The Chemistry of Fluorocarbon Sulfonic Acids. I. Preparation of Anhydrides and Sulfonyl Halides

GEORGE VAN DYKE TIERS

Contribution No. 240 from the Central Research Department,
Minnesota Mining & Manufacturing Company, St. Paul 19, Minnesota

Received July 16, 1962

The reaction of phosphorus pentachloride with cyclic fluorocarbon sulfonic acids leads first, with loss of hydrogen chloride, to a high melting solid, which decomposes upon strong heating to yield the sulfonic anhydride. The non-cyclic acids produce a mixture of anhydride and sulfonyl chloride. The higher-boiling sulfonic anhydrides are cleaved, above 200°, by metal salts such as sodium fluoride, zinc chloride, and aluminum chloride. Sulfonyl fluorides and chlorides may thus be prepared in good yield; however only half of the anhydride is available for conversion. A new and very powerful chlorodeoxygenation reagent, $PCl_5 \cdot 2ZnCl_2$, is introduced. It reacts directly with fluorocarbon sulfonate salts to produce the sulfonyl chlorides in high purity and in very high yields.

While the preparation and properties of perfluorinated sulfonic acids[1-6] and of their derivatives[2-7] have been reported, the reactions of these sulfonic acids have been set forth rather sketchily.[2-4,6] The object of the present paper is to describe several reactions of these acids having preparative significance.

The reaction of phosphorus pentachloride with the sulfonic acids is reported to yield the corresponding sulfonyl chlorides,[2,4,6] some anhydride also being noted.[2] Yields are variable for the *n*-perfluoroalkanesulfonyl chlorides, but are exceedingly small when the perfluoro cycloalkane sulfonic acids are so treated, the sulfonic anhydride instead being produced in high yield. The reaction proceeds in two definite stages, in the first of which hydrogen chloride is evolved and a fluffy white solid is formed. From the infusibility of this solid it may be suspected of being ionic, but the plausible structure $R_fSO_3^-PCl_4^+$ does not correspond to the stoichiometry since two sulfonate groups are involved. Perhaps the cation has the structure $R_fSO_2\text{–}OPCl_3^+$. When heated very strongly this solid is decomposed to yield the anhydride and phosphorus oxychloride.

There are certain synthetic advantages to be gained by use of the sulfonic anhydrides rather than the halides; these derive chiefly from their considerably higher boiling points which permit reactions to be effected at atmospheric pressure rather than in sealed vessels. The preparation of higher sulfonamides from strongly basic amines, such as piperidine, goes readily at room temperature; but weak amines, for example aniline and *p*-aminobenzoic acid, require much stronger heating. Such extreme conditions may result in decomposition of the nonfluorocarbon portion of the molecule; notably, in the case of *p*-aminobenzoic acid, reaction at 200° led to appreciable amounts of decarboxylation.

The cleavage of sulfonic anhydrides by metal salts, which may be represented by the following equation is of particular utility for the synthesis of fluorocarbon

$$(R_fSO_2)_2O + M^+X^- \longrightarrow R_fSO_2X + R_fSO_3^-M^+$$

sulfonyl fluorides; these compounds have hitherto only been obtained as endproducts of electrochemical fluorination.[1-5] For this purpose sodium fluoride was employed successfully; however, little or no yield of sulfonyl chloride resulted when potassium chloride was substituted in the reaction. Aluminum chloride and zinc chloride were effective, making it likely that the problem is one of effective contact. The perfluorocycloalkanesulfonyl chlorides were first isolated thus. A defect, for synthetic purposes, of all sulfonic anhydride reactions is that only one-half of the molecule can be used effectively, the rest being "downgraded" to sulfonate salt as shown in the preceding equation.

It has been noted that the fluorinated sulfonyl chlorides possess superior reactivity as compared to the sulfonyl fluorides which are produced by electrofluorination.[2,4] As yields of CF_3SO_2F by the latter process are very high,[2-4] it is of particular interest to provide a convenient method for the production of sulfonyl chlorides, including CF_3SO_2Cl, from the sulfonyl fluorides by a route involving not too many steps. Previous syntheses[2,4-6] have required the free and substantially anhydrous fluorocarbon sulfonic acids which have been liberated from the sulfonate salts first formed in the alkaline hydrolysis of the sulfonyl fluorides. An obvious shortcut would be the direct utilization of the sulfonate salts, for example by reaction with thionyl chloride or phosphorus pentachloride after the fashion well known for ordinary organic sulfonic salts.[8] Unfortunately, the fluorocarbon sulfonates are unreactive up to the dissociation temperature of phosphorus pentachloride, *ca.* 162°. One might suspect that poor contact between reagents was responsible for the failure, but the addition of phosphorus oxychloride had no beneficial effect. A more vigorous chlorodeoxygenation reagent which is usable at higher temperatures is needed. The complex of phosphorus pentachloride with aluminum chloride is an ionic salt, $PCl_4^+ \ AlCl_4^-$.[9] Owing to its high melting point, 343°,[9] it failed to react with potassium perfluoro (4-ethylcyclohexane) sulfonate even upon strong heating. When the lower-melting sodium chloroaluminate was added to provide a liquid phase, some of the desired sulfonyl chloride was indeed produced.

---

[1] P. W. Trott and T. J. Brice, 126th National Meeting of the American Chemical Society, New York, N. Y., 1954; Abstracts, p. 42-M.

[2] T. J. Brice and P. W. Trott, U. S. Patent 2,732,398 (January 24, 1956).

[3] J. Burdon, L. Farazmand, M. Stacey, and J. C. Tatlow, *J. Chem. Soc.*, 2574 (1957).

[4] T. Gramstad and R. N. Haszeldine, *ibid.*, 2640 (1957).

[5] T. Gramstad and R. N. Haszeldine, *ibid.*, 173 (1956).

[6] R. N. Haszeldine and J. M. Kidd, *ibid.*, 2901 (1955); 4228 (1954).

[7] H. A. Brown, 128th National Meeting of the American Chemical Society, Minneapolis, 1955; Abstracts, p. 29-M.

[8] R. B. Wagner and H. D. Zook, "Synthetic Organic Chemistry," John Wiley and Sons, Inc., New York, N. Y., 1953, p. 821.

[9] Ya. A. Fialkov and Ya. B. Bur'yanov, *Dokl. Akad. Nauk, SSSR*, **92**, 585 (1953); *Chem. Abstr.*, **48**, 5708 (1954).

TABLE I

PHYSICAL PROPERTIES AND YIELDS OF SEVERAL FLUOROCARBON SULFONIC ANHYDRIDES AND SULFONYL HALIDES

Compound	B.p., °C.	n^{25}_D	Infrared band position for —SO_2X^a, μ	Yield, %
$(4\text{-}CF_3\text{-cyclo-}C_6F_{10}SO_2)_2O$	267–269	1.3443	6.76, 6.83 13.50, 13.75[b]	63[c]
$(4\text{-}C_2F_5\text{-cyclo-}C_6F_{10}SO_2)_2O$	207 (60 mm.)	1.3489	6.75, 6.83 13.71 broad[b]	95
$4\text{-}CF_3\text{-cyclo-}C_6F_{10}SO_2F$	131–132	1.3172	6.78	80
CF_3SO_2Cl	32	1.3315	6.98	94
$n\text{-}C_8F_{17}SO_2Cl$	121 (100 mm.) 108 (60 mm.)	(1.3278)[d] m.p. 36.5–7.5°	7.00	85[e]
$4\text{-}C_2F_5\text{-cyclo-}C_6F_{10}SO_2Cl$	118 (100 mm.) 105 (60 mm.)	1.3518[f]	7.01	53[c,g]

[a] Only the structure-sensitive S=O asymmetric stretching frequency is listed. [b] Very strong; presumably this is the S—O stretching frequency. [c] Yield was no doubt higher, as there were substantial losses in handling. [d] d^{25}_4 = 1.861; measured rapidly on the super cooled liquid. [e] Also 7% of the anhydride. [f] d^{25}_4 = 1.914. [g] Also 17% of the anhydride.

A more suitable low-melting complex was sought, and it was found that phosphorus pentachloride dissolves readily in well-stirred molten zinc chloride until the composition reaches $PCl_5 \cdot 2ZnCl_2$. Further additions result merely in dissociation of the excess phosphorus pentachloride; heavy losses of this component may also occur if the mixture is not stirred during the preparation. The stoichiometric compound, $PCl_5 \cdot 2ZnCl_2$, has m.p. 190°, and begins to evolve phosphorus trichloride and chlorine at 250°; if excess zinc chloride is present this dissociation temperature is raised yet further. Curiously, this simple inorganic compound had not been reported in the literature at the time this work was carried out; since then it has been described,[10] but no reactions of it were presented.

When metal salts of the fluorocarbon sulfonic acids were treated with $PCl_5 \cdot 2ZnCl_2$, or with solutions of it in excess zinc chloride, the corresponding sulfonyl chlorides were produced in high yield, little or none of the anhydride being formed. This would appear to be the method of choice for such preparations, since the intermediate sulfonate salt can be stored conveniently until such time as the chloride is desired. The volatile by-product, phosphorus oxychloride, is removed by distillation, highly pure sulfonyl chlorides being thereby recovered.

A technical advantage is realized when the zinc salt of the sulfonic acid is used, since the resulting zinc chloride, unlike potassium chloride, does not cause the reaction mixture to become semisolid. For this purpose it is desirable to use calcium hydroxide for the original alkaline hydrolysis of the sulfonyl fluoride, since the resulting highly soluble calcium salt is readily freed of excess base by treatment with carbon dioxide followed by filtration, which also removes the calcium fluoride produced in the reaction. The readily soluble zinc sulfonate is then obtained by metathesis with zinc sulfate. Other metal salts may be prepared in like fashion.

Physical properties and yields for the sulfonyl halides and anhydrides prepared in this research are presented in Table I. Literature values, where available, were generally confirmed, though $n\text{-}C_8F_{17}SO_2Cl$ was shown to be a solid of m.p. 36.5–37.5°; Gramstad and Haszeldine, had reported it as a liquid but gave the wrong refractive index. Presumably they did not have a sample of pure $n\text{-}C_8F_{17}SO_2Cl$.

Experimental

Materials.—The fluorinated sulfonic acids and their salts, dried at 110°, were available in these laboratories, having been prepared by the described methods.[2–5] They were of good purity, this being further demonstrated by analytical data gathered on their derivatives, and reported below. The $PCl_5 \cdot 2ZnCl_2$ reagent, m.p. 190°, was prepared by adding phosphorus pentachloride to well-stirred molten zinc chloride in an open round bottomed flask, until a limiting gain in weight, corresponding exactly to the stoichiometric amount, was observed. The lower-melting solution of $PCl_5 \cdot 2ZnCl_2$ in 2 moles of zinc chloride was prepared similarly, except that only half the gain in weight was permitted; no significance should be attached to this exact composition as no freezing-point maximum is observed. For synthetic purposes the weight *gain* is the important quantity, as it corresponds to usable phosphorus pentachloride.

Perfluoro(4-ethylcyclohexane)sulfonic Anhydride.—In a 500-ml. distilling flask fitted with air condenser was placed 200 g. (0.433 mole) of perfluoro(4-ethylcyclohexane)sulfonic acid and 50.0 g. (0.240 mole) of phosphorus pentachloride. Upon warming of the well mixed reagents frothing occurred, copious quantities of hydrogen chloride being given off; the remaining material became a porous, snow white, and apparently infusible plaster-like solid. With strong heating to *ca.* 180° decomposition occurred, and on further heating for over 3 hr. to *ca.* 225° about 90% of the theoretical amount of phosphorus oxychloride distilled and was collected. Some of the excess phosphorus pentachloride remained in the flask, but otherwise the product was liquid. It was cooled to room temperature and washed repeatedly with water to remove phosphorus halides and unchanged sulfonic acid. The crude sulfonic anhydride, 192 g. (97.5%), had n^{25}_D = 1.3486; after vacuum fractionation at 60 mm. there was recovered 187.1 g. (95%) the physical properties of which are listed in Table I.

Anal. Calcd. for $C_{16}F_{30}O_5S_2$: C, 21.20; F, 62.89. Found: C, 21.4; F, 63.4.

Related Reactions.—The reaction of 2.0 g. of perfluoro(4-ethylcyclohexane) sulfonic anhydride with 3 ml. of piperidine occurred at room temperature. The piperidide, 1.1 g. (95%), was recovered by dilution with water. It had m.p. 100–104° (recrystallized from ethanol).

Anal. Calcd. for $C_{13}H_{10}F_{15}NO_2S$: N, 2.65. Found: N, 2.69.

The anilide was prepared by heating the sulfonic anhydride with aniline to *ca.* 180°; the two immiscible phases suddenly coalesced and reacted. The product was dissolved in aqueous sodium carbonate, precipitated by acid, and recrystallized from concentrated aqueous acetic acid; it had m.p. 120–121°.

Anal. Calcd. for $C_{14}H_6F_{15}NO_2S$: C, 31.30; N, 2.61. Found: C, 31.4; N, 2.59. The 4-carboxyanilide was prepared similarly from 4-aminobenzoic acid, and had m.p. 234–235°.

Anal. Calcd. for $C_{15}H_6F_{15}NO_4S$: C, 30.99; N, 2.41. Found C, 31.1; N, 2.41. From this reaction there was also isolated some anilide, identified by melting point and mixture melting point with the authentic sample described previously.

---

(10) About three years after completion of this work, the author chanced to see a long paper on complexes of phosphorus pentachloride by, as he recalls, a Scandinavian author. Now, five years later, no record remains, and a diligent search of *Chem. Abstracts* and of likely journals has failed to locate it.

The sulfonic anhydride did not react at elevated temperatures with potassium chloride. When the anhydride, 40 g. (0.044 mole), and aluminum chloride, 10 g. (0.075 mole), were strongly heated in a 100-ml. distilling flask, volatile products were collected which, upon fractional distillation, gave 12.8 g. (60%) of 4-$C_2F_5C_6F_{10}SO_2Cl$, b.p. 184°, $n^{25}D$ 1.3516. The same product was obtained in slightly better yield, *ca.* 75%, when an equivalent amount of freshly fused zinc chloride was substituted for the aluminum chloride. A limitation, despite the relatively good yields, is that half of the sulfonic anhydride molecule is unavailable in these reactions.

Perfluoro-(4-methylcyclohexane)sulfonic anhydride was made in exactly similar fashion, except that only half as much sulfonic acid had been employed. The excess phosphorus pentachloride was driven off with heating and clogged the apparatus; handling losses resulted and the yield (63%) was not truly representative. The sulfonic anhydride was isolated by fractional distillation. Despite the excess of phosphorus pentachloride used here, none of the corresponding sulfonyl chloride could be detected in any fraction by infrared spectroscopy.

Anal. Calcd. for $C_{14}F_{26}O_5S_2$: C, 20.86; F, 61.27. Found: C, 21.0; F, 61.0. The piperidide prepared as above, had m.p. 89–99° (isomer mixture).

Anal. Calcd. for $C_{12}H_{10}F_{13}NO_2S$: N, 2.92. Found: N, 2.80.

A similar reaction of perfluoro(*n*-octane)sulfonic anhydride[4] with piperidine yielded the piperidide, m.p. 77.5–78.5° (lit., m.p. 75–76.5°[2]; 77°[4]). The anhydride had been prepared from the acid by reaction with phosphorus pentachloride (mole ratio 2:1), about a 10% yield of sulfonyl chloride also having been produced.

Perfluoro(4-methylcyclohexane)sulfonyl Fluoride.—In a 25-ml. flask fitted with a 10-cm. fractionating column filled with 1/16-in. "Helipak" (reg. t.m., Podbielniak Co.), was placed 20.8 g. (0.026 mole) of perfluoro(4-methylcyclohexane)sulfonic anhydride and 4.2 g. (0.10 mole) of sodium fluoride. The flask was slowly heated to 220° over a period of 10 hr. (more rapid heating should not be harmful), and refluxing volatile materials were taken off occasionally. The product, 8.5 g. (80%), boiled at 131–132° and had $n^{25}D$ 1.3172, in excellent agreement with reported data.[2]

Anal. Calcd. for $C_7F_{14}O_2S$: C, 20.30; F, 64.23. Found: C, 20.1; F, 64.2.

Perfluoroöctanesulfonyl Chloride.—Dried potassium perfluorooctanesulfonate, 240 g. (0.45 mole) was heated with $PCl_5 \cdot 2ZnCl_2$, 274 g. (0.57 mole of phosphorus pentachloride) and 156 g. of zinc chloride (1.14 moles) in a 1-l. distilling flask at 100 mm. until no more volatiles were collected. The distillate was fractionally distilled at reduced pressure and yielded, in two experiments, 201 g. (87%) and 192 g. (83%) of *n*-$C_8F_{17}SO_2Cl$, b.p. 121° (100 mm.), m.p. 36.5–7.5°.

Anal. Calcd. for $C_8ClF_{17}O_2S$: Cl, 6.84. Found: Cl, 6.95. Higher-boiling residues, *ca.* 6–8%, were shown by infrared analysis to be virtually pure perfluoöctanesulfonic anhydride.

When instead $PCl_5 \cdot 2ZnCl_2$ was used, the yield of sulfonyl chloride fell to 73–78%, much larger amounts of anhydride, *ca.* 18%, being recovered. The pasty, viscous condition of the reaction mixture may have been responsible for the lower yield, since less zinc chloride was present to establish a liquid phase; presumably some of the undissolved sulfonate salt reacted with sulfonyl chloride to give the anhydride.

Perfluoro(4-ethylcyclohexane)sulfonyl Chloride.—In a similar fashion 12.0 g. (0.024 mole) of dried potassium perfluoro(4-ethylcyclohexane)sulfonate reacted with 12.9 g. (0.027 mole) of $PCl_5 \cdot 2ZnCl_2$. Upon fractional distillation there was obtained 5.1 g. (53%) of 4-$C_2F_5C_6F_{10}SO_2Cl$, b.p. 118° (100 mm.).

Anal. Calcd. for $C_8ClF_{15}O_2S$: C, 19.99; F, 59.30; Cl, 7.38. Found: C, 20.0; F, 59.4; Cl, 7.48. Difficulties were encountered in the mixing of the reagents which would have been alleviated by use of $PCl_5 \cdot 4ZnCl_2$, and the 17% yield of anhydride might have been reduced appreciably also.

Trifluoromethanesulfonyl Chloride.—Dried zinc trifluoromethanesulfonate, 250 g. (0.69 mole), reacted with $PCl_5 \cdot 2ZnCl_2$, 928 g. (1.93 mole), by heating to 260° for 8 hr. at atmospheric pressure in a stirred 2-l. distilling flask. Upon fractional distillation of the volatile products, 220.1 g. (94%), of highly pure CF_3SO_2Cl, b.p. 32°, $n^{25}D$ 1.3315, was obtained. When the potassium salt was used instead, the sulfonyl chloride was obtained in somewhat lower yield, 80–85%, but equal purity.

Acknowledgment.—The author thanks Ray A. Malzahn for assistance with some of the sulfonyl chloride preparations, and Dr. J. J. McBrady for infrared analyses which greatly benefitted the research.

3-Indoleacetic Acid

HERBERT E. JOHNSON AND DONALD G. CROSBY

Research Department, Union Carbide Chemicals Company, South Charleston 3, West Virginia

Received September 1, 1961

The synthesis of indoleacetic acid in high yield by the reaction of indole with potassium glycolate at 250° is described. Selected methylated indoles also undergo this reaction as do salts of other α-hydroxy acids. The probable mechanism of the reaction is discussed.

3-Indoleacetic acid, its higher homologs, and their simple derivatives have been, over a period of the last twenty-five years, the subject of extensive investigation regarding their plant-growth regulating properties. A great many useful effects have been discovered, especially with the acetic and butyric acids, but the synthetic effort required to prepare these materials has precluded any practical agricultural applications. This communication describes a method by which indoleacetic acid may be readily prepared, namely by the direct reaction of indole with potassium glycolate.

Numerous examples of the reaction of simple primary and secondary alcohols with various indoles are known. For example, benzyl alcohol, hexahydrobenzyl alcohol, butanol, cyclohexanol, and others react with indole in the presence of a base and a nickel catalyst at 145–185° to give the corresponding 3-alkylated indoles.[1] At 210–220°, indole and alcohols react similarly in the presence of alkoxide and without a nickel catalyst, as do 2- and 7-methylindoles.[2,3] 2-Carboxyindole, however, reacts only with primary alcohols giving the 3-derivatives with concomitant loss of the carboxyl group.[2] Ethylene glycol and 2-ethoxyethanol gave 3-ethylindole under these conditions, while ethanolamine and *N,N*-diethylethanolamine gave no tryptamine derivatives or other characterizable products.[2] The reaction of other complex alcohols with indole apparently has not been reported.

Initial experiments in which indole and butyl glycolate were allowed to react together at 185° with a nickel catalyst, as described by Pratt and Botimer,[1] provided only traces of the desired ester. Further investigation led to heating indole with potassium

---

[1] E. F. Pratt and L. W. Botimer, *J. Am. Chem. Soc.*, **79**, 5248 (1957).

[2] R. H. Cornforth and R. Robinson, *J. Chem. Soc.*, **1942**, 680.

[3] B. Oddo and C. Alberti, *Gazz. chim. ital.*, **63**, 236 (1933); *Chem. Abstr.*, **27**, 3933 (1933).