Organic Chemistry

Reactions of nitronates derived from simple nitro alkanes with some thio-stabilized cationic intermediates

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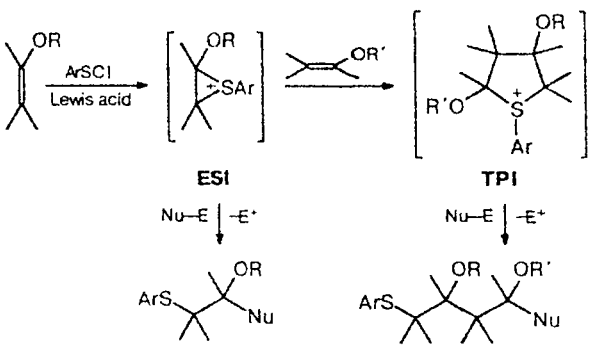
Trimethylsilyl and DBU nitronates derived from nitromethane and nitropropanes do not undergo *C*-alkylation by episulfonium (ESI) or thiophanium (TPI) cationic intermediates. The above-mentioned derivatives of 1-nitropropane react with ESI and TPI to give the corresponding products of *O*-alkylation of 1-chloro-1-oxyiminopropane. The reactions of DBU nitronates derived from nitromethane and 2-nitropropane with ESI or TPI proceed as *O*-alkylation followed by standard fragmentation of the initially formed nitronate intermediates to give methyl (4-tolylthio)acetate or methyl 2,2-dimethyl-3-methyloxy-(4-tolylthio)butanoate respectively.

Key words: episulfonium ions, thiophanium ions, silyl nitronates, aliphatic nitro compounds, Lewis acids, alkylation.

Recently a new general method for the formation of carbon—carbon bonds has been proposed[1]; the method involves kinetically separable addition of an electrophile (Ad_E) and a nucleophile to double bonds occurring *via* sulfur-containing cationic intermediates, episulfonium ions (ESI) and thiophanium ions (TPI) (Scheme 1). Being soft carbocationic electrophiles, these intermediates are able to alkylate many C-nucleophiles (trialkylsilyl enolates, allylsilanes, benzyl- and allylmagnesium halides, electron-donating arenes, *etc.*) to give, after elimination of easily leaving groups Me_3Si^+, XMg^+, or H^+, polyfunctional covalent products (Scheme 1).[1]

To develop further the above methodology, it seemed expedient to study the reactions of ESI and TPI with ionic and covalent derivatives of nitro compounds,

Scheme 1



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namely salts of nitronic acids and trimethylsilyl nitronates. It should be borne in mind that, unlike the nucleophiles studied previously, ambident nitronates can undergo electrophilic attack on both the α-carbon atom and the oxygen atom.

Competitive *C*- and *O*-alkylation of ionic nitronates is well known[2a,3a]; however, the reactions of silyl nitronates with electrophilic alkylating agents have scarcely been studied.

Results and Discussion

As investigation objects, we have chosen derivatives of simple nitroalkanes: 1-nitropropane (**1a**), nitromethane (**1b**), and 2-nitropropane (**1c**). Salts **2a—c** (DBU nitronates), prepared by mixing equimolar amounts of 1,8-diazabicyclo[5.4.0]undec-7-ene (DBU) and the corresponding nitro compounds in CH_2Cl_2, and the corresponding trimethylsilyl esters of *aci*-nitromethane (**3b**) and *aci*-2-nitropropane (**3c**) were used without isolation. The trimethylsilyl ester of *aci*-1-nitropropane (**3a**) was introduced in the reactions after isolation and vacuum distillation.[4]

In this work, we studied the reactions of nitronates **2a—c** and **3a—c** with model ESI **4** and TPI **5**.

ESI and TPI were generated from the *in situ* synthesized products of the Ad_E addition of *p*-toluenesulfenyl chloride to methyl vinyl ether or to 3,4-dihydro-2*H*-pyran in the presence of $TiCl_4$ or $SnCl_4$ in CH_2Cl_2 or $LiClO_4$ in $MeNO_2$ as Lewis acids.[5]

We found that the use of silyl nitronate **3a** as the "concluding" nucleophile for ESI **4a,b** or TPI **5a** results in the formation of *O*-alkyloxyiminoyl chlorides **6a,b** or **7a**, respectively, in moderate yields (Scheme 2).

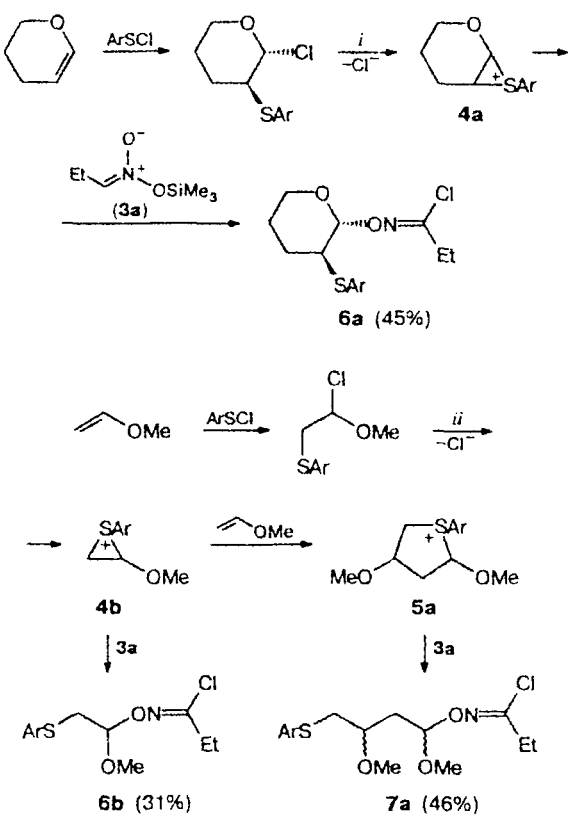
The structures of products **6a,b** and **7a** were established by NMR spectroscopy and high-resolution mass spectrometry. Compounds **6a,b** are formed as single stereoisomers, while **7a** is produced as a 1 : 1 mixture of two diastereomers having identical configurations of the C=N bond, according to the ^{13}C NMR data (see Experimental).

The mechanism of formation of oxyimino derivatives **6** and **7** has not been specially studied. However, the results obtained can be interpreted in terms of a scheme including coordination of a Lewis acid (LA) to the oxygen atoms of silyl nitronate **3a** followed by transformation of the latter into the corresponding hydroxyiminoyl chloride **A**. The reaction ends with *O*-alkylation of intermediate **A** by ESI **4a,b** or TPI **5a** (Scheme 3).

Chloride ion is generated at the step of formation of ESI from the adducts of *p*-toluenesulfenyl chloride with methyl vinyl ether or 3,4-dihydro-2*H*-pyran (see Scheme 2).

Thus, within the framework of Scheme 3, it is assumed that products **6** or **7** are formed when the electrophilic attack by the cationic intermediate is directed at hydroxyiminoyl chloride **A**, generated from **3a** under the reaction conditions, rather than at silyl nitronate **3a**.

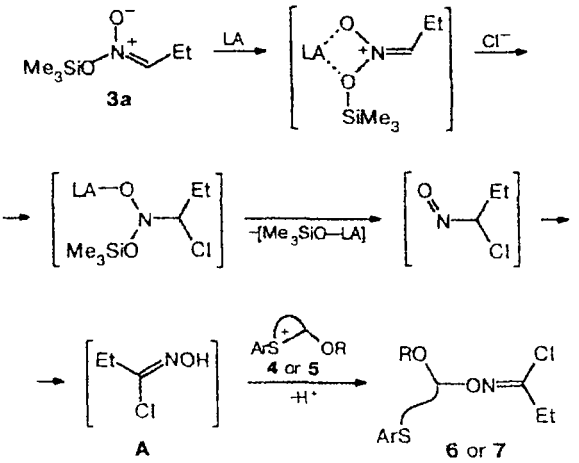
Scheme 2



Ar = *p*-C_6H_4Me

i. $LiClO_4$ in $MeNO_2$, −20 °C; *ii*. $TiCl_4$ in CH_2Cl_2, −78 → 0 °C.

Scheme 3



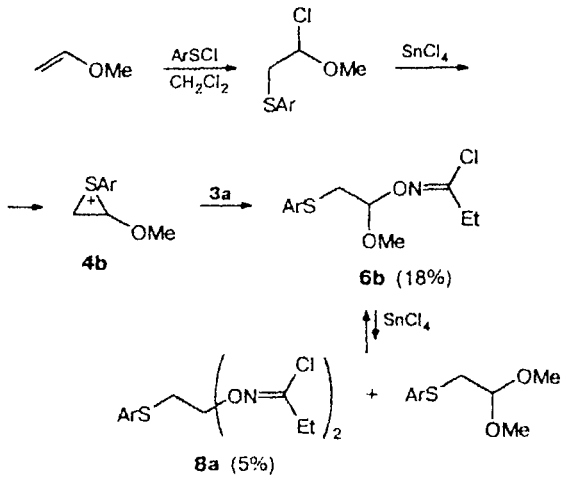
LA = Li^+, $TiCl_4$ or $SnCl_4$

It should be noted that the formation of oxyiminoyl chlorides from primary *aci*-nitro compounds under the action of carboxylic acid chlorides[6—8] and the formation

of α-chlorohydroxyiminoyl chlorides from conjugated nitroalkenes under the action of $TiCl_4$ [9] have been described in the literature.

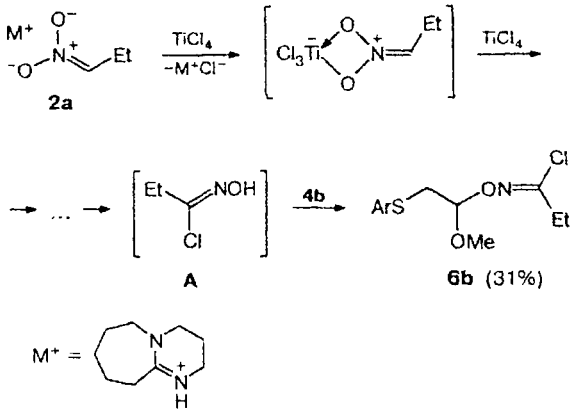
The yields of compounds **6b** and **7a** in the presence of $TiCl_4$ are somewhat higher than those in the presence of $SnCl_4$, because the latter compound is able to induce exchange of substituents at the acetal center, as indicated by the isolation of product **8a** in a relatively low yield (Scheme 4).

Scheme 4



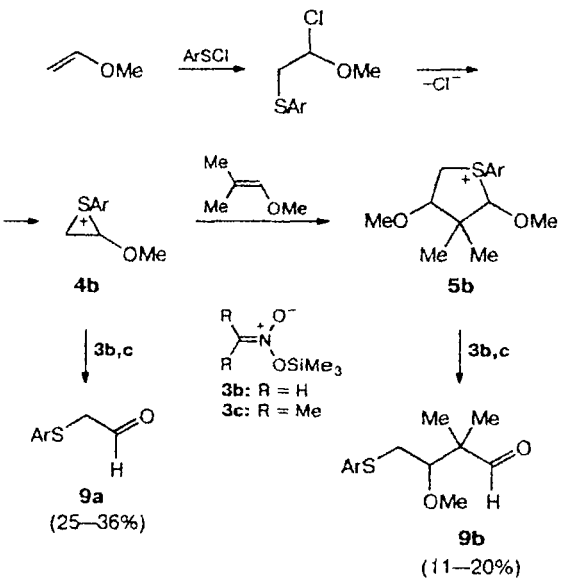
When DBU nitronate **2a** is made to react with **4b** instead of silyl nitronate **3a**, the yield of oxyiminoyl chloride **6b** somewhat increases. We believe that in this case, Ti nitronate is formed as an intermediate (Scheme 5).

Scheme 5



Alkylation of trimethylsilyl esters of *aci*-nitromethane (**3b**) and *aci*-2-nitropropane (**3c**) by cationic intermediates **4b** or **5b** (prepared by addition of **4b** to 1-methoxy-2-methylpropene) under the conditions presented in Scheme 2 affords complex mixtures of products, from which only the products of hydrolysis of cationic intermediates, aldehydes **9a,b**, can be isolated in low yields (Scheme 6).

Scheme 6



This may be due to the instability of ester **3b** under the reaction conditions (see also Ref. 4) and also to the fact that the intermediate oxime of type **A** cannot be generated from the trimethylsilyl ester of secondary nitro compound **3c**. Aldehydes **9** can arise upon the reaction of cationic intermediates with the products of fast decomposition of silyl nitronates **3b,c** on treatment with Lewis acids (see Experimental).

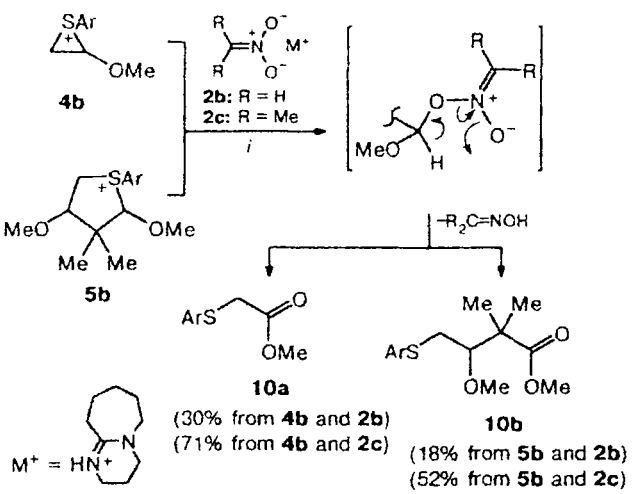
In order to avoid the undesirable processes associated with the decomposition of silyl nitronates, we studied alkylation of salts **2b,c** by the same intermediates **4b** and **5b**. In this case, methyl *p*-tolylthioacetate (**10a**) and methyl 2,2-dimethyl-3-methoxy-4-(*p*-tolylthio)butanoate (**10b**), respectively, are formed as the major reaction products (Scheme 7).

The formation of esters **10** can be easily explained by assuming that DBU nitronates **2b,c** undergo *O*-alkylation by intermediates **4b** and **5b**. The route of fragmentation of intermediate nitronates presented in Scheme 7 is typical of alkyl nitronates having hydrogen atoms in the α-position of the alkyl fragment.[2b]

Thus, in none of the studied examples were any *C*-alkylation products detected. Since the negative charge in nitronates is mainly concentrated on oxygen atoms,[3b] this result indicates that the reaction of stabilized cationic intermediates (ESI and TPI) is obviously charge controlled.

At the same time, it is clear that enhancement of the stabilization of the initial carbocation or difficulty of the traditional fragmentation of the *O*-alkylation product,

Scheme 7

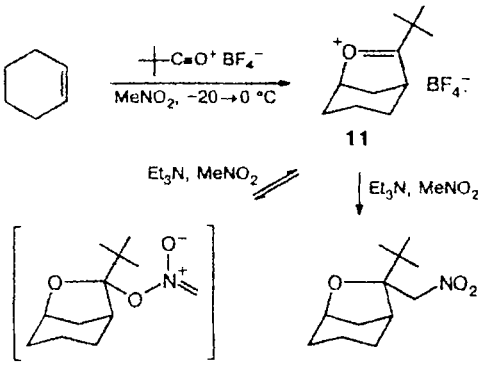


i. $LiClO_4$ in $MeNO_2$, −20 °C.

shown in Scheme 7, or both these factors acting simultaneously can enable *C*-alkylation of nitronates by soft carbocationic reagents. A large series of transformations of ionic and covalent nitronates can be interpreted in this context, for example, oxyiminomethylation[10,11] (the Mannich reaction) and reactions with triphenylmethyl[2c] or tropylium[12] cations.

The reaction of nitromethane with carboxonium salt **11** in the presence of Et_3N [13] (Scheme 8) is an example most pertinent to this problem.

Scheme 8



Experimental

^1H and ^{13}C NMR spectra were recorded on a Bruker AM-300 spectrometer (300.13 and 75.5 MHz, respectively) in $CDCl_3$ at 27 °C using tetramethylsilane as an internal standard. The ^1H and ^{13}C NMR signals were assigned using ^1H—^1H and ^1H—^{13}C 2D correlation spectra, ^{13}C DEPT spectra, selective polarization transfer (SPT), and ^{13}C NMR spectra with incomplete proton decoupling (GATED decoupling mode).

Mass spectra were recorded on a Varian MAT CH-6 spectrometer. High-resolution mass spectra were run on a VG 7070E-HF spectrometer.

All the reactions were carried out in anhydrous solvents under dry argon; the course of the reactions was monitored by TLC.

Petroleum ether with b.p. 60—70 °C was used for chromatography and extraction.

Commercially available initial compounds, 3,4-dihydro-2*H*-pyran, Lewis acids, DBU, Et_3N, and Me_3SiCl, were distilled over calcium hydride; $LiClO_4$ was dried for 2 h at 240 °C (0.5 Torr).

Trimethylsilyl esters of *aci*-nitromethane and *aci*-2-nitropropane,[14] trimethylsilyl ester of *aci*-1-nitropropane,[4] 2-methyl-1-methoxypropene,[15] vinyl methyl ether,[16] and *p*-toluenesulfenyl chloride[17] were prepared by known procedures. The two latter reagents were used as solutions in CH_2Cl_2.

Preparation of a solution of toluenesulfenyl chloride with methyl vinyl ether in CH_2Cl_2. Vinyl methyl ether (0.5 mmol, 0.33 mL of a 1.5 *M* solution in CH_2Cl_2) was added at −78 °C to a solution of *p*-TolSCl (0.5 mmol) in 10 mL of CH_2Cl_2.

The reaction of ESI 4b with silyl nitronate 3a in the presence of $TiCl_4$. Preparation of [2-methoxy-2-(1-chloropropylideneamino)oxyethyl] 4-tolyl sulfide (6b). $TiCl_4$ (0.11 g, 0.55 mmol) was added at −78 °C to the solution of chloro adduct (0.5 mmol) prepared according to the above procedure. Silyl nitronate **3a** (0.24 g, 1.5 mmol) was added to the solution of ESI **4b** thus obtained. The mixture was kept for 30 min at −78 °C and for 22 h at 5 °C. The reaction mixture was diluted with a saturated aqueous solution of $NaHCO_3$ (10 mL) and extracted with CH_2Cl_2 (3×15 mL); the combined extracts were washed with brine and dried with Na_2SO_4. After evaporation of the solvents *in vacuo*, the product was isolated by column chromatography (EtOAc—petroleum ether, 1 : 20), which gave 0.044 g (31%) of *O*-alkoxyiminoyl chloride **6b**, R_f 0.55 (EtOAc—petroleum ether, 1 : 15), as a colorless oil. ^1H NMR, δ: 1.19 (t, 3 H, Me, J = 7.6 Hz); 2.32 (s, 3 H, MePh); 2.50 (q, 2 H, CH_2, J = 7.6 Hz); 3.18 (dd, 1 H, CH_AS, J = 6.1 Hz, J = 14.0 Hz); 3.29 (dd, 1 H, CH_BS, J = 5.1 Hz, J = 14.0 Hz); 3.47 (s, 3 H, MeO); 5.07 (dd, 1 H, CHOMe, J = 5.1 Hz, J = 6.1 Hz); 7.10 and 7.31 (both d, 4 H_{arom}, J = 8.2 Hz). ^{13}C NMR, δ: 11.1 (Me), 21.0 (MePh), 30.7 (CH_2), 37.4 (CH_2S), 56.4 (MeO), 106.1 (CHOMe), 129.7 (2 CH_{arom}), 130.6 (2 CH_{arom}), 132.0 and 136.5 (2 C_{arom}), 142.8 (CCl). High-resolution MS: found m/z 287.0771 [M^+]; $C_{13}H_{18}ClNO_2S$; calculated m/z 287.0747.

The reaction of ESI 4b with silyl nitronate 3a in the presence of $SnCl_4$. Preparation of [2-methoxy-2-(1-chloropropylideneamino)oxyethyl] 4-tolyl sulfide (6b) and {2,2-bis[(1-chloropropylideneamino)oxy]ethyl} 4-tolyl sulfide (8a). At −20 °C, silyl nitronate **3a** (0.24 g, 1.5 mmol) and $SnCl_4$ (0.14 g, 0.55 mmol) were added successively to the solution of chloro adduct (0.5 mmol) prepared as described previously, and the mixture was kept for 1.5 h at −20 °C and for 2.5 h at 5 °C, diluted with a saturated aqueous solution of $NaHCO_3$ (10 mL), and extracted with ether (3×20 mL). The combined extracts were washed with brine and dried with Na_2SO_4. After evaporation of the solvents *in vacuo*, the product was isolated by column chromatography (EtOAc—petroleum ether, 1 : 20), which gave 0.026 g (18%) of *O*-alkyloxyiminoyl chloride **6b** and 0.009 g (5%) of bis(oxyiminoyl chloride) **8a**, R_f 0.62 (EtOAc—petroleum ether, 1 : 15), as a colorless oil. ^1H NMR, δ: 1.18 (t, 6 H, 2 Me, J = 7.3 Hz); 2.32 (s, 3 H, MePh); 2.51 (q, 4 H, 2 CH_2, J = 7.3 Hz); 3.35 (d, 2 H, CH_2S, J =

5.9 Hz); 5.77 (t, 1 H, CH, J = 5.9 Hz); 7.10 and 7.35 (both d, 4 H_{arom}, J = 8.1 Hz). ^{13}C NMR, δ: 11.1 (Me), 21.0 (MePh), 30.6 (CH_2), 36.0 (CH_2S), 106.6 (CH), 129.7 (2 CH_{arom}), 131.2 (2 CH_{arom}), 131.5 and 136.9 (2 C_{arom}), 143.8 (CCl). High-resolution MS: found m/z 362.0626 [M^+]; $C_{15}H_{20}Cl_2N_2O_2S$; calculated m/z 362.0623.

The reaction of ESI 4b with DBU nitronate 2a in the presence of $TiCl_4$. Preparation of [2-methoxy-2-(1-chloropropylideneamino)oxyethyl] 4-tolyl sulfide (6b). 1-Nitropropane (0.14 g, 1.53 mmol) was added in one portion at 0 °C to a stirred solution of DBU (0.23 g, 1.5 mmol) in CH_2Cl_2 (5 mL), and the mixture was kept for 7—10 min at a temperature not exceeding 5 °C. At −78 °C, $TiCl_4$ (0.30 g, 1.55 mmol) was added to the solution of DBU nitronate, and the mixture was kept for 5 min at −78 °C. Then a solution of the chloro adduct in CH_2Cl_2 (5 mL) was added dropwise, and the mixture was kept for 3 h at −78 °C and for 17 h at −10 °C. Then it was worked-up as described in the above procedure. After evaporation of the solvents *in vacuo*, the product was isolated by column chromatography (EtOAc—petroleum ether, 1 : 20), which gave 0.050 g (31%) of *O*-alkyloxyiminoyl chloride **6b**.

The reaction of TPI 5a with silyl nitronate 3a in the presence of $TiCl_4$. Preparation of [2,4-dimethoxy-4-(1-chloropropylideneamino)oxybutyl] 4-tolyl sulfide (7a). At −70 °C, $TiCl_4$ (0.11 g, 0.55 mmol) and methyl vinyl ether (1.0 mmol, 0.67 mL of a 1.5 *M* solution in CH_2Cl_2) were added successively to the solution of chloro adduct (0.5 mmol) prepared by the procedure described above. After 20 min, silyl nitronate **3a** (0.32 g, 2.0 mmol) was added, and the mixture was kept for 30 min at −70 °C and for 6 h at 5 °C. Then it was diluted by a saturated aqueous solution of $NaHCO_3$ (10 mL) and extracted with CH_2Cl_2 (3×15 mL), and the combined extracts were washed with brine and dried with Na_2SO_4. After evaporation of the solvents *in vacuo*, the product was isolated by column chromatography (EtOAc—petroleum ether, 1 : 15), which gave two isomers of sulfide **7a**.

(1) Less polar isomer, R_f = 0.42 (EtOAc—petroleum ether, 1 : 10), 0.040 g (23%). ^1H NMR, δ: 1.20 (t, 3 H, Me, J = 7.3 Hz); 2.03 (ddd, 1 H, CH_A, J = 4.4 Hz, J = 8.1 Hz, J = 14.3 Hz); 2.14 (ddd, 1 H, CH_B, J = 4.6 Hz, J = 7.3 Hz, J = 14.3 Hz); 2.31 (s, 3 H, MePh); 2.53 (q, 2 H, CH_2, J = 7.3 Hz); 3.01 (dd, 1 H, CH_AS, J = 6.1 Hz, J = 13.4 Hz); 3.08 (dd, 1 H, CH_BS, J = 5.6 Hz, J = 13.4 Hz); 3.35 (s, 3 H, MeO); 3.45 (s, 3 H, MeO); 3.52 (m, 1 H, CHOMe); 5.16 (dd, 1 H, OCHOMe, J = 4.4 Hz, J = 7.3 Hz); 7.09 and 7.28 (both d, 4 H_{arom}, J = 8.3 Hz). ^{13}C NMR, δ: 11.2 (Me), 21.0 (MePh), 30.7 (CH_2CCl), 37.5 and 38.6 (CH_2S, CH_2CH), 56.0 (MeO), 57.4 (MeO), 76.6 (CHOMe), 105.1 (OCHOMe), 129.7 (2 CH_{arom}), 130.1 (2 CH_{arom}), 132.8 and 136.2 (2 C_{arom}), 142.2 (CCl). High-resolution MS: found m/z 345.1171 [M^+]; $C_{16}H_{24}ClNO_3S$; calculated m/z 345.1165.

(2) More polar isomer, R_f = 0.38 (EtOAc—petroleum ether, 1 : 10), 0.040 g (23%). ^1H NMR, δ: 1.20 (t, 3 H, Me, J = 7.3 Hz); 1.96 (ddd, 1 H, CH_A, J = 4.2 Hz, J = 8.6 Hz, J = 14.7 Hz); 2.23 (ddd, 1 H, CH_B, J = 4.1 Hz, J = 7.6 Hz, J = 14.7 Hz); 2.31 (s, 3 H, MePh); 2.52 (q, 2 H, CH_2, J = 7.3 Hz); 2.95 (dd, 1 H, CH_AS, J = 6.4 Hz, J = 13.4 Hz); 3.08 (dd, 1 H, CH_BS, J = 5.2 Hz, J = 13.4 Hz); 3.33 (s, 3 H, MeO); 3.43 (m, 1 H, CHOMe); 3.44 (s, 3 H, MeO); 5.14 (dd, 1 H, OCHOMe, J = 4.2 Hz, J = 7.6 Hz); 7.09 and 7.28 (2 d, 4 H_{arom}, J = 8.3 Hz). ^{13}C NMR, δ: 11.2 (Me), 21.0 (MePh), 30.6 (CH_2CCl), 37.5 and 38.5 (CH_2S, CH_2CH), 56.0 (MeO), 57.4 (MeO), 76.4 (CHOMe), 105.0 (OCHOMe), 129.6 (2 CH_{arom}), 130.4 (2 CH_{arom}), 132.6 and 136.3 (2 C_{arom}), 142.3 (CCl). High-resolution MS: found m/z 345.1171 [M^+]; $C_{16}H_{24}ClNO_3S$; calculated m/z 345.1165.

The reaction of ESI 4a with silyl nitronate 3a in the presence of $LiClO_4$. Preparation of *trans*-2-[(1-chloropropylideneamino)oxy]-3-(4-tolylthio)tetrahydropyran (6a). At −20 °C, 3,4-dihydro-2*H*-pyran (0.137 mL, 1.5 mmol) and a suspension of $LiClO_4$ (0.6 g, 7.5 mmol) in 2 mL of CH_2Cl_2 were added dropwise to a stirred solution of *p*-TolSCl (0.24 g, 1.5 mmol) in 20 mL of CH_2Cl_2; after 10 min of stirring, silyl nitronate (0.51 mL, 3 mmol) **3a** was added to the reaction mixture. The mixture was stirred at the same temperature for an additional 1 h, diluted with 10 mL of distilled water, extracted with ether (2×20 mL), and dried with $MgSO_4$. After evaporation of the solvents *in vacuo*, the product was isolated by column chromatography (EtOAc—petroleum ether, 1 : 15), which gave 0.141 g (45%) of tetrahydropyran **6a**, R_f = 0.37 (EtOAc—petroleum ether, 1 : 15), as a colorless oil. Found (%): C, 57.31; H, 6.63; Cl, 10.84; S, 9.80. $C_{15}H_{20}ClNO_2S$. Calculated (%): C, 57.40; H, 6.42; Cl, 11.30; S, 10.22. ^1H NMR, δ: 1.20 (t, 3 H, Me, J = 7.4 Hz); 1.56, 1.76, 1.94, and 2.27 (all m, 4 H, 2 ring CH_2); 2.33 (s, 3 H, MePh); 2.53 (dq, 2 H, CH_2Me, J = 2.0 Hz, J = 7.4 Hz); 3.32 (dt, 1 H, CH_eS, J = 4.3 Hz, J = 6.7 Hz); 3.66 (ddd, 1 H, CH_eO, J = 3.9 Hz, J = 6.1 Hz, J = 12.0 Hz); 3.94 (ddd, 1 H, CH_aO, J = 3.4 Hz, J = 8.1 Hz, J = 12.0 Hz); 5.22 (d, 1 H, CH_eO, J = 4.3 Hz); 7.11 and 7.38 (both d, 4 H_{arom}, J = 7.9 Hz). ^{13}C NMR, δ: 11.2 (Me); 21.1 (MePh); 22.8, 26.5, and 30.6 (2 ring CH_2, chain CH_2); 46.4 (CHS); 63.2 (CH_2O); 103.2 (CHO); 129.8 (2 CH_{arom}); 130.6 (C_{arom}); 133.1 (2 CH_{arom}); 137.6 (C_{arom}); 143.9 (CCl). MS, m/z: 313 (M^+, 6%), 252 (1), 207 (26), 189 (25), 177 (5), 161 (13), 150 (11), 135 (7), 123 (12), 91 (8).

Preparation of solutions of DBU nitronates 2a—c in CH_2Cl_2 (see Ref. 14). The corresponding nitroalkane (1.2 mmol) was added in one portion to a stirred solution of DBU (0.17 g, 1.1 mmol) in CH_2Cl_2 (2 mL), and the mixture was kept for 7—10 min at a temperature not exceeding 5 °C. The homogeneous solutions of DBU nitronates **2a—c** (1.1 mmol) thus obtained were used for subsequent transformations.

Preparation of solutions of trimethylsilyl nitronates 3b,c in CH_2Cl_2. A solution of Me_3SiCl (0.13 g, 1.2 mmol) in CH_2Cl_2 (1 mL) was added dropwise with cooling (0 °C) and vigorous stirring over a period of 5 min to the solution of the corresponding DBU nitronate (1.1 mmol) prepared as described above, and the mixture was kept for 30 min at 0 °C. The transparent colorless solutions of silyl nitronate **3b,c** (1.1 mmol) thus obtained were used for subsequent transformations.

The reaction of ESI 4b with silyl nitronates 3b,c. Preparation of 2-(4-tolylthio)acetaldehyde (9a). A bright orange solution of *p*-TolSCl (0.5 mmol) in $MeNO_2$ (4 mL) was titrated with vigorous stirring at −20 °C with a solution of methyl vinyl ether until the color completely disappeared; then a transparent colorless solution of $LiClO_4$ (0.22 g, 2.1 mmol) in $MeNO_2$ (4 mL) was added, and the mixture was stirred for 20 min, while maintaining the temperature below −20 °C (slight turbidity). A solution of silyl nitronate **3b** (1.1 mmol) or **3c** (1.1 mmol), prepared as described above, was added at −30 °C to the solution of ESI **4b** thus obtained. The mixture was kept for 1 h at −20 °C and for 2 h at 0 °C (until the precipitate of LiCl appeared), concentrated *in vacuo* (1 Torr) at a temperature of not higher than 0 °C to approximately 1/3 its volume, and extracted with cooled (0 °C) petroleum ether (6×5 mL). After evaporation of the petroleum ether at 20 °C (15 Torr), the residue was analyzed by ^1H NMR spectroscopy. The spectrum contained signals for aldehyde **9a** formed

in the reaction and no signals for the initial silyl nitronates **3b** and **3c**.

The product was isolated by column chromatography (EtOAc—petroleum ether, 1 : 5), which gave 0.02 g (25%; in the case of **4b** + **3b**) and 0.03 g (36%; in the case of **4b** + **3c**) of aldehyde **9a**, R_f 0.25 (EtOAc—petroleum ether, 1 : 5), as a yellowish oil. Found (%): C, 65.09; H, 6.00; S, 19.31. $C_9H_{10}OS$. Calculated (%): C, 65.06; H, 6.02; S, 19.28. ^{1}H NMR, δ: 2.30 (s, 3 H, Me); 3.54 (d, 2 H, CH_2, ^3J = 3.5 Hz); 7.08 (d, 2 H, CH, ^3J = 8.1 Hz); 7.26 (d, 2 H, CH); 9.52 (t, 1 H, CH=O).

Variation of the reaction conditions (an increase in the reaction time to 12 h at 0 °C or its decrease to 1 h at −20 °C) or the isolation conditions (treatment of the reaction mixture with water followed by extraction with ether) did not affect the yield of aldehyde **9a**.

The reaction of TPI 5b with silyl nitronates 3b,c. Preparation of 3-methoxy-2,2-dimethyl-4-(4-tolylthio)butyraldehyde (9b). 1-Methoxy-2-methylpropene (0.06 g, 0.7 mmol) was added in one portion at −25 °C to the solution of ESI **4b** (0.5 mmol) in $MeNO_2$ (8 mL), prepared as described previously, and the mixture was kept at this temperature for 30 min (until the precipitate of LiCl appeared). To the solution of TPI **5b** thus obtained, the prepared (see above) solution of silyl nitronate **3b** (1.1 mmol) or **3c** (1.1 mmol) was added at −30 °C. The mixture was kept for 1 h at −20 °C and for 4 h at 0 °C, concentrated *in vacuo* (1 Torr) at a temperature not exceeding 0 °C to approximately 1/3 its volume, and extracted with cooled (0 °C) petroleum ether (6×5 mL). After evaporation of the petroleum ether at 20 °C (15 Torr), the residue was analyzed by ^{1}H NMR spectroscopy; the spectrum contained signals for aldehyde **9b** formed in the reaction and no signals for the initial silyl nitronates **3b** and **3c**.

The product was isolated by column chromatography (EtOAc—petroleum ether, 1 : 10), which gave 0.014 g (11%; in the case of **5b** + **3b**) and 0.025 g (20%; in the case of **5b** + **3c**) of aldehyde **9b**, R_f 0.20 (EtOAc—petroleum ether, 1 : 10), as a yellowish oil. Found (%): C, 66.65; H, 7.93; S, 12.74. $C_{14}H_{20}O_2S$. Calculated (%): C, 66.67; H, 7.94; S, 12.70. ^{1}H NMR, δ: 1.05 (s, 3 H, Me); 1.10 (s, 3 H, Me); 2.32 (s, 3 H, $C_{Ar}\underline{Me}$); 2.96 (dd, 1 H, $C\underline{H}_a H_b$, ^2J = 13.8 Hz, ^3J = 7.5 Hz); 3.05 (dd, 1 H, $CH_a\underline{H}_b$, ^3J = 3.9 Hz); 3.50 (m, 1 H, C<u>H</u>OMe); 3.51 (s, 3 H, OMe); 7.11 (d, 2 H, CH, ^3J = 8.0 Hz); 7.29 (d, 2 H, CH); 9.56 (s, 1 H, CH=O). ^{13}C NMR, δ: 17.8 (Me); 18.7 (Me); 20.9 ($C_{Ar}\underline{Me}$); 36.1 (CH_2); 50.9 ($\underline{C}Me_2$); 60.5 (OMe); 84.0 (<u>C</u>HOMe); 129.7 ($\underline{C}_{Ar}H$); 130.2 ($\underline{C}_{Ar}H$); 132.2 ($\underline{C}_{Ar}S$); 136.5 ($\underline{C}_{Ar}Me$); 204.5 (CH=O).

Variation of the reaction conditions (an increase in the reaction time to 18 h at 0 °C or decrease to 3 h at −20 °C) or the isolation conditions (treatment of the reaction mixture with water followed by extraction with ether) did not affect the yield of aldehyde **9b**.

The reaction of ESI 4b with DBU nitronates 2b,c. Preparation of methyl (4-tolylthio)acetate (10a). The solution of DBU nitronate **2b** (1.1 mmol) or **2c** (1.1 mmol) (see above) was added at −30 °C to a solution of ESI **4b** (0.5 mmol) in $MeNO_2$ (8 mL), prepared as described above (see the synthesis of **9a**), and the mixture was kept for 1 h at −30 °C and for 2 h at 0 °C (until the precipitate of LiCl appeared). Then it was poured into the two-phase system ether—saturated aqueous solution of $NaHCO_3$ and stirred at 0 °C, the aqueous layer was extracted with ether (3×10 mL), and the combined extracts were washed with brine and dried with Na_2SO_4. After evaporation of the solvents *in vacuo*, the product was isolated by column chromatography (EtOAc—petroleum ether, 1 : 5), which gave 0.03 g (30%; in the case of **4b** + **2b**) and 0.07 g (71%; in the case of **4b** + **2c**) of ether **10a**, R_f 0.20 (EtOAc—petroleum ether, 1 : 5), as a colorless oil. Found (%): C, 61.24; H, 6.10; S, 16.30. $C_{10}H_{12}O_2S$. Calculated (%): C, 61.22; H, 6.12; S, 16.33. ^{1}H NMR, δ: 2.30 (s, 3 H, Me); 3.58 (s, 2 H, CH_2); 3.67 (s, 3 H, OMe); 7.09 (d, 2 H, CH, ^3J = 8.0 Hz); 7.31 (d, 2 H, CH). ^{13}C NMR, δ: 20.7 (Me); 36.8 (CH_2); 52.1 (OMe); 129.5 ($\underline{C}_{Ar}H$); 130.4 ($\underline{C}_{Ar}H$); 130.8 ($\underline{C}_{Ar}S$); 136.9 ($\underline{C}_{Ar}Me$); 169.9 (C=O).

The reaction of TPI 5b with DBU nitronates 2b,c. Preparation of methyl 3-methoxy-2,2-dimethyl-4-(4-tolylthio)butanoate (10b). The solution of DBU nitronate **2b** or **2c** (see above) was added at −25 °C to a solution of TPI **5b** (0.5 mmol) in $MeNO_2$ (8 mL), prepared by the above-described procedure (see synthesis of **9b**), and the mixture was kept for 1 h at −25 °C and for 6 h at 0 °C (until the precipitate of LiCl appeared). Then it was poured into the two-phase system ether—saturated aqueous solution of $NaHCO_3$ and stirred at 0 °C, the aqueous layer was extracted with ether (3×10 mL), and the combined extracts were washed with brine and dried with Na_2SO_4. After evaporation of the solvents *in vacuo*, the product was isolated by column chromatography (EtOAc—petroleum ether, 1 : 7), which gave 0.025 g (18%; in the case of **5b** + **2b**) and 0.073 g (52%; in the case of **5b** + **2c**) of ether **10b**, R_f 0.3 (EtOAc—petroleum ether, 1 : 7), as a colorless oil. Found (%): C, 63.80; H, 7.80; S, 11.36. $C_{15}H_{22}O_3S$. Calculated (%): C, 63.83; H, 7.80; S, 11.35. ^{1}H NMR, δ: 1.11 (s, 3 H, Me); 1.15 (s, 3 H, Me); 2.36 (s, 3 H, $C_{Ar}\underline{Me}$); 3.02 (dd, 1 H, $C\underline{H}_A H_B$, ^2J = 14.0 Hz, ^3J = 7.8 Hz); 3.11 (dd, 1 H, $CH_A\underline{H}_B$, ^3J = 3.4 Hz); 3.50 (m, 1 H, C<u>H</u>OMe); 3.52 (s, 3 H, OMe); 3.70 (s, 3 H, CO_2Me); 7.17 (d, 2 H, CH, ^3J = 8.1 Hz); 7.34 (d, 2 H, CH). ^{13}C NMR, δ: 17.8 (Me); 18.7 (Me); 20.9 ($C_{Ar}\underline{Me}$); 36.1 (CH_2); 50.9 ($\underline{C}Me_2$); 51.7 ($CO_2\underline{Me}$); 60.5 (OMe); 83.9 (<u>C</u>HOMe); 129.7 ($\underline{C}_{Ar}H$); 130.2 ($\underline{C}_{Ar}H$); 132.2 ($\underline{C}_{Ar}S$); 136.4 ($\underline{C}_{Ar}Me$); 170.5 (C=O).

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References

1. W. A. Smit, R. Caple, and I. P. Smoliakova, *Chem. Rev.*, 1994, **94**, 2359.
2. A. T. Nielsen, in *The Chemistry of the Nitro and Nitroso Groups*, Ed. H. Feuer, Interscience, New York, 1970, **1**, (a) pp. 417—430; (b) pp. 417—422 and 444—451; (c) pp. 429.
3. S. S. Novikov, G. A. Shvekhgeimer, V. V. Sevostyanova, and V. A. Shlyapochnikov, *Khimiya alifaticheskikh i atsiklicheskikh nitrosoedinenii* [*Chemistry of Aliphatic and Acyclic Nitro Compounds*], Khimiya, Moscow, 1974, (a) pp. 26—30; (b) pp. 355—360 (in Russian).
4. K. B. G. Torssell and O. Zeuthen, *Acta Chem. Scand.*, 1978, **B32**, 118.
5. M. I. Lazareva, Yu. K. Kryshchenko, A. D. Dil'man, E. Haiford, R. Caple, and V. A. Smit, *Izv. Akad. Nauk, Ser. Khim.*, 1998, 924 [*Russ. Chem. Bull.*, 1998, **47**, 895 (Engl. Transl.)].
6. W. Steinkopf and B. Juergens, *J. Prakt. Chem.*, 1911, **84**, 686.
7. C. D. Nenitzescu and D. A. Isacescu, *Bull. Soc. Chim. Romania*, 1932, **14**, 53; *Chem. Abstrs.*, 1933, **27**, 964.

8. H. Wieland and Z. Kitasato, *Chem. Ber.*, 1929, **62B**, 1250.
9. E. Francotte, R. Merenyi, B. Vandenbulcke-Coyette, and H. G. Viehe, *Helv. Chim. Acta*, 1981, **64**, 1208.
10. H. H. Bayer and L. Urbas, in *The Chemistry of the Nitro and Nitroso Groups*, Ed. H. Feuer, Interscience, New York, 1970, **2**, pp. 117—130.
11. A. V. Kalinin, E. T. Apasov, S. L. Ioffe, V. P. Kozyukov, and Vik. P. Kozyukov, *Izv. Akad. Nauk SSSR, Ser. Khim.*, 1985, **11**, 2635 [*Bull. Acad. Sci. USSR, Div. Chem. Sci.*, 1985, **34**, 2442 (Engl. Transl.)].
12. M. Bersohn, *J. Am. Chem. Soc.*, 1961, **83**, 2137.
13. O. V. Lyubinskaya. Ph. D. Thesis (Chem.), N. D. Zelinsky Institute of Organic Chemistry, Moscow, 1976, 131 pp. (in Russian)
14. J. M. Aizpurua, M. Oiarbide, and C. Palomo, *Tetrahedron Lett.*, 1987, **28**, 5361.
15. T. Okuyama, T. Foeno, H. Nakatsuji, and J. Furukawa, *J. Am. Chem. Soc.*, 1967, **89**, 5826.
16. W. H. Watanabe and L. E. Conlon, *J. Am. Chem. Soc.*, 1957, **79**, 2828.
17. W. H. Mueller and P. E. Butler, *J. Am. Chem. Soc.*, 1968, **90**, 2075.

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