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Stereoselective Synthesis of Alcohols, XXIII[1]

Transfer of Chirality on Addition of (α-Chloroallyl)boronates to Aldehydes

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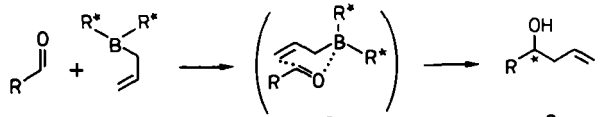
The preparation of the (α-chloroallyl)boronate **4** of 92% e.e. is described. Its addition to achiral aldehydes resulted in the homoallyl alcohols **6** of 82–92% e.e. Cooperative diastereoface selectivity on addition of *ent*-**4** to isopropylideneglyceraldehyde (**22**) gave the product **23** of high diastereomeric purity. Reagent control of stereoselectivity on addition of **4** to **22** resulted in **25** of 77% diastereomeric purity.

Stereoselektive Synthese von Alkoholen, XXIII[1]

Chiralitätsübertragung bei der Addition von (α-Chlorallyl)boronsäureestern an Aldehyde

Die Darstellung des (α-Chlorallyl)boronsäureesters **4** mit 92% e.e. wird beschrieben. Seine Addition an achirale Aldehyde ergab die Homoallylalkohole **6** mit 82–92% e.e. Bei der Addition von *ent*-**4** an Isopropylidenglycerinaldehyd (**22**) führte die kooperative Diastereoseitendifferenzierung zum Produkt **23** hoher Diastereomerenreinheit. In der Reaktion von **4** mit **22** ergab die Stereokontrolle durch das Reagenz den Alkohol **25** mit einer Diastereomerenreinheit von 77%.

In the field of asymmetric syntheses the addition of chiral organometallic reagents to aldehydes and prochiral ketones has been under active investigation during the last decade[2]. Typical examples for such reagents are the allylboron compounds **1** having chiral residues on boron[3,4]. Their addition to aldehydes leads to the homoallyl alcohols **3**, a reaction in which the extent of asymmetric induction has been constantly improved, now frequently reaching and in some cases exceeding the 90% e.e. level[5].



1 **2** **3**

The addition of the allylboron compounds **1** to aldehydes proceeds via cyclic six-membered transition states **2**. In the reactions mentioned above asymmetric induction resulted from chiral control elements which were affixed to the periphery

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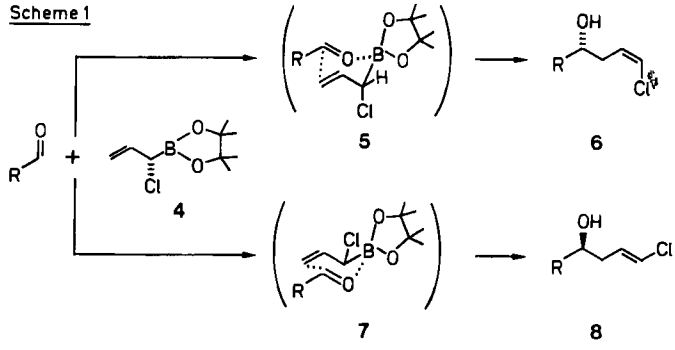
of the transition state. It is therefore gratifying that such high levels of asymmetric induction could be reached at all.

A more direct influence on the transition state geometry could be reached if the element of chiral control is integrated into the cyclic array. This would apply to the addition of α-substituted allyl metal compounds to aldehydes. Recently others[6] and we[7] have reported such reactions[8], the principle of which is illustrated in the following scheme:

Scheme 1



(1)

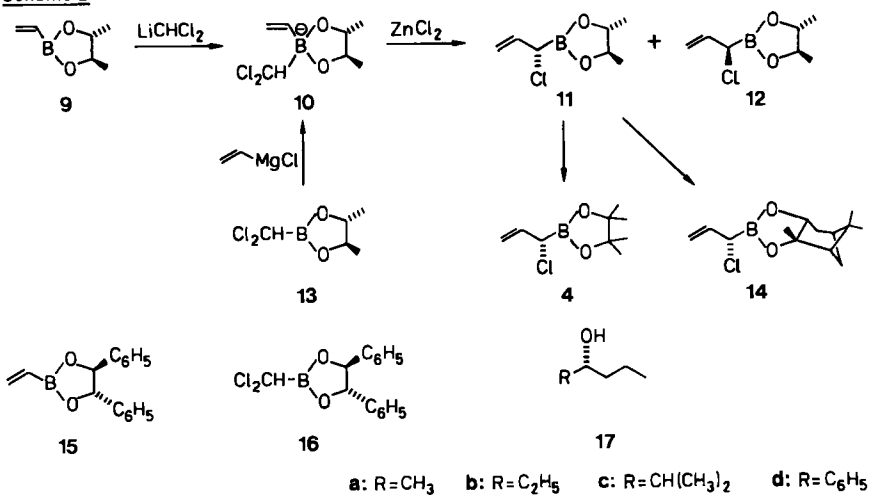
a: R=CH$_3$ **b**: R=C$_2$H$_5$ **c**: R=CH(CH$_3$)$_2$ **d**: R=C$_6$H$_5$

Provided that the addition of the (α-chloroallyl)boronate **4** to the aldehyde occurs only via a single cyclic transition state, the chirality of **4** should be completely transferred to the product, e.g. via the chair transition state **5** to the homoallyl alcohol **6**. Our previous investigation of racemic α-substituted allylboronates[1] has, however, shown that not only the transition state **5** in which the chlorine occupies an axial position is transversed, but also the alternative chair transition state **7** having chlorine in an equatorial position, thus leading to a homoallyl alcohol **8** with an *E*-double bond. While the product **8** should also be formed with complete transfer of chirality, it becomes evident from Scheme 1 that starting from a single enantiomer of **4** the configurations in the resulting two homoallyl alcohols **6** and **8** happen to be opposite. Thus, even if **6** and **8** are diastereomers that could be separated in principle, a reaction leading solely to either **6** or **8** would clearly be preferred. Considerations of the availability of starting materials and the results of our previous study in the racemic series[1] suggest that the (α-chloroallyl)boronates **4** are the best choice at present, since they yield predominantly (95:5) one diastereomer, **6**. We therefore report here in detail our studies[7] on the syntheses and reactions of nonracemic (α-chloroallyl)boronates **4**.

Synthesis of Nonracemic (α-Chloroallyl)boronates

Recently *Matteson*[9] developed a procedure for the preparation of homochiral (α-chloroalkyl)boronates. The key element of his procedure is the rearrangement of an ate-complex (cf. **10**) in the presence of $ZnCl_2$ to reach high levels of asymmetric induction.

Scheme 2



To apply this reaction to the preparation of homochiral (α-chloroallyl)boronates we could start from either the vinylboronate **9** or the (dichloromethyl)boronate **13**[9]. Reaction of **9** with (dichloromethyl)lithium at −100°C followed by rearrangement in the presence of $ZnCl_2$ led to the (α-chloroallyl)boronates **11** and **12**. These were immediately transesterified with pinacol to the (α-chloroallyl)boronate **4**, because it is the pinacol esters that result in high diastereoselectivity **6/8** on addition to aldehydes[1]. The ratio of **11/12** could not be ascertained from the ^{13}C NMR spectrum. Hence, the enantiomeric purity of **4** could only be estimated to be >82% e.e. based on the enantiomeric purity of the homoallyl alcohol **6** derived thereof (see below).

The reaction of the (dichloromethyl)boronate **13**[9] with vinylmagnesium chloride led similarly via the ate-complex **10** to the allylboronates **11** and **12** and eventually to **4**. The enantiomeric excess of the latter was estimated to be 92%.

We also tested (1*S*,2*S*)-1,2-diphenyl-1,2-ethanediol[10] as chiral auxiliary. Analogous reaction of the vinylboronate **15** led to *ent*-**4** of 62% e.e., while reaction of **16** yielded *ent*-**4** of 77% e.e. Thus, with both chiral auxiliaries the route starting from the (dichloromethyl)boronate led to a product of higher enantiomeric purity. Although both reactions seemingly involve the same ate-complex, the nature of the counterion, Li versus MgCl, or the nature and amount of excess halide present in the reagents may be responsible for this effect, influencing the extent of asymmetric induction in the step **10**→**11** or the extent of epimerisation **11**→**12**[11].

To ascertain the absolute configuration of **4** a sample of **11** (from **13**) was transesterified with (+)-2,3-pinanediol[12] to give **14** as the main product, which showed the diagnostic[13] doublet in the ^1H NMR spectrum at δ = 1.174, while *epi*-**14** obtained similarly from **16** showed the doublet at δ = 1.159. This established that the (α-chloroallyl)boronate **4** prepared from **13** as indicated has the *S*-configuration.

Addition of (α-Chloroallyl)boronates to Aldehydes

The chiral (α-chloroallyl)boronate **4** was added to representative aldehydes as described in the racemic series[1]. The enantiomeric excess of the resulting homoallyl alcohols **6** was determined by ^{19}F NMR spectroscopy of the corresponding MTPA-esters[14], cf. Table.

Table 1. Enantiomere purity of the alcohols **6** and **17**

	R	6:8	6 e.e.	configuration	17 o.p. (%)	calc.[a]
a	CH_3	95:5	92	(*S*)-(+)	75	83
b	CH_3CH_2	96:4	89	(*S*)-(+)	85	85
c	$(CH_3)_2CH$	95:5	92	–	–	
c	$(CH_3)_2CH$	95:5	82[b]	(*R*)-(+)	84	71
d	C_6H_5	94:6	92	(*R*)-(+)	73 76[c]	81

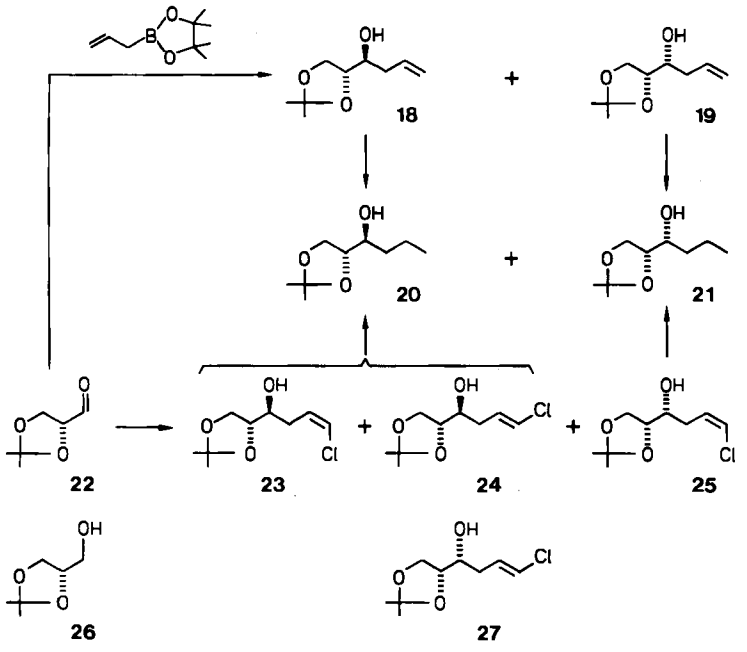
[a] Expected e.e. on the basis that **8** gives *ent*-**17** on hydrogenation. – [b] From **4** prepared via **9**. – [c] e.e. from the ^{19}F NMR of the MTPA-Ester.

In order to determine the absolute configuration of the products, the crude mixture of **6** and **8** was subjected to catalytic hydrogenation resulting in hydrogenolysis of the carbon-chlorine bond as well as saturation of the double bond. This led to the alcohols **17**, the rotation of which could be compared to values for samples of known absolute configuration. The optical purity of the alcohols **17** was lower than that of their precursors **6**, because hydrogenation of the contaminating diastereomer **8** leads to *ent*-**17**. The decrease in enantiomeric purity on going from **6** to **17** corresponds roughly to the content of **8**, cf. Table. The differences between expected and measured values seem not too serious in view of the well known uncertainties of optical purities.

The data in the table show that the addition of **4** to aldehydes occurs with a high degree of chirality transfer. We presume that the enantiomeric purity of the product **6** corresponds to the enantiomeric purity of the allylboronate **4** and that therefore the transfer of chirality is quantitative. Moreover, having established the absolute configuration of both the educt **4** and the product homoallyl alcohols **6**, these data are consistent with the notion that the reaction occurs via the cyclic six-membered transition state **5** in chair conformation.

While the use of **4** as chiral reagent allows the preparation of homoallyl alcohols **6** of high e.e., this can be accomplished by other methods as well[3–5]. The challenge of today is to have chiral reagents of such a diastereoface differentiating power that stereochemical control can be exercised on addition to chiral aldehydes[15]. In order to gain relevant information we investigated the addition of **4** to D-isopropylideneglyceraldehyde (**22**). The choice of this aldehyde was dictated by the fact that the stereostructure of the products **23**, **24**, **25** could be readily established by correlation with the known compounds **18** and **19**[16].

Scheme 3



		23	24 or 27[a]	25
0.85 eq. *ent*-**4** 92% ee	45%	94 (98.5)	2[b] (1.5)	4 (0)
0.9 eq. **4** 92% ee	39%	11 (0)	12 (14)	77 (86)

a) The numbers refer to product with an *E*-double bond, which may be **27** instead of **24**.

b) The numbers in parentheses are those expected for reaction of enantiomerically pure **4** and *ent*-**4**, respectively.

For this purpose the aldehyde **22** was treated with racemic **4** to give 81% of **23**, **24**, and **25** in a ratio of 54 : 6.5 : 39.5, the component with an *E*-double bond being the minor constituent. The ratio deviates only marginally from the expected **23** : (**24** + **25**) = 1 : 1. Hydrogenation of this mixture gave 94% of a 60 : 40 mixture of **20** and **21**. This ratio requires the connections **23** + **24** → **20** and **25** → **21**. For structural assignment of **20** and **21** the aldehyde **22** was converted[16] into a 74 : 26 mixture of the known compounds **18** and **19**. Hydrogenation of this mixture resulted quantitatively in a 75 : 25 mixture of **20** and **21**, the structures of which were thus established. We turned next to the reactions of the aldehyde **22** with the chiral allylboronate **4** and with its enantiomer *ent*-**4** prepared similarly by using (2*S*,3*S*)-2,3-butanediol[17]. The product ratios were estimated from the ^{13}C NMR spectra and are given in Scheme 3. We see that the combination of **22** with *ent*-**4** gives essentially pure **23**, whereas with **4** the products **24** and **25** result in a 1 : 6 ratio.

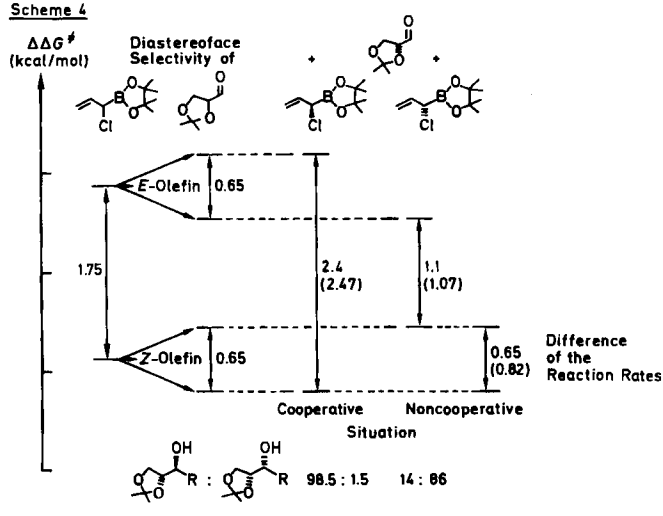
In the latter experiment the 11% of **23** initially caused some concern[7], since starting from **4** of 92% e.e. only 4% of **23** were to be expected, based on a quantitative conversion of **22** into products. Is the formation of the "excess" of **23** due to partial racemisation of **22**? In a control experiment **22** was reacted with 0.5 equivalents of **4**. The remaining **22** was reduced with $NaBH_4$ to give **26**, the optical purity of which was identical[18] within $\pm 5\%$ to a sample prepared by direct reduction of **22**. The formation of the "excess" of **23** could simply be due to a kinetic effect if the combination **22** + *ent*-**4** reacts faster than that of **22** with **4**. Therefore the aldehyde **22** was reacted with 5 equivalents of racemic **4** to give **23**, **24**, and **25** in a 81 : 3 : 16 ratio, revealing that *ent*-**4** indeed reacts four times more rapidly with **22** than does **4**. Thus, in view of the low (40–45%) conversion in the reaction of **22** with **4** of 92% e.e. the "excess" of **23** may completely be caused by preferential reaction of the 4% of *ent*-**4** in **4**.

While the experimental results are derived from reactions of **4** and *ent*-**4** of 92% e.e., the values for the reactions of the enantiomerically pure reagents are principally more interesting. These "corrected" values are given in Scheme 3 in parentheses.

Discussion

The situation, in which a chiral reagent such as **4** is reacted with a chiral substrate such as **22**, is typically related to the discussion of double stereodifferentiation. Indeed our data give a particularly clear cut example. *Heathcock*[19] has outlined the numerical relationships between the selectivities of the individual reactants and the overall selectivity that can be achieved. In our case, the diastereoface selectivity of **4** is expressed in the **6**/**8**-selectivity, i.e. 95 : 5 corresponding to a $\Delta\Delta G^{\neq}$ of 1.75 kcal/mol. The diastereoface selectivity of the aldehyde **22** is smaller[16], in the order of 3 : 1 corresponding to a $\Delta\Delta G^{\neq}$ of 0.65 kcal/mol.

Scheme 4



The cooperative case is found in the reaction of **22** with *ent*-**4**, in which both selectivities are multiplied (the $\Delta\Delta G^{\neq}$-values are to be added resulting in a $\Delta\Delta G^{\neq}$ = 2.4 kcal/mol, cf. Scheme 4). Not only is the asymmetric induction of the aldehyde reinforced, we accordingly find less product **27** with an *E*-double bond.

On the other hand, if we want to exert reagent control of stereoselectivity[15] in the case of **22** reacting with **4**, we recognize the limits of our system: First, the reaction becomes slower, because the unfavoured transition state has a higher energy (experimentally by 0.82 kcal/mol) corresponding to the $\Delta\Delta G^{+}$ of the diastereoface differentiation of the aldehyde (0.65 kcal/mol). This fact alone would do no harm, if we would not at the same time lower the transition state energy of the competing reaction leading to the product·**24** with an *E*-double bond. In the end we were indeed able to override the stereocontrol exerted by the aldehyde, but only to the extent of 86%, since now the product **24** is formed to a higher extent (14%, $\Delta\Delta G^{+} = 1.07$ kcal/mol), than on reaction with an achiral aldehyde (5%). Even with this drawback the reagent **4** is among the best reagents to generate a structure such as **25** by overriding the asymmetric induction from the aldehyde **22**[4].

Scheme 4 demonstrates the relative transition state energies of this system, which are responsible for the extent of diastereoselection. Our inability to override completely the asymmetric induction from the aldehyde **22** can be traced to the diastereofacial discrimination of the reagent **4** ($\Delta\Delta G^{+} = 1.75$ kcal/mol), which is still too low. A value of >3 kcal/mol corresponding to a >99.5% diastereoselectivity of the reagent remains the goal to be reached[15].

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Experimental Part

All temperatures quoted are non corrected. – ^{1}H NMR spectra: Bruker WH-400. – ^{19}F NMR spectra: Varian XL-100. – ^{13}C NMR spectra: Varian CFT-20 and XL-100. – Preparative gas chromatography: Aerograph A-90-P3, 1.5 m × 0.6 cm column with a) 5% SE 30 on chromosorb G, AW-DMCS, 60–80 mesh; b) 5% Apiezon M as above; c) 5% Carbowax as above. – Rotations: Perkin-Elmer Polarimeter 141.

Preparation of the Allylboronates

1. *(4R,5R)-2-Ethenyl-4,5-dimethyl-1,3,2-dioxaborolane* (**9**): To a solution of 30 ml (0.27 mol) of trimethoxyborane in 125 ml of dry ether was added at −70°C over 45 min 118 ml (0.248 mol) of a 2.1 M solution of vinylmagnesium chloride in THF. After reaching room temperature the mixture was acidified under cooling with a solution of 21 ml (0.25 mol) of conc. HCl in 62.5 ml of water. After addition of 0.1 g of phenothiazine the phases were separated and the aqueous phase was extracted three times with 50 ml each of *n*-octanol. The combined organic phases were concentrated i.vac. from a bath of 80°C and the residue was distilled to give 41.9 g (57%) of *ethenylbis(n-octyloxy)borane* as colourless oil of b.p. 105–108°C/0.01 Torr. – ^{1}H NMR (400 MHz, $CDCl_3$): δ = 0.88 (t, *J* = 6.9 Hz, 6H), 1.27–1.30 (m, 20H), 1.53–1.59 (m, 4H), 3.87 (t, *J* = 6.7 Hz, 4H), 5.90–6.11 (m, 3H). – ^{13}C NMR ($CDCl_3$): δ = 14.0, 22.6, 25.8, 29.3 (2 signals), 31.7, 31.8, 63.6, 134.6.

$C_{18}H_{37}BO_2$ (296.3) Calc. C 72.97 H 12.59 Found C 73.05 H 12.57

After stirring 2.02 g (22.4 mmol) of (2*R*,3*R*)-2,3-butanediol and 6.72 g (22.7 mmol) of ethenylbis(*n*-octyloxy)borane for 4 h at room temperature the mixture was distilled to give 1.88 g (67%) of **9** as colourless liquid, b.p. 60–62°C/80 Torr. – ^{1}H NMR ($CDCl_3$): δ =

1.31–1.35 (m, 6H), 4.01–4.08 (m, 2H), 5.88 (dd, J = 19.5 and 13.7 Hz, 1H), 6.04 (d, broad, J = 13 Hz, 1H), 6.17 (dd, J = 19.5 and 4.0 Hz, 1H). – ^{13}C NMR ($CDCl_3$): δ = 20.6, 80.0, 137.1.

λ =	589	578	546	436	365 nm
$[\alpha]_\lambda^{20}$ (c = 8.95, benzene)	+6.5	+6.5	+6.3	+1.5	–18.0

$C_6H_{11}BO_2$ (126.0) Calc. C 57.21 H 8.80 Found C 57.25 H 8.82

2. *2-[(1S)-1-Chloro-2-propenyl]-4,4,5,5-tetramethyl-1,3,2-dioxaborolane* (**4**) *from* **9**: To a solution of 1.53 g (18 mmol) of dichloromethane in 30 ml of dry THF was added at –100°C a precooled solution of 9.2 ml (14.5 mmol) of a 1.58 M solution of *n*-butyllithium in *n*-hexane. After stirring the resulting suspension for 30 min at –100°C a solution of 1.90 g (14.5 mmol) of **9** in 6 ml of dry THF was injected. After stirring for 10 min at –100°C a solution of 1.02 g (7.5 mmol) of anhydrous $ZnCl_2$ in 12 ml of dry THF was added. The mixture was allowed to reach 0°C. After stirring for 3 h at this temperature the mixture was concentrated at 25°C i.vac. The residue was taken up in 40 ml of petroleum ether (40–60°C) resulting in a two phase system to which were added 1.18 g (15.2 mmol) of 2,3-dimethyl-2,3-butanediol and 6 ml of water. After stirring for 30 min the phases were separated and the aqueous phase was extracted twice with 10 ml each of petroleum ether (40–60°C). The combined organic extracts were dried over Na_2SO_4 and concentrated to give 2.82 g of crude **4**. For spectral data of racemic **4** see lit.[1].

3. *2-[(1S)-1-Chloro-2-propenyl]-4,4,5,5-tetramethyl-1,3,2-dioxaborolane* (**4**) *from* **13**: The benzene/isopropyl alcohol-azeotrope was slowly distilled over a 25 cm column from a solution of 2.50 g (27.7 mmol) of (2*R*,3*R*)-2,3-butanediol and 5.95 g (27.9 mmol) of (dichloromethyl)diisopropoxyborane[20] in 50 ml of dry benzene. Fractionation of the residue yielded 4.77 g (94%) of (4*R*,5*R*)-2-(dichloromethyl)-4,5-dimethyl-1,3,2-dioxaborolane (**13**) as colourless liquid of b.p. 78–80°C/14 Torr, cf. lit.[9]. – ^{1}H NMR ($CDCl_3$): δ = 1.36–1.41 (m, 6H), 4.20–4.24 (m, 2H), 5.40 (s, 1H).

A sample (1.01 g, 5.5 mmol) of **13** was taken up in 10 ml of dry ether and treated with 0.49 g (6.2 mmol) of pyridine. The solids were filtered after 1.5 h, washed twice with 5 ml of ether and dried i.vac. to give 0.38 g (26%) of colourless crystals, dec.p. 111.5°C.

λ =	589	578	546	436	365 nm
$[\alpha]_\lambda^{20}$ (c = 7.76, CH_2Cl_2)	–37.9	–39.7	–46.1	–89.8	–172

$C_{10}H_{14}BCl_2NO_2$ (262.0)	Calc.	C 45.85	H 5.39	Cl 27.07	N 5.35
	Found	C 45.70	H 5.39	Cl 27.12	N 5.34

To a solution of 2.70 g (14.8 mmol) of **13** in 50 ml of dry THF was added at –78°C 7.0 ml (14.7 mmol) of a 2.1 M solution of vinylmagnesium chloride in THF. After 15 min a solution of 2.00 g (14.7 mmol) of anhydrous $ZnCl_2$ in 25 ml of dry THF was injected. The mixture was allowed to reach 0°C. After stirring for 4 h at this temperature the mixture was filtered under exclusion of moisture and the filtrate was concentrated i.vac. The residue was treated with 35 ml of petroleum ether (40–60°C) and filtered again. To the filtrate containing **11** was added 2.0 g (17 mmol) of 2,3-dimethyl-2,3-butanediol. Stirring resulted in a homogeneous solution to which was added 5 ml of water. After stirring for 30 min the aqueous phase was separated and extracted once with 10 ml of ether. The combined organic extracts were dried over Na_2SO_4 and concentrated to give 2.41 g of a light tan oil. The ^{1}H NMR spectrum revealed it to contain 80% of **4** and 20% of 2,3-dimethyl-2,3-butanediol.

ent-**4** was similarly prepared starting from (2*S*,3*S*)-2,3-butanediol[17].

4. *2-[(1R)-1-Chloro-2-propenyl]-4,4,5,5-tetramethyl-1,3,2-dioxaborolane* (*ent*-**4**) *from* **15**: The toluene/*n*-butanol-azeotrope was distilled over a 25 cm column from a solution of 4.29 g (20 mmol) of (1*S*,2*S*)-1,2-diphenyl-1,2-ethanediol[21] and of 3.68 g (20 mmol) of di-*n*-butoxyethenylborane[22] in 30 ml of toluene. Removal of the toluene i.vac. gave 4.98 g (100%) of **15** as light tan oil. A sample was bulb to bulb distilled from a bath of 140°C at 10^{-2} Torr. – ^{1}H NMR ($CDCl_3$): δ = 5.21 (s, 2H), 6.08 (dd, *J* = 13.7 and 19.4 Hz, 1H), 6.20 (dd, *J* = 4.1 and 13.7 Hz, 1H), 6.40 (dd, *J* = 4.2 and 19.4 Hz, 1H), 7.30–7.42 (m, 10H). – ^{13}C NMR ($CDCl_3$): δ = 86.4, 125.7, 128.2, 128.7, 138.6, 140.1.

λ =	589	578	546	436	365 nm
$[\alpha]_\lambda^{20}$ (*c* = 12.42, benzene)	−3.3	−3.8	−5.2	−18.0	−52.2

$C_{16}H_{15}BO_2$ (250.1) Calc. C 76.84 H 6.05 Found C 76.85 H 6.13

4.93 g (19.7 mmol) of **15** was converted as described under 2. into 2.75 g of crude *ent*-**4** after bulb to bulb distillation.

5. *2-[(1R)-1-Chloro-2-propenyl]-4,4,5,5-tetramethyl-1,3,2-dioxaborolane* (*ent*-**4**) *from* **16**: (4*S*,5*S*)-2-(Dichloromethyl)-4,5-diphenyl-1,3,2-dioxaborolane (**16**) was prepared as described in the racemic series[1]. Its pyridine adduct, m.p. 101–103°C, had the following rotation:

λ =	589	578	546	436	365 nm
$[\alpha]_\lambda^{20}$ (*c* = 10.59, CH_2Cl_2)	+29.2	+30.2	+34.5	+58.9	+95.5

The (dichloromethyl)boronate was converted into (4*S*,5*S*)-2-[(1*R*)-1-Chloro-2-propenyl]-4,5-diphenyl-1,3,2-dioxaborolane as described under 3. in 76% yield. A solution of 3.89 g (ca. 13 mmol) of the latter in 40 ml of petroleum ether (40–60°C) was stirred for 30 min with 1.54 g (13.0 mmol) of 2,3-dimethyl-2,3-butanediol. The mixture was filtered and the filtrate concentrated to give 2.53 g of crude *ent*-**4** as colourless oil.

6. *(+)-2,3-Pinanediyl (1-Chloro-2-propenyl)boronate* (**14**): 0.30 g (1.7 mmol) of **11** from experiment 3. in 10 ml of petroleum ether (40–60°C) was stirred for 10 min with 0.26 g (1.5 mmol) of (+)-2,3-pinanediol[12] of ca. 92% e.e. After addition of 2 ml of water the mixture was stirred for 15 h and the phases were separated. The aqueous phase was extracted twice with 5 ml each of petroleum ether (40–60°C). The combined organic extracts were dried over Na_2SO_4 and concentrated to give 0.39 g (100%) of crude **14**. The 400 MHz ^{1}H NMR spectrum showed a diastereomer ratio of ca. 10:1.

(4*S*,5*S*)-2-[(1*R*)-1-Chloro-2-propenyl]-4,5-diphenyl-1,3,2-dioxaborolane from experiment 5. was converted similarly into *epi*-**14**. The 400 MHz ^{1}H NMR spectrum showed a diastereomer ratio of ca. 1:5.

Addition of the (α-Chloroallyl)boronate 4 to Aldehydes

The (α-chloroallyl)boronate **4** was added to aldehydes as described in the racemic series[1]. Samples were purified by preparative g.c. and converted[23] into their MTPA-esters. Their enantiomeric excess was determined from the ^{19}F NMR spectra.

7. *[S-(Z)]-(+)-5-Chloro-4-penten-2-ol* (**6a**): 92% e.e. A sample of **6a** containing 5% of **8a** had the following rotation:

λ =	589	578	546	436	365 nm
$[\alpha]_\lambda^{20}$ (*c* = 3.74, ethanol)	+2.4	+2.7	+3.2	+5.1	+8.3

0.36 g (3.0 mmol) of the above sample was dissolved in 10 ml of dry methanol. After addition of 0.50 g (9.0 mmol) of KOH and of few milligrams of 5% Pt on charcoal (Fluka) the mixture was hydrogenated at atmospheric pressure for 3 d. After filtration, the filtrate

was acidified with 6 ml of 1 N HCl and neutralized with solid $NaHCO_3$. The solution was extracted three times with 5 ml each of CH_2Cl_2. The combined organic phases were washed once with 2 ml of water, dried over Na_2SO_4 and concentrated. The residue was purified by preparative g.c. (c, 50°C) to give *(2S)-2-pentanol* (**17a**) as colourless liquid. – $[\alpha]_D^{20}$ = +13.5 (*c* = 8.29, benzene); cf. $[\alpha]_D^{20}$ = +17.87 (*c* = 4.030, benzene)[24,25].

8. *[S-(Z)]-(+)-6-Chloro-5-hexen-3-ol* (**6b**): 89% e.e., a sample containing 4% of **8b** had the following rotation:

λ =	589	578	546	436	365 nm
$[\alpha]_\lambda^{20}$ (*c* = 9.15, ethanol)	+9.2	+9.6	+11.0	+20.2	+35.3

3.0 mmol of the above sample was hydrogenated as described under 7. Preparative g.c. (c, 65°C) gave *(3S)-(+)-3-hexanol* (**17b**) as colourless liquid. $[\alpha]_D^{20}$ = +7.00 (*c* = 7.55, ethanol); cf. $[\alpha]_D^{20}$ = –8.21 (*c* = 11.5, ethanol)[25,26].

9. *[R-(Z)]-(+)-6-Chloro-2-methyl-5-hexen-3-ol* (**6c**): 92% e.e., a sample containing 5% of **8c** showed the following rotation:

λ =	589	578	546	436	365 nm
$[\alpha]_\lambda^{19}$ (*c* = 9.69, $CDCl_3$)	+23.9	+24.9	+28.5	+51.0	+85.6

A sample of 82% e.e. was hydrogenated as described under 7. to give *(R)-(+)-2-methyl-3-hexanol* (**17c**) after g.c. purification (c, 80°C). – $[\alpha]_D^{19}$ = +19.7 (*c* = 3.51, ethanol); cf. $[\alpha]_D^{20}$ = +23.34 (*c* = 4.971, ethanol)[24,25].

10. *[R-(Z)]-(+)-4-Chloro-1-phenyl-3-buten-1-ol* (**6d**): 92% e.e., a sample, melting range 35–40°C, containing 6% of **8d** showed the following rotation:

λ =	589	578	546	436	365 nm
$[\alpha]_\lambda^{20}$ (*c* = 6.86, ethanol)	+10.9	+11.4	+12.7	+18.7	+22.2

2.7 mmol of the above sample was hydrogenated as described under 7. to give 82% of *(R)-(+)-1-phenyl-1-butanol* (**17d**) as colourless solid with a melting range 31–42.5°C. – $[\alpha]_D^{20}$ = +33.7 (*c* = 6.17, benzene); cf. $[\alpha]_D^{27}$ = –45.93 (*c* = 6.1, benzene)[25,27]. – The crude product was converted[23] into the MTPA-ester which showed 76% e.e.

11. *(4R)-4-(4-Chloro-1-hydroxy-3-butenyl)-2,2-dimethyl-1,3-dioxolane* (**23**, **24**, **25**): A mixture of 1.73 g (13.3 mmol) of (4*R*)-2,2-dimethyl-1,3-dioxolane-4-carbaldehyde (**22**)[28] and 2.14 g (10.6 mmol) of 2-(1-chloro-2-propenyl)-4,4,5,5-tetramethyl-1,3,2-dioxaborolane (*rac*-**4**) in 5 ml of CH_2Cl_2 was allowed to react for 15 h. After addition of 1.98 g (13.3 mmol) of triethanolamine the mixture was stirred for 2 h and filtered over 175 g of basic alumina with CH_2Cl_2. Concentration of the eluate yielded 1.76 g (81%) of a 54:6.5:39.5 mixture of **23**, **24**, and **25** (^{13}C NMR). A sample was purified by preparative g.c. (b, 150°C). – ^1H NMR ($CDCl_3$) **23** and **25**: δ = 1.37 and 1.38 (2 s, 3H), 1.44 and 1.45 (2 s, 3H), 2.04 (d, *J* = 3.3 Hz, 0.6H, OH), 2.32 (d, *J* = 5.2 Hz, 0.4H, OH), 2.32–2.55 (m, 2H), 3.60–3.66 (m, 0.4H), 3.75–3.81 (m, 0.4H), 3.85–3.90 (m, 0.6H), 3.91–4.09 (m, 2.6H), 5.90 (q, *J* = 7.2 Hz, 0.6H), 5.95 (q, *J* = 7.1 Hz, 0.4H), 6.16 (dt, *J* = 7.1 and 1.6 Hz, 0.4H), 6.18 (dt, *J* = 7.1 and 1.6 Hz, 0.6H). – ^{13}C NMR ($CDCl_3$) **23**: δ = 25.0, 26.3, 30.8, 64.9, 70.1, 78.1, 109.0, 120.0, 127.2; **24**: 34.6, 65.4, 70.5, 77.8, 109.0, 119.3, 129.3; remaining signals obscured; **25**: δ = 25.1, 26.4, 31.1, 65.8, 71.0, 78.4, 109.3, 119.8, 127.0.

$C_9H_{15}ClO_3$ (206.7) Calc. C 52.31 H 7.32 Cl 17.15 Found C 52.37 H 7.38 Cl 17.42

0.52 g (2.5 mmol) of the above sample of **23**, **24**, and **25** was hydrogenated as described under 7. For the workup 6 ml of saturated aqueous NH_4Cl-solution were used instead of 1 N HCl. The crude product was bulb to bulb distilled from a bath of 50°C to give 0.41 g

(94%) of *(4R)-4-(1-hydroxybutyl)-2,2-dimethyl-1,3-dioxolane* (**20** and **21**), the ^1H and ^{13}C NMR spectra were identical to those of a sample described under 12.

(4*R*)-2,2-Dimethyl-1,3-dioxolane-4-carbaldehyde (**22**) was similarly treated with **4** and *ent*-**4**, respectively. In the latter reaction a 94:2:4 mixture of **23**, **24**, and **25** was purified by preparative g.c. (a, 130°C) to show the following rotation:

λ =	589	574	546	436	365 nm
$[\alpha]_\lambda^{20}$ (c = 9.67, benzene)	−7.4	−7.8	−8.8	−15.3	−25.4

12. *(4R)-4-(1-Hydroxybutyl)-2,2-dimethyl-1,3-dioxolane* (**20** and **21**): 1.38 g (8.0 mmol) of a mixture of **18** and **19**[16] was dissolved in 15 ml of dry methanol and hydrogenated in the presence of solid K_2CO_3 and 5% Pt on charcoal (Fluka) for 1 d at atmospheric pressure. After filtration, the filtrate was concentrated and the residue bulb to bulb distilled from a bath of 50°C to give 1.40 g of **20**/**21** as colourless oil. A sample was purified by preparative g.c. (b, 120°C). – ^1H NMR ($CDCl_3$): δ = 0.94 (2 t, J = 7 Hz, 3H), 1.25–1.62 (m, 4H), 1.37 (2 s, 3H), 1.44 (2 s, 3H), 2.00 (d, J = 2.7 Hz, 0.75H, OH), 2.17 (d, J = 5.1 Hz, 0.25H, OH), 3.50–3.53 (m, 0.25H), 3.72–3.75 (m, 0.25H), 3.80–3.83 (m, 0.75H), 3.89–4.06 (m, 2.75H). – ^{13}C NMR ($CDCl_3$) **20**: δ = 13.7, 18.6, 25.0, 26.2, 34.8, 64.8, 70.3, 78.6, 108.6; **21**: δ = 18.4, 26.3, 35.2, 65.7, 71.6, 79.1, 108.9, remaining signals obscured.

13. *Control Experiments:* A solution of 1.48 g (11.4 mmol) of (4*R*)-2,2-dimethyl-1,3-dioxolane-4-carbaldehyde (**22**) in 5 ml of CH_2Cl_2 was treated at 0°C with 1.19 g (5.9 mmol) of crude 4 for 1 h. Addition of a solution of 0.21 g (5.5 mmol) of $NaBH_4$ in 5 ml of ethanol led to extensive foaming. After stirring for 15 h the mixture was concentrated i.vac. and the residue filtered over 30 g of basic alumina with ether as eluent. The resulting 2.01 g liquid was bulb to bulb distilled from a bath of 50°C to give 1.74 g of a mixture containing 2,3-dimethyl-2,3-butanediol, *(4S)-4-(hydroxymethyl)-2,2-dimethyl-1,3-dioxolane* (**26**) as well as **23**, **24**, and **25**. The alcohol **26** was separated from this mixture by preparative g.c. (a, 80–90°C) to give a sample of 90% purity. – ^1H NMR ($CDCl_3$): δ = 1.36 (s, 3H), 1.43 (s, 3H), 1.87 (t, J = 5.9 Hz, OH), 3.55–3.61 (m, 1H), 3.70–3.76 (m, 1H), 3.77–3.80 (m, 1H), 4.01–4.05 (m, 1H), 4.20–4.26 (m, 1H). – $[\alpha]_D^{20}$ = +11.2 ± 0.5 (c = 4.38, methanol).

The same sample of **22** was reduced directly with $NaBH_4$[18] to give **26** with $[\alpha]_D^{20}$ = +11.2 ± 0.3 (c = 6.09, methanol); cf. lit.[18]: $[\alpha]_D^{25}$ = +11.3 (c = 5.175, methanol).

CAS Registry Numbers

4: 90670-71-6 / *ent*-**4**: 100791-64-8 / *rac*-**4**: 100895-92-9 / **6a**: 90760-62-6 / **6b**: 90760-63-7 / **6c**: 90760-64-8 / **6d**: 90760-65-9 / **9**: 100791-63-7 / **11**: 90670-70-5 / **13**: 89618-71-3 / **13** · C_5H_5N: 100791-73-9 / **14**: 85893-32-9 / *epi*-**14**: 100895-91-8 / **15**: 100791-65-9 / **16**: 100791-66-0 / **16** · C_5H_5N: 100811-98-1 / **17a**: 26184-62-3 / **17b**: 6210-51-1 / **17c**: 90670-72-7 / **17d**: 22144-60-1 / **18**: 79364-35-5 / **19**: 87604-46-4 / **20**: 100791-67-1 / **21**: 100791-68-2 / **22**: 15186-48-8 / **23**: 100791-69-3 / **24**: 100791-70-6 / **25**: 100791-71-7 / **26**: 22323-82-6 / ethenylbis(*n*-octyloxy)borane: 100791-62-6 / (dichloromethyl)diisopropoxyborane: 62260-99-5 / di-*n*-butoxyethenylborane: 6336-45-4 / (2*R*,3*R*)-2,3-butanediol: 24347-58-8 / 2,3-dimethyl-2,3-butanediol: 76-09-5 / (1*S*,2*S*)-1,2-diphenyl-1,2-ethanediol: 2325-10-2 / (+)-2,3-pinanediol: 18680-27-8 / (4*S*,5*S*)-2-[(1*R*)-1-chloro-2-propenyl]-4,5-diphenyl-1,3,2-dioxaborolane: 100791-72-8

[1] For part XXII see: *R. W. Hoffmann* and *B. Landmann*, Chem. Ber. **119**, 1039 (1986).
[2] *G. Solladie*, in *J. D. Morrison* (Editor), Asymmetric Synthesis, Vol. 2, S. 157, Academic Press, New York 1983.
[3] *T. Herold, U. Schrott*, and *R. W. Hoffmann*, Chem. Ber. **114**, 359 (1981); *R. W. Hoffmann* and *T. Herold*, ibid. **114**, 375 (1981); *H. C. Brown* and *P. K. Jadhav*, J. Am. Chem. Soc. **105**, 2092 (1983); Tetrahedron Lett. **25**, 1215 (1984); J. Org. Chem. **49**, 4089 (1984); *H. C. Brown, P. K. Jadhav*, and *P. T. Perumal*, Tetrahedron Lett. **25**, 5111 (1984); *P. K. Jadhav, K. S. Bhat, P. T. Perumal*, and *H. C. Brown*, J. Org. Chem. **51**, 432 (1986).
[4] *W. R. Roush* and *M. Kageyama*, Tetrahedron Lett. **26**, 4327 (1985); *W. R. Roush, A. E. Walts*, and *L. K. Hoong*, J. Am. Chem. Soc. **107**, 8186 (1985); *W. R. Roush* and *R. L. Halterman*, ibid. **108**, 294 (1986).
[5] Another successfull approach to homoallyl alcohols of high e.e. has been developed by *P. A. Bartlett, W. S. Johnson*, and *J. D. Elliott*, J. Am. Chem. Soc. **105**, 2088 (1983), cf. also *R. Imwinkelried* and *D. Seebach*, Angew. Chem. **97**, 781 (1985); Angew. Chem., Int. Ed. Engl. **24**, 765 (1985).
[6] *D. J. S. Tsai* and *D. S. Matteson*, Organometallics **2**, 236 (1983); *M. M. Midland* and *S. B. Preston*, J. Am. Chem. Soc. **104**, 2330 (1982); *V. J. Jephcote, A. J. Pratt*, and *E. J. Thomas*, J. Chem. Soc., Chem. Commun. **1984**, 800; *H. C. Brown, P. K. Jadhav*, and *K. S. Bhat*, J. Am. Chem. Soc. **107**, 2564 (1985).
[7] *R. W. Hoffmann* and *B. Landmann*, Angew. Chem. **96**, 427 (1984); Angew. Chem., Int. Ed. Engl. **23**, 437 (1984); *R. W. Hoffmann*, Chem. Scr. **25**, 53 (1985).
[8] Cf. also the chirality transfer in reactions of allylsilanes with aldehydes via open chain transition states: *T. Hayashi*, Chem. Scr. **25**, 61 (1985).
[9] *K. M. Sadhu, D. S. Matteson, G. D. Hurst*, and *J. M. Kurosky*, Organometallics **3**, 804 (1984).
[10] *F. Dietl, J. Haunschild*, and *A. Merz*, Tetrahedron **41**, 1193 (1985).
[11] *D. S. Matteson* and *E. Erdik*, Organometallics **2**, 1083 (1983).
[12] *R. Ray* and *D. S. Matteson*, Tetrahedron Lett. **21**, 449 (1980).
[13] *D. S. Matteson*, personal communications 1984.
[14] *J. A. Dale, D. L. Dull*, and *H. S. Mosher*, J. Org. Chem. **34**, 2543 (1969).
[15] *S. Masamune, W. Choy, J. S. Petersen*, and *L. R. Sita*, Angew. Chem. **97**, 1 (1985); Angew. Chem., Int. Ed. Engl. **24**, 1 (1985).
[16] *C. H. Heathcock, S. D. Young, J. P. Hagen, M. C. Pirrung, C. T. White*, and *D. VanDerveer*, J. Org. Chem. **45**, 3846 (1980); *J. Mulzer* and *A. Angermann*, Tetrahedron Lett. **24**, 2843 (1983); *R. W. Hoffmann, A. Endesfelder*, and *H. J. Zeiß*, Carbohydrate Res. **123**, 320 (1983).
[17] *V. Schurig, B. Koppenhöfer*, and *W. Buerkle*, J. Org. Chem. **45**, 538 (1980).
[18] cf. *J. J. Baldwin, A. W. Raab, K. Mensler, B. H. Arison*, and *D. E. McClure*, J. Org. Chem. **43**, 4876 (1978).
[19] *C. H. Heathcock, M. C. Pirrung, J. Lampe, C. T. Buse*, and *S. D. Young*, J. Org. Chem. **46**, 2290 (1981).
[20] *M. W. Rathke, E. Chao*, and *G. Wu*, J. Organomet. Chem. **122**, 145 (1976).
[21] *A. Collet*, Synthesis **1973**, 664; *F. Dietl, A. Merz*, and *R. Tomahogh*, Tetrahedron Lett. **23**, 5255 (1982).
[22] *D. S. Matteson*, Organomet. Chem. Rev. **1**, 1 (1966).
[23] cf. *T. Herold, U. Schrott*, and *R. W. Hoffmann*, Chem. Ber. **114**, 359 (1981).
[24] *R. H. Pickard* and *J. Kenyon*, J. Chem. Soc. **103**, 1923, 1957, 1958, (1913).
[25] *J. Jacques, C. Gros*, and *S. Bourcier*, in *H. B. Kagan* (Editor), Stereochemistry, Vol. 4, G. Thieme, Stuttgart 1977.
[26] *J. L. Coke* and *R. S. Shue*, J. Org. Chem. **38**, 2210 (1973).
[27] *K. Mislow* and *C. L. Hamermesh*, J. Am. Chem. Soc. **77**, 1590 (1955).
[28] *E. Baer* and *H. O. L. Fischer*, J. Biol. Chem. **128**, 463 (1939).

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