Journal of Fluorine Chemistry, *28* (1985) 219–227

Received: October 1, 1984; accepted: November 30, 1984

ON THE REACTIONS OF DIMETHYLSULFOXIDE WITH ACYL FLUORIDES - PUMMERER REARRANGEMENTS AND FORMATION OF MONOFLUOROMETHYL ESTERS

HORST G. LANGE AND JEAN'NE M. SHREEVE*

Department of Chemistry, University of Idaho, Moscow, ID 83843 (U.S.A.)

SUMMARY

In stoichiometry-dependent reactions, dimethylsulfoxide (DMSO) reacts with acyl fluorides, $R_fC(O)F$ (R_f = F, CF_3), to yield CH_3SCH_2F and $R_fC(O)OCH_2F$, while CH_3SCH_2Cl and $FC(O)OCH_2Cl$ are obtained with COClF. Oxalyl difluoride, $C_2O_2F_2$, reacts with DMSO to give CH_3SCH_2F and FCH_2OCH_2F.

INTRODUCTION

Dimethylsulfoxide (DMSO) reacts with acyl chlorides [1] and other chlorinated Lewis acids, such as $SiCl_4$, BCl_3 [2], $COCl_2$ and PCl_5 [3], to yield CH_3SCH_2Cl as a result of the Pummerer rearrangement [4]. However, little is known about reactions of DMSO with fluorinated Lewis acids and no work has been done on reactions with acyl fluorides.

Boron trifluoride, WF_6 and SiF_4 are reported to yield complexes of DMSO [5-7]. The identification of $CH_2FS(O)H$ among the numerous degradation products of the controlled fluorination of DMSO with IF_5 [8] was doubted, since a reaction with SF_4 yielded FCH_2OCH_2F [7], whose spectra appear to be almost identical to those reported for the DMSO-IF_5 product. The ether, FCH_2OCH_2F, is also produced in low yield by the reaction of WF_6 with DMSO [7]. Although no mechanistic work has been done on the reactions of DMSO with Lewis acids, the identification of CH_2F-containing products may indicate a Pummerer rearrangement to be responsible for inducing the fluorination.

Due to the ever increasing interest in organofluorine chemistry, there is a strong demand for inexpensive, easy and selective ways to introduce fluorine into organic molecules. For that reason we investigated the reactions of DMSO

0022-1139/85/$3.30

with COF_2, $COClF$, $CF_3C(O)F$ and $C_2O_2F_2$ in an attempt to extend the applicability of the Pummerer rearrangement to the synthesis of monofluoromethylsulfides, i.e., the transformation of $RS(O)CH_3$ into $RSCH_2F$.

RESULTS AND DISCUSSION

When $COCl_2$ was reacted with DMSO, CH_3SCH_2Cl was formed [3]. Carbonyl chloride fluoride also gave only the latter sulfide with no trace of migration of fluorine. This is in keeping with greater mobility of chlorine. Reactions of COF_2, $CF_3C(O)F$ and $C_2O_2F_2$ with DMSO proceeded smoothly at 25°C without solvent to form CH_3SCH_2F as the Pummerer product. The fact that under the same conditions, DMSO is unreactive with $CH_3C(O)F$ or $C_6H_5C(O)F$ indicates that the presence of strong electrogenative substituents greatly facilitates the Pummerer rearrangement.

In a rather surprising reaction of diphenyl sulfoxide with $SiCl_4$, phenyl(p-chlorophenyl) sulfide was produced [2]. This appears to be a Pummerer-type reaction in spite of the absence of hydrogen in the position α to sulfur. Our attempts to react acyl fluorides with diphenylsulfoxide were not successful.

Although no by-product formation is reported from reactions of $COCl_2$ or other chlorinated Lewis acids with DMSO, we found that a variety of by-products did form in the reactions of acyl fluorides. In addition to the expected methyl(monohalogenomethyl) sulfides, monohalogenomethylesters of the corresponding fluorocarboxylic acids were identified as important by-products. However, in the reaction of DMSO with oxalyl difluoride, we observed only FCH_2OCH_2F instead of an oxalic acid monofluoromethylester (Table 1).

Reactant stoichiometry controls the products formed. For example, in the reaction of DMSO with COF_2 relatively good yields of CH_3SCH_2F (70%) or $FC(O)OCH_2F$ (38%) are obtained by using a deficiency or excess of COF_2, respectively. Notably, the stable $FC(O)OCH_2F$ combines the two very unstable molecules $FC(O)OH$ and CH_2FOH.

A similar behavior is noted for reactions between $CF_3C(O)F$ or $C_2O_2F_2$ and DMSO as recorded in Table 1 and in the experimental section. Moreover, the reactions of COF_2 or $C_2O_2F_2$ with DMSO also result in the formation of a more highly fluorinated sulfide, CH_3SCHF_2. It was impossible to increase the percentage yield of the latter or to form more highly fluorinated species, e.g., CH_3SCF_3, regardless of the stoichiometry used.

Table 1 Major products identified in the reactions of DMSO with acyl fluorides, $R_fC(O)F$

$R_fC(O)F \mid DMSO$ R_f	Stoichiometric Ratio	Product(s)* (Yield and Rel. Distribution)
Cl	1:2	CH_3SCH_2Cl (59.2%)**
Cl	1:1	$FC(O)OCH_2Cl$ (27.6%), CH_3SCH_2Cl, CH_3SSCH_3 (0.51:0.76:1)
Cl	2:1	$FC(O)OCH_2Cl$ (42.3%), CH_3SCH_2Cl
F	1:2	CH_3SCH_2F (70%), CH_3SSCH_3 (tr.)
F	1:1	$FC(O)OCH_2F$ (17.4%), CH_3SCH_2F, CH_3SCHF_2 (1:0.17:0.05)
F	2:1	$FC(O)OCH_2F$ (38.4%), FCH_2OCH_2F, CH_3SCHF_2, $CH_3SC(O)F$ (1:0.17:0.14:0.08)
CF_3	1:2	CH_3SCH_2F, $CF_3C(O)OCH_2F$ (0.86:1)
CF_3	1:1	$CF_3C(O)OCH_2F$ (16.3%), CH_3SSCH_3 (1:0.41)
CF_3	2:1	$CF_3C(O)OCH_2F$ (34.0%)
FC(O)	1:2	CH_3SCH_2F (74.7%)
FC(O)	1:1	CH_3SCH_2F, FCH_2OCH_2F, CH_3SCHF_2 (1:0.67:0.13)
FC(O)	2:1	FCH_2OCH_2F, CH_3SCH_2F, CH_3SCHF_2, CH_3SSCH_3 (1:0.29:0.16:0.05)

* For trace products, see experimental section.

** Percentage yield for isolated compound; rel. distribution taken from ^1H, ^{19}F-NMR spectra before separation.

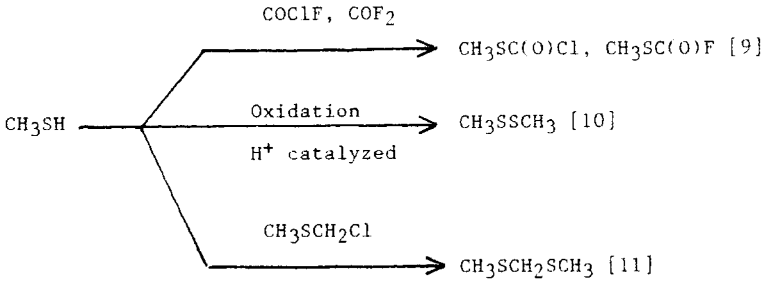
Although it is difficult to propose a reaction sequence from such a complicated set of reaction products, with the issue being further complicated by the low overall yields observed in several cases, some general remarks can be made. The following two reaction steps could easily explain the observed major products:

$$CH_3S(O)CH_3 + R_fC(O)F \longrightarrow CH_3SCH_2F + R_fC(O)OH \quad (1)$$

$$CH_3SCH_2F + R_fC(O)OH \longrightarrow CH_3SH + R_fC(O)OCH_2F \quad (2)$$

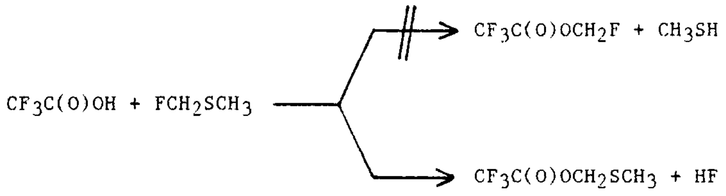
$$R_f = F,\ CF_3$$

Methanethiol may cause the formation of several by-products in a well-known manner:



However, CH_3SH was not detected regardless of the stoichiometric ratio DMSO/$R_fC(O)F$ employed. Due to the extreme instability of FC(O)OH, it is not possible to check the crucial step (2) by reacting this acid with CH_3SCH_2F. However, $CF_3C(O)OH$ reacted with CH_3SCH_2F to yield $CF_3C(O)OCH_2SCH_3$ and HF. An analogous reaction was observed with $(CF_3CO)_2O$.

No products formed by C-S cleavage were found. Thus CH_3SCH_2F shows the usual behavior of other halogenomethylsulfides, e.g. CH_3SCH_2Cl, reacting by heterolytic cleavage of the carbon-halogen bond:



$$(CF_3CO)_2O + FCH_2SCH_3 \longrightarrow CF_3C(O)OCH_2SCH_3 + CF_3C(O)F$$

These results do not allow a simple explanation of CH_2F-ester formation due to S-CH_2F cleavage by an acid or an acid anhydride. Presently the very surprising formation of monofluoromethylester in the reaction of COF_2 or $CF_3C(O)F$ is not fully understood.

Small amounts of FCH_2OCH_2F and $ClCH_2OCH_2Cl$ (see experimental section) which accompany the formation of halogenomethylesters may be due to the extreme sensitivity of these esters toward protolysis. The unstable alcohols FCH_2OH and $ClCH_2OH$, which result from acid-catalyzed ester cleavage, are known to undergo readily acid-catalyzed self-condensation to yield the corresponding ethers [12].

EXPERIMENTAL

General

Infrared spectra were recorded with a Perkin-Elmer 599B spectrometer using a 10 cm cell fitted with KBr windows. ^1H and ^{19}F NMR spectra were obtained on a Varian EM 360L NMR spectrometer. $CDCl_3$ was used as a solvent, CCl_3F and TMS were used as internal references. Chemical shifts upfield from the reference signal are assigned negative values. GC/MS and MS spectra were recorded with a VG 7070 HS mass spectrometer.

Materials

DMSO (Baker) was dried using activated molecular sieves (3 Å), and checked for any CH_3SCH_3 content by GC prior to its use. COF_2, COClF, CF_3COF (PCR) and $C_2O_2F_2$ (Hynes) were used as received. $(CF_3CO)_2O$ was prepared from $CF_3C(O)OH$ (Pfaltz and Bauer) using the literature method [13].

Experimental procedure

All reactions of DMSO with acyl fluorides were carried out at room temperature using stainless steel Hoke cylinders. No solvent was used. Reaction time 12 h, molar ratios DMSO/acyl fluoride 1:1 (gives usually mixtures of sulfide and ester), 2:1 (favors sulfide formation) and 1:2 (favors ester formation).

The calculated amount of $R_fC(O)F$ (R_f = Cl, F, CF_3, COF) was condensed onto 3 mL (3.29 g ≅ 42 mmol) DMSO. For DMSO/$R_fC(O)F$ ≅ 2:1, 6 mL (~82 mmol) DMSO was used. After warming up to room temperature, the reaction mixture was shaken for 12 h. Using standard vacuum line techniques, partial product separation was achieved by passing the volatiles through traps maintained at -40°, -60°, -78° and -196°C. CH_3SCH_2F stops at -60°C. $FC(O)OCH_2F$, $CF_3C(O)OCH_2F$ and $FC(O)OCH_2Cl$ were collected at -78°C and purified by repeated low temperature fractionation. After separation the purity of CH_3SCH_2F and the esters was established by ^1H and ^{19}F NMR spectroscopy. The esters are colorless, mobile, extremely moisture sensitive liquids which are readily volatile at room temperature. They decompose slowly on standing in glass vessels at room temperature but are conveniently stored at -78°C. All products have been identified using ^1H and/or ^{19}F NMR, IR and GC/MS spectroscopy. The spectroscopic data for the new esters are given below. The spectral properties of the other compounds agree with those already published. Yields of the esters are based on DMSO consumed. Yields of CH_3SCH_2X are based on $R_fC(O)F$. Relative product distribution of fluorinated compounds is given in brackets [ ].

Reactions of DMSO with COClF (stoichiometric ratio)

a) DMSO/COClF ≅ 1:1

Approximately 2.0 g of a colorless liquid was collected in the trap at -78°C. ^{1}H and ^{19}F NMR and GC/MS spectra showed that it consisted mainly of $FC(O)OCH_2Cl$, CH_3SCH_2Cl and CH_3SSCH_3 [rel. distribution 0.51:0.76:1] together with minor amounts of $ClCH_2OCH_2Cl$, $CH_3SC(O)Cl$, $CH_3SC(O)F$, $CH_3SCH_2SCH_3$ and CH_3SCH_3. Repeated low temperature fractionation gave 1.3 g of $FC(O)OCH_2Cl$ (27.6% yield). No fluorine containing sulfide was detected.

b) DMSO/COClF ≅ 2:1

2.4 g CH_3SCH_2Cl (≅ 59.2% yield) was obtained in the trap at -40°C.

c) DMSO/COClF ≅ 1:2

2.5 g $FC(O)OCH_2Cl$ was collected in the trap at -78°C. ^{1}H NMR spectra showed major impurities to be CH_3SSCH_3 and CH_3SCH_2Cl. Repeated low temperature fractionation gave 2.0 g of pure $FC(O)OCH_2Cl$ (42.3% yield).

d) Spectral data for $FC(O)OCH_2Cl$

^{19}F: $\phi(C(O)\underline{F})$ = -18.0 ppm (s); ^{1}H $\delta(O\underline{CH_2}Cl)$ = 5.80 ppm (s)

IR (gas, 20 torr): 3000 w, 2920 w, 1860 vs, 1450 w, 1350 m, 1270 s, 1230 vs, 1070 s, 1025 m, 905 m, 565 m, cm^{-1}.

MS (15 eV): M^+ 112 (0.44); M^+-CO 84 (2.62); M^+-Cl 77 (100); M^+-COF 65 (56.13); CH_2Cl^+ 49 (87.47); COF^+ 47 (63.80); correct $^{35/37}$Cl isotopic pattern.

Reaction of DMSO with COF_2 (stoichiometric ratio)

a) DMSO/COF_2 ≅ 1:1

A colorless liquid (1.7 g) was collected in the trap at -78°C. It consisted of $FC(O)OCH_2F$, CH_3SCH_2F and CH_3SCHF_2 [rel. distribution 1:0.17:0.05] as well as traces of $CH_3SC(O)F$. The traps at -60° and -40°C contained mainly CH_3SSCH_3 contaminated with small amounts of CH_3SCH_3. Repeated low temperature fractionation yielded 0.7 g pure $FC(O)OCH_2F$ (17.4% yield).

b) DMSO/COF_2 ≅ 2:1

Low temperature fractionation yielded 2.35 g CH_3SCH_2F (70% yield), which was collected in the trap at -60°C. Only minor amounts of CH_3SSCH_3 were identified in the trap at -40°C.

c) DMSO/COF_2 ≅ 1:2

A colorless liquid (2.31 g) was obtained in the trap at -78°C. It consisted of $FC(O)OCH_2F$, FCH_2OCH_2F, CH_3SCHF_2 and $CH_3SC(O)F$ [rel. distribution 1:0.17:0.14:0.08]. Repeated low temperature fractionation gave 1.55 g of pure $FC(O)OCH_2F$ (38.4% yield). The trap at -60°C contained CH_3SSCH_3 along with minor amounts of CH_3SCH_3.

d) Spectral data for $FC(O)OCH_2F$

^{19}F: $\phi(C(O)\underline{F}) = -19.1$ ppm (d); $\phi(OCH_2\underline{F}) = -159.7$ ppm (td)

^1H: $\delta(O\underline{CH}_2F) = 5.81$ ppm (d); ^2J (F,H) = 50 Hz, ^4J (F,F) = 4.1 Hz

IR (gas, 20 torr): 3000 m, 2940 w, 1860 vs, 1285 sh, 1250 vs, 1185 m, 1065 vs, 1030 s, 925 m, 785 m, 740 w, 605 m, cm^{-1}.

MS (15 eV): M^+ 96 (0.17); M^+-H 95 (5.61); M^+-F 77 (5.61); M^+-CH_2F 63 (2.81); M^+-CO_2 52 (0.17); CH_2FO^+ 49 (100); COF^+ 47 (33.23)

e) Spectral data for CH_3SCH_2F [13]

^{19}F: $\phi(CH_2\underline{F}) = -189.7$ ppm (tq)

^1H: $\delta(CH_3) = 2.20$ ppm (d); $^4J(F,H) = 2.0$ Hz

$\delta(\underline{CH}_2F) = 5.60$ ppm (d); $^2J(F,H) = 52$ Hz

MS (70 ev): M^+ 80 (100); M^+-H 79 (19.4); M^+-CH_3 65 (58.5); M^+-F 61 (7.2); M^+-H-HF 59 (16.60); correct ^{34}S isotopic pattern.

f) Spectral data for CH_3SCHF_2 [14]

^{19}F: $\phi(CH\underline{F}_2) = -97.3$ ppm (d)

^1H: $\delta(C\underline{H}F_2) = 6.78$ ppm (t); $^2J(F,H) = 57$ Hz

$\delta(\underline{CH}_3) = 2.30$ ppm (s)

MS: M^+ 98 (100); M^+-CH_3 83 (15.1); FCS^+ 63 (5.9); CHF_2^+ 51 (44.9); correct ^{34}S isotopic pattern.

Reaction of DMSO with CF_3COF (stoichiometric ratio)

a) DMSO/$CF_3COF \cong 1:1$

A colorless mixture (1.60 g) of $CF_3C(O)OCH_2F$ and CH_3SSCH_3 with traces of CH_3SCH_3 were obtained in the trap at -78°C. The distribution ester/disulfide was 1:0.41. Repeated low temperature fractionation gave 1.0 g of pure $CF_3C(O)OCH_2F$ (16.3% yield). Traps at -60°C and -40°C contained increasing amounts of CH_3SSCH_3 in addition to only small amounts of ester. No CH_3SCH_2F, CH_3SCHF_2 or FCH_2OCH_2F were identified.

b) DMSO/$CF_3COF \cong 2:1$

The contents of the trap at -78°C (2.4 g) showed CH_3SCH_2F in addition to considerable amounts of $CF_3C(O)OCH_2F$ (rel. distribution 0.86:1). Besides CH_3SCH_2F, small amounts of CH_3SSCH_3 and CH_3SCH_3 were identified in the trap maintained at -60°C.

c) DMSO/$CF_3COF \cong 1:2$

In the trap at -78°C, 2.6 g $CF_3C(O)OCH_2F$ (containing CH_3SSCH_3 as a slight impurity) was collected. Repeated low temperature fractionation gave 2.08 g of pure $CF_3C(O)OCH_2F$ (34% yield). No CH_3SCH_2F was identified.

d) Spectral data for $CF_3C(O)OCH_2F$

^{19}F: $\phi(\underline{CF_3}CO)$ = -76.7 ppm (s), $\phi(OCH_2\underline{F})$ = -161.0 ppm (t)

^{1}H: $(O\underline{CH_2}F)$ = 5.93 ppm (d); ^{2}J (F,H) = 50 Hz

IR (gas, 20 torr): 3000 mw, 2940 m, 1815 vs, 1350 m, 1245 vs, 1190 vs, 1125 vs, 1075 vs, 1015 vs, 830 w, 780 w, 740 w, cm^{-1}.

MS (CI): M^+ +H 147 (0.25); M^+-H 145 (0.25); M^+-OH 129 (2.64); M^+-F 127 (8.31); M^+-CHF 115 (5.37); M^+-COF 100 (9.60); M^+-HCOF 99 (100); CF_3CO^+ 97 (23.08); M^+-CF_3 77 (4.46); CF_3^+ 69 (57.34); $OCOF^+$ 63 (100).

Reaction of DMSO with $C_2O_2F_2$ (stoichiometric ratio)

a) DMSO/$C_2O_2F_2$ ≅ 1:1

A colorless liquid (2.2 g) was obtained in the trap at -78°C. It consisted o CH_3SCH_2F, FCH_2OCH_2F, CH_3SCHF_2 [rel. distribution 1:0.67:0.13], small amounts of CH_3SSCH_3 and traces of CH_3SCH_3 and $CH_3SC(O)F$.

b) DMSO/$C_2O_2F_2$ ≅ 2:1

Collected in the trap at -78°C was 2.9 g CH_3SCH_2F (slightly contaminated with CH_3SSCH_3 and CH_3SCH_3). Repeated low temperature fractionation gave 2.50 g of pure CH_3SCH_2F (74.7% yield).

c) DMSO/$C_2O_2F_2$ ≅ 1:2

In the trap at -78°C, 2.1 g of a mixture of FCH_2OCH_2F, CH_3SCH_2F, CH_3SCHF_2 and CH_3SSCH_3 [rel. distribution 1:0.29:0.16:0.05]. Traces of CH_3SCH_3 and $CH_3SC(O)F$ were identified as minor impurities. Traps at -60° and -40°C contained only CH_3SSCH_3.

Reaction of CH_3SCH_2F with CF_3COOH

Equimolar amounts of CH_3SCH_2F (0.8 g, ~10 mmol) and $CF_3C(O)OH$ were mixed and stirred for 20 min at 0°C. Slow distillation at 40°C/10^{-2} torr yields 1.65 g pure $CF_3C(O)OCH_2SCH_3$ as a colorless, moisture sensitive liquid (95% yield).

Reaction of CH_3SCH_2F with $(CF_3CO)_2O$

A mixture of 0.8 g CH_3SCH_2F (~10 mmol) and 2.31 g $(CF_3CO)_2O$ (~11 mmol) was stirred for 30 min at 0°C. $CF_3C(O)F$ was identified by comparing IR and ^{19}F NMR spectra with authentic material. $CF_3C(O)F$ and excess $(CF_3CO)_2O$ were removed at -20°C/10^{-2} torr affording a quantitative yield of $CF_3C(O)OCH_2SCH_3$.

Spectral data for $CF_3C(O)OCH_2SCH_3$

^{19}F: $\phi(\underline{CF_3}C(O)O)$ = -76.0 ppm (s)

^1H: $\delta(\underline{CH_3}S)$ = 2.30 ppm (s); $\delta(\underline{CH_2})$ = 5.40 ppm (s)

IR: (film, KBr plates): 3000 mw, 2940 w, 1790 vs, 1450 m, 1350 m, 1245 vs, 1180 vs, 1135 s, 1060 s, 730 m, 640 m, cm^{-1}.

MS (15 eV): M^+ 174 (68.54); $CF_3C(O)OCH_2^+$ 127 (4.81); $CF_3OCH_2^+$ 99 (22.83); CF_3^+ 69 (42.23); $CH_3SCH_2^+$ (80.33); $CH_2SCH_2^+$ 60 (100); shows correct $^{32/34}S$-isotopic pattern.

ACKNOWLEDGEMENT

H. G. L. is grateful to the Heinrich-Hertz-Stiftung des Landes Nordrhein-Westfalen/West-Germany. Acknowledgment is expressed to the donors of the Petroleum Research Fund, administered by the American Chemical Society and to the National Science Foundation (Grant CHE-8100156) for the support of this research. Dr. G. D. Knerr obtained the mass spectra.

REFERENCES

1 E.H. Amono-Neizer, S.K. Ray, R.A. Shaw and B.C. Smith, J. Chem. Soc. (1961), 3224.

2 M.F. Lappert and J.K. Smith, J. Chem. Soc. (1961), 3224.

3 J.R. Gauvreau, S. Poignant and G.J. Martin, Tetrahedron Lett., **21**, (1980), 1319.

4 E. Block, 'Reactions of Organosulfur Compounds', Academic Press, New York, 1978, pp. 154.

5 R.G. Laughlin, J. Org. Chem., **25**, (1960), 864.

6 V. Gutmann and K. Utvary, Monatsh., **90**, (1959), 706.

7 J.I. Darragh, A.M. Noble, D.W.A. Sharp and J.M. Winfield, J. Inorg. Nucl. Chem., **32**, (1970), 1745.

8 E.W. Lawless and G.J. Hennon, Tetrahedron Lett., **58**, (1968), 6075.

9 G.A. Olah, S.J. Kuhn and R.E.A. Dear, J. Am. Chem. Soc., **87**, (1965), 1317.

10 L. Field, in S. Oae (ed.), 'Organic Chemistry of Sulfur,' Plenum Press, New York, 1977, p. 303.

11 A. Schoeberl and A. Wagner in Houben-Weyl (ed.), 'Methoden der Organischen Chemie,' Georg Thieme, Stuttgart 1955, Vol. 'Schwefel-, Selen- und Tellur- Verbindungen,' p. 204.

12 G.A. Olah, S. Yu, G. Liang, G.D. Matseescu, M.R. Bruce, D.J. Donovan and M. Arvanaghi, J. Org. Chem., **46** (1981), 571.

13 R.K. Marat and A.F. Janzen, Can. J. Chem., **55**, (1977), 3031.

14 J. Hine and J.J. Porter, J. Am. Chem. Soc., **82**, (1960), 6118.