Isomerization and 1,3-dipolar cycloaddition of *gem*-difluorinated NH-azomethine ylides in the reaction of difluorocarbene with diarylmethanimines*

M. S. Novikov,[a] A. F. Khlebnikov,[a] K. A. Khistyaev,[a] and I. Magull[b]*

[a]St. Petersburg State University, Department of Chemistry, 26 Universitetskii prosp., 198504 St. Petersburg, Russian Federation. Fax: +7 (812) 428 6939. E-mail: Alexander.Khlebnikov@pobox.spbu.ru
*[b]Institute of Inorganic Chemistry of Georg-August University, 4 Tammannstrasse, D-37077 Goettingen, Germany***

Reaction of difluorocarbene with diarylmethanimines leads to the formation of *gem*-difluorinated NH-azomethine ylides, two types of competing transformations of which are found to be characteristic: a formal 1,2-H shift into *N*-(difluoromethyl)imines and 1,3-dipolar cycloaddition to electron-deficient multiple bonds. α,α,α-Trifluoroacetophenones are efficient dipolar traps for difluoro NH-ylides, the addition of which to the dipole proceeds regioselectively with the formation of 4-fluoro-2,5-dihydrooxazoles. According to the quantum-chemical calculations by the DFT B3LYP/6-31G* method, 1,3-dipolar cycloaddition of difluorinated NH-azomethine ylides to a C=O bond with the formation of 4-fluoro derivatives of oxazole has lower barrier of activation than the reaction, leading to another regioisomer; the formal 1,2-H shift in the ylide occurs intermolecularly with participation of an imine, a precursor of the ylide.

Key words: azomethine ylides, difluorocarbene, cycloaddition, fluorine-substituted heterocycles.

Reactions of 1,3-dipolar cycloaddition of azomethine ylides to multiple bonds are the basis of important synthetic method for the preparation of five-membered nitrogen heterocycles.[3] NH-Azomethine ylides,[4—6] as well as so called *N*-metallated azomethine ylides,[7] turned out to be efficient building blocks for the synthesis of *N*-unsubstituted heterocyclic systems. Additional opportunities for the application of these 1,3-dipoles are opened by the presence of a leaving group in them (CN, OTMS, SMe), which transforms them into synthetic equivalents of nitrile ylides, synthons for the preparation of derivatives of 1-pyrroline,[8] 2-oxazoline,[9] and other compounds.[10] Known methods for the generation of NH-ylides include desilylation of nitrogen-containing silanes,[3] thermolysis of aziridines,[11] prototropy of azomethines,[2,7,12] 1,2- and 1,4-silatropy of α-silylimines and -amides, respectively,[13—15] 1,4-stannotropy of *N*-(stannylmethyl)-thioamides,[16] decarboxylation of α-amino acids,[17] and condensation of an aldehyde with *N*-unsubstituted α-amino acid.[18,19] These methods allow one to generate ylides and, consequently, to obtain target heterocycles with such functional groups as CO_2R, CN, NRR′, and =NR. For the synthesis of halo-containing NH-heterocycles, halogenated NH-ylides would have been used, however, methods for the generation of such intermediates have not been known until recently.[1,2] We have developed a method for the generation of *gem*-difluorinated NH-azomethine ylides, experimental and theoretical investigations of their chemical properties have been carried out, and potentialities of their application for the synthesis of 4-fluoro-3-oxazoline derivatives have been demonstrated.

Reaction of fluoro carbenes with compounds, containing a C=N bond, is the only method for the generation of unstable fluorinated azomethine ylides, which can be successfully trapped only by means of 1,3-dipolar cycloaddition.[20—27] Cycloaddition of *gem*-difluorinated azomethine ylides is a final step in the domino-process, including *in situ* generation of difluorocarbene (by the reduction of CF_2Br_2 with lead in the presence of Bu_4NBr) and its addition to a substrate, containing a C=N bond, with the formation of an ylide.[20,23—27] According to the standard procedure, *gem*-difluorinated azomethine ylide is generated by the stirring or ultrasonic irradiation at 35—40 °C of a mixture of azomethine, CF_2Br_2, Pb,

* For preliminary communication, see. Refs 1 and 2.

** Institut für anorganische Chemie, Georg-August-Universität Göttingen, D-37077 Göttingen, 4 Tammannstrasse, Germany.

Published in Russian in *Izvestiya Akademii Nauk. Seriya Khimicheskaya,* No. 5, pp. 1051—1060, May, 2008.

1066-5285/08/5705-1070

Bu_4NBr, and dipolarophile in anhydrous dichloromethane.[28] For the trapping of formed nucleophilic 1,3-dipoles, highly active dipolarophiles, for example, dimethyl acetylenedicarboxylate (DMAD), are the most efficient. However, when carbene methods for the generation of azomethine ylides are used, the possibility of application of DMAD is determined by the nucleophilicity of a precursor of azomethine ylide, the corresponding imine. Thus, if for the fixing of difluoroylides from *N*-aryl-substituted imines, due to their relatively low nucleophilicity, DMAD can be used, then in case of more nucleophilic *N*-alkyl-substituted imines, the yields of cycloadducts become extremely low.[28] As it turned out, *N*-unsubstituted imines, diarylmethanimines, react with DMAD so fast that difluorocarbene cannot compete with it and difluoro ylide cannot be generated under given conditions. For the trapping of difluoro ylides, substituted at the nitrogen atom, less electrophilic dipolarophiles can be used (for example, methyl methacrylate), which, however, should be taken in a large excess.[29]

Taking into account the fact that methyl methacrylate does not show high activity toward NH-imines and its excess does not prevent generation and reactions of difluorocarbene, we attempted to use it for the trapping of difluoro-NH-azomethine ylide (**1a**), which is forming from benzophenone imine (**2a**) and difluorocarbene. The reaction of imine **2a**, CF_2Br_2, Pb, and Bu_4NBr in the presence of 5 equiv. of methyl methacrylate under ultrasonic irradiation resulted in a mixture, which consisted only of benzophenone and *N*-(benzhydrylidene)difluoromethylamine **3a** (Scheme 1). After chromatographic purification on SiO_2 imine **3a** was isolated in 9% yield (with 10% of admixture of benzophenone), which was identified by ^1H and ^{13}C NMR spectra.

Obviously, imine **3a** is the product of a formal 1,2-H shift in ylide **1a**. In fact, the GLC data show that analogous reaction, carried out in the absence of methyl methacrylate, gave similar result. The product of cycloaddition of intermediate NH-ylide **1a** to methyl methacrylate, *viz.*, difluoropyrrolidine **4**, as well as the product of its hydrolysis, the corresponding lactam, have not been found in the reaction mixture. This attests the fact that isomerization of ylide **1a** into imine **3a** proceeds faster, than cycloaddition of ylide **1a** to the double bond of methyl methacrylate.

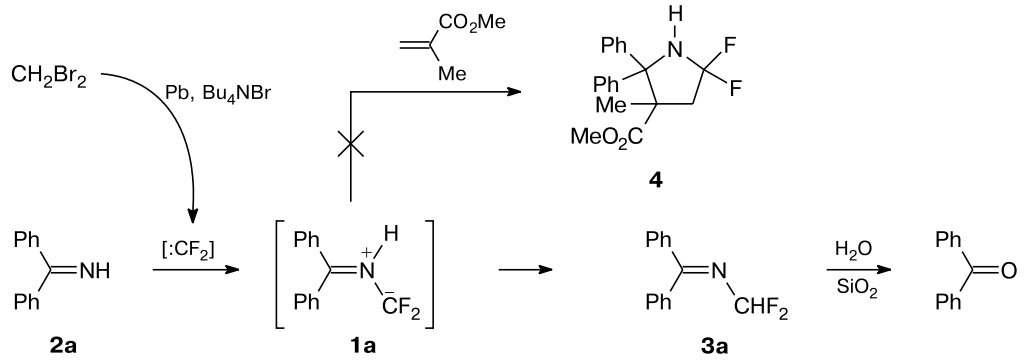
1,3-Dipolar cycloaddition of ylide **1a** was successful when carbonyl compounds were used as the dipolarophiles. Only ketones can be used as the C=O dipolarophiles for the interception of NH-ylide **1a**, since aldehydes such as acetaldehyde and benzaldehyde, which most often are used as the traps for various 1,3-dipoles, react rather fast with the ylide precursor, imine **1a**. At the same time, many ketones do not have enough electrophilicity for the efficient interception of difluoroazomethine ylides.[30] Calculation of the global electrophilicity indexes ω for a number of ketones and methyl methacrylate as the standard inactive dipolarophile according to the scheme,[31] which is used for the evaluation of activity of dienophiles and dipolarophiles,[32] gave for acetone, methyl methacrylate, acetophenone, and fluorenone the following values ω = 0.94, 1.36, 1.59, and 2.25 eV, respectively. The latter ketone, which has the global electrophilicity index considerably higher than that for methyl methacrylate and has insignificant steric requirement to nucleophilic attack, was tested by us as a potential dipole trap for NH-ylide **1a**.

The reaction of imine **2a** with difluorocarbene in the presence of 3 equiv. of fluorenone led to fluorooxazoline **5**, which was isolated by column chromatography in 21% yield (Scheme 2).

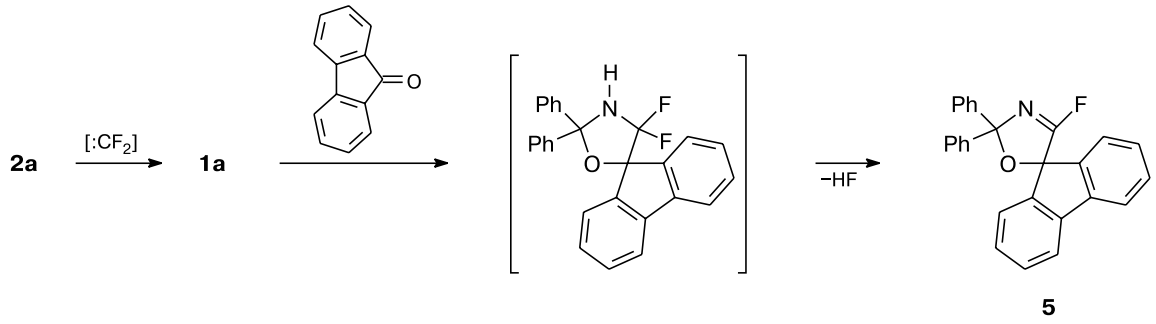
α,α,α-Trifluoroacetophenone **6a** (global index ω = 2.25 eV, as for fluorenone) is also active toward ylide **1a**. The reaction of CF_2Br_2, lead, imine **2a**, and α,α,α-trifluoroacetophenone **6a** (taken in equimolar amounts) in the presence of Bu_4NBr after chromatography of the reaction mixture resulted in the formation of fluorooxazoline **7a** in 15% yield (Scheme 3, Table 1). According to GLC and TLC data, benzophenone difluoromethylimine **3a** and benzophenone were found in the reaction mixture in addition to oxazoline **7a**.

Fluorooxazolines **5** and **7a** are representatives of a new class of fluorine-containing heterocycles, therefore,

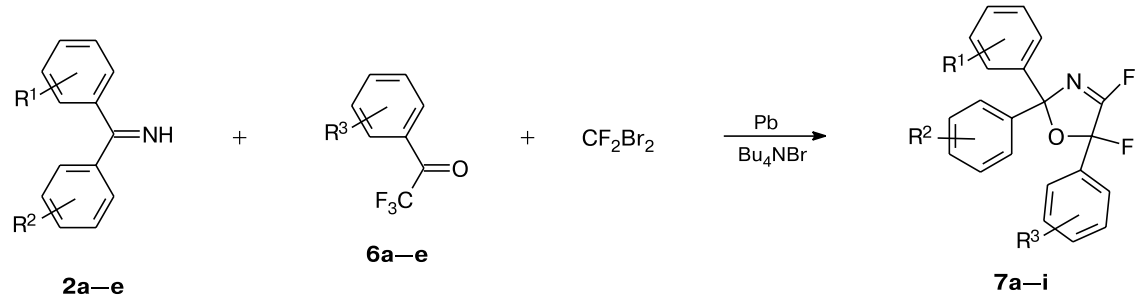
Scheme 1



Scheme 2



Scheme 3



optimization of conditions for their synthesis has been undertaken.

Effects of such factors as concentration and ratio of reagents and presence or absence of ultrasonic irradiation on the yield of compound **7a** have been studied. The reaction was also carried out in various temperature regimes with the use of both active lead (Pb*)[28] and common lead metal. It was found that the yield of oxazoline **7a** strongly depends on the ratio of reagents. The highest yield (66%) was reached in the experiment with the use of three-fold excess of dipolarophile at 30—40 °C under ultrasonic irradiation. The exchange of common lead metal for the active lead, obtained by the reduction of lead acetate with sodium borohydride in aqueous acetic acid does not result in an increase in the yield of oxazoline. The reaction time varies from several hours to a week or more depending on the concentration of the reagents. An increase in the reaction time is observed when very concentrated solutions were used, which, apparently, is caused by the increase in viscosity of the reaction mixture. A decrease in temperature from 40 to 20 °C leads to an increase in the reaction time without change in the product yield.

Table 1. Reaction of difluorocarbene with imines in the presence of trifluoroacetophenones

Imine	R^1	R^2	Ketone	R^3	Oxazoline	Yield (%)
1a	H	H	**6a**	H	**7a**	66
1b	4-Cl	4-Cl	**6a**	H	**7b**	61
1c	4-Cl	4-CN	**6a**	H	**7c**	10*
1d	4-CF_3	4-CF_3	**6a**	H	**7d**	12
1e	3-CF_3	3-CF_3	**6a**	H	**7e**	38
1a	H	H	**6b**	4-Me	**7f**	63
1a	H	H	**6c**	4-Cl	**7g**	54
1a	H	H	**6d**	4-F	**7h**	76
1a	H	H	**6e**	3-CF_3	**7i**	74

* A mixture of stereoisomers.

An additional experiment has been carried out, in which difluorocarbene was generated by the reduction of CF_2Br_2 with a zinc dust, however, the yield of fluorooxazoline **7a** in this case turned out to be lower, 37%.

In conclusion, the use of lead filings and the following ratio of the reagents: imine : Pb : Bu_4NBr : CF_2Br_2 : $PhCOCF_3$ = 1 : 3 : 3 : 3 : 3 in 5 mL of dichloromethane per 1 mmol of imine at 30—40 °C and ultrasonic irradiation are the optimal conditions for the synthesis of fluorooxazoline **7a**. These conditions were used for the reactions of difluorocarbene with a number of the ring substituted diarylmethanimines **2b—e** in the presence of unsubstituted trifluoroacetophenone **6a** and for the reaction of unsubstituted diphenylmethanimine **2a** in the presence of a number of substituted trifluoroacetophenones **6b—e**. The yields of fluorooxazolines **7b—i** are given in Table 1. The corresponding benzophenone was formed as the by-product in all the cases.

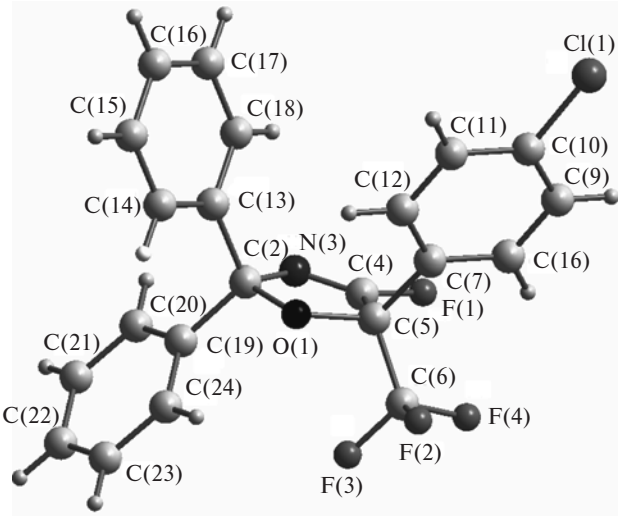


Fig. 1. General view of molecule **7g**.

Structures of obtained fluorooxazolines **7a—i** were established by ^{1}H, ^{13}C NMR and IR spectroscopy and confirmed by the elemental analysis data. There are no signals of nonaromatic protons in the ^{1}H NMR spectra, whereas ^{13}C NMR spectra contain signals coming from the substituted fluorooxazoline fragment: a multiplet signal of C(5) atom in the region δ_C 82.2—85.5, a dublet signal of C(2) atom at δ_C 106.4—108.1, a quartet of dublets corresponding to the CF_3 group at δ_C 120.1—122.4, and a dublet signal of C(4) atom at δ_C 157.9—160.8. In the IR spectrum, a band of the stretching vibrations of the C=N bond in the region 1720—1735 cm^{-1} is present.[33]

In addition, the structures of compounds were confirmed by the results of X-ray analysis performed for fluoride **7g** (Fig. 1).

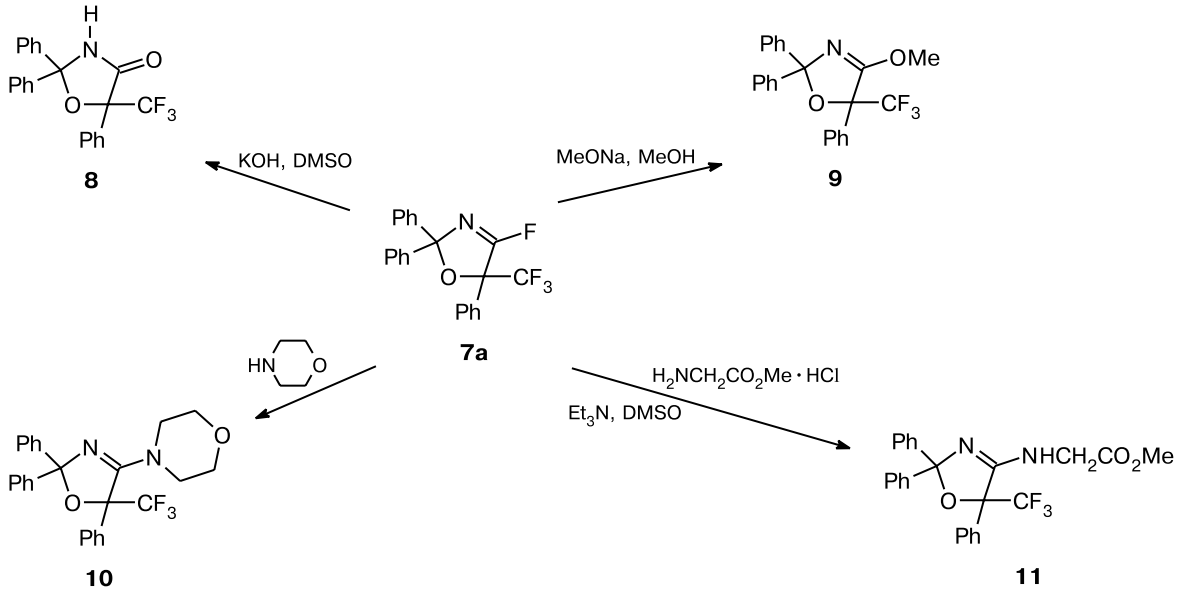
We showed that fluorine atom in fluorooxazolines **7a—i** can be easily substituted for other functional groups by the action of nucleophilic reagents. Thus, treatment of fluorooxazoline **7a** with equimolar amount of KOH in DMSO leads to lactam **8** in 91% yield (Scheme 4).

The stirring of fluorooxazoline **7a** and equimolar amount of sodium methoxide in methanol for 1 day gives methoxy derivative **9** in 89% yield. The keeping of fluorooxazoline **7a** in morpholine for 2 days leads to the product of substitution of the fluorine, *viz.*, morpholine derivative **10**, in 76% yield, whereas the stirring of a mixture of fluorooxazoline **7a** and equimolar amounts of methyl glycinate hydrochloride and triethylamine in DMSO for 2 days gives methyl ester of *N*-heteryl-substituted glycine **11** in 88% yield.

Despite the readiness of the formal substitution of fluorine atom for nucleophiles, fluorooxazoline **7a** is stable against acidic reagents: it does not undergo decomposition under reflux in concentrated HCl for 8 h.

Thus, the experimental results allow one to conclude that the *gem*-difluorinated NH-azomethine ylides can be generated by the reaction of difluorocarbene with diarylmethanimines. One of prospective synthetic applications of these 1,3-dipoles is a preparation of 4-fluoro-3-oxazoline derivatives by the reaction of lead, CF_2Br_2, diarylmethanimine, and trifluoromethylketone. As it could be seen from Table 1, the yields of oxazolines with electron-withdrawing substituents in the aryl rings of the imine are considerably low. In addition, gas chromatographic analysis of the reaction mixtures showed that in all the cases, the corresponding benzophenone *N*-difluoromethylimine **3a—e** is formed, the content of which increases in the reaction of imines **2c—e** with electron-withdrawing substituents. This allows one to suggest that a decrease in the

Scheme 4



yield of oxazolines **7** is caused by the competing isomerization of ylide **1** into imine **3**. Obviously, the increase of NH-acidity of ylides **1c—e**, caused by the CF_3 and CN substituents, should facilitate transformation **1** → **3**. In this connection, clarification of the mechanism of ylide isomerization, which can proceed either as the intramolecular transfer of hydrogen atom or as the intermolecular process with participation of the starting imine, is very important for the practical application of proposed method for the synthesis of fluorooxazolines.

To obtain information on the mechanism of isomerization and evaluate kinetic stability of difluorinated NH-ylides **1**, we have undertaken a theoretical investigation of isomerization and cycloaddition reactions for the simplest NH-ylide $H_2C{=}N(H)^+{-}(CF_2)^-$ (**1f**) by the B3LYP/6-31G* method.

Two mechanisms for isomerization of ylide **1f** into imine **3f** can be suggested: an intramolecular transfer of the hydrogen atom and an intermolecular transfer of the proton with participation of imine **2f** (Scheme 5).

According to the calculation, the intramolecular transfer of the hydrogen atom in ylide **1f** can take place *via* transition state **TS1** (Fig. 2) with free energy of activation 30.0 kcal mol^{-1} (Fig. 3). However, as it could be seen from the diagram (see Fig. 3), there exists the more favorable intramolecular process for ylide **1f**: the 1,3-cyclization into aziridine, the activation barrier to which is considerably low and is equal to 20.6 kcal mol^{-1} (**TS5**). At the same time, even this value of $\Delta G^{\neq}$ is too high for such a reaction of difluoroazomethine ylides to take place. In fact, examples of 1,3-cyclization of *gem*-difluorinated azomethine ylides into the corresponding aziridines are not known.[20,23—27] Since the reaction of formation of ylide from imine and difluorocarbene is reversible,[34] difluoroylides dissociate to imine and difluorocarbene in the absence of possibility to react with relatively low barrier of activation (for example, in some cycloaddition reactions). As the calculation (*see* Fig. 3) showed, the activation barrier to dissociation of unsubstituted difluoroylide **2f** (**TS4**) is equal to 9.4 kcal mol^{-1}. Difluorocarbene under these conditions is gradually consumed in the reactions with the lower barriers, for example, in the dimerization reaction leading to the formation of tetrafluoroethylene.[35—37]

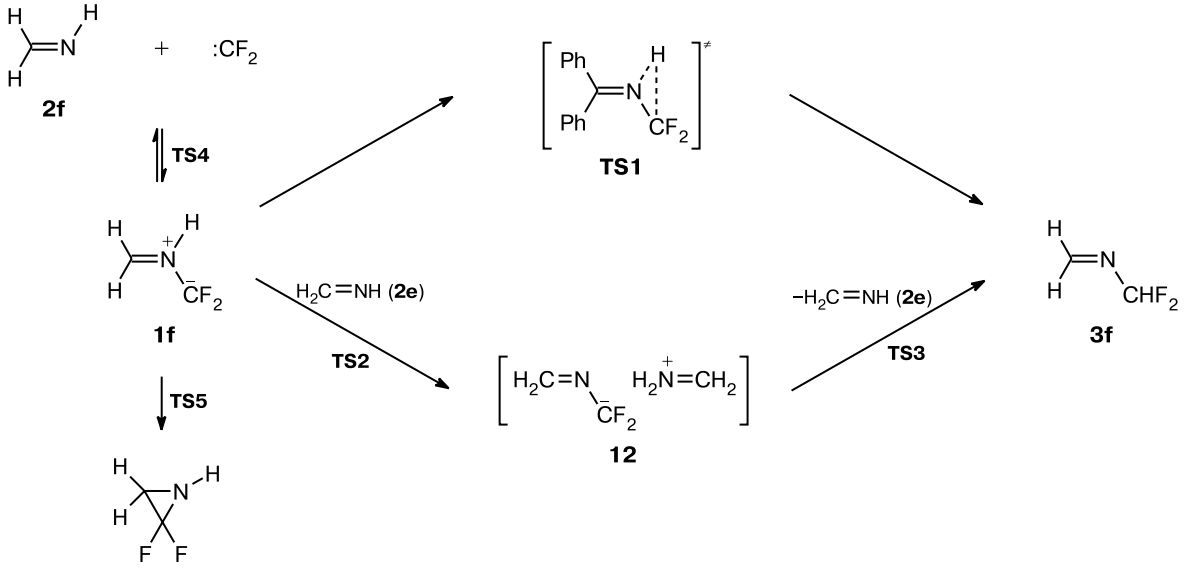
An intermolecular proton transfer with participation of starting imine **2f** is energetically more favorable. It proceeds stepwise *via* intermediate **12** (see Fig. 2): (1) the deprotonation of ylide with imine with activation barrier of 16.8 kcal mol^{-1} (**TS2**), leading to the formation of ion pair **12**, (2) the proton transfer to the CF_2 group (**TS3**) with the barrier of activation of 4.0 kcal mol^{-1} (Fig. 4).

To compare barriers of activation of isomerization and dissociation reactions of ylide **1f** with barrier of activation of its cycloaddition to the C=O bond of a carbonyl compound, a model reaction of ylide **1f** with acetone has been also calculated (Scheme 6).

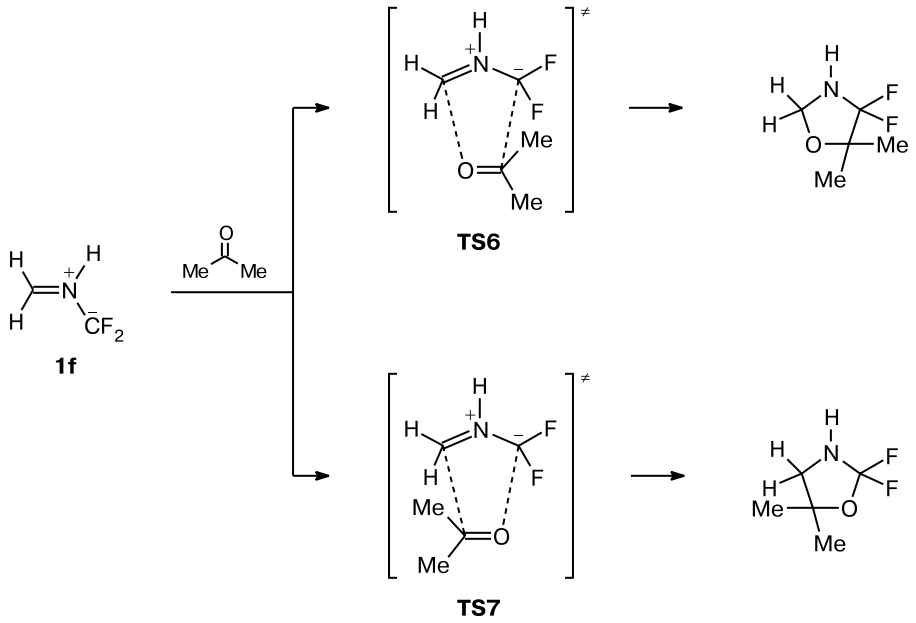
A calculated barrier of activation to the cycloaddition reaction of ylide **1f** to the C=O bond of acetone, which leads to 4,4- and 2,2-difluoro-5,5-dimethyloxazolidines, is equal to 10.0 (**TS6**) and 14.7 kcal mol^{-1} (**TS7**), respectively (Fig. 5).

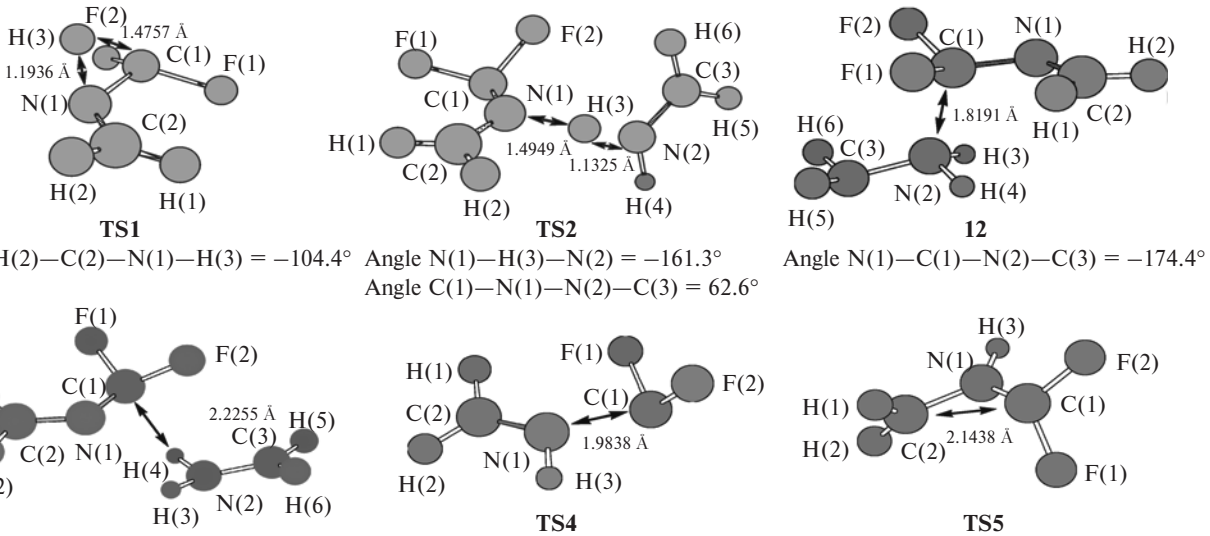
Thus, the obtained experimental data on the cycloaddition reaction of ylides **1a—e** to ketones, in which only one oxazoline regioisomer was obtained, completely agrees with the calculated results predicting the formation of the 4-fluorooxazoline derivatives. The isomerization of ylide **1f** into imine **3f** has higher barrier and can proceed only

Scheme 5



Scheme 6





Angle H(2)—C(2)—N(1)—H(3) = −104.4°

Angle N(1)—H(3)—N(2) = −161.3°

Angle C(1)—N(1)—N(2)—C(3) = 62.6°

Angle N(1)—C(1)—N(2)—C(3) = −174.4°

Angle N(2)—C(1)—N(2)—C(3) = −120.5°

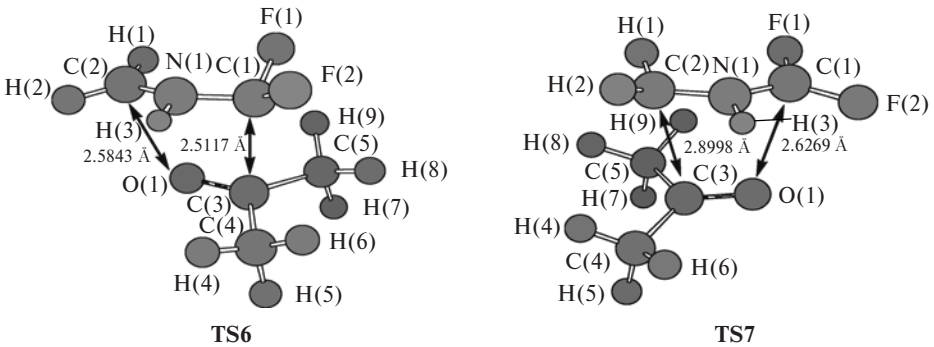


Fig. 2. Calculated geometric parameters of transition states **TS1**—**TS7** and intermediate **12**.

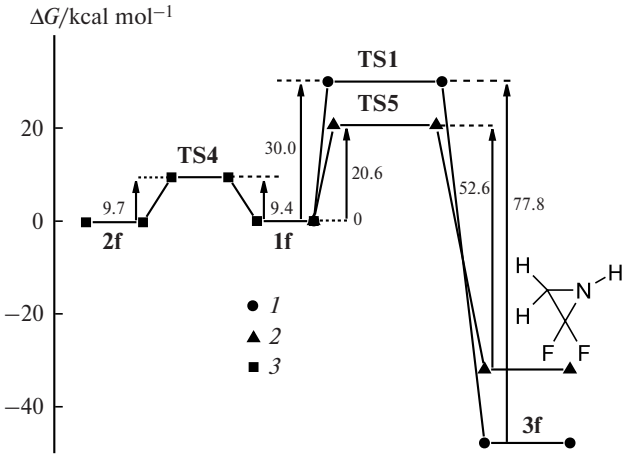


Fig. 3. Energy profiles of monomolecular reactions of ylide **1f**: intramolecular isomerization (*1*), cyclization (*2*), and dissociation (*3*).

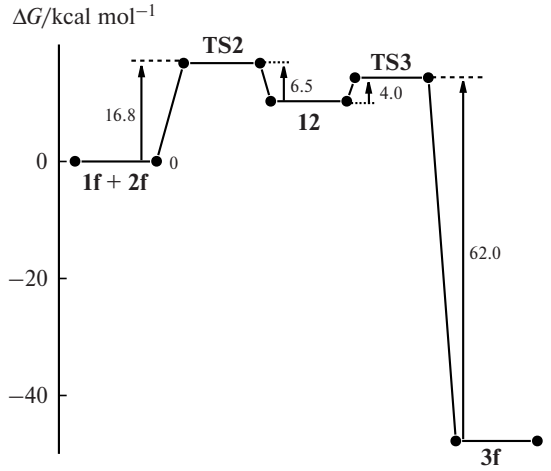


Fig. 4. Energy profile of intermolecular isomerization of ylide **1f**.

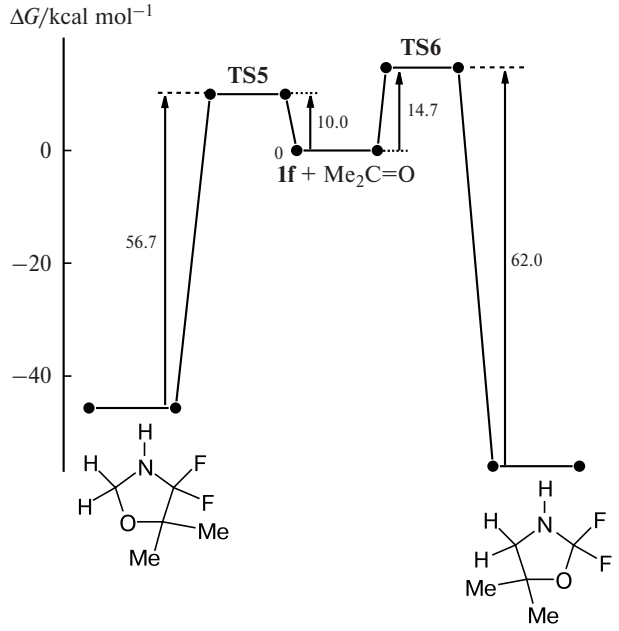


Fig. 5. Energy profiles of cycloaddition reactions of ylide **1f** to acetone.

with participation of starting imine **1e** through the intermediate formation of an ion pair. In another words, for the selected model system ($H_2C{=}N(H)^+{-}(CF_2)^-$ + $H_2C{=}NH$ + Me_2CO), the reaction of 1,3-dipolar cycloaddition of the ylide to the carbonyl group is more favorable than its isomerization into difluoromethylimine. When we take the real objects, *viz.*, ylides **1a—e** and ketones **5**, containing bulky substituents both in the ylide and in the dipolarophile, this difference in energies, apparently, can diminish, since additional steric interactions should facilitate an increase in the barrier to cycloaddition to a greater extent than in the barrier to intermolecular proton transfer.

Obtained experimental and calculated data allow one to conclude that *gem*-difluorinated NH-azomethine ylides, formed from diarylmethanimines and difluorocarbene, can undergo two types of transformations, isomerization into *N*-(difluoromethyl)imines and 1,3-dipolar cycloaddition to electron-deficient multiple bonds. α,α,α-Trifluoroacetophenones are efficient dipole traps for the carbene-generated difluorinated NH-ylides, an addition of which to the dipole proceeds with complete regioselectivity to form 4-fluoro-2,5-dihydrooxazoles. A formal 1,2-H shift of *gem*-difluorinated NH-azomethine ylides is a competing to the cycloaddition direction of the reaction, which occurs with participation of a precursor of the ylide, diarylmethanimine, through the deprotonation—protonation. 4-Fluoro-2,5-dihydrooxazoles, the products of multicomponent reaction of dibromodifluoromethane, lead, diarylmethanimine, and trifluoroacetophenone, easily react with O- and N-nucleophiles (hydroxides and alkoxides of alkali metals, primary and secondary amines) to substitute the fluorine atom.

Experimental

Melting points of substances were determined on a Boetius heating apparatus, and uncorrected values are given. ^{1}H and ^{13}C NMR spectra were recorded on a Bruker DPX-300 spectrometer (^{1}H, 300 MHz; ^{13}C, 75 MHz), ^{19}F NMR spectra (235.3 MHz) were recorded on a Bruker Avance DRX-250 spectrometer. Elemental analysis was performed on a HP-185B CHN-analyzer. Reaction progress was monitored by TLC on ALUGRAM SIL G/UV_{254} plates. Gas-chromatographic analysis was carried out with the use of 1.8 m column with 5% SE-30/Diatomit C phase, the gradient temperature was ramped from 80 to 280 °C, at a rate of 16 °C min^{-1}. X-Ray analysis for compound **7g** was performed on a STOE IPDS II difractometer (graphite monochromator, λ(Mo-Kα) = 0.71073 Å, temperature 133(2) K, θ/2θ scanning technique). Merck 60/200 silica gel was used for the separation of reaction mixtures by column chromatography. Tetrabutylammonium bromide was dried in a desiccator over P_2O_5.

Quantum-chemical calculations were performed with the use of the Gaussian 03 program package.[38] Optimization of the geometry of reagents, products, intermediates, and transition states was performed by the B3LYP/6-31G* method. Frequency

analysis of all the transition states showed that in their vibrational spectra, only one normal vibration with imaginary frequency is present. The location of transition states in the same with reagents and products energy profile was traced through by the internal reaction coordinate (IRC).[39]

Starting imines **2a—e** were synthesized according to the procedure described earlier.[40]

Reaction of diarylmethanimines with difluorocarbene (general procedure). Lead filings (1.243 g, 6 mmol), diphenylmethanimine (0.362 g, 2 mmol), tetrabutylammonium bromide (1.932 g, 6 mmol), dibromodifluoromethane (0.55 mL, 6 mmol), and anhydrous dichloromethane (10 mL) were placed in a round-bottom flask. If the reaction was carried out in the presence of dipolarophiles, either methyl methacrylate (5 equiv.) or aryl trifluoromethyl ketone or fluorenone (3 equiv.) were added to the mixture. The flask was corked in such a way that the system could have held some excess pressure, and it was placed into an ultrasonic bath (160 W). The processing was carried out at 30—40 °C and continued until all the lead metal was consumed. Dichloromethane was removed, the residue was separated by column chromatography on silica gel (eluent hexane—diethyl ether). Crystalline products were recrystallized from hexane or from hexane—diethyl ether.

***N*-(Diphenylmethylene)difluoromethanamine (3a).** Compound **3a** (0.042 g, 9%) was obtained from imine **2a** (0.362 g, 2 mmol) according to the general procedure with addition of methyl methacrylate (1.0 g, 10 mmol) as a colorless liquid. ^{1}H NMR ($CDCl_3$), δ: 6.35 (t, 1 H, CHF_2, $J_{H,F}$ = 70.5 Hz); 7.28—7.85 (m, 8 H, Ph). ^{13}C NMR ($CDCl_3$), δ: 115.2 (t, CHF_2, $^1J_{C,F}$ = 231.8 Hz), 127.9, 128.1, 128.4, 129.7, 129.9, 134.0, 137.3 (Ar), 176.7 (t, CPh_2, $^3J_{C,F}$ = 15.7 Hz). According to the ^{1}H NMR data, the product contains ~10% of benzophenone.

4-Fluoro-2,2-diphenyl-2,5-dihydro-9′*H*-spiro[1,3-oxazole-5,9′-fluorene] (5). Compound **5** (0.161 g, 21%) was obtained from imine **2a** (0.362 g, 2 mmol) and fluorenone according to the general procedure, m.p. 82—84 °C (from hexane). Found (%): C, 82.74; H, 4.81; N, 3.46. $C_{27}H_{18}FNO$. Calculated (%): C, 82.85; H, 4.63; N, 3.58. IR ($CHCl_3$), ν/cm^{-1}: 1725 (C=N). ^{1}H NMR ($CDCl_3$), δ: 7.01—7.91 (m, 18 H, Ar). ^{13}C NMR ($CDCl_3$), δ: 89.7 (d, C(5), $^2J_{C,F}$ = 38.4 Hz), 105.8 (d, C(2), $^3J_{C,F}$ = 21.6 Hz), 120.3, 125.2, 125.8, 128.0, 128.3, 128.4, 130.5, 140.7, 141.4, 144.7 (Ar), 166.7 (d, C(4), $^1J_{C,F}$ = 294.3 Hz).

4-Fluoro-2,2,5-triphenyl-5-(trifluoromethyl)-2,5-dihydro-1,3-oxazole (7a). Compound **7a** (0.515 g, 66%) was obtained from imine **2a** (0.362 g, 2 mmol) and trifluoroacetophenone **6a** according to the general procedure. Physical and spectroscopic characteristics and X-ray data for compound **7a** are given in Ref. 1.

Compound **7a** (0.288 g, 37%) was also obtained by similar procedure from imine **2a** (0.362 g, 2 mmol) with the use of zinc dust (0.39 g, 6 mmol) instead of lead (the reaction time was 150 h).

2,2-Bis(4-chlorophenyl)-4-fluoro-5-phenyl-5-(trifluoromethyl)-2,5-dihydro-1,3-oxazole (7b). Compound **7b** (0.551 g, 61%) was obtained from imine **2b** (0.5 g, 2 mmol) and trifluoroacetophenone **6a** according to the general procedure as colorless glass-like substance. IR (CCl_4), ν/cm^{-1}: 1730 (C=N). ^{1}H NMR ($CDCl_3$), δ: 7.22—7.72 (m, 13 H, Ar). ^{13}C NMR ($CDCl_3$), δ: 82.2 (quint, C(5), $^2J_{C,F}$ = 32.8 Hz), 106.6 (d, C(2), $^3J_{C,F}$ = 21.4 Hz), 120.1 (d.q, CF_3, $^1J_{C,F}$ = 286.6 Hz, $^3J_{C,F}$ = 5.0 Hz), 126.2, 127.1, 128.5, 128.6, 128.8, 130.1, 131.3, 134.5, 134.6, 139.1, 140.4, 140.8 (Ar), 160.4 (d, C(4), $^1J_{C,F}$ = 299.8 Hz). According to the ^{1}H NMR data, the product contains ~5% of the corresponding benzophenone.

4-[2-(4-Chlorophenyl)-4-fluoro-5-phenyl-5-(trifluoromethyl)-2,5-dihydro-1,3-oxazol-2-yl]benzonitrile (7c). Compound **7c** (0.089 g, 10%) was obtained from imine **2c** (0.481 g, 2 mmol) and trifluoroacetophenone **6a** according to the general procedure as a colorless oily mixture of stereoisomers in ratio 2 : 1. ^{1}H NMR ($CDCl_3$), δ: 7.23—7.79 (m, Ar). ^{13}C NMR ($CDCl_3$), δ of major isomer: 85.3 (m, C(5)), 106.21 (d, C(2), $^3J_{C,F}$ = 21.6 Hz), 118.2 (CN), 122.4 (m, CF_3,), 126.1—146.1 (Ar), 160.7 (d, C(4), $^1J_{C,F}$ = 299.9 Hz). ^{13}C NMR ($CDCl_3$), δ of minor isomer: 85.3 (m, C(5)), 106.18 (d, C(2), $^3J_{C,F}$ = 21.3 Hz), 118.1 (CN), 122.4 (m, CF_3,), 126.1—146.4 (Ar), 160.7 (d, C(4), $^1J_{C,F}$ = 299.9 Hz). According to the ^{1}H NMR data, the product contains ~5% of the corresponding benzophenone.

4-Fluoro-5-phenyl-5-(trifluoromethyl)-2,2-bis(4-trifluoromethylphenyl)-2,5-dihydro-1,3-oxazole (7d). Compound **7d** (0.120 g, 12%) was obtained from imine **2d** (0.634 g, 2 mmol) and trifluoroacetophenone **6a** according to the general procedure, m.p. 88—89 °C (from hexane). Found (%): C, 55.12; H, 2.83; N, 2.46. $C_{24}H_{13}F_{10}NO$. Calculated (%): C, 55.29; H, 2.51; N, 2.69. IR (KBr), ν/cm^{-1}: 1725 (C=N). ^{1}H NMR ($CDCl_3$), δ: 7.39—7.85 (m, 13 H, Ar). ^{13}C NMR ($CDCl_3$), δ: 85.4 (quint, C(5), $^2J_{C,F}$ = 33.0 Hz), 106.4 (d, C(2), $^3J_{C,F}$ = 21.4 Hz), 121.9 (q.d, CF_3, $^1J_{C,F}$ = 286.5 Hz, $^3J_{C,F}$ = 4.9 Hz), 123.7 (q, CF_3, $^1J_{C,F}$ = 273.1 Hz), 123.8 (q, CF_3, $^1J_{C,F}$ = 272.6 Hz), 125.3—125.7 (m), 126.0, 126.1 (m), 127.7 (m), 128.9, 130.5, 130.8 (q, Ar, $^4J_{C,F}$ = 32.6 Hz), 144.9, 145.2 (Ar), 160.8 (d, C(4), $^1J_{C,F}$ = 300.6 Hz). ^{19}F NMR ($CDCl_3$), external standard C_6F_6, δ: 82.2 (q, F—C(4), $J_{F,F}$ = 3.2 Hz), 86.6 (d, CF_3, $J_{F,F}$ = 3.2 Hz), 99.3 (CF_3), 99.4 (CF_3).

4-Fluoro-5-phenyl-5-(trifluoromethyl)-2,2-bis(3-trifluoromethylphenyl)-2,5-dihydro-1,3-oxazole (7e). Compound **7e** (0.395 g, 38%) was obtained from imine **2e** (0.634 g, 2 mmol) and trifluoroacetophenone **6a** according to the general procedure, m.p. 79—80 °C (from hexane). Found (%): C, 55.09; H, 2.72; N, 2.94. $C_{24}H_{13}F_{10}NO$. Calculated (%): C, 55.29; H, 2.51; N, 2.69. IR (KBr), ν/cm^{-1}: 1725 (C=N). ^{1}H NMR ($CDCl_3$), δ: 7.39—8.13 (m, 13 H, Ar). ^{13}C NMR ($CDCl_3$), δ: 85.5 (quint, C(5), $^2J_{C,F}$ = 32.7 Hz), 106.3 (d, C(2), $^3J_{C,F}$ = 21.4 Hz), 121.9 (q.d, CF_3, $^1J_{C,F}$ = 286.4 Hz, $^4J_{C,F}$ = 4.9 Hz), 123.5 (q, CF_3, $^1J_{C,F}$ = 274.2 Hz), 123.6 (q, CF_3, $^1J_{C,F}$ = 272.6 Hz), 122.3—142.9 (Ar), 160.9 (d, C(4), $^1J_{C,F}$ = 300.9 Hz).

4-Fluoro-5-(4-methylphenyl)-2,2-diphenyl-5-(trifluoromethyl)-2,5-dihydro-1,3-oxazole (7f). Compound **7f** (0.503 g, 63%) was obtained from imine **2a** (0.362 g, 2 mmol) and ketone **6b** according to the general procedure, m.p. 86—87 °C (from hexane). Found (%): C, 69.20; H, 4.26; N, 3.48. $C_{23}H_{17}F_4NO$. Calculated (%): C, 69.17; H, 4.29; N, 3.51. IR (KBr), ν/cm^{-1}: 1720 (C=N). ^{1}H NMR ($CDCl_3$), δ: 2.37 (s, 3 H, Me); 7.19—7.71 (m, 14 H, Ar). ^{13}C NMR ($CDCl_3$), δ: 21.0 (CH_3), 85.0 (q.d, C(5), $^2J_{C,F}$ = 34.0 Hz, $^2J_{C,F}$ = 32.5 Hz), 107.5 (d, C(2), $^3J_{C,F}$ = 21.3 Hz), 122.3 (d.q, CF_3, $^1J_{C,F}$ = 286.9 Hz, $^4J_{C,F}$ = 4.7 Hz), 125.8, 125.9, 126.3 m, 128.1 (q, $^4J_{C,F}$ = 4.1 Hz), 128.2, 129.3, 139.9, 141.9, 142.4 (Ar), 160.4 (d, C(4), $^1J_{C,F}$ = 298.6 Hz).

5-(4-Chlorophenyl)-4-fluoro-2,2-diphenyl-5-(trifluoromethyl)-2,5-dihydro-1,3-oxazole (7g). Compound **7g** (0.279 g, 54%) was obtained from imine **2a** (0.22 g, 1.23 mmol) and ketone **6c** according to the general procedure, m.p. 81—82 °C (from hexane—diethyl ether). Found (%): C, 62.89; H, 3.52; N, 3.22. $C_{22}H_{14}ClF_4NO$. Calculated (%): C, 62.94; H, 3.36; N, 3.34. IR (KBr), ν/cm^{-1}: 1725 (C=N). ^{1}H NMR ($CDCl_3$), δ: 7.28—7.71 (m, 14 H, Ar). ^{13}C NMR ($CDCl_3$), δ: 84.5 (q.d, C(5), $^2J_{C,F}$ = 34.5 Hz, $^2J_{C,F}$ = 32.9 Hz), 107.8 (d, C(2), $^3J_{C,F}$ = 21.0 Hz), 120.1 (q.d, CF_3,

$^1J_{C,F}$ = 286.9 Hz, $^4J_{C,F}$ = 4.9 Hz), 125.7, 125.8, 127.8, 128.3, 128.4, 128.9, 129.5, 129.6, 136.2, 141.5, 142.0 (Ar), 159.4 (d, C(4), $^1J_{C,F}$ = 298.6 Hz). ^{19}F NMR ($CDCl_3$), external standard C_6F_6, δ: 79.5 (q, FC(4), $J_{F,F}$ = 3.2 Hz); 86.6 (d, CF_3, $J_{F,F}$ = 3.2 Hz). X-ray results: $C_{22}H_{14}ClF_4NO$, *M* 419.79, a crystal system is monoclinic, a space group is *P* 1 21/*c* 1 (No. 14), *a* = 9.5109(10) Å, *b* = 21.8761(19) Å, *c* = 9.9407(10) Å, α = 90.00°, β = 117.352(8)°, γ = 90°, *V* = 1837.04(30) Å^3, *Z* = 4, d_{calc} = 1.518 g cm^{-3}, 1.86—24.75°, 7804 reflections, 2945 from them were independent ones (R_{int} = 0.0343), 2474 reflections were with $I \geq 2\sigma(I)$, R_1 = 0.0282 ($I \geq 2\sigma(I)$), R_{All} = 0.0358, wR_2 = 0.0742. Complete crystallographic data as the CIF file were deposited with the Cambridge structural database (CCDC No. 674678).***

4-Fluoro-5-(4-fluorophenyl)-2,2-diphenyl-5-(trifluoromethyl)-2,5-dihydro-1,3-oxazole (7h). Compound **7h** (0.613 g, 76%) was obtained from imine **2a** (0.362 g, 2 mmol) and ketone **6d** according to the general procedure, m.p. 73—74 °C (from hexane). Found (%): C, 65.47; H, 3.62; N, 3.43. $C_{22}H_{14}F_5NO$. Calculated (%): C, 65.51; H, 3.50; N, 3.47. IR (KBr), ν/cm^{-1}: 1720 (C=N). ^{1}H NMR ($CDCl_3$), δ: 7.07—7.80 (m, 14 H, Ar). ^{13}C NMR ($CDCl_3$), δ: 84.5 (q.d, C(5), $^2J_{C,F}$ = 34.7 Hz, $^2J_{C,F}$ = 33.0 Hz), 107.7 (d, C(2), $^3J_{C,F}$ = 21.1 Hz), 115.6, 115.9 (Ar), 122.1 (q.d, CF_3, $^1J_{C,F}$ = 286.6 Hz, $^3J_{C,F}$ = 4.5 Hz), 125.8, 126.9, 128.3, 128.4, 128.6, 141.6, 142.2 (Ar), 159.7 (d, C(4), $^1J_{C,F}$ = 298.6 Hz), 163.5 (d, Ar, $^1J_{C,F}$ = 249.3 Hz).

4-Fluoro-2,2-diphenyl-5-(trifluoromethyl)-5-[3-(trifluoromethyl)phenyl]-2,5-dihydro-1,3-oxazole (7i). Compound **7i** (0.666 g, 74%) was obtained from imine **2a** (0.362 g, 2 mmol) and ketone **6e** according to the general procedure, m.p. 62—63 °C (from hexane). IR (CCl_4), ν/cm^{-1}: 1735 (C=N). ^{1}H NMR ($CDCl_3$), δ: 7.31—7.98 (m, 14 H, Ar). ^{13}C NMR ($CDCl_3$), δ: 84.5 (q.d, C(5), $^2J_{C,F}$ = 34.7 Hz, $^2J_{C,F}$ = 33.0 Hz), 108.1 (d, C(2), $^3J_{C,F}$ = 20.7 Hz), 122.0 (q.d, CF_3, $^1J_{C,F}$ = 286.6 Hz, $^4J_{C,F}$ = 4.7 Hz), 123.6 (q, CF_3, $^1J_{C,F}$ = 272.5 Hz), 123.8, 125.7, 125.8, 126.7 (q, $^3J_{C,F}$ = 3.7 Hz), 128.3, 128.4, 129.3, 129.5 (m), 131.4 (q, $^2J_{C,F}$ = 32.9 Hz), 132.1, 132.2, 133.1 (m), 141.4, 142.0 (Ar), 159.2 (d, C(4), $^1J_{C,F}$ = 298.4 Hz).

2,2,5-Triphenyl-5-(trifluoromethyl)oxazolidin-4-one (8). Potassium hydroxide (0.165 g, 3 mmol) was added to a solution of oxazoline **7a** (0.15 g, 0.39 mmol) in DMSO (10 mL) and the mixture was stirred for 24 h at ~20 °C. The reaction mixture was poured in 5% aqueous HCl (50 mL), the product was extracted with diethyl ether (2S20 mL), the ethereal layer was washed with water and dried with Na_2SO_4. The solvent was distilled off and after recrystallization of the residue, compound **8** (0.137 g, 91%) was obtained, m.p. 153—154 °C (from diethyl ether). Found (%): C, 69.08; H, 4.13; N, 3.58. $C_{22}H_{16}F_3NO_2$. Calculated (%): C, 68.93; H, 4.21; N, 3.65. IR (CCl_4), ν/cm^{-1}: 3420 (N—H), 1720 (C=O). ^{1}H NMR ($CDCl_3$), δ: 7.21—7.75 (m, 15 H, Ph); 10.09 (s, 1 H, NH). ^{13}C NMR ($CDCl_3$), δ: 82.1 (q, C(5), $^2J_{C,F}$ = 30.7 Hz), 95.5 (C(2)), 122.4 (q, CF_3, $^1J_{C,F}$ = 284.6 Hz), 125.7, 126.2, 126.8, 127.9, 128.2, 128.4, 128.6, 128.7, 129.3, 131.4, 141.4, 141.9 (Ph), 168.0 (C(4)).

4-Methoxy-2,2,5-triphenyl-5-(trifluoromethyl)-2,5-dihydro-1,3-oxazole (9). Oxazoline **7a** (0.14 g, 0.36 mmol) was dissolved in MeOH (7 mL), MeONa (0.1 g, 1.85 mmol) was added and the mixture was kept for 24 h at ~20 °C. The needle-like crystals formed were filtered off and dried in air. The filtrate was poured in water and extracted with diethyl ether. The ethereal layer was washed with water and after diethyl ether was removed, additional portion of crystalline product was obtained. The total yield of compound **9** after recrystallization from methanol was 140 mg (94%). Physical and spectroscopic data for compound **9** are given in Ref. 1.

2,2,5-Triphenyl-4-[5-(trifluoromethyl)-2,5-dihydro-1,3-oxazol-4-yl]morpholine (10). Oxazoline **7a** (0.05 g, 0.13 mmol) was dissolved in morpholine (0.87 g, 10 mmol) and the mixture was kept for 48 h at ~20 °C. Water (2 mL) was added to the reaction mixture and it was kept for additional 3 days at ~20 °C. A precipitate formed was filtered off, dried *in vacuo* (0.05 Torr) and after recrystallization from hexane—diethyl ether, compound **10** (44 mg, 76%) was obtained. Physical and spectroscopic data for compound **10** are given in Ref. 1.

Methyl 2-[2,2,5-triphenyl-5-(trifluoromethyl)-2,5-dihydro-1,3-oxazol-4-ylamino]acetate (11). Methyl glycinate hydrochloride (0.047 g, 0.38 mmol) and triethylamine (0.076 g, 0.75 mmol) were added to a solution of oxazoline **7a** (0.145 g, 0.38 mmol) in a mixture of DMSO (4 mL) and diethyl ether (0.5 mL), the mixture was stirred for 1 week at ~20 °C. Then the reaction mixture was poured in water and extracted with diethyl ether (2S20 mL), the solvent was removed and after recrystallization, compound **11** (0.15 g, 88%) was obtained, m.p. 174—175 °C (from hexane—diethyl ether). Found (%): C, 65.96; H, 4.65; N, 6.17. $C_{25}H_{21}F_3N_2O_3$. Calculated (%): C, 66.07; H, 4.66; N, 6.16. ^{1}H NMR ($CDCl_3$), δ: 3.79 (3 H, Me); 4.30 (m, 2 H, CH_2); 5.08 (br.s, 1 H, NH); 7.19—7.65 (m, 15 H, Ph). ^{13}C NMR ($CDCl_3$), δ: 44.9 (CH_2), 52.3 (CH_3), 89.4 (q, C(5), $^2J_{C,F}$ = 29.3 Hz), 111.5 (C(2)), 123. 9 (q, CF_3, $^1J_{C,F}$ = 286.9 Hz), 125.9, 126.1, 127.0, 127.2, 127.3, 127.7, 127.8, 128.4, 129.2, 133.4, 144.7, 144.9 (Ph), 155.8 (C(4)), 170.2 (C=O).

This work was financially supported by the Russian Foundation for Basic Research (Project No. 08-03-00112a).

References

1. K. A. Khistiaev, M. S. Novikov, A. F. Khlebnikov, J. Magull, *Tetrahedron Lett.*, 2008, **49**, 1237.
2. M. S. Novikov, A. F. Khlebnikov, K. A. Khistyaev, *Tez. dokl. XVIII Mendeleevskogo s"ezda po obshchei i prikladnoi khimii* [*Abstracts of the XVIII Mendeleev Congress on General and Applied Chemistry*] *(Moscow, September 23—28, 2007)*, Moscow, 2007, **1**, 368 (in Russian).
3. *Synthetic Applications of 1,3-Dipolar Cycloaddition Chemistry Toward Heterocycles and Natural Products*, Eds A. Padwa, W. H. Pearson, John Wiley and Sons, New York, 2002.
4. R. Grigg, *Chem. Soc. Rev.,* 1987, **16**, 89.
5. S. Kanemasa, *Rep. Inst. Advanced Material Study*, 1988, **2**, 149.
6. K. Kawashima, A. Kakehi, M. Noguchi, *Tetrahedron*, 2007, **63**, 1630.
7. R. Grigg, M. J. Slater, M. A. B. Sarker, *Tetrahedron*, 2006, **62**, 10332.
8. K. Washizuka, S. Minakata, I. Ryu, M. Komatsu, *Tetrahedron*, 1999, **55**, 12969.

*** A copy can be ordered at: CCDC, 12 Union Road, Cambridge CB2 1EZ, UK (e-mail: deposit@ccdc.cam.ac.uk, http://www.ccdc.cam.ac.uk/deposit).

9. O. Tsuge, S. Kanemasa, K. Matsuda, *J. Org. Chem.*, 1986, **51**, 1997.
10. Y. Tominaga, K. Ogata, S. Kohra, M. Hojo, A. Hosomi, *Tetrahedron Lett.*, 1991, **32**, 5987.
11. T. Schirmeister, *Lieb. Ann.*, 1997, 1895.
12. S. Kanemasa, *Synlett*, 2002, 1371.
13. Y. Oderaotoshi, W. Cheng, S. Fujitomi, Y. Kasano, S. Minakata, M. Komatsu, *Org. Lett.*, 2003, **5**, 5043.
14. H. Okada, T. Akaki, Y. Oderaotoshi, S. Minakata, M. Komatsu, *Tetrahedron*, 2003, **59**, 197.
15. M. Komatsu, H. Okada, T. Akaki, Y. Oderaotoshi, S. Minakata, *Org. Lett.*, 2002, **4**, 3505.
16. M. Komatsu, Y. Kasano, J.-I. Yonemori, Y. Oderaotoshi, S. Minakata, *Chem. Commun.*, 2006, 526.
17. R. Grigg, H. Q. N. Gunaratne, *Chem. Commun.*, 1982, 384.
18. I. Coldham, K. M. Crapnell, J.-C. Fernàndez, J. D. Moseley, R. Rabot, *J. Org. Chem.*, 2002, **67**, 6181.
19. R. Grigg, V. Sridharan, S. Surendrakumar, *Tetrahedron*, 1988, **44**, 4953.
20. A. F. Khlebnikov, M. S. Novikov, R. R. Kostikov, *Usp. Khim.*, 2005, **74**, 183 [*Russ. Chem. Rev.*, 2005, **74**, 171 (Engl. Transl.)].
21. A. S. Konev, M. S. Novikov, A. F. Khlebnikov, *Tetrahedron Lett.*, 2005, **46**, 8337.
22. A. S. Konev, A. F. Khlebnikov, M. S. Novikov, *Zh. Org. Khim.*, 2007, **43**, 292 [*Russ. J. Org. Chem.*, 2007, **43**, 286 (Engl. Transl.)].
23. I. V. Voznyi, M. S. Novikov, A. F. Khlebnikov, Yu. Kopf, R. R. Kostikov, *Zh. Org. Khim.*, 2004, **40**, 226 [*Russ. J. Org. Chem.*, 2004, **40**, 199 (Engl. Transl.)].
24. M. S. Novikov, A. F. Khlebnikov, M. A. Egarmin, Yu. Kopf, R. R. Kostikov, *Zh. Org. Khim.*, 2004, **40**, 1542 [*Russ. J. Org. Chem.*, 2004, **40**, 1493 (Engl. Transl.)].
25. M. S. Novikov, A. F. Khlebnikov, I. V. Voznyi, O. V. Besedina, R. R. Kostikov, *Zh. Org. Khim.*, 2005, **41**, 372 [*Russ. J. Org. Chem.*, 2005, **41**, 361 (Engl. Transl.)].
26. M. S. Novikov, A. F. Khlebnikov, M. V. Shevchenko, R. R. Kostikov, D. Vidovic, *Zh. Org. Khim.*, 2005, **41**, 1527 [*Russ. J. Org. Chem.*, 2005, **41**, 1496 (Engl. Transl.)].
27. M. S. Novikov, A. F. Khlebnikov, M. A. Egarmin, M. V. Shevchenko, V. A. Khlebnikov, R. R. Kostikov, D. Vidovic, *Zh. Org. Khim.*, 2006, **42**, 1811 [*Russ. J. Org. Chem.*, 2006, **42**, 1800 (Engl. Transl.)].
28. M. S. Novikov, A. F. Khlebnikov, E. S. Sidorina, R. R. Kostikov, *J. Chem. Soc., Perkin Trans. 1*, 2000, 231.
29. M. S. Novikov, A. F. Khlebnikov, A. E. Masalev, R. R. Kostikov, *Tetrahedron Lett.*, 1997, **38**, 4187.
30. M. S. Novikov, A. F. Khlebnikov, A. Krebs, R. R. Kostikov, *Eur. J. Org. Chem.*, 1998, 133.
31. R. G. Parr, L. V. Szentpály, S. J. Liu, *J. Am. Chem. Soc.*, 1999, **121**, 1922.
32. P. Pérez, L. R. Domingo, M. J. Aurell, R. Contreras, *Tetrahedron*, 2003, **59**, 3117.
33. M. Nishida, H. Fukaya, T. Abe, *J. Fluor. Chem.* 1996, **76**, 3.
34. M. S. Novikov, Doctor Theses, St. Petersburg State Univ., St. Petersburg, 2007, 308 pp. (in Russian).
35. W. J. R. Tyerman, *Trans. Faraday Soc.*, 1969, **65**, 1188.
36. P. K. Chowdhury, *J. Phys. Chem.*, 1995, **99**, 12084.
37. F. Battin-Leclerc, A. P. Smith, G. D. Hayman, T. P. Murrells, *J. Chem. Soc., Faraday Trans.*, 1996, **92**, 3305.
38. M. J. Frisch, G. W. Trucks, H. B. Schlegel, G. E. Scuseria, M. A. Robb, J. R. Cheeseman, J. A. Montgomery, Jr., T. Vreven, K. N. Kudin, J. C. Burant, J. M. Millam, S. S. Iyengar, J. Tomasi, V. Barone, B. Mennucci, M. Cossi, G. Scalmani, N. Rega, G. A. Petersson, H. Nakatsuji, M. Hada, M. Ehara, K. Toyota, R. Fukuda, J. Hasegawa, M. Ishida, T. Nakajima, Y. Honda, O. Kitao, H. Nakai, M. Klene, X. Li, J. E. Knox, H. P. Hratchian, J. B. Cross, C. Adamo, J. Jaramillo, R. Gomperts, R. E. Stratmann, O. Yazyev, A. J. Austin, R. Cammi, C. Pomelli, J. W. Ochterski, P. Y. Ayala, K. Morokuma, G. A. Voth, P. Salvador, J. J. Dannenberg, V. G. Zakrzewski, S. Dapprich, A. D. Daniels, M. C. Strain, O. Farkas, D. K. Malick, A. D. Rabuck, K. Raghavachari, J. B. Foresman, J. V. Ortiz, Q. Cui, A. G. Baboul, S. Clifford, J. Cioslowski, B. B. Stefanov, G. Liu, A. Liashenko, P. Piskorz, I. Komaromi, R. L. Martin, D. J. Fox, T. Keith, M. A. Al-Laham, C. Y. Peng, A. Nanayakkara, M. Challacombe, P. M. W. Gill, B. Johnson, W. Chen, M. W. Wong, C. Gonzalez, J. A. Pople, *Gaussian 03 (Revision B.05.02)*, Gaussian, Inc., Pittsburgh (PA), 2003.
39. C. Gonzalez, H. B. Schlegel, *J. Phys. Chem.*, 1990, **94**, 5523.
40. P. L. Pickard, T. L. Tolbert, in *Organic Synthesis*, Ed. W. E. Parham, Wiley, New York, 1964, **44**, 51.

Received January 9, 2008;
in revised form March 14, 2008