

Determination of Fluorine in Organic Compounds

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The study of the chemistry of fluorine, beginning with the early research of Moissan and continuing with the brilliant investigations of Otto Ruff, has attracted an ever growing number of chemists. Elementary fluorine is one of the most active and vigorous substances known to man. However, in spite of its great activity, fluorine can form compounds of extraordinary stability when it is linked with carbon, particularly when more than one fluorine atom is attached to a single carbon atom. Such substances resist decomposition by almost all of the ordinary chemical reagents. The great stability of these fluorine compounds has resulted in their use as refrigerant fluids in certain popular brands of refrigerators, and in their being patented for use as fire extinguishers, insecticides, moth-repellants and pharmaceuticals. Of great interest to scientists is the fact that these compounds are non-toxic to human beings, since they are not decomposed in the lungs when inhaled. Accordingly, their use involves no health hazard, which is especially important in chemicals used in the home. Their stability suggests many more uses for these materials, one of the possible applications being as a general anesthetic.

At the present time, research in fluorine chemistry is being carried on in many university and industrial laboratories, particularly the study of the preparation, properties, and uses of organic compounds containing fluorine. The increasing research on these compounds and their increasingly widespread industrial application has called attention to the desirability of simple methods for determining fluorine. The lack of an entirely adequate analytical method often presents a serious obstacle to research. The unsatisfactory nature of the methods heretofore used in the analysis of these stable compounds is illustrated by the fact that one method which used a complicated apparatus took four and a half hours to decompose a single sample. Other investigators noted that it took a week of heating at a high temperature to decompose some of these fluorine compounds so that they could be analyzed. A recent statement by Henne, Whaley, and Stevenson (26), in an article dealing with the preparation of organic fluorides, will illustrate this point: "Fluorine analyses, which are difficult and tedious, were performed at crucial points only. In general, the analytical results have a tendency to be slightly low, and this is attributed to the great difficulty of obtaining a complete decomposition of these extremely stable compounds."

The determination of halogen, including fluorine, in organic compounds consists of two principal steps: (1) decomposition of the sample to yield ionizable halogen, and (2) determination of the halide ion. Several satisfactory procedures exist for the decomposition of organic compounds containing halogen other than fluorine, including the Carius method of heating with nitric acid in a closed tube, oxidation by sodium peroxide in a Parr bomb, combustion in oxygen, or hydrogenation in the presence of a suitable catalyst. Each of these decomposition methods

has its advantages and its limitations. After decomposition of the chloro, bromo, or iodo compound, various standard methods provide for the separation and determination of the halide ion.

Difficulties are introduced in the analysis of aromatic fluorine compounds or highly fluorinated aliphatic compounds because of the stability of the carbon to fluorine bond. Meyer states (33) that the other halogens in halofluoro compounds can be determined by the Carius method or by lime fusion in glass without splitting out the fluorine. The presence of fluorine also may increase the difficulty of determining chlorine in chlorofluoro compounds. Henne and Renoll (24) state that the chlorine in certain chlorofluoropropanes could be determined only by the Carius method, which required a whole week of continuous heating at 250° C. to 300° C. to yield quantitative results. The Carius method, even if sufficiently drastic to decompose fluoro compounds, is unsatisfactory because the resulting hydrogen fluoride or hydrofluoric acid attacks the glass of the reaction tube.

The methods at present described in the literature, with few exceptions, either do not work for the more stable compounds or are described in insufficient detail and without sufficient experimental verification to permit their use. Most of the fluorine compounds for which analyses are reported are of comparatively low fluorine content, commonly having only a single fluorine atom in a molecule of high molecular weight. This choice of compounds makes the methods appear better than they actually are for two reasons: (1) a relatively large error on the basis of fluorine present appears as a small percentage error; and (2) applicability of the method to the more stable compounds containing two or three fluorine atoms on a single carbon atom is not tested.

Since the standard texts and references on organic analysis fail in most cases even to mention the topic, it is worth while to summarize the methods which have been proposed in the literature for the decomposition of organic fluoro compounds and the recovery of fluoride ion in a determinable form. Meyer (33) and Bockemüller (4, 5) give the most extensive discussions of the topic but the principle of the methods described is not clearly indicated nor is the method of determining fluoride ion shown; moreover, the treatment is incomplete and non-critical. Table I classifies the methods which have been suggested in the literature, and which are discussed in the following paragraphs. This classification is based upon the recent one of Elving and Ligett (14) which did not, however, describe the methods mentioned nor indicate the applicability of the various procedures.

TABLE I.—Decomposition of Organic Compounds Containing Fluorine

- I. Oxidation Methods
 - A. Combustion in oxygen (4, 31, 36, 38)
 - B. Fusion with sodium peroxide (13, 19, 28, 39, 46)
 - C. Alkaline oxidation (3)
- II. Reduction Methods
 - A. Combustion in hydrogen (8, 50, 51)
 - B. Treatment with sodium in liquid ammonia (18, 52)
 - C. Treatment with alkali metal in organic solvent (53, 54)
 - D. Alkali metal fusion (1, 14, 29, 40, 41, 42, 43, 47)

III. Methods Involving Alkaline Fusion

A. Fusion with calcium oxide (2, 11, 12, 15, 25, 30, 34, 44, 45, 48)

B. Fusion with sodium carbonate or hydroxide (6, 16)

IV. Methods Involving Reaction with Silicon Dioxide

A. Corrosive action on glass (7, 22, 37)

B. Combustion over silicon dioxide using oxygen and hydrogen (10, 23, 24, 27)

V. Hydrolytic Methods (21, 32, 35, 49)

Oxidation Methods. The fluorine in methyl and ethyl fluorides was determined by Moissan (36) by combustion in a stream of oxygen in a copper tube containing a mixture of 80 per cent cupric oxide and 20 per cent lead monoxide. Bockemüller (4) burned samples of organic fluorides mixed with calcium carbonate in a platinum boat in a platinum tube; the fluorine was converted into calcium fluoride. The results for five compounds were good to ± 0.3 absolute per cent of fluorine present. It has been suggested (31) that the fluorine in gaseous organic fluorides be determined by burning the compound in oxygen on a hot platinum wire; the hydrofluoric acid formed is absorbed in an excess of standard alkali solution. Paterno (38) was able to determine fluorine by combustion under 25 atmospheres pressure in a calorimetric bomb containing potassium iodide and iodate, iodine equivalent to the fluorine was liberated and determined by titration with standard thiosulfate solution.

The determination of fluorine by oxidation of the organic fluoride with sodium peroxide in a Parr bomb seems to be successful with many compounds (13, 19, 39). The filling commonly used in the bomb consists of 0.5 gram of sample (not over 0.1 gram fluorine), 0.5 gram of sugar or starch, and 14 grams of sodium peroxide. Shoesmith, Sosson, and Slater (46) found that certain fluoro compounds explode spontaneously when mixed with the peroxide in an open vessel. Küster and Neunhoffer (28) claimed to be able to decompose organic fluorides by ignition in a nickel crucible with calcium peroxide or with a mixture of sodium carbonate and sodium peroxide.

Blum and Vaubel (3) were able to determine the fluorine content of fluorine derivatives of proteins by fusion with sodium hydroxide and potassium nitrate in a nickel dish and precipitation of barium fluoride along with barium sulfate from the resulting extract.

Reduction Methods. The reduction methods for converting fluorine in organic compounds to fluoride ion use either hydrogen gas or free alkali metal. Cadenbach (8) suggested vaporizing the compound in a stream of hydrogen and burning the resulting mixture. Tetrafluoromethane had been detected by burning the suspected gas with hydrogen and noting the etching action of the flame (50). Treadwell and Zurcher (51) determined the fluorine and chlorine in three methane derivatives and one benzene derivative by burning the sample with hydrogen and a little air in a narrow platinum capillary and analyzing the resulting condensate for hydrofluoric and hydrochloric acids.

In 1931, Vaughan and Nieuwland (52) reported that fluoride ion could be recovered from organic fluorides by treatment of the liquid ammonia solution of the compound with metallic sodium. Results were

reported for four aromatic and one aliphatic compound. This method was also used by Govaert (18). Earlier, the presence of fluorine in 2-fluoro-6-nitrobenzoic acid had been shown by fusion with sodium and evolution of hydrofluoric acid from the resulting properly prepared residue (29). Ruff and coworkers (41, 42, 43) reported decomposing fluoromethane, fluoroform, and trifluoronitromethane, allowing the gases to stream into an evacuated quartz tube containing heated sodium in an iron boat. Complete destruction was apparently not secured even after repeated passage over the hot sodium metal and the amount of residual gas had to be determined. Simons and Block (47) were able to decompose fluorocarbons by an analogous technic with fairly good results. Wallach and Heusler (53) described a procedure for determining the fluorine in fluorobenzene which consists of keeping at 100° C. for several days a sealed tube containing equal volumes of the compound and of dry benzene, and sodium wire. Whearty (54) refluxed alcoholic solutions of fluorinated chlorobenzenes with metallic potassium and determined the fluoride ion formed by precipitation as calcium fluoride. Unfortunately, the results reported for fluorine fitted a probable formula in only one of the three analyses reported. Piccard and Buffat (40) analyzed fluorobenzene for fluorine by heating the compound to 400° C. with metallic potassium in an evacuated tube; the fluoride ion formed was determined by conductometric titration with calcium chloride. The results on three samples of fluorobenzene were ± 0.4 absolute per cent of the correct value. Potassium fusion has been used to detect the presence of fluorine in aromatic compounds (1).

The most thorough investigation of the reduction technic for the determination of fluorine in organic compounds was made by Elving and Ligett (14). The procedure which they developed depends upon decomposition of the compound by heating with sodium or potassium metal in an evacuated sealed glass tube at a moderately elevated temperature, i.e., 350° C. to 450° C., and determination of the resulting alkali fluoride by standard methods. The most applicable procedure for the latter seems to be precipitation of the fluoride ion as lead chlorofluoride and determination of the fluoride content of the precipitate by titration with standard silver nitrate solution (17, 20), using Volhard's method with the addition of nitrobenzene to avoid the necessity of filtering the precipitated silver chloride (9). The same technic serves for the analysis of chloro, bromo, and iodo compounds and has several advantages over the procedures commonly employed in these determinations. Analytical results were presented for twenty-four organic halogen compounds, including samples which were in the gaseous, liquid, or solid state, and which represented examples from the aliphatic, aromatic, alicyclic and heterocyclic series. Compounds with fluorine content as high as 60 per cent and two or three fluorine atoms on the same carbon atom were successfully analyzed. The procedure permitted the simultaneous determination of chlorine and fluorine in chlorofluoro organic compounds.

Since the paper describing this procedure was published, hundreds of organic halogen compounds, a majority of which contained fluorine, have been successfully analyzed by this technic. Other analysts have

also found the method applicable in analyzing organic fluorides which resisted decomposition by other means.

Methods Involving Alkaline Fusion. Several investigators have endeavored to apply the Liebig lime fusion method to organic fluorine-containing compounds. Attempts to carry out the fusion in glass resulted in the formation of some silicon tetrafluoride and in partial loss of sample (45). The use of a platinum tube improved the results but the latter were still in error by one or more absolute per cent (2, 11, 12). Meyer and Hub (34) asserted that to remove fluorine linked to an aromatic nucleus it is necessary to decompose the compound at 1000° C., which they did by heating the sample mixed with calcium oxide in an open nickel tube to yellow heat for two hours. The results on *o*-fluorobenzoic acid and *o*-fluorobenzamide were appreciably low. Better results were reported (15, 48) in analyzing the three fluorobenzoic acids and analogous fluorine compounds by this method. Ruff and Keim (44) found the correct fluorine to chlorine ratio on passing trichlorofluoromethane mixed with steam and nitrogen over hot calcium oxide in a platinum tube. Henne and Renoll (25) analyzed chlorofluoropropanes by decomposition over red hot calcium oxide in a small steel bomb. Unfortunately, no experimental details were given except the chlorine to fluorine ratios found, the accuracy being ± 0.05 for calculated ratios of 0.75 to 1.67. In an article by MacNevin and Baxley (30) applying the method of Henne and Renoll to the determination of chlorine in organic compounds, no mention is made concerning the details of the fluorine determination. Brauns (6) reported that fluoroacetyl sugars are decomposed by careful ignition with sodium carbonate, while Freudenberg and coworkers (16) were able to decompose ethyl phenylfluoroacetate by prolonged fusion with sodium hydroxide.

Methods Involving Reaction with Silicon Dioxide. The ready formation and volatility of silicon tetrafluoride under suitable conditions has been utilized in several methods proposed for the determination of fluorine in organic compounds. Several procedures have been used to determine the amount of fluorine from the empirically calibrated loss in weight of a glass plate exposed to the hydrofluoric acid formed when the compound is suitably treated with sulfuric acid, or by the similar loss in the glass vessel in which the reaction occurs (22, 37). In the most recent procedure (7) of this type, the sample is treated with potassium nitrate and sulfuric acid in a Pyrex flask, 1 mg. loss in the weight of the flask corresponding to 1.2 mg. of fluorine. The procedure requires about 4 hours. Hubbard and Henne (27) described a method for the simultaneous determination of chlorine and fluorine in aliphatic compounds which consisted of passing a measured amount of the gaseous or vaporized compound mixed with air or oxygen through a quartz tube heated to 900°C. and packed with crushed silica. The tube is then swept successively with oxygen, nitrogen, hydrogen (to remove absorbed silicon fluoride and to reduce silicon oxyfluoride), and nitrogen. The exit gases are passed through an absorbent solution containing sodium hydroxide and hydrogen peroxide, and the fluoride and chloride formed

are determined in separate portions of the solution. In a later paper, Henne and Renoll (24) mentioned that only the gaseous and highly volatile chlorofluoropropanes could be analyzed by decomposition over white hot silica. Calfee, Bigelow and coworkers (10) described a procedure based on Hubbard and Henne's method; a single combustion took 4.5 hours, exclusive of time needed to prepare and weigh the sample and to determine the halides in the absorbent solution. These workers reported the results for two methane and three ethane chlorofluoro derivatives. In 1938, a patent (23) was issued to Henne for detecting volatile organic fluorine derivatives in air, which was based on bringing the suspected air into contact with incandescent silica and passing the resulting gas into contact with ammonia to form a white cloud or precipitate.

Hydrolytic Methods. The stability of the carbon to fluorine bond is lessened, and the fluorine can be removed by hydrolysis, if oxygen is linked to the carbon in a carbonyl linkage as in acid fluorides. Helferich and coworkers (21) reported that d-glucosyl fluoride would surrender all its fluorine on ten minutes heating in acid solution. They also reported successful results on using the lime fusion method on this compound. Acetyl fluoride was decomposed by heating with an aqueous solution of calcium chloride (32), and Swarts (49) asserted that fluorine in the side chain of aromatic compounds could be removed by heating to 200°C. with concentrated sulfuric acid or by heating to 150°C. with water in a sealed tube. Moissan (35) found that the fluorine in alkyl fluorides is converted to silicon tetrafluoride on standing for seven or eight days with sulfuric acid in a buret over mercury.

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