hexane/2-propanol (95:5, v/v) (**1**), *n*-hexane/diisopropyl ether (50:50, v/v) (**2**), *n*-hexane/ethanol (90:10, v/v) (**3**), or *n*-hexane/*tert*-butyl methyl ether (50:50, v/v) (**4**) (HPLC-grade solvents purchased from Merck); detection, 215 nm; *T*, ambient temperature; injection volume, 20 μL (10 mg of the sample material dissolved in 1 mL of the eluent). The retention times of the antipodes of **1**−**4** are listed in Table 3. For typical chromatograms, see the Supporting Information.

Determination of the Enantiomeric Purities of the Antipodes of 2 and 4 by Capillary Gas Chromatography. The (*R*)- and (*S*)-enantiomers of **2** and **4** were separated, after transformation into the corresponding trifluoroacetates, by capillary gas chromatography [gas chromatograph, HP 6890; Lipodex E column (0.25 mm i.d. × 23 m, film thickness 0.15 μm), Chrompack; carrier gas, hydrogen; temperature program, 50 °C (1 min) to 200 °C (10 min) with 3 °C/min; injector temperature, 180 °C; split, 1:80; detector, FID; detector temperature, 250 °C]. The retention times of the antipodes of **2** and **4** are listed in Table 4.

Derivatization of 2 for the GC Studies. Pyridine (150 μL) and *N*-methylbis(trifluoroacet)amide (MBTFA) (150 μL) were added to a 4-mg sample of **2** and the mixture was kept at room temperature for 30 min. After the excess pyridine and MBTFA were blown off with a stream of nitrogen, the residue was dissolved in toluene (150 μL) and a 0.5-μL sample of this solution injected into the gas chromatograph.

Derivatization of 4 for the GC Studies. A 4-mg sample of **4** was treated with pyridine (100 μL) and trifluoroacetic anhydride (100 μL) under the same conditions as described for the derivatization of **2**. For typical chromatograms, see the Supporting Information.

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Supporting Information Available: NMR data for the MTPA esters **29a**/**29b**−**33a**/**33b** and chromatograms obtained for the analytical liquid-chromatographic (HPLC) and gas-chromatographic separation of the (*R*)- and (*S*)-enantiomers of **2** (4 pages). Ordering information is given on any current masthead page.

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