J. prakt. Chem. 338 (1996) 270–278

Journal für praktische Chemie
Chemiker-Zeitung

Aziridines. 69 [1]

Reactions of N-Acylaziridines with Sodium Metal and Sodium Naphthalenide. Elimination of Olefines

Pen-Yuan Lin

Taipei (Taiwan), School of Pharmacy, Pharmaceutical Chemistry, Taipei Medical College

Konstantinos Bellos, Jürgen Werry, Petros Assithianakis, Rainer Weiß, Thomas Mall, Gunther Bentz and Helmut Stamm

Heidelberg, Faculty of Pharmacy, University

Received August 28th, 1995 respectively November 10th, 1995

Dedicated to Prof. Hans Suschitzky on the Occasion of his 80th Birthday

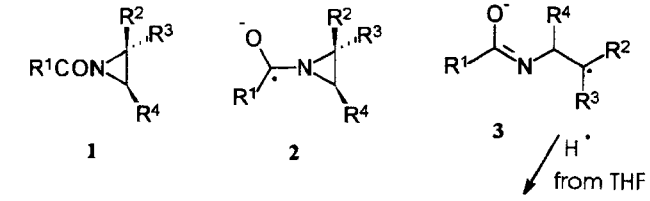
Abstract. Reactions of N-acylaziridines **1a–g** (N-benzoyl except **1d**) with sodium or naphthalenide $N^{\cdot-}$ in THF provide a variety of products that usually arise via the aziridino ketyls **2**. Homolytic ring opening of **2** generates the amidatoalkyl radicals **3**. Only with a very short reaction time were small amounts of benzil or benzoylnaphthalenes obtained indicating a reversible trapping of **2** by dimerization or coupling with $N^{\cdot-}$. Homolysis of **2** produced always the more stable **3** apart from reactions of monomethylaziridines **1c,d** where the primary radical ***i*-3c,d** is kinetically favoured. The amides $R^1CONHCHR^4CHR^2R^3$ (**9**, isopropylamides ***i*-9c,d** from **1c,d**) were usually the main products. **9** arise from **3** either by H atom abstraction from THF (probably in sodium metal runs) or by reduction of **3** to carbanions **5** that abstract a proton from THF ($N^{\cdot-}$ runs). Addition of **5a** (R^{2-4} = H) to **1a** gives finally the ketone **8a**. Self reaction of primary radical **3a** is dimerization. Self reaction of tertiary or secondary radicals is disproportionation when an allylamide arises. This isomerizes to an enamide unless it is conjugated. $R^2R^3C{=}CHR^4$ and R^1CONH_2 arise (probably) always. The mechanism, possibly a cyclic process of anion **6**, is not clear.

A short paper [2] in 1984 described the first electron attachments to N-acylaziridines **1** by means of sodium metal, naphthalenide $N^{\cdot-}$ or anthracenide $A^{\cdot-}$. Background was a proposal to explain the very curious regioselectivity in nucleophilic ring opening of **1b** and analogues of it. Several subsequent papers centred round this SET proposal and verified it in a few cases. The proposed radical intermediates **2** and **3**, however, are better studied with the methods of the above short paper that reported only the very first results including **9a,b,i** and **8b** as main products.

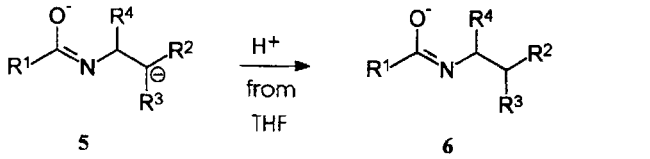
Reactions of N-pivaloylaziridines with $N^{\cdot-}$ or $A^{\cdot-}$ have recently [3] been found to differ in some aspects from reactions of N-aroylaziridines as described in ref. [2]. Certain details of the reported [4] reactions of **1h,j** with $N^{\cdot-}$ are rather surprising. So, there is a need to complete and to extend the work of ref. [2]. Reactions of several N-benzoylaziridines with Na and $N^{\cdot-}$ are now described in detail. Na automatically excludes any inner-sphere SET. Reactions with $A^{\cdot-}$ have some peculiarities and will be dealt with separately except for a few reactions without these peculiarities. One N-pivaloylaziridine (**1d**) was included for a special comparison.

Results and Discussion

The reaction sequence **1** → **2** → **3** needs no comment but two alternatives have to be considered for the subsequent formation of **8** and **9**, i. e. with and without intermediacy of carbanion **5**. It was reported [3] that

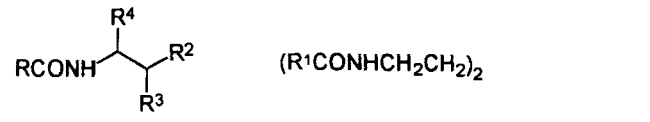


1 2 3

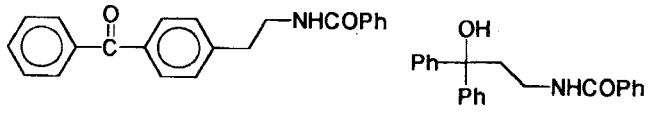


5 6

7 8



9 10



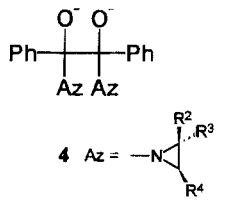
11 12

1–3, 6–10	R^1	R^2	R^3	R^4
a	Ph	H	H	H
b	Ph	Me	Me	H
c	Ph	Me	H	H
d	*t*-Bu	Me	H	H
e	Ph	Ph	H	CH_2Ph
f	Ph	*t*-Bu	Ph	H
g	Ph	*t*-Bu	CH_2Ph	H
h	Ph	Ph	H	Ph
i	Ph	Ph	H	H
j	Ph	Me	Me	Ph

i-3, i-5, i-6, i-9: R^2 and R^3 interchanged

Scheme 1

reactions of **3** (R^1 = *t*-Bu) with **2**, $N^{\cdot-}$ or $A^{\cdot-}$ are faster than H abstraction from the solvent and that **3** + $A^{\cdot-}$ as well as **3** + **2** produced **9** via **5**. More than a trace of ketone **8** (R^1 = *t*-Bu) was obtained only with the counter ion Li^+ quite in accord with a slow proton abstraction by R–Li^+ and its increased tendency to additions. As for N-aroylaziridines, **8** has never been found when **1** was trapped as carbonyl adduct in the initial phase of an inner-sphere SET [5]. The **3** + **2** path to **7** and hence to **8** in homogeneous reactions of **1** (R^1 = Ph) is now ruled out as follows. Reaction of benzophenone ketyl with **1a** in THF provided 30% of **9a** and 7% of **11** besides 59% of not converted **1a**. No **12** was found. No



other products were obtained when the ketyl was generated from PhCOPh and „anthracene hydride" AH^- (anion of 9,10-dihydroanthracene). This points to the limits of inferring the chemistry of **3** by analogy to alkyl radicals which under similar conditions provide *p*-alkylbenzophenone and 1,1-diphenylalkanol as main products [6]. Ketone **8** arises from **1a** and carbanion **5**.

Reactions of **1a** with Na or $N^{\cdot-}$ are listed in Table 1. Ethylamide **9a** is usually the main product but **10a** is always found too and even can become the main product (run 4). The unexpected very low solubility of **10a** in most solvents is responsible for the reported [2] apparently low yield. Without special care, **10a** may be retained and lost on the chromatographic column. Formation of dimers of alkyl radicals R· generated from RHal proceeds via R^- by its reaction with a second molecule RHal [7]. The analogous path to **10a** can be excluded. The hard carbanion **5a** and **1a** would form **7a** (cf. e. g. ref. [8]). Thus, **10a** results from real dimerization of **3a**.

Lack of ketone **8a** in run 1 despite a very slow conversion of **1a** indicates that reduction **3a** → **5a** does not play a substantial role under heterogeneous conditions. Without a dissolved electron source **3a** seems to live long enough both to dimerize despite a low concentration and to form **6a** directly from **3a** and THF [9].

Benzoic acid **14** is formed by hydrolysis of not converted **1a** when the reaction was not quenched with acid. Benzamide **13**, in contrast, must originate from **3a**. In reactions with benzoylaziridines it is often found or (probably) escaped detection. The unexpected **13** is devoid of markant ^{1}H-NMR signals and is soluble in the aqueous phase that in early runs was disposed of. Formation of **13** will be discussed below. **3a** cannot have a long lifetime in the homogeneous runs 2–4 but here the fast step **1a** → **2a** followed by rapid homolysis [10] may build up transient concentrations that favour dimerization (see also the discussion below). The outcome of runs 2 and 4 was unchanged within the experimental precision when **1a** was added by injection (not given in Table 1).

Holy [11] found quantitative ketyl dimerization forming benzil **15** and benzoin from ethyl benzoate and $N^{\cdot-}$. This contrasts sharply with the low yield of **15** in the short-term run 4 and with the absence of **15** in long-term runs. The same observation was made with **1f** (see below). There is clearly a reversible dimerization of **2a** and a disappearance of **4a** by irreversible reactions of

Table 1 SET reactions of **1a** in THF at room temperature. Dependence of product distribution on experimental conditions.

run[a]	mmol of reagents			ml of	time[b]	yield [c] of products							
	Na	N[d]	**1a**	THF		**9a**	**8a**	**10a**	**AN ADHN**	**13**	**14**	**15**	**1a**
1	7.5		5	60	3 d	(49)	0	6	0	(28)[e]	(11)		
2	5	6	5	130	15–30 min/ 55 min	(32)	(6)	(12)	(2)[f]		(15)		15
3	15	16	5	130	15–30 min/ 30 min	(40)	(6)	(26)	(2)[f]	2			
4	15	16	5	130	10 s/2 min		24[e]	(11)	31	(4)[f]		3	3

[a]) Runs are serially numbered throughout all Tables. [b]) Specification before a diagonal line gives the time required for the addition of **1** (THF solution). [c]) Yields in parentheses were calculated from ^{1}H-NMR spectra of product mixtures. tr = trace. [d]) **N** = naphthalene, **A** = anthracene. [e]) Impure. [f]) See text.

3a. Thus, in the reported [4] detection of **15** after a reaction of five days a correspnding part of **4j** must have been stabilized or trapped preventing a dissociation to **2j**. Monoprotonation of **4j** would prevent the dissociation but where could the proton come from? The only acidic structure was a benzyl group in **1j** and in intermediates or products. **4** resemble alkoxide ions whose basicity is greatly enhanced at low concentrations in solvents like DMSO or THF [12]. Since monoprotonated **4** must be stabilized by a strong internal hydrogen bridge, it appears possible that a co-operation of both effects may result in some monoprotonation of **4j** by a benzylic proton. The ketyl dimer (**4**, Az replaced by OEt) in Holy's report certainly will eliminate two EtO^- and pick up one electron forming the very stable semidione of **15**. Benzoin was obviously not formed [4] from **1j** excluding the analogous elimination for **4j**.

Reversible formation of unprotonated **4a** may perhaps play a role in the dimerization of **3a**. When the two **2a** produced by dissociation of one **4a** undergo ring opening faster that they diffuse away, the dimerization of the arising two **3a** may come close to an in cage process. Ring opening will be fast [10] but surely cannot compete with diffusion. However, the four ions generated by the dissociation of **4** may form a cluster or "paramagnetic dimer" as described [13] for the ketyl of benzophenone.

Mixtures of amidoethylated naphthalenes (**AN**) and/or amidoethylated dihydronaphthalenes (**ADHN**) were probably also formed in runs 2–4 since small fractions in the proper chromatographic sequence showed ^{1}H-NMR spectra with the following details: triplets (J = 6.5 Hz) at 3.10 ppm and 3.40 ppm, a quartet (J = 6.5 z) at 3.90 ppm, an integral ratio of these signals to the aromatic signals smaller than expected for products derived from **1a** without incorporation of naphthalene or dihydronaphthalene.

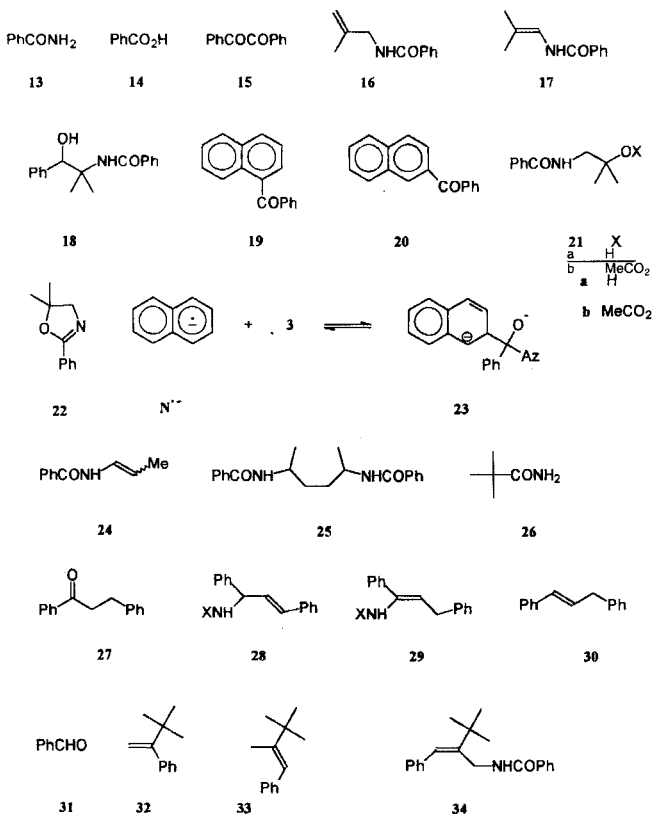
Reactions of dimethylaziridine **1b** are described in Table 2. Main product was **9b** in runs 6 and 7 but was **13** in the heterogeneous run 5. Part of **13** in run 5 is formed by hydrolysis of enamide **17** that arises by slow isomerization of methallylamide **16** or it's nitranion rather [1a]. This part is 25% (28% minus 3%) at most since disproportionation of the tertiary radical **3b** yields equimolar quantities of **9b** and **16**. A comparison with runs 6 and 7 makes one suspect that 3% of **17** in run 7 is only the small rest of a significantly greater amount.

Ketone **8b** was found twice, once together with its dihydro derivative **18**. Both compounds were not obtained pure but ^{1}H-NMR gives clear evidence for their structures. By analogy with run 1 one may tend to exclude the carbanion path to **8b** in the heterogeneous run 5. However, the competing reactions with the solvent in run 1 and 5 will differ in rates. The primary

Table 2 SET reactions of **1b** in THF at room temperature. Dependence of product distribution on experimertal conditions.

run[a]	mmol of reagents			ml of	time[b]	yield [c] of products								
	Na	N[d]	**1b**	THF		**9b**	**16**	**17**	**18**	**8b**	**13**	**14**	**19**	**20**
5[f]	7.6			50	3 d	28		3	(3)[e]	(2)[e]	(48)	7		
6[g]	10	10	4.9	70	5 d	52		28		tr				
7[h]	5.6	6	5	130	10 s/0 s	(28)	(17)						(4)	(1)

[a–e]) See Table 1. [f]) Artifact of not converted **1b**: 8% of **21a**. [g]) Early experiment in which **13** escaped detection.
[h]) Artifacts of not converted **1b**: 19% of **21b**, 3% of **22**.



Scheme 2

radical **3a** should abstract a hydrogen faster than the tertiary radical **3b** does while carbanion **5a** deprotonates THF certainly more slowly than **5b** does. Surprising is the formation of **18**. It requires that the precursor **7b** eliminates an aziridine anion (**Az-b**$^-$) so that the generated carbonyl group can be reduced to the corresponding ketyl. The assumed elimination of an aziridine anion from **7** should remain unnoticed when the arising ketyl can rapidly be deprotonated by the aziridine anion forming a stable enolate. Some minor products in runs 6 and 7 were not identified and may well include dimethylated **AN** and **ADHN** as described [3] for the pivaloyl analogue of **1b**.

The two benzoylnaphthalenes **19** and **20** were detected only when the reaction time was 10 seconds from the beginning of the **1b** addition until quenching with acid (run 7). This indicates the transient formation of **23** (and isomer) from the combination of $N^{\cdot-}$ with **2b** (Scheme 2). The back reaction followed by step **2** → **3** prevents the isolation of **19** or **20** after long reaction. The same behaviour was found with **1f** (see below). Homolytic dissociation of **23** (and isomer) may be regarded as the first example of a benzylic fragmentation in the naphthalene series. So far, it has been described in the anthracene series only (cp. ref. [14] and lit. cited). Water converts **23** and its isomer to the dihydro derivatives of **19** and **20** wich easily will aromatize to **19** and **20**. In principle, the aromatization could occur prior to workup by elimination of NaH from **23** (or isomer) [15] but the aromatized intermediates should not disappear with time. A part of **1b** did not react in run 7and was converted by acetic acid to **21b** and **22** and probably also to a part of **16**. About 9% of **16** may arise in this way as follows from a separate experiment with **1b** and acetic acid in THF (appendix to run 7).

It was expected that the ketyls **2c,d** produce two isomeric radicals each and it was hoped that the relative yields of the main products, i. e. the ratio *i*:*n* of isopropylamide **i-9** to *n*-propylamide ***n*-9** would be of diagnostic value. The unnecessary prefix *n*- for **9c,d** etc. may be helpful in the following discussion. Reactions of **1c,d** with only Na are listed in Table 3 (runs 8 and 9). The ratio *i*:*n* was 4.7 with **1c** and 1.5 with **1d**. The primary radicals ***i*-3** should be favoured kinetically by frontier orbital control [16] and the secondary radicals ***n*-3** thermodynamically. When **3** + THF → **6** is the only path to **9** in heterogeneous runs and when the formation of other products from **3** is ignored one would expect the ratio *i*:*n* to be independent of the acyl group in **1** as long as the rates of the interconversions ***i*-3**/***n*-3** are not affected. Runs 8 and 9, however, show a pronounced influence of the acyl group. But the real discrepancy may be smaller than *i*:*n* indicates. One should consider, for instance, the enamide **24**. The ratio of ***i*-9c** : (***n*-9c** + **24**) is 3.1. The remaining discrepancy between **1c** and

Table 3 SET reactions of **1c,d,e** with sodium metal. Regioselectivity of homolytic ring opening.

run[a]	mmol of reagents Na	1	ml of THF	time[b]	yields[c] of products 9	13	14	26	24	25	27	Az-H
8	7.7	5 **1c**	45	7 d	(28) **i-9c** (6) **9c**	5	tr		3[d]	tr		
9	20	10.4 **1d**	100	6 d	(26) **i-9d** (17) **9d**			(14)				
10	15	3 **1e**	100	10 d	47 **9e**	(27)[e]					5	(3)[f]

[a-c]) See Table 1. [d]) More trans than cis. [e]) Crude estimate, yield less than 41%. [f]) Crude estimate, yield less than 8%.

Table 4 SET reactions of **1f**. Dependence of product distribution on experimental conditions.

run[a]	mmol of reagents			ml of	time[b]	yields[c] of products						
	Na	N[d]	A[d]	**1f**	THF		**9f**	**13**	**32**	**AzH-f**	**15**	**20**	**3**[e]
11	6		3	70	3 d	(58)	10	19	(6)				
12	7	8		2.5	80	6 d	(53)	30	(37)	(6)			tr
13	5	6		1.5	70	10 s/1 min	(44)	tr	(4)	(8)	(4)	(1.4)	tr
14	5	6		1.5	70	10 s/0 s	(45)			(13)	2	1.7	tr
15	5		6	1.5	70	7 d	44	33	(42)				tr

[a-d]) See Table 1. [e]) Identified by ^{1}H-NMR, MS or TLC in chromatographic fractions with the odour of **31**.

1d, unfortunately, cannot serve for a reliable mechanistic discussion. A high and differring volatility and water solubility of the isomeric **9d** may cause a different loss during workup. The solubilities were not investigated but a higher vapor pressure was proven by a simple experiment. Two open vials containing 30 mg of one isomer were kept at the same place. After 6 days ***i*-9d** had lost 11 mg in weight, ***n*-9d** only 7 mg. Thus, the real ratio *i*:*n* in run 9 must be higher than found but in order to reach 3.1 the real yields should have been 65% of ***i*-9d** and 21% of ***n*-9d**. Although a reliable conclusion is, unfortunately, not possible one cannot exclude that even in heterogeneous runs a part of **3** may perhaps be reduced to **5** by means of a fairly long living ketyl. This would result for **1c** in a higher ratio i:n than for **1d**.

Self reaction of the primary radical **3a** is dimerization, that of the tertiary radical **3b** is disproportionation. Consequently, one would expect dimerization of ***i*-3c,d** and perhaps disproportionation of ***n*-3c,d**. One component of a small late chromatographic fraction (*main component* **13**) of run 8 showed ^{1}H-NMR signals (Me: 1.22, d, J = 6.4 Hz; $NCCH_2$: 1.62, m_c; NCH: 4.18; NH: 6.28 s br; ArH: 7.32–7.45 and 7.73) compatible with structure **25** formed by dimerization of ***i*-3c**. The chemical shifts may be compared with corresponding signals of **10a** ($NCCH_2CH_2CN$: 1.72–1.77) and of ***i*-9c** (NCH: 4.27; Me: 1.26, d, J = 6.4 Hz). There is only one methyl doublet in accordance with the *meso* isomer of **25** but another isomer may possibly have been in the next fraction. Disproportionation of ***n*-3c,d** should provide the nitranions of ***n*-9c,d** (i. e. **6c,d**) and of the corresponding allylamides that are expected to isomerize to enamides. Indeed, good ^{1}H-NMR evidence in run 8 for *cis-trans* isomers of **24** was obtained. Both isomers were not pure. – The yields of the unsubstituted amides **13** and **26** are probably low owing to loss during workup.

In contrast to **2c,d** seems ring opening of **2e** to be regiospecific. **9e** was the main product in run 10. Dihydrochalcone **27** is the final product of an eliminative fission of **1e** triggered off by deprotonation of the benzyl group. Fission of the phenylsulfonyl analogue of **1e** is known [17] to yield **27** and the unsubstituted amide via **28** and **29** (X = $PhSO_2$). The analogous path with X = benzoyl can account for only 5% of **13**. One may suspect that here and in the other runs an alternative path from **1** to **13** exists in which the carbon skeleton of the aziridine ring is eliminated in the form of an olefine. In runs 1–9 this olefine would have been ethene, isobutene or propene. In run 10, it ought to be **30**. ^{1}H-NMR signals described [18] for **30** were not found in the first chromatographic fraction but it is unlikely that **30** survives until the end of the run. **30** should be a good electron acceptor and its carbanion should easily arise under the experimental conditions and react further. – No indication of disproportionation of **3e** was found. No enamide was detected nor 1,3-diphenylacetone that would be formed by hydrolysis of this enamide. The aziridine base AzH–e resulting from hydrolysis of not converted **1e** is easily to find in contrast to the bases **AzH** in runs 1-9.

Reactions of **1f,g** (Tables 4 and 5) included reactions with $A^{\cdot-}$. Complications expected [3, 19] for reactions with $A^{\cdot-}$ seem to be absent with **1f,g**. There was practically no difference in reactions with $N^{\cdot-}$ and $A^{\cdot-}$. Steric hindrance slows down coupling of **3f,g** with both radical anions. **9f** (Table 4) is always the main product from **1f**. Detection of olefine **32** up to 40% confirms the olefine elimination as source of **13**. The yield of **13** was always smaller than that of **32** pointing to the difficulty in avoiding some loss of **13**. The good side of this deficit is that it practically excludes the enamide path to **13** even as by-path. Moreover, no enamide was detected in runs 11–15. The properties of this enamide are known [1b]. It appears that direct generation of an enamide structure from **3** is difficult. Formation of this enamide by loss of a proton from the carbenium analogue of **3f** is also difficult (maximum 3% [1b]). Benzil **15** and benzoylnaphthalene **20** were detected in short-term runs only, findings already discussed with **1a,b**. The aziridine base **AzH-f** arises from not converted **1f**

Table 5 SET reactions of **1g**. Dependence of product distribution on experimental conditions.

run[a)]	mmol of reagents				ml of	time[b)]	yields[c)] of products					
	Na	N[d)]	A[d)]	**1g**	THF		**9g**	**13**	**33**	**34**	**AzH-g**	**31**[e)]
16	9			3	70	7 d	(58)	4	10	(11)	(3)	
17	5	8		2.5	90	9.5 h	(53)	(10)	(7)	(10)	(7)	tr
18			7	3	90	9.5 h	(62)	7	(3)	(13)	(4)	tr

[a-d)] See Table 1. [e)] Identified by ^{1}H-NMR, MS or TLC in chromatographic fractions with the odour of **31.**

or from **4** and **23**. Traces of **31** found in the homogeneous runs will be discussed below.

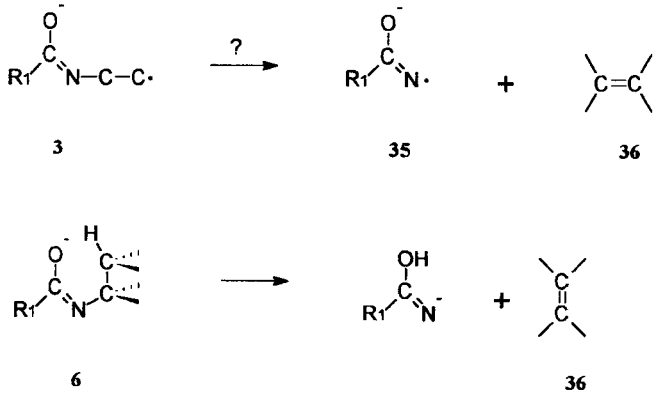
1g (Table 5) behaved quite similar to **1f** except for some disproportionation of **3f** (allylamide **34**) and for the lower yields of **13** and olefine. The first formed olefine with terminal double bond isomerizes to the substituted styrene **33**. No enamide was formed from **34**. Isomerization can only generate a more stable isomer. The conjugation in **34** seems to lower the energy more than that in the enamide anion (C=C–N=C–O).

Two sources of **31** may be considered. **2f,g** (**2h** in ref. [4]) may pick up a hydrogen atom to provide a non-radical anion that survives until it can yield **31** by protonation and elimination of **AzH**. A possible hydrogen donor is **3** [20]. On the other hand, monoprotonated **4f–h** suffer from steric crowding that may force heterolytic cleavage of the central C–C bond yielding **1f–h** and the same surviving precursor of **31** as before.

Formation of olefines **35** and amides **13** or **26** is obviously a general phenomenon in SET reactions of **1**. Reasonably, one can consider only three candidates for this elimination, i. e. **3**, **5** and **6**. Laurent [4] proposed **6h**. Only 5–10% elimination can be deduced from his report. The olefine (stilbene) was not found but 5% of 1,2-diphenylethane seemed to indicate 5% elimination of stilbene. The majority of **13** (35% total yield) came from hydrolysis (25%) of the corresponding enamide leaving 10% for the eliminative path.

An attractive idea is β-cleavage of radical **3** (Scheme 3, top) with generation of olefine **36** (general formula) and ionic amide radical **35**, a type of intermediate that seems to be unknown. The influence of polar effects on nitrogen centred radicals [21] is compatible with olefine elimination from **3**. Cleavage of dianion **5** could yield either **35** and the radical anion **36**$^{\cdot-}$ (homolysis) or **36** and the dianion of the unsubstituted amide (heterolysis). **36**$^{\cdot-}$ would be relatively stable if **36** is stilbene, for instance. In fact, Laurent [4] isolated "dihydrostilbene" but no stilbene from **1h** and **N**$^{\cdot-}$. Heterolytic cleavage of **5** appears less likely unless the amide dianion is stabilized, e. g. by counter ion Li^+.

Laurent's proposal (Scheme 3, bottom) was based on the decomposition of uncharged carboxamides at about



Scheme 3

600°C [22] and on it mechanistic description as intramolecular concerted process with a cyclic transition state [23]. This proposal appears quite reasonable, but one important question is, whether this reaction can proceed at room temperature. Cope, Hofmann and Chugaev elimination require elevated temperatures. Moreover, **6a,i** did not show any sign of instability when synthesized from **1a,i** and **AH**$^-$ [16, 19]. Despite this apparent stability of **6** two simple experiments were performed which did not generate **6** from **1.** Deprotonation of **9a** by means of tritylsodium in THF was chosen for the generation of **6a**. The reactions were quenched with methanol, once after 30 minutes, once after three days. Only 57% and 28% of **9a** were recovered in contrast with the stability of **6a,i** when generated from **1a,i** and **AH**$^-$. Something seems to retard or even suppress the fragmentation of **6** in the latter case. The time dependence of the decomposition of **6a** (43% and 72%) is not compatible with simple first order kinetics.

The proposed cyclic fragmentation of **6** may be correct but at present it cannot explain why **6a** decomposes slowly under certain conditions and seems to be rather stable under other conditions. One point may be essential. The oxygen of **6** must not be blocked or shielded by the counter ion. So, the question arises whether an equimolar amount of AH$^-$Na$^+$ suppresses the dissociation of **6**Na$^+$. Nevertheless, contributions by another elimination mechanism cannot be ruled out especially

when an olefine of the styrene or stilbene type is produced. For instance gives **1f** more elimination than **1g**.

Experimental

^{1}H-NMR: Bruker WM 250, AC 200, AC 300, $CDCl_3$. IR: Perkin-Elmer 283, KBr tablets unless otherwise stated. Chromatography: silica gel Merck, 0.063–0.2 mm, column diameter 3 cm unless otherwise stated, mixtures analyzed by ^{1}H-NMR. Preparative TLC: plates 5717 Merck, silica gel 60F254, 2 mm thick, 20 × 20 cm. Abbreviations: Chr. (chromatography), corr. (corresponding), dic. (CH_2Cl_2), EA (ethyl acetate), T (toluene).

Na pieces were used unless otherwise stated. All reactions were performed in dry THF under dry N_2 with continuous stirring. Workup began with evaporation. The residue was taken up in dic. and washed with water (wash water extracted with solvent given). The organic layer was evaporated. Further treatment of the residue is given below.

All aziridines **1** and **AzH** are known [3, 14, 5b, 16]. Products are described in ref. [1b]: **34**; [5b]: **9a,b,e**; [16]: **9c,f,g**, *i*-**9c**; [24]: **16**, **22**; [25]: **21a**.

Reactions of 1a with benzophenone ketyl

(a) 1.18 g (6.5 mmol) of PhCOPh and 249 mg (5.4 mmol) of Na (50% dispersion in hard paraffin) were stirred in 50 ml of THF for 7 h. A solution of 730 mg (5 mmol) of **1a** in 20 ml of THF was added within 5 min. The reaction was quenched with acetic acid after 15 min. Chr. (1.5×90 cm, dic./EA 7:1) provided PhCOPh, 434 mg (59%) of **1a**, 109 mg (7%) of **11** and 224 mg (30%) of **9a**.

N-[2-(4-Benzoylphenyl)ethyl]benzamide (**11**)

M.p. 115–117°C. IR (cm^{-1}): 3300, 1638, 1541. ^{1}H-NMR δ: 3.02 (t, J = 7.0, $NCCH_2$), 3.73 (m_c, NCH_2), 6.60 (t br, J = 6.5, NH), 7.27–7.51 (m, 8 ArH), 7.71–7.79 (m, 6 *o*-H).

(b) A solution of 1.125 g (6.25 mmol) of dihydroanthracene in 70 ml of THF was cooled with liquid N_2. 5 mmol of BuLi (hexane solution) was added. At room temperature, a solution of 904 mg (5 mmol) of PhCOPh in 20 ml of THF was added. A solution of 730 mg (5 mmol) of **1a** in 20 ml of THF was added within 15 min.. The reaction was quenched with acetic acid after 2.5 h. Workup similar to above provided all nitrogen-free compounds, 266 mg (36%) of **1a**, 164 mg (10%) of **11** and 127 mg (17%) of **9a**.

General procedure for the heterogeneous runs

See the Tables. Na (run 6: dispersion, 45% in white oil) was stirred in THF for some minutes. **1** was added (in runs 11 and 16 dissolved in 10–20 ml of the THF given. The reactions were not quenched.

General procedure for the homogeneous runs

See the Tables. Part of the THF (30 ml in runs 2–4, 10 ml in runs 6 and 12–15, 20 ml in runs 17–18) given in the Tables was used to dissolve **1**. Na and **N** or **A** were stirred in THF for 1 d. The solution of **1** was added within about 15 min unless 10 s (rapid flow from a dropping funnel) is stated in the Tables. The reaction was quenched with acetic acid (runs 2–4, 7) or MeOH (runs 11–15, 17–18).

Run 1

The residue (680 g) consisted of 362 mg (49%) of **9a**, 48 mg (6%) of **10a** (characterization see run 2), 170 mg (28%) of **13** and 66 mg (11%) of **14**.

Run 2

Chr. (40 cm, dic./EA 25:1) provided 569 mg of **N**, 110 mg (15%) of **1a** and 27 mg (2%) of a mixture assumed to consist of **AN** and **ADHN**. EA/dic. (1:1) provided 271 mg of mixture *a* consisting of 232 mg of **9a** and 39 mg (6%) of **8a**. MeOH gave 223 mg of a mixture that was extracted with hot EA/MeOH (3:1). Evaporation of the filtered extract yielded 134 mg of mixture *b* that contained (internal calibration) 89 mg (12%) of **10a**. The wash water (EA) yielded 100 mg of a mixture of 10 mg (total 24 mg corr. to 32%) of **9a** and 90 mg (15%) of **14**. A part of mixture *a* was dissolved in CCl_4 and 4 times washed with water to remove **9a**. Evaporation of the CCl_4 solution yielded pure **8a**. Preparative TLC (EA) of 40 mg of mixture *b* provided 18 mg of pure **10a** that was identical with an authentic sample prepared from 1,4-diaminobutane and benzoyl chloride.

N-(2-Benzoylethyl)benzamide (**8a**)

M.p. 82°C. IR (cm^{-1}): 3320, 1660, 1635, 1545, 1535, 1530. ^{1}H-NMR δ: 3.33 (t, J = 5.7, $NCCH_2$), 3.88 (dt, J = 5.5/5.7, NCH_2), 7.15 (s br, NH), 7.37–7.50 (m, 6 ArH), 7.84 (m_c, 4 *o*-H).

N,N'-Dibenzoyl-1,4-diaminobutane (**10a**)

M.p. 175–177°C. IR (cm^{-1}): 3325, 1630, 1534. ^{1}H-NMR δ: 1.72–1.77 (m, NCH_2CH_2CN), 3.51–3.59 (m, NCH_2CCCH_2N), 6.52 (s br, 2 NH), 7.41–7.51 (m, 6 ArH), 7.79–7.82 (m, 4 *o*-H).

Run 3

Chr. (40 cm, dic./EA 25:1) yielded hydrocarbons and 34 mg (2%) of products assumed to be **AH** and **ADHN**. EA/dic. 1:1 provided 309 mg of a mixture of 276 mg of **9a** and 33 mg (6%) of **8a.** MeOH yielded 342 mg of a mixture that was extracted with hot EA/MeOH 3:1. Evaporation of the filtered extract yielded 303 mg of a mixture containing (internal calibration) 194 mg (26%) of **10a**. The wash water provided (EA) 37 mg of a mixture of 24 mg (total 300 mg corr. to 40%) of **9a** and 13 mg (2%) of **13**.

Run 4

(Chr. (40 cm, dic.) provided hydrocarbons and 16 mg (3%) of **15**. EA/dic. 1:2 yielded 52 mg (4%) of products, assumed to be **AN** and **ADHN**, and 74 mg of a mixture of 5 mg of **9a** and 69 mg (11%) of **8a**. Continued elution yielded 175 mg of a mixture containing **9a** and small amounts of unknown products so that the total yield of **9a** is <180 mg (<24%). EA/dic. 1:3 gave 229 mg (31%) of **10a**.

Run 5

Chr. (30 cm, T/EA 3:1) provided 22 mg (3%) of **17**, 27 mg of a mixture of 18 mg (2%) of **8b** and 9 mg of **9b**. MeOH/EA/T 1:2:6 gave 254 mg (total 263 mg corr. to 29%) of **9b**, 26 mg (3%) of impure **18**, 43 mg (7%) of **14**, 75 mg of **13** and 290 mg of a mixture of 215 mg (total 290 mg corr. to 48%) of **13**

and 75 mg (8%) of **21a**.

N-(2,2-Dimethylvinyl)benzamide (**17**)

M.p. 69–70°C. IR (cm^{-1}): 3320, 3300, 1690, 1645, 1635, 1520, 1515. ^{1}H-NMR δ: 1.71 (s, 1 Me), 1.77 (s, 1 Me), 6.74 (d, J = 10.3, C=CH), 7.40–7.58 (m, 3 ArH), 7.75–7.85 (m, 2 *o*-H).

N-(2-Benzoyl-2-methylpropyl)benzamide (**8b**)

^{1}H-NMR δ: 1.47 (s, 2 Me), 3.71 (d, J = 6.5, NCH_2), 6.92 (t br, J = 6, NH), 7.38–7.50 (m, 6 ArH), 7.74–7.81 (m, 4 *o*-H).

N-(3-Hydroxy-2-methyl-3-phenylpropyl)benzamide (**18**)

^{1}H-NMR δ: 0.88 (s, 1 Me), 0.94 (s, 1 Me), 3.12 (dd, J = 5.3/13.9, 1 H of NCH_2), 3.78 (dd, J = 6.8/13.9, 1 H of NCH_2), 4.52 (s, OCH), 7.30 (s br, O–C–Ph), 7.40–7.51 (m, 3 ArH), 7.81 (d, J = 8.2, 2 *o*-H of COPH).

21a is known [25] but without ^{1}H-NMR data. δ: 1.24 (2, 2 Me), 3.43 (d, J = 6.0, NCH_2), 7.03 (t br, J = 5.4, NH), 7.27–7.50 (m, 3 ArH), 7.79 (d, J = 8.2, 2 *o*-H).

Run 6

Chr. (60 cm, dic./EA 20:1) yielded hydrocarbons, 239 mg (28%) of **17**, 115 mg of unknown products and 447 mg (52%) of **9b**.

Run 7

Chr. (40 cm, dic.) yielded 521 mg of naphthalene, 40 mg of **19** and 16 mg of a mixture of 8 mg (total 48 mg, corr. to 4%) and 8 mg (1%) of **20**. EA/dic. 1:10 provided 154 mg of unknown products and 394 mg of a mixture of 245 mg (28%) of **9b** and 149 mg (17%) of **16**. EA yielded 242 mg of a mixture of 220 mg (19%) of **21b** and 22 mg (3%) of **22**. Treatment (6 min) of **1b** in THF with acetic acid formed 18% of **16**, 58% of **21b** and 23% of **22**.

Run 8

Chr. (30 cm, T/EA 3:2) provided 9 mg of impure **24** (*cis-trans* 1:1), 18 mg (2%) of impure ***trans*-24** (**24** total 27 mg corr. to 3%), 277 mg of a mixture of 215 mg (28%) of ***i*-9c** and 52 mg (6%) of **9c**. EA/MeOH 1:1 yielded 31 mg (5%) of **13** containing traces of **14** and of a compound assumed to be **25** (^{1}H-NMR data in the text).

N-(2-Methylvinyl)benzamide (**24**)

***trans*-24** ^{1}H-NMR δ: 1.71 (dd, J = 7.2/1.7, Me), 4.96 (dq, J = 16.3/7.2, NC=CH), 6.95 (m_c, NHCH=C), 7.2–7.5 (m), 7.81 (d, J = 8.3, 2 *o*-H). – ***cis*-24** ^{1}H-NMR δ: 1.73 (dd, J = 7.3/1.4, Me), 5.32 (dq, J = 14.2/7.3, NC=CH), 7.78 (d, J = 8.2, 2 *o*-H), other signals could not be distinguished from signals of *trans* isomer and of unknown products.

Run 9

Chr. (35 cm, T/EA 10:1) yielded 560 mg of a mixture of 335 mg (26%) of ***i*-9d** and 225 mg (17%) of **9d**. Further elution gave 152 mg (14%) of **26** (^{1}H-NMR δ: 1.25 (s, tBu), 5.56 (s vbr, NH_2). Authentic ***i*-9d** and **9d** were prepared from pivaloyl chloride and the amines.

N-Propylpivaloylamide (**9d**)

M.p. 105°C. IR (cm^{-1}): 3325, 1630, 1535. ^{1}H-NMR δ: 0.92 (t, J = 7.3, NCCMe), 1.20 (s, *t*-Bu), 1.52 (sext, J = 7.3, $NCCH_2$), 3.21 (dt, J = 5.9/7.2, NCH_2), 5.78 (s br, NH).

N-Isopropylpivaloylamide (***i*-9d**)

M.p. 33°C. IR (cm^{-1}): 3360, 1640, 1540. ^{1}H-NMR δ: 1.15 (d, J = 7.6, 2 Me), 1.18 (s, *t*-Bu), 4.08 (dt, J = 6.5/7.8, NCH), 5.42 (s br, NH).

Run 10

Chr. (40 cm, T) provided 125 mg of unknown products, 30 mg (5%) of **27** and 98 mg of unknown products. dic. yielded 440 mg (47%) of **9e** and 50 mg of very impure **AzH-e** (<8%, crude estimate 3%). EA yielded 153 mg of very impure **13** (<41%, crude estimate 27%).

Run 11

Chr. (60 cm, dic.) provided 92 mg (19%) of **32**. EA yielded 517 mg of a mixture of 484 mg (58%) of **9f** and 37 mg (10%) of **13**.

3,3-Dimethyl-2-phenyl-1-butene (**32**)

Oil (rather volatile). IR film (cm^{-1}): 1639, 1628. ^{1}H-NMR δ: 1.11 (s, *t*-Bu), 4.76 (d, J = 1.7, 1 H of $C=CH_2$), 5.17 (d, J = 1.7, 1 H of $C=CH_2$), 7.10–7.17 (m, 2 *o*-H), 7.21–7.30 (m, 3 ArH).

Run 12

Analysis of the crude product mixture gave 163 mg (37%) of **32** (lost during workup and storage owing to the volatility). Chr. (60 cm, dic.) provided 998 mg of naphthalene and a fraction containing **31** (^{1}H-NMR, odour). EA provided 401 mg of a mixture of 375 mg (53%) of **9f** and 26 mg (6%) of **AzH-f**. The wash water yielded (EA) 90 mg (30%) of **13**.

Run 13

Analysis of the crude product mixture gave 10 mg (4%) of **32**. Chr. (60 cm, dic.) yielded 690 mg of naphthalene and 12 mg of a mixture of 7 mg (4%) of **15** and 5 mg (1.4%) of **20**. This mixture contained a trace of **31** (odour and TLC). EA yielded 205 mg of a mixture of 184 mg (44%) of **9f** and 21 mg (8%) of **AzH-f**. The wash water provided (EA) a trace of **13**.

Run 14

Chr. (60 cm, dic.) provided 707 mg of naphthalene, 3 mg (2%) of **15** and 6 mg (1.7%) of **20** (odour of **31**). EA gave 223 mg of a mixture of 188 mg (45%) of **9f** and 35 mg (13%) of **AzH-f**.

Run 15

Chr. (60 cm, dic.) provided hydrocarbons, 101 mg (42%) of **32**, a fraction with an odour of **31** and 20 mg of anthraquinone. EA gave 185 mg (44%) of **9f**. The wash water provided (EA) 60 mg (33%) of **13**.

Run 16

Chr. (60 cm, dic.) provided 50 mg of **33**. EA yielded 627 mg of a mixture of 511 mg (58%) of **9g**, 101 mg (11%) of **34** and 15 mg (3%) of **AzH-g**. The wash water gave (EA) 15 mg (4%) of **13**.

1-Phenyl-2,3,3-trimethyl-1-butene (**33**)

Oil. IR film (cm^{-1}): 1644. ^{1}H-NMR δ: 1.15 (s, *t*-Bu), 1.82 (d, J = 1.2, C=CMe), 6.34 (s br, C=CH), 7.13–7.35 (m, Ph).

Run 17

Chr. (60 cm, dic.) provided a mixture of 980 mg of naphthalene and 32 mg (7%) of **33**. A mixture of unknown products followed. EA gave 527 mg of a mixture of 394 mg (53%) of **9g**, 98 mg (10%) of **34** and 32 mg (7%) of **AzH-g**. The wash water provided (EA) 30 mg (10%) of **13**.

Run 18

Analysis of the crude product mixture gave 16 mg (3%) of **33**.

Chr. (60 cm, dic.) provided hydrocarbons, a small fraction containing **31** and 10 mg of anthraquinone followed by 684 mg of a mixture of 546 mg (62%) of **9g**, 116 mg (13%) of **34** and 22 mg (4%) of **AzH-g**. The wash water provided (EA) 25 mg (7%) of **13**.

Experiments on the stability of 6a

770 mg (6 mmol) of naphthalene and 140 mg (6 mmol) of Na were stirred in 30 ml of THF for 1 d. A solution of 2.2 g (9 mmol) of $CHPh_3$ in 15 ml of THF was injected. After 40 min a solution of 735 mg (4.9 mmol) of **9a** in 5 ml of THF was injected. 1 ml of MeOH was added after 30 min..Chr. (30 cm, $CHCl_3$/EA 9:1) provided hydrocarbons and 420 mg (57%) of **9a**. A reaction time of 3 d yielded 209 mg (28%) of **9a**.

References

[1] (a) Part 68: J. Werry, P.-Y. Lin, P. Assithianakis, H. Stamm, J. Chem. Soc., Perkin Trans. 1, in the press; (b) Part 67: K. Bellos, H. Stamm, J. Org. Chem. **60** (1995) 5661; (c) Part 66 = [14]

[2] H. Stamm, P. Assithianakis, R. Weiß, G. Bentz, B. Buchholz, J. Chem. Soc., Chem. Comm. **1984**, 753

[3] P.-Y. Lin, J. Werry, G. Bentz, H. Stamm, J. Chem. Soc., Perkin Trans. 1 **1993**, 1139

[4] D.Archier-Jay, N. Besbes, A. Laurent, E. Laurent, S. Lesniak, R. Tardivel, Bull. Soc. Chim. Fr. **1989**, 537

[5] (a) H. Stamm, T. Mall, R. Falkenstein, J. Werry, D. Speth, J. Org. Chem. **54** (1989) 1603; (b) H. Stamm, A. Sommer, A. Woderer, W. Wiesert, T. Mall, P. Assithianakis, J. Org. Chem. **50** (1985) 4946

[6] J. F. Garst, C. D. Smith, J. Am. Chem. Soc. **98** (1976) 1520

[7] J. F. Garst, Accounts Chem. Res. **4** (1971) 400

[8] A. Hassner, A. Kascheres, Tetrahedron Lett. **1970**, 4623

[9] A rate constant 5.5×10^5 $M^{-1}s^{-1}$ has been found for hydrogen abstraction from THF by cyclopropyl radical: L. J. Johnston, J. C. Scaiano, K. U. Ingold, J. Am. Chem. Soc. **106** (1984) 4877. Pseudo-first-order rates in THF were found to be 2×10^3 s^{-1} for a tertiary radical: M. Newcomb, S. U. Park, J. Am. Chem. Soc. **108** (1986) 4132

[10] The rate of the related ring opening of cyclopropyl radical is 10^8 s^{-1}: M. Newcomb, A. G. Glenn, J. Am. Chem. Soc. **111** (1989) 275

[11] M. Vora, M. Holy, J. Org. Chem. **40** (1975) 3144

[12] The apparent acidity of alcohols in DMSO or THF is comparable to that of $CHPh_3$ when alcohol concentration is low: E. C. Steiner, J. M. Gilbert, J. Am. Chem. Soc. **85** (1963) 3054; D. Alprim, J. E. Bares, J. C. Branco, F. G. Bordwell, J. Org. Chem. **43** (1978) 5024. Intramolecular protonation of an alkoxide by a (particular) benzyl group has been described: S. Bradamante, R. Ferraccioli, G. A. Pagani, J. Chem. Soc., Perkin Trans. 1 **1987**, 515.

[13] N. Hirahota, Metal Ketyls and Related Radical Ions – Electronic Structures and Ion Pair Equilibria, in: Radical Ions, Ed.: E. T. Kayser, L. Kevan, Part of the series: Reactive Intermediates in Organic Chemistry, Ed.: G. A. Olah, J. Friedman, Interscience Publishers, New York 1968, p. 52–58

[14] K. Bellos, H. Stamm, J. Prakt. Chem. **335** (1995) 269

[15] Elimination of NaH from anions of dihydronaphthalens has been described: S. Bank, T. A. Lois, M. C. Prislopski, J. Am. Chem. Soc. **91** (1969) 5407 and lit. cited therein. Analogous formulation of LiH elimination: R. L. Eppley, J. A. Dixon, J. Am. Chem. Soc. **90** (1968) 1606

[16] J. Werry, H. Stamm, P.-Y. Lin, R. Falkenstein, G. Fries, H. Irngartinger, Tetrahedron **45** (1989) 5015

[17] H. Stamm, D. Speth, Chem. Ber. **122** (1989) 1795

[18] E. K. Raunio, W. A. Bonner, J. Org. Chem. **31** (1966) 396

[19] H. Stamm, R. Falkenstein, Chem. Ber. **123** (1990) 2227

[20] Cp.: V. Rautenstrauch, Tetrahedron **44** (1988) 1613

[21] P. Mackiewicz, R. Furstoss, Tetrahedron **34** (1978) 3241, 3253; R. S. Neale, Synthesis **1971**, 1

[24] H. E. Baumgarten, F. A. Bower, R. A. Setterquist, R. E. Allen, J. Am. Chem. Soc. **80** (1958) 4588

[23] J. F. Bieron, F. J.Dinan, in: Chemistry of Amides, Ed.: J. Zabicky, Interscience Publishers, London, New York, 1970, p. 280

[24] B. Buchholz, H. Stamm, Isr. J. Chem. **27** (1986) 17

[25] D. V.-Kashelikar, P. E. Fanta, J. Org. Chem. **26** (1961) 1841

Address for correspondence:
Prof. Dr. H. Stamm
Universität Heidelberg
Fakultät Pharmazie
Im Neuenheimer Feld 346
D-69120 Heidelberg, Germany