Aqueous Fluorination of Carboxylic Acid Salts

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Direct fluorination of aqueous alkali salts of malonic, succinic, glutaric, adipic, azelaic, and sebacic acids proceeded with decarboxylation yielding ω -fluorocarboxylic acids and α, ω -difluoroalkanes. Monocarboxylic acids vielded 1-fluoroalkanes. Nonanoic acid, decanoic acid, and monomethyl adipate were used as substrates. 1-Fluoroalkanes and α, ω -difluoroalkanes underwent additional random fluorination. Fluorination of aqueous sodium p-nitrobenzoate gave p-fluoronitrobenzene. An ionic mechanism is proposed for these decarboxylative fluorination reactions.

As a part of a program on direct liquid phase fluorination of organic compounds in progress at this laboratory for the past several years, the fluorination of aqueous alkali salts of aliphatic carboxylic acids was investigated. The primary objective of this work was to extend the scope of liquid phase fluorination technique, previously applied in the fluorination of nitrogenous compounds,^{1,2} nitronate salts,³ aromatic compounds,^{4,5} and aliphatic esters,⁶ to other classes of organic compounds.

Electrochemical fluorination of short-chain carboxylic acids yields predominantly perfluoroalkanes,⁷ but small amounts of the corresponding perfluoroacyl fluorides have also been obtained.⁸ Carboxylic acids with six or more carbon atoms yield cyclic ethers as the major products.⁹ The electrochemical fluorination of acvl halides to perfluoro acid fluorides is one of the most important applications of the electrochemical method. Dibasic acid fluorides, such as adipoyl and succinoyl, have been fluorinated in this manner to give dibasic perfluoro acid fluorides and monoacid fluorides.⁸ The partial electrochemical fluorination of propionic and butyric acids was reported¹⁰ to give mixtures of monofluoro derivatives in very low yields.

Very little work has been reported on direct fluorination of carboxylic acids. Bockemuller¹¹ obtained β and γ -fluoro derivatives in the liquid phase fluorination of *n*-butyric acid, its anhydride, and chloride, and β fluoroisobutyric acid in the fluorination of isobutyric acid. Bockemuller also investigated direct fluorination of acetic, succinic, and glutaric anhydrides, and acetic acid, in carbon tetrachloride, but found that all these substrates were unreactive. Miller and Prober¹² studied exhaustive fluorination of acetyl fluoride in the vapor phase at 100° and reported low yields of fluoroacetyl fluoride and difluoroacetyl fluoride. Liquid phase fluorination of acetic anhydride gave fluoroacetic acid and diffuoroacetic acid.6

Fichter and Brunner,¹³ whose work comes closest to

(9) C. F. Irwin, R. G. Brenner, A. F. Benning, F. B. Downing, H. M. Parmelee, and W. V. Wirtz, *Ind. Eng. Chem.*, **39**, 350 (1947).
(10) C. Slesser and S. R. Schram, Ed., "Preparation, Properties, and Technology of Fluorine and Organic Fluorine Compounds," McGraw-Hill Book

(12) W. T. Miller and M. Prober, J. Amer. Chem. Soc., 70, 2602 (1948).

the present study as far as the experimental technique is concerned, investigated the fluorination of aqueous potassium acetate in the presence of potassium carbonate and obtained methanol, formaldehyde, carbon dioxide, and ethylene. Fluorination of potassium propionate gave ethanol, acetaldehyde, and ethylene.

In the present work the fluorinations were conducted by passing fluorine diluted with nitrogen into aqueous solutions of alkali salts of carboxylic acids at 0-5° and, Thus, the in some cases, at ambient temperatures. fluorination of aqueous disodium adipate using 2 mol of fluorine at 0-5° was completed in 5 hr. The reaction proceeded smoothly and fluorine was well consumed. At the end of the reaction ca. 40% of the adipic acid was recovered. The major reaction product, obtained in 40% yield (23% conversion), was identified as 5fluoropentanoic acid on the basis of its elemental analysis, nmr spectra (see Experimental Section for details), and the reported¹⁴ physical properties for the compound. The acid was also esterified to the known methyl 5-fluoropentanoate.

A small amount of a volatile liquid obtained in the above experiment analyzed for approximately $C_4H_7F_3$. Its infrared spectrum showed a typical fluoroalkane structure, and gas chromatographic analysis indicated that the material was a mixture of several compounds. Based on the analytical data and its physical properties (bp 75-80°), the material appeared to be a mixture of randomly fluorinated butanes. The individual components were not isolated in this case, and it is possible that some of the more volatile fluorobutane isomers were lost during the process of fluorination.

Since the characterization of the fluoroalkane mixture obtained in the fluorination of disodium adipate presented some experimental problems, the fluorination of longer chain dicarboxylic acids was examined next with the primary objective of characterizing α, ω -diffuoroalkanes. The fluorination of disodium sebacate using 2 mol of fluorine gave a liquid boiling in the range of The gas chromatographic analysis fluorooctanes. showed that this material was a mixture of at least five components. The compound present in the mixture at ca. 60% concentration was separated by gas chromatography and identified as 1.8-difluorooctane on the basis of elemental analysis and nmr spectra.

A small amount of a high-boiling liquid, isolated on further distillation of the crude reaction product, was identified as 9-fluorononanoic acid on the basis of reported¹⁴ physical properties. The acid was also esterified to the known¹⁴ ethyl 9-fluorononanoate. In this

⁽¹⁾ V. Grakauskas, Abstracts, the 140th National Meeting of the American Chemical Society, Chicago, Ill., Sept 1961, p 23M.

⁽²⁾ V. Grakauskas, Third International Symposium on Fluorine Chemistry, Munich, Sept 1965.

⁽³⁾ V. Grakauskas and K. Baum, J. Org. Chem., 33, 3080 (1968).

⁽⁴⁾ V. Grakauskas, ibid., in press

⁽⁵⁾ V. Grakauskas, Fourth International Symposium on Fluorine Chemistry, Estes Park, Colo., July 1967.

V. Grakauskas, J. Org. Chem., 34, 963 (1969).

⁽⁷⁾ For general discussion, see M. Stacey, J. C. Tatlow, and A. G. Sharpe, Advan. Fluorine Chem., 1, 145 (1960). (8) H. M. Scholberg and H. G. Brice, U. S. Patent 2,717,871 (1955).

<sup>Co., Inc., New York, N. Y., 1951, p 485.
(11) W. Bockemuller, Ann., 506, 20 (1933).</sup>

⁽¹³⁾ F. Fichter and E. Brunner, Helv. Chim. Acta, 12, 573 (1929).

⁽¹⁴⁾ F. L. M. Pattison, S. B. D. Hunt, and J. B. Stothers, J. Org. Chem., 21, 883 (1950).

experiment ca. 50% of the sebacic acid was recovered. In another experiment using dipotassium sebacate and 3 mol of fluorine, a higher yield of fluorooctanes was obtained.

The relatively poor utilization of fluorine in the fluorination of adipic and sebacic acid salts, as well as in other cases to be discussed later, seems to be the result of a side reaction. The fluorination of aqueous sodium hydroxide is the standard method for preparing oxygen difluoride¹⁵ and therefore it is not surprising that a significant portion of fluorine is consumed in the side reaction during the fluorination of aqueous alkali carboxylates. No attempts were made to determine the effect of pH of the fluorination mixture on the efficiency of fluorine utilization in decarboxylation reactions, but it seems reasonable to suspect that pH is the major reaction variable. Approximately half of the fluorine was utilized in the reaction with alkali carboxylates under the reaction conditions employed in this study.

The fluorination of several other dicarboxylic acids, azelaic, malonic, glutaric, and succinic, gave analogous results to those obtained with adipic and sebacic acids. Disodium azelate yielded a mixture of 1,7-difluoroheptane and randomly fluorinated 1,7-difluoroheptanes, analyzing for approximately C7H12.5F2.5. 1,7-Difluoroheptane, the predominant component is this mixture, was isolated by gas chromatography and identified by nmr spectra. The monofluorination product was esterified and ethyl 8-fluorooctanoate was identified on the basis of reported¹⁴ physical properties. The fluorination of disodium malonate gave fluoroacetic acid in ca. 1% yield, characterized by proton nmr spectrum, and also by comparing its properties with those reported¹⁶ for the acid. The yield might have been distorted by the isolation technique: the fluorination was conducted in a dilute solution and it is possible that not all fluoroacetic acid was extracted.

The fluorination of potassium glutarate and potassium succinate gave 4-fluorobutyric and 3-fluoropropionic acids, respectively, in low yields. No attempts have been made in these cases to isolate α, ω -difluoroalkanes.

The fluorination of aqueous alkali salts of monocarboxylic acids was examined next, but some difficulties were encountered with the characterization of reaction products. 1-Fluoroalkanes, the products of these reactions, underwent random fluorination simultaneously with the fluorination of acids leading to a mixture of fluorocarbons. The unique proximity in boiling points of monofluoro and polyfluoro derivatives of an organic compound made the separation of such mixtures a difficult task.

The fluorination of aqueous sodium nonanoate yielded a liquid boiling in the range of fluorooctanes. Its infrared spectrum was typical of fluoroalkanes. The gas chromatographic analysis showed that the material was a mixture containing at least six components. The compound present in the mixture at the highest concentration (ca. 50%) was separated and identified as 1-fluorooctane on the basis of its elemental analysis and the proton nmr spectrum. The isolation and identification of other components in the mixture, presumably polyfluoro isomers of octane, could not be accomplished by gas chromatography because of very similar retention times.

The fluorination of aqueous potassium decanoate using 1 mol of fluorine proceeded analogously to that of nonanoate, yielding a mixture of fluorononanes analyzing for approximately $C_{9}H_{18.5}F_{1.5}$. The yield of fluoroalkanes in the above two reactions was low and large amounts of unreacted acids were recovered.

The fluorination of aqueous sodium methyl adipate using 1 mol of fluorine gave methyl 5-fluoropentanoate in 14% yield. The compound was identified by nmr

$$CH_3O_2C(CH_2)_4CO_2^- + F_2 \xrightarrow{(H_2O)}$$

 $F(CH_2)_4CO_2CH_3 + F^- + CO_2$

spectra and by comparing its properties with those reported¹⁷ for the ester.

The fluorination of aqueous alkali salts of aromatic carboxylic acids was investigated briefly. No products could be isolated in the fluorination of sodium benzoate. The reaction mixture darkened considerably and some dark, viscous oil deposited. Recently it was shown that aromatic compounds undergo facile fluorination yielding addition⁴ and substitution⁵ products and it became apparent that fluorination in the aromatic nucleus would interfere with the decarboxylative fluorination of aromatic carboxylic acids. Although this conclusion seems to be generally correct, it appeared that the decarboxylative fluorination of electronegatively substituted aromatic carboxylic acids might compete, at least to a certain degree, with the fluorination in the aromatic nucleus which was shown to be the case. The fluorination of aqueous sodium p-nitrobenzoate gave pfluoronitrobenzene in 4% yield, identified by fluorine analysis and infrared spectrum and by comparing its physical properties with those of *p*-fluoronitrobenzene. No attempts were made to identify other reaction products or to recover the unreacted *p*-nitrobenzoic acid.

In a few cases the fluorination of aqueous carboxylic acids was briefly investigated, but no indication of decarboxylative fluorination was noticed. The fluorine was apparently consumed in random fluorination of the hydrocarbon chains of the acids as observed by Bochemuller.11

The results of aqueous fluorination of adipic and sebacic acids salts showed that dicarboxylic acids underwent stepwise fluorination by decarboxylation and yielded ω -fluorocarboxylic acids and γ, ω -difluoroalkanes. The water-insoluble γ, ω -diffuoroalkanes underwent additional random fluorination leading to mixtures of polyfluoroalkanes. The fact that the recovered

$$(CH_2)_n \xrightarrow{CO_2^-} + F_2 \xrightarrow{(H_2O)} F + CO_2 + F^-$$

$$(CH_2)_n \xrightarrow{F} + CO_2 + F^-$$

$$\downarrow F_2 \xrightarrow{F} F(CH_2)_n F + CO_2 + F^-$$

(17) F. L. M. Pattison, J. Amer. Chem. Soc., 78, 2255 (1956).

⁽¹⁵⁾ D. M. Yost, "Inorganic Synthesis," Vol. I, H. S. Booth, Ed., Mc-Graw-Hill Book Co., Inc., New York, N. Y., 1939, p 109. (16) B. C. Saunders and G. J. Stacey, J. Chem. Soc., 1773 (1948).

starting material and ω -fluorocarboxylic acids were not randomly fluorinated indicated that random fluorination occurred after α, ω -difluoroalkanes were produced. Apparently, α, ω -diffuoroalkanes solubilize fluorine better than water, and a higher concentration of fluorine in the organic phase provides favorable conditions for random fluorination. It would appear that random fluorination could be suppressed by a variety of means, for example, by removing α, ω -diffuoroalkanes as they are produced, either mechanically or by extraction, but this was not attempted in the present work.

The observation that little, if any, random fluorination occurs in the aqueous phase also indicates that fluorine reacts at a much faster rate with the carboxylate anion than with the hydrocarbon chain of an acid.

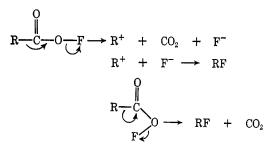
Aqueous fluorination of alkali carboxylates can be looked upon as a special case of the Hunsdieker reaction.¹⁸ Although the reaction conditions differ greatly, the fluorination of aqueous alkali salts and the bromination of dry silver salts of carboxylic acids proceed by the loss of carbon dioxide yielding 1-haloalkanes in the case of monobasic acids, or α, ω -dihaloalkanes when dibasic carboxylic acids are used. It is generally agreed that the initial step in the Hunsdieker reaction involves the formation of acyl hypobromite intermediates, but there is no general agreement regarding the subsequent steps of the mechanism.¹⁹ A free-radical mechanism is favored by most investigators, but some arguments have been present for an ionic mechanism.²⁰⁻²³

Aqueous fluorination of alkali carboxylates most likely also proceeds via acyl hypofluorite intermediates. Whereas only indirect evidence exists for acyl hypobromites, several acyl hypofluorites have actually been isolated. Cady and coworkers obtained trifluoroacetyl hypofluorite in the vapor phase fluorination of trifluoroacetic acid²⁴ and showed²⁵ that the compound decomposes into carbon dioxide and tetrafluoromethane by a free-radical mechanism. Pentafluoropropionyl hypofluorite, synthesized by Steward and Cady²⁶ in a similar manner, decomposed into hexafluoroethane and carbon dioxide. Although both free-radical and ionic mechanisms might be considered in the aqueous fluorination of carboxylic acid salts, we favor the latter primarily because of a strongly polar medium in which these reactions were conducted. The relative insta-

$$\operatorname{RCO}_2$$
-Na⁺ + F₂ $\xrightarrow{(H_2O)}$ [RCO₂F] + NaF

bility of perfluoroacly hypofluorites observed by Cady suggest that acyl hypofluorites are even less stable and decompose into alkyl fluorides and carbon dioxide. An ionic solvent-cage mechanism or SNi decomposition mechanism would be expected to be favored in a polar medium.

- (21) G. Darzens and M. Meyer, C. R. Acad. Sci., Paris, 237, 1334 (1953).
 (22) K. B. Wiberg and T. M. Shryne, J. Amer. Chem. Soc., 77, 2774 1955).
- (23) S. L. Levitt and E. R. Malinvski, ibid., 77, 4517 (1955).
- (24) G. H. Cady and K. B. Kellog, *ibid.*, 75, 2501 (1953).
- (25) R. D. Steward and G. H. Cady, *ibid.*, **77**, 6110 (1955).
 (26) A. Menefee and G. H. Cady, *ibid.*, **76**, 2020 (1954).



The decomposition of acyl hypofluorites by a freeradical mechanism, analogous to that proposed by Cady for the decomposition of perfluoroacyl hypofluorites, cannot be eliminated but seems to be less likely under the present reaction conditions. It would appear that a free-radical decomposition of acyl hypofluorites would have resulted in side reaction products not detected in the present work. Thus, Stump, Oliver, and Podgeti²⁷ reported that the decarboxylation of nitrite esters of perfluorosuccinic acid and perfluoroglutaric acid, either by pyrolysis or ultraviolet irradiation, gave large amounts of by-products arising from free-radical side reactions.

Similarities and differences between aqueous fluorination of carboxylic acids salts and the Hunsdieker reaction might be rationalized as follows. In aqueous solution, fluorine reacts with carboxylic acid anions to give acyl hypofluorites. Under similar conditions, chlorine or bromine either do not react at all with carboxylic acid anions or if the acyl hypohalite intermediates are formed they decompose to carboxylic acids as it is in the case when moisture is present in the Hunsdieker reaction. Cady's finding that trifluoroacetyl hypofluorite is stable in the presence of water²⁴ suggests that acyl hypofluorites produced in aqueous fluorination reactions are not decomposed by water but rather undergo decarboxylation reactions in a similar manner as do acyl hypochlorites or acyl hypobromites under anhydrous reaction conditions.

Experimental Section

General.-Fluorinations were carried out in a glass, standard taper, three-necked flasks fitted with a mechanical stirrer, a glass tube extending below the liquid level used as a gas inlet, and a standard taper thermometer well with an opening for gas exit. Standard fluorine-handling hardware²⁸ was used and the fluorine was diluted with nitrogen (1:3 to 1:6 ratio). Safety shielding is strongly recommended.29

Fluorination of Disodium Adipate.—A solution of 292.2 g (2.0 mol) of adipic acid in 3500 ml of water containing 160 g (4.0 mol) of sodium hydroxide was fluorinated at 0-5° until 4 mol of fluorine was consumed (5 hr). The fluorination mixture containing ca. 5–10 ml of water-insoluble liquid was acidified with 50% sulfuric acid. A white solid which precipitated on acidification was filtered, washed with three 200-ml portions of methylene chloride, and dried in the air: weight 120 g; mp 150-153°, alone, or when mixed with an authentic sample of adipic acid.

The methylene chloride washings were used to extract the aqueous filtrate. The extract was dried, filtered, and the filtrate was distilled to give 55 g of a colorless liquid: bp $57-58^{\circ}$ (0.1 mm); n²⁵D 1.4090; identified as 5-fluoropentanoic acid [lit.¹⁴ bp 90° (4 mm); n²⁵D 1.4078, 1.4080]; yield 40% (23% conversion).

⁽¹⁸⁾ For a general review on the Hunsdieker reaction, see: (a) R. G. Johnson and R. K. Ingham, *Chem. Rev.*, **56**, 219 (1956); (b) Houben-Weyl, "Methoden der organischen Chemie," E. Muller, Ed., Vol. V/4, 4th ed. Georg Thieme Verlag, Stuttgart, 1960, pp 488-500.

 ⁽¹⁹⁾ W. E. Doering and M. Farber, J. Amer. Chem. Soc., 71, 1514 (1949);
 J. W. Wilt, *ibid.*, 77, 6397 (1955).

⁽²⁰⁾ M. Rottenberg, Experientia, 7, 432 (1951).

⁽²⁷⁾ E. C. Stump, W. H. Oliver, and C. D. Padgeti, J. Org. Chem., 33, 2102 (1958).

⁽²⁸⁾ Allied Chemical Corp., Data Sheet PD-TA-84513A.

⁽²⁹⁾ Although no problems were encountered in the present work, direct fluorination of organic compounds must be considered a potentially dangerous operation and adequate safety precautions should be exercised.

Anal. Caled for C₅H₆FO₂: C, 50.0; H, 7.55; F, 15.8. Found: C, 50.2; H, 7.1; F, 15.4.

The fluorine nmr spectrum exhibited one signal at ϕ 219.5, a triplet, $J_{\text{HF}_{ferm}} = 47.1$ cps, of triplets, $J_{\text{HF}_{ric}} = 25.9$ cps (superposition of triplets made the signal appear as a symmetrical quintet), with additional fine 1-3 H-F splitting. The proton nmr pectrum exhibited five signals: a singlet at δ 11.70 was assigned to the carboxylic proton; a doublet, $J_{\text{HF}} = 47.6$ cps of triplets, $J_{\text{H-H}} \cong 5.5$ cps, at δ 4.44 to the FCH₂ protons; a triplet at δ 2.41 to the -CH₂CO₂H protons; and two partially superimposed complex multiplets centering at δ 1.62 and 1.87 to the protons of β and γ methylene groups. The area ratio of the signals was approximately 1:2:2:2:2.

Redistillation of methylene chloride removed in the isolation of the acid yielded 7.5 g of a colorless liquid, bp 75-80°. The infrared spectrum showed bands at 3.4 (m), 3.5 (m), 6.83 (w), 7.21 (m), and a broad absorption envelope at $8.9-9.7 \mu$.

Anal. Calcd for C₄H₇F₃: C, 42.9; H, 6.2; F, 50.9. Found: C, 41.8; H, 5.8; F, 51.8.

Methyl 5-Fluoropentanoate.—To a solution of 6.0 g of 5-fluoropentanoic acid above in 50 ml of methanol was added 2 drops of concentrated sulfuric acid and the mixture was refluxed for 5 hr. The solution was cooled to 10°, added to 200 ml of ice water, and extracted with three 50-ml portions of methylene chloride. The combined extracts were distilled to give 5.5 g of methyl 5-fluoropentanoate: bp 62-63° (18 mm); $n^{25}p$ 1.3975 [lit.¹⁷ bp 72-74° (25 mm); $n^{25}p$ 1.3973].

Fluorination of Sodium Methyl Adipate.—A solution of 80 g (0.5 mol) of monomethyl adipate in 750 ml of water containing 20 g (0.5 mol) of sodium hydroxide was fluorinated at 3-5° until 0.5 mol of fluorine was consumed. The fluorination mixture was made basic by adding 15 g of sodium hydroxide and the resulting solution was extracted with 100 ml of methylene chloride. The extract was distilled to give 19 g of a colorless liquid: bp 74-75° (25 mm); n^{25} D 1.3979; identified as methyl 5-fluoropentanoate¹¹ [lit.¹⁴ bp 72-74° (25 mm); n^{25} D 1.3973]; yield 14.2%.

The fluorine nmr spectrum in carbon tetrachloride exhibited a triplet, $J_{\rm HF_{sten}} = 47.5$ cps, of triplets, $J_{\rm HF_{ste}} = 25.7$ cps, at ϕ 219.5. The proton nmr spectrum exhibited five signals: a doublet, $J_{\rm HF} = 47.4$ cps, of triplets, $J_{\rm HH} \cong 5.5$ cps, assigned to the FCH₂ protons; a singlet at δ 3.68, to the OCH₂ proton of the ester group; a triplet of δ 2.38, to the -CH₂CO₂- protons; and two partially overlapping multiplets centered at δ 1.62 and δ 1.87, to the protons of β and γ methylenes. The area ratio of the above signals was 2:3:2:2:2. A very weak doublet of δ 5.70, $J_{\rm HF} \cong 51$ cps, was assigned to the -CO₂CH₂F protons of fluoromethyl 5-fluoropentanoate, present as an impurity, on the basis of reported⁶ proton nmr spectrum of fluoromethyl esters.

Fluorination of Disodium Sebacate.—A solution of 101 g (0.5 mol) of sebacic acid in 1500 ml of water containing 42 g (1.05 mol) of sodium hydroxide was fluorinated at $10 \pm 5^{\circ}$ until 1 mol of fluorine was consumed (3.5 hr). The fluorination mixture was made basic with 100 ml of 50% aqueous sodium hydroxide and extracted with three 100-ml portions of diethyl ether. The combined ether extracts were distilled to give 22 g of a colorless liquid: bp 34-36° (0.2 mm); $n^{25}p$ 1.3885 (lit.³⁰ for 1,8-diffuoro-octane, $n^{25}p$ 1.3933).

Anal. Calcd for $C_{8}H_{15}F_{3}$: C, 57.1; H, 8.8; F, 33.9. Found: C, 57.1; H, 8.7; F, 33.9.

The proton nmr spectrum in carbon tetrachloride exhibited a very intense broad signal centered at δ 1.6, a weak complex multiplet at δ 1.67, and two complex multiplets of equal area at δ 4.0 and 4.75. The chemical shift and the structure of the latter two multiplets suggested that they represented several superimposed doublets of triplets of FCH₂ groups. The fluorine nmr spectrum exhibited six complex multiplets at ϕ 116.2, 182.6, 185.0, 189.7, 219.5, 222.1, and 230.9, the most intense of which at ϕ 219.5, an overlapping triplet, $J_{\rm HFcem} = 47.6$ cps, of triplets, $J_{\rm HFice} \cong 24$ cps, was assigned to the terminal FCH₂ fluorines of 1,8-diffuoroctane based on analogy with the fluorine nmr spectra of 5-fluoropentanoic acid and methyl 5-fluoropentanoate (see above). The infrared spectrum indicated a typical fluoroalkane structure.

Gas chromatographic analysis using 24 ft $\times 1/4$ in. column of 10% Carbowax 4000 on Fluoropak 80, 95°, He flow rate 50 cc/min, showed that the mixture at ca. 60% concentration was sep-

arated (retention time 42 min) and identified as 1,8-difluorooctane.

Anal. Caled for $C_8H_{16}F_2$: C, 63.96; H, 10.74; F, 25.30. Found: C, 63.4; H, 10.4; F, 25.4.

The proton nmr spectrum (in microcell) exhibited a doublet, $J_{\rm HF} = 47.7$ cps, of triplets at $\delta 4.35$ assigned to the FCH₂ protons (the high-field triplet was broadened). A poorly resolved multiplet at $\delta 1.85$ was assigned to the FCH₂CH₂- methylene protons, and a broadened signal at $\delta 1.39$ to the remaining protons in the chain. The area ratio of the signals agreed well with the required 1:1:2.

The alkaline aqueous phase was acidified with 50% aqueous sulfuric acid. A white solid which precipitated on acidification was filtered, washed with three 100-ml portions of diethyl ether, and dried in air: weight 48.5 g; mp $133-135^{\circ}$, alone or when mixed with an authentic sample of sebacic acid. The filtrate was extracted with four 100-ml portions of diethyl ether. The etheral extracts, combined with the ether washings above, were distilled to give 3.5 g of a colorless liquid, bp $102-104^{\circ}$ (0.2 mm), n^{25} D 1.4285, which was identified as 9-fluorononanoic acid on the basis of the reported¹⁴ boiling point, $100-101^{\circ}$ (0.15 mm), and refractive index, n^{25} D 1.4289, for the compound.

9-Fluorononanoic acid above, 2.5 g, was dissolved in 10 ml of absolute ethanol, 1 drop of concentrated sulfuric acid added, and the mixture was refluxed for 4.0 hr. The solution was cooled, added to 50 g of crushed ice, and the resulting mixture was extracted with 15 ml of methylene chloride. The extract was distilled to give 2.5 g of colorless liquid: bp 76-78° (0.2 mm); n^{25} D 1.4190. The compound was identified as ethyl 9-fluorononanoate on the basis of the reported¹⁴ boiling point, 87-88° (1 mm), and refractive index, 1.4191, for the ester.

In another experiment, a solution of 162 g (0.8 mol) of sebacic acid in 1500 ml of water containing 132 g of 85% potassium hydroxide (2.0 mol of KOH) was fluorinated at $25\text{--}30^\circ$ until 1.5 mol of fluorine was consumed. At this stage, the fluorination was interrupted, another 1.0 mol of potassium hydroxide added to the reaction mixture, and the fluorination was resumed and continued until an additional 1.0 mol of fluorine was consumed. The pH of the reaction mixture at the end of fluorination was 6–7, and a large amount of water-insoluble heavy liquid was present. The mixture was acidified with 50% sulfuric acid to pH 1–2, and extracted with three 200-ml portions of methylene chloride. The combined extracts were distilled to give (1) 91 g of colorless liquid, bp 33–36° (0.2 mm); (2) 20 g of slightly dark liquid, bp 101–105° (0.1 mm); and (3) dark, viscous distillation residue amounting to 20 g.

Anal. of fraction 1. Calcd for $C_8H_{15}F_8$: C, 57.1; H, 8.8; F, 33.9. Found: C, 55.6; H, 8.2; F, 34.8.

The proton and fluorine nmr spectra were identical with those above, with the exception that the ϕ 116.4 signal in the fluorine spectrum was resolved into a doublet, $J_{\rm HF_{rem}} = 56.8$ cps, of triplets, $J_{\rm HF_{ric}} = 16.6$ cps, suggesting the presence of $-\rm CHF_2$ groups.

The material of fraction 2 above was esterified with ethanol yielding 12.5 g of ethyl 9-fluorononanoate: bp $76-79^{\circ}$ (0.2 mm); n^{25} D 1.4190.

The distillation residue (3) was not characterized, but probably contained mainly unreacted sebacic acid. The material crystallized at room temperature.

Fluorination of Disodium Azelate.—A solution of 376.5 g (2.0 mol) of azelaic acid in 3500 ml of water containing 160 g (4.0 mol) of sodium hydroxide was fluorinated at 5° until 3.0 mol of fluorine was consumed (3.0 hr). The fluorination mixture was acidified with 200 g of concentrated sulfuric acid and filtered. The filter cake was washed with two 250-ml portions of methylene chloride and the white solid was dried: weight 150 g; mp 105–106°, alone or when mixed with an authentic sample of azelaic acid. The aqueous filtrate was extracted with two 400-ml portions of methylene chloride, the extracts were combined solution was distilled to give 60 g of a colorless liquid, bp 30–35° (0.2 mm). The material was redistilled to give (1) 4.5 g of colorless liquid, bp 23–25° (0.5 mm), and (2) 55 g of colorless liquid, bp 32–33° (0.1 mm).

Anal. of fraction 1. Calcd for $C_7H_{12}F_4$: C, 48.8; H, 7.0; F, 44.2. Found: C, 48.0; H, 6.8; F, 45.0.

Anal. of fraction 2. Calcd for $C_7H_{14}F_2$: C, 61.7; H, 10.4; F, 29.9. Calcd for $C_7H_{13}F_3$: C, 54.5; H, 8.5; F, 37.0. Found: C, 56.8; H, 9.2; F, 31.2.

⁽³⁰⁾ F. L. M. Pattison and R. G. Woolford, J. Amer. Chem. Soc., 79, 2308 (1957).

The proton nmr spectrum of fraction 2 exhibited five broadened, partially superimposed complex multiplets centered at approximately δ 4.4, 3.6, 2.3, 1.8, and 1.4. The δ 4.4 and δ 3.6 multiplets, equal in area, seem to represent the FCH₂protons of several α -fluoroalkanes, $J_{\mathrm{HF}_{gim}} = 47 \mathrm{~cps}$.

The distillation residue amounting to ca. 100 g, $bp > 80^{\circ}$ (0.1 mm), was dissolved in 250 ml of methanol, 2 drops of concentrated sulfuric acid added, and the resulting solution was refluxed for 6 hr. The mixture was cooled, added to 1200 ml of ice water, and extracted with 100 ml of methylene chloride. The extract was distilled to give 65 g of colorless liquid, bp 59-61° (0.1 mm), identified as methyl 8-fluorooctanoate on the basis of the reported¹⁴ boiling point, 106.5–107° (9 mm), for the ester.

Anal. Calcd for C₉H₁₇FO₂: C, 61.3; H, 9.7; F, 10.8. Found: C, 60.9; H, 9.4; F, 11.4.

The proton nmr spectrum exhibited five signals. A doublet. $J_{\rm HF} = 47.7$ cps, of triplets, $J_{\rm HH} \cong 5.5$ cps, at 4.34 was assigned to the FCH₂ protons; a singlet of δ 3.64 to the -OCH₃ protons of the ester group; a triplet at δ 2.29 to the -CH₂CO₂- protons; a poorly resolved multiplet at δ 1.75 to the -CH₂CH₂CO₂protons; and an intense broad signal centered at δ 1.38 to the protons of the internal methylene groups. The area ratio of the signals was approximately 2:3:2:2:8. The fluorine nmr spectrum exhibited a single signal, a triplet, $J_{\text{HF}_{gem}} = 48 \text{ cps}$, of triplets, $J_{\text{HFree}} \cong 24 \text{ cps}$, at $\phi 218.7$. Additional fine splitting due to 1,3 H-F coupling was visible.

In another experiment, a solution of 94 g (0.5 mol) of azelaic acid in 1500 ml of water containing 44 g (1.1 mol) of sodium hydroxide was fluorinated at 0-5° until 1.1 mol of fluorine was consumed (2.5 hr) (very smooth fluorination); pH of reaction mixture at the end of the run was 5-6. The reaction mixture was extracted with two 150-ml portions of methylene chloride and the combined extracts were distilled to give 32 g of a colorless liquid, bp 33-35° (0.2 mm).

Anal. Found: C, 53.5; H, 7.8; F, 33.0.

Gas chromatographic analysis indicated that the material contained at least six components. The most predominant compound present in the mixture, 1,7-difluoroheptane, was separated by gas chromatography.

Anal. Calcd for C₇H₁₄F₂: C, 61.73; H, 10.36; F, 27.90. Found: C, 60.9; H, 9.7; F, 28.5.

The proton nmr spectrum exhibited three signals. A doublet, $J_{\rm HF} = 47.3$ cps, of triplets, $J_{\rm HF} \cong 5.6$ cps, at δ 4.46 assigned to the FCH₂ protons, a complex multiplet centered at δ 1.88, assigned to the FCH2CH2- protons, a broad signal centered at δ 1.40, assigned to the protons of the three remaining methylene groups. The area ratio of the three signals was approximately 2:2:3.

On further distillation the crude reaction product yielded 35 g of a colorless liquid, bp 85-88° (0.05 mm), which partially solidified to a white crystalline solid at room temperature. The material was identified as 8-fluorooctanoic acid on the basis of reported¹⁴ physical properties: bp 145-148° (10 mm); mp 34-35°.

Anal. Caled for C₈H₁₅FO₂: C, 59.2; H, 9.3; F, 11.7. Found: C, 58.6; H, 8.7; F, 13.5. Fluorination of Disodium Malonate.—A solution of 208 g

(2.0 mol) of malonic acid in 1600 ml of water containing 160 g (4.0 mol) of sodium hydroxide was fluorinated at 0-5° until 2.0 mol of fluorine was consumed. The solution was acidified with 50% sulfuric acid and extracted with six 100-ml portions of diethyl ether. The combined ether extracts were dried, filtered, and the filtrate was distilled to give 2.2 g of a colorless liquid, bp 37-39° (0.2 mm), n²⁵D 1.3800, which solidified at room temperature. The differential thermal analysis showed an endotherm of 166°, indicating that this was the boiling point of the compound. The compound was identified as fluoroacetic acid on the basis of reported¹⁶ physical properties, bp 167-168.5, mp 31-32°, for the acid.

The proton nmr spectrum in water exhibited a doublet, $J_{\rm HF} =$ 47 cps, at δ 5.00. Sodium 2,2-dimethyl-2-silapentane-5-sulfonate (SDSS) was used as internal reference.

4-Fluorobutyric Acid.—A solution of 33 g (0.25 mol) of glutaric acid in 450 ml of water containing 40 g of 85% potassium hy-droxide (0.6 mol of KOH) was fluorinated at 10° until 0.3 mol of fluorine was consumed. The fluorination mixture was acidified with 50% sulfuric acid, extracted with three 100-ml portions of methylene chloride, and the combined extracts were distilled to give 4.5 g of 4-fluorobutyric acid: bp 62-63° (3 mm); n²⁵D 1.4010 [lit.¹⁴ bp 60-62° (2 mm)].

3-Fluoropropionic Acid.—A solution of 23.6 g (0.2 mol) of succinic acid in 450 ml of water containing 0.5 mol of potassium hydroxide was fluorinated and the reaction product isolated as above to give 2.1 g of 3-fluoropropionic acid: bp $100-101^{\circ}$ (25 mm); n^{26} D 1.3884 [lit.¹⁴ bp 97° (29 mm); n^{25} D 1.3888].

Fluorination of Sodium Nonanoate.-- A solution of 79 g (0.5 mol) of nonanoic acid in 1400 ml of water containing 22 g (0.55 mol) of sodium hydroxide was fluorinated at 0-5° until 0.5 mol of fluorine was consumed (3.0 hr). The reaction mixture was extracted with two 150-ml portions of methylene chloride and the combined extracts were distilled to give 18 g of a colorless liquid, bp 50-60° (25 mm). Gas chromatographic analysis indicated that the material was a mixture of at least six components. The predominant component present in the mixture to the extent of ca. 50% was separated by gas chromatography and identified as 1-fluorooctane.

Anal. Calcd for C₈H₁₇F: C, 72.7; H, 13.0; F, 14.4. Found: C, 71.7; H, 12.6; F, 14.4.

The proton nmr spectrum exhibited a doublet, J_{HFgem} 47.5 cps, of triplets, $J_{\rm HH_{ric}} \cong 5.6$ cps, at δ 4.38 assigned to the FCH₂- protons; a broad poorly resolved multiplet centered at δ 1.9 and an intense broad signal at δ 1.37 were assigned to the protons of the other six methylene groups; and a poorly resolved triplet at δ 0.88, assigned to the protons of the CH₃ group. The approximate area ratio of FCH₂-, -CH₂-, and -CH₃ signals was the required 2:12:3.

The aqueous solution was acidified with 50% sulfuric acid, extracted with four 150-ml portions of diethyl ether, and the combined extracts were distilled to give 51 g of colorless liquid, bp 85-86° (0.1 mm), which was identified as the starting material (65% recovery) by comparing its infrared spectrum with that of nonanoic acid. Elemental analysis indicated no fluorine.

Fluorination of Potassium Decanoate.-A solution of 43 g (0.25 mol) of decanoic acid in 350 ml of water containing 0.3mol of potassium hydroxide was fluorinated at 15-20° until 0.25 mol of fluorine was consumed. At this stage, the fluorination was interrupted, another 0.2 mol of potassium hydroxide was added to the solution, and the fluorination was resumed and continued until another 0.25 mol of fluorine was consumed. Total fluorination time was 3.5 hr. The reaction mixture was made basic with 50% aqueous potassium hydroxide and extracted with 75

with 50% addeds potassium hydroxide and extracted with 75 ml of methylene chloride. The extract was distilled to give 19 g of a colorless liquid: bp 30-40° (0.3 mm); n^{25} D 1.4015. Anal. Calcd for C₉H₁₉F: C, 74.0; H, 13.0; F, 13.0. Calcd for C₉H₁₈F₂: C, 65.8; H, 11.0; F, 23.2. Found: C, 67.8; H, 12.2; F, 19.7.

The infrared spectrum was typical for fluoroalkanes: at 3.4 and 3.5 $\mu,$ aliphatic CH stretching; at 6.85 and 7.23 $\mu,$ -CH₂ and CH₈ deformations; a broad absorption envelope with peaks at 8.9, 9.5, and 9.9 μ indicated CF bonding.

Fluorination of Sodium p-Nitrobenzoate.-- A solution of 167.1 g (1.0 mol) of p-nitrobenzoic acid in 1200 ml of water containing 44 g (1.1 mol) of sodium hydroxide was fluorinated at $0-5^{\circ}$ until ca. 0.5 mol of fluorine was consumed. The fluorination mixture was made strongly alkaline with 20 g (0.5 mol) of sodium hydroxide and the resulting solution was extracted with two 150ml portions of methylene chloride. The combined extracts were distilled to give 2.8 g of *p*-fluoronitrobenzene: bp 202-204°; *n*²⁵D 1.5350 (lit.^{31,32} bp 203-204°; *n*²⁵D 1.5340. *Anal.* Calcd for C₆H,NFO₂: F, 13.5. Found: F, 14.1.

The infrared spectrum was identical with that of an authentic sample of *p*-fluoronitrobenzene.

Registry No.—Disodium adipate, 7486-38-6; sodium methyl adipate, 5877-45-2; disodium sebacate, 17265-14-4; disodium azelate, 17265-13-3; disodium malonate 141-95-7; sodium nonanoate, 14047-60-0; potassium decanoate, 13040-18-1; sodium p-nitrobenzoate, 3847-57-2.

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