Geminal systems

64.* *N*-Alkoxy-*N*-chloroureas and *N*,*N*-dialkoxyureas

V. G. Shtamburg,[a] R. G. Kostyanovsky,[b] A. V. Tsygankov,[c] V. V. Shtamburg,[a] O. V. Shishkin,[d] R. I. Zubatyuk,[d] A. V. Mazepa,[e] and S. V. Kravchenko[f]*

[a]Ukranian State University of Chemical Technology,
8 ul. Gagarina, 49005 Dnepropetrovsk, Ukraine.
Fax: +38 (056) 473397. E-mail: stamburg@gmail.com
[b]N. N. Semenov Institute of Chemical Physics, Russian Academy of Sciences,
4 ul. Kosygina, 119991 Moscow Russian Federation.
Fax: +7 (495) 938 2156. E-mail: kost@chph.ras.ru
[c]Kirovograd Flying Academy of the National Aircraft University,
1 ul. Dobrovol´skogo, 25005 Kirovograd, Ukraine.
E-mail: geminalsystemsn@gmail.com
[d]Institute of Single Crystals of the National Academy of Sciences of the Ukraine,
60 ul. Lenina, 61001 Kharkov, Ukraine.
E-mail: shishkin@xray.isc.kharkov.com
[e]A. V. Bogatskii Physicochemical Institute of the National Academy of Sciences of the Ukraine,
86 ul. Lyustdorfskaya doroga, 65080 Odessa, Ukraine.
E-mail: almazepa@rambler.ru
[f]Dnepropetrovsk State Agrarian University,
25 ul. Voroshilova, 49600 Dnepropetrovsk, Ukraine.
E-mail: svtailor@ukr.net

Molecular and crystal structures of *N*-alkoxy-*N*-chloroureas and *N*,*N*-dialkoxyureas were studied together with those of *N*-alkoxyureas as reference compounds. *N*-Alkoxy-*N*-chloroureas were found to have an elongated N—Cl bond and a shortened N—O(Alk) bond due to the $n_{O(Alk)} \rightarrow \sigma^*_{N-Cl}$ anomeric effect. Alcoholysis of *N*-alkoxy-*N*-chloro derivatives of urea, *N´*-arylureas, and carbamates in the presence of silver trifluoroacetate leads to sterically hindered *N*,*N*-dialkoxyureas, *N*,*N*-dialkoxy-*N´*-arylureas, and *N*,*N*-dialkoxycarbamates, respectively.

Key words: *N*-alkoxy-*N*-chloroureas, anomeric effect, *N*-acyloxy-*N*-alkoxyureas, *N*-alkoxy-*N*-chlorocarbamates, alcoholysis, ureas, carbamates.

"Anomeric" amides bearing two electronegative heteroatoms on the nitrogen atom possess a special complex of structural and chemical properties.[2—13] The oxygen atom of an *N*-alkoxy group is one of such heteroatoms most frequently encountered with.[1—13] The optimization of the electron density distribution over the N—X and N—OR σ-bonds in *N*-alkoxy-*N*-X-amides (X = Cl, OC(O)R, OR´) leads to the increase in the sp^3-character of the amide nitrogen atom.[2—13] The thus arising pyramidality of the nitrogen atom sterically facilitates the $n_{O(R)} \rightarrow \sigma^*_{N-X}$ orbital interaction ("anomeric effect"[2]), which leads to the destabilization of the N—X bond, promoting either its homolysis,[2,6,12,14] or a nucleophilic substitution at the amide nitrogen atom.[2—13,15—18] Alcoholysis of *N*-alkoxy-*N*-chloroureas gave *N*,*N*-dialkoxyureas.[15—18] *N*-Acyloxy-*N*-alkoxybenzamides were synthesized from *N*-alkoxy-*N*-chlorobenzamides.[2—5,18] *N*-Alkoxy-*N*-chloroureas on reacting with sodium and potassium carboxylates selectively transform to *N*-acyloxy-*N*-alkoxyureas,[18—21] while *N*-alkoxy-*N*-chlorocarbamates convert to *N*-acyloxy-*N*-alkoxycarbamates.[18,20,22] Alcoholysis of *N*-acyloxy-*N*-alkoxyureas with primary and secondary alcohols at room temperature selectively leads to *N*,*N*-dialkoxyureas, whereas alcoholysis of *N*-acyloxy-*N*-alkoxycarbamates with primary alcohols allows one to obtain earlier unknown *N*,*N*-dialkoxycarbamates.[18,22]

Earlier, the pyramidality of the amide nitrogen atom was strictly confirmed by X-ray diffraction studies only for *N*-acyloxy-*N*-alkoxybenzamides,[10] and only recently this was also established for *N*,*N*-dialkoxybenzamides.[13]

* For Part 63, see Ref. 1.

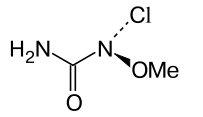
Published in Russian in *Izvestiya Akademii Nauk. Seriya Khimicheskaya,* No. 1, pp. 0062—0075, January, 2015.
1066-5285/15/6401-0062

Table 1. Characteristic bond distances (*d*) in *N*-alkoxy-*N*-chloroureas **1**—**4** and *N*-methoxyurea (**6**)

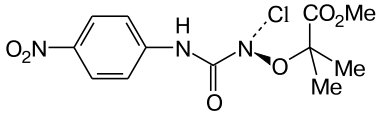
Compound	*d*/Å			
	N(1)—C(=O)	N(2)—C(=O)	N—Cl	N—OMe(Alk)
1[23]	1.4429(15)	1.3202(16)	1.7563(11)	1.3984(13)
2[23]	1.4719(8)	1.3536(8)	1.7572(5)	1.4204(7) (CMe_2CO_2Me)
3A[25]	1.447(1)	1.324(1)	1.757(1)	1.383(1)(OEt)
3B[25]	1.447(1)	1.324(1)	1.670(3)	1.318(7)(OEt)
4	1.440(5)—1.447(5)	1.340(5)—1.350(4)	1.740(4)—1.751(3)	1.389(4)—1.401(4)
6	1.367(3)	1.322(3)	—	1.411(2)

In this connection, in the present work we studied the structures of *N*-alkoxy-*N*-chloroureas and *N*,*N*-dialkoxyureas and considered in more details the nucleophilic substitution reactions of the X group in *N*-alkoxy-*N*-X-ureas (X = Cl, OC(O)R) and *N*-alkoxy-*N*-chlorocarbamates under alcoholysis conditions.*

The X-ray diffraction studies of the structure of *N*-chloro-*N*-methoxyurea (**1**) and *N*-alkoxy-*N*-chloro-*N*´-(4-nitrophenyl)urea (**2**) obtained by the chlorination of the corresponding *N*-alkoxy-*N*-H-ureas with Bu^tOCl showed that in both compounds the nitrogen atom of the geminal system O—N—Cl has a pyramidal configuration,[23] *i.e.*, is in the sp^3-hybridization state. The sum of the bond angles at this nitrogen atom (Σβ) is 328.6° (**1**) and 325.8° (**2**). The second nitrogen atom has a trigonal planar configuration.

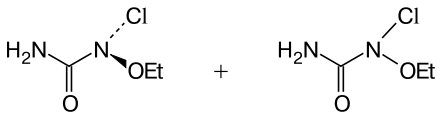


1



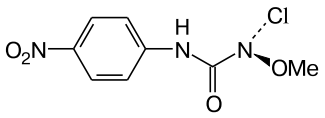
2

In the crystal structure of *N*-chloro-*N*-ethoxyurea **3** (see Ref. 25), a disordering of molecules was observed because of the inversion of the nitrogen atom in the geminal system O—N—Cl. Two isomers **3A** and **3B** existing in the crystal (the relative occupancies are 88.5 and 11.5%) differ in the degree of pyramidality of the nitrogen atom (Σβ 328.9 and 350.5°, respectively). As a result, the N—Cl bond distances also noticeably differ in these two isomers (Table 1).



3A **3B**

Similar disordering caused by the inversion of the nitrogen atom is also observed in the structure of *N*-chloro-*N*-methoxy-*N*´-(4-nitrophenyl)urea **4** (see Ref. 26, Fig. 1, Tables 1 and 2). There are six molecules (**A**—**F**) of compound **4** in the independent part of the unit cell.



4

Molecules **E** and **F** are disordered over two positions 1 and 2 due to the inversion of nitrogen atom N(1) with the relative occupancies 60 : 40%. Nitrogen atom N(1) has a trigonal pyramidal configuration. The sum of the bond angles centered on the atom is 329.3(7)—332.4(7)° in non-disordered molecules **A**—**D** and 327(2)—335(1)° in disordered molecules **E**—**F**, the deviation of atom N(1) from the plane of bonded to it atoms is 0.469(4)—0.497(3) Å in molecules **A**—**D** and 0.438(7)—0.52(1) Å in molecules **E**—**F**. The lone pair of electrons (LP) on atom N(1) is oriented virtually perpendicular to the carbamoyl fragment (the absolute values of torsion angles lp(N(1))—N(1)—C(1)—N(2) are 92—99° in molecules **A**—**D** and 67—84° in molecules **E**—**F**, where lp(N(1)) is an idealized position of the LP on atom N(1)). Such an orientation of the LP on atom N(1), besides the n—π-conjugation, is additionally stabilized by the formation of the intramolecular hydrogen bond N(2)—H...O(2) (in molecules **A**—**D**: H...O is 2.04—2.10 Å, N—H...O is 109—112°; in molecules **E**—**F**: H...O is 2.12—2.34 Å, N—H...O is 100—108°). The methyl group has the *sc*-orientation relative to the LP of atom N(1) (the absolute values of torsion angles lp(N(1))—N(1)—

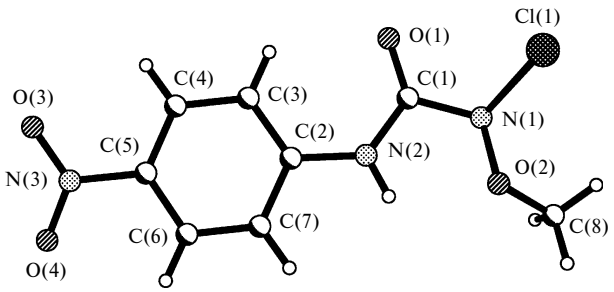


Fig. 1. Structure of *N*-chloro-*N*-methoxy-*N*´-(4-nitrophenyl)-urea (**4**).

* For preliminary communications, see Refs 20, 21, 23, and 24.

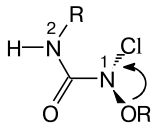
Table 2. Intermolecular hydrogen bonds and angles in *N*-chloro-*N*-methoxy-*N*′-(4-nitrophenyl)urea (**4**)

D—H...A	Bonded molecules [operation of symmetry]	*d*(H...A) /Å	D—H...A /deg
N(2)—H...O(1)	**B**...**D** [1 − *x*,1 − *y*, −*z*]	2.38	148
	D...**A** [−0.5 + *x*, 0.5 − *y*, −0.5 + *z*]	2.38	154
	E...**C** [1 − *x*, −*y*, −*z*]	2.17	161
	F...**B** [1 − *x*,1 − *y*, −*z*]	2.22	166
C(8)—H...O(4)	**A**...**C** [2 − *x*, 1 − *y*, 1 − *z*]	2.49	148
	B...**C** [1 − *x*,1 − *y*, −*z*]	2.49	165
C(3)—H...O(4)	**D**...**E**	2.47	125
C(4)—H...O(3)	**A**...**D** [2.5 − *x*, 0.5 − *y*, 0.5 − *z*]	2.49	128
C(4)—H...O(1)	**E**...**F1** [2 − *x*, 1 − *y*, −*z*]	2.44	143
C(6)—H...O(3)	**F**...**E**	2.49	127
C(8)—H...O(3)	**C**...**B** [0.5 − *x*, −0.5 + *y*, 0.5 − *z*]	2.55	152
	E...**E** [−0.5 + *x*, 0.5 − *y*, −0.5 + *z*]	2.45	151
C(7)—H...O(1)	**C**...**E** [−0.5 + *x*, 0.5 − *y*, 0.5 + *z*]	2.42	149
	D...**A** [−0.5 + *x*, 0.5 − *y*, −0.5 + *z*]	2.57	136
C(8)—H...O(1)	**E**...**C** [1 − *x*, −y, −*z*]	2.60	125
C(7)—H...Cl(1)	**D**...**A** [−0.5 + *x*, 0.5 − *y*, −0.5 + *z*]	2.75	154

O(2)—C(8) are 31—36° in molecules **A**—**D** and 28—37° in molecules **E**—**F**). In all the molecules, the carbamoyl fragment is planar (the absolute values of torsion angles O(1)—C(1)—N(2)—C(2) are 0.9(6)—5.4(6)°). In molecules **A**—**D** and at position 1 of molecule **F**, the benzene ring lies virtually in this plane (the absolute values of torsion angles C(1)—N(2)—C(2)—C(3) are 4.2(7)—12.3(6)°, whereas in molecules **D** and **F2** it slightly deviates from this plane (the corresponding absolute values of torsion angles are 27.7(9)—30.8(5)°). The coplanar arrangements of these fragments is stabilized by the formation in molecules **A**—**D** and **F1** of intramolecular hydrogen bond C(3)—H...O(1) (H...O is 2.14—2.29 Å, C—H...O is 120—123°). In molecules **E** and **F2**, this interaction is noticeably weaker and can be classified as an attractive contact (H...O is 2.43—2.46 Å, C—H...O is 111—114°). The nitro group is virtually in the plane of the benzene ring (the absolute values of torsion angles C(4)—C(5)—N(3)—O(3) are 2.7(5)—12.5(5)°).

In crystal, molecules are bonded between each other by hydrogen bonds (see Table 2).

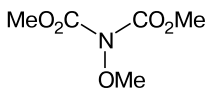
In *N*-alkoxy-*N*-chloroureas **1**—**4**, the N(1)—C(1) and N(2)—C(1) bonds are nonequivalent: the first is longer, whereas the second is shorter as compared to the N—C bond distances in urea (1.350(1) Å)[27] and amides[13] (1.359 Å). This indicates that the sp^3-hybridized nitrogen atom N(1) of the Cl—N—O group is conjugated with the C=O bond of the carbamoyl group to a lesser extent than the sp^2-hybridized nitrogen atom N(2) of the NH_2 and NHAr groups. The N—Cl bond in *N*-alkoxy-*N*-chloroureas **1**, **2**, and **4** is elongated as compared to the calculated N—Cl bond distance in *N*-chloroformamide (1.735 Å)[2], the N—Cl bond distance in substituted *N*-chloro-*N*-phenylacetamides (1.71—1.72 Å),[28] and *N*-chloroimides (1.676—1.691 Å).[29—31]



1—4

R = H (**1**), Ar (**2**—**4**)

This elongation of the N—Cl bond in *N*-alkoxy-*N*-chloroureas **1**, **2**, and **4** indicates its destabilization, facilitating the nucleophilic substitution of the chlorine atom, and is apparently due to the anomeric effect $n_{O(Alk)} \rightarrow \sigma^*_{N-Cl}$[2,8,9,15]. This is also confirmed by the close N—OMe bond distance values of nitrogen atom N(1) of pyramidal configuration in compounds **1** and **4** (see Table 1) to the N—OMe bond distance (1.396(1) Å) in *N*-methoxyimide **5**, the nitrogen atom in which has a completely planar configuration, *i.e.*, is in the sp^2-hybridization state.[25] Such a shortening of the N—OMe bond in *N*-chloro-*N*-methoxyureas **1** and **4** is explained by the domination of the anomeric effect $n_{O(Me)} \rightarrow \sigma^*_{N-Cl}$ in these compounds.

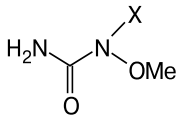


5

Earlier, it was shown that the nature of an *N*-alkoxy group in *N*-acyloxy-*N*-alkoxyureas significantly affected the degree of pyramidality of nitrogen atom in the geminal system O—N—O.[25] Therefore, it is correctly to consider

the influence of the nature of substituent X in *N*-X-*N*-alkoxyureas on the structure of the molecule for the same *N*-alkoxy group.

Within the *N*-X-*N*-methoxyurea family (X = Cl (**1**),[23] H (**6**), OAc (**7**),[25] OMe (**8**),[21] OPr^i (**9**), OBu^t (**10**)), unsubstituted *N*-methoxyurea **6**, the structure of which was studied by X-ray crystallography (Fig. 2, see Tables 1 and 3), was taken as a comparison reference.



6—10

N-Acetoxy-*N*-methoxyurea (**7**) was synthesized by the reaction of *N*-chloro-*N*-methoxyurea (**1**) with AcONa (see Ref. 23), *N*,*N*-dimethoxyurea (**8**) was obtained by methanolysis of either *N*-chloro-*N*-methoxyurea (**1**) (see Ref. 23) or *N*-acetoxy-*N*-methoxyurea (**7**) (see Refs 21 and 25). *N*-Isopropoxy-*N*-methoxyurea (**9**) and *N*-*tert*-butoxy-*N*-methoxyurea (**10**) were obtained by alcoholysis of *N*-chloro-*N*-methoxyurea (**1**) with the corresponding alcohol in the presence of CF_3CO_2Ag (Scheme 1). The structure of *N*,*N*-dialkoxyureas **9** and **10** were also studied by X-ray diffraction analysis (Figs 3 and 4, Table 3).

We found that alcoholysis of *N*-alkoxy-*N*-chloroureas in the presence of CF_3CO_2Ag, supposedly following the S_N1 mechanism, has proved a convenient method for the synthesis of poorly available *N*,*N*-dialkoxyureas **9** and **10**. Alternative approaches to the preparation of *N*,*N*-dialkoxyureas **9** and **10** appeared to be ineffective. *N*-Alkoxy-*N*-chloroureas[17] and *N*-acetoxy-*N*-alkoxyureas[18] do not undergo *tert*-butanolysis, probably, because of the steric hindrance for the nucleophilic substitution at the nitrogen atom by the S_N2 mechanism.[18] The reaction of *N*-chloro-*N*-methoxyurea **1** with the solution of AcONa in isopropyl alcohol leads to *N*-acetoxy-*N*-methoxyurea **7**, which is

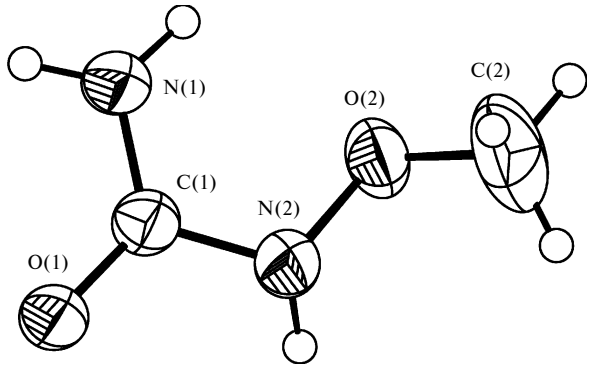


Fig. 2. Structure of *N*-methoxyurea (**6**).

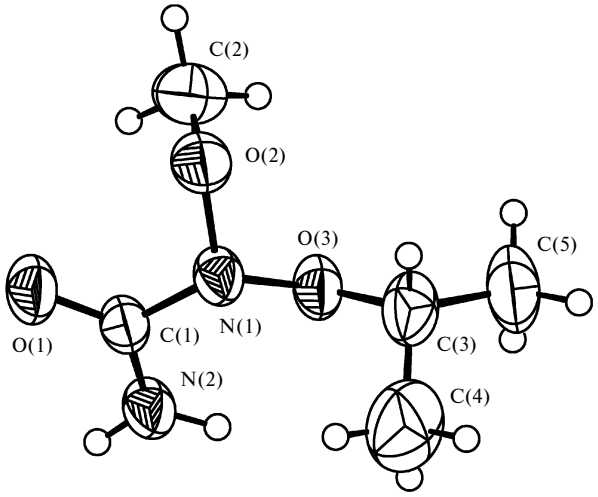
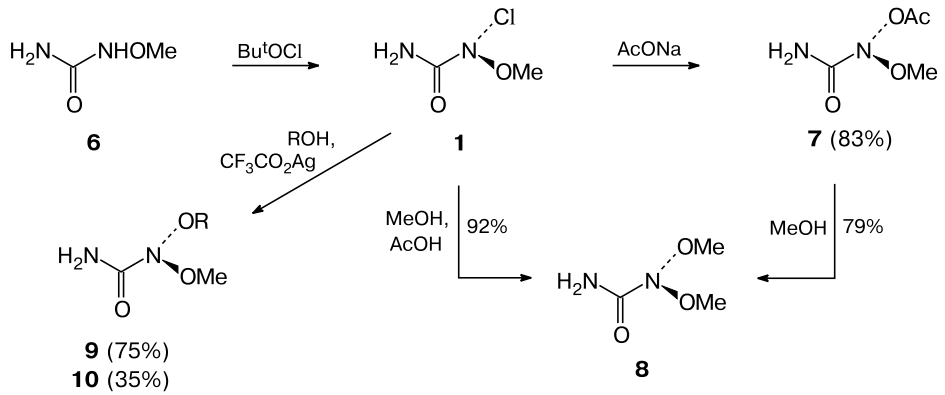


Fig. 3. Structure of *N*-isopropoxy-*N*-methoxyurea (**9**).

stable to isopropanolysis at room temperature (Scheme 2). However, ethanolysis of *N*-acetoxy-*N*-methoxyurea **7** gives *N*-ethoxy-*N*-methoxyurea (**11**). At the same time, *N*-acetoxy-*N*-butoxyurea (**12**) undergoes isopropanolysis

Scheme 1



R = Pr^i (**9**), Bu^t (**10**)

Table 3. Some structural parameters in *N*-methoxyurea (**6**) and *N*-X-*N*-methoxyureas **1** and **7—10**

Compound	X	$\Sigma\beta_{N(1)}$/deg	*d*/Å				$\nu_{C=O}$/cm^{-1}
			N—OMe	N_{sp^3}—C(=O)	N_{sp^2}—C(=O)	C=O	
1[23]	Cl	329.0(2)	1.3984(13)	1.4429(15)	1.3202(16)	1.2264(15)	1710
6	H	338.0	1.411(2)	1.367(3)	1.322(3)	1.244(2)	1685
7[25]	OAc	332.1(1)	1.401(2)	1.445(2)	1.317(2)	1.2324(16)	1708
8[21]	OMe	331.8(2)	1.397(2), 1.401(2)	1.438(2)	1.320(3)	1.220(2)	1720
9	OPr^i	332.0(6)	1.401(3), 1.408(3)	1.449(3)	1.304(4)	1.217(4)	—
10	OBu^t	331.6(2)	1.406(2), 1.408(2) (Bu^t)	1.438(3)	1.322(3)	1.217(2)	1712

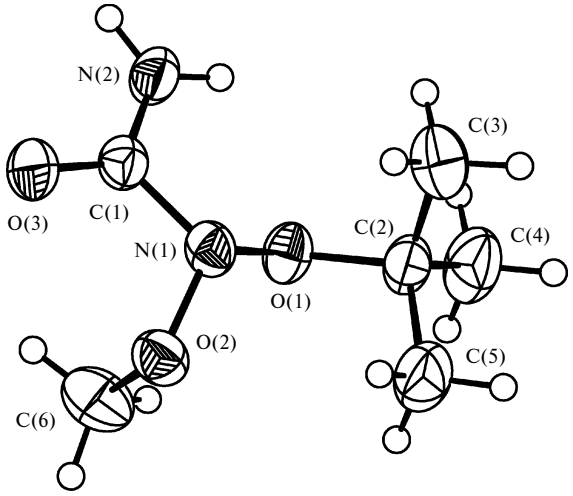


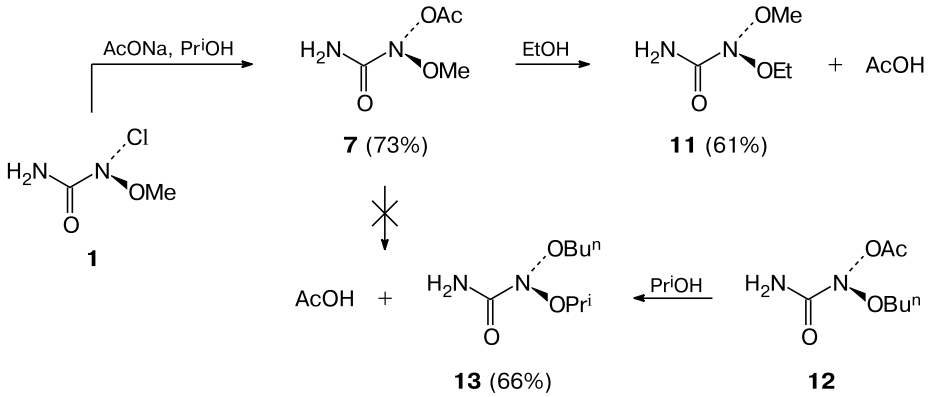
Fig. 4. Structure of *N*-*tert*-butoxy-*N*-methoxyurea (**10**).

at room temperature with the formation of *N*-butoxy-*N*-isopropoxyurea (**13**).

It can be suggested that in *N*-acetoxy-*N*-butoxyurea (**12**), the nitrogen atom of the geminal system O—N—O has a larger degree of pyramidality as compared to that of the nitrogen atom in *N*-acetoxy-*N*-methoxyurea (**7**). This causes a stronger destabilization of the N—OAc bond due to the anomeric effect $n_{O(Bu)} \rightarrow \sigma^*_{N-OAc}$ and a stronger sensitivity to isopropanolysis observed for *N*-acetoxy-*N*-butoxyurea (**12**).

In the molecule of *N*-methoxyurea (**6**), proceeding from the refined coordinates of the hydrogen atoms (which also agree with the geometry of the intermolecular hydrogen bonds), nitrogen atom N(2) (the NHOMe group) has almost planar configuration, $\Sigma\beta = 338°$, the configuration of atom N(1) (the NH_2 group) also is close to planar ($\Sigma\beta = 357°$). The C(2)—O(2) bond of the methoxy group is oriented toward the LP of nitrogen atom N(2) (torsion angle C(2)—O(2)—N(2)—lpN(2) is 23°), whereas the carbamoyl substituent is oriented virtually perpendicular to it (torsion angle N(1)—C(1)—N(2)—lpN(2) is 96°). For *N*-methoxyurea (**6**) in crystal, the formation of the intermolecular hydrogen bonds is observed: N(1)—H(1a)...O(1)^i [*i*: $1 + x, y, z$] (H...O is 2.26(3) Å, N—H...O is 138(2)°), N(1)—H(1b)...O(1)^{ii} [*ii*: $-x, 2 - y, -z$] (H...O is 2.09(3) Å, N—H...O is 169(3)°), and N(2)—H(2)...O(1)^{iii} [*iii*: $-x, 1 - y, -z$] (H...O is 2.11(3) Å, N—H...O is 174(2)°), which bind the molecules in layers parallel to the plane (0 0 1).

Scheme 2



The structure of *N*-isopropoxy-*N*-methoxyurea (**9**) is similar to the structure of *N*,*N*-dimethoxyurea (**8**) studied earlier.[21] Nitrogen atom N(1) has a trigonal pyramidal configuration, $\Sigma\beta = 332.0(6)°$ and deviates from the plane of atoms bonded to itself by $h_N = 0.444(2)$ Å. The conformation of compound **9** is close to the conformation of *N*,*N*-dimethoxyurea **8** (see Ref. 21). The methyl and the isopropyl groups have, respectively, the *ap*- and the *sp*-orientation relative to the LP of N(1) (torsion angle lpN(1)—N(1)—O(2)—C(2) is 178°, whereas torsion angle lpN(1)—N(1)—O(3)—C(3) is −25°). The carbamoyl group is oriented virtually perpendicular to the LP of N(1) (torsion angle lpN(1)—N(1)—C(1)—O(1) = 86°). This conformation is additionally stabilized by the attractive intramolecular contact H(2b)...O(2) of 2.27 Å. The isopropyl group is in the staggered conformation relative to the N(1)—O(3) bond (torsion angle N(1)—O(3)—C(3)—H(3) = = −48°). In crystal, molecules of urea **9** are bonded in double chains along the axis *a* by hydrogen bonds N(2)—H(2a)...O(1)^{i} [*i*: $1/2 + x$, $-1/2 - y$, $-z$] (H...O is 2.10(3) Å, N—H...O is 169(4)°) and N(2)—H(2b)...O(2)^{ii} [*ii*: $1 + x$, y, z] (H...O is 2.25(4) Å, N—H...O is 162(3)°).

In *N*-*tert*-butoxy-*N*-methoxyurea (**10**), nitrogen atom N(1) (the geminal system O—N—O) has also a trigonal pyramidal configuration. For atom N(1), $\Sigma\beta = 331.6(2)°$, the deviation from the plane of atoms directly bonded to itself (h_N) is equal to 0.447(2) Å. The conformation of urea **10** is close to the conformation of urea **9**. The methyl and the *tert*-butyl groups have, respectively, the *ap*- and the *sp*-orientation relative to the LP of atom N(1) (torsion angle lpN(1)—N(1)—O(1)—C(1) is −178°, torsion angle lpN(1)—N(1)—O(2)—C(6) is 19°). The carbamoyl group is oriented virtually perpendicular to the LP of atom N(1) (torsion angle lpN(1)—N(1)—C(1)—O(3) is −83°), that, besides the n—p-conjugation, is stabilized by the formation of a shortened intramolecular attractive contact H(2b)...O(1) of 2.21 Å, which cannot be classified as a hydrogen bond because of the small value of the angle N(2)—H(2b)...O(1) of 105°. The *tert*-Butyl group is in the staggered conformation relative to the N(1)—O(1) bond (torsion angle N(1)—O(1)—C(2)—C(3) is −61.3(2)°). Atom N(2) has a trigonal planar configuration, like in *N*,*N*-dimethoxyurea (**8**)[21] and urea **9**.

In crystal, molecules of urea **10** are bonded in the centrosymmetric dimers by hydrogen bonds N(2)—H(2a)...O(3^{i}) [*i*: $-x$, $1 - y$, $-z$] (H...O is 2.11 Å, N—H...O is 172°).

Thus, the conformations of *N*-alkoxy-*N*-methoxyureas **9** and **10** are close to the conformation of *N*,*N*-dimethoxyurea (**8**),[21] whereas the degrees of pyramidality of nitrogen atom N(1) (*N*,*N*-dialkoxyamino group) and the N—OMe bond lengths do not differ much, despite the presence of bulky isopropoxy (**9**) and *tert*-butoxy groups (**10**) (see Table 3).

As it follows from Table 3, the replacement of the hydrogen atom in *N*-methoxy-*N*-H-urea (**6**) with an electronegative substituent X (X = Cl, OAc, OAlk) leads to a sharp increase in the pyramidality of the nitrogen atom in the geminal system X—N—O(Me). The vibration frequencies of the carbamoyl C=O group increase in parallel, that confirms the versatility of the Glover test on pyramidality of the amide nitrogen atom.[2,8—10,32]

The N—O(Me) bond length in *N*-methoxyurea (**6**) is significantly larger than those of the corresponding N—O(Me) bonds in *N*-methoxy-*N*-X-ureas **1** and **7—10** (see Table 3). Since the N—O(Me) bond of the nitrogen atom with the pyramidal configuration (compounds **1** and **7—10**) cannot be shorter than a similar bond at the nitrogen atom in almost planar configuration (*N*-methoxyurea **6**), a shortening of the N—O(Me) bond occurs in *N*-methoxy-*N*-X-ureas **1** and **7—10**, probably, due to the anomeric effect $n_{O(Me)} \rightarrow \sigma^*_{N-X}$.

Some nonequivalence of the N—C(=O) amide bonds observed in *N*-methoxyurea (**6**) is much larger in *N*-methoxy-*N*-X-ureas **1** and **7—10** (see Tables 1 and 3). It is probable that, like in compound **4**, the LP of the sp^3-hybridized nitrogen atom N(1) has weaker conjugation with the carbamoyl C=O bond than the LP of the sp^2-hybridized nitrogen atom N(2).

In *N*-methoxyurea (**6**), the C(1)=O(1) bond is elongated to 1.244(2) Å (an average value is 1.23 Å).[33] In *N*-methoxy-*N*-X-ureas **1** and **7—10**, the C=O bond is noticeably shorter (see Table 3), that is characteristic of the anomeric amides with the sp^3-hybridized nitrogen atom.[2,32]

Structural specific features of the *N*-methoxy-*N*-X-*N*′-(4-nitrophenyl)urea family (X = H (**14**), Cl (**4**), OMe (**15**)) were studied. *N*-Methoxy-*N*-H-*N*′-(4-nitrophenyl)-urea (**14**)[26] have been chosen as a structural comparison reference with *N*-chloro-*N*-methoxy-*N*′-(4-nitrophenyl)-urea (**4**) and *N*,*N*-dimethoxy-*N*′-(4-nitrophenyl)urea (**15**).

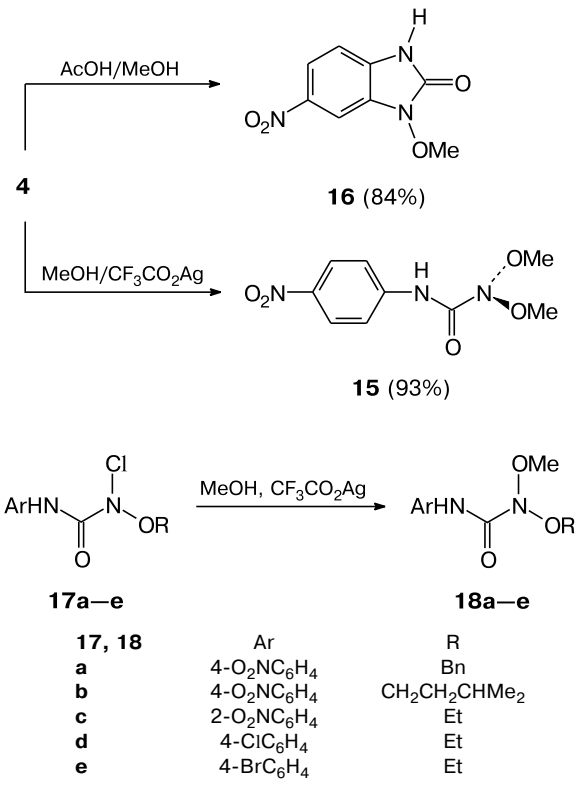
Methanolysis of *N*-chloro-*N*-methoxy-*N*′-(4-nitrophenyl)urea (**4**) in the presence of AcONa leads to 1-methoxy-6-nitro-3,4-dihydrobenzimidazol-2-one (**16**),[34] whereas in the presence of CF_3CO_2Ag to *N*,*N*-dimethoxy-*N*′-(4-nitrophenyl)urea (**15**)[24] (Scheme 3).

Similarly, *N*-alkoxy-*N*′-aryl-*N*-chloroureas (**17a—e**) were converted to *N*,*N*-dialkoxy-*N*′-arylureas (**18a—e**).[24]

According to the X-ray diffraction data, nitrogen atom N(1) in *N*-methoxy-*N*-H-*N*′-4-nitrophenylurea (**14**) (Fig. 5, Table 4) has configuration close to the planar, $\Sigma\beta = 343.5(4)°$.

It should be noted that the position of the hydrogen atom, which determines pyramidality of this nitrogen atom, was refined independently and found to correspond to the direction of the intermolecular hydrogen bond N(1)—H(1)...O(2)^{i} [*i*: $1 - x$, $2 - y$, $2 - z$] (H...O is 2.092(19) Å, N—H...O is 169.8(19)°), which binds the molecules in crystal in the centrosymmetric dimers. In the molecule of urea **14**, the LP of atom N(1) is arranged virtually perpendicular to the plane of the carbamoyl frag-

Scheme 3



17, 18	Ar	R
a	4-$O_2NC_6H_4$	Bn
b	4-$O_2NC_6H_4$	$CH_2CH_2CHMe_2$
c	2-$O_2NC_6H_4$	Et
d	4-ClC_6H_4	Et
e	4-BrC_6H_4	Et

ment (torsion angle N(2)—C(2)—N(1)—lpN(1) = 102°). The NO—Me bond is oriented toward the LP of N(1) (torsion angle C(1)—O(1)—N(1)—lpN(1) = –8°). Nitrogen atom N(2) has virtually a planar configuration (Σβ = = 358.3(4)°), that also corresponds to the direction of the formed weak intermolecular hydrogen bond N(2)—H(2)...O(2)^{ii} [*ii*: $1-x$, $1/2+y$, $3/2-z$] (H...O is 2.43(2) Å, N—H...O is 157.4(16)°). The carbonyl group is slightly turned relative to the plane of the benzene ring (torsion angle C(4)—C(3)—N(2)—C(2) = 32.3(3)°). But this, apparently, does not disturb the conjugation between the aromatic and the carbamoyl fragments, as well as provides a possibility for the formation of a weak intramolecular hydrogen bonds N(2)—H(2)...O(1) (H...O is 2.150(19) Å, N—H...O is 112.6(16)°) and C(4)—H(4)...O(2) (H...O is 2.43 Å, C—H...O is 112°).

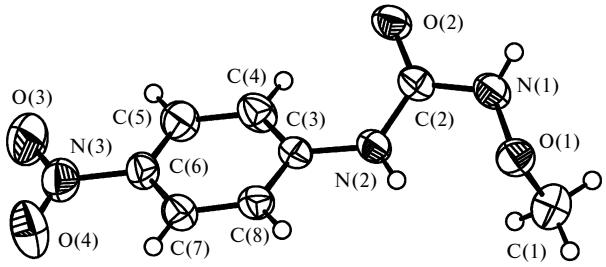


Fig. 5. Structure of *NH*-*N*-methoxy-*N*′-(4-nitrophenyl)-urea (**14**).

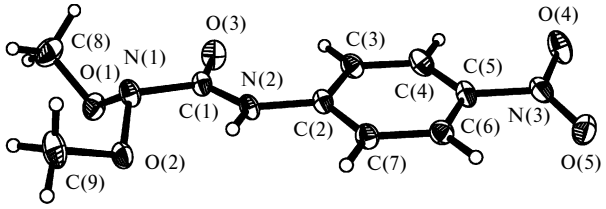


Fig. 6. Structure of *N*,*N*-dimethoxy-*N*′-(4-nitrophenyl)-urea (**15**).[24]

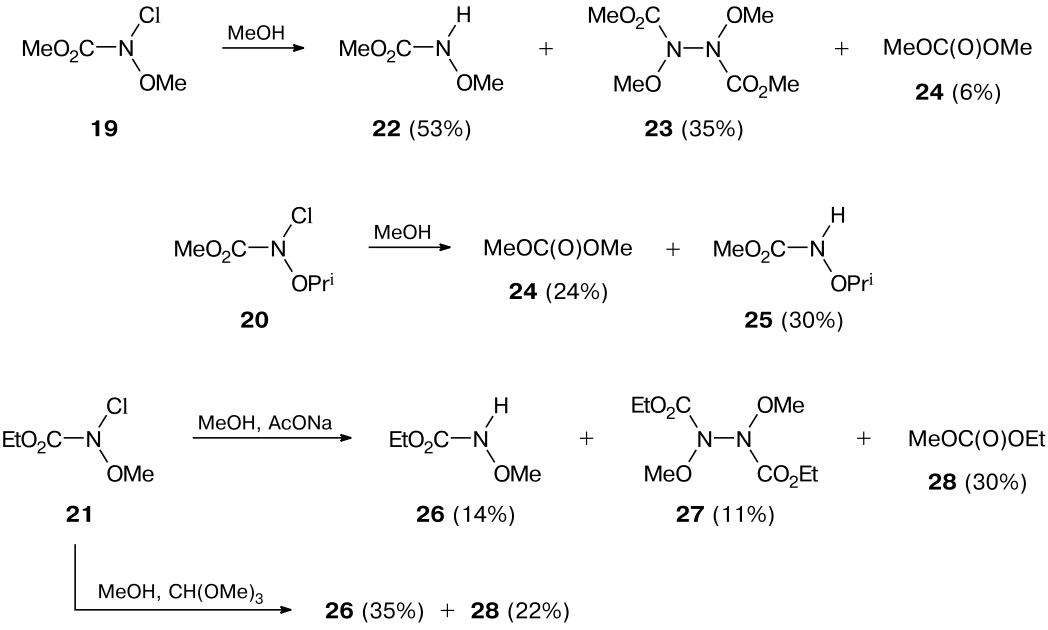
According to the X-ray diffraction data,[24] in *N*,*N*-dimethoxy-*N*′-(4-nitrophenyl)urea (**15**) nitrogen atom N(1) has a pronounced trigonal pyramidal configuration (Σβ = = 324.0(2)°, h_N = 0.508(3) Å) (Fig. 6). In the unsubstituted *N*,*N*-dimethoxyurea (**8**), the degree of pyramidality of the nitrogen atom of *N*,*N*-dimethoxyamino group is considerably lower (see Table 3). Thus, *N*,*N*-dimethoxy-*N*′-(4-nitrophenyl)urea (**15**) in the degree of pyramidality of its amide nitrogen atom approaches the "most pyramidal" acyclic amides, the S. Glover's *N*-acyloxy-*N*-alkoxybenzamides (Σβ = 323.51°, h_N = 0.513 Å).[10]

In compound **15**, the LP of N(1) is arranged virtually perpendicular to the plane of the carbamoyl fragment (torsion angle O(3)—C(1)—N(1)—lp(N(1)) = –83.1°). The C—O bonds of two methoxy groups are oriented toward the LP of atom N(1) (torsion angle C(8)—O(1)—N(1)—lp(N(1)) = 7.0° and torsion angle C(9)—O(2)—N(1)—lp(N(1)) = 32.7°). The N—OMe bonds in compound **15** are slightly longer (see Table 4) than the corresponding bonds in *N*,*N*-dimethoxyurea (**8**)[21] and *N*,*N*-dialkoxyureas **9** and **10**.

Table 4. Comparison of structural specific features of *N*-X-*N*-methoxy-*N*′-(4-nitrophenyl)ureas **4**, **14**, and **15**

Compound	X	$\Sigma\beta_{N(1)}$/deg	*d*/Å			
			N—OMe	N(1)—C(=O)	N(2)—C(=O)	C=O
4	Cl	326.6(2)—335.9(1)	1.389(4)—1.401(4)	1.440(5)—1.447(5)	1.340(5)—1.350(4)	1.203(4)—1.213(5)
14	H	343.5(4)	1.4055(19)	1.368(2)	1.355(2)	1.233(2)
15	OMe	324.0(2)	1.418(3) 1.412(3)	1.441(3)	1.357(3)	1.204(3)

Scheme 4



In *N*,*N*-dimethoxyurea **15**, the aryl substituent is coplanar to the carbamoyl fragment (torsion angle C(3)—C(2)—N(2)—C(1) = 5.4(4)°), whereas the nitro group is slightly turned relative to the plane of the benzene ring (torsion angle C(4)—C(5)—N(3)—O(4) = 13.4(4)°). The conformation of molecule **15**, besides the conjugation effects, is also stabilized due to the formation of intramolecular hydrogen bonds N(2)—H(2)...O(2) (H...O is 2.13 Å, N—H...O is 108°) and C(3)—H(3)...O(3) (H...O is 2 24 Å, C—H...O is 122°).

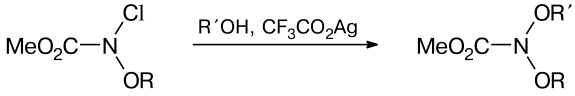
In crystal, molecules **15** are bound by intermolecular hydrogen bonds N(2)—H(2)...O(4′) [−1 + *x*, 0.5 − *y*, −0.5 + *z*] (H...O is 2.27 Å, N—H...O is 155°), as well as by stacking interactions between the π-systems of two molecules combined by the translation along the axis *a* (the center of the benzene ring is placed over the middle of the C(1)—N(2) bond at a 3.50 Å distance).

For the family of *N*-methoxy-*N*-X-*N*′-(4-nitrophenyl)ureas, on going from *N*-methoxy-*N*′-(4-nitrophenyl)-urea (**14**) to ureas **4** and **15**, *i.e.*, replacing the H atom (X = H (**14**)) with an electronegative substituent (X = Cl (**4**), OMe (**15**)), the degree of pyramidality of the nitrogen atom in the geminal system O—N—X sharply increases, as does the nonequivalence of the carbamoyl N—C(=O) bonds (see Table 4). Like in the case of the family of *N*-methoxy-*N*-X-ureas **1** and **7**—**10**, this phenomenon can be explained by the fact that the sp^3-hybridized nitrogen atom N(1) (of the O—N—X group) is conjugated to a lesser extent with the C=O bond of the carbamoyl group than the sp^2-hybridized nitrogen atom N(2) of the NH_2 group. On going from urea **14** to ureas **4** and **15**, a noticeable shortening of the C=O bond is observed (see Table 4), probably, due to the same reasons as for the family of *N*-methoxy-*N*-X-ureas **1** and **7**—**10**.

Methanolysis of *N*-alkoxy-*N*-chlorocarbamates **19**—**21** with either MeOH, or a solution of AcONa in MeOH, or a solution of $CH(OMe)_3$ in MeOH (to bind HCl) (Scheme 4) leads to a mixture of *N*-alkoxy-*N*-H-carbamates **22**, **25**, **26**, *N*,*N*′-dialkoxy-*N*,*N*′-bis(alkoxycarbonyl)hydrazines **23**, **27** (the reduction products), and carbonates **24**, **28** (the fragmentation products).

However, carrying out the alcoholysis of *N*-alkoxy-*N*-chlorocarbamates **19**, **20**, and **29**—**31** in the presence of CF_3CO_2Ag makes it possible to obtain *N*,*N*-dialkoxycarbamates **32**—**39**, including sterically hindered *N*,*N*-diisopropoxycarbamate (**34**) and *N*-alkoxy-*N*-*tert*-butoxycarbamates **37** and **38** (Scheme 5).

Scheme 5



19, 20, 29—31 **32—39**

Product	R	R′	Yield	Starting compounds **19**, **20**, **29**—**31** (R)	R′OH
32	Pr^i	Me	52	**20** (Pr^i)	MeOH
33	Pr^i	Et	59	**20** (Pr^i)	EtOH
	Et	Pr^i	45	**29** (Et)	Pr^iOH
34	Pr^i	Pr^i	59	**20** (Pr^i)	Pr^iOH
35	Bu^n	Me	77	**30** (Bu^n)	MeOH
36	Oct^n	Me	76	**31** (Oct^n)	MeOH
37	Me	Bu^t	36	**19** (Me)	Bu^tOH
38	Et	Bu^t	11	**29** (Et)	Bu^tOH
39	Et	Et	46	**29** (Et)	EtOH

The degree of pyramidality of the nitrogen atom in *N*-alkoxy-*N*-chlorocarbamates was not determined, but it can be expected to be lower than in *N*-alkoxy-*N*-chloroureas, similarly to carbamate and urea *N*-acyloxy-*N*-alkoxy derivatives.[20] For methyl *N*-(4-chlorobenzoyloxy)-*N*-methoxycarbamate, Σβ is 334.1° (see Ref. 20), whereas for *N*-acetoxy-*N*-ethoxyurea Σβ is 333.6° (see Ref. 20); for *N*-(4-chlorobenzoyloxy)-*N*-ethoxyurea Σβ is 329.32(8)° (see Ref. 25), whereas for *N*-butoxy-*N*-(4-chlorobenzoyloxy)urea Σβ is 323.8° (see Ref. 21). A decrease in the pyramidality of the nitrogen atom leads to a decrease in the destabilization of the N—Cl bond due to the anomeric effect $n_{O(Alk)} \rightarrow \sigma^*_{N-Cl}$ (see Refs 2 and 32). This, in turn, hinders the nucleophilic substitution at the nitrogen atom by the S_N2-like mechanism. However, in the case of alcoholysis in the presence of CF_3CO_2Ag, this is not that significant, since the nucleophilic substitution, obviously, follows the S_N1-like mechanism through the formation of the nitrenium cation.

In conclusion, it was found that *N*-chloro-*N*-methoxy-*N*′-(4-nitrophenyl)urea (**4**) exists in crystal in six forms, differing in the degree of pyramidality of the nitrogen atom of the geminal system O—N—Cl and the bond lengths. Replacement of the H atom in *N*-methoxy-*N*-X-ureas **1** and **7**—**10** with the substituent X (X = Cl, OAc, OAlk) leads to a significant increase in the degree of pyramidality of the nitrogen atom in the geminal system X—N—O(Me) and to the shortening of the N—O(Me) bond. This can be regarded as a structural confirmation of the domination of the anomeric effect $n_{O(Me)} \rightarrow \sigma^*_{N-X}$ in compounds **1** and **7**—**10**. Carrying out the alcoholysis of *N*-alkoxy-*N*-chloro derivatives of urea, *N*′-arylureas, and carbamates in the presence of silver trifluoroacetate is a convenient method for the preparation of *N*,*N*-dialkoxyureas, *N*,*N*-dialkoxy-*N*′-arylureas, and *N*,*N*-dialkoxycarbamates, respectively.

Experimental

^{1}H NMR spectra were recorded on Varian VXP-300 (300 MHz), Mercury-400 (400 MHz), and Bruker Avance DRX-500 spectrometers (500 MHz) using Me_4Si as an internal standard. ^{13}C NMR spectra were recorded on Varian VXP-300 (75 MHz) and Mercury-400 (100 MHz) spectrometers in $CDCl_3$. IR spectra were obtained on a UR-20 spectrometer in KBr pellets or for neat samples. Mass spectra were recorded on a VG 770-70EQ mass spectrometer in the FAB mode (FAB). GLC analysis was performed on a Tsvet-5 chromatograph (a flame-ionizing detector, a 2400×3 glass column, 5% SE-30 on Chromaton-AW). X-ray diffraction studies were performed on a Xcalibur 3 automated four-circle diffractometer. Solvents were purified according to the standard methods: MeCN and CH_2Cl_2 were distilled over P_2O_5, MeOH and EtOH over Ca, Et_2O and PhH over Na.

***N*-Chloro-*N*-methoxyurea (1)** was obtained according to the procedure published earlier.[23]

***N*-Chloro-*N*-methoxy-*N*′-(4-nitrophenyl)urea (4)** was obtained according to the known procedure[26] by the chlorination of *N*-methoxy-*N*′-(4-nitrophenyl)urea (**6**) with Bu^{t}OCl. Yellowish white crystals with m.p. 98—102 °C (CH_2Cl_2) (Ref. 26: 120 °C). ^{1}H NMR (300 MHz, $CDCl_3$), δ: 3.96 (s, 3 H, OMe); 7.71 (d, 2 H, C(2)H, C(6)H, J = 9.3 Hz); 8.22 (br.s, 1 H, NH); 8.26 (d, 2 H, C(3)H, C(5)H, ^3J = 9.3 Hz). MS (FAB), m/z (I_{rel} (%)): 248 $[M + H]^+$ (15), 246 $[M + H]^+$ (40), 119 (100).

Crystals of compound **4** are monoclinic, from CH_2Cl_2, $C_8H_8N_3O_4Cl$, at 100 K a = 13.0232(6) Å, b = 21.0805(7) Å, c = 22.4324(11) Å, β = 90.573(4)°, V = 6158.2(5) Å^3, M_r = 245.62, Z = 24, space group $P2_1/n$, d_{calc} = 1.59 g cm^3, μ(Mo-Kα) = = 0.38 mm^{-1}, F(000) = 3024. The unit cell parameters and intensities of 26976 reflections (13934 independent, R_{int} = 0.043) were measured on a Xcalibur 3 automated four-circle diffractometer (Mo-Kα, graphite monochromator, CCD detector, ω-scan technique, $2\theta_{max}$ = 57.76°).

The structure was solved by the direct method using the SHELX-97 software.[35] Positions of hydrogen atoms were calculated geometrically and refined using a riding model with $U_{iso} = nU_{eq}$ for the bearing atom (n = 1.5 for methyl groups and n = 1.2 for other hydrogen atoms). The structure was refined on F^2 by the full-matrix least squares method in anisotropic approximation for nonhydrogen atoms to wR_2 = 0.147 on 13934 reflections (R_1 = 0.067 on 8645 reflections with $F > 4\sigma(F)$, S = 1.06). In the structure refining, the limitations were imposed on the bond distances involving disordered atoms, which were assumed to be equal to the average distances for the corresponding bonds in the nondisordered molecules with the 0.005 Å accuracy. The limitations were also imposed on the equality of the tensor components of anisotropic vibrations along the bond lines involving disordered atoms with the 0.01 Å^2 accuracy, as well as on the mutual equality of the tensor components for the disordered atom C(1) of molecule **F** with the 0.01 Å^2 accuracy. The code in the Cambridge Crystallographic Data Center CCDC is 870254.

***N*-Methoxyurea (6).** A cooled solution of concentrated HCl (7 mL, 75.86 mmol) in water (10 mL) was added to a solution of $MeONH_2$ (2.38 g, 50.57 mmol) cooled to 0 °C, the solution obtained was allowed to stand at −10 °C for 20 min, then NaOCN (6.90 g, 106.2 mmol) was added in portions over 1 h at −(5—10) °C with stirring. The reaction mixture was allowed to stand for 1 h at −5 °C and 4 days at 17—20 °C. A solid phase was filtered off, washed with water (2 mL), a combined aqueous filtrate was concentrated *in vacuo* at 20 °C. The solid residue was extracted first with boiling Pr^i_2O (50 mL) over 30 min, then with boiling $CHCl_3$ (3×50 mL). The organic extracts were allowed to stand for 24 h at 5 °C, a precipitate formed was filtered off, the filtrates were 2/3 concentrated *in vacuo* to obtain an additional amount of *N*-methoxyurea (**6**). The overall yield of *N*-methoxyurea (**6**) was 3.19 g (70%), colorless crystals, m.p. 78—81 °C ($CHCl_3$). ^{1}H NMR (300 MHz, $(CD_3)_2SO$), δ: 3.52 (s, 3 H, NOMe); 6.39 (br.s, 2 H, NH_2); 9.06 (br.s, 1 H, NHO). IR (KBr), ν/cm^{-1}: 3415 (NH); 1685 (C=O). Found (%): N, 30.95. $C_2H_6N_2O_2$. Calculated (%): N, 31.10.

Crystals of compound **6** are triclinic, from $CHCl_3$, $C_2H_6N_2O_2$, at 298 K a = 4.9905(16) Å, b = 6.842(3) Å, c = 7.412(3) Å, α = 77.33(4)°, β = 72.60(3)°, γ = 72.07(4)°, V = 227.51(15) Å^3, M_r = 90.09, Z = 2, space group $P1$, d_{calc} = 1.315 g cm^{-3}, μ(Mo-Kα) = 0.115 mm^{-1}, F(000) = 96. The unit cell parameters and intensities of 1696 reflections (1050 independent, R_{int} = = 0.017) were measured on a Xcalibur 3 automated four-circle

diffractometer (Mo-Kα, graphite monochromator, CCD detector, ω-scan technique, $2\theta_{max} = 58.32°$).

The structure was solved by the direct method using the SHELX-97 software.[35] Positions of hydrogen atoms of the methyl group were calculated geometrically and refined using a riding model with $U_{iso} = 1.5U_{eq}$ for the bearing atom. The hydrogen atoms at the nitrogen atoms were refined independently in isotropic approximation. The structure was refined on F^2 by the full-matrix least squares method in anisotropic approximation for nonhydrogen atoms to $wR_2 = 0.181$ on 1050 reflections ($R_1 = 0.059$ on 756 reflections with $F > 4\sigma(F)$, $S = 1.04$). The registration code in the Cambridge Crystallographic Data Center CCDC is 948639.

***N*-Acetoxy-*N*-methoxyurea (7).** *N*-Chloro-*N*-methoxyurea (**1**) (0.305 g, 2.448 mmol) was added to a solution of AcONa (0.250 g, 3.05 mmol) in Pr^iOH (10 mL). The mixture was stirred for 18 h at 17—18 °C and allowed to stand for another 25 h at this temperature. A precipitate formed was filtered off and washed with Et_2O (10 mL). A combined filtrate was concentrated *in vacuo* at 7 Torr, the residue was extracted with CH_2Cl_2 (16 mL), the extract was concentrated *in vacuo* at 10 Torr to obtain *N*-acetoxy-*N*-methoxyurea (**7**) (0.266 g, 73%), colorless crystals, m.p. 98—100 °C. The product was identified by the comparison of its ^{1}H NMR and mass spectra with those of an authentic sample.[25] ^{1}H NMR (300 MHz, $CDCl_3$), δ: 2.22 (s, 3 H, NOAc); 3.91 (s, 3 H, NOMe); 5.90 (br.s, 1 H, NH); 6.03 (br.s, 1 H, NH). MS (FAB, Na^+) *m/z* (I_{rel} (%)): 319 $[2\ M + Na]^+$ (17), 171 $[M + Na]^+$ (100).

Attempted isopropanolysis of *N*-acetoxy-*N*-methoxyurea (7). A solution of *N*-acetoxy-*N*-methoxyurea **7** (0.0148 g, 0.100 mmol) in Pr^iOH (4 mL) was allowed to stand for 90 h at 17—19 °C, then concentrated *in vacuo* at 5 Torr to obtain the starting *N*-acetoxy-*N*-methoxyureas (**7**) (0.0148 g, 100%), which was identified by the comparison of its ^{1}H NMR spectrum with that of an authentic sample.

***N*-Isopropoxy-*N*-methoxyurea (9).** A solution of *N*-chloro-*N*-methoxyurea (**1**) (0.127 g, 1.002 mmol) in Et_2O (3 mL) was added to a solution of CF_3CO_2Ag (0.248 g, 1.123 mmol) in Pr^iOH (5 mL) at −10 °C. The temperature of the reaction mixture was raised to 15 °C over 18 h, then, AcONa (0.10 g) was added, the mixture was stirred for 15 min, Pr^iOH was evaporated *in vacuo* (5 Torr). The residue was extracted with CH_2Cl_2 (17 mL), the extract was concentrated *in vacuo*. The residue was dissolved in PhH (7 mL), hexane (2 mL) was added, and the mixture was allowed to stand for 20 h at 5 °C. A precipitate formed was filtered off, washed with a mixture of PhH—hexane, a combined filtrate was concentrated *in vacuo* to obtain *N*-isopropoxy-*N*-methoxyureas (**9**) (0.114 g, 75%), colorless crystals, m.p. 67—68 °C (CH_2Cl_2). ^{1}H NMR (400 MHz, $CDCl_3$), δ: 1.289 (d, 6 H, NOCH<u>Me</u>$_2$, J = 6.4 Hz); 3.781 (s, 3 H, NOMe); 4.299 (sept, 1 H, J = 6.4 Hz); 5.392 (br.s, 1 H, NH); 5.901 (br.s, 1 H, NH). MS (FAB), *m/z* (I_{rel} (%)): 149 $[M + H]^+$ (64), 77 (100). Found (%): N, 18.64. $C_5H_{12}N_2O_3$. Calculated (%): N, 18.91.

Crystals of **9** orthorhombic, from CH_2Cl_2—hexane, $C_{15}H_{12}N_2O_3$, at 298 K, M_r = 148.17, a = 5.2528(8) Å, b = 11.2347(12) Å, c = 14.108(3) Å, V = 832.6(2) Å^3, space group $P2_12_12_1$, $Z = 4$, $d_{calc} = 1.182$ g cm^{-3}, μ(Mo-Kα) = 0.097 mm^{-1}, $F(000) = 320$. The unit cell parameters and intensities of 16840 reflections (2135 independent, $R_{int} = 0.054$) were measured on a Xcalibur 3 automated four-circle diffractometer (Mo-Kα, graphite monochromator, Sapphire-3 CCD detector, ω-scan technique, $2\theta_{max} = 58.95°$). The structure was solved by the dual-space method of the SHELXD program[35] and refined by the full-matrix least squares method in anisotropic approximation for nonhydrogen atoms using the SHELXL program.[35] Positions of hydrogen atoms were found from the difference synthesis of electron density. The hydrogen atoms at the carbon atoms were refined using a riding model with $U_{iso} = nU_{eq}$ for the bearing atom (n = 1.5 for the methyl groups and n = 1.2 for the methine hydrogen atom). Positions and isotropic thermal parameters for the hydrogen atoms of the amino group were refined independently. The final Q factors are as follows: $wR_2 = 0.170$ on all the independent reflections, $R_1 = 0.060$ on 1463 reflections with $I > 2\sigma(I)$. The registration code in the Cambridge Crystallographic Data Center CCDC is 989308.

***N-tert*-Butoxy-*N*-methoxyurea (10).** A solution of *N*-chloro-*N*-methoxyurea **1** (0.190 g, 1.523 mmol) in Bu^tOH (3 mL) was added to a solution of CF_3CO_2Ag (0.410 g, 1.856 mmol) in a mixture of Bu^tOH (7 mL) and Et_2O (3 mL) at −24 °C. The temperature of the reaction mixture was raised to 16 °C over 18 h, a precipitate of AgCl was filtered off and washed with Et_2O (8 mL). A combined filtrate was concentrated *in vacuo* (5 Torr), a solution of AcONa (0.19 g, 2.32 mmol) in MeOH (5 mL) was added to the residue. The mixture obtained was concentrated *in vacuo*, the residue was extracted with CH_2Cl_2 (15 mL). The extract was dried with $MgSO_4$, filtered, and washed with CH_2Cl_2 (5 mL). A combined filtrate was concentrated *in vacuo*, the residue was washed with cold (5 °C) hexane (2 mL), then extracted with CH_2Cl_2 (15 mL). The extract was filtered through a thick filter and concentrated *in vacuo*, the residue was allowed to stand at 5 Torr to obtain product **10** (0.086 g, 35%), colorless crystals, m.p. 115—118 °C (CH_2Cl_2—hexane). ^{1}H NMR (300 MHz, $CDCl_3$), δ: 1.36 (s, 9 H, $NOCMe_3$); 3.72 (s, 3 H, NOMe); 5.50 (br.s, 1 H, NH); 5.95 (br.s, 1 H, NH). IR (KBr), ν/cm^{-1}: 3427 (NH), 1712 (C=O). MS (FAB), *m/z* (I_{rel} (%)): 163 $[M + H]^+$ (10), 57 Bu^{t+} (100). MS (FAB, K^+), *m/z* (I_{rel} (%)): 201 $[M + K]^+$ (34), 57 Bu^{t+} (100). Found (%): N, 17.09. $C_6H_{14}N_2O_3$. Calculated (%): N, 17.27.

Crystals of ureas **10** are monoclinic, from a mixture of CH_2Cl_2—hexane, $C_{16}H_{14}N_2O_3$, at 298 K a = 14.429(5) Å, b = 6.332(2) Å, c = 10.334(5) Å, V = 892.6(6) Å^3, M_r = 162.19, $Z = 4$, space group $P2_1/c$, $d_{calc} = 1.207$ g cm^{-3}, μ(Mo-Kα) = = 0.10 mm^{-1}, $F(000) = 352$. The unit cell parameters and intensities of 6089 reflections (1761 independent, $R_{int} = 0.059$) were measured on a Xcalibur 3 automated four-circle diffractometer (Mo-Kα, graphite monochromator, CCD detector, ω-scan technique, $2\theta_{max} = 60.88°$).

The structure was solved by the direct method using the SHELX-97 software.[35] Positions of hydrogen atoms were calculated geometrically and refined using a riding model with $U_{iso} = nU_{eq}$ for the bearing atom (n = 1.5 for the methyl group and n = 1.2 for other hydrogen atoms). The structure was refined on F^2 by the full-matrix least squares method in anisotropic approximation for nonhydrogen atoms to $wR_2 = 0.099$ on 1761 reflections ($R_1 = 0.044$ on 988 reflections with $F > 4\sigma(F)$, $S = 0.97$). The registration code in the Cambridge Crystallographic Data Center CCDC is 885614.

***N*-Ethoxy-*N*-methoxyurea (11)** was obtained by ethanolysis of *N*-acetoxy-*N*-methoxyurea **7** (70 h, 15 °C) according to the standard procedure[18] in 88% yield and identified by the comparison with an authentic sample[18] based on their ^{1}H NMR spectra. ^{1}H NMR (300 MHz, $CDCl_3$), δ: 1.33 (t, 3 H, OCH_2<u>Me</u>,

J =6.9 Hz); 3.84 (s, 3 H, NOMe); 4.13 (q, 2 H, OC<u>H</u>$_2$Me, J = 6.9 Hz); 5.64 (br.s, 1 H, NH); 5.96 (br.s, 1 H, NH). MS (FAB, Na^+), m/z (I_{rel} (%)): 157 [M + Na]$^+$ (22), 137 (14), 89 (25), 72 (77), 58 (100). Found (%): C, 35.93; H, 7.80; N, 20.69. $C_4H_{10}N_2O_3$. Calculated (%): C, 35.82; H, 7.51; N, 20.88.

***N*-Butoxy-*N*-isopropoxyurea (13)** was obtained by isopropanolysis of *N*-acetoxy-*N*-butoxyurea **12** (see Ref. 18) (138 h, 23 °C) according to the standard procedure[18] in 66% yield, colorless liquid, n_D^{22} 1.4518. ^{1}H NMR (300 MHz, $CDCl_3$), δ: 0.94 (t, 3 H, O(CH$_2$)$_3$<u>Me</u>, J = 7.2 Hz); 1.29 (d, 6 H, OCH<u>Me</u>$_2$, J = 6.3 Hz); 1.42 (sext, 2 H, OCH$_2$CH$_2$<u>CH</u>$_2$Me, J = 7.2 Hz); 1.65 (quint, 2 H, OCH$_2$C<u>H</u>$_2$CH$_2$Me, J = 7.2 Hz); 4.01 (t, 2 H, OC<u>H</u>$_2$CH$_2$CH$_2$Me, J = 7.2 Hz); 4.30 (sept, 1 H, OC<u>H</u>Me$_2$, J = 6.3 Hz); 5.52 (br.s, 1 H, NH); 5.91 (br.s, 1 H, NH). IR (KBr), ν/cm^{-1}: 3360 (NH), 1720 (C=O). Found (%): N, 14.38. $C_8H_{18}N_2O_3$. Calculated (%): N, 14.72.

***N*-Methoxy-*N*′-(4-nitrophenyl)urea (14)** was obtained from methoxyamine and *p*-nitrophenyl isocyanate in PhH according to the known procedure,[26] yellowish crystals. m.p. 145—147 °C (Ref. 26: m.p. 152 °C). ^{1}H NMR (300 MHz, $(CD_3)_2SO$), δ: 3.65 (s, 3 H, OMe); 7.89 (d, 2 H, C(2)H, C(6)H, J = 9.6 Hz); 8.19 (d, 2 H, C(3)H, C(5)H, J = 9.6 Hz); 9.58 (br.s, 1 H, NH); 9.97 (br.s, 1 H, NHO). IR (KBr), ν/cm^{-1}: 3224 (NH); 3215 (NH); 1664 (C=O); 1510 (NO_2); 1344 (NO_2).

Crystals of urea **14** are monoclinic, from Pr^{i}OH, at 298 K, $C_8H_9N_3O_4$, M_r = 211.18, a = 10.4233(10) Å, b = 10.2913(7) Å, c = 8.9659(6) Å, β = 99.660(7)°, V = 948.13(12) Å^3, space group $P2_1/c$, Z = 4, d_{calc} = 1.479 g cm^{-3}, μ(Mo-Kα) = 0.121 mm^{-1}, F(000) = 440. The unit cell parameters and intensities of 8870 reflections (2266 independent, R_{int} = 0.035) were measured on a Xcalibur 3 automated four-circle diffractometer (Mo-Kα, graphite monochromator, Sapphire-3 CCD detector, ω-scan technique, $2\theta_{max}$ = 58.3°). The structure was solved by the dual-space method of the SHELXD program[35] and refined by the full-matrix least squares method in anisotropic approximation for nonhydrogen atoms using the SHELXL program.[35] Positions of hydrogen atoms were found from the difference synthesis of electron density. The hydrogen atoms at the carbon atoms were refined using a riding model with $U_{iso} = nU_{eq}$ for the bearing atom (n = 1.5 for the methyl group and n = 1.2 for the aromatic hydrogen atoms). Positions and isotropic thermal parameters of the hydrogen atoms at the heteroatoms were refined independently. The final Q factors are as follows: wR_2 = 0.117 on all the independent reflections, R_1 = 0.046 on 1346 reflections with $I > 2\sigma(I)$. The registration code in the Cambridge Crystallographic Data Center CCDC is 989291.

***N*,*N*-Dimethoxy-*N*′-(4-nitrophenyl)urea (15).** A solution of *N*-chloro-*N*′-methoxy-*N*-(4-nitrophenyl)urea **4** (0.099 g, 0.403 mmol) in CH_2Cl_2 (2 mL) was added to a solution of CF_3CO_2Ag (0.107 g, 0.484 mmol) in MeOH (5 mL) at −27 °C, which was accompanied by precipitation of AgCl. The reaction mixture was slowly heated to 8 °C over 16 h, then AcONa (0.082 g, 1.00 mmol) was added, MeOH was removed *in vacuo* at 20 Torr. The residue was extracted with CH_2Cl_2 (15 mL), the extract was concentrated *in vacuo*, the residue was extracted with PhH (15 mL). The benzene extract was concentrated *in vacuo* at 20 Torr, the residue was allowed to stand *in vacuo* at 5 Torr to obtain *N*,*N*-dimethoxy-*N*′-(4-nitrophenyl)urea (**15**) (0.091 g, 93%), pale yellow crystals, m.p. 81—83 °C (PhH—hexane). ^{1}H NMR (300 MHz, $CDCl_3$), δ: 3.97 (s, 6 H, N(OMe)$_2$); 7.72 (d, 2 H, C(2)H, C(6)H, J = 9.3 Hz); 8.18 (br.s, 1 H, NH); 8.26 (d, 2 H, C(3)H, C(5)H, J = 9.3 Hz). ^{13}C NMR (100 MHz, $CDCl_3$), δ: 62.23 (OMe), 118.75 (C(2), C(6)), 124.84 (C(3), C(5)), 142.25 (C(1)), 143.86 (C(4)), 156.24 (NHC(O)). MS (FAB), m/z (I_{rel} (%)): 242 [M + H]$^+$ (82), 210 [M + H − −MeOH]$^+$ (100). Found (%): C, 44.79; H, 4.83; N, 17.25. $C_9H_{11}N_3O_5$. Calculated (%): C, 44.82; H, 4.60; N, 17.42.

Crystals of compound **15** are monoclinic, grown at −20 °C in a mixture of CH_2Cl_2—hexane, $C_9H_{11}N_3O_5$, at 100 K a = 4.8371(3) Å, b = 16.9591(11) Å, c = 12.7986(9) Å, β = 92.609(7)°, V = 1048.82(12) Å^3, M_r = 241.21, Z = 4, space group $P2_1/c$, d_{calc} = 1.528 g cm^{-3}, μ(Mo-Kα) = 0.126 mm^{-1}, F(000) = 504. The tested crystal was a non-merohedral twin, in which the components gave the contributions of 0.58 : 0.42 and turned with respect to each other by 180° along the axis a. The unit cell parameters and intensities of 9049 reflections (4131 independent, R_{int} = 0.072) were measured on a Xcalibur 3 automated four-circle diffractometer (Mo-Kα, graphite monochromator, CCD detector, ω-scan technique, $2\theta_{max}$ = 57.74°).

The structure of compound **15** was solved by the direct method using the SHELX-97 software.[35] Positions of hydrogen atoms were calculated geometrically and refined using a riding model with $U_{iso} = nU_{eq}$ for the bearing atom (n = 1.5 for the methyl groups and n = 1.2 for other hydrogen atoms). The structure was refined on F^2 by the full-matrix least squares method in anisotropic approximation for nonhydrogen atoms to wR_2 = 0.145 on 4037 reflections (R_1 = 0.059 on 2316 reflections with $F > 4\sigma(F)$, S = 0.98). The registration code in the Cambridge Crystallographic Data Center CCDC is 776941.

***N*-Benzyloxy-*N*-chloro-*N*′-(4-nitrophenyl)urea (17a)** and ***N*-benzyloxy-*N*-methoxy-*N*′-(4-nitrophenyl)urea (18a)**. A solution of Bu^{t}OCl (0.637 g, 5.67 mmol) in CH_2Cl_2 (5 mL) was added to a solution of *N*-benzyloxy-*N*′-(4′-nitrophenyl)urea (0.126 g, 0.438 mmol) in CH_2Cl_2 (5 mL) at −20 °C, the mixture was allowed to stand for 5 min at −20 °C and 5 h at 4 °C, then concentrated *in vacuo*. The residue was allowed to stand at 5 Torr to obtain *N*-benzyloxy-*N*-chloro-*N*′-(4-nitrophenyl)urea (**17a**), yellow crystals with m.p. 89—91 °C (with decomp.), quantitative yield. ^{1}H NMR (300 MHz, $CDCl_3$), δ: 5.10 (s, 2 H, $NOCH_2$); 7.44—7.52 (m, 5 H, Ph); 7.48 (d, 2 H, C(2)H, C(6)H, J = 9.0 Hz); 7.87 (br.s, 1 H, NH); 8.18 (d, 2H, C(3)H, C(5)H, J = 9.0 Hz). MS (FAB), m/z (I_{rel} (%)): 324 [M + H]$^+$ (11), 322 [M + H]$^+$ (28), 91 Bn$^+$ (100). Found (%): Cl, 10.95. $C_{14}H_{12}ClN_3O_4$. Calculated (%): Cl, 11.02.

N-Benzyloxy-*N*-chloro-*N*′-(4-nitrophenyl)urea (**17a**) was dissolved in MeOH (3 mL) at −35 °C, followed by a rapid addition of a solution of CF_3CO_2Ag (0.106 g, 0.482 mmol) in MeOH (2.5 mL). The temperature of the reaction mixture was raised to 16 °C over 20 h, a precipitate of AgCl was filtered off and washed with MeOH (5 mL), a solution of AcONa (0.08 g) in MeOH (4 mL) was added to the filtrate. The reaction mixture was allowed to stand at 16 °C over 2 h, then concentrated *in vacuo*. The residue was extracted with CH_2Cl_2 (15 mL), the extract was dried with $MgSO_4$ and then concentrated *in vacuo* to obtain *N*-benzyloxy-*N*-methoxy-*N*′-(4-nitrophenyl)urea (**18a**) (0.138 g, 99%), a dense yellowish oil, solidifying upon a prolonged storage at 5 °C to a pale yellow solid compound with m.p. 65—67 °C. ^{1}H NMR (300 MHz, $CDCl_3$), δ: 3.85 (s, 3 H, NOMe); 5.12 (s, 2 H, $NOCH_2$); 7.40—7.50 (m, 5 H, Ph); 7.56 (d, 2 H, C(2)H, C(6)H, J = 9.3 Hz); 7.96 (br.s, 1 H, NH); 8.20 (d, 2 H, C(3)H, C(5)H, J = 9.3 Hz). IR (KBr), ν/cm^{-1}: 3313 (NH); 1700 (C=O); 1580 (NO_2); 1332 (NO_2). MS (FAB), m/z (I_{rel} (%)): 318 [M + H]$^+$

(14), 91 Bn^+ (100). Found (%): C, 56.58; H, 4.72; N, 13.02. $C_{15}H_{15}N_3O_5$. Calculated (%): C, 56.78; H, 4.77; N, 13.24.

Compounds **17b,c,e** were obtained similarly to compound **17a**.

***N*-Chloro-*N*-(3-methylbutoxy)-*N´*-(4-nitrophenyl)urea (17b)**, the yield was 94%, colorless crystals, m.p. 88—89 °C (with decomp.). ^{1}H NMR (300 MHz, $CDCl_3$), δ: 1.00 (d, 6 H, $CH\underline{Me}_2$, J = 6.6 Hz); 1.67 (q, 2 H, $OCH_2\underline{CH}_2CH$, J = 6.6 Hz); 1.74 (nonet, 1 H, $CH_2\underline{CH}Me_2$, J = 6.6 Hz); 4.19 (t, 2 H, $NO\underline{CH}_2CH_2$, J = 6.6 Hz); 7.69 (d, 2 H, C(2)H, C(6)H, J = 9.3 Hz); 8.26 (d, 2 H, C(3)H, C(5)H, J = 9.3 Hz); 8.28 (br.s, 1 H, NH). Found (%): N, 14.05; Cl, 11.65. $C_{12}H_{16}ClN_3O_4$. Calculated (%): N, 13.93; Cl, 11.75.

***N*-Chloro-*N*-ethoxy-*N´*-(2-nitrophenyl)urea (17c)** was washed with hexane, the yield was 67%, yellow crystals, m.p. 65—66 °C (with decomp.). ^{1}H NMR (300 MHz, $CDCl_3$), δ: 1.48 (t, 3 H, $OCH_2\underline{Me}$, J = 7.2 Hz); 4.27 (q, 2 H, $O\underline{CH}_2Me$, J = 7.2 Hz); 7.29 (t, 1 H, C(4)H, J = 8.4 Hz); 7.74 (t, 1 H, C(5)H, J = 8.4 Hz); 8.30 (d, 1 H, C(6)H, J = 8.4 Hz); 8.74 (d, 1 H, C(3)H, J = 8.4 Hz); 11.41 (br.s, 1 H, NH). Found (%): N, 16.08; Cl, 13.43. $C_9H_{10}ClN_3O_4$. Calculated (%): N, 16.18; Cl, 13.65.

***N´*-(4-Bromophenyl)-*N*-chloro-*N*-ethoxyurea (17e)**, the yield was 89%, colorless crystals, m.p. 75—75.5 °C (with decomp.). ^{1}H NMR (300 MHz, $CDCl_3$), δ: 1.40 (t, 3 H, $OCH_2\underline{Me}$, J = 6.9 Hz); 4.20 (q, 2 H, $O\underline{CH}_2Me$, J = 6.9 Hz); 7.41 (d, 2 H, C(2)H, C(6)H, ^3J = 9.3 Hz); 7.48 (d, 2 H, C(3)H, C(5)H, J = 9.3 Hz); 7.95 (br.s, 1 H, NH). MS (EI, 70 eV), m/z (I_{rel} (%)): 296 $[M]^+$ (2), 294 $[M]^+$ (8), 292 $[M]^+$ (6), 61 (100). MS (FAB), m/z (I_{rel} (%)): 297 $[M + H]^+$ (7), 295 $[M + H]^+$ (29), 293 $[M + H]^+$ (23), 259 (100). Found (%): C, 36.50; H, 3.62. $C_9H_{10}BrClN_2O_2$. Calculated (%): C, 36.83; H, 3.43.

***N*-Chloro-*N´*-(4-chlorophenyl)-*N*-ethoxyurea (17d)** was obtained according to the procedure published earlier.[34]

Compounds **18b—e** were obtained similarly to compounds **15** and **18a**.

***N*-Methoxy-*N*-(3-methylbutoxy)-*N´*-(4-nitrophenyl)urea (18b)**, the yield was 91%, a pale yellow dense oil. ^{1}H NMR (300 MHz, $CDCl_3$), δ: 1.00 (d, 6 H, $CH\underline{Me}_2$, J = 6.6 Hz); 1.67 (q, 2 H, $OCH_2\underline{CH}_2CH$, J = 6.6 Hz); 1.78 (nonet, 1 H, $CH_2\underline{CH}Me_2$, J = 6.6 Hz); 3.94 (s, 3 H, NOMe); 4.19 (t, 2 H, $NO\underline{CH}_2CH_2$, J = 6.6 Hz); 7.71 (d, 2 H, C(2)H, C(6)H, J = 9.0 Hz); 8.18 (br.s, 1 H, NH); 8.26 (d, 2 H, C(3)H, C(5)H, J = 9.0 Hz). MS (FAB), K^+, m/z (I_{rel} (%)): 336 $[M + K]^+$ (81), 298 $[M + H]^+$ (16), 71 (100). Found (%): C, 52.31; H, 6.68; N, 14.03. $C_{13}H_{19}N_3O_5$. Calculated (%): C, 52.52; H 6.44; N, 14.13.

***N*-Ethoxy-*N*-methoxy-*N´*-(2-nitrophenyl)urea (18c)**, the yield was 98%, a dense light yellow liquid, n_D^{21} 1.5641, upon prolonged storage solidifies to yellow crystals. ^{1}H NMR (300 MHz, $CDCl_3$), δ: 1.45 (t, 3 H, $OCH_2\underline{Me}$, J = 6.9 Hz); 3.96 (s, 3 H, NOMe); 4.25 (q, 2 H, $O\underline{CH}_2Me$, J = 6.9 Hz); 7.23 (t, 1 H, C(4)H, J = 8.4 Hz); 7.71 (t, 1 H, C(5)H, J = 8.4 Hz); 8.28 (d, 1 H, C(6)H, J = 8.4 Hz); 8.76 (d, 1 H, C(3)H, J = 8.4 Hz); 11.19 (br.s, 1 H, NH). IR (KBr), ν/cm^{-1}: 3330 (NH); 1749 (C=O); 1510 (NO_2); 1340 (NO_2). MS (FAB), m/z (I_{rel} (%)): 256 $[M + H]^+$ (17), 224 $[M + H - MeOH]^+$ (100). Found (%): N, 16.32. $C_{10}H_{13}N_3O_5$. Calculated (%): N, 16.46.

***N´*-(4-Chlorophenyl)-*N*-ethoxy-*N*-methoxyurea (18d)**, the yield was 62%, a yellowish dense oil. ^{1}H NMR (300 MHz, $CDCl_3$), δ: 1.37 (t, 3 H, $OCH_2\underline{Me}$, J = 7.2 Hz); 3.90 (s, 3 H, NOMe); 4.18 (q, 2 H, $O\underline{CH}_2Me$, J = 7.2 Hz); 7.30 (d, 2 H, C(2)H, C(6)H, J = 9.3 Hz); 7.46 (d, 2 H, C(3)H, C(5)H, J = 9.3 Hz); 7.90 (br.s, 1 H, NH). MS (FAB), m/z (I_{rel} (%)): 247 $[M + H]^+$ (5), 245 $[M + H]^+$ (13), 215 $[M - MeO]^+$ (40), 213 $[M - MeO]^+$ (100), 201 (8), 199 (33), 156 (18), 154 (37). Found (%): N, 11.40. $C_{10}H_{13}ClN_2O_3$. Calculated (%): N, 11.45.

***N´*-(4-Bromophenyl)-*N*-ethoxy-*N*-methoxyurea (18e)**, the yield was 92%, a yellowish dense oil. ^{1}H NMR (300 MHz, $CDCl_3$), δ: 1.39 (t, 3 H, $OCH_2\underline{Me}$, J = 7.2 Hz); 3.92 (s, 3 H, NOMe); 4.21 (q, 2 H, $O\underline{CH}_2Me$, J = 7.2 Hz); 7.43 (d, 2 H, C(2)H, C(6)H, J = 9.0 Hz); 7.48 (d, 2 H, C(3)H, C(5)H, J = 9.0 Hz); 7.91 (br.s, 1 H, NH). Found (%): N, 9.78. $C_{10}H_{13}BrN_2O_3$. Calculated (%): N, 9.69.

Methyl *N*-chloro-*N*-methoxycarbamate (19) was obtained according to the known procedure.[14]

Methyl *N*-chloro-*N*-isopropoxycarbamate (20) was obtained by chlorination of methyl *N*-isopropoxycarbamate (**25**) Bu^tOCl according to the known procedure for the preparation of *N*-alkoxy-*N*-chlorocarbamates,[18] the yield was 98%, a yellow liquid. ^{1}H NMR (300 MHz, $CDCl_3$), δ: 1.28 (d, 6 H, $NOCH\underline{Me}_2$, J = 6.3 Hz); 3.91 (s, 3 H, CO_2Me); 4.31 (sept, 1 H, $NOC\underline{H}Me_2$, J = 6.3 Hz). IR (neat), ν/cm^{-1}: 1780 (C=O). Found (%): Cl, 21.04. $C_5H_{10}ClNO_3$. Calculated (%): Cl, 21.15.

Ethyl *N*-chloro-*N*-methoxycarbamate (21) was obtained according to the procedure published earlier.[18]

Methanolysis of methyl *N*-chloro-*N*-methoxycarbamate (19). A solution of methyl *N*-chloro-*N*-methoxycarbamate (**19**) (0.549 g, 3.938 mmol) in MeOH (5 mL) was allowed to stand at 15 °C for 1 h, MeOH was distilled off *in vacuo* (20 Torr) and condensed in a cooled trap. The residue was extracted with a mixture of Et_2O (7 mL) and hexane (7 mL), the extract was concentrated *in vacuo* (20 Torr), the residue was fractionally distilled *in vacuo* (3 Torr) to obtain methyl *N*-methoxycarbamate (**22**) (0.221 g, 53%) and *N*,*N´*-dimethoxy-*N*,*N´*-bis(methoxycarbonyl)hydrazine (**23**) (0.144 g, 35%), which were identified by the comparison of their ^{1}H NMR spectra with the spectra of authentic samples.[14] ^{1}H NMR of carbamate **22** (300 MHz, $CDCl_3$), δ: 3.73 (s, 3 H, NOMe); 3.79 (s, 3 H, CO_2Me); 7.53 (br.s, 1 H, NH). ^{1}H NMR of hydrazine **23** (400 MHz, $CDCl_3$), δ: 3.902 (s, 6 H, NOMe); 3.916 (s, 6 H, CO_2Me). GLC analysis showed that the methanol condensate contained dimethyl carbonate **24** (0.022 g, 6.23%).

Methanolysis of methyl *N*-chloro-*N*-isopropoxycarbamate (20). A solution of methyl *N*-chloro-*N*-isopropoxycarbamate (**20**) (0.570 g, 3.40 mmol) in MeOH (10 mL) was allowed to stand at 16 °C for 20 h, then concentrated *in vacuo* (17 Torr), collecting the condensate in a trap. The residue was allowed to stand at 20 °C and 8 Torr for 1 h to obtain methyl *N*-isopropoxycarbamate (**25**) (0.137 g, 30%), a colorless liquid, n_D^{21} 1.4250, which was identified based on the ^{1}H NMR spectrum. ^{1}H NMR (300 MHz, $CDCl_3$), δ: 1.15 (d, 6 H, $NOCH\underline{Me}_2$, J = 6.3 Hz); 3.68 (s, 3 H, CO_2Me); 3.98 (sept, 1 H, $NOC\underline{H}Me_2$, J = 6.3 Hz); 7.33 (br.s, 1 H, NH). GLC analysis showed that the methanol condensate contained dimethyl carbonate **24** (0.072 g, 23.5%).

Methanolysis of ethyl *N*-chloro-*N*-methoxycarbamate (20) in the presence of AcONa. A mixture of MeOH (5 mL) and AcONa (1.85 g) was added to ethyl *N*-chloro-*N*-methoxycarbamate **20** (1.23 g, 7.312 mmol). The reaction mixture was allowed to stand at 30—31 °C for 4 days, then MeOH was distilled off *in vacuo* (20 Torr) and condensed in a cooled trap, the residue was extracted with Et_2O (40 mL). The extract was concentrated *in vacuo* (20 Torr), the residue was subjected to chromatography on a column (Al_2O_3, Et_2O—hexane). to obtain ethyl *N*-methoxycarbamate (**26**) (0.092 g, 11%) and *N*,*N´*-bis(ethoxycarbonyl)-*N*,*N´*-dimethoxyhydrazine (**27**) (0.124 g, 14%), which were iden-

tified based on the ^{1}H NMR spectra (see Refs 18 and 36). GLC analysis showed that the methanol condensate contained methyl ethyl carbonate **28** (0.230 g, 30%).

Methanolysis of ethyl *N*-chloro-*N*-methoxycarbamate (20) in the presence of $CH(OMe)_3$. A solution of $CH(OMe)_3$ (0.630 g, 5.969 mmol) in MeOH (5 mL) was added to ethyl *N*-chloro-*N*-methoxycarbamate **20** (0.611 g, 3.979 mmol) at −8 °C, the mixture was allowed to stand at −8 °C for 1 h and at 5 °C for 20 h. MeOH was distilled off *in vacuo* (20 Torr) and condensed in a cooled trap, the residue was allowed to stand at 20 °C and 8 Torr for 20 min to obtain ethyl *N*-methoxycarbamate (**26**) (0.165 g, 35%), which was identified based on the ^{1}H NMR spectrum by the comparison with an authentic sample.[36] ^{1}H NMR (300 MHz, $CDCl_3$), δ: 1.30 (t, 3 H, $CO_2CH_2\underline{Me}$, J = 6.9 Hz); 3.73 (s, 3 H, NOMe); 4.23 (q, 2 H, $CO_2\underline{CH_2}Me$, J = 6.9 Hz); 7.87 (br.s, 1 H, NH). GLC analysis showed that the methanol condensate contained methyl ethyl carbonate **28** (0.093 g, 22%).

Methyl *N*-chloro-*N*-ethoxycarbamate (29) was obtained by chlorination of methyl *N*-ethoxycarbamate[36] with Bu^tOCl according to the known procedure,[18] the yield was 98%, a yellowish liquid. ^{1}H NMR (300 MHz, $CDCl_3$), δ: 1.31 (t, 3 H, $NOCH_2\underline{Me}$, J = 6.9 Hz); 3.92 (s, 3 H, CO_2Me); 4.07 (q, 2 H, $NO\underline{CH_2}Me$, J = 6.9 Hz). IR (neat), ν/cm^{-1}: 1795 (C=O). Found (%): Cl, 22.85. $C_4H_8ClNO_3$. Calculated (%): Cl, 23.09.

Methyl *N*-butoxy-*N*-chlorocarbamate (30) and **methyl *N*-chloro-*N*-octyloxycarbamate (31)** were obtained according to our procedure published earlier.[18]

Methyl *N*-isopropoxy-*N*-methoxycarbamate (32). Methyl *N*-chloro-*N*-isopropoxycarbamate (**20**) (1.371 g, 8.179 mmol) was added to a solution of CF_3CO_2Ag (1.90 g, 8.59 mmol) in MeOH (11 mL) at −26 °C, the temperature of the reaction mixture was raised to 14 °C over 22 h. Then, AcONa (0.80 g, 9.81 mmol) was added, after 1 h a precipitate formed was filtered off and washed with CH_2Cl_2 (15 mL), a combined filtrate was concentrated *in vacuo*. The residue was extracted with hexane (20 mL), the hexane extract was concentrated *in vacuo*, the residue was distilled *in vacuo* at 3 Torr to obtain methyl *N*-isopropoxy-*N*-methoxycarbamate (**32**) (0.700 g, 52%), a colorless liquid, b.p. 50—53 °C (3 Torr), n_D^{23} 1.4168. ^{1}H NMR (300 MHz, $CDCl_3$), δ: 1.29 (d, 6 H, $NOCH\underline{Me}_2$, J = 6.3 Hz); 3.77 (s, 3 H, NOMe); 3.86 (s, 3 H, CO_2Me); 4.27 (sept, 1 H, $NOC\underline{H}Me_2$, J = 6.3 Hz). ^{13}C NMR (75 MHz, $CDCl_3$), δ: 20.9 ($NOCH\underline{Me}_2$); 54.4 ($CO_2\underline{Me}$); 60.2 ($NO\underline{Me}$); 60.4 ($NO\underline{C}HMe_2$); 159.7 (C=O). IR (KBr), ν/cm^{-1}: 1770 (C=O). MS (EI, 70 eV), m/z (I_{rel} (%)): 163 $[M]^+$ (3.4), 105 (5.6), 91 (14.0), 60 (21.3), 59 (54.8), 58 (24.3), 46 (16.9), 45 (36.7), 44 (21.3), 43 (100). Found (%): C, 44.23; H, 8.17; N, 8.42. $C_6H_{13}NO_4$. Calculated (%): C, 44.17; H, 8.03; N, 8.58.

Methyl *N*-ethoxy-*N*-isopropoxycarbamate (33) was obtained according to a similar procedure by ethanolysis of methyl *N*-chloro-*N*-isopropoxycarbamate (**20**) in the presence of CF_3CO_2Ag in 59% yield and by isopropanolysis of methyl *N*-chloro-*N*-ethoxycarbamate (**29**) in the presence of CF_3CO_2Ag in 45% yield, a colorless liquid, n_D^{21} 1.4200. ^{1}H NMR (300 MHz, $CDCl_3$), δ: 1.293 (t, 3 H, $NOCH_2\underline{Me}$, J = 7.2 Hz); 1.295 (d, 6 H, $NOCH\underline{Me}_2$, J = 6.3 Hz); 3.86 (s, 3 H, CO_2Me); 4.06 (q, 2 H, $NOC\underline{H}_2Me$, J = 7.2 Hz); 4.28 (sept, 1 H, $NOC\underline{H}Me_2$, J = 6.3 Hz). Found (%): C, 47.19; H, 8.67; N, 7.74. $C_7H_{15}NO_4$. Calculated (%): C, 47.45; H, 8.53; N, 7.90.

Methyl *N,N*-diisopropoxycarbamate (34). Methyl *N*-chloro-*N*-isopropoxycarbamate (**20**) (0.673 g, 4.017 mmol) was rapidly dissolved in Pr^iOH (2 mL) with cooling to −27 °C, the solution obtained was rapidly added to a solution of CF_3CO_2Ag (1.065 g, 4.821 mmol) in Pr^iOH (5 mL) cooled to −27 °C. The temperature of the reaction mixture was raised to 11 °C over 19 h, AcONa (0.46 g, 5.61 mmol) was added, and the mixture was stirred for 2 h. A precipitate formed was filtered off and washed with CH_2Cl_2, the filtrate was concentrated *in vacuo*. The residue was twice extracted with a mixture of CH_2Cl_2 (7 mL) and hexane (5 mL), the combined extracts were concentrated *in vacuo*, the residue was distilled *in vacuo* at 2 Torr to obtained methyl *N*,*N*-diisopropoxycarbamate (**34**) (0.456 g, 59%), a colorless liquid, n_D^{20} 1.4189. ^{1}H NMR (300 MHz, $CDCl_3$), δ: 1.29 (d, 12 H, $NOCH\underline{Me}_2$ J = 6.3 Hz); 3.85 (s, 3 H, CO_2Me); 4.28 (sept, 2 H, $NOC\underline{H}Me_2$, J = 6.3 Hz). Found (%): C, 50.31; H, 8.71; N, 7.08. $C_8H_{17}NO_4$. Calculated (%): C, 50.25; H, 8.96; N, 7.32.

Methyl *N*-butoxy-*N*-methoxycarbamate (35) was obtained according to a similar procedure by methanolysis of methyl *N*-butoxy-*N*-chlorocarbamate (**30**) in the presence of CF_3CO_2Ag in 77% yield and identified based on the ^{1}H NMR spectrum by comparison with an authentic sample.[18]

Methyl *N*-methoxy-*N*-octyloxycarbamate (36) was obtained according to a similar procedure by methanolysis of methyl *N*-chloro-*N*-octyloxycarbamate (**31**) in the presence of CF_3CO_2Ag in 76% yield and identified based on the ^{1}H NMR spectrum by comparison with an authentic sample.[18]

Methyl *N*-*tert*-butoxy-*N*-methoxycarbamate (37). A solution of CF_3CO_2Ag (1.39 g, 6.06 mmol) in Et_2O (3 mL) was added to a solution of methyl *N*-chloro-*N*-methoxycarbamate **19** (0.769 g, 5.510 mmol) in Bu^tOH (9 mL) at 18 °C with stirring. The reaction mixture was allowed to stand in dark at 18 °C for 20 h, then a precipitate of AgCl was filtered off and washed with Et_2O (9 mL), the combined filtrate was concentrated *in vacuo* (5 Torr). The residue was dissolved in MeOH (3 mL) and stirred with AcONa (0.56 g, 6.5 mmol). Then, the reaction mixture was concentrated *in vacuo*, the residue was extracted with a mixture of CH_2Cl_2 (7 mL) and hexane (7 mL), the extract was concentrated *in vacuo*, the residue was extracted with hexane (8 mL). The extract was concentrated *in vacuo*, the residue was distilled on a collar micro distillation apparatus at 5 Torr and 65—70 °C to obtain methyl *N*-*tert*-butoxy-*N*-methoxycarbamate (**37**) (0.350 g, 36%), a colorless liquid. ^{1}H NMR (500 MHz, $CDCl_3$), δ: 1.322 (s, 9 H, $NOBu^t$); 3.697 (s, 3 H, NOMe); 3.865 (s, 3 H, CO_2Me). Found, (%): C, 47.62; H, 8.39; N, 7.81. $C_7H_{15}NO_4$. Calculated (%): C, 47.45; H, 8.53; N, 7.90.

Methyl *N*-*tert*-butoxy-*N*-ethoxycarbamate (38). A solution of methyl *N*-chloro-*N*-ethoxycarbamate (**29**) (0.641 g, 4.176 mmol) in Et_2O (2 mL) was added to a mixture of Bu^tOH (5 mL) and Et_2O (2 mL) at −20 °C. The reaction mixture was allowed to stand at −20 °C for 1 h and at 4 °C for 10 days, then concentrated *in vacuo* by 70%, followed by the addition of a solution of AcONa (0.41 g, 5 mmol) in MeOH (8 mL). The mixture was allowed to stand at 4 °C for 2 days, CH_2Cl_2 (5 mL) was added, a precipitate was filtered off. The filtrate was concentrated *in vacuo*, the residue was extracted with a mixture of CH_2Cl_2 (6 mL) and hexane (16 mL). The extract was dried with $MgSO_4$ and filtered, the filtrate was concentrated *in vacuo*, the residue was fractionally distilled on a collar micro distillation apparatus to obtain methyl *N*-*tert*-butoxy-*N*-ethoxycarbamate (**38**) (0.0874 g, 11%), a colorless liquid, b.p. 78—82 °C (6 Torr). ^{1}H NMR (300 MHz, $CDCl_3$), δ: 1.26 (t, 3 H, $NOCH_2\underline{Me}$, J = 7.2 Hz); 1.32 (s, 9 H, $NOBu^t$); 3.86 (s, 3 H, CO_2Me); 4.01

(q, 2 H, NOC<u>H</u>$_2$Me, J = 7.2 Hz). MS (FAB), m/z (I_{rel} (%)): 192 $[M + H]^+$ (100); 146 $[M - Et]^+$ (60); 136 (75).

Methyl *N,N*-diethoxycarbamate (39) was obtained according to a similar procedure by ethanolysis of methyl *N*-chloro-*N*-ethoxycarbamate **29** in the presence of CF_3CO_2Ag in 46% yield, a colorless liquid, b.p. 46—47 °C (2 Torr), n_D^{25} 1.4139. ^{1}H NMR (300 MHz, $CDCl_3$), δ: 1.30 (t, 6 H, NOCH$_2$C<u>H</u>$_3$, J = 7.2 Hz); 3.87 (s, 3 H, CO_2Me); 4.07 (q, 4 H, NOC<u>H</u>$_2$Me, J = 7.2 Hz). ^{13}C NMR (75 MHz, $CDCl_3$), δ: 13.40 (OCH$_2$<u>C</u>H$_3$); 54.25 (CO_2Me); 69.86 (O<u>C</u>H$_2$Me); 159.84 (C=O). MS (EI, 70 eV), m/z (I_{rel} (%)): 164 $[M + H]^+$ (0.4); 163 $[M]^+$ (2.0), 118 (1.7), 105 (3.1), 104 (2.7), 59 (59.8), 43 (100). Found (%): C, 44.08; H, 8.14; N, 8.51. $C_6H_{13}NO_4$. Calculated (%): C, 44.17; H, 8.03; N, 8.58.

This work was financially supported by the State Foundation for Basic Research of Ukraine (Grant F-53/105-2013) and the Russian Foundation for Basic Research (Project No. 13-03-90460 of Program 07-RFFI-01).

References

1. V. G. Shtamburg, O. V. Shishkin, R. I. Zubatyuk, V. V. Shtamburg, A. V. Tsygankov, A. V. Mazepa, G. K. Kadorkina, R. G. Kostyanovsky, *Mendeleev Commun.*, 2013, **23**, 289.
2. S. A. Glover, *Tetrahedron*, 1998, **54**, 7229.
3. G. R. Gerdes, S. A. Glover, J. F. Ten Have, C. A. Rowbottom, *Tetrahedron Lett.*, 1989, **30**, 2649.
4. J. J. Campbell, S. A. Glover, G. P. Hammond, C. A. Rowbottom, *J. Chem. Soc., Perkin Trans. 2*, 1991, 2067.
5. A. M. Bonin, S. A. Glover, G. P. Hammond, *J. Chem. Soc.*, *Perkin Trans. 2*, 1994, 1173.
6. J. M. Buccigross, S. A. Glover, G. P. Hammond, C. A. Rowbottom, *Aust. J. Chem.*, 1995, **48**, 353.
7. S. A. Glover, G. P. Hammond, A. M. Bonin, *J. Org. Chem.*, 1998, **63**, 9684.
8. A. Rauk, S. A. Glover, *J. Org. Chem.*, 1996, **61**, 2337.
9. S. A. Glover, A. Rauk, *J. Org. Chem.*, 1999, **64**, 2340.
10. A.-M. E. Gillson, S. A. Glover, D. J. Tucker, P. Turner, *Org. Biomol. Chem.*, 2003, **1**, 3430.
11. K. L. Cavanagh, S. A. Glover, H. L. Price, R. R. Schumacher, *Aust. J. Chem.*, 2009, **62**, 700.
12. K. M. Digianantonio, S. A. Glover, J. P. Johns, A. A. Rosser, *Org. Biomol. Chem.*, 2011, **9**, 4116.
13. S. A. Glover, J. M. White, A. A. Rosser, K. M. Digianantonio, *J. Org. Chem.*, 2011, **76**, 9757.
14. V. G. Shtamburg, V. F. Rudchenko, Sh. S. Nasibov, I. I. Chervin, R. G. Kostyanovsky, *Bull. Acad. Sci. USSR*, *Div. Chem. Sci.* (*Engl. Transl.*), 1981, **30**, 423 [*Izv. Akad. Nauk SSSR*, *Ser. Khim.*, 1981, 449].
15. V. F. Rudchenko, R. G. Kostyanovsky, *Russ. Chem. Rev.*, 1998, **67**, 179.
16. V. F. Rudchenko, V. I. Shevchenko, S. M. Ignatov, R. G. Kostyanovsky, *Bull. Acad. Sci. USSR, Div. Chem. Sci.* (*Engl. Transl.*), 1983, **32**, 2174 [*Izv. Akad. Nauk SSSR*, *Ser. Khim.*, 1983, 2411].
17. V. F. Rudchenko, V. I. Shevchenko, R. G. Kostyanovsky, *Bull. Acad. Sci. USSR*, *Div. Chem. Sci.* (*Engl. Transl.*), 1986, **35**, 543 [*Izv. Akad. Nauk SSSR*, *Ser. Khim.*, 1986, 598].
18. V. G. Shtamburg, E. A. Klots, A. P. Pleshkova, V. I. Avramenko, S. P. Ivonin, A. V. Tsygankov, R. G. Kostyanovsky, *Russ. Chem. Bull.* (*Int. Ed.*), 2003, **52**, 2251 [*Izv. Akad. Nauk*, *Ser. Khim.*, 2003, 2132].
19. V. G. Shtamburg, A. P. Pleshkova, V. N. Serdyuk, S. P. Ivonin, *Zh. Org. Khim.*, 1999, **35**, 1578 [*Russ. J. Org. Chem.* (*Engl. Transl.*), 1999, **35**].
20. O. V. Shiskin, R. I. Zubatyuk, V. G. Shtamburg, A. V. Tsygankov, E. A. Klots, A. V. Mazepa, R. G. Kostyanovsky, *Mendeleev Commun.*, 2006, **16**, 222.
21. V. G. Shtamburg, O. V. Shishkin, R. I. Zubatyuk, S. V. Kravchenko, A. V. Tsygankov, V. V. Shtamburg, V. B. Distanov, R. G. Kostyanovsky, *Mendeleev Commun.*, 2007, **17**, 178.
22. V. G. Shtamburg, A. P. Pleshkova, V. N. Serdyuk, S. P. Ivonin, *Zh. Org. Khim.*, 1999, **35**, 1120 [*Russ. J. Org. Chem.* (*Engl. Transl.*), 1999, **35**].
23. V. G. Shtamburg, O. V. Shishkin, R. I. Zubatuk, S. V. Kravchenko, A. V. Tsygankov, A. V. Mazepa, E. A. Klots, R. G. Kostyanovsky, *Mendeleev Commun.*, 2006, **16**, 323.
24. V. G. Shtamburg, A. V. Tsygankov, M. V. Gerasimenko, O. V. Shishkin, R. I. Zubatyuk, A. V. Mazepa, R. G. Kostyanovsky, *Mendeleev Commun.*, 2011, **21**, 50.
25. O. V. Shishkin, V. G. Shtamburg, R. I. Zubatiuk, D. A. Olefir, A. V. Tsygankov, A. V. Prosyanik, A. V. Mazepa, R. G. Kostyanovsky, *Chirality*, 2009, **21**, 642.
26. J. Perronnet, J.-P. Demoute, *Gazzet. Chim. Ital.*, 1982, **112**, 507.
27. S. Swaminathan, B. M. Craven, *Acta Cryst.*, 1984, **B40**, 300.
28. S.-Q. Dou, B.T. Gowda, H. Paulus, A. Weiss, *Z. Naturforsch.*, *A: Phys. Sci.*, 1994, **49**, 1136.
29. R. N. Brown, *Acta Crystallogr.*, 1961, **14**, 711.
30. F. Belaj, E. Nachbaur, *Monatsch. Chem.*, 1987, **118**, 1077.
31. F. Belaj, E. Nachbaur, G. Faleschini, R. Janoschek, *Heteroatom. Chem.*, 1991, **2**, 487.
32. S. A. Glover, in *The Chemistry of Hydroxylamines, Oximes and Hydroxamic Acids*, Eds Z. Rappoport, J. F. Liebman, John Wiley and Sons, Ltd, New York, 2009, 839—923.
33. H.-B. Burgi, J. D. Dunitz, in *Structure correlation*, **2**, VCH, Weinheim, 1994, 741—784.
34. V. G. Shtamburg, O. V. Shishkin, V. V. Shtamburg, R. I. Zubatyuk, A. V. Mazepa, R. G. Kostyanovsky, *Chem. Heterocycl. Compd.* (*Engl. Transl.*), 2013, **49**, 1034 [*Khim. Geterotsikl. Soedin.*, 2013, 1282].
35. G. Sheldrick, *Acta Crystallogr.*, *Sect. A*, 2008, **64**, 112.
36. R. J. Crawford, R. Raaph, *J. Org. Chem.*, 1963, **28**, 2419.

Received February 25, 2014;
in revised form May 26, 2014