Chiral Ureas with Two Electronegative Substituents at 1-N: An Unusual Case of Coexisting Pyramidal and Almost Planar 1-N Atoms in the Same Crystal

OLEG V. SHISHKIN,¹ VASILY G. SHTAMBURG,² ROMAN I. ZUBATYUK,¹ DMITRIY A. OLEFIR,²
ALEXANDER V. TSYGANKOV,² ALEXANDER V. PROSYANIK,² ALEXANDER V. MAZEPA,³ AND REMIR G. KOSTYANOVSKY^{1,4*}

¹STC "Institute for Single Crystals", National Academy of Sciences of Ukraine, Kharkov, Ukraine

²Ukrainian State Chemical Technological University, Dnepropetrovsk, Ukraine

³A.V. Bogatsky Physiko-Chemical Institute, National Academy of Sciences of Ukraine, Odessa, Ukraine

⁴Laboratory of Stereochemistry, N.N. Semenov Institute of Chemical Physics, Russian Academy of Sciences, Moscow, Russian Federation

Dedicated to the 160th Anniversary of Louis Pasteur's Discovery

ABSTRACT XRD studies of structure of *N*-acetoxy-*N*-methoxyurea and *N,N*-bis(methoxycarbonyl)-*N*-methoxyimide have revealed that in *N*-methoxy-*N*-X-ureas (X = OAc, Cl, OMe, N⁺C₅H₅) the additional shortening of N—OMe bond took place, which arising from an $n_{O(OMe)}-\sigma^*_{N-X}$ anomeric orbital interaction. XRD studies of *N*-chloro-*N*-ethoxyurea crystal have revealed the presence of two kinds of anomeric nitrogen configuration in the O—N—Cl group in the form of a pyramidal configuration and a planar configuration for same 1-N nitrogen atom. XRD studies of *N*-4-chlorobenzoyloxy-*N*-ethoxyurea have revealed that the degree of pyramidal of the 1-N nitrogen in *N*-aroyloxy-*N*-alkoxyureas is tuned by orientation of benzoyl group with respect to the N—O bond, which in turn depends of size of *N*-alkoxy group. *Chirality* 21:642–647, 2009. © 2008 Wiley-Liss, Inc.

KEY WORDS: *N*-acyloxy-*N*-alkoxyureas; *N*-chloro-*N*-alkoxyureas; nitrogen configuration; bond length

INTRODUCTION

The bonding of the nitrogen atom to two electronegative substituents possessing lone electron pairs (e.g., alkoxy groups in *N,N*-dialkoxy-*N*-*tert*-alkylamines¹) stabilizes pyramidal of the nitrogen atom and increases its inversion barrier.^{1–4} The pyramidal of nitrogen in the O—N—X geminal system (X = OC(O)R, OAlk, N⁺C₅H₅, Cl) in *N*-acyloxy-*N*-alkoxycarbamates,⁵ *N*-acyloxy-*N*-alkoxyureas,^{5,6} *N,N*-dialkoxyureas,⁶ *N*-alkoxy-*N*-(1-pyridinium)urea salts,⁶ and *N*-chloro-*N*-alkoxyureas⁷ has been established by XRD study of their structure.

In these compounds, the shortening of the N—OAlk bond and the elongation of the N—X bond are observed, which we regard as being an $n_{O(Alk)}-\sigma^*_{N-X}$ orbital interaction, called the anomeric effect.⁸ Most prominently, this phenomenon arises in *N*-alkoxy-*N*-(1-pyridinium)-*N*-*tert*-alkylamines salts.⁴ In the case of *N*-methoxy-*N*-(pyridinium)-*N*-*tert*-alkylamine salt,⁴ it was observed that the N—OMe bond shortened up to 1.41 Å,⁶ compared with 1.50 Å in MeNH—OMe⁹ and up to 1.46 Å for the N—O bond in *O*-ethyl-*N*-9-triptycylhydroxylamine.¹⁰ Also in this salt,⁴ elongation of the N—N⁺ bond to 1.47 Å was found when compared with 1.45 Å for N—N bond length in hydrazine.¹¹ The N—N⁺ bond length is similar to N—N bond length, which is observed in NF₂—NF₂ (1.49 Å¹²) and (MeO)₂N—N(OMe)₂ (1.48 Å¹³) where this elongation

is caused by $n_F-\sigma^*_{N-N}$ and $n_{O(OMe)}-\sigma^*_{N-N}$ anomeric interactions,¹³ respectively.

This N—N⁺ bond destabilization by the $n_{O(OMe)}-\sigma^*_{N-N}$ interaction causes possibility of nucleophilic substitution of pyridinium group in *N*-methoxy-*N*-(pyridinium)-*N*-*tert*-alkylamine salts⁴ and *N*-alkoxy-*N*-(pyridinium)-*N'*,*N'*-dimethylurea salt.⁶

The high electronegativity of O- and X-ligands supports the pyramidal configuration of the nitrogen in O—N—X geminal systems.⁸ However, it is possible that the degree of 1-N nitrogen pyramidal may depend of the nature of the *N*-alkoxy group. Because of this phenomenon, it is difficult to carry out the correct analysis of the X-substituent effect on the N—OAlk bond length for *N*-acyloxy-*N*-alkoxyurea with different kinds of *N*-alkoxy groups. The correct analysis only becomes possible for the series of *N*-alkoxy-*N*-X-ureas having the same *N*-alkoxy group. But for

Contract grant sponsor: Russian Foundation for Basic Research; Contract grant number: 06-030-32840.

Contract grant sponsor: Russian Academy of Sciences.

*Correspondence to: Remir G. Kostyanovsky, N.N. Semenov Institute of Chemical Physics, Russian Academy of Sciences, Moscow 119991, Russian Federation. E-mail: kost@center.chph.ras.ru

Received for publication 22 May 2008; Accepted 8 September 2008

DOI: 10.1002/chir.20668

Published online 31 October 2008 in Wiley InterScience (www.interscience.wiley.com).

the series of simplest *N*-methoxy-*N*-X-ureas (X = OAc (**1**), Cl (**2**), OMe (**3**), $\text{N}^+\text{C}_5\text{H}_5$ (**4**)) only the structure of *N*-acetoxy-*N*-methoxyurea **1**⁷ remains unstudied at this time.

EXPERIMENTAL

***N,N*-bis(methoxycarbonyl)-*N*-methoxyimide. (5)** was obtained as colorless crystals from methyl *N,N*-dimethoxycarbamate¹⁴ by storing for 6 mo at 15°C, m.p. 52–54°C. ¹H NMR (300 MHz, CDCl₃) δ : 3.83 (s, 3H, NOME); 3.92 (s, 6H, CO₂Me). MS (FAB, m/z , I_{rel} (%)): 164 [$\text{M}+\text{H}$]⁺ (100); 149 (21.8). Found (%): C, 36.73; H, 5.77; N, 8.49. Calc. for C₅H₉NO₅(5): C, 36.81; H, 5.56; N, 8.59.

***N*-Chloro-*N*-ethoxyurea (7).** A mixture of solution of *t*-BuOCl (0.89 g, 8.24 mmol) in CH₂Cl₂ (10 ml) and *N*-ethoxyurea (0.57 g, 5.49 mmol) was kept at 20°C for 1 h. The solution was evaporated in vacuo and was kept at 20°C and 2 Torr for 0.5 h, yielding 0.76 g (100%) *N*-chloro-*N*-ethoxyurea **7** as a white solid, m.p. 53–54°C (with decomp.), after crystallization colorless crystals, m.p. 54–55°C (with decomp.) (CH₂Cl₂–C₆H₁₄). ¹H NMR (300 MHz, CDCl₃): 1.26 (t, 3H, OCH₂Me, J = 7.2); 4.04 (q, 2H, OCH₂Me, J = 7.2); 6.09 (br.s, 2H, NH₂). IR (ν/cm^{−1}): 1725 (C=O). MS (FAB, H⁺, m/z , I_{rel} (%)): 141 [$\text{M}+\text{H}$]⁺ (32); 139 [$\text{M}+\text{H}$]⁺ (100). Found (%): Cl, 25.20. Calc. for C₃H₇ClN₂O₂ (%): Cl, 25.59.

***N*-4-Chlorobenzoyloxy-*N*-ethoxyurea (8).** 4-ClC₆H₄CO₂Na (6.27 mmol, 6.27 g) and a solution of *N*-chloro-*N*-ethoxyurea **8** (3.12 mmol, 0.43 g) in MeCN (20 ml) were stirred at 20°C for 43 h, then CH₂Cl₂ (10 ml) was added. The solid was filtered off, the filtrate was evaporated to 50% in vacuo, the precipitate was filtered off, and the filtrate was further evaporated in vacuo. The residue was extracted by CH₂Cl₂ (18 ml), the extract was evaporated in vacuo, yielding 0.19 g (23.5%) *N*-4-chlorobenzoyloxy-*N*-ethoxyurea **8** as colorless crystals, m.p. 109–111°C (with decomp.) (Me₂CO–Et₂O–C₆H₁₄). ¹H NMR (300 MHz, CDCl₃): 1.29 (t, 3H, OCH₂Me, J = 7.2); 4.17 (q, 2H, OCH₂Me, J = 7.2); 5.96 (br.s, 2H, NH₂); 7.42 (d, 2H, C₆H₄, J = 9); 7.96 (d, 2H, C₆H₄, J = 9). IR (ν/cm^{−1}): 3470 (NH), 1760 (C=O). MS (FAB, Na⁺, m/z , I_{rel} (%)): 283 [$\text{M}+\text{Na}$]⁺ (23); 281 [$\text{M}+\text{Na}$]⁺ (100). Found (%): C, 46.18; H, 4.01; N, 10.94. Calc. for C₁₀H₁₁ClN₂O₄ (%): C, 46.44; H, 4.29; N, 10.83.

X-ray diffraction study of compounds **1**, **5**, **7**, and **8** was performed at Xcalibur 3 diffractometer (graphite-monochromated MoK_α CCD detector, ω -scans). Structures were solved by direct methods and refined by full-matrix least squares procedure in anisotropic approximation for nonhydrogen atoms using SHELX-97 program package.¹⁵ Hydrogen atoms of methylene and methyl groups were placed in calculated positions and included into refinement within riding model with $U_{\text{iso}}(\text{H}) = nU_{\text{eq}}(\text{C})$ ($n = 1.2$ for CH₂ groups and $n = 1.5$ for CH₃ groups). Hydrogen atoms of amino group were refined isotropically independently. During refinement of the structures **7ALT** and **7ART**, the O(2)–C(2), C(2)–C(3) and O(1)–C(1) bonds were restrained to have the same bond length in two conformers, with standard deviation of 0.02 Å. Crystal data are

summarized in the Table 3. Full set of atomic coordinates, bond lengths, and bond angles have been deposited at the Cambridge Crystallographic Data Centre (CCDC). These data can be obtained free of charge via www.ccdc.cam.ac.uk/conts/retrieving.html or deposit@ccdc.cam.ac.uk.

RESULTS AND DISCUSSION

Therefore, we have studied the crystal structure of **1** by means of XRD[†].

The X-ray diffraction study of *N*-acetoxy-*N*-methoxyurea **1** (see Fig. 1) revealed that amide O–N(1)–O–nitrogen N(1) has a pyramidal configuration (the sum of bond angles centered on this atom ($\Sigma\beta$) is 332.1(1)°, the deviation from the plane of bonded atoms (h_{N}) is 0.446(2) Å). The orientation of substituents around the lone pair of N(1) is almost identical to that observed in *N*-acetoxy-*N*-ethoxyurea.⁵ The O–Me and O–C(=O) bonds have *sp* and *ap*-orientations with respect to lone pair (Lp) of N(1) atom (the C(1)–O(1)–N(1)–Lp(N1) and C(3)–O(4)–N(1)–Lp(N1) torsion angles are 175.4° and 13.8°, respectively). Pyramidalicity of the N(1) atom in molecule **1** is higher when compared with *N*-acetoxy-*N*-ethoxyurea⁵ ($\Sigma\beta = 333.6(2)^\circ$ and $h_{\text{N}} = 0.431(2)$ Å). This results in weaker conjugation between LpN(1) and carbonyl C(=O)–NH fragment, as evidenced from the longer N–C(=O) bond in **1** (1.446(2) Å) compared with *N*-acetoxy-*N*-ethoxyurea⁵ (1.426(3) Å), and also from shorter H₂N–C(O) bond (1.316(2) Å compared with 1.330(3) Å). At the same time, the N–OAlk and N–OAc bonds have somewhat greater length in urea **1** when compared with *N*-acetoxy-*N*-ethoxyurea⁵ (1.401(2) Å and 1.434(2) Å in urea **1**; 1.398(2) Å and 1.426(3) Å in *N*-acetoxy-*N*-ethoxyurea,⁵ respectively). In urea **1** the N(2) atom has planar configuration ($\Sigma\beta_{\text{N2}} = 359.9^\circ$).

The molecules of **1** form centrosymmetrical dimers in the crystal because of the N(2)–H(2NA)···O(4) hydrogen bonds (H···O 2.05 Å, N–H···O 171°).

In *N*-methoxy-*N*-X-ureas **1–4**, the highest degree of pyramidalicity is observed in ureas **1** and **2**. It was demonstrated that in these ureas X-group is readily substituted by nucleophiles.^{5–7} In salt **4** the nitrogen pyramidalicity degree is lower. In all cases, the N(1)–C(=O) bond is longer than the N(2)–C(=O) bond. This difference in bond lengths arises, first, from preferable conjugation of the carbonyl group with the planar nitrogen atom N(2) than with the pyramidal nitrogen atom N(1), second, from the difference between C–N(*sp*³) and C–N(*sp*²) bonds.

[†]Asymmetric nitrogen, Part 104. For Part 103 see ref. 16.

Fig. 1. Molecular structure of **1**. Selected bond lengths (Å) and bond angles (°): O(1)–N(1) 1.434(2), O(4)–N(1) 1.401(2), O(1)–C(1) 1.385(2), O(2)–C(1) 1.194(2), O(3)–C(2) 1.232(2), O(4)–C(3) 1.443(2), N(1)–C(2) 1.445(2), N(2)–C(2) 1.317(2), C(1)–C(4) 1.494(2); O(4)–N(1)–O(1) 108.68(10), O(4)–N(1)–C(2) 111.70(11), O(1)–N(1)–C(2) 111.75(11), C(1)–O(1)–N(1) 114.5(1), N(1)–O(4)–C(3) 114.5(1), O(2)–C(1)–O(1) 123.3(1), O(2)–C(1)–C(4) 127.4(2), O(1)–C(1)–C(4) 109.3(1), O(3)–C(2)–N(2) 126.4(2), O(3)–C(2)–N(1) 118.0(1), N(2)–C(2)–N(1) 115.1(1). [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com.]

orbital cause this revealed additional shortening of N–O(Me) bond as well as the elongation of N–X bond^{5–7} in molecules of family of anomeric ureas **1–4**.

For the case of the *N*-chloro-*N*-alkoxyureas, it was also demonstrated that the degree of the nitrogen pyramidality also depends of the nature of the *N*-alkoxy group.⁷ In *N*-chloro-*N*-methoxyurea **2**, $\Sigma\beta = 329.0^\circ$ and $h_N = 0.500 \text{ Å}^7$. In *N*-chloro-*N*-alkoxyurea **6** possessing a bulky *N*-alkoxy group, the degree of nitrogen pyramidality is somewhat greater ($\Sigma\beta = 325.8^\circ$ and $h_N = 0.533 \text{ Å}^7$).

To continue the investigation of the influence of the *N*-alkoxy group type on the degree of nitrogen pyramidality, we studied the structure of *N*-chloro-*N*-ethoxyurea **7**¹⁶ using XRD. The crystals of **7** were grown from CH_2Cl_2 -hexane mixture at -20°C , and the XRD study was carried out at 100 (structure **7LT**) and 250 K (structure **7RT**). It was found that in the crystal urea **7** exists as a mixture of two conformers (**7A** and **7B**) with population A:B = 89:11% in structure **7LT** and 84:16% in structure **7RT**. These two conformers of **7** differ in the configuration of the N(1) atom (Fig. 3, Table 2). In conformation **7A** the N(1) atom is strongly pyramidal ($h_N = 0.499 \text{ Å}$ and $\Sigma\beta = 328.93(8)^\circ$ in **7LT** and $h_N = 0.491 \text{ Å}$, $\Sigma\beta = 329.7(1)^\circ$ in **7RT**) similar to *N*-chloro-*N*-alkoxyureas **2** and **6**. In conformation **7B** this nitrogen atom adopts significantly flattened configuration ($h_N = 0.264 \text{ Å}$ and $\Sigma\beta = 350.5(4)^\circ$ in **7LT** and $h_N = 0.256 \text{ Å}$, $\Sigma\beta = 350.7(5)^\circ$ in **7RT**) similar to

Fig. 2. Molecular structure of **5**. Selected bond lengths (Å) and bond angles (°): O(1)–N(1) 1.396(1), O(1)–C(1) 1.448(2), O(2)–C(2) 1.338(2), O(2)–C(3) 1.450(2), O(3)–C(2) 1.197(2), O(4)–C(4) 1.338(2), O(4)–C(5) 1.449(2), O(5)–C(4) 1.200(2), N(1)–C(4) 1.396(2), N(1)–C(2) 1.397(2); O(1)–N(1)–C(4) 118.2(1), O(1)–N(1)–C(2) 117.8(1), C(4)–N(1)–C(2) 123.8(1), N(1)–O(1)–C(1) 109.8(1), C(2)–O(2)–C(3) 114.2(1), C(4)–O(4)–C(5) 115.0(1), O(3)–C(2)–O(2) 125.5(1), O(3)–C(2)–N(1) 124.7(1), O(2)–C(2)–N(1) 109.9(1), O(5)–C(4)–O(4) 126.0(1), O(5)–C(4)–N(1) 124.6(1), O(4)–C(4)–N(1) 109.4(1). [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com.]

For these ureas, the lengths of the N–O(Me) bond are similar. It may be supposed that this could be caused only by the similar degree of pyramidality of the N(1) atom. To check this suggestion, we have studied the structure of *N,N*-bis(methoxycarbonyl)-*N*-methoxyimide **5*** by means of X-ray diffraction (Fig. 2). This compound was found to be a product of the methyl *N,N*-dimethoxycarbamate¹⁴ decomposition after the long storage. We believed that in imide **5** the nitrogen must have a planar configuration causing some shortening of N–OMe bond length relative to N–OMe bond lengths in ureas **1–4**.

In imide **5** the nitrogen configuration is almost planar ($\Sigma\beta$ is $359.7(1)^\circ$ and h_N is $0.031(1) \text{ Å}$) in contrast to that in ureas **1–4**. Both MeOC(O)-groups and N(1) atom lie near the same (plane within 0.05 Å). The C(1)–O(1) bond adopts an orthogonal orientation with respect to this plane (the C(1)–O(1)–N(1)–C(4) torsion angle is $89.3(1)^\circ$). The planar configuration of N(1) atom causes the considerable shortening of the N–C bonds ($1.397(2)$ and $1.396(2) \text{ Å}$) compared with the N–C bonds in anomeric ureas **1–4** (1.44 – 1.45 Å , see Table 1). At the same time, the length of the N–O(Me) bond ($1.396(2) \text{ Å}$) of planar nitrogen N(1) in molecule **5** is close to those found in the molecules **1–4** containing highly pyramidal nitrogen atoms. This fact reveals the additional shortening of N–O(Me) bond lengths of pyramidal 1-N nitrogen in $\text{H}_2\text{NC(O)N(X)OMe}$ ureas **1–4**. Undoubtedly, the length of planar atom (sp^2) N–O(Me) bond cannot be similar to the length of pyramidal atom (sp^3) N–O(Me) bond without additional shortening. It could be supposed that this phenomenon results from the action of $n_{\text{O(Me)}} \rightarrow \sigma^*_{\text{N-X}}$ anomeric interaction.⁹ The transfer of lone pair electron density from the oxygen atom of the MeO-group into the $\sigma^*_{\text{N-X}}$

TABLE 1. Some structural parameters of H₂NC(O)N(X)OMe ureas 1–4 and (MeO₂C)₂NOMe 5

Parameter	X				
	OAc, 1	Cl, 2 ⁷	OMe, 3 ⁶	N ⁺ C ₅ H ₅ , 4 ⁶	For (MeO ₂ C) ₂ NOMe 5
Σβ _{N1} (°)	332.1(1)	329.0(2)	331.8(2)	333.9(1)	359.7(1)
h _{N1} (Å)	0.446(2)	0.500(1)	0.444(2)	0.431(2)	0.031(1)
N–OMe length (Å)	1.401(2)	1.398(1)	1.398(3), 1.399(2)	1.400(2)	1.396(1)
N(1)–C(=O) length (Å)	1.445(2)	1.443(2)	1.438(2)	1.452(2)	
N(2)–C(=O) length (Å)	1.317(2)	1.320(2)	1.320(3)	1.323(2)	1.397(2), 1.396(2)

that in common ureas. The difference in configuration of the N(1) atom results in disordering of the ethoxy group, chlorine atom, and oxygen atom of carbonyl group.

Flattened configuration of the N(1) atom in conformation **7B** causes significant shortening of the N–Cl bond (by 0.09 Å in **7LT** and 0.15 Å in **7RT**) and the N–O bond (by 0.07 Å in **7LT** and 0.06 Å in **7RT**). This results from drastic change of intramolecular interactions within molecule **7** because of change of N(1) atom configuration. Orientation of the ethoxy group with respect to lone pair of the nitrogen atom in conformers **7A** and **7B** indicates that the Lp(N1)→σ*(C2–C3) orbital interaction is possible only in conformer **7A**. The N(1)–O(2)–C(2)–C(3) torsion angle in conformer **7A** is –177.8(1)° in **7LT** and –179.7(3)° in **7RT**. In conformation **7B** this angle is 83(2)° (**7LT**) and 89(2)° (**7RT**). But this orbital interaction cannot strictly regards as an anomeric interaction. It should be noted that the change of pyramidity degree of the N(1) atom does not influence on the length of N(1)–C(1) bond. Detailed inspection of the thermal ellip-

soid of the C(1) atom does not indicate any even a small potential disorder.

Despite of difference in structure of two conformers of molecule **7**, both of them have similar crystal packing and character of intermolecular interactions in the solid state. In the crystal molecules of **7** exist as centrosymmetric dimers because of intermolecular hydrogen bonds N(2)–H(2NB)···O(1)' (1–x,1–y,1–z) (H···O 2.07 Å, N–H···O 174° (7A, **LT**), 2.10 Å, 171° (7B, **LT**), 2.04 Å, 172° (7A, **RT**), 2.06 Å, 174° (7B, **RT**). These dimers form infinite chains along crystallographic direction (0 0 1) because of weak intermolecular hydrogen bonds N(2)–H(2NA)···O(1) (x,0.5–y,–0.5+z) (H···O 2.28 Å, N–H···O 154° (7A, **LT**), 2.34 Å, 164° (7B, **LT**), 2.33 Å, 156° (7A, **RT**), 2.41 Å, 165° (7B, **RT**).

Similar amounts of relative populations of both conformation of molecule **7** at 100 and 250 K and also the absence of strong short intermolecular contacts between disordered atoms of conformations **A** and **B** prevent conclusions about the nature of this disordering in the crystal of **7**. For example, both statistic disordering with the absence of transfer between conformations **A** and **B** and dynamic disordering having the negligible temperature dependence of free energies are possible.

As well as in *N*-chloro-*N*-alkoxyureas and *N*-acyloxy-*N*-alkoxyureas, the type of *N*-acyloxy substituent and *N*-alkoxy substituent have a significant influence on nitrogen pyramidity degree and overall conformation of molecule. The XRD study of *N*-4-chlorobenzoyloxy-*N*-ethoxyurea **8** (see Fig. 4) revealed that pyramidity at N(1) (Σβ = 329.32(8)° and h_N = 0.470(1) Å) is somewhat higher than in *N*-acetoxy-*N*-methoxyurea **1** and in *N*-acetoxy-*N*-ethoxyurea.⁵ But the degree of pyramidity in **8** is considerably smaller when compared with *N*-4-chlorobenzoyloxy-

Fig. 3. The structure of conformations **7A** (black) and **7B** (white) in *N*-chloro-*N*-ethoxyurea.

TABLE 2. Selected bond length (Å) and bond angles (°) in conformations **7A** and **7B**

	7LT		7RT	
	A	B	A	B
Cl(1)–N(1)	1.757(1)	1.670(3)	1.755(2)	1.610(3)
O(2)–N(1)	1.383(1)	1.318(7)	1.370(2)	1.307(8)
N(1)–C(1)	1.447(1)		1.439(2)	
N(2)–C(1)	1.324(1)		1.315(2)	
O(1)–C(1)–N(1)–Cl(1)	29.8(2)	–20.2(7)	31.5(3)	–22(1)
O(1)–C(1)–N(1)–O(2)	150.4(1)	–165.6(7)	152.4(2)	–168(1)

Fig. 4. Molecular structure of **8**. Selected bond lengths (Å) and bond angles (°): O(1)–C(1) 1.380(1), O(1)–N(1) 1.437(1), O(2)–C(1) 1.204(1), O(3)–C(2) 1.223(1), O(4)–N(1) 1.4022(1), O(4)–C(3) 1.452(1), N(1)–C(2) 1.459(1), N(2)–C(2) 1.331(1), O(4)–N(1)–O(1) 108.80(7), O(4)–N(1)–C(2) 110.75(8), O(1)–N(1)–C(2) 109.77(8). [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com.]

N-(*n*-butyloxy)urea ($\Sigma\beta = 323.8^\circ$ and $h_N = 0.511 \text{ Å}^6$) and *N*-benzyloxy-*N*-benzyloxybenzamides ($\Sigma\beta = 323.51^\circ$ – 324.14°).¹⁷

Molecule **8** contains two almost planar fragments: the benzyloxy group (the C(5)–C(4)–C(1)–O(2) torsion angle is $4.7(1)^\circ$) and the $\text{NH}_2\text{--C(=O)--N}$ moiety. The benzyloxy group is oriented toward the bisect of the

C(2)–N(1)–O(4) bond angle (the C(2)–N(1)–O(1)–C(1) and C(2)–N(1)–O(1)–C(1) torsion angles are $56.6(1)^\circ$ and $-64.8(1)^\circ$, respectively). In contrast to *N*-4-chlorobenzoyloxy-*N*-(*n*-butyloxyurea)⁶ and *N*-benzyloxy-*N*-benzyloxy amides¹⁷ in compound **8**, this substituent with the carbonyl group located at endo to the nitrogen pyramid. The ethoxy group is turned with respect to the $\text{NH}_2\text{--C(=O)}$ bond (the N(2)–C(2)–N(1)–O(4) torsion angle is $-31.7(1)^\circ$) and it has *-sc* conformation (the N(1)–O(4)–C(3)–C(10) torsion angle is $-70.1(1)^\circ$).

The anomeric interaction $n_{\text{O(Et)}} \rightarrow \sigma^*_{\text{NOC(O)Ar}}$ within the O–N–O fragment leads to a significant elongation of the N(1)–O(1) (1.437(1) Å) bond when compared with N(1)–O(4) (1.4022(1) Å). In urea **8** the N(1)–O(1) bond is slightly longer when compared with *N*-acetoxy-*N*-ethoxyurea⁵ and is close to that in *N*-acetoxy-*N*-methoxyurea **1**. In *N*-4-chlorobenzoyloxy-*N*-(*n*-butyloxy)urea,⁶ this N–OC(O)Ar bond is somewhat longer (1.447(2) Å).⁶

Value of the amide N(1)–C(=O) bond (1.459(1) Å) indicates on a weak conjugation between the lone pair of the N(1) atom and the π -system of carbonyl group and this bond is even longer than reported for high pyramidal *N*-acyloxy-*N*-alkoxyureas^{5,6} and *N*-acyloxy-*N*-alkoxyamides.¹⁷ The N(2) atom has very flattened configuration ($\Sigma\beta_{\text{N2}} = 354(2)^\circ$). The N(2)–C(=O) bond is much shorter (1.331(1) Å) than N(1)–C(=O) bond. In *N*-4-chlorobenzoyloxy-*N*-(*n*-butyloxy)urea,⁶ this N–C(=O) bond is somewhat shorter (1.321(2) Å).⁶

In the crystal, molecules of **8** exist as centrosymmetric dimers because of intermolecular hydrogen bonds N(2)–H(2NB)···O(3)' ($-x, y, 2z$) (H··O 2.07 Å, N··H··O 168°).

Replacement of ethoxy group in molecules **8** by butoxy substituent in *N*-4-chlorobenzoyloxy-*N*-(*n*-butyloxy)urea⁶ results in changes of conformation and geometrical param-

TABLE 3. Crystal data and structure refinement for **1**, **5**, **8**, **7ALT** and **7ART** conformations

	1	5	7ALT	7ART	8
Temperature (K)	100	100	100	250	100
Crystal system	Monoclinic	Monoclinic	Monoclinic	Monoclinic	Triclinic
Space group	$P2_1/c$	$P2_1/n$	$P2_1/c$	$P2_1/c$	$P\bar{1}$
<i>a</i> (Å)	11.1338(8)	7.5027(3)	8.3467(2)	8.5594(6)	7.0438(10)
<i>b</i> (Å)	6.2359(5)	6.9365(3)	7.4406(2)	7.4585(5)	7.4780(9)
<i>c</i> (Å)	10.0614(7)	13.8194(5)	10.2170(3)	10.3026(6)	11.7202(15)
α (°)	90	90	90	90	85.569(10)
β (°)	97.440(6)	98.611(4)	96.999(2)	97.740(5)	84.911(11)
γ (°)	90	90	90	90	70.315(12)
<i>V</i> (Å ³)	692.67(9)	711.09(5)	629.79(3)	651.73(7)	578.24(13)
<i>Z</i>	4	4	4	4	2
<i>d</i> _{calc} (g cm ^{−3})	1.42	1.52	1.46	1.41	1.49
μ (mm ^{−1})	0.13	0.14	0.52	0.50	0.335
<i>F</i> (0 0 0)	312	344	288	288	268
$2\theta_{\text{max}}$ (°)	60	52.8	60	60	60
Reflections collected	3290	2261	7806	4119	11415
Unique reflections	1945 $R_{\text{int}} = 0.021$	1409 $R_{\text{int}} = 0.014$	1831 $R_{\text{int}} = 0.025$	1870 $R_{\text{int}} = 0.020$	3320 $R_{\text{int}} = 0.024$
Number of parameters	101	103	127	127	172
R_1 [$I > 2\sigma(I)$]	0.041 [1194]	0.036 [1151]	0.033 [1725]	0.043 [1323]	0.033 [2973]
wR_2 (all data)	0.102	0.102	0.079	0.119	0.086
GOF	1.00	1.06	1.04	1.08	1.07
CCDC reference number	679787	679788	681996	681997	698694

ters of molecule. In *N*-4-chlorobenzoyloxy-*N*-(*n*-butyloxy) urea,⁶ the benzoyloxy group has an opposite orientation when compared with urea **8**. Because of rotation around the N—O bond, the carbonyl group of this substituent is oriented in the same direction as lone pair of amide nitrogen atom.⁶ Other conformational parameters of molecule remain almost unchanged. In urea **8**, this change causes a significant decrease of the amide nitrogen pyramidal-ity when compared with *N*-4-chlorobenzoyloxy-*N*-(*n*-butyl-oxy)urea.⁶ In latter, the parallel orientation of the lone pair of the amide nitrogen and carbonyl group should lead to considerable repulsion between lone pairs of heteroatoms. This may explain elongation of the N—OC(O)Ar bond in molecule of *N*-4-chlorobenzoyloxy-*N*-(*n*-butyloxy)urea when compared with urea **8**.

CONCLUSIONS

We can therefore conclude that the degree of pyramidal-ity of amide nitrogen in the compound may be tuned by the orientation of benzoyloxy substituent. However, results of X-ray diffraction study of compounds **8** and *N*-4-chlorobenzoyloxy-*N*-(*n*-butyloxy)urea⁶ reveal that orienta-tion of this substituent in turn can be tuned by the size of the *N*-alkoxy group.

LITERATURE CITED

1. Kostyanovsky RG, Rudchenko VF, Shtamburg VG, Chervin II, Nasibov SS. Synthesis, configurational stability, and resolution *N,N*-dialkoxy-amines into antipodes. *Tetrahedron* 1981;37:4245–4254.
2. Rudchenko VF. Reactions, and properties of ONO systems. *Chem Rev* 1993;93:725–739.
3. Rudchenko VF, Kostyanovsky RG. Geminal systems O—N—Hal. Derivatives of *N*-halogenhydroxylamines. *Usp Khim* 1998;67:203–218.
4. Stamburg VG, Tsygankov AV, Klots EA, Fedyanin IV, Lyssenko KA, Kostyanovsky RG. *N,N*-Dimethoxy-*N*-*tert*-alkylamines: new synthesis method and the crystal structure of the precursor. *Mendelev Comm* 2006;2:84–85.
5. Shishkin OV, Zubatyuk RI, Shtamburg VG, Tsygankov AV, Klots EA, Mazepa AV, Kostyanovsky RG. Pyramidal amide nitrogen in *N*-acyloxy-*N*-alkoxyureas and *N*-acyloxy-*N*-alkoxycarbamates. *Mendelev Comm* 2006;4:222–223.
6. Shtamburg VG, Shishkin OV, Zubatuk RI, Kravchenko SV, Tsygankov AV, Shtamburg VV, Distanov VB, Kostyanovsky RG. Synthesis, structure and properties of *N*-alkoxy-*N*-(1-pyridinium)urea salts, *N*-acyloxy-*N*-alkoxyureas and *N,N*-dialkoxyureas. *Mendelev Comm* 2007;1:178–180.
7. Shtamburg VG, Shishkin OV, Zubatuk RI, Kravchenko SV, Tsygankov AV, Mazepa AV, Klots EA, Kostyanovsky RG. *N*-Chloro-*N*-alkoxyureas: synthesis, structure and properties. *Mendelev Comm* 2006;6:323–325.
8. Glover SA. Anomeric amides—structure, properties and reactivity. *Tetrahedron* 1998;54:7229–7271.
9. Rankin DWH, Todd MR, Riddell FG, Turner ES. The molecular structures of *O*-methylhydroxylamine, *N*-methylhydroxylamine, *N,O*-dimethylhydroxylamine and *N,N,O*-trimethylhydroxylamine in the gas phase, determined by electron diffraction. *J Mol Struct* 1981;71:171–182.
10. Yamamoto G, Agawa C, Minoura M. Static and dynamic stereochemistry of *O*-substituted *N*-tritylcylhydroxylamines. *Bull Chem Soc Jpn* 2003;76:825–829.
11. Tsuboi M, Overend J. Amino wagging and inversion in hydrazines: K_R branch of the antisymmetric wagging band of NH_2NH_2 . *J Mol Spectr* 1974;52:256–268.
12. Cardillo MJ, Bauer SH. Structures of gauche- and trans-tetrafluorohydrazine as determined by electron diffraction. *Inorg Chem* 1969;8:2086–2092.
13. Antipin MYu, Struchkov YuT, Rudchenko VF, Ignatov SM, Kostyanovsky RG. Geminal systems. 49. Molecular structure of tetramethoxyhydrazine in a crystal. *Bull Acad Sci USSR Div Chem Sci (Engl Transl)* 1989;38:1672–1675.
14. Shtamburg VG, Klots EA, Pleshkova AP, Avramenko VI, Ivonin SP, Tsygankov AV, Kostyanovsky RG. Synthesis and alcoholysis of *N*-acyloxy-*N*-alkoxy derivatives of ureas, carbamates, and benzamides. *Izv Akad Nauk Ser Khim* 2003;10:2132–2140. [*Russ Chem Bull Int Ed* 2003;52:2251–2260].
15. Sheldrick GM. SHELX97—programs for crystal structure analysis (Release 97-2). Institut für Anorganische Chemie der Universität, Tammanstrasse 4, D-3400 Göttingen, Germany, 1998.
16. Kostyanovsky RG, Lyssenko KA, Krutius ON, Kostyanovsky VR. The isomorphism of chiral ammonium salts $\text{Ph}(\text{Al})\text{N}^+\text{Et}(\text{Me})\text{X} \cdot \text{CHCl}_3$, $\text{X} = \text{Br}, \text{I}$. Asymmetric Nitrogen. Part 103. *Mendelev Comm* 2008; (in press).
17. Gillson A-ME, Glover SA, Tucker DJ, Turner P. Crystal structures and properties of mutagenic *N*-acyloxy-*N*-alkoxyamides—“most pyramidal” acyclic amides. *Org Biomol Chem* 2003;1:3430–3437.