Direct Fluorination of Diarylacetylenes to Diaryltetrafluoroethanes with Convenient F_2 Equivalent Nitrosonium Tetrafluoroborate–Pyridinium Polyhydrogen Fluoride[1]

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Selective fluorination of organic compounds is of considerable interest in medicinal and materials' chemistry.[2] Elemental fluorine diluted with inert gases (such as N_2, He, etc.) is incresingly used in organic fluorinations.[3] But the procedure still represents problems for the average laboratory. A convenient F_2 equivalent reagent is therefore of substantial interest.

Direct fluorination of acetylenes to tetrafluoroethanes have been reported. Addition of F_2 gas to diphenylacetylene in methanol solution led to formation of tetrafluorodiphenylethane in 23% yield.[4] Addition of fluorine diluted in nitrogen gas to diarylacetylenes in Freon 11 also yielded terafluoroethanes.[5] However, in both reactions due to high reactivity of elemental fluorine, many byproducts were obtained. In 1986, Rozen *et al.* reported the reaction of alkynes with excess IF prepared directly from I_2 and F_2.[6a] In the case of diphenylacetylene, the product 1,1-difluoro-2,2-diiododiphenylethane was subsequently converted to 1,1,2,2–tetrafluorodiphenylethane in 60% yield. However, the reaction was carried out only in the case of diphenylacetylene and preparation of IF is inconvenient in most laboratories. Xenon difluoride-induced tetrafluorination of phenylacetylenes has also been reported.[6b]

In our continued investigation of fluorination reactions we would like to report direct one-step tetrafluorination of diarylacetylenes with nitrosonium tetrafluoroborate ($NO^+BF_4^-$) and pyridinium polyhydrogen fluoride (PPHF) reagent[7] which acts as a convenient *in situ* F_2 equivalent reagent.

$NO^+ BF_4^-$ is completely soluble in PPHF (60 wt % HF) at 0 °C. To this clear colorless solution was dropwise added diphenylacetylene in CH_2Cl_2 and the resulting red colored mixture was stirred under nitrogen for 24 h at room temperature. After aqueous workup 1,1,2,2-tetrafluorodiphenylethane was obtained in 75% yield. Under similar reaction conditions, other tetrafluoroethanes were obtained from the corresponding diarylacetylenes in 38–75% yields (see Table 1). The major byproducts were α,α-difluoro ketones and benzoic acid.

Table 1. Fluorination of Arylacetylenes

substrate	products	yield (a)
Ph-C≡C-	$PhCF_2CF_2Ph$	75
Ph-C≡C-(p-CH_3)	$PhCF_2CF_2$-(p-CH_3)	52
Ph-C≡C-(p-CF_3)	$PhCF_2CF_2$-(p-CF_3)	45
Ph-C≡C-(p-F)	$PhCF_2CF_2$-(p-F)	50
Ph-C≡C-(p-OCH_3)	$PhCF_2CF_2$-(p-OCH_3)	38
Ph-C≡C-CH_2CH_3	$PhCF_2CF_2CH_2CH_3$ + $PhCF_2CF{=}CHCH_3$	39 45

(a) Isolated yields

When 1-phenyl-1-butyne was allowed to react with the $NO^+BF_4^-$ and PPHF reagent system, in addition to 1-phenyl-1,1,2,2-tetrafluorobutane (39%), 1-phenyl-1,1,2-trifluoro-2-butene (45%) was also isolated. In the case of 4-octyne a more complex product mixture was obtained and isolation of discernible products proved to be difficult.

The proposed mechanism for the fluorination of diphenylacetylene **1** is shown in Scheme 1. Initially "NOF" generated from $NO^+BF_4^-$ and PPHF adds to the triple bond to give 1-fluoro-2-nitrosostilbene (**2**). In the acidic solution, **2** is protonated to the corresponding oximino cation **3**, which then reacts with fluoride ion to produce difluoro ketoxime **4**. The ketoxime **4** undergoes further nitosative fluorination to **5**.[8] The intermediate **5** is again protonated to **6** under acidic conditions and **6** subsequently undergoes nucleophilic displacement by fluoride ion to 1,1,2,2-tetrafluoro **7** and $H_2N_2O_2$ (**8**) (**8** decomposes to N_2O and H_2O[9]). The mechanism is in accord with that which we earlier proposed for the conversion of ketoximes to *gem*-difluoro compounds using $NO^+BF_4^-$ in PPHF.[7]

In the case of 1-phenyl-1-butyne, 1-phenyl-1,1,2-trifluorobutene is also produced. The mechanism for the formation of trifluoroalkene product is suggested in Scheme 2 involving an intermediate such as **6** followed by elimination which competes with tetrafluorination.

In summary, a novel and convenient method for the direct fluorination of arylacetylenes to the corresponding tetrafluoroethanes using $NO^+BF_4^-$ PPHF is reported. We are continuing studies of the reaction of this F_2 equivalent reagent system with other substrates.

Experimental Section

General Information. Diarylacetylenes were prepared by reacting iodoarenes with cuprous phenylacetylide in refluxing pyridine.[10] Pyridinium polyhydrogen fluoride (60 wt % HF) can

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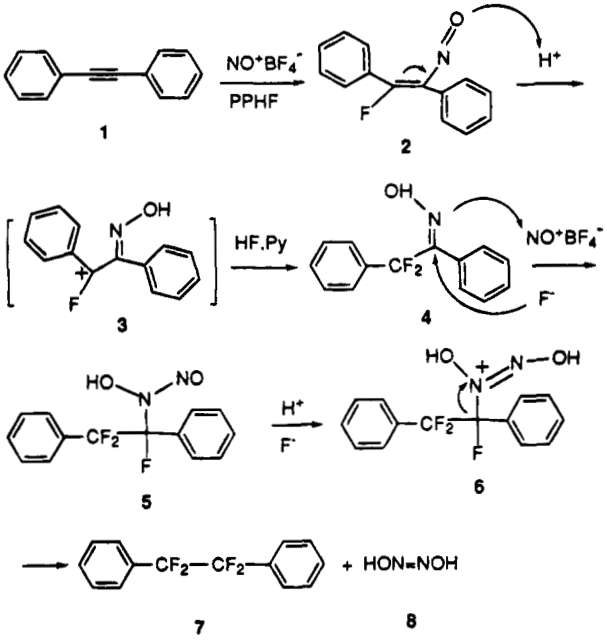
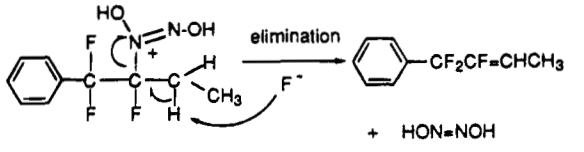
Scheme 1. Fluorination of Diphenylacetylene



Scheme 2. Fluorination of 1-Phenyl-1-butyne



be conveniently prepared in the laboratory by condensing the needed amount of anhydrous hydrogen fluoride at low temperature (−78 °C) into a polyethylene bottle containing pyridine in a well-ventilated hood.[11]

Typical procedure for the reaction of diphenylacetylene and $NO^+BF_4^-$/PPHF (60 wt % HF). Diphenylacetylene (0.356 g, 2 mmol) in CH_2Cl_2 (2 mL) was added dropwise by syringe to a 50 mL polyethylene bottle containing $NO^+BF_4^-$ (0.70 g, 6 mmol) and PPHF (8 mL, 60 wt % HF) at 0 °C under nitrogen. The mixture was stired for 24 h at room temperature. The reaction mixture was quenched with ice water (100 mL) and extracted with diethyl ether (3 × 25 mL). The combined organic layer is washed with 5% $NaHCO_3$ (50 mL) and water (2 × 50 mL) and dried over $MgSO_4$. After evaporation of the solvent, the crude product chromatographed on a silica gel columm (pentane as eluent). **Tetrafluorodiphenylethane** was obtained as white crystals (0.38 g, 75% yield): mp 120−121 °C (lit.[12] mp 122−123 °C); ^1H NMR δ 7.42−7.47 (m); ^{19}F NMR −112 ppm (s) (ϕ* 0.0 ppm for $CFCl_3$); MS, *m/e* 254 (16), 127 (100), 77 (13); HRMS calcd 254.0718, found 254.0708.

1,1,2,2-Tetrafluoro-1-(*p*-tolyl)-2-phenylethane: mp 102−103 °C (lit.[5] 102−103 °C); ^1H NMR δ 2.37 (3H, s), 7.17−7.46 (9H, m); ^{13}C NMR δ 21.32 (s), 116.68 (tt, J_{C-F} = 249.7.1 Hz, $^2J_{C-F}$ = 33.4 Hz), 116.83 (tt, J_{C-F} = 253.1 Hz, $^2J_{C-F}$ = 36.4 Hz), 126.9 (t, $^3J_{C-F}$ = 6.3 Hz), 126.96 (t, $^3J_{C-F}$ = 6.5 Hz), 128.03, 128.76, 130.82, 131.0 (t, $^2J_{C-F}$ = 24.0 Hz), 131.0 (t, $^2J_{C-F}$ = 20.6 Hz), 141; ^{19}F NMR −111.35, −111.75 ppm; MS, *m/e* 268 (9), 141 (100), 127 (21), 91 (8); HRMS calcd 268.0875, found 268.0872.

1,1,2,2-Tetrafluoro-1-(*p*-trifluoromethylphenyl)-2-phenylethane: mp 48 °C (lit.[5] 45−48 °C); ^1H NMR δ 7.38−7.71 (m); ^{13}C NMR 116.07 (tt, J_{C-F} = 251.2 Hz, $^2J_{C-F}$ = 36.2 Hz), 116.5 (tt, J_{C-F} = 252.7 Hz, $^2J_{C-F}$ = 36.3 Hz), 123.6 (q, J_{C-F} = 272.45 Hz), 125.16 (t, $^3J_{C-F}$ = 3.01 Hz), 126.90 (t, $^3J_{C-F}$ = 6.4 Hz), 127.63 (t, $^3J_{C-F}$ = 6.8 Hz), 128.3, 130.27 (t, $^2J_{C-F}$ = 24.1 Hz), 131.2, 131.77 (d, $^3J_{C-F}$ = 4.1 Hz), 133.10 (q, $^2J_{C-F}$ = 33.2 Hz), 134.56 (t, $^2J_{C-F}$ = 25.6Hz); ^{19}F NMR −63.02, −111.50, −111.98 ppm; MS *m/e* 322 (8), 303 (10), 195 (13), 127 (100); HRMS calcd 322.0592, found 322.0608.

1,1,2,2-Tetrafluoro-1-(*p*-fluorophenyl)-2-phenylethane: mp 115−116 °C; ^1H NMR δ 7.05−7.12 (m), 7.43 (m); ^{13}C NMR 115.31 (d, $^2J_{C-F}$ = 22.0 Hz), 116.39 (tt, J_{C-F} = 252.7 Hz, $^2J_{C-F}$ = 36.2 Hz), 116.5 (tt, J_{C-F} = 252.7 Hz, $^2J_{C-F}$ = 36.0 Hz), 126.9 (t, $^3J_{C-F}$ = 6.4 Hz), 128.14, 129.27 (q, $^2J_{C-F}$ = 6.4 Hz), 131.0 (t, $^3J_{C-F}$ = 1.1 Hz), 164.3 (d, J_{C-F} = 250.9 Hz); ^{19}F NMR −109.16, −111.11 ppm; MS, *m/e* 272 (19), 145 (96), 127 (100); HRMS calcd 272.0624, found 272.0624.

1,1,2,2-Tetrafluoro-1-(p-methoxyphenyl)-2-phenylethane: mp 38−39 °C; ^1H NMR δ 3.84 (s), 7.33−7.44 (m); ^{13}C NMR 55.3, 113.47, 116.75 (tt, J_{C-F} = 251.3 Hz, $^2J_{C-F}$ = 36.5 Hz), 116.83 (tt, J_{C-F} = 251.32 Hz, $^2J_{C-F}$ = 35.6 Hz), 122.97 (t, $^2J_{C-F}$ = 25.3 Hz), 126.9 (t, $^3J_{C-F}$ = 6.5 Hz), 128.0, 128.5 (t, $^3J_{C-F}$ = 6.5 Hz), 130.8, 131.65 (t, $^2J_{C-F}$ = 18.6 Hz), 161.4; ^{19}F NMR −110.81, −111.84 ppm; MS, *m/e* 284 (8), 157 (100), 127 (20), 114 (13); HRMS calcd 284.0824, found 284.0815.

1,1,2,2,-Tetrafluoro-1-phenylbutane: ^1H NMR δ 1.07 (3H, t, J = 7.4 Hz), 1.89−2.19 (2H, m), 7.43 (5H, br m); ^{19}F NMR −112.30 (2F, s), −117.40 ppm (2F, t, $^3J_{H-F}$ = 18.45 Hz); MS, *m/e* 206 (20), 127 (100); HRMS calcd 206.0716, found 206.0712.

***trans*-1,1,2-Trifluoro-1-phenyl-2-butene:** ^1H NMR δ 1.62−1.69 (3H,m), 5.29 (1H, d quartet, $^3J_{H-H}$ = 6.8 Hz, $^3J_{H-F}$ = 34.40 Hz), 7.52 (5H, m); ^{19}F NMR −99.98 (2F, d, $^3J_{F-F}$ = 18.82 Hz), −131.51 ppm (1F, quintet, $^3J_{F-F}$ = 19.17 Hz, $^3J_{F-H}$ = 33.50 Hz); MS, *m/e* 186 (100), 171 (55), 108 (16), 151 (30), 127(80), 108 (16); HRMS calcd 186.0657, found 186.0649.

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