32.4, 68.9, 74.9, 112.0, 116.4, 117.0, 124.5, 128.1, 131.1, 133.2, 147.9, 153.0 ppm; mass spectrum (FAB), m/z 980, 982, 984 (M^+, 26, 89, 46), 213 (1,4-dioxo-2,3-dimethylene-5-bromobenzene, 100).

Protonation of 1a with Gaseous Hydrogen Chloride. Gaseous hydrogen chloride was bubbled through a 0.02 M solution of **1a** in chloroform or methylene chloride, whereat the color of the yellow solution turned red. The experiment can be carried out in deuterated solvents in a NMR tube for direct NMR spectroscopic monitoring of the formation of **20**: ^{1}H NMR (200 MHz, CD_2Cl_2, 263 K) δ 1.10 (t, 6 H), 1.85 (m, 4 H), 3.64 (m, 4 H), 4.35 and 4.53 (AB, 4 H), 4.29 and 4.79 (AB, 4 H), 6.22 (s, 1 H); ^{13}C NMR (50 MHz, $CDCl_3$, 293 K) 10.9, 23.7, 32.8, 60.2, 78.3, 129.8, 132.0, 151.9, 158.0, 221.0 ppm.

Acknowledgment. Financial support by the Deutsche Forschungsgemeinschaft is gratefully acknowledged.

Registry No. **1a**, 117408-79-4; **1b**, 138572-23-3; **1c**, 117408-80-7; **1d**, 139200-57-0; **2b**, 138572-22-2; **2c**, 139200-58-1; **3b**, 139200-59-2; **3c**, 117408-82-9; **4a**, 117408-77-2; **4b**, 139200-60-5; **4c**, 117408-78-3; **4d**, 139200-61-6; **5**, 72022-68-5; **6**, 527-18-4; **7a**, 139200-62-7; **7b**, 139200-63-8; **7c**, 117408-74-9; **7d**, 139200-64-9; **8a**, 117408-75-0; **8b**, 139200-65-0; **8c**, 117408-76-1; **8d**, 139200-66-1; **10**, 139200-68-3; **11**, 139200-70-7; **12**, 139200-72-9; **13**, 139200-73-0; **19b**, 139200-74-1; **19c**, 117408-81-8; **20**, 139200-75-2; 1,4-bis(hexyloxy)-2,3-dimethylbenzene, 139200-76-3; 1,4-bis(butyloxy)-2,3-dimethylbenzene, 139200-77-4; 2,3-dimethyl-*p*-hydroquinone, 608-43-5; hexanoyl chloride, 142-61-0; 1-bromopropane, 106-94-5; 1-bromobutane, 109-65-9; 1-bromohexane, 111-25-1.

Supplementary Material Available: Positional parameters and their estimated standard deviations (Table 1), bond distances (Table 2), bond angles (Table 3), dihedral angles between planes (Table 4) of **1a**, and ^{1}H NMR spectra of selected compounds (28 pages). This material is contained in many libraries on microfiche, immediately follows this article in the microfilm version of the journal, and can be ordered from the ACS; see any current masthead page for ordering information.

Chiral Synthesis via Organoboranes. 34. Selective Reductions. 47. Asymmetric Reduction of Hindered α,β-Acetylenic Ketones with *B*-Chlorodiisopinocampheylborane to Propargylic Alcohols of Very High Enantiomeric Excess. Improved Workup Procedure for the Isolation of Product Alcohols

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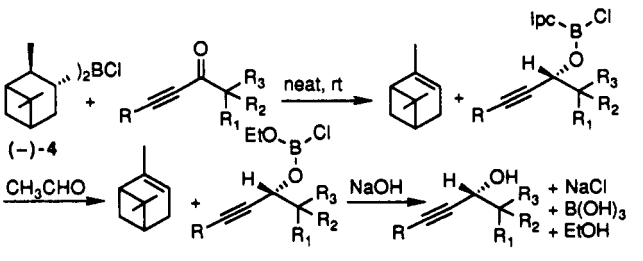
The Midland reagent, Alpine-Borane (**2a**), is excellent for the asymmetric reduction of many acetylenic ketones, but it fails with hindered derivatives. On the other hand, *B*-chlorodiisopinocampheylborane (DIP-Chloride, **4**) reacts with hindered α,β-acetylenic ketones to provide the corresponding propargylic alcohols in 96 to ≥99% ee. The reaction is in accordance with the tentative mechanism proposed earlier. While 4-phenyl-3-butyn-2-one is reduced in only 21% ee, **4** reduces 4-methyl-1-phenyl-1-pentyn-3-one in 53% ee and 4,4-dimethyl-1-phenyl-1-pentyn-3-one in ≥99% ee. The generality of this observation is demonstrated by reducing a series of hindered acetylenic ketones with increasing steric requirements and differing electronic environments. Thus, 2,2-dimethyl-4-tridecyn-3-one, 1-cyclopentyl-4,4-dimethyl-1-pentyn-3-one, and 3,3-dimethyl-5-tetradecyn-4-one are all reduced to the corresponding alcohols in ≥99% ee. 4,4-Dimethyl-1-pentadecen-6-yn-5-one and 2-methyl-2-phenyl-4-tridecyn-3-one are reduced in 96% ee and 97% ee, respectively. A modified and operationally simpler workup procedure for obtaining the alcohols in high isolated yields is described. Comparison of reagent **4** with **2a** is also made, making clear the range of applicability of each reagent. This development makes it possible to reduce asymmetrically any acetylenic ketone by a judicious choice of either **2a** or **4**.

Asymmetric reduction of prochiral ketones, one of the best methods for the preparation of optically active *secondary* alcohols,[2] became more practical when Brinkmeyer and Kapoor reported[3] the successful reduction of alkynyl ketones to the corresponding propargylic alcohols in 62–84% ee with Mosher's (2*S*,3*R*)-(+)-4-(dimethylamino)-1,2-diphenyl-3-methyl-2-butanol (Aldrich, Chirald)–$LiAlH_4$ (LAH) complex (**1**).[4] Until this discovery in 1977 aralkyl ketones had been the only class of ketones that had provided satisfactory asymmetric reduction. Since then asymmetric reduction of ketones has developed into a major area of asymmetric synthesis.[5] Of the many classes of ketones that can be reduced asymmetrically, the class of α,β-acetylenic ketones has achieved special importance because the product alcohol retains the acetylenic moiety which can be transformed into many other functional groups[6] and many research groups have sought to

Scheme I



(1) Postdoctoral Research Associate on a Grant from the U.S. Army Research Office.

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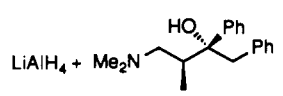
0022-3263/92/1957-2379$03.00/0

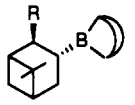
develop efficient reagents for the chiral reduction of alkynyl ketones in high ee.[7]

Cohen et al. also studied the Chirald–LAH mixture for the asymmetric reduction of alkynyl ketones.[8] Vigneron and Bloy modified LAH with *N*-methylephedrine and 3,5-dimethylphenol to develop a comparable reagent.[9] Midland's *B*-isopinocampheyl-9-borabicyclo[3.3.1]nonane (Aldrich, Alpine-Borane **2a**)[10] and NB-Enantrane (**2b**)[11] proved to be extremely efficient trialkylborane reducing agents for the reduction of alkynyl ketones. Recently, we described Eapine-Borane (**2c**) and Prapine-Borane (**2d**) for the reduction of acetylenic ketones.[12] Noyori's Binal-H (**3**) is another good reagent for the reduction of prochiral alkynyl ketones with predictable stereochemistry.[13]

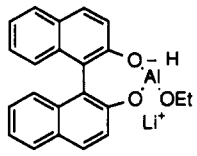


1 : 2.33 Darvon alcohol (Chirald®)

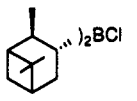
1



2a R = Me, Alpine-Borane
2b R = $-CH_2CH_2OBnz$, NB-Enantrane
2c R = Et, Eapine-Borane
2d R = *n*-Pr, Prapine-Borane



3
Binal-H



(–)-Ipc_2BCl, **(–)-4**
(–)-DIP-Chloride

The high ee achieved in the reduction of alkynyl ketones with **1** was accounted for by a transition-state model which considers the alkynyl group as equivalent to an aryl group.[3] This model predicts the actual configurations of the product alcohols. Brinkmeyer found that the reaction is very sensitive to the temperature and the rate of addition of the ketone. Analysis of the correlation between structural features in the ketone and the enantioselectivity achieved in the reduction reveals that branching at the α'-carbon increases the enantioselectivity. Corey utilized this reagent mixture to reduce *tert*-butyl alkynyl ketones and obtained 73–94% ee for the product alcohols.[14] In the reduction of *tert*-alkyl alkynyl ketones, **1** generally induces ee in the range of 50–90%. However, Wender and co-workers recently reported the highest chiral induction achieved prior to this study, 98% ee, for the reduction of a hindered alkynyl ketone with **1**.[15] The real nature of **1** is not known and the generality of this reaction has not been studied.

Alpine-Borane is also very sensitive to steric effects. An isopropyl group at the α' position of the carbonyl moiety increases the ee, compared to a primary alkyl group, but a *tert*-butyl group next to the carbonyl moiety retards the rate of reduction and the ketone fails to undergo chiral reduction even under neat condition.[16] On the contrary, Noyori's results with **3** reveal that the ee decreases with branching at the α position of the carbonyl group. Indeed, **3** completely fails to reduce α-*tert*-alkyl ketones.[13] Moreover, the reagent is far more complex than indicated by the simple formulation **3**.[13b]

We had recently reported (–)-*B*-chlorodiisopinocampheylborane ($^dIpc_2BCl$, Aldrich, (–)-DIP-Chloride, **4**) as an excellent reagent for the reduction of aralkyl ketones.[17] Since our introduction of this reagent, it has been utilized for such asymmetric reductions in several syntheses, especially involving pharmaceuticals.[18] On the basis of the tentative mechanism of reduction, the capability of this reagent in reducing α-*tert*-alkyl ketones to alcohols of high ee was anticipated and demonstrated. However, the reactions were very slow. Initially, we tested this reagent for a standard series of ketones[5] and found it to be poor for the reduction of unhindered alkynyl ketones. Indeed, we had reported that our standard alkynyl ketone 4-phenyl-3-butyn-2-one (**5b**) was reduced to the corresponding propargylic alcohol (**6b**) in only 21% ee, which provided the first impression that **4** is ineffective for the chiral reduction of acetylenic ketones. However, the rate of reduction was much faster than that of other classes of ketones. A combination of this factor and the fact that **4** is capable of reducing hindered ketones in very high ee suggested that **4** could be efficient for the reduction of hindered alkynyl ketones. We undertook a study of the effect of increasing the steric bulk on the carbon α' to the carbonyl moiety in the acetylenic ketones. A series of hindered acetylenic ketones were synthesized and subjected to chiral reduction with **4** achieving the synthesis of the product propargylic alcohols in gratifying high ee. The results of this study are presented in this paper.

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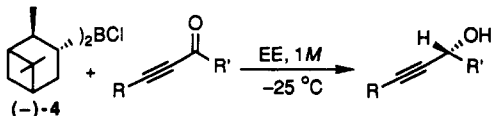
Results and Discussion

(−)-DIP-Chloride (4) reduces 4-phenyl-3-butyn-2-one (**5b**) in ethyl ether (EE) at −25 °C within 1 h to the corresponding (*R*)-propargylic alcohol in 21% ee. The parent acetylenic ketone, 3-butyn-2-one (**5a**), was reduced under similar conditions to the (*R*)-alcohol **6a** in 17% ee. In order to investigate the effect of increased steric bulk at the α′ position of the carbonyl moiety, we synthesized 1-phenyl-1-pentyn-3-one (**5c**), 4-methyl-1-phenyl-1-pentyn-3-one (**5d**), and 4,4-dimethyl-1-phenyl-1-pentyn-3-one (**5e**) from phenylacetylene and the corresponding acid chloride using a literature procedure.[19] Reduction of **5c** with **4** under our standard conditions provided the corresponding alcohol **6c** in 81% yield. Analysis of the α-methoxy-α-(trifluoromethyl)phenylacetate (MTPA ester)[20] of the alcohol, performed on a SPB-5 capillary column, showed an ee of 28%. Increasing the bulk of R′ to an isopropyl group (**5d**) yielded the product alcohol **6d** in 53% ee. Finally, a further increase in the bulk of R′ to the *tert*-butyl group (**5e**) yielded the product alcohol **6e** in ≥99% ee (eq 1). The latter reaction required 6 d for completion under standard conditions (EE, 1 M, −25 °C). However, conducting the reaction at room temperature (rt) without solvent resulted in complete reduction in 8 h, providing the product alcohol in 98% ee.



(1)

5a R = H, R′ = Me **6a** R = H, R′ = Me : 17% ee
5b R = Ph, R′ = Me **6b** R = Ph, R′ = Me : 21% ee
5c R = Ph, R′ = Et **6c** R = Ph, R′ = Et : 28% ee
5d R = Ph, R′ = *i*-Pr **6d** R = Ph, R′ = *i*-Pr : 53% ee
5e R = Ph, R′ = *t*-Bu **6e** R = Ph, R′ = *t*-Bu : ≥99% ee, 98% ee (rt)

Modified Workup Procedure. We utilized a modified workup procedure for the isolation of the product alcohols after reduction. Our original workup procedure[17] utilized diethanolamine to remove the boron components as a solid. However, we recently discovered that a modified workup procedure offered major advantages (Scheme I). This procedure involves treatment of the reaction mixture, following reduction of the ketone, with 1.1 equiv of acetaldehyde at rt for 6–12 h depending on the steric size of the ketone used. This achieves the complete elimination of the second α-pinene moiety from the reagent (^{11}B NMR; δ 18 ppm). Aqueous sodium hydroxide is added to the mixture and the organics are extracted with EE. Distillation provides α-pinene (≥95% recovery) and the product alcohol (70–92% yield).

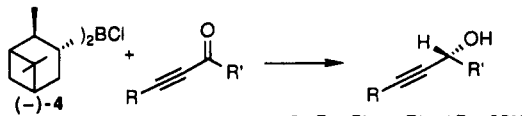
This modified workup procedure has the following advantages. (1) It avoids the formation of the solid diethanolamine complex byproduct and the problem of its disposal. (2) Scaling up for industrial-scale application of DIP-Chloride is thereby made easier. (3) The chiral auxiliary, α-pinene, is recovered completely in high ee, unlike the earlier procedure where 50% of the chiral auxiliary was isolated as the complex. Recycling the recovered α-pinene completely makes this reduction process more economical. (4) The yield of the product alcohol is improved considerably, since the alcohol products are not occluded in the solid diethanolamine complex. A comparison of the yields by the two isolation procedures is included in Table I. As can be seen the yields achieved are at least 10% higher than those realized by the earlier workup procedure. (5) Best of all, the new workup procedure is operationally simpler. Moreover, there is no detectable difference in the ee of the product alcohols realized from both workup procedures.

Table I. Asymmetric Reduction of Acetylenic Ketones Using DIP-Chloride (4)

compd	RC≡CC(O)R′ R	R′	react temp	react time	% yield[a] A	B	% ee[b]
5a	H	Me	−25 °C	2 h	70	83	17
5b	Ph	Me	−25 °C	2 h	78[c]	92	21
5c	Ph	Et	−25 °C	2 h		90	28
5d	Ph	*i*-Pr	−25 °C	2 h		85	53
5e	Ph	*t*-Bu	−25 °C	6 d	70	80	≥99
5e	Ph	*t*-Bu	rt	8 h	71	80	98
5f	Cyp[d]	*i*-Pr	−25 °C	2 h	72	81	39
5g	Cyp	*t*-Bu	rt	24 h	67	76	97
5h	*n*-Oct	*i*-Pr	−25 °C	2 h		86	26
5i	*n*-Oct	*t*-Bu	−25 °C	10 d		76	≥99
5i	*n*-Oct	*t*-Bu	rt	20 h		77	98
5j	*n*-Oct	$C(Me)_2Et$	rt	48 h	65	72	≥99
5k	*n*-Oct	$C(Me)Et_2$	rt	7 d		70	≥99
5l	*n*-Oct	CEt_3	rt	14 d		69	≥99
5m	*n*-Oct	$C(Me)_2$allyl	rt	24 h		71	96
5n	*n*-Oct	$C(Me)_2Ph$	rt	24 h		70	97

[a] A = diethanolamine workup,[17] B = acetaldehyde workup. [b] ee determined as their MTPA esters on a capillary GC. [c] From ref 17. [d] Cyp = cyclopentyl.

Generality of the Reduction. The generality of the observation that the enantiomeric excess increases with increase in the steric requirement of the group at the α′ position of the carbonyl moiety in hindered acetylenic ketones was then tested. The phenyl groups in **5d** and **5e** were replaced by either a cyclopentyl or an *n*-octyl group[19] and reduced with **4**. While 1-cyclopentyl-4-methyl-1-pentyn-3-one (**5f**) in EE at −25 °C was reduced within 2 h to the acetylenic alcohol **6f** in 39% ee, the rate of reduction of the corresponding *tert*-butyl analogue, 1-cyclopentyl-4,4-dimethyl-1-pentyn-3-one (**5g**), was very slow. Conducting the reaction at rt under neat condition, the reduction was complete in 20 h and the alcohol **6g** was obtained in 97% ee. Again, a similar effect was observed for the reduction of 2-methyl-4-tridecyn-3-one (**5h**) and 2,2-dimethyl-4-tridecyn-3-one (**5i**). Here 26% ee and 98% ee respectively were realized for the corresponding isopropyl and *tert*-butyl propargylic alcohol **6h** and **6i**. The reaction of **5i** with **4** at −25 °C was complete in 10 d, providing the product alcohol in ≥99% ee, whereas a rt reaction without solvent was complete in 20 h and provided **6i** in 98% ee. In all the cases the isolated yield of the alcohols was 70–80%. The results are summarized in Table I (eq 2).



(2)

5e R = Ph, R′ = *t*-Bu **6e** R = Ph, R′ = *t*-Bu: 98% ee
5f R = Cyp, R′ = *i*-Pr **6f** R = Cyp, R′ = *i*-Pr: 39% ee
5g R = Cyp, R′ = *t*-Bu **6g** R = Cyp, R′ = *t*-Bu: 97% ee
5h R = *n*-Oct, R′ = *i*-Pr **6h** R = *n*-Oct, R′ = *i*-Pr: 26% ee
5i R = *n*-Oct, R′ = *t*-Bu **6i** R = *n*-Oct, R′ = *t*-Bu: 98% ee

To investigate the limits of steric bulk that can be accommodated in the reduction with **4**, in other words, to see whether the ee would drop after reaching a maximum at any stage if the steric bulk of the α′ group of the acetylenic ketone is increased gradually, we synthesized several acetylenic ketones with α′ groups bulkier than the *tert*-butyl group. While 3,3-dimethyl-5-tetradecyn-4-one (**5j**) could be synthesized using the same procedure as used

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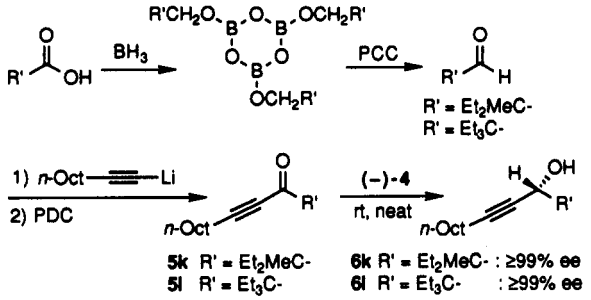
Scheme II



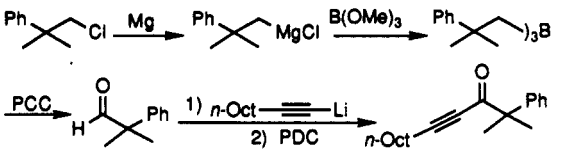
for the *tert*-butyl ketones,[19] the yield of ketones dropped drastically in the synthesis of 3-ethyl-3-methyl-5-tetradecyn-4-one (**5k**) and 3,3-diethyl-5-tetradecyn-4-one (**5l**). Attempted syntheses utilizing an earlier but similar literature procedure[21] increased the yields modestly, but they were still very low. This could be due to the steric bulk of the acid chloride used. Finally, these ketones were prepared using yet another literature procedure based on reaction of the aldehyde with the alkynyllithium, followed by oxidation of the intermediate alcohol.[14] The necessary aldehydes were prepared from the commercially available acids using a procedure developed in these laboratories involving reduction with diborane, followed by oxidation with pyridinium chlorochromate (PCC)[22] (Scheme II).

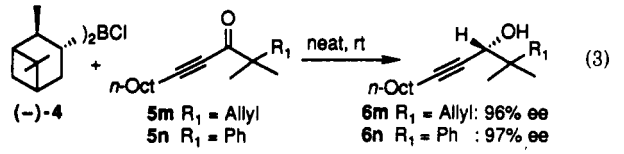
For example, 2-ethyl-2-methylbutyric acid on reduction with BMS gave the boroxine which upon oxidation with PCC in dichloromethane gave 2-ethyl-2-methylbutanal in 50% yield. The rate of reaction of the boroxine with PCC was dependent on the steric requirements of the boroxine. Earlier we had reported that it required 1 h for the oxidation of unhindered boroxines.[22] However, it took 3 h for the formation of 2-ethyl-2-methylbutanal. This was converted to the corresponding alkynol by treatment with alkynyllithium which was then oxidized to obtain the ketone **5k**. An identical procedure was used to synthesize **5l**. The precursor aldehyde in this case was prepared from triethylacetic acid. In this case oxidation of the boroxine intermediate with PCC required 12 h.

Ketones **5j–l** were treated with **4** at rt under neat condition. Quite expectedly, the reaction rate was dependent on the steric size of the group α' to the carbonyl moiety (Table I). As can be seen, while the reaction was complete in 20 h when the group was *tert*-butyl, a dimethylethylcarbinyl group decreased the rate to 48 h. A diethylmethylcarbinyl group adjacent to the carbonyl group made the reaction slower (7 d) and the ketone with a triethylcarbinyl group adjacent to the carbonyl group required 14 d for completion of the reaction. In all of these cases the alcohols were isolated in ~70% yield and in ≥99% ee. *Thus, 4 proved itself to be unique in that it showed consistently high ee for the product propargylic alcohols derived from hindered acetylenic ketones.*

To test the efficiency of the reagent **4** on hindered ketones with differeing electronic environments, we synthesized 4,4-dimethyl-1-pentadecen-6-yn-5-one (**5m**) and 2-methyl-2-phenyl-4-tridecyn-3-one (**5n**) from 1-decynyllithium and the corresponding aldehyde. The 2-methyl-2-phenylpropanal necessary to prepare **5n** was synthesized from the corresponding Grignard reagent (2-methyl-2-phenylpropyl)magnesium chloride by treatment with trimethyl borate,[23] followed by oxidation with PCC (Scheme III).[24] These two ketones gave the product propargylic alcohols in 96% and 97% ee, respectively (eq 3).

Scheme III





(3)

The configuration of all the alcohols produced from the reduction with (−)-**4** is expected to be (*R*) based on the configuration of known propargylic alcohols **6a** and **6b** and based on the tentative mechanism of reduction with **4** which assumes the acetylenic moiety as the group of lesser steric requirement as compared to any alkyl group.[17] In fact, reductions with **4** have been used as a method for unambiguous assignment of configuration.[25] We obtained the propargylic alcohol of opposite configuration, i.e., the (*S*) isomer in 97% ee by treating **5n** with (+)-**4** derived from (−)-α-pinene.

To compare the effectiveness of reagent **4** with that of the commonly used organoborane reagent for the reduction of acetylenic ketones, **2a**, we subjected ketones **5a–e** to reduction with **2a**. The enantiomeric excess of the product alcohol depended on the steric environment of the alkyl group α' to the carbonyl moiety. The ee increased from 82% for the ketone with a methyl group (**5b**) to 97% ee for an ethyl group (**5c**) and in the case of the ketone with an isopropyl group (**5d**) the alcohol was obtained in ≥99% ee. Increasing the steric requirement further to a *tert*-butyl group adjacent to the carbonyl moiety made the reaction very sluggish. Midland had reported that *tert*-butyl alkynyl ketones do not undergo reductions under normal conditions.[10] However, he had reported that under very high hydrostatic pressures (6000 atm), 83% of the ketone could be reduced in 2.5 d to the corresponding alcohol in 100% ee.[26] We found that under neat condition at rt there is a slow reduction, 50% in 14 d as shown by the ^{11}B NMR spectrum of an aliquot of the reaction mixture. Analysis of the product alcohol after workup of the reaction mixture at this stage showed it to be of 80% ee. The decrease in ee might have arisen from the dehydroboration of the reagent followed by achiral reduction by the 9-BBN produced.[27] Since the reductions of *tert*-butyl acetylenic ketones with **2a** were slow, other *tert*-alkyl acetylenic ketones were not subjected to Alpine-Borane reduction. However, the isopropyl acetylenic ketones **5f** and **5h** were reduced with **2a** and the product alcohols were obtained in ≥99% ee.

All of the above results are summarized in Table II with a comparison of the efficiency of **4** for the same reductions. As can be seen, **2a** is excellent for those ketones with steric

(21) Tohda, Y.; Sonogashira, K.; Hagihara, N. *Synthesis* **1977**, 777.
(22) (a) Brown, H. C.; Rao, C. G.; Kulkarni, S. U. *Synthesis* **1979**, 704. (b) Brown, H. C.; Kulkarni, S. U.; Rao, C. G.; Patil, V. D. *Tetrahedron* **1986**, *42*, 5515.
(23) Srebnik, M.; Cole, T. E.; Ramachandran, P. V.; Brown, H. C. *J. Org. Chem.* **1989**, *54*, 6085.
(24) Rao, C. G.; Kulkarni, S. U.; Brown, H. C. *J. Organomet. Chem.* **1979**, *172*, C20.
(25) (a) Oberlender, R.; Nichols, D. E.; Ramachandran, P. V.; Srebnik, M. *J. Pharm. Pharmacol.* **1987**, *39*, 1055. (b) Potin, D.; Dumas, F.; d'Angelo, J. *J. Am. Chem. Soc.* **1990**, *111*, 3483.
(26) (a) Midland, M. M.; McLoughlin, J. I. *J. Org. Chem.* **1984**, *49*, 1316. (b) Midland, M. M.; McLoughlin, J. I.; Gabriel, J. *J. Org. Chem.* **1989**, *54*, 159.
(27) Midland, M. M.; Tramontano, A.; Zderic, S. A. *J. Organomet. Chem.* **1978**, *156*, 203.

Table II. Comparison of Asymmetric Reduction of Acetylenic Ketones with DIP-Chloride (4) and Alpine-Borane (2a)

ketone reduced	increasing steric requirement of R′	RC≡CC(O)R′ R	R′	% ee[a-c] Alpine-Borane	% ee[a,d] DIP-Chloride
5a	Me	H	Me	77[e]	17
5b	Me	Ph	Me	82[e]	21
5c	Et	Ph	Et	97	28
5d	*i*-Pr	Ph	*i*-Pr	≥99	53
5f	*i*-Pr	Cyp[h]	*i*-Pr	≥99	39
5h	*i*-Pr	*n*-Oct	*i*-Pr	≥99	26
5e	*t*-Bu	Ph	*t*-Bu	80[f]	≥99
5e	*t*-Bu	Ph	*t*-Bu	80[f]	98[b]
5i	*t*-Bu	*n*-Oct	*t*-Bu	*g*	≥99
5m	CMe_2allyl	*n*-Oct	CMe_2allyl	*g*	96[b]
5n	CMe_2Ph	*n*-Oct	CMe_2Ph	*g*	97[b]
5j	CMe_2Et	*n*-Oct	CMe_2Et	*g*	≥99[b]
5k	$CMeEt_2$	*n*-Oct	$CMeEt_2$	*g*	≥99[b]
5l	CEt_3	*n*-Oct	CEt_3	*g*	≥99[b]

[a] ee determined as their MTPA esters on a capillary GC. [b] For a neat reaction at rt. [c] Corrected for the optical purity of 92% ee α-pinene. [d] For a reaction at −25 °C. [e] From ref 16. [f] 50% reaction was complete in 14 d. [g] Reaction very slow. [h] Cyp = cyclopentyl.

bulk upto an isopropyl group where 4 fails to achieve good enantioselection. When the groups are as bulky as or are bulkier than a *tert*-butyl group, **2a** fails to react whereas **4** gives excellent enantioselection. Evidently, **2a** and **4** are complimentary to each other. Together, these two borane reagents could reduce unhindered and hindered alkynyl ketones to essentially optically pure propargylic alcohols.

In conclusion, we have demonstrated the utility of DIP-Chloride for the reduction of a wide range of hindered alkynyl ketones. Several hitherto unknown hindered acetylenic ketones have been synthesized and converted to the corresponding propargylic alcohols in high yields and in essentially optically pure form. Reagents **2a** and **3** fail to reduce these type of hindered ketones. Most of the other reducing agents fail to achieve consistency. Consequently, this development makes it possible to reduce any α,β-acetylenic ketone in very high ee by a judicious choice of either **2a** or **4**. A modified and operationally simplified workup procedure for the isolation of the alcohols in high yields has been reported. This new workup procedure facilitates scaling up of such asymmetric reductions. Moreover, **4** is superior to other reagents due to the following advantages: (1) the reaction conditions are simple (neat, rt), (2) the workup is very easy, (3) the yields of product alcohols are very high; (4) both enantiomers of the reagent are readily available,[17] (5) the chiral auxiliary can be recycled with only small make-up necessary, (6) unlike **1** and **3** the real nature of reagent **4** is known and the configuration of the product alcohols can be predicted, and, most important of all, (7) the enantiomeric excess is consistently very high.

Experimental Section

General Methods. Techniques for handling air-sensitive compounds have been previously described.[28] ^1H, ^{13}C, and ^{11}B NMR spectra were plotted on a Varian Gemini-300 spectrometer and IR spectra were plotted on a Perkin-Elmer 1420 ratio recording spectrophotometer. Mass spectra were recorded with a Finnigan Model 4000 gas chromatograph–mass spectrometer. GC analyses were done on a OV-3 column ($^1/_8$ in. × 6 ft) using a Varian 3400 gas chromatograph having a flame ionization detector and a built-in integrator. Analyses of the MTPA esters were performed on a Hewlett-Packard 5890A gas chromatograph using a Supelcowax glass capillary column (15 m), or a SPB-5 capillary column (30 m), at appropriate temperatures and integrated using a Hewlett-Packard 3390A integrator. Optical rotations were measured using a Rudolph Autopol III polarimeter.

Materials. Ethyl ether (Mallinckrodt) was used as such. DIP-Chloride, Alpine-Borane, 3-butyn-2-one, 4-phenyl-3-butyn-2-one, phenylacetylene, 1-decyne, cyclopentylacetylene, 2,2-dimethyl-4-pentenal, 1-chloro-2-methyl-2-phenylpropane, trimethyl borate, PCC, PDC, ethanolamine, diethanolamine, propionyl chloride, isobutyryl chloride, and trimethylacetyl chloride were all obtained from Aldrich Chemical Co. 2,2-Dimethylbutyric acid was obtained from Aldrich and converted to the acid chloride using a literature procedure.[29] 3-Methyl-3-pentanoic acid was obtained from Narchem Corporation and triethylacetic acid was obtained from Pfaltz and Bauer and they were converted to the corresponding aldehydes by adapting a literature procedure.[22] Preparation of the acetylenic ketones is detailed below. α-Methoxy-α-(trifluoromethyl)phenylacetic acid (MTPA) was obtained from Aldrich Chemical Co. and converted to the acid chloride using Mosher's procedure.[20]

Preparation of the Acetylenic Ketones. Method A. Reaction of Acid Chloride with Acetylene in the Presence of CuI. General Procedure. To 100 mL of toluene were added 0.01 mol of CuI and 10 mL of triethylamine. This mixture was heated until the CuI dissolved (~0.5 h). The required terminal acetylene (100 mmol) was added to this followed by the acid chloride (100 mmol), and the solution was stirred at 80 °C for 6 h. Then, methanol (10 mL) was added and the solvent was removed under reduced pressure. Water was added to the residue and the organics were extracted with EE, dried over $MgSO_4$, and distilled. Unreacted acetylene was collected as a forerun followed by the acetylenic ketone. The yields described in individual cases below are those based on the recovered acetylene.

Method B. Reaction of Alkynyllithium with Aldehyde Followed by Oxidation with PDC. General Procedure. *n*-Butyllithium (51 mmol, 2.01 M in hexane, 25.4 mL) was added to the acetylene (50 mmol) in 40 mL THF at 0 °C. After stirring for 0.5 h at 0 °C, the mixture was cooled to −78 °C and the aldehyde (50 mmol) was added dropwise. After an additional stirring at −78 °C for 1 h, the mixture was warmed to rt and an aqueous workup gave the propargylic alcohol.

A solution of the above propargylic alcohol (25 mmol) in 3 mL of CH_2Cl_2 was added dropwise over a period of 30 min to a well-stirred suspension of PDC (20.86 g, 37 mmol) in 75 mL of CH_2Cl_2 in the presence of 4.4 g of 4-Å molecular sieves. The reaction mixture was stirred for an additional 15 h. It was then diluted with 15 mL of dry EE and filtered through silica gel. The filtrate was concentrated and distilled.

Preparation of individual ketones and their physical characteristics are detailed below.

1-Phenyl-1-pentyn-3-one (5c). Propionyl chloride (100 mmol) was treated with 100 mmol of phenylacetylene as described in method A to provide **5c** in 65% yield: bp 98–100 °C/1.0 mmHg.

4-Methyl-1-phenyl-1-pentyn-3-one (5d). Isobutyryl chloride (100 mmol) was treated with 100 mmol of phenylacetylene as in method A to provide the ketone in 70% yield: bp 93–95 °C/0.4 mmHg (lit.[21] bp 130 °C/3 Torr).

4,4-Dimethyl-1-phenyl-1-pentyn-3-one (5e). Trimethylacetyl chloride (100 mmol) was treated with phenylacetylene as in method A to provide the ketone in 70% yield: bp 75–77 °C/0.4 mmHg (lit.[19] bp 95–96/2 mmHg).

1-Cyclopentyl-4-methyl-1-pentyn-3-one (5f). Cyclopentylacetylene was treated with isobutyryl chloride as described in method A: yield of ketone 70%: bp 59–61 °C/0.4 mmHg; IR ν_{max} cm^{-1} (neat) 2204 (C≡C), 1668 (C=O); ^1H NMR δ ($CDCl_3$) 1.18 (d, J = 6.9 Hz, 6 H, $CH(CH_3)_2$), 1.58–1.68 (m, 2 H, $(CH_2)CH$), 1.7–1.8 (m, 4 H, $H_2C(CH_2)_2CH_2$), 1.92–2.04 (m, 2 H, $HCCH_2$-), 2.62 (quint, J = 6.96 Hz, 1 H, $CHMe_2$), 2.80 (quint, J = 6.93 Hz, 1 H, C≡CCH); ^{13}C NMR δ ($CDCl_3$) 18.08 (C_5), 25.18 (C_3'), 30.11 (C_1'), 33.32 (C_2'), 43.05 (C_4), 79.28 (C_1), 99.41 (C_2), 192.61 (C_3); MS EI m/z 149 $(M - CH_3)^+$, 121 $(M - C_3H_7)^+$ (100), 136 $(M - C_2H_5)^+$; CI m/z 165 MH^+ (100).

1-Cyclopentyl-4,4-dimethyl-1-pentyn-3-one (5g). Cyclopentylacetylene was treated with trimethylacetyl chloride to

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(29) Hoffman, W. F.; Alberts, A. W.; Anderson, P. S.; Chen, J. S.; Smith, R. L.; Willard, A. K. *J. Med. Chem.* **1986**, *29*, 849.

provide **5i** in 76% yield: bp 64–66 °C/0.4 mmHg; IR ν_{max} cm^{-1} (neat) 2203 (C≡C), 1668 (C=O); ^1H NMR δ ($CDCl_3$) 1.19 (s, 9 H, $C(CH_3)_3$), 1.58–1.68 (m, 2 H (CH_2)CH), 1.7–1.8 (m, 4 H, $H_2C(CH_2)_2CH_2$), 1.9–2.05 (m, 2 H, $HCCH_2$-), 2.81 (quint, J = 6.3 Hz, 1 H, C≡CCH); ^{13}C NMR δ ($CDCl_3$) 25.14 (C_3'), 26.02 (C_5), 30.16 (C_1'), 33.32 (C_2'), 44.69 (C_4), 78.33 (C_1), 99.97 (C_2), 194.66 (C_3); MS EI m/z 163 $(M - CH_3)^+$, 121 $(M - C_4H_9)^+$, 150 $(M - C_2H_4)^+$; CI m/z 179 $(MH)^+$ (100).

2-Methyl-4-tridecyn-3-one (5h). This ketone was prepared from 1-decyne and isobutyryl chloride as described in method A: yield 70%; bp 92–94 °C/0.4 mmHg; IR ν_{max} cm^{-1} (neat) 2210 (C≡C), 1671 (C=O); ^1H NMR δ ($CDCl_3$) 0.88 (t, J = 6.96 Hz, 3 H, $CH_3(CH_2)_7$), 1.18 (d, J = 6.96 Hz, 6 H, $(CH_3)_2$), 1.3 (m, 8 H, $(CH_2)_4CH_3$), 1.4 (m, 2 H, -C≡C$(CH_2)_2CH_2$-), 1.59 (m, 2 H, -C≡CCH_2CH_2-), 2.37 (t, J = 6.9 Hz, 2 H, -C≡CCH_2-), 2.64 (quint, J = 6.96 Hz, 1 H, $CHMe_2$); ^{13}C NMR δ ($CDCl_3$) 14.08 (C_{13}), 18.03 (C_1), 19.00, 22.65, 27.80, 28.88, 28.99, 29.12, 29.26, 31.81, 43.03 (C_2), 79.83 (C_5), 95.35 (C_4), 192.50 (C_3); MS EI m/z 165 $(M - C_3H_7)^+$, 55 $(C_4H_7)^+$ (100); CI m/z 209 $(MH)^+$.

2,2-Dimethyl-4-tridecyn-3-one (5i). This ketone was prepared from 1-decyne and trimethylacetyl chloride as described in method A: yield 72%; bp 94–96 °C/0.4 mmHg; IR ν_{max} cm^{-1} (neat) 2211 (C≡C), 1668 (C=O); ^1H NMR δ ($CDCl_3$) 0.85 (t, J = 6.6 Hz, 3 H, CH_3), 1.2 (s, 9 H, $C(CH_3)_3$), 1.3 (m, 8 H $(CH_2)_4CH_3$), 1.42 (m, 2 H, -C≡C$(CH_2)_2CH_2$-), 1.6 (quint, J = 6.93 Hz, 2 H, -C≡CCH_2CH_2-), 2.38 (t, J = 6.93 Hz, 2 H, -C≡CCH_2-); ^{13}C NMR δ ($CDCl_3$) 14.08 (C_{13}), 19.01, 22.65, 26.12, (C_1), 27.83, 28.88, 28.99, 29.13, 31.81, 44.61 (C_2), 78.89 (C_5), 95.75 (C_4), 194.39 (C_3); MS EI m/z 222 (M^+), 207 $(M - CH_3)^+$, 165 $(M - C_4H_9)^+$; CI m/z 223 $(MH)^+$ (100).

3,3-Dimethyl-5-tetradecyn-4-one (5j). 2,2-Dimethylbutyric acid was converted to the acid chloride using a literature procedure.[29] This was treated with 1-decyne as in method A to provide **5j** in 50% yield: bp 99–101 °C/0.4 mmHg; IR ν_{max} cm^{-1} (neat) 2211 (C≡C), 1668 (C=O); ^1H NMR δ ($CDCl_3$) 0.83 (t, J = 7.56 Hz, 3 H, CH_3CH_2CCO), 0.88 (t, J = 5.94 Hz, 3 H, CH_3-$(CH_2)_7$), 1.14 (s, 3 H, CH_3CCO), 1.14 (s, 3 H, CH_3CCO), 1.28 (m, 8 H, $(CH_2)_4CH_3$), 1.38–1.46 (m, 2 H, -C≡C$(CH_2)_2CH_2$-), 1.58 (m, 2 H, -C≡CCH_2CH_2-), 1.64 (quint, J = 7.5 Hz, 2 H, $COCCH_2CH_3$), 2.38 (t, J = 6.0 Hz, 2 H, -C≡CCH_2-); ^{13}C NMR δ ($CDCl_3$) 8.93 (C_1), 14.09 (C_{14}), 19.00, 22.65, 23.42 ($C_3(CH_3)_2$), 27.82, 28.88, 28.99, 29.15, 31.80, 32.40, 48.30 (C_3), 79.16 (C_6), 95.21 (C_5), 194.47 (C_4); MS CI m/z 237 $(MH)^+$, 71 $(C_5H_{11})^+$ (100). Anal. Calcd for $C_{16}H_{28}O$: C, 81.29; H, 11.94. Found: C, 80.99; H, 12.15.

3-Ethyl-3-methyl-5-tetradecyn-4-one (5k). (a) 2-Ethyl-2-methylbutanal. The aldehyde was prepared from the corresponding acid using our procedure reported earlier.[22] In a 250-mL round-bottomed flask provided with a septum inlet, magnetic stirring bar, and a reflux condenser attached to a connecting tube leading to a mercury bubbler was placed 2-ethyl-2-methylbutyric acid (7.81 g, 60 mmol) in EE (75 mL). Borane–methyl sulfide (6.2 mL, 60 mmol) was added dropwise and the evolution of gas ceased when the mixture was refluxed for 3 h. An ^{11}B NMR spectrum of an aliquot showed a singlet at δ 18. Solvents and methyl sulfide were removed under vacuum and the product was dissolved in CH_2Cl_2 and added dropwise to a well-stirred suspension of PCC (14.3 g, 66 mmol) in CH_2Cl_2 taken in a 500-mL round-bottomed flask, equipped as described above. The stirred mixture was heated under reflux for 2.5 h and diluted with EE (150 mL). The supernatant was filtered through silica, concentrated (Widmer column), and distilled to give 3.05 g of 2-ethyl-2-methylbutanal: yield 50%; bp 128–130 °C/736 mmHg (lit.[30] bp 132–33 °C).

(b) 3-Ethyl-3-methyl-5-tetradecyn-4-ol. This was prepared from the above aldehyde and 1-decynyllithium as described in method B in 61% yield: bp 179–83 °C/1.2 mmHg; IR ν_{max} cm^{-1} (neat) 3430 (OH), 2226 (C≡C).

(c) 3-Ethyl-3-methyl-5-tetradecyn-4-one (5k). The alcohol prepared above was oxidized with PDC as described in method B to provide **5k** in 77% yield: bp 116–18 °C/0.2 mmHg; IR ν_{max} cm^{-1} (neat) 2207 (C≡C), 1667 (C=O); ^1H NMR δ ($CDCl_3$) 0.81 (t, J = 7.59 Hz, 6 H, $(CH_3CH_2)_2CCO$), 0.88 (t, J = 7.02 Hz, 3 H, $CH_3(CH_2)_7$), 1.07 (s, 3 H, $CH_3C(Et)_2$), 1.28 (m, 8 H $(CH_2)_4CH_3$), 1.4 (m, 2 H, -C≡C$(CH_2)_2CH_2$-), 1.52 (m, 2 H, $C(Me)(Et)CH_2CH_3$), 1.56 (m, 2 H, -C≡CCH_2CH_2-), 1.74 (hext, J = 6.54 Hz, 2 H, $C(Me)(Et)CH_2CH_3$), 2.37 (t, J = 7.08 Hz, 2 H, -C≡CCH_2-); ^{13}C NMR δ ($CDCl_3$) 8.62 (C_1), 14.08 (C_{14}), 18.86 (C_3-CH_3), 19.00, 22.66, 27.84, 28.88, 28.99, 29.16, 30.48, 31.81, 52.04 (C_3), 79.46 (C_6), 94.57 (C_5), 194.44 (C_4); MS EI m/z 251 $(MH)^+$, 85 $(C_6H_{13})^+$ (100); CI m/z 251 $(MH)^+$ (100).

3,3-Diethyl-5-tetradecyn-4-one (5l). (a) 2,2-Diethylbutanal. This aldehyde was prepared from triethylacetic acid in 45% yield following the procedure described for the synthesis of 2-ethyl-2-methylbutanal (**5k** (**a**)): bp 156–58 °C/742 mmHg.

(b) 3,3-Diethyl-5-tetradecyn-4-ol. This alcohol was prepared in 55% yield from the aldehyde prepared as above and 1-decynyllithium using the procedure described in method B: bp 144–45 °C/0.4 mmHg; IR ν_{max} cm^{-1} (neat) 3450 (OH), 2209 (C≡C).

3,3-Diethyl-5-tetradecyn-4-one (5l). The alcohol prepared as above was oxidized with PDC as described in method B to provide **5l** in 83% yield: bp 128–32 °C/0.35 mmHg; IR ν_{max} cm^{-1} (neat) 2208 (C≡C), 1665 (C=O); ^1H NMR δ ($CDCl_3$) 0.76 (t, J = 7.44 Hz, 9 H, $(CH_3CH_2)_3CCO$), 0.88 (t, J = 7.2 Hz, 3 H, $CH_3(CH_2)_7$), 1.28 (m, 8 H $(CH_2)_4CH_3$), 1.36–1.44 (m, 2 H, -C≡C$(CH_2)_2CH_2$-), 1.60 (m, 2 H, -C≡CCH_2CH_2-), 1.635 (q, J = 7.41 Hz, 6 H, $(CH_2CH_3)_3$), 2.37 (t, J = 7.11 Hz, 2 H, -C≡CCH_2-); ^{13}C NMR δ ($CDCl_3$) 8.04 (C_1), 14.09 (C_{14}), 18.98, 22.66, 25.25, 27.83, 28.87, 28.98, 29.16, 31.80, 55.20 (C_3), 79.60 (C_6), 93.96 (C_5), 194.77 (C_4); MS EI m/z 235 $(M - C_2H_5)^+$, 57 $(C_4H_9)^+$ (100); CI m/z 265 $(MH)^+$ (100). Anal. Calcd for $C_{18}H_{32}O$: C, 81.75; H, 12.19. Found: C, 81.42; H, 12.45.

4,4-Dimethyl-1-pentadecen-6-yn-5-one (5m). (a) 4,4-Dimethyl-1-pentadecen-6-yn-5-ol. 2,2-Dimethyl-4-pentenal (Aldrich) was treated with 1-decynyllithium as described in method B to provide the alcohol in 75% yield: bp 149–50 °C/0.3 mmHg; IR ν_{max} cm^{-1} (neat) 3420 (OH), 2224 (C≡C).

(b) 4,4-Dimethyl-1-pentadecen-6-yn-5-one (5m). The alcohol from above was oxidized to the ketone with PDC in 83% yield: bp 120–22 °C/0.2 mmHg; IR ν_{max} cm^{-1} (neat) 2206 (C≡C), 1668 (C=O); ^1H NMR δ ($CDCl_3$) 0.88 (t, J = 6.9 Hz, 3 H, $CH_3(CH_2)_7$), 1.16 (s, 6 H, $(CH_3)_2CCO$), 1.28 (m, 8 H $(CH_2)_4CH_3$), 1.42 (m, 2 H, -C≡C$(CH_2)_2CH_2$-), 1.59 (m, 2 H, -C≡CCH_2CH_2-), 2.34 (td, J = 7.41 Hz, 2 H, -CH_2CH=CH_2), 2.39 (t, J = 6.96 Hz, 2 H, -C≡CCH_2-), 5.06 (m, 2 H, CH=CH_2), 5.63–5.77 (m, 1 H, CH=CH_2); ^{13}C NMR δ ($CDCl_3$) 14.09 (C_{15}), 19.02, 22.64, 23.66 ($C_4(CH_3)_2$), 27.79, 28.89, 28.98, 29.13, 31.79, 43.69 (C_3), 47.96 (C_4), 79.07 (C_7), 95.88 (C_6), 118.15 (C_1), 133.76 (C_2), 193.66 (C_5); MS EI m/z 248 M^+, 233 $(M - CH_3)^+$, 207 $(M - C_3H_5)^+$, 55 $(C_4H_7)^+$ (100); CI m/z 249 $(MH)^+$ (100).

2-Methyl-2-phenyl-4-tridecyn-3-one (5n). (a) (2-Methyl-2-phenylpropyl)magnesium Chloride. To a dry 1-L round-bottomed flask equipped with septum inlet, reflux condenser, magnetic stirring bar, and mercury bubbler were added 5.19 g of activated magnesium and a crystal of iodine. The apparatus was flushed with dry nitrogen and 1 mL of 1-chloro-2-methyl-2-phenylpropane in 15 mL of EE was added. The reaction was initiated by heating the solution to reflux after which the rest of the chloride (31.2 mL in 153 mL of EE) was slowly added, under reflux conditions. The mixture was brought to rt and standardized. The molarity of the solution was estimated to be 1.19 (yield 97%).

(b) 2-Methyl-2-phenylpropanal. To a 500 mL round-bottomed flask equipped as in part **a** was added 159 mL of a solution of the Grignard reagent prepared as above (1.19 M, 189.2 mmol), and the solution was cooled to −78 °C. Trimethyl borate (7.16 mL, 63.06 mmol) was added slowly during 1 h and the mixture was allowed to warm to rt and maintained at this temperature for 24 h. The reaction was followed by ^{11}B NMR spectrometry. When the reaction was complete (^{11}B, δ 80), the magnesium salts were filtered under nitrogen and washed with pentane and the filtrate was added dropwise to a well-stirred suspension of PCC (38.3 g, 180 mmol) in 150 mL of CH_2Cl_2 taken in a 500-mL round-bottomed flask with the fittings as in part **a**. After the initial vigorous reaction subsided, the mixture was stirred for 12 h at rt, diluted with 200 mL of EE, and filtered through 70 g of silica gel in a sintered glass funnel. The residue in the flask was triturated with ether (3 × 50 mL) and solvents were removed on a rotary evaporator. The resulting liquid on distillation provided 6.05 g (65% yield) of 96% GC pure 2-methyl-2-phenylpropanal

(30) Sarel, S.; Newman, M. S. *J. Am. Chem. Soc.* **1956**, *78*, 5416.

bp 97–100 °C/13 mmHg (lit.[31] bp 150 °C/10 mmHg).

(c) 2-Methyl-2-phenyl-4-tridecyn-3-ol. The aldehyde from above was treated with 1-decynyllithium to obtain 2-methyl-2-phenyl-4-tridecyn-3-ol in 90% yield: bp 174–78 °C/0.4 mmHg; IR ν_{max} cm^{-1} (neat) 3430 (OH), 2225 (C≡C).

(d) 2-Methyl-2-phenyl-4-tridecyn-3-one (5n). Oxidation of the alcohol to the ketone was done according to procedure B. The ketone was obtained in 85% yield as a brownish yellow oil: bp 155–59 °C/0.35 mmHg; IR ν_{max} cm^{-1} (neat) 2210 (C≡C), 1668 (C=O); ^{1}H NMR δ ($CDCl_3$) 0.89 (t, J = 6.6 Hz, 3 H, $CH_3(CH_2)_7$), 1.1–1.3 (m, 1 H, O*H*), 1.28 (m, 8 H, $(CH_2)_4CH_3$), 1.38 (m, 2 H, $-C{\equiv}C(CH_2)_2CH_2-$), 1.56 (s, 6 H, $(CH_3)_2$), (m, 2 H, $-C{\equiv}CCH_2CH_2-$), 2.2 (t, J = 6.38 Hz, 2 H, $-C{\equiv}CCH_2-$), 7.2–7.4 (m, 5 H, Ph); ^{13}C NMR δ ($CDCl_3$) 14.10 (C_{13}), 18.91, 22.65, 25.02 (C_1), 27.58, 28.61, 29.08, 31.81, 52.49 (C_2), 79.41 (C_5), 96.89 (C_4), 126.46, 126.89, 128.44, 143.28 (C_1'), 191.12 (C_3); MS EI m/z 186 ($M - C_7H_{14}$)$^+$, 119 ($PhC(CH_3)_2$)$^+$ (100); CI m/z 285 $(MH)^+$ (100).

Reduction of Acetylenic Ketones with (-)-DIP-Chloride. General Procedure. (a) At -25 °C. An oven-dried, 50-mL round-bottom flask equipped with a side arm, magnetic stirring bar, and a connecting tube was cooled to rt in a stream of nitrogen. (-)-DIP-Chloride (3.52 g, 11 mmol) was transferred to the flask in a glove bag and dissolved in EE (10 mL). The solution was cooled to -25 °C, and the ketone (10 mmol) was added. The reaction was followed by ^{11}B NMR spectrometry after aliquots were methanolyzed at -25 °C at periodic intervals. When the reaction was complete (^{11}B, δ 32), the mixture was warmed to 0 °C and acetaldehyde (0.73 mL, 13 mmol) was added dropwise (exothermic reaction!). The mixture was warmed to rt and stirred for 3 h when the ^{11}B NMR spectrum showed a singlet at δ 18. Sodium hydroxide (6 N, 10 mL) was added to the mixture and the organics were extracted with EE. The combined extracts were washed with brine, dried over $MgSO_4$, and distilled to separate the α-pinene and the product alcohol. The alcohol was further purified by preparative GC with appropriate columns (SE-30 or Carbowax 20M). The rotation was measured. The MTPA ester of the alcohol was prepared by the standard procedure.[20] Racemic alcohols of the ketones made by method A were obtained by reduction with $NaBH_4$. All the racemic alcohols were converted to the MTPA esters and analyzed on a capillary GC to obtain the diastereomeric pairs of peaks. Then the optically active esters were analyzed to obtain the enantiomeric excess.

(b) At rt. For a reaction at rt, with the same set up as above, the ketone was added to the solid reagent and stirred. The solid dissolved within 20–30 min. The reaction was monitored by ^{11}B NMR spectrometry. At periodic intervals, an aliquot of the thick reaction mixture was transferred into an NMR tube, diluted with EE, and methanolyzed for plotting the NMR spectra. After completion of the reaction (^{11}B, δ 32), EE was added to the mixture followed by acetaldehyde at 0 °C. The rest of the workup is as described for the reaction at -25 °C.

3-Butyn-2-ol (6a). 3-Butyn-2-one (25 mmol) was treated with (-)-**4** (27 mmol) in EE at -25 °C. The reaction was complete within 2 h. Workup as described above provided the alcohol in 83% yield: bp 63–67 °C/150 mmHg. Analysis of its MTPA ester on a Supelcowax capillary column showed it to be of 17% ee in the (*R*)-isomer.

A diethanolamine workup[17] provided the alcohol in 70% yield and in 17% ee.

4-Phenyl-3-butyn-2-ol (6b). Earlier we had reported the reduction of the ketone **5b** in THF at -25 °C and had obtained 21% ee for this reduction.[17] The reaction was repeated in EE at -25 °C using the modified workup procedure to obtain the alcohol boiling at 104–106 °C/0.35 mmHg in 92% yield and 21% ee.

1-Phenyl-1-pentyn-3-ol (6c). 1-Phenyl-1-pentyn-3-one (10 mmol) was treated with (-)-**4** (11 mmol) in EE at -25 °C. The reaction was complete in 2 h. Workup as described above provided **6c** in 90% yield: bp 112–16 °C/1 mmHg. Analysis as the MTPA ester on a SPB-5 capillary column showed an ee of 28%.

4-Methyl-1-phenyl-1-pentyn-3-ol (6d). **5d** (10 mmol) was treated with 11 mmol of (-)-**4** in EE at -25 °C. The reaction was complete in 2 h. Workup as usual provided **6d** in 85% yield: bp 110–12 °C/0.35 mmHg; $[\alpha]_D^{22.8}$ = 0.57° (*c* = 6.4, $CHCl_3$). Analysis of its MTPA ester on a SPB-5 capillary column showed it to be of 53% ee: IR ν_{max} cm^{-1} (neat) 3374 (OH), 2220 (C≡C); ^{1}H NMR δ ($CDCl_3$) 1.058 (d, J = 6.81 Hz, 3 H, CH_3), 1.08 (d, J = 7.41 Hz, 3 H, CH_3), 1.97–2.01 (m, 2 H, O*H*, and C*H*Me_2), 4.4 (d, J = 5.58 Hz, 1 H, C*H*OH), 7.3 (m, 3 H, Ph), 7.4 (m, 2 H, Ph); ^{13}C NMR δ ($CDCl_3$) 17.57 (C_5), 18.18 (C_5), 34.74 (C_4), 68.43 (C_3), 85.62 (C_1), 88.92 (C_2), 122.77 (C_1'), 128.28, 128.34, 131.71; MS EI m/z 174 M^+, 131 ($M - C_3H_7$)$^+$; CI m/z 175 $(MH)^+$, 157 $(MH - H_2O)^+$.

4,4-Dimethyl-1-phenyl-1-pentyn-3-ol (6e). (a) At -25 °C. **5e** (10 mmol) was treated with 11 mmol of (-)-**4** in EE at -25 °C. The reaction was very slow and required 6 d for completion. Workup as usual provided **6e** in 75% yield: bp 121–22 °C/0.35 mmHg. Analysis as the MTPA ester on a SPB-5 capillary column showed only a single peak on the chromatogram corresponding to only one isomer present, i.e., ≥99% ee.

A diethanolamine workup provided the alcohol in 70% yield.

(b) At rt. The above reaction was repeated without solvent at rt. The reaction was complete in 8 h. The product alcohol was isolated in 79% yield: bp 122 °C/0.35 mmHg; $[\alpha]_D^{23.9}$ = 2.14° (*c* = 5.0, $CHCl_3$). Analysis of the MTPA ester showed an ee of 98%: IR ν_{max} cm^{-1} (neat) 3358 (OH), 2200 (C≡C); ^{1}H NMR δ ($CDCl_3$) 1.05 (s, 9 H, $(CH_3)_3$), 2.3 (br s, 1 H, O*H*), 4.25 (s, 1 H, C*H*OH), 7.2 (m, 3 H, Ph), 7.4 (m, 2 H, Ph); ^{13}C NMR δ ($CDCl_3$) 25.40 (C_5), 36.11 (C_4), 71.78 (C_3), 85.65 (C_1), 89.06 (C_2), 122.83 (C_1'), 128.26, 131.67; MS EI m/z 188 M^+, 173 ($M - CH_3$)$^+$, 131 ($M - CMe_3$)$^+$ (100); EI m/z 188 M^+, 171 ($MH - H_2O$)$^+$ (100).

1-Cyclopentyl-4-methyl-1-pentyn-3-ol (6f). 1-Cyclopentyl-4-methyl-1-pentyn-3-one (10 mmol) was reduced with (-)-**4** in EE at -25 °C. The reaction was complete in 2 h. Workup as usual provided the corresponding propargylic alcohol **6f** in 81% yield: bp 64–66 °C/0.4 mmHg; $[\alpha]_D^{23.4}$ = 0.94° (*c* = 3.39, $CHCl_3$). Analysis as the MTPA ester showed it to be of 39% ee: IR ν_{max} cm^{-1} (neat) 3361 (OH), 2228 (C≡C); ^{1}H NMR δ ($CDCl_3$) 0.96 (d, J = 5.49 Hz, 3 H, $CHCH_3$), 0.98 (d, J = 5.46 Hz, 3 H, $CHCH_3$), 1.5–2.00 (m, 10 H, $CH(CH_3)_2$, C_4H_8 and OH), 2.64 (d quint, J = 7.5, 1.8 Hz, 1 H, C*H*C≡CCH(OH)), 4.15 (d, J = 4.47 Hz, C*H*OH); ^{13}C NMR δ ($CDCl_3$) 17.44 (C_5), 18.18 (C_5), 24.93, 30.16 (C_1'), 33.92, 34.74 (C_4), 68.13 (C_3), 79.38 (C_1), 90.46 (C_2).

1-Cyclopentyl-4,4-dimethyl-1-pentyn-3-ol (6g). The ketone **5g** (10 mmol) was added to the reagent (11 mmol) at rt. The solid reagent went into solution within 15 min. The reaction was complete in 20 h. Workup as usual provided the alcohol **6g** in 76% yield: mp 57–58 °C; $[\alpha]_D^{25}$ 5.71° (*c* = 1.33, $CHCl_3$). Analysis of the MTPA ester showed an ee of 97%: IR ν_{max} cm^{-1} (neat) 3420 (OH), 2230 (C≡C); ^{1}H NMR δ ($CDCl_3$) 0.87 (s, 9 H, $(CH_3)_3$), 1.5–1.95 (m, 8 H, $-(CH_2)_4-$), 2.64 (d quint, J = 7.23 Hz, 1.86 Hz, 1 H, $-C{\equiv}CCHCH_2$), 3.98 (dd, J = 5.79, 1.86 Hz, 1 H, C*H*OH); ^{13}C NMR δ ($CDCl_3$) 24.90, 25.30 (C_5), 30.17 (C_1'), 33.89, 35.91 (C_4), 71.64 (C_3), 79.35 (C_1), 90.55 (C_2); MS EI m/z 180 M^+, 163 ($M - OH$)$^+$, 57 $C_4H_9^+$; CI m/z 181 $(MH)^+$, 163 $(MH - H_2O)^+$.

2-Methyl-4-tridecyn-3-ol (6h). Ketone **5h** (10 mmol) was treated with 11 mmol of the reagent (-)-**4** in EE at -25 °C. The reaction was complete in 2 h. Workup provided the alcohol **6h** in 86% yield: bp 100–102 °C/0.4 mmHg; $[\alpha]_D^{23.4}$ -0.98° (*c* = 3.25, $CHCl_3$). Analysis of the MTPA ester showed an ee of 26%: IR ν_{max} cm^{-1} (neat) 3393 (OH), 2213 (C≡C); ^{1}H NMR δ ($CDCl_3$) 0.88 (t, J = 6.4 Hz, 3 H, $CH_3(CH_2)_7$), 0.977 (d, J = 6.54 Hz, 3 H, CH_3), 0.997 (d, J = 5.85 Hz, 3 H, CH_3), 1.27 (m, 8 H $(CH_2)_4CH_3$), 1.37 (m, 2 H, $-C{\equiv}C(CH_2)_2CH_2-$), 1.51 (m, 2 H, $-C{\equiv}CCH_2CH_2-$), 1.64 (s, O*H*), 1.74 (s, O*H*) 1.84 (m, J = 5.88 Hz, 1 H, $CH(CH_3)_2$), 2.21 (dt, J = 7.05, 2.01 Hz, 2 H, $-C{\equiv}CCH_2-$), 4.15 (br t, 1 H, C*H*OH); ^{13}C NMR δ ($CDCl_3$) 14.09 (C_{13}), 17.44 (C_1), 18.13 (C_1), 18.69, 22.67, 28.75, 28.85, 29.09, 29.20, 31.85, 34.72 (C_2), 68.19 (C_3), 79.86 (C_5), 86.29 (C_4); MS EI m/z 193 ($M - OH$)$^+$, 55 $(C_4H_7)^+$ (100); CI m/z 211 $(MH)^+$, 193 $(MH - H_2O)^+$.

2,2-Dimethyl-4-tridecyn-3-ol (6i). At -25 °C. **5i** (10 mmol) was treated with 11 mmol of the reagent (-)-**4** in EE at -25 °C. The reaction was very slow and required 10 d for completion. Workup as usual provided the alcohol **6i** in 76% yield: bp 106–108 °C/0.4 mmHg. Analysis as the MTPA ester showed an ee of ≥99%.

At rt. The above reaction, without solvent, at rt was complete in 20 h. The alcohol was obtained in 77% yield and in 98% ee: $[\alpha]_D^{23}$ 4.41° (*c* = 1.61, $CHCl_3$); IR ν_{max} cm^{-1} (neat) 3401 (OH), 2225

(31) Tamaru, Y.; Yamada, Y.; Inoue, K.; Yamamoto, Y.; Yoshida, A. *J. Org. Chem.* **1983**, *48*, 1286.

(C≡C); ^{1}H NMR δ ($CDCl_3$) 0.88 (t, J = 7.08 Hz, 3 H, $CH_3(CH_2)_7$), 0.98 (s, 9 H, $(CH_3)_3$), 1.27 (m, 8 H $(CH_2)_4CH_3$), 1.37 (m, 2 H, $-C{\equiv}C(CH_2)_2CH_2-$), 1.51 (quint, J = 7.14 Hz, 2 H, $-C{\equiv}CCH_2CH_2-$), 2.05 (br s, 1 H, OH), 2.21 (dt, J = 7.11, 1.92 Hz, 2 H, $-C{\equiv}CCH_2-$), 4.0 (t, J = 1.92 Hz, 1 H, CHOH); ^{13}C NMR δ ($CDCl_3$) 14.10 (C_{13}), 18.70, 22.68, 25.31 (C_1), 28.78, 28.88, 29.09, 29.22, 31.86, 35.85 (C_2), 71.62 (C_3), 79.92 (C_5), 86.25 (C_4); MS EI m/z 222 $(M)^+$, 207 $(M - CH_3)^+$ (100), 165 $(M - C_4H_9)^+$, 57 $(C_4H_9)^+$; CI m/z 223 $(MH)^+$.

3,3-Dimethyl-5-tetradecyn-4-ol (6j). **5j** (5 mmol) was treated with 5.5 mmol of the reagent (−)-**4** at rt. The reaction was complete in 48 h. Workup provided the alcohol **6j** in 72% yield: bp 110–12 °C/0.4 mmHg; $[\alpha]^{23.8}_D$ 2.36° (c = 3.6, $CHCl_3$). Analysis of the MTPA ester showed an ee of ≥99%: IR ν_{max} cm^{-1} (neat) 3422 (OH), 2227 (C≡C); ^{1}H NMR δ ($CDCl_3$) 0.86 (t, J = 7.53 Hz, 3 H, $CH_3CH_2CMe_2$), 0.88 (t, J = 7.65 Hz, 3 H, $CH_3(CH_2)_7$), 0.91 (s, 3 H, $EtCCH_3$), 0.93 (s, 3 H, $EtCCH_3$), 1.28 (m, 8 H, $(CH_2)_4CH_3$), 1.32–1.42 (m, 4 H, $(CH_2)_2$), 1.49 (q, J = 7.7 Hz, 2 H, $CH_3CH_2CMe_2$), 1.66 (s, 1 H, OH), 2.21 (dt, J = 6.87, 2.07 Hz, 2 H, $-C{\equiv}CCH_2-$), 4.08 (br s, 1 H, CHOH); ^{13}C NMR δ ($CDCl_3$) 8.20 (C_1), 14.10 (C_{14}), 18.72, 21.86 (C_3-CH_3), 22.02 (C_3-CH_3), 22.67, 28.75, 28.87, 29.07, 29.22, 30.59, 31.84, 38.39 (C_3), 70.54 (C_4), 79.81 (C_6), 86.50 (C_5).

Repetition of the above reaction and diethanolamine workup provided the alcohol in 65% yield and ≥99% ee.

3-Ethyl-3-methyl-5-tetradecyn-4-ol (6k). **5k** (5 mmol) was treated with 5.5 mmol of the reagent (−)-**4** at rt. The reaction was complete in 7 d. Workup provided the alcohol **6k** in 70% yield: bp 179–83 °C/1.2 mmHg; $[\alpha]^{24.3}_D$ 2.46° (c = 7.54, $CHCl_3$); IR ν_{max} cm^{-1} (neat) 3431 (OH), 2226 (C≡C); ^{1}H NMR δ ($CDCl_3$) 0.824 (t, J = 7.47 Hz, 6 H, $(CH_3CH_2)_2$), 0.875 (s, CH_3CEt_2), 0.88 (t, J = 6.6 Hz, 3 H, $CH_3(CH_2)_7$), 1.28 (m, 8 H, $(CH_2)_4CH_3$), 1.4 (m, 4 H, $-C{\equiv}CCH_2(CH_2)_2-$), 1.5 (q, J = 7.14 Hz, 4 H, $(CH_2CH_3)_2$), 1.75 (br s, 1 H, OH), 2.21 (dt, J = 6.87, 1.98 Hz, 2 H, $-C{\equiv}CCH_2-$), 4.18 (t, J = 1.89 Hz, 1 H, CHOH); ^{13}C NMR δ ($CDCl_3$) 7.86 (C_1), 7.91 (C_1), 14.11 (C_{14}), 18.75, 19.38 (C_3–CH_3), 22.70, 26.93 (C_2), 27.26 (C_2), 28.77, 28.89, 29.10, 29.25, 31.86, 40.50 (C_3), 68.86 (C_4), 79.86 (C_6), 86.62 (C_5); MS EI m/z 237 $(M - CH_3)^+$, 223 $(M - C_2H_5)^+$; CI m/z 253 MH^+, 235 $(MH - H_2O)^+$ (100). Anal. Calcd for $C_{17}H_{32}O$: C, 80.89; H, 12.78. Found: C, 80.75; H, 13.1.

3,3-Diethyl-5-tetradecyn-4-ol (6l). **5l** (5 mmol) was treated with 5.5 mmol of the reagent (−)-**4** at rt. The reaction was complete in 14 d. Workup provided the alcohol **6l** in 69% yield: bp 144–45 °C/0.4 mmHg; $[\alpha]^{23}_D$ 2.94° (c = 3.19, $CHCl_3$); IR ν_{max} cm^{-1} (neat) 3453 (OH), 2209 (C≡C); ^{1}H NMR δ ($CDCl_3$) 0.87 (t, J = 7.65 Hz, 9 H, $(CH_3CH_2)_3$), 0.88 (t, J = 6.78 Hz, 3 H, $CH_3(CH_2)_7$), 1.28 (m, 8 H, $(CH_2)_4CH_3$), 1.4–1.6 (m, 11 H, $CH_3CH_2)_3$, $-(CH_2)_2-$, and OH), 2.21 (dt, J = 6.93, 2.01 Hz, 2 H, $-C{\equiv}CCH_2-$), 4.25 (br t, 1 H, CHOH); ^{13}C NMR δ ($CDCl_3$) 8.04 (C_1), 8.27 (C_1), 8.41 (C_1), 14.10 (C_{14}), 18.80, 22.68, 25.26 (C_2), 25.94 (C_2), 28.69, 28.89, 28.98, 29.08, 29.16, 31.85, 42.29 (C_3), 68.63 (C_4), 80.25 (C_6), 86.98 (C_5); MS EI m/z 266 $(M)^+$, 249 $(M - OH)^+$, 237 $(M - C_2H_5)^+$, 57 $C_4H_9^+$ (100); CI m/z 265 $(MH - H_2)^+$, 249 $(MH - H_2O)^+$ (100).

4,4-Dimethyl-1-pentadecen-6-yn-5-ol (6m). **5m** (5 mmol) was treated with 5.5 mmol of the reagent (−)-**4** at rt. The reaction was complete in 48 h. Workup provided the alcohol **6m** in 71% yield: bp 149–50 °C/0.3 mmHg; $[\alpha]^{23.8}_D$ −8.16° (c 7.14, $CHCl_3$). Analysis of the MTPA ester on a SPB-5 capillary GC showed 96% ee: IR ν_{max} cm^{-1} (neat) 3420 (OH), 2225 (C≡C); ^{1}H NMR δ ($CDCl_3$) 0.88 (t, J = 6.57 Hz, 3 H, $CH_3(CH_2)_7$), 0.95 (s, CH_3C(CHOH)CH_2), 0.96 (s, CH_3C(CHOH)CH_2), 1.28–1.6 (m, 12 H, $(CH_2)_6$), 1.8 (1 H, OH), 2.13 (m), 2.22 (dt, J = 6.87, 1.98 Hz, 2 H, $-C{\equiv}CCH_2-$), 4.05 (br t, 1 H, CHOH), 5.02–5.1 (m, 2 H, $CH{=}CH_2$), 5.78–5.92 (m, 1 H, $CH{=}CH_2$); ^{13}C NMR δ ($CDCl_3$) 14.10 (C_{15}), 18.71, 22.53, 22.66, 28.74, 28.88, 29.08, 29.22, 31.85, 38.73, 42.84, 70.49 (C_5), 79.57 (C_7), 86.77 (C_6), 117.45 (C_1), 135.17 (C_2); MS EI m/z 250 $(M)^+$, 233 $(M - OH)^+$, 207 $(M - C_3H_7)^+$, 55 $C_4H_7^+$ (100); CI m/z 249 $(MH - H_2)^+$, 233 $(MH - H_2O)^+$ (100). Anal. Calcd for $C_{17}H_{30}O$: C, 81.54; H, 12.07. Found: C, 81.74; H, 12.36.

2-Methyl-2-phenyl-4-tridecyn-3-ol (6n). **5n** (5 mmol) was treated with 5.5 mmol of the reagent (−)-**4** at rt. The reaction was complete in 24 h. Workup provided the alcohol **6n** in 70% yield: bp 175–78 °C/0.4 mmHg; $[\alpha]^{25}_D$ 23.16° (c 4.13, $CHCl_3$).

The above reaction was repeated with (+)-**4**. The alcohol was obtained in 71% yield and in 97% ee: IR ν_{max} cm^{-1} (neat) 3431 (OH), 2226 (C≡C); ^{1}H NMR δ ($CDCl_3$) 0.88 (t, J = 6.12 Hz, 3 H, $CH_3(CH_2)_7$), 1.28 (m, 10 H, $(CH_2)_5$), 1.41 (s, 3 H, CH_3CPh), 1.45 (s, 3 H, CH_3CPh), 1.61 (s, 2 H, $-C{\equiv}CCH_2CH_2$), 2.18 (m, 3 H, $-C{\equiv}CCH_2CH_2$ and OH), 4.02 (s, 1 H, CHOH), 7.25 (m, 1 H, Ph), 7.35 (m, 2 H, Ph), 7.45 (m, 2 H, Ph); ^{13}C NMR δ ($CDCl_3$) 13.71 (C_{13}), 18.71, 22.68, 23.11, 25.37, 28.62, 28.86, 29.10, 29.21, 31.86, 43.14, 71.50 (C_3), 79.13 (C_4), 87.05 (C_5), 126.39, 126.88, 128.10, 145.32; MS EI m/z 286 M^+, 119 $(PhC(CH_3)_2)^+$ (100); CI m/z 287 $(MH - H_2)^+$, 269 $(MH - H_2O)^+$ (100).

Reduction of Ketones with Alpine-Borane. The reduction of 4-methyl-1-phenyl-1-pentyn-3-one is representative. To a 50-mL round-bottomed flask fitted as usual[21] was added 14 mmol of the reagent, followed by 4-methyl-1-phenyl-1-pentyn-3-one (10 mmol), and the mixture was stirred at rt. The reaction was followed by ^{11}B NMR spectrometry of an aliquot dissolved in EE. When the reaction was complete (16 h, ^{11}B, δ 52), acetaldehyde (0.28 mL, 5 mmol) was added at 0 °C, and the solution was stirred for 30 min. The α-pinene liberated during the reaction was collected using a high vacuum pump (0.01 mmHg, 6 h). EE (20 mL) was then added to the reaction mixture followed by ethanolamine (0.84 mL) and stirring continued for 1 h during which time the boron components precipitated. This was then filtrated and washed with pentane. The filtrate was concentrated and distilled at high vacuum to obtain 4-methyl-1-phenyl-1-pentyn-3-ol, bp 110–12 °C/0.35 mmHg; yield 1.17 g (80%). The MTPA ester of the alcohol was prepared and analyzed on an SPB-5 (30 m) capillary GC column which indicated 92% ee, corrected to 100% ee.

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Registry No. **2a**, 64106-79-2; **4**, 85116-37-6; **5a**, 1423-60-5; **5b**, 1817-57-8; **5c**, 19307-74-5; **5d**, 5923-10-4; **5e**, 32398-67-7; **5f**, 139313-47-6; **5g**, 139313-48-7; **5h**, 139313-49-8; **5i**, 139313-50-1; **5j**, 139313-51-2; **5k**, 139313-52-3; **5l**, 139313-53-4; **5m**, 139313-54-5; **5n**, 139313-55-6; **6a**, 42969-65-3; **6b**, 73922-81-3; **6c**, 104662-02-4; **6d**, 139313-56-7; **6e**, 132350-97-1; **6f**, 139313-57-8; **6g**, 139313-58-9; **6h**, 139313-59-0; **6i**, 139313-60-3; **6j**, 139313-61-4; **6k**, 139313-62-5; **6l**, 139313-63-6; **6m**, 139313-64-7; **6n**, 139313-65-8; propionyl chloride, 79-03-8; phenylacetylene, 536-74-3; isobutyryl chloride, 79-30-1; cyclopentylacetylene, 930-51-8; trimethylacetyl chloride, 3282-30-2; 1-decyne, 764-93-2; 2,2-dimethylbutyric acid, 595-37-9; 2-ethyl-2-methylbutyric acid, 19889-37-3; 2-ethyl-2-methylbutanal, 26254-88-6; 3-ethyl-3-methyl-5-tetradecyn-4-ol, 139404-55-0; triethylacetic acid, 813-58-1; 2,2-diethylbutanal, 26254-89-7; 3,3-diethyl-5-tetradecyn-4-ol, 139404-56-1; 2,2-dimethyl-4-pentenal, 5497-67-6; 4,4-dimethyl-1-pentadecen-6-yn-5-ol, 139404-57-2; 1-chloro-2-methyl-2-phenylpropane, 515-40-2; 2-methyl-2-phenylpropanol, 3805-10-5; 2-methyl-2-phenyl-4-tridecyn-3-ol, 139404-58-3.

Supplementary Material Available: ^{1}H and ^{13}C NMR spectra of the ketones **5f–n** and the alcohols **6d–n** (40 pages). This material is contained in many libraries on microfiche, immediately follows this article in the microfilm version of the journal, and can be ordered from the ACS; see any current masthead page for ordering information.