ISSN 1070-4280, Russian Journal of Organic Chemistry, 2011, Vol. 47, No. 3, pp. 421–432. © Pleiades Publishing, Ltd., 2011.
Original Russian Text © Yu.B. Koptelov, S.P. Saik, A.P. Molchanov, S.I. Selivanov, 2011, published in Zhurnal Organicheskoi Khimii, 2011, Vol. 47, No. 3, pp. 428–438.

# Generation of Azomethine Imines via Opening of the Diaziridine Ring in Unsymmetrically Substituted 6-Aryl-1,5-diazabicyclo-[3.1.0]hexanes and Their Transformations

**Yu. B. Koptelov, S. P. Saik, A. P. Molchanov, and S. I. Selivanov**

*St. Petersburg State University, Universitetskii pr. 26, St. Petersburg, 198504 Russia*
*e-mail: koptelov@JK7283.spb.edu*

Received July 5, 2010

**Abstract**—Thermally induced opening of the diaziridine ring at the carbon–nitrogen bond in unsymmetrically substituted 6-aryl-1,5-diazabicyclo[3.1.0]hexanes is characterized by low regioselectivity which is likely to be determined by the inductive effect of substituents in the trimethylene bridge. 1,3-Dipolar cycloaddition of the resulting azomethine imines to phenyl isocyanate is regioselective: it occurs at the double carbon–nitrogen bond with predominant formation of the corresponding *cis* adducts due to dipolarophile approach to *Z*-azomethine imine at the sterically less hindered side. Analogous approach of dipolarophile is also observed in the reaction with *N*-arylmaleimides.

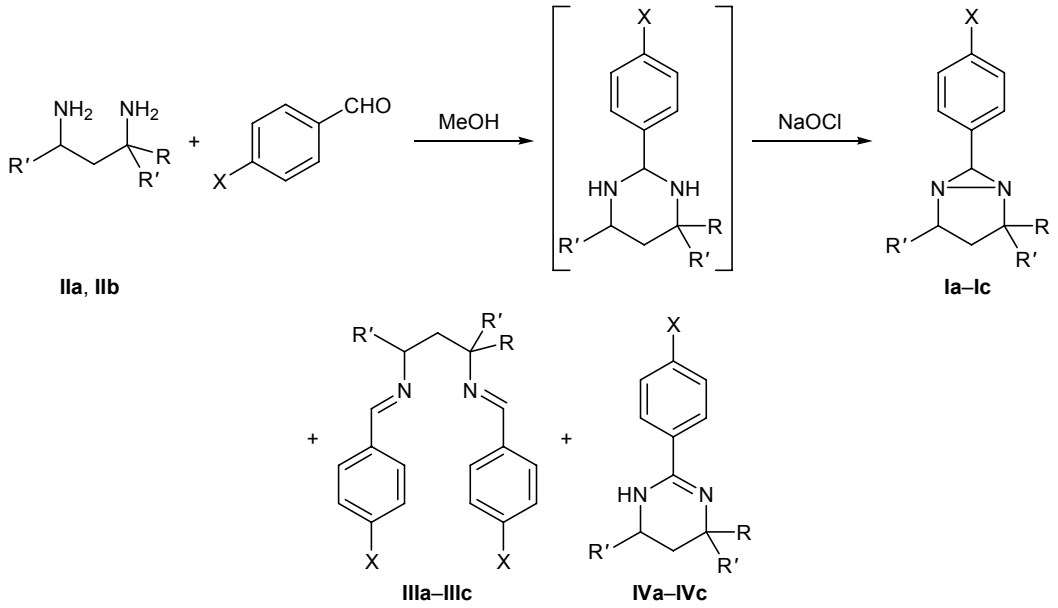
**DOI:** 10.1134/S1070428011030171

Azomethine imines, especially those fused to a cyclic system at both nitrogen atoms or nitrogen and carbon atoms, may be useful as initial compounds for the preparation of a wide series of fused heteropolycyclic and spiro-fused heterocyclic systems [1]. A convenient method for the generation of azomethine imines in which both nitrogen atoms are incorporated into a pyrazolidine fragment is based on thermal opening of the diaziridine ring in 6-aryl-1,5-diazabicyclo-[3.1.0]hexanes at the carbon–nitrogen bond [2]. If no 1,3-dipolarophile is present in the reaction mixture, highly reactive and labile azomethine imines thus formed undergo isomerization into the corresponding 4,5-dihydro-1*H*-pyrazoles [3, 4]. Introduction of a substituent into position *2* of 6-aryl-1,5-diazabicyclo-[3.1.0]hexane molecule violates symmetric structure of the bicyclic system. However, opening of the diaziridine ring in 2-oxo derivatives occurs strictly regioselectively at the carbon–nitrogen bond contiguous to the carbonyl group [5], whereas thermolysis of 6-aryl-2-methyl-1,5-diazabicyclo[3.1.0]hexanes is characterized by low regioselectivity [6]; isomerization of unstable intermediate azomethine imines leads to the formation of mixtures of 1-arylmethyl-5-methyl-4,5-dihydro-1*H*-pyrazoles and 1-arylmethyl-3-methyl-4,5-dihydro-1*H*-pyrazoles at a ratio of ~6:5 (55:45%).

In the present work we examined the regioselectivity in the opening of the diaziridine ring in 6-aryl-substituted 2-phenyl- and 2,2,4-trimethyl-1,5-diazabicyclo[3.1.0]hexanes and the stereoselectivity in the reactions of azomethine imines thus formed with 1,3-dipolarophiles (1,3-dipolar cycloaddition). We were especially interested in thermal decomposition of diazabicyclohexane **Ib** having three substituents in the trimethylene bridge. On the one hand, the presence of two methyl groups in position *2* increases strain in the bicyclic system, which should affect the mode of opening of the three-membered ring; on the other hand, opening of the diaziridine fragment at the carbon–nitrogen bond contiguous to the quaternary carbon atom could give rise to azomethine imine lacking a hydrogen atom for the subsequent 1,4-H shift leading to 4,5-dihydro-1*H*-pyrazole derivative.

Unsymmetrically substituted 6-aryl-1,5-diazabicyclo[3.1.0]hexanes **Ia**–**Ic** were synthesized in 11–30% yields according to known procedure involving condensation of 4-methoxy- and 4-bromobenzaldehydes with substituted propane-1,3-diamines **IIa** and **IIb** and subsequent oxidation of intermediate substituted hexahydropyrimidines with sodium hypochlorite [2] (Scheme 1). Initial propane-1,3-diamines were prepared in turn by catalytic hydrogenation of dihydropyrazoles [7]. It should be noted that the yields of the corresponding symmetric analogs, 6-(4-methoxyphenyl)- [2] and 6-(4-bromophenyl)-1,5-diazabicyclo[3.1.0]-hexanes [8], were considerably higher, 52 and 70%,

**Scheme 1.**




**I**, **III**, **IV**, R = Ph, R′ = H, X = Br (**a**); R = R′ = Me, X = Br (**b**), MeO (**c**); **II**, R = Ph, R′ = H (**a**); R = R′ = Me (**b**).

respectively. The structure of diazabicyclohexanes **Ia**–**Ic** was confirmed by spectral data. The $^1$H NMR spectra of all 6-aryl-1,5-diazabicyclo[3.1.0]hexanes **Ia**–**Ic** in $CDCl_3$ contained characteristic singlets at δ 3.10–3.28 ppm from the CH proton in the diaziridine ring.

We previously showed that symmetric 6-aryl-1,5-diazabicyclo[3.1.0]hexanes exist as *exo*-6 isomers due to hindered inversion of the diaziridine ring [8] and that 6-aryl-2-methyl-1,5-diazabicyclo[3.1.0]hexanes have the structure of *exo*,*exo* isomers [6]. As follows from analysis of the 2D $^1$H NMR (NOESY) spectrum of compound **Ic** (Fig. 1), 6-aryl-2,2,4-trimethyl-1,5-diazabicyclo[3.1.0]hexanes **Ib** and **Ic** are also *exo*,*exo* isomers having, like their monomethyl analogs, a *boat* conformation. This is indicated by spatial interaction between one proton in the methylene group (δ 2.04 ppm) and the CH proton in the diaziridine ring (δ 3.16 ppm).

Presumably, 6-(4-bromophenyl)-2-phenyl-1,5-diazabicyclo[3.1.0]hexane (**Ia**) should have a similar steric structure. The $^1$H NMR spectrum of **Ia** in $CDCl_3$ contained the following signals, δ, ppm: 1.93 m (1H, $J$ = 8.0, 13.4 Hz) and 2.37 m (1H, $J$ = 8.9, 13.4 Hz) ($CH_2$), 3.25 d.d.d (1H, $J$ = 8.0, 8.1, 12.0 Hz) and 3.60 m (1H, $J$ = 8.9, 12.0 Hz) ($CH_2$), 3.28 s (1H, NCHN), 4.83 m (1H, $J$ = 8.6 Hz, PhC**H**), as well as signals belonging to aromatic protons.

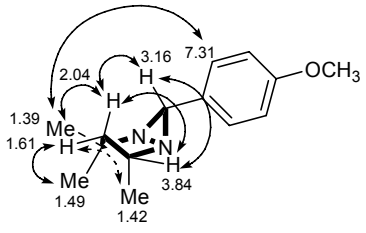
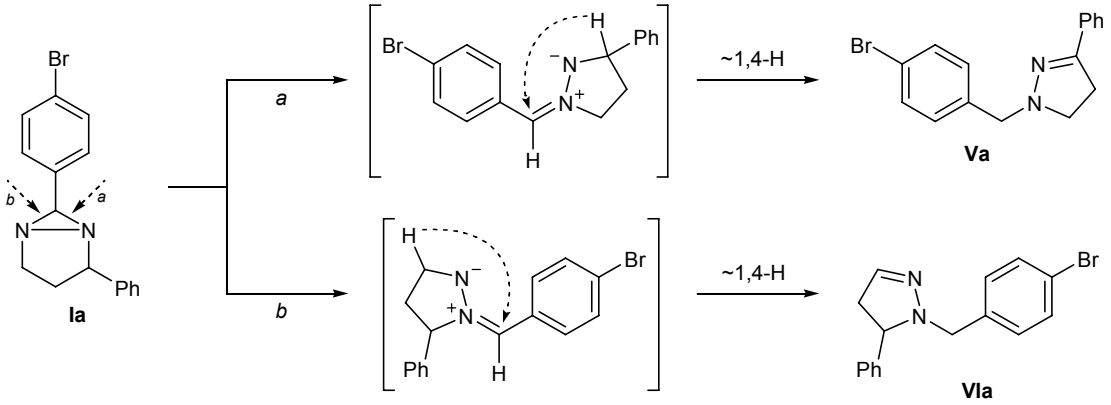



**Fig. 1.** Principal nuclear Overhauser effects in the two-dimensional $^1$H NOESY spectrum of compound **Ic**.

Apart from signals corresponding to compounds **Ia**–**Ic**, the NMR spectra of the reaction mixtures contained signals assignable to the initial aldehydes, Schiff bases **IIIa**–**IIIc** and amidines **IVa**–**IVc**, and compound **IVa** was isolated as individual substance (yield 48%). Unlike the synthesis of symmetric 6-aryl-1,5-diazabicyclo[3.1.0]hexanes (where the main by-products were Schiff bases like **III**) [4], in our case the main by-products were amidines **IVa**–**IVc** resulting from oxidation of hexahydropyrimidines. A probable reason is steric hindrances to oxidative cyclization of hexahydropyrimidines having substituents in position *4*(*6*) to the corresponding diaziridines **Ia**–**Ic**.

Compounds **Ia**–**Ic** were subjected to thermolysis under conditions analogous to those reported for 6-aryl-1,5-diazabicyclo[3.1.0]hexanes [2, 4, 8, 9], i.e., by heating in boiling *p*- or *o*-xylene (bp 138 and 144°C, respectively). In all cases the reaction was complete in ~25 min (TLC), which is typical of diaziridine ring opening in 6-aryl-1,5-diazabicyclo[3.1.0]-hexanes. After removal of the solvent, the reaction mixtures were analyzed by $^1$H NMR.

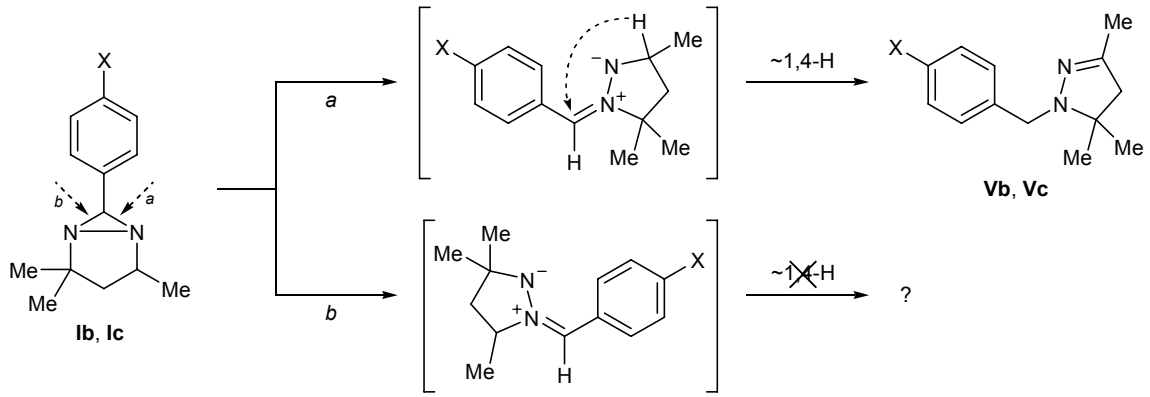
**Scheme 2.**




Opening of the three-membered ring in unsymmetrically substituted 1,5-diazabicyclohexanes at carbon–nitrogen bonds can follow two pathways (*a* and *b*) leading to the formation of the corresponding regioisomeric azomethine imines which then undergo isomerization via 1,4-H shift into 4,5-dihydro-1*H*-pyrazole derivatives. Thermolysis of 6-(4-bromophenyl)-2-phenyl-1,5-diazabicyclo[3.1.0]hexane (**Ia**) in the absence of 1,3-dipolarophile gave a mixture of isomeric dihydropyrazoles **Va** and **VIa** at a ratio of ~52 : 48 (Scheme 2). The isomer ratio was determined on the basis of the $^1$H NMR spectrum of the reaction mixture from the intensities of the benzylic proton signals. These signals appeared as a singlet at δ 4.29 ppm for isomer **Va** (the corresponding signal of 1-benzyl-3-phenyl-4,5-dihydro-1*H*-pyrazole in DMSO-$d_6$ was located at δ 4.28 ppm [10], and of 1-benzyl-3-methyl-4,5-dihydro-1*H*-pyrazole, at δ 4.10 ppm [11]) and two doublets at δ 3.79 and 4.23 ppm ($^2J$ = 14.0 Hz) for isomer **VIa**. No appreciable amounts of any other compounds were detected in the reaction mixture by $^1$H NMR spectroscopy.

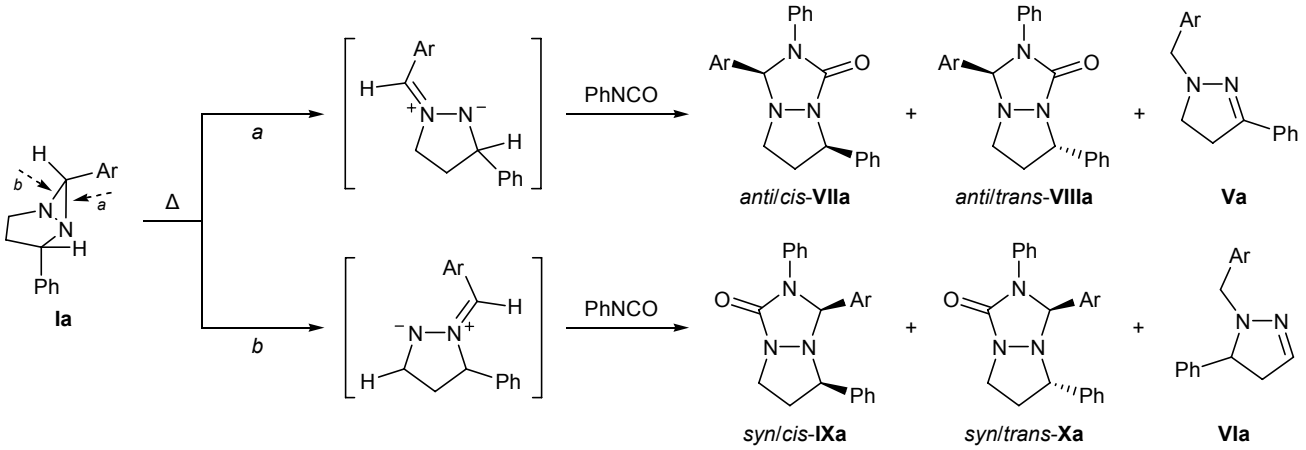
Opening of the diaziridine ring in 6-aryl-2,2,4-trimethyl-1,5-diazabicyclo[3.1.0]hexanes **Ib** and **Ic** along pathway *b* seemed to be preferred. We believed that in this case elimination of additional steric strain due to the presence of two methyl groups in the α-position with respect to the nitrogen atom (in fact, a latent *tert*-butyl group) should be more efficient. The resulting azomethine imine lacks hydrogen atom necessary for 1,4-H shift, so that isomerization into the corresponding dihydropyrazole is impossible. However, the $^1$H NMR spectra of the reaction mixtures obtained by thermolysis of compounds **Ib** and **Ic** showed the presence of only dihydropyrazoles **Vb** and **Vc** (≥85–90% of the overall amount of products) which could be formed via cleavage of the diaziridine fragment exclusively along pathway *a* (Scheme 3). Compounds that could be formed according to pathway *b* were not detected. The $^1$H NMR spectra of the reaction mixtures also contained signals from *para*-substituted benzaldehydes (~10%); the latter may result from hydrolysis of azomethine imines generated by cleavage of the initial diaziridine along pathway *b*.

**Scheme 3.**




X = Br (**b**), MeO (**c**).

**Scheme 4.**




Ar = 4-$BrC_6H_4$.

Dihydropyrazoles **Vb** and **Vc** characteristically showed in the $^1$H NMR spectra singlets from methyl protons at δ 1.19–1.21 (6H) and 1.91–1.94 ppm (3H) and methylene protons at δ 2.46–2.48 (2H) and 3.90–3.95 ppm (2H), as well as doublets from aromatic protons at δ 7.30 (1H, $J$ = 8.0 Hz) and 7.43 ppm (1H, $J$ = 8.0 Hz) for **Vb** and at δ 6.88 (1H, $J$ = 8.6 Hz) and 7.37 ppm (1H, $J$ 8.6 Hz) for **Vc**. The spectrum of **Vc** additionally contained a singlet at δ 3.80 ppm (3H) from protons in the methoxy group.

Taking into account our previous data obtained for 2-methyl-substituted 6-aryl-1,5-diazabicyclo[3.1.0]-hexanes [6], the observed regioselectivity of diaziridine ring opening in diazabicyclohexanes **Ia**–**Ic** may be rationalized in terms of a weak inductive effect of the methyl or phenyl group in position *2*. Assuming thermal polarization of the $C^6$–$N^5$ bond (*a*) in **Ib** and **Ic**, two donor methyl groups should exert a stronger destabilizing effect on the transition state, as compared to the effect of one methyl group upon polarization of the $C^6$–$N^1$ bond (*b*); as a result, dihydropyrazoles **Vb** and **Vc** are formed. By contrast, electron-withdrawing phenyl group stabilizes transition state with a partial negative charge on the neighboring nitrogen atom, and compound **Va** slightly prevails among the products.

By thermolysis of diazabicyclohexane **Ia** in the presence of phenyl isocyanate we obtained mixtures of all four possible regio- and stereoisomeric cycloaddition products **VIIa**–**Xa** (Scheme 4). According to the $^1$H NMR data, the reaction mixture also contained appreciable amounts of dihydropyrazoles **Va** and **VIa** (~24%) at a ratio of 62 : 38 (52 : 48 in the absence of dipolarophile). These findings are likely to indicate somewhat higher reactivity of intermediate azomethine imine formed according to pathway *b* in the cycloaddition to phenyl isocyanate. Thermal opening of the diaziridine ring in compound **Ia** in the presence of phenyl isocyanate was characterized by the same regioselectivity as in the absence of dipolarophile. The ratio of *anti* adducts **VIIa** and **VIIIa** and *syn* adducts **IXa** and **Xa** was ~44 : 56, and the ratio of *cis* (**VIIa** + **IXa**) and *trans* adducts (**VIIIa** + **Xa**) was ~62 : 38.

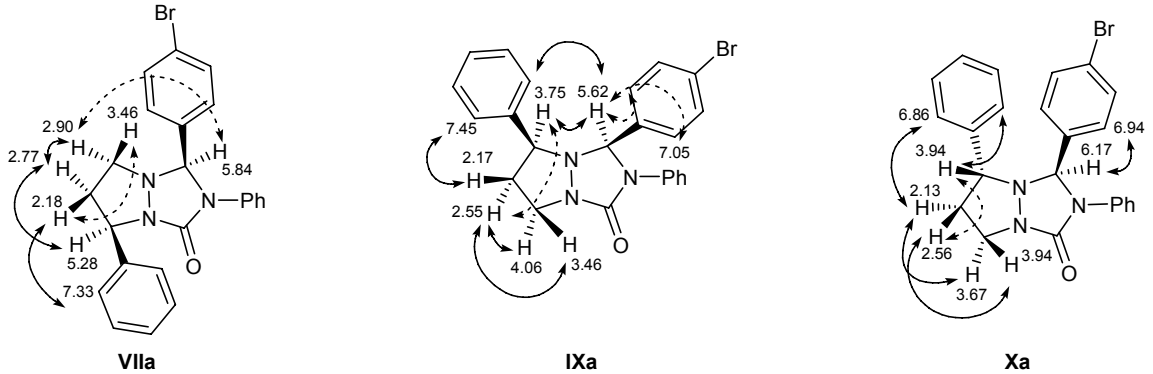
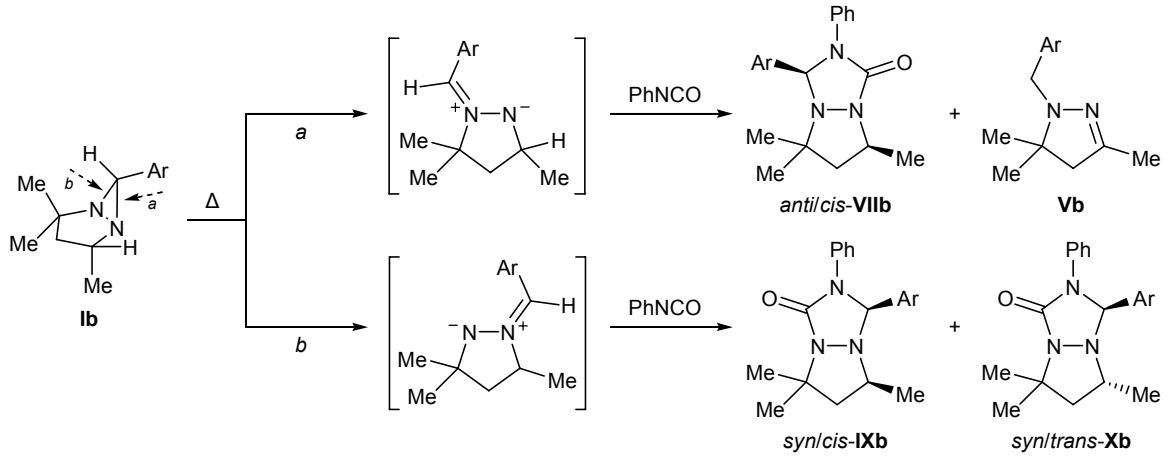



**Fig. 2.** Principal nuclear Overhauser effects in the $^1$H NOESY spectra of compounds **VIIa**, **IXa**, and **Xa**.

**Scheme 5.**




Ar = 4-$BrC_6H_4$.

Figure 2 shows the main signals and spatial interactions (nuclear Overhauser effects) of protons in compounds **VIIa**, **IXa**, and **Xa**, which gave rise to cross peaks in the 2D $^1$H NMR spectra (NOESY) recorded from solutions in $CDCl_3$. We failed to isolate compound **VIIIa** as individual substance, but in the $^1$H NMR spectrum of the product mixture enriched in adduct **VIIIa** we observed multiplet signals from methylene protons at δ 2.10 (1H), 2.35 (1H), and 2.69 ppm (2H), a multiplet at δ 5.24 ppm (1H) and a singlet at δ 6.37 ppm (1H) from methine protons, and signals from aromatic protons in the region δ 7.08–7.51 ppm (14H).

According to the $^1$H NMR data, thermolysis of 6-(4-bromophenyl)-2,2,4-trimethyl-1,5-diazabicyclo-[3.1.0]hexane (**Ib**) in the presence of phenyl isocyanate gave a mixture of products containing compounds **VIIb** and **Vb** (resulting from cleavage of the $C^6$–$N^5$ bond) together with adducts **IXb** and **Xb** which were formed via opening of the $C^6$–$N^1$ bond (pathway *b*, Scheme 5). As noted above, thermolysis of diazabicyclohexane **Ib** in the absence of dipolarophile afforded no products corresponding to pathway *b*. Thus, unlike four adducts formed by thermolysis of diazabicyclohexane **Ia**, only three products were detected in analogous transformation of compound **Ib**. The fraction of dihydropyrazole **Vb** in the reaction mixture did not exceed ~14%, and no protons signals assignable to 4-bromobenzaldehyde were observed in the $^1$H NMR spectrum of the reaction mixture. The regioselectivity in diaziridine ring opening in compound **Ib** was estimated at ~78:22 in favor of pathway *a* (**VIIb**, **Vb**). In keeping with the $^1$H NMR data, *anti* adduct **VIIb** considerably prevailed: the ratio *anti*-**VIIb**/*syn*-(**IXb** + **Xb**) was 76:24, and *cis* isomers **VIIb** and **IXb** were the major products: *cis*-(**VIIb** + **IXb**)/*trans*-**Xb** = 92:8.

Some proton chemical shifts and spatial interactions between protons in adducts **VIIb** and **IXb**, which were observed in their 2D $^1$H NMR spectra (NOESY) recorded from solutions in $CDCl_3$, are shown in Fig. 3. Compound **Xb** was not isolated as analytically pure sample, and its relative configuration was determined by comparing its $^1$H NMR spectrum with those of compound **Xa** and analogous thermolysis products of 2-substituted 6-aryl-1,5-diazabicyclo[3.1.0]hexanes [6]. Adduct **Xb** displayed in the $^1$H NMR spectrum signals from protons in the methyl groups at δ, ppm: 0.65 d (3H, $J$ = 6.1 Hz), 1.55 s (3H), and 1.58 s (3H), methylene protons at 1.73 d.d (1H, $J$ = 7.9, 12.3 Hz) and 2.14 d.d (1H, $J$ = 7.4, 12.3 Hz), methine protons at 3.11 d.q (1H, $J$ = 6.1, 7.4, 7.9 Hz) and 6.04 s (1H), and aromatic protons in the region 7.02–7.49 ppm (9H).

Presumably, the observed relatively high stereoselectivity of 1,3-dipolar cycloaddition in the thermolysis of 2-substituted 6-aryl-1,5-diazabicyclohexanes **Ia**

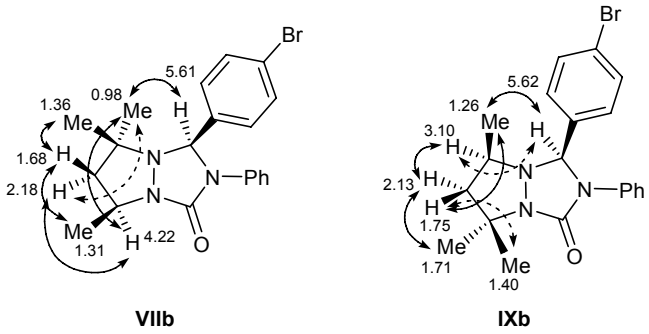
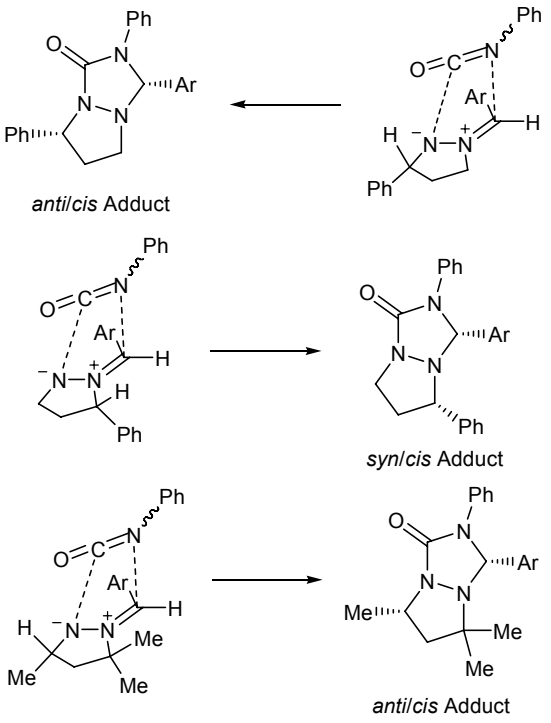



**Fig. 3.** Principal nuclear Overhauser effects in the $^1$H NOESY spectra of compounds **VIIb** and **IXb**.

and **Ib** in the presence of phenyl isocyanate (*cis*/*trans* ratio 62–92/8–38) is determined by preferential dipolarophile approach to intermediate azomethine imine at the side opposite to the methyl or phenyl group in the pyrazolidine ring, i.e., at the least sterically hindered side (Scheme 6). Probable ways of dipolarophile approach ensuring minimal spatial interaction between phenyl isocyanate and azomethine imine are shown in Scheme 6. In the other cases, spatial interactions between the NCO fragment and substituent in position *2* of the pyrazolidine ring are considerably stronger. Here, it is assumed that, like stable azomethine imines having an oxo group in the α-position [12], nonstabilized azomethine imine resulting from thermolysis of 6-aryl-1,5-diazabicyclo[3.1.0]hexanes **Ia** and **Ib** also has *Z* configuration.

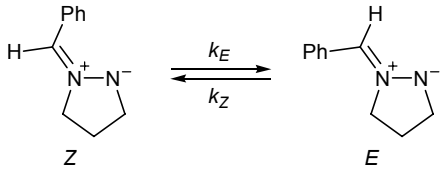
**Scheme 6.**




In fact, *E* configuration of azomethine imine should be characterized by fairly strong destabilizing spatial interaction between the aryl and methyl (phenyl) groups, and the formation of *cis*-isomeric cycloaddition product requires phenyl isocyanate approach at the side corresponding to the methyl (phenyl) group, which seems to be improbable.

Quantum-chemical calculation (DFT, 6-31G basis set, B3LYP functional, Gaussian-03 [13]) of the enthalpies of formation of the *Z* and *E* isomers of dipole generated by thermolysis of 6-phenyl-1,5-diazabicyclo[3.1.0]hexane indicated higher stability of the former ($\Delta\Delta H_{Z-E}$ = –5.2 kcal/mol); and the calculated difference in the Gibbs energies ($\Delta\Delta G_{Z-E}$ = –5.1 kcal/mol) suggests insignificant contribution of the *E* isomer in the equilibrium state ($k_Z/k_E \approx 600$ at 140°C; Scheme 7). Therefore, we believe that the reaction with phenyl isocyanate involves azomethine imine having *Z* configuration.

**Scheme 7.**

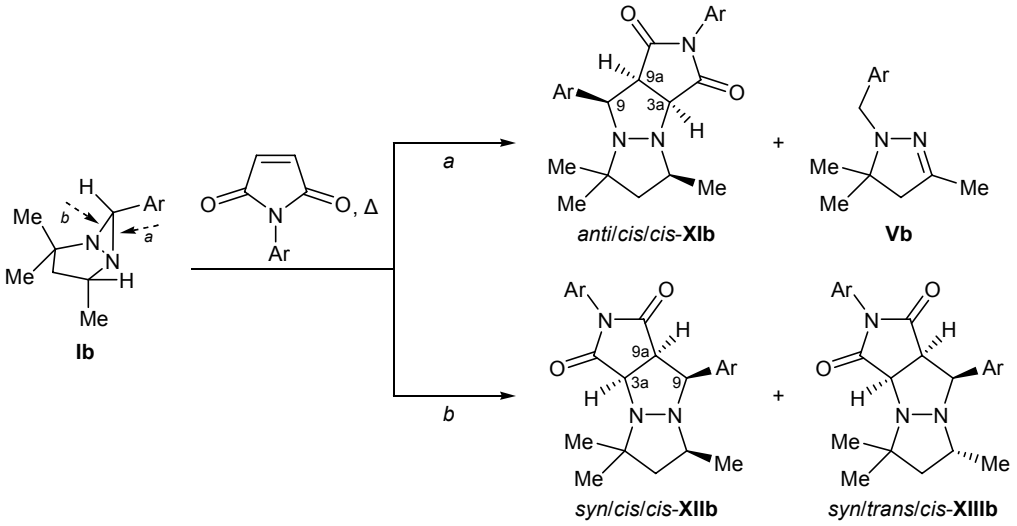



Our results led us to conclude that thermally induced cleavage of the diaziridine ring in 2-methyl-, 2,2,4-trimethyl-, and 2-phenyl-substituted 6-aryl-1,5-diazabicyclo[3.1.0]hexanes in the presence of phenyl isocyanate gives mainly adducts with *cis* orientation of the aryl and methyl (CHMe) or phenyl groups as a result of dipolarophile approach at the less sterically hindered side of intermediate unstable *Z*-dipole, i.e., at the side opposite to the methyl or phenyl group.

Thermal decomposition of 6-(4-bromophenyl)-2,2,4-trimethyl-1,5-diazabicyclo[3.1.0]hexane (**Ib**) in the presence of *N*-(4-bromophenyl)maleimide gave a mixture of compounds containing dihydropyrazole **Vb** (~28%) and three cycloaddition products **XIb**–**XIIIb** (~72%) (Scheme 8). The ratio of the adducts was determined on the basis of the intensities of the 9-H and 3a-H signals in the $^1$H NMR spectra. The ratio of the products formed along pathways *a* and *b* was ~70:30. The fraction of *anti* adduct **XIb** was slightly greater [*anti*-**XIb**/*syn*-(**XIIb** + **XIIIb**) = 56:44], and the ratio *cis*-(**XIb** + **XIIb**)/*trans*-**XIIIb** was ~79:21; i.e., the major products were isomers with *cis* orientation of the 4-bromophenyl and methyl (CHMe) groups. The addition of *N*-(4-bromophenyl)maleimide to azomethine imines generated by thermolysis of diazabicyclohexane **Ib** occurred exclusively as a result of *exo* approach, yielding *cis*-fused (9-H, 9a-H) pyrrolopyrazoles **XIb**–**XIIIb**.

Figure 4 shows principal spatial interactions between protons in molecule **XIb**, which give rise to cross peaks in the 2D $^1$H NMR spectrum (NOESY, $CDCl_3$). Adduct **XIIb** was not isolated as analytically pure substance. In the $^1$H NMR spectrum ($CDCl_3$) of crude product **XIIb** we observed signals (δ, ppm) from methyl protons at 1.21 d (3H, $J$ = 6.2 Hz), 1.49 s (3H),

**Scheme 8.**




Ar = 4-$BrC_6H_4$.

and 1.52 s (3H), methylene protons at 1.67 d.d (1H, $J$ = 6.4, 12.8 Hz) and 2.20 d.d (1H, $J$ = 9.6, 12.8 Hz), methine protons at 3.00 d.d.q (1H, $J$ = 6.2, 6.4, 9.6 Hz), 4.13 d.d (2H, $J$ = 9.0, 9.2 Hz), 4.37 d (1H, $J$ = 9.0 Hz), and 4.62 d (1H, $J$ = 9.2 Hz), and aromatic protons at 6.66–7.49 d (8H). Compound **XIIIb** displayed the following signals in the $^1$H NMR spectrum of the reaction mixture ($CDCl_3$), δ, ppm: 0.65 d (3H, $J$ = 6.2 Hz, Me), 3.19 m (1H), 4.20 d (1H, $J$ = 5.0 Hz, CH). The structures of adducts **XIIb** and **XIIIb** shown in Scheme 8 were assigned by comparing their $^1$H NMR spectra with the spectra of thermolysis products of compound **Ib** in the presence of phenyl isocyanate.

Thermolysis of 6-(4-bromophenyl)- and 6-(4-methoxyphenyl)-2,2,4-trimethyl-1,5-diazabicyclo[3.1.0]-hexanes **Ib** and **Ic** in the presence of *N*-mesitylmaleimide gave mixtures consisting mainly of dihydropyrazole **Vb** or **Vc** and the corresponding benzaldehyde (>90%). These results indicated that the main transformation pathway of labile sterically hindered azomethine imine in the presence of sterically hindered maleimide is formal 1,4-H-shift. No cycloaddition products were detected.

Analysis of possible modes of approach of *N*-arylmaleimides to azomethine imines generated from 6-aryl-2,2,4-trimethyl-1,5-diazabicyclo[3.1.0]hexanes confirmed our above assumption that these dipoles have *Z* configuration. As follows from Scheme 9, the presence of three methyl groups in the pyrazolidine fragment completely prevents *endo* approach of maleimide to azomethine imine, regardless of the configuration of the latter (*E* or *Z*) and structure of the former. *exo* Approach of *N*-mesitylmaleimide having two substituents in the *ortho* positions to *Z*-dipole is impossible because of strong steric interactions between the *ortho* substituents in the benzene ring of the imide and benzene ring of the dipole. On the other hand, such approach should be possible when the dipole has *E* configuration; in this case, considerable amount of the corresponding *trans* adduct would be formed. However, no cycloaddition products with *N*-mesitylmaleimide were detected. Likewise, *N*-arylmaleimides having no *ortho* substituents, e.g., *N*-(4-bromophenyl)maleimide, should react with *E*-azomethine imine to give *trans* adducts as a result of *exo* approach of the imide, but the reaction mixtures contained only the *cis* adducts which could be formed only from *Z*-azomethine imine.

Thus the stereoselectivity in the cycloaddition of *N*-arylmaleimides to azomethine imines generated by

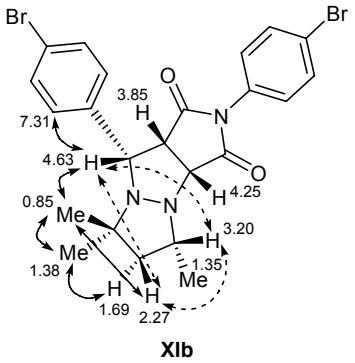
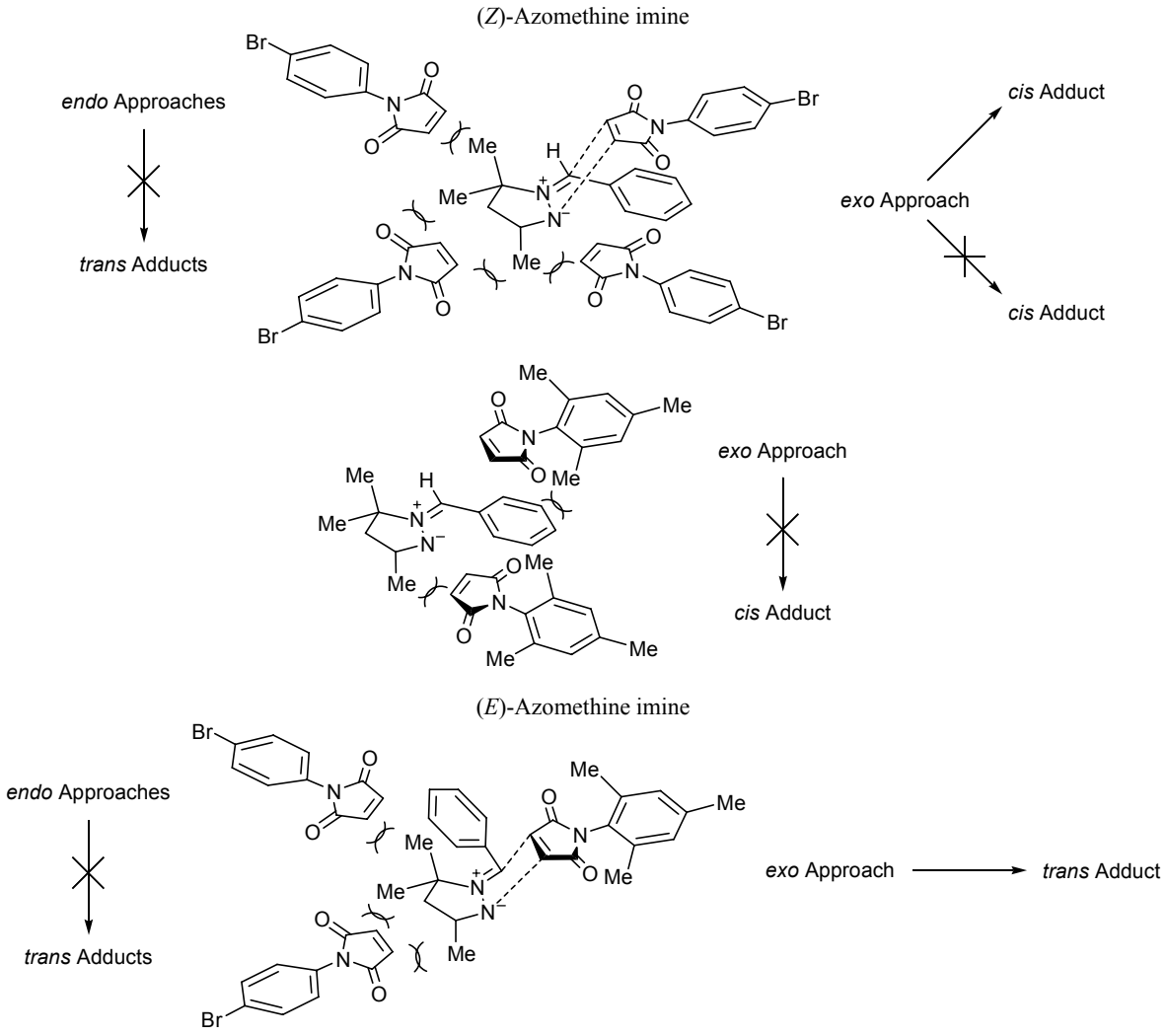



**Fig. 4.** Principal nuclear Overhauser effects in the $^1$H NOESY spectrum of compound **XIb**.

**Scheme 9.**




thermolysis of unsymmetrically substituted 6-aryl-1,5-diazabicyclo[3.1.0]hexanes is determined (as in the reactions with phenyl isocyanate) by dipolarophile approach at the less sterically hindered side of intermediate azomethine imine which is likely to have *Z* configuration.

## EXPERIMENTAL

The IR spectra were recorded on a UR-20 spectrometer from 1–2% solutions in chloroform. The $^{1}H$ and $^{13}C$ NMR spectra were measured on a Bruker DPX-300 spectrometer at 300.130 and 75.468 MHz, respectively, using $CDCl_3$ as solvent and reference ($CHCl_3$, δ 7.26 ppm; $CDCl_3$, $\delta_C$ 77.16 ppm) [14]. *N*-Arylmaleimides were synthesized according to standard procedure [15]. Aqueous sodium hypochlorite was prepared as described in [16]. Initial propane-1,3-diamines **IIa** and **IIb** were synthesized by hydrogenation of the corresponding 4,5-dihydropyrazoles [7] which were prepared in turn according to the procedures reported in [17–19].

**6-(4-Bromophenyl)-2-phenyl-1,5-diazabicyclo-[3.1.0]hexane (Ia).** A solution of 10.1 g (0.055 mol) of 4-bromobenzaldehyde in 80 ml of methanol was added dropwise over a period of 1.5 h to 8.2 g (0.055 mol) of 1-phenylpropane-1,3-diamine (**IIa**), maintaining the temperature at 0–5°C. The cooling bath was removed, the mixture was stirred for 1 h at room temperature and evaporated by half under reduced pressure, and 32 ml (0.061 mol) of a 1.90 N solution of sodium hypochlorite was added dropwise over a period of 1 h on cooling with ice water. The mixture was stirred for 1 h at room temperature, 150 ml of water and 100 ml of benzene were added, the organic phase was separated, and the aqueous phase was extracted with benzene

(3×40 ml). The extracts were combined with the organic phase, dried over $Na_2SO_4$, and evaporated by half under reduced pressure, and an equal amount of diethyl ether was added to the residue. The precipitate of compound **IVa** was filtered off, and the filtrate was evaporated. The solid residue was purified by colum chromatography on silica gel (Silicagel L, 35–70 μm, substrate–sorbent weight ratio 1:7, eluent hexane–ethyl acetate, 7:1). Diaziridine **Ia** isolated from the eluate contained 90% of the main substance; it was purified by recrystallization from diethyl ether with addition of hexane. Yield 2.6–2.8 g (15–16%), mp 143–144°C. IR spectrum, $cm^{-1}$: 3080, 3050, 2990, 2975, 2950, 1600, 1520, 1500, 1435, 1260, 1080, 1030. $^1H$ NMR spectrum, δ, ppm: 1.93 m (1H), 2.37 m (1H, $CH_2$, $J$ = 8.9, 13.4 Hz), 3.25 d.d.d (1H, $CH_2N$, $J$ = 8.0, 8.1, 12.0 Hz), 3.28 s (1H, NCHN), 3.60 m (1H, $CH_2N$, $J$ = 8.9, 12.0 Hz), 4.83 m (1H, C**H**Ph, $J$ = 8.6 Hz), 7.23–7.49 m (9H, $H_{arom}$). $^{13}C$ NMR spectrum, $\delta_C$, ppm: 30.8 ($CH_2$), 51.4 ($CH_2$), 57.1 (CH), 66.7 (CH), 122.7 ($C_{arom}$), 126.5 (2C, $CH_{arom}$), 127.1 ($CH_{arom}$), 128.6 (2C, $CH_{arom}$), 129.3 (2C, $CH_{arom}$), 131.5 (2C, $CH_{arom}$), 136.1 ($C_{arom}$), 143.6 ($C_{arom}$). Found, %: C 60.96; H 4.81; N 8.89. $C_{16}H_{15}BrN_2$. Calculated, %: C 60.94; H 4.92; N 8.74.

**2-(4-Bromophenyl)-4-phenyl-1,4,5,6-tetrahydropyrimidine (IVa).** $^1H$ NMR spectrum, δ, ppm: 1.82 m (1H, $CH_2$), 2.10 m (1H, $CH_2$), 3.50 m (2H, $CH_2N$), 4.62 d.d (1H, C**H**Ph, $J$ = 5.6, 7.5 Hz), 3.95–5.21 br.s (1H, NH), 7.28–7.41 m (5H, $H_{arom}$), 7.50 d (2H, $H_{arom}$, $J$ = 8.4 Hz), 7.60 d (2H, $H_{arom}$, $J$ = 8.4 Hz).

**6-(4-Bromophenyl)-2,2,4-trimethyl-1,5-diazabicyclo[3.1.0]hexane (Ib).** A solution of 10.0 g (0.086 mol) of 2-methylpentane-2,4-diamine (**IIb**) in 35 ml of methanol was cooled to 0–5°C, and 0.086 mol of 4-bromobenzaldehyde was added in two 8.0-g portions: the first portion was dissolved in 50 ml of methanol and added over a period of 0.5 h, and the second portion was dissolved in 100 ml of methanol and added over a period of 1.5 h. The cooling bath was removed, the mixture was stirred for 1 h at room temperature and evaporated by half under reduced pressure, and 45 ml (0.106 mol) of a 2.35 N solution of sodium hypochlorite was added dropwise to the residue over a period of 0.5 h on cooling with ice water. The mixture was stirred for 1 h at room temperature, 150 ml of water and 100 ml of benzene were added, the organic phase was separated, and the aqueous phase was extracted with benzene (3×40 ml). The combined extracts were dried over sodium sulfate, the solvent was distilled off under reduced pressure, and the residue was purified by column chromatography on silica gel (Silicagel L, 160–200 μm, substrate–sorbent weight ratio 1:7, gradient elution: hexane, hexane–ethyl acetate, 15:1). We isolated 15 g of a mixture of products containing ~90% of diaziridine **Ib**. Compound **Ib** was purified by recrystallization from hexane. Yield 7.3 g (30%), mp 73°C. IR spectrum, ν, $cm^{-1}$: 3035, 2980, 2945, 2920, 2880, 1605, 1500, 1470, 1430, 1385, 1345, 1305, 1260, 1184, 1125, 1110, 1080, 1050, 1025. $^1H$ NMR spectrum, δ, ppm: 1.37 s (3H, Me), 1.40 d (3H, Me, $J$ = 7.2 Hz), 1.47 s (3H, Me), 1.61 m (1H, $CH_2$, $J$ = 13.6 Hz), 2.01 d.d (1H, $CH_2$, $J$ = 9.2, 13.6 Hz), 3.14 s (1H, NCHN), 3.84 m (1H, C**H**Me, $J$ = 7.6, 9.2 Hz), 7.24 d (2H, $H_{arom}$, $J$ = 7.9 Hz), 7.44 d (2H, $H_{arom}$, $J$ = 7.9 Hz). $^{13}C$ NMR spectrum, $\delta_C$, ppm: 23.7 ($CH_3$), 26.6 ($CH_3$), 31.1 ($CH_3$), 43.4 ($CH_2$), 57.8 (CH), 62.3 (CH), 65.7 (**C**$Me_2$), 122.4 ($C_{arom}$), 129.1 (2C, $CH_{arom}$), 131.5 (2C, $CH_{arom}$), 136.8 ($C_{arom}$). Found, %: C 60.94; H 4.92; N 8.74. $C_{16}H_{15}BrN_2$. Calculated, %: C 60.96; H 4.81; N 8.89.

**6-(4-Methoxyphenyl)-2,2,4-trimethyl-1,5-diazabicyclo[3.1.0]hexane (Ic).** A solution of 9.4 g (0.069 mol) of 4-methoxybenzaldehyde in 35 ml of methanol was added dropwise over a period of 30 min to a solution of 8.0 g (0.069 mol) of 2-methylpentane-2,4-diamine (**IIb**) in 35 ml of methanol, cooled to 0–5°C. The cooling bath was removed, and the mixture was stirred for 1 h at room temperature. The resulting solution was cooled with ice water, 30 ml (0.073 mol) of a 2.44 N solution of sodium hypochlorite was added dropwise over a period of 20 min, and the mixture was stirred for 1 h at room temperature. The organic phase was separated, and the aqueous phase was treated with chloroform (3×20 ml). The extract was dried over $Na_2SO_4$, the solvent was distilled off, and the oily residue was purified by column chromatography (Silicagel L, 100–200 μm, substrate–sorbent weight ratio 1:25, eluent hexane–ethyl acetate). The oily substance thus isolated was dissolved in a minimal amount of ethyl acetate–hexane (1:1), and the solution was frozen with liquid nitrogen. Yield 1.9 g (12%), mp 54–55°C. $^1H$ NMR spectrum, δ, ppm: 1.37 s (3H, Me), 1.40 d (3H, Me, $J$ = 7.2 Hz), 1.46 s (3H, Me), 1.60 d.d (1H, $CH_2$, $J$ = 1.4, 13.6 Hz), 2.01 d.d (1H, $CH_2$, $J$ = 9.4, 13.6 Hz), 3.14 s (1H, NCHN), 3.77 s (3H, OMe), 3.82 d.d.q (1H, C**H**Me, $J$ = 1.4, 7.2, 9.4 Hz), 6.84 d (2H, $H_{arom}$, $J$ = 8.7 Hz), 7.29 d (2H, $H_{arom}$, $J$ = 8.7 Hz). $^{13}C$ NMR spectrum, $\delta_C$, ppm: 23.8 ($CH_3$), 26.6 ($CH_3$), 31.2 ($CH_3$), 43.5 ($CH_2$), 55.4 ($OCH_3$), 58.2 (CH), 62.1 (CH), 65.8 (**C**$Me_2$), 113.9 (2C, $CH_{arom}$), 128.5 (2C, $CH_{arom}$), 129.9 ($C_{arom}$), 159.9 ($C_{arom}$). Found, %:

C 72.37; H 8.51; N 12.14. $C_{14}H_{20}N_2O$. Calculated, %: C 72.38; H 8.68; N 12.06.

**Thermolysis of diazabicyclohexanes Ia–Ic in the absence of dipolarophiles.** A 0.1–1.0 M solution of diazabicyclohexane **Ia**–**Ic** in *p*- or *o*-xylene was heated under stirring at a bath temperature of 140 and 145°C, respectively, over a period of 20–25 min. The mixture was cooled, and the solvent was distilled off under reduced pressure. The ratio of isomers **V** and **VI** in the reaction mixture did not depend on the concentration of the initial diazabicyclohexane (according to the $^1$H NMR data).

**1-(4-Bromobenzyl)-3-phenyl-4,5-dihydro-1*H*-pyrazole (Va) and 1-(4-bromobenzyl)-5-phenyl-4,5-dihydro-1*H*-pyrazole (VIa).** Isomer ratio **Va**/**VIa** 48:52. Compound **Va**: $^1$H NMR spectrum, δ, ppm: 2.95–3.04 m (2H, $CH_2$), 3.05–3.15 m (2H, $CH_2$), 4.29 s (2H, $CH_2$), 7.16 d (2H, $H_{arom}$, $J$ = 8.3 Hz), 7.27–7.50 (5H, $H_{arom}$), 7.65 m (2H, $H_{arom}$, $J$ = 8.3 Hz). Compound **VIa**: $^1$H NMR spectrum, δ, ppm: 2.67 m (1H, $CH_2$), 2.95–3.08 m (1H, $CH_2$), 3.79 d (1H, $CH_2$, $J$ = 14.0 Hz), 4.04 d.d (1H, $CH_2$, $J$ = 14.6, 10.1 Hz), 4.23 d (1H, $CH_2$, $J$ = 14.0 Hz), 6.76 s (1H, CH), 7.27–7.50 (9H, $H_{arom}$).

**1-(4-Bromobenzyl)-3,5,5-trimethyl-4,5-dihydro-1*H*-pyrazole (Vb).** $^1$H NMR spectrum, δ, ppm: 1.19 s (6H, Me), 1.91 s (3H, Me), 2.47 s (2H, $CH_2$), 3.90 s (2H, $CH_2$), 7.30 d (2H, $H_{arom}$, $J$ = 8.3 Hz), 7.43 d (2H, $H_{arom}$, $J$ = 8.3 Hz).

**1-(4-Methoxybenzyl)-3,5,5-trimethyl-4,5-dihydro-1*H*-pyrazole (Vc).** $^1$H NMR spectrum, δ, ppm: 1.21 s (6H, Me), 1.94 s (3H, Me), 2.48 s (2H, $CH_2$), 3.80 s (3H, OMe), 3.95 s (2H, $CH_2$), 6.88 d (2H, $H_{arom}$, $J$ = 8.7 Hz), 7.37 d (2H, $H_{arom}$, $J$ = 8.7 Hz).

**Thermolysis of diazabicyclohexanes Ia and Ib in the presence of dipolarophiles.** An equivalent amount of the corresponding dipolarophile was added to a solution of diazabicyclohexane **Ia** or **Ib** in 2–3 ml of *p*- or *o*-xylene, and the mixture was heated under stirring at a bath temperature of 140–145°C over a period of 25 min. The mixture was cooled, and the solvent was distilled off under reduced pressure.

***rel*-(3*R*,7*S*)-3-(4-Bromophenyl)-2,7-diphenylperhydropyrazolo[1,2-*a*][1,2,4]triazol-1-one (VIIa), *rel*-(3*R*,7*R*)-3-(4-bromophenyl)-2,7-diphenylperhydropyrazolo[1,2-*a*][1,2,4]triazol-1-one (VIIIa), *rel*-(3*R*,5*R*)-3-(4-bromophenyl)-2,5-diphenylperhydropyrazolo[1,2-*a*][1,2,4]triazol-1-one (IXa), and *rel*-(3*R*,5*S*)-3-(4-bromophenyl)-2,5-diphenylperhydropyrazolo[1,2-*a*][1,2,4]triazol-1-one (Xa)** were obtained from 278 mg (0.88 mmol) of diazabicyclohexane **Ia** and 105 mg (0.88 mmol) of phenyl isocyanate. The product mixture was separated by column chromatography (Silicagel L, 35–70 μm, substrate–sorbent weight ratio 1:160, eluent hexane–ethyl acetate, 8:1). The separation process was monitored by thin-layer chromatography (Silufol UV-254; hexane–ethyl acetate, 5:1; double elution; development with iodine vapor). The overall preparative yield of all isomers was 297 mg (78%). According to the $^1$H NMR data, the ratio of isomers **Xa**/**IXa**/**VIIIa**/**VIIa** was ~0.97:1.0:0.36:1.19.

Compound **VIIa**. Yield 64 mg (17%), mp 168–170°C. IR spectrum, ν, cm$^{-1}$: 3080, 3040 s, 2970, 2940, 2920, 1715 s (C=O), 1600, 1530, 1510, 1425, 1380 s, 1350, 1320, 1290, 1255, 1180, 1115, 1060, 1040. $^1$H NMR spectrum, δ, ppm: 2.18 m (1H, $CH_2$), 2.77 m (1H, $CH_2$), 2.90 m (1H, $CH_2$), 3.46 m (1H, $CH_2$), 5.28 m (1H, C**H**Ph), 5.84 s (1H, CH), 7.05–7.13 m (1H, $H_{arom}$), 7.18–7.39 m (9H, $H_{arom}$), 7.44–7.54 m (4H, $H_{arom}$). $^{13}$C NMR spectrum, δ, ppm: 36.0 ($CH_2$), 54.4 ($CH_2$), 59.8 (CH), 78.3 (CH), 119.7 (2C, $CH_{arom}$), 123.0 ($C_{arom}$), 124.4 ($CH_{arom}$), 125.9 (2C, $CH_{arom}$), 127.1 ($CH_{arom}$), 128.6 (4C, $CH_{arom}$), 129.3 (2C, $CH_{arom}$), 132.2 (2C, $CH_{arom}$), 137.1 ($C_{arom}$), 137.9 ($C_{arom}$), 143.1 ($C_{arom}$), 161.1 (C=O). Found, %: C 63.39; H 5.00; N 9.51. $C_{23}H_{20}BrN_3O$. Calculated, %: C 63.60; H 4.64; N 9.67.

Compound **VIIIa**. Yield 3 mg (0.8%). $^1$H NMR spectrum, δ, ppm: 2.10 m (1H, $CH_2$), 2.35 m (1H, $CH_2$), 2.69 m (2H, $CH_2$), 5.24 m (1H, C**H**Ph), 6.37 s (1H), 7.08–7.51 m (14H, $H_{arom}$).

Compound **IXa**. Yield 30 mg (8%), mp 142–143°C. IR spectrum, ν, cm$^{-1}$: 3060 s, 3040 s, 2900, 1715 s (C=O), 1600, 1530, 1510, 1470, 1425, 1380 s, 1325, 1295, 1260, 1160, 1100, 1060, 1040. $^1$H NMR spectrum, δ, ppm: 2.17 m (1H, $CH_2$), 2.55 m (1H, $CH_2$), 3.46 m (1H, $CH_2$, $J$ = 3.1 Hz), 3.75 d.d (1H, C**H**Ph, $J$ = 7.1, 10.7 Hz), 4.06 m (1H, $CH_2$), 5.62 s (1H, CH), 7.02–7.11 m (3H, $H_{arom}$), 7.30 d (2H, $H_{arom}$, $J$ = 7.6 Hz), 7.40–7.49 m (9H, $H_{arom}$). $^{13}$C NMR spectrum, $\delta_C$, ppm: 36.2 ($CH_2$), 44.8 ($CH_2$), 67.9 (CH), 75.6 (CH), 118.7 (2C, $CH_{arom}$), 123.0 ($C_{arom}$), 124.0 ($CH_{arom}$), 128.2 (2C, $CH_{arom}$), 128.3 (2C, $CH_{arom}$), 128.7 ($CH_{arom}$), 129.2 (2C, $CH_{arom}$), 129.3 (2C, $CH_{arom}$), 132.1 (2C, $CH_{arom}$), 136.5 ($C_{arom}$), 137.9 ($C_{arom}$), 138.2 ($C_{arom}$), 161.6 (C=O). Found, %: C 63.41; H 4.62; N 9.48. $C_{23}H_{20}BrN_3O$. Calculated, %: C 63.60; H 4.64; N 9.67.

Compound **Xa**. Yield 50 mg (13%), mp 121–122°C. IR spectrum, ν, cm$^{-1}$: 3090, 3045 s, 2980,

2960, 1710 s (C=O), 1600, 1530, 1520, 1430, 1400 s, 1255, 1180, 1110, 1080, 1060, 1040. $^1$H NMR spectrum, δ, ppm: 2.13 m (1H, $CH_2$), 2.56 m (1H, $CH_2$), 3.67 m (1H, $CH_2$), 3.94 d.d (1H, C**H**Ph, $J$ = 7.1, 10.7 Hz), 6.17 s (1H, CH), 6.75–7.33 m (14H, $H_{arom}$). $^{13}$C NMR spectrum, $\delta_C$, ppm: 36.6 br.s ($CH_2$), 44.5 ($CH_2$), 63.3 br.s (CH), 75.0 (CH), 121.1 (2C, $CH_{arom}$), 123.3 ($C_{arom}$), 124.6 ($CH_{arom}$), 127.0 ($CH_{arom}$), 127.5 (2C, $CH_{arom}$), 128.1 (2C, $CH_{arom}$), 128.9 (2C, $CH_{arom}$), 129.8 (2C, $CH_{arom}$), 132.4 (2C, $CH_{arom}$), 136.1 br.s ($C_{arom}$), 137.4 ($C_{arom}$), 139.6 ($C_{arom}$), 162.3 (C=O). Found, %: C 63.62; H 4.74; N 9.55. $C_{23}H_{20}BrN_3O$. Calculated, %: C 63.60; H 4.64; N 9.67.

***rel*-(3*R*,7*R*)-3-(4-Bromophenyl)-5,5,7-trimethyl-2-phenylperhydropyrazolo[1,2-*a*][1,2,4]triazol-1-one (VIIb), *rel*-(3*R*,5*S*)-3-(4-bromophenyl)-5,7,7-trimethyl-2-phenylperhydropyrazolo[1,2-*a*][1,2,4]triazol-1-one (IXb), and *rel*-(3*R*,5*R*)-3-(4-bromophenyl)-5,7,7-trimethyl-2-phenylperhydropyrazolo[1,2-*a*][1,2,4]triazol-1-one (Xb)** were obtained from 267 mg (0.95 mmol) of diazabicyclohexane **Ib** and 114 mg (0.95 mmol) of phenyl isocyanate. The product mixture was separated by column chromatography (Silicagel L, 35–70 μm, substrate–sorbent weight ratio 1:125, hexane–ethyl acetate, 10:1). The separation process was monitored by TLC (Silufol UV-254, hexane–ethyl acetate, 5:1, double elution, development with iodine vapor). The overall preparative yield of all isomers was 297 mg (65%). According to the $^1$H NMR data, the isomer ratio **Xb**/**IXb**/**VIIb** was ~8.6:2.0:1.0.

Compound **VIIb**. Yield 139 mg (37%), mp 147–148°C. IR spectrum, ν, cm$^{-1}$: 3080 s, 2980 s, 2945, 2880, 1705 s (C=O), 1600, 1535, 1500, 1410, 1385 s, 1365, 1260, 1240, 1220, 1180, 1110, 1060, 1030. $^1$H NMR spectrum, δ, ppm: 0.98 s (3H, Me), 1.31 d (3H, Me, $J$ = 6.4 Hz), 1.36 s (3H, Me), 1.68 m (1H, $CH_2$), 2.18 d.d (1H, $CH_2$, $J$ = 7.7, 12.1 Hz), 4.22 m (1H, C**H**Me, $J$ = 6.4, 7.7 Hz), 5.61 s (1H, C**H**Ar), 7.04 m (1H, $H_{arom}$), 7.22–7.31 m (4H, $H_{arom}$), 7.43–7.51 m (4H, $H_{arom}$). $^{13}$C NMR spectrum ($CDCl_3$), $\delta_C$, ppm: 19.4 ($CH_3$), 22.5 ($CH_3$), 25.1 ($CH_3$), 48.6 ($CH_2$), 52.2 (CHMe), 64.3 ($CMe_2$), 73.3 (CHAr), 118.7 (2C, $CH_{arom}$), 122.7 ($C_{arom}$), 123.7 ($CH_{arom}$), 128.3 (2C, $CH_{arom}$), 129.2 (2C, $CH_{arom}$), 132.2 (2C, $CH_{arom}$), 137.7 ($C_{arom}$), 138.2 ($C_{arom}$), 161.4 (C=O). Found, %: C 59.71; H 5.29; N 10.26. $C_{20}H_{22}BrN_3O$. Calculated, %: C 60.01; H 5.54; N 10.50.

Compound **IXb**. Yield 20 mg (5%), mp 138–139°C. IR spectrum, ν, cm$^{-1}$: 3080 s, 2980 s, 2940, 2870, 1705 s (C=O), 1600, 1535, 1510, 1420, 1395 s, 1365, 1300, 1280, 1260, 1240, 1200, 1110, 1080, 1020. $^1$H NMR spectrum, δ, ppm: 1.26 d (3H, Me, $J$ = 5.9 Hz), 1.40 s (3H, Me), 1.71 s (3H, Me), 1.75 d.d (1H, $CH_2$, $J$ = 10.0, 12.1 Hz), 2.13 d.d (1H, $CH_2$, $J$ = 7.0, 12.1 Hz), 3.10 d.d.q (2H, C**H**Me, $J$ = 5.9, 7.0, 10.0 Hz), 5.62 s (1H, ArC**H**), 7.02 m (1H, $H_{arom}$), 7.20–7.29 m (4H, $H_{arom}$), 7.37 d (2H, $H_{arom}$, $J$ = 8.1 Hz), 7.44 d (2H, $H_{arom}$, $J$ = 8.4 Hz). $^{13}$C NMR spectrum, $\delta_C$, ppm: 17.5 ($CH_3$), 25.7 ($CH_3$), 31.3 ($CH_3$), 50.7 ($CH_2$), 60.2 (**C**HMe), 61.6 (**C**Me$_2$), 76.3 (**C**HAr), 120.0 (2C, $CH_{arom}$), 122.8 ($C_{arom}$), 123.8 ($CH_{arom}$), 128.6 (2C, $CH_{arom}$), 129.1 (2C, $CH_{arom}$), 132.0 (2C, $CH_{arom}$), 137.9 ($C_{arom}$), 138.3 ($C_{arom}$), 157.1 (C=O). Found, %: C 59.64; H 5.45; N 10.40. $C_{20}H_{22}BrN_3O$. Calculated, %: C 60.01; H 5.54; N 10.50.

Compound **Xb**. Yield 16 mg (4%), purity ~90%. $^1$H NMR spectrum, δ, ppm: 0.65 d (3H, Me, $J$ = 6.1 Hz), 1.55 s (3H, Me), 1.58 s (3H, Me), 1.73 d.d (1H, $CH_2$, $J$ = 7.9, 12.3 Hz), 2.14 d.d (1H, $CH_2$, $J$ = 7.4, 12.3 Hz), 3.11 d.d.q (2H, C**H**Me, $J$ = 6.1, 7.4, 7.9 Hz), 6.04 s (1H, ArC**H**), 7.02 m (1H, $H_{arom}$), 7.14–7.35 m (6H, $H_{arom}$), 7.49 d (2H, $H_{arom}$, $J$ = 8.4 Hz).

***rel*-(3a*R*,5*R*,9*S*,9a*S*)-2,9-Bis(4-bromophenyl)-5,7,7-trimethylperhydropyrazolo[1,2-*a*]pyrrolo[3,4-*c*]pyrazole-1,3-dione (XIb), *rel*-(3a*R*,7*S*,9*S*,9a*S*)-2,9-bis(4-bromophenyl)-5,5,7-trimethylperhydropyrazolo[1,2-*a*]pyrrolo[3,4-*c*]pyrazole-1,3-dione (XIIb), and *rel*-(3a*R*,7*R*,9*S*,9a*S*)-2,9-bis(4-bromophenyl)-5,5,7-trimethylperhydropyrazolo[1,2-*a*]pyrrolo[3,4-*c*]pyrazole-1,3-dione (XIIIb)** were obtained from 202 mg (0.72 mmol) of diazabicyclohexane **Ib** and 181 mg (0.72 mmol) of *N*-(4-bromophenyl)maleimide. The isomer mixture was separated by column chromatography (Silicagel L, 35–70 μm, substrate–sorbent weight ratio 1:200, gradient elution with hexane–ethyl acetate, 5:1 and 3:1). The separation process was monitored by TLC (Silufol UV-254, hexane–ethyl acetate, 3:1, development with iodine vapor). The isomer ratio **XIb**/**XIIb**/**XIIIb** in the reaction mixture was ~2.45:1.0:0.9 ($^1$H NMR data).

Compound **XIb**. Yield 70 mg (25%), mp 205–206°C (decomp.). IR spectrum, ν, cm$^{-1}$: 3030, 2970, 2880, 1800, 1720 v.s (C=O), 1600, 1495 s, 1380 s, 1300, 1250, 1230, 1190 s, 1160, 1120, 1070, 1020. $^1$H NMR spectrum, δ, ppm: 0.85 s (3H, Me), 1.35 d (3H, Me, $J$ = 6.2 Hz), 1.38 s (3H, Me), 1.69 d.d (1H, $CH_2$, $J$ = 6.9, 12.7 Hz), 2.27 d.d (1H, $CH_2$, $J$ = 9.7, 12.7 Hz), 3.20 d.d.q (1H, C**H**Me, $J$ = 6.2, 6.9, 9.7 Hz), 3.85 d.d (1H, CH, $J$ = 7.5, 9.9 Hz), 4.25 d (1H, CH, $J$ =

7.5 Hz), 4.63 d (1H, C**H**Ar, $J$ = 9.9 Hz), 7.02 d (2H, $H_{arom}$, $J$ = 8.5 Hz), 7.31 d (2H, $H_{arom}$, $J$ = 8.2 Hz), 7.45 d (2H, $H_{arom}$, $J$ = 8.2 Hz), 7.54 d (2H, $H_{arom}$, $J$ = 8.5 Hz). $^{13}$C NMR spectrum, $\delta_C$, ppm: 20.4 ($CH_3$), 26.5 ($CH_3$), 32.7 ($CH_3$), 47.2 ($CH_2$), 52.5 (CH), 59.4 (CH), 63.5 (C), 65.4 (CH), 66.4 (CH), 122.0 ($C_{arom}$), 122.3 ($C_{arom}$), 127.6 (2C, $CH_{arom}$), 129.4 (2C, $CH_{arom}$), 130.7 ($C_{arom}$), 131.8 (2C, $CH_{arom}$), 132.3 (2C, $CH_{arom}$), 138.1 ($C_{arom}$), 172.9 (C=O), 174.4 (C=O). Found, %: C 51.66; H 4.41; N 7.58. $C_{23}H_{23}Br_2N_3O_2$. Calculated, %: C 51.80; H 4.35; N 7.88.

Compound **XIIb**. Yield 15 mg (4%), purity ~85%. $^1$H NMR spectrum, δ, ppm: 1.21 d (3H, Me), 1.49 s (3H, Me), 1.52 s (3H, Me), 1.67 d.d (1H, $CH_2$, $J$ = 6.4, 12.8 Hz), 2.20 d.d (1H, $CH_2$, $J$ = 9.6, 12.8 Hz), 3.00 d.d.q (1H, C**H**Me, $J$ = 6.2, 6.4, 9.6 Hz), 4.13 d.d (1H, CH, $J$ = 9.0, 9.2 Hz), 4.37 d (1H, CH, $J$ = 9.0 Hz), 4.62 d (1H, C**H**Ar, $J$ = 9.2 Hz), 6.66 d (2H, $H_{arom}$, $J$ = 7.3 Hz), 7.31 d (2H, $H_{arom}$, $J$ = 7.3 Hz), 7.43 d (2H, $H_{arom}$, $J$ = 8.3 Hz), 7.49 d (2H, $H_{arom}$, $J$ = 8.3 Hz).

Compound **XIIIb**. Some signals in the $^1$H NMR spectrum of the reaction mixture, δ, ppm: 0.65 d (3H, Me, $J$ = 6.2 Hz), 4.20 d (1H, CH, $J$ = 5.0 Hz).

## REFERENCES


1. Grashey, R., *1,3-Dipolar Cycloaddition Chemistry*, Padwa, A., Ed., New York: Wiley, 1984, chap. 1, p. 733; Rodina, L.L., Kolberg, A., and Schulze, B., *Heterocycles*, 1998, vol. 49, p. 587.
2. Koptelov, Yu.B., Kim, M.Kh., Molchanov, A.P., and Kostikov, R.R., *Russ. J. Org. Chem*., 1999, vol. 35, p. 110.
3. Trofimov, V.V., Koptelov, Yu.B., Molchanov, A.P., and Kostikov, R.R., *Zh. Org. Khim*., 1994, vol. 30, p. 1389.
4. Molchanov, A.P., Sipkin, D.I., Koptelov, Yu.B., and Kostikov, R.R., *Russ. J. Org. Chem*., 2001, vol. 37, p. 841.
5. Schulz, M. and West, G., *J. Prakt. Chem*., 1970, vol. 312, p. 161; Geissler, G., Menz, I., Angermüller, K., and Tomaschewski, G., *J. Prakt. Chem*., 1983, vol. 325, p. 197; Geissler, G., Fust, W., Krüger, B., and Tomaschewski, G., *J. Prakt. Chem*., 1983, vol. 325, p. 205.
6. Koptelov, Yu.B. and Saik, S.P., *Russ. J. Org. Chem*., 2006, vol. 42, p. 1501.
7. Kost, A.N., Golubeva, G.A., and Terent'ev, A.P., *Dokl. Akad. Nauk SSSR*, 1959, vol. 129, p. 1300.
8. Molchanov, A.P., Sipkin, D.I., Koptelov, Yu.B., Kopf, J., and Kostikov, R.R., *Russ. J. Org. Chem*., 2003, vol. 39, p. 1338.
9. Molchanov, A.P., Sipkin, D.I., Koptelov, Yu.B., Kopf, J., and Kostikov, R.R., *Russ. J. Org. Chem*., 2004, vol. 40, p. 67.
10. Gnichtel, H. and Köhler, C., *Justus Liebigs Ann. Chem*., 1990, p. 775.
11. Gomtsyan, A., Koenig, R.J., and Lee, C.-H., *J. Org. Chem*., 2001, vol. 66, p. 3613.
12. Turk, C., Svete, J., Stanovnik, B., Golič, L., Golič-Grdadolnič, S., Golobič, A., and Selič, L., *Helv. Chim. Acta*, 2001, vol. 84, p. 146.
13. Frisch, M.J., Trucks, G.W., Schlegel, H.B., Scuseria, G.E., Robb, M.A., Cheeseman, J.R., Montgomery, J.A., Vreven, T., Jr., Kudin, K.N., Burant, J.C., Millam, J.M., Iyengar, S.S., Tomasi, J., Barone, V., Mennucci, B., Cossi, M., Scalmani, G., Rega, N., Petersson, G.A., Nakatsuji, H., Hada, M., Ehara, M., Toyota, K., Fukuda, R., Hasegawa, J., Ishida, M., Nakajima, T., Honda, Y., Kitao, O., Nakai, H., Klene, M., Li, X., Knox, J.E., Hratchian, H.P., Cross, J.B., Adamo, C., Jaramillo, J., Gomperts, R., Stratmann, R.E., Yazyev, O., Austin, A.J., Cammi, R., Pomelli, C., Ochterski, J.W., Ayala, P.Y., Morokuma, K., Voth, G.A., Salvador, P., Dannenberg, J.J., Zakrzewski, V.G., Dapprich, S., Daniels, A.D., Strain, M.C., Farkas, O., Malick, D.K., Rabuck, A.D., Raghavachari, K., Foresman, J.B., Ortiz, J.V., Cui, Q., Baboul, A.G., Clifford, S., Cioslowski, J., Stefanov, B.B., Liu, G., Liashenko, A., Piskorz, P., Komaromi, I., Martin, R.L., Fox, D.J., Keith, T., Al-Laham, M.A., Peng, C.Y., Nanayakkara, A., Challacombe, M., Gill, P.M.W., Johnson, B., Chen, W., Wong, M.W., Gonzalez, C., and Pople, J.A., *GAUSSIAN-03*, Pittsburgh PA: Gaussian, 2003.
14. Gottlieb, H.E., Kotlyar, V., and Nudelman, A., *J. Org. Chem*., 1997, vol. 62, p. 7512.
15. Kanhaiya, S.R., Blanton, C., and De Witt, S., *J. Org. Chem*., 1982, vol. 47, p. 502.
16. Karyakin, Yu.V., *Chistye khimicheskie reaktivy* (Pure Chemicals), Moscow: Goskhimizdat, 1947, p. 408.
17. Ioffe, B.V. and Burmanova, N.B., *Khim. Geterotsikl. Soedin*., 1971, p. 1225.
18. Curtius, Th. and Wirsing, F., *J. Prakt. Chem*., 1894, vol. 50, p. 531.
19. Denmark, S.E. and Kim, S.H., *Synthesis*, 1992, p. 229.