Cleavage of Carbon–Carbon Bonds with High Stereochemical Control. 6. Asymmetric Synthesis of Chiral C-Centered Organosilanes by Haller–Bauer Cleavage of Optically Active, Nonenolizable α-Silyl Phenyl Ketones[1]

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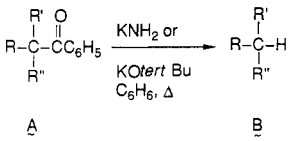
Sequential alkylation and methylation of *l*-menthyl ester **10** provides diastereomeric mixtures in which **12** is slightly enhanced over **13**. Conversely, C-silylation and alkylation of propionate ester **11** delivers **13** in excess. In either case, a single chromatography suffices to give product with 80–100% diastereomeric purity. Conversion of purified **12** to optically active phenyl ketones **20** of known absolute configuration is accomplished in four steps. Haller–Bauer cleavage ($NaNH_2$ or KNH_2 in refluxing benzene) of **20** delivers the tertiary silanes **21** with 88–92% retention of configuration. Consequently, the intermediate α-silyl carbanions are generated in chiral condition and protonated almost exclusively on that surface from which benzamide is departing. Comparison is made with the similar ability of benzyl carbanions to retain configuration under identical conditions of C–C bond cleavage.

The cleavage of nonenolizable ketones by amide and alkoxide bases as in A → B (the Haller–Bauer reaction[3]) is of mechanistic and preparative interest because of its capacity for high stereochemical retention in the intermediate carbanion under the appropriate conditions.[1,4,5]



A B

The fragmentation is recognized to proceed well when the leaving group is constituted of a benzylic[1,3,4] or cyclopropyl carbanion,[5] but not at all when only alkyl groups are present.[1,3a] As part of our detailed study of this process, we became interested in expanding the scope of the Haller–Bauer reaction to include a wider range of functionalized molecules. Owing to the capability of R_3Si substituents to stabilize carbanions very effectively,[6] largely by redistribution of the electrons through polarization,[7] we have proceeded to examine the response of α-silyl ketones to strong bases in various solvents.

This investigation was also driven by recognition of the need for a *general* synthetic route to optically active C-centered organosilanes,[8] a class of molecules that is rapidly gaining interest in its own right[9] and as important mechanistic probes.[10] Accordingly, the focus in this paper is predominantly on optically active open-chain α-silyl ketones. Bond scission in these systems is shown to proceed with preservation of configuration to deliver silanes of known absolute stereochemistry.[11] A companion paper[12] delineates the manner in which cyclic α-silyl ketones respond to Haller–Bauer conditions. Defined by these studies is a utilitarian route to optically active tertiary silanes that features reliable stereochemical predictability.

Table I. Reactivity of 7 toward Different Bases[a]

base	solvent	product	isolated yield, %
$LiNH_2$	C_6H_6	**6**	89
$NaNH_2$	C_6H_6	**9**	29
$NaNH_2$	*n*-$BuNH_2$	–	–
KO-*t*-Bu	C_6H_6	8	66
KO-*t*-Bu	*t*-BuOH	8	72

[a] Reaction performed at the reflux temperature of the solvent.

Results

A Racemic Test Case. The sensitivity of β-keto silanes to thermal rearrangement at quite modest temperatures has long been recognized.[13] Regiospecific enolate formation by desilylation of these compounds with certain nucleophiles is no less well-known.[14] In order to assess

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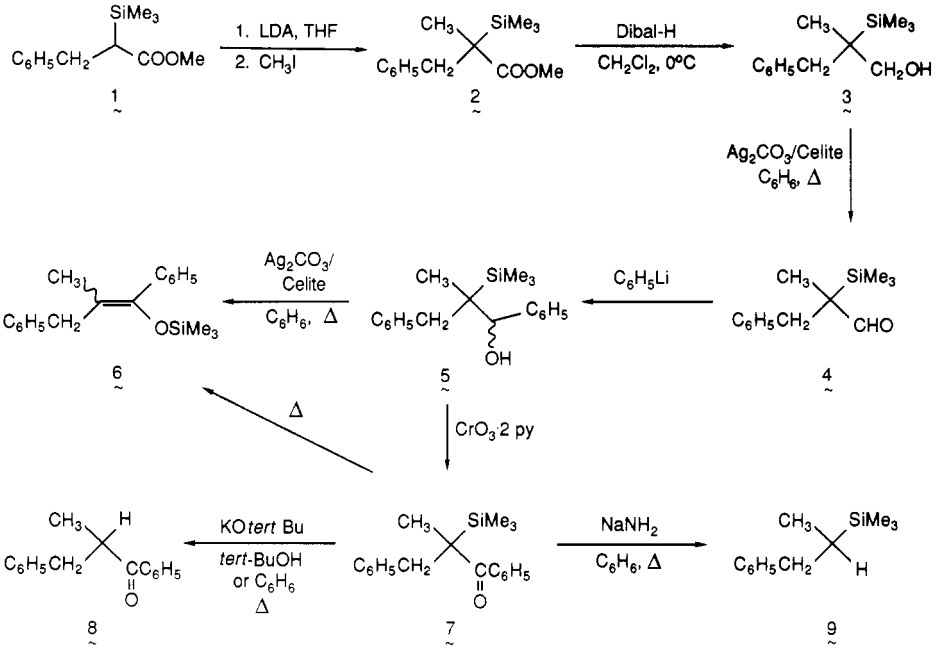
Scheme I



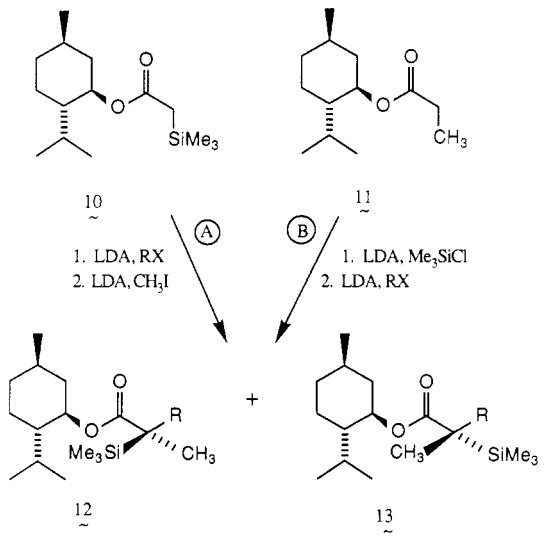
how these chemical properties might impact on projected transformations of the Haller–Bauer type, the racemic carbonyl compound **7** was first prepared (Scheme I) and exposed in turn to various bases and solvent systems.

Benzylation of the lithium salt of methyl (trimethylsilyl)acetate gave **1**. Generation of a quaternary center α to the carbonyl function was achieved straightforwardly and with high efficiency (91%) by direct methylation. Careful reduction of **2** with Dibal-H afforded **3** (94%) without measurable interference from Peterson olefination. Oxidation of **3** with the Fetizon reagent[15] in refluxing benzene made available the aldehyde **4** without event. In contrast, recourse to the same conditions for oxidation of carbinol **5** gave rise uniquely to the silyl enol ether **6**. However, this unwanted C → O silyl migration was easily skirted by making recourse instead to the Collins reagent.[16]

In order to gain some insight into the reactivity of **7**, a series of five experiments was undertaken. These are collected in Table I. There it is seen that recourse to lithium amide in benzene, the customarily least reactive Haller–Bauer reagent combination,[1,4a,b] resulted only in conversion to **6**. Accordingly, this base is not capable of intercepting the Brook rearrangement. Substitution of sodium amide did give the desired debenzoylated product **9**, although only in modest yield. A solvent change to *n*-butylamine provided no characterizable product. The results show further that *tert*-butoxide ion, in either benzene or *tert*-butyl alcohol, functions to desilylate **7** and form **8** cleanly. Consequently, the debenzoylation of β-silyl ketones is restricted to $NaNH_2$ and presumably the more reactive KNH_2 in an inert solvent such as benzene. Since these happen to be the classical conditions for the Haller–Bauer reaction,[3] a detailed analysis of the stereochemical parameters of this bond cleavage in such organosilicon compounds was undertaken.

Preparation and Absolute Configuration of the β-Silyl Ketones. *l*-Menthyl esters offered an attractive, cheap, and efficient means for preparing **7** and allied ketones with recognizable levels of enantiomeric excess and known absolute configuration. Incorporation of the trimethylsilyl group could be realized in good yield by silylation of either *l*-menthyl acetate (to give **10**) or the propionate **11** by suitable extension of Rathke's methodology.[17] Expectedly, the somewhat higher levels of steric

Scheme II



	Direction A			Direction B		
	initial		purified[a]	initial		purified[a]
R	12 : 13		12	12 : 13		13
a, CH_2Ph	55	45	>99% de	31	69	20:80
b, $CH_2CH{=}C(CH_3)_2$	55	45	82% de	38	62	10:90
c, CH_2CH_2Ph	55	45	>99% de	25	75	8:92
d, $(CH_2)_4CH_3$	50	50	89% de	38	62	10:90

[a] These figures apply to 40–50% mass return of the starting mixture after one chromatography. For **12a** and **12c**, crystallization was also effected.

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Table II. Crystallographic Details for 12a

formula	$C_{23}H_{38}O_2Si$
formula wt, amu	374.64
space group	$P2_1$
a, Å	9.493 (2)
b, Å	6.651 (2)
c, Å	18.391 (3)
β, deg	96.64 (1)
vol, Å^3	1153
Z	2
density (calcd), g/cm^3	1.08
crystal size	0.22 mm × 0.34 mm × 0.42 mm
radiation	Mo Kα with graphite monochromator
linear abs coeff, cm^{-1}	1.10
temperature	−118 °C
2θ limits	$4° \le 2\theta \le 52°$
scan speed	2.0–24.0 deg/min in 2θ
background time/scan time	0.5
scan range	$(K\alpha_1 - 1.0)°$ to $(K\alpha_2 + 1.1)°$
data collected	$+h,-k,\pm l$
unique data	2483
unique data, with $F_o^2 > 2\sigma(F_o^2)$	2194
final number of variables	234
$R(F)$[a]	0.035
$R_w(F)$[b]	0.035
error in observation of unit wt, e	1.59
R (on F for $F_o^2 > 3\sigma(F_o^2)$)	0.033

[a] $R(F) = \sum||F_o| - |F_c||/\sum|F_o|$. [b] $R_w(F) = [\sum w(|F_o| - |F_c|)^2/\sum w|F_o|^2]^{1/2}$ with $w = 1/\sigma^2(F_o)$.

hindrance encountered in the second route caused yields to be lower. Nonetheless, the two processes are nicely complementary in their diastereoselectivity (Scheme II). Thus, by alkylation of **10** first with the bromide or iodide of the targeted substituent R and subsequently with methyl iodide, diastereomeric mixtures arose in which the levels of **12** were slightly enhanced over those of **13**. Conversely, capture of the enolate of C-silylated **11** delivered **13** in excess. In every instance, a single chromatography of the reaction mixtures derived from **10** sufficed to give samples of **12** (first to elute) of high % de. Since diastereomers **13** eluted last, heightened de was more difficult to achieve on a preparative scale.

Esters **12a** and **12c** proved to be highly crystalline compounds. By means of an X-ray crystallographic analysis of **12a** at −118 °C, it proved ultimately possible to set absolute stereochemistry for all the illustrated examples. The crystallographic details can be found in Table II and the final ORTEP diagram in Figure 1.

The consistency of the trends within the **12**/**13** series of esters happens to be extraordinarily good (Table III). For example, the α-methyl singlet in **12** invariably appears downfield of that in **13**. The analogous trend is seen for >C*H*OC(O)–. Characteristically as well, the $(CH_3)_3Si$–, >CHO*C*(O)–, and >*C*HOC(O)– carbons of **12** are all shielded relative to those in the respective diastereomer.

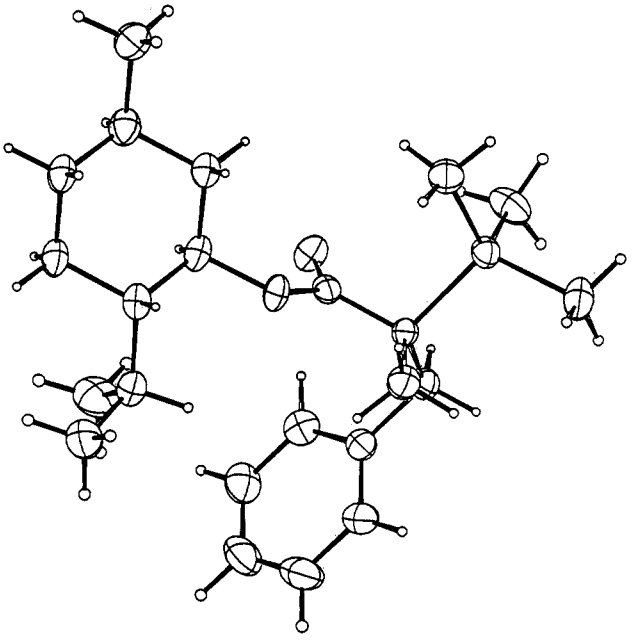
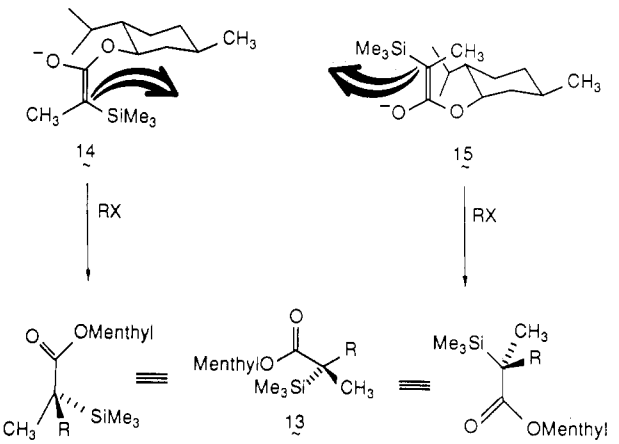


Figure 1. ORTEP drawing for **12a**. Non-hydrogen atoms are drawn with 50% probability thermal ellipsoids, while the hydrogen atoms are portrayed with an artificially small radius.

Scheme III



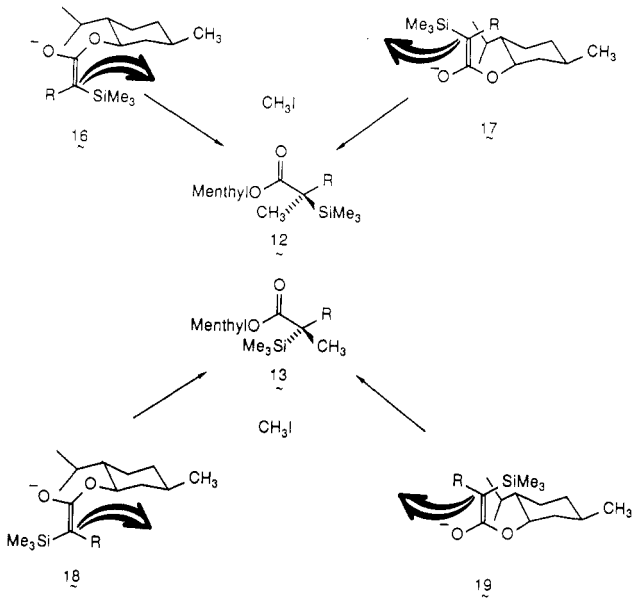
Two competing factors contribute to the observed diastereoselective alkylation of these enolates. In principle, two isomers of each enolate can result, with the trimethylsilyl substituent residing cis or trans to the menthol group. In addition, the electrophile may approach a given enolate anion from either π surface. Four reaction profiles are consequently available. The results summarized in Scheme II reveal that the greater diastereoselectivity accrues via route B and that **13** is kinetically favored. The predominance of product having the *S* configuration is

Table III. Selected Physical and Spectral Properties of 12 and 13

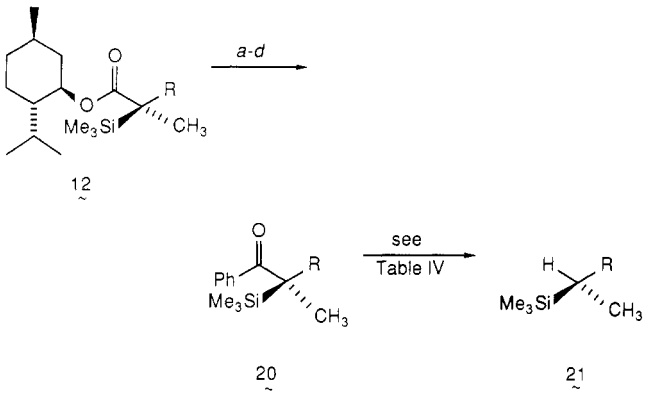
diastereomer:	12a	13a	12b	13b	12c	13c	12d	13d
MPLC elution[a]	first	second	first	second	first	second	first	second
^{1}H NMR, δ								
α-Me singlet	1.03	1.00	1.12	1.09	1.22	1.20	1.14	1.12
α-acyloxy proton	4.69	4.61	4.69	4.62	4.72	4.63	4.69	4.58
^{13}C NMR, ppm								
$(CH_3)_3Si$	−3.76	−3.58	−3.72	−3.55	−3.72	−3.62	−3.69	−3.64
CHO*C*(O)	175.87	176.55	176.44	176.73	176.40	176.55	176.76	176.96
*C*HOC(O)	73.81	74.50	73.52	73.92	73.83	74.17	73.52	73.89
$[\alpha]^{25}_D$ ($CHCl_3$),[b] deg	−56.6[c]	−8	−58	+3.5	+3.1[c]	−70	−33	−43

[a] Silica gel (elution with 0.75–1.25% ethyl acetate in petroleum ether). [b] Values of extrapolated 100% optical purity on the basis of $[\alpha]_D$ values for at least two diastereomeric mixtures (±2°). [c] Crystalline compounds; measured $[\alpha]_D$.

Scheme IV



Scheme V



[a] Dibal-H, CH_2Cl_2, 0 °C. [b] Ag_2CO_3, Celite. [c] PhLi. [d] CrO_3·py_2.

consistent with preferential approach to **14** and **15** as shown in Scheme III. The isopropyl substituent stemming from the chiral auxiliary can reasonably be expected to shield the α surface of these anions (as drawn). Since the diastereoselectivity levels do vary somewhat with the electrophile employed, steric effects in the coreagent do have some influence.

Enolate **14** having the more bulky trimethylsilyl group trans to the solvated oxyanion center may dominate the reaction mixture. The equivalent species encountered via route A would be **16** (Scheme IV), where the small methyl group is now replaced by the more space demanding R. The steric contributions of R impact as well on **17**. With the thermodynamic advantages of these isomers consequently lowered, formation of their isomers **18** and **19** may well now be kinetically competitive. Diastereoselection would be lessened as a result. For these reasons, path A was predicted a priori to be less stereocontrolled.

The purified esters **12** were transformed as before into the benzoyl derivatives **20** without perturbation of the stereogenic center (Scheme V).

Haller–Bauer Cleavage and Product Stereochemistry. Enantiomerically enriched ketones **20c** and **20d** were first exposed to sodium and potassium amides in refluxing anhydrous benzene because product silanes **21c** and **21d** had been prepared previously in optically active condition.[9c] As a result, the percent enantiomeric excess and absolute configuration for each product could be derived directly from its measured optical rotation. The yields and stereochemical course of these reactions are compiled in Table IV.

Table IV. Haller–Bauer Cleavage of Optically Active 20a–d (C_6H_6 Solution at the Reflux Temperature)[a]

substrate (% ee)	$[\alpha]^{23}_D$, deg (c C_6H_6)	base	product % ee	optical course % ret[b]	% inv[c]
20d (89)	+67.7 (7.3)	$NaNH_2$	74	92	8
		KNH_2	68	88	12
20c (99)	+135.3 (2.6)	$NaNH_2$	81	91	9
		KNH_2	77	88	12
20b (46)	+10.1 (2.1)	$NaNH_2$	$[\alpha]^{23}_{365}$ +24.6° (CH_2Cl_2)[d]		
		KNH_2			
20a (99)	+66.1 (4.6)	$NaNH_2$	$[\alpha]^{23}_D$ +31.6 (CCl_4)[d]		
		KNH_2			

[a] Duplicate experiments at a minimum. [b] Retention. [c] Inversion. [d] Extrapolated values for enantiomerically pure **21b** and **21a** based on consistent 92% and 88% retention levels for $NaNH_2$ and KNH_2, respectively.

Both fragmentations are seen to proceed with high levels of retention, the optical course being consistently somewhat higher with sodium as the counterion. These results demonstrate that the acyclic α-silyl carbanions generated in this manner are capable of being protonated without loss of stereochemistry with 15–20% greater efficiency than their α-phenyl counterparts.[4a,b]

The cited isolated yields are rather low. To some degree, this is due to the volatility of the silanes and our selection of preparative gas chromatography as the method for their purification.

If the same retention–inversion profiles are assumed to apply to **20a** and **20b**, then the $[\alpha]_D$ values for optically pure silanes **21a** and **21b** can be approximated with a high level of confidence (see Table IV). Pertinent to this issue is the realization that the same optical rotation is arrived at irrespective of whether the extrapolation is made from the data recorded for the sodium amide or potassium amide reactions. It follows, of course, that the absolute configurations of **21a** and **21b** are believed to be correctly assigned.

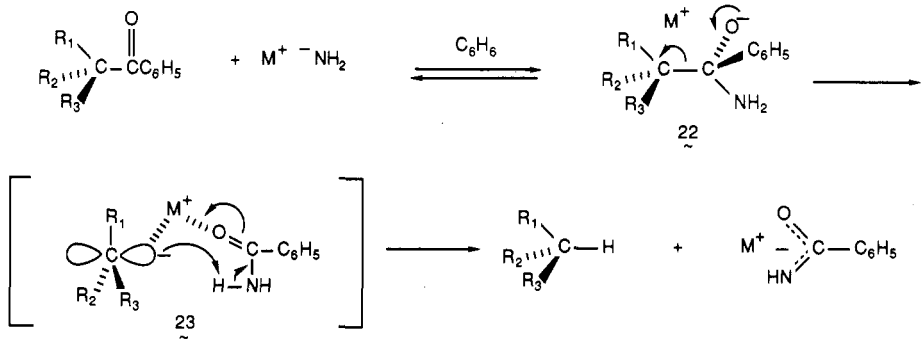
Discussion

The data compiled in Table IV reveal that nonenolizable β-keto silanes experience deacylation when heated with amide bases in benzene with almost complete retention of configuration. The likely mechanistic pathway is shown in Scheme VI. Three effects require explanation: (1) benzene is a solvent especially conducive to stereospecific Haller–Bauer cleavage; (2) cleavage with potassium amide occurs faster than with sodium amide; (3) comparison of the magnitudes of stereochemical retention in **12a–d** with those of related systems carrying benzylic stabilizing groups[4a,b] shows appreciably higher levels of control when silicon is present.

The first of these effects can be accounted for in terms of the dielectric constant of benzene (ϵ = 2). In his pioneering carbanion work, Cram called early attention to the fact that product pairs such as **23** are more tightly coordinated in nondissociating solvents of this type.[18,19] In the present instance, the α-silyl carbanion is held in close proximity to the proton donor benzamide by mutual

(18) Cram, D. J.; Kopecky, K. R.; Hauck, F.; Langemann, A. *J. Am. Chem. Soc.* **1959**, *81*, 5754.
(19) Cram, D. J. *The Fundamentals of Carbanion Chemistry*; Academic Press: New York, 1965; Chapter IV.

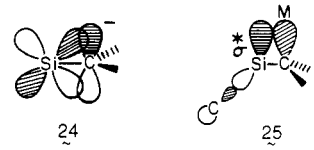
Scheme VI



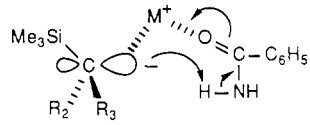
sharing of electron pairs to the metal cation. Since the stereochemical fate of the carbanion is *largely* determined by the properties of its environment rather than by its configuration, and because the benzamide is necessarily positioned initially on that side of the carbanion from which it departed, a proton can be delivered to the reactive intermediate most rapidly from that surface originally occupied by the leaving group. For a competing process to operate would require disruption of the solvation shell, extensive rotation of one species relative to the other within the solvent cage, or some alternative energy-demanding destruction of the structural environment originally set in place.

The rates of Haller–Bauer cleavage are likely to be more dependent on the character of the metal cation in a solvent such as benzene than in hydroxylic solvents. On this basis, the initial attack that generates **22** is certain to be affected by relative differences in the level of positive charge shielding offered by the particular metal cation. Since, for positively charged alkali metals, this effect is greater for potassium than for sodium, the less tightly bound amide ion in KNH_2 can be anticipated to emerge as the more nucleophilic and to engage more vigorously in the 1,2-addition. The lessened level of coordination within **22** when M^+ is potassium should likewise result in accelerated bond fragmentation.

The present study disclosed not only that α-silyl carbanions can be generated within a chiral matrix but that protonation of these reactive species takes place with higher levels of retention than when a phenyl group is substituted for silicon. Where benzylic substrates are involved, the associated carbanions are very likely planar due to delocalization of negative charge into the benzene ring. While second-row elements such as silicon are recognized to stabilize carbanions with considerably greater effectiveness than their first-row counterparts,[6] the manner in which this occurs has been contested over the years. Early rationalization of this phenomenon favored the d_π–p_π model **24** as the source of the stabilizing influence.[20] More recently, the relative importance of d orbitals has been largely downplayed in favor of stabilization by means of the high polarizability of Si and the presence of an empty σ^* orbital on the hetero atom. Overlap with the filled orbital of a flanking carbanionic center as in **25** can suitably account for the observed stabilization.[7,20]



Although the consequences of all this on the actual preferred geometry of the carbon carrying the negative charge have been little addressed, it may well be that α-silyl carbanions are not as effectively planar as their benzylic congeners. The sensitivity of the Haller–Bauer process to small hybridization differences of this type may be especially keen. If such is the case, then α-silyl carbanions would be expected to be captured with heightened stereochemical retention, since a somewhat lessened electron density is present on the anterior portion of the intermediate at any given time (see **26**).



That the ground state of silyl-substituted carbanions may not be fully planar should not be construed to imply that there exists a substantive barrier to racemization in these (and allied) systems. On the other hand, the nonplanarity phenomenon can contribute to some degree to the overall reaction stereospecificity. The accompanying paper examines the consequences of trimethylsilyl substitution on the Haller–Bauer cleavage of selected benzoylcycloalkanes.[12]

Experimental Section

Methyl 2-(Trimethylsilyl)-3-phenylpropionate (1). Methyl (trimethylsilyl)acetate (10.22 g, 69.9 mmol) was dissolved in anhydrous tetrahydrofuran (20 mL) and added dropwise to a cold (−78 °C), magnetically stirred solution of lithium diisopropylamide (72.0 mmol) in the same solvent (80 mL). After 30 min, benzyl bromide (12.1 g, 70.6 mmol) in tetrahydrofuran (20 mL) was introduced, and the reaction mixture was allowed to warm to room temperature during 1 h, diluted with ether, and washed with ammonium chloride solution (50 mL), water (3 × 50 mL), and brine (3 × 50 mL). After drying, the solvent was evaporated and the residue was chromatographed (silica gel, gradient elution with 2–4% ethyl acetate in petroleum ether). Bulb-to-bulb distillation of the concentrate (145–151 °C/0.4 Torr) furnished **1** as a colorless oil (10.76 g, 65%): IR (neat, cm^{-1}) 2955, 1720, 1490, 1455, 1435, 1255, 1215, 1150; ^1H NMR (300 MHz, $CDCl_3$) δ 7.35–7.22 (m, 5 H), 3.65 (s, 3 H), 3.20 (dd, J = 14.4, 11.7 Hz, 1 H), 2.81 (dd, J = 14.4, 3.3 Hz, 1 H), 2.45 (dd, J = 11.7, 3.3 Hz, 1 H), 0.21 (s, 9

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H); MS m/z (M^+) calcd 236.1232, obsd 236.1232.

Methyl 2-Methyl-2-(trimethylsilyl)-3-phenylpropionate (2). A solution of 1 (15.05 g, 63.8 mmol) in anhydrous tetrahydrofuran (20 mL) was added dropwise to a cold (−78 °C), magnetically stirred solution of lithium diisopropylamide (72.0 mmol) in the same solvent (70 mL). After 30 min, methyl iodide (11.4 g, 80.3 mmol) was introduced in one portion, and the reaction mixture was allowed to warm to room temperature during 3 h. Workup in the predescribed manner followed by silica gel chromatography (elution with 3% ethyl acetate in petroleum ether) gave 2 (14.45 g, 91%) after chromatography. Recrystallization from ether–petroleum ether furnished colorless prisms, mp 63–64 °C: IR (CH_2Cl_2, cm^{-1}) 2960, 1705, 1600, 1495, 1450, 1195, 1180; ^1H NMR (300 MHz, $CDCl_3$) δ 7.41–7.23 (m, 5 H), 3.82 (s, 3 H), 3.67 (d, J = 13.5 Hz, 1 H), 2.62 (d, J = 13.5 Hz, 1 H), 1.19 (s, 3 H), 0.28 (s, 9 H); MS m/z (M^+) calcd 250.1389, obsd 250.1392.

Anal. Calcd for $C_{14}H_{22}O_2Si$: C, 67.15; H, 8.86. Found: C, 67.16; H, 8.85.

2-Methyl-2-(trimethylsilyl)-3-phenylpropanol (3). A cold (0 °C), magnetically stirred solution of 2 (12.80 g, 51.1 mmol) was treated dropwise with Dibal-H in hexane (109 mL of 1.0 M, 109 mmol) during 20 min. After 1 h at 0 °C, methanol was introduced, the reaction mixture was diluted with sodium potassium tartrate solution, and stirring was maintained at room temperature for 1 h. The product was extracted into ether (4 × 150 mL), and the combined organic phases were washed with ammonium chloride solution and brine prior to drying. Following solvent evaporation, the residue was distilled in a Kugelrohr apparatus (175–180 °C/0.4 Torr) to give 3 as a colorless low-melting solid (10.72 g, 94%): IR (neat, cm^{-1}) 3580, 3460, 3030, 2950, 2900, 2860, 1600, 1490, 1450, 1245; ^1H NMR (300 MHz, C_6D_6) δ 7.24–7.12 (m, 5 H), 3.25 (d, J = 10.1 Hz, 1 H), 3.20 (d, J = 10.1 Hz, 1 H), 2.94 (d, J = 13.1 Hz, 1 H), 2.51 (d, J = 13.1 Hz, 1 H), 0.72 (s, 3 H), 0.69 (s, 1 H), 0.11 (s, 9 H); ^{13}C NMR (20 MHz, C_6D_6) 138.56, 130.93, 127.95, 126.10, 67.71, 39.15, 27.75, 17.63, −2.88 ppm; MS m/z (M^+ − Me_3SiOH) calcd 132.0939, obsd 132.0954.

2-Methyl-2-(trimethylsilyl)-3-phenylpropanal (4). Fetizon reagent (18.4 g, ca. 32 mmol) was added to benzene (150 mL) and heated at the reflux temperature under a Dean–Stark trap for 1 h to remove entrapped water. A 1.026-g (4.6 mmol) sample of 3 was added, and the mixture was refluxed for 1.5 h. The cooled slurry was filtered through Celite, and the filtrate was evaporated to leave a pale yellow oil. Bulb-to-bulb distillation (150 °C/0.4 Torr) of this material afforded 4 (792 mg, 78%) as a colorless oil: IR (neat, cm^{-1}) 3060, 3030, 2955, 2800, 2690, 1690, 1600, 1580, 1495, 1455, 1255; ^1H NMR (300 MHz, C_6D_6) δ 9.75 (s, 1 H), 7.30–7.05 (m, 5 H), 3.60 (d, J = 13.9 Hz, 1 H), 2.60 (d, J = 13.9 Hz, 1 H), 1.03 (s, 3 H), 0.15 (s, 9 H); ^{13}C NMR (20 MHz, C_6D_6) 203.93, 138.87, 129.97, 128.40, 126.49, 47.95, 37.26, 13.82, −4.08 ppm; MS m/z (M^+) calcd 220.1283, obsd 220.1266.

Anal. Calcd for $C_{13}H_{20}OSi$: C, 70.85; H, 9.15. Found: C, 70.52; H, 9.12.

1,3-Diphenyl-2-methyl-2-(trimethylsilyl)propanol (5). A solution of 4 (716 mg, 3.2 mmol) in anhydrous ether (25 mL) was cooled to −78 °C, treated with phenyllithium (3.9 mmol in ether–cyclohexane), and stirred at this temperature for 1 h. Water was added, and the mixture was allowed to warm to room temperature. The separated organic layer was washed with water and brine prior to drying. Rapid chromatography (silica gel, elution with 5% ethyl acetate in petroleum ether) gave a 4:1 mixture of diastereomers 5 (549 mg, 57%) as a white solid: IR (CH_2Cl_2, cm^{-1}) 3545, 3030, 2960, 2910, 1600, 1495, 1455, 1250; MS m/z ($M^+ - H_2O$) calcd 280.1647, obsd 280.1645.

Major diastereomer: ^1H NMR (300 MHz, C_6D_6) δ 7.25–7.04 (m, 10 H), 4.51 (s, 1 H), 3.28 (d, J = 13.1 Hz, 1 H), 2.33 (d, J = 13.1 Hz, 1 H), 1.10 (br s, 1 H), 0.94 (s, 3 H), 0.03 (s, 9 H).

Minor diastereomer: ^1H NMR (300 MHz, C_6D_6) δ 7.25–7.04 (m, 10 H), 4.22 (s, 1 H), 3.32 (d, J = 13.0 Hz, 1 H), 2.57 (d, J = 13.0 Hz, 1 H), 1.10 (br s, 1 H), 0.90 (s, 3 H), 0.02 (s, 9 H).

1,3-Diphenyl-1-[(trimethylsilyl)oxy]-2-methyl-1-propene (6). A 458-mg (1.5 mmol) sample of 5 was treated with the Fetizon reagent (9.2 g) as before to give 6 (408 mg, 90%) after bulb-to-bulb distillation (205 °C/0.2 Torr): IR (neat, cm^{-1}) 3085, 3065, 3030, 2960, 2910, 1650, 1600, 1495, 1450, 1440, 1295, 1255, 1120; ^1H NMR (300 MHz, C_6D_6) δ 7.41 (td, J = 7.5, 1.2 Hz, 4 H), 7.28 (t, J = 7.4 Hz, 2 H), 7.17–7.08 (m, 4 H), 3.73 (s, 2 H), 1.64 (s, 3 H), 0.05 (s, 9 H); ^{13}C NMR (75 MHz, C_6D_6) 145.33, 141.39, 139.27, 129.71, 129.20, 128.64, 128.07, 126.14, 115.59, 38.04, 17.46, 0.74 ppm; MS m/z (M^+) calcd 296.1596, obsd 296.1592.

Anal. Calcd for $C_{19}H_{24}OSi$: C, 76.97; H, 8.16. Found: C, 76.89; H, 8.20.

1,3-Diphenyl-2-methyl-2-(trimethylsilyl)-1-propanone (7). Chromium trioxide (720 mg, 7.2 mmol) was slurried in dichloromethane (10 mL). Pyridine (1.15 mL, 14.3 mmol) was added dropwise, and the resulting red slurry was stirred at room temperature for 10 min. This solution was transferred via cannula to a magnetically stirred solution of 5 (441 mg, 148 mmol) in dichloromethane (5 mL). After 30 min, the insolubles were separated by filtration through Celite (ether wash) and the filtrate was evaporated. The residual oil was purified by MPLC on silica gel (elution with 2.5% ethyl acetate in petroleum ether) to give pure 7 as a colorless oil (276 mg, 63%): IR (neat, cm^{-1}) 3065, 3030, 2960, 1645, 1600, 1575, 1495, 1455, 1255, 1225, 845; ^1H NMR (300 MHz, C_6D_6) δ 7.22–6.95 (m, 10 H), 4.06 (d, J = 13.3 Hz, 1 H), 2.43 (d, J = 13.3 Hz, 1 H), 1.22 (s, 3 H), 0.09 (s, 9 H); ^{13}C NMR (75 MHz, C_6D_6) 207.80, 141.90, 138.77, 129.58, 128.63, 127.41, 126.81, 126.04, 125.57, 46.86, 40.40, 17.35, −4.03 ppm; MS m/z (M^+) calcd 296.1596, obsd 296.1586.

Anal. Calcd for $C_{19}H_{24}OSi$: C, 76.97; H, 8.16. Found: C, 76.80; H, 8.19.

Haller–Bauer Cleavage Reactions of 7. Ketone 7 (40–70 mg) was dissolved in the reaction solvent (benzene or *tert*-butyl alcohol), and the base (10–15 equiv) was added. The stirred reaction mixture was heated at the reflux temperature for 12–16 h under nitrogen, allowed to cool, and extracted with pentane (20 mL). The pentane solution was washed with brine (3 × 20 mL) and dried. If the volatile Haller–Bauer product was detected, the pentane solution was concentrated by distillation through a Vigreux column until ca. 2 mL of solution remained. 2-(Trimethylsilyl)-1-phenylpropane (8) was isolated by preparative gas chromatography: IR (CCl_4, cm^{-1}) 3080, 3060, 3030, 2960, 2860, 1600, 1495, 1455, 1250, 845; ^1H NMR (300 MHz, $CDCl_3$) δ 7.46–7.33 (m, 3 H), 7.28–7.23 (m, 2 H), 2.95 (dd, J = 13.7, 4.0 Hz, 1 H), 2.34 (dd, J = 13.7, 11.0 Hz, 1 H), 1.09–0.99 (m, 1 H), 0.93 (d, J = 6.9 Hz, 3 H), 0.10 (s, 9 H); ^{13}C NMR (75 MHz, $CDCl_3$) 142.73, 128.81, 128.05, 125.48, 38.04, 22.08, 13.66, −3.33 ppm; MS m/z (M^+) calcd 192.1334, obsd 192.1348.

When no Haller–Bauer cleavage product was detected by gas chromatography, TLC analysis (5% ethyl acetate in petroleum ether) revealed whether the trimethylsilyl enol 6 (higher R_f than ketone 7) or the ketone 8 (lower R_f than 7) was formed. Silyl enol ether 6 was isolated by filtration of the pentane solution through silica gel and evaporation to leave material having those physical properties reported above.

Ketone 8 was isolated by chromatography (silica gel, elution with 2.5% ethyl acetate in petroleum ether): IR (neat, cm^{-1}) 3060, 3020, 2965, 2930, 1675, 1595, 1580, 1495, 1450, 1230; ^1H NMR (300 MHz, $CDCl_3$) δ 7.95–7.92 (m, 2 H), 7.58–7.43 (m, 3 H), 7.30–7.16 (m, 5 H), 3.76 (hextuplet, J = 6.9 Hz, 1 H), 3.18 (dd, J = 13.7, 6.3 Hz, 1 H), 2.71 (dd, J = 13.7, 7.8 Hz, 1 H), 1.21 (d, J = 6.9 Hz, 3 H); ^{13}C NMR (20 MHz, $CDCl_3$) 203.22, 139.75, 136.49, 132.57, 128.87, 128.36, 128.16, 128.03, 125.99, 45.52, 39.28, 17.21 ppm; MS m/z (M^+) calcd 224.1201, obsd 224.1203.

***l*-Menthyl (Trimethylsilyl)acetate (10).** *l*-Menthyl acetate (4.95 g, 25.0 mmol)[25] was added to a solution of lithium diisopropylamide (25.0 mmol) in anhydrous tetrahydrofuran (25 mL) at −78 °C during 5 min. After 30 min, hexamethylphosphoramide

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(10 mL) was introduced, and the reaction mixture was stirred for a further 10 min before trimethylsilyl chloride (3.42 g, 32 mmol) was added. The solution was allowed to warm to room temperature over 1 h. Extraction with ether and repeated washing of the combined organic phases with ammonium chloride solution (6 × 50 mL) and brine (3 × 50 mL) prior to drying and solvent evaporation gave an oil. Column chromatography of this material followed by bulb-to-bulb distillation (155 °C/0.2 Torr) afforded **10** as a colorless oil (5.92 g, 88%): IR (neat, cm^{-1}) 2960, 2930, 2880, 1715, 1455, 1245; ^1H NMR (300 MHz, $CDCl_3$) δ 4.61 (td, J = 10.9, 4.3 Hz, 1 H), 1.99–1.76 (m, 2 H), 1.88 (d, J = 11.8 Hz, 1 H), 1.79 (d, J = 11.8 Hz, 1 H), 1.43 (m, 1 H), 1.30 (m, 1 H), 1.1–0.7 (m, 3 H), 0.86 (d, J = 6.8 Hz, 6 H), 0.72 (d, J = 7.0 Hz, 3 H), 0.09 (s, 9 H); ^{13}C NMR (20 MHz, $CDCl_3$) 171.59, 73.19, 46.95, 41.07, 34.17, 31.16, 26.69, 25.93, 23.23, 21.74, 20.48, 15.98, –1.62 ppm; MS m/z ($M^+ - C_{10}H_{18}$) calcd 115.0579, obsd 115.0566; $[\alpha]^{23}_D$ –48.7° (c 6.1, $CHCl_3$).

Anal. Calcd for $C_{15}H_{30}O_2Si$: C, 66.61; H, 11.18. Found: C, 66.60; H, 11.15.

***l*-Menthyl 2-(Trimethylsilyl)-3-phenylpropionate.** *l*-Menthyl (trimethylsilyl)acetate (**10**, 10.0 g, 37.0 mmol) in dry tetrahydrofuran (10 mL) was added dropwise to a cold (–78 °C), magnetically stirred solution of lithium diisopropylamide (40.0 mmol) in the same solvent (40 mL) during 10 min. Twenty minutes later, benzyl bromide (6.5 g, 38 mmol) was introduced, and the reaction mixture was allowed to warm to room temperature overnight. After the customary aqueous workup, silica gel chromatography (elution with 1% ethyl acetate in petroleum ether), and bulb-to-bulb distillation (200–205 °C/0.4 Torr), the product ester was isolated as a colorless oil (8.32 g, 63%). On standing, the major diastereomer crystallized. After two recrystallizations from methanol–water, the diastereomer showed constant optical rotation.

For the major diastereomer: mp 69–70 °C; IR ($CHCl_3$, cm^{-1}) 3010, 2960, 2930, 2870, 1695, 1600, 1495, 1455, 1255, 845; ^1H NMR (300 MHz, $CDCl_3$) δ 7.22–7.14 (m, 5 H), 4.60 (td, J = 10.7, 4.5 Hz, 1 H), 3.07 (dd, J = 14.2, 12.2 Hz, 1 H), 2.72 (dd, J = 14.2, 2.8 Hz, 1 H), 2.33 (dd, J = 12.2, 2.8 Hz, 1 H), 1.85 (m, 1 H), 1.65–0.6 (series of m, 8 H), 0.86 (d, J = 6.5 Hz, 3 H), 0.69 (d, J = 7.0 Hz, 3 H), 0.49 (d, J = 6.9 Hz, 3 H), 0.15 (s, 9 H); MS m/z (M^+) calcd 360.2485, obsd 24.99; $[\alpha]^{25}_D$ –60.4° (c 3.6, $CHCl_3$).

Anal. Calcd for $C_{22}H_{36}O_2Si$: C, 73.28; H, 10.06. Found: C, 73.35; H, 10.05.

For the minor diastereomer (not isolated pure): ^1H NMR (300 MHz, $CDCl_3$) δ 7.27–7.12 (m, 5 H), 4.56 (td, J = 10.8, 4.4 Hz, 1 H), 3.11 (dd, J = 14.9, 12.0 Hz, 1 H), 2.80 (dd, J = 14.9, 3.5 Hz, 1 H), 2.36 (dd, J = 12.0, 3.5 Hz, 1 H), 1.9–0.7 (series of m, 9 H), 0.84 (d, J = 6.6 Hz, 3 H), 0.77 (d, J = 7.0 Hz, 3 H), 0.58 (d, J = 6.9 Hz, 3 H), 0.15 (s, 9 H).

***l*-Menthyl 2-Methyl-2-(trimethylsilyl)-3-phenylpropionate (12a/13a).** A solution of the preceding ester (8.32 g, 22.6 mmol, mixture of diastereomers) in dry tetrahydrofuran (10 mL) was added dropwise to a solution of lithium diisopropylamide (30 mmol) in the same solvent (30 mL) at –78 °C. After 1 h at this temperature, methyl iodide (4.5 g, 32 mmol) was introduced and the reaction mixture was allowed to warm to room temperature. Following the usual aqueous workup, the resulting yellow oil was subjected to silica gel chromatography (elution with 1% ethyl acetate in petroleum ether). The front half of the product band was collected and concentrated (3.7 g, 44%). Three crystallizations from methanol–water at 5 °C furnished colorless needles, mp 68 °C, of the major diastereomer **12a** (2.5 g, 29%): IR ($CHCl_3$, cm^{-1}) 3090, 3060, 3010, 2960, 2870, 1680, 1600, 1455, 1260, 1250, 845; ^1H NMR (300 MHz, $CDCl_3$) δ 7.24–7.13 (m, 5 H), 4.69 (td, J = 10.8, 4.4 Hz, 1 H), 3.55 (d, J = 13.4 Hz, 1 H), 2.44 (d, J = 13.4 Hz, 1 H), 1.98 (br d, J = 11.9 Hz, 1 H), 1.69–1.47 (m, 4 H), 1.30–1.21 (m, 1 H), 1.03 (s, 3 H), 1.0–0.7 (m, 3 H), 0.90 (d, J = 6.6 Hz, 3 H), 0.74 (d, J = 7.0 Hz, 3 H), 0.63 (d, J = 6.9 Hz, 3 H), 0.14 (s, 9 H); ^{13}C NMR (75 MHz, $CDCl_3$) 175.87, 139.03, 130.07, 127.76, 126.00, 73.81, 47.06, 41.31, 39.28, 38.40, 34.32, 31.48, 25.44, 23.02, 22.11, 20.84, 16.08, 15.81, –3.75 ppm; MS m/z (M^+ – menthene) calcd 236.1232, obsd 236.1248; $[\alpha]^{25}_D$ –56.6°, $[\alpha]^{25}_{578}$ –58.8°, $[\alpha]^{25}_{546}$ –66.2°, $[\alpha]^{25}_{436}$ –106.9°, $[\alpha]^{25}_{365}$ –154.1° (c 1.4, $CHCl_3$).

For the minor diastereomer **13a**, a yellowish oil of 60% de (44% by route B): ^1H NMR (300 MHz, $CDCl_3$) δ 7.29–7.09 (m, 5 H), 4.61 (td, J = 10.8, 4.3 Hz, 1 H), 3.49 (d, J v= 13.8 Hz, 1 H), 2.55 (d, J = 13.8 Hz, 1 H), 2.17–1.89 (m, 2 H), 1.80–1.21 (m, 4 H), 1.1–0.7 (m, 3 H), 1.00 (s, 3 H), 0.88 (d, J = 6.6 Hz, 3 H), 0.87 (d, J = 7.1 Hz, 3 H), 0.75 (d, J = 6.8 Hz, 3 H), 0.13 (s, 9 H); ^{13}C NMR (75 MHz, $CDCl_3$) 176.55, 138.76, 129.75, 127.86, 126.09, 47.11, 41.18, 39.81, 37.82, 34.29, 31.39, 25.51, 22.82, 22.05, 21.09, 16.20, 15.71, –3.58 ppm.

X-ray Crystallographic Analysis of 12a. Crystals of this ester are clear and colorless. The morphology is that of a hexagonal rod, and the crystal used for data collection was cut from such a rod. Preliminary examination of the diffraction pattern on a Syntex (Nicolet) P1 diffractometer equipped with an LT-1 low-temperature device indicated a monoclinic crystal system with systematic absences $0k0$, $k = 2n + 1$. The cell constants a = 9.493 (2) Å, b = 6.651 (2) Å, c = 18.391 (3) Å, and β = 96.64 (1)° were determined at –118 °C on the basis of the centering of 20 reflections with 2θ values in the range 20–29° (Mo Kα radiation, λ(Kα) = 0.71069 Å).

Intensities were measured by the θ–2θ scan method at –118 °C because of the low melting point for this compound. Six standard reflections were measured after every 100 reflections and gave no indication of crystal decomposition. Data reduction was done with the CRYM crystallographic computing package.[21]

Since a reasonable calculated density is obtained for Z = 2 and since one enantiomer of the molecule is expected to be present in the unit cell, the space group possibilities are reduced to just one, $P2_1$. The structure was solved by locating the position of the Si atom from a Patterson map. The Si atom was then phased on in the DIRDIF procedure,[22] and the whole molecule appeared on the resulting electron density map. The correct enantiomer was chosen on the basis of the known stereochemistry of the menthyl portion. The y coordinate of the Si atom was fixed in order to define the origin with respect to the polar y axis. The SHELX-76 package[23] was used for all full-matrix least-squares refinements. Most of the hydrogen atoms were located in a difference electron density map after the anisotropic refinement stage had been reached. The hydrogen atoms were included in the model as fixed contributions in their calculated positions with C–H = 0.98 Å and $B_H = B_{C(iso)} + 1.0$ Å^2. The methyl-group hydrogen atoms were idealized to sp^3 geometry on the basis of their locations in the difference electron density map. The final refinement cycle for the 2194 intensities with $F_o^2 > 2\sigma(F_o^2)$ and the 234 variables (anisotropic non-hydrogen atoms and hydrogen atoms fixed) resulted in agreement indices of R = 0.035 and R_w = 0.035 (based on F). The final difference electron density map has maximum and minimum peak heights of 0.19 and –0.19 e/Å^3. Complex neutral atom scattering factors supplied by the SHELX-76 package were used in the calculations.[24]

***l*-Menthyl 2-(Trimethylsilyl)-5-methyl-4-hexenoate.** Treatment of **10** (5.20 g, 19.2 mmol) with prenyl bromide (3.50 g, 23.5 mmol) in the presence of LDA in the predescribed manner afforded 6.28 g (96%) of the alkylated ester as a 55:45 mixture of diastereomers (^1H NMR analysis), which were not separated: IR (neat, cm^{-1}) 2960, 2930, 2875, 1710, 1450, 1245, 1135; MS m/z (M^+) calcd 338.2641, obsd 338.2612.

For the major diastereomer: ^1H NMR (300 MHz, $CDCl_3$) δ 5.08 (m, 1 H), 4.69 (dt, J = 10.8, 4.3 Hz, 1 H), 2.5–2.4 (m, 1 H), 2.1–0.6 (series of m, 11 H), 1.65 (br s, 3 H), 1.60 (br s, 3 H), 0.89 (d, J = 6.5 Hz, 6 H), 0.73 (d, J = 6.8 Hz, 3 H), 0.09 (s, 9 H).

For the minor diastereomer: ^1H NMR (300 MHz, $CDCl_3$) δ 5.08 (m, 1 H), 4.67 (dt, J = 10.9, 4.4 Hz, 1 H), 2.5–2.4 (m, 1 H), 2.1–0.6 (series of m, 11 H), 1.65 (br s, 3 H), 1.60 (br s, 3 H), 0.89 (d, J = 6.9 Hz, 3 H), 0.88 (d, J = 6.6 Hz, 3 H), 0.75 (d, J = 6.0 Hz, 3 H), 0.09 (s, 9 H).

***l*-Menthyl 2,5-Dimethyl-2-(trimethylsilyl)-4-hexenoate (12b/13b).** A 6.00-g (17.7 mmol) sample of the above ester was methylated as for **12a/13a** to give **12b/13b**, a colorless oil, as a 55:45 mixture of diastereomers (capillary GC analysis) (5.96 g, 95%): IR (neat, cm^{-1}) 2960, 2930, 2870, 1455, 1375, 1245, 1225; MS m/z (M^+) calcd 352.2803, obsd 352.2800.

Anal. Calcd for $C_{21}H_{40}O_2Si$: C, 71.53; H, 11.43. Found: C, 71.42; H, 11.42.

MPLC of the mixture on silica gel provided **12b** of 82% de (41%): ^1H NMR (300 MHz, $CDCl_3$) δ 5.10–5.05 (m, 1 H), 4.69 (td, J = 10.8, 4.3 Hz, 1 H), 1.99–1.89 (m, 3 H), 1.68 (s, 3 H), 1.68–1.31 (m, 4 H), 1.60 (s, 3 H), 1.12 (s, 3 H), 0.89 (d, J = 6.6

Hz, 3 H), 0.88 (d, J = 7.0 Hz, 3 H), 0.75 (d, J = 6.9 Hz, 3 H), 0.75 (m, 3 H), 0.07 (s, 9 H); ^{13}C NMR (75 MHz, $CDCl_3$) 176.44, 132.99, 120.75, 73.52, 47.09, 41.14, 37.03, 34.31, 32.26, 31.41, 25.75, 25.71, 22.93, 22.02, 20.86, 17.85, 16.42, 15.69, -3.72 ppm; $[\alpha]^{22}_D$ -51.5°, $[\alpha]^{22}_{578}$ -53.8°, $[\alpha]^{22}_{546}$ -60.8°, $[\alpha]^{22}_{436}$ -100.3°, $[\alpha]^{22}_{365}$ -150.1° (c 7.0,$CHCl_3$).

For **13b**: colorless oil of 80% de (43% by route B); ^{1}H NMR (300 MHz, $CDCl_3$) δ 5.06-5.01 (m, 1 H), 4.62 (td, J = 10.8, 4.3 Hz, 1 H), 2.58 (m, 1 H), 2.13-1.95 (m, 3 H), 1.69 (s, 3 H), 1.68-1.59 (m, 4 H), 1.59 (s, 3 H), 1.09 (s, 3 H), 1.10-0.80 (m, 3 H), 0.90 (d, J = 6.5 Hz, 3 H), 0.88 (d, J = 7.1 Hz, 3 H), 0.73 (d, J = 6.9 Hz, 3 H), 0.07 (s, 9 H); ^{13}C NMR (75 MHz, $CDCl_3$) 176.73, 133.18, 120.81, 73.92, 47.20, 41.18, 36.94, 34.36, 32.19, 31.43, 25.81, 25.77, 22.97, 22.07, 21.07, 17.85, 16.53, 15.61, -3.55 ppm.

***l*-Menthyl 2-(Trimethylsilyl)-4-phenylbutyrate.** Phenethyl iodide (5.60 g, 24.0 mmol) was added to the enolate formed from **10** (5.95 g, 22.0 mmol) and LDA (24.0 mmol) in tetrahydrofuran (25 mL) as above. After workup, there was isolated 3.89 g (47%) of the ester as a colorless oily 55:45 mixture (^{1}H NMR analysis) of diastereomers: IR (neat, cm^{-1}) 3080, 3060, 3010, 2960, 2870, 2830, 1708, 1600, 1455, 1255, 845; ^{1}H NMR (300 MHz, $CDCl_3$) δ 7.39-7.23 (m, 5 H), 4.80 (m, 1 H), 2.81-2.79 (m, 1 H), 2.56 (m, 1 H), 2.20-2.01 (m, 4 H), 1.79-1.72 (m, 2 H), 1.64-1.44 (m, 2 H), 1.17-0.83 (m, 13 H), 0.15 (s, . H); MS m/z (M^+) calcd 374.2641, obsd 374.2658.

***l*-Menthyl 2-Methyl-2-(trimethylsilyl)-4-phenylbutyrate (12c/13c).** Methylation of the above ester (3.86 g, 10.3 mmole as before gave after workup 4.03 g (100%) of a 55:45 mixture of diastereomers (capillary GC analysis): IR (neat, cm^{-1}) 3080, 3060, 3020, 2950, 2910, 2865, 1703, 1600, 1495, 1455, 1250, 1235, 845; MS m/z ($M^+ - C_{10}H_{18}$) calcd 250.1389, obsd 250.1394.

MPLC of the mixture on silica gel provided **12c** (34%) as colorless crystals, mp 60.5 °C (from methanol-water): ^{1}H NMR (300 MHz, $CDCl_3$) δ 7.26-7.15 (m, 2 H), 7.13-7.10 (m, 3 H), 4.72 (td, J = 10.9, 4.4 Hz, 1 H), 2.61 (td, J = 12.7, 4.9 Hz, 1 H), 2.40 (td, J = 12.6, 4.1 Hz, 1 H), 2.20 (td, J = 12.9, 4.1 Hz, 1 H), 2.02-1.87 (m, 2 H), 1.68-1.60 (m, 2 H), 1.54-1.31 (m, 3 H), 1.22 (s, 3 H), 1.07-0.71 (m, 3 H), 0.86 (d, J = 6.5 Hz, 3 H), 0.85 (d, J = 7.0 Hz, 3 H), 0.72 (d, J = 7.0 Hz, 3 H), 0.00 (s, 9 H); ^{1o}C NMR (75 MHz, $CDCl_3$) 176.40, 142.92, 128.45, 128.35, 125.72, 73.83, 47.20, 41.44, 37.01, 36.73, 34.35, 31.51 (2 C), 25.87, 22.96, 22.11, 20.95, 16.60, 15.74, -3.72 ppm; $[\alpha]^{25}_D$ +3.1°, $[\alpha]^{25}_{578}$ +3.5°, $[\alpha]^{25}_{546}$ +4.8°, $[\alpha]^{25}_{436}$ +16.3°, $[\alpha]^{25}_{365}$ +43.8° (c 2.2, $CHCl_3$).

Anal. Calcd for $C_{24}H_{40}O_2Si$: C, 74.17; H, 10.37. Found: C, 74.01; H, 10.41.

For **13c**: colorless oil of 80% de (44% by route B); ^{1}H NMR (300 MHz, $CDCl_3$) δ 7.25-7.09 (m, 5 H), 4.63 (td, J = 10.9, 4.3 Hz, 1 H), 2.67 (td, J = 12.7, 4.9 Hz, 1 H), 2.38-2.18 (m, 2 H), 2.06-1.85 (m, 2 H), 1.65-1.32 (m, 5 H), 1.20 (s, 3 H), 1.14-0.76 (m, 3 H), 0.86 (d, J = 7.3 Hz, 3 H), 0.85 (d, J = 5.9 Hz, 3 H), 0.73 (d, J = 7.0 Hz, 3 H), 0.00 (s, 9 H); ^{13}C NMR (75 MHz, $CDCl_3$) 176.55, 142.62, 128.36, 128.28, 125.77, 74.17, 47.25, 41.40, 37.04, 36.45, 34.37, 31.57, 31.49, 25.74, 22.85, 22.09, 21.04, 16.58, 15.63, -3.62 ppm; $[\alpha]^{22}_D$ -62.5° (c 2.1, $CHCl_3$), $[\alpha]^{25}_D$ calcd for 100% purity = -69.8°.

***l*-Menthyl 2-(Trimethylsilyl)heptanoate.** The enolate of **10** (5.90 g, 20.8 mmol) was alkylated with n-pentyl iodide (4.95 g, 25 mmol) as before. There was isolated 4.26 g (59%) of the ester as a 70:30 mixture of diastereomers: IR (neat, cm^{-1}) 2930, 2865, 1710, 1455, 1255, 845; ^{1}H NMR (300 MHz, $CDCl_3$) δ 4.75-4.60 (m, 1 H), 2.04-1.52 (m, 6 H), 1.49-1.20 (m, 9 H), 1.12-0.85 (m, 12 H), 0.80-0.73 (m, 3 H), 0.07 (s, 9 H); MS m/z ($M^+ - C_{10}H_{18}$) calcd 202.1389, obsd 202.1322.

***l*-Menthyl 2-Methyl-2-(trimethylsilyl)heptanoate (12d/13d).** The above ester (4.26 g, 12.5 mmol) was methylated under the predescribed conditions to yield 4.11 g (93%) of a 50:50 mixture of **12d** and **13d**: IR (neat, cm^{-1}) 2960, 2930, 2870, 1703, 1470, 1455, 1385, 1375, 1370, 1255, 1235, 845; MS m/z ($M^+ - C_{10}H_{18}$) calcd 216.1546, obsd 216.1534.

Anal. Calcd for $C_{21}H_{42}O_2$: C, 71.12; H, 11.94. Found: C, 71.34; H, 12.10.

MPLC of the mixture on silica gel provided **12d** (40%) as a colorless oil of 89% de: ^{1}H NMR (300 MHz, $CDCl_3$) δ 4.69 (td, J = 10.8, 4.3 Hz, 1 H), 1.96-1.87 (m, 3 H), 1.69-1.61 (m, 2 H), 1.49-0.83 (series of m, 15 H), 1.14 (s, 3 H), 0.88 (d, J = 7.0 Hz, 3 H), 0.87 (d, J = 7.6 Hz, 3 H), 0.73 (d, J = 6.9 Hz, 3 H), 0.04 (s, 9 H); ^{13}C NMR (75 MHz, $CDCl_3$ 176.76, 73.52, 47.15, 41.26, 36.76, 34.35, 33.99, 32.42, 31.46, 25.77, 24.59, 22.92, 22.60, 22.08, 20.95, 16.44, 15.70, 14.00, -3.69 ppm; $[\alpha]^{23}_D$ -33.3°, $[\alpha]^{23}_{578}$ -34.7°, $[\alpha]^{23}_{546}$ -38.9°, $[\alpha]^{23}_{436}$ -62.1°, $[\alpha]^{23}_{365}$ -88.3° (c 2.9, $CHCl_3$).

For **13d**: colorless oil of 80% de (41%); ^{1}H NMR (300 MHz, $CDCl_3$) δ 4.58 (td, J = 10.8, 4.3 Hz, 1 H), 2.08-1.86 (m, 3 H), 1.69-1.63 (m, 2 H), 1.49-0.78 (series of m, 15 H), 1.12 (s, 3 H), 0.89 (d, J = 6.8 Hz, 6 H), 0.72 (d, J = 7.0 Hz, 3 H), 0.04 (s, 9 H); ^{13}C NMR (75 MHz, $CDCl_3$) 176.96, 73.89, 47.24, 41.30, 36.95, 34.39, 34.07, 32.56, 31.44, 25.58, 25.11, 22.84, 22.77, 22.09, 21.03, 16.33, 15.65, 14.12, -3.64 ppm; $[\alpha]^{23}_D$ -39.6°, $[\alpha]^{23}_{578}$ -41.2° $[\alpha]^{23}_{546}$ -46.3°, $[\alpha]^{23}_{436}$ -72.1°, $[\alpha]^{23}_{365}$ -96.8° (c 3.8, $CHCl_3$).

Prototypical Example of Route B. *l*-Menthyl propanoate (5.4 g, 25.0 mmol) exhibiting $[\alpha]^{23}_D$ -83.14° (c 9.7, $CHCl_3$)[26] was added to a solution of lithium diisopropylamide (25.0 mmol) in dry tetrahydrofuran (25 mL) at -78 °C over 5 min. After an additional 30 min, HMPA (10 mL) was added, and the reaction mixture was stirred for 10 min longer. Trimethylsilyl chloride (3.47 g, 32 mmol) was introduced, and the solution was allowed to warm to room temperature over 1 h. The product was taken up in ether (250 mL) and washed with saturated ammonium chloride solution (6 × 50 mL) and brine (3 × 50 mL). After drying and solvent evaporation, the residual oil was purified by silica gel chromatography (elution with 3% ethyl acetate in petroleum ether) and subsequent bulb-to-bulb distillation (200 °C/0.2 Torr). There was isolated 2.37 g (33%) of *l*-menthyl 2-(trimethylsilyl)propanoate as a colorless oil: IR (film, cm^{-1}) 2960, 2880, 1710, 1455, 1310, 1255, 1245, 845; ^{1}H NMR (300 MHz, $CDCl_3$) δ 4.71-4.61 (m, 1 H), 2.05-1.80 (m, 3 H), 1.75-1.65 (m, 2 H), 1.55-1.3 (m, 2 H) [1.15 (d, J = 7.2 Hz, 3 H, minor diastereomer) and 1.18 (d, J = 7.1 Hz, 3 H, major diastereomer) over (m, 3 H)], 0.88 (d, J = 7 Hz, 6 H) [0.75 (d, J = 6.8 Hz, 3 H, minor diastereomer) and 0.74 (d, J = 6.9 Hz, 3 H, major diastereomer)], 0.07 (s, H); MS m/z ($M^+ - C_{16}H_{18}$) calcd 146.0763, obsd 146.0804.

A 2.25-g (7.9 mmol) sample of the ester was transformed into its enolate with LDA in tetrahydrofuran at -78 °C and treated with 7.9 mmol of benzyl bromide. Product purification by silica gel chromatography (elution with 2% ethyl acetate in petroleum ether) afforded 2.53 g of an oil of 85% purity containing 31% of **12a** and 69% of **13a** (capillary GC analysis). Further purification by MPLC (silica gel, 1% ethyl acetate in petroleum ether) gave a colorless oil (44% yield) composed of 20% of **12a** and 80% of **13a**.

Hydride Reduction of the Diastereomerically Purified *l*-Menthyl Esters 12a-d. A. (*R*)-(-)-2-Methyl-2-(trimethylsilyl)-3-phenylpropanol. The crystalline **12a** (>98% de, 2.74 g, 7.31 mmol) was dissolved in dichloromethane (25 mL), cooled to 0 °C, treated with diisobutylaluminum hydride (16 mL of 1.0 M in hexanes, 16.0 mmol), and stirred at 0 °C for 1 h. Methanol (1 mL), ether (100 mL), and sodium potassium tartrate solution were sequentially added, and the reaction mixture was allowed to warm to room temperature during 3 h. The organic phase was separated, washed with brine (3 × 50 mL), dried, and concentrated. The residue was purified by MPLC (silica gel, elution with 5% ethyl acetate in petroleum ether) followed by bulb-to-bulb distillation (175-185 °C/0.4 Torr). The alcohol was obtained as a colorless oil (1.28 g, 79%), which solidified on standing; mp 35-40 °C. The spectral properties of this material were identical with those reported above: $[\alpha]^{23}_D$ -5.7°, $[\alpha]^{23}_{578}$ -5.9°, $[\alpha]^{23}_{546}$ -6.6°, $[\alpha]^{23}_{463}$ -10.3°, $[\alpha]^{23}_{365}$ -14.5° (c 4.6, C_6H_6).

B. (*R*)-(-)-2,5-Dimethyl-2-(trimethylsilyl)-4-hexen-1-ol. Treatment of **12b** (46% de, 3.21 g, 9.10 mmol) with Dibal-H (20 mmol) gave 1.17 g (64%) of the alcohol after MPLC (silica gel, elution with 6% ethyl acetate in petroleum ether): IR (neat, cm^{-1}) 3400, 2960, 2920, 2860, 1450, 1325, 1250, 845; ^{1}H NMR (300 MHz, C_6D_6) δ 5.29 (tq, J = 7.7, 0.7 Hz, 1 H), 3.34 (d, J = 2.8 Hz, 2 H), 2.12 (d, J = 7.7 Hz, 2 H), 1.67 (s, 3 H), 1.56 (d, J = 0.7 Hz, 3 H), 0.82 (s, 3 H), 0.73 (br s, 1 H), 0.08 (s, 9 H); ^{13}C NMR (75 MHz, C_1D_6) 132.56, 121.89, 69.40, 33.16, 27.98, 26.09, 18.31, 17.87, -2.58 ppm; MS m/z ($M^+ - Me_3SiOH$) calcd 110.1096, obsd 110.1132; $[\alpha]^{25}_D$ -0.95°, $[\alpha]^{25}_{578}$ -0.98°, $[\alpha]^{25}_{546}$ -1.10°, $[\alpha]^{25}_{476}$ -1.9°, $[\alpha]^{25}_{365}$ -3.0° (c C_6H_6).

(26) Akiyama, F.; Tokura, N. *Bull. Chem. Soc. Jpn.* **1966**, *39*, 131.

C. (*R*)-(−)-2-Methyl-2-(trimethylsilyl)-4-phenylbutanol. Reduction of **12c** (>98% de, 1.25 g, 3.25 mmol) with Dibal-H (10 mmol) in the predescribed manner afforded the alcohol as a colorless oil (617 mg, 81%) after bulb-to-bulb distillation (200–205 °C/0.4 Torr): IR (neat, cm^{-1}) 3590, 3400, 3080, 3060, 3025, 2950, 2900, 2860, 1600, 1580, 1495, 1455, 1250, 840; ^1H NMR (300 MHz, C_6D_6) δ 7.23–7.09 (m, 5 H), 3.34 (d, J = 11.8 Hz, 1 H), 3.31 (d, J = 11.8 Hz, 1 H), 2.57–2.52 (m, 2 H), 1.72–1.66 (m, 2 H), 0.82 (s, 3 H), 0.76 (br s, 1 H), 0.07 (s, 9 H); ^{13}C NMR (75 MHz, C_6D_6) 142.75, 127.68, 127.64, 124.95, 68.15, 36.77, 30.23, 26.08, 17.18, −3.53 ppm; MS m/z ($M^+ - H_2O$) calcd 218.14918, obsd 218.1504; $[\alpha]^{24}_D$ −2.2°, $[\alpha]^{24}_{578}$ −2.3°, $[\alpha]^{24}_{546}$ −2.6°, $[\alpha]^{24}_{436}$ −5.2°, $[\alpha]^{24}_{365}$ −9.7° (*c* 2.7, C_6H_6).

D. (*R*)-(−)-2-Methyl-2-(trimethylsilyl)heptanol. Ester **12d** of 89% de (1.68 g, 4.74 mmol) was treated with Dibal-H as above. MPLC on silica gel (elution with 10% ethyl acetate in petroleum ether) followed by bulb-to-bulb distillation (140–145 °C/0.4 Torr) gave the alcohol as a colorless oil (688 mg, 72%): IR (neat, cm^{-1}) 3460, 2960, 2930, 2860, 1465, 1455, 1250, 840; ^1H NMR (300 MHz, C_1D_6) δ 3.30 (d, J = 3.6 Hz, 2 H), 1.40–1.17 (m, 8 H), 0.90 (t, J = 6.9 Hz, 3 H), 0.79 (s, 3 H), 0.65 (br s, 1 H), 0.07 (s, 9 H); ^{13}C NMR (75 MHz, C_6D_6) 69.48, 35.22, 33.43, 26.90, 24.21, 23.04, 18.40, 14.34, −2.43 ppm; MS m/z ($M^+ - Me_3SiOH$) calcd 112.1252, obsd 112.1236; $[\alpha]^{25}_D$ −0.3°; $[\alpha]^{25}_{578}$ −0.3°, $[\alpha]^{25}_{546}$ −0.3°, $[\alpha]^{25}_{436}$ −0.8°, $[\alpha]^{25}_{365}$ −1.7° (*c* 4.6, C_6H_6).

Fetizon Oxidation of the Enantiomerically Enriched Alcohols. A. (*R*)-(−)-2-Methyl-2-(trimethylsilyl)-3-phenylpropanal. A sample of optically pure alcohol (538 mg, 2.42 mmol) was oxidized with freshly prepared Fetizon reagent[15] (18.5 g) in benzene (70 mL) during 6 h as described for racemic **3**. Workup and bulb-to-bulb distillation (144–160 °C/0.5 Torr) afforded 439 mg (82%) of the aldehyde as a waxy white solid, mp 46–53 °C: spectroscopically identical with racemic **4**; $[\alpha]^{24}_D$ −53.9°, $[\alpha]^{24}_{578}$ −56.6°, $[\alpha]^{24}_{546}$ −65.4°, $[\alpha]^{24}_{436}$ −123.7°, $[\alpha]^{24}_{365}$ −229.4 (*c* 3.4, C_6H_6).

B. (*R*)-(−)-2,5-Dimethyl-2-(trimethylsilyl)-4-hexenal. Treatment of the alcohol (46% ee, 1.14 g, 5.7 mmol) with 20 g of the Fetizon reagent[15] in the predescribed manner gave 756 mg (67%) of the aldehyde as a colorless oil: IR (neat, cm^{-1}) 2960, 2920, 2695, 1685, 1450, 1375, 1250; ^1H NMR (300 MHz, C_6D_6) δ 9.98 (s, 1 H), 5.05 (m, 1 H), 2.58 (dd, J = 14.5, 6.3 Hz, 1 H), 2.08 (dd, J = 14.5, 8.5 Hz, 1 H), 1.57 (d, J = 0.5 Hz, 3 H), 1.48 (s, 3 H), 1.08 (s, 3 H), −0.10 (s, 9 H); ^{13}C NMR (20 MHz, C_6D_6) 204.40, 133.49, 121.05, 46.58, 30.09, 25.75, 17.74, 13.90, −3.92 ppm; MS m/z (M^+) calcd 198.1440, obsd 198.1438; $[\alpha]^{24}_D$ −19.1°, $[\alpha]^{24}_{578}$ −22.6°, $[\alpha]^{24}_{546}$ −49.4°, $[\alpha]^{24}_{436}$ −117.0° (*c* 1.8, C_6H_6).

Anal. Calcd for $C_{11}H_{22}OSi$: C, 66.60; H, 11.18. Found: C, 66.76; H, 11.16.

C. (*R*)-(+)-2-Methyl-2-(trimethylsilyl)-4-phenylbutanal. From 591 mg (2.50 mmol) of the optically pure alcohol and 13.5 g of the Fetizon reagent,[15] there was isolated 474 mg (81%) of the aldehyde as a sticky white solid, mp 39–46 °C, after bulb-to-bulb distillation (190–195 °C/0.4 Torr): IR (neat, cm^{-1}) 3080, 3055, 3025, 2950, 2860, 2800, 2690, 1688, 1600, 1580, 1495, 1450, 1255, 845; ^1H NMR (300 MHz, C_6D_6) δ 9.50 (s, 1 H), 7.18–7.04 (m, 5 H), 2.53–2.43 (m, 1 H), 2.37–2.20 (m, 2 H), 1.58–1.48 (m, 1 H), 1.09 (s, 3 H), −0.18 (s, 9 H); ^{13}C NMR (75 MHz, C_6D_6) 204.20, 142.58, 128.75, 128.68, 126.26, 46.40, 34.08, 32.24, 13.44, −4.18 ppm; MS m/z ($M^+ - C_7H_7$) calcd 143.0892, obsd 143.0902; $[\alpha]^{24}_D$ +21.6°, $[\alpha]^{24}_{578}$ +22.3°, $[\alpha]^{24}_{546}$ +24.1°, $[\alpha]^{24}_{436}$ +23.7°, $[\alpha]^{24}_{365}$ −49.1° (*c* 2.6, C_6H_6).

Anal. Calcd for $C_{14}H_{22}OSi$: C, 71.73; H, 9.46. Found: C, 71.96; H, 9.32.

D. (*R*)-(−)-2-Methyl-2-(trimethylsilyl)heptanal. Oxidation of 89% ee alcohol (675 mg, 3.34 mmol) with 14.4 g (25 mmol) of Fetizon reagent[15] as before gave 549 mg (82%) of the aldehyde as a colorless oil after bulb-to-bulb distillation at 130 °C and 1.5 Torr: IR (neat, cm^{-1}) 2960, 2930, 2860, 2690, 1690, 1460, 1255, 845; ^1H NMR (300 MHz, C_6D_6) δ 9.51 (s, 1 H), 1.94–1.85 (m, 1 H), 1.30–0.89 (series of m, 7 H), 1.05 (s, 3 H), 0.85 (t, J = 7.0 Hz, 3 H), −0.11 (s, 9 H); ^{13}C NMR (75 MHz, C_6D_6) 204.64, 46.29, 32.77, 31.51, 25.60, 22.88, 14.21, 13.36, −4.07 ppm; MS m/z ($M^+ - C_4H_9$) calcd 143.0892, obsd 143.0713; $[\alpha]^{25}_D$ −43.0°, $[\alpha]^{25}_{578}$ −45.9°, $[\alpha]^{25}_{546}$ −56.0°, $[\alpha]^{25}_{436}$ −144.7°, $[\alpha]^{25}_{365}$ −428.7° (*c* 6.4, C_6H_6).

Anal. Calcd for $C_{11}H_{24}OSi$: C, 65.93; H, 12.07. Found: C, 65.80; H, 12.10.

Phenyl Addition to and Oxidation of the Enantiomerically Enriched Aldehydes. A. (*R*)-(+)-1,3-Diphenyl-2-methyl-2-(trimethylsilyl)-1-propanone (20a). The optically pure *R*-(−) aldehyde (648 mg, 2.95 mmol) was treated with phenyllithium (4.2 mmol) in ether at −78 °C according to the method described for **5**. There was isolated 810 mg of a mixture of diastereomeric alcohols, which was directly oxidized with the chromium trioxide–pyridine complex as described for **7**. MPLC purification (silica gel, elution with 2.5% ethyl acetate in petroleum ether) afforded **20a** as a colorless oil (468 mg, 54%), which solidified on standing, mp 61–62 °C: the spectral properties were identical with those reported for the racemic compound; $[\alpha]^{25}_D$ +66.1°, $[\alpha]^{25}_{578}$ +69.7°, $[\alpha]^{25}_{546}$ +82.8°, $[\alpha]^{25}_{436}$ +175.2° (*c* 4.6, C_6H_6).

B. (*R*)-(+)-1-Phenyl-2,5-dimethyl-2-(trimethylsilyl)-4-hexen-1-one (20b). Treatment of the aldehyde (46% ee, 703 mg, 3.55 mmol) with phenyllithium (5.6 mmol) followed by oxidation as per the above gave **20b** (321 mg, 33%) as a colorless oil: IR (neat, cm^{-1}) 3060, 2970, 2930, 1650, 1600, 1575, 1455, 1445, 1380, 1255, 1240, 845; ^1H NMR (300 MHz, C_6D_6) δ 7.54–7.49 (m, 2 H), 7.08–7.04 (m, 3 H), 5.30 (m, 1 H), 3.14 (dd, J = 14.4, 6.0 Hz, 1 H), 2.20 (dd, J = 14.4, 8.1 Hz, 1 H), 1.60 (s, 3 H), 1.55 (s, 3 H), 1.35 (s, 3 H), 0.02 (s, 9 H); ^{13}C NMR (20 MHz, C_6D_6) 208.13, 142.88, 133.66, 129.84, 128.00, 127.47, 121.81, 46.82, 34.31, 25.81, 18.90, 18.00, −2.82 ppm; MS m/z (M^+) calcd 274.1753, obsd 274.1731; $[\alpha]^{24}_D$ +10.1°, $[\alpha]^{24}_{578}$ +10.7°, $[\alpha]^{24}_{546}$ +12.9°, $[\alpha]^{24}_{436}$ +31.6° (*c* 2.1, C_6H_6).

Anal. Calcd for $C_{17}H_{26}OSi$: C, 74.39; H, 9.55. Found: C, 74.53; H, 9.60.

C. (*R*)-(+)-1,4-Diphenyl-2-methyl-2-(trimethylsilyl)-1-butanone (20c). Reaction of the optically pure aldehyde (451 mg, 1.93 mmol) with phenyllithium followed by oxidation as before gave **20c** (416 mg, 70%) as colorless prisms, mp 81 °C (from pentane): IR ($CHCl_3$, cm^{-1}) 3000, 2950, 1635, 1600, 1575, 1255, 845; ^1H NMR (300 MHz, C_6D_6) δ 7.58–7.54 (m, 2 H), 7.19–7.04 (m, 8 H), 2.83–2.74 (m, 1 H), 2.69–2.55 (m, 2 H), 1.70–1.60 (m, 1 H), 1.37 (s, 3 H), −0.05 (s, 9 H); ^{13}C NMR (75 MHz, C_6D_6) 207.46, 142.94, 142.47, 130.16, 128.75 (2 C), 128.62, 127.85, 126.16, 46.85, 38.72, 32.34, 18.98, −3.03 ppm; MS m/z (M^+) calcd 310.1753, obsd 310.1745; $[\alpha]^{22}_D$ +135.3°, $[\alpha]^{22}_{578}$ +142.4°, $[\alpha]^{22}_{546}$ +165.8°, $[\alpha]^{22}_{436}$ +333.4° (*c* 2.6, C_6H_6).

Anal. Calcd for $C_{20}H_{26}OSi$: C, 77.36; H, 8.44. Found: C, 76.95; H, 8.32.

D. (*R*)-(+)-1-Phenyl-2-methyl-2-(trimethylsilyl)-1-heptanone (20d). Reaction of this aldehyde (89% de, 525 mg, 2.6 mmol) with phenyllithium followed by Collins oxidation as outlined earlier delivered 472 mg (65%) of **20d** as a colorless oil: IR (neat, cm^{-1}) 3060, 3025, 2960, 2930, 2870, 2860, 1645, 1600, 1585, 1465, 1445, 1255, 845; ^1H NMR (300 MHz, C_6D_6) δ 7.63–7.59 (m, 2 H), 7.13–7.11 (m, 3 H), 2.52 (m, 1 H), 1.48–1.23 (m, 7 H), 1.40 (s, 3 H), 0.91 (t, J = 6.8 Hz, 3 H), 0.07 (s, 9 H); ^{13}C NMR (75 MHz, C_6D_6) 207.77, 142.68, 130.01, 128.00 (obscured by solvent), 127.59, 46.67, 35.86, 32.90, 25.55, 22.87, 18.92, 14.27, −2.94 ppm; MS m/z (M^+) calcd 276.1909, obsd 276.1913; $[\alpha]^{23}_D$ +67.7°, $[\alpha]^{23}_{578}$ +71.3°, $[\alpha]^{23}_{546}$ +83.7°, $[\alpha]^{23}_{436}$ +180.2° (*c* 7.3, C_6H_6).

Anal. Calcd for $C_{17}H_{28}OSi$: C, 73.85; H, 10.21. Found: C, 73.93; H, 10.25.

Haller–Bauer Cleavages of 20a–d. The ketone (55–75 mg) was dissolved in benzene (2 mL) and added to a slurry of sodium or potassium amide (ca. 20 equiv) in the same solvent (2 mL). The mixture was heated at reflux for 2.5 h (for KNH_2) or 4 h (for $NaNH_2$). The cooled mixture was extracted with pentane (20 mL), and the pentane solution was washed with ammonium chloride solution and brine prior to drying. The solution was concentrated by distillation of solvent through a 6-in. Vigreux column. Preparative gas chromatography (7 ft × 0.25 in. 20% SE-30, 85–130 °C) gave the pure silanes.

A. (*R*)-(+)-1-Phenyl-2-(trimethylsilyl)propane (21a). For spectral properties, see above.

Experiment 1 ($NaNH_2$): 35% yield, $[\alpha]^{24}_D$ +26.7° (*c* 0.6, CCl_4).
Experiment 2 ($NaNH_2$): 27% yield, $[\alpha]^{25}_D$ +26.7° (*c* 1.5, CCl_4).
Experiment 3 (KNH_2): 30% yield, $[\alpha]^{24}_D$ +24.0° (*c* 1.9, CCl_4).
Experiment 4 (KNH_2): 22% yield, $[\alpha]^{25}_D$ +23.7° (*c* 1.5, CCl_4).

B. (*R*)-(+)-2-Methyl-5-(trimethylsilyl)-2-hexene (21b): IR (CH_2Cl_2, cm^{-1}) 2960, 2870, 1455, 1375, 1245, 865, 845; ^1H NMR (300 MHz, $CDCl_3$) δ 5.14 (m, 1 H), 2.14–2.06 (m, 1 H), 1.87–1.77 (m, 1 H), 1.70 (d, J = 0.6 Hz, 3 H), 1.60 (s, 3 H), 0.90 (d, J = 7.4

Hz, 3 H), 0.70–0.60 (m, 1 H), –0.03 (s, 9 H); ^{13}C NMR (75 MHz, $CDCl_3$) 131.06, 125.25, 30.31, 25.77, 20.80, 17.75, 14.18, –3.12 ppm; MS m/z (M^+) calcd 170.1491, obsd 170.1502.

Experiment 1 ($NaNH_2$): 9% yield, $[\alpha]^{25}_{365}$ +9.6° (*c* 0.3, CH_2Cl_2). Experiment 2 ($NaNH_2$): 8% yield, $[\alpha]^{25}_{365}$ +9.6° (*c* 0.2, CH_2Cl_2). Experiment 3 (KNH_2): 14% yield, $[\alpha]^{25}_{365}$ +8.5° (*c* 0.9, CH_2Cl_2). Experiment 4 (KNH_2): 14% yield, $[\alpha]^{25}_{365}$ +8.6° (*c* 0.6, CH_2Cl_2).

C. (*R*)-(+)-1-Phenyl-3-(trimethylsilyl)butane (21c): IR (C_6H_6, cm^{-1}) 2850, 1245, 840; ^1H NMR (300 MHz, C_6D_6) δ 7.21–7.07 (m, 5 H), 2.74 (ddd, *J* = 13.5, 10.1, 4.9 Hz, 1 H), 2.44 (ddd, *J* = 13.5, 10.0, 6.9 Hz, 1 H), 1.78 (dddd, *J* = 13.6, 10.1, 6.9, 3.8 Hz, 1 H), 1.37 (dddd, *J* = 13.6, 10.7, 10.0, 4.9 Hz, 1 H), 0.95 (d, *J* = 7.3 Hz, 3 H), 0.59 (ddq, *J* = 10.7, 3.8, 7.3 Hz, 1 H), –0.07 (s, 9 H); ^{13}C NMR (75 MHz, C_6D_6) 143.12, 128.72, 128.62, 125.95, 35.30, 34.25, 19.47, 14.00, –3.24 ppm; MS m/z ($M^+ - CH_3$) calcd 191.1256, obsd 191.1303.

Experiment 1 ($NaNH_2$): 7% yield, $[\alpha]^{21}_D$ +12.1° (*c* 0.3, C_6H_6). Experiment 2 ($NaNH_2$): 16% yield, $[\alpha]^{21}_D$ +12.7° (*c* 0.7, C_6H_6). Experiment 3 (KNH_2): 18% yield, $[\alpha]^{22}_D$ +11.2° (*c* 0.8, C_6H_6). Experiment 4 (KNH_2): 26% yield, $[\alpha]^{21}_D$ +11.8° (*c* 1.2 C_6H_6).

D. (*R*)-(+)-2-(Trimethylsilyl)heptane (21d): IR ($CHCl_3$, cm^{-1}) 2950, 2922, 2850, 1465, 1245, 838; ^1H NMR (300 MHz, C_6D_6) δ 1.55–1.41 (m, 2 H), 1.37–1.08 (series of m, 6 H), 0.94 (dd, *J* = 7.4 Hz, 3 H), 0.89 (t, *J* = 6.9 Hz, 3 H), 0.63–0.53 (m, 1 H), –0.01 (s, 9 H); ^{13}C NMR (75 MHz, C_6D_6) 32.40, 32.16, 28.74, 23.08, 19.89, 14.36, 14.24, –3.09 ppm; MS m/z (M^+) 172.1648, obsd 172.1646.

Experiment 1 ($NaNH_2$): 32% yield, $[\alpha]^{22}_D$ +28.4° (*c* 1.3, C_6H_6). Experiment 2 ($NaNH_2$): 33% yield, $[\alpha]^{22}_D$ +29.2° (*c* 1.3, C_6H_6). Experiment 3 (KNH_2): 16% yield, $[\alpha]^{24}_D$ +27.6° (*c* 0.7, C_6H_6). Experiment 4 (KNH_2): 8% yield, $[\alpha]^{23}_D$ +27.3° (*c* 0.3, C_6H_6).

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Supplementary Material Available: Tables V and VI of final bond lengths and angles and VII and VIII of final positional and thermal parameters, as well as the numbering scheme (Figure 2), for **12a** (6 pages). Ordering information is given on any current masthead page.

Cleavage of Carbon–Carbon Bonds with High Stereochemical Control. 7. Chiral α-Silyl Benzoylcycloalkanes Undergo Base-Catalyzed Cleavage with Retention of Configuration When Not Sterically Congested[1]

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The cyclic phenyl ketone (–)-1 has been prepared in a manner that allows definition of its absolute configuration. On being heated with sodium and potassium amide in benzene, (–)-1 undergoes C–C bond cleavage with outstanding (96–98%) levels of configurational retention. This conclusion required interconversion of (–)-1-(trimethylsilyl)-3-isopropylidenecyclopentane (**2**) with (*S*)-(–)-3-(trimethylsilyl)cyclopentene (**3**). The racemic ketones **21**, **22**, **36**, and **37** have also been synthesized and subjected to the Haller–Bauer process. In each case, the resultant cyclic silanes were demonstrated to arise by virtually exclusive stereochemical retention. In the case of **28**, an example where the benzoyl carbonyl group is sterically shielded, desilylation was the kinetically dominant reaction with these bases. These results are interpreted on the basis of initial α-silyl carbanion formation within a solvent shell that also encases benzamide. The benefits derived from these special solvational features are predicted not to be useful for extending stereocontrol to targets requiring the operation of intermediate energy-demanding steps.

The ability of optically active tertiary phenyl ketones bearing an α-silyl substituent to undergo Haller–Bauer deacylation with high levels of stereochemical retention has been documented.[1,2] In these acyclic cases, the additional α substitution has consisted of methyl and an alkyl, alkenyl, or aralkyl group. A ready and general synthetic entry to chiral, nonracemic C-centered organosilanes[3,4] has thereby been made available. As useful as this advance has been, it remained to address the crucial question of its adaptability to cyclic systems. We have therefore proceeded to examine the response of several judiciously chosen five- and six-membered α-silyl benzoylcycloalkanes to cleavage with amide bases. The special emphasis given to stereochemistry has been rewarded by confirmation that this process ranks as perhaps the most stereospecific carbon–carbon bond cleavage yet uncovered.[5]

Results

An Optically Active Cyclopentyl Substrate. A structural property especially suited to assessing the stereochemical course of cleavage reactions is optical activity. Implementation of this probe does require, however, that the absolute configurations of the starting material and product be known without question. Beyond that, we wished not to introduce steric compression near the reaction site as a possible source of complication this early

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(5) Comparison is made particularly with the structurally related α-phenyl analogues[6] as well as with Cram's very extensive and systematic study of the base-catalyzed cleavage of tertiary alcohols.[7]

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