Stereoselective Intermolecular Carbolithiation of Open-Chain and Cyclic 1-Aryl-1-alkenyl *N*,*N*-Diisopropylcarbamates Coupled with Electrophilic Substitution. Observation of *p*-Carboxylation in a Benzyllithium Derivative

Jan Georg Peters, Michael Seppi, Roland Fröhlich,[36a] Birgit Wibbeling,[36a] Dieter Hoppe*

Institut für Organische Chemie der Westfälischen Wilhelms-Universität Münster, Corrensstraße 40, 48149 Münster, Germany
Fax +49(251)8339772; E-mail: dhoppe@uni-muenster.de

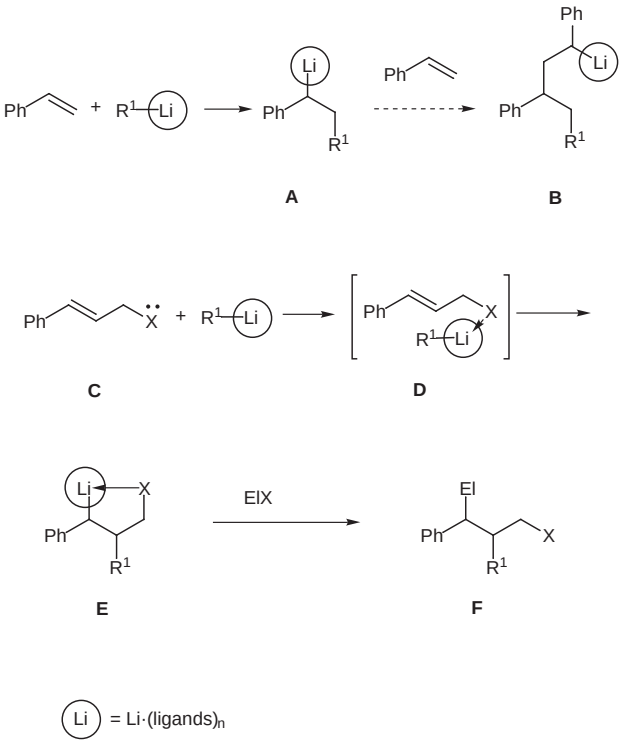
Received 8 November 2001

Abstract: 1-Aryl-1-alkenyl *N*,*N*-diisopropylcarbamates (**1**) are obtained from alkyl aryl ketones and *N*,*N*-diisopropylcarbamoyl chloride (*Cb*Cl) by heating with excess pyridine. These undergo facile *syn*-carbolithiation by alkyllithium/diamine and produce configurationally stable lithiated benzyl carbamates, which have been trapped with different electrophiles. If the reaction is carried out in the presence of chiral diamines, such as (−)-sparteine or (−)-α-isosparteine, moderate enantiofacial differentiation is observed.

Key words: 1-alkenyl carbamates, benzyl carbamates, chiral benzyllithium compounds, carbolithiation, (−)-sparteine

The intermolecular nucleophilic addition of organolithium to an alkene is the first step in anionic polymerisation reactions of styrene.[1] For synthetically useful carbolithiation reactions,[2] the formation of intermediate A must proceed much more rapidly than the next addition step. Thus, special stabilization of A is required[3] as was demonstrated by Normant et al., utilizing cinnamyl derivatives C bearing a Lewis-basic substituent X (X = OR, NR_2) as substrates in carbolithiation reactions.[3,4] The complex-induced proximity effect (CIPE),[5] arising from the formation of the complex D, causes a rapid addition reaction to form the stabilized adduct E, which can be trapped by many different electrophilic reagents.[6] In addition to two carbon-carbon bond formations, up to two stereogenic centers are established. Usually, high diastereoselectivity is observed and, moreover, in the presence of chiral ligands such as (−)-sparteine,[7] high enantiofacial selectivity at the prostereogenic double bond is achieved (Scheme 1).[8]

We expected that 1-aryl-1-alkenyl carbamates of type **1** could be ideal substrates for CIPE-driven stereoselective formation of secondary α-carbamoyloxy-benzyllithium compounds **G** by carbolithiation reactions.[9,10–12] A related study, concerning the carbolithiation of different 1-arylethenyl *N*,*N*-diethylcarbamates was published as a short communication by Snieckus et al.[13] when our work was in progress. We had discovered that chiral compounds **G**, prepared by deprotonation, are configurationally stable at low temperatures and these are substituted



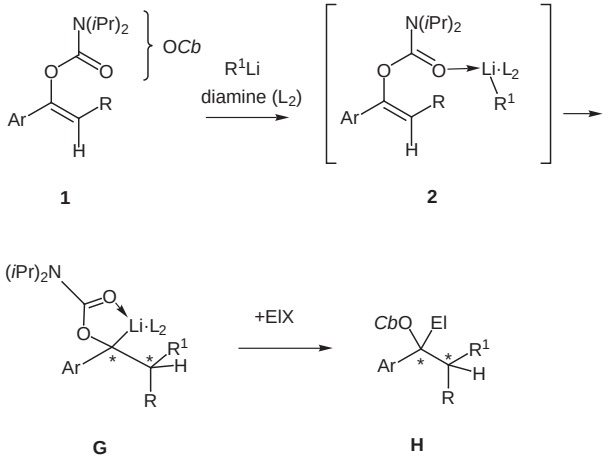
Scheme 1

by proton acids with retention and by most other electrophiles with inversion of the configuration. Thus a convenient stereoselective approach for the preparation of more complex chiral benzyl derivatives of type **H** seemed possible (Scheme 2).[14]

The vinyl carbamates **1a**–**f** were prepared by heating the appropriate ketones **3** with *N*,*N*-diisopropylcarbamoyl chloride (**4**)[15] and pyridine (1.9–3.0 equiv) for 2–9 days.[16] Presumably, the reaction proceeds via the enol of **3** (Scheme 3, Table 1). The stilbene derivatives *Z*-**1d**/*E*-**1d** were obtained in a ratio of 68:32 and could be separated by chromatography on silica gel. The crystalline isomer *Z*-**1d** was subjected to a X-ray structure analysis (Figure 1).[17] As expected, the torsion around the O−C=O bond in *Z*-**1d** is more restricted than that in *E*-**1d**; whereas the ^{1}H NMR-absorption in $CDCl_3$ of the two isopropyl protons in *E*-**1d** coincide at 3.97 ppm, two separate, sharp signals (3.77 and 4.34 ppm) appear for *Z*-**1d**. The latter

Synthesis 2002, No. 3, 18 02 2002. Article Identifier:
1437-210X,E;2002,0,03,0381,0392,ftx,en;T10601SS.pdf.

ISSN 0039-7881



2	a	b	c
Ar	C_6H_5	α-Naphth	2-$MeOC_6H_4$
R	H	H	H

Scheme 2

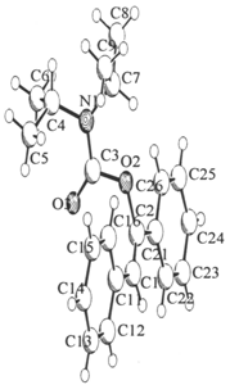
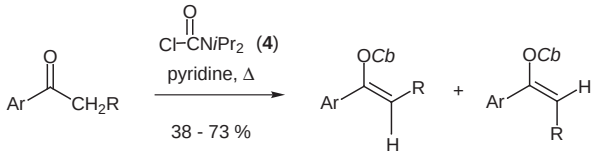


Figure 1 X-ray structure of *Z*-**1d**[17]



1	a	b	c	d	e	f
Ar	C_6H_5	α-Naphth	2-$MeOC_6H_4$	C_6H_5	C_6H_5	3-$(CH_2)_2C_6H_4$
R	H	H	H	C_6H_5	$C(CH_3)_3$	

Scheme 3

undergo line broadening when warming the sample from 25 °C to 55 °C. Consequently, two enantiomeric atropoisomers are found in the crystal (Figure 1).[17]

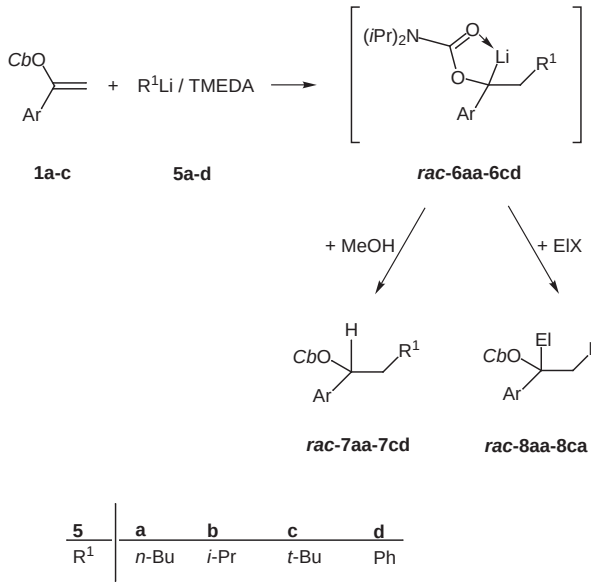
For carbolithiation of the β-non-prostereogenic vinyl carbamates, to a solution of the alkyllithium (1.4 equiv) **5a**–**c** and *N*,*N*,*N*',*N*'-tetramethylethylenediamine (TMEDA, 1.4 equiv) in toluene–hexane at −78 °C, the appropriate carbamate **1a**–**c** was added dropwise and stirring continued for 5–15 hours. After formation of the lithium compound *rac*-**6aa-cc**,[18] either methanol (for the preparation of the secondary benzyl carbamates *rac*-**7aa-cc**) or another electrophile such as CO_2 (followed by methylation of

Table 1 Preparation of the 1-Alkenyl *N*,*N*-Diisopropylcarbamates **1a-c**, *E*/*Z*-**1d**, *E*/*Z*-**1e** and **1f**

Product[a]	Ar	R	Reaction Time (d)/ Temperature (°C)	Equiv of **4**	Equiv of Pyridine	Yield (%)	mp (°C)	Purification[b]
1a	C_6H_5	H	6/95	1.5	3.0	73	64–65[c]	E–PE; 1:20→1:4
1b	α-Naphthyl	H	9/reflux	1.5	3.0	38[d]	oil	E–PE; 1:10→1:1
1c	2-(MeO)C_6H_4	H	9/reflux	1.5	3.0	44	81–83[e]	triple recryst. from PE at −20 °C
E/*Z*-**1d**	C_6H_5	C_6H_5	6/100	1.5	2.7	66	89[f]	E–PE; 1:20→1:5[g]
E/*Z*-**1e**	C_6H_5	$C(CH_3)_3$	2/reflux	2.5	1.9	34	53–54[h]	E–PE; 1:20→1:10[i]
1f	3-$C_6H_4(CH_2)_2$		9/reflux	1.5	3.0	73	81–82[e]	recryst. from PE at −20 °C

[a] All compounds gave correct C,H-analyses (C ± 0.4, H ± 0.3) and showed infrared absorption at 1710–1695 cm^{-1} (C=ONR_2).
[b] Column chromatography on silica gel; E = Et_2O, PE = petroleum ether (bp 30–50 °C).
[c] From the melt.
[d] After additional kugelrohr distillation.
[e] From PE.
[f] *Z*-Isomer.
[g] Isomers were separated; *E*-Isomer: Yellow oil, 21%; *Z*-Isomer: Colourless crystals, 45%.
[h] *Z*-Isomer.
[i] Yielded an oil (*E*/*Z*, 10:90); *Z*-Isomer precipitated on standing.

the crude product with diazomethane), chlorotrimethylsilane, or chlorotrimethylstannane was added (*rac*-**8aa-ca**, Scheme 4). Aqueous workup at room temperature and chromatographic separation afforded the expected products *rac*-**7aa-cc** or *rac*-**8aa-ca**, respectively, in good yields (Table 2).



5	a	b	c	d
R^1	*n*-Bu	*i*-Pr	*t*-Bu	Ph

Scheme 4

Similarly, the reaction of stilbene carbamate *Z*-**1d** was carried out. Using toluene as solvent, stirring for 1 hour at −78 °C and warming the reaction mixture for 45 minutes to −15 °C for completion of the addition reaction provided the best yields (Scheme 5, Table 2). Here, two diastereomeric products *rac*-**9** and *rac*-**10** are possible (Scheme 5, Table 2). Protonation of the reaction mixture with methanol afforded the pure secondary carbamate *rac*-**9a** with (1*R**,2*R**) configuration; the latter one was confirmed by an X-ray crystal structure analysis[19] (Figure 2). Since the protonation of this type of benzyllithium compounds proceeds with retention of the configuration,[20] clear evidence for a *syn*-stereochemistry of the addition step is presented. The reaction of methyl iodide yielded a diastereomeric mixture of *rac*-**9c**/*rac*-**10c** in a ratio of 13:87 with 61% yield. Although the configurations have not been established rigorously, the high preference of methyl iodide for stereoinversion substitution reactions with benzyllithium compounds, as it had been found previously,[10b,c] leads to the assignment of the (1*S**,2*R**) configuration for the major product **10c**.

Surprisingly, the diastereomer *E*-**1d** did not undergo addition of *n*-butyllithium/TMEDA; β−elimination of lithium carbamate led to the formation of diphenylethyne (**11**) in high yield (Scheme 6). The β-proton of *E*-**1d** is in an ideal position for being removed by the base, being complexed by the carbamate group.

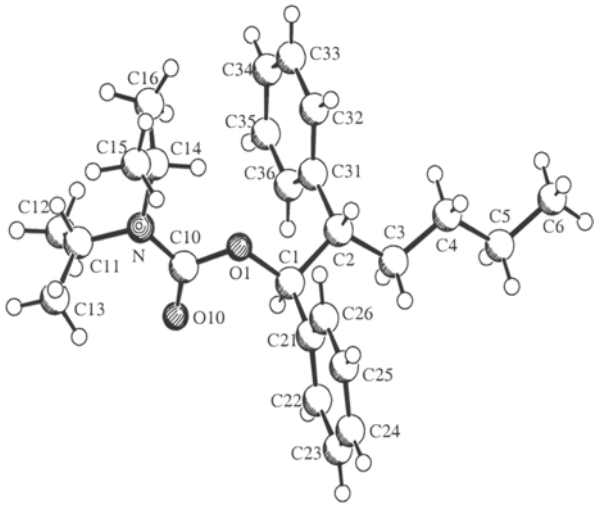
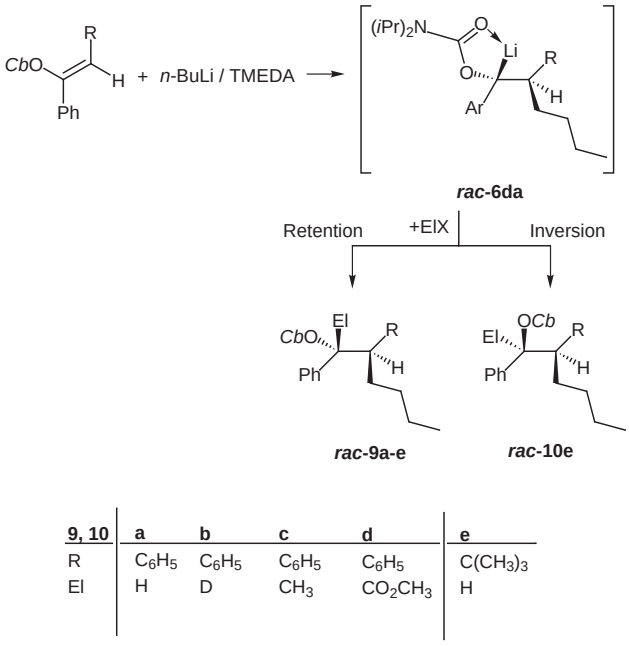


Figure 2 X-ray structure of *rac*-**9a**[19]



9, 10	a	b	c	d	e
R	C_6H_5	C_6H_5	C_6H_5	C_6H_5	$C(CH_3)_3$
El	H	D	CH_3	CO_2CH_3	H

Scheme 5

Scheme 6

Starting from the *tert*-butyl derivative **1e** (*Z*/*E*, 90:10) the reaction with *n*-butyllithium (3 h at −40 °C) and quenching with methanol leads to diastereomerically pure **9e** (Table 2).

The reaction of the cyclic enol carbamate **1f** with *n*-butyllithium and *tert*-butyllithium, respectively, after protonolysis gave rise to the formation of the *trans* alkyl-

Table 2 Compounds Prepared by Carbolithiation of **1a**–**1c**, *Z*-**1d**, *Z*-**1e**, **1f, 18,** and Reaction with Electrophiles

Entry	Substrate	Method	Organolithium Reagent[k]	Electrophile	Reaction Time (h)	Product	Ar	R^1	El	Yield (%)	mp (°C)
1	**1a**	A	*n*-BuLi	MeOH[g]	0.5	**7aa**	C_6H_5	$(CH_2)_3CH_3$	H	85	oil
2		A	PhLi	MeOH[g]	0.5	**7ad**	C_6H_5	C_6H_5	H	54	oil
3		A	*n*-BuLi	CO_2[a,h]	0.5	**8aa**	C_6H_5	$(CH_2)_3CH_3$	CO_2Me	72	oil
4		A	*i*-PrLi	CO_2[a,h]	0.5	**8ab**	C_6H_5	$CH(CH_3)_2$	CO_2Me	71	oil
5		A	*t*-BuLi	CO_2[a,h]	0.5	**8ac**	C_6H_5	$C(CH_3)_3$	CO_2Me	75	89–90[b]
6		A	*n*-BuLi	Me_3SiCl[i]	15	**8ba**	C_6H_5	$(CH_2)_3CH_3$	$SiMe_3$	49	oil
7		A	*n*-BuLi	Me_3SnCl[j]	15	**8ca**	C_6H_5	$(CH_2)_3CH_3$	$SnMe_3$	62	oil
8	**1b**	A	*n*-BuLi	MeOH[g]	0.5	**7ba**	α-Naphthyl	$(CH_2)_3CH_3$	H	54	oil
9		A	*i*-PrLi	MeOH[g]	0.5	**7bb**	α-Naphthyl	$CH(CH_3)_2$	H	91	oil
10		A	*t*-BuLi	MeOH[g]	0.5	**7bc**	α-Naphthyl	$C(CH_3)_3$	H	90	104–105[c]
11	**1c**	A	*n*-BuLi	MeOH[g]	0.5	**7ca**	2-(MeO)C_6H_4	$(CH_2)_3CH_3$	H	25	oil
12		A	*i*-PrLi	MeOH[g]	0.5	**7cb**	2-(MeO)C_6H_4	$CH(CH_3)_2$	H	53	oil
13		A	*t*-BuLi	MeOH[g]	0.5	**7cc**	2-(MeO)C_6H_4	$C(CH_3)_3$	H	91	oil
14	*Z*-**1d**	B	*n*-BuLi	MeOH	0.25	**9a**	–	C_6H_5[n]	H	87	100[c]
15		B	*n*-BuLi	MeOD[l]	0.25	**9b**	–	C_6H_5[n]	D	89	100[c]
16		B	*n*-BuLi	MeI[m]	0.25	**9c/10c**	–	C_6H_5[n]	Me	61	n.b.[d]
17		B	*n*-BuLi	CO_2[a,h]	0	**9d/10d**	–	C_6H_5[n]	CO_2Me	29	oil[e]
18		B	*n*-BuLi	Me_3SiCl[i]	1	**9a**	–	C_6H_5[n]	H	51	100[c]
19		B	*n*-BuLi	Me_3SnCl[j]	0.5	**9a**	–	C_6H_5[n]	H	58	100[c]
20	*Z*-**1e**	C	*n*-BuLi	MeOH[g]	0	**9e**	–	$C(CH_3)_3$[n]	H	84	oil
21	**1f**	D	*n*-BuLi	MeOH[g]	0	**12a**	–	–	H	78	oil
22		D	*n*-BuLi	CO_2[a,h]	0	**13a**	–	–	CO_2Me	24	oil
23		E	*t*-BuLi	CO_2[a,h]	0	**17**	–	–	–	79	123–124[c]
24		E	*t*-BuLi	MeOH[g]	0	**15a**	–	–	H	51[f]	oil
25		E	*t*-BuLi	MeOD[l]	0	**15b**	–	–	D	95	oil
26	**18**	F	*t*-BuLi	MeOH[g]	0.5	**21a**	–	–	H	88	oil
27		F	*t*-BuLi	Me_3SnCl[j]	24	**21b**	–	–	$SnMe_3$	43	oil

[a] Subsequent methylation with diazomethane.
[b] From the melt.
[c] From Et_2O–petroleum ether.
[d] Mixture of diastereomers; *l*:*u* 87:13.
[e] Mixture of diastereomers; *l*:*u* 79:21.
[f] 49 % of the starting material were recovered.
[g] Method A: 0.2 mL, 6 mmol, Method B: 0.1 mL, 2.5 mmol, Method C, E: 1 mL, Method D, F: 0.5 mL.
[h] Method A: stream of dry CO_2 for 30 min, Method B: stream of dry CO_2 for 45 min, Method D, E: stream of dry CO_2 for 1 h.
[i] 270 mg, 2.5 mmol.
[j] 1.0 M solution in hexanes, Method A: 2.0 mL, 2.0 mmol, Method B: 2.5 ml. 2.5mmol, Method F: 1.2 mmol.
[k] Method A, B: 1.05 mmol added; Method C 1.4 mmol added; Method D: 1.2 mmol; Method E: 1 mmol; Method F: 1.10 mmol; the reagents have the following concentrations: *n*-BuLi (1.6 M in hexanes), *i*-PrLi (0.22 M in pentane), *t*-BuLi (1.5 M in pentane), PhLi (2 M in cyclohexane–Et_2O).
[l] Method B: 0.15 mL, 2.5 mmol, Method E: 0.5 mL, 12.3 mmol.
[m] Method B: 360 mg, 2.5 mmol.
[n] See residue R in Scheme 5.

substituted 2-alkyl tetrahydronaphthalenes *rac*-**12a**/*rac*-**12b** (Scheme 7); the ^{1}H NMR coupling constants between ^{1}H-1 and ^{1}H-2 are 6.2 Hz (**12a**) and 5.1 Hz (**12b**). The *trans*-configuration of compounds **12a**, **15a**, and **15b** is in accordance with that expected; the *syn*-addition of alkyllithium onto the double bond of **1f**, followed by protonation with retention of configuration leads to the observed relative configuration. Carboxylation of the intermediate **9fa** to form the carboxylic acid, isolated in the form of the methyl ester **13d**, took place in surprisingly low yield. The shown stereochemistry of the carboxylate *rac*-**13a** had to be deduced indirectly: We had demonstrated that the carboxylation of lithiated secondary benzyl carbamates proceeds with inversion of configuration,[10b,c] although in cyclic cases some erosion of stereospecificity might occur.[10d] In the case of *rac*-**6fa**, the butyl residue, *cis* to lithium, should reinforce the tendency for antarafacial attack of the electrophile.

The characterization of the methyl carboxylate, prepared via nucleophilic *tert*-butylation and carboxylation, gave a surprising result. The X-ray analysis[21] (Figure 3) revealed the *p*-position of the carboxylic group and the *cis*-configuration ($J_{H\text{-}1,H\text{-}2}$ = 1.9 Hz) of the ester **17**.

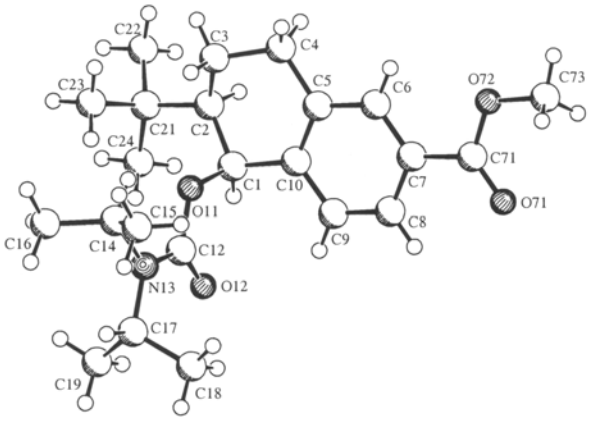
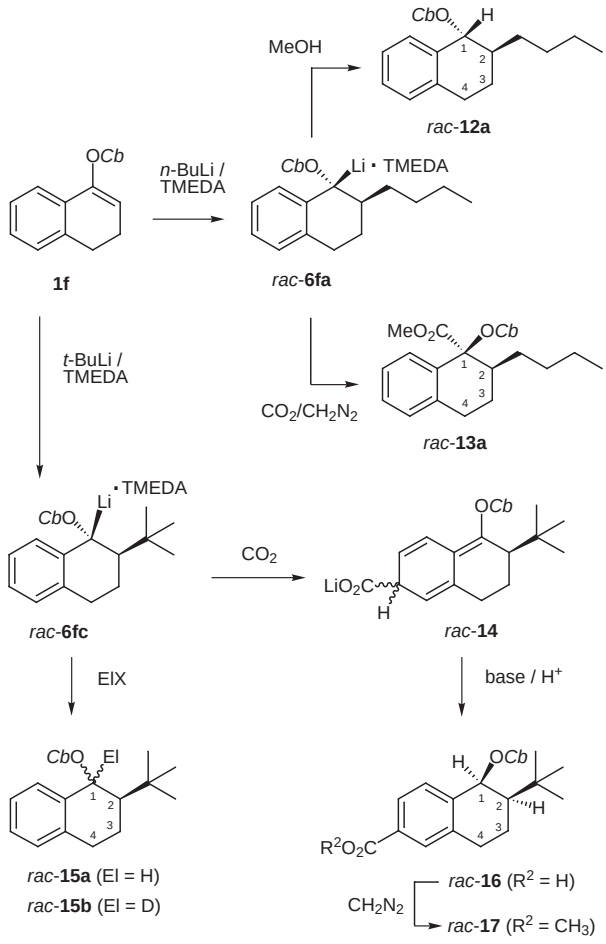


Figure 3 X-ray structure of *rac*-**17**[21]

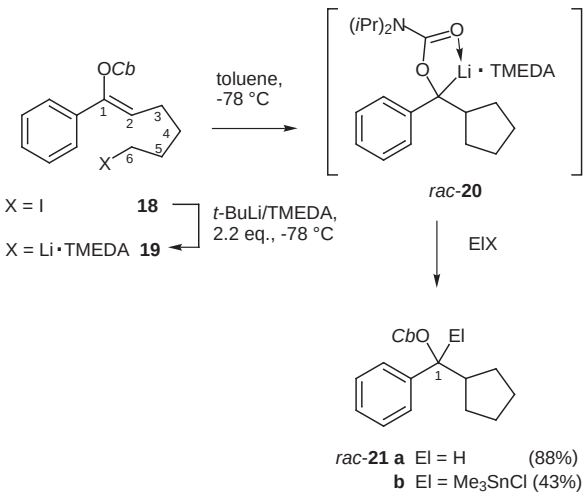
Obviously, the benzylic position in intermediate *rac*-**6fc** is sterically hindered to such an extent, that carbon dioxide attacks the *p*-position of the phenyl ring, although the electron density there is comparably low. The (alkylidenecyclohexadiene)carboxylate **14** formed will rapidly undergo rearomatization, combined with a kinetically controlled protonation in the benzylic position from the less shielded α-face, leading to the thermodynamically unfavourable *cis*-diastereomer **16**.

In contrast to competing *p*-substitution reactions of benzylic radicals,[22] reports on corresponding carbanionic reactions are rare. Attack at the *para* position was first observed by Wittig et al.[23] during the benzoylation of sodium triphenyl-(triphenylmethyl)aluminate. Fraenkel et al. found *p*-substitution occuring during the carbolithiation of α-methylstyrene with *tert*-butyllithium and subsequent bis-trimethylsilylation.[24]



Scheme 7

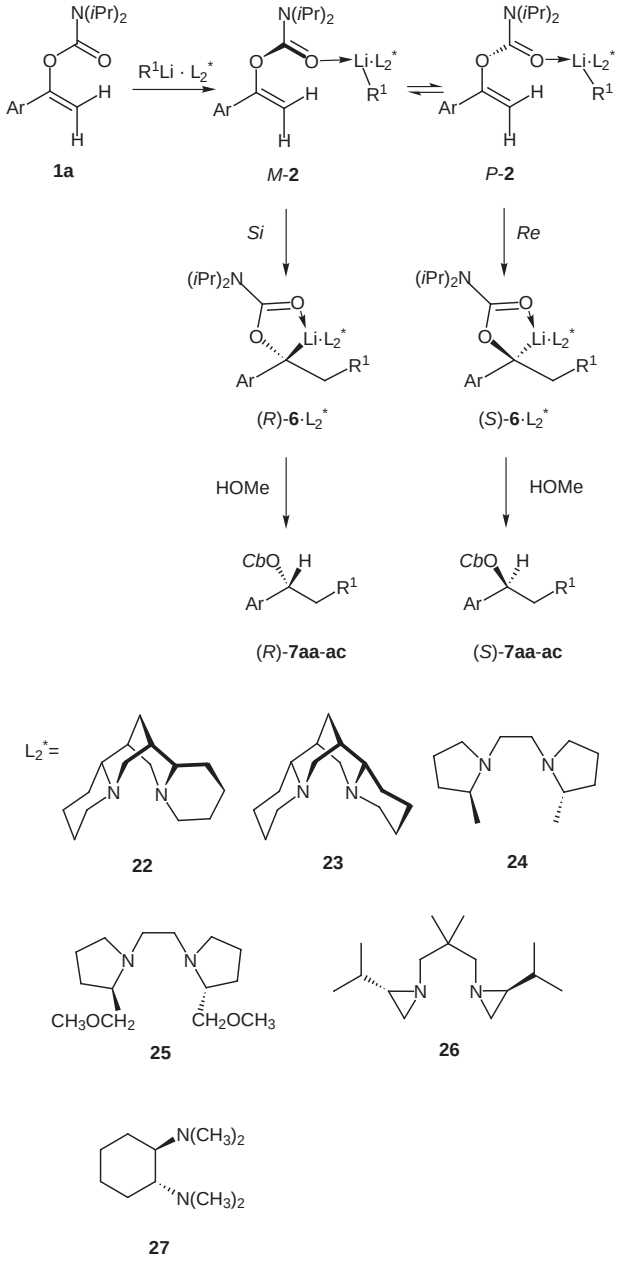
The intramolecular version of the carbolithiation reaction proceeds with great ease (Scheme 8). Iodide[25] **18** undergoes smooth iodine-lithium exchange[26] and the intermediate **19** cyclizes to form the cyclopentyl-substituted benzyllithium *rac*-**20**, which is trapped by protonation (*rac*-**21a**, 88%) or by stannylation (*rac*-**21b**, 43%).



Scheme 8

The complexed conformers *P*/*M*-**2**, formed by the coordination of R^1Li (**5a**–**d**) and a chiral ligand L_2^* (**22**–**27**), will react with the C=C bond in an intramolecular *syn*-addition to form the benzyllithium derivatives (*R*)-**6**·L_2^* and (*S*)-**6**·L_2^*, which are configurationally stable and can be trapped (Scheme 9). Overall, the sequence provides enantiofacial attack at the styrene double bond. Note, that the carbanionic centre in the reagent is not stereogenic; any differentiation is due to the chiral ligand L_2^*. Only a few efficient examples for such a strategy are known.[7,8,27]

α-Styryl carbamate **1a** was allowed to react with each 1.4 equivalents of R^1Li and L_2^* in toluene for 5 hours at −78 °C and then the benzyllithium compound was trapped to yield the chain-extended benzyl carbamate **7aa**–**ac**; after purification, the enantiomeric excess was determined.



Scheme 9

The absolute configuration was assessed by independent asymmetric synthesis[28] of (+)-**7aa** and comparison of the sense of optical rotation and ^1H NMR shift experiments with that of (−)-**7aa** produced via the carbolithiation sequence.

The data are collected in Table 3. Best results were obtained with *n*-BuLi/(−)-α-isosparteine[29] (**23**) (58% ee, entry 2) and *i*-PrLi/(−)-sparteine (**22**) (44% *ee*, entry 8). With diamines **24**–**26**[30] and **27**,[31] less than 22% ee were achieved. This demonstrates, that (as in many cases) (−)-sparteine[32] and (−)-α-isosparteine[16] lithium complexes have superior efficiency. The substituted carbamates **1b**–**1f** provided even lower enantioselectivities.[33]

As a consequence, we assume that the problem of enantioselective additions onto vinyl carbamates is due to the interconversion of the conformers *M*-**2** and *P*-**2** being too slow, and the energetic barrier is in the magnitude of the activation energies of the competing diastereomorphic addition step.

All reactions which are sensitive to moisture or air were carried out under argon. All solvents were purified by distillation and dried, if necessary, prior to use. ^1H and ^{13}C NMR spectra were recorded on a Bruker AM 300 spectrometer. Optical rotations were recorded on a Perkin-Elmer polarimeter 241. Melting points were obtained on a Gallenkamp melting point apparatus MFB-595 and are uncorrected. Products were purified by flash column chromatography on silica gel (40–63 μm) using Et_2O and petroleum ether, PE (30–50 °C) as solvents.

Preparation of Enol Carbamates 1a–c, *E*/*Z*-1d, *E*/*Z*-1e, 1f; General Procedure

The ketone (25 mmol), carbamoyl chloride **4** (37.5–75 mmol, see Table 1) and anhyd pyridine (48–75 mmol, see Table 1) were heated to 95 °C or reflux and stirred for 2–9 d (see Table 1). The cooled reaction mixture was poured onto crushed ice (50 g) and 2 N aq HCl (120 mL), extracted with Et_2O (3 × 50 mL) and the collected extracts were neutralized with sat. $NaHCO_3$ solution (50 mL). After drying ($MgSO_4$ or Na_2SO_4), the solvents were evaporated and the crude product was purified by flash column chromatography on silica gel or recrystallisation to yield enol carbamates **1a**–**c**, *E*/*Z*-**1d**, *E*/*Z*-**1e** and **1f** (see Table 1).

(*Z*)-6-Iodo-1-phenyl-1-hexenyl *N*,*N*-Diisopropylcarbamate (18)

1-Phenyl-prop-2-enyl *N*,*N*-Diisopropylcarbamate:

To a solution of 1-phenylprop-2-enol[34] (3.95 g, 29.4 mmol) in anhyd THF (20 mL), NaH (1.77 g, 44.1 mmol) was added slowly and the mixture was stirred for 1.2 h. After cooling (ice bath) solid carbamoyl chloride **4** (7.46 g, 45.6 mmol) was added in small portions. The mixture was stirred for 16 h at r.t. Sat. NH_4Cl solution (15 mL) was added to destroy the excess of NaH and the THF was evaporated subsequently. After extraction with Et_2O (3 × 20 mL) the combined ethereal solutions were dried (Na_2SO_4) and the solvent evaporated in vacuo. The crude product was purified by flash chromatography (Et_2O–PE, 1:6) and yielded 1-phenyl-prop-2-enyl *N*,*N*-diisopropylcarbamate (6.40 g, 24.5 mmol, 84%) as a colourless oil; R_f 0.57 (Et_2O–PE, 1:4).

IR (film): 1720 (C=ONR$_2$), 770, 760 (C_6H_5).

Table 3 Carbolithiation of **1a** in the Presence of Optically Active Ligands L_2^*

Entry	Reagent R^1Li[f]	Ligand L_2^*	Product[a]	Yield (%)	er [ee(%)] *S*/*R*-**7**/**8**	$[\alpha]_D^{20}$
1	*n*-BuLi (**5a**)	**22**	(−)-**7aa**	86	65:35 (30)[b]	
2	*n*-BuLi (**5a**)	**23**	(−)-**7aa**	63	79:21 (58)[b]	−1.9 (*c* = 1.01, CH_2Cl_2)
3	*n*-BuLi (**5a**)	**24**	(−)-**7aa**	83	51:49 (2)[b]	
4	*n*-BuLi (**5a**)	**25**	(−)-**7aa**	73	58:42 (16)[b]	
5	*n*-BuLi (**5a**)	**26**	(−)-**7aa**	81	40:60 (20)[b]	
6	*n*-BuLi (**5a**)	**27**	(−)-**7aa**	47	61:39 (22)[b]	
7	*n*-BuLi (**5a**)	**22**	(−)-**8aa**	83	65:35 (30)[c,d]	−0.8 (*c* = 0.97, MeOH)
8	*i*-PrLi (**5b**)	**22**	(+)-**8ab**	80	28:72 (44)[c,d]	+4.3 (*c* = 1.00, MeOH)
9	*t*-BuLi (**5c**)	**22**	(+)-**8ac**	77	38:62 (24)[d,e]	+1.4 (*c* = 1.15, MeOH)

[a] Prepared by Method A (see experimental section) and Table 2.
[b] Determined by ^1H NMR shift experiments with 7.5 mol% (+)-Eu(hfc)$_3$ in C_6D_6.
[c] Determined by ^1H NMR shift experiments with 45 mol% (+)-Eu(hfc)$_3$ in C_6D_6.
[d] Assignment of the absolute configuration tentatively by comparison of the sense of optical rotation with known compounds.
[e] Determined by ^1H NMR shift experiments with 51 mol% (+)-Eu(hfc)$_3$ in C_6D_6.
[f] Method A: 1.05 mmol added; the reagents have the following concentrations: *n*-BuLi (1.6 M in hexanes), *i*-PrLi (0.22 M in pentane), *t*-BuLi. (1.5 M in pentane), PhLi (2 M in cyclohexane–Et_2O).

Table 4 Selected NMR-Data of 1-Alkenyl *N*,*N*-Diisopropylcarbamates **1a**–**c**, *E*/*Z*-**1d**, *E*/*Z*-**1e** and **1f** (see Scheme 3)[a]

Product	^1H NMR (300 MHz, $CDCl_3$), δ, *J* (Hz)			^{13}C NMR (75 MHz, $CDCl_3$), δ			
	H-2	R	Ar	C-1	C-2	R	Ar
1a	4.98 (H_α, d), 5.40 (H_β, d, $^2J_{2,2}$ = 1.9)	–	7.20–7.60	153.26	101.19	–	124.90, 128.32, 128.48, 135.43
1b	5.14 (H_α, d), 5.48 (H_β, d, $^2J_{2,2}$ = 1.0)	–	3.84 (s, OCH_3), 6.87–6.96, 7.22–7.29, 7.36	153.84	106.05	–	55.78 (OCH_3), 111.52, 120.75, 125.20, 129.04, 129.89
1c	5.15 (H_α, d), 5.35 (H_β, d, $^2J_{2,2}$ = 1.4)	–	7.41–7.55, 7.60, 7.80–7.85	153.36	105.07	–	125.06, 125.74, 126.18, 128.22, 128.93, 130.95, 133.64, 134.53
E-**1d**	6.47	7.07–7.40 (Ar-H)	7.07-7.40	147.97	119.22	126.71–135.33 (Ar-C)	126.71–135.33
Z-**1d**	6.66	7.18–7.56 (Ar-H)	7.18–7.56	146.95	116.78	124.77–136.84 (Ar-C)	124.77–136.84
E-**1e**	5.50	0.97 [s, $C(CH_3)_3$]	7.17–7.44	145.17	124.58	31.22 [$C(CH_3)_3$], 32.27 [$C(CH_3)_3$]	127.23, 127.41, 128.22, 137.75
Z-**1e**	5.62	1.20 [s, $C(CH_3)_3$]	7.17–7.44	145.17	124.58	30.32 [$C(CH_3)_3$], 32.27 [$C(CH_3)_3$]	127.23, 127.41, 128.22, 137.75
1f	5.68 (t, $^3J_{2,3}$ = 4.8)	2.43 (dt, $^3J_{3,4}$ = 8.4, CH_2CH_2-Ar), 2.87 (t, CH_2CH_2-Ar)	7.05–7.25	145.98	114.87	22.09 (CH_2CH_2-Ar), 27.60 (CH_2CH_2-Ar)	120.76, 126.29, 127.38, 127.51, 131.53, 136.41

[a] NMR-data of the *Cb* group is omitted.

^1H NMR ($CDCl_3$, 300 MHz): δ = 1.23 [m, 12 H, $CH(CH_3)_2$], 3.95 [m, 2 H, $CH(CH_3)_2$], 5.21 (dd, 1 H, $^2J_{3\alpha,3\beta}$ = 1.6 Hz, $^3J_{2,3\alpha}$ = 10.7 Hz, 3-H_α), 5.34 (dd, 1 H, $^3J_{2,3\beta}$ = 17.2 Hz, 3-H_β), 6.05 (ddd, 1 H, $^3J_{1,2}$ = 5.6 Hz, 2-H), 6.24 (d, 1 H, 1-H), 7.21–7.43 (m, 5 H, C_6H_5).

^{13}C NMR ($CDCl_3$, 75 MHz): δ = 21.49 [$CH(CH_3)_2$], 46.37 [$CH(CH_3)_2$], 77.85 (C-1), 116.50 (C-3), 127.52, 128.10, 128.79, 140.30 (C_6H_5), 137.87 (C-2), 155.05 (C=ONR_2).

Anal. Calcd for $C_{16}H_{21}NO_2$ (261.36): C, 73.53; H, 8.87. Found: C, 73.37; H, 9.05.

Table 5 Selected NMR-Data of Carbamates **7aa–cc, 8aa–ac, 9a–e, 10c–d** (see Scheme 4 and Scheme 5)[a,b]

Product	^{1}H NMR (300 MHz, $CDCl_3$), δ, *J* (Hz)			^{13}C NMR (75 MHz, $CDCl_3$), δ			
	H-2	R/R^1	El	C-1	C-2	R/R^1	El
7aa	1.70–2.00 (m, H_α, H_β)	0.87 (m, CH_3), 1.10–1.45 [m, $(CH_2)_3$]	5.69 (dd, $^3J_{1,2\alpha}$ = 5.0, $^3J_{1,2\beta}$ = 8.8)	76.66	25.18	13.88 (CH_3), 22.41, 31.55, 36.77 [$(CH_2)_3$]	–
7ad	3.09 (dd, $^2J_{2\alpha,2\beta}$ = 13.6, $^3J_{1,2\alpha}$ = 6.7), 3.22 (dd, $^3J_{1,2\beta}$ = 7.1)	7.03–7.34 (m, C_6H_5)	5.96 (dd, $^3J_{1,2\alpha}$ = 6.7, $^3J_{1,2\beta}$ = 7.1)	77.63	43.94	126.69–130.02 (C_6H_5)	–
7ba	1.92–2.11 (m, H_α, H_β)	0.85 (m, CH_3), 1.22–1.29 [m, $(CH_2)_3$]	6.52 (t, $^3J_{1,2}$ = 6.2)	75.53	38.65	16.00 (CH_3), 24.56, 27.69, 33.70 [$(CH_2)_3$]	–
7bb	1.75–1.80 and1.98–2.04 (m, H_α, H_β)	0.96 and 1.04 (d, $^3J_{CH_3,CH}$ = 6.4, CH_3), 1.75–1.80 (m, CH)	6.60 (dd, $^3J_{1,2\alpha}$ = 4.3, $^3J_{1,2\beta}$ = 6.9)	72.33	25.77	22.27 (CH_3), 23.61 (CH),	–
7bc	1.76 (dd, $^2J_{2\alpha,2\beta}$ = 14.9, $^3J_{1,2\alpha}$ = 2.8), 2.06 (dd, $^3J_{1,2\beta}$ = 9.2)	1.03 [s, $C(CH_3)_3$]	6.68 (dd, $^3J_{1,2\alpha}$ = 2.8, $^3J_{1,2\beta}$ = 9.2)	71.51	50.86	30.38 and 31.32 [$C(CH_3)_3$]	–
7ca	1.70–1.90 (m, H_α, H_β)	0.85 (m, CH_3), 1.22–1.29 [m, $(CH_2)_3$]	6.12 (t, $^3J_{1,2}$ = 6.2)	71.67	36.27	14.33 (CH_3), 22.88, 25.53, 32.01 [$(CH_2)_3$]	–
7cb	1.52–1.71 (m, H_α, H_β)	0.92–0.98 (d, $^3J_{CH_3,CH}$ = 6.2, CH_3), 1.72–1.84 (m, CH)	6.19 (dd, $^3J_{1,2\alpha}$ = 4.5, $^3J_{1,2\beta}$ = 8.1)	69.89	27.62	22.34 and 22.49 (CH_3), 25.04 (CH),	–
7cc	1.58 (dd, $^2J_{2\alpha,2\beta}$ = 14.6, $^3J_{1,2\alpha}$ = 2.9), 1.80 (dd, $^3J_{1,2\beta}$ = 8.3)	0.96 [s, $C(CH_3)_3$]	6.25 (dd, $^3J_{1,2\alpha}$ = 2.9, $^3J_{1,2\beta}$ = 8.3)	69.42	50.29	30.25 and 31.01 [$C(CH_3)_3$]	–
8aa	2.20–2.35 and 2.65–2.80 (ddd, $^2J_{2\alpha,2\beta}$ = 14.5, $^3J_{2\alpha,3\alpha/\beta}$ = 4.5/11.9, $^3J_{2\beta,3\alpha/\beta}$ = 4.8, 11.2)	0.75–0.85 (m, CH_3), 0.90–1.45 [m, $(CH_2)_3$]	3.65 (s, OCH_3)	85.64	24.00	15.45 (CH_3), 24.00, 33.17, 37.79 [$(CH_2)_3$]	53.86 ($COOCH_3$), 174.15 ($COOCH_3$)
8ab	2.35 and 2.65 (dd, $^2J_{2\alpha,2\beta}$ = 15.0, $^3J_{2\alpha/\beta,3}$ = 4.5, 7.4)	0.67 and 0.86 (d, $^3J_{CH_3,CH}$ = 6.7, CH_3), 1.39–1.53 (m, CH)	3.65 (s, OCH_3)	84.10	44.05	23.27 and 24.47 (CH_3), 23.60 (CH),	52.27 ($COOCH_3$), 172.64 ($COOCH_3$)
8ac	2.45 and 2.89 (d, $^2J_{2\alpha,2\beta}$ = 15.0)	0.77 [s, $C(CH_3)_3$]	3.59 (s, OCH_3)	83.79	46.51	30.09 and 31.11 [$C(CH_3)_3$]	52.14 ($COOCH_3$), 172.81 ($COOCH_3$)
8ba	2.03 / 2.26 (m, H_α, H_β)	0.82 (t, CH_3), 1.10-1.61 [m, $(CH_2)_3$]	−0.10 [$Si(CH_3)_3$]	81.91	23.52	13.95 (CH_3), 22.50, 32.27, 36.53 [$(CH_2)_3$]	−1.05, −0.68, −0.34 [$Si(CH_3)_3$]
8ca	1.95–2.30 (m, H_α, H_β)	0.82 (t, CH_3), 1.10–1.60 [m, $(CH_2)_3$]	−0.02 [$Sn(CH_3)_3$]	84.61	25.08	14.00 (CH_3), 22.52, 32.19, 39.77 [$(CH_2)_3$]	−6.00 [$Sn(CH_3)_3$]
9a	3.03 (ddd, $^3J_{1,2}$ = 8.8, $^3J_{2,3\alpha/\beta}$ = 4.1, 9.1)	7.13–7.34 (m, C_6H_5)	5.90 (d, $^3J_{1,2}$ = 8.8)	79.56	52.02	13.78 (CH_3), 22.44, 29.24, 31.60 [$(CH_2)_3$]	–
9b	3.03 (dd, $^3J_{2,3\alpha/\beta}$ = 5.1, 9.7)	7.08–7.36 (m, C_6H_5)	–	79.56	51.90	13.76 (CH_3), 22.43, 29.23, 31.58 [$(CH_2)_3$]	–
9c/ 10c	3.00 and 3.16 (dd, $^3J_{2,3\alpha/\beta}$ = 2.9, 11.9)	6.80 –7.73 (m, C_6H_5)	1.90 and 1.93 (CH_3)	85.77	58.47	13.79 (CH_3), 22.52, 29.86, 30.36 [$(CH_2)_3$]	10.92 (CH_3)
9d	3.96 (dd, $^3J_{2,3\alpha/\beta}$ = 2.9, 12.1)	6.83–7.35 (m, C_6H_5)	3.67 (s, OCH_3)	85.36	51.25	13.81 (CH_3), 22.38, 29.79, 30.83 [$(CH_2)_3$]	52.00 ($COOCH_3$), 172.33 ($COOCH_3$)
10d	3.55 (dd, $^3J_{2,3\alpha/\beta}$ = 3.1, 12.2)	6.82–7.30 (m, C_6H_5)	3.67 (s, OCH_3)	85.93	51.69	13.78 (CH_3), 22.34, 29.01, 29.59 [$(CH_2)_3$]	54.62 ($COOCH_3$), 171.15 ($COOCH_3$)
9e	1.65–1.73 (m, H_α, H_β)	0.93 [s, $C(CH_3)_3$]	5.88 (d, $^3J_{1,2}$ = 6.4)	77.65	52.99	28.86 and 32.77 [$C(CH_3)_3$]	–

[a] NMR data of the aryl group (**7aa**–**7cc**, **8aa**–**ac**) and the *Cb* group is omitted; infrared absorptions at 1710–1690 cm^{-1} (C=ONR$_2$).
[b] All compounds gave correct C,H-analyses (C ± 0.4, H ± 0.3) or correct exact mass analyses.

(*Z*)-[1-Phenyl-6-(tetrahydropyran-2-yloxy)-hex-1-enyl] *N*,*N*-Diisopropylcarbamate:

To a solution of (−)-sparteine (305 mg, 1.30 mmol) in a *n*-BuLi solution (1.6 M, 0.72 mL, 1.15 mmol) in hexane, 1-phenyl-prop-2-enyl *N*,*N*-diisopropylcarbamate (261 mg, 1.00 mmol), dissolved in toluene (1.0 mL), was added at −78 °C and stirred for 30 min. A solution of 1-iodo-3-(tetrahydropyran-2-yloxy)-propane[35] (297 mg, 1.10 mmol) in toluene (1.0 mL) was added slowly. After stirring for another 4 h at −78 °C, the mixture was warmed to r.t. and sat. NH_4Cl solution (5 mL) was added. The organic layer was separated and the aq phase extracted with CH_2Cl_2 (3 × 10 mL). The collected extracts were dried (Na_2SO_4) and the solvent was evaporated in vacuo. Purification by flash column chromatography (Et_2O–PE, 1:3) afforded the enol carbamate (208 mg, 52%) as a colourless oil; R_f 0.16 (Et_2O–PE, 1:2). The (*Z*)-configuration was confirmed by a ^1H NMR–NOE experiment.

IR (film): 1720 (C=ONR$_2$), 770, 760 (C_6H_5).

^1H NMR ($CDCl_3$, 300 MHz): δ = 1.23 [m, 12 H, CH(CH_3)$_2$], 1.45–1.90 [m, 10 H, 4-H$_2$, 5H$_2$, O$_2$CH(CH_2)$_3$], 2.20 (dt, 1 H, $^3J_{2,3}$ = 7.4 Hz, 3-H), 3.35–3.54, 3.70–3.91 (2 × m, 4 H, 6-H$_2$, OCHROCH_2), 3.94–4.12 [m, 2 H, CH(CH$_3$)$_2$], 4.54–4.60 (m, 1 H, OCHRO), 5.79 (t, 1 H, 2-H), 7.19–7.43 (m, 5 H, C_6H_5).

^{13}C NMR ($CDCl_3$, 75 MHz): δ = 20.04 (C-4-THP), 20.93, 22.08 [CH(*C*H$_3$)$_2$], 25.09, 26.21, 26.47 (C-3, C-4, C-3-THP), 29.98 (C-5-THP), 31.18 (C-5), 46.66, 46.99 [*C*H(CH$_3$)$_2$], 62.66 (C-6-THP), 67.73 (C-6), 99.22 (C-2-THP), 118.09 (C-2), 124.86, 128.41, 129.21, 136.68 (*C*$_6$H$_5$), 147.04 (C-1), 153.27 (C=O).

(*Z*)-(6-Hydroxy-1-phenylhex-1-enyl) *N*,*N*-diisopropylcarbamate:

(*Z*)-[1-Phenyl-6-(tetrahydropyran-2-yloxy)-hex-1-enyl] *N*,*N*-diisopropylcarbamate (202 mg, 0.50 mmol) and Amberlyst 15 (200 mg) in MeOH (3 mL) were stirred for 6 h. After filtration, the Amberlyst was intensively eluted with Et_2O (5 × 2 mL, sonification bath) and the combined organic phases were evaporated in vacuo. A second filtration (silica gel, Et_2O–PE, 1:3) yielded the alcohol (159 mg, 100%) as a colourless oil; R_f 0.37 (Et_2O).

IR (film): 3350 (OH), 1710 (C=ONR$_2$), 770, 760 (C_6H_5).

^1H NMR ($CDCl_3$, 300 MHz): δ = 1.12–1.49 [m, 12 H, CH(CH_3)$_2$], 1.49–1.73 (m, 4 H, 4-H$_2$, 5H$_2$), 2.21 (dt, 1 H, $^3J_{2,3}$ = 7.5 Hz, 3-H), 3.64 (t, 1 H, $^3J_{5,6}$ = 8.2 Hz, 6-H$_2$); 4.03 [sept, 2 H, CH(CH$_3$)$_2$], 5.79 (t, 1 H, 2-H), 7.16–7.45 (m, 5 H, C_6H_5).

^{13}C NMR ($CDCl_3$, 75 MHz): δ = 20.92, 22.09 [CH(*C*H$_3$)$_2$], 25.53, 26.23, (C-3, C-4), 32.73 (C-5), 46.65, 47.11 [*C*H(CH$_3$)$_2$], 63.03 (C-6), 118.01 (C-2), 124.86, 128.10, 128.74, 136.59 (*C*$_6$H$_5$), 147.17 (C-1), 153.44 (C=O).

Anal. Calcd for $C_{19}H_{29}NO_3$ (319.45): C, 71.44; H, 9.15. Found: C, 71.54; H, 9.41.

(*Z*)-(6-Iodo-1-phenyl-1-hexenyl) *N*,*N*-diisopropylcarbamate (**18**):

To a stirred solution of (*Z*)-(6-hydroxy-1-phenylhex-1-enyl) *N*,*N*-diisopropylcarbamate (2.07 g, 6.48 mmol), triphenylphosphine (2.21 g, 8.42 mmol), and imidazole (575 mg, 8.42 mmol) in Et_2O–MeCN (3:1, 40 mL), I_2 (1.73 g, 6.80 mmol) was added slowly in small portions until the solution remained pale yellow. After stirring for 1.5 h, $Na_2S_2O_3$ (1 g) was added and the mixture was stirred for a further 5 min. After filtration, Et_2O (50 mL) was added and the solvent was evaporated. The procedure was repeated three times to remove MeCN completely. The residue was purified by flash column chromatography (Et_2O–PE, 1:6) to afford iodide **18** (2.33 g, 84%) as colourless crystals; R_f 0.53 (Et_2O–PE, 1:4), mp 80–81 °C (Et_2O–PE). The (*Z*)-configuration of the double bond was confirmed by a ^1H NMR–NOE experiment.

IR (KBr): 1710 (s, C=ONR$_2$), 770, 760 (C_6H_5).

^1H NMR ($CDCl_3$, 300 MHz): δ = 1.12–1.49 [m, 12 H, CH(CH_3)$_2$], 1.49–1.70 (m, 4 H, 4-H$_2$,), 1.81 (m, 2 H, 5-H$_2$), 2.21 (dt, 1 H, $^3J_{2,3}$ = 7.5 Hz, 3-H), 3.18 (t, 1 H, $^3J_{5,6}$ = 8.1 Hz, 6-H$_2$), 4.03 [sept, 2 H, CH(CH$_3$)$_2$], 5.76 (t, 1 H, 2-H), 7.16–7.45 (m, 5 H, C_6H_5).

^{13}C NMR ($CDCl_3$, 75 MHz): δ = 6.96 (C-6), 20.92, 22.09 [CH(*C*H$_3$)$_2$], 25.49, 28.99 (C-3, C-4), 33.54 (C-5), 47.01 [*C*H(CH$_3$)$_2$], 117.38 (C-2), 124.90, 128.17, 128.74, 136.52 (*C*$_6$H$_5$), 147.47 (C-1), 153.17 (C=O).

Anal. Calcd for $C_{19}H_{28}NO_2I$ (429.34): C, 53.15; H, 6.57. Found: C, 53.55; H, 6.87.

Preparation of 7aa–cc, 8aa–ca, 9a–e, 10c,d, 12a, 13a, 17, 21a,b; General Procedures

Carbolithiation Procedures

Method A: To a stirred solution of the chiral diamine [1.05 mmol (Table 3, entry 1–9)], or TMEDA (122 mg, 1.05 mmol) in toluene (1.0 mL) at −78 °C the appropriate organolithium reagent (1.05 mmol) was added, directly followed by the enol carbamate (0.75 mmol), dissolved in toluene (1.0 mL). After stirring for 5 h at −78 °C, the electrophile (Table 2), was introduced. The reaction mixture was stirred at −78 °C for the time given in Table 2 before the workup.

Method B: To a stirred solution of TMEDA (160mg, 1.4 mmol) (Table 2) and *Z*-**1d** (323 mg, 1.00 mmol) in toluene (3.0 mL) at −78 °C the *n*-BuLi solution was added. After stirring (Table 2, entry 14: 5 h; entry 15: 50 min at −78 °C, 30 min at −15 °C, then −78 °C; entry 16: 1.5 h; entry 17: 1 h; entry 18, 19: 5 h), the electrophile was introduced. The reaction mixture was stirred at −78 °C for the time given in Table 2 before the workup.

Method C: To a stirred solution of TMEDA (163 mg, 1.4 mmol) and *n*-BuLi (1.6 M in hexane, 0.89 mL, 1.4 mmol) in toluene (1.5 mL) at −78 °C, **1e** (303 mg, 1.00 mmol), dissolved in toluene (1.0 mL), was added. After stirring for 3 h at −40 °C MeOH (1 mL, 25 mmol) was injected. The workup followed directly.

Method D: To a stirred solution of TMEDA (130 mg, 1.20 mmol) and *n*-BuLi (1.6 M in hexane, 0.75 mL, 1.20 mmol) in toluene (2.0 mL) at −78 °C, **1f** (273 mg, 1.00 mmol), dissolved in toluene (1.0 mL), was added. After stirring for 4 h at −78 °C, the electrophile was injected. The workup followed directly.

Method E: To a stirred solution of TMEDA (163 mg, 1.40 mmol) and *t*-BuLi (1.5 M in pentane, 0.93 mL, 1.40 mmol) in toluene (2.0 mL) at −78 °C, **1f** (273 mg, 1.00 mmol), dissolved in toluene (1.0 mL), was added, directly following the injection of *t*-BuLi. After stirring for 4 h at −78 °C, the electrophile was injected. The workup followed directly.

Method F: To a stirred solution of TMEDA (209 mg, 1.80 mmol) and Iodide **17** (322 mg, 0.75 mmol) in toluene (5.0 mL) at −78 °C *t*-BuLi (1.5 M in pentane; 1.10 mL, 1.65 mmol) was added. After stirring for 6.5 h at −78 °C, the electrophile was injected. The reaction mixture was stirred at −78 °C [Table 2, entry 26: 0.5 h; entry 27: 24 h] before the workup.

General Workup

After Carboxylation: MeOH (0.5 mL) and then aq HCl (2 N, 10 mL) were injected into the reaction mixture. After warming to r.t., the layers were separated, the aq phase was extracted with Et_2O (3 × 10 mL), the combined etheral phases were dried (Na_2SO_4 or $MgSO_4$) and the Et_2O was evaporated in vacuo. The remaining solution in toluene was treated with etheral CH_2N_2 until a pale yellow colour persisted. After stirring for 1 h, silica gel (100 mg) was added and the suspension was stirred for 30 min in order to destroy excessive CH_2N_2. The crude product was purified by flash column chromatography (Et_2O–PE, 1:20→1:6).

Other electrophiles: MeOH (0.5 mL) and then aq HCl (2 N, 10 mL) were injected into the reaction mixture. After warming to r.t., the layers were separated, the aq phase was extracted with Et_2O (3 × 10 mL) and the combined organic phases were dried and neutralized (solid Na_2SO_4 or $MgSO_4$; with a little $NaHCO_3$). The solvent was evaporated and the crude product purified by flash column chromatography (Et_2O–PE, 1:20→1:1).

rac-trans-2-Butyl-1,2,3,4-tetrahydronaphth-1-yl *N,N*-Diisopropylcarbamate (*rac*-12a)

Method D, yield: 256 mg (78%); colourless oil; R_f 0.33 (Et_2O–PE 1:9).

IR (film): 1695 (C=ONR$_2$), 770, 740 (C_6H_4).

^{1}H NMR ($CDCl_3$, 300 MHz): δ = 0.88 [m, 3 H, $(CH_2)_3CH_3$], 1.21 [m, 12 H, $CH(CH_3)_2$], 1.10–1.55 [m, 5 H, $(CH_2)_3CH_3$], 1.63 (m, 1 H, 3-H$_\alpha$), 1.95–2.12 (m, 2 H, H-2, 3-H$_\beta$), 2.78 (m, 2 H, 4-H$_2$); 3.50–4.40 [m, 2 H, $CH(CH_3)_2$], 5.76 (d,1 H, $^3J_{1,2}$ = 6.2 Hz, 1-H), 7.05-7.31 (m, 4 H, C_6H_4).

^{13}C NMR ($CDCl_3$, 75 MHz): δ = 14.05 [$(CH_2)_3CH_3$], 21.02 [$CH(CH_3)_2$], 22.95, 26.76, 29.25 [$(CH_2)_3CH_3$], 24.40 (C-4), 30.46 (C-3), 38.98 (C-2), 45.80 [$CH(CH_3)_2$], 74.61 (C-1), 125.89, 127.34, 128.56, 129.53, 135.66, 137.35 (C_6H_4), 156.01 (C=ONR$_2$).

Anal. Calcd for $C_{21}H_{33}NO_2$ (331.49): C, 76.09; H, 10.03. Found: C, 76.03; H, 9.74.

rac-(1*R**,2*R**)-2-Butyl-1-methoxycarbonyl-1,2,3,4-tetrahydronaphth-1-yl *N,N*-Diisopropylcarbamate (*rac*-13a)

Method D, yield: 70 mg (24%); colourless oil; R_f 0.45 (Et_2O–PE, 1:5).

IR (film): 1750 (C=OOMe), 1700 (C=ONR$_2$), 775, 750 (C_6H_4).

^{1}H NMR ($CDCl_3$, 300 MHz): δ = 0.87 [m, 3 H, $(CH_2)_3CH_3$], 1.10–1.48 [m, 6 H, $(CH_2)_3CH_3$], 1.21 [m, 12 H, $CH(CH_3)_2$], 1.88–1.99 (m, 1 H, 2-H), 2.44–2.72 (m, 2 H, 3-H$_2$), 2.75–3.05 (m, 2 H, 4-H$_2$), 3.68 (s, 3 H, OCH_3), 3.70–4.15 [m, 2 H, $CH(CH_3)_2$], 7.05–7.24, 7.74–7.79 (m, C_6H_4).

^{13}C NMR ($CDCl_3$, 75 MHz): δ = 13.91 [$(CH_2)_3CH_3$], 20.96, 21.72 [$CH(CH_3)_2$], 22.37, 26.52, 29.15 [$(CH_2)_3CH_3$], 22.77 (C-3), 24.39 (C-4), 37.62 (C-2), 45.99, 46.44 [$CH(CH_3)_2$], 52.09 (OCH_3), 82.29 (C-1), 125.26, 127.91, 128.76, 129.60, 133.39, 138.32 (C_6H_4), 153.86 (C=ONR$_2$), 172.29 (C=O).

Anal. Calcd for $C_{23}H_{35}NO_4$ (389.53): C, 70.09; H, 9.06. Found: C, 69.99; H, 9.25.

rac-cis-2-*tert*-Butyl-6-methoxycarbonyl-1,2,3,4-tetrahydronaphth-1-yl *N,N*-Diisopropylcarbamate (17)

Method E, yield: 230 mg (79%); colourless crystals; R_f 0.47 (Et_2O–PE, 1:4); mp 123–124 °C (Et_2O–PE).

IR (KBr): 1735 (C=OOMe), 1700 (C=ONR$_2$), 780, 750 (C_6H_4).

^{1}H NMR ($CDCl_3$, 300 MHz): δ = 1.06 [s, 9 H, $C(CH_3)_3$], 1.10–1.33 [m, 12 H, $CH(CH_3)_2$], 1.45–1.59 (m, 1 H, 2-H), 1.87–2.03 (m, 2 H, 4-H$_2$), 2.75–2.90, 3.02–3.14 (m, 2 H, 3-H$_2$), 3.55–4.05 [m, 2 H, $CH(CH_3)_2$], 3.89 (s, 3 H, OCH_3), 6.34 (d, 1 H, $^3J_{1,2}$ = 1.9 Hz, 1-H), 7.48, 7.77, 7.80 (d, d, s, 3 H, $^3J_{7,8}$ = 8.1 Hz, C_6H_3).

^{13}C NMR ($CDCl_3$, 75 MHz): δ = 19.96 (C-3), 21.08, 21.60 [$CH(CH_3)_2$], 22.17 [$C(CH_3)_3$], 28.86 (C-2), 30.44 (C-4), 32.87 [$C(CH_3)_3$], 45.90, 46.74 [$CH(CH_3)_2$], 52.34 (OCH_3), 70.64 (C-1), 127.23, 130.29, 130.46 (C-5, C-7, C-8), 129.95 (C-6), 137.33 (C-4a), 142.51 (C-8a), 155.10 (C=ONR$_2$), 167.49 (C=O).

Anal. Calcd for $C_{23}H_{35}NO_4$ (405.57): C, 70.09; H, 9.06. Found: C, 70.16; H, 8.86.

rac-trans-2-*tert*-Butyl-1,2,3,4-tetrahydronaphth-1-yl *N,N*-Diisopropylcarbamate (15a)

Method E, yield: 167 mg (51%), colourless oil; R_f 0.43 (Et_2O–PE, 1:5).

IR (film): 1695 (C=ONR$_2$), 770, 740 (C_6H_4).

^{1}H NMR ($CDCl_3$, 300 MHz): δ = 0.98 [s, 9 H, $C(CH_3)_3$], 0.98–1.24 [m, 12 H, $CH(CH_3)_2$], 1.49 (ddt, 1 H, $^2J_{3\alpha,3\beta}$ = 13.1 Hz, $^3J_{2,3\alpha}$ = 10.5 Hz, $^3J_{3\alpha,4\alpha/\beta}$ = 4.8 Hz, 3-H$_\alpha$), 1.89 (ddd, 1 H, $^3J_{1,2}$ = 5.1 Hz, $^3J_{2,3\beta}$ = 5.2 Hz, 2-H), 2.06 (ddd, 1 H, 3-H$_\beta$), 2.66–2.88 (m, 2 H, 4-H$_2$), 3.50–4.10 [m, 2 H, $CH(CH_3)_2$], 6.11 (d, 1 H, 1-H), 7.02–7.42 (m, 4 H, C_6H_4).

^{13}C NMR ($CDCl_3$, 75 MHz): δ = 21.41 [$CH(CH_3)_2$], 24.91 (C-4), 28.45 [$C(CH_3)_3$], 28.88 (C-3), 29.52 [$C(CH_3)_3$], 46.14 [$CH(CH_3)_2$], 50.36 (C-2), 72.80 (C-1), 126.53, 127.72, 127.97, 130.06 (C-5, C-6, C-7, C-8), 137.55, 139.95 (C-4a, C-8a), 155.78 (C=ONR$_2$).

Anal. Calcd for $C_{21}H_{33}NO_2$ (331.49): C, 76.09; H, 10.03. Found: C, 76.23; H, 10.26.

rac-(1*R**,2*R**)-2-*tert*-Butyl-1-deutero-1,2,3,4-tetrahydronaphth-1-yl *N,N*-Diisopropylcarbamate (15b)

Method E, yield: 315 mg (95%); colourless oil; R_f 0.45 (Et_2O–PE, 1:5).

IR (film): 1695 (C=ONR$_2$), 770, 740 (C_6H_4).

^{1}H NMR ($CDCl_3$, 300 MHz): δ = 0.95 [s, 9 H, $C(CH_3)_3$], 0.98–1.24 [m, 12 H, $CH(CH_3)_2$], 1.49 (ddt, 1 H, $^2J_{3\alpha,3\beta}$ = 13.1 Hz, $^3J_{2,3\alpha}$ = 10.5 Hz, $^3J_{3\alpha,4\alpha/\beta}$ = 4.8 Hz, 3-H$_\alpha$), 1.89 (dd, 1 H, $^3J_{2,3\beta}$ = 5.2 Hz, 2-H), 2.06 (ddd, 1 H, 3-H$_\beta$), 2.66–2.88 (m, 2 H, 4-H$_2$), 3.50–4.10 [m, 2 H, $CH(CH_3)_2$], 7.02–7.42 (m, 4 H, C_6H_4).

^{13}C NMR ($CDCl_3$, 75 MHz): δ = 21.41 [$CH(CH_3)_2$], 24.91 (C-4), 28.45 [$C(CH_3)_3$], 28.88 (C-3), 29.52 [$C(CH_3)_3$], 46.14 [$CH(CH_3)_2$], 50.36 (C-2), 72.80 (C-1), 126.53, 127.72, 127.97, 130.06 (C-5, C-6, C-7, C-8), 137.55, 139.95 (C-4a, C-8a), 155.78 (C=ONR$_2$).

The degree of deuteration (96%) was determined from the 1-H-signal in the ^{1}H NMR spectrum.

rac-(1-Cyclopentyl-1-phenyl-methyl) *N,N*-Diisopropylcarbamate (21a)

Method F, yield: 199 mg (88%); colourless oil; R_f 0.35 (Et_2O–PE, 1:4).

IR (film): 1700 (C=ONR$_2$), 770 (C_6H_5).

^{1}H NMR ($CDCl_3$, 300 MHz): δ = 1.07–1.25 [m, 20 H, $CH(CH_2)_4$, $CH(CH_3)_2$], 2.37 (sext, 1 H, $^3J_{1,2}$ = 7.5 Hz, 2-H), 3.75–4.10 [m, 2 H, $CH(CH_3)_2$], 5.52 (d, 1 H, 1-H), 7.18–7.30 (m, 5 H, C_6H_5).

^{13}C NMR ($CDCl_3$, 75 MHz): δ = 21.09 [$CH(CH_3)_2$], 25.24, 29.21, 29.57 [$CH(CH_2)_4$], 45.84 [$CH(CH_3)_2$], 80.21 (C-1), 126.93, 127.19, 128.00, 128.19 (C_6H_5), 155.09 (C=ONR$_2$).

Anal. Calcd for $C_{19}H_{29}NO_2$ (303.44): C, 75.21; H, 9.63. Found: C, 75.25; H, 9.63.

rac-(1-Cyclopentyl-1-phenyl-1-trimethylstannyl)-methyl *N,N*-Diisopropylcarbamate (21b)

Method F, yield: 150 mg (43%); colourless oil; R_f 0.61 (Et_2O–PE, 1:9).

IR (film): 1690 (C=ONR$_2$), 770 (C_6H_5).

^{1}H NMR ($CDCl_3$, 300 MHz): δ = −0.02 [s, 9 H, $^2J_{Sn\text{-}C\text{-}H}$ = 25.2 Hz, $Sn(CH_3)_3$], 1.20–1.83 [m, 20 H, $CH(CH_2)_4$, $CH(CH_3)_2$], 2.81 (quin, 1 H, 2-H), 3.90–4.16 [sept, 2 H, $^3J_{CH,CH_3}$ = 6.7 Hz, $CH(CH_3)_2$], 6.92–7.34 (m, 5 H, C_6H_5).

^{13}C NMR ($CDCl_3$, 75 MHz): δ = −4.29 ($SnCH_3$), 21.45, 22.31 [$CH(CH_3)_2$], 24.58, 24.79, 27.99, 31.68 [$CH(CH_2)_4$], 46.74, 47.00 [$CH(CH_3)_2$], 50.24 [$CH(CH_2)_4$], 86.50 (C-1), 123.83, 125.05, 128.68, 128.96, 129.76, 127.54 (C_6H_5), 157.33 (C=ONR$_2$).

HRMS (EI, 70 eV): *m/z* calcd for $C_{22}H_{37}NO_2Sn–CH_3$: 452.16116; found: 452.16199.

Anal. Calcd for $C_{22}H_{37}NO_2Sn$ (466.24): C, 56.67; H, 8.00. Found: C, 57.15; H, 8.16.

Acknowledgement

Generous support by the Fonds der Chemischen Industrie and Deutsche Forschungsgemeinschaft (SFB 424) is gratefully acknowledged.

References

(1) (a) Ziegler, K.; Gellert, H. G. *Liebigs Ann. Chem.* **1950**, *567*, 195. (b) Morton, M. *Anionic Polymerisation: Principles and Practice*; Academic Press: New York, **1963**.
(2) Review: Marek, I. *J. Chem. Soc., Perkin Trans 1* **1999**, 535.
(3) Review on early work: Klumpp, G. W. *Recl. Trev. Chim. Pay-Bas* **1986**, *105*, 1.
(4) (a) Klein, S.; Marek, I.; Normant, J.-F. *J. Org. Chem.* **1994**, *59*, 2925. (b) Mück-Lichtenfeld, C.; Ahlbrecht, H. *Tetrahedron* **1996**, *52*, 10025.
(5) Review: Beak, P.; Meyers, A. I. *Acc. Chem. Res.* **1986**, *19*, 356.
(6) The sense of diastereoselectivity, by which **F** is formed, depends on the configuration of intermediate **E** and the stereochemistry of the substitution step.
(7) (a) Klein, S.; Marek, I.; Poisson, J.-F.; Normant, J. F. *J. Am. Chem. Soc.* **1995**, *117*, 8853. (b) Norsikian, S.; Marek, I.; Poisson, J. F.; Normant, J. F. *J. Org. Chem.* **1997**, *62*, 4898. (c) Norsikian, S.; Marek, I.; Normant, J.-F. *Tetrahedron Lett.* **1997**, *38*, 7523. (d) Norsikian, S.; Marek, I.; Poisson, J. F.; Normant, J. F. *Chem.– Eur. J.* **1999**, *5*, 2055.
(8) For further enantioselective, intramolecular reactions of achiral lithium alkenyl compounds, being complexed at the cation by (–)-sparteine, see: (a) Bailey, W. F.; Mearly, M. J. *J. Am. Chem. Soc.* **2000**, *122*, 6787. (b) Sanz Gil, G.; Groth, U. M. *J. Am. Chem. Soc*. **2000**, *122*, 6789.
(9) Racemates: Hoppe, D.; Brönneke, A. *Synthesis* **1982**, 1045.
(10) For preparation of chiral benzyl lithium compounds by deprotonation of optically active precursors, see: (a) Hoppe, D.; Carstens, A.; Krämer, T. *Angew. Chem. Int. Ed. Engl.* **1990**, *29*, 1424. (b) Carstens, A.; Hoppe, D. *Tetrahedron* **1994**, *30*, 6097. (c) Derwing, C.; Hoppe, D. *Synthesis* **1996**, 149. (d) Derwing, C.; Frank, H.; Hoppe, D. *Eur. J. Org. Chem.* **1999**, 3519. (e) Hammerschmidt, F.; Hanninger, A.; Peric Simov, B.; Völlenkle, H.; Werner, A. *Eur. J. Org. Chem.* **1999**, 3511.
(11) For further configurationally stable benzyllithiums: (a) Hoppe, D.; Kaiser, B.; Stratmann, O.; Fröhlich, R. *Angew. Chem. Int. Ed. Engl.* **1997**, *36*, 2784. (b) Stratmann, O.; Kaiser, B.; Fröhlich, R.; Meyer, O.; Hoppe, D. *Eur. J. Org. Chem.* **2001**, 423.
(12) Reviews: (a) Hoppe, D.; Hense, T. *Angew. Chem. Int. Ed. Engl.* **1997**, *36*, 2282. (b) Beak, P.; Basu, A.; Gallagher, D. J.; Park, Y. S.; Thayumanavan, S. *Acc. Chem. Res.* **1996**, *29*, 552.
(13) Superchi, S.; Sotomayor, N.; Miao, G.; Joseph, B.; Campbell, M. G.; Snieckus, V. *Tetrahedron Lett.* **1996**, *37*, 6061.
(14) High simple diastereoselectivity may result from the *syn*-addition process.
(15) Hoppe, D.; Hanko, R.; Brönneke, A.; Lichtenberg, F.; van Hülsen, E. *Chem. Ber.* **1985**, *118*, 2822.
(16) Heinl, T.; Retzow, S.; Hoppe, D.; Fraenkel, G. *Chem.– Eur. J.* **1999**, *5*, 3464.
(17) X-ray crystal structure analysis of **1d**: formula $C_{21}H_{25}NO_2$, M = 323.42, colourless crystal 0.40 × 0.40 × 0.20 mm, a = 12.118(2), b = 13.509(2), c = 23.090(4) Å, β = 92.32(1)°, V = 3776.8(11) Å^3, ρ_{calc} = 1.138 g cm^{-3}, μ = 0.72 cm^{-1}, no absorption correction (0.994 ≤ C ≤ 0.999), Z = 8, monoclinic, space group $P2_1/c$ (No. 14), λ = 0.71073 Å, T = 293 K, ω/2θ scans, 6700 reflections collected (+h,+k, ±l), [(sinθ)/λ] = 0.59 Å^{-1}, 6374 independent (R_{int} = 0.028) and 3227 observed reflections [$I \geq 2\ \sigma(I)$], 441 refined parameters, R = 0.048, wR^2 = 0.114, max. residual electron density 0.45 (–0.23) e Å^{-3}, hydrogens calculated and refined as riding atoms, two almost identical molecules in the asymmetric unit, differences in the torsion angles C1–C2–O2–C3 and C31–C32–O32–C33.[36]
(18) If not denoted otherwise in Tables: the first letter corresponds to the substrate and the second letter corresponds to the carbolithiation reagent.
(19) X-ray crystal structure analysis of **9a**: formula $C_{25}H_{35}NO_2$, M = 381.54, colourless crystal 0.70 × 0.50 × 0.30 mm, a = 29.416(5), c = 11.006(2) Å, V = 9524(3) Å^3, ρ_{calc} = 1.064 g cm^{-3}, μ = 0.66 cm^{-1}, empirical absorption correction via ψ scan data (0.928 ≤ C ≤ 0.999), Z = 16, tetragonal, space group $I4_1/a$ (No. 88), λ = 0.71073 Å, T = 293 K, ω/2θ scans, 8176 reflections collected (+h, ±k,+l), [(sinθ)/λ] = 0.59 Å^{-1}, 4011 independent (R_{int} = 0.099) and 1859 observed reflections [$I \geq 2\ \sigma(I)$], 258 refined parameters, R = 0.062, wR^2 = 0.161, max. residual electron density 0.18 (–0.17) e Å^{-3}, hydrogens calculated and refined as riding atoms.[36]
(20) See Ref.[10] For a further example: Laqua, H.; Fröhlich, R.; Wibbeling, B.; Hoppe, D. *J. Organomet. Chem.* **2001**, *624*, 96.
(21) X-ray crystal structure analysis of **17**: formula $C_{23}H_{35}NO_4$, M = 389.52, colourless crystal 0.30 × 0.25 × 0.15 mm, a = 10.689(1), b = 10.717(1), c = 10.953(1) Å, α = 101.53(1), β = 96.47(1), γ = 108.18(1)°, V = 1147.2(2) Å^3, ρ_{calc} = 1.128 g cm^{-3}, μ = 0.76 cm^{-1}, no absorption correction (0.978 ≤ T ≤ 0.989), Z = 2, triclinic, space group $P\bar{1}$ (No. 2), λ = 0.71073 Å, T = 293 K, ω and φ scans, 8217 reflections collected (±h, ±k, ±l), [(sinθ)/λ] = 0.65 Å^{-1}, 5220 independent (R_{int} = 0.020) and 4004 observed reflections [$I \geq 2\ \sigma(I)$], 261 refined parameters, R = 0.052, wR^2 = 0.138, max. residual electron density 0.17 (–0.16) e Å^{-3}, hydrogens calculated and refined as riding atoms.[36]
(22) Tolbert, L. M.; Martone, D. P. *J. Org. Chem.* **1983**, *38*, 1185.
(23) (a) Wittig, G.; Bub, O. *Liebigs Ann. Chem.* **1950**, *566*, 113. (b) Wittig, G.; Gonsior, L.; Vogel, H. *Liebigs Ann. Chem.* **1965**, *688*, 1.
(24) Fraenkel, G.; Geckle, M. J.; Kaylo, A.; Estes, D. W. *J. Organomet. Chem.* **1980**, *197*, 249.
(25) Iodide **18** was prepared from 1-phenylprop-2-enol by carbamoylation, a deprotonation-γ-alkylation sequence with a ω-oxy-2-(tetrahydropyranyloxy)propyl iodide, deprotection of the hydroxy group and conversion to the iodide; see experimental section.
(26) (a) Winkler, H. J. S.; Winkler, H. *J. Am. Chem. Soc.* **1966**, *88*, 964. (b) Winkler, H. J. S.; Winkler, H. *J. Am. Chem. Soc.* **1966**, *88*, 969. (c) Bailey, W. F.; Patricia, J. J.; Del Gobbo, V. C.; Jarret, R. M.; Okarma, P. J. *J. Org. Chem.* **1985**, *50*, 1999. (d) Bailey, W. F.; Nurmi, T. T.; Patricia, J. J.; Wang, W. *J. Am. Chem. Soc.* **1987**, *109*, 2442. (e) Bailey, W. F.; Khanolkar, A. D.; Gavaskar, K.; Ovaska, T. V.; Rossi, K.; Thiel, Y.; Wiberg, K. B. *J. Am. Chem. Soc.* **1991**, *113*, 5720.
(27) See also footnote 15 in Ref.[13]
(28) Pentyl phenyl ketone was submitted to an asymmetric reduction by (+)-diisopinocampheylchloroborane and the

resulting alcohol was subsequently carbamoylated by *N*,*N*-diisopropylcarbamoyl chloride (**4**) in pyridine: (a) Brown, H. C.; Chandrasekharan, J.; Ramachandran, P. V. *J. Am. Chem. Soc.* **1988**, *110*, 1539. (b) See Ref.[15]

(29) Galinousky, F.; Knoth, P.; Fischer, W. *Monatsh. Chem.* **1955**, *86*, 1014.

(30) Behrens, K. *Dissertation*; University of Münster: Germany, **1997**.

(31) (a) Benson, S. C.; Cai, P.; Colon, M.; Haiza, M. A.; Tokles, M.; Snyder, J. K. *J. Org. Chem.* **1988**, *53*, 5335. (b) Würthwein, E.-U.; Behrens, K.; Hoppe, D. *Chem.– Eur. J.* **1999**, *5*, 3459.

(32) Beak, P.; Kerrick, S. T.; Wu, S.; Chu, J. *J. Am. Chem. Soc.* **1999**, *116*, 3231.

(33) Peters, J. G. *Dissertation*; University of Münster: Germany, **2000**.

(34) Ramsden, H. E.; Leebrick, J. R.; Rosenberg, S. D.; Miller, E. H.; Walburn, J. J.; Balint, A. E. *J. Org. Chem.* **1957**, *22*, 1602.

(35) Cox, G. G.; Moody, C. J.; Austin, D. J.; Padwa, A. *Tetrahedron* **1993**, *49*, 5109.

(36) (a) X-ray analysis. (b) X-ray data sets were collected with Enraf-Nonius CAD4 and Nonius Kappa CCD diffractometers, the later one equipped with a rotating anode generator Nonius FR591. Programs used: data collection EXPRESS (Nonius B.V., 1994) and COLLECT (Nonius B.V., 1998), data reduction MolEN (K. Fair, Enraf-Nonius B.V., 1990) and Denzo-SMN: Otwinowski, Z.; Minor, W. *Methods in Enzymology* **1997**, *276*, 307. (c) Absorption correction for CCD data SORTAV: Blessing, R. H. *Acta Crystallogr.* **1995**, *A51*, 33. (d) Blessing, R. H. *J. Appl. Crystallogr.* **1997**, *30*, 421. (e) Structure solution SHELXS-86 and SHELXS-97: Sheldrick, G. M. *Acta Crystallogr.* **1990**, *A46*, 467. (f) Sheldrick, G. M. *Structure refinement SHELXL-93 and SHELXL-97*; Universität Göttingen: Germany, **1997**. (g) Graphics: Keller, E. *SCHAKAL*; Universität Freiburg: Germany, **1997**. (h) Crystallographic data (excluding structure factors) for the structure reported in this paper have been deposited with *Cambridge Crystallographic Data Centre* as supplementary publication No. CCDC-156957–156959. Copies of the data can be obtained free of charge on application to The Director, CCDC, 12 Union Road, Cambridge CB2 1EZ, UK (fax: int. code+44(1223)336-033; e-mail: deposit@ccdc.cam.ac.uk).