155. Preparation and C-Alkylation of Enantiomerically Pure *S*-Phenyl Aziridinecarbothioates. On the Structure of Small-Ring Ester Lithium Enolates

by **Robert Häner**[1]), **Bernardo Olano**[2]), and **Dieter Seebach***

Laboratorium für Organische Chemie der Eidgenössischen Technischen Hochschule, ETH-Zentrum, Universitätstrasse 16, CH–8092 Zürich

Dedicated to Professor Dr. *Ulrich Schöllkopf* on the occasion of his 60th birthday

(30.VII.87)

Racemic and enantiomerically pure methyl *N*-(*tert*-butyl)-*N*-benzyl- and *N*-1-(phenylethyl)aziridinecarboxylates are prepared by known methods and converted to phenyl thioesters (**1**, **2**, **15**, **16**; *Schemes 2* and *3*). These are deprotonated with lithium diisopropylamide (LDA) and BuLi (for removal of diisopropylamine) in THF at dry-ice temperature. The resulting lithiated species are surprizingly stable and are deuterated, alkylated (CH_3, C_2H_5, allyl, benzyl), and added to aldehydes and nitroolefins in good yields (50–80%, 18 examples; *Schemes 1* and *4–6*). The configurational stability of the lithiated species is studied, and conclusions about their structures are drawn. Thus, a C(α)-lithiated ester (see **L**, *Scheme 9*) or an *O*-lithiated 'enolate' (see **M**) with pyramidalized C(β)-atom is proposed for the species from levorotatory *S*-phenyl *N*-benzylaziridinecarbothioate which does not undergo racemization after 1 h at −60° (THF solution).

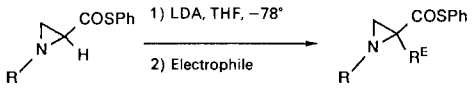
1. Introduction and Goal. – In a preliminary communication, we recently described the lithiation of the *S*-phenyl aziridinecarbothioates **1** and **2** [1]. In contrast to the corresponding *O*-alkyl esters, these were cleanly metalated by lithium diisopropylamide (LDA) and reacted with various electrophiles to give the products **3**–**10**. A general discussion of the specific problems associated with carbanionoid three-membered heterocycles is given in [1], the compounds **2**–**10** shown in *Scheme 1* are fully characterized in the *Exper. Part.* We became immediately interested in investigating non-racemic aziridines in these reactions for two reasons: *a)* for possible applications in syntheses of enantiomerically pure compounds (EPC) [2]; *b)* to gain information about the structure of small-ring ester enolates [3].

---

[1]) Part of the Dissertation of *R. H.*, ETH No. 8265, Zürich, 1987.

[2]) Postdoctoral research assistant, on leave from the Universidad de Oviedo, Spain, 1986/87.

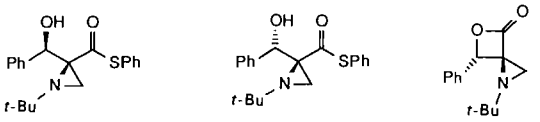
Scheme 1



1, 2 *(racemic)* **3–9** *(racemic)*

Edukt	R	Electrophile	R^E	Product	Yield [%]	Diastereoselectivity[a])
1	*t*-Bu	CH_3CHO	$CH_3CH(OH)$	**3**	70	88:12[b])
		PhCHO	PhCH(OH)	**4**	87[c])	74:26[d])
		β-nitrostyrene	$NO_2CH_2CH(Ph)$	**5**	75	72:28
		CH_3I/DMPU[e])	CH_3	**6**	60	–
2	Bn	PhCHO	PhCH(OH)	**7**	71	77:23[b])
		CH_3I/DMPU[e])	CH_3	**8**	61	–
		$PhCH_2Br$/DMPU[e])	$PhCH_2$	**9**	62	–

[a]) Determined by ^{1}H-NMR. [b]) Diastereoisomers not separated. [c]) Includes 16% of lactone **10**. [d]) Corrected for lactone **10**. [e]) DMPU = *N,N*-dimethylpropyleneurea.

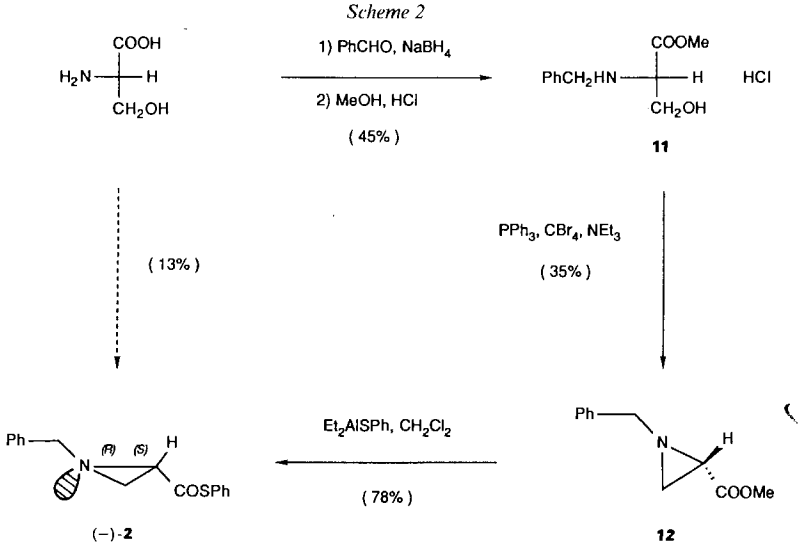


4a **4b** **10**

(only one enantiomer shown)

2. Preparation of *S*-Phenyl *N*-Benzyl- and *N*-[(*S*)-(1-Phenylethyl)]aziridin-2-carbothioates; the Chiral Starting Materials. – Following a sequence of reactions applied for the cyclization of threonine [4], we converted (*S*)-serine through *N*-benzylserine ester **11** to the aziridine derivative **12**, the methyl-ester moiety of which was transformed [5] to the phenyl-thioester group (→(−)-**2**, see *Scheme 2*). The (*R,S*)-configuration (*trans*) of this

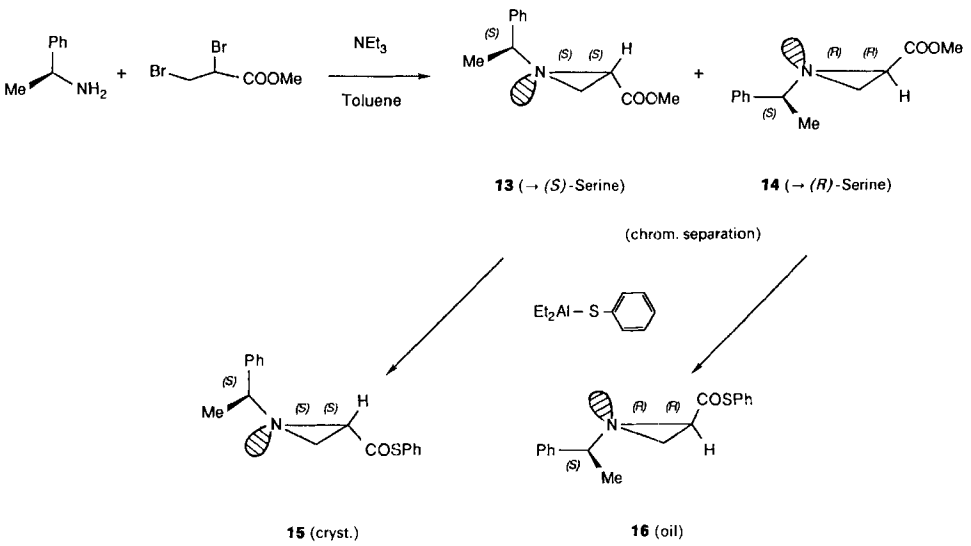
Scheme 2



compound follows from the high-field ^{1}H-NMR spectrum (NOE measurements and unchanged spectra from −100 to +100°). The overall yield of the four-step sequence was 13%, not enough to render (−)-**2** a useful starting material for syntheses[3]).

A more convenient access to aziridine esters of either chirality sense at the stereogenic ring C-atom was pointed out to us by *J. P. Obrecht*[4]): the two diastereoisomers **13** and **14** obtained as a 1:1 mixture [7] in 85% yield from (*S*)-(1-phenylethyl)amine and *rac*-2,3-dibromopropionate (both commercial) were separated by flash chromatography (40-g scale on 1 kg of silica gel) and almost quantitatively converted to the crystalline thioester **15** and its oily diastereoisomer **16**. The configuration of the methyl esters **13** and **14** was determined by acidic ring opening ($HClO_4/H_2O$) and hydrogenolysis ($Pd(OH)_2/C$) to (*S*)- and (*R*)-serine, respectively, establishing the configurations of all four aziridines shown in *Scheme 3*.

Scheme 3



3. Deprotonation, Deuterolysis, and Methylation of the *trans*-(2*S*)-Aziridine Thioester (−)-2 with Retention of Configuration. – Treatment of the thioester (−)-**2** with base[5]) and CD_3OD or CH_3I/DMPU[6]) as shown in *Scheme 4* gave, after isolation, still optically active products **17** and (−)-**8**, respectively.

---

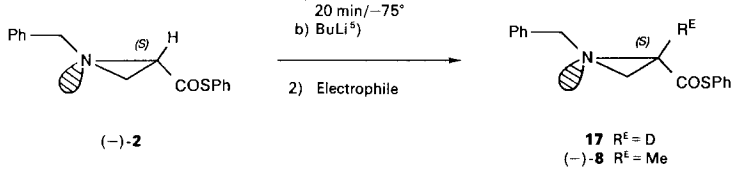
[3]) *N*-Tritylserine ester can also be cyclized [6a]. We plan to apply the N-unprotected aziridine ester thus available in future investigations with substituents on the N-atom [6b] different from those used here.

[4]) We thank Dr. *J. P. Obrecht* (*Socar AG*, Dübendorf, Switzerland) for a private communication about the ease with which diastereoisomers such as **13** and **14** can be chromatographically separated.

[5]) For complete D-incorporation, it was necessary to first add LDA, then an equivalent amount of BuLi, followed by the D^+ source (without BuLi, only 80% D-incorporation). For the discovery and explanation of this effect see [8], for applications see [9–13].

[6]) DMPU = 'Dimethylpropyleneurea' (= 1,3-dimethyl-3,4,5,6-tetrahydro-2(1*H*)-pyrimidinone); this cosolvent has very similar effects as HMPA, but is not toxic [14] [15].

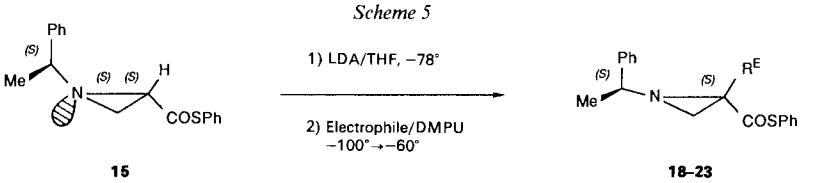
Scheme 4



The optical rotation of the deuterated product **17** was of the same sign and of almost identical value[7]) as those of the starting material (–)-**2**. The methylated compound (–)-**8** showed a lower value of $[\alpha]_D$ than (–)-**2**, but again with the same sign[8]); we assume that methylation also took place with retention.

4. Diastereoselective Deuteration and Alkylations of the Phenylethyl-Substituted Aziridines 15 and 16. – The crystalline diastereoisomer **15** was treated with LDA and BuLi (*cf. Footnote 5*) in THF at –75° and the resulting solution[9])[10]) quenched after 30 min with CD_3OD. Workup led to the isolation of > 98% deuterated starting material, *i.e.* of **18**, with unchanged $[\alpha]_D$. Thus, again, retentive electrophilic substitution had occurred. Reactions with other electrophiles which were added as DMPU solutions[10]) gave the products **19**–**23** shown in *Scheme 5* (50–80% yield after purification). All compounds

Scheme 5



15 **18–23**

Electrophile	R^E	Product (yield [%]) (single isomer)
CH_3OD[a])	D	**18**[b])
CH_3I	CH_3	**19** (62)
CH_3CH_2I	CH_3CH_2	**20** (51)
CH_2=CH–CH_2Br	CH_2=CH–CH_2	**21** (59)
$PhCH_2Br$	$PhCH_2$	**22** (60)
Ph–CH=CH–NO_2[c])	O_2NCH_2–CH–Ph	**23** (79)

[a]) 1) LDA, THF, –78°, 20 min; 2) BuLi; 3) MeOD, –95°, no DMPU present; see also *Scheme 8*.

[b]) A combined yield of *ca.* 55% of **18** and the corresponding methyl ester **13** of (2*S*)-configuration (formed in the quenching step), is obtained, see also *Scheme 8* and *Sect. 5*.

[c]) Added without DMPU, diastereoisomers not separated, see *Footnote 11*.

[7]) Substituting CD_3OD by CH_3OH in the quenching step of an otherwise identical procedure gave (–)-**2** of unchanged optical activity.

[8]) We observed in many other heterocyclic amino-acid derivatives that replacement of a H- by a D-atom with retention did not change the sign of $[\alpha]_D$, see *e.g.* [10] [12b] [16] and *Brewster's* rule [17].

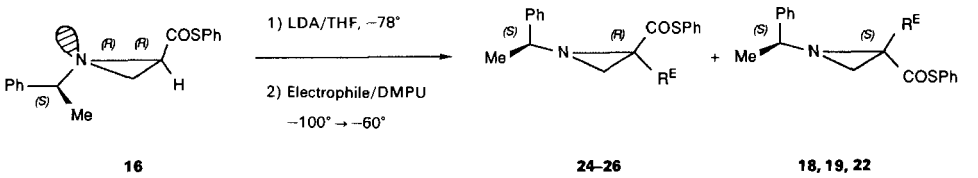
[9]) The solutions were mostly of wine-red colour which almost disappeared upon raction with the electrophiles. In the case of the benzyl derivative **2**, we noticed that the purest samples gave only slightly yellow solutions with LDA, see also *Footnote 10*.

[10]) Deprotonation in the presence of DMPU[6]) gave more deeply coloured solutions and lower yields of products.

18–22 were single diastereoisomers[11]) as shown by 300-MHz ^{1}H-NMR spectroscopy of the crude products and had specific rotations ranging from −140 to −170°; we assume that they all have (2*S*)-configuration. In the ^{1}H-NMR spectra of the alkylated products, certain signals were broad and showed typical coalescence behaviour (the benzyl derivative **22** gave sharp signals when measured at 87.5° in DMSO[12])). This shows that invertomers [18] are present, slowly equilibrating on the NMR time scale at room temperature: obviously, introduction of a substituent R^E causes the enthalpy difference between the *cis*- and the *trans*-isomer to decrease as compared to the starting material with a H-atom in the α-position to the carbonyl group.

We were surprised to find that the reactions of the liquid diastereoisomer **16** with electrophiles were much less selective than those of **15**, see *Scheme 6*: while the major products **24–26** were the stereoisomers of those (**18**, **19**, **22**) obtained from **15**, up to 33% crossover occurred.

Scheme 6



16 **24–26** **18, 19, 22**

Electrophiles	R^E	Products (ratio)	Yield [%]
CH_3OD[a])	D	**24**/**18** (2:1)[b])	–[b])
CH_3I	CH_3	**25**/**19** (4:1)	51
$PhCH_2Br$	$PhCH_2$	**26**/**22** (2:1)[c])	57

[a]) 1) LDA, THF, −78°; 2) BuLi; 3) CH_3OD, −95°, no DMPU present; see also *Scheme 8*.

[b]) A *ca.* 60% total yield of **18**/**24** and the corresponding deuterated methyl esters **27**/**28** (formed during quenching) was obtained; the ratio 2:1 is that of (**24** + **28**)/(**18** + **27**); see *Scheme 8* and *Sect. 5*.

[c]) Diastereoisomers not separated.

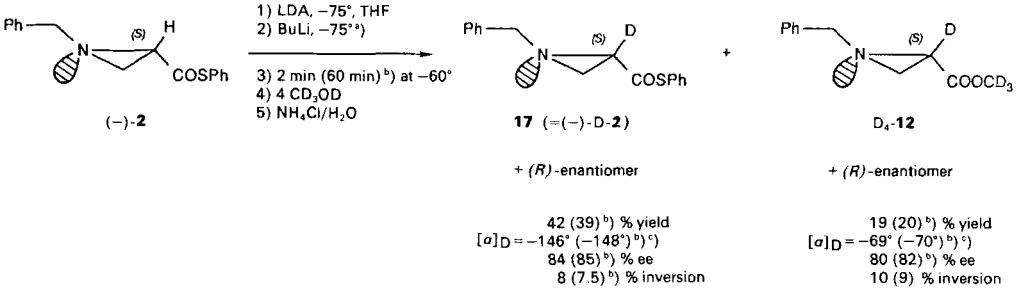
5. Configurational Stability of the Lithiated Aziridine Thioesters. – There could be two reasons for the loss of selectivity in going from the lithiated thioester **15** to **16**: *i)* The lithiated derivative of **16** ((1*R*,2*R*,1′*S*)-configuration) exhibits a smaller diastereotopic-face selectivity in its reactions with electrophiles than the isomer from **15** ((1*S*,2*S*,1′*S*)-configuration). *ii)* The lithio derivative of **16** equilibrates with the more stable lithiated **15**, before reaction occurs.

To be able to decide between these two possibilities, we kept solutions of all three lithiated aziridine thioesters, obtained from the *N*-benzyl and the two *N*-phenylethyl derivatives (−)-**2**, **15**, and **16**, respectively, at different temperatures before quenching with CD_3OD; the analysis was complicated by partial transesterification of the

[11]) The *Michael* adduct **23** to β-nitrostyrene was a mixture of two diastereoisomers (3:1) which are probably epimeric at the phenyl-substituted stereogenic center of the 2-nitro-1-phenylethyl moiety (compare with the additions to trigonal centers shown in *Scheme 1*).

[12]) Compounds **7**–**9**, and **26** showed also coalescence behaviour (sharp signals only at elevated temperatures).

Scheme 7

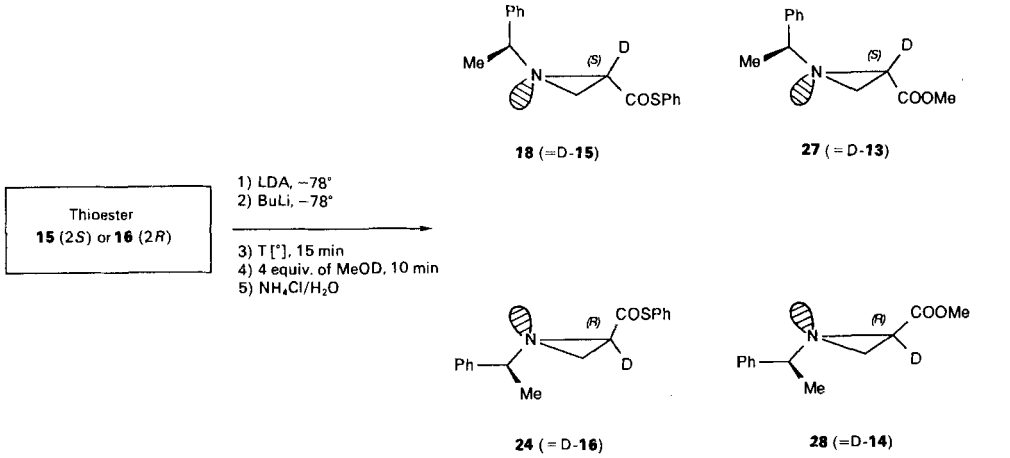


a) See *Footnote 5* for the necessity of removing $(i\text{-}Pr)_2NH$ before quenching in order to achieve higher D-incorporations [8].

b) All numbers in round brackets refer to the 60-min experiment.

c) Determined after flash-chromatographic separation, see *Exper. Part.*

Scheme 8



Starting material	T [°] in step 3) in cooling bath	Yields of deuterated products after chromatography [%][a]					Degree of isomerization in isolated products [%]
		18 ((2*S*)-config.)	**27**	**24** ((2*R*)-config.)	**28**	Tot.[b]	
15	−95°	41	12	< 1	< 1	53	trace
15	−78°	39	15	< 1	< 1	54	trace
15	−60°	32	14	3	1	50	8
15	−60°[c])	76	18	6	< 1	–[c])	6[c])
16	−95°	17	6	31	4	58	40
16	−78°	16	5	35	6	62	34
16	−60°	28	9	13	4	54	69
16	−60°[c])	48	13	36	3	–[c])	61[c])

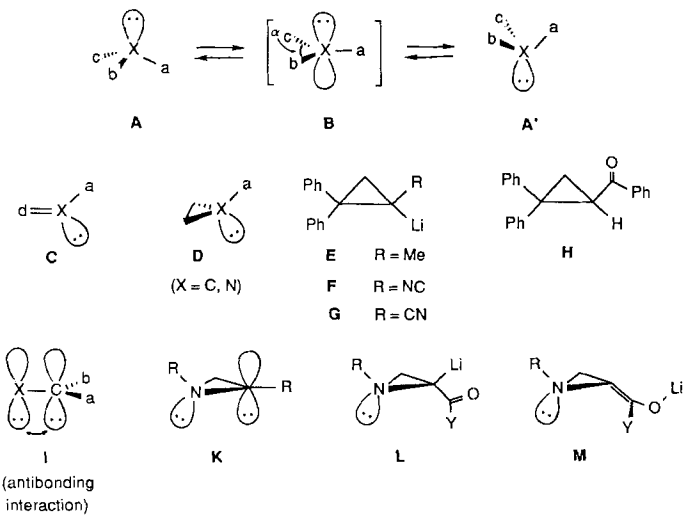
a) The ratios **18**/**24**/**27**/**28** as determined from the ^{1}H-NMR spectra of the crude products were very similar.

b) The missing material consisted of polar compounds moving slowly on the chromatography column.

c) The solution was kept for 60 min at −60° before quenching; the crude mixture was not chromatographed, the ratios were determined from its ^{1}H-NMR spectrum and used to calculate the percentages given in this line.

phenylthio ester to the methyl ester by the methanol[13]). The results are collected in *Schemes 7* and *8*. Solutions of the lithium derivatives from (−)-**2** and from **15** could be kept for 1 h at −60° without giving rise to more than 10% of deuterated product with inverted configuration at C(2), see the enantiomeric excess of D-**2** and D_4-**12** in *Scheme 7* and the ratio (**18** + **27**)/(**24** + **28**) in *Scheme 8*. In contrast, the thioester **16** underwent deuteration with inversion of configuration at the α-position to the carbonyl group to the extend of more than 60% under the same conditions *(Scheme 8)*. Thus, the lithiated species from **16** isomerizes to the more stable one derived from **15**, and this causes the different selectivity of their reactions with electrophiles. The observed process of isomerization, if monomolecular, should have a free enthalpy of activation in the order of 15 kcal/mol and the stability difference between the two species may be as small as 150 cal/mol[14]): on the other hand, the barrier for the lithiated phenyl *N*-benzylaziridinecarbothioate (from (−)-**2**) to go to its enantiomer must be higher (⩽ 10% inversion after 1 h at −60°). Can any conclusions about the structures of the lithiated intermediates involved in these reactions be drawn[15])[16])?

Scheme 9



[13]) Thus, LiOMe undergoes a reaction which we were surprised not to observe with LDA [1] [3]: LiOMe was acylated by the phenylthio ester under comparable conditions (−78°, THF solution). While mixtures of the thioesters and methyl esters were always present in the enolate/CH_3OD- or enolate/CD_3OD-quenching products (see *Exper. Part*), LiOMe converted the thioesters **15** and **16** to the corresponding methyl esters **13** and **14** quantitatively at room temperature.

[14]) a) For a first-order reaction with a half life of 10 min at −60° (213 K), the *Eyring* equation gives a $\Delta G^{\neq} = 15.2$ kcal/mol. b) For *N*-benzylaziridine, an activation enthalpy of 19.2 kcal/mol at +105° was determined [19] for the *N*-inversion. c) A 6:4 equilibrium ratio at −78° corresponds to an enthalpy difference between two species of $\Delta\Delta G^{\circ} = 0.16$ kcal/mol.

[15]) Since only 50–60% of the material balance of the reactions were accounted for (*cf. Footnote b* in *Scheme 8*), drawing conclusions might be as risky as in a murder case without a corpse.

[16]) Unfortunately, we were so far not able to isolate crystals of lithiated small-ring carboxylic-acid derivatives suitable for X-ray structure analysis. See the discussion about the cyclopropane case in [3] and ref. cit. therein.

6. Structural Conclusions. – The inversion of a trigonal pyramidal atom with a non-bonding electron pair (**A** in *Scheme 9*) occurs through a trigonal planar transition state **B** with the electron pair in a p-orbital [19] [20]. Factors stabilizing **A** or destabilizing **B** increase the barrier to inversion (**A**→**A'**). On the other hand, destabilization of **A** or stabilization of **B** facilitates the inversion. Besides the central atom X[17]), the nature of the substituents is decisive. While conjugatively anion-stabilizing groups – such as the C=O in an amide – lead to planarization, σ-acceptors – such as RO and halogen atoms – stabilize the pyramidal geometry (increased σ-character and thus decreased polarizability of the bonds in the planar arrangement!) [19] [21] [22]. An increased barrier to inversion also results (*I*-strain [23]), when the angle α in **B** (ideally 120°) is decreased. In the extreme case of $\alpha = 0°$, formally with an sp^2-hybridized center, the barrier is very high (*cf.* vinylic metal derivatives [24–26], imines [27], **C** in *Scheme 9*). A 60° angle (see **D**, metallated cyclopropanes, aziridines) raises the energy of the transition state **B** sufficiently for certain derivatives to be configurationally stable enough for isolation at room temperatures [22] [28]. *Walborsky* and coworkers showed that the configuration at the lithiated center of the cyclopropane **E** is not inverted at room temperature [29] [30] and that the corresponding isocyanide **F** is configurationally stable below −52° [31]. The isomeric nitrile[18])[19]) **G** equilibrates with its enantiomer even at −78° [34], and the ketone **H** racemizes upon base treatment in protic solvent[19]) [35]. These results demonstrate that the small-ring angle strain does no more prevent rapid inversion, if we go from methyl to conjugatively anion-stabilizing substituents such as acyl. However, the introduction of an additional heteroatom in the three-membered ring, as present in our lithiated aziridines from **2**, **15**, and **16**, should increase the barrier to inversion further. Certain α-alkoxy- and α-amino-substituted organolithium compounds are known to be configurationally stable [36–39], and diaziridines as well as oxaziridines have drastically higher barriers than aziridines [40]. The non-bonding electron pair of the heteroatom leads to a destabilization in the transition state (see **I** and **K** in *Scheme 9*)[20]), so that even a lithiated acyl-substituted C-atom becomes a stable stereogenic center[21]). Thus, we assume that the lithiated aziridine thioesters generated in the reactions described here are either *C*-lithiated species **L** or *O*-lithiated species **M** with pronounced pyramidalization of the enolate C(β)-atom.

---

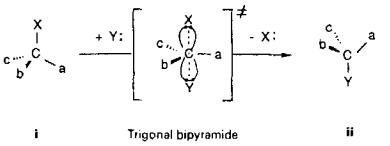
[17]) The barrier increases, as we go to elements X of higher rows of the periodic chart and as we go to elements of smaller electronegativity whithin a row [19].

[18]) A recent crystal-structure analysis shows lithio phenyl acetonitrile to be an *N*-lithiated ketene imine [32].

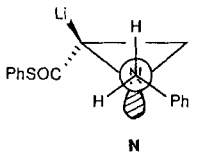
[19]) H/D-Exchange with retention of configuration was observed with the non-lithiated nitrile (**G**, H instead of Li) in protic solvents [33].

[20]) Only part of the conjugative destabilization [22a] [41] indicated by **I** is present in **K**, due to the sp^3-hybridization of the N-atom.

[21]) The same factors causing a relative stabilization or destabilization of the trigonal pyramidal geometry **A** and the trigonal planar geometry **B** (see *Scheme 9*) are effective in the S_N2 reaction, see **i**→trigonal bipyramide→**ii**. The trigonal-bipyramide transition state is stabilized by π- or conjugative acceptors (*cf.* a = CO) and by σ-donors (*cf.* a = Li [24] [42] [43]), and it is destabilized by π-donors, by σ-acceptors and by *I*-strain [23] [44a]; things are, however, complicated in the S_N2 case by the fact that we are dealing with a bimolecular process in which the transition state may be neutral of charged. See also the discussion of the '*β-trans*-axial' and of the 'vicinal-axial' substituent effect on S_N2 reactivity in [44b].

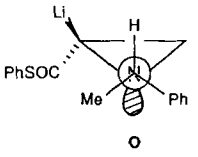


[22]) See also the discussion and the numerous references given in our recent paper on lithiated cyclopropane carboxylates [3].



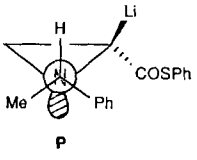
N

from (–)-**2** (1*R*,2*S*)



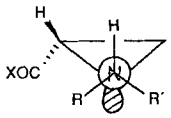
O

from **15** (1*S*,2*S*,1'*S*)



P

from **16** (1*R*,2*R*,1'*S*)



Q

Conformation around the exocyclic N–C bond as determined by four X-ray crystal-structure analyses, see [61–63]

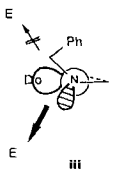
This assumption is supported by the known structures of *N*-acyldiaziridines [45], and it is compatible with all our observations[22]). A planar enolate would hardly lead to retentive substitution[23]) which we observe in all three cases studied[24]). Pyramidalization [52] of the C(*β*)-atom of enolate double bonds or C-metallated 'enolates' (and analogues) have been discussed before [3] [10] [48–50] [53–60], the chances are very good that the aziridine-ester-derived ones really are pyramidalized[16]).

Why is the Li-derivative from the aziridine thioester **16** less stable than those from **2** and **15**? For comparison, we have drawn the *C*-lithiated structures **N**, **O**, and **P** as *Newman* projections along the exocyclic C–N bonds. We chose a conformation around this bond with the H-atom above the three-membered ring, as found in the crystal structures[25]) of four aziridinecarboxylic-acid derivatives **Q** [61–63]. This presentation shows[26]) that there is most steric hindrance[14c]) in **P** derived from the thioester **16**.

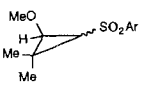
How could Li compound **P** be inverted to give products derived from the diastereoisomer **O**? This is a much tougher question to answer, we are not able to do so. For **P** going to **O**, the configuration on both ring positions would have to be inverted. If this happens first on the C-atom[14a]) – we expect the barrier to be higher for N-inversion[14b]) – a

---

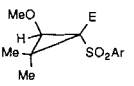
[23]) A stereoelectronic effect [46] of the electron pair on the N-atom would have to be responsible for electrophile (E) attack from the face of the three-membered ring on which the benzyl or phenylethyl substituent is located in a planar enolate. The direction of the N-electron pair as enforced by the geometry of the three-membered ring is such that we would rather expect an inversion (see **iii** to be also sterically more favorable; compare, however, more reasonable situations for such stereoelectronic effects to operate [10] [46] [47–50]).



iii



iv



v

[24]) In another carbanionoid cyclopropane derivative generated from *cis*- or *trans*-**iv** and LDA, the exclusive formation of the *trans*-product **v** was interpreted as resulting from preferential reaction of the more stable lithiated *trans*-derivative (Li and CH_3O *cis* to each other) with electrophiles [51].

[25]) For steric reasons, the same conformation should be favoured in all *N*-alkylaziridines, also in solution, and also with one of the C-atoms of the ring deprotonated as in our case.

[26]) This statement would still hold, if we chose the *O*-lithiated structures, or if the COSPh and the *CH(R)Ph* groups would be in a *cis*-position on the aziridine ring.

[27]) This would give the observed product by deuterolysis (substitution of Li by D with retention at the C-atom), workup, and isolation at room temperature (inversion at the N-atom).

cis-disubstituted aziridine results[27]) which could then be inverted at the N-atom. These two processes do not take place with the serine-derived Li compound from (–)-**2**, otherwise it would racemize which it does not[28]) at –60°.

NMR investigations with labelled substrates are being undertaken to learn more about the structure and reactivity of these interesting species. The results will be published in due course, together with synthetic applications.

We thank the *Ministerio de Educación y Ciencia de España* for a post-doctoral fellowship for *B. O.* Generous financial support of this work by the *Sandoz AG*, Basel, and supply of amino acids by the *Degussa AG*, Hanau-Wolfgang, are gratefully acknowledged.

Experimental Part

General. All solvents for reactions were dried before use. The temp. was measured with a *Pt-100* thermometer. TLC: silica gel plates *60 F_{254} (Merck)* revealed with UV light or ninhydrin soln. (in the case of amino acids). Flash chromatography (FC): *Merck* silica gel (mesh size 0.040–0.063). Specific rotations: *Perkin-Elmer 241* polarimeter; $CHCl_3$ or EtOH solns. at 25°; *c* in g/100 ml. M.p.: *Büchi 510* melting-point apparatus; uncorrected. IR spectra: *Perkin-Elmer 297* spectrometer; film, KBr discs, or $CHCl_3$ soln. ^1H- and ^{13}C-NMR spectra: *Varian-EM-390, -AN-100, -XL-100,* and *CFT-20* as well as *Bruker-300* instruments; TMS as internal standard. MS: 70 eV; *Hitachi-Perkin-Elmer-RMU-6M* instrument.

A) General Procedures (GP). – *GP 1: Preparation of Methyl 1-(1-Phenylethyl)aziridine-2-carboxylates.* To a soln. of methyl 2,3-dibromopropionate (25 ml, 195 mmol) in toluene (100 ml), Et_3N (55 ml, 390 mmol) in toluene (100 ml) was added (ice bath). After stirring for 5 min, (*S*)-(1-phenylethyl)amine (25 ml, 195 mmol) in toluene (100 ml) was added dropwise. The suspension was refluxed for 3 h, cooled to r.t., and filtered. The solvent was evaporated under reduced pressure and the residue was purified by FC (*ca.* 950 g silica gel, hexane/AcOEt 3:1) to give **13** and **14**.

GP 2: Preparation of S-*Phenyl Aziridine-2-carbothioates.* To a soln. of Et_3Al (2.05 ml, 15 mmol) in CH_2Cl_2 (15 ml) thiophenol (1.8 ml, 15 mmol) was added dropwise at 0°. After stirring for 15 min, the cooling bath was removed, a soln. of the corresponding alkyl aziridine-2-carboxylate (10 mmol) in CH_2Cl_2 (5 ml) was added, and the soln. was stirred for 6 h at r.t. After addition of Et_2O (15 ml), the reaction was carefully quenched with 3% HCl soln. (2 ml) and the insoluble matter filtered. The org. layer was washed twice with 1% NaOH and sat. NaCl soln., dried ($MgSO_4$), and evaporated under reduced pressure.

GP 3: Deprotonation of S-*Phenyl Aziridine-2-carbothioates and Reaction of the Enolate with Electrophiles (Method A).* To a soln. of LDA (4.4 mmol) in THF (10 ml), a soln. of the thioester (4.0 mmol) in THF (2 ml) was added dropwise at –78°. After stirring for 30 min, the soln. was cooled to –100°, a soln. of the electrophile (5.0 mmol) in THF (2 ml) was added dropwise, and within 30 min, the mixture was warmed to –78°. The reaction was quenched with sat. NH_4Cl soln. (5 ml), warmed to r.t. and diluted with Et_2O (50 ml). The org. layer was washed with sat. NH_4Cl and sat. NaCl soln., dried ($MgSO_4$), and evaporated. The product was purified by FC (pentane/Et_2O).

GP 4: Deprotonation of S-*Phenyl Aziridine-2-carbothioates and Reaction of the Enolate with Electrophiles (Method B).* To a soln. of LDA (4.4 mmol) in THF (10 ml), a soln. of the thioester (4.0 mmol) in THF (2 ml) was added dropwise at –78°. After stirring for 30 min, a soln. of the electrophile (5.0 mmol) in THF/DMPU (2 ml:4 ml) was added dropwise at –78° and stirring continued for 2 h at this temp. The soln. was warmed to r.t., diluted with Et_2O (50 ml), and washed with sat. NH_4Cl and sat. NaCl soln. The org. layer was dried and evaporated. The product was purified by FC (pentane/Et_2O).

B) Compounds of *Scheme 1.* – rac-S-*Phenyl 1-(*tert-*Butyl)aziridine-2-carbothioate* (**1**). From Et_3Al (10.2 ml, 75 mmol), thiophenol (8.3 g, 75 mmol), and methyl 1-(*tert*-butyl)aziridine-2-carboxylate[29]) (7.85 g, 50 mmol; *GP 2*).

---

[28]) It is remarkable that the degree of racemization of lithiated (–)-**2** is the same, within experimental error, after 2 and 60 min. Originally, this suggested to us that the racemization may occur during the treatment of (–)-**2** with LDA, before BuLi addition (the $(i\text{-}Pr)_2NH$ might have acted as a proton source). However, control experiments with (–)-**2** (and **15**) in which the BuLi addition was omitted showed that this is not the case (see *Exper. Part*).

[29]) Obtained (84% yield) by following the procedure described in [64].

After bulb-to-bulb distillation **1** (9.04 g, 77%) was obtained as a slightly yellow oil which solidified on cooling. B.p. 110°/0.05 Torr. The ^{1}H-NMR: in accordance with that given in [65].

rac-S-*Phenyl 1-Benzylaziridine-2-carbothioate* (**2**). From Et_3Al (2.05 ml, 15 mmol), thiophenol (1.67 g, 15 mmol), and methyl 1-benzylaziridin-2-carboxylate[30]) (2.05 g, 10 mmol; *GP 2*). After FC (pentane/Et_2O 70:30) 2.07 g (77%) of **2** were obtained as a colourless oil. IR (film): 3060, 3030, 1690, 745, 690. ^{1}H-NMR ($CDCl_3$, 300 MHz): 1.91 (*d*, *J* = 6.4, H–C(3)); 2.39 (*d*, *J* = 2.7, H–C(3)); 2.50 (*dd*, *J* = 6.6, 2.7, H–C(2)); 3.58, 3.73 (*AB*, *J* = 13.7, PhCH_2); 7.29–7.48 (*m*, 10 arom. H). ^{13}C-NMR ($CDCl_3$, 20 MHz): 36.14 (*t*); 44.71 (*d*); 63.12 (*t*); 127.36, 128.00, 128.44, 129.03, 134.59 (5*d*); 137.62 (*s*); 196,89 (*s*). MS: 270 (0.9, $M^{+\cdot}$ + 1), 160 (100), 132 (81), 106 (95), 91 (93). Anal. calc. for $C_{16}H_{15}NOS$ (269.37): C 71.34, H 5.61, N 5.20; found: C 71.49, H 5.54, N 5.22.

rac-S-*Phenyl 1-(* tert-*Butyl)-2-(1-hydroxyethyl)aziridine-2-carbothioate* (**3**). From **1** (0.470 g, 2.0 mmol) and acetaldehyde (0.220 g, 5.0 mmol; *GP 3*), a crude product was obtained (^{1}H-NMR (300 MHz): diastereoisomer ratio of 88:12). After FC (pentane/Et_2O 90:10→0:100), **3** (0.391 g, 70%) was obtained as a colourless viscous oil (diastereoisomer ratio 92:8). IR ($CHCl_3$): 3400 (br.), 2970, 2870, 1680. ^{1}H-NMR ($CDCl_3$, 300 MHz, major diastereoisomer): 1.16 (*s*, *t*-Bu); 1.29 (*d*, *J* = 6.2, CH_3CH); 1.96 (*s*, H–C(3)); 2.37 (*s*, H–C(3)); 3.60 (br. *s*, OH); 4.10 (*q*, *J* = 6.2, CH_3C*H*); 7.33–7.44 (*m*, 5 arom. H); additional signals from minor diastereoisomer: 1.20 (*s*, *t*-Bu); 1.41 (*d*, *J* = 6.5, CH_3CH); 1.99 (*s*, H–C(3)); 2.26 (*s*, H–C(3)); 3.85 (*q*, *J* = 6.5, OH). ^{13}C-NMR ($CDCl_3$, 75 MHz; major diastereoisomer): 18.83 (*q*); 26.67 (*t*); 28.21 (*q*); 54.56 (*s*); 54.70 (*s*); 65.44 (*d*); 129.33 (*d*); 129.66 (*d*); 134.12 (*d*); 197.62 (*s*); additional signals from minor diastereoisomer: 21.64; 28.42; 30.63; 67.83. MS: 280 (2, $M^{+\cdot}$ + 1), 279 (1, $M^{+\cdot}$), 142 (50), 86 (100), 57 (62). Anal. calc. for $C_{15}H_{21}NO_2S$ (279.41): C 64.48, H 7.58, N 5.01; found: C 64.43, H 7.50, N 5.20.

rac-S-*Phenyl* u- *and* l-*1-(* tert-*Butyl)-2-(α-hydroxybenzyl)aziridin-2-carbothioate* (**4a** and **4b**) *and* rac-1-*(* tert-*Butyl)-6-phenyl-1-aza-5-oxaspiro[2.3]hexan-4-one* (**10**). *Method A:* From **1** (0.940 g, 4.0 mmol) and benzaldehyde (0.530 g, 5.0 mmol; *GP 3*). After FC (pentane/Et_2O 90:10→50:50), **4a** (0.872 g, 64%), **4b** (0.096 g, 7%), and **10** (0.150 g, 16%) were obtained.

4a: Colourless crystals. M.p. (pentane/Et_2O) 110.0–110.8°. IR ($CHCl_3$): 3350 (br.), 2990, 2890, 1685. ^{1}H-NMR ($CDCl_3$, 300 MHz): 1.18 (*s*, *t*-Bu); 2.21 (*s*, H–C(3)); 2.38 (*s*, H–C(3)); 4.10 (br., OH); 5.05 (*s*, PhC*H*); 7.09–7.13 (*m*, 2 arom. H); 7.32–7.40 (*m*, 8 arom. H). ^{13}C-NMR ($CDCl_3$, 75 MHz): 26.28 (*t*); 28.23 (*q*); 54.93 (*s*); 71.70 (*d*); 127.24 (*d*); 128.37 (*d*); 129.44 (*d*); 129.87 (*d*); 134.21 (*d*); 139.6 (*s*); 197.08 (*s*). MS: 235 (25, $M^{+\cdot}$ – 106), 57 (100), 41 (42). Anal. calc. for $C_{20}H_{23}NO_2S$ (341.48): C 70.35, H 6.79, N 4.10; found: C 70.31, H 6.87, N 4.03.

4b: Colourless crystals. M.p. (pentane/Et_2O) 135.4–135.8°. IR ($CHCl_3$): 3560 (br.), 3060, 2970, 2870, 695, 690. ^{1}H-NMR ($CDCl_3$, 300 MHz): 1.20 (*s*, *t*-Bu); 2.17 (*d*, *J* = 0.9, H–C(3)); 2.44 (*d*, *J* = 0.9, H–C(3)); 3.52 (br. *d*, *J* = 5, OH); 4.68 (br. *d*, *J* = 5, PhC*H*); 7.11–7.14 (*m*, 2 arom. H); 7.28–7.41 (*m*, 8 arom. H). MS: 342 (0.5, $M^{+\cdot}$ + 1), 235 (14, $M^{+\cdot}$ – 106), 204 (94), 148 (97), 110 (80), 57 (100), 41 (57). Anal. calc. for $C_{20}H_{23}NO_2S$ (341.48): C 70.35, H 6.79, N 4.10; found: C 70.29, H 6.71, N 3.95.

10: Colourless crystals. M.p. (pentane/Et_2O) 38.5–39.0°. IR ($CHCl_3$): 2970, 2870, 1825 (br.). ^{1}H-NMR ($CDCl_3$, 300 MHz): 1.21 (*s*, *t*-Bu), 1.73 (*d*, *J* = 1.3, H–C(2)); 2.38 (*d*, *J* = 1.3, H–C(2)); 5.49 (*s*, 1 arom H); 7.31–7.40 (*m*, 5 arom. H); irradiation at *t*-Bu signal gave positive NOE for H–C(6) and CH_2(2), *i.e.* N–C(3) bond is *cis* to the H–C(6) bond. ^{13}C-NMR ($CDCl_3$, 75 MHz): 27.84 (*q*); 31.68 (*t*); 55.32 (*s*); 78.97 (*d*); 126.53 (*d*); 128.72 (*d*); 129.28 (*d*). MS: 231 (3, $M^{+\cdot}$), 125 (75, $M^{+\cdot}$ – 106), 57 (100). Anal. calc. for $C_{14}H_{17}NO_2$ (231.30): C 72.70, H 7.41, N 6.06; found: C 72.66, H 7.46, N 6.01.

Method B [1]: From **1** (0.471 g, 2.0 mmol) and benzaldehyde (0.530 g, 5.0 mmol, *GP 3*). A soln. of chlorotris(dimethylamino)titanium (4.0 mmol) in THF[31]) was added dropwise at –78°, and the mixture stirred for 30 min at this temp. before adding benzaldehyde. A crude mixture was obtained (^{1}H-NMR (300 MHz): **4a**/**4b** 93:7). After FC (pentane/Et_2O 90:10→50:50) **4a** (0.790 g, 57%) was obtained.

rac-S-*Phenyl 1-(* tert-*Butyl)-2-(2-nitro-1-phenylethyl)aziridine-2-carbothioate* (**5**). From **1** (0.705 g, 3.0 mmol) and β-nitrostyrene (0.596 g, 4.0 mmol; *GP 3*), a crude product (1.25 g) was obtained (^{1}H-NMR (300 MHz): diastereoisomer ratio 72:28). After FC (pentane/Et_2O 90:10→75:25), the major diastereoisomer (0.604 g, 53%) and the minor one (0.256 g, 22%) of **5** were obtained.

Major diastereoisomer: colourless crystals. M.p. (pentane) 96.6–97.2°. IR ($CHCl_3$): 2970, 1680. ^{1}H-NMR ($CDCl_3$, 300 MHz): 1.10 (*s*, *t*-Bu); 1.86 (*s*, H–C(3)); 2.36 (*s*, H–C(3)); 4.28 (*dd*, *J* = 7.9, 6.6, 1 H); 4.56 (*dd*, *J* = 13.5, 8.0, 1 H); 4.92 (*dd*, *J* = 13.5, 6.5, 1 H); 7.13–7.16 (*m*, 2 arom. H); 7.24–7.40 (*m*, 8 arom. H). ^{13}C-NMR ($CDCl_3$, 75 MHz): 28.11 (*q*); 28.76 (*t*); 45.83 (*d*); 52.19 (*s*); 55.01 (*s*); 76.94 (*t*); 128.30, 128.80, 128.93, 129.41,

---

[30]) Obtained (68%) by using the method described in [66].

[31]) Prepared by mixing tetrakis(dimethylamino)titanium (3 equiv.) and titanium tetrachloride (1 equiv.) in THF at –30° and then warming to r.t.

129.80, 134.30 (6*d*); 136.3 (*s*); 198.4 (*s*). MS: 384 (0.6, $M^{+\cdot}$), 110 (97), 57 (100). Anal. calc. for $C_{21}H_{24}N_2SO_3$ (384.50): C 65.60, H 6.29, N 7.29; found: C 65.69, H 6.28, N 7.03.

Minor diastereoisomer: colourless crystals. M.p. (pentane/Et_2O) 120.8–121.8°. IR ($CHCl_3$): 2970, 1680. ^{1}H-NMR ($CDCl_3$, 300 MHz): 1.15 (*s*, *t*-Bu); 2.14 (*s*, H–C(3)); 2.50 (*s*, H–C(3)); 3.32 (*dd*, *J* = 11.6, 3.9, PhC*H*); 4.99 (*dd*, *J* = 13.7, 3.9, 1 H, CH_2NO_2); 5.39 (*dd*, *J* = 13.7, 11.7, 1 H, CH_2NO_2); 7.03–7.07 (*m*, 2 arom. H); 7.23–7.41 (*m*, 8 arom. H). Anal. calc. for $C_{21}H_{24}N_2SO_3$ (384.50): C 65.60, H 6.29, N 7.29; found: C 65.64, H 6.34, N 7.16.

rac-S-*Phenyl 1-(*tert*-Butyl)-2-methylaziridine-2-carbothioate* (**6**). From **1** (1.18 g, 5.0 mmol) and MeI (0.910 g, 6.4 mmol; *GP 4*). After FC (pentane/Et_2O 94:6), **6** (0.744 g, 60%) was obtained as a colourless oil. IR (film): 2970, 2870, 1690, 745, 690. ^{1}H-NMR ($CDCl_3$, 300 MHz): 1.26 (*s*, *t*-Bu); 1.63 (*s*, CH_3); 1.92 (*d*, *J* = 2.5, H–C(3)); 2.11 (*d*, *J* = 2.5, H–C(3)); 7.36–7.39 (*m*, 5 arom. H). ^{13}C-NMR ($CDCl_3$, 75 MHz): 13.89 (*q*); 28.93 (*q*); 35.40 (*t*); 46.34 (*s*); 54.23 (*s*); 128.58 (*d*); 128.80 (*d*); 134.63 (*d*); 203.68 (*s*). MS: 249 (3, $M^{+\cdot}$), 56 (100). Anal. calc. for $C_{14}H_{19}NOS$ (249.38): C 67.43, H 7.68, N 5.62; found: C 67.24, H 7.57, N 5.55.

rac-S-*Phenyl 1-Benzyl-2-(α-hydroxybenzyl)aziridine-2-carbothioate* (**7**). From **2** (1.08 g, 4.0 mmol) and benzaldehyde (0.530 g, 5.0 mmol; *GP 3*), a crude product (1.49 g) was obtained (^{1}H-NMR (300 MHz): diastereoisomer ratio 77:23). After FC (pentane/Et_2O 90:10→30:70) with 1.40 g of this product, **7** (1.11 g, 74%) was collected as a colourless viscous oil (diastereoisomer ratio 3:1). IR ($CHCl_3$): 3550 (br.), 3400 (br.), 3060, 3000, 1675. ^{1}H-NMR ((D$_6$)DMSO/D_2O, 100°, 300 MHz, diastereoisomer mixture): 2.28–2.36 (*m*, 2 H–C(3)); 3.79–3.87, 4.04–4.09 (2*m*, PhCH_2); 5.12, 5.30 (2*s*, ratio 26:74, PhC*H*(OH)); 7.19–7.50 (*m*, 15 arom. H). MS: 375 (< 0.2, $M^{+\cdot}$), 91 (100). Anal. calc. for $C_{23}H_{21}NO_2S$ (375.49): C 73.57, H 5.64, N 3.73; found: C 73.73, H 5.80, N 3.82.

rac-S-*Phenyl 1-Benzyl-2-methylaziridine-2-carbothioate* (**8**). From **2** (0.470 g, 1.75 mmol) and MeI (0.370 g, 2.6 mmol; *GP 4*). After FC (pentane/Et_2O 75:25), **8** (0.301 g, 61%) was obtained as a colourless viscous oil. IR ($CHCl_3$): 3060, 3000, 1690. ^{1}H-NMR ($CDCl_3$, 63.5°, 300 MHz): 1.52 (*s*, CH_3); 1.70 (*s*, H–C(3)); 2.44 (*s*, H–C(3)); 3.83 (*s*, PhCH_2); 7.25–7.49 (*m*, 5 arom. H); 7.37 (*s*, 5 arom. H). ^{13}C-NMR ($CDCl_3$, 75 MHz): 11.06 (*q*); 42.11 (*t*); 47.31 (*s*); 56.31 (*t*); 127.08 (*d*); 127.65 (*d*); 128.41 (*d*); 128.97 (*d*); 134.78 (*d*); 138.79 (*s*). MS: 283 (0.5, $M^{+\cdot}$), 176 (98), 146 (94), 91 (100). Anal. calc. for $C_{17}H_{17}NOS$ (283.40): C 72.05, H 6.05, N 4.94; found: C 72.19, H 5.97, N 5.13.

rac-S-*Phenyl 1,2-Dibenzylaziridine-2-carbothioate* (**9**). From **2** (0.540 g, 2.0 mmol) and benzyl bromide (0.60 g, 3.5 mmol; *GP 4*). After FC (pentane/Et_2O 80:20), **9** (0.400 g, 56%) was obtained as a colourless viscous oil. IR ($CHCl_3$): 3060, 3000, 1690, 695. ^{1}H-NMR ((D$_6$)DMSO, 100°, 300 MHz): 2.08 (*d*, *J* = 0.90, H–C(3)); 2.40 (*d*, *J* = 0.7, H–C(3)); 3.30, 3.47 (*AB*, *J* = 16.2, PhCH_2); 3.75, 4.01 (*AB*, *J* = 13.9, PhCH_2); 7.20–7.48 (*m*, 15 arom. H): ^{13}C-NMR ($CDCl_3$, 20 MHz): *ca.* 33.0 (*m*, undistinct); 40.69 (*t*); 51.30 (*s*); 56.54 (*t*); 126.42, 127.14, 127.81, 128.43, 128.96, 134.72 (6*d*); 137.81 (*s*); 138.69 (*s*); 200.61 (*s*). MS: 359 (6, $M^{+\cdot}$), 250 (94), 91 (100). Anal. calc. for $C_{23}H_{21}NOS$ (359.49): C 76.85, H 5.89, N 3.90; found: C 76.77, H 5.96, N 4.12.

C) Preparation of (−)-(*S*)-2 and its Reactions. – *Methyl (−)-(*S*)-1-Benzylaziridine-2-carboxylate* (**12**). To a soln. of PPh_3 (13.1 g, 50 mmol) and CBr_4 (16.6 g, 50 mmol) in CH_2Cl_2 (150 ml), *N*-benzylserine methyl ester hydrochloride (**11**)[32] (9.80 g, 40 mmol) and Et_3N (16 ml, 100 mmol) were added at 0°. After addition of $CHCl_3$ (50 ml), the mixture became a clear dark-red soln. and was stirred overnight at r.t. After cooling again to 0°, PPh_3 (13.1 g, 50 mmol), CBr_4 (16.6 g, 50 mmol), and NEt_3 (16 ml, 100 mmol) were added and, after refluxing for 2 h, the ^{1}H-NMR of the soln. showed that all **11** had disappeared. The soln. was cooled to r.t., stirred twice with Et_2O (100 ml), filtered, and evaporated. The product was purified by FC (pentane/Et_2O 30:70) and bulb-to-bulb distillation to give **12** (2.66, 35%) as a colourless oil. (Other attempts led to **12** in different yields (14–38%)). B.p. 90°/0.01 Torr. $[\alpha]_D = -85.3°$ (*c* = 1.03, EtOH). IR ($CHCl_3$): 2990, 2950, 1740, 695. ^{1}H-NMR ($CDCl_3$, 300 MHz): 1.76 (*dd*, *J* = 6.3, 1.1, 1 ring H); 2.22 (*dd*, *J* = 6.3, 3.2, 1 ring H); 2.27 (*dd*, *J* = 3.0, 1.1, 1 ring H); 3.55 (*AB*, *J* ≈ 14, PhCH_2); 3.73 (*s*, CH_3O); 7.27–7.35 (*m*, 5 arom. H). ^{13}C-NMR ($CDCl_3$, 75 MHz): 34.53 (*t*); 37.37 (*d*); 52.21 (*q*); 63.93 (*t*); 127.34 (*d*); 128.05 (*d*); 128.41 (*d*); 137.66 (*s*); 171.11 (*s*). MS: 191 (6, $M^{+\cdot}$), 91 (100), 45 (61).

S-*Phenyl (−)-(*S*)-1-Benzylaziridine-2-carbothioate* ((−)-**2**). From Et_3Al (2.7 ml, 20 mmol), thiophenol (2.21 g, 20 mmol), and **12** (2.62 g, 13.7 mmol; *GP 2*). After FC (pentane/Et_2O 70:30) of the crude residue (−)-**2** was obtained (2.86 g, 78%) as colourless crystals. M.p. 51.6–52.0° (Et_2O). $[\alpha]_D = -173.7°$ (*c* = 1.16, EtOH). IR ($CHCl_3$): 3060, 3000, 1690. ^{1}H-NMR ($CDCl_3$, 300 MHz): 1.88 (*d*, *J* = 6.6, H–C(3)); 2.36 (*dd*, *J* = 2.7, 0.9, H–C(3)); 2.47 (*dd*, *J* = 6.6, 2.8, H–C(2)); 3.57, 3.70 (*AB*, *J* = 13.6, PhCH_2); 7.29–7.43 (*m*, 10 arom. H). ^{1}H-NMR ((D$_6$)DMSO, 300 MHz): 2.07 (*dd*, *J* = 6.6, 1.2, H–C(3)); 2.24 (*dd*, *J* = 2.7, 1.2, H–C(3)); 2.74 (*dd*, *J* = 6.6, 2.7, H–C(2)); 3.6 (*AB*, *J* ≈ 14, PhCH_2); 7.29–7.45 (*m*, 10 arom. H); the spectrum did not show essential changes on

---

[32]) Obtained by esterification of the corresponding acid in MeOH/HCl (reflux) followed by crystallization from acetone; m.p. 134–135° ([67]: m.p. (acetone/Et_2O) 139°).

heating at higher temps. ($\leq +100°$); likewise, decreasing the temp. ($\geq -100°$, in (D_8)THF) led to a broadening of the signals due to changes in the viscosity of the solvent. ^{13}C-NMR ($CDCl_3$, 300 MHz): 36.30 (*t*); 44.80 (*d*); 63.27 (*t*); 127.43 (*d*); 128.01 (*d*); 128.46 (*d*); 129.08 (*d*); 129.20 (*d*); 134.64 (*d*); 137.49 (*s*); 197.24 (*s*). MS: 270 (2, $M^{+\cdot}$ + 1), 269 (0.4, $M^{+\cdot}$), 160 (99), 132 (100), 106 (99), 91 (99), 65 (99). Anal. calc. for $C_{16}H_{15}NOS$ (269.37): C 71.34, H 5.61, N 5.20; found: C 71.28, H 5.61, N 5.14.

Irradiation at the PhCH_2 signal gave positive NOE for H–C(2) and H–C(3), *cis* to each other, thus $PhCH_2$ is *cis* to both these H-atoms and *trans* to COSPh.

S-*Phenyl (–)-(*S*)-1-Benzyl(2-*^{2}*H)aziridine-2-carbothioate* (**17** (≡(–)-D-**2**)). *Method C:* To a soln. of LDA (1.05 mmol) in THF (5 ml), a soln. of (–)-**2** (0.269 g, 1.0 mmol) in THF (1 ml) was added dropwise at –78°. After stirring for 20 min, a soln. of CD_3OD (0.5 ml) in THF (1.5 ml) was dropped slowly. Then, sat. NH_4Cl soln. (2 ml) was added, the mixture diluted with Et_2O (20 ml), the org. phase washed twice with sat. NaCl soln., dried (Na_2SO_4), and evaporated. The crude residue was purified by FC (pentane/Et_2O 70:30) to give 0.2 g (74%) of the product (^{1}H-NMR (300 MHz): 80% deuteration). $[\alpha]_D = -173.9°$ (*c* = 1.18, EtOH). ^{1}H-NMR ($CDCl_3$, 300 MHz): 1.88 (*s*, under neath signal of undeuterated compounds, total 1 H, ring H); 2.36 (*s*, 1 ring H); 2.47 (*dd*, *J* = 6.6, 2.8, 0.20 H, H–C(2)); 3.57, 3.69 (*AB*, *J* = 13.6, PhCH_2); 7.26–7.42 (*m*, 10 arom. H).

Method D: As *Method C*, but before the addition of CD_3OD, BuLi (1.05 mmol) was slowly dropped and the soln. stirred for 5 min: 0.170 g (63%) of **17** (^{1}H-NMR (300 MHz): complete deuteration). M.p. (Et_2O) 50.8–51.1°. $[\alpha]_D = -172.5°$ (*c* = 1.06, EtOH). After two recrystallizations from Et_2O, $[\alpha]_D = -176.1°$ (*c* = 0.94, EtOH). IR ($CHCl_3$): 3060, 3000, 1690, 695, 690. ^{1}H-NMR ($CDCl_3$, 300 MHz): 1.88 (*s*, H–C(3)); 2.36 (*d*, *J* = 0.8, H–C(3)); 3.57, 3.70 (*AB*, *J* = 13.6, PhCH_2); 7.26–7.43 (*m*, 10 arom. H). ^{13}C-NMR ($CDCl_3$, 75 MHz): 36.29 (*t*); 44.49 (*t*, *J* = 26.2); 63.2 (*t*); 127.33 (*d*); 127.90 (*d*); 128.38 (*d*); 128.98 (*d*); 129.12 (*d*); 134.53 (*d*); 137.36 (*s*); 197.09 (*s*). MS: 270 (< 0.2, $M^{+\cdot}$), 161 (67), 91 (100). Anal. calc. for $C_{16}H_{14}DNOS$ (270.38): C 71.08, H + D 5.97, N 5.18; found: C 71.03, H + D 5.53, N 5.33.

Method E: As *Method D*, but with 0.5 g (1.85 mmol) of (–)-**2** and before the addition of CD_3OD (0.32 ml, 7.4 mmol), the soln. was warmed to –60°. FC (pentane/Et_2O 70:30→30:70) yielded **17** (0.210 g, 42%) and D_4-**12** (0.068 g, 19%). **17:** $[\alpha]_D = -146.0°$ (*c* = 1.1, EtOH; e.e. 84%). D_4-**12**: $[\alpha]_D = -68.6°$ (*c* = 0.95, EtOH; e.e. 80%)[33]. ^{1}H-NMR (300 MHz): no undeuterated material.

D_4-**12**: ^{1}H-NMR ($CDCl_3$, 300 MHz): 1.74 (*s*, H–C(3)); 2.26 (*s*, H–C(3)); 3.54 (*s*, PhCH_2); 7.27–7.35 (*m*, 5 arom. H). ^{13}C-NMR ($CDCl_3$, 75 MHz): 34.47 (CH_2); 37.04 (*t*, CD); 50.51 (*m*, CD_3); 63.88 (CH_2); 127.40 (CH); 128.09 (CH); 128.48 (CH); 137.71 (C); 171.21 (C).

Method F: i) As *Method D*, but with 0.672 g (2.5 mmol) of (–)-**2**, and before quenching with CD_3OD, the soln. was warmed to –60° and stirred at –60° for 60 min. FC (pentane/Et_2O 70:30→30:70) gave **17** (0.265 g, 39%) and D_4-**12** (0.100 g, 20%). After FC, **17** showed an $[\alpha]_D = -148.1°$ (*c* = 1.05, EtOH; e.e. 85%) and D_4-**12** showed an $[\alpha]_D = -69.7°$ (*c* = 1.0, EtOH; e.e. 82%)[33]. *ii)* As *Method C*, but with 0.676 g (2.5 mmol) of (–)-**2**. Before quenching, the soln. was warmed to –60° and stirred for 60 min at –60°. FC (pentane/Et_2O 70:30→30:70) gave **17** (0.263 g, 39%; 75% deuterated) and D_4-**12** (0.111 g, 23%; 77% deuterated). **17:** $[\alpha]_D = -146.6°$ (*c* = 1.4, EtOH; e.e. 84%). D_4-**12**: $[\alpha]_D = -69.0°$ (*c* = 0.95, EtOH; e.e. 81%)[33].

*Deprotonation/Protonation of (–)-***2**. It was carried out following *Method C* and by using MeOH instead of CD_3OD: 0.158 g (59%) of (–)-**2**. $[\alpha]_D = -170.6°$ (*c* = 1.0, EtOH).

S-*Phenyl (–)-(*S*)-1-Benzyl-2-methylaziridine-2-carbothioate* ((–)-**8**). From (–)-**2** (0.538 g, 2.0 mmol) and MeI (1.28 g, 9.0 mmol; *GP 4*). After FC (pentane/Et_2O 75:25), (–)-**8** (0.414 g, 73%) was obtained as a colourless viscous oil. $[\alpha]_D = -106.1°$ (*c* = 1.05, EtOH). IR ($CHCl_3$): 3060, 3000, 1685 (br.), 690. ^{1}H-NMR ($CDCl_3$, 300 MHz): 1.52 (br. *s*, CH_3); 1.72 (br. *s*, H–C(3)); 2.44 (*s*, H–C(3)); 3.83 (*AB*, *J* = 14.4, PhCH_2); 7.27–7.50 (*m*, 10 arom. H). ^{13}C-NMR ($CDCl_3$, 75 MHz): 11.19 (*q*); 42.17 (*t*); 47.38 (*s*); 56.35 (*t*); 126.99 (*d*); 127.57 (*d*); 128.30 (*d*); 128.86 (*d*); 134.65 (*d*); 138.72 (*s*); 201.53 (*s*). MS: 283 (0.5, $M^{+\cdot}$), 176 (98), 146 (94), 91 (100). Anal. calc. for $C_{17}H_{17}NOS$ (283.40): C 72.05, H 6.05, N 4.94; found: C 72.19, H 5.97, N 5.13.

D) (Phenylethyl)aziridine Derivatives. – *Methyl (–)-(2*S*,1'*S*)-1-(1-Phenylethyl)aziridine-2-carboxylate* (**13**). From methyl 2,3-dibromopropionate (195 mmol), Et_3N (390 mmol), and (*S*)-(1-phenylethyl)amine (195 mmol; *GP 1*). FC (hexane/AcOEt 75:25) yielded **13** (18 g, 45%). Colourless oil. B.p. 65–70°/0.05 Torr. $[\alpha]_D = -112.3°$ (*c* = 1.85, $CHCl_3$). IR (film): 3060, 3020, 1740 (br.), 765, 700. ^{1}H-NMR ($CDCl_3$, 300 MHz): 1.48 (*d*, *J* = 6.6, CH_3); 1.58 (*dd*, *J* = 6.4, 1.0, H–C(3)); 2.13 (*dd*, *J* = 3.1, 1.0, H–C(3)); 2.21 (*dd*, *J* = 6.4, 3.1, H–C(2)); 2.54 (*q*, *J* = 6.6, PhC*H*); 3.74 (*s*, CH_3O); 7.21–7.39 (*m*, 5 arom. H). ^{13}C-NMR ($CDCl_3$, 20 MHz): 22.64 (*q*); 33.41 (*t*); 37.47 (*d*);

---

[33]) The enantiomeric excess (e.e.) of D_4-**12** is calculated from the $[\alpha]_D$ value of **12** assuming that there is practically no difference between both values taken from enantiomerically pure compounds, see also *Footnote 8*.

51.56 (*q*); 69.29 (*d*); 126.38 (*d*); 126.78 (*d*); 127.88 (*d*); 143.00 (*s*); 170.66 (*s*). MS: 205 (4.1, $M^{+\cdot}$), 204 (9.1, $M^{+\cdot}-1$), 105 (100). Anal. calc. for $C_{12}H_{15}NO_2$ (205.26): C 70.22, H 7.37, N 6.82; found: C 69.93, H 7.47, N 6.75.

Methyl (+)-(2R,1'S)-1-(1-Phenylethyl)aziridine-2-carboxylate (**14**). From methyl 2,3-dibromopropionate (195 mmol), Et_3N (390 mmol), and (*S*)-(1-phenylethyl)amine (195 mmol; *GP 1*). FC (hexane/AcOEt 75:25) gave **14** (16 g, 40%). Colourless oil. B.p. 55–60°/0.05 Torr. $[\alpha]_D = +50.5°$ (*c* = 1.65, $CHCl_3$). IR (film): 3060, 3020, 1745 (br.), 760, 700. ^{1}H-NMR ($CDCl_3$, 300 MHz): 1.45 (*d*, *J* = 6.6, CH_3); 1.76 (*d*, *J* = 6.4, H–C(3)); 2.07 (*dd*, *J* = 6.4, 3.1, H–C(2)); 2.33 (*d*, *J* = 3.1, H–C(3)); 2.56 (*q*, *J* = 6.6, PhC*H*); 3.65 (*s*, CH_3O); 7.19–7.35 (*m*, 5 arom. H). ^{13}C-NMR ($CDCl_3$, 20 MHz): 23.04 (*q*); 34.47 (*t*); 36.52 (*d*); 51.60 (*q*); 69.33 (*d*); 126.07 (*d*); 126.79 (*d*); 128.06 (*d*); 143.30 (*s*); 170.54 (*s*). MS: 205 (1.3, $M^{+\cdot}$), 204 (8.0, $M^{+\cdot}-1$), 190 (32), 105 (100). Anal. calc. for $C_{12}H_{15}NO_2$ (205.26): C 70.22, H 7.37, N 6.82; found: C 70.15, H 7.63, N 6.71.

S-Phenyl (–)-(2S,1'S)-1-(1-Phenylethyl)aziridine-2-carbothioate (**15**). From Et_3Al (3.7 ml, 26.9 mmol), thiophenol (3.2 ml, 26.9 mmol), and **13** (3.7 g, 17.9 mmol; *GP 2*), **15** (4.8 g, 95%) was obtained and recrystallized from pentane/Et_2O (*ca.* 3:2). M.p. 65.2–65.6° (colourless crystals). $[\alpha]_D = -152.4°$ (*c* = 1.1, $CHCl_3$). IR (KBr): 3060, 3020, 1690, 750, 700. ^{1}H-NMR ($CDCl_3$, 300 MHz): 1.52 (*d*, *J* = 6.5, CH_3); 1.74 (*dd*, *J* = 6.6, 0.9, H–C(3)); 2.22 (*dd*, *J* = 2.7, 0.9, H–C(3)); 2.50 (*dd*, *J* = 6.6, 2.7, H–C(2)); 2.67 (*q*, *J* = 6.5, PhC*H*); 7.20–7.44 (*m*, 10 arom. H). ^{13}C-NMR ($CDCl_3$, 75 MHz): 23.34 (*q*); 35.87 (*t*); 45.03 (*d*); 68.95 (*d*); 126.54 (*d*); 127.12 (*d*); 127.74 (*s*); 128.22 (*d*); 128.84 (*d*); 134.41 (*d*); 143.24 (*s*); 197.43 (*s*). MS: 284 (0.3, $M^{+\cdot}+1$), 174 (49), 105 (100). Anal. calc. for $C_{17}H_{17}NOS$ (283.39): C 72.05, H 6.05, N 4.94; found: C 71.70, H 5.95, N 4.88.

S-Phenyl (+)-(2R,1'S)-1-(1-Phenylethyl)aziridine-2-carbothioate (**16**). From Et_3Al (3 ml, 21.9 mmol), thiophenol (2.6 ml, 21.9 mmol), and **14** (3.0 g, 14.6 mmol; *GP 2*), **16** (3.7 g, 90%) ware obtained and distilled. B.p. 100–105°/5.10^{-5} Torr (colourless viscous oil). $[\alpha]_D = +201.3°$ (*c* = 1.0, $CHCl_3$). IR (film): 3060, 3020, 1695 (br.), 750, 700. ^{1}H-NMR ($CDCl_3$, 300 MHz): 1.49 (*d*, *J* = 6.6, CH_3); 1.90 (*dd*, *J* = 6.6, 1.0, H–C(3)); 2.36 (*dd*, *J* = 6.6, 2.7, H–C(2)); 3.43 (*dd*, *J* = 2.7, 1.0, H–C(3)); 2.66 (*q*, *J* = 6.6, PhC*H*); 7.24–7.46 (*m*, 10 arom. H). ^{13}C-NMR ($CDCl_3$, 20 MHz): 23.58 (*q*); 36.24 (*t*); 44.32 (*d*); 69.44 (*d*); 126.62 (*d*); 127.24 (*d*); 127.71 (*s*); 128.35 (*d*); 128.94 (*d*); 134.50 (*d*); 143.30 (*s*); 196.86 (*s*). MS: 283 (< 0.2, $M^{+\cdot}$), 174 (69), 105 (100). Anal. calc. for $C_{17}H_{17}NOS$ (283.39): C 72.05, H 6.05, N 4.94; found: C 71.81, H 6.13, N 4.97.

Deprotonation/Deuteration of **15**. *Method G:* As *Method D* with **15** (1.0 g, 3.5 mmol). Before quenching, the soln. was cooled to –95° (*ca.* 15 min) and then MeOD (0.6 ml, 14 mmol) added dropwise and the mixture stirred for 10 min at –95°. By FC (pentane/Et_2O 75:25) gave **18** (0.407 g, 41%) and **27** (0.087 g, 12%). The ^{1}H-NMR (300 MHz) of the crude mixture: traces of **24** and **28**.

Method H: As *Method D* with **15** (1.0 g, 3.5 mmol). MeOD was slowly added at –78° and the mixture stirred for 10 min at –78°. FC (pentane/Et_2O 75:25) gave **18** (0.388 g, 39%) and **27** (0.108 g, 15%). ^{1}H-NMR (300 MHz) of the crude mixture: traces of **24** and **28**.

Method I: As *Method D* with **15** (1.0 g, 3.5 mmol). Before quenching, the soln. was warmed to –60° (*ca.* 15 min), MeOD added dropwise at –60° and the mixture stirred for 10 min. FC (pentane/Et_2O 75:25) yielded **18** (0.318 g, 32%), **24** (0.030 g, 3%), **27** (0.101 g, 14%), and **28** (0.007 g, 1%).

Method K: i) As *Method D* with **15** (0.303 g, 1.07 mmol). Before quenching, the soln. was warmed to –60° and kept for 60 min at –60°. Then, MeOD was added dropwise and the mixture stirred for 10 min at –60°. After workup, 0.222 g of crude product were obtained. ^{1}H-NMR (300 MHz): **18**/**24**/**27**/**28** 76:6:18: < 1. *ii)* As *Method C* with **15** (0.313 g, 1.1 mmol). Before quenching, the soln. was warmed to –60° and stirred for 60 min at –60°. It was slowly quenched with MeOD and stirred for additional 10 min. Workup gave 0.261 g of the crude product (77% deuterated). ^{1}H-NMR (300 MHz): **18**/**24**/**27**/**28** 81:6:13: < 1.

Deprotonation/Deuteration of **16**. *Method G:* From **16** (1.502 g, 5.3 mmol) and after FC (pentane/Et_2O 75:25) **18** (0.256 g, 17%), **24** (0.467 g, 31%), **27** (0.066 g, 6%), and **28** (0.044 g, 4%) were obtained.

Method H: From **16** (1.422 g, 5.0 mmol) and after FC (pentane/Et_2O 75:25), **18** (0.227 g, 16%), **24** (0.497 g, 35%), **27** (0.052 g, 5%), and **28** (0.062 g, 6%) were obtained.

Method I: From **16** (1.241 g, 4.4 mmol) and after FC (pentane/Et_2O 75:25), **18** (0.350 g, 28%), **24** (0.162 g, 13%), **27** (0.082 g, 9%), and **28** (0.036 g, 4%) were obtained.

Method K: i) From **16** (0.336 g, 1.2 mmol), 0.246 g of a crude product were obtained. ^{1}H-NMR (300 MHz): **18**/**24**/**27**/**28** 48:36:13:3.

S-Phenyl (–)-(2S,1'S)-1-(1-Phenylethyl)(2-^{2}H)aziridine-2-carbothioate (**18** (≡D-**15**)). From **15** or **16** and MeOD following *Methods G–K*. Recrystallized from pentane/Et_2O (*ca.* 3:2). M.p. 65.8–66.2° (colourless crystals). $[\alpha]_D = -159.3°$ (*c* = 0.75, $CHCl_3$). ^{1}H-NMR ($CDCl_3$, 300 MHz): 1.52 (*d*, *J* = 6.5, CH_3); 1.75 (*s*, H–C(3)); 2.22 (*d*, *J* = 0.9, H–C(3)); 2.68 (*q*, *J* = 6.5, PhC*H*); 7.20–7.44 (*m*, 10 arom. H). ^{13}C-NMR ($CDCl_3$, 20 MHz): 23.36 (*q*); 35.78 (*t*); 69.07 (*d*); 126.78 (*d*); 127.35 (*d*); 128.01 (*s*); 128.44 (*d*); 129.08 (*d*); 134.64 (*d*); 143.54 (*s*). *Signals*

corresponding to *C*D and *C*O were not recognized. MS: 285 (0.2, $M^{+\cdot}$ + 1), 175 (53), 105 (100). Anal. calc. for $C_{17}H_{16}DNOS$ (284.40): C 71.79, H + D 6.38, N 4.92; found: C 71.38, H + D 6.02, N 4.56.

S-Phenyl (+)-(2R,1'S)-1-(1-Phenylethyl)(2-^{2}H)aziridine-2-carbothioate (**24**(≡D-**16**)). From **15** or **16** and MeOD following *Methods G–K*. B.p. 98–103°/2·10^{-5} Torr (colourless viscous oil). $[\alpha]_D$ = +202.6° (*c* = 0.7, $CHCl_3$). ^{1}H-NMR ($CDCl_3$, 300 MHz): 1.49 (*d*, *J* = 6.6, CH_3); 1.91 (*d*, *J* = 1.0, H–C(3)); 2.43 (*d*, *J* = 1.0, H–C(3)); 2.66 (*q*, *J* = 6.6, PhC*H*); 7.24–7.46 (*m*, 10 arom. H). ^{13}C-NMR ($CDCl_3$, 20 MHz): 29.67 (*q*); 36.29 (*t*); 69.59 (*d*); 126.73 (*d*); 127.35 (*d*); 127.79 (*s*); 128.48 (*d*); 129.03 (*d*); 120.10 (*d*); 134.60 (*d*); 143.42 (*s*). Signals corresponding to *C*D and *C*O were not recognized. MS: 285 (0.3, $M^{+\cdot}$ + 1), 175 (47), 105 (100). Anal. calc. for $C_{17}H_{16}DNOS$ (284.40): C 71,79, H + D 6.38, N 4.92; found: C 72.34, H + D 6.07, N 4.96.

Methyl (–)-(2S,1'S)-1-(1-Phenylethyl)(2-^{2}H)aziridine-2-carboxylate (**27**(≡D-**13**)). From **15** or **16** and MeOD following *Methods G–K*. B.p. 50–55°/4·10^{-5} Torr (colourless oil). $[\alpha]_D$ = –106.8° (*c* = 1.0, $CHCl_3$). ^{1}H-NMR ($CDCl_3$, 300 MHz): 1.47 (*d*, *J* = 6.5, CH_3); 1.61 (*s*, H–C(3)); 2.14 (*s*, H–C(3)); 2.55 (*q*, *J* = 6.5, PhC*H*); 3.76 (*s*, CH_3O); 7.21–7.39 (*m*, 5 arom. H). ^{13}C-NMR ($CDCl_3$, 20 MHz): 22.92 (*q*); 33.66 (*t*); 37.47 (*t*, *J* = 26.7); 51.95 (*q*); 69.68 (*d*); 126.71 (*d*); 127.10 (*d*); 128.18 (*d*); 143.26 (*s*); 171.05 (*s*). MS: 206 (2.5, $M^{+\cdot}$), 205 (7.7, $M^{+\cdot}$ – 1), 105 (100). Anal. calc. for $C_{12}H_{14}DNO_2$ (206.27): C 69.88, H + D 7.82, N 6.79; found: C 69.61, H + D 7.51, N 6.68.

Methyl (+)-(2R,1'S)-1-(1-Phenylethyl)(2-^{2}H)aziridine-2-carboxylate (**28**(≡D-**14**)). From **15** or **16** and MeOD following *Methods G–K*. B.p. 40–45°/4·10^{-5} Torr (colourless oil). $[\alpha]_D$ = +53.6° (*c* = 0.75, $CHCl_3$). ^{1}H-NMR ($CDCl_3$, 300 MHz): 1.46 (*d*, *J* = 6.6, CH_3); 1.78 (*s*, H–C(3)); 2.33 (*d*, *J* = 1.0, H–C(3)); 2.57 (*q*, *J* = 6.6, PhC*H*); 3.67 (*s*, CH_3O); 7.19–7.35 (*m*, 5 arom. H). ^{13}C-NMR ($CDCl_3$, 20 MHz): 23.33 (*q*); 34.71 (*t*); 51.95 (*q*); 69.66 (*d*); 126.36 (*d*); 127.09 (*d*); 128.36 (*d*); 143.55 (*s*). Signals corresponding to *C*D and *C*O were not recognized. MS: 206 (1.3, $M^{+\cdot}$), 205 (8.8, $M^{+\cdot}$ – 1), 191 (34), 105 (100). Anal. calc. for $C_{12}H_{14}DNO_2$ (206.27): C 69.88, H + D 7.82, N 6.79; found: C 69.77, H + D 7.47, N 6.76.

S-Phenyl (–)-(2S,1'S)-2-Methyl-1-(1-phenylethyl)aziridine-2-carbothioate (**19**). From **15** (0.592 g, 2 mmol) and MeI (0.2 ml, 3 mmol; *GP 4*). After FC (pentane/Et_2O 75:25), **19** (0.368 g, 62%) was obtained. B.p. 110–115°/0.05 Torr (colourless viscous oil). $[\alpha]_D$ = –146.7° (*c* = 1.05, $CHCl_3$). ^{1}H-NMR ($CDCl_3$, 300 MHz): 1.49 (*d*, *J* = 6.4, PhCH–C*H*$_3$); 1.52 (br. *s*); 1.63 (*s*, CH_3–C(2)); 2.26 (br. *s*, H–C(3)); 3.30 (br. *q*, PhC*H*) (^{1}H-NMR (90 MHz): 3.3 (*q*, *J* = 6, PhC*H*)); 7.24–7.50 (*m*, 10 arom. H). ^{13}C-NMR ($CDCl_3$, 75 MHz): 11.06 (*q*); 24.56 (*q*); 40.95 (*t*); 47.88 (*s*); 61.54 (*d*); 126.85 (*d*); 127.16 (*s*); 128.43 (*d*); 128.83 (*d*); 128.88 (*d*); 134.71 (*d*); 144.73 (*s*); *ca.* 202.3 (br. *s*). MS: 297 (1.1, $M^{+\cdot}$), 188 (35), 105 (100). Anal. calc. for $C_{18}H_{19}NOS$ (297.42): C 72.69, H 6.44, N 4.71; found: C 72.74, H 6.66, N 4.57.

S-Phenyl (–)-(2S,1'S)-2-Ethyl-1-(1-phenylethyl)aziridine-2-carbothioate (**20**). From **15** (1.506 g, 5.3 mmol) and EtI (0.7 ml, 7.4 mmol; *GP 4*). After FC (pentane/Et_2O 75:25), **20** (0.837 g, 51%) was obtained. B.p. 115–120°/4·10^{-5} Torr (colourless viscous oil). $[\alpha]_D$ = –157.4° (*c* = 1.1, $CHCl_3$). ^{1}H-NMR ($CDCl_3$, 300 MHz): 1.18 (br. *t*, CH_3CH_2) (^{1}H-NMR (90 MHz): 1.2 (*t*, *J* = 7.5, CH_3CH_2)); 1.48 (*d*, *J* = 6.1, PhCH–C*H*$_3$); 1.52 (br. *s*, H–C(3)); 1.82–2.10 (*m*, CH_3CH_2); 2.23 (br. *s*, H–C(3)); 3.35 (*q*, *J* = 6.1, PhC*H*); 7.22–7.43 (*m*, 10 arom. H). ^{13}C-NMR ($CDCl_3$, 75 MHz): 11.99 (br. *t*); 19.70 (br. *q*); 24.43 (*q*); 38.95 (*t*); 52.66 (*s*); 60.98 (*d*); 126.88 (*d*); 127.10 (*s*); 128.37 (*d*); 128.88 (*d*); 134.74 (*d*); 144.83 (*s*); *ca.* 201.5 (br. *s*). MS: 312 (0.4, $M^{+\cdot}$ + 1), 202 (59), 105 (100). Anal. calc. for $C_{19}H_{21}NOS$ (311.45): C 73.27, H 6.80, N 4.50; found: C 73.26, H 6.76, N 4.39.

S-Phenyl (–)-(2S,1'S)-2-Allyl-1-(1-phenylethyl)aziridine-2-carbothioate (**21**). From **15** (1.0 g, 3.5 mmol) and allyl bromide (0.44 ml, 4.9 mmol; *GP 4*). After FC (pentane/Et_2O 75:25), **21** (0.667 g, 59%) was obtained and recrystallized from pentane/Et_2O (*ca.* 1:1). M.p. 61.4–62.4° (colourless crystals). $[\alpha]_D$ = –168.2° (*c* = 1.0, $CHCl_3$). IR (KBr): 3060, 3020, 1700, 935 (br.), 750, 700, 680. ^{1}H-NMR ($CDCl_3$, 300 MHz): 1.49 (*d*, *J* = 6.1, CH_3); 1.62 (br., H–C(3)); 2.25 (br. *s*, H–C(3)); 2.64–2.81 (*m*, CH_2=CH–C*H*$_2$); 3.40 (*q*, *J* = 6.1, PhC*H*); 5.09–5.21 (*m*, CH_2=CH–CH_2); 5.93–5.99 (*m*, CH_2=C*H*–CH_2); 7.25–7.44 (*m*, 10 arom. H). ^{13}C-NMR ($CDCl_3$, 75 MHz): 24.48 (*q*); *ca.* 31.24 (br.); 39.08 (*t*); 51.09 (*s*); 61.08 (*d*); 117.53 (*t*); 126.88 (*d*); 127.17 (*s*); 128.42 (*d*); 128.92 (*d*); 134.36 (*d*); 134.73 (*d*); 144.73 (*s*). The signal corresponding to *C*O was not recognized. MS: 324 (0.6, $M^{+\cdot}$ + 1), 323 (0.8, $M^{+\cdot}$), 214 (39), 105 (100). Anal. calc. for $C_{20}H_{21}NOS$ (323.46): C 74.27, H 6.54, N 4.33; found: C 74.07, H 6.70, N 4.05.

S-Phenyl (–)-(2S,1'S)-2-Benzyl-1-(1-phenylethyl)aziridine-2-carbothioate (**22**). From **15** (1.0 g, 3.5 mmol) and benzyl bromide (0.62 ml, 4.9 mmol; *GP 4*). After FC (pentane/Et_2O 75:25), **22** (0.783 g, 60%) was obtained as a colourless viscous oil. $[\alpha]_D$–147.7° (*c* = 0.9, $CHCl_3$). IR (film): 3060, 3020, 1695 (br.), 745, 700. ^{1}H-NMR ($CDCl_3$, 300 MHz): 1.42 (*q*, *J* = 6.4, CH_3); 1.70 (br., H–C(3)); 2.32 (br. *s*, H–C(3)); 3.11–3.18 (*m*, 1 H, PhCH_2); 3.44 (*q*, *J* = 6.4, PhC*H*CH_3); 3.53–3.60 (*m*, 1 H, PhCH_2); 7.15–7.46 (*m*, 15 arom. H). ^{1}H-NMR ((D_6)DMSO, 300 MHz, at +87.5°): 1.35 (*d*, *J* = 6.4, CH_3); 1.91 (*s*, H–C(3)); 2.27 (*s*, H–C(3)); 3.24, 3.48 (*AB*, *J* = 15.4, PhCH_2); 3.59 (*q*, *J* = 6.4, PhC*H*CH_3); 7.18–7.48 (*m*, 15 arom. H). ^{13}C-NMR ($CDCl_3$, 75 MHz): 24.32 (CH_3), *ca.* 31.0 (br., CH_2); *ca.* 39.5 (br., CH_2); 51.97 (C); 61.22 (CH); 126.24 (CH); 126.63 (CH); 126.98 (CH); 128.19 (CH); 128.74 (CH);

129.09 (CH); 134.50 (CH); 144.35 (C). The signal corresponding to *C*O is not recognized. MS: 373 (< 0.2, $M^{+\cdot}$), 264 (14), 105 (100). Anal. calc. for $C_{24}H_{23}NOS$ (373.52): C 77.18, H 6.21, N 3.75; found: C 77.07, H 6.45, N 3.63.

S-Phenyl (2S,1'S)-2-(2-Nitro-1-phenylethyl)-1-(1-phenylethyl)aziridine-2-carbothioate (**23**). From **15** (2.0 g, 7 mmol) and β-nitrostyrene (1.6 g, 10.5 mmol; *GP 3*), a crude product (2.963 g) was obtained. ^{1}H-NMR (300 MHz): diastereoisomer ratio *ca.* 3:1. After FC (pentane/Et_2O 75:25) 2.389 g (79%) of **23** were collected as a slightly coloured viscous oil (diastereoisomer ratio 73:27). ^{1}H-NMR ($CDCl_3$, 300 MHz; diastereoisomer mixture): 1.53 (*d*, *J* = 6.2, CH_3); 1.96, 2.02–2.23 (2 br., H–C(3), ratio 27:73); 2.38, 2.46 (2 br. *s*, H–C(3), ratio 27:73); 3.48 (*m*, 2 PhC*H*); 4.52–4.63 (*m*, 1 H, CH_2NO_2); 4.99–5.09 (*m*, 1H, CH_2NO_2); 7.13–7.47 (*m*, 15 arom. H). MS (mixture): 432 (0.1, $M^{+\cdot}$), 105 (100).

S-Phenyl (+)-(2R,1'S)-2-Methyl-1-(1-phenylethyl)aziridine-2-carbothioate (**25**). From **16** (0.694 g, 2.5 mmol) and MeI (0.24 ml, 3.7 mmol; *GP 4*), a crude product (0.487 g) was obtained. ^{1}H-NMR (300 MHz): **25**/**19** 81:19. After FC (pentane/Et_2O 75:25), 0.379 g (51%) of **25**/**19** (4:1) was obtained. From the mixture, **25** was isolated by recrystallization (pentane/Et_2O *ca.* 1:3). M.p. 101.8–102.2°. $[\alpha]_D$ = +235.9° (*c* = 1.1, $CHCl_3$). ^{1}H-NMR ($CDCl_3$, 300 MHz): 1.33 (br. *s*, CH_3–C(2)); 1.51 (*d*, *J* = 6.4, PhCHCH_3); 1.72 (*s*, H–C(3)); 2.47 (*s*, H–C(3)); 3.31 (*q*, *J* = 6.4, PhC*H*); 7.21–7.52 (*m*, 10 arom. H). ^{13}C-NMR ($CDCl_3$, 75 MHz): 11.30 (*q*); 24.99 (*q*); 41.47 (*t*); 47.95 (*s*); 62.68 (*d*); 126.65 (*d*); 127.00 (*s*); 127.43 (*d*); 127.91 (*d*); 129.33 (*d*); 134.79 (*d*); 144.64 (*s*); 201.43 (*s*). MS: 297 (0.2, $M^{+\cdot}$), 188 (99), 160 (83), 105 (100). Anal. calc. for $C_{18}H_{19}NOS$ (297.42): C 72.69, H 6.44, N 4.71; found: C 72.57, H 6.59, N 4.67.

S-Phenyl (2R,1'S)-2-Benzyl-1-(1-phenylethyl)aziridine-2-carbothioate (**26**). From **16** (1.197 g, 4.2 mmol) and benzylbromide (0.75 ml, 6 mmol; *GP 4*), a crude product (1.583 g) was obtained. ^{1}H-NMR (300 MHz): **26**/**22** 69:31. After FC (pentane/Et_2O 75:25), 0.893 g (57%) of **26**/**22** (2:1) was collected. ^{1}H-NMR ($CDCl_3$, 300 MHz; mixture): 1.50 (*d*, *J* = 6.4, CH_3); 1.81 (*s*, H–C(3)); 2.49 (br. *s*, H–C(3)); 2.80–2.85 (*m*, 1 H, PhCH_2); 3.26–3.32 (*m*, 1 H, PhCH_2); 3.40 (*q*, *J* = 6.4, PhC*H*CH_3); 7.14–7.50 (*m*, 15 arom. H). ^{1}H-NMR ((D_6)DMSO, 300 MHz, at +87.5°; mixture): 1.45 (*d*, *J* = 6.4, CH_3); 2.07 (*d*, *J* = 0.9, H–C(3)); 2.46 (*s*, H–C(3)); 2.98–3.15 (*AB*, *J* = 15.6, PhCH_2, partially covered by the signal of H_2O); 3.58 (*q*, *J* = 6.4, PhC*H*CH_3); 7.07–7.51 (*m*, 15 arom. H). ^{13}C-NMR ($CDCl_3$, 75 MHz; mixture): 25.35 (br., CH_3); 31.12 (br., CH_2); 40.33 (br., CH_2); 52.23 (C); 62.46 (br., CH); 126.12–129.51; 134.73 (CH); 144.51 (C). The signal corresponding to *C*O is not recognized. MS from the mixture: 373 (0.2, $M^{+\cdot}$), 264 (39), 105 (100).

Reaction of **15** *and* **16** *with MeOLi. Method L:* To a soln. of MeOD (0.31 ml, 7.2 mmol) in THF (4 ml), BuLi (3.6 mmol) was added dropwise at –78°. After stirring for 5 min, a soln. of **15** or **16** (0.5 g, 1.8 mmol) in THF (4 ml) was added. The cooling bath was removed and the mixture stirred for 2 h at r.t., diluted with Et_2O (20 ml), and successively washed with sat. NH_4Cl, 1N NaOH, and sat. NaCl solns. The org. layer was dried ($MgSO_4$) and evaporated to give **13** (0.295 g, 80% starting from **15**) or **14** (0.291 g, 79% starting from **16**).

Method M: As *Method L* with **16**. After its addition in THF soln., the mixture was stirred for another 10 min at –78° and then quenched with sat. NH_4Cl and worked up as described in *Method L* to give 0.382 g of crude **14**/**16** (1:10).

Hydrolysis of **13**/**14**. *Followed by Hydrogenolysis. Hydrolysis.* A mixture of **13** or **14** (5 g, 24.4 mmol) and 20% $HClO_4$ soln. (140 ml) was heated at 80° for 30 h. The soln. was cooled to r.t. and chromatographed on *Dowex-50* column (H^+ form, 195 g) to give N-*(1-phenylethyl)serine* (3.4 g (67%) from **13** and 3.3 g (65%) from **14**) as a white solid.

Hydrogenolysis. The *N*-(1-phenylethyl)serines were separately dissolved in EtOH/H_2O 1:1 (*ca.* 300 ml), 20% $Pd(OH)_2$/C (1.5 g) was added to each soln., and the mixtures were stirred under H_2 (1 atm) for 24 h at r.t. The solns. were filtered through *Celite*, evaporated, and the obtained solids were chromatographed on *Dowex-50* column (H^+ form, 135 g) to give serine (0.890 g (35%) starting from **13** and 0.829 g (32%) starting from **14**). After the recrystallization from H_2O/EtOH, the (*S*)-serine from **13** showed an $[\alpha]_D$ = –6.5° (*c* = 0.8, H_2O) and the (*R*)-serine from **14**, an $[\alpha]_D$ = +5.9° (*c* = 0.8, H_2O).

REFERENCES

[1] D. Seebach, R. Häner, *Chem. Lett. Jpn.* **1987,** 49.

[2] D. Seebach, R. Imwinkelried, Th. Weber, in 'Modern Synthetic Methods 1986', Ed. R. Scheffold, Springer-Verlag, Berlin, 1986, Vol. 4, p. 125–259.

[3] D. Seebach, R. Häner, Th. Maetzke, *Helv. Chim. Acta* **1986,** *69,* 1655.

[4] H. Rapoport, K. J. Shaw, J. R. Luly, *J. Org. Chem.* **1985,** *50,* 4515.

[5] S. M. Weinreb, R. P. Hatch, *J. Org. Chem.* **1977,** *42,* 3960, and ref. cited therein.

[6] a) K. Okawa, K. Nakajima, F. Takai, T. Tanaka, *Bull. Chem. Soc. Jpn.* **1978,** *51,* 1577; b) J. E. Baldwin, R. M. Adlington, N. G. Robinson, *J. Chem. Soc., Chem. Commun.* **1987,** 153.

[7] K. Harada, I. Nakamura, *J. Chem. Soc., Chem. Commun.* **1978,** 522.

[8] D. Seebach, J. D. Dunitz, Th. Laube, *Helv. Chim. Acta* **1985,** *68,* 1373.

[9] D. Seebach, J. D. Aebi, *Helv. Chim. Acta* **1985,** *68,* 1507.

[10] D. Seebach, J. D. Aebi, M. Gander-Coquoz, R. Naef, *Helv. Chim. Acta* **1987,** *70,* 1194.

[11] D. Seebach, H.-F. Chow, R. F. W. Jackson, M. A. Sutter, S. Thaisrivongs, J. Zimmermann, *Liebigs Ann. Chem.* **1986,** 1281.

[12] a) D. Seebach, Th. Weber, *Helv. Chim. Acta* **1985,** *68,* 155; b) D. Seebach, Th. Weber, R. Aeschimann, Th. Maetzke, *ibid.* **1986,** *69,* 1365.

[13] C. Tamm, P. Strazewski, *Helv. Chim. Acta* **1986,** *69,* 1041.

[14] D. Seebach, T. Mukhopadhyay, *Helv. Chim. Acta* **1982,** *65,* 385.

[15] *Chimia* **1985,** *39,* 147.

[16] D. Seebach, M. Boes, R. Naef, W. B. Schweizer, *J. Am. Chem. Soc.* **1983,** *105,* 5390.

[17] M. H. Brewster, *J. Am. Chem. Soc.* **1959,** *81,* 5475; *ibid.* **1959,** *81,* 5483; *ibid.* **1959,** *81,* 5493.

[18] K. Mislow, A. Rauk, L. C. Allen, *Angew. Chem.* **1970,** *82,* 453; *ibid. Int. Ed.* **1970,** *9,* 400.

[19] J. B. Lambert, *Topics Stereochem.* **1971,** *6,* 19.

[20] J. W. Henderson, *Chem. Soc. Rev.* **1973,** *2,* 397.

[21] H. A. Bent, *Chem. Rev.* **1961,** *61,* 275.

[22] a) D. Felix, A. Eschenmoser, *Angew. Chem.* **1968,** *80,* 197; *ibid. Int. Ed.* **1968,** *7,* 224; b) R. G. Kostyanovskii, Z. E. Samojlova, I. I. Chervin, *Tetrahedron Lett.* **1969,** 719; V. F. Rudchenko, O. A. D'Yachenko, A. B. Zolotoi, L. O. Atovmyan, I. I. Chervin, R. G. Kostyanovskii, *Tetrahedron* **1982,** *38,* 961.

[23] H. C. Brown, M. Gerstein, *J. Am. Chem. Soc.* **1950,** *72,* 2926; H. C. Brown, R. S. Fletcher, R. B. Johannesen, *ibid.* **1951,** *73,* 212.

[24] M. Duraisamy, H. M. Walborsky, *J. Am. Chem. Soc.* **1984,** *106,* 5035.

[25] a) S. I. Miller, W. G. Lee, *J. Am. Chem. Soc.* **1959,** *81,* 6313; b) H. M. Walborsky, R. B. Banks, *Bull. Soc. Chim. Belg.* **1980,** *89,* 849, and ref. cited therein.

[26] P. Caramella, K. N. Houk, *Tetrahedron Lett.* **1981,** *22,* 819.

[27] C. G. Mc Carty, in 'The Chemistry of the Carbon-Nitrogen Double Bond', Ed. S. Patai, J. Wiley and Sons, New York, 1970, Chapt. 9.

[28] S. J. Brois, *J. Am. Chem. Soc.* **1968,** *90,* 506; *ibid.* **1968,** *90,* 508.

[29] H. M. Walborsky, F. J. Impastato, *J. Am. Chem. Soc.* **1959,** *81,* 5835; H. M. Walborsky, F. J. Impastato, A. E. Young, *ibid.* **1964,** *86,* 3283.

[30] F. J. Impastato, H. M. Walborsky, *J. Am. Chem. Soc.* **1962,** *84,* 4838; H. M. Walborsky, L. E. Allen, H. J. Traenckner, E. J. Powers, *J. Org. Chem.* **1971,** *36,* 2937.

[31] M. P. Periasamy, H. M. Walborsky, *J. Am. Chem. Soc.* **1974,** *96,* 3711; *ibid.* **1977,** *99,* 2631.

[32] G. Klebe, K. H. Böhn, M. Marsch, G. Boche, *Angew. Chem.* **1987,** *99,* 62; *ibid. Int. Ed.* **1987,** *26,* 78.

[33] H. M. Walborsky, A. A. Youssef, J. M. Motes, *J. Am. Chem. Soc.* **1962,** *84,* 2465; H. M. Walborsky, J. M. Motes, *ibid.* **1970,** *92,* 2445.

[34] H. M. Walborsky, F. M. Hornyak, *J. Am. Chem. Soc.* **1955,** *77,* 6026.

[35] J. M. Motes, H. M. Walborsky, *J. Am. Chem. Soc.* **1970,** *92,* 3697.

[36] a) H. Roder, G. Helmchen, E.-M. Peters, K. Peters, H.-G. von Schnering, *Angew. Chem.* **1984,** *96,* 895; *ibid. Int. Ed.* **1984,** *23,* 898; b) D. Hoppe, R. Hanko, A. Brönneke, F. Lichtenberg, E. van Hülsen, *Chem. Ber.* **1985,** *118,* 2822, and ref. cited therein; c) D. Hoppe, Th. Krämer, *Angew. Chem.* **1986,** *98,* 171; *ibid. Int. Ed.* **1986,** *25,* 160.

[37] W. C. Still, C. Sreekumar, *J. Am. Chem. Soc.* **1980,** *102,* 1201.

[38] J. S. Sawyer, T. L. Macdonald, G. J. Mc Garvey, *J. Am. Chem. Soc.* **1984,** *106,* 3376; G. J. Mc Garvey, M. Kimura, *J. Org. Chem.* **1985,** *50,* 4655.

[39] P.v. Ragué von Schleyer, T. Clark, A.J. Kos, G.W. Spitznagel, C. Rohde, D. Arad, K.N. Houk, N.G. Rondan, *J. Am. Chem. Soc.* **1984,** *106,* 6467.
[40] a) W.D. Emmons, *J. Am. Chem. Soc.* **1957,** *79,* 5739; b) A. Mannschreck, R. Radeglia, E. Gründemann, R. Ohme, *Chem. Ber.* **1967,** *100,* 1778; see also ref. [19].
[41] F.A.L. Anet, R.D. Trepka, D.J. Cram, *J. Am. Chem. Soc.* **1967,** *89,* 357.
[42] D. Seebach, R. Dammann, H.J. Lindner, B. Kitschke, *Helv. Chim. Acta* **1979,** *62,* 1143.
[43] K. Kitatani, T. Hiyama, H. Nozaki, *Bull. Chem. Soc. Jpn.* **1977,** *50,* 1600; K. Kitatani, H. Yamamoto, T. Hiyama, H. Nozaki, *ibid.* **1977,** *50,* 2158.
[44] a) D. Seebach, H. Yamaguchi, K. Kawada, T. Okamoto, E. Egner, H.J. Lindner, M. Braun, R. Dammann, M. Liesner, H. Neumann, *Chem. Ber.* **1976,** *109,* 1589; R.W. Gray, C.B. Chapleo, T. Vergnani, A.S. Dreiding, M. Liesner, D. Seebach, *Helv. Chim. Acta* **1976,** *59,* 1547; D. Seebach, H.J. Lindner, B. Kitschke, M. Liesner, *ibid.* **1977,** *60,* 1151; D. Seebach, H. Neumann, R. Dammann, *ibid.* **1979,** *62,* 1162; b) A.C. Richardson, *Carbohydr. Res.* **1969,** *10,* 395.
[45] O.A. Dyachenko, L.O. Atovmyan, S.M. Aldolshin, A.E. Polyakov, R.G. Kostyanovskii, *J. Chem. Soc., Chem. Commun.* **1976,** 50.
[46] a) P. Deslongchamps, in 'Stereoelectronic Effects in Organic Chemistry', 'Organic Chemistry Series', Ed. J.E. Baldwin, Pergamon Press, Oxford–New York, 1983, Vol. 1; b) A.J. Kirby, in 'The Anomeric Effect and Related Stereoelectronic Effects at Oxygen', 'Reactivity and Structure Concepts in Organic Chemistry', Springer-Verlag, Berlin, 1983, Vol. 15.
[47] A.I. Meyers, B.A. Lefker, *Tetrahedron Lett.* **1987,** *28,* 1745, and ref. cited therein.
[48] P. Magnus, T. Gallagher, P. Brown, J.C. Huffmann, *J. Am. Chem. Soc.* **1984,** *106,* 2105.
[49] a) Th. Laube, Dissertation, ETH No. 7649, Zürich, 1984; b) D. Seebach, R. Amstutz, Th. Laube, W.B. Schweizer, J.D. Dunitz, *J. Am. Chem. Soc.* **1985,** *107,* 5403.
[50] A. Ndibwawi, P. Deslongchamps, *Can. J. Chem.* **1986,** *64,* 1788.
[51] A. Padwa, M.W. Wannamaker, *Tetrahedron Lett.* **1986,** *27,* 2555.
[52] W.H. Watson, in 'Stereochemistry and Reactivity of Systems Containing π-Electrons', 'Methods in Stereochemical Analysis', Ed. A.P. Marchand, Verlag Chemie International, Deerfield Beach, 1983, Vol. 3.
[53] a) L. Lochmann, D. Lim, *J. Organomet. Chem.* **1973,** *50,* 9; b) J. Dekker, J. Boersma, G.J.M. van der Kerk, *J. Chem. Soc., Chem. Commun.* **1983,** 553.
[54] O. Itoh, N. Yamamoto, H. Fujimoto, K. Ichikawa, *J. Chem. Soc., Chem. Commun.* **1979,** 101.
[55] H.-U. Reissig, I. Böhm, *J. Am. Chem. Soc.* **1982,** *104,* 1735.
[56] L. Gorrichon, P. Maroni, Ch. Zedde, *J. Organomet. Chem.* **1983,** *252,* 267.
[57] B.A. Feit, R. Elser, U. Melamed, I. Goldberg, *Tetrahedron* **1984,** *40,* 5177.
[58] Y. Kai, P. Knochel, S. Kwiatkowski, J.D. Dunitz, J.F.M. Oth, D. Seebach, H.-O. Kalinowski, *Helv. Chim. Acta* **1982,** *65,* 137.
[59] H.-U. Wagner, G. Boche, *Helv. Chim. Acta* **1983,** *66,* 842.
[60] C. Fehr, J. Galindo, *Helv. Chim. Acta* **1986,** *69,* 228.
[61] A.E. Mishnev, Ya.Ya. Bleidelis, A.V. Eremeev, F.D. Polyak, B.S. Kataev, *Zh. Strukt. Khim.* **1982,** *23,* 86 (*CA:* **1983,** *98,* 107720k).
[62] A.V. Eremeev, F.D. Polyak, A.E. Mishnev, Ya.Ya. Bleidelis, E.E. Liepin'sh, Sh.S. Nasibrov, I.I. Chervin, R.G. Kostyanovskii, *Khim. Get. Soedin., SSSR* **1982,** 1495; (*CA:* **1983,** *98,* 89088d).
[63] J.R. McCarthy, C.L. Barney, M.J. O'Donnell, J.C. Huffmann, *J. Chem. Soc., Chem. Commun.* **1987,** 469.
[64] J.A. Deyrup, C.L. Moyer, *J. Org. Chem.* **1970,** *35,* 3424.
[65] R.A. Gorsky, J. Dagli, V.A. Patronik, J. Wemple, *Synthesis* **1974,** 811.
[66] M.A. Stolberg, J.J. O'Neil, T. Wagner-Jauregg, *J. Am. Chem. Soc.* **1953,** *75,* 5045.
[67] E. Hardegger, F. Szabo, P. Liechti, Ch. Rostetter, W. Zankowska-Jasinska, *Helv. Chim. Acta* **1968,** *51,* 78.