Journal of Fluorine Chemistry, 21 (1982) 385–392

Received: April 21, 1982

CONVERSION OF DIARYLIODONIUM SALTS TO ARYL FLUORIDES

MICHAEL VAN DER PUY

Buffalo Research Laboratory, Allied Corporation
20 Peabody Street, Buffalo, New York 14210 (U.S.A.)

SUMMARY

The preparation of aryl fluorides by the reaction of diaryliodonium salts with KF is discussed. Generally, best results were obtained when the salt $Ar_2I^+X^-$ was heated with KF in the absence of solvent. The counterion, X^-, must be non-nucleophilic.

INTRODUCTION

Diaryliodonium salts are well known to react with nucleophiles such as the halide anions (Cl^-, Br^-, I^-) and a variety of other nucleophiles [1-4]. In this way, aryl halides, ethers, amines and phenols can be prepared.

$$Ar_2I^+ + Nuc^- \rightarrow ArI + ArNuc$$

The use of diaryliodonium salts as starting materials for aryl fluorides, however, has been virtually unexplored. Although diaryliodonium fluorides are known, they have not been used extensively, perhaps due to difficulties associated with either preparation or isolation. Caserio et al.[5] reported that they were unable to obtain an elemental analysis of 4-methoxydiphenyliodonium fluoride due to its hygroscopic and unstable nature. Although it was reported to decompose at its melting point, the products of the decomposition were not stated. Schonewaldt et al.[6] reported the synthesis of 4'-(3-carboxy-4-acetoxy)-biphenylyl-4-anisoyliodonium fluoride and its decomposition in dimethylformamide(DMF) at 115°C to O-acetyl-5-(4-fluorophenyl) salicylic acid, although no yield was reported. This seems to

0022-1139/82/0000-0000/$02.75

be the only example to date where an aryl fluoride has been prepared from an iodonium fluoride (but as will be shown below, this method is likely to have resulted in the formation of the non-fluorinated product also (O-acetyl-5-phenylsalicylic acid)). The objective of the present study was to demonstrate the feasibility of forming aryl fluorides from iodonium salts, to avoid synthesis of iodonium fluorides, and, if possible, eliminate radical reactions competing with the desired S_NAr process.

RESULTS AND DISCUSSION

In view of the potential difficulties in the preparation of diaryliodonium fluorides, the decomposition of iodonium salts having other counterions, but in the presence of fluoride ion, was examined. The problem in using other counterions can be appreciated by the following example. When diphenyliodonium chloride was heated in DMF to 135-140°C in the presence of KF, chlorobenzene and fluorobenzene were both formed in a ratio of about six. This is not surprising since the hard nucleophile fluoride ion must compete with the softer (higher energy HOMO) chloride ion and attack what must be a rather soft electrophilic center. The preference for the formation of chlorobenzene might have been expected from the trend observed for the rates of decomposition of $(C_6H_5)_2I^+X^-$ $(X = I^- > Br^- > Cl^-)$ [4].

In addition to nucleophilic displacement of iodobenzene, iodonium salts can decompose thermally, by way of a radical process [5,7]. Subsequent reactions of aryl radicals with solvent is of some concern from a practical standpoint, since fluorinated aromatics have boiling points near those of the corresponding hydrocarbons. As expected, this was a significant reaction pathway in DMF (Table 1, method a). Thus, when diphenyliodonium tetrafluoroborate was heated in DMF in the presence of KF, iodobenzene, fluorobenzene and benzene were formed. The latter two were formed in a ratio of about seven.

$$(C_6H_5)_2I^+BF_4^- \xrightarrow[DMF]{KF} C_6H_5I + C_6H_5F + C_6H_6$$

TABLE 1

Decomposition of diaryliodonium salts

No.	Compound	Method Of Decomposition*	Temp (°C)	Time (h)	Product (% Yield)
(1)	$(C_6H_5)_2I^+BF_4$	a	120-150	2	C_6H_5F(54), C_6H_6 (8)
(2)	$4\text{-}CH_3OC_6H_4I^+C_6H_5$ CF_3COO^-	a	115	2	C_6H_5F(46), C_6H_6 (6)
(3)	$4\text{-}CH_3OC_6H_4I^+C_6H_5$ $p\text{-}CH_3C_6H_4SO_3^-$	a	120	2	C_6H_5F(61), C_6H_6 (9)
(4)	$(C_6H_5)_2I^+Cl^-$	a	115	6	C_6H_5Cl(65), C_6H_5F(11), C_6H_6(2)
(5)	$(C_6H_5)_2I^+BF_4^-$	b	218-223	3.5	C_6H_5F (67)
(6)	$(m\text{-}NO_2C_6H_4)_2I^+BF_4^-$	b	211-233	3	$m\text{-}FC_6H_4NO_2$ (41)
(7)	$(C_6H_5)_2I^+BF_4^-$	c	160-170	20	C_6H_5F (85)
(8)	$(m\text{-}NO_2C_6H_4)_2I^+BF_4$	c	210-235	0.6	$m\text{-}FC_6H_4NO_2$ (38)
(9)	$(p\text{-}CH_3OC_6H_4)_2I^+BF_4^-$	c	190-195	8	$p\text{-}FC_6H_4OCH_3$ (44)
(10)	$(p\text{-}ClC_6H_4)_2I^+BF_4^-$	c	180-190	5.5	$p\text{-}FC_6H_4Cl$ (39)

*Method a, reaction in DMF with added KF; method b, thermolysis in absence of KF or solvent; method c, with KF present but no solvent.

Using benzonitrile as the solvent, however, gave better results, although the solubility of KF in this solvent is poor. For example, when 3,3'-dinitrodiphenyliodonium fluoroborate was heated with KF in benzonitrile, m-fluoronitrobenzene was formed in about 38% yield, while nitrobenzene was absent.

The thermal decomposition of iodonium fluoroborates in the absence of solvents was also briefly examined. Reutov et al. [8] have shown that diaryliodonium tetrafluoroborates undergo exchange with labeled aryl iodides when heated to their decomposition points (210-225°C). The products were labeled iodonium fluoroborates. Levit et al. [9] heated the fluoroborates at 200°C in a closed system using cyclohexane as solvent. They reported that fluorobenzene and benzene were formed. Results obtained for the thermal decomposition of the tetrafluoroborates in the absence of solvents are given in Table 1 (method b). Fair to good yields of fluorinated products were obtained for C_6H_5F (67%) and m-$NO_2C_6H_4F$ (41%). Neither benzene nor nitrobenzene were found. An apparent exception, however, is the thermal decomposition of 4,4'-dimethoxydiphenyliodonium fluoroborate at 220°C, which gave several products, including anisole, but no p-fluoroanisole. The difference in behavior seen for these compounds may be the result of more favorable radical or electron-transfer pathways for iodonium salts bearing electron-donating substituents on the ring, relative to the nucleophilic substitution process, which would be less favorable with these substituents. Even in the nucleophilic substitution process, however, the exact nature of the nucleophile is unclear. Are iodonium fluorides and BF_3 formed first, or does the loss of BF_3 occur in the same step as the formation of the aryl fluoride?

Although the decomposition of the diaryliodonium fluoroborates are generally in excess of 210°C [8], it was found that the decomposition of these salts in the presence of KF could occur substantially below 210°C, but above the melting point of the organic salt. Thus, when KF and diphenyliodoniu fluoroborate were heated to 160-170°C (decomposition point of this salt is 210°C), fluorobenzene was formed in 85% yield, again free of benzene. Other fluorobenzenes

$$Ar_2I^+X^- + KF \rightarrow ArI + ArF + KX$$

produced in this way were p-fluorochlorobenzene, m-fluoronitrobenzene, and even p-fluoroanisole (method C, Table 1). Each was free of the non-fluorinated substituted benzene. Presumably, KF dissolves in the molten salt and reacts with it.

This method has less advantage over the thermal decomposition of the fluoroborate salt alone when the melting point of the salt is high. However, other iodonium salts with lower melting points can be used, provided the anion is essentially non-nucleophilic. For example, 4-methoxydiphenyliodonium trifluoroacetate, when heated with KF to 165-170°C for 4h, afforded fluorobenzene in 57% yield. In this case, some p-fluoroanisole was also produced (8%).

The above example illustrates an important point in the decomposition of unsymmetrical diaryliodonium salts. That is, the nucleophile will end up predominantly on the ring bearing the most electron-withdrawing group (or the less powerful electron donating group). Symmetrical diaryliodonium salts are therefore not always required in the synthesis of a particular aryl fluoride.

While it can be readily seen from the above results that the preparation of ArF from iodonium salts has limitations, the method also has potential advantages over other current methods. First, as aryl iodides are by-products produced in high yield, recycle to the iodonium salt is possible. Second, the iodonium method, like the Balz-Schiemann reaction, can be used in the preparation of aryl fluorides which possess electron-donating groups. This is a limitation in the displacement method in which, for example, a substituted chlorobenzene is treated with KF in an aprotic solvent. Third, the iodonium method has a potential advantage over the Balz-Schiemann reaction in the selectivity observed in the formation of starting material. The Balz-Schiemann reaction uses as starting material an aryl amine. Generally, these are readily available by nitration, followed by reduction of a benzene derivative. The nitration step usually results in a mixture of ortho and para isomers. In contrast, the preparation of substituted iodonium salts involves coupling reactions of high regioselectivity. For example, while nitration of chlorobenzene gives a mixture of 30% ortho and 70% para nitrochlorobenzenes, the coupling of p-chlorophenyliodoso diacetate with chlorobenzene occurs 2% ortho and 98% para [10]. It is worthy to note that, as was seen in the examples, symmetrical diaryliodonium salts are not always necessary for the preparation of a particular aryl fluoride.

For the purpose of preparing aryl fluorides from diaryliodonium salts it is also important to realize that the preparation and isolation of iodonium fluorides is unnecessary. The counterion can be any substantially non-nucleophilic anion including fluoroborate, tosylate, trifluoroacetate, or trifluoromethylsulfonate anions. This provides greater flexibility in the preparation of the desired iodonium salt and eliminates a metathesis reaction to generate the iodonium fluoride.

EXPERIMENTAL

Preparation of iodonium salts

The preparation and properties of the materials used in entries 1,2 and 4 of Table 1 are given in reference 11.

4-Methoxydiphenyliodonium tosylate was prepared by the condensation of phenyliodoso hydroxytosylate [12] with anisole using the procedure of reference 13.

Procedures for the preparation of compounds in entries 6 and 9 of Table 1 are found in reference 14.

4,4'-Dichlorodiphenyliodonium tetrafluoroborate was prepared by Beringer's method [11] for the synthesis of the chloride, except that 50% HBF_4 was used instead of conc HCl (mp 178-182°C).

Preparation of aryl fluorides

The following examples illustrate the methods outlined in the text. Yields were based on iodonium salt added and were not optimized. Conversions were not determined.

Method a (See Table 1)

In a 100 mL flask fitted with a reflux condenser, 2.0 g (0.034 mol) of KF was flamed under vacuum. After cooling under an N_2 atmosphere, 7.0 g (16.5 mmol) of 4-methoxydiphenyliodonium trifluoroacetate and 75 mL dry DMF were added. The mixture was heated to 109-118°C for 2h. The cooled solution was diluted with 100 mL of water and extracted with CH_2Cl_2. The methylene chloride layer was analyzed by GC using benzotrifluoride as internal standard (1/8" x 10' OV-101 (10%) on Chromosorb, injection port temperature 190°C). The yield of fluorobenzene was 46%, while the ratio of fluorobenzene to benzene was about eight.

Method b

The fluoroborates were heated under N2 in an oil bath for the times and temperatures given in the Table. Yields were determined by GC.

Method c

Diphenyliodonium tetrafluoroborate (5.54 g, 15 mmol) and dry KF (3.0 g, 52 mmol) were heated in a flask (under N_2) fitted with a reflux condenser to 160-170°C for 20h. The liquid products were dissolved in CH_2Cl_2 containing internal GC standard. The residue weighed 4.2 g. Analysis of the liquid products indicated a near quantitative conversion of the iodonium salt and a yield of fluorobenzene of 85%.

4-Methoxydiphenyliodonium trifluoroacetate (15.8 g, 37 mmol) and dry KF (3.5 g, 60 mmol) were heated under N_2 for 4h at 165-170°C. Analysis of the product mixture at this time indicated yields of fluorobenzene (57.4%), benzene (0%), anisole (0%), iodobenzene (26.3%), 4-iodoanisole (56.8%, 4-fluoroanisole (8.3%), and phenyl trifluoroacetate (9%).

REFERENCES

1 F.M. Beringer, E.M. Gindler, M. Rapoport and R.J. Taylor, J. Amer. Chem. Soc., 81 (1959) 351.

2 F.M. Beringer, E.J. Geering, I. Kuntz and M. Mausner, J. Phys. Chem., 60 (1956) 141.

3 F.M. Beringer and R.A. Falk, J. Chem. Soc., (1964) 4442.

4 F.M. Beringer and M. Mausner, J. Amer. Chem. Soc., 80 (1958) 4535.

5 M.C. Caserio, D.L. Glusker and J.D. Roberts, J. Amer. Chem. Soc., 81 (1959) 336.

6 E.F. Schonewaldt, G.G. Hazen and R.F. Shuman, U.S. Patent 3,660,372 (1972).

7 R.B. Sandin and R.K. Brown, J. Amer. Chem. Soc., 69 (1947) 2253.

8 O.A. Reutov, G.A. Ertel and O.A. Ptitsina, Doklady Acad. Nauk. SSSR, 133 (1960) 1108.

9 A.F. Levit, I.Z. Korostyshevskii and I.P. Gragerov, Z. Org. Chem., 6 (1970) 1878.

10 D.J. LeCount and J.A.W. Reid, J. Chem. Soc.(C), (1967) 1298.

11 F.M. Beringer, R.A. Falk, M. Karniol, I. Lillien, G. Masullo, M. Mausner and E. Sommer, J. Amer. Chem. Soc., 81 (1959) 342.

12 G.F. Koser and R.H. Wettach, J. Org. Chem., 42 (1977) 1476.

13 O.Y. Neiland and B.Y. Karele, J. Org. Chem. USSR (Eng. Translation), 6 (1970) 889.

14 G.G. Lyatiev, O.A. Ptitayna and O.A. Reutov, J. Org. Chem. USSR (Eng. Translation), 5 (1969) 400.