115463-49-5; **10b**, 115586-53-3; **10c**, 115463-52-0; **10d**, 115463-53-1; **10e**, 115463-50-8; **10f**, 88130-99-8; **11a**, 115510-72-0; **11b**, 115463-55-3; **11c**, 115510-75-3; **11d**, 115510-76-4; **11e**, 115510-73-1; **11f**, 88197-30-2; 4β-H-**12a**, 115510-84-4; 4β-H-**12b**, 115510-85-5; 4β-H-**12c**, 115510-88-8; 4β-H-**12d**, 115510-89-9; 4β-H-**12e**, 115510-86-6; 4α-H-**13a**, 115510-78-6; 4α-H-**13b**, 115510-79-7; 4α-H-**13c**, 115510-82-2; 4α-H-**13d**, 115510-83-3; 4α-H-**13e**, 115510-80-0; (+)-nopinone, 38651-65-9.

Chiral Synthesis via Organoboranes. 21. Allyl- and Crotylboration of α-Chiral Aldehydes with Diisopinocampheylboron as the Chiral Auxiliary

Herbert C. Brown,* Krishna S. Bhat,[1] and Ramnarayan S. Randad[1]

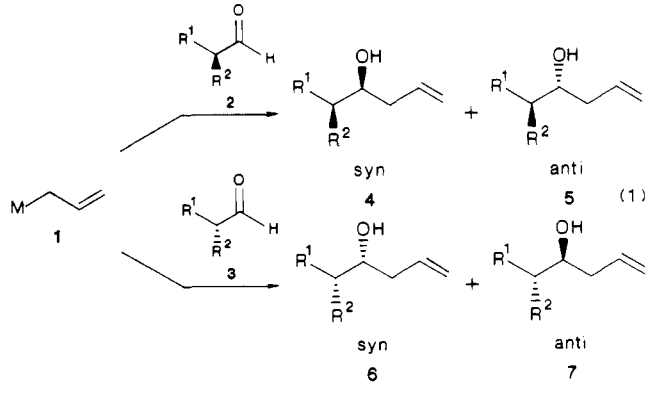
H. C. Brown and R. B. Wetherill Laboratories of Chemistry, Purdue University, West Lafayette, Indiana 47907

Received November 15, 1988

B-Allyldiisopinocampheylboranes [**18**, prepared from (+)-α-pinene; **19**, prepared from (−)-α-pinene] have been screened for diastereofacial selectivity in their reaction with α-substituted chiral aldehydes. Both syn and anti products have been obtained in very high diastereoselectivities. Further, (*E*)-crotyldiisopinocampheylboranes [**20**, prepared from (+)-α-pinene; **21**, prepared from (−)-α-pinene] and (*Z*)-crotyldiisopinocampheylboranes [**22**, prepared from (+)-α-pinene; **23**, prepared from (−)-α-pinene] have been used for diastereofacial selectivity in their reaction with α-substituted chiral aldehydes. These crotylboranes, **20–23**, are highly diastereoselective reagents and the corresponding (3,4- and 4,5)-anti,syn, -anti,anti, and -syn,anti products have been obtained in very high facial selectivities; even the syn,syn product has been obtained in moderately good facial selectivity. Finally, the relative efficiencies of the various chiral auxiliaries utilized in the literature for the allyl- and crotylboration have been compared with those achieved by the diisopinocampheylboron moiety.

The reaction of allylic organometallic reagents and enolate equivalents with carbonyl compounds, the utility of the resulting alcohols in the construction of complex molecules, and their essential feature as biosynthetic intermediates have been amply demonstrated.[2-5] Many allylic organometallic reagents (allyl-M, such as M = Li, B, Si, Sn, etc.) react smoothly with carbonyl compounds to yield the corresponding homoallylic alcohols.[6] Reactions of this type have significant advantages over enolate-derived products in that the newly formed alkenes may be readily transformed into aldehydes and the operation repeated. In addition, the alkenes may be selectively epoxidized, thus readily introducing a third chiral center. Our objective for research in this area, required to support applications in natural products synthesis, is the development of methodology and/or reagents suitable for the synthesis of each diastereomeric relationship with exceptional selectivity and control. Although considerable effort has been devoted to the elucidation of the stereochemistry of the reactions of allylic organometallic compounds with achiral aldehydes, only recently have studies begun in earnest to probe the factors influencing aldehyde diastereofacial selectivity. Consequently, the full potential of allylic metal compounds in acyclic stereoselective synthesis is far from realized.

Like enolates, allylorganometallic reagents react with α-substituted chiral aldehydes to furnish diastereomeric mixtures of syn (**4** and **6**) and anti (**5** and **7**) alcohols (eq 1). This transformation generates two new stereochemical



(1)

relationships and, potentially, four diastereomeric products. Similarly, crotyl organometallic reagents react with chiral aldehydes to furnish diastereomeric mixtures of (3,4- and 4,5)-anti,syn (**10** and **12**), -anti,anti (**11** and **13**), -syn,anti (**15** and **17**), and -syn,syn (**14** and **16**) alcohols (eq 2).

Thus, this transformation generates three new stereochemical relationships and potentially eight diastereomeric

(1) Postdoctoral research associates on Grants GM 10937-25 from the National Institutes of Health.

(2) (a) Heathcock, C. H. In *Asymmetric Synthesis*; Morrison, J. D., Ed.; Academic Press: New York, 1984; Vol. 3, p 111. (b) Evans, D. A.; Nelson, J. V.; Taber, T. R. *Top. Stereochem.* **1982**, *13*, 1. (c) Mukaiyama, T. *Org. React. (N.Y.)* **1982**, *28*, 203.

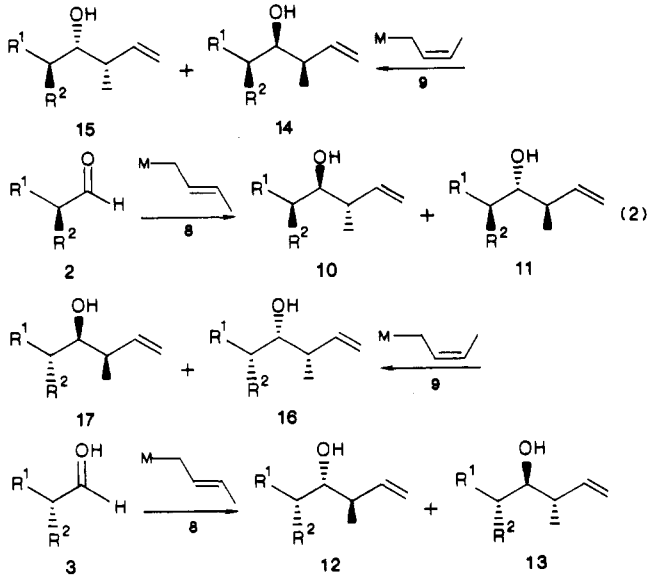
(3) (a) Masamune, S.; Choy, W.; Peterson, J. S.; Sita, L. R. *Angew. Chem., Int. Ed. Engl.* **1985**, *24*, 1. (b) McGarvey, G. J.; Kimura, M.; Oh, T.; Williams, J. M. *J. Carbohydr. Chem.* **1984**, *3*, 125. (c) Reetz, M. T. *Angew. Chem., Int. Ed. Engl.* **1984**, *23*, 556. (d) Yamamoto, Y.; Maruyama, K. *Heterocycles* **1982**, *18*, 357. (e) Masamune, S.; Hirama, M.; Mori, S. *J. Am. Chem. Soc.* **1981**, *103*, 1568. (f) Bartlett, P. A. *Tetrahedron* **1980**, *36*, 2.

(4) (a) Roush, W. R.; Palkowitz, A. D.; Palmer, M. A. J. *J. Org. Chem.* **1987**, *52*, 316. (b) Roush, W. R.; Palkowitz, A. D. *J. Am. Chem. Soc.* **1987**, *109*, 953. (c) Roush, W. R.; Adam, M. A.; Walts, A. E.; Harris, D. J. *J. Am. Chem. Soc.* **1986**, *108*, 3422 and references cited therein. (d) Roush, W. R.; Halterman, R. L. *Ibid* **1986**, *108*, 294. (e) Roush, W. R.; Adam, M. A.; Harris, D. J. *J. Org. Chem.* **1985**, *50*, 2000. (f) Roush, W. R.; Walts, A. E.; Hoong, L. K. *J. Am. Chem. Soc.* **1985**, *107*, 8186. (g) Roush, W. R.; Walts, A. E. *Tetrahedron Lett.* **1985**, *26*, 3427.

(5) (a) Hoffmann, R. W.; Weidmann, U. *Chem. Ber.* **1985**, *118*, 3966 and references cited therein. (b) Hoffmann, R. W.; Ditrich, K.; Froech, S. *Tetrahedron* **1985**, *41*, 5517. (c) *Tetrahedron Lett.* **1984**, *25*, 1781. (d) Hoffman, R. W.; Endesfelder, A.; Zeiss, H. *J. Carbohydr. Res.* **1983**, *123*, 320. (e) Hoffmann, R. W.; Zeiss, H. J.; Ladner, W.; Tabche, S. *Chem. Ber.* **1982**, *115*, 2357. (f) Hoffman, R. W.; Ladner, W. *Tetrahedron Lett.* **1979**, *4653*. (g) Hoffmann, R. W.; Herold, T. *Chem. Ber.* **1981**, *114*, 375.

(6) (a) Hoffmann, R. W. *Angew. Chem., Int. Ed. Engl.* **1982**, *21*, 555. (b) Yamamoto, Y.; Yatagai, H.; Maruyama, K. *J. Am. Chem Soc.* **1981**, *103*, 1969. (c) Kramer, G. W.; Brown, H. C. *J. Organomet. Chem.* **1977**, *132*, 9. (d) *J. Org. Chem.* **1977**, *42*, 2292. (e) Schlosser, M.; Hartmann, J. *J. Am. Chem. Soc.* **1976**, *98*, 4674. (f) Schlosser, M. *Angew. Chem., Int. Ed. Engl.* **1974**, *13*, 701.

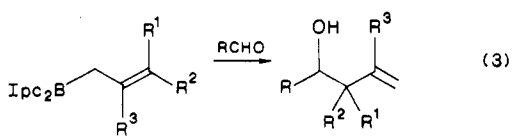
0022-3263/89/1954-1570$01.50/0



products. Enantiomeric homoallyl alcohol units of both syn and anti configurations (eq 1 and 2) constitute a characteristic structural feature of numerous macrolide and polyether antibiotics.[7] The major problem in stereocontrol concerns the selectivity between syn and anti products, which differ in the relative configuration of the newly formed stereocenter at the aldehyde carbonyl position with respect to the existent stereocenter originally present in the aldehyde. Although considerable effort has been devoted to the elucidation of the stereochemistry of the reaction of allylic metal compounds with chiral aldehydes, the stereoselectivity achieved in such syntheses has usually been relatively low. Hence, the development of new allylic organometallic reagents possessing high stereoselectivities remains a desirable goal.

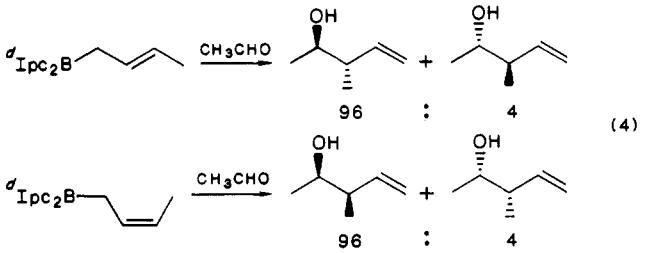
Of the numerous allylic metal compounds that have been considered, the allylic borane compounds seem particularly well suited for applications in acyclic stereoselective synthesis.[4,5] First of all, stereochemically defined substituted allylic organoborane reagents are readily accessible by several flexible synthetic routes. Second, the stereochemical information present in the reagent is transmitted predictably to a syn or anti relationship in the product via cyclic transition states. These two synthetically significant features are not shared by any other group of allylic metal reagents.

At the outset of our studies, relatively little information was available regarding the stereochemistry of the reactions of allylic organoboranes with chiral aldehydes. We have observed that many allylic derivatives, Ipc_2BR, R = allyl, 2-methylallyl, 3,3-dimethylallyl, 2-cyclohexenyl, (*Z*)- and (*E*)-crotyl, γ-methoxyallyl (Ipc = isopinocampheyl) are readily synthesized and, on treatment with aldehydes, yield the corresponding homoallylic alcohols with exceptionally high optical purities[8] (eq 3).



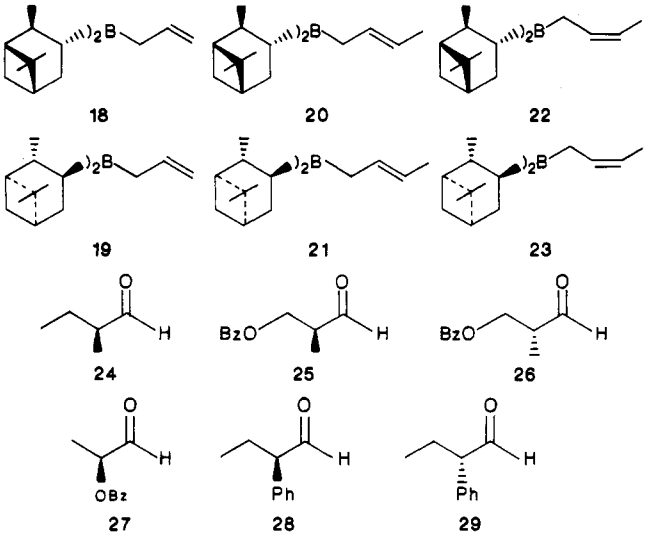
(R^1, R^2, R^3 = H; R^1, R^2 = CH_3, R^3 = H; R^1, R^2 = H, R^3 = CH_3; R^1 = OCH_3, R^2, R^3 = H)

Further, use of the isomerically pure (*Z*)- or (*E*)-crotyldiisopinocampheylborane reagent makes possible the stereocontrolled formation of two asymmetric centers at one time (eq 4). Indeed by judicious use of (*Z*)- and (*E*)-crotylborane reagents with Ipc groups from (+)- or (−)-α-pinene, it is possible to synthesize all four possible isomers of 3-methyl-4-penten-2-ol in high optical yield.[8b]



The evidence is that boron is especially valuable in providing stereocontrolled addition of allylic groups to the aldehydes. Moreover, the isopinocampheyl group readily obtained by the hydroboration of α-pinene appears to possess significant advantages as a chiral auxillary. There is considerable interest in extending this promising asymmetric synthesis of both syn- and anti-homoallyl alcohols (eq 1 and 2) by employing *B*-allyl- and *B*-crotyldiisopinocampheylboranes with chiral aldehydes.

In this paper, we report the high diastereoselective addition of *B*-allyldiisopinocampheylboranes [$^dIpc_2$B-allyl (**18**), $^lIpc_2$B-allyl (**19**)][9] and *B*-crotyldiisopinocampheylboranes [$^dIpc_2$B-(*E*)-crotyl (**20**), $^lIpc_2$B-(*E*)-crotyl (**21**), $^dIpc_2$B-(*Z*)-crotyl (**22**), and $^lIpc_2$B-(*Z*)-crotyl (**23**)][9] with chiral aldehydes (*S*)-2-methylbutyraldehyde (**24**), (*S*)-3-(benzyloxy)-2-methylbutyraldehyde (**25**), (*R*)-3-(benzyloxy)-2-methylbutyraldehyde (**26**), (*S*)-2-(benzyloxy)-propionaldehyde (**27**), (*R*)-2-phenylbutraldehyde (**28**), and (*S*)-2-phenylbutyraldehyde (**29**) to yield the enantiomeric homoallyl alcohols of either the syn or anti structure in high optical purities. Preliminary accounts of these studies have appeared.[10]



(7) (a) Masamune, S.; Choy, W. *Aldrichimica Acta* **1982**, *15*, 47. (b) Brooks, D. W.; Kellogg, R. P. *Tetrahedron Lett.* **1982**, *23*, 4991. (c) Evans, D. A.; Takacs, J. M.; McGee, L. R.; Ennis, M. D.; Mathre, D. J.; Bartroli, J. *Pure Appl. Chem.* **1981**, *53*, 110.

(8) (a) Brown, H. C.; Jadhav, P. K.; Bhat, K. S. *J. Am. Chem. Soc.* **1988**, *110*, 1535. (b) Brown, H. C.; Bhat, K. S. *J. Am. Chem. Soc.* **1986**, *108*, 293. (c) Brown, H. C.; Jadhav, P. K.; Bhat, K. S. *J. Am. Chem. Soc.* **1985**, *107*, 2564. (d) Brown, H. C.; Jadhav, P. K.; Perumal, P. T. *Tetrahedron Lett.* **1984**, *25*, 5111. (e) Brown, H. C.; Jadhav, P. K. *Ibid.* **1984**, *25*, 1215. (f) Brown, H. C.; Jadhav, P. K. *J. Am. Chem. Soc.* **1983**, *105*, 2092.

(9) $^dIpc_2$B- from (+)-α-pinene; $^lIpc_2$B- from (−)-α-pinene.

(10) (a) Brown, H. C.; Bhat, K. S.; Randad, R. S. *J. Org. Chem.* **1987**, *52*, 3701. (b) Brown, H. C.; Bhat, K. S.; Randad, R. S. *J. Org. Chem.* **1987**, *52*, 319.

Results and Discussion

Reaction of *B*-Allyldiisopinocampheylboranes with Chiral Aldehydes 24–29. The reagents, *B*-allyldiisopinocampheylboranes, **18** and **19**, are readily obtained by hydroboration of α-pinene [**18**, prepared from (+)-α-pinene; **19**, prepared from (−)-α-pinene].[11a] Reactions of **18** and **19** with chiral aldehydes **24-29** were carried out at −78 °C in ether solvent on a 10-mmol scale. These reactions are extremely rapid and are complete in less than 3 h at −78 °C. The reaction mixture was worked up with either alkaline hydrogen peroxide to oxidize the boron intermediate or monoethanolamine[8c] to precipitate it. The diastereofacial selectivities of the reagents **18** and **19** with chiral aldehydes **24–29** were easily assessed by monitoring the overall diastereoselectivities achieved in the reaction.

The reagent **18** adds to chiral aldehyde **24** with very high diastereofacial selectivity (96:4). In the reaction of antipodal reagent **19**, the facial selectivity is completely reversed (5:95). Similar selectivities are exhibited by the reagents **18** and **19** with aldehydes **25–27** (the reagent **18** furnished the selectivities 94:4, 98:2, 94:6 and antipodal reagent **19** furnished the selectivities 2:98, 5:95, and 4:96 with **25**, **26**, **27**, respectively). Even the aldehyde **28**, with a more bulky α-substituent, exhibited excellent facial selectivity (2:98) with the reagent **19** and a moderately lower facial selectivity (67:33) with reagent **18**. Similar selectivities are observed for the antipodal aldehyde **29** with the reagents **18**, and **19** (the reagent **18** providing 97:3 and **19** providing 26:76). The results are summarized in Table I.

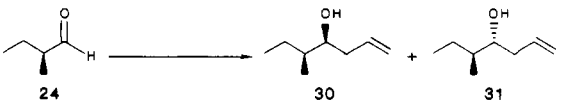
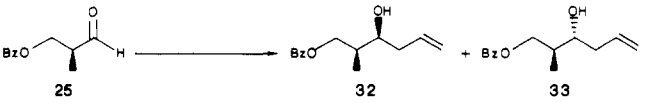
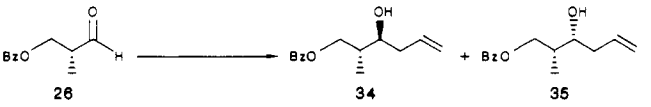
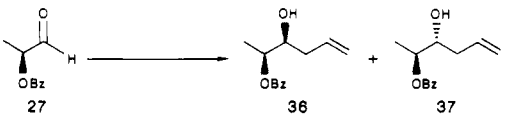
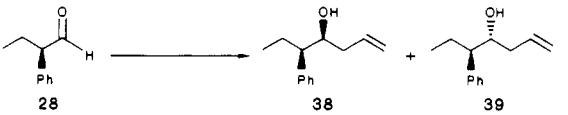
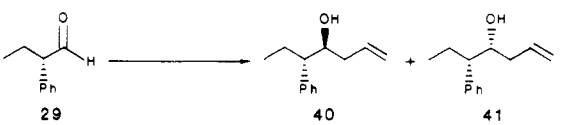
Reaction of (*E*)-Crotyldiisopinocampheylboranes 20 and 21 with Chiral Aldehydes 24–27. The reagents (*E*)-crotyldiisopinocampheylboranes (**20** and **21**) are readily obtained in high stereochemical purity according to the procedure previously reported from our laboratory.[11b] All crotylboration reactions with chiral aldehydes were carried out at −78 °C on a 10-mmol scale, in ether solvent. These reactions are observed to be rapid and require less than 3 h at −78 °C. The reaction mixture was worked up by using either alkaline hydrogen peroxide or monoethanolamine[8c] to remove the boron intermediate. The diastereofacial selectivities of the reagents **20** and **21** with chiral aldehydes **24-27** are easily assessed by monitoring the overall diastereoselectivities achieved in the reaction. The results are summarized in Table II.

It is observed that the reaction of (*E*)-crotylboranes **20** and **21** with aldehydes **24–27** are highly stereoselective and the corresponding (3,4- and 4,5)-anti,syn or -anti,anti products are obtained in very high facial selectivities.

Reaction of (*Z*)-Crotyldiisopinocampheylboranes 22 and 23 with Chiral Aldehydes 24–27. The reagents (*Z*)-crotyldiisopinocampheylboranes, **22** and **23**, are readily obtained in high stereochemical purity according to the procedure previously reported from our laboratory.[11b] All crotylboration reactions were carried out on 10-mmol scale at −78 °C in ether solvent. These reactions are observed to be rapid and require less than 3 h at −78 °C. The reaction mixture was worked up by using alkaline hydrogen peroxide to oxidize the boron intermediate or monoethanolamine[8c] to precipitate it. The diastereofacial selectivities of the reagents **22** and **23** with chiral aldehydes **24–27** are easily assessed by monitoring the overall diastereoselectivities achieved in the reaction. The result are summarized in Table III.

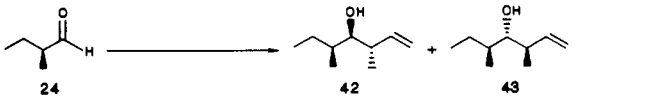
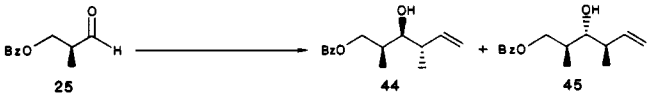
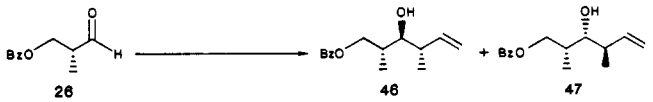
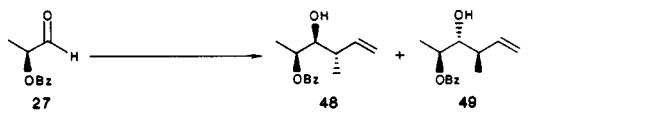
(11) (a) Brown, H. C.; Jadhav, P. K.; Bhat, K. S.; Perumal, P. T. *J. Org. Chem.* **1986**, *51*, 432. (b) Brown, H. C.; Bhat, K. S. *J. Am. Chem. Soc.* **1986**, *108*, 5919.

Table I. Reaction of Chiral Aldehydes 24–29 with the Reagents 18 and 19[a,b]

aldehydes[c]	reagents[h]	diastereomeric products/ratio
	$^{d}Ipc_2B$-allyl (**18**)	96:4[d,f]
	$^{l}Ipc_2B$-allyl (**19**)	5:95[d,f]
	$^{d}Ipc_2B$-allyl (**18**)	96:4[e,g]
	$^{l}Ipc_2B$-allyl (**19**)	2:98[e,g]
	$^{d}Ipc_2B$-allyl (**18**)	98:2[e,g]
	$^{l}Ipc_2B$-allyl (**19**)	5:95[e,g]
	$^{d}Ipc_2B$-allyl (**18**)	94:6[e,f]
	$^{l}Ipc_2B$-allyl (**19**)	4:96[e,f]
	$^{d}Ipc_2B$-allyl (**18**)	67:33[d,f]
	$^{l}Ipc_2B$-allyl (**19**)	2:98[d,f]
	$^{d}Ipc_2B$-allyl (**18**)	97:3[d,f]
	$^{l}Ipc_2B$-allyl (**19**)	26:74[d,f]

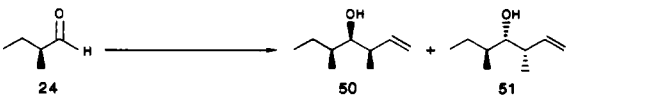
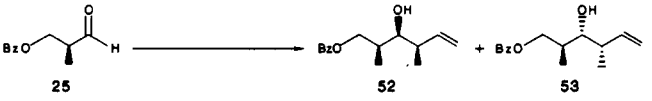
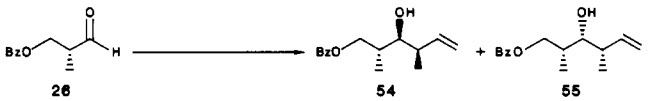
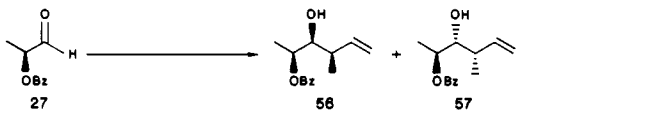
[a] All of the reactions were carried out with a 1:1 molar ratio of reagent to chiral aldehyde. [b] Reactions were carried out at −78 °C under a nitrogen atmosphere. [c] Chiral aldehydes (**24**, 95% ee; **25** and **26**, >98% ee; **28** and **29**, 80–85% ee) were prepared, stored, and used in solution. The optical purity of all aldehydes were routinely checked by comparing the optical rotations of the corresponding alcohols produced by BMS reduction of the aldehydes. [d] The ratios of diastereomers were determined by capillary GC analysis of the MTPA esters[23] of the product alcohols using a column, methylsilcone, 50 m × 0.25 mm. In addition to the presence of the desired two diastereomers, the capillary GC analysis revealed the presence of 2–9% of the other two diastereomers, presumably arising from the presence of small amounts of the other enantiomeric aldehyde. Hence, the diastereomeric ratios were calculated from the two most prominent products postulated to arise from the enantiomerically pure aldehyde present in major amounts. [e] The ratios of diastereomers were obtained by direct capillary GC analysis of the product alcohols using a column, methyl silicone, 50 m × 0.25 mm, or Supelcowax 10, 15 m × 0.25 mm. [f] Configurations of the newly formed stereocenter at the aldehydic carbonyl position are predicted by analogy to the configuration realized in the products obtained in the reaction of allyldiisopinocampheylborane derivaties with achiral aldehydes.[11a] [g] These compounds have been previously described in the literature. The configurations of the newly formed stereocenter at the aldehydic carbonyl position are confirmed by compared the ^{13}C NMR spectral data provided in the literature.[24] [h] Ipc_2B-allyl = *B*-allyldiisopinocampheylborane; *d* = derived from (+)-α-pinene; *l* = derived from (−)-α-pinene.

Table II. Reaction of Chiral Aldehydes 24–27 with the Reagents 20 and 21[a,b]

aldehydes[c]	reagents[h]	diastereomeric products/ratio
	$^{d}Ipc_2B$-(*E*)-crotyl (20)	96:4[d,f]
	$^{l}Ipc_2B$-(*E*)-crotyl (21)	9:91[d,f]
	$^{d}Ipc_2B$-(*E*)-crotyl (20)	98:2[e]
	$^{l}Ipc_2B$-(*E*)-crotyl (21)	5:95[e,g]
	$^{d}Ipc_2B$-(*E*)-crotyl (20)	94:6[e,g]
	$^{l}Ipc_2B$-(*E*)-crotyl (21)	2:98[e,g]
	$^{d}Ipc_2B$-(*E*)-crotyl (20)	95:5[d,f]
	$^{l}Ipc_2B$-(*E*)-crotyl (21)	3:97[d,f]

[a-g] See Table I. [h] Ipc_2B-(*E*)-crotyl = (*E*)-crotyldiisopinocampheylborane; *d* = derived from (+)-α-pinene; *l* = derived from (−)-α-pinene.

Table III. Reactions of Chiral Aldehydes 24–27 with the Reagents 22 and 23[a,b]

aldehydes[c]	reagents[h]	diastereomeric products/ratio
	$^{d}Ipc_2B$-(*Z*)-crotyl (22)	82:18[d,f]
	$^{l}Ipc_2B$-(*Z*)-crotyl (23)	4:96[d,f]
	$^{d}Ipc_2B$-(*Z*)-crotyl (22)	92:8[e,g]
	$^{l}Ipc_2B$-(*Z*)-crotyl (23)	5:95[e,g]
	$^{d}Ipc_2B$-(*Z*)-crotyl (22)	94:6[e,g]
	$^{l}Ipc_2B$-(*Z*)-crotyl (23)	9:91[e,g]
	$^{d}Ipc_2B$-(*Z*)-crotyl (22)	73:27[e,f]
	$^{l}Ipc_2B$-(*Z*)-crotyl (23)	1:99[e,f]

[a-g] See Table I. [h] Ipc_2B-(*Z*)-crotyl = (*Z*)-crotyldiisopinocampheylborane; *d* = derived from (+)-α-pinene; *l* = derived from (−)-α-pinene.

It is striking that the reactions of the crotylboranes **22** and **23** with the chiral aldehydes **24–27** are highly stereoselective and the corresponding (3,4- and 4,5)-syn,anti products have been obtained in excellent facial selectivities. Even the (3,4- and 4,5)-syn,syn products have been obtained with moderately good facial selectivities.

Preparation of the Chiral Aldehydes 24–29. (*S*)-(+)-2-Methylbutanal (**24**) was prepared in 94–97% ee and 75–80% yield by pyridinium chlorochromate oxidation of commerically available (from Aldrich) (*S*)-(−)-2-methyl-1-butanol, in the presence of anhydrous sodium acetate as buffer.[12] Alternately, **24** was obtained according to the literature method in high optical purity >97% ee, but in 30–35% chemical yield.[5e]

(*S*)-(+)-3-(Benzyloxy)-2-methylpropanal (**25**) was prepared in >98% ee and 80–85% yield from commercially available (from Aldrich) optically active methyl 3-hydroxy-2-methylpropionate following the literature method.[4a,13] Alternatively, **25** was obtained in comparable optical purity and chemical yield from (*S*)-(+)-methyl 3-hydroxy-2-methylpropionate by first protecting the hydroxy group as the benzyl ether (by treating the alcohol with benzyl bromide in the presence of silver oxide, following a similar procedure described by K. Mislow et al.[14]) and then reducing the corresponding ester to the aldehyde **25**, using diisobutylaluminum hydride (DIBAH), following a similar procedure described in the literature.[15] The enantiomer **26** was obtained similarly from (*R*)-(−)-methyl 3-hydroxy-2-methylpropionate available from Aldrich.

(*S*)-(−)-2-(Benzyloxy)propionaldehyde (**27**) was prepared according to a literature procedure[16] from (*S*)-(+)-2-(benzyloxy)-1-propanol in >96% ee and 85–90% yield. Alternatively, **27** was prepared in >98% ee and 90–92% yield directly from (*S*)-ethyl-2-(benzyloxy)propionate by using DIBAH.[15]

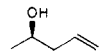
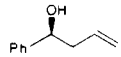
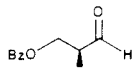
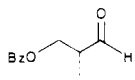
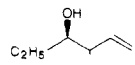
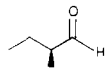
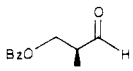
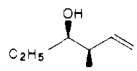
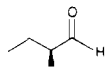
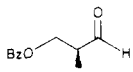
(*S*)-2-Phenylbutyraldehyde (**28**) was prepared in 80–85% ee and 70% yield by reduction of the commercially available (*S*)-(+)-2-phenylbutyric acid (from Aldrich) by using the thexylchloroborane methyl sulfide complex.[17] A similar procedure was used to obtain **29** from (*R*)-(−)-2-phenylbutyric acid.

The optical purity of each aldehyde was determined by establishing the optical purity of the alcohol obtained by reducing the aldehydes with BMS. We have previously shown that such reductions proceed without detectable racemization.[18] Attempts to purify the aldehydes by distillation or preparative GC or by column chromatography results in considerable racemization. Since the diastereoselectivity of the reactions of aldehydes with a chiral reagent depends on the optical purity of the aldehyde, crude aldehydes were used as soon as possible following their preparation.

Comparison of Chiral Auxiliaries. In recent years many allylic organoborane reagents possessing different chiral auxiliaries, **58–61**, have been reported to furnish homoallylic alcohols with variable diastereoselectivities and enantioselectivities following their reaction with both achiral and chiral aldehydes. We wanted to compare the relative effectiveness of these chiral auxiliaries with those

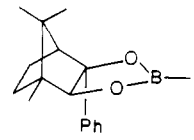
(12) Corey, E. J.; Suggs, J. W. *Tetrahedron Lett.* **1975**, 2647.
(13) Meyers, A. I.; Babiak, K. A.; Campbell, A. L.; Comins, D. L.; Fleming, M. P.; Henning, R.; Heuschmann, M.; Hudspeth, J. P.; Kane, J. M.; Reider, P. J.; Roland, D. M.; Shimizu, K., Tomioka, K.; Walkup, R. D. *J. Am. Chem. Soc.* **1983**, *105*, 5015.
(14) Mislow, K.; O'Brien, R. E.; Schaefer, H. *J. Am. Chem. Soc.* **1962**, *84*, 1940.
(15) Banfi, L.; Bernardi, A.; Colombo, L.; Gennari, C.; Scolastico, C. *J. Org. Chem.* **1984**, *49*, 3784.
(16) Wuts, P. G. M.; Bigelow, S. S. *J. Org. Chem.* **1983**, *48*, 3489.
(17) Brown, H. C.; Cha, J. S.; Nazar, B.; Yoon, N. M. *J. Am. Chem. Soc.* **1984**, *106*, 8001.
(18) Brown, H. C.; Imai, T.; Desai, M. C.; Singaram, B. *J. Am. Chem. Soc.* **1985**, *107*, 4980.

Table IV. Relative Effectiveness of Various Auxiliaries in the Chiral Allyl- and Crotylboration of Representative (Common) Aldehydes

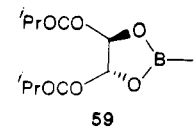
aldehyde	product	d or l[a]	reagents				
			Ipc_2BR	58 BR	59 BR	60 BR	61 BR
			R = Allyl				
CH_3CHO		d	93% ee[8f]	86% ee[5g]			
C_6H_5CHO		d	93% ee[8f]	36% ee[5g]	71% ee[4f]	85% ee[19]	
	32:33	d	96:4		83:17[4a]		
	32:33	l	2:98		20:80		
	34:35	d	98:2			93:7[19]	
	34:35	l	5:95			7:93	
			R = (E)-Crotyl				
C_2H_5CHO		d	92% ee[8b]				96% ee[20]
	42:43	d	96:4	92:8[5e]			
	42:43	l	9:91	76:24			
	44:45	d	98:2		95:5[4a]		
	44:45	l	5:95		14:86		
			R = (Z)-Crotyl				
C_2H_5CHO		d	92% ee[8b]				86% ee[20]
	50:51	d	82:18	55:45[5e]			
	50:51	l	4:96	5:95			
	52:53	d	92:8		50:50[4a]		
	52:53	l	5:95		9:91		

[a] d refers to the reagents derived from (+)-α-pinene, (+)-camphor glycol, (R,R)-tartrate esters. (R,R)-N,N'-dibenzyl-N,N'-ethylenetartramide (DBETA) and (R,R)-2,5-dimethylborolane, respectively. l refers to the corresponding enantiomeric reagents.

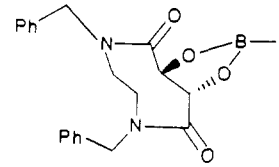
of the diisopinocampheylboron moiety in allylboration and crotylboration of identical aldehydes under similar condition. The available data are tabulated in Table IV.



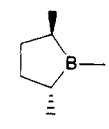
58



59



60



61

Examination of the data in Table IV reveals that the reaction of achiral aldehydes with allyl and crotyl reagents possessing the chiral auxiliaries **58**[5,6] and **59**[4] provides the corresponding homoallylic alcohols in low and variable enantiomeric excess as compared to the results realized with reagents possessing the diisopinocampheylboron moiety. On the other hand, reagents utilizing the chiral auxiliaries **60**[19] and **61**[20] provide comparable selectivities with achiral aldehyde. However, in the reaction of allyl and crotyl reagents with chiral aldehydes, the diisopinocampheylboron moiety again appears to be superior. Reagents possessing the diisopinocampheylboron moiety have provided the desired diastereomer in very high diastereomeric purity merely by selecting the appropriate enantiomeric reagents and aldehydes. Thus, the chirality of the reagents controlled the overall diastereofacial selectivities achieved. Reagent based on the chiral auxiliary **58** has provided the products, which differ greatly for the matched and mismatched pair of reactants, whereas **59** has provided improved diastereoselection exhibiting a decreased sensitivity to the use of matched or mismatched reactants. Finally, the modified chiral auxiliary **60** has exhibited selectivities comparable to those realized with the diisopinocampheylboron group. These two chiral auxiliaries, Ipc_2B and **60**, generally dominate the situation and appear relatively insensitive to the use of matched or mismatched reagents.

Even though the reagents possessing chiral auxiliaries **60** and **61** provide comparable selectivities with those achieved by Ipc_2B–, both **60** and **61** suffer from a serious disadvantage in requiring preparation by relatively involved procedures. On the other hand, the diisopinocampheyl moiety is readily obtained by simple hydroboration of α-pinene, available commercially in both enantiomeric forms at a relatively economical cost. Furthermore, the diisopinocampheylboron reagent provides the corresponding homoallylic alcohols from both achiral and chiral aldehydes consistently in very high enantiomeric and diastereomeric purities. Hence, at this time it would appear that the reagent utilizing the diisopinocampheylboron moiety is presently the reagent of choice for allyl- and crotylboration of both achiral and chiral aldehydes.[21]

(19) Private communication from William R. Roush.
(20) Garcia, J.; Kim, B. M.; Masamune, S. *J. Org. Chem.* **1987**, *52*, 4831.

Conclusions

It is clear from these results that the allyldiisopinocampheylboranes, 18 and 19, and the crotyldiisopinocampheylboranes, 20–23, are highly diastereoselective and enantioselective reagents with chiral and achiral aldehydes, with the stereochemistry at the newly formed C–C bond being controlled simply by selecting the appropriate enantiomeric reagent. In this way the chirality of the reagent controls the overall diastereofacial selectivity achieved in the reaction. This synthesis is operationally very simple, providing access to all possible stereoisomers in high optical purity merely by selecting the proper antipode of the reagents and aldehydes. Further, ozonolysis of these homoallylic alcohols should provide the corresponding aldehydes, which on further treatment with (*E*)- or (*Z*)-crotyldiisopinocampheylboranes, would provide the higher homoallylic alcohol with two additional stereocenters in high stereoselectivity. Hence, this repeating process should provide a convenient route to the numerous macrolide and polyether antibiotics.

Experimental Section

General. The reaction flasks and other glass equipment were dried in an oven (140 °C, 12–18 h) and assembled in a steam of dry nitrogen. Special experimental techniques used in handling of air-sensitive materials are described in detail elsewhere.[22] Tetrahydrofuran (THF) was distilled over benzophenone ketyl and stored under a nitrogen atmosphere in an ampule. Solvent ether was dried over molecular sieves. The ^{11}B NMR spectra were recorded by using a Varian FT-80A instrument. The chemical shifts are in δ relative to $BF_3{\cdot}OEt_2$. The ^1H NMR spectra were recorded on either a Varian T-60 (60 MHz) or a Perkin-Elmer R-32 (90 MHz) instrument. The ^{13}C NMR spectra were recorded on a Varian FT-80A or XL-200 instrument. GC analysis was carried out with a Hewlett-Packard 5740 Chromatograph with use of (a) a 9 ft × 0.125 in. column packed with 10% Carbowax 20M on Chromosorb W (100–120 mesh) or (b) a 9 ft × 0.125 in. column packed with 10% OV-101 on Chromosorb W (100–120 mesh). The homoallylic alcohols were purified from other chemical impurities by preparative GC using a 6 ft × 0.5 in. column packed with 20% SP-2100 on Chromosorb W (60–80 mesh). All yields reported are for products isolated by fractional distillation.

Stereochemical Determination. Diastereomeric ratios were determined by capillary GC analysis using columns (a) Supelcowax 10, 15 m × 0.25 mm, or (b) methylsilicone, 50 m × 0.25 mm.

Removal of Chiral Auxiliary. In all cases the chiral auxiliary, Ipc_2B–, was removed from the reaction mixture either by oxidation with alkaline H_2O_2, or by precipitation with ethanolamine. In the latter case the Ipc_2BOMe is readily obtained by dissolving the ethanolamine adduct in methanol and adding dilute hydrochloric acid in ether to neutralize the amine. These procedures are described in detail in the following section.

General Procedure for Reactions of *B*-Allyldiisopinocampheylboranes 18 and 19 with Chiral Aldehydes 24–29. Reagents 18 and 19 were prepared with allylmagnesium bromide and either *B*-methoxydiisopinocampheylborane or *B*-chlorodiisopinocampheylborane according to the procedure described earlier from our laboratory.[11a]

In a typical experiment, a solution of 18 (10 mmol, 1 M in ether) was cooled to −78 °C and 10 mL of a 1 M solution of aldehyde 24 (10 mmol) in ether was added dropwise, maintaining the reaction temperature at −78 °C. Following addition, the reaction mixture was stirred at −78 °C for 3 h to insure completion of the reaction.

Two different procedures can be used to destroy or remove the chiral auxiliary Ipc_2B– from the desired product. In one case, oxidation, the reaction mixture is treated with alkaline H_2O_2 to convert the material to boric acid and isopinocampheol, both readily removed. In the second procedure, the reaction mixture is treated with ethanolamine, quantitatively precipitating the Ipc_2B– ethanolamine adduct. The latter procedure is preferred for those cases where the boiling point of the product is too close to that of isopinocampheol to permit a simple separation by distillation. In large-scale preparation the ethanolamine procedure makes possible the recovery and recycle of the chiral auxiliary.

(A) Oxidation Procedure. The above reaction mixture was quenched with 8 mL of 3 M NaOH solution, then slowly warmed to room temperature, and oxidized with 30% H_2O_2, all operations being carried out under nitrogen. The organic layer was separated, washed with water (10 mL) and brine (2 × 10 mL), and dried over anhydrous $MgSO_4$, and solvent was evaporated. The product alcohol was separated from isopinocampheol by careful fractional distillation.

(B) Ethanolamine Procedure. The reaction mixture was freed of magnesium salts by passing through a filteration chamber under a nitrogen atmosphere. The solvent was removed under reduced pressure (25 °C/15 mm/1 h), and residue was dissolved in dry *n*-pentane (10 mL). The borinate was cooled to 0 °C and treated with 0.6 mL (10 mmol) of ethanolamine. The contents were stirred at 0 °C for 0.5 h and allowed to warm to room temperature, and stirring was continued for additional 1 h. A white crystalline solid (^{11}B NMR δ + 13) indicated the formation of the ethanolamine adduct. The reaction mixture was then cooled to 0 °C and filtered. The solid ethanolamine adduct was washed with cold pentane (2 × 10 mL). The residue after removal of solvent from the combined filtrate was distilled to provide the homoallylic alcohol.

The distillate was used directly for determination of the stereochemical purity. To obtain the spectral data and optical rotation, the distillate was further purified by preparative GC. (The diastereomeric ratios of the purified sample were in good agreement with the observed diastereomeric ratios of the sample before purification).

Mixtures of 30 and 31 obtained from the reactions of 18 or 19 with 24 were derivatized with the Mosher acid chloride [from (+)-MTPA],[23] and the resulting esters were analyzed by capillary GC, column b, temperature 130 °C. The retention times for the corresponding esters are as follows: 30, 80.88 min, and 31, 84.28 min; for the diastereomeric esters obtained from enantiomeric 30, 82.55 min, and 31, 83.12 min. The reaction of 18 with 24 provided the diastereomers 30 and 31 (96:4): yield, 81%; α^{23}_D −9.8° (neat, l = 0.5); ^{13}C NMR for 30 ($CDCl_3$, Me_4Si) δ 11.60, 13.31, 25.82, 39.12, 39.59, 73.73, 117.25, 135.62. The reaction of 19 and 24 provided the diastereomers 30 and 31 (5:95): yield, 83%; α^{23}_D +10.48° (neat); ^{13}C NMR for 31 ($CDCl_3$, Me_4Si) δ 11.49, 14.72, 24.85, 38.35, 40.05, 74.42, 117.63, 135.67.

Mixtures of 32 and 33 obtained from the reactions of 18 or 19 with 25 were easily analyzed by capillary GC, column a, temperature 140 °C, with retention times for 32, 40.29 min, and for 33, 37.91 min. The reaction of 18 with 25 provided the diastereomers 32 and 33 (96:4): yield, 80%; $[\alpha]^{23}_D$ −8.6° (*c* 4.4, MeOH); ^{13}C NMR for 32 ($CDCl_3$, Me_4Si) δ 10.77, 37.74, 39.02, 72.66, 73.38, 74.36, 116.96, 127.55, 128.37, 135.63, 138.32. The reaction of 19 with 25 provided the diastereomers 32 and 33 (2:98): yield, 78%; $[\alpha]^{23}_D$ −4.8° (*c* 3.6, MeOH); ^{13}C NMR for 33 ($CDCl_3$, Me_4Si) δ 13.87, 38.17, 39.32, 73.38, 74.29, 74.54, 117.02, 127.59, 128.37, 135.33, 137.53. Similarly, the reaction of 18 and 26 provided the diastereomers 34 and 35 (98:2) and the reaction of 19 with 26 provided the diastereomers 34 and 35 (5:95).

Mixtures of 36 and 37 obtained from the reactions of 18 or 19 with 27 were directly analyzed by capillary GC, column b, temperature 115 °C. The retention times were 50.80 min for 36 and for 37, 51.64 min. The reaction of 18 and 27 provided the diastereomers 36 and 37 (94:6) yield, 80%; $[\alpha]^{23}_D$ +17.6° (*c* 5.2, MeOH); ^{13}C NMR for 36 ($CDCl_3$, Me_4Si) δ 15.50, 37.66, 71.11, 74.34, 77.58, 117.01, 127.69, 127.81, 128.44, 135.06, 138.62. The reaction of 19 with 27 provided the diastereomers 36 and 37 (4:96): yield, 75%; $[\alpha]^{23}_D$ +34.4° (*c* 5.5, MeOH); ^{13}C NMR for 37 ($CDCl_3$,

(21) Thomas, E. J.; Merifield, E.; Steel, P. G. *J. Chem. Soc., Chem. Commun.* **1987**, *1826*.

(22) For techniques, see: Brown, H. C.; Kramer, G. W.; Levy, A. B.; Midland, M. M. *Organic Synthesis via Boranes*; Wiley-Interscience: New York, 1975; p 191.

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

(24) Heathcock, C. H.; Kiyooka, S.; Blumenkopf, T. A. *J. Org. Chem.* **1984**, *49*, 4214.

Me_4Si) δ 13.99, 37.12, 70.88, 72.89, 77.46, 117.28, 127.63, 128.41, 135.09, 138.74.

Mixtures of **38**, **39**, **40**, and **41** obtained from the reaction of **28** and **29** with the reagents **18** and **19** were derivatized with the Mosher acid chloride, and the resulting esters were analyzed by capillary GC, column b, temperature 200 °C. The retention times for the corresponding esters are **38**, 28.98 min; **39**, 31.86 min; **40**, 31.45 min; and **41**, 30.12 min. The reaction of **18** with **28** provided a mixture of diastereomers **38**, **39**, and **40** (61.0:30.5:8.5): yield, 74%; $[\alpha]^{23}_D$ −9.44° (*c* 1, MeOH); ^{13}C NMR for **38** ($CDCl_3$, Me_4Si) δ 12.14, 24.96, 39.67, 53.39, 73.79, 117.31, 126.59, 128.31, 129.15, 135.30, 141.28. The reaction of **19** with **28** provided a mixture of diastereomers **38**, **39**, **40**, **41** (1.7:88.5:2.7:7.0): yield, 78% $[\alpha]^{23}_D$ −5.24° (neat); ^{13}C NMR for **39** ($CDCl_3$, Me_4Si) δ 12.09, 24.30, 39.82, 54.15, 74.48, 118.00, 126.49, 128.44, 128.61, 129.16, 135.21, 142.42. Similarly, the reaction of **18** with **29** provided a mixture of diastereomers **38**, **39**, **40**, and **41** (4.5:1.9:91.3:2.3) and the reaction of **19** with **29** provided a mixture of diastereomers **38**, **39**, **40**, and **41** (0.6:9.3:23.5:66.5).

General Procedure for Reactions of Crotyldiisopinocampheylboranes 20–23 with Chiral Aldehydes 24–27. The reagents **20–23** were freshly prepared in high stereochemical purity, according to the following procedure. Ten milliliters of a 1 M solution of **20** (10 mmol) in THF was cooled to −78 °C, and 10 mL of a 1 M solution of aldehyde **24** (10 mmol) was added dropwise, maintaining the reaction temperature at −78 °C. Following addition, the reaction mixture was stirred at −78 °C for 3 h, quenched with 15 mL of 3 M NaOH solution, slowly warmed to room temperature, and oxidized with 30% H_2O_2. The organic phase was separated, washed with water (10 mL) and brine (2 × 10 mL), and dried over anhydrous $MgSO_4$. After removal of the solvent, the residue was carefully fractionated. Distillate was directly used for stereochemical purity determination. The distillate was then purified by preparative GC and used for the NMR spectra and optical rotation.

Mixtures of **42**, **43**, **50**, and **51**, obtained from the reaction of **24** with the reagents **20–23**, were easily analyzed by capillary GC, column b, temperature 55 °C. The retention times were **42**, 25.08 min; **43**, 26.45 min; **50**, 27.90 min; and **51**, 28.43 min. The reaction of **20** with **24** provided a mixture of diastereomers **42**, **43**, and **50** (94.5:5:0.5): yield, 75%; $[\alpha]^{23}_D$ −3.32° (neat); ^{13}C NMR for **42** ($CDCl_3$, Me_4Si) δ 11.66, 12.51, 16.69, 26.86, 36.51, 41.87, 76.92, 115.91, 141.50. The reaction of **21** and **24** provided a mixture of diastereomers **42**, **43**, and **51** (9:90:1): yield, 70%; α^{23}_D −4.96° (neat, *l* 0.5); ^{13}C NMR for **43** ($CDCl_3$, Me_4Si) δ 11.30, 15.76, 17.28, 23.75, 37.61, 40.85, 79.06, 115.74, 140.22. The reaction of **22** with **24** provided a mixture of diastereomers **42**, **50**, and **51** (2:80:18): yield, 73%; $[\alpha]^{23}_D$ +17.97° (neat); ^{13}C NMR for **50** ($CDCl_3$, Me_4Si) δ 11.43, 12.67, 15.59, 26.80, 37.06, 41.46, 77.72, 114.15, 141.74. The reaction of **23** with **24** provided a mixture of **43**, **50**, and **51** (2:4:94): yield, 79%; $[\alpha]^{23}_D$ −12.18° (neat, *l* 0.5); ^{13}C NMR for **51** ($CDCl_3$, Me_4Si) δ 11.13, 13.08, 15.53, 23.95, 37.26, 40.31, 78.58, 114.16, 142.31.

Mixtures of **44**, **45**, **52**, and **53**, obtained from the reaction of **25** with the reagents **20–23**, were easily analyzed by capillary GC, column a, temperature 145 °C. The retention times were **44**, 37.72 min; **45**, 32.63 min; **52**, 39.58 min; and **53**, 35.38 min. The reaction of **25** with **20** provided a mixture of **44** and **45** (98:2): yield, 87%; $[\alpha]^{23}_D$ +8.45° (*c* 6.9, MeOH); ^{13}C NMR for **44** ($CDCl_3$, Me_4Si) δ 10.12, 16.68, 35.41, 41.83, 73.32, 74.66, 75.57, 115.42, 127.53, 128.37, 138.56, 141.81. The reaction of **25** with **21** provided a mixture of **44** and **45** (5:95): yield, 84%; $[\alpha]^{23}_D$ −13.19° (*c* 6.1, MeOH); ^{13}C NMR for **45** ($CDCl_3$, Me_4Si) δ 14.09, 17.73, 36.41, 41.23, 73.52, 75.11, 79.39, 115.15, 127.69, 128.46, 138.09, 140.00. The reaction of **25** with **22** provided a mixture of **52** and **53** (92:8): yield, 83%; $[\alpha]^{23}_D$ +8.38° (*c* 6.2, MeOH); ^{13}C NMR for **52** ($CDCl_3$, Me_4Si) δ 9.88, 17.02, 35.58, 41.99, 73.38, 75.31, 76.84, 114.43, 127.56, 128.25, 128.41, 138.25, 141.35. The reaction of **25** with **23** provided a mixture of **52** and **53** (5:95): yield, 78%; $[\alpha]^{23}_D$ −17.46° (*c* 4.7, MeOH); ^{13}C NMR for **53** ($CDCl_3$, Me_4Si) δ 13.59, 14.61, 35.84, 41.15, 73.53, 74.41, 78.69, 114.40, 127.66, 128.03, 128.42, 138.06, 142.35. Similarly, the reaction of **26** with the reagent **20** and **21** provided the mixture of diastereomers **46** and **47** in the ratio of 96:6 and 2:98, respectively. The reaction of **26** with the reagents **22** and **23** provided a mixture of diastereomers **54** and **55** in the ratio of 94:6 and 9:91, respectively.

Mixtures of **48** and **49** obtained from the reaction of **27** with reagents **20** and **21** were analyzed by capillary GC column b, temperature 115 °C; retention times for **48**, 65.79 min; and **49**, 73.82 min. The reaction of **27** with **20** provided a mixture of **48** and **49** (95:5): yield, 80%; $[\alpha]^{23}_D$ +17.92° (*c* 3.07, MeOH); ^{13}C NMR for **48** ($CDCl_3$, Me_4Si) δ 15.52, 17.62, 40.42, 70.94, 76.61, 78.32, 114.96, 127.64, 127.76, 128.39, 138.56, 140.03. The reaction of **27** with **21** provided the mixture of **48** and **49** (3:97): yield, 85%; $[\alpha]^{23}_D$ +37.41° (*c* 3.7, MeOH); ^{13}C NMR for **49** ($CDCl_3$, Me_4Si) δ 14.05, 16.50, 39.50, 70.64, 76.06, 76.80, 115.14, 127.64, 127.98, 128.37, 138.71, 140.53.

Mixtures of **56** and **57** obtained from the reaction of **27** with the reagents **22** and **23** were analyzed by capillary GC column b, temperature 115 °C; the retention times were **56**, 65.17 min; and **57**, 67.21 min. The reaction of **27** with **22** provided the mixture of **56** and **57** (73:27): yield, 74%; $[\alpha]^{23}_D$ +28.65° (*c* 4.5, MeOH); ^{13}C NMR for **56** ($CDCl_3$, Me_4Si) δ 15.27, 16.25, 40.97, 70.99, 75.42, 78.44, 114.37, 127.62, 127.76, 128.36, 138.62, 141.81. The reaction of **27** with **23** provided the mixture of **56** and **57** (1:99): yield, 78%; $[\alpha]^{23}_D$ +9.47° (*c* 4.4, MeOH); ^{13}C NMR for **57** ($CDCl_3$, Me_4Si) δ 13.08, 16.19, 40.29, 70.61, 76.11, 114.82, 127.64, 128.39, 138.69, 140.76.

Acknowledgment. The financial support from the National Institutes of Health (Grant GM 10937-25) is gratefully acknowledged. We also thank Professor William R. Roush, Indiana University, Bloomington, Indiana, for providing comparative spectroscopic data for compounds **44**, **45**, **52**, and **53**.

Registry No. **18**, 85116-38-7; **19**, 106356-53-0; **20**, 99438-29-6; **21**, 99493-12-6; **22**, 99397-92-9; **23**, 99438-30-9; **24**, 1730-97-8; **25**, 79027-28-4; **26**, 79026-61-2; **27**, 81445-44-5; **28**, 42307-60-8; **29**, 106356-54-1; **30**, 99342-24-2; **30** ((+)-MTPA ester), 118949-56-7; **31**, 99328-46-8; **31** ((+)-MTPA ester), 119065-14-4; **32**, 106357-32-8; **33**, 89046-67-3; **34**, 94233-74-6; **35**, 94233-73-5; **36**, 94233-72-4; **37**, 94233-71-3; **38**, 106268-79-5; **38** ((+)-MTPA ester), 118949-57-8; **39**, 106268-80-8; **39** ((+)-MTPA ester), 119065-15-5; **40**, 106268-77-3; **40** ((+)-MTPA ester), 119065-16-6; **41**, 106268-78-4; **41** ((+)-MTPA ester), 119065-17-7; **42**, 82917-20-2; **43**, 82917-21-3; **44**, 106357-28-2; **45**, 106357-29-3; **46**, 108814-35-3; **47**, 119065-11-1; **48**, 109333-88-2; **49**, 109430-15-1; **50**, 82917-17-7; **51**, 82917-18-8; **52**, 106357-31-7; **53**, 106357-30-6; **54**, 119065-12-2; **55**, 119065-13-3; **56**, 109430-16-2; **57**, 109430-17-3; *d*-**58** (R = allyl), 67760-74-1; *d*-**58** (*R* = (*E*)-crotyl), 119065-20-2; *l*-**58** (R = (*E*)-crotyl), 119065-19-9; *d*-**58** (R = (*Z*)-crotyl), 73037-27-1; *l*-**58** (R = (*Z*)-crotyl), 82917-24-6; *d*-**59** (R = allyl), 99417-55-7; *l*-**59** (R = allyl), 99493-25-1; *d*-**59** (R = (*E*)-crotyl), 99687-40-8; *l*-**59** (R = (*E*)-crotyl), 99745-86-5; *d*-**59** (R = (*Z*)-crotyl), 106357-20-4; *l*-**59** (R = (*Z*)-crotyl), 106357-33-9; *d*-**60** (R = allyl), 112897-02-6; *l*-**60** (R = allyl), 119065-18-8; *d*-**61** (R = (*E*)-crotyl), 110457-31-3; **61** (R = (*Z*)-crotyl), 110508-40-2; CH_3CHO, 75-07-0; C_6H_5CHO, 100-52-7; C_2H_5CHO, 123-38-6; (*R*)-$CH_3CH(OH)CH_2CH{=}CH_2$, 64584-92-5; (*S*)-$PhCH(OH)CH_2CH{=}CH_2$, 77118-87-7; (3*R*,4*S*)-$C_2H_5CH(OH)CH(CH_3)CH{=}CH_2$, 95273-28-2; (3*R*,4*R*)-$C_2H_5CH(OH)CH(CH_3)CH{=}CH_2$, 95273-29-3.