Reactions of Nitrogen Dioxide with Organic Halogen Compounds. I. Synthesis of Fluoro Aldehydrols and Fluoro Ketols from Fluoro Alcohols

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Long-chain fluoro aldehydrols, free of the corresponding fluorocarboxylic acids, can be prepared conveniently and in good yield by passing a mixture of a primary fluoro alcohol, nitric oxide, and air over an inert surface heated at 300–400°. In similar manner, oxidation of the secondary fluoro alcohol, 1H,3H,5H-octafluoro-3-pentanol (**13**), by nitrogen dioxide at 400° gives the corresponding fluoro ketone hydrate (**14**). 1H,9H-Hexadecafluoro-1,1-nonandiol (**3b**), a typical fluoro aldehydrol prepared by this method, reacts with conventional carbonyl reagents, such as sodium bisulfite, hydroxylamine hydrochloride, and semicarbazide hydrochloride, to yield unusually stable derivatives of the fluoro aldehyde. The aldehydrol (**3b**) reacts with 2 moles of benzonitrile in sulfuric acid to give 1H,9H-1,1-bis(benzamido)hexadecafluorononane (**12**). Action of fuming nitric acid on the fluoro aldoxime (**9**) derived from **3b** affords a bis(fluoroalkyl)furoxan (**10**) in 50% yield, a reaction which may involve intermediacy of a 1-nitroso-1-nitrofluoroalkane (**11**).

Nitrogen dioxide and its dimer, dinitrogen tetroxide,[1] are known to undergo a wide variety of reactions with organic compounds, giving products that might be classified as arising primarily by processes of addition, substitution, or oxidation. For example, the facile addition of dinitrogen tetroxide to olefins[2] and acetylenes[3] in solvents has been studied thoroughly and found to afford *vic*-dinitro alkanes, nitro nitrites, nitro nitrates, dinitro olefins, etc. Substitution reactions, exemplified by the nitration of aliphatic and aromatic hydrocarbons[4] and the nitrosation and nitration of amines and alcohols,[5] also have been examined by a number of workers. Oxidation of organic compounds by dinitrogen tetroxide has, however, received relatively scant attention[6] in spite of the fact that this type of reaction is probably the oldest of the three. Indeed, it was not until Levy and Scaife[2] found how to minimize the oxidation reactions of nitrogen dioxide that research on the chemistry of this compound began to advance significantly.

The work described in this and the following two papers was undertaken in view of the relative resistance toward oxidative degradation of organic compounds containing a high proportion of halogen. In particular, this paper reports the selective oxidation of several primary fluoro alcohols[7] and one secondary fluoro alcohol by nitrogen dioxide at high temperatures. Oxidation of primary fluoro alcohols with nitrogen dioxide at 300–400° in a hot tube has been found to be a convenient source of hydrated fluoro aldehydes, *i.e.*, fluoro aldehydrols.[8]

In 1955 Field and Grundy[9] reported that substituted benzyl alcohols are converted at 0–25° to the corresponding aldehydes in 91–98% yields by equimolar amounts of dry dinitrogen tetroxide dissolved in chloroform. This type of reaction appeared, for all practical purposes, to be limited to benzylic alcohols. Thus, a year later Langenbeck and Richter[10] demonstrated the oxidation of primary alkanols and diols to the corresponding mono- and dicarboxylic acids with dinitrogen tetroxide in inert solvents at −10 to 18°. Kinetic analysis of these reactions indicated that aldehydes were not formed as intermediates and 2-phenylethanol and 3-phenylpropanol were oxidized to the corresponding aldehydes in only 14% and trace yield, respectively.

Results

The fluoro alcohol, 1H,1H,5H-octafluoro-1-pentanol, was recovered unchanged after treatment for 3 days at room temperature with excess dinitrogen tetroxide dissolved in methylene chloride.[11] However, 1H,1H,9H-hexadecafluoro-1-nonanol (**1b**) was oxidized by nitrogen dioxide (2 moles) at 110° in an autoclave

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[1] Dinitrogen tetroxide exists in equilibrium with the free radical, nitrogen dioxide, but the latter predominates at higher temperatures. At 27° the tetroxide is about 20% dissociated; at about 140° dissociation is complete. *Cf.* P. Gray and A. D. Yoffe, *Chem. Rev.*, **55**, 1069 (1955), for a review of the structure, reactivity, and physical properties of the nitrogen dioxide–dinitrogen tetroxide system.

[2] For example, N. Levy and C. W. Scaife, *J. Chem. Soc.*, 1093 (1946); H. Baldock, N. Levy, and C. W. Scaife, *ibid.*, 2627 (1949); H. Shechter and F. Conrad, *J. Am. Chem. Soc.*, **75**, 5620 (1953); H. Shechter, J. J. Gardikes, and A. H. Pagano, *ibid.*, **81**, 5420 (1959); J. L. Riebsomer, *Chem. Rev.*, **36**, 157 (1945); T. E. Stevens, *J. Chem. Soc.*, **81**, 3593 (1959).

[3] See, for example, H. H. Schlubach and W. Rott, *Ann.*, **594**, 59 (1955); J. P. Freeman and W. D. Emmons, *J. Am. Chem. Soc.*, **79**, 1712 (1957); K. N. Campbell, J. Shavel, and B. K. Campbell, *ibid.*, **75**, 2400 (1953).

[4] The nitration of aliphatic and aromatic compounds by the oxides of nitrogen is reviewed by A. V. Topchiev, "Nitration of Hydrocarbons," Pergamon Press Ltd., London, 1959, p. 226 ff.

[5] E. H. White and W. R. Feldman, *J. Am. Chem. Soc.*, **79**, 5832 (1957); M. Anabor, *ibid.*, **76**, 3603 (1954); C. C. Addison, N. Hodges, and J. C. Sheldon, *Chem Ind.* (London), 1338 (1953); *cf.* also ref. 4.

[6] A recent example of the use of dinitrogen tetroxide as a useful oxidizing reagent in organic chemistry is the oxidation of alkyl sulfides of sulfoxides without further oxidation to sulfones [C. C. Addison and J. C. Sheldon, *J. Chem. Soc.*, 2705 (1956)]. Oxidation of negatively substituted quinols to *p*-benzoquinones by mixed nitrogen oxides, predominantly dinitrogen tetroxide, has been described by A. G. Brook [*ibid.*, 5040 (1952)] and by K. Wallenfels [*Angew. Chem.*, **63**, 142 (1961)].

[7] The primary α,α,ω-trihydrofluoroalkanols described in this paper are available in developmental quantities from the Organic Chemicals Department, E. I. du Pont de Nemours and Co., Wilmington 98, Del.

[8] A. L. Henne, R. L. Pelley, and R. M. Alm report that efforts to prepare trifluoroacetaldehyde by oxidation of trifluoroethanol failed using "conventional" reagents, *e.g.* sodium dichromate in sulfuric acid [*J. Am. Chem. Soc.*, **72**, 3370 (1950)]. H. Shechter and F. Conrad report that the oxidation of 1,1,1-trifluoropropane with nitric acid in the presence of oxygen at about 450° affords trifluoroacetaldehyde in small (20–40%) yield (*ibid.*, 3371). D. R. Husted and A. H. Albrecht [U. S. Patent 2,568,500 (1951)] and M. Braid [U. S. Patent 2,852,569 (1958)] describe the preparation of fluoro aldehydrols by reduction of fluorocarboxylic acids with lithium aluminum hydride. N. O. Brace describes the preparation of α,α ω-trihydroperfluoroaliphatic hemiacetals of ω-hydroperfluoro aliphatic aldehydes by photochlorination of α,α,ω-trihydroperfluoro alcohols [U. S. Patent 2,842,601 (1958) and *J. Org. Chem.*, **26**, 4005 (1961)]. Pyrolysis of the hemiacetals affords the ω-hydrofluoroaliphatic aldehydes. R. N. Haszeldine claims the preparation of R_fCH_2CHO by catalytic hydrogenation of the vinyl ethers, $R_fCH{=}CHOR$ [Canadian Patent 618,346 (1961)]. M. Braid and F. Lawlor claim the oxidation of trifluoroethanol to trifluoroacetic acid and/or trifluoroacetaldehyde with oxygen or a peroxy compound in the presence of certain heavy metal oxides [U. S. Patent 3,038,936 (1962)].

[9] B. O. Field and J. Grundy, *J. Chem. Soc.*, 1110 (1955); *cf.* also J. B. Cohen and H. T. Calvert, *ibid.*, **71**, 1050 (1897).

[10] W. Langenbeck and M. Richter, *Ber.*, **89**, 202 (1956).

[11] This experiment was carried out by Dr. D. W. Wiley, Central Research Department, E. I. du Pont de Nemours and Co., Inc.

TABLE I

OXIDATION OF PRIMARY FLUORO ALCOHOLS TO FLUORO ALDEHYDROLS BY NO_2

Fluoro alcohol, $H(CF_2)_nCH_2OH$ $n =$	Temp. of hot tube, °C.	Alcohol, g./hr.	NO, ml./sec.	Air, ml./sec.	Organic material balance, %[a]	Purity of crude aldehydrol, %[b]	Conversion to aldehydrol, %	M.p. of crude product, °C.
6	375	13	2.5	2.5	55			58–60
6	300	10	1.9	4.2	65	50–60	33–39	60–63
8	230	10	2.8	4.2		low	low	45–50
8	275	7	2.8	4.2	74		71	90–92
8	280	10	5.5	8.3	72	83	60	92–93
8	300	10	2.5	4.0	91	93	85	79–83; 80–84
8	304	16	5.5	8.3	95	50	47	73–76
8	318	20	5.5	8.3	93	50	46	
8	325	10	5.5	8.3	44		39	90–92
8	338	20	6.5	8.3	83	83	69	
10	320	17	5.5	8.3	92	40	37	86–95

[a] After evaporation of gaseous products at room temperature. [b] In most instances estimated by carbonyl analysis (*cf.* ref. 14).

over a period of 10 hr. to give, as the major product, 9H-hexadecafluorononanoic acid (2) in 69% yield.

$$\underset{\mathbf{1b}}{H(CF_2)_8CH_2OH} \xrightarrow{NO_2} \underset{\mathbf{2}}{H(CF_2)_8CO_2H}$$

At significantly lower temperatures, with shorter reaction times or with equimolar quantities of nitrogen dioxide, conversions to the carboxylic acid diminished and recovery of unchanged fluoro alcohol increased.

Turning to the hot-tube reaction technique, we found that fluoro aldehydrols could be obtained conveniently, quickly, and in good yields by passing a mixture of excess nitric oxide,[12,13] air,[13] and a primary fluoro alcohol through a Pyrex tube packed with glass or quartz chips and heated at 300–400°.

$$\underset{\mathbf{1}}{H(CF_2)_nCH_2OH} \xrightarrow{NO_2} \underset{\mathbf{3}}{H(CF_2)_nCH(OH)_2}$$

1a, $n = 6$ **3a**, $n = 6$
b, $n = 8$ **b**, $n = 8$
c, $n = 10$ **c**, $n = 10$

This technique proved especially convenient for the preparation of long-chain fluoro aldehydrols which are nonhygroscopic solids at room temperature; they could be collected and separated from gaseous coproducts simply by permitting them to condense on the walls of an air-cooled condenser attached to the exit of the reaction tube. In the largest single run, carried out over a period of 32 hr. of continuous operation, 7.7 kg. of the C_9 fluoro alcohol (**1b**) was passed through a 6.5-cm. diameter Pyrex tube partially filled with 600 ml. of quartz chips and maintained at 380 ± 10°. Nitric oxide and air were passed through the tube, each at a rate of 7 ml./sec. This gave 6.6 kg. of crude 1H,9H-hexadecafluoro-1,1-nonanediol (**3b**), estimated by gas chromatography and titrimetric carbonyl analysis[14] to be 70 ± 3% pure aldehydrol. A single crystallization from benzene gave the aldehydrol in 96% purity and in 57% conversion. Additional runs on a smaller scale (10–100 g.) gave fluoro aldehydrols **3a**, **3b**, and **3c** from the corresponding alcohols in conversions ranging from 33 to 85%. These runs are summarized in Table I.

Gas chromatographic analysis of a typical batch of crude aldehydrol **3b** indicated the virtual absence (less than 0.1%) of the corresponding fluorocarboxylic acid (2). This observation was at first quite surprising in view of the fact, mentioned earlier, that action of nitrogen dioxide on the primary fluoro alcohol (**1b**) in an autoclave at a lower temperature gives primarily the corresponding fluorocarboxylic acid (**2**). Subsequent experiments showed, however, that the acid 2, even if it were formed[15] as a by-product of the oxidation, would not survive the conditions of the hot-tube reaction. Thus, when acid 2 was passed through a packed tube heated at 350°, together with nitric oxide–air, it underwent complete conversion to a mixture composed primarily of gaseous products accompanied by a small amount (5–10% by weight) of volatile liquid.[15]

Mechanism of Oxidation.—A study of the mechanism of the oxidation of fluoro alcohols to fluoro aldehydrols has not been undertaken. The known chemistry of nitrogen dioxide does, however, suggest a reasonable reaction scheme.

Nitrogen dioxide, because of its free-radical character, is prone, especially at high temperatures, to abstract hydrogen from an organic molecule leaving an alkyl radical.[16] Combination of another molecule of nitrogen dioxide with the radical so produced can occur with formation of either a nitro or a relatively unstable nitrite compound.[16] Abstraction of a hydrogen atom from the methylene group of a primary fluoro alcohol would give rise to the radical represented by structure **4** in eq. 1. Combination of this radical with nitrogen

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[12] To facilitate metering, a mixture of (excess) nitric oxide and air was used rather than pure nitrogen dioxide (b.p. 21°). The gases were mixed in a chamber outside the reaction tube to ensure complete reaction since the rate of this reaction is known to decrease with increasing temperature [M. Bodenstein, *et al.*, *Z. physik. Chem.* [Leipzig], **100**, 87, 106 (1922)].

[13] No oxidation of the fluoro alcohols was observed when they were passed through a reaction tube at 400° with either nitric oxide or air alone.

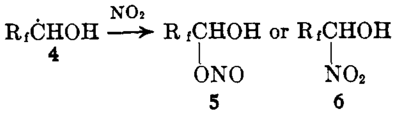
[14] S. Siggia, "Quantitative Organic Analysis," 2nd Ed., John Wiley and Sons, Inc., New York, N. Y., 1954, p. 28.

[15] The gaseous products from the degradation of fluorocarboxylic acid **2** were not identified. Infrared analysis of the volatile liquid obtained indicated that it was a mixture of ω–H–α-nitroperfluoro alkanes similar to those described in the next part of this series [*J. Org. Chem.*, **29**, 284 (1964)]. Since the gaseous or liquid products from the hot-tube degradation of acid **2** were neither sought nor found among the products from the hot-tube oxidation of fluoro alcohol **1b**, no evidence exists for the formation (and degradation) of acid **2** during the hot-tube oxidation of fluoroalcohol **1b** to fluoro aldehydrol **3b**. Nevertheless, in view of the autoclave experiments, this seems more likely to us than the alternative possibility that the fluoro alcohol (**1b**) and the fluoro aldehydrol (**3b**) are completely resistant toward oxidation of fluorocarboxylic acid **2** in the presence of nitrogen dioxide in a hot tube at 300–400°. Formation of fluorocarboxylic acids and their degradation to volatile products, as side reactions in the hot-tube synthesis of fluoro aldehydrols, would, furthermore, account for the low material balance of nongaseous organic products generally found in these hot-tube syntheses (Table I).

[16] P. Gray and A. D. Yoffe, *Chem. Rev.*, **55**, 1094, 1102 (1955).

$$R_fCH_2OH + NO_2 \longrightarrow \underset{4}{R_f\dot{C}HOH} + HNO_2 \qquad (1)$$

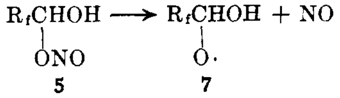
$$2HNO_2 \longrightarrow H_2O + NO + NO_2 \qquad (2)$$



$$\underset{4}{R_f\dot{C}HOH} \xrightarrow{NO_2} \underset{5}{R_f\underset{ONO}{\underset{|}{C}}HOH} \text{ or } \underset{6}{R_f\underset{NO_2}{\underset{|}{C}}HOH} \qquad (3)$$

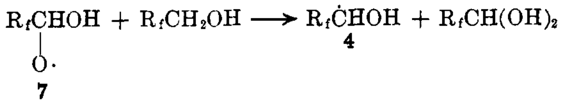
dioxide in the manner depicted by eq. 3 would afford an α-hydroxynitrite (5) or an α-hydroxynitro (6) intermediate.

Decomposition of the nitrite (5) by homolytic O–N bond fission[17] would give a radical species 7 which, by abstracting a hydrogen atom from another molecule of



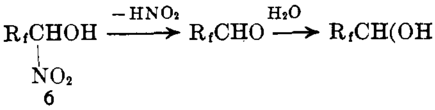
$$\underset{5}{R_f\underset{ONO}{\underset{|}{C}}HOH} \longrightarrow \underset{7}{R_f\underset{O\cdot}{\underset{|}{C}}HOH} + NO \qquad (4)$$

fluoro alcohol, would regenerate another radical 4 and afford a molecule of fluoro aldehydrol (eq. 5). Decomposition of the nitrocarbinol (6) would be expected



$$\underset{7}{R_f\underset{O\cdot}{\underset{|}{C}}HOH} + R_fCH_2OH \longrightarrow \underset{4}{R_f\dot{C}HOH} + R_fCH(OH)_2 \qquad (5$$

to afford fluoroaldehyde and, ultimately, by combination with water (from eq. 2), fluoro aldehydrol.



$$\underset{6}{R_f\underset{NO_2}{\underset{|}{C}}HOH} \xrightarrow{-HNO_2} R_fCHO \xrightarrow{H_2O} R_fCH(OH)_2$$

Vapor Pressure of Fluoro Aldehydrols.—Although, as expected, the melting points of the three fluoro aldehydrols **3a, 3b,** and **3c** exceed those of the corresponding fluoro alcohols[18] **1a, 1b,** and **1c,** so also do their apparent vapor pressures. Table II compares the vapor pressures of the C_9 fluoro alcohol (**1b**) and the fluoro aldehydrol (**3b**) as measured in a Sickle cell over a range of temperatures. Gas chromatography substantiates the unusual volatility of the fluoro aldehydrols relative to the fluoro alcohols. Figure 1 shows a plot of the log of retention times *vs.* chain length of the three fluoro alcohols and the corresponding fluoro aldehydrols on polar and nonpolar columns[19] operated at 175°. It is clear that, for given chain lengths, the fluoro alcohols have a significantly greater retention time than the corresponding fluoro aldehydrols. This is interpreted to be a consequence of the fact that the order of elution of closely related compounds from nonpolar columns is generally in the order of decreasing vapor pressures.[20] The unexpectedly high vapor pressures of the fluoro aldehydrols may be due to their partial dissociation into water and relatively volatile fluoro aldehydes.

TABLE II

VAPOR PRESSURES OF 1H,9H-HEXADECAFLUORO-1,1-NONANEDIOL (**3b**) AND 1H,1H,9H-HEXADECAFLUORO-1-NONANOL (**1b**)

	Vapor pressures, mm. of Hg	
Temp., °C.	Fluoro aldehydrol **3b**	Fluoro alcohol **1b**
25	<1	<1
50	7	<1
60	12	
70	32	3
80	71	8
90	143	12
100	225	21
110	350	33
120	489	49
130	668	

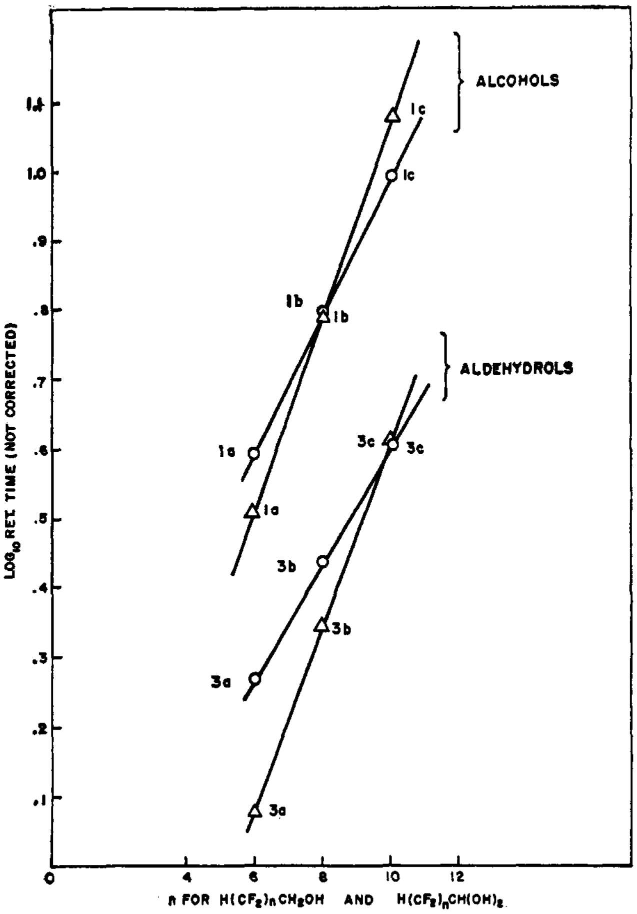


Fig. 1.—Column packings (see ref. 19): Δ, 20% tetrakis-(1H,1H,5H-octafluoropentyl and 1H,1H,7H-dodecafluoroheptyl)-pyromellitate in "Columpak" (Fisher Scientific); ○, 25% Dow Corning high vacuum grease on 60–80-mesh "Celite."

Reactions of Fluoro Aldehydrols.—Relatively few derivatives of fluoro aldehydes or fluoro aldehydrols are reported in the literature. We have observed that, at least for the long-chain fluoro aldehydrol (**3b**), solid carbonyl derivatives are easily prepared directly from the *gem* diol without first resorting to a dehydration step. For example, a water–methanol solution of the aldehydrol (**3b**) and sodium bisulfite rapidly deposits a sparingly soluble bisulfite adduct (**8**). Somewhat surprisingly, this salt is recovered unchanged after

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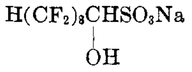
[17] Literature dealing with the homolytic decomposition of nitrites is surveyed by P. Gray, P. Rothbone, and A. Williams, *J. Chem. Soc.*, 3932 (1960), and by A. L. Nussbaum and C. H. Robinson, *Tetrahedron*, **17**, 48 (1962).

[18] The fluoro alcohols **1a**, **1b**, and **1c** are reported to melt at −14°, 69°, and 102°, respectively [D. R. Baer, *Ind. Eng. Chem.*, **51**, 829 (1959)]. The corresponding fluoro aldehydrols **3a**, **3b**, and **3c** melt at 67°, 95–96° (or 105–107°, *cf.* Experimental), and 113–114°, respectively.

[19] A Perkin-Elmer vapor fractometer, Model 154-B, was employed using helium as the carrier gas at an inlet pressure of 10 p.s.i. and a flow rate of 35 ml./min. Column packing designated "nonpolar" was 25% Dow Corning high vacuum grease on 60–80-mesh "Celite" and was 2 m. in length. Packing designated "polar" was 20% tetrakis(1H,1H,5H-octafluoropentyl and 1H,1H,7H-dodecafluoroheptyl)pyromellitate on "Columnpak" (Fisher Scientific) and was also 2 m. in length. Samples were injected as solutions in acetone into a preheater at 14°.

[20] *Cf.* for example, F. H. Pollard and C. J. Hardy, in D. H. Desty "Vapour Phase Chromatography," Academic Press, Inc., New York, N. Y., 1957, p. 115.



$H(CF_2)_8CH(OH)SO_3Na$

8

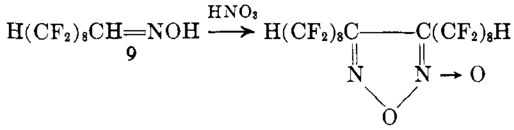
$H(CF_2)_8CH{=}NOH$

9

treatment for 1 hr. with boiling 10% aqueous hydrochloric acid. The aldoxime (**9**), prepared from the reaction of excess hydroxylamine hydrochloride with the aldehydrol (**3b**) in water–methanol, likewise shows unusual stability. It is recovered unchanged after treatment for 1 hr. with 85% sulfuric acid or for 12 hr. in boiling benzene with excess phosphorus pentachloride, reagents which generally bring about the Beckmann rearrangement of aliphatic or aromatic oxides.[21]

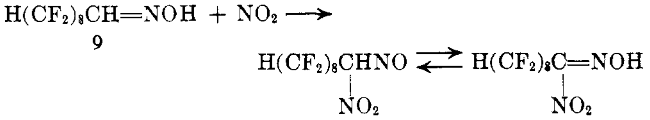
Aldoxime **9** appears to be predominantly, or totally, of one configuration for its proton magnetic resonance spectrum exhibits only one triplet peak ascribable to hydrogen on the doubly bonded carbon.[22]

Oxidation of aldoxime **9** with fuming (90%) nitric acid gives the bisfluoroalkylfuroxan (**10**) in 50% yield.[23] A relatively dense liquid, **10** ($d^{30}{}_4$ 1.89), solidifying at 29°, exhibits the typical infrared[24] and ultraviolet[25] absorption spectra characteristic of furoxans. Its hydrogen n.m.r. spectrum consists of a single triplet (J = 51 c.p.s.) at τ 3.25. The most striking feature of the reaction affording this furoxan is a transient, but clearly visible, blue color that pervades the organic phase of the reaction mixture for 10–15 min. Kornblum[26] in his study of the reactions of sodium nitrite with organic halide compounds offers evidence for formation of (blue) pseudonitroles and nitrolic acids as intermediates. The latter apparently decompose with loss of nitrous acid to give nitrile oxides which dimerize to furoxans.[27] Addition of nitronium ion[28] to aldoxime **9** would produce a colored pseudonitrole (**11a**).



9

10



$$H(CF_2)_8CH{=}NOH + NO_2 \longrightarrow H(CF_2)_8CH(NO)NO_2 \rightleftarrows H(CF_2)_8C(NO_2){=}NOH$$

9 11a 11b

Decomposition of the pseudonitrole (**11a**), probably by way of its tautomer the colorless nitrolic acid (**11b**), would, by analogy to the Kornblum mechanism, give a fluoroalkylnitrile oxide and then, by dimerization, the bisfluoroalkylfuroxane (**10**). From one oxidation of the

$$11 \xrightarrow{-HNO_2} H(CF_2)_8C{\equiv}N \longrightarrow 10$$

aldehydrol (**3b**) with nitric acid, 9H-hexadecafluorononanoic acid (**2**) was isolated in about 15% yield. This acid may have originated from intermediate **11** since nitrolic acids are known to decompose into carboxylic acids.[26]

One experiment was carried out to determine whether a product formally derived from the *gem* diol group of **3b** could be prepared. Two moles of benzonitrile were indeed found to react with 1 mole of diol **3b** in the presence of fuming sulfuric acid to give the dibenzamido derivative (**12**).

$$\underset{\mathbf{3b}}{H(CF_2)_8CH(OH)_2} + 2C_6H_5CN \longrightarrow \underset{\mathbf{12}}{H(CF_2)_8CH(NHCOC_6H_5)_2}$$

Fluoro Ketone Hydrates.—Secondary fluoro alcohols can be oxidized to fluoro ketone hydrates by nitrogen dioxide. Thus, when 1H,3H,5H-octafluoro-3-pentanol (**13**) together with nitric oxide and air were passed through a Pyrex tube packed with quartz chips heated at 400°, 1H,5H-octafluoro-3,3-pentanediol (**14**)

$$\underset{\mathbf{13}}{HCF_2CF_2CH(OH)CF_2CF_2H} \longrightarrow \underset{\mathbf{14}}{HCF_2CF_2C(OH)_2CF_2CF_2H}$$

was obtained in 54% conversion, based on gas chromatography. Since the diol (**14**) also can be prepared in good yield by oxidation of the alcohol (**13**) with chromic acid,[29] further study of the oxidation of this and other secondary fluoro alcohols with nitrogen dioxide has not been pursued.

Experimental[30]

Oxidation of Primary Fluoro Alcohols.[31]—Table I summarizes the conditions used for oxidizing three fluoro alcohols[7] to fluoro aldehydrols. No efforts have been made to find optimum conditions for these oxidations. The following describes one experiment in detail.

1H,1H,9H-Hexadecafluoro-1-nonanol (20 g., 0.047 mole) was added dropwise[32] over a 2-hr. period to a Pyrex glass tube (about 50 cm. long and 4-cm. inside diameter) partly filled with 300 ml. of quartz chips (6–14 mesh) and heated at 300° while nitric oxide (2.5 cc./sec.) and air (4.0 cc./sec.) were metered into the tube.[12] Attached in series to the bottom of the reaction tube were an air condenser, about 2.5 cm. in diameter and 50 cm. long, and a two-necked round-bottom flask immersed in a solid carbon dioxide–acetone cooling bath. When addition of the alcohol had been completed, 13 g. of a white solid, m.p. 80–84°, was scraped from the walls of the air condenser and 5.5 g. of a slightly moist solid, m.p. 79–83°, was isolated from the cold trap after evaporation of the volatile components. The higher melting solid, 1H,9H-hexadecafluoro-1,1-nonanediol (**3b**), was analyzed without purification.

Anal. Calcd. for $C_9H_4F_{16}O_2$: C, 24.1; H, 0.90; F, 67.7; mol. wt., 449. Found: C, 24.4; H, 1.28; F, 67.0; mol. wt. (ebullioscopic in acetone), 460, 460.

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[21] The resistance of this fluoro aldoxime to rearrangement might be ascribed to the effect of the electron-attracting fluoroalkyl group in inhibiting the required direction of heterolysis of the N–O bond (*cf.* for example, E. S. Gould, "Mechanism and Structure in Organic Chemistry," Henry Holt and Co., New York, N. Y., 1959, p. 618 ff).

[22] J. A. Pople, W. G. Schneider, and H. J. Bernstein, "High-Resolution Nuclear Magnetic Resonance," McGraw-Hill Book Co., Inc., New York, N. Y., 1959, p. 374.

[23] L. W. Kissinger, W. E. McQuistion, and M. Schwartz have described the synthesis of bisperfluoroalkylfuroxans by reaction of dinitrogen tetroxide with diazo compounds of the type R_fCHN_2 ("Symposium on Nitro Aliphatic Chemistry," Purdue University, Lafayette, Ind., May 26, 1961).

[24] N. E. Boyer, G. M. Czerniak, H. S. Gurowsky, and H. R. Snyder, *J. Am. Chem. Soc.*, **77**, 4238 (1955).

[25] J. N. Boyer, V. Toggweiler, and G. A. Stoner, *ibid.*, **79**, 1748 (1958).

[26] N. Kornblum, R. K. Blackwood, and D. D. Mooberry, *ibid.*, **78**, 1501 (1956); N. Kornblum and V. M. Weaver, *ibid.*, **80**, 4333 (1958).

[27] J. H. Boyer and H. Alul [*ibid.*, **81**, 4237 (1959)] invoke nitrolic acid and nitrile oxide intermediates in the reaction of benzaldoxime with dinitrogen tetroxide to give diphenylfuroxan.

[28] Nitronium ion is a well-authenticated species and is known in many nitrations with nitric acid to be the attacking electrophile. *Cf.*, for example, E. S. Gould, "Mechanism and Structure in Organic Chemistry," Henry Holt and Co., New York, N. Y., 1959, p. 419 ff.

[29] Unpublished work of Dr. D. C. England, Central Research Department, E. I. du Pont de Nemours and Co., Inc.

[30] Melting points are uncorrected.

[31] R. M. Scribner, U. S. Patent 2,980,738 (1961). A process for preparing fluoro ketone hydrates by oxidation of secondary fluoro alcohols with nitrogen dioxide also is described.

[32] Solid fluoro alcohols were kept molten for dropwise addition by heating the dropping funnel with an infrared lamp.

Combination of the two portions of crude aldehydrol and reaction with hydroxylamine hydrochloride in methanol followed by titration of the hydrogen chloride liberated[14] showed that it averaged 93% purity. Recrystallization of 8 g. of the crude aldehydrol from 40 ml. of benzene gave 2.8 g. of a waxy, amorphous solid melting at 95–96°. Concentration of the mother liquor to 20 ml. gave an additional crop of white solid (0.3 g.) melting at 105–107°. Brace also has observed the melting points of the two forms of the aldehyde hydrate prepared by a different method[8] to be 95–96° and 105–106°,[33] respectively. Reaction of crude 1H,9H-hexadecafluoro-1,1-nonanediol with a water–ethanol solution of 2,4-dinitrophenylhydrazine in 6 *N* sulfuric acid gave a 2,4-dinitrophenylhydrazone, m.p. 122°.[33] In like manner, 1H,11H-eicosafluoro-1,1-undecanediol, m.p. 113–114°, gave a 2,4-dinitrophenylhydrazone melting at 141–143°.[33]

1H,9H-Hexadecafluorononanol Oxime (9).—Hydroxylamine hydrochloride (15 g., 0.2 mole) dissolved in 15 ml. of water was added to 23 g. (0.05 mole) of 1H,9H-hexadecafluorononane-1,1-diol (m.p. 90–94°) in 70 ml. of methanol. The clear solution was allowed to stand at room temperature for 4 hr. and then heated at reflux for 15–20 min. Methanol was removed under vacuum, and the residual oil was poured into water and extracted with two 150-ml. portions of ether. The ether extract was washed with water and dried over magnesium sulfate. Fractional distillation through an 8-in. spinning-band column gave 22.6 g. of oxime, b.p. 95° (9 mm.), m.p. 42.0–42.5°.

Anal. Calcd. for $C_9H_3F_{16}NO$: C, 24.3; H, 0.67; N, 3.14. Found: C, 24.5; H, 0.72; N, 2.67.

The proton magnetic resonance spectrum[34] of the oxime consisted of a singlet at $\tau -1.19$ (NOH), a triplet (J = 51 c.p.s.) at 3.32 split further into triplets (J = 5 c.p.s.) (HCF_2CF_2–), and an overlapping triplet (J = 8 c.p.s.) at 2.32 (–$CF_2CH{=}N$–). Infrared analysis (potassium bromide) showed a strong band at 3.0 (λ_{OH}) and a very weak band at 6.05 μ ($\lambda_{C=N}$).

3,4-Bis(8H-hexadecafluoro)-1,2,5-oxadiazole N-Oxide (10).—Ten grams (0.023 mole) of the C_9 fluoro aldehyde oxime was added in small portions to 35 ml. of vigorously stirred 90% fuming nitric acid. The temperature of the mixture gradually rose from 26 to 42° and a transient, dark blue color appeared. Stirring was continued for 20 min. after addition was completed. The colorless mixture was poured into 100 g. of ice, and the water was extracted with two 75-ml. portions of ether. The combined ether extracts were washed with four 25-ml. portions of 5% sodium hydroxide and then with water. Evaporation of the ether gave 8.7 g. of a light yellow semisolid that on distillation through a single-plate, short-pass column gave 6.4 g. (65%) of the furoxan. Redistillation through a 6-in. spinning-band column gave an analytical sample, b.p. 125° (0.5 mm.), that on cooling in Dry Ice solidified to an amorphous solid, m.p. 29°, $d^{30}{}_4$ 1.89.

Anal. Calcd. for $C_{18}H_2F_{32}N_2O_2$: C, 24.4; H, 0.23; F, 68.6; N, 3.16; mol. wt., 886. Found: C, 24.6; H, 0.34; F, 68.4; N, 3.04; mol. wt. (f.p., benzene), 990.

The p.m.r. spectrum of this compound consisted of a single triplet (J = 51 c.p.s.) centered at τ 3.25 split further into triplets (J = 5 c.p.s.). The infrared absorption spectrum, in essential agreement with spectra reported by Boyer, *et al.*,[24] for furoxans, showed bands at 6.05 ($\lambda_{C=N}$), 6.80, and 7.12 ($\lambda_{ON \rightarrow O}$), 7.50 ($\lambda_{N-O}$), 9.70 ($\lambda_{\text{furoxan ring system}}$), and 11.55 μ ($\lambda_{\text{furoxan ring}}$). Ultraviolet absorption (ethyl alcohol) was at a maximum at 266 mμ ($\epsilon_{\max}$ 3910), which agrees with the range 255–285 mμ assigned by Boyer, *et al.*,[25] to furoxans.

1H,9H-1,1-Dibenzamidohexadecafluorononane (12).—To 2.85 g. (6.3 mmoles) of $H(CF_2)_8CH(OH)_2$ in 50 ml. of concentrated sulfuric acid and 50 ml. of fuming sulfuric acid was added 1.4 g. (13.6 mmoles) of benzonitrile. The mixture was stirred at room temperature for 1 hr. and poured into 500 g. of ice. Extraction of the aqueous solution with three 150-ml. portions of ether gave, on evaporation of the ether, 1.9 g. of white solid (46% yield), m.p. 217–218°, after two crystallizations from ethyl acetate.

Anal. Calcd. for $C_{23}H_{14}F_{16}N_2O_2$: C, 42.3; H, 2.14; N, 4.28. Found: C, 42.2; H, 2.23; N, 4.41.

The infrared spectrum was consistent with the assigned structure, showing bands at 3.0 (λ_{NH}), at 5.59 ($\lambda_{\text{secondary amide I}}$), and at 6.45 μ ($\lambda_{\text{secondary amide II}}$).

1H,9H-1-Hydroxyhexadecafluoro-1-nonanesulfonic Acid Sodium Salt (8).—To a filtered solution of 50 g. (0.36 mole) of sodium bisulfite in 200 ml. of water and 200 ml. of methanol was added with vigorous stirring and all at once 20 g. (0.045 mole) of the aldehydrol (**3b**). Immediately after dissolution of the aldehydrol a precipitate appeared. The resulting slurry was heated gently on a steam cone for about 15 min., cooled, and filtered. The white solid remaining after washing the filter cake with three 50-ml. portions of cold water, three 50-ml. portions of alcohol, and finally with generous amounts of ether weighed 17.4 g. (74%) and was analytically pure bisulfite adduct. It did not melt up to 300°.

Anal. Calcd. for $C_9H_3F_{16}NaO_4S$: S, 5.98. Found: S, 5.84.

The infrared spectrum exhibited a strong band at 3.10 (hydroxyl), a moderately strong band at 7.25, and a strong band at 8.35 μ; the latter two bands may be associated with the sulfonate group.[35]

1H,9H-Hexadecafluorononanal Semicarbazone.—An aqueous solution of semicarbazide hydrochloride was added to a solution of 4.5 g. (0.01 mole) of the aldehydrol (**3b**) in ethanol, and water and ethanol were added as necessary to make the mixture homogeneous. The mixture was heated on a steam cone for 30 min. and then stored at room temperature overnight. Collection by filtration of the crystals that appeared and recrystallization from benzene gave 3.4 g. (71%) of the semicarbazone as silvery white plates, m.p. 154–155°.

Anal. Calcd. for $C_{10}H_5F_{16}N_3O$: C, 24.7; H, 1.03; N, 8.62. Found: C, 24.9; H, 1.32; N, 9.03.

The infrared absorption spectrum of this compound (in potassium bromide) showed moderately strong bands at 5.84, 6.00, 6.15, and 6.25 μ. The ultraviolet absorption spectrum showed $\lambda_{\max}^{EtOH}$ 243 mμ (ϵ 15,000). The p.m.r. spectrum[34] consisted of a broad complex multiplet (NH, NH_2) centered 128 c.p.s. to low field from tetramethylsilane and having a total area 1.5 times the total area of the remaining peaks. The latter peaks, resembling the corresponding peaks for oxime 9, consisted of a triplet (J = 51 c.p.s.) centered at τ 3.17 split further into triplets (J = 5 c.p.s.) and an overlapping set of triplets (J = 8 c.p.s.) centered at 2.48.

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(33) N. O. Brace, Ref. 8 and unpublished experiments.

(34) The n.m.r. spectra were taken with a Varian Associates 60-Mc. high resolution spectrometer. Solutions in deuterioacetone were used with tetramethylsilane as an internal standard.

(35) L. J. Bellamy, "The Infrared Spectra of Complex Molecules," John Wiley and Sons, Inc., New York, N. Y., 1954.