Synthesis and Stereochemistry of Allenes. 2. Absolute Configurations of 1-Halogeno-3,4,4-trimethylpenta-1,2-dienes and 3,4,4-Trimethylpent-1-yn-3-ol

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The absolute configuration of (+)-*t*-Bu(Me)C(OH)C≡CH ((+)-**2a**) has been reassigned *S*.* This is shown by chemical correlation to its constitutional isomer (*S*)-*t*-Bu(H)C(OH)C≡CMe, applying organocopper(I) reactions of known anti stereochemistry. Reaction of $LiCuX_2$ with esters of (+)-**2a** gives (−)-*t*-Bu(Me)C=C=C(H)X (X = Cl, **1a**; X = Br, **1b**). The *R* configuration is attributed to these levorotatory halogenoallenes, on the basis of the known anti stereochemistry of the 1,3-substitution and the *S* configuration of (+)-**2a**. These new assignments lift a considerable confusion in the literature concerning absolute configurations of **1a** and **2a**. Implications regarding (semi)empirical rules, relating the sign of the optical rotation of a chiral allene to its configuration, are discussed.

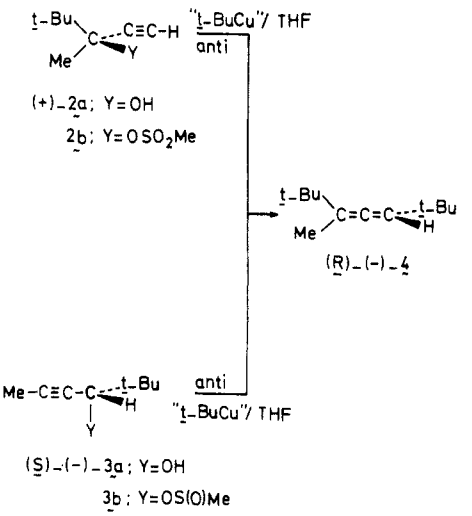
Introduction

Halogenoallenes are interesting compounds from a synthetic point of view, they have, for instance, been used to prepare leukotrienes and naturally occurring allenediynes.[2] Chiral halogenoallenes may be used to obtain chiral alkyl- or aryl-substituted allenes and acetylenes via highly stereoselective transition-metal-mediated reactions.[3] Optically active halogenoallenes have also received attention from a theoretical point of view, e.g., (vacuum) circular dichroism studies[4] and calculations of their optical rotations.[5] Furthermore, synthesis and absolute configurations of optically active halogenoallenes are currently of interest to the biochemical community, since compounds that posses a chiral bromoallene functionality occur in certain marine algea.[6]

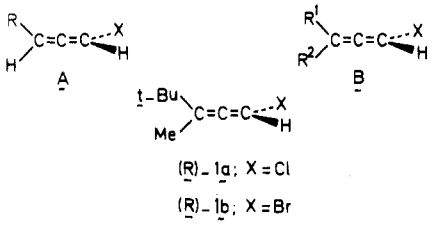
Recently, we have reported the synthesis and absolute configurations of several enantiomerically enriched halogenoallenes.[4,7-9] Knowledge about absolute configurations of halogenoallenes is necessary, in order to establish the stereochemical pathway of their subsequent substitution reactions using, e.g., nickel(0)[10] or palladium(0) complexes[11] or organocopper(I) reagents.[12]

The absolute configurations of many halogenoallenes

Scheme I



(types A and B, respectively; X = Cl, Br, I) in relation to the sign of their optical rotation are known. However,



concerning the configurations of 1-halogeno-3,4,4-trimethylpenta-1,2-dienes **1**, considerable confusion can be noted in the literature.[3,5,8,13,14] The *S* configuration has been assigned to (−)-**1a** on the basis of chemical correlation to the propynylic alcohol (+)-**2a**,[14a] the configuration of which was in turn based on Prelog's rule.[15] The absolute configuration of (−)-**1b** has been assigned *R*.[14b] Thus a heterochiral[16] relationship between (−)-**1a** and (−)-**1b** is hitherto presumed, in contrast with the homochirality that

(1) (a) Department of Inorganic Chemistry. For Part 1, see ref 9. (b) Department of Organic Chemistry.

(2) (a) Landor, S. R., Ed. *The Chemistry of the Allenes*; Academic: London, 1982; Vol. 1, Chapters 1-4. (b) Schuster, H. F.; Coppola, G. M. *Allenes in Organic Synthesis*, Wiley: New York, 1984. (c) Corey, E. J.; Kang, J. *J. Am. Chem. Soc.* **1981**, *103*, 4618. (d) Landor, P. D.; Landor, S. R.; Leighton, P. *J. Chem. Soc., Perkin Trans. 1* **1975**, 1628.

(3) (a) Corey, E. J.; Boaz, N. W. *Tetrahedron Lett.* **1984**, *25*, 3059. (b) Elsevier, C. J.; Mooiweer, H. H.; Kleijn, H.; Vermeer, P. *Tetrahedron Lett.* **1984**, *25*, 5571.

(4) Elsevier, C. J.; Vermeer, P.; Gedanken, A.; Runge, W. *J. Am. Chem. Soc.* **1985**, *107*, 2537.

(5) (a) Ruch, E.; Runge, W.; Kresze, G. *Angew. Chem.* **1973**, *85*, 10. (b) Runge, W.; Kresze, G. *J. Am. Chem. Soc.* **1977**, *99*, 5597. (c) Runge, W. In *The Chemistry of Ketenes, Allenes and Related Compounds*; Patai, S., Ed.; Wiley: Chichester, 1980; Part 1, Chapter 3.

(6) (a) Feldman, K. S.; Crawford Mechem, C.; Nader, L. *J. Am. Chem. Soc.* **1982**, *104*, 4011. (b) Suzuki, T.; Koizumi, K.; Suzuki, M.; Kurosawa, E. *Chem. Lett.* **1983**, 1639. (c) Suzuki, M.; Kurosawa, E.; Furasaki, A.; Katsuragi, S.; Matsumoto, T. *Chem. Lett.* **1984**, 1033. (d) Kennedy, D. J.; Selby, I. A.; Cowe, H. J.; Cox, P. J.; Thomson, R. H. *J. Chem. Soc., Chem. Commun.* **1984**, 153 and references cited.

(7) Elsevier, C. J.; Meijer, J.; Tadema, G.; Stehouwer, P. M.; Bos, H. J. T.; Vermeer, P.; Runge, W. *J. Org. Chem.* **1982**, *42*, 2194.

(8) Elsevier, C. J.; Bos, H. J. T.; Vermeer, P.; Spek, A. L.; Kroon, J. *J. Org. Chem.* **1984**, *49*, 379.

(9) Elsevier, C. J.; Vermeer, P.; Gedanken, A.; Runge, W. *J. Org. Chem.* **1985**, *50*, 364.

(10) Caporusso, A. M.; Da Settimo, F.; Lardicci, L. *Tetrahedron Lett.* **1985**, *26*, 5105.

(11) Elsevier, C. J.; Vermeer, P. *J. Org. Chem.* **1985**, *50*, 3042.

(12) Kalli, M.; Landor, P. D.; Landor, S. R. *J. Chem. Soc., Perkin Trans. 1* **1973**, 1347. See also ref 3.

(13) Caporusso, A. M.; Zoppi, A.; Da Settimo, F.; Lardicci, L. *Gazz. Chim. Ital.* **1985**, *115*, 293.

(14) (a) Landor, S. R.; Evans, J. *J. Chem. Soc.* **1965**, 2553. (b) Landor, S. R.; Demetriou, B.; Evans, R. J. D.; Greskowiac, R.; Davey, P. *J. Chem. Soc., Perkin Trans. 2* **1972**, 1995.

(15) (a) Prelog, V. *Helv. Chim. Acta* **1953**, *36*, 308. (b) Prelog, V. *Bull. Soc. Chim. Fr.* **1956**, 987.

(16) Ruch, E. *Angew. Chem.* **1977**, *89*, 67. Two chiral species are homochiral when they exhibit similar geometric or physical features, e.g., for the same absolute stereochemistry the same sign of optical rotation; otherwise they are heterochiral.

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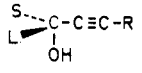
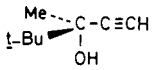
is normally observed for halogenoallenes of types A and B.[4,7-9] Recently, a publication appeared in which both (−)-**1a** and (−)-**1b** were assigned the *S* configuration.[13] Semiempirical theories of optical rotations of chiral allenes[9,17] predict *R* configurations for both levorotatory **1a** and **1b**, however. In view of our interest in the stereochemical course of palladium mediated conversion of type B halogenoallenes (cf. ref 11, 18) an unambigous assignment of absolute configuration to (−)-**1a** and (−)-**1b** was deemed necessary. As the configurational assignments for **1a** and **1b** depend heavily on that for **2a**,[14] we shall first ascertain the correct absolute configuration of (+)-**2a**.

Results

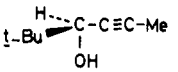
The configuration of (+)-**2a** has been correlated to that of (−)-**3a** in the following way (see Scheme I). The methanesulfinate **3b** of the secondary ethynyl alcohol (−)-**3a** (59% ee) was regio- and stereoselectively converted into trialkylallene (−)-**4** ($[\alpha]^{20}_D$ −21.3° (CH_2Cl_2)) by means of a *tert*-butyl heterocuprate. It has been well established,[19] that comparable organocopper(I)-induced 1,3-substitutions of propynylic esters take place with high levels of anti stereoselectivity. As the absolute configuration of (−)-**3a** is definitely *S*,[20] the anti stereochemistry of the reaction imposes the *R* configuration upon (−)-**4**.[21] Conversion of the tertiary alcohol (+)-**2a**, via its methanesulfonate **2b** using the same *t*-BuCu reagent as above, yielded the identical trialkylallene (*R*)-(−)-**4** ($[\alpha]^{20}_D$ −6.7° (CH_2Cl_2)). Since both reactions, depicted in Scheme I, occur with anti stereoselectivity, the absolute configuration of (+)-**2a** turns out to be *S*.

Additional support for the assignment of the *S* configuration to (+)-**2a** was obtained from chiral lanthanide NMR shift experiments using Eu(tbc)$_3$. In the ^{1}H NMR spectra of enriched (+)-**2a** as well as (−)-**3a**, the signal due to the *tert*-butyl protons of the major diastereomer occurred at the higher field. Assuming that the *tert*-butyl group in the Eu complexes of both (+)-**2a** and (−)-**3a** will occupy the same position of least steric hindrance, whereas the small adjacent groups (Me and H, respectively) will take the sterically more congested positions, the groups around the chiral carbon atoms of (+)-**2a** and (−)-**3a** will be arranged as is shown below. Hence, as (−)-**3a** has the *S* configuration,[20] the absolute configuration of (+)-**2a** is also *S*.





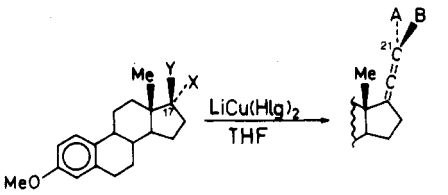
(S)-2a



(S)-3a

(17) Elsevier, C. J.; Vermeer, P.; Runge, W. *Isr. J. Chem.* **1986**, *26*, 174.
(18) Elsevier, C. J.; Kleijn, H.; Boersma, J.; Vermeer, P. *Organometallics* **1986**, *5*, 716.
(19) (a) Rona, P.; Crabbé, P. *J. Am. Chem. Soc.* **1969**, *91*, 3289. (b) Luche, J. L.; Barreiro, E.; Dollat, J. M.; Crabbé, P. *Tetrahedron Lett.* **1975**, 4615. (c) Tadema, G.; Everhardus, R. H.; Westmijze, H.; Vermeer, P. *Tetrahedron Lett.* **1978**, 3935. (d) Ollson, L.-I.; Claesson, A. *Acta Chem. Scand., Ser. B* **1979**, *B33*, 679. (e) Elsevier, C. J.; Meijer, J.; Westmijze, H.; Vermeer, P.; Van Dijck, L. A. *J. Chem. Soc., Chem. Commun.* **1982**, 84. (f) Haces, A.; Van Kruchten, E. M. G. A.; Okamura, W. H. *Tetrahedron Lett.* **1982**, *23*, 2707. (g) Fleming, I.; Terrett, N. K. *Tetrahedron Lett.* **1983**, *24*, 4151.
(20) (a) Corey, E. J.; Boaz, N. W. *Tetrahderon Lett.* **1984**, *25*, 3055. (b) We prepared this alcohol from (−)-4,4-dimethylpent-1-yn-3-ol, of which *S* configuration is also known: Weidmann, R.; Schoofs, A.; Horeau, A. *Bull. Soc. Chim. Fr.* **1976**, 645.
(21) The stereochemistry of this reaction has been reported: Mooiweer, H. H.; Elsevier, C. J.; Wijkens, P.; Vermeer, P. *Tetrahedron Lett* **1985**, *26*, 65.

Scheme II

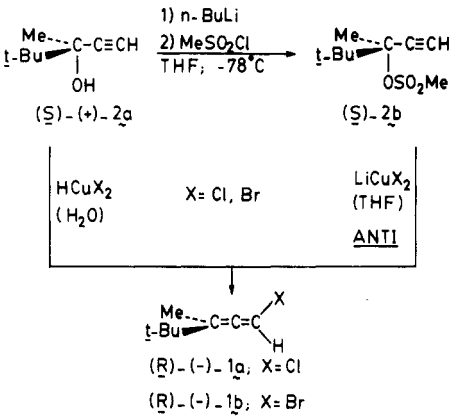


X= C≡CH, Y= OSO_2Me — anti 1,3-subst. → A= Hlg, B= H

X= OS(O)Me, Y= C≡CH — anti 1,3-subst. → A= H, B= Hlg

Hlg= Cl, Br

Scheme III



(S)-(+)-2a — (S)-2b

(R)-(−)-1a; X= Cl

(R)-(−)-1b; X= Br

The absolute configurations of the 1-halogeno-3,3-dialkylallenes **1a** and **1b** were established by correlation with (*S*)-**2a**, via 1,3-substitution of the propynylic methanesulfinate **2b** using $LiCuX_2$ (X = Cl, Br). It has been shown, that these 1,3-substitutions (yielding halogenoallenes) proceed with definite anti stereochemistry for both secondary as well as tertiary propynylic systems.[7-9] For instance, both epimeric (at C-17) esters of mestranol afforded the respective 21α- and 21β-halogenoallenes with more than 98% anti stereoselectivity (Scheme II).[8]

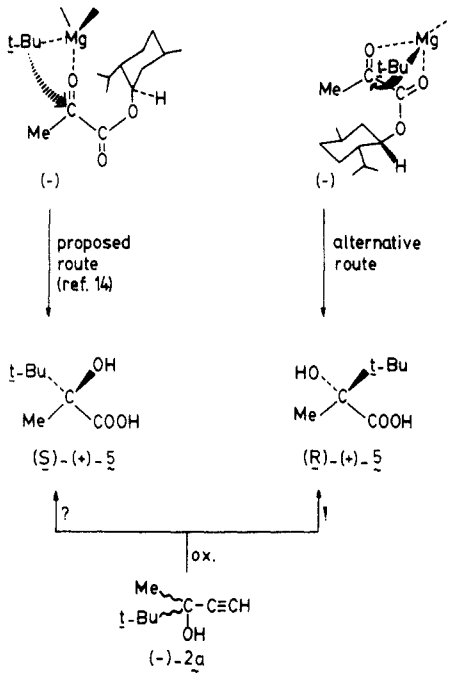
In view of these facts, the conversion of methanesulfonate (*S*)-**2b** by means of $LiCuCl_2$ or $LiCuBr_2$ in THF will occur with anti stereochemistry, giving rise to the formation of (*R*)-**1a** and (*R*)-**1b**, respectively (Scheme III). Starting from (*S*)-(+)-**2a**, levorotatory chloroallene **1a** ($[\alpha]^{20}_D$ −9.6° (CH_2Cl_2)) and bromoallene **1b** ($[\alpha]^{20}_D$ −18.3° (CH_2Cl_2)) were formed regiospecifically (>99% by GLC). On the basis of the above considerations and the assignment of *S* configuration to (+)-**2a**, it is concluded that both *levorotatory* **1a** and **1b** possess the *R* absolute configuration.

Discussion

The presented results are at variance with earlier configurational assignments to **1a**, **1b**, and **2a**.[13,14] It appears now, that these errors have mainly originated from the incorrectly assigned configuration to alcohol **2a**. The configuration of (−)-**2a** has been established by correlation to (+)-2-hydroxy-2,3,3-trimethylbutanoic acid [(+)-**5**] (Scheme IV).[14a] In turn, the configuration of (+)-**5** was obtained by using Prelog's rule,[15] assuming a preferred anti disposition of the carbonyl groups of the chiral α-keto ester in the transition state.[14a] Although such a geometry may occur, it is also conceivable and according to Whitesell[22]

(22) Whitesell, J. K. *Acc. Chem. Res.* **1985**, *17*, 280.

Scheme IV



even very likely that due to complexation of the two carbonyl functions by the organomagnesium species (see Scheme IV), a gauche or syn conformation is favored. Then, the diastereodifferentiating reaction of *t*-BuMgX with (–)-menthyl pyruvate[14a] will take the opposite course. The alternative part of Scheme IV will be followed, resulting in correlation of (–)-**2a** to (*R*)-(+)-**5**. This is in concert with the derived *S* configuration for (+)-**2a** (vide supra).[33]

Since it has been found[13,14] that reactions of the hydrogen dihalocuprates $HCuX_2$ with (+)-**2a** yield levorotatory **1a** and **1b** (albeit in lower optical yield than using $LiCuX_2$ reagents), it appears that these reactions proceed with anti stereoselectivity (Scheme III). These findings are in line with results concerning the stereochemistry of the reaction of $HCuX_2$ with secondary propynylic systems.[23]

The absolute configurations of several chiral allenes have been assigned according to the empirical rule of Lowe,[24] which relates the sign of the optical rotation at 589 nm of chiral allenes to their absolute configurations. This rule has been founded on the known configurations of four disubstituted chiral allenes and a single trisubstituted one, the latter being chloroallene **1a**. As it is shown in this paper that the configuration of (–)-**1a** is the opposite of what was hitherto assumed, obviously the empirical basis for Lowe's rule relies on wrong premises.[25] A better, semiempirical, approach is furnished by the socalled "chirality functions approach" due to Ruch and Runge.[5] With a simple algebraic equation, the absolute configurations of all arbitrarily substituted chiral allenes reported in the literature, including the revised configurations of **1a** and **1b**, are predicted correctly from the sign of their optical rotation.[17]

(23) Elsevier, C. J.; Vermeer, P. *J. Org. Chem.* **1984**, *49*, 1649.
(24) Lowe, G. *Chem. Commun.* **1965**, 411.
(25) For 1,3-disubstituted allenes this rule predicts the correct configuration. As hydrogen is less polarizable than any other substituent in the Lowe–Brewster system, coincidentally the correct configuration *S*-(+) will be predicted in case of 1,3-disubstituted optically active allenes on the basis of the sign of their rotations for any sequence of group polarizabilities, as long as all the polarizability values have the same sign.

Experimental Section

General Remarks. All reactions were carried out under an inert atmosphere of dry nitrogen. Solvents were purified and dried according to standard procedures. ^1H and ^{13}C NMR spectra were recorded on Varian EM-390 and Bruker AC-100 spectrometers, respectively, using CCl_4 or $CDCl_3$ as solvents. Mass spectra (GC/MS) were determined on a HP 5710A gas chromatograph with a capilary column (Chrompack CPSil5-CB) combined with a HP 5980A mass spectrometer (EI, 70 eV). Infrared spectra were recorded on a Perkin-Elmer 457 IR spectrometer. Optical rotations were measured in a Perkin-Elmer 241 polarimeter, using capillary or standard cuvettes (*c* 0.9–1.2 g/100 mL; *l* = 1 dm) at 20 °C. Enantiomeric excess of propynylic alcohols was determined by ^1H NMR using the chiral shift reagents $Eu(TBC)_3$ and $Eu(TFC)_3$.

Materials. For preparation of copper(I) halides and lithium halides, see ref 7. Methanesulfonyl chloride and pinacolon were purchased from E. Merck/Darmstadt. *n*-Butyllithium was purchased from Metallgesellschaft A.G. Frankfurt/Main, West Germany, as a 1.5 M solution in hexane. Methanesulfinyl chloride was synthesized from dimethyl disulfide and chlorine in acetic anhydride.[26] 4,4-Dimethylpent-1-yn-3-ol was prepared according to ref 27. Ethynyltriphenylsilane was prepared from chlorotriphenylsilane and ethynylmagnesium bromide.

Copper(I) Reagents. Organocopper(I) reagents, RCu, were prepared according to ref 28. Lithium dihalocuprates, $LiCuX_2$, were prepared according to ref 7 and 8. The hydrogen dihalocuprate $HCuBr_2$ was obtained according to ref 23.

(1*R*,2*S*)-(–)-*N*-Methylephedrine Methyl Ether. To a solution of 62.7 g (0.35 mol) (–)-*N*-methylephedrine, in a mixture of THF (300 mL) and HMPT (90 mL) was added 240 mL of 1.5 M *n*-butyllithium at –70 °C. After the mixture was stirred during 30 min, 51.0 g (0.36 mol) of MeI was carefully added, and stirring was continued for 4 h at 45 °C. Normal workup and recrystallization from benzene/hexane afforded 40.8 g (0.21 mol, 61%) of pure (1*R*,2*S*)-(–)-*N*-methylephedrine methyl ether: $[\alpha]^{20}_D$ –74.5° ($CHCl_3$, *c* 2.5); ^1H NMR (CCl_4) δ 7.12 (br m, 5 H), 4.25 (d, 1 H), 3.17 (s, 3 H), 2.59 (dq, 1 H), 2.28 (s, 6 H), 0.97 (d, 3 H).

(*S*)-(+)-3,4,4-Trimethylpent-1-yn-3-ol (2a, Optically Enriched). To a solution of 24.18 g (0.085 mol) of ethynyltriphenylsilane in 100 mL of diethyl ether was added 58.6 mL of 1.45 M (0.085 mol) *n*-butyllithium at –70 °C. After the mixture was stirred for 30 min at –70 °C, a solution of 16.43 g (0.085 mol) of (–)-*N*-methylephedrine methyl ether in 50 mL of ether was added. After another 30 min at –70 °C, a solution of 5.01 g (0.050 mol) of pinacolone in 100 mL of ether was added over a period of 1 h. Stirring was continued for 2 h at –70 °C, then the reaction mixture was worked up by pouring it into HCl/water (300 mL, pH 4) and extracting the aqueous layer with ether (3 × 100 mL). The combined organic layers were dried ($MgSO_4$) and evaporated at reduced pressure. The yield was 18.46 g (96%) $Ph_3SiC{\equiv}CC(OH)Me(t\text{-}Bu)$.[29]

Desilylation was carried out according to Eaborn.[30] After distillation the yield was 4.92 g (0.039 mol; 78%) of chemically pure alcohol **2a** (99% by GLC): bp 45–47 °C (15 mmHg); ee 18% ($Eu(TBC)_3$ and $Eu(TFC)_3$); $[\alpha]^{20}_D$ +0.06° (neat); $[\alpha]^{20}_D$ +0.78° (CH_2Cl_2, *c* 1.1); IR (NaCl; ν cm^{-1}) 2100 (C≡C), 3300 (≡CH), 3350–3700 (OH); ^1H NMR (CCl_4) δ 2.29 (s, 1 H), 1.40 (s, 3 H), 1.03 (s, 9 H).

(*S*)-(–)-4,4-Dimethylpent-1-yn-3-ol (Optically Enriched). Optical enrichment was obtained following a method of kinetic resolution.[31] Thus, 136 mL of 1.45 M (0.20 mol) *n*-BuLi was

(26) Douglass, I. B.; Farah, B. S.; Thomas, E. G. *J. Org. Chem.* **1961**, *26*, 1996.
(27) Evans, R. J. D.; Landor, S. R.; Taylor Smith, R. *J. Chem. Soc.* **1963**, 1506.
(28) Westmijze, H.; Vermeer, P. *Synthesis* **1979**, 390.
(29) (–)-*N*-methylephedrine methyl ether can be recycled by adjusting the pH of the water layer to pH 8 and extraction with ether (3 × 100 mL). After drying the organic layer ($MgSO_4$) and evaporation at reduced pressure, chemically and optically pure (–)-*N*-methylephedrine methyl ether was recovered in 85–90% yield.
(30) Eaborn, C.; Walton, D. R. M. *J. Organomet. Chem.* **1965**, *4*, 217.

added to a solution of racemic 4,4-dimethylpent-1-yn-3-ol (22.4 g, 0.20 mol) in 500 mL of dry diethyl ether under nitrogen. To the resulting solution was added 31.5 g (0.10 mol, 0.5 equiv) of *N*-phthaloyl-(*S*)-phenylalanine acylchloride (prepared from *N*-phthaloyl-(*S*)-phenylalanine and PCl_5 in benzene) in 400 mL of dry diethyl ether at −70 °C over a period of 2 h. Stirring was continued during 1 h at −65 °C, and then the reaction mixture was poured into 1000 mL of 2 M HCl and 400 mL of EtOAc in a funnel. After vigorous shaking the organic layer was separated. The water layer was extracted with diethyl ether (3 × 100 mL). The combined organic fractions were thoroughly washed with (4 × 100 mL) 10% aqueous $NaHCO_3$ solution, dried over $MgSO_4$, and concentrated at reduced pressure. The residue consisted of a mixture of diastereomerically enriched ester and enantiomerically enriched alcohol. The alcohol was carefully distilled off at ca. 0.1 mmHg and was redistilled, yielding 8.4 g (0.075 mol, 75%) of (−)-4,4-dimethylpent-1-yn-3-ol of 59% ee (Eu(TBC)$_3$ and Eu(TFC)$_3$). The ester fraction was transesterified by using NaOMe/MeOH and the liberated alcohol worked up and distilled, to yield 7.9 g (0.071 mol, 71%) of the antipode in 62% ee (Eu(TFC)$_3$). $[\alpha]^{20}_D$ −10.2° and +10.6° (neat); $[\alpha]^{20}_{D,max}$ −17.2° [20b]; bp 39–40 °C (17 mmHg); IR (NaCl; ν, cm^{-1}) 2110 (C≡C), 3300 (≡CH); ^{1}H NMR (CCl_4) δ 3.90 (d, 1 H), 2.28 (d, 1 H, ^4J = 2.4 Hz), 0.95 (s, 9 H).

(*S*)-(−)-2,2-Dimethylhex-4-yn-3-ol (3a, Optically Enriched). To a solution of (*S*)-(−)-4,4-dimethylpent-1-yn-3-ol (0.56 g, 0.0050 mol; 59% ee) in 25 mL of THF was added 6.90 mL of 1.45 M (0.010 mol) *n*-butyllithium at −50 °C. After the mixture was stirred for 30 min at −60 °C, 1.90 g (0.0075 mol) of I_2 was added. Stirring was continued at 25 °C during 30 min, and workup was accomplished by pouring the reaction mixture into an aqueous $Na_2S_2O_3$ solution and extraction with ether/pentane (1/1). After drying the organic fractions over $MgSO_4$ and removal of the solvent under reduced pressure, chemically pure (>99% by GLC) optically enriched (*S*)-4,4-dimethyl-1-iodopent-1-yn-3-ol (59% ee) was obtained: yield, 1.18 g (95%). The acetylenic iodide was converted into **3a** according to the following procedure: To a well-stirred solution of methylcopper(I) (0.0055 mol) in dry THF was added, at −70 °C, 1.13 g (0.0048 mol) of (*S*)-4,4-dimethyl-1-iodopent-1-yn-3-ol in 1 mL of THF at once. After being stirred for 5 min at −70 °C, the mixture was poured into 100 mL of aqueous 2–3% NH_4Cl solution containing NaCN (ca. 1 g) and was extracted with ether/pentane 50/50 (v/v; 2 × 150 mL). After washing with water (5 × 250 mL) and drying ($MgSO_4$), the solvent was evaporated in vacuo. Yield of chemically pure (>98% by GLC) (*S*)-(−)-2,2-dimethylhex-4-yn-3-ol (59% ee) was 0.54 g (0.0043 mol, 90%): bp 48–49 °C (18 mmHg); ee 59% (Eu(TFC)$_3$ and Eu(TBC)$_3$); $[\alpha]^{20}_D$ −10.46° (CH_2Cl_2, *c* 0.85); $[\alpha]^{20}_{D,max}$ (calcd) 17.7° (CH_2Cl_2); IR (NaCl; ν, cm^{-1}) 2105 (C≡C); ^{1}H NMR (CCl_4) δ 3.78 (q, 1 H), 1.88 (d, 3 H) 0.98 (s, 9 H).

Conversions of Propynylic Substrates. The methanesulfonate **2b** and methanesulfinate **3b** esters of propynylic alcohols **2a** and **3a**, respectively, were prepared according to standard procedures.[32]

(*R*)-(−)-2,2,3,6,6-Pentamethylhepta-3,4-diene (4, Optically Enriched). To a well-stirred solution of 0.0020 mole of (*t*-BuCuBr)MgCl in 20 mL of dry THF was added, at −70 °C, 0.0020 mol (0.41 g of **2b** or 0.38 g of **3b**) of the propynylic ester, dissolved in 1 mL of THF, at once. After being stirred during 3–5 min at −70 °to −60 °C, the mixture was poured into 100 mL of aqueous 2–3% NH_4Cl containing NaCN (ca. 0.5 g) and was extracted with pentane (3 × 20 mL). After washing with water (5 × 100 mL) and drying the extracts over K_2CO_3, the pentane was evaporated at reduced pressure. The crude allene was purified by flash chromatography over alumina, with pentane as the eluent. After preparative GLC (see below), chemically pure (99% by GLC) (*R*)-(−)-**4** was obtained as a colorless oil in 0.28–0.30 g (85–90%) yield, $[\alpha]^{20}_D$ −21.3° (CH_2Cl_2, *c* 0.8), obtained from 59% ee (*S*)-**3b**, $[\alpha]^{20}_D$ −6.7° (CH_2Cl_2, *c* 1.2) obtained from 18% ee (*S*)-**2b**: $[\alpha]^{20}_{D,max}$ (calcd) 36–38° (CH_2Cl_2); mass spectrum, *m*/*z* 166 ($M^{\cdot+}$, 10%), 109 ($(M - C_4H_9)^+$, 21%), 57 ($C_4H_9^+$, 100%); IR (NaCl; ν, cm^{-1}]) 1958 (C=C=C); ^{1}H NMR (CCl_4) δ 4.96 (q, 1 H), 1.68 (d, 3 H, ^5J = 1.8 Hz), 1.05 (s, 9 H), 1.00 (s, 9 H); ^{13}C NMR ($CDCl_3$) δ 197.4 (C(4)), 109.8 (C(3)), 102.3 (C(5)), 33.2 (C(2)), 31.9 (C(6)), 30.2 (C(7)), 29.1 (C(1)), 15.2 (C(8)).

(*R*)-(−)-1-Chloro-3,4,4-trimethylpenta-1,2-diene (1a, Partially Enriched). To a stirred solution of 0.38 g (0.0030 mol) of (*S*)-(+)-**2a** (18% ee) in 15 mL of THF were successively added, at −70 °C, 0.0030 mol of *n*-BuLi in hexane and, at once, 0.0035 mol of methanesulfonyl chloride. After 2 min at −65 °C, a solution of the $LiCuCl_2$ (0.0030 mol) was added in one portion. The mixture was allowed to warm to 20 °C in 15–20 min. The crude chloroallene was isolated by pouring the mixture into 100 mL of saturated aqueous NH_4Cl solution, containing ca. 0.5 g of NaCN. The aqueous layer was then extracted with pentane (2 × 25 mL), the combined organic fractions were washed with water (5 × 50 mL) and dried over K_2CO_3. After careful evaporation of the solvent at 100 mmHg, to give 0.40 g (0.0028 mol, 93%) of crude **1a**, the chloroallene was purified from traces of polymeric materials by column chromatography over alumina, using pentane as the eluent. The pure chloroallene **1a** was obtained by preparative GLC as a colorless liquid in 0.20-g yield (70%): $[\alpha]^{20}_D$ −9.63° (CH_2Cl_2, *c* 0.95); mass spectrum, *m*/*z* 146 ($M^{\cdot+}$, 3%), 109 ($(M - Cl)^+$, 35%) [for ^{37}Cl], 57 ($C_4H_9^+$, 100%); IR (NaCl; ν, cm^{-1}) 1954 (C=C=C); ^{1}H NMR ($CDCl_3$) δ 5.94 (q, 1 H), 1.80 (d, 3 H, ^5J = 2.0 Hz), 1.08 (s, 9 H); ^{13}C NMR ($CDCl_3$) δ 198.3 (C(2)), 120.9 (C(3)), 87.2 (C(1)), 34.4 (C(4)), 28.6 (C(5)), 15.2 (C(6)).

(*R*)-(−)-1-Bromo-3,4,4-trimethylpenta-1,2-diene (1b, Partially Enriched). The procedure was the same as for **1a**, now with $LiCuBr_2$ as the reagent. In this case, no preparative GLC was necessary, yield, 0.49 g (86%) of (−)-**1b**: $[\alpha]^{20}_D$ −18.31° (CH_2Cl_2, *c* 1.12); mass spectrum, *m*/*z* 190 ($M^{\cdot+}$, 18%), 109 ($(M - Br)^+$, 73%) [for ^{81}Br], 57 ($C_4H_9^+$, 100%); IR (NaCl; ν, cm^{-1}) 1949 (C=C=C); ^{1}H NMR ($CDCl_3$) δ 5.88 (q, 1 H), 1.82 (d, 3 H, ^5J = 2.0 Hz), 1.08 (s, 9 H); ^{13}C NMR ($CDCl_3$) δ 198.6 (C(2)), 120.0 (C(3)), 71.4 (C(1)), 34.1 (C(4)), 28.6 (C(5)), 14.7 (C(6)).

(*R*)-(−)-1-Bromo-3,4,4-trimethylpenta-1,2-diene (1b, Partially Enriched). The propynylic alcohol (*S*)-(+)-**2a** (0.38 g, 0.0030 mol) was added, at 25 °C, to a solution of $HCuBr_2$ (0.0030 mol) in water. After the resulting mixture was shaken for 48 h, the product was isolated according to ref 23, yielding 0.49 g (0.0026 mol, 87%) of pure (>99% by GLC) bromoallene **1b**: $[\alpha]^{20}_D$ −6.26° (neat); $[\alpha]^{20}_D$ −6.25° (CH_2Cl_2, *c* 0.90); other physical constants as above.

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(31) Tadema, G.; Wÿkens, P.; Elsevier, C. J.; Vermeer, P., unpublished results. See Elsevier, C. J. Ph.D. Thesis, University of Utrecht, 1984. This method was used for the enrichment of α-ethynyl alcohols RCH(OH)C≡CH, which resulted in: R = Ph, 55% ee; R = Me, 27% ee; R = *n*-octyl, 25% ee. Tertiary ethynyl alcohols such as **3a** could not be enriched by the described method, so an enantioselective synthesis was devised (see Experimental Section).

(32) Vermeer, P.; Westmijze, H.; Kleijn, H.; Van Dijck, L. A. *Recl. Trav. Chim. Pays-Bas* **1978**, *97*, 56.

(33) **Note added in proof.** During the review process the *R* configuration was assigned to the benzoate ester of (−)-**2a**, on the basis of circular dichroic data: Caporusso, A. M.; Rosini, C.; Lardicci, L.; Polizzi, C.; Salvadori, P. *Gazz. Chim. Ital.* **1986**, *116*, 467.