

ON THE ORIGIN OF BASE CONCENTRATION EFFECT ON STEREO-
AND REGIOSELECTIVITY IN ALKOXIDE-PROMOTED E2 REACTIONS:
A CONSEQUENCE OF SUBSTRATE SOLVATION BY METAL IONS*

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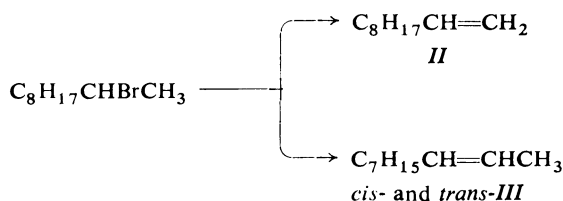
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The title problem has been investigated in the reaction of 2-decyl bromide with $t\text{-C}_4\text{H}_9\text{OK}/t\text{-C}_4\text{H}_9\text{OH}$ system employing 18-crown-6 ether and an "inert" salt ($t\text{-C}_4\text{H}_9\text{OLi}$) as mechanistic probes. From olefin-distribution data and a subsidiary kinetic evidence it has been inferred that the investigated effect originates from a concentration-dependent substrate solvation by metal ions in the transition state.

Reports accommodated in the past decades showing that stereo as well as regioselectivity of alkali alkoxide promoted E2 eliminations varies sometimes significantly with base concentration¹⁻⁴. A wide occurrence of this phenomena has been observed particularly in the reaction of 2-alkyl halides and tosylates in solvents of low polarity^{2,4}. A gradual increase of *cis*-2-alkene/*trans*-2-alkene and 1-alkene/*trans*-2-alkene ratios with increasing base concentration was found in the reaction proceeding in *anti*-fashion^{5,6}.

Two mechanistic concepts have been proposed for explanation of the intriguing results involving either a concentration-dependent competition of several base species^{1,2} or a concentration-dependent metal-ion solvation of substrate^{4,7} in the elimination.



SCHEME 1

* Part L in the series Elimination Reactions; Part IL: Collect. Czech. Chem. Commun. 48, 3552 (1983).

In this paper we have attempted to distinguish between the two concepts in the reaction of 2-decyl bromide with $t\text{-C}_4\text{H}_9\text{OK}/t\text{-C}_4\text{H}_9\text{OH}$ system (Scheme 1) employing 18-crown-6 ether and an "inert" alkali salt ($t\text{-C}_4\text{H}_9\text{OLi}$) as mechanistic probes.

EXPERIMENTAL

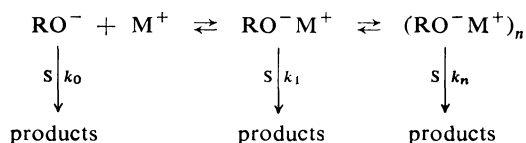
Materials: 2-Decyl bromide and 18-crown-6 ether were available from previous work^{7,8}.

Alkoxide solutions: Stock solution of potassium and lithium tert-butoxide were prepared by dissolving the clean metals in dry tert-butanol and the concentration determined titrimetrically. The stock solution of 18-crown-6 ether was prepared by dissolving a weighted amount of the freshly recrystallized, vacuum-dried crown in tert-butanol. The reaction media required in the study were prepared by appropriate mixing of the stock solutions.

Determination of olefin-isomer composition and reaction rates: The same GLC procedures have been employed as described earlier⁷. The results are summarized in Tables I and II.

RESULTS AND DISCUSSION

The two alternative concepts proposed for explanation of the base concentration effect on olefin-isomer distribution in alkoxide-promoted E2 reactions are visualized in Schemes 2 and 3. In the first scheme (Scheme 2) a concentration-dependent competition among dissociated, ion-paired and/or ion-aggregated alkoxide species



Parallel reaction of several alkoxide base species with a single substrate (S)

SCHEME 2

is postulated in the reaction, the assumption being that the participating species differ each from the other in elimination selectivity. Several ingenious models of ion-paired or ion-aggregated alkoxide base endowed with an enhanced propensity for the terminal and *cis*-olefin isomer formation have been proposed⁹⁻¹². In the other scheme (Scheme 3), a concentration-dependent coordination (solvation) of the substrate leaving group (X) with metal ion (metal alkoxide) is the key factor^{4,7}, the assumption being that the metal-ion solvated and the free (non-solvated) substrate forms compete in the reaction for a single base species giving rise again to different olefin-isomer distribution, respectively. A simple model of the metal-ion solvated substrate form endowed with an enhanced propensity for the terminal and *cis*-isomer formation has been also proposed previously⁴ (vide infra). As we pointed out, Schemes 2 and 3 are kinetically indistinguishable⁷.

TABLE I

First-order rate constants and olefin-isomer distribution from the elimination of 2-decyl bromide in $t\text{-C}_4\text{H}_9\text{OK-t-C}_4\text{H}_9\text{OH}$ solution at 25°C : The effects of 18-crown-6 and $t\text{-C}_4\text{H}_9\text{OK}$ concentration

Entry	[Crown] mol l^{-1}	[$t\text{-C}_4\text{H}_9\text{OK}$] mol l^{-1}	% <i>II</i> ^a	% <i>trans-III</i> ^a	% <i>cis-III</i> ^a	k ^a s^{-1}
1	0.490	0.490	56.0 ± 0.7	36.7 ± 0.6	7.3 ± 0.4	$(1.4 \pm 0.1) \cdot 10^{-2}$
2	0.245	0.245	56.2 ± 0.6	36.4 ± 0.4	7.4 ± 0.2	$(5.4 \pm 0.3) \cdot 10^{-3}$
3	0.123	0.123	55.8 ± 0.7	36.3 ± 0.4	7.9 ± 0.2	$(2.1 \pm 0.1) \cdot 10^{-3}$
4	0.061	0.061	55.0 ± 0.6	37.2 ± 0.4	7.7 ± 0.2	$(7.8 \pm 0.6) \cdot 10^{-4}$
5	0.031	0.031	55.8 ± 0.5	36.9 ± 0.4	7.2 ± 0.3	$(3.4 \pm 0.1) \cdot 10^{-4}$
6	0.245	0.490	57.9 ± 0.6	34.6 ± 0.5	7.5 ± 0.7	$(6.0 \pm 0.2) \cdot 10^{-3}$
7	0.123	0.490	59.5 ± 0.4	33.2 ± 0.5	7.3 ± 0.3	$(2.4 \pm 0.1) \cdot 10^{-3}$
8	0.061	0.490	60.8 ± 0.8	32.2 ± 0.6	7.0 ± 0.3	$(8.0 \pm 0.2) \cdot 10^{-4}$
9	0.031	0.490	61.3 ± 0.7	31.5 ± 0.5	7.2 ± 0.2	$(4.0 \pm 0.2) \cdot 10^{-4}$
10	0.000	0.490	78.9 ± 1.0	13.3 ± 0.9	7.8 ± 0.6	$(1.9 \pm 0.1) \cdot 10^{-6}$
11	0.031	0.653	64.1 ± 0.8	29.2 ± 0.5	6.7 ± 0.4	$(3.6 \pm 0.1) \cdot 10^{-4}$
12	0.031	0.566	63.1 ± 0.4	30.3 ± 0.2	6.5 ± 0.3	$(4.3 \pm 0.2) \cdot 10^{-4}$
13	0.031	0.250	59.9 ± 0.4	33.2 ± 0.3	6.9 ± 0.2	$(4.8 \pm 0.1) \cdot 10^{-4}$
14	0.031	0.120	57.8 ± 0.3	35.1 ± 0.4	7.1 ± 0.2	$(4.9 \pm 0.2) \cdot 10^{-4}$
15	0.031	0.061	56.7 ± 0.5	36.3 ± 0.6	7.0 ± 0.3	$(4.6 \pm 0.1) \cdot 10^{-4}$

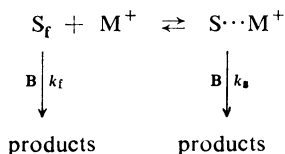
^a Mean values and standard mean deviations based on 15–20 samples from two kinetic runs.

TABLE II

The effect of $t\text{-C}_4\text{H}_9\text{OLi}$ on the olefin-isomer distribution and first-order rate constants from elimination of 2-decyl bromide in $0.1\text{M-t-C}_4\text{H}_9\text{OK-t-C}_4\text{H}_9\text{OH}$ solution at 80°C

Entry	[$t\text{-C}_4\text{H}_9\text{OLi}$] mol l^{-1}	% <i>II</i> ^a	% <i>trans-III</i> ^a	% <i>cis-III</i> ^a	k_1 s^{-1}
1	0.00	75.5	14.6	9.9	$\sim 4.5 \cdot 10^{-5}$
2	0.03	76.4	13.7	9.9	— ^b
3	0.09	76.8	13.3	9.9	— ^b
4	0.18	76.9	13.3	9.7	— ^b
5	0.26	78.1	12.5	9.4	— ^b
6	0.34	79.5	11.6	8.9	— ^b
7	0.34 ^c	70.0	17.8	12.2	$\sim 1.0 \cdot 10^{-6}$

^a Average from three measurements; ^b not determined; ^c data from the reaction of 2-decyl bromide with $t\text{-C}_4\text{H}_9\text{OLi}$ in tert-butanol.



Parallel reaction of a free (S_f) and metal-ion solvated ($S \cdots M^+$) substrate with a single active base (B)

SCHEME 3

The Effect of Base Concentration in the Presence of 18-Crown-6

From ebulliometric studies it is known¹³ that 18-crown-6 ether in $t\text{-C}_4\text{H}_9\text{OK}/t\text{-C}_4\text{H}_9\text{OH}$ system converts quantitatively the prevailing (monomeric) ion pairs into the 1 : 1 crown-complexed species. Also it is known that the crown enhances^{14,15} elimination rates in the alkoxide solution and changes pronouncedly distribution of olefin-isomers in the reaction^{6,8}. These properties make from 18-crown-6 ether a very convenient mechanistic tool for understanding the effect of base concentration since, as a simple consideration suggests, operation of the crown in the alternative Schemes 2 and 3 is entirely different.

In Scheme 2, addition of 18-crown-6 ether will intercept the base species competition by introducing a new active base species in the reaction. Provided that the crown-complexed species is much more reactive than the uncomplexed ones present in the solution, a catalytic amount of the crown suffices to suppress base species competition in the olefin-forming reaction.

In Scheme 3, 18-crown-6 ether will intercept the competition between the free and metal-ion solvated substrate forms by complexation of the substrate solvating metal cation. Owing to 1 : 1 stoichiometry in the crown- $t\text{-C}_4\text{H}_9\text{OK}$ complex formation, an equimolar amount of the crown is requisite for a complete exclusion of the metal-ion solvated substrate form from the reaction.

In this way, the consideration shows that a simple distinction between the two alternative schemes may be attained by a comparison of the effects of base concentration from the reaction performed in the presence of catalytic and stoichiometric amounts of 18-crown-6 ether, respectively. The pertinent experimental data from the elimination of 2-decyl bromide in $t\text{-C}_4\text{H}_9\text{OK}/t\text{-C}_4\text{H}_9\text{OH}$ system are presented in Figs 1a and 1b. As Fig. 1a shows, no significant changes in olefin-isomer composition have been induced by changing the overall base concentration (0.03–0.49 mol \cdot l^{-1}) in the stoichiometric presence of the crown ($[\text{t-C}_4\text{H}_9\text{OK}] : [\text{crown}]$ ratio 1 : 1). Fig. 1b shows, on the other hand, that very marked changes have been induced in the corresponding reaction involving only catalytic (0.03 mol l^{-1}) amount of the crown. On increasing $t\text{-C}_4\text{H}_9\text{OK}$ concentration (0.03–0.65 mol l^{-1}), the percentage

of 1-alkene (*II*) increases and that of *trans*-2-alkene (*trans-III*) decreases gradually, in apparent analogy with the results we obtained previously^{4,7} in the complete absence of the crown (*vide infra*).

A complementary evidence is obtained from another experiment, in which the overall concentration of $t\text{-C}_4\text{H}_9\text{OK}$ was kept constant (0.49 mol l^{-1}) whereas the concentration of 18-crown-6 varied between the catalytic (0.03 mol l^{-1}) and the stoichiometric (0.49 mol l^{-1}) extremes. When the olefin-isomer distribution data from the experiment were plotted as a function of the free base concentration ($[\text{t-C}_4\text{H}_9\text{OK}]_{\text{free}} = 0.49 - [\text{18-crown-6}]$), almost identical slopes were obtained (Fig. 1c) as in the experiment from the Fig. 1b.

In this way it follows that an equimolar amount of 18-crown-6 is indispensable for a suppression of base concentration effect on olefin-isomer distribution in the elimination reaction. A strong evidence is thus provided in support of the competition of substrate forms from Scheme 3, in contradistinction with the concept of base species competition from Scheme 2.

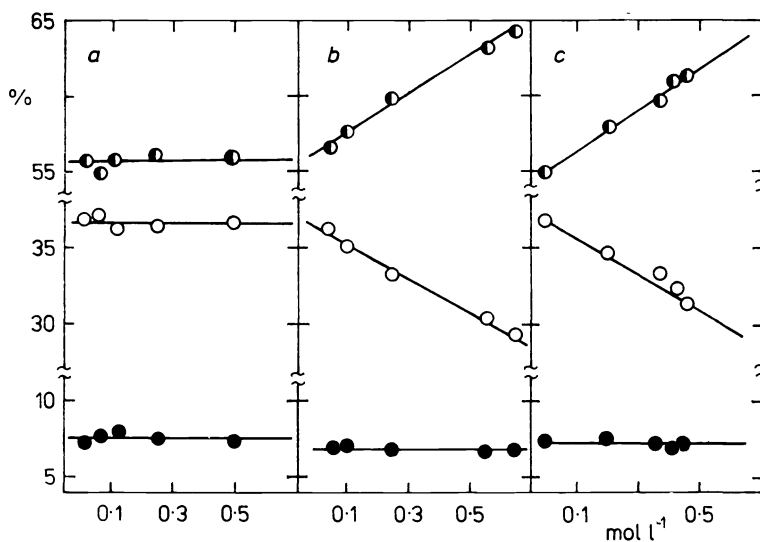


FIG. 1

Changes in olefin-isomer distribution in the reaction of 2-decyl bromide in $t\text{-C}_4\text{H}_9\text{OK-t-C}_4\text{H}_9\text{OH}$ system induced by: *a* varying the overall base concentration, $[\text{t-C}_4\text{H}_9\text{OK}]_{\text{tot}}$, in the stoichiometric (1 : 1) presence of 18-crown-6 ether; *b* varying the overall base concentration, $[\text{t-C}_4\text{H}_9\text{OK}]_{\text{tot}}$, in the catalytic (0.03 mol l^{-1}) presence of 18-crown-6 ether; *c* varying the 18-crown-6 ether concentration in $0.49\text{M-t-C}_4\text{H}_9\text{OK-t-C}_4\text{H}_9\text{OH}$ solution. Plotted as a function of a crown-non-complexed base concentration ($0.49 - [\text{18-crown-6}]$); ● 1-decene, ○ *trans*-2-decene, ● *cis*-2-decene

It might be argued that the non-stoichiometric amounts of the crown employed in the experiments from Figs 1b and 1c do not suffice to suppress the free alkoxide base from operation so that the observed effect could be due to a competition between the crown-complexed and free active base. To exclude such an eventuality, we have supplemented the olefin isomer composition study by kinetic measurements (Table I). As it follows from a comparison of the first-order rate constants in entries 9 and 10, the elimination in 0.49M-t-C₄H₉OK-t-C₄H₉OH solution proceeds more than 200 times faster in the catalytic presence (0.03 mol l⁻¹) than in the complete absence of 18-crown-6; in the stoichiometric (1 : 1) presence of the crown the rate difference approaches already the factor of 10⁴ (entries 1 and 10). It indicates that the free (non-complexed with crown) potassium alkoxide does not participate significantly (> 1%) in any experiment from Figs 1b and 1c.

The Effect of Base Concentration Simulated by an "Inert" Alkali Salt

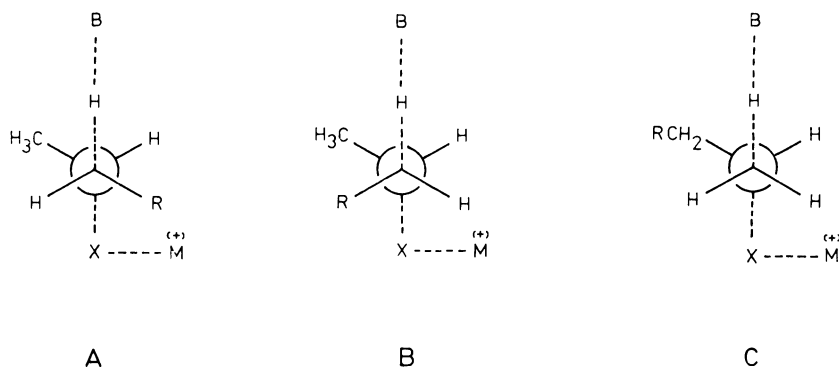
Another insight into the origin of base concentration effect is provided by the experiment in which we followed changes in olefin-isomer distribution in 2-decyl bromide elimination in 0.1M-t-C₄H₉OK-t-C₄H₉OH solution induced by addition of the corresponding lithium alkoxide (t-C₄H₉OLi). As Table II shows (entry 1–6), the proportion of 1-decene increases and that of *trans*-2-decene decreases gradually on increasing concentration of t-C₄H₉OLi in the reaction, in apparent analogy with the results in Figs 1b and 1c.

The complementary kinetic data in Table II show that 2-decyl bromide reacts about 50 times faster in 0.1M-t-C₄H₉OK-t-C₄H₉OH than in 0.34M-t-C₄H₉OLi-t-C₄H₉OH solution (entries 1 and 7, respectively). The eventuality that the observed changes in olefin-isomer composition in entries 1–6 in Table II arise from a competition between t-C₄H₉OK and t-C₄H₉OLi base is thus ruled out. In this way it follows that the effect of base concentration can be simulated by an inert alkali salt. Another argument is thus provided in support of the view that base concentration effect on the olefin-isomer distribution originates from substrate solvation by metal ions as it is postulated in the Scheme 3.

Synergism between the "Active" and the "Passive" Alkoxide Species in Steering the Elimination Course

The results of the preceding experiments make it worthwhile to examine in a more detail the role which may play the "active" and the "passive" alkoxide species in Scheme 3. As the "active" base (B) we denote the alkoxide species which is involved in the proton abstraction from C_β-H bond whereas the metal-ion involving species (M⁺) which coordinates with the substrate leaving group and participates electrophilically in C_α-X breaking is referred to as the "passive" one.

We proposed previously that the "passive" alkoxide species may be responsible for the enhanced propensity to terminal and *cis*-olefin isomer formation from the metal-ion solvated form of substrate. A simple conformational analysis of *anti*-elimination (Scheme 4) led us to suggest⁴ that substrate solvation by metal ion in the conformation required for *trans*-olefin formation is sterically hindered. Steric interference between the metal ion and the alkyl portion of the substrate is assumed to be the responsible factor which selectively disfavours the *trans*-alkene formation (A). In the formation of *cis*- and terminal alkenes (B and C, respectively), the inter-



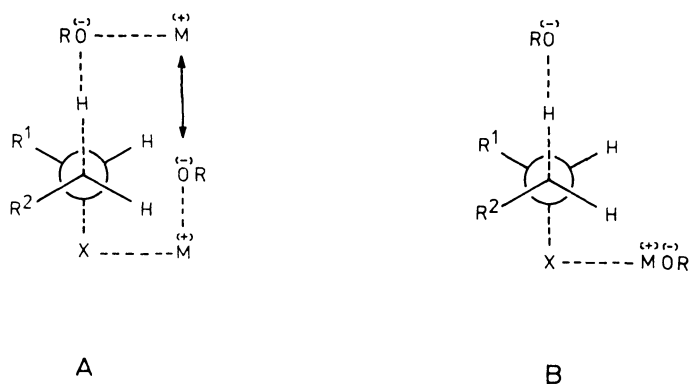
SCHEME 4

ference can be avoided by solvating the leaving group from that side where only hydrogen substituents are located. In this way, the metal-ion solvation may also account well for the observed effect of base concentration in Figs 1b and 1c, because contribution from the metal-ion solvated substrate will increase with increasing concentration of the "passive" alkoxide species in the elimination reaction.

As it concerns the steric role played by the "active" base species in Schemes 3 and 4, a very direct insight can be obtained from a comparison of the olefin-isomer distribution data from the reaction of 2-decyl bromide in 0.49M- $t\text{-C}_4\text{H}_9\text{OK}$ - $t\text{-C}_4\text{H}_9\text{OH}$ solution performed in the absence and in the catalytic (0.03 mol l^{-1}) presence of 18-crown-6, respectively (Table III). It can be assumed that the two compared reactions differ only in the "active" base.

In the elimination performed in the absence of the crown ether, we assume that the "active" and the "passive" alkoxide species are identical being most probably monomeric ion pairs⁷. A simple consideration suggests that an attractive interaction between the opposite poles of the "active" and "passive" alkoxide species may arise in the transition state (Scheme 5, A), which weakens the electrostatic bindings within the individual ion pairs. The "passive" species thus becomes a stronger

electrophile whereas the "active" species becomes a stronger base. In this way, a synergetic effect arises in the reaction.



SCHEME 5

In the corresponding reaction performed in the catalytic presence of 18-crown-6 ether, the "active" base is probably a free alkoxide anion ($t\text{-C}_4\text{H}_9\text{O}^-$) or a negatively charged, crown-complexed ion-triplet*, $[(t\text{-C}_4\text{H}_9\text{O}^-)_2\text{K}^+; 18\text{-crown-6}]$. Neither of

TABLE III

Effect of base concentration on olefin-isomer distribution in the reaction of 2-decyl bromide with 0.49M- $t\text{-BuOK-t-BuOH}$ in the absence and in the presence of catalytic amounts (0.03 mol l^{-1}) of 18-crown-6

[$t\text{-BuOK}$] mol l^{-1}	Crown absent ^a		Crown present	
	% 1-alkene	<i>trans</i> : <i>cis</i>	% 1-alkene	<i>trans</i> : <i>cis</i>
0.07	74.5	1.3	57.3	5.2
0.16	75.2	1.2	58.4	5.0
0.33	76.2	1.1	60.6	4.8
0.67	79.1	1.0	65.0	4.3

^a Data taken from ref.⁷.

* Operation of the ion-triplet is substantiated by kinetic analysis showing that in the reaction performed in the presence of crown (Table I, entry 1–9) the apparent kinetic order in respect to 1 : 1 crown-complexed $t\text{-C}_4\text{H}_9\text{OK}$ is 1.35 ± 0.05 . Baciocchi with coworkers¹⁴ reached to analogous conclusion in the elimination from 1-bromo-2-phenylethane.

the two alternative species is prone to attractive interaction with monomeric ion-pair contributing as the "passive" component. No significant synergetic effect arises therefore in the elimination performed in the stoichiometric as well as in catalytic presence of 18-crown-6 ether (Scheme 5, B).

Owing to the synergetic effect, contribution of the metal-ion solvated form of substrate to elimination is probably higher in the absence than in the presence of the crown. This, in accord with the conformational prediction based on Scheme 4 may satisfactorily explain the observation that the proportion of 1-alkene and *cis*-2-alkene is always much higher in the former than in the latter reaction (Table III).

REFERENCES

1. Závada J., Svoboda M.: *Tetrahedron Lett.* 1972, 23.
2. Bartsch R. A., Pruss G. M., Cook D. M., Buswell R. L., Bushaw B. A., Wieggers K. E.: *J. Am. Chem. Soc.* 95, 6745 (1973).
3. Baciocchi E., Corsano S., Ruzziconi R.: *J. Chem. Soc., Perkin Trans. 2*, 1977, 436.
4. Závada J., Pánková M., Bartsch R. A., Cho B. R.: *Collect. Czech. Chem. Commun.* 46, 850 (1981).
5. Bartsch R. A.: *J. Am. Chem. Soc.* 93, 3683 (1971).
6. Bartsch R. A., Závada J.: *Chem. Rev.* 80, 453 (1980).
7. Závada J., Pánková M., Vitek A.: *Collect. Czech. Chem. Commun.* 46, 3247 (1981).
8. Pánková M., Závada J.: *Collect. Czech. Chem. Commun.* 42, 1981 (1977).
9. Závada J., Pánková M., Svoboda M., Schlosser M.: *J. Chem. Soc., Chem. Commun.* 1973, 168.
10. Závada J., Pánková M., Svoboda M.: *Collect. Czech. Chem. Commun.* 41, 3778 (1976).
11. Schlosser M., Jan G., Byrne E., Sicher J.: *Helv. Chim. Acta* 56, 1630 (1973).
12. Bartsch R. A.: *Acc. Chem. Res.* 8, 239 (1975).
13. Pechanec V., Kocián O., Halaška V., Pánková M., Závada J.: *Collect. Czech. Chem. Commun.* 46, 2166 (1981).
14. Alunni S., Baciocchi E., Peruci P.: *J. Org. Chem.* 41, 2636 (1976).
15. Závada J., Pánková M.: *Collect. Czech. Chem. Commun.* 45, 3150 (1980).

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