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Δ^2-Isoxazolines from Arylcyclopropanes: III.* Phenylcyclopropanes Substituted in Three-Membered Ring in Reaction with Nitrosyl Chloride Activated with Oxides of Sulfur(IV, VI)

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Abstract—The reaction of phenylcyclopropanes substituted in the three-membered ring with nitrosyl chloride activated with sulfur(IV, VI) oxides provided in good yield substituted 5-phenylisoxazolines as a mixture of structural isomers.

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We showed formerly that nitrosyl chloride activated with sulfur(IV, VI) oxides could be successfully applied to the synthesis of 5-arylisoxazolines from arylcyclopropanes [1, 2]. We found therewith that the complex $NOCl{\cdot}2SO_3$ formed by reaction of nitrosyl chloride with sulfur trioxide was an efficient nitrosating reagent and made it possible to bring into the reaction arylcyclopropanes both with donor and acceptor substituents in the aromatic ring [1].

Table 1. Nitrosation of 1,1- and 1,2-substituted phenylcyclopropanes **I–VIII** with the complex $NOCl{\cdot}2SO_3$ in a ratio 1:1; 0°C, CH_2Cl_2, reaction time 1 h

No. of initial compound, isomeric composition, *cis*:*trans*, %	No. of compound obtained	Yield, %	Isomeric composition, **A**:**B**
I	**IX**	93	1:0
II	**X**	85[a]	1:0
III, 40:60	**XI**	99	2:1
IV, 100% *cis*	**XII**	99	1:0
V, 60:40	**XIII**	82[b]	5:1
VI, 100% *trans*	**XIV**	99	1:0
VII, 100% *trans*	**XV**	99	1.7:1
VIII, 100% *trans*	**XVI**	99	1:1

[a] 1.5 excess of reagent was used, reaction time 1.5 h.
[b] Recovered 15% of initial cyclopropane *trans*-(**V**).

* For communication II, see [1].

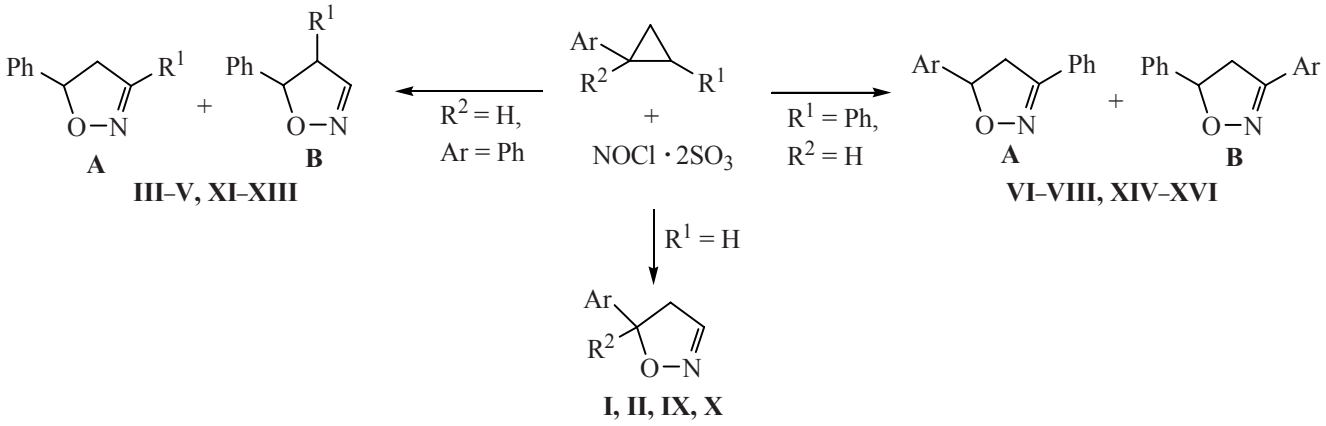
The goal of this study was the establishment of the regiochemical features of the reaction and the evaluation of substrates reactivity in order to determine the area of the reaction applicability. To this end we used substituted phenylcyclopropanes with various nature of substituents and also distinguished by their position in the small ring: 1-methyl-1-phenyl- (**I**), 1,1-bis(4-nitrophenyl)- (**II**), 1-methyl-2-phenyl- (**III**), 1-halo-2-phenyl- (**IV** and **V**), and 1-aryl-2-phenylcyclopropanes **VI–VIII**. 1,2-Disubstituted phenylcyclopropanes were brought into the reaction as a mixture of *cis*-, *trans*-isomers (Tables 1 and 2). Nitrosation of substituted phenylcyclopropanes was carried out under standard conditions developed earlier for monoarylcyclopropanes [2, 3].

At the use for nitrosating agent of the complex $NOCl{\cdot}2SO_3$ the reaction with all substrates cleanly proceeded under mild conditions. As reaction products the corresponding isoxazolines **IX–XVI** were isolated in high yields (Scheme 1). The reaction conditions and experimental results are compiled in Table 1.

The structure of compounds obtained was confirmed by NMR and IR spectroscopy [4]. The composition of previously unknown compounds was established by elemental analysis or mass spectrometry.

The lower activity of the nitrosyl chloride in the liquid sulfur dioxide somewhat decreases the preparative value of this nitrosation system but makes it possible to reveal fine trends in the reaction, for instance, those related to the effect of electronic factors on the process in the cases

Scheme 1.



R^1 = CH_3 (**III, XI**), Br (**IV, XII**), Cl (**V, XIII**); Ar = 4-$MeOC_6H_4$ (**VI, XIV**), 4-MeC_6H_4 (**VII, XV**), 4-IC_6H_4 (**VIII, XVI**); R^2 = Me, Ar = Ph (**I, IX**); R^2 = Ar = 4-$NO_2C_6H_4$ (**II, X**).

where the more active complex $NOCl \cdot 2SO_3$ levels the influence of the substituents.

For instance, among the brought into the reaction with the nitrosyl chloride activated with sulfur(IV) oxide cyclopropanes **I–V** only the most reactive substrates **I, III**, and **IV** were able to react under comparable conditions (Table 2).

In event of 1-methyl-1-phenylcyclopropane (**I**) the reaction proceeded actively with a quantitative conversion of hydrocarbon **I** and with the formation of 5-methyl-5-phenylisoxazoline (**IX**) in 80% yield. According to NMR spectra in 12% yield was obtained 3-phenyl-3-chlorobutyronitrile (**XVII**), which in the course of the chromatographic separation of the reaction products partially converted into *trans*-3-methyl-3-phenylacrylonitrile (**XVIII**).

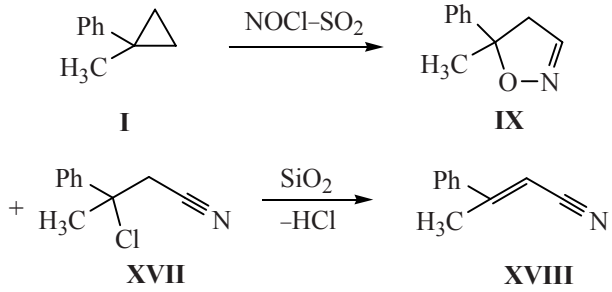


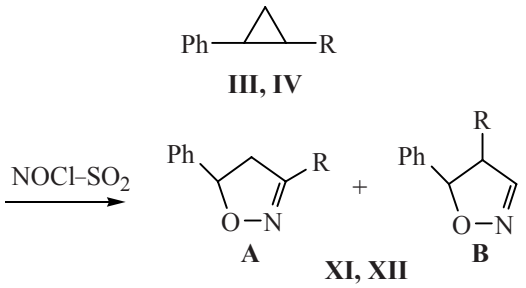
Table 2. Nitrosation of 1,1- and 1,2-substituted phenylcyclopropanes **I–V** with nitrosyl chloride in liquid sulfur dioxide at –40°C

No. of initial compound, isomeric composition, *cis* : *trans*, %	Time, h	Ratio (**I–V**): NOCl	Reaction products (yield, %)
I	2	1 : 2	**IX** (80[a])
II	2	1 : 5	**II** (100)
III, 13 : 20	2	1 : 2	**III** (44[b]), **XI** (40)
	3	1 : 5	**III** (24[b]), **XI** (60)
IV, 2 : 1	18	1 : 2	**IV** (54[c]), **XII** (25)
V, 9 : 5	3	1 : 5	**V** (100)

[a] According to NMR spectra of the reaction mixture formed also 12% of 3-phenyl-3-chlorobutyronitrile.
[b] 100% of *trans*-isomer.
[c] *cis–trans*, 3:2, reaction temperature –20°C.

The formation of nitrile **XVII** may be due to side processes occurring at excess of nitrosyl chloride in the system by an attack of the latter on the unsubstituted carbon atom of the cyclopropane ring [1].

1-Methyl-2-phenylcyclopropane (**III**) proved to be less active than 1-methyl-1-phenylcyclopropane (**I**). Even at the five-fold excess of the reagent only 76% of hydrocarbon **III** entered in the reaction: from this amount was isolated 60% of isoxazoline **XI** as a mixture of two structural isomers **A** and **B** in a ratio 5:1.



R = CH_3 (**III, XI**), Br (**IV, XII**).

From 1-bromo-2-phenylcyclopropane (**IV**) we succeeded to obtain the corresponding isoxazoline **XII** also in the form of a mixture of two structural isomers only at–20°C, and its yield did not exceed 25%.

Cyclopropane **II** as well as 1-phenyl-2-chlorocyclopropane (**V**) did not react under the given conditions.

The reaction of 1,2-diarylcyclopropanes with nitrosyl chloride in the liquid sulfur dioxide we had investigated before [5]. 1,2-Diarylcyclopropanes proved to be more reactive than 1-alkyl-2-phenylcyclopropanes. For instance, 1,2-diphenylcyclopropane reacted completely (–40°C, 3 h, 5-fold excess of NOCl) giving 3,5-diphenylisoxazoline in 82% yield. Therewith the most active 1,2-diarylcyclopropanes required only a slight excess of the nitrosyl chlorideotherwise formed a considerable amount of the corresponding 3-diaryl-1,3-dichloropropanes. In the case of 1,2-bis(4-methoxyphenyl)cyclopropane (**XIX**) at the five-fold excess of the nitrosyl chloride the corresponding 1,3-bis(4-methoxyphenyl)-1,3-dichloropropane was the only reaction product. In the previous report [5] we did not find an appropriate explanation to this fact.

The thorough analysis of the published data [6] showed that under the conditions of nitrosation when the initial diarylcyclopropane possessed a low first ionization potential permitting its oxidation with the nitrosonium cation to the arenonium cation-radical, the SET mechanism could occur. In this connection we assume the following Scheme 2 of 1,3-diaryl-1,3-dichloropropanes formation.

In reaction of the nitrosyl chloride with diarylcyclopropanes possessing a low ionization potential **VI, XIX** might form cation-radical **XX** that further might react along two routes. If the nitrosation of arylcyclopropanes **VI, XIX** is carried out with a slight excess of NOCl (route *a*), cation-radical **XX** can react with NO molecule within a tight ion pair after the oxidation of cyclopropane forming further the isoxazoline. At excess nitrosyl chloride in the system (route *b*) intermediate **XX** might react with the molecule NOCl which can act as a source of chlorine radical. Cation **XXI** reacting further with the second NOCl molecule or chloride anion gives the side product 1,3-diaryl-1,3-dichloropropane (**XXII**).

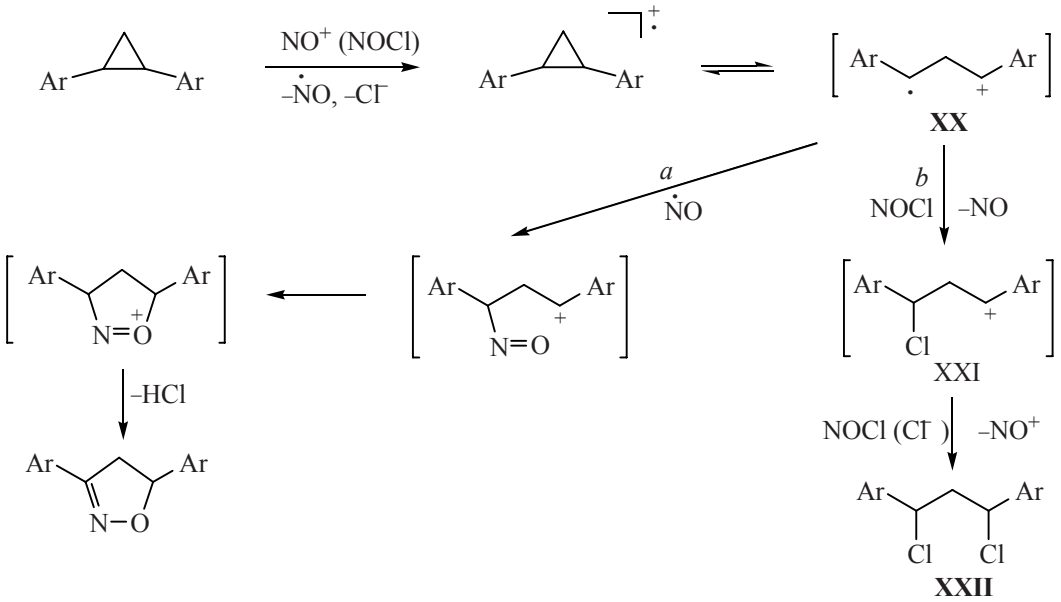
At the nitrosation of 1,2-diarylcyclopropanes with the complex $NOCl \cdot 2SO_3$ were obtained practically in quantitative yields 3,5-diarylisoxazolines without the formation of the corresponding 1,3-dichlorides **XXII**. This result fits to the assumed scheme for, firstly, the bond N→Cl should be essentially polarized as compared to the molecule NOCl, and secondly, no excess nitrosyl chloride occurs in the reaction mixture.

A special attention should be paid to the analysis of the isomeric composition of the reaction products.

In the presence of several substituents in the cyclopropane ring a concurrent processes can occur related to the opening of different bonds in the small ring resulting in the structural isomers of isoxazolines.

The opening of the three-membered ring in 1,1-disubstituted cyclopropanes is possible as a result of

Scheme 2.



cleavage of bonds C^1–C^2 or C^2–C^3. The nitrosation of cyclopropanes **I** and **II** proceeded regiospecifically with the opening of exclusively the C^1–C^2 bond and the formation in each case of a single product with substituents in the position *5* of the isoxazoline ring.

The structure of compounds **IX** and **X** was unambiguously established from the chemical shifts and multiplicity of the signals in the ^{1}H NMR spectra and was confirmed by comparison with the published data [4, 7].

The set of proton signals of the isoxazoline ring of compound **IX** corresponds to an *ABX* system. Two signals at 2.98 and 3.04 ppm appear like doublets of doublets with a large geminal (17.5 Hz) and small vicinal coupling constants (1.8 Hz, coupling with the proton CH=N). In the region of aromatic protons signal at 7.01 ppm (a one-proton triplet) is observed corresponding to the proton CH=N.

The presence of identical substituents in compound **X** led to a degenerate system of the protons of the isoxazoline ring corresponding to A_2X state. Therewith we observe only a weakly resolved two-proton doublet at 2.87 ppm with a small vicinal coupling (1.8 Hz) and a triplet corresponding to the proton CH=N, at 6.59 ppm with the same constant.

With unsymmetrical 1,2-disubstituted cyclopropanes the cleavage of any bond in the cyclopropane fragment would result in the formation of isomeric isoxazolines.

The nitrosation of 1-alkyl- and 1-halo-2-phenylcyclopropanes **III–V** in each case led to the formation of only two isomers (Scheme 1, Table 1).

For instance, in the reaction of 1-methyl-2-phenylcyclopropane (**III**) with NOCl in liquid SO_2 we obtained 3-methyl-5-phenyl- (**XI-A**) and 4-methyl-5-phenylisoxazolines (**XI-B**) in a ratio 5:1. The nitrosation with the complex $NOCl{\cdot}2SO_3$ gave isomers **A** and **B** in a ratio 2:1 (Table 1). Likewise, for compounds **IV** and **V** were obtained isomeric isoxazolines **XII** and **XIII**.

The structure of compounds **XI–XIII** was established from the chemical shifts and multiplicity of the signals in the ^{1}H NMR spectra [4].

We attempted to study the effect of the electronic and sterical factors on the direction of the opening of the three-membered ring.

In order to reveal the effect of the electronic factor on the isomeric composition of the products we studied the nitrosation with the complex $NOCl{\cdot}2SO_3$ of a series of unsymmetrical 1-aryl-2-phenylcyclopropanes **VI–VIII** containing substituents in one of the aromatic rings.

It was found that unsymmetrical 1-aryl-2-phenylcyclopropanes formed a single or a mixture of two isoxazolines depending on the electron-donor characteristics of substituents.

For instance, with 1-(4-methoxyphenyl)-2-phenylcyclopropane (**VI**) the reaction was regiospecific affording exclusively 5-(4-methoxyphenyl)-3-phenylisoxazoline (**XIV-A**) owing apparently to the strong donor effect of the methoxy group on the stabilization of the intermediately formed carbocation.

From 1-aryl-2-phenylcyclopropanes **VII** and **VIII** formed isomeric isoxazolines (Scheme 1), however therewith exclusively opened the C^1–C^2 bond as indicated by the chemical shifts and multiplicity of the signals in the ^{1}H NMR spectra of compounds obtained [8]. The formation of **A** and **B** isomers in this case was caused by the possibility of two ways of NO^+ addition to the three-membered ring at the C^1–C^2 bond due to the asymmetry of the substituents.

The ratio of **A** and **B** isomers for isoxazolines **XV** and **XVI** obtained and characterized in the mixture by the data of ^{1}H NMR spectra is given in Table 1. The conclusion on isomers ratio was done based on the intensity of signals of protons H^5 of the isoxazoline ring at 5.6–5.7 ppm with a difference in the chemical shifts of 0.1 ppm. The assignment of signals in the ^{1}H NMR spectra of compounds **XIV-A**, **XV-A,** and **XV-B** was carried out using published data [8].

The proton signals in the unknown compounds **XVI-A** and **XVI-B** were identified based on the data of GC-MS of the isomers mixture with the prevalence of isomer **B** applying the procedure developed formerly for establishing the structure of analogous isoxazolines [8].

The presence in the mass spectrum of the minor isomer of the peak of molecular ion M^+ 349 and also of ions with the masses 230 (I_{rel} 100%) and 117 (I_{rel} 11.1%) corresponding to $[4\text{-I-}C_6H_4CH{=}CH_2]^{+\cdot}$ and phenylazirinium fragment ions made it possible to ascribe to this compound the structure **XVI-A**. to the second isomer with the characteristic fragment ions 349 (100%), 243 (17.2%), and 104 (31.5%), corresponding to ions M^+, 4-iodophenylazirin-ium and $[C_6H_5CH{=}CH_2]^{+\cdot}$ was assigned **XVI-B** structure.

Comparing the intensities of peaks of isomers in the mass-chromatograms with the intensities of proton signals in the ^{1}H NMR spectrum we were able to assign completely the proton signals of isoxazoline ring.

The analysis of the reactivity of phenylcyclopropanes substituted in the trimethylene ring (Tables 1 and 2), and also the isomeric composition of the reaction products confirm the electrophilic character of the nitrosation of arylcyclopropanes in keeping with the previously suggested scheme assuming that the reaction proceeds through the formation of benzyl carbocation [2].

Thus for cyclopropanes **VI–VIII** the stabilizing action is seen of the aryl system on the benzyl carbocation in the series I < CH_3 < CH_3O owing to positive electronic effects of the substituents. The introduction of acceptor substituents (halogen atoms) into the small ring significantly decreased the reactivity of substrates leading to low yield of the target products under comparable reaction conditions at the use of the less active nitrosating systems NOCl–SO_2.

Comparing the activity of 1,1- and 1,2-methylphenylcyclopropanes (**I, III**) among themselves and with phenylcyclopropane [5] in the reaction with nitrosyl chloride activated with sulfur dioxide it is possible to conclude that the methyl substituent in compound **I** increases the reactivity of the latter apparently because of the donor effect of the alkyl group and because of the additional stabilization of the intermediate benzyl carbocation.

The donor effect of the methyl group in the isomeric 1-methyl-2-phenylcyclopropane (**III**) is not so apparent: its reactivity is comparable with that of phenylcyclopropane or is even lower. This is caused evidently on the one hand by the decrease in the energy of the C^1–C^2 bond due to the spatial interaction of the methyl group and the phenyl substituent thus increasing the activity of the cyclopropane ring, but on the other hand in the *trans*-isomer exist spatial obstacles to the approach of the nitrosating species. Consequently, cyclopropane **III** has a moderate reactivity, and a second isomer **XI-B** appears indicating the significant role of the sterical factor in the formation of the reaction products.

At the nitrosation with the complex NOCl·$2SO_3$ the fraction of isomer **XI-B** considerably grows presumably because for the more active reagent (complex NOCl·$2SO_3$) the energy difference between C^1–C^2 and C^1–C^3 bonds becomes insignificant, and the prevalence of the attack in one of the possible directions levels. However the sterical reasons cannot be excluded, when the more bulky complex NOCl·$2SO_3$ prefers to attack on the least substituted carbon atom of the three-membered ring.

A fact calls for attention that in the case of *cis*-1-bromo-2-phenylcyclopropane (**IV**) the reaction occurs regiospecifically giving isoxazoline **XII** exclusively in the form of **A** isomer, and from 1-phenyl-2-chlorocyclopropane (**V**) taken as a mixture of *cis*-, *trans*-isomers with the former prevailing are obtained both isomers with predominant content of isomer **A** (Table 1). Thus in the *cis*-isomer at the lack of steric hindrances the reaction occurs at the least strong C^1–C^2 bond.

In event of 1,2-diarylcyclopropanes the opening occurs exclusively at the C^1–C^2 bond when the nitrosation is carried out with NOCl in the liquid sulfur dioxide, and in the case of symmetrical cyclopropanes formes a single isomer 3,5-diarylisoxazoline [5]. This feature of 1,2-diarylcyclopropanes is known also for the other examples [9] testifying to the prevalence of the electronic factor over the sterical one at the attack of an electrophilic species on the small ring of 1,2-diarylcyclopropanes.

Therefore on the substrates under investigation it was demonstrated that the regiochemistry of the small ring opening depends mostly on the electronic factors (the possibility of stabilization of the intermediately formed carbocation) and on the strength of the attacked bond, as shown by the isomeric composition of the reaction products. The role of the steric factor requires further study by an example of more versatile models.

EXPERIMENTAL

^1H and ^{13}C NMR spectra were registered from solutions of compounds in $CDCl_3$ on spectrometers Varian XR-400 and Avance-400 at operating frequencies 400 and 100 400 MHz respectively (internal reference HMDS). IR spectra were recorded on a spectrophotometer UR-20 from mulls in mineral oil or from thin films. GC-MS measurements were performed on a Finnigan MAT SSQ 7000 instrument (ionizing energy 70 eV, quartz capillary column OV-1 (25 m), programmed heating mode from 70 (2 min) to 280°C (10 min), heating rate 20 deg/min). Melting points were measured in an open capillary placed in a heating block.

The initial arylcyclopropanes **I–VIII** were synthesized by the known procedures: 1-methyl-1-phenyl- (**I**), 1-halo-2-phenylcyclopropanes **IV** and **V**, by reduction of the corresponding dichloro- and dibromophenylcyclopropanes [10–12], 1,1-bis(4-nitrophenyl)cyclopropane (**II**), by nitration of the corresponding hydrocarbon [13], 1-alkyl- and 1-aryl-2-phenylcyclopropanes **III, VI**, and **VII**, by decomposition of the corresponding pyrazolines [14],

1-(4-iodophenyl)-2-phenylcyclopropane (**VIII**), by direct iodination of 1,2-diphenylcyclopropane [15].

***trans*-1-(4-Iodophenyl)-2-phenylcyclopropane (VIII)**. mp 150–151°C. ^{1}H NMR spectrum, δ, ppm: 1.55 m (1H, ^3J 5.7, ^3J 14.0, ^2J 11.3 Hz), 1.61 m (1H, ^3J 5.3, ^3J 13.8, ^2J 11.3 Hz), 2.27 m (2H), 7.02 d (2H, ^3J 8.3 Hz), 7.28 d (2H, ^3J 7.8 Hz), 7.45 t (3H, ^3J 7.8 Hz), 7.74 d (2H, ^3J 8.3 Hz). ^{13}C NMR spectrum, δ, ppm: 18.48, 27.77, 28.42, 90.67 (C^{4}I), 125.93, 126.11 (C$^{4'}$H), 128.03, 128.64, 137.50, 142.13 (C^1, C$^{1'}$), 142.39 (C^1, C$^{1'}$). Mass spectrum, *m/z* (I_{rel}, %): $[M]^+$ 320 (100), 193 (94), 178 (61), 165 (21), 115 (99), 102 (6), 91 (21), 77 (6), 63 (8).

General procedure of the synthesis of isoxazolines from arylcyclopropanes and NOCl·2SO$_3$. To a dispersion of 1.0 mmol of NOCl·2SO$_3$ in 10 ml of dichloromethane was added at 0°C equimolar amount of arylcyclopropane in 2 ml of dichloromethane. The precipitate at once partially dissolved, and the solution turned colored. On completion of the reaction (TLC monitoring) the reaction mixture was neutralized with a water solution of Na_2CO_3, washed with water. The water solutions were extracted with dichloromethane (3×10 ml), the organic extracts were combined and dried with Na_2SO_4. The solution was evaporated, and the reaction products were isolated by chromatography.

As a result of the reaction of 0.080 g (0.28 mmol) of 1,1-bis-(4-nitrophenyl)cyclopropane (**II**) with 0.108 g (0.47 mmol) of NOCl·2SO$_3$ for 1.5 h at 0°C we obtained after recrystallization from ethyl acetate 0.075 g (85%) of **5,5-bis(4-nitrophenyl)isoxazoline (X)**, R_f 0.31 (ethyl acetate–petroleum ether, 1:1). IR spectrum, ν, cm^{-1}: 2980–2870, 1600, 1530, 1475, 1380, 1360. ^{1}H NMR spectrum, δ, ppm: 2.87 d (2H, CH_2, ^3J 1.8 Hz), 6.59 t (1H, HC=N, ^3J 1.8 Hz), 7.09 d (4H, ^3J 9.0 Hz), 7.89 d (4H, ^3J 9.0 Hz). ^{13}C NMR spectrum, δ, ppm: 48.46, 88.47 (CHO), 123.99, 126.82 (C^4, C$^{4'}$), 126.92, 145.89 (CH=N), 149.29 (C^1, C$^{1'}$) [7].

As a result of a reaction of 0.090 g (0.45 mmol) of 1-bromo-2-phenylcyclopropane (**IV**) (100% *cis*-isomer) with 0.101 g (0.45 mmol) of NOCl·2SO$_3$ for 1 h at 0°C we obtained after chromatographic separation on a column (SiO_2, 40/100 μm, ethyl acetate–petroleum ether, 1:3) 0.1 g (99%) of **3-bromo-5-phenyloxazoline (XII-A)**, R_f 0.75 (ethyl acetate–petroleum ether, 1:1). ^{1}H NMR spectrum, δ, ppm: 3.22 d.d (1H, CH_2, ^2J 17.2, ^3J 9.0 Hz), 3.63 d.d (1H, CH_2, ^2J 17.2, ^3J 10.8 Hz), 5.69 d.d (1H, CHO, ^3J 10.8, ^3J 9.0 Hz), 7.30–7.45 m (5H).

As a result of a reaction of 0.303 g (2.00 mmol) of 1-phenyl-2-chlorocyclopropane (**V**) (*cis–trans*, 9:5) with 0.450 g (2.00 mmol) of NOCl·2SO$_3$ for 1 h at 0°C we obtained after chromatographic separation on a column (SiO_2, 40/100 μm, ethyl acetate–petroleum ether, 1:3) 0.045 g (15%) of cyclopropane **V** (100% *trans*-isomer); 0.238 g (66%) of **5-phenyl-3-chloroisoxazoline (XIII-A)**, R_f 0.65 (ethyl acetate–petroleum ether, 1:1). ^{1}H NMR spectrum, δ, ppm: 3.12 d.d (1H, CH_2, ^2J 17.1, ^3J 9.4 Hz), 3.52 d.d (1H, CH_2, ^2J 17.1, ^3J 10.9 Hz), 5.70 d.d (1H, HCO, ^3J 10.9, ^3J 9.4 Hz), 7.30–7.40 m (5H). ^{13}C NMR spectrum, δ, ppm: 46.09, 83.71 (CHO), 125.84, 128.68 (C^4), 128.82, 139.13 (C^1), 148.36 (CH=N); and 0.059 g (17%) **5-phenyl-4-chloroisoxazoline (XIII-B)**, R_f 0.42 (ethyl acetate–petroleum ether, 1:1). ^{1}H NMR spectrum, δ, ppm: 4.97 d.d (1H, C^{4}H, ^3J 3.2, ^3J 1.8 Hz), 5.62 d (1H, HCO, ^3J 3.2 Hz), 7.26 d (1H, HC=N, ^3J 1.8 Hz), 7.30–7.40 m (5H). ^{13}C NMR spectrum, δ, ppm: 66.00, 88.76 (CHO), 125.19, 128.95 (C^4), 129.10, 136.93 (C^1), 144.54 (CH=N). Found for isomer mixture, %: C 59.52; H 4.46. C_9H_8ClNO. Calculated, %: C 59.50; H 4.41.

As a result of a reaction of 0.11 g (0.34 mmol) of 1-(4-iodophenyl)-2-phenylcyclopropane (**VIII**) with 0.09 g (0.39 mmol) of NOCl·2SO$_3$ for 1 h at 0°C we obtained 0.12 g (99%) of a mixture of **5-(4-iodophenyl)-3-phenyl-isoxazoline (XVI-A)** and **3-(4-iodophenyl)-5-phenyl-isoxazoline (XVI-B)** in a ratio 1:1, according to ^{1}H NMR data. After chromatographic separation on a column (SiO_2, 40/100 μm, ethyl acetate–petroleum ether, 1:3) we isolated 0.075 g of a mixture of **XVI-A** and **XVI-B** in a ratio 1:3. Compound **XVI-A**. ^{1}H NMR spectrum, δ, ppm: 3.32 d.d (1H, CH_2, ^2J 16.6, ^3J 8.5 Hz), 3.78 d.d (1H, CH_2, ^2J 16.6, ^3J 11.1 Hz), 5.73 d.d (1H, HCO, ^3J 11.1, ^3J 8.5 Hz), 7.13 d (2H, ^3J 8.6 Hz), 7.37 m (5H), 7.74 d (2H, ^3J 8.6 Hz). Mass spectrum, *m/z* (I_{rel}, %): $[M]^+$ 349 (78.6), 246 (3), 230 (100), 217 (4.1), 204 (11.2), 192 (15.3), 165 (4.1), 145 (3), 129 (4.2) 117 (11.1), 103 (10.6), 89 (4.5), 77 (20.1), 63 (2.5), 50 (10.1). Compound **XVI-B**. ^{1}H NMR spectrum, δ, ppm: 3.27 d.d (1H, CH_2, ^2J 16.7, ^3J 8.0 Hz), 3.77 d.d (1H, CH_2, ^2J 16.7, ^3J 11.0 Hz), 5.67 d.d (1H, HCO, ^3J 11.0, ^3J 8.0 Hz), 7.12 d (2H, ^3J 8.4 Hz), 7.40 m (5H), 7.69 d (2H, ^3J 8.4 Hz). Mass spectrum, *m/z* (I_{rel}, %): $[M]^+$ 349 (100), 332 (8), 320 (1.5) 271 (2), 243 (17.2), 222 (1), 207 (2.3), 192 (16.1), 165 (2), 150 (1), 127 (2.2), 104 (31.5), 77 (15.5), 51 (10.1).

General procedure of the synthesis of isoxazolines from arylcyclopropanes and nitrosyl chloride in liquid sulfur dioxide. Into a test tube was charged 0.003 mol of arylcyclopropane, it was cooled to –60°C,

a calculated quantity of NOCl was added in solution in dichloromethane, and 5 ml of liquid SO_2. The test tube was tightly stoppered, warmed to the required temperature, shaken till the formation of a homogeneous solution, and maintained at the desired temperature. After a lapse of the required time the reaction mixture was diluted with 20 ml of cooled dichloromethane, the mixture was warmed to 0°C, and the organic layer was neutralized with a water solution of Na_2CO_3, and then washed with water. The water layer was extracted with dichloromethane, the combined organic solutions were dried with sodium sulfate. The solution was evaporated, the residue was subjected to chromatography on silica gel. Yields of compounds obtained are compiled in Table 2.

As a result of a reaction of 0.132 g (1 mmol) of 1-methyl-1-phenylcyclopropane (**I**) and 0.130 g (2 mmol) of NOCl in 5 ml of SO_2 for 2 h at –40°C after the standard workup of the reaction mixture and the chromatographic isolation on a column (SiO_2, 40/100 μm, ethyl acetate–petroleum ether, 1:3) we isolated 0.007 g (4%) of ***trans*-3-methyl-3-phenylacrylonitrile (XVIII),** R_f 0.80. IR spectrum, ν, cm^{-1}: 2225 (CN). ^{1}H NMR spectrum, δ, ppm: 2.46 d (3H, CH_3, ^4J 1.1 Hz), 5.61 q (1H, ^4J 1.1 Hz), 7.38–7.45 m ($5H_{apOm.}$) [16]; 0.015 g (8%) of **3-phenyl-3-chlorobutyronitrile (XVII)**, R_f 0.75. IR spectrum, ν, cm^{-1}: 2250 (CN). ^{1}H NMR spectrum, δ, ppm: 2.09 s (3H, CH_3), 3.08 d (1H, CH_2, ^2J 16.7 Hz), 3.16 d (1H, CH_2, ^2J 16.7 Hz), 7.29 d (1H, ^3J 7.2 Hz), 7.34 m (2H), 7.51 d (2H, ^3J 7.8 Hz); 0.129 g (80%) of **5-methyl-5-phenylisoxazoline (IX)**, R_f 0.50. ^{1}H NMR spectrum, δ, ppm: 1.62 s (3H, CH_3), 2.98 d.d (1H, CH_2, ^2J 17.5, ^3J 1.8 Hz), 3.04 d.d (1H, CH_2, ^2J 17.5, ^3J 1.8 Hz), 6.98 t (1H, HC=N, ^3J 1.8 Hz), 7.18 d (1H, ^3J 7.7 Hz) 7.25 t (2H, ^3J 7.7 Hz) 7.32 d (2H, ^3J 7.7 Hz) [17].

As a result of a reaction of 0.132 g (1 mmol) of 1-methyl-2-phenylcyclopropane (**III**) and 0.328 g (5 mmol) of NOCl in 5 ml of SO_2 for 3 h at–40°C after the standard workup of the reaction mixture and the chromatographic isolation on a column (SiO_2, 40/100 μm, ethyl acetate–petroleum ether, 1:3) we isolated 0.030 g (24%) of cyclopropane **III** (100% *trans*-isomera), 0.080 g (50%) of **3-methyl-5-phenyl-isoxazoline (XI-A),** R_f 0.50. ^{1}H NMR spectrum, δ, ppm: 2.01 t (3H, CH_3, ^4J 1.0 Hz), 2.89 d.d.q (1H, CH_2, ^2J 17.0, ^3J 8.2, ^4J 1.0 Hz), 3.34 d.d.q (1H, CH_2, ^2J 17.0, ^3J 10.8, ^4J 1.0 Hz), 5.54 d.d (1H, HCO, ^3J 10.8, ^3J 8.2 Hz), 7.30–7.35 m (5H); 0.016 g (10%) of **4-methyl-5-phenylisoxazoline (XI-B),** R_f 0.37. ^{1}H NMR spectrum, δ, ppm: 1.35 d (3H, CH_3, ^3J 7.1 Hz), 3.29 m (1H, C^4H), 5.02 d (1H, HCO, ^3J 8.0 Hz), 7.12 br.s, 7.30–7.40 m (5H).

As a result of a reaction of 0.200 g (1 mmol) of 1-bromo-2-phenylcyclopropane (**IV**) and 0.130 g (2 mmol) of NOCl in 5 ml of SO_2 for 18 h at –20°C after the standard workup of the reaction mixture and the chromatographic isolation on a column (SiO_2, 40/100 μm, ethyl acetate–petroleum ether, 1:3) we isolated 0.10 g (54%) of cyclopropane **IV**, 0.047 g (21%) of **3-bromo-5-phenylisoxazoline (XII-A)**, 0.010 g (4%) of **4-bromo-5-phenylisoxazoline (XII-B),** R_f 0.60. ^{1}H NMR spectrum, δ, ppm: 5.02 d.d (1H, C^4H, ^3J 2.8, ^3J 1.6 Hz), 5.86 d (1H, HCO, ^3J 2.8 Hz), 7.30 d (1H, HC=N, ^3J 1.6 Hz), 7.36–7.41 m (5H).

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REFERENCES

1. Bondarenko, O.B., Gavrilova, A.Yu., Kazantseva, M.A., Tikhanushkina, V.N., Nifant'ev, E.E., Saginova, L.G., and Zyk, N.V., *Zh. Org. Khim.,* 2007, vol. 43, p. 566.
2. Bondarenko, O.B., Gavrilova, A.Yu., Kazantseva, M.A., Tikhanushkina, V.N., Nifant'ev, E.E., Saginova, L.G., Zyk, N.V., *Zh. Org. Khim.,* 2006, vol. 42, p. 265.
3. Bondarenko, O.B., Gavrilova, A.Yu., Saginova, L.G., Zyk, N.V., and Zefirov, N.S., *Izv. Akad. Nauk, Ser. Khim.,* 2003, p. 741.
4. Gazzaeva, R.A., Shabarov, Yu.S., and Saginova, L.G., *Khim. Geterotsikl. Soedin.,* 1983, 738.
5. Bondarenko, O.B., Gavrilova, A.Yu., Saginova, L.G., and Zyk, N.V., *Zh. Org. Khim.,* 2003, 39, 1084.
6. Mizuno, K., Ichinose, N., Tamai, T., and Otsuji, Y., *J. Org. Chem.,* 1992, 57, 4669; Mochalov, S.S., Kuz'min, Ya.I., Fedotov, A.N., Trofimova, E.V., Gazzaeva, R.A., Shabarov, Yu.S., and Zefirov, N.S., *Zh. Org. Khim.,* 1998, 34, 1379.
7. Saginova, L.G., Mokhammad, Al'khamdan, and Petrosyan, V.S., *Vestn. MGU, Ser. Khim.,* 1999, 40, 46
8. Saginova, L.G., Kukhareva, I.L., Lebedev, A.T., and Shabarov, Yu.S., *Zh. Org. Khim.,* 1991, 27, 1852.
9. Cychkova, L.D. and Shabarov, Yu.S., *Zh. Org. Khim.,* 1985, vol. 21, p. 292; Bondarenko, O.B., Voevodskaya, T.I., Saginova, L.G., Tafeenko, V.A. and Shabarov, Yu.S., *Zh. Org. Khim.,* 1987, vol. 23, p. 1736.
10. Mochalov, S.S., Kosynkin, O.V., Yudin, I.D., Zavod-

skikh, N.A., Shabarov, Yu.S., and Zefirov, N.S., *Khim. Geterotsikl. Soedin.,* 1994, p. 472.
11. D'yachenko, A.I. and Korneva, O.S., *Izv. Akad. Nauk SSSR., Ser. Khim.,* 1980, p. 2432.
12. Novokreshchennykh, V.D., *Cand. Sci. (Chem.) Dissertation*, Moskva, 1982.
13. Markees, D.G. and Burger, A., *J. Am. Chem. Soc.,* 1949, vol. 71, p. 2031.
14. Kizhner, N.M., *Zh. Ros. Fiz. Khim. Obshch*., 1912, vol. 44, p. 863.
15. Saginova, L.G., Bondarenko, O.B., Shabarov, Yu.S., and Gazzaeva, R.A., *Zh. Org. Khim.,* 1984, vol. 10, p. 2124.
16. Descotes, G. and Laconche, P., *Bull. Soc. Chim.,* 1968, p. 2149.
17. Gazzaeva, R.A., Shabarov, Yu.S., and Saginova, L.G., *Khim. Geterotsikl. Soedin.,* 1984, p. 309.