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SYNTHESIS OF AROMATIC FLUORIDES THROUGH DIAZOTIZATION  
IN ANHYDROUS HYDROGEN FLUORIDE

by

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## Table of Contents

Introduction -----	1
The Experimental Studies -----	9
Figure 1. Decomposition Apparatus -----	10
Discussion of Results -----	41
A General Method for the Preparation of Aromatic Fluorides -----	41
Table I. Aromatic Fluorides Synthesized Through Diazotization in Anhydrous Hydrogen Fluoride -----	44
Identities of Fluoro-Products -----	48
Table II. Comparison of the Experimental and Literature Values of Physical Properties for the Fluoro-Products Syn- thesized -----	50
Comparison With the Schiemann Reaction --	52
Effect of Ring Substituents Upon De- composition -----	54
Table III. Comparison of the Yields of Aromatic Fluorides Obtained Through Diazotization in Anhydrous Hydrogen Fluoride and by the Schiemann Reaction --	55
Table IV. The Relative Ease of De- composition of Diazonium Fluorides in Anhydrous Hydrogen Fluoride -----	56
Summary -----	62
Bibliography -----	63

SYNTHESIS OF AROMATIC FLUORIDES THROUGH DIAZOTIZATION  
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Introduction

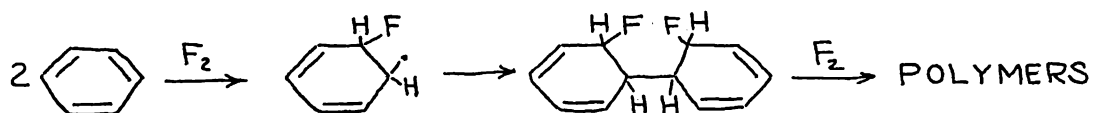
Knowledge of the element fluorine and its compounds has been advanced in slow, uncertain steps from the time Ampère suggested<sup>1</sup> to Sir Humphry Davy that hydrofluoric acid, which had been described as early as 1768 by Marggraf,<sup>2</sup> was a compound of hydrogen and an unknown element, through the moment on June 26, 1886 when Moissan<sup>3</sup> isolated and characterized this free element, and on into the next century where most of the investigational work on the synthesis and properties of organic fluorine compounds was carried out almost solely by the Belgian chemist Frédéric Swarts, until about the year 1925.

Until that time, accurate information was so completely lacking that most technical men regarded all organic compounds of fluorine as dangerous laboratory curiosities, and indeed this extremely misleading viewpoint was not completely eradicated until after the commercial production of the "Freons", which are used as refrigerants in household cooling machines and in air conditioning equipment, was pioneered by Midgley and Henne in 1930.<sup>4</sup> Anhydrous hydrogen fluoride was made available commercially shortly thereafter and elemental fluorine, itself, was placed on the market in

1946. These events have awakened great interest in the synthesis of organic fluorine compounds, which have found use as refrigerants, dyes, plastics, insecticides, and pharmaceuticals.<sup>5</sup> The synthesis of fluorocarbons<sup>6</sup> has led to a particularly interesting group of compounds which have proved to be valuable as highly stable and chemically resistant lubricating oils, lubricant additives, and heat transfer and dielectric media.

At present most such commercial applications of fluorine chemistry involve the use of aliphatic fluorine compounds since they are cheaply prepared by relatively simple methods from readily available materials.<sup>6,7,8</sup> It is expected that aromatic fluorides will prove to be of equal or perhaps even greater value as chemical intermediates when they can be economically prepared on a large scale. For example, a fluorine analog of DDT has been reported to be superior as an insecticide.<sup>9</sup> According to the concept of isosterism,<sup>10</sup> chemotherapeutic agents containing fluorine substituted for the isosteric hydroxy and amino groups may be valuable medicinals.<sup>11</sup> Fluorinated azo dyes suitable for use with cellulose derivatives, silk, wool, nylon, vinyl acetate-vinyl chloride copolymers, and protein synthetics have been prepared.<sup>12</sup> Copolymer of butadiene with m-fluorostyrene appears to be superior, particularly in resistance to failure due to flexing, to the butadiene-styrene copolymer GR-S.<sup>13</sup>

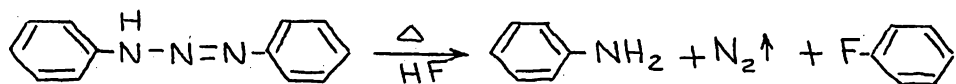
Attempts to synthesize aromatic fluorides have followed a number of varied paths to achieve more or less limited degrees of success. The action of elementary fluorine upon aromatic compounds has been thoroughly investigated,<sup>14 to 19</sup> but only mixtures of polymeric substances result. This is presumably the result of the tendency of elementary fluorine to react with aromatic double bonds rather than to substitute for nuclear hydrogen atoms.<sup>15</sup> With benzene itself, for example, fluorine appears to react as follows:



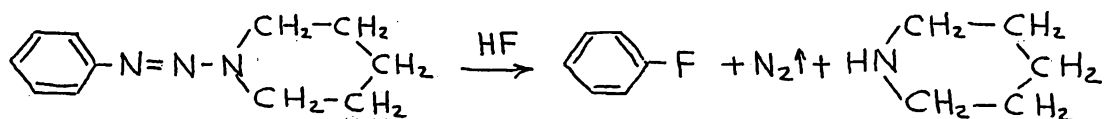
Lead tetrafluoride has been reported to act upon acetanilide to give a 10% yield of *p*-fluoroacetanilide, although in other cases no reaction occurs or tars and polymers are formed.<sup>20</sup> The same limitations<sup>21</sup> apply to the reaction of phenyliodofluoride,  $C_6H_5IF_2$ , with aromatic compounds, except that a small yield of the *p*-fluoroderivative has been obtained from dimethylaniline. Aromatic fluorides can be prepared from aromatic halides by replacement reactions with hydrogen fluoride or metallic fluorides in only special cases where the halogen-carbon bond is weakened by the presence of other groups on the benzene ring. Thus 2,4-dinitrofluorobenzene may be prepared in good yield by heating 2,4-dinitrochlorobenzene with potassium fluoride in the presence of an inert solvent.<sup>22,23</sup>

More successful methods for the synthesis of aromatic fluorides involve the replacement of the aromatic amino group with fluorine through diazotization. Unfortunately the methods of Sandmeyer<sup>24</sup> and Gatterman,<sup>25</sup> which involve the decomposition of aqueous solutions of aryl-diazonium salts in the presence of catalysts such as cuprous halides or powdered copper to produce good yields of aromatic iodides, bromides, chlorides, and cyanides, give poor yields when applied to the synthesis of aromatic fluorides. Fluorobenzene is thereby obtained from aniline in yields of only a little over 20%,<sup>26,27</sup> and a large amount of phenol is formed through reaction with the water present. Hodgson<sup>28</sup> attributes the poor results obtained under such conditions to the fact that in aqueous solution hydrofluoric acid is largely ionized as  $H^+$  and  $HF_2^-$ , and that the yields of fluorocompounds are due to reaction of the diazonium ion with non-ionized HF, the  $HF_2^-$  anion being unreactive. Omission of the usual Sandmeyer and Gattermann catalysts produces no deleterious effects, and increasing the concentration of the hydrofluoric acid raises the yields of the aromatic fluorides. Thus Swarts<sup>29</sup> prepared *p*- and *m*-fluoronitrobenzene in yields of 70 and 50% respectively by using 70% hydrofluoric acid.

Another reaction leading to the formation of aromatic fluorides involves the decomposition of diazoamino compounds by warming with concentrated hydrofluoric acid according to the equation:<sup>30,31</sup>



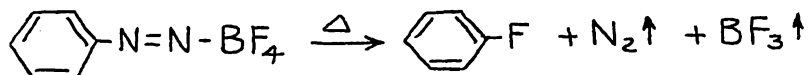
At best only one-half of the aromatic amine used can be converted by this method, and the yields are usually less than 50% due to the formation of resinous byproducts. In a similar fashion, aryldiazopiperidides are split by treatment with concentrated hydrofluoric acid at room temperature to yield aromatic fluorides as follows:<sup>26,27</sup>



The yields are usually less than 50%, and due to its vigorous nature, the reaction cannot be safely carried out with larger than 10 g. quantities.

The most successful method, which is used for almost all of present day preparative work in the synthesis of aromatic fluorides, is the so called "Schiemann reaction". This method, which was originated by Gunther Balz and Gunther Schiemann<sup>32</sup> after the announcement<sup>33</sup> of the isolation of stable solid diazonium borofluorides, and which was then further extended by Schiemann,<sup>34 to 39</sup> is based upon the thermal decomposition of such solid dry diazonium borofluorides to give aromatic fluorides in good yields as follows:





The diazonium borofluorides, which are formed when concentrated fluoboric acid, or an aqueous solution of sodium fluoborate<sup>40</sup> is added to an aqueous solution of the diazotized amine prepared in the usual manner, are isolated by virtue of their low solubilities in water, and in contrast to most diazonium salts, are quite stable when dry, but they are slowly decomposed by the action of light. Upon heating they usually decompose smoothly and without violence in the manner indicated above. In similar fashion, several little-studied diazonium salts, such as benzenediazonium hexafluorophosphate,<sup>41</sup> benzenediazonium hexafluoroantimonate,<sup>42</sup> and p-carbethoxybenzenediazonium hexafluoro-silicate,<sup>43</sup> have been reported to give rise to small amounts of aromatic fluorides when thermally decomposed in a dry state.

The Schiemann reaction has been modified by Roe and Hawkins<sup>44</sup> to permit the synthesis of heterocyclic fluorine<sup>compounds</sup> by diazotization of the corresponding amines in either aqueous or ethanolic concentrated fluoboric acid solution through addition of solid sodium nitrite or gaseous ethyl nitrite at 0°. The decomposition is then carried out either immediately by warming the diazotization reaction mixture, or by separating the precipitated diazonium fluo-

boride and warming it while suspended in petroleum ether.

The methods for the synthesis of aromatic fluorides hitherto discussed are not well suited for adaption to the economical production of such compounds on a large scale, either because of the low yields obtained or because of the expense of the reactants and of carrying out the operations involved. This is illustrated by the prices quoted<sup>a</sup> for quantity sales of the following typical aromatic fluorides:

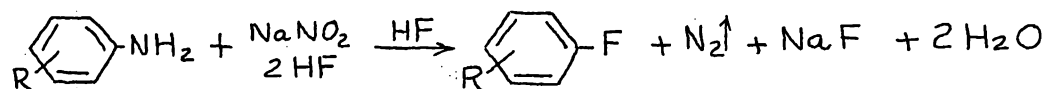
Fluorobenzene -----	\$ 35.00/ Kg.
p-Fluorotoluene -----	55.00 "
p-Fluoronitrobenzene -----	75.00 "
p-Fluorobenzoic acid -----	450.00 "

Replacement of the aromatic amino group with fluorine through formation and decomposition of the corresponding diazonium fluorides in liquid anhydrous hydrogen fluoride appears to be a method which will be satisfactory for the production of aromatic fluorides at relatively low cost. The operations involved consist of preparation of a solution of the desired aromatic amine in an excess of anhydrous hydrogen fluoride, which serves both as reactant and solvent, slow addition of solid sodium nitrite to the cooled gently agitated solution, decomposition of the diazonium fluoride by warming the solution under reflux to a temperature that depends upon the particular amine used,

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<sup>a</sup> Private communication from Fluor-Syn Laboratories, Milwaukee, Wisconsin, May 1948.

and separation of the aromatic fluoride from the excess hydrogen fluoride and other by-products. Although as indicated by the following general overall equation for such syntheses,



2 moles of water are formed for each mole of aromatic amine diazotized, most of the excess hydrogen fluoride could be largely recovered by rectification<sup>45</sup> and recycled. In addition, due to its low solubility in water, most of the sodium fluoride formed could be economically recovered quite easily, and perhaps sold as an ingredient for inorganic insecticidal mixtures, or be reconverted through reaction with sulfuric acid to hydrogen fluoride.

Although fluorobenzene was prepared from aniline through diazotization in anhydrous hydrogen fluoride as early as 1934,<sup>46</sup> the general applicability of this method for the synthesis of other typical aromatic fluorides has not been investigated. Other published works on this subject include a brief discussion of German fluorobenzene production during the recent World War,<sup>47</sup> and the report by Bradlow and VanderWerf<sup>11</sup> that *m*-fluorophenol may be synthesized from *m*-aminophenol through diazotization in anhydrous hydrogen fluoride. The following studies, which are reported for the first time in this paper, show that this method is successful in many cases, and that because

of its simplicity it is often preferable to the methods now commonly used for the synthesis of aromatic fluorides upon a laboratory scale.

### The Experimental Studies<sup>a,b</sup>

General Procedure.—Approximately 20 moles of anhydrous hydrogen fluoride<sup>c</sup> was slowly added to 1 mole of the purified amine contained in a two-neck, one-liter monel metal<sup>d</sup> flask cooled in ice-water. The solution was stirred at 0° with a stainless steel paddle stirrer<sup>e</sup> while 82.8 g. (1.2 moles) of reagent grade sodium nitrite<sup>f</sup> was added in small portions over an hour's time. The metal flask was then attached to the decomposing apparatus shown in Figure 1. This consisted of a copper reflux coil(2)<sup>g</sup> welded into.

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<sup>a</sup> All refractive indices and melting points are corrected. Boiling points are not corrected.

<sup>b</sup> All analyses were carried out by the Clark Micro-analytical Laboratory, Urbana, Illinois.

<sup>c</sup> Commercial grade hydrogen fluoride from the Harshaw Chemical Co., Cleveland, Ohio, was distilled directly from the tank into the reaction vessel.

<sup>d</sup> Monel metal proved superior to copper or stainless steel. All metal flasks were obtained from the Scientific Glass Apparatus Co., Bloomfield, New Jersey.

<sup>e</sup> This consisted of a single arc-shaped blade 3 inches in diameter and 3/4 inch in depth; purchased from the Wilkens-Anderson Co., Chicago, Illinois.

<sup>f</sup> Dried overnight at 110° and powdered for convenience in addition; purchased from Merck Co., Rahway, N. J.

<sup>g</sup> Six 7 inch diameter turns of 3/4 inch O. D. copper tubing obtained from a large size water heater.

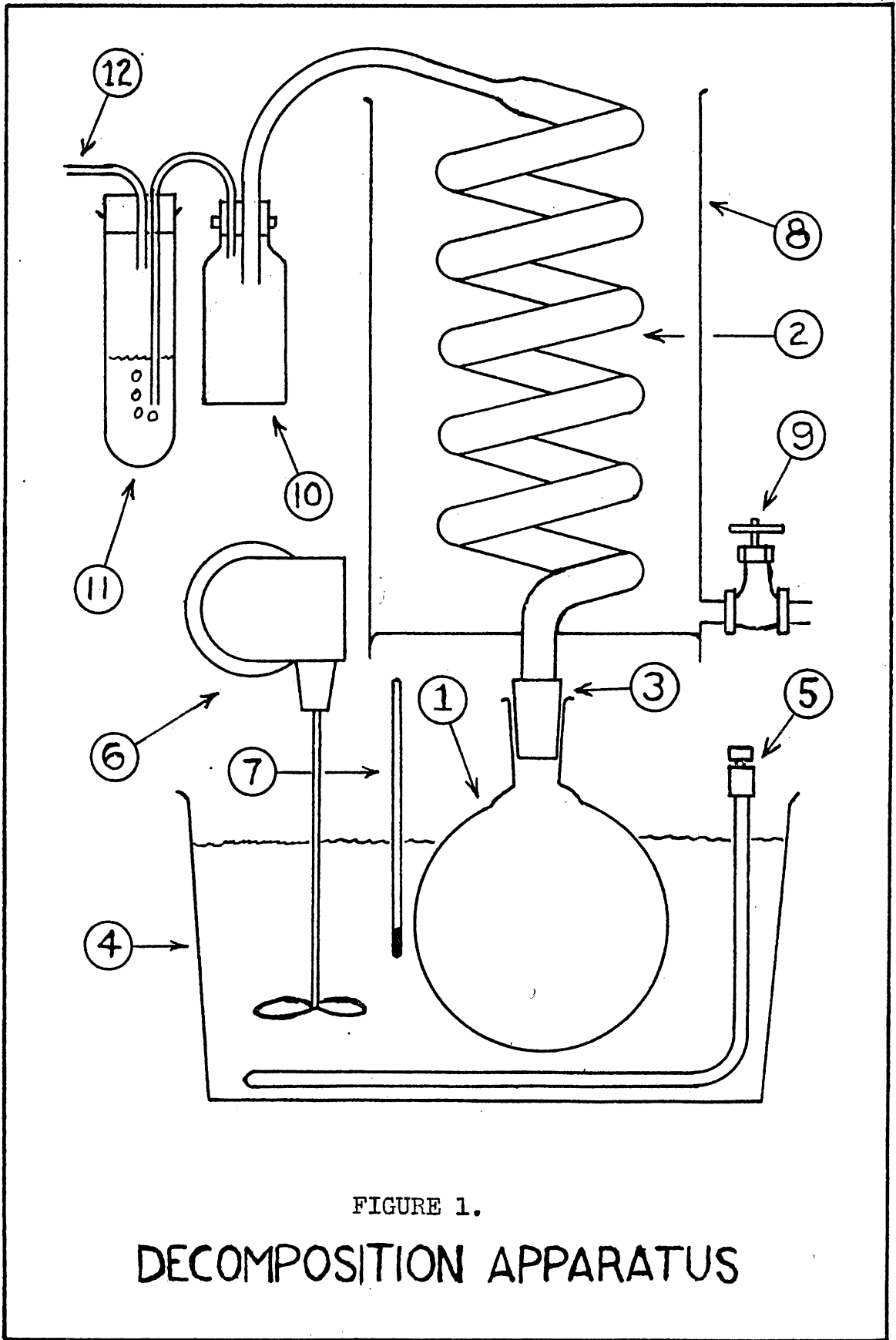


FIGURE 1.

DECOMPOSITION APPARATUS

a 5 gallon solvent can(8) (top removed) which had been painted and insulated with a covering of asbestos. The coil was cooled with crushed ice; excess water was run to the drain through a valve(9). Connection to the flask was made by means of a 24/40 standard taper metal joint(3).<sup>a</sup> The second neck (not shown in Figure 1.) was closed with a rubber stopper bearing a copper thermometer well.<sup>b</sup> The flask was heated by a water bath(4) containing a motor driven stirrer(6), a thermometer(7), and a 500 watt heat-coil(5),<sup>c</sup> which was controlled by a Variac transformer. The temperature of the bath was slowly increased until a moderate evolution of nitrogen was indicated by the bubbler (11), which was connected to the reflux coil through a safety trap(10). Heating was continued and the temperature slowly raised until nitrogen evolution ceased.

In most cases the reaction mixtures were cooled, diluted with about 200 g. of ice, and steam distilled from a metal flask. The distillates were condensed by passage through a water-jacketed 1/2 inch copper tube. Very little hydrofluoric acid distills under these conditions, and it is possible to use an ordinary glass condenser 10 to 15

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<sup>a</sup> Machined from solid copper stock by the Lawrence Iron Works.

<sup>b</sup> Made by welding shut one end of an 8 inch piece of 5/8 inch O. D. copper tubing.

<sup>c</sup> Purchased from the American Instrument Co., Silver-spring, Maryland.

times before failure, depending upon the circumstances involved. The crude products thus obtained were filtered off if solids, and recrystallized from a suitable solvent. Liquid products were either separated directly with a separatory funnel, or extracted and taken up in diethyl-ether. The liquids or ether solutions were washed with 5% potassium hydroxide solution when permissible to remove traces of phenolic by-products, and then treated with suitable drying agents, such as "Drierite" or anhydrous calcium chloride to remove traces of water. In some cases, as for example in the syntheses of the fluorobenzoic acids, it was possible to filter the fluoro-products directly, if they were precipitated as solids when the reaction mixtures were diluted with ice. In the cases of basic products, such as 2-fluoro-3-methylpyridine, as much excess hydrogen fluoride as possible was evaporated on a steam bath before the reaction mixtures were diluted with ice. The residues were then made basic to litmus with 10% aqueous potassium hydroxide solution, and extracted with ether to remove the products. All products gave positive qualitative tests for fluorine content when subjected to fusion with metallic sodium, and tested for fluoride ion with an alizarin-zirconium spot test.<sup>48</sup> All reported procedures represent best methods, chosen after repeated trial runs under various conditions. In some cases as many as six such preliminary experiments, devised to reveal optimum conditions for a given synthesis, were run.

Fluorobenzene.-A solution of 93.1 g. (1.0 mole) of freshly distilled aniline,<sup>a</sup> b. p. 181.5-181.7° at 736 mm., in 411 g. (20.5 moles) of anhydrous hydrogen fluoride contained in a 1-liter, 2-neck monel metal flask was cooled in an ice bath to 0°, and slowly diazotized by addition, with mechanical stirring of 82.8 g. (1.2 moles) of powdered sodium nitrite in small portions over a period of an hour. The flask was then connected to the decomposition apparatus and slowly warmed to 30°, as indicated by a thermometer in a copper thermometer well carried in the side-neck of the flask. Moderate evolution of nitrogen, about 2 bubbles per second, was then then indicated by the bubbler. The temperature of the water bath was slowly raised over a period of three hours until nitrogen evolution had ceased. The temperature of the reaction mixture was then 40°. The metal flask was then disconnected and cooled in an ice bath. The reaction mixture was diluted by addition with shaking of about 200 g. of crushed ice. The entire contents of the monel flask were then poured and rinsed with several portions of distilled water into a 2-liter copper flask, and then subjected to steam distillation. The distillate contained crude fluorobenzene as a water-insoluble oil, which was isolated with a separatory funnel, and washed with 50 ml. of 5% aqueous potassium hydroxide solution to remove any phenol. The crude fluorobenzene thus obtained

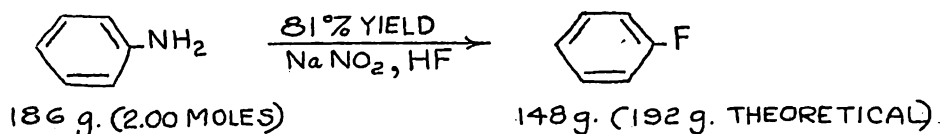
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<sup>a</sup> From the Eastman Kodak Co., Rochester, N. Y.; all amines used were from Eastman unless otherwise noted.



weighed 79.2 g. (82.4% yield of the theoretical as calculated on the aniline used), and upon distillation from a 200 ml. modified-Claisen flask<sup>a</sup> through a 10 inch Vigreux column gave 73.3 g. (76.3% yield) of pure fluorobenzene, b. p. 84-85° at 735 mm.,  $n_{D}^{20} = 1.4599$ . Balz and Schiemann<sup>32</sup> report b. p. 85° at 760 mm., and Schiemann and Pollarsky<sup>36</sup> report  $n_{D}^{20} = 1.46673$  for pure fluorobenzene.

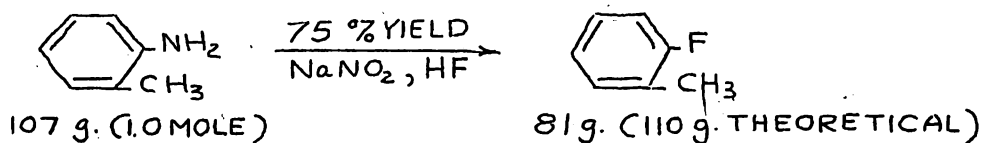
The preparation of fluorobenzene upon a larger scale was carried out by diazotizing a solution of 186.2 g. (2.0 moles) of aniline in 760 g. (38.0 moles) of anhydrous hydrogen fluoride, contained in a 2-liter stainless steel flask, by the addition of 158.7 g. (2.3 moles) of sodium nitrite over a period of 1½ hours at a temperature of 0°. Decomposition was carried out by allowing the reaction mixture to stand overnight at room temperature, about 30°, while the system was connected to the ice-cooled reflux coil. Steam distillation, followed by washing with 5% aqueous potassium hydroxide solution, gave 159 g. (87.1% yield) of crude fluorobenzene, which was distilled through a 10 inch Vigreux column to give 147.9 g. (81.1% yield) of pure fluorobenzene.



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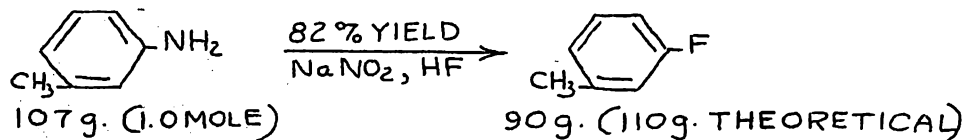
<sup>a</sup> Equipped with a sealed-in thermometer well, and standard taper joints.

o-Fluorotoluene.—A solution of 107.1 g. (1.0 mole) of o-toluidine, b. p. 196-198° at 754 mm., in 405 g. (20.3 moles) of anhydrous hydrogen fluoride, contained in a 1-liter monel metal flask, was diazotized in the usual manner by the addition of 82.8 g. (1.2 moles) of sodium nitrite at 0° over an hour's time. The decomposition, which was carried out as described before, was noted to have already begun, as evidenced by slow evolution of nitrogen, when the diazotization was completed at 0°, and was concluded two hours later when the reaction mixture had warmed to 25°. The crude o-fluorotoluene, obtained after steam distillation and washing with 5% potassium hydroxide solution, weighed 82.2 g. (74.5% yield). Distillation through a 10-inch Vigreux column gave 80.7 g. (73.2% yield) of pure o-fluorotoluene, b. p. 112.0-112.5° at 732 mm.,  $n_D^{31.0}$  1.4679. No sign of any decomposition, such as etching of glass, odor of hydrogen fluoride or visual changes in the product, could be detected when the o-fluorotoluene was distilled at 112° at atmospheric pressure. Holleman<sup>49</sup> reports b. p. 114° at 760 mm., and Schiemann, et al.<sup>38</sup> report  $n_D^{21}$  1.47383 for pure o-fluorotoluene.

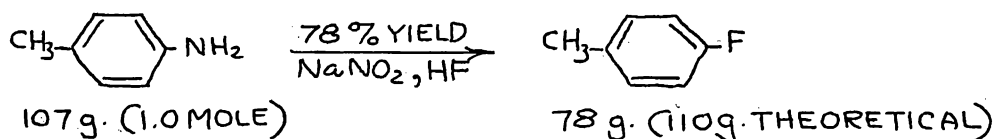


m-Fluorotoluene.—A solution of 107.1 g. (1.0 mole) of m-toluidine, b. p. 199-200° at 737 mm., in 415 g. (20.7 moles) of anhydrous hydrogen fluoride, contained in a 1-

liter monel metal flask, was diazotized at 0° with 82.8 g. (1.2 moles) of sodium nitrite. Decomposition was carried out from 15 to 30° over a period of two hours. Steam distillation, followed by a wash with 5% potassium hydroxide solution, gave 92.5 g. (83.9% yield) of crude *m*-fluorotoluene. Distillation through a 10-inch Vigreux column gave 80.4 g. (82.0% yield) of pure *m*-fluorotoluene, b. p. 113.5-114.0° at 737 mm.,  $n_{D}^{27.2} = 1.4672$ . This agrees with the literature values of b. p. 115° at 756 mm.,<sup>38</sup> and  $n_{D}^{27} = 1.4652$ .<sup>38</sup>



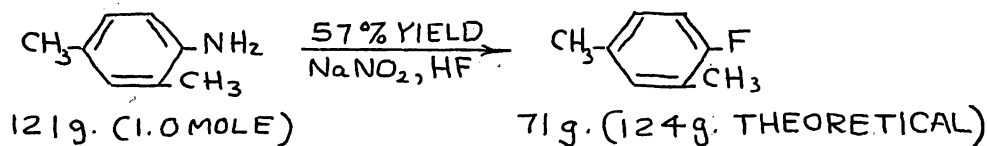
*p*-Fluorotoluene.—A solution of 107.1 g. (1.0 mole) of *p*-toluidine, b. p. 197-198° at 738 mm., m. p. 44-45°, in 370 g. (18.5 moles) of anhydrous hydrogen fluoride, contained in a 1-liter monel metal flask, was diazotized at 0° with 82.8 g. (1.2 moles) of sodium nitrite. Decomposition was carried out in five hours over a temperature range of 20 to 60°. Steam distillation, followed by washing with 5% potassium hydroxide solution, gave 89.5 g. (81.2% yield) of crude *p*-fluorotoluene. Upon distillation through a 10-inch Vigreux column, 86.0 g. (77.7% yield) of pure *p*-fluorotoluene, b. p. 115-116° at 740 mm.,  $n_{D}^{27.2} = 1.4662$ , was obtained. This agrees with the literature values of b. p. 116° at 756 mm.,<sup>32</sup> and  $n_{D}^{27} = 1.4647$ <sup>38</sup> for pure *p*-fluorotoluene.



2-Fluoro-1,3-dimethylbenzene.—A solution of 17.0g. (0.14 mole) of 2-amino-1,3-dimethylbenzene, b. p. 212-214° at 735 mm., in 76.2 g. (3.8 moles) of anhydrous hydrogen fluoride, contained in a 500 ml. stainless steel flask, was diazotized at 0° by the addition of 11.6 g. (0.17 mole) of sodium nitrite over a period of an hour. The decomposition, as evidenced by a steady evolution of nitrogen, required eight hours over a temperature range of 25 to 75°. The reaction mixture, which appeared to contain considerable tar, was exhaustively steam distilled, but only a very small amount of a water-insoluble oil was obtained. This was taken up in ether, and the solution was extracted with a 30 ml. portion of ether. The combined extract was dried overnight over "Drierite" and sodium fluoride, and then filtered and evaporated to give 1.9 g. of a yellow oil, b. p. 80-105° at 26 mm., of strong phenolic odor, that gave a weak positive test for fluorine. Treatment of this oil with 20 ml. of 5% potassium hydroxide solution gave a clear solution. Hence only a trace, if any 2-fluoro-1,3-dimethylbenzene was formed. The preparation of this compound by other methods has not been reported in the literature.

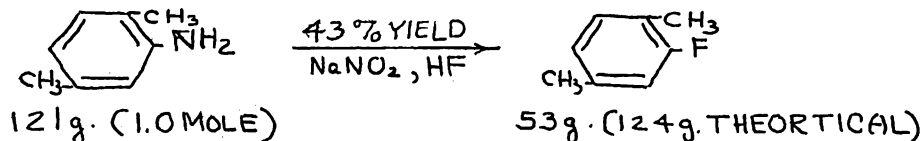
4-Fluoro-1,3-dimethylbenzene.—A solution of 121.2 g.

(1.0 mole) of 4-amino-1,3-dimethylbenzene, b. p. 100.5-101.0° at 5 mm., in 428 g. (21.4 moles) of anhydrous hydrogen fluoride, contained in a 1-liter monel metal flask, was diazotized at 0 to 5° by addition of 82.8 g. (1.2 moles) of sodium nitrite. The diazotization, which required two hours, appeared to proceed rather slowly, as evidenced by the evolution of brown fumes when the sodium nitrite was added too rapidly. Decomposition required 2½ hours at 20 to 45°. After steam distillation and washing with 5% potassium hydroxide solution, 75.2 g. (60.5% yield) of crude 4-fluoro-1,3-dimethylbenzene was obtained. Distillation through a 10-inch Vigreux column gave 71.1 g. (57.2% yield) of pure 4-fluoro-1,3-dimethylbenzene, b. p. 46.5-47.0° at 20.5 mm.,  $n_D^{27.5} = 1.4725$ . About 10 ml. of the pure product was redistilled at atmospheric pressure, b. p. 141-142° at 735 mm., and no sign of any decomposition was observed. Balz and Schiemann<sup>32</sup> report b. p. 143-144° at 749 mm. for pure 4-fluoro-1,3-dimethylbenzene.



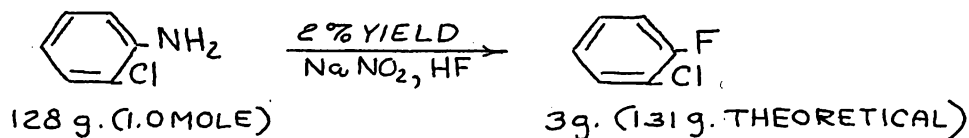
2-Fluoro-1,4-dimethylbenzene.—A solution of 121.2 g. (1.0 mole) of 2-amino-1,4-dimethylbenzene, b. p. 108.5-109.0° at 21 mm., in 450 g. (22.5 moles) of anhydrous hydrogen fluoride, contained in a 1-liter monel metal flask, was diazotized by addition of 82.8 g. (1.2 moles) of

sodium nitrite at 0 to 7°. The diazotization proceeded rather slowly and required two hours. The decomposition was completed in three hours over a temperature range of 15 to 35°. After steam distillation and washing with 5% potassium hydroxide solution, 61.8 g. (49.3% yield) of crude 2-fluoro-1,4-dimethylbenzene was obtained. Distillation through a 10-inch Vigreux column gave 53.0 g. (42.6% yield) of pure 2-fluoro-1,4-dimethylbenzene, b. p. 49.5° at 25 mm., b. p. 139.8-140.1° at 734 mm., m. p. -7 to -6°,  $n_{D}^{29.6} = 1.4727$ ,  $d_{27.1} = 0.9809$ . Calculated for  $C_8H_9F$ , C: 77.39%, H: 7.30%; found, C: 77.30%, H: 7.35%. No decomposition was observed when the product was distilled at atmospheric pressure at 140°.

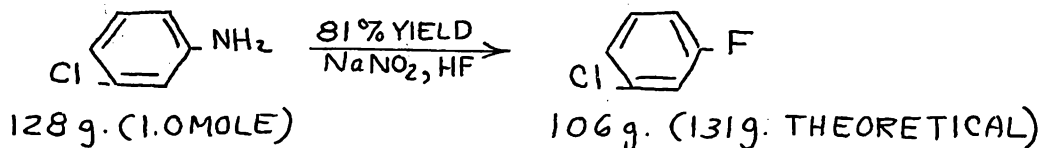


o-Fluorochlorobenzene.—A solution of 127.6 g. (1.0 mole) of o-chloroaniline, b. p. 100° at 20 mm., in 383 g. (19.1 moles) of anhydrous hydrogen fluoride was diazotized at 0° by addition of 82.8 g. (1.2 moles) of sodium nitrite. Practically no decomposition, as evidenced by only slight and irregular evolution of nitrogen, was brought about by heating twenty hours at a temperature of 75°. Steam distillation of the reaction mixture gave only a few ml. of water-insoluble oil, which was taken up in ether and washed with 5% potassium hydroxide solution. The ether was

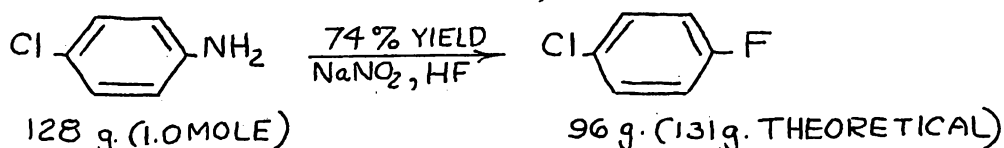
evaporated on a steam bath, and the crude product remaining was distilled from a 50 ml. modified Claisen flask to give 2.5 g. (1.9% yield) of o-fluorochlorobenzene, b. p. 137.5-139.5° at 741 mm.,  $n_{D}^{27.5} = 1.4979$ . This agrees with the value reported by Rinkes<sup>50</sup> of b. p. 138.5° at 760 mm. for pure o-fluorochlorobenzene.



m-Fluorochlorobenzene.—A solution of 127.6 g. (1.0 mole) of m-chloroaniline, b. p. 113.5-114.0° at 18.5 mm., in 405 g. (20.2 moles) of anhydrous hydrogen fluoride was diazotized at 0° by addition of 82.8 g. (1.2 moles) of sodium nitrite. Decomposition required three hours over a temperature range of 30 to 60°. Steam distillation, followed by a wash with 5% potassium hydroxide solution gave 109.4 g. (83.8% yield) of crude m-fluorochlorobenzene. By distillation through a 10-inch Vigreux column 106.3 g. (81.4% yield) of pure m-fluorochlorobenzene, b. p. 124.0-124.5° at 724 mm.,  $n_{D}^{27.2} = 1.4918$ , was obtained. This is in agreement with the values b. p. 127.6° at 760 mm., and  $n_{D}^{27.0} = 1.4911$  reported by Booth, Elsey, and Burchfield.<sup>51</sup>



p-Fluorochlorobenzene.-A solution of 127.6 g. (1.0 mole) of p-chloroaniline, m. p. 71-72° after recrystallization from 50% by volume ethanol-water solution, in 429 g. (21.4 moles) of anhydrous hydrogen fluoride, contained in a 1-liter monel metal flask, was diazotized at 0° by addition of 82.8 g. (1.2 moles) of sodium nitrite. Decomposition required thirty hours at 64°. Steam distillation, followed by a wash with 5% potassium hydroxide solution, gave 98.8 g. (75.7% yield) of crude p-fluorochlorobenzene. Distillation through a 10-inch Vigreux column gave 96.3 g. (73.6% yield) of pure p-fluorochlorobenzene, b. p. 128.0-128.5° at 734 mm.,  $n_{D}^{31.0} = 1.4896$ . This value is in agreement with that reported, b. p. 130° at 756 mm., by Ingold and Vass<sup>52</sup> for pure p-fluorochlorobenzene.



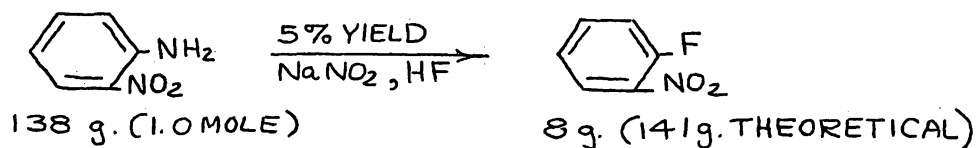
o-Fluoronitrobenzene.-A solution of 138.1 g. (1.0 mole) of o-nitroaniline,<sup>a</sup> m. p. 70.5-71.5° after recrystallization from 95% ethanol, in 400 g. (20.0 moles) of anhydrous hydrogen fluoride, contained in a 1-liter monel metal flask, was diazotized at 0° with 82.8 g. (1.2 moles) of sodium nitrite. Only very slight decomposition occurred after eighteen hours of heating at 70 to 75°. Steam

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<sup>a</sup> From the Monsanto Chemical Co., St. Louis, Mo.



distillation gave only a few ml. of amber colored liquid, which was taken up in ether, and washed with 5% potassium hydroxide solution. After drying over "Drierite", the ether was evaporated on a steam bath leaving a yellow oil, which was distilled from a 25 ml. modified Claisen flask to give 7.6 g. (5.4% yield) of *o*-fluoronitrobenzene, b. p. 115-116° at 22 mm.,  $n_D^{32.0} = 1.5528$ . This is in agreement with the values b. p. 115.5° at 22mm., reported by Holleman,<sup>53</sup> and  $n_D^{17.2} = 1.53261$ , reported by Swarts,<sup>54</sup> for pure *o*-fluoronitrobenzene.

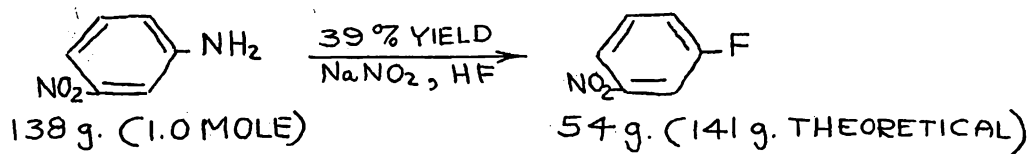


*m*-Fluoronitrobenzene.—A solution of 138.1 g. (1.0 mole of *m*-nitroaniline,<sup>a</sup> m. p. 114-114.5° after recrystallization from 95% ethanol, in 391 g. (19.6 moles) of anhydrous hydrogen fluoride, contained in a 1-liter monel metal flask, was diazotized at 0° with 82.8 g. (1.2 moles) of sodium nitrite. Decomposition required heating fifteen hours at 70°. Steam distillation, followed by washing with 5% potassium hydroxide solution, gave 59.7 g. (42.3% yield) of crude *m*-fluoronitrobenzene. Distillation through a 10-inch Vigreux column gave 54.3 g. (38.5% yield) of pure *m*-fluoronitrobenzene, b. p. 91.5-92° at 22 mm., m. p. 2 to 3°

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<sup>a</sup> From the Coleman and Bell Co.

$n_{D}^{24.0} = 1.5241$ . The literature values for pure *m*-fluoro-nitrobenzene are b. p.  $86^{\circ}$  at 19 mm.,<sup>36</sup> m. p.  $1.69^{\circ}$ ,<sup>56</sup> and  $n_{D}^{17.2} = 1.5280$ .<sup>55</sup> Considerable tar had formed in the steam distillation flask indicating that the diazonium fluoride may not have completely decomposed. The pure product exhibited an unusual phenomenon when freezing. When supercooled a few degrees below its melting point, while contained in a small flask cooled in an ice-salt bath, numerous small scattered specks of solid slowly appeared on the glass surface. Each increased in size until it met its neighbors. The solid coating slowly expanded inward until the entire melt had solidified.

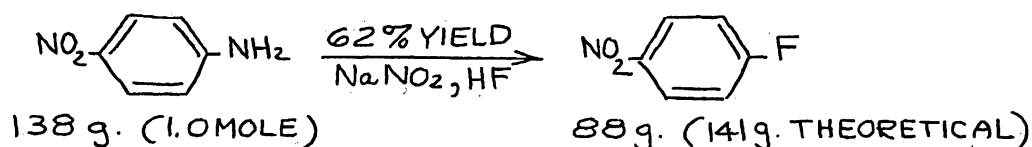


*p*-Fluoronitrobenzene.—A solution of 138.1 g. (1.0 mole) of *p*-nitroaniline,<sup>a</sup> m. p.  $148-149^{\circ}$  after recrystallization from a solution of 20% by volume of acetone in absolute ethanol, in 405 g. (20.3 moles) of anhydrous hydrogen fluoride, contained in a 1-liter monel metal flask, was diazotized at  $0^{\circ}$  with 82.8g. (1.2 moles) of sodium nitrite. Decomposition required six hours of heating over a temperature range of  $50$  to  $75^{\circ}$ . Steam distillation, followed by washing with 5% potassium hydroxide

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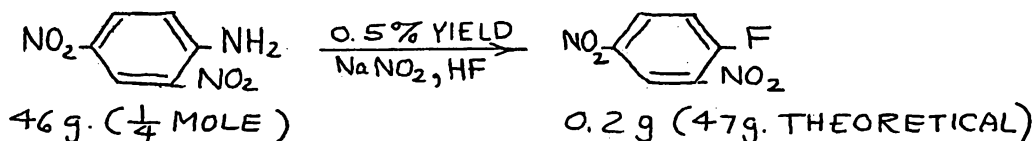
<sup>a</sup> From the Sherwin-Williams Co.

solution, gave 91.0 g. (64.5% yield) of crude *p*-fluoro-nitrobenzene. After distillation through a 10-inch Vigreux column, 87.5 g. (62.0% yield) of pure *p*-fluoro-nitrobenzene, a pale green liquid, b. p. 199.5-200.5° at 740 mm., m. p. 19.7-20.0°,  $n_{D}^{32.0} = 1.5261$ , was obtained. The literature gives b. p. 204° at 757 mm.,<sup>36</sup> m. p. 21.5,<sup>53</sup> and  $n_{D}^{20} = 1.5316$ .<sup>36</sup>

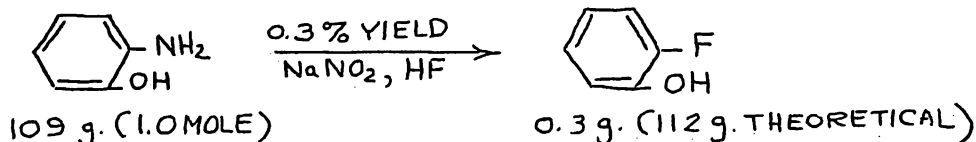


1-Fluoro-2,4-dinitrobenzene.—A solution of 45.8 g. (0.25 mole) of 2,4-dinitroaniline, m. p. 177-178° after recrystallization from 50% by volume aqueous acetone solution, in 135 g. (6.8 moles) of anhydrous hydrogen fluoride, contained in a 500 ml. stainless steel flask, was diazotized at 0° by addition of 20.7 g. (0.30 mole) of sodium nitrite over a period of  $\frac{1}{2}$  hour. Only slight decomposition was produced by heating twenty hours at 85°. The reaction mixture was transferred to a 1-liter copper beaker, and heated on a steam bath for several hours to evaporate as much excess hydrogen fluoride as possible. The residue, a semi-solid mass containing a great deal of tar, was cooled in an ice bath, and treated with 25% ammonia water until basic to litmus. The resulting mixture was extracted with 6-50 ml. portions of ether. The combined ether extract was dried over "Drierite", and evaporated

leaving about 4 g. of a black semi-solid mass. This was transferred to a 25 ml. modified Claisen flask, and distilled to give 0.2 g. (0.5% yield) of 1-fluoro-2,4-dinitrobenzene, b. p. 175-176° at 24 mm. The literature gives b. p. 178° at 25 mm.<sup>29</sup> for pure 1-fluoro-2,4-dinitrobenzene.



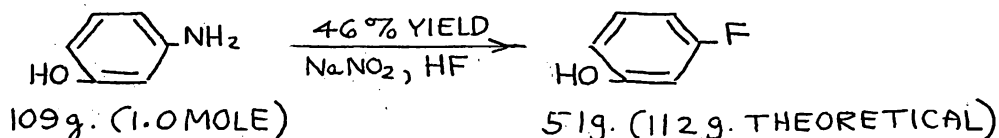
o-Fluorophenol. A solution of 109.1 g. (1.0 mole) of o-aminophenol, m. p. 173° after recrystallization three times from 95% ethanol, in 437 g. (21.9 moles) of anhydrous hydrogen fluoride, contained in a 1-liter monel metal flask, was diazotized with difficulty at 0 to 5° by addition of 82.8 g. (1.2 moles) of sodium nitrite over a period of three hours. Only slight decomposition was produced by heating twenty hours over a temperature range of 50 to 80°. Steam distillation caused the reaction mixture to turn to tar, and the distillate, which contained only a few drops of water-insoluble oil, was extracted with 6-50 ml. portions of ether. The combined ether extracts were dried over "Drierite". The ether was distilled off through an 18-inch Vigreux column, and the remaining residue, a small amount of yellow oil, was transferred to a 25 ml. modified Claisen flask. Distillation gave 0.3 g. (0.3% yield) of o-fluorophenol, b. p. 148-151° at 757 mm. The literature gives b. p. 151-152° at 760 mm.<sup>29</sup> for pure o-fluorophenol.



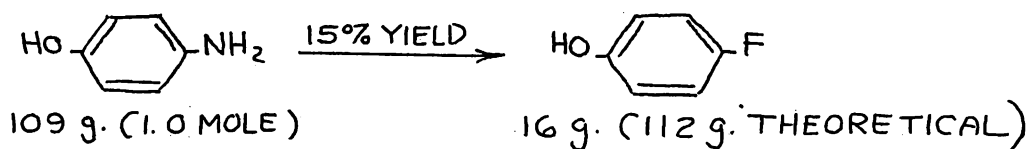
m-Fluorophenol.—A solution of 109.1 g. (1.0 mole) of m-aminophenol, m. p. 121.5–123° after recrystallization three times from hot water, in 393 g. (19.7 moles) of anhydrous hydrogen fluoride, contained in a 1-liter monel metal flask, was diazotized at 0° by addition of 82.8 g. (1.2 moles) of sodium nitrite. Decomposition required three hours heating over a temperature range of 15 to 35°. The reaction mixture, which contained considerable tar, was steam distilled. The distillate, which contained a small layer of water-insoluble oil, was extracted with 6–50 ml. portions of ether. The ether solution, which was dried over "Drierite", was distilled through a 10-inch Vigreux column to give 51.0 g. (45.5% yield) of pure m-fluorophenol, b. p. 177–179° at 742 mm.,  $n_D^{23.0} = 1.5018$ . The literature gives b. p. 177.8° at 760 mm.,<sup>29</sup> for pure m-fluorophenol.

When the above synthesis was repeated using m-aminophenol, m. p. 120–123° after one recrystallization from hot water, 39.9 g. (35.0% yield) of pure m-fluorophenol, b. p. 176–178° at 739 mm., was obtained.

The use of m-aminophenol, m. p. 118–122° without any purification yielded only 19.0 g. (15.7% yield) of pure m-fluorophenol, b. p. 174–177° at 737 mm.

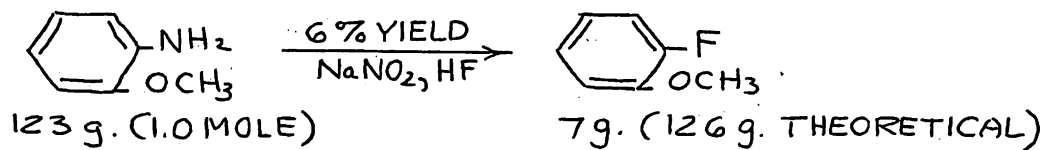


p-Fluorophenol.—A solution of 109.1 g. (1.0 mole) of p-aminophenol, m. p. 185-186° with decomposition after recrystallization from hot water and treatment with activated charcoal six times, in 386 g. (19.3 moles) of anhydrous hydrogen fluoride, contained in a 1-liter monel metal flask, was diazotized at 0° by addition of 82.8 g. (1.2 moles) of sodium nitrite. Decomposition required six hours heating over a temperature range of 20 to 48°. The reaction mixture contained a large amount of tar, and when steam distilled, gave only a small amount of water-insoluble oil. The distillate was extracted with 6-50 ml. portions of ether. The combined ether extract was dried over "Drierite" and distilled through a 10-inch Vigreux column to give 16.2 g. (14.5% yield) of p-fluorophenol, b. p. 94-96° at 24 mm. Swarts<sup>29</sup> reported b. p. 102-105° at 30 mm. for pure p-fluorophenol.



o-Fluoroanisole.—A solution of 123.3 g. (1.0 mole) of o-anisidine, b. p. 230-231° at 730 mm., in 380 g. (19.0 moles) of anhydrous hydrogen fluoride, contained in a 1-liter stainless steel

flask, was diazotized at 0° by the addition of 82.8 g. (1.2 moles) of sodium nitrite. Only slight decomposition was obtained by heating four hours at 85°. A large amount of tar was formed during the steam distillation, and the distillate contained only a small amount of water-insoluble oil, which was taken up in ether, and dried over "Drierite". The ether was distilled off through a 10-inch Vigreux column, and the residue was distilled from a 25 ml. modified Claisen flask to give 7.4 g. (5.8% yield) of *o*-fluoroanisole, b. p. 67-69° at 25 mm.,  $n_{D}^{27.5} = 1.5213$ . About 2 g. of higher boiling residue and hold-up was left. Schiemann<sup>39</sup> reports b. p. 64° at 17 mm. for pure *o*-fluoroanisole.



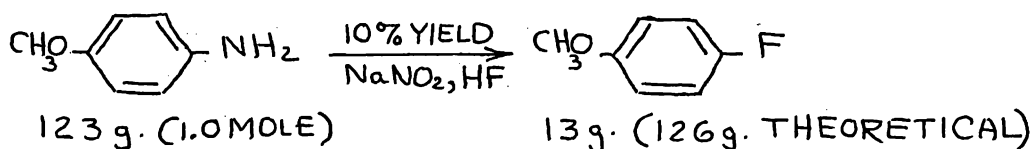
*m*-Fluoroanisole.—A solution of 86.0 g. (0.70 mole) of *m*-anisidine,<sup>a</sup> b. p. 121-122.5° at 12 mm., in 286 g. (14.3 moles) of anhydrous hydrogen fluoride, contained in a 1-liter monel flask, was diazotized at 0° by addition of 58.0 g. (0.84 mole) of sodium nitrite. Decomposition required heating four hours over a temperature range of 15 to 40°. The reaction mixture contained a large amount of tar, and upon steam distillation, yielded no water-insoluble

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<sup>a</sup> From the Buck Research Laboratories.

product. Thus, only a trace, if any, m-fluoroanisole was formed.

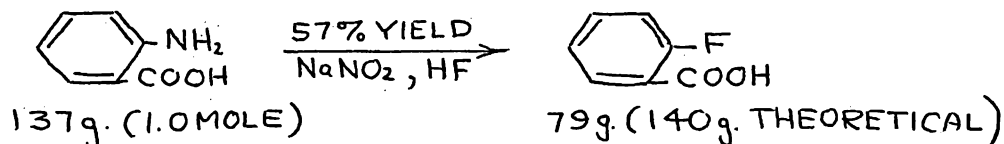
p-Fluoroanisole.—A solution of 123.3 g. (1.0 mole) of p-anisidine, m. p. 55–56° after purification twice by dissolving in dilute hydrochloric acid, boiling of the solution with activated charcoal, filtering, reprecipitating by addition of excess ammonia water, and drying in air, in 378 g. (18.9 moles) of anhydrous hydrogen fluoride, contained in a 1-liter monel metal flask, was diazotized at 0° by addition of 82.8 g. (1.2 moles) of sodium nitrite over a period of two hours. The decomposition required sixteen hours of heating at 75°. The reaction mixture contained a large amount of tar, and upon steam distillation gave only a small amount of water-insoluble oil. This oil was taken up in ether, washed with 5% potassium hydroxide solution, and distilled through a 10-inch Vigreux column to give 12.6 g. (10.0% yield) of p-fluoroanisole, b. p. 154–156° at 741 mm.,  $n_{D}^{32.6} = 1.4813$ . Rinkes<sup>50</sup> reported b. p. 157° at 760 mm. for pure p-fluoroanisole.



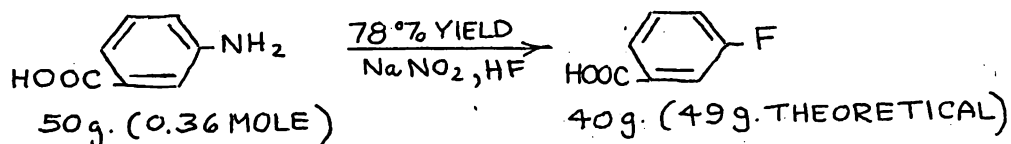
o-Fluorobenzoic Acid.—A solution of 137.1 g. (1.0 mole) of anthranilic acid, m. p. 145–146° after recrystallization from hot water, in 420 g. (21.0 moles) of anhydrous hydrogen fluoride, contained in a 1-liter monel



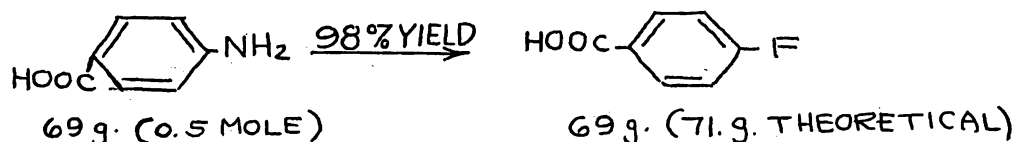
metal flask, was diazotized at 0° by addition of 82.8 g. (1.2 moles) of sodium nitrite. Decomposition required six hours of heating over a temperature range of 50 to 75°. The reaction mixture was cooled, diluted with ice, and filtered to yield crude o-fluorobenzoic acid, which was recrystallized from hot water to give 79.4 g. (56.6% yield) of pure o-fluorobenzoic acid, m. p. 124-126° Dippy and Williams report <sup>57</sup> m. p. 126.5° for pure o-fluorobenzoic acid.



m-Fluorobenzoic Acid.—A solution of 50.0 g. (0.36 mole) of m-aminobenzoic acid, m. p. 178-180° after recrystallization from hot water, in 153 g. (7.7 moles) of anhydrous hydrogen fluoride, contained in a 500 ml. stainless steel flask, was diazotized at 0° by the addition of 30.2 g. (0.44 mole) of sodium nitrite over a period of one hour. Decomposition required heating nine hours over a temperature range of 35 to 70°. The reaction mixture was cooled, diluted with ice, and filtered to obtain crude m-fluorobenzoic acid, which was extracted with 6-50 ml. portions of ether. The combined ether extract was filtered and evaporated to give 39.7 g. (77.7% yield) of pure m-fluorobenzoic acid, m. p. 122.5-123.5°. Dippy and Williams <sup>57</sup> reported m. p. 124° for pure m-fluorobenzoic acid.



p-Fluorobenzoic Acid.—A solution of 68.6 g. (0.5 mole) of p-aminobenzoic acid, m. p. 187-189° after recrystallization from hot water, in 219 g. (11.0 moles) of anhydrous hydrogen fluoride, contained in a 1-liter<sup>a</sup> monel metal flask, was diazotized at 0° by addition of 41.4 g. (0.6 mole) of sodium nitrite. Decomposition required heating twelve hours over a temperature range of 35 to 55°. The reaction mixture was cooled, diluted with ice, and filtered to yield crude p-fluorobenzoic acid, which was dissolved by extraction with 3-50 ml. portions of ether. The ether solution was filtered and evaporated to give 68.7 g. (98.4% yield) of pure p-fluorobenzoic acid, m. p. 181-182.5°. Koopal<sup>57</sup> reported m. p. 182.6° for pure p-fluorobenzoic acid.

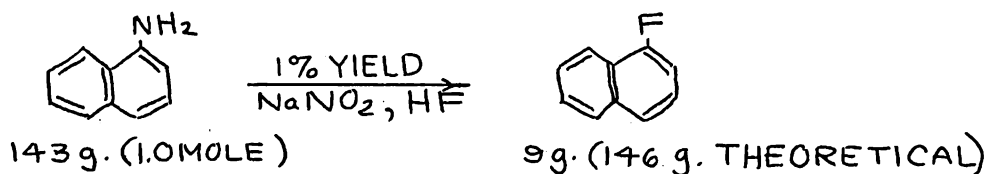


α-Fluoronaphthalene.—A solution of 143.2 g. (1.0 mole) of α-naphthylamine, m. p. 49-50° after recrystallization from a solution of 25% by volume of ethanol in

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<sup>a</sup> This size flask is recommended because a 1-mole run in a preliminary experiment foamed over during the decomposition.

water, in 393 g. (19.7 moles) of anhydrous hydrogen fluoride, contained in a 1-liter monel metal flask, was diazotized at 0° by the addition of 82.8 g. (1.2 moles) of sodium nitrite over a period of 1½ hours. Decomposition required heating ten hours over a temperature range of 40 to 65°. The reaction mixture, which contained a large amount of tar, was rapidly steam distilled for three hours, but the distillate contained only a small amount of water-insoluble oil, which was taken up in ether, washed with 5% potassium hydroxide solution, and the ether evaporated in a 25 ml. modified Claisen flask. The residue was distilled to give 1.6 g. (1.1% yield) of  $\alpha$ -fluoronaphthalene, b. p. 205-205° at 735 mm.,  $n_{D}^{33.0} = 1.5337$ . Only 0.7 g. of higher boiling residue and hold-up was left. Ekbon and Mauzelius<sup>59</sup> reported b. p. 212° at 768 mm., and Schiemann et al.<sup>38</sup> reported  $n_{D}^{19.5} = 1.59389$  for pure  $\alpha$ -fluoronaphthalene.

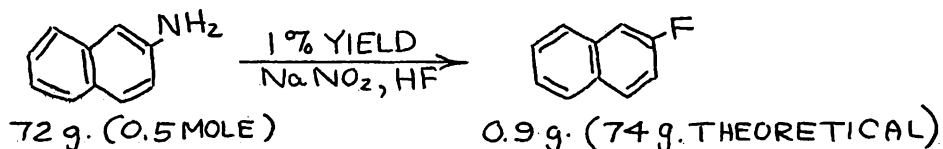


$\beta$ -Fluoronaphthalene.—A solution of 71.5 g. (0.5 mole) of  $\beta$ -naphthylamine,<sup>a</sup> m. p. 112-112.5° after recrystallization from 50% by volume aqueous ethanol, in 215 g. (10.8 moles) of anhydrous hydrogen fluoride, contained in a 1-liter

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<sup>a</sup> From the Kahlbaum Co., Berlin.

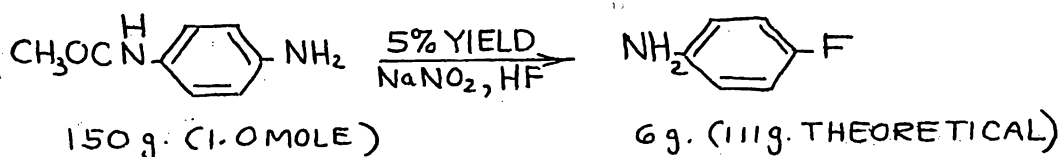
monel metal flask, was diazotized at  $0^{\circ}$  by addition of 41.4 g. (0.60 mole) of sodium nitrite over a period of  $1\frac{1}{2}$  hours. Decomposition required heating ten hours over a temperature range of  $30$  to  $70^{\circ}$ . The reaction mixture, which contained a large amount of tar, was steam distilled, but the distillate contained only a few crystals of solid, crude  $\beta$ -fluoronaphthalene, which was filtered off, and recrystallized from 50% aqueous ethanol to give 0.9 g. (1.2% yield) of pure  $\beta$ -fluoronaphthalene, m. p.  $61$ - $62^{\circ}$ . Schiemann, Guéffroy, and Winkelmueller<sup>37</sup> reported m. p.  $61^{\circ}$  for pure  $\beta$ -fluoronaphthalene.



p-Fluoroaniline.—A solution of 150.2 g. (1.0 mole) of p-aminoacetanilide, m. p.  $164.5$ - $165^{\circ}$  after recrystallization twice from hot water, in 417 g. (20.8 moles) of anhydrous hydrogen fluoride, contained in a 1-liter monel metal flask, was diazotized at  $0^{\circ}$  by the addition of 82.8 g. (1.2 moles) of sodium nitrite. Decomposition required heating three hours over a temperature range of  $45$  to  $70^{\circ}$ . The reaction mixture, which contained a small amount of tar, was transferred to a 1-liter copper beaker, and heated on a steam bath for several hours to evaporate as much excess hydrogen fluoride as possible. The residue, a black semi-solid, mass, was cooled and treated with 10% potassium

hydroxide solution until basic to litmus. Then an aqueous solution containing 2 moles of potassium hydroxide was added, and the entire mixture was transferred to a 3-liter glass flask and slowly steam distilled for four hours. The distillate,  $4\frac{1}{2}$  liters, was extracted with ether for a week in a continuous liquid-liquid extractor. The ether extract, about 500 ml., was dried over "Drierite", and distilled through a 10-inch Vigreux column until all the ether had been removed. The residue, which was an oil weighing about 11 g., was transferred to a 25 ml. modified Claisen flask, and distilled to give 6.0 g. (5.4% yield) of *p*-fluoroaniline, b. p.  $185-188^\circ$  at 740 mm.,  $n_{D}^{31.6} = 1.5413$ . Swarts<sup>60</sup> reported b. p.  $187^\circ$  at 753 mm., and Schiemann and Pollarsky<sup>36</sup> reported  $n_{D}^{20} = 1.5394$  for pure *p*-fluoroaniline.

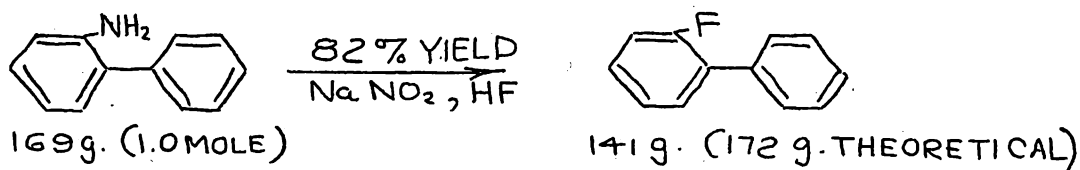
Repetition of the above experiment using 2.4 moles instead of 1.2 moles of sodium nitrite per mole of amine gave only 5.1 g. (4.6% yield) of *p*-fluoroaniline, b. p.  $185-188^\circ$  at 740 mm.



*o*-Difluorobenzene.—A solution of 32.4 g. (0.30 mole) of *o*-phenylenediamine, m. p.  $103-104^\circ$  after recrystallization twice from hot water, in 80 g. (4 moles) of anhydrous hydrogen fluoride, contained in a 500 ml. copper flask, cooled to  $0^\circ$ , was added slowly in small portions to a

solution of 49.7 g. (0.72 mole) of sodium nitrite in 120 g. (6 moles) of anhydrous hydrogen fluoride cooled to 0°, contained in a 500 ml. stainless steel flask, over a period of ½ hour. The mixture was heated at 25 to 70° for a period of ten hours, during which time about 8 liters of a mixture of nitrogen and nitric oxide gases, as indicated by the brown color produced when discharged into the atmosphere, were evolved. When the reaction mixture, which contained considerable tar, was steam distilled, no water-insoluble product was obtained. Therefore no o-difluorobenzene was synthesized by the above method.

o-Fluorodiphenyl.-A solution of 169.2 g. (1.0 mole) of o-aminodiphenyl, m. p. 48.5-49.0° after recrystallization from 50% by volume aqueous ethanol, in 394 g. (19.7 moles) of anhydrous hydrogen fluoride, contained in a 1-liter monel metal flask, was diazotized at 0° by the addition of 82.8 g. (1.2 moles) of sodium nitrite. Decomposition required heating two hours over the temperature range 20 to 32°. The reaction mixture was diluted, and filtered to yield a black mass of crude o-fluorodiphenyl, which was recrystallized from petroleum ether, b. p. 30-40°, to give 141.0 g. (81.9% yield) of pinkish-white o-fluorodiphenyl, m. p. 73-75°. Schiemann and Roselius<sup>35</sup> reported m. p. 73.5° for pure o-fluorodiphenyl.

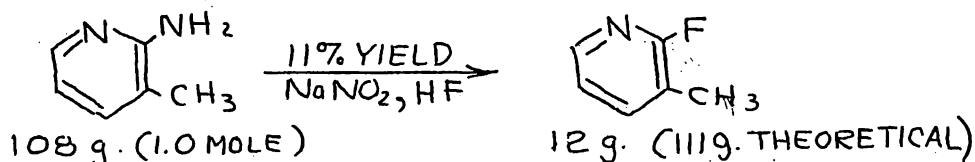


2-Fluoro-3-methylpyridine.—A solution of 108 g. (1.0 mole) of 2-amino-3-methylpyridine,<sup>a</sup> b. p. 120-121<sup>0</sup> at 33 mm., in 435 g. (21.8 moles) of anhydrous hydrogen fluoride, contained in a 1-liter stainless steel flask, was diazotized at 0° by addition of 82.8 g. (1.2 moles) of sodium nitrite. Decomposition required heating twenty-four hours over a temperature range of 25 to 70°. The reaction mixture was transferred to a 1-liter copper beaker, and heated on a steam bath to evaporate as much excess hydrogen fluoride as possible. The residue was cooled, and treated with 10% aqueous potassium hydroxide solution until basic to litmus. The resulting mixture was extracted with 5-150 ml. portions of ether. The combined ether extract was dried by filtering through anhydrous sodium sulfate, and distilled in successive portions through an 18-inch Vigreux column. The residue, about 15 g., was transferred to a 25 ml. modified Claisen flask, and distilled through a 10-inch Vigreux column to give 11.7 g. (10.6% yield) of pure 2-fluoro-3-methylpyridine, b. p. 144-146° at 737.,  $n_D^{27.6} = 1.4724$ . The product was a colorless

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<sup>a</sup> From the Reilly Tar and Chemical Co., Indianapolis, Indiana.

oil of strong pyridine-like odor, which was slightly soluble in cold water and completely soluble in dilute hydrochloric acid solution. This compound has since been prepared in larger amount and in better yield by the method of Roe and Hawkins,<sup>44</sup> and analyzed and characterized by John Minor,<sup>61</sup> who reports b. p. 145.5° at 735 mm. for pure 2-fluoro-3-methylpyridine.

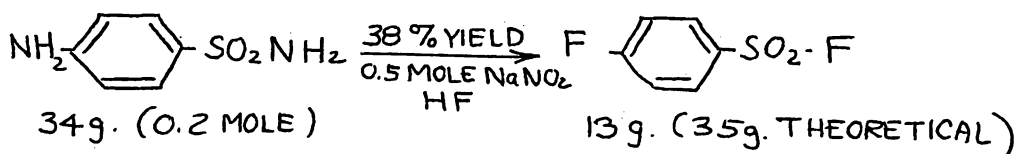


Cyclohexyl Fluoride.—A solution of 99.2 g. (1.0 mole) of cyclohexylamine, b.p. 132-134° at 732 mm., in 404 g. (20.2 moles) of anhydrous hydrogen fluoride, contained in a 1-liter monel metal flask, was diazotized at 0° by addition of 82.8 g. (1.2 moles) of sodium nitrite. Sudden evolution of hydrogen fluoride vapors with each addition of sodium nitrite indicated that evolution of nitrogen occurred during the diazotization. Only slight and irregular nitrogen evolution occurred when the reaction mixture was heated under reflux for nine hours over a temperature range of 30 to 75°. Steam distillation gave no water-insoluble product, and hence no cyclohexyl fluoride was formed by this method. The residue remaining after the steam distillation had the strong odor of cyclohexanol.

p-Fluorobenzenesulfonyl Fluoride.—An attempt to prepare p-fluorobenzenesulfonamide in the usual manner by



diazotizing p-aminobenzenesulfonamide with a 1.8 molar ratio of sodium nitrite gave none of the desired product, but only tar and a few drops of an oil of strong cinnamon odor. The experiment was repeated using 8.4 moles of sodium nitrite per mole of amine as follows: A solution of 34.4 g. (0.20 mole) of p-aminobenzenesulfonamide, m. p. 166-167° after recrystallization from 75% by volume ethanol-water solution, in 80 g. (4.0 moles of anhydrous hydrogen fluoride, contained in a 500 ml. stainless steel flask, was treated at 0° by addition of 33.2 g. (0.48 mole) of sodium nitrite over a period of an hour. The evolution of hydrogen fluoride vapors with each addition of sodium nitrite indicated that some nitrogen evolution occurred during the addition of the sodium nitrite. Decomposition required ten hours heating over a temperature range of 48 to 80°. Steam distillation of the reaction mixture gave about 18 g. of a yellow oil, which was separated, dried over "Drierite", and distilled through a 10-inch Vigreux column to give 13.4 g. (38.1% yield) of p-fluorobenzene-sulfonyl fluoride, an almost colorless liquid containing a faint tinge of yellow and of strongcinnamon-like odor, b. p. 98.2-98.5° at 25 mm., m. p. 14.2-15.0°,  $n_{D}^{20.7} = 1.4725$ ,  $d_{25.0}^{25.0} = 1.1282$ .

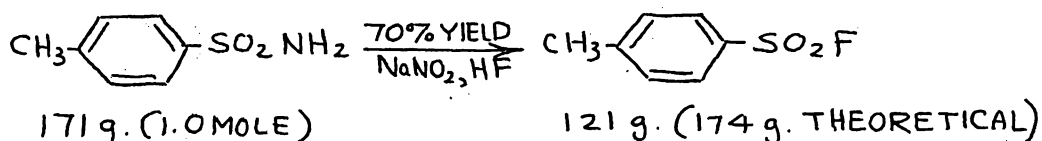


An attempt to prove the structure of the p-fluorobenzenesulfonyl fluoride, a new compound, by conversion to the known p-fluorobenzenesulfonamide by boiling with 25% ammonia failed, as the sulfonyl fluoride was recovered unchanged. Similarly no reaction could be brought about by heating with ammonium carbonate according to the method of Huntress and Carten.<sup>62</sup>

Heating 0.5 g. of p-fluorobenzenesulfonyl fluoride with 25 ml. of liquid anhydrous ammonia in a 100 ml. glass tube sealed in a metal bomb tube for 2½ hours at 57° did give 0.4 g. of p-fluorobenzenesulfonamide, m. p. 125-126° after recrystallization from 50% by volume aqueous ethanol, which did not depress the melting point of an authentic sample of p-fluorobenzenesulfonamide prepared by the action of first chlorosulfonic acid, and then ammonia, on fluorobenzene.<sup>63</sup>

p-Toluenesulfonyl Fluoride.-A solution of 171.2 g. (1.0 mole) of p-toluenesulfonamide, m. p. 135-136° after recrystallization from a 25% by volume ethanol-water solution, in 378 g. (18.9 moles) of anhydrous hydrogen fluoride, contained in a 1-liter monel metal flask, was treated at 0° by addition of 82.8 g. (1.2 moles) of sodium nitrite. Evolution of hydrogen fluoride vapors during the addition of the sodium nitrite indicated that nitrogen evolution was occurring during that period. The reaction mixture was heated four hours over a temperature range of 0 to 70°, but

only very slight and irregular gas evolution was observed. The reaction mixture was then cooled, diluted with ice, and filtered to obtain crude *p*-toluenesulfonyl fluoride. This was taken up by extraction with 6-50 ml. portions of ether. The combined ether solution was filtered and evaporated to give 121.3 g. (69.6% yield) of pure *p*-toluenesulfonyl fluoride, m. p. 43.0-43.5°. Davies and Dick<sup>64</sup> reported m. p. 43-44° for pure *p*-toluenesulfonyl fluoride.



Corrosion Test of Illium-G.— The following test was carried out to ascertain whether or not Illium-G, a nickel-chromium alloy, would be suitable for use in the construction of hydrogen fluoride-diazotization reaction vessels. A flat cylindrical test sample of Illium-G<sup>a</sup>, 17.2 sq. cm. in area and weighing 30.5558 g., was placed in a 200 ml. stainless steel cup containing the reaction mixture resulting from the preparation of a 0.1 mole run of fluorobenzene in the usual manner. The sample was allowed to stand thus for fifteen hours. After washing and drying, the sample was found to weigh 30.5540 g., a loss of 1.8 mg. This is a rate of corrosion of 1.8/17.2/15/24 or 0.167 mg./sq. cm./day, or a rate of penetration of 0.0028 inch per year. This indicates highly satisfactory service under the

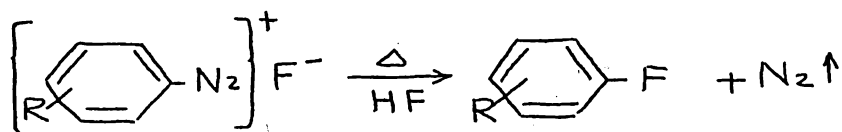
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<sup>a</sup> From the Burgess-Parr Co., Freeport, Illinois.

conditions encountered in the production of fluorobenzene.

Discussion of Results

A General Method for the Preparation of Aromatic Fluorides.—The experimental work presented in the previous section describes a study of a general method for the preparation of aromatic fluorides through diazotization of the corresponding amines in anhydrous hydrogen fluoride and subsequent thermal decomposition of the substituted benzene diazonium fluorides while dissolved in the original reaction medium as indicated by the following equations:



The diazotization is carried out by adding, with stirring, a small excess of solid sodium nitrite to a cooled solution of the amine in anhydrous hydrogen fluoride. Usually 18 to 22 moles of anhydrous hydrogen fluoride are used for each mole of amine as preliminary studies<sup>65</sup> indicated that a maximum yield of fluorobenzene was obtained when approximately 19 moles of anhydrous hydrogen fluoride was used for each mole of aniline. Likewise, Swarts<sup>29</sup> recommended the use of 20 moles of hydrofluoric acid per mole of aniline in the synthesis of fluorobenzene through

diazotization in 70% hydrofluoric acid. The optimum hydrogen fluoride - amine ratio may vary for different amines, and its exact value should be determined for each individual case if production at high yields is desired. The decomposition phase of the reaction, which is carried out under a reflux condenser, may be followed by observing the rate of nitrogen evolution. The decompositions take place smoothly without danger of detonation, and in every case may be controlled by regulating the reaction temperature. The mode of separation of the fluoro-products from the reaction mixture depends upon the physical and chemical properties of the product, and in many cases may be accomplished simply by steam distillation or filtration.

The yields obtained in the experiments using m-aminophenol purified to various degrees, and the fact that the use of technical grade sodium nitrite in preliminary experiments did not give satisfactory results even for fluorobenzene, indicate that all reactants should be as pure as possible for best results. The catalytic effect of the metal flasks may play an important role in the decomposition of the diazonium fluorides, but this was not investigated except for observation of the fact that no qualitative difference was noted in the rate of decomposition of phenyldiazonium fluoride in copper, stainless steel, and monel metal flasks.

During the course of the experimental work con-

siderable difficulty due to corrosion was encountered, especially with copper and "18-8" stainless steel. Monel metal gave much better results, but failed in several experiments. A test sample of the nickel-chromium alloy, Inconel-G, was found to have a highly satisfactory rate of corrosion of 0.167 mg./sq. cm./day or 0.0028 inch/ year when exposed to the conditions encountered in the synthesis of fluorobenzene. A number of other materials of construction, which were not tested, may prove to be of value in the fabrication of vessels used for diazotization in anhydrous hydrogen fluoride. Thus, mild steel has been found<sup>66</sup> to be satisfactory for use with mixtures of hydrogen fluoride and sodium nitrite as long as the water content of the mixtures is maintained below 30%. Inconel has also been recommended<sup>67</sup> for use with mixtures containing hydrogen fluoride, nitrous acid, and water. A silica-free, hydrofluoric acid resistant glass has been developed,<sup>68</sup> but is not available commercially.

The value of diazotization in anhydrous hydrogen fluoride as a general synthetic method for the preparation of aromatic fluorides is clearly shown by the summary of the experimental results presented in Table I. Good yields of fluoro-compounds were obtained in more than half of the 32 experiments. The reaction and decomposition conditions described may be improved by further study. The crude yields of the unpurified fluoro-products, as reported in the experimental section, were usually 3 to 6% higher, which

TABLE I

## AROMATIC FLUORIDES SYNTHESIZED THROUGH DIAZOTIZATION IN ANHYDROUS HYDROGEN FLUORIDE

Aromatic fluoride	% Yield pure fluoride	Decomposition conditions Hours at °C.	
Fluorobenzene	76.3 to 81.1	3	30-40
<i>o</i> -Fluorotoluene	73.2	2	0-25
<i>m</i> -Fluorotoluene	82.0	2	15-30
<i>p</i> -Fluorotoluene	77.7	5	20-60
2-Fluoro-1,3-dimethylbenzene	none <sup>a</sup>	8	25-75
4-Fluoro-1,3-dimethylbenzene	57.2	2.5	20-45
2-Fluoro-1,4-dimethylbenzene	42.6	3	15-35
<i>o</i> -Fluorochlorobenzene	1.9 <sup>b</sup>	20	75
<i>m</i> -Fluorochlorobenzene	81.4	3	30-60
<i>p</i> -Fluorochlorobenzene	73.6	30	64
<i>o</i> -Fluoronitrobenzene	5.4 <sup>b</sup>	18	70-75
<i>m</i> -Fluoronitrobenzene	38.4	15	70
<i>p</i> -Fluoronitrobenzene	62.0	6	50-75
1-Fluoro-2,4-dinitrobenzene	0.5 <sup>b</sup>	20	85
<i>o</i> -Fluorophenol	0.3 <sup>b</sup>	20	50-80
<i>m</i> -Fluorophenol	45.5	3	15-35
<i>p</i> -Fluorophenol	14.5 <sup>a</sup>	6	20-48
<i>o</i> -Fluoroanisole	5.8 <sup>b</sup>	4	85
<i>m</i> -Fluoroanisole	none <sup>a</sup>	4	15-40
<i>p</i> -Fluoroanisole	10.0 <sup>a</sup>	16	75
<i>o</i> -Fluorobenzoic acid	56.6	6	50-75

TABLE I (CONTINUED)

<u>m</u> -Fluorobenzoic acid	77.7	9	35-70
<u>p</u> -Fluorobenzoic acid	98.4	12	35-55
$\alpha$ -Fluoronaphthalene	1.1 <sup>a</sup>	10	40-65
$\beta$ -Fluoronaphthalene	1.2 <sup>a</sup>	10	30-70
<u>p</u> -Fluoroaniline	5.4 <sup>a</sup>	3	45-70
<u>o</u> -Difluorobenzene	none <sup>a</sup>	10	25-70
<u>o</u> -Fluorodiphenyl	81.9	2	20-52
<u>2</u> -Fluoro- <u>3</u> -methylpyridine	10.6	24	25-70
Cyclohexyl fluoride	none	9	30-75
<u>p</u> -Fluorobenzenesulfonyl Fluoride	38.1	10	48-80
<u>p</u> -Toluenesulfonyl fluoride	69.6	4	0-70

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<sup>a</sup> A large quantity of tar was formed during decomposition.

<sup>b</sup> The diazonium fluoride was so stable that it could not be decomposed by heating at the temperatures obtainable at reflux under atmospheric pressure; this was evidenced by scant or no nitrogen evolution during the period of heating, and by the formation of large amounts of tar during the steam distillation of the reaction mixture.



would be important from an industrial viewpoint. Also the yields in some cases could be considerably improved by recovering volatile fluoro-products from the nitrogen gas before its discharge.

When the general method failed or only low yields were obtained, one of two causes was usually at fault. In some cases, as 2-fluoro-1,3-dimethylbenzene, *p*-fluorophenol, *m*- and *p*-fluoroanisole,  $\alpha$ - and  $\beta$ -fluoronaphthalene, and *p*-fluoroaniline, a large amount of tar was formed during decomposition. Certain ortho-substituted amines, such as *o*-chloroaniline, *o*-nitroaniline, 1-fluoro-2,4-dinitroaniline, *o*-fluorophenol, and *o*-fluoroanisole, gave diazonium fluorides that were too stable to be decomposed at the temperatures obtainable by refluxing the reaction mixtures at atmospheric pressure. This extreme stability is believed to be due to an electronic interaction between such ortho-substituted groups, which will be discussed later. It is possible that these stable diazonium fluorides may be decomposed to the corresponding fluorides by heating under pressure to attain higher temperature.

The fact that *p*-aminoacetanilide gives only a small yield of *p*-fluoroaniline may be understood when it is considered that acetylated aromatic amines easily react with nitrogen trioxide,  $N_2O_3$  to give nitrosoacetyl amines, which decompose readily by a free radical mechanism to yield biaryl compounds.

The preparation of *o*-difluorobenzene from *o*-phenyl-

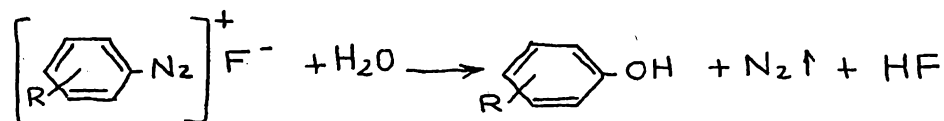
enediamine was not anticipated to be successful in so much as tetrazotization of two amino groups ortho to one-another has never been accomplished, but the experiment was carried out to see whether or not such a reaction might be possible in anhydrous hydrogen fluoride. The procedure of Griess,<sup>70</sup> which is recommended for the preparation of *m*- and *p*-phenylenetetrazo-compounds, and which consists of reversing the usual order of addition of the nitrite solution to the solution of the aromatic amine, was used.

The synthesis of 2-fluoro-3-methylpyridine in a yield of about 11% indicates that the method of diazotization in anhydrous hydrogen fluoride may have at least limited application for the preparation of heterocyclic fluorides. The negative result obtained with cyclohexyl amine suggests, as expected, that the method will find no use in the preparation of aliphatic fluorides.

An unexpected result was obtained in the case of *p*-aminobenzenesulfonamide. Diazotization with sodium nitrite in slight excess of a molar ratio with the amine gave no *p*-fluoroacetanilide, as anticipated, but only tar and a small amount of a water-insoluble oil of strong cinnamon odor. When the molar ratio of sodium nitrite to amine was increased to a little over 2 to 1, the yield of the oil, which has been shown to be *p*-fluorobenzenesulfonyl fluoride, was greatly increased. Thus the amino group in the amide was replaced by fluorine as was the amino group attached to the benzene ring. Such a reaction is unusual since amides

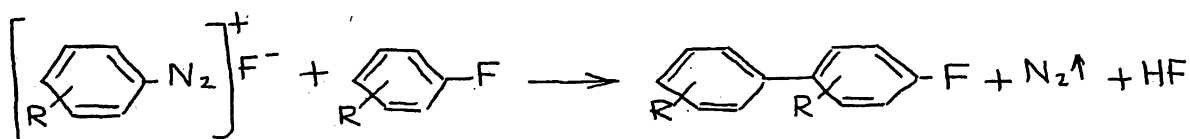
ordinarily convert to acids when treated with nitrous acid. The generality of the reaction is indicated by its successful extension to the synthesis of *p*-toluenesulfonyl fluoride.

Identities of Fluoro-Products.—Establishment of the identities of the fluoro-products prepared in the experimental study rests upon two main arguments. The first is the fact that an atom or group replacing another usually does so with the overall result that it is attached to the same carbon atom of the parent organic compound. While many exceptions may be pointed out in the aliphatic series, this statement holds for almost all reactions involving replacement of atoms or groups attached to the benzene ring, and no simple reactions involving replacement of an aromatic amino group with a change in relative position on the benzene ring have been reported. In the case of replacement of the aromatic amino group through diazotization and decomposition in anhydrous hydrogen fluoride only two logical possibilities exist besides introduction of fluorine. These are introduction of the hydroxyl group by reaction of the diazonium fluorides with the water formed in diazotization:



and of aryl groups by a Friedel-Crafts type of reaction between the diazonium fluorides and the fluoro-aromatics

already formed:



In both cases such products can easily be distinguished and separated from the "normal" fluoro-products by virtue of the differences in their boiling points, and in the case of phenolic products by solubility in aqueous alkaline solution. The second argument is comparison of physical properties with those reported in the literature for the compounds which have been prepared by other methods. Such a comparison is presented in Table II, which follows. Comparison of refractive indices gives evidence of only secondary value as the temperatures at which such data are reported and observed vary widely.

All new compounds reported for the first time in this paper have been characterized more thoroughly. Thus a carbon and hydrogen analysis was carried out for 2-fluoro-1,4-dimethylbenzene, and the structure of *p*-fluorobenzenesulfonyl fluoride was proved by conversion to a known compound, *p*-fluorobenzenesulfonamide. In the case of 2-fluoro-3-methylpyridine, identification was made by comparison of physical properties with those of a larger amount of the same substance prepared later in better yield by the method of Roe and Hawkins,<sup>44</sup> and analyzed and characterized by John Minor.<sup>61</sup>

TABLE II

COMPARISON OF THE EXPERIMENTAL AND LITERATURE VALUES OF PHYSICAL PROPERTIES FOR THE FLUORO-PRODUCTS SYNTHESIZED

Aromatic fluoride	Physical properties	
	Experimental	Reported
Fluorobenzene	b.p. 84-5° @ 735mm.; 85° @ 760mm. <sup>32</sup> $n_{32.0}^D$ 1.4599; $n_{20}^D$ 1.46673. <sup>36</sup>	
o-Fluorotoluene	b.p. 112.0-.5° @ 732mm.; 114° @ 760mm. <sup>49</sup> $n_{31.0}^D$ 1.4679; $n_{21}^D$ 1.47383. <sup>38</sup>	
m-Fluorotoluene	b. p. 113.5-4.0° @ 737mm.; 115° @ 756mm. <sup>38</sup> $n_{27.2}^D$ 1.4672; $n_{27}^D$ 1.4652. <sup>38</sup>	
p-Fluorotoluene	b.p. 115-6° @ 740mm.; 116° @ 756mm. <sup>32</sup> $n_{27.2}^D$ 1.4662; $n_{27}^D$ 1.4647. <sup>38</sup>	
4-Fluoro-1,3-dimethylbenzene	b. p. 141-2° @ 735 mm.; 143-4° @ 749mm. <sup>32</sup>	
o-Fluorochlorobenzene	b.p. 137.5-9.5° @ 741 mm.; 138.5° @ 760mm. <sup>50</sup>	
m-Fluorochlorobenzene	b.p. 124.0-.5° @ 724mm.; 127.6° @ 760mm. <sup>51</sup> $n_{27.2}^D$ 1.4918; $n_{27.0}^D$ 1.4911. <sup>51</sup>	
p-Fluorochlorobenzene	b.p. 128.0-.5° @ 734mm.; 130° @ 756mm. <sup>52</sup>	
o-Fluoronitrobenzene	b.p. 115-6° @ 22mm.; 115.5° @ 22mm. <sup>53</sup> $n_{32.0}^D$ 1.5528; $n_{17.2}^D$ 1.53231. <sup>54</sup>	
m-Fluoronitrobenzene	b.p. 91.5-92° @ 22mm.; 86° @ 19mm. <sup>36</sup> $n_{24.0}^D$ 1.5241; $n_{17.2}^D$ 1.5280. <sup>55</sup> m.p. 2-3°; 1.69°. <sup>56</sup>	
p-Fluoronitrobenzene	b.p. 199.5-200.5° @ 740mm.; 204° @ 757mm. <sup>36</sup> $n_{32.0}^D$ 1.5261; $n_{20}^D$ 1.5316. <sup>36</sup> m.p. 19.7-20.0°; 21.5°. <sup>53</sup>	

TABLE II (CONTINUED)

1-Fluoro-2,4-dinitrobenzene	b.p. 175-6° @24mm.; 178° @25mm. 29
o-Fluorophenol	b.p. 148-151° @737 mm.; 151-2° @760mm. 29
m-Fluorophenol	b.p. 177-9° @742mm.; 177.8° @ 760mm. 29
p-Fluorophenol	b.p. 94-6° @24mm.; 102-5° @ 760mm. 29
o-Fluoroanisole	b.p. 67-9° @ 25mm.; 64° @ 17mm. 39
p-Fluoroanisole	b.p. 154-6° @741mm.; 157° @760mm. 50
o-Fluorobenzoic acid	m.p. 124-9°; 126.5° 57
m-Fluorobenzoic acid	m.p. 122.5-3.5°; 124° 57
p-Fluorobenzoic acid	m.p. 181-2.5°; 182.6° 58
o-Fluoronaphthalene	b.p. 203-5° 735mm.; 212° @768mm. 59 n <sup>33.0</sup> <sub>D</sub> 1.5357; n <sup>19.5</sup> <sub>D</sub> 1.59389. 38
m-Fluoronaphthalene	m.p. 61-2°; 61° 37
p-Fluoroaniline	b.p. 185-8° @740mm.; 187° @753mm. 60 n <sup>31.6</sup> <sub>D</sub> 1.5413; n <sup>20</sup> <sub>D</sub> 1.5394. 36
o-Fluorodiphenyl	m.p. 73-5°; 73.5° 35
2-Fluoro-3-methylpyridine	b.p. 144-6° @737mm.; 145.5° @735mm. 61
p-Toluenesulfonyl fluoride	m.p. 43.0-.5°; 43-4° 64

Comparison With the Schiemann Reaction.—Since the Schiemann reaction is widely used for the synthesis of aromatic fluorides in present day preparative work, a brief comparison will be made of its merits and limitations with those of the method of diazotization and decomposition in anhydrous hydrogen fluoride. In general it may be said that, all other factors being equal, the method of diazotization in anhydrous hydrogen fluoride is more convenient, when proper equipment such as metal flasks and a metal reflux coil are at hand, than is the Schiemann reaction because the latter is a three-step process involving first the preparation of a water-insoluble diazonium borofluoride, second the through drying of this salt, and third the thermal decomposition of the dry salt. Although the method of diazotization in anhydrous hydrogen fluoride is carried out in two distinct operations, diazotization and decomposition, the diazonium fluorides are not isolated, and both operations are carried out consecutively in the same metal flask and in the same reaction medium. On the other hand the Schiemann reaction requires no special equipment, but may be carried out in ordinary glass apparatus.

Both methods provide excellent means of preparing fluoro-derivatives of aromatic hydrocarbons except in the naphthalene series with the anhydrous hydrogen fluoride method, and except when an attempt is made to introduce a fluorine atom into a position ortho to an alkyl group by the Schiemann method. Thus in the preparation of *o*-fluoro-

toluene the Schiemann reaction, when carried out in the usual manner, gives only a trace of the desired product, while a high yield is obtained through diazotization in anhydrous hydrogen fluoride. Schiemann, himself<sup>1</sup>, claims a 90% yield for the decomposition phase of this reaction, but other workers have consistently obtained only tar and a trace of o-fluorotoluene by following Schiemann's directions.<sup>71</sup>

The preparation of fluorophenols directly from the corresponding aminophenols is not possible with the Schiemann reaction because the solubility of the diazonium borofluorides in water is too great to permit their isolation. However, o- and p-fluoroanisole, are prepared in good yields by the use of the Schiemann reaction. m-Fluoroanisole cannot be made by that method because its diazonium borofluoride decomposes spontaneously at room temperature.<sup>11</sup> Diazotization and decomposition in anhydrous hydrogen fluoride gives poor yields of o- and p-fluorophenols, but a good yield of m-fluorophenol. Thus in this case the new method proves to be a valuable supplement to the established Schiemann procedure.

Application of the Schiemann method to the synthesis of fluorobenzoic acids directly from the aminobenzoic acids gives very poor results as much tar is formed in the decomposition.<sup>57</sup> All three of the simple fluorobenzoic acids have been prepared in good yields through diazotization of the corresponding aminobenzoic acids in anhydrous hydrogen fluoride.



A comparison of the yields obtained in the preparation of a variety of aromatic fluorides by both the anhydrous hydrogen fluoride method, and by that of the Schiemann method is presented in Table III. Of the whole those obtained by the first mentioned method are somewhat higher.

Effect of Ring Substituents Upon Decomposition.-As indicated in Table I, the various diazonium fluorides studied were found to differ widely in the temperatures at which they decomposed to yield aromatic fluorides. In order to facilitate correlation of the molecular structures of the diazonium fluorides with ease of decomposition, the decomposition conditions indicated in Table I have been rated upon an arbitrary, relative scale of 1 to 10, as shown in Table IV. The most rapid decomposition have been given a rating of one, and the most difficult a rating of ten. Although the differences are fairly evident from the qualitative descriptions of the decomposition conditions, the lack of precise kinetic data introduces an element of human error, and hence some of the assignments differing only by a point or two are more or less arbitrary. A few of the decompositions listed in Table I that are considered abnormal have been omitted from Table IV to avoid confusion.

The formation of aromatic fluorides by decomposition of benzene diazonium fluorides and its derivatives most

TABLE III

COMPARISON OF THE YIELDS OF AROMATIC FLUORIDES OBTAINED THROUGH DIAZOTIZATION IN ANHYDROUS HYDROGEN FLUORIDE AND BY THE SCHIEMANN REACTION

Aromatic fluoride	% Yield by anhydrous HF	% Yield by Schiemann In de- Of boro- compo- Over- fluoride: sition: all:		
Fluorobenzene	81	63	100	63 <sup>32</sup>
<i>o</i> -Fluorotoluene	75	72	90	65 <sup>34</sup>
		good	trace	trace <sup>71</sup>
<i>m</i> -Fluorotoluene	82	79	87	69 <sup>34</sup>
<i>p</i> -Fluorotoluene	78	67	97	65 <sup>32</sup>
4-Fluoro-1,3-dimethylbenzene	57	31	100	31 <sup>32</sup>
<i>m</i> -Fluorochlorobenzene	81	?	?	60 <sup>51</sup>
<i>o</i> -Fluoronitrobenzene	5	74 <sup>32</sup>	19 <sup>36</sup>	14
<i>m</i> -Fluoronitrobenzene	39	80 <sup>32</sup>	54 <sup>36</sup>	43
<i>p</i> -Fluoronitrobenzene	62	100 <sup>32</sup>	52 <sup>36</sup>	52
<i>o</i> -Fluoroanisole	6	52	67	35 <sup>38</sup>
<i>m</i> -Fluoroanisole	0	82	64	53 <sup>38</sup>
		Decomposed spontaneously at room temperature <sup>11</sup>		
<i>p</i> -Fluoroanisole	10	85	67	57 <sup>38</sup>
<i>o</i> -Fluorobenzoic acid	57	?	?	7 <sup>57</sup>
<i>m</i> -Fluorobenzoic acid	78	?	?	5 <sup>57</sup>
<i>p</i> -Fluorobenzoic acid	98	?	?	0 <sup>57</sup>
$\alpha$ -Fluoronaphthalene	1	91	60	55 <sup>37</sup>
$\beta$ -Fluoronaphthalene	1	90	69	62 <sup>37</sup>
<i>o</i> -Fluorodiphenyl	82	85	89	76 <sup>35</sup>

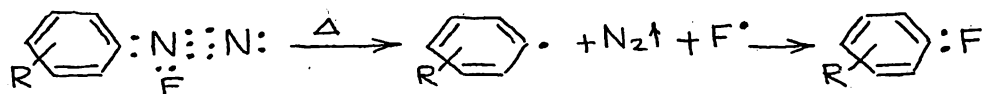
TABLE IV

THE RELATIVE EASE OF DECOMPOSITION OF DIAZONIUM FLUORIDES  
IN ANHYDROUS HYDROGEN FLUORIDE

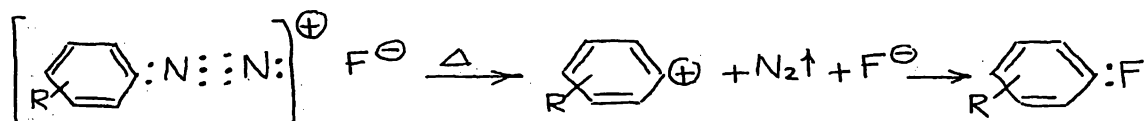
Aromatic fluoride	Relative ease of decomposition
Fluorobenzene	3
<i>o</i> -Fluorotoluene	1
<i>m</i> -Fluorotoluene	2
<i>p</i> -Fluorotoluene	4
4-Fluoro-1,3-dimethylbenzene	3
2-Fluoro-1,4-dimethylbenzene	3
<i>o</i> -Fluorochlorobenzene	10
<i>m</i> -Fluorochlorobenzene	6
<i>p</i> -Fluorochlorobenzene	8
<i>o</i> -Fluoronitrobenzene	10
<i>m</i> -Fluoronitrobenzene	8
<i>p</i> -Fluoronitrobenzene	7
1-Fluoro-2,4-dinitrobenzene	10
<i>o</i> -Fluorophenol	10
<i>m</i> -Fluorophenol	3
<i>p</i> -Fluorophenol	4
<i>o</i> -Fluoroanisole	10
<i>m</i> -Fluoroanisole	3
<i>p</i> -Fluoroanisole	8
<i>o</i> -Fluorobenzoic acid	7
<i>m</i> -Fluorobenzoic acid	6
<i>p</i> -Fluorobenzoic acid	5

likely proceeds by either a free radical or an ionic mechanism, i. e.

Free radical:

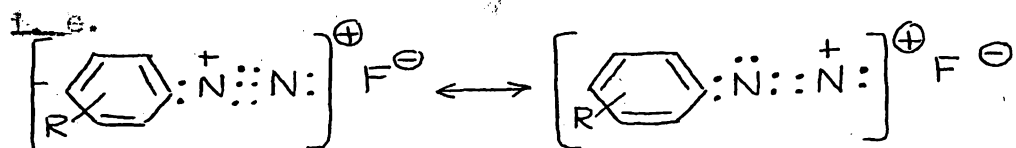


Ionic:



Although some evidence exists<sup>72 to 79</sup> supporting a free radical mechanism for the decomposition of diazonium compounds, the evidence is fragmentary, and most authorities<sup>80 to 82</sup> support the ionic mechanism in formulating such reaction. Hence the results obtained in this study will be interpreted from such a viewpoint.

It is evident from Table IV that the ease with which substituted benzene diazonium fluorides undergo decomposition in anhydrous hydrogen fluoride varies not only with the nature of the substituted group but also with the position on the benzene ring relative to the diazonium group. Examination of both of the possible resonance structures for such substituted benzene diazonium fluorides,



leads to the simple conclusion that their tendencies to lose nitrogen and form a carbonium ion should be increased if the nature and position of the substituted group R are such that the electron density of the carbon atom bonded to nitrogen is increased, while the opposite effect would be expected if the group R caused the electron density at that carbon atom to be reduced. The stability of the carbonium ion would be greatly increased by any factor which tends to distribute the positive charge over the carbonium ion. In general this theory is substantiated.

Thus diazonium fluorides substituted with alkyl groups, which have a tendency to increase the electron density on the benzene ring, decompose quite easily. The same result is observed in the case of diazonium fluorides substituted with the hydroxyl group, except in the ortho position, when a very stable diazonium fluoride results.

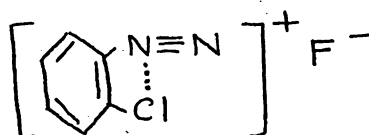
On the other hand diazonium fluorides substituted with groups that have a strong tendency to withdraw electrons from the benzene ring, such as the carboxyl and nitro groups, are considerably more difficult to decompose. The relatively high stability of diazonium fluorides substituted with chlorine is in line with the large inductive effect associated with that element.<sup>83</sup>

Tables I and IV show that an ortho-substituted diazonium fluoride was involved in every case that failed to decompose when heated at the highest temperatures attainable (usually about 75 to 85°) under reflux at atmospheric

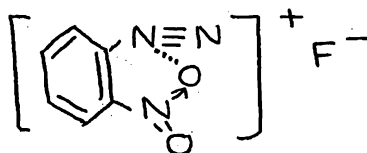
pressure. Examples of such behavior are shown by o-chloro-, o-nitro-, o-hydroxy-, and o-methoxybenzenediazonium fluorides. On the other hand o-methyl-, and o-phenylbenzenediazonium fluorides decompose almost spontaneously. Such abrupt differences in behavior cannot be charged off to mere electron lending or withdrawing tendencies to the benzene ring, and indeed the extremely stable group of diazonium fluorides contains members from both classes of such groups. It is therefore proposed that such ortho-substituted diazonium fluorides owe their stabilities to some form of electronic interaction, similar in nature to that encountered in hydrogen bonding, between the diazonium and the ortho-substituted groups.

Such interactions in the above-named cases can be formulated as follows:

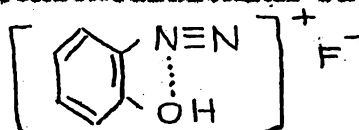
For o-chlorobenzediazonium fluoride:



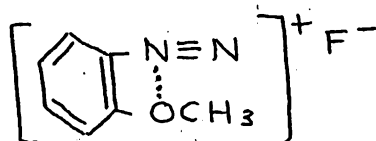
For o-nitrobenzenediazonium fluoride:



For o-hydroxybenzenediazonium fluoride:



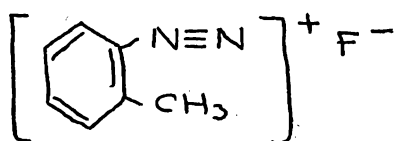
For o-methoxybenzenediazonium fluoride:



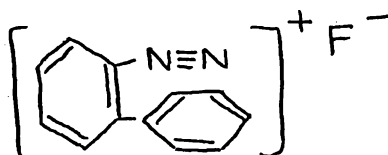
The electronic interactions in these cases are attractions, probably primarily electrostatic in nature, between the positively charged diazonium group and portions of the adjacent group that bear a high electron density. Such distribution of the positive charge on the diazonium group over a larger portion of the molecule would indeed be expected to confer added stability upon the carbon to nitrogen bond.

No such electronic interactions would be possible in the cases of o-methyl-, and o-phenylbenzene diazonium fluorides, i. e.

For o-methylbenzenediazonium fluoride:



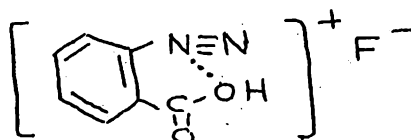
For o-phenylbenzenediazonium fluoride:



and experiment shows that they decompose easily below room temperature. The fact that they decompose easier than

benzenediazonium fluoride itself, indicates that the steric effect of the adjacent methyl and phenyl groups may assist to a slight degree in weakening the carbon-nitrogen bond.

*o*-Carboxybenzenediazonium fluoride represents an intermediate case, as it is decomposed by moderate heating. As would be expected the interaction here is not as strong as in the more stable cases:



Attempts to interpret the results for diazonium fluorides substituted with the same group in *o*-, *m*-, and *p*-positions are not clear cut, and indeed no completely plausible theoretical interpretation can yet be drawn from the state of our present knowledge.



Summary

1. The replacement of the aromatic amino group by fluorine through diazotization and decomposition in anhydrous hydrogen fluoride has been carried out successfully in the preparation of sixteen aromatic fluorides, previously prepared by other methods. One heterocyclic amine has been prepared in fair yield by this method, while application of the reaction in the aliphatic series gave a negative result.

2. Three new compounds, 2-fluoro-1,4-dimethylbenzene, 2-fluoro-3-methylpyridine, and *p*-fluorobenzenesulfonyl fluoride, have been prepared by diazotization in anhydrous hydrogen fluoride, and characterized for the first time.

3. A new reaction has been discovered which allows the synthesis of aromatic sulfonyl fluorides from aromatic sulfonamides through reaction with sodium nitrite in anhydrous hydrogen fluoride. Two aromatic sulfonyl fluorides have been prepared by this method.

4. The effect of various substituting groups upon the ease of decomposition of benzenediazonium fluoride and its derivatives has been studied, and a theory proposed to correlate the experimental results. A new class of atomic interactions, similar to hydrogen bonding, has been proposed to explain the extreme stability of certain *o*-substituted benzenediazonium fluorides.

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