

[CONTRIBUTION FROM THE DEPARTMENT OF CHEMISTRY, DUKE UNIVERSITY]

The Action of Elementary Fluorine upon Organic Compounds. XX. The Fluorination of Mono-, Di- and Trimethylamine, Ethylenediamine and Ethyleneimine¹

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This paper describes the direct fluorination under many conditions of a number of different types of aliphatic amines. Mono-, di- and trimethylamines underwent not only the expected perfluorination, but also simultaneous dealkylation, alkylation and dimerization such that, for example, $(\text{CH}_3)_2\text{NH}$ gave CF_3NF_2 , $(\text{CF}_3)_2\text{NF}$, $(\text{CF}_3)_3\text{N}$ and $(\text{CF}_3)_2\text{N}-\text{N}(\text{CF}_3)_2$, together with other products. It was also shown that CH_3NH_2 and $(\text{CH}_3)_3\text{N}$ did not evolve N_2 during fluorination, although in the former case no nitrogen balance could be obtained. Ethylenediamine, in addition to the expected cleavage and dimerization, gave significant amounts of $\text{CF}_3\text{N}=\text{NCF}_3$; while 10% of the nitrogen in the sample was evolved as N_2 . The related $\text{CH}_2\text{CH}_2\text{NH}$ yielded pure $(\text{CF}_3)_2\text{NF}$, and much $\text{CF}_3\text{N}=\text{NCF}_3$, which has been shown to be stable itself at 500° , stable to

fluorine at 400° but to undergo fluorinolysis at 500° to yield $\text{CF}_4 + \text{N}_2$. Various free radical mechanisms to explain these results have been discussed.

A preceding paper⁴ has described the fluorination of acetonitrile, which yielded the interesting compounds $\text{CF}_3\text{CF}_2\text{NF}_2$ and $\text{CF}_2=\text{NF}$, but no elementary nitrogen. This paper extends that work and presents the results of the direct fluorination of a series of representative amines.

Unexpectedly, each of these yielded essentially the same basic products under all conditions studied. They were CF_4 ; an inseparable mixture of $\text{CF}_3\text{NF}_2 + \text{C}_2\text{F}_6$; a similar mixture of $\text{CF}_3\text{CF}_2\text{NF}_2 + (\text{CF}_3)_2\text{NF}$; and a volatile perfluorinated dimer cut, mol. wt. 180–300, together with other products of lesser importance. This indicated that the fluorinations took place by simultaneous substitution, cleavage, dimerization and polymerization, and that the free radical mechanisms involved were similar in all cases.

Mono-, di- and trimethylamines were fluorinated in a T-reactor over copper metal, and the most important reactions which took place, other than substitution, were dealkylation, alkylation and dimerization. For example, dimethylamine characteristically yielded under favorable conditions significant amounts of CF_4 , $\text{CF}_3\text{NF}_2 + \text{C}_2\text{F}_6$ (dealkylation), $(\text{CF}_3)_2\text{NF} + \text{CF}_3\text{CF}_2\text{NF}_2$ (substitution), $(\text{CF}_3)_3\text{N}$ (alkylation) and volatile dimers, mol. wt. 221–308, half of which consisted of pure $(\text{CF}_3)_2\text{N}-\text{N}(\text{CF}_3)_2$, b.p. -2 to -1° (200 mm.),⁵ f.p. -61° .

On the other hand, methylamine gave much CF_4 , $\text{CF}_3\text{NF}_2 + \text{C}_2\text{F}_6$ (substitution), $(\text{CF}_3)_2\text{NF} + \text{CF}_3\text{CF}_2\text{NF}_2$ (alkylation) and nothing else. From Table IA, it is obvious that the greater part of the nitrogen involved was unaccounted for. Consequently a run was made using helium as diluent, and the final exit gases tested for nitrogen by the lithium method,⁴ but none was found. The fate of this nitrogen still remains an unsolved problem.

Finally, in this group, trimethylamine produced

(1) This material was presented at the September, 1954, Meeting of the American Chemical Society in New York, and has been abstracted from portions of the Doctorate Thesis by Jay A. Gervasi and the Master's Thesis by Morton Brown which were presented to Duke University in February and May, 1954, respectively.

(2) Research Assistant, Office of Naval Research, 1950–1951; Allied Chemical and Dye Corporation Fellow, 1951–1953; Research Assistant, Office of Ordnance Research, Fall, 1953.

(3) Research Assistant, Office of Ordnance Research, Spring, 1954. Grateful acknowledgment is also made to the Duke University Research Council for generous support.

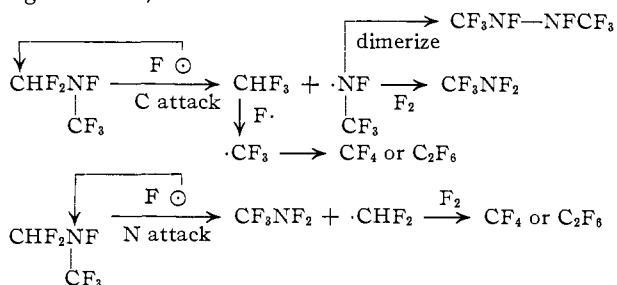
(4) J. A. Cuculo and L. A. Bigelow, *THIS JOURNAL*, **74**, 710 (1952).

(5) R. N. Haszeldine, *J. Chem. Soc.*, 102 (1951), has reported the b.p. as $54-56^\circ$ at 1 atm.

less CF_4 , $\text{CF}_3\text{NF}_2 + \text{C}_2\text{F}_6$ (small but definite two-stage dealkylation), $(\text{CF}_3)_2\text{NF} + \text{CF}_3\text{CF}_2\text{NF}_2$ (one-stage dealkylation), $(\text{CF}_3)_3\text{N}$ (substitution) and volatile dimers, mol. wt. 203–334. There was also definite, although not conclusive, evidence that this dimer fraction contained $\text{CF}_3\text{NF}-\text{NCF}_3$ or isomers, $\text{CF}_3\text{NF}-\text{N}(\text{CF}_3)_2$ and $(\text{CF}_3)_2\text{N}-\text{N}(\text{CF}_3)_2$. Also, a qualitative nitrogen balance was obtained, and no elementary nitrogen evolved.

These reactions may be accounted for readily by modern free radical organic chemistry, but such mechanisms usually proceed simultaneously by numerous routes, only a few of which can be detailed here. A fluorine atom may attack hydrogen, carbon or nitrogen in an amine molecule, followed by further fluorination, cleavage, dealkylation, coupling, alkylation or dimerization; while any of these changes may take place at any point during the progressive replacement of hydrogen by fluorine in the molecule.

Selecting arbitrarily the following example, dealkylation may proceed by either carbon or nitrogen attack, as



The carbon attack is highly favored, not only statistically, but also since fluorine and nitrogen do not combine readily. On the other hand, alkylation seems to proceed by an attack upon hydrogen linked either to nitrogen or to carbon, followed by coupling, as

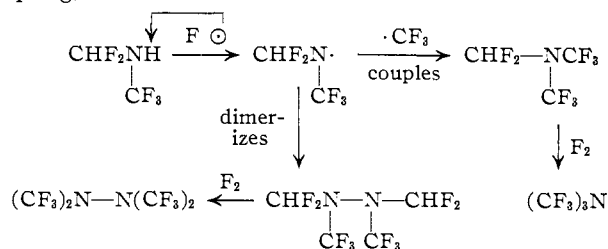


TABLE I
THE RECTIFICATION OF FLUORINATED MONO-, DI- AND TRIMETHYLAMINES
A. CH_3NH_2 ; R , 0.054 mole/hr.; MR , 5:1:15; T , 100°; time 22 hr.; crude 20 cc.

Fract.	Chief product	Boiling range, °C.	Molecular wt.		Liq. vol. % of total condensate
			Obsd.	Calcd.	
1	CF_4	-130 to -129	88-91	88	52
2	....	-98 to -93	82-67	..	13
3	$\text{CF}_3\text{NF}_2 + \text{C}_2\text{F}_6$	-79	118-132	..	13
4	$\text{CF}_2\text{CF}_2\text{NF}_2 + (\text{CF}_3)_2\text{NF}$	-40	172-176	171	22
B. $(\text{CH}_3)_2\text{NH}$; R , 0.051 mole/hr.; MR , 5:1:15; T , 275°; time 10 hr.; crude 23 cc.					
1	CF_4	-130 to -129	87-88	88	44
2	Transition	-129 to -81	85-78	..	2
3	$\text{CF}_3\text{NF}_2 + \text{C}_2\text{F}_6$	-81 to -79	124-129	..	7
4	$\text{CF}_3\text{CF}_2\text{NF}_2 + (\text{CF}_3)_2\text{NF}$	-39	165-168	171	22
5	$(\text{CF}_3)_3\text{N}$	-11	218-221	221	11
6	Residue	..	221-238	..	13
C. $(\text{CH}_3)_3\text{N}$; R , 0.050 mole/hr.; MR , 7:1:21; T , 275°; time 12 hr.; crude 41 cc.					
1	CF_4	-128	85-87	88	22
2	....	-92 to -88	86-96	..	5
3	$\text{CF}_3\text{NF}_2 + \text{C}_2\text{F}_6$	-79	127-134	..	5
4	$\text{CF}_3\text{CF}_2\text{NF}_2 + (\text{CF}_3)_2\text{NF}$	-40 to -39	167-171	171	12
5	Transition	-13 to -11	203-224	..	12
6	$(\text{CF}_3)_3\text{N}$	-11	224	221	20
7	....	6 to 7	210-213	..	10
8	....	16 to 17	241-248	..	5
9	Residue	..	274-334	..	10

The Fluorination of Mono-, Di- and Trimethylamine.—In this series a dozen runs were made, using different samples, reactors and operating conditions; but only one characteristic detailed description and data for three representative rectifications will be presented here as follows. Methylamine from the cylinder, controlled by a needle valve and metered by a calibrated flow meter, at the rate (R) of 0.054 mole/hr., was diluted with 10 l./hr. of N_2 , and the mixture led directly into the T-reactor maintained at an equilibrium temperature (T) of 100°, where it met and reacted with 0.27 mole/hr. of F_2 carried in on 10 l./hr. of N_2 , such that the molar reaction ratio (MR) (F_2 :sample: N_2) was 5:1:15, corresponding to a fluorination ratio of 5:1 and a dilution ratio of 1:3. The exit gases were passed over sodium fluoride pellets at about 100° to remove HF, and then condensed, first by Dry Ice and then by liquid air. After 22 hr. roughly 20 cc. of crude product had condensed, which was then passed through a solution containing 5% NaHSO_3 and 3% NaOH in a counter-current flow stabilizer, but the loss in all cases was small. Finally the stabilized product was rectified carefully in a Booth-Podbielniak low-temperature fractionating unit with the results shown in the condensed Table I.

Fractions A_3 , B_3 and C_3 , as well as A_4 , B_4 and C_4 represent known inseparable mixtures of the indicated constituents; while fractions B_5 and C_{7-8} are the so-called volatile dimers.

Fraction C_6 .—This portion was carefully redistilled and yielded very nearly pure $(\text{CF}_3)_3\text{N}$, b.p. -10.5°, f.p. -116 to -115°, mol. wt. 224; known b.p. -7 to -6°,⁵ mol. wt. calcd. 221.

Fractions $C_{7,8}$ and 9 may well have contained $\text{CF}_3\text{NF}-\text{NF}-\text{CF}_3$ or isomers, mol. wt. (calcd.) 204; $\text{CF}_3\text{NF}-\text{N}(\text{CF}_3)_2$, mol. wt. (calcd.) 254; and the known $(\text{CF}_3)_2\text{N}-\text{N}(\text{CF}_3)_2$, mol. wt. (calcd.) 304.

Run B was repeated for 32 hr. at 285° with similar results and 7 cc. of fraction B_6 was thus obtained, which on careful redistillation yielded pure $(\text{CF}_3)_2\text{N}-\text{N}(\text{CF}_3)_2$ (3 cc.), b.p. -2 to -1° at 200 mm., f.p. -61°, mol. wt. 305; known b.p. 54-56°,⁵ mol. wt. calcd. 304.

To determine whether or not elementary N_2 was being evolved during the fluorination of CH_3NH_2 , run A was repeated at 275° using helium as diluent, and the stabilized exit gases tested for nitrogen by the lithium method.⁴ Since no NH_3 was evolved, no N_2 was present in the exit gases. Trimethylamine was also fluorinated in the unpacked ring reactor using helium as diluent, but under very different conditions, yet with much the same result, and the exit gases were tested as above, but again no N_2 was evolved.

The Fluorination of Ethylenediamine.—Twelve different fluorinations of this compound have been run under widely varying conditions, and a detailed description of a representative member of this series follows. Ethylenediamine, diluted with 5.8 l./hr. of N_2 , was carried from a modified, electrically heated, glass saturator, similar to that previously described,⁸ maintained at 70° at the rate of 0.031 mole/hr. into the central ring of the unpacked concentric ring reactor heated to 250°, where it met and reacted with 0.248 mole/hr. of undiluted fluorine coming in through the outer ring. At the same time, however, the middle ring carried 123 l./hr. of barrier N_2 , such that the molar reaction ratio was 8:1:175, corresponding to a reaction ratio of 8:1 and a dilution ratio of 1:22. Under these circumstances the sample burned with a pale blue diffusion flame, as observed in a test glass reactor and, after 24 hr., roughly 43 cc. of crude product had been condensed by Dry Ice and liquid air in traps provided with 6-mm. stopcocks to reduce back pressure. The volatile portion of this product was stabilized and carefully rectified in the usual manner, with the results shown in Table II.

TABLE II
THE RECTIFICATION OF FLUORINATED ETHYLENEDIAMINE

Fract.	Chief product	Boiling range, °C.	Molecular wt.		Liq. vol. % of total condensate
			Obsd.	Calcd.	
1	CF_4	-128 to -109	84-89	88	38
2	....	-96 to -81	67-80	..	10
3	CF_3NF_2	-78 to -76	117-119	121	10
4	$(\text{CNF}_2)_2$	-43 to -40	156-160	166	4
5	$\text{CF}_3\text{CF}_2\text{NF}_2$	-40 to -37	166-170	171	7
6	$\text{CF}_3\text{N}=\text{NCF}_3$	-33 to -31	165-167	166	7
7	....	-23 to -2	175-206	..	4
8	Stbin. loss	.....	.....	..	7
9	Non-volatile	.....	.....	..	14

Fraction 2.—This fraction contained a portion, b.p. -91°, mol. wt. 70-85, which appeared frequently during these fluorinations, but has not yet been identified.

Fraction 3.—This portion was essentially pure CF_3NF_2 , known b.p. -76°,¹¹ mol. wt. calcd. 121. Such material when obtained by the fluorination of the various methylamines (see above) was always contaminated by C_2F_6 .

Fraction 4.—This material was redistilled and yielded the pure known isomeric mixture $(\text{CNF}_2)_2$, b.p. -40°,

(11) R. N. Haszeldine, *J. Chem. Soc.*, 1966 (1950).

f.p. -128° , mol. wt. 166 (calcd. 166) in exact agreement with Ruff.¹²

Fraction 6.—Central cut was pure $\text{CF}_3\text{N}=\text{NCF}_3$, b.p. -32° , f.p. -133° , mol. wt. 166; known¹³ b.p. -32° , f.p. -132° , mol. wt. calcd. 166.

Fraction 7.—This portion may have contained $(\text{CNF}_2)_2$ as $\text{CF}_3\text{NF}-\text{NCF}_3$ or isomer.

The above run was then repeated using helium as diluent and the stabilized exit gases tested for N_2 by the lithium method.⁴ In this case it was found that 9.8% of the nitrogen entering the reactor had been evolved as N_2 during the fluorination. In a blank run 40% of the N_2 in a known gas sample could be recovered by this method; and this factor was used in the calculations.

The Fluorination of Ethyleneimine.—Purified ethyleneimine was fluorinated in the jet reactor with the top half at 120° and the secondary reactor at 100° . The sample diluted with 5.1 l./hr. of N_2 was carried from a glass saturator similar to that previously described⁸ maintained at 0° at the rate of 0.028 mole/hr., and then further diluted by 1.8 l./hr. of N_2 , after which it passed into the reactor through the turbulent jet, where it met and reacted with 0.140 mole/hr. of fluorine such that the molar reaction ratio was 5:1:10. After 12 hr. the crude product, amounting to 28 cc., was collected, stabilized by alkaline bisulfite, and rectified in the usual manner, with the results shown in Table III; while a similar run at the ratio of 4:1:8 gave much the same results.

TABLE III

THE RECTIFICATION OF FLUORINATED ETHYLENEIMINE

Fract.	Chief product	Boiling range, $^{\circ}\text{C}$.	Molecular wt.		Liq. vol. % of total condensate
			Obsd.	Calcd.	
1	CF_4	-129 to -116	77-89	88	7
2	....	-90 to -58	90-132	..	9
3	$(\text{CF}_3)_2\text{NF}$	-55 to -37	132-179	171	18
4	$\text{CF}_3\text{N}=\text{NCF}_3$	-36 to -27	161-173	166	20
5	....	-23 to -5	178-218	..	16
6	$(\text{CF}_3)_2\text{N}-\text{N}(\text{CF}_3)_2$	-32 to 0 (200 mm.)	229-327	304	14
7	Stbln. loss	.....	.....	..	11
8	Residue	.....	.....	..	5

Fraction 2.—This portion boiled mostly at -76° and consisted essentially of the inseparable mixture of CF_3NF_2 + C_2F_6 .

(12) O. Ruff and F. Giese, *Ber.*, **69B**, 604 (1936).

(13) O. Ruff and W. Willenberg, *ibid.*, **73B**, 724 (1940).

Fraction 3.—About two-thirds of this fraction was pure $(\text{CF}_3)_2\text{NF}$, b.p. -38° , f.p. -171° , mol. wt. 170-173; known b.p. -38° ,¹⁴ f.p. -171° ,⁴ mol. wt. calcd. 171.

Fraction 4.—At least half of this material had b.p. -33 to -32° , with an average mol. wt. 165 (see above).

Fraction 5.—About one-third of this sample had b.p. -16 to -14.5° , average mol. wt. 188 (see Paper XXI).

Fraction 6.—About half of this portion was pure $(\text{CF}_3)_2\text{N}-\text{N}(\text{CF}_3)_2$, b.p. -3 to -1° at 200 mm., f.p. -61° , average mol. wt. 305 (see above).

The Fluorination of Hexafluoroazomethane.—Purified $\text{CF}_3\text{N}=\text{NCF}_3$, b.p. -33 to -31° , contained in a small cylinder, was metered at the rate of 0.099 mole/hr., diluted with N_2 at the rate of 7.3 l./hr., and the mixture passed into the high temperature reactor described above maintained at 275° , where it met with undiluted fluorine entering at the rate of 0.099 mole/hr., such that the molar reaction ratio was 1:1:3. The product was passed over sodium fluoride at 100° , and after 1 hr. 15 cc. of material had been condensed, which was stabilized by 5% NaOH and rectified in the usual manner; but the unchanged sample was recovered in 92% yield. Similar runs were made at the ratio of 1:1:0 at both 275° and 400° , with the same result, although the contact was short. Finally a run was made at 1:1:0 and 500° , when a reaction took place, and the crude product (9 cc.) was stabilized and rectified in the usual manner with the results shown in Table IV.

TABLE IV

THE RECTIFICATION OF FLUORINATED $\text{CF}_3\text{N}=\text{NCF}_3$

Chief product	Boiling range, $^{\circ}\text{C}$.	Molecular wt.		Liq. vol. % of total condensate
		Obsd.	Calcd.	
CF_4	-129 to -123	86-89	88	83
C_2F_6	-82 to -75	134-140	138	6
$\text{CF}_3\text{N}=\text{NCF}_3$	-34 to -28	161-167	166	11

In the above run the final exit gases, swept along by a little diluent helium which had been introduced into the crude product, were stabilized over 10% NaOH + 10% NaHSO_3 , dried by liquid air, and then passed directly over lithium at 60° for the subsequent determination of their N_2 content in the usual manner. In this way 79% of the N_2 in the original sample was accounted for as ammonia.

(14) J. Thompson and J. H. Emeleus, *J. Chem. Soc.*, 3080 (1949).

DURHAM, N. C.

[CONTRIBUTION FROM THE CARVER FOUNDATION AND THE DEPARTMENT OF CHEMISTRY, TUSKEGEE INSTITUTE]

Preparation and Properties of Some α -Fluoroethers^{1,2}

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Various metal fluorides were examined as fluorine-for-chlorine exchange agents with $\text{CCl}_3\text{CHClOR}$. The efficiency of the exchange was found to descend in approximately the order HgF_2 , TlF , AgF , KF , Al_2F_6 , CrF_3 . Compounds of the general formula CCl_3CHFOR and CH_2FOR (where R is Me, Et, Pr, Bu and allyl) were prepared using HgF_2 and their physical and chemical properties examined. All attempts to prepare CH_3CHFOR and $\text{CH}_2\text{FOCH}_2\text{CH}=\text{CH}_2$ were unsuccessful.

While references in the literature are abundant for di- and polyfluoroethers, information on the monofluoroethers is very scarce, and no work at all seems to have been reported on the α -fluoroethers. The purpose of this work was therefore to investigate the preparation and properties of α -fluoroethers.

When heated, the α -halogenated ethers decom-

(1) From part of a thesis submitted by Charles C. Allain in partial fulfillment of the requirements for the degree of Master of Science, Tuskegee Institute, 1955.

(2) Presented at the Fall Meeting of the American Chemical Society, September, 1955.

pose and polymerize into dark viscous mixtures. In exchange reactions between a metal fluoride and halogenated ethers, the difficulty is in finding a metal fluoride which will exchange its fluorine for halogen at a temperature low enough so as to minimize the decomposition of both the reactant and product. Mercuric fluoride was found to exchange its fluorine for the α -chlorine in some halogenated ethers. The reaction was smooth, and little decomposition took place. Compounds of the type CCl_3CHFOR and CH_2FOR (Tables I and II) were prepared.