α-Methoxycarbonyl-containing polyflouroalkylsulfenyl chlorides

A. Yu. Sizov,* V. M. Rogovik, A. F. Kolomiets, and A. V. Fokin

A. N. Nesmeyanov Institute of Organoelement Compounds, Russian Academy of Sciences,
28 ul. Vavilova, 117813 Moscow, Russian Federation.
Fax: 007 (095) 135 5085. E-mail:afokin@ineos.ae.ru

New α-methoxycarbonyl-containing polyfluoroalkylsulfenyl chlorides were obtained. Reactions of sulfenyl chlorides containing primary, secondary and tertiary α-methoxycarbonylpolyfluoroalkyl groups at the sulfur atom with some unsaturated, carbonyl, aromatic, and heteroaromatic compounds were studied.

Key words: conjugate electrophilic addition, α-methoxycarbonyl group, polyflouroalkylsulfenyl chlorides, sulfenylation.

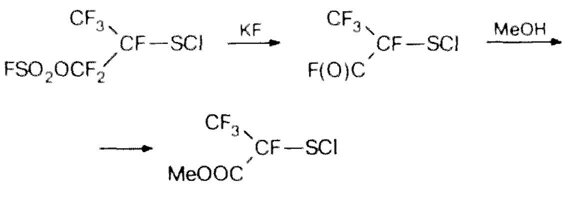
Polyfluoroalkylsulfenyl chlorides attract considerable attention as highly reactive compounds holding much promise for the synthesis of diverse fluorine-containing organosulfur compounds based on them.[1] Among them, sulfenyl chlorides containing various functional groups, which widen their synthetic potential and permit them to be used in the syntheses of heterocyclic compounds, are of particular interest.[2]

Of α-methoxycarbonyl-containig polyfluoroalkylsulfenyl chlorides, only α-methoxycarbonylhexafluoroisopropylsulfenyl chloride (**1**) is known at present; its properties in reactions with unsaturated compounds and phenols have been studied.[3–6]

In the present paper we consider the syntheses of other representatives of this group of compounds, namely, α-methoxycarbonyltetrafluoroethylsulfenyl (**2**) and methoxycarbonyldifluoromethylsulfenyl (**3**) chlorides, and study the chemical properties of sulfenyl chlorides **1**—**3** more extensively.

Synthesis of sulfenyl chlorides

It has been shown previously[7] that the conjugate electrophilic addition of sulfur chlorides and fluorosulfonic acid to hexafluoropropene affords a mixture of products consisting predominantly of 2-(chlorothio)hexafluoropropyl fluorosulfate, which, when heated with potassium fluoride, is converted into α-fluorocarbonyltetrafluoroethylsulfenyl chloride. We showed that treatment of the latter with an equimolar amount of methanol gives sulfenyl chloride **2** in 84 % yield.



2

We also found that tetrafluoroethylene or trifluoromethyl trifluorovinyl ether react with sulfur dichloride and fluorosulfonic acid in a similar way. These reactions, proceeding more vigorously than that with hexafluoropropene, afford mixtures of products, in which the yield of sulfenyl chlorides (**4**, **5**) is no more than 20 %. The main reaction products are mixtures of polysulfides (**6**, **7**) in which trisulfides (**6a**, **7a**) predominate.

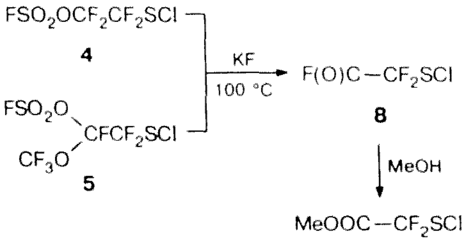
$$XCF{=}CF_2 + SCl_2 + FSO_3H \longrightarrow$$

$$\longrightarrow FSO_2OCFXCF_2SCl + (FSO_2OCFXCF_2)_2S_n$$

4: X = F **6**: X = F (**6a**: *n* = 3)
5: X = OCF$_3$ **7**: X = OCF$_3$ (**7a**: *n* = 3)

The direction of the addition in the reaction with trifluoromethyl trifluorovinyl ether was determined based on ^{19}F NMR chemical shifts and on the transformations of the reaction products.

Heating (100 °C) sulfenyl chloride **4** with potassium fluoride gave fluorocarbonyldifluoromethylsulfenyl chloride (**8**), which readily reacts with an equimolar amount of methanol to give sulfenyl chloride **3** in 76 % yield. Sulfenyl chloride **5** also reacts with KF; however, in this case, the trifluoromethoxy group is the leaving fragment, and the reaction also yields sulfenyl chloride **8**. The formation of **8** confirms the reaction route assumed for the addition of SCl$_2$ and HSO$_3$F to perfluorinated methyl vinyl ether.



3

Translated from *Izvestiya Akademii Nauk. Seriya Khimicheskaya*, No. 7, pp. 1745—1752, July, 1996.

It should be noted that polysulfides resulting from conjugate electrophilic addition involving hexafluoropropene, tetrafluoroethylene, and perfluorinated methyl vinyl ether were also converted into sulfenyl chlorides **2** and **3**. The scheme including heating with KF, methanolysis, and subsequent chlorination of the resulting polysulfides seems even somewhat more convenient, since this makes it possible to use an excess of methanol and to avoid the formation of low-boiling volatile acyl fluorides. For example, heating trisulfides **6a** and **7a** with KF affords bis(fluorocarbonyldifluoromethyl) trisulfide (**9**), whose reaction with excess methanol yields bis(methoxycarbonyldifluoromethyl) trisulfide (**10**). Chlorolysis of compound **10** was accomplished by excess chlorine in a sealed glass ampule at 90—95 °C for 5 h. The resulting sulfenyl chloride **3** and SCl_2 are readily separated by fractionation.

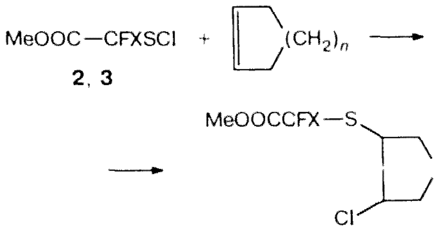
$$\mathbf{6a},\ \mathbf{7a} \xrightarrow{KF} \underset{\mathbf{9}}{(F(O)CCF_2)_2S_3} \xrightarrow{MeOH}$$

$$\longrightarrow \underset{\mathbf{10}}{(MeOOCCF_2)_2S_3} \xrightarrow{Cl_2} \mathbf{3}$$

Like other polyfluoroalkylsulfenyl chlorides, sulfenyl chlorides **2** and **3** are yellow labile liquids, distillable without decomposition under atmospheric pressure.

Reactions of sulfenyl chlorides with unsaturated compounds

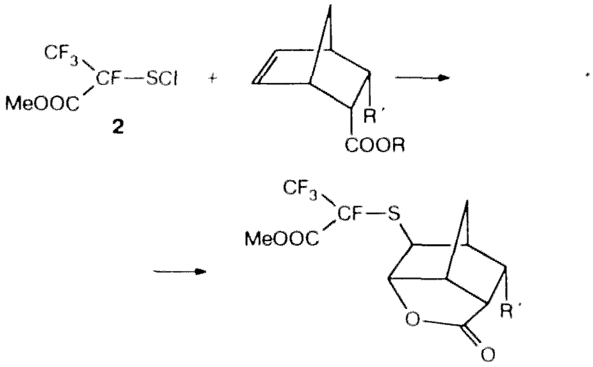
The chemical properties of α-methoxycarbonyl-containing polyfluoroalkylsulfenyl chlorides **1—3** are largely determined by the presence of the sulfenyl chloride group as well as by the effect of the polyfluoroalkyl fragment on the group. For example, similarly to compound **1**,[5] sulfenyl chlorides **2** and **3** add at the double bond of cycloalkenes, these reactions occurring much more readily than that with compound **1**. For example, the reaction of sulfenyl chloride **3** with cyclopentene at −30 °C is completed in a period of 20—30 min and gives sulfide **11** in 86 % yield.



11—14

X = F; *n* = 1 (**11**), 2 (**12**)
X = CF_3, *n* = 1 (**13**), 2 (**14**)

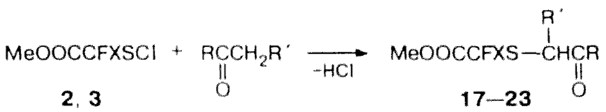
Similarly to other polyfluoroalkylsulfenyl chlorides,[6] compound **2** reacts with norbornenecarboxylic acid or with dimethyl norbornenedicarboxylate at −10 to −20 °C to give the products of thiolactonization (**15**, **16**). At the same time, these reactions involving sulfenyl chloride **3** occur ambiguously even under very mild conditions.



15: R = R' = H
16: R = Me; R' = COOMe

Reactions with carbonyl compounds

Reactions of polyfluoroalkylsulfenyl chlorides with carbonyl compounds have been comprehensively studied in relation to trifluoromethyl sulfenyl chloride, 1-trifluoromethyl-2-chloroethylsulfenyl chloride, and 1,2-bis(chlorosulfenyl)tetrafluoroethane.[1] The effects of the electrophilicity of the polyfluoroalkyl group and of the steric situation at the sulfur atom on the conditions under which these reactions occur have not been studied previously. We showed that aliphatic and arylaliphatic ketones capable of enolization react more readily with sulfenyl chloride **3**. For example, the reaction of **3** with ethyl acetoacetate at 20—25 °C without solvents is completed in a period of 5 h, and the completion of the reaction with acetophenone requires 20 h. The reactions of sulfenyl chloride **2** with ethyl acetoacetate, acetylacetone, acetone, acetophenone, and cyclohexanone under the same conditions are completed only in periods of 40—150 h.

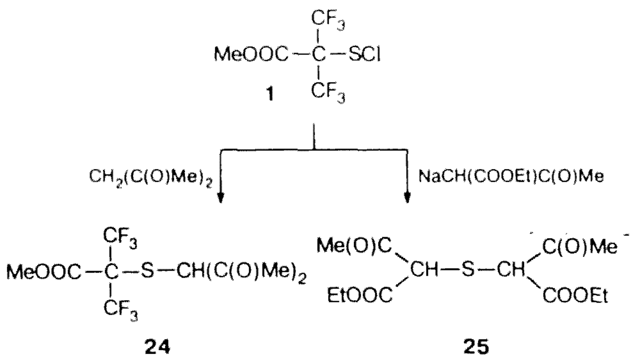


$$\underset{\mathbf{2,\ 3}}{MeOOCCFXSCl} + \underset{\substack{\parallel\\ O}}{RC}CH_2R' \xrightarrow[-HCl]{} \underset{\mathbf{17-23}}{MeOOCCFXS-\overset{\overset{R'}{|}}{C}H\underset{\substack{\parallel\\ O}}{C}R}$$

X = F, R = Me, R' = COOEt (**17**),
R = Ph, R' = H (**18**);
X = CF_3, R = Me, R' = COOEt (**19**),
R = Me, R' = C(O)Me (**20**),
R = Me, R' = H (**21**),
R = Ph, R' = H (**22**),
R, R' = $-(CH_2)_4-$ (**23**).

The yields of polyfluoroalkylsulfenylated carbonyl compounds **17—23** are equal to 60—80 %. The time needed for the completion of the reaction was determined based on the instant at which the evolution of hydrogen chloride ceased.

However, sulfenyl chloride **1** does not react even with easily enolized ketones without a solvent. We were able to involve it into these reactions only in acetonitrile, which specifically solvates the S—Cl bond in sulfenyl chlorides. For example, the reaction with acetylacetone in boiling acetonitrile gave the corresponding adduct **24** in 37 % yield. The reaction occurs ambiguously and, together with adduct **24**, it affords the corresponding disulfide and a number of other products. The attempt to conduct the reaction of sulfenyl chloride **1** with the sodium derivative of ethyl acetoacetate resulted unexpectedly in the formation of bis(ethoxycarbonylacetylmethyl) sulfide (**25**) in 51 % yield.

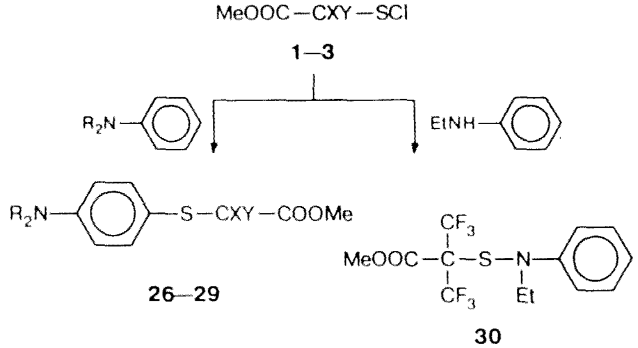


Possibly, the adduct formed in this reaction from sulfenyl chloride **1** and ethyl acetoacetate is cleaved at the C—S bond through the action of a second molecule of the sodium derivative of ethyl acetoacetate. However, it cannot be ruled out that compound **25** results from a complex radical and ionic reaction involving conversion of compound **1** into the thiyl radical, which undergoes desulfurization.

Spectroscopic studies of polyfluoroalkylsulfenylated carbonyl compounds showed that, unlike the derivatives of ketones, the substituted β-dicarbonyl compounds **17**, **19**, **20**, and **24** exist virtually entirely in the enol form, which is in agreement with the data obtained previously.[1] The ^{1}H NMR spectra of these compounds (in $CDCl_3$) exhibit a signal in the 14—17 ppm region (OH), and the IR spectra contain an absorption band corresponding to the OH group at 2990—3000 cm^{-1}.

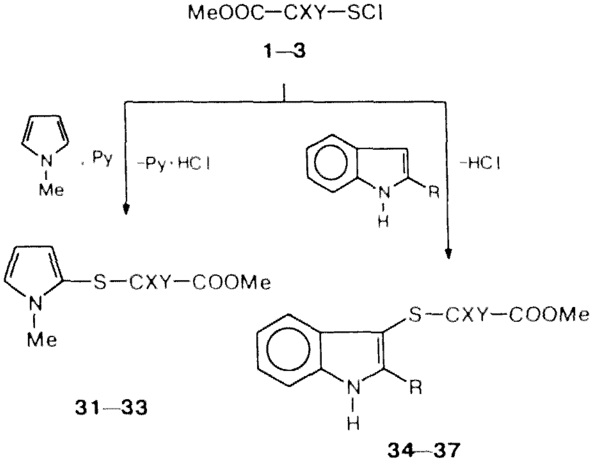
Reactions of sulfenyl chlorides with aromatic and heteroaromatic compounds

In recent years, interest in polyfluoroalkylsulfenylated aromatic and heteroaromatic compounds has grown, due to the prospects of discovering among them biologically active compounds with valuable properties. We showed that sulfenyl chlorides **1—3** react with various π-donor type aromatic and heteroaromatic substances. For example, sulfenyl chlorides **1—3** react at 20 °C with *N,N*-dialkylanilines, taken in excess in order to bind HCl, to give *para*-sulfenylation products (**26—29**). In the reaction of sulfenyl chloride **1** with *N*-etyhylaninile, only the adduct at the nitrogen atom (**30**) was obtained.



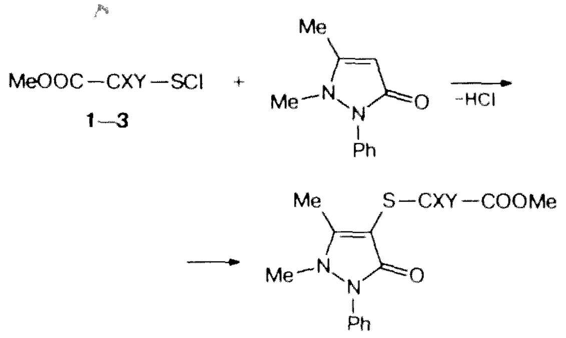
R = Me, X = Y = F (**26**), X = CF$_3$, Y = F (**27**),
X = Y = CF$_3$ (**28**);
R = Et, X = Y = CF$_3$ (**29**)

Among heteroaromatic compounds, only those possessing high π-donor ability react with sulfenyl chlorides **1—3** without a catalyst. For example, the reaction with *N*-methylpyrrole in the presence of pyridine gives the products of substitution at position 2 (**31—33**) in 43—88 % yields. Indoles react with the sulfenyl chlorides studied in the absence of acceptors of HCl to afford products of C(3)-sulfenylation (**34—37**). Electron-releasing substituents in the pyrrole ring somewhat facilitate the reaction; for example, 2-methylindole forms an adduct with compound **3** even in the cold. To remove HCl, the reaction mixture must be heated to boiling.



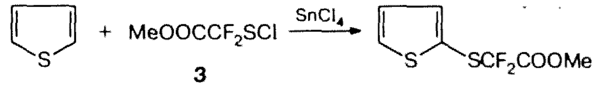
X = Y = F (**31**), R = H, X = Y = F (**34**),
X = CF$_3$, Y = F (**32**), X = CF$_3$, Y = F (**35**),
X = Y = CF$_3$ (**33**) X = Y = CF$_3$ (**36**)
R = Me, X = Y = F (**37**)

Among heteroaromatic compounds containing five-membered rings with two heteroatoms, 2,3-dimethyl-1-phenylpyrazol-5-one could be involved in the reactions with sulfenyl chlorides **1—3** in the absence of HCl acceptors or catalysts; these reactions give sulfenylated products of substitution at the C(4) atom (**38—40**) in high yields.



38: X = Y = F
39: X = CF_3, Y = F
40: X = Y = CF_3

Thiophene is much more difficult to involve in sulfenylation. Monosulfenylation with sulfenyl chloride **3** occurs only in the presence of $SnCl_4$ as a catalyst and affords the product of C(2)-substitution in 76 % yield. Sulfenyl chlorides **1** and **2** form no sulfenylation products under these conditions; instead, the reaction yields only the corresponding disulfides.



41

Our results imply that α-methoxycarbonyl-containing polyfluoroalkylsulfenyl chlorides are accessible for investigation, possess relatively high reactivity, and are interesting precursors of fluorine- and sulfur-containing compounds of a variety of types. The comparative study of the reactivities of sulfenyl chlorides containing primary, secondary, and tertiary polyfluoroalkyl groups at the sulfur atom with respect to unsaturated and carbonyl compounds and π-donor type aromatic and heteroaromatic systems carried out by us indicates that as the electron-withdrawing properties and branching of the polyfluoroalkyl groups increase, their reactivity substantially decreases. The synthetic potential of the α-methoxycarbonyl group of sulfenyl chlorides **1—3** for the synthesis of new fluorine- and sulfur-containing compounds and heterocycles will be considered in subsequent communications.

Experimental

^1H and ^{19}F NMR spectra were recorded on a Bruker-AC-200F spectrometer operating at 200.00 and 188.31 MHz, respectively. The chemical shifts (δ) are presented in ppm with respect to tetramethylsilane (^1H, internal standard) or to CF_3COOH (^{19}F, external standard). The R_f values for the compounds obtained are given for Silica gel 60 F 254 TLC-Sheets (Merck) and for the CCl_4—acetone system. The spots were detected by absorption in UV light. IR spectra (ν/cm^{-1}) were obtained in CCl_4 using a UR-20 spectrometer. Physical and spectral characteristics and the data of elemental analyses of compounds **2—41** are listed in Table 1.

α-(Methoxycarbonyl)tetrafluoroethylsulfenyl chloride (2). Methanol (1.6 g, 50 mmol) was added dropwise with stirring and cooling (−10 to 0 °C) to α-(fluorocarbonyl)tetrafluoroethylsulfenyl chloride (10.7 g, 50 mmol). The mixture was heated to 20 °C, kept until the evolution of HF ceased (10 h), and fractionated, n_D^{20} = 1.3970.

The reaction of SCl_2, HSO_3F, and tetrafluoroethylene. A twofold molar excess of tetrafluoroethylene was bubbled through a stirred mixture of SCl_2 (30.9 g, 300 mmol) and HSO_3F (90.0 g, 900 mmol) at a rate of 2 L h^{-1}, the temperature being maintained below 30—35 °C. The mixture was poured onto ice, and the organic layer was separated, dried with $MgSO_4$, and fractionated to give 16.0 g (20 %) of 2-(fluorosulfonyloxy)tetrafluoroethylsulfenyl chloride (**4**), n_D^{20} = 1.3725, and 31.0 g (38.8 %) of a mixture of polysulfides, fractionation of which gave 21.4 g (26.8 %) of bis(2-fluorosulfonyloxytetrafluoroethyl) trisulfide (**6a**), n_D^{20} = 1.4037.

The reaction of SCl_2, HSO_3F, and perfluorinated methyl vinyl ether under similar conditions afforded a mixture of 17.5% 2-trifluoromethoxy-2-fluorosulfonyloxytrifluoroethylsulfenyl chloride (**5**), n_D^{20} = 1.3610, 32.5 % bis(2-trifluoromethoxy-2-fluorosulfonyloxytrifluoroethyl) trisulfide (**7a**), n_D^{20} = 1.3845, and 44.6 % polysulfides **7**.

Fluorocarbonyldifluoromethylsulfenyl chloride (8). A mixture of sulfenyl chloride **4** (9.3 g, 35 mmol) or sulfenyl chloride **5** (11.6 g, 35 mmol) and potassium fluoride (5.0 g, 86 mmol) was heated, stirred for 30 min at 100—110 °C, and fractionated.

Bis(2-fluorocarbonyldifluoromethyl) trisulfide (**9**) was obtained from trisulfides **6a** and **7a** in a similar way.

Methoxycarbonyldifluoromethylsulfenyl chloride (3). a. Methanol (1.0 g, 31 mmol) was added dropwise with stirring and cooling (−10 to 0 °C) to sulfenyl chloride **8** (5.2 g, 32 mmol). The mixture was kept for 1 h at 0 °C and heated to 20 °C; 5 h later, it was fractionated, n_D^{20} = 1.4267.

b. Methanol (4.8 g, 150 mmol) was added dropwise with stirring and cooling (−10 to 0 °C) to trisulfide **9** (29.0 g, 100 mmol). The mixture was heated to 20 °C, kept at this temperature for 24 h, and fractionated to give 24.2 g (77 %) of bis(2-methoxycarbonyldifluoromethyl) trisulfide **10**, n_D^{20} = 1.4748; this compound was placed into a glass tube in which a twofold molar excess of chlorine was condensed. The tube was sealed, maintained for 5 h at 90—95 °C, cooled and opened, and the contents were fractionated.

Methoxycarbonyldifluoromethyl 2-chlorocyclopentlyl sulfide (11). Cyclopentene (0.34 g, 5.0 mmol) was added with stirring and cooling (−30 °C) to sulfenyl chloride **3** (0.8 g, 4.5 mmol). The mixture was maintained at this temperature until its color disappeared (30 min), heated to 20 °C, and fractionated, n_D^{20} = 1.4718.

The following compounds were prepared by a similar procedure: **methoxycarbonyldifluoromethyl 2-chlorocyclohexyl sulfide (12)**, reaction temperature 0 °C, reaction duration, 1 h, n_D^{20} = 1.4787; **α-methoxycarbonyltetrafluoroethyl 2-chlorocyclopentlyl sulfide (13)**, 20 °C, 5 h, n_D^{20} = 1.4430; **α-methoxycarbonyltetrafluoroethyl 2-chlorocyclohexyl sulfide (14)**, 20 °C, 8 h, n_D^{20} = 1.4537.

4-(α-Methoxycarbonyltetrafluoroethylthio)-6-oxatricyclo[3.2.1.1^{3,8}]nonan-7-one (15). A solution of bicyclo[2.2.1]hept-5-en-2-carboxylic acid (1.4 g, 10 mmol) in 2 mL of ether was added with cooling and stirring (−20 to −10 °C) to sulfenyl chloride **2** (2.3 g, 10 mmol) in 2 mL of ether. The mixture was kept at this temperature until the reaction was completed (20 h), and the precipitate that formed was

Table 1. Yields, properties, spectral characteristics, and elemental analysis data for compounds **2**—**41**

Compound	Yield (%)	B.p./°C (p/Torr) [M.p./°C]	Found/Calculated (%)			Molecular formula	^{19}F NMR (δ, J/Hz)*	^1H NMR (δ, J/Hz)*
			C	H	F			
2	84	141—143	21.44 21.19	1.35 1.32	33.40 33.55	$C_4H_3ClF_4O_2S$	−4.5 (d, 3 F, CF_3, J = 11); 74.1 (q, 1 F, CF, J = 11)	4.2 (s, Me)
3	76	137—139	20.49 20.40	1.73 1.70	21.41 21.53	$C_3H_3ClF_2O_2S$	7.21 (s, CF_2)	4.0 (s, Me)
4	20	108—110	9.28 9.01	—	35.51 35.65	$C_2ClF_5O_3S_2$	−128.8 (t, 1 F, SO_3F, J = 7.5); 5.5 (m, 2 F, CF_2O); 18.7 (m, 2 F, CF_2S)	—
5	18	124—125	10.73 10.82	—	39.52 40.00	$C_3ClF_7O_4S_2$	−128.0 (m, 1 F, SO_3F); −23.8 (m, 3 F, CF_3O); 15.1 (m, 2 F, CF_2S); 16.3 (m, 1 F, CFO)	—
6a	27	89—91 (3)	9.81 9.72	—	38.17 38.46	$C_4F_{10}O_6S_5$	−128.5 (m, 1 F, SO_3F); 5.5 (m, 2 F, CF_2O); 18.6 (m, 2 F, CF_2S)	—
7a	33	80—82 (1)	11.27 11.50	—	42.31 42.49	$C_6F_{14}O_8S_5$	−128.4 (m, 1 F, SO_3F); −23.8 (m, 3 F, CF_3O); 15.1 (m, 2 F, CF_2S); 16.3 (m, 1 F, CFO)	—
8	68	52—54	—	—	—	C_2ClF_3OS	−96.5 (t, 1 F, C(O)F, J = 6); 10.9 (d, 2 F, CF_2, J = 6)	—
9	72	75—76 (40)	—	—	—	$C_4F_6O_2S_3$	−93.8 (t, 1 F, C(O)F, J = 6); 10.9 (d, 2 F, CF_2, J = 6)	—
10	74	114—115 (1)	22.99 22.93	1.95 1.91	24.11 24.20	$C_6H_6F_4O_4S_3$	8.2 (s, CF_2)	4.0 (s, Me)
11	86	85—86 (1)	39.42 39.26	4.55 4.50	15.27 15.54	$C_8H_{11}ClF_2O_2S$	2.74 and 3.71 (CF_2, AB system, J = 219)	1.60—2.60 (m, 6 H, $3CH_2$); 3.82 (m, 1 H, CHS); 3.95 (s, 3 H, Me); 4.36 (m, 1 H, CHCl)
12	78	98—99 (1)	41.62 41.78	5.07 5.03	14.41 14.70	$C_9H_{13}ClF_2O_2S$	3.23 and 3.69 (CF_2, AB system, J = 219)	1.35—2.50 (m, 8 H, 4 CH_2); 3.56 (m, 1 H, CHS); 3.93 (s, 3 H, Me); 4.14 (m, 1 H, CHCl)
13	74	88—89 (1)	36.71 36.67	3.72 3.74	25.98 25.81	$C_9H_{11}ClF_4O_2S$	−3.2 and −3.0 (d, 3 F, CF_3, J = 12); 68.2 and 70.7 (q, 1 F, CF, J = 12), 1 : 1 ratio	1.60—2.10 (m, 4 H); 2.30 (m, 1 H); 2.57 (m, 1 H); 3.68 (m, 1 H, CHS); 3.80 (d, 3 H, Me, J = 2.5); 4.28 and 4.45 (m, 1 H, CHCl, 1 : 1 ratio)
14	81	101—102 (1)	39.07 38.90	4.20 4.21	24.55 24.64	$C_{10}H_{13}ClF_4O_2S$	−3.1 and −3.0 (d, 3 F, CF_3, J = 12); 68.5 and 69.8 (q, 1 F, CF, J = 12), 1 : 1 ratio	1.30—2.50 (m, 8 H, 4 CH_2); 3.55 (m, 1 H, CHS); 3.80 (d, 3 H, Me, J = 2.0); 4.20 (m, 1 H, CHCl)
15	80	[80—81]	43.95 43.90	3.65 3.66	23.07 23.17	$C_{12}H_{12}F_4O_4S$	−2.99 and −2.98 (d, 3 F, CF_3, J = 11.8); 70.5 and 70.6 (q, 1 F, CF, J = 11.8), 1 : 1 ratio	1.68—2.21 (m, 4 H); 2.56 (m, 2 H); 3.12 (s, 1 H); 3.27 (m, 1 H); 3.97 (d, 3 H, Me, J = 1); 4.65 and 4.80 (d, 1 H, CHO, J = 5.0)

(to be continued)

Table 1 (*continued*)

Compound	Yield (%)	B.p./°C (*p*/Torr) [M.p./°C]	Found/Calculated (%)			Molecular formula	^{19}F NMR (δ, *J*/Hz)*	^{1}H NMR (δ, *J*/Hz)*
			C	H	F			
16	68	[48—50]	43.56 43.52	3.60 3.63	19.47 19.69	$C_{14}H_{14}F_4O_6S$	−3.0 and 2.95 (d, 3 F, CF_3, *J* = 11.5); 68.0 and 69.9 (q, 1 F, CF, *J* = 11.5), 3 : 1 ratio	1.75 (m, 1 H); 2.08 (m, 1 H); 2.85 (m, 2 H); 3.15 (m, 1 H); 3.36 (m, 1 H); 3.76 and 3.77 (s, 3 H, Me, 1:3 ratio); 3.92 (m, 1 H); 4.02 and 4.05 (s, 3 H, Me, 3 : 1 ratio); 4.75 (m, 1 H, CHO)
17	79	86—87 (2)	40.11 40.00	4.41 4.44	13.95 14.07	$C_9H_{12}F_2O_5S$	7.8 (s, CF_2)	1.39 (t, 3 H, Me, *J* = 7); 2.40 (s, 3 H, Me); 3.90 (s, 3 H, Me); 4.27 (q, 2 H, CH_2, *J* = 7); 14.18 (s, 1 H, OH)
18	66	129—131 (1)	50.86 50.77	3.79 3.85	14.38 14.62	$C_{11}H_{10}F_2O_3S$	5.4 (s, CF_2)	3.94 (s, 3 H, Me); 4.52 (s, 2 H, CH_2); 7.53—7.98 (m, 5 H, Ph)
19	81	72—73 (1)	37.63 37.50	3.78 3.75	23.52 23.75	$C_{10}H_{12}F_4O_5S$	−3.8 (d, 3 F, CF_3, *J* = 11.2); 73.2 (q, 1 F, CF, *J* = 11.2)	1.38 (t, 3 H, Me, *J* = 7); 2.40 (s, 3 H, Me); 3.87 (s, 3 H, Me); 4.28 (q, 2 H, CH_2, *J* = 7); 14.20 (s, 1 H, OH)
20	77	109—110 (12)	37.42 37.24	3.38 3.44	26.05 26.21	$C_9H_{10}F_4O_4S$	−3.9 (d, 3 F, CF_3, *J* = 11.7); 71.4 (q, 1 F, CF, *J* = 11.7)	2.35 (s, 6 H, 2Me); 3.80 (s, 3 H, Me); 17.00 (s, 1 H, OH)
21	60	117—119 (15)	33.95 33.87	3.20 3.23	30.44 30.65	$C_7H_8F_4O_3S$	−3.7 (d, 3 F, CF_3, *J* = 12); 70.2 (q, 1 F, CF, *J* = 12)	1.61 (s, 3 H, Me); 2.80 (s, 2 H, CH_2); 3.83 (s, 3 H, Me)
22	73	[54—55]	46.49 46.45	3.22 3.23	24.45 24.52	$C_{12}H_{10}F_4O_3S$	−3.6 (d, 3 F, CF_3, *J* = 12); 71.0 (q, 1 F, CF, *J* = 12)	3.85 (s, 3 H, Me); 4.50 (s, 2 H, CH_2); 7.55—7.85 (m, 5 H, Ph)
23	65	114—115 (1)	41.78 41.67	4.20 4.17	26.45 26.39	$C_{10}H_{12}F_4O_3S$	−5.01 and −4.99 (d, 3 F, CF_3, *J* = 12); 73.0 and 74.2 (q, 1 F, CF, *J* = 12), 2 : 1 ratio	1.70—2.10 (m, 5 H); 2.40 (m, 2 H); 2.70 (m, 1 H); 3.93 and 3.95 (s, 3 H, Me, 1 : 2 ratio); 4.00 (m, 1 H, CHS)
24	37	82—83 (1)	35.46 35.29	3.01 2.94	33.28 33.53	$C_{10}H_{10}F_6O_4S$	−12.7 (s, 2 CF_3)	2.32 (s, 6 H, 2Me); 3.85 (s, 3 H, Me); 17.20 (s, 1 H, OH)
25	51	[95—96]	49.54 49.66	6.15 6.21	—	$C_{12}H_{18}O_6S$	—	1.35 (m, 3 H, Me); 2.40 (m, 3 H, Me); 4.20 (m, 2 H, CH_2); 13.45 and 13.75 (s, OH)
26	71	[57—58]	50.43 50.57	4.99 4.98	14.32 14.56	$C_{11}H_{13}F_2NO_2S$	6.5 (s, CF_2)	3.02 (s, 6 H, 2Me); 3.70 (s, 3 H, Me); 6.41 (d, 2 H, *J* = 9.4); 7.30 (d, 2 H, *J* = 9.4)
27	69	[43—44]	46.42 46.30	4.22 4.18	24.18 24.44	$C_{12}H_{13}F_4NO_2S$	−3.7 (d, 3 F, CF_3, *J* = 12); 68.1 (q, 1 F, CF, *J* = 12)	3.00 (s, 6 H, 2Me); 3.66 (s, 3 H, Me); 6.23 (d, 2 H, *J* = 9.3); 7.34 (d, 2 H, *J* = 9.3)
28	54	[66—67]	43.32 43.21	3.62 3.60	31.65 31.58	$C_{13}H_{13}F_6NO_2S$	−13.2 (s, 2 CF_3)	2.95 (s, 6 H, 2Me); 3.39 (s, 3 H, Me); 6.50 (d, 2 H, *J* = 9.8); 7.34 (d, 2 H, *J* = 9.8)

(to be continued)

Table 1 (*continued*)

Compound	Yield (%)	B.p./°C (*p*/Torr) [M.p./°C]	Found / Calculated (%)			Molecular formula	^{19}F NMR (δ, *J*/Hz)*	^{1}H NMR (δ, *J*/Hz)*
			C	H	F			
29	50	[36–37]	46.32 46.27	4.38 4.37	29.39 29.30	$C_{15}H_{17}F_6NO_2S$	−13.2 (s, 2 CF_3)	1.18 (t, 6 H, 2 Me, *J* = 7.3); 3.32 (q, 4 H, 2 CH_2, *J* = 7.3); 3.46 (s, 3 H, Me); 6.50 (d, 2 H, *J* = 9.7); 7.35 (d, 2 H, *J* = 9.7)
30	68	92–94 (1)	43.44 43.21	3.63 3.60	31.27 31.58	$C_{13}H_{13}F_6NO_2S$	−14.7 and −13.3 (q, 2 CF_3, *J* = 11)	1.25 (t, 3 H, Me, *J* = 7); 3.30 (s, 3 H, Me); 4.01 (q, 2 H, CH_2, *J* = 7); 7.23 (m, 5 H, Ph)
31	75	82–83 (1)	43.32 43.44	4.05 4.07	17.02 17.19	$C_8H_9F_2NO_2S$	6.7 (s, CF_2)	3.70 (s, 3 H, Me); 3.73 (s, 3 H, Me); 6.24 (m, 1 H); 6.63 (m, 1 H); 7.09 (m, 1 H)
32	88	85–86 (1)	40.02 39.85	3.37 3.32	27.89 28.04	$C_9H_9F_4NO_2S$	−3.5 (d, 3 F, CF_3, *J* = 11.5); 68.6 (q, 1 F, CF, *J* = 11.5)	3.72 (s, 3 H, Me); 3.74 (s, 3 H, Me); 6.23 (m, 1 H); 6.65 (m, 1 H); 7.10 (m, 1 H)
33	44	89–91 (1)	37.51 37.38	2.89 2.80	35.25 35.51	$C_{10}H_9F_6NO_2S$	−12.9 (s, 2 CF_3)	3.56 (s, 3 H, Me); 3.74 (s, 3 H, Me); 6.23 (m, 1 H); 6.65 (m, 1 H); 7.10 (m, 1 H)
34	52	[74–75]	51.49 51.36	3.42 3.50	14.56 14.79	$C_{11}H_9F_2NO_2S$	6.2 (s, CF_2)	3.60 (s, 3 H, Me); 7.25 (m, 2 H); 7.55 (m, 1 H); 7.70 (m, 1 H); 7.75 (m, 1 H); 11.20 (br.s, 1 H, NH)
35	64	[100–101]	47.12 46.91	2.98 2.93	24.63 24.75	$C_{12}H_9F_4NO_2S$	−3.8 (d, 3 F, CF_3, *J* = 11); 67.7 (q, 1 F, CF, *J* = 11)	3.52 (s, 3 H, Me); 7.26 (m, 2 H); 7.53 (m, 1 H); 7.68 (m, 1 H); 7.76 (d, 1 H, *J* = 2.8); 11.20 (br.s, 1 H, NH)
36	57	[114–116]	43.79 43.70	2.50 2.52	31.85 31.93	$C_{13}H_9F_6NO_2S$	−13.3 (s, 2 CF_3)	3.30 (s, 3 H, Me); 7.26 (m, 2 H); 7.57 (m, 1 H); 7.71 (m, 1 H); 7.80 (d, 1 H, *J* = 2.8); 11.25 (br.s, 1 H, NH)
37	78	[111–112]	53.19 53.14	4.04 4.06	13.88 14.02	$C_{12}H_{11}F_2NO_2S$	6.2 (s, CF_2)	2.27 (s, 3 H, Me); 3.76 (s, 3 H, Me); 7.30–7.64 (m, 4 H); 10.00 (br.s, 1 H, NH)
38	73	[143–144]	51.34 51.22	4.23 4.27	11.27 11.58	$C_{14}H_{14}F_2N_2O_3S$	6.5 (s, CF_2)	2.40 (s, 3 H, Me); 3.35 (s, 3 H, Me); 3.70 (s, 3 H, Me); 7.45–7.58 (m, 5 H, Ph)
39	81	[106–108]	47.81 47.62	3.67 3.70	19.96 20.11	$C_{15}H_{14}F_4N_2O_3S$	−3.6 (d, 3 F, CF_3, *J* = 12); 71.0 (q, 1 F, CF, *J* = 12)	2.44 (s, 3 H, Me); 3.38 (s, 3 H, Me); 3.77 (s, 3 H, Me); 7.45 (m, 5 H, Ph)
40	72	[107–108]	44.92 44.86	3.29 3.27	26.41 26.64	$C_{16}H_{14}F_6N_2O_3S$	−13.4 (s, 2 CF_3)	2.35 (s, 3 H, Me); 3.30 (s, 3 H, Me); 3.82 (s, 3 H, Me); 7.40–7.61 (m, 5 H, Ph)
41	77	95–96 (1)	37.75 37.50	2.61 2.68	16.58 16.96	$C_7H_6F_2O_2S_2$	6.6 (s, CF_2)	3.89 (s, 3 H, Me); 7.22 (dd, 1 H, *J* = 5.5 and 3.7); 7.47 (dd, 1 H, *J* = 3.7 and 7.83 (dd, 1 H, *J* = 5.5 and 1.4)

* Solvents: $CDCl_3$ for **2**, **3**, **8**, **9**, and **11–25**; CD_3CN for **4–7**, **10**, **30–33**, **37–41**; and acetone-d_6 for **26–29** and **34–36**.

separated and washed with hexane. IR: 1720 (C=O), 1750 (C=O).

2-Methoxycarbonyl-4-(α-methoxycarbonyltetrafluoroethylthio)-6-oxatricyclo[3.2.1.1^{3,8}]nonan-7-one (**16**) was prepared in a similar way except that the mixture was kept at −20 to −10 °C for 10 days. IR: 1785 (C=O), 1750 (C=O), 1730 (C=O).

Ethyl 2-(methoxycarbonyldifluoromethylthio)acetoacetate (17). Ethyl acetoacetate (1.3 g, 10 mmol) was added with stirring and cooling (−10 to 0 °C) to sulfenyl chloride **3** (1.8 g, 10 mmol). The mixture was heated to 20 °C, kept until the evolution of HCl ceased (5 h), and fractionated. IR: 3000 (OH), 1765 (C=O), 1600 (C=C), n_D^{20} = 1.4700.

The following compounds were obtained by a similar procedure: **methoxycarbonyldifluoromethylthioacetophenone (18)**, reaction duration 20 h, IR: 1760 (C=O), 1700 (C=O), R_f = 0.53 (10 : 1), n_D^{20} = 1.5295; **ethyl 2-(α-methoxycarbonyltetrafluoroethylthio)acetoacetate (19)**, reaction duration 40 h, IR: 3000 (OH), 1760 (C=O), 1600 (C=C), n_D^{20} = 1.4445; **3-(α-methoxycarbonyltetrafluoroethylthio)-2,4-pentanedione (20)**, reaction duration 40 h, IR: 3000 (OH), 1770 (C=O), 1595 (C=C), n_D^{20} = 1.4465; **(α-methoxycarbonyltetrafluoroethylthio)acetone (21)**, reaction duration 100 h, n_D^{20} = 1.4228; **(α-methoxycarbonyltetrafluoroethylthio)acetophenone (22)**, reaction duration 100 h,, R_f = 0.59 (10 : 1); **2-(α-methoxycarbonyltetrafluoroethylthio)cyclohexan-1-one (23)**, reaction duration 150 h, n_D^{20} = 1.4508.

3-(α-Methoxycarbonylhexafluoroisopropylthio)pentane-2,4-dione (24). A solution of sulfenyl chloride **1** (2.8 g, 10 mmol) and acetylacetone (1.0 g, 10 mmol) in 15 mL of acetonitrile was boiled until the evolution of HCl was completed (15 h) and fractionated. IR: 3000 (OH), 1775 (C=O), 1600 (C=C), n_D^{20} = 1.4580.

Bis(ethoxycarbonylacetylmethyl) sulfide (25). Sulfenyl chloride **1** (5.5 g, 20 mmol) was added with stirring and cooling (−30 °C) to a suspension of sodium ethyl acetoacetate (3.0 g, 20 mmol) in 20 mL of ether. The mixture was slowly heated to 20 °C and stirred for 1 h, the precipitate was filtered off and fractionated, and the resulting oil (b.p. 100—110 °C at 1 Torr) was recrystallized from hexane.

***N,N*-Dimethyl-4-(methoxycarbonylthio)aniline (26).** At 0—5 °C, a solution of sulfenyl chloride **3** (1.8 g, 10 mmol) in 5 mL of chloroform was added dropwise with stirring to *N,N*-dimethylaniline (2.4 g, 20 mmol) in 20 mL of chloroform. The mixture was heated to 20 °C, kept for 24 h, and washed with water (3×50 mL). The organic layer was separated and dried with $MgSO_4$, the solvent was evaporated *in vacuo*, and the residue was crystallized from pentane, R_f = 0.63 (10 : 1).

The following compounds were obtained by a similar procedure: ***N,N*-dimethyl-4-(α-methoxycarbonyltetrafluoroethylthio)aniline (27)**, R_f = 0.64 (10 : 1); ***N,N*-dimethyl-4-(α-methoxycarbonylhexafluoroisopropylthio)aniline (28)**, R_f = 0.55 (5 : 1); and ***N,N*-diethyl-4-(α-methoxycarbonylhexafluoroisopropylthio)aniline (29)**, R_f = 0.59 (5 : 1).

***N*-(α-Methoxycarbonylhexafluoroisopropylthio)-*N*-ethylaniline (30).** At 0 °C, a solution of sulfenyl chloride **1** (2.7 g, 10 mmol) in 10 mL of ether was added dropwise with stirring to a solution of *N*-ethylaniline (2.4 g, 20 mmol) in 30 mL of ether. The mixture was heated to 20 °C and stirred for 2 h, the precipitate was filtered off, and the residue was fractionated, n_D^{20} = 1.4670.

1-Methyl-2-(methoxycarbonyldifluoromethylthio)pyrrole (31). At 10 °C, a solution of sulfenyl chloride **3** (1.8 g, 10 mmol) in 10 mL of chloroform was added dropwise with stirring to *N*-methylpyrrole (0.8 g, 10 mmol) and pyridine (0.8 g, 10 mmol) in 10 mL of chloroform. The mixture was kept for 5 h at 20 °C and washed with 5% HCl and with water (2×50 mL). The organic layer was separated, dried with $MgSO_4$, and fractionated, R_f = 0.73 (10 : 1), n_D^{20} = 1.4575.

Other substituted *N*-methylpyrroles were prepared in a similar way except that the mixture was boiled for 2 or 3 h: **1-methyl-2-(α-methoxycarbonyltetrafluoroethylthio)pyrrole (32)**, R_f = 0.71 (10 : 1), n_D^{20} = 1.4595; and **1-methyl-2-(α-methoxycarbonylhexafluoroisopropylthio)pyrrole (33)**, R_f = 0.70 (10 : 1), n_D^{20} = 1.4550.

3-(Methoxycarbonyldifluoromethylthio)indole (34). At 5—10 °C, sulfenyl chloride **3** (1.8 g, 10 mmol) was added dropwise with stirring to a solution of indole (1.2 g, 10 mmol) in 10 mL of benzene; formation of a precipitate was observed. The mixture was slowly heated to 20 °C, maintained at this temperature for 1 h, and boiled until the evolution of HCl was completed (5 h). The solvent was removed *in vacuo*, and the residue was crystallized from hexane, R_f = 0.29 (10 : 1).

3-(α-Methoxycarbonyltetrafluoroethylthio)indole (35), R_f = 0.36 (10 : 1); **3-(α-methoxycarbonylhexafluoroisopropylthio)indole (36)**, R_f = 0.47 (10 : 1); and **2-methyl-3-methoxycarbonyldifluoromethylthio)indole (37)**, R_f = 0.32 (10 : 1) were prepared in a similar way.

2,3-Dimethyl-4-(methoxycarbonyldifluoromethylthio)-1-phenylpyrazol-5-one (38). At 0—5 °C, sulfenyl chloride **3** (1.8 g, 10 mmol) was added dropwise with stirring to a solution of 2,3-dimethyl-1-phenylpyrazol-5-one (1.9 g, 10 mmol) in 15 mL of chloroform. The mixture was heated to 20 °C, kept for 3 h, and boiled until the evolution of HCl was completed (5 h). The solvent was evaporated *in vacuo*, and the residue was crystallized from hexane, R_f = 0.42 (10 : 1).

2,3-Dimethyl-4-(α-methoxycarbonyltetrafluoroethylthio)-1-phenylpyrazol-5-one (39), R_f = 0.13 (4 : 1); and **2,3-dimethyl-4-(α-methoxycarbonylhexafluoroisopropylthio)-1-phenylpyrazol-5-one (40)**, R_f = 0.35 (3 : 1) were prepared in a similar way.

2-(Methoxycarbonyldifluoromethylthio)thiophene (41). At −50 °C, 3 drops of $SnCl_4$ were added with stirring to a solution of sulfenyl chloride **3** (1.8 g, 10 mmol) and thiophene (0.9 g, 11 mmol) in 10 mL of chloroform. The mixture was slowly (over a period of 5 h) heated to 20 °C, kept until the evolution of HCl was completed (15 h), washed with 5% hydrochloric acid (2×50 mL) and with water (2×50 mL), dried with $MgSO_4$, and fractionated, R_f = 0.69 (10 : 1), n_D^{20} = 1.5105.

References

1. A. Yu. Sizov, A. F. Kolomiets, and A. V. Fokin, *Usp. Khim.*, 1992, **61**, 940 [*Russ. Chem. Rev.*, 1992, **61** (Engl. Transl.)].
2. I. V. Koval', *Usp. Khim.*, 1995, **64**, 781 [*Russ. Chem. Rev.*, 1995, **64** (Engl. Transl.)].
3. Yu. V. Zeifman, L. T. Lantseva, and I. L. Knunyants, *Izv. Akad. Nauk SSSR, Ser. Khim.*, 1978, 2640 [*Bull. Acad. Sci. USSR, Div. Chem. Sci.*, 1978, **27**, 2362 (Engl. Transl.)].
4. A. Yu. Sizov, A. F. Kolomiets, and A. V. Fokin, *Izv. Akad. Nauk SSSR, Ser. Khim.*, 1988, 1186 [*Bull. Acad. Sci. USSR, Div. Chem. Sci.*, 1988, **37**, 1045 (Engl. Transl.)].
5. A. Yu. Sizov, V. V. Linev, N. V. Kondrashov, A. F. Kolomiets, and A. V. Fokin, *Izv. Akad. Nauk SSSR, Ser. Khim.*, 1990, 150 [*Bull. Acad. Sci. USSR, Div. Chem. Sci.*, 1990, **39**, 435 (Engl. Transl.)].
6. A. Yu. Sizov, A. F. Kolomiets, and A. V. Fokin, *Izv. Akad. Nauk SSSR, Ser. Khim*, 1991, 1619 [*Bull. Acad. Sci. USSR, Div. Chem. Sci.*, 1991, **40**, 1435 (Engl. Transl.)].
7. A. V. Fokin, A. I. Rapkin, V. I. Matveenko, and O. V. Verenikin, *Izv. Akad. Nauk SSSR, Ser. Khim.*, 1988, 2367 [*Bull. Acad. Sci. USSR, Div. Chem. Sci.*, 1988, **37**, 2132 (Engl. Transl.)].

Received December 29, 1995