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Effect of Catalyst on the Fluorination of Methyl-Substituted Benzenes with Xenon Difluoride

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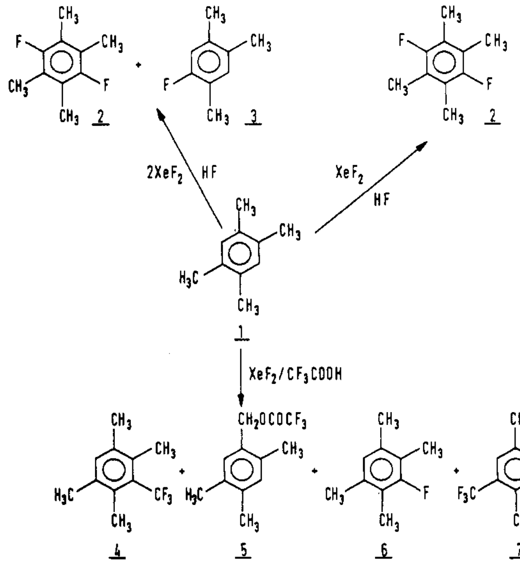
The course of acid-catalyzed liquid-phase fluorination of methyl-substituted benzene derivatives with xenon difluoride depends strongly on the structure and concentration of the substrate, its molar ratio to xenon difluoride, and the catalyst. HF-catalyzed fluorination of 1,2,4,5-tetramethylbenzene (1) with an equimolar amount of xenon difluoride gave a small amount of 1,4-difluoro product 2, while reaction with 2 equiv of xenon difluoride, besides difluoro product 2, also gave the demethylated product 1-fluoro-2,4,5-trimethylbenzene (3), which was also formed by HF-catalyzed fluorination of 1,3,4-trimethylbenzene. Trifluoroacetic acid catalyzed fluorination of 1 is much more complex, resulting in the four products 1-(trifluoromethyl)-2,3,5,6-tetramethylbenzene (4), 2,4,5-trimethylbenzyl trifluoroacetate (5), 1-fluoro-2,3,5,6-tetramethylbenzene (6), and 1-(trifluoromethyl)-2,3,4,5-tetramethylbenzene (7), the distribution depending on the amount of CF_3COOH used. Similar results were also observed in the fluorination of 1,2,3-trimethylbenzene and 1,3,5-trimethylbenzene.

The course of the fluorination of organic molecules with xenon difluoride depends on the structure of the molecules, the catalyst and solvent used, and the temperature; homolytic and heterolytic Xe–F bond cleavage was suggested.[1] Filler and co-workers have done pioneering work on the fluorination of aromatic molecules in the liquid phase,[2–5] while MacKenzie and Fajer have studied xenon difluoride reactions with aromatic compounds in the vapor phase.[6] Liquid-phase fluorination of various substituted benzene derivatives gave fluorinated products in high yield, while the fluorination of 1,3,5-trineopentylbenzene gave a complex mixture of 13 components, and 2% of 1-fluoro-2,4,6-trineopentylbenzene was isolated.[3] Some of the reasons for the complex course of the reaction could be the high molar ratio of xenon difluoride to substrate (6.73:2.7), the high concentration of substrate, or the structure of the substrate. We have already demonstrated that fluorination of 9,10-dihydroanthracene and triptycene must be carried out at much higher dilution.[7] It has also been demonstrated that electrophilic reactions of alkyl aromatics could also lead to side-chain substitution,[8] and fluorination of hexamethylbenzene with XeF_2 gave pentamethylbenzyl fluoride.[9] A small change in the structure of an organic molecule could dramatically change the course of trifluoroacetic acid catalyzed fluorinations. Reactions with *cis*- or *trans*-1-phenylpropene resulted in the formation of vicinal difluorides over β-fluorocarbonium ions, while the reaction with styrene led to five products via fluoro radicals, trifluoromethyl radicals, and trifluoroacetoxy radicals formed by decomposition of $FXeOCOCF_3$.[10]

Interest in obtaining a better knowledge of the effect of the organic molecule on XeF_2 reactivity prompted our investigation of reactions of methyl-substituted benzene derivatives in the presence of hydrogen fluoride or trifluoroacetic acid.

Scheme I



Results and Discussion

The reaction of 1 mmol of 1,2,4,5-tetramethylbenzene (1, Scheme I) in 2 mL of methylene chloride with 1 mmol of xenon difluoride in the presence of a catalytic amount of hydrogen fluoride gave only tar after 30 min, while the same reaction in 10 mL of methylene chloride resulted in the formation of a mixture containing 70% of the starting material, 1,4-difluorotetramethylbenzene, and tar. The mass spectrum of the tar contained signals at *m/e* 434 ($C_{30}H_{36}F_2$) and 302 ($C_{20}H_{24}F_2$), indicating the dimerization and trimerization reactions already observed in other aromatic systems.[1–4] The formation of hydroxy derivatives was also observed when no attention was paid to moisture exclusion. Reaction of 1 with 2 mmol of XeF_2 in the presence of hydrogen fluoride gave, besides tar, a small amount of 1,4-difluorotetramethylbenzene (2) and 1-fluoro-2,4,5-trimethylbenzene (3) in the ratio of 3:2. The demethylated product 3 was also formed by the fluorination of 1,2,4-trimethylbenzene. Fluorination of 1,2,4,5-tetramethylbenzene (1) with xenon difluoride in the presence of trifluoroacetic acid resulted in the formation of the following four products (Scheme I), isolated by

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(2) Shaw, M. J.; Weil, J. A.; Hyman, H. H.; Filler, R. *J. Am. Chem. Soc.* **1970**, *92*, 5096–5099.

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Table I. Effect of the Amount of CF_3COOH on the Product Distribution in the Fluorination of 1,2,4,5-Tetramethylbenzene (1) and 1,3,5-Trimethylbenzene (8) with Xenon Difluoride[a]

Fluorination of 1

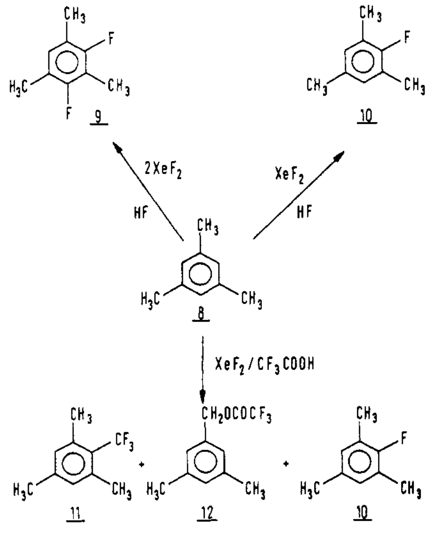
mmol of CF_3COOH	distribution, % 4	5	6	7
0.5	32	25	39	4
1.0	46	25	23	6
1.5	48	28	17	7

Fluorination of 8

mmol of CF_3COOH	distribution, % 11	12	10
0.5	18	18	64
1.0	24	24	52
1.5	25	25	50

[a] Relative yields were determinated by ^{19}F NMR. Each experiment was repeated several times; the maximum error was ±2%. All reactions were carried out at 25 °C with 1 mmol of substrate and 1 mmol of XeF_2 in 2 mL of methylene chloride, and 0.5, 1.0, or 1.5 mL of a 1 M solution of CF_3COOH in methylene chloride was added.

Scheme II

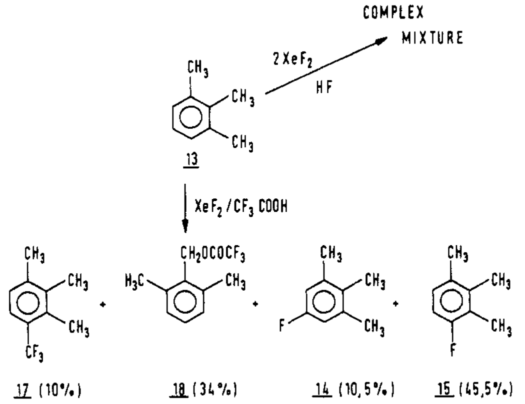


preparative GLC: 1-(trifluoromethyl)-2,3,5,6-tetramethylbenzene (4), 2,4,5-trimethylbenzyltrifluoroacetate (5), 1-fluoro-2,3,5,6-tetramethylbenzene (6), and 1-(trifluoromethyl)-2,3,4,5-tetramethylbenzene (7).

The effect of the amount of trifluoroacetic acid on product distribution, determined by ^{19}F NMR spectroscopy, is presented in Table I. Larger amounts of CF_3COOH increased the amount of trifluoromethyl-substituted product (4), diminished the amount of fluoro-substituted product (6), and slightly increased the amount of rearranged product (7), while the amount of trifluoroacetate remained nearly unchanged. The complex course of the reaction in the presence of trifluoroacetic acid has already been observed in the fluorination of styrene and diphenylacetylene.[10]

HF-catalyzed fluorination of 1,3,5-trimethylbenzene (8, Scheme II) in the presence of equimolar amounts of XeF_2 resulted in the formation of monofluoro product 10, while reaction with 2 mmol of XeF_2 gave one main product in 30% yield, which was isolated by preparative GLC. On the basis of the spectroscopic data, we established the structure of product 9 as 1,3-difluoro-2,4,6-trimethylbenzene. Trifluoroacetic acid catalyzed reaction of 8 gave 1-(trifluoromethyl)-2,4,6-trimethylbenzene (11), 3,5-dimethylbenzyltrifluoroacetate (12), and 1-fluoro-2,4,6-trimethylbenzene (10). The effect of the amount of CF_3COOH on the product distribution is presented in Table I.

Scheme III



HF-catalyzed fluorination of 1,2,3-trimethylbenzene (13, Scheme III) gave a 1:2 mixture of 1-fluoro-3,4,5-trimethylbenzene (14) and 1-fluoro-2,3,4-trimethylbenzene (15). Further fluorination of the mixture of the two monofluoro products 14 and 15 gave 1,2-difluoro-3,4,5-trimethylbenzene (16), while reaction of 1,2,3-trimethylbenzene (13) with 2 mmol of XeF_2 gave a complex mixture of up to ten products. CF_3COOH-catalyzed reaction with 13 gave four products in relative yields as noted in Scheme III.

It was demonstrated that the structure of the aromatic molecule plays an important role in the course of XeF_2 fluorinations, and the effect of the amount of XeF_2 and the concentration of the organic substrate on the product formation was again confirmed. The products of CF_3COOH-catalyzed fluorinations could be explained in a way similar to that for those already observed,[10] i.e., the formation of xenon fluoride–trifluoroacetate, which can further decompose, thus forming intermediates (·F, ·CF_3, ...) and reacting further to the products observed.

Experimental Section

IR spectra were recorded by using a Perkin-Elmer 727B spectrometer, ^{19}F NMR spectra with a JEOL JNM PS 100, and ^1H NMR spectra on a JEOL JNM 60 H1 from CCl_4 or $CDCl_3$ solutions, with Me_4Si or CCl_3F as an internal reference. Mass spectra and high-resolution measurements were taken on a CEC 21-210 spectrometer. Gas–liquid partition chromatography was carried out with a Varian Aerograph Model 2700 under conditions noted later for each experiment.

Materials. Methyl-substituted benzenes are commercially available and were distilled before use. Hydrogen fluoride of Fluka Purum quality was used without further purification. Trifluoroacetic acid was distilled before use. Methylene chloride was purified[11] and stored over molecular sieves. Xenon difluoride was prepared by a photosynthetic method,[12] and its purity was better than 99.5%.

Fluorination of 1,2,4,5-Tetramethylbenzene (1). (A) HF-Catalyzed Reactions. To a solution of 1 (2 mmol) in methylene chloride (20 mL) in a Kel-F vessel was added xenon difluoride (2 mmol) at 25 °C and under stirring. Trace amounts of hydrogen fluoride were introduced to the reaction mixture. After 30 min, xenon gas evolution ceased, and the reaction mixture was diluted with methylene chloride (20 mL), washed with an aqueous solution of $NaHCO_3$ and with water, and dried over anhydrous Na_2SO_4. The solvent was evaporated in vacuo, and 245 mg of crude reaction mixture, containing large amounts of tar, was obtained. The

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[11] Weissberger, A., Ed. "Technique of Organic Chemistry"; Interscience: New York, 1955; Vol. VII.

[12] Williamson, S. M. *Inorg. Synth.* 1968, *11*, 147–151.

mixture was then sublimed under reduced pressure, resulting in 130 mg of a mixture of **1** and small amounts of 1,4-difluoro-2,3,5,6-tetramethylbenzene (**2**). Fluorination of 2 mmol of **1** in 20 mL of methylene chloride with 4 mmol of xenon difluoride, catalyzed by hydrogen fluoride, after the workup procedure, gave 230 mg of a mixture, which after sublimation under reduced pressure resulted in 120 mg of a mixture of the two products **2** and **3** in the ratio of 3:2 (determined by ^{19}F NMR). The products were isolated by preparative GLC (SE-30 10%, Chromosorb A 45/60, T = 135 °C).

1,4-Difluoro-2,3,5,6-tetramethylbenzene (2): yield 30 mg (8.8%) of crystalline product; mp 55–56 °C; NMR $\delta(F)$ −126 (br s), $\delta(CH_3)$ 2.2 (br s); mass spectrum; calcd for $C_{10}H_{12}F_2$ m/e 170.0907, found m/e 170.0910; m/e (relative intensity) 170 (M^+, 90), 155 (100), 91 (20).

1-Fluoro-2,4,5-trimethylbenzene (3): yield 20 mg (7%) of white volatile crystals; mp 25 °C; NMR $\delta(F)$ −126.5 (m), $\delta(CH_3)$ 2.22 (9 H, br s), $\delta(H_6)$ 6.55 (1 H, d, J_{FH} = 9 Hz), $\delta(H_3)$ 6.7 (1 H, d, J_{FH} = 7.5 Hz); mass spectrum, calcd for $C_9H_{11}F$ m/e 138.0845, found m/e 138.0848; m/e (relative intensity) 138 (M^+, 85), 123 (100), 109 (10), 91 (5), 77 (8).

(B) CF_3COOH-Catalyzed Reactions. To a solution of **1** (2 mmol) in methylene chloride (20 mL) were added 2 mmol of xenon difluoride and 2 mL of 1 M CH_3COOH in methylene chloride under stirring. After 30 min the reaction mixture was diluted with methylene chloride (10 mL), washed with aqueous $NaHCO_3$ and with water, and dried over anhydrous Na_2SO_4, and the solvent was evaporated in vacuo. The crude reaction mixture was analyzed by ^{19}F NMR, and four products were isolated by preparative GLC (DDP 12%, Chromosorb Regular 100, T = 150 °C).

1-(Trifluoromethyl)-2,3,5,6-tetramethylbenzene (4): yield 45 mg (11%) of white crystals; mp 35–36.5 °C (lit.[13] mp 37–38 °C); NMR $\delta(CF_3)$ −75.5 (m), $\delta(CH_3)$ 2.25 (6 H, m), 2.02 (6 H, m), $\delta(H_4)$ 6.9 (1 H, br s); mass spectrum calcd for $C_{11}H_{13}F_3$ m/e 202.0969, found m/e 202.0980, m/e (relative intensity) 202 (M^+, 100), 187 (90), 133 (50), 91 (15), 77 (10).

2,4,5-Trimethylbenzyl trifluoroacetate (5): yield 30 mg (6%) of white crystals; mp 44–44.5 °C; NMR $\delta(CF_3)$ −75 (s), $\delta(CH_3)$ 2.3 (3 H, br s), $\delta(CH_3)$ 2.2 (6 H, br s), $\delta(CH_2)$ 5.26 (2 H, s), $\delta(H)$ 7.0 (1 H, br s), 6.9 (1 H, br s); mass spectrum, calcd for $C_{12}H_{13}O_2F_3$ m/e 246.0867, found m/e 246.0853; m/e (relative intensity) 246 (M^+, 25), 227 (5), 191 (30), 133 (100), 132 (55), 100 (35), 93 (25), 92 (60), 91 (30), 77 (10).

1-Fluoro-2,3,5,6-tetramethylbenzene (6): yield 25 mg (8%) of white crystals; mp 52–53 °C; NMR $\delta(F)$ −122 (br s), $\delta(CH_3)$ 2.2 (6 H, br s), 2.1 (6 H, br s), $\delta(H)$ 6.6 (1 H, br s); mass spectrum, calcd for $C_{10}H_{13}F$ m/e 152.1011, found m/e 152.1010; m/e (relative intensity) 152 (M^+, 70), 137 (100), 91 (10), 77 (5).

1-(Trifluoromethyl)-2,3,4,5-tetramethylbenzene (7): yield 30 mg (7.5%) of white crystals; mp 34–34.5 °C (lit.[13] mp 34–35 °C); NMR $\delta(CF_3)$ −52 (m), $\delta(CH_3)$ 2.2 (9 H, br s), 2.3 (3 H, br s), $\delta(H)$ 7 (1 H, br s); mass spectrum, calcd for $C_{11}H_{13}F_3$ m/e 202.0963, found m/e 202.0990; m/e (relative intensity) 202 (M^+, 100), 187 (90), 133 (45).

The effect of the amount of trifluoroacetic acid on product distribution formed by fluorination of **1**, as determined by ^{19}F NMR, is presented in Table I.

Fluorination of 1,3,5-Trimethylbenzene (8). (A) HF-Catalyzed Fluorination. To a solution of **8** (2 mmol) in methylene chloride (4 mL) was added 2 mmol of xenon difluoride, and under stirring a catalytic amount of HF was introduced into the reaction mixture. After 20 min, xenon gas evolution had ceased, and after the usual workup procedure, 210 mg of crude reaction mixture was obtained. GLC separation (DDP 12%, Chromosorb Regular 100, T = 140 °C) resulted in 80 mg (29%) of colorless liquid 1-fluoro-2,4,6-trimethylbenzene (**10**).[14]

HF-catalyzed fluorination of a solution of 2 mmol of **8** in 4 mL of methylene chloride with 4 mmol of xenon difluoride, after the workup procedure and GLC separation, gave 95 mg (30%) of colorless liquid 1,3-difluoro-2,4,6-trimethylbenzene (**9**).[14]

1-Fluoro-2,4,6-trimethylbenzene (10): NMR $\delta(F)$ −130.5 (m), $\delta(CH_3)$ 2.15 (6 H, br s), 2.10 (3 H, br s), $\delta(H)$ 6.6 (2 H, dm, J_{FH} = 7 Hz); mass spectrum, m/e (relative intensity) 138 (M^+, 80), 137 (20), 123 (100), 91 (5), 77 (5).

1,3-Difluoro-2,4,6-trimethylbenzene (9): NMR $\delta(F)$ −122 (d, J_{FH} = 7 Hz), $\delta(CH_3)$ 2.1 (9 H, br s), $\delta(H)$ 6.6 (1 H, t, J_{HF} = 7 Hz); mass spectrum, m/e (relative intensity) 156 (M^+, 80), 155 (40), 141 (100).

(B) CF_3COOH-Catalyzed Fluorination. To a solution of **8** (2 mmol) in methylene chloride (8 mL) were added 2 mmol of xenon difluoride and 2 mL of 1 M CF_3COOH in methylene chloride under stirring. After the workup procedure, 270 mg of crude reaction mixture resulted, which was analyzed by ^{19}F NMR, and **10** (27%), **11** (21%), and **12** (14%) were isolated by preparative GLC (DDP 12%, Chromosorb Regular 100, T = 150 °C).

1-(Trifluoromethyl)-2,4,6-trimethylbenzene (11): yield 80 mg (21%) of colorless liquid;[13] NMR $\delta(CF_3)$ −55 (m), $\delta(CH_3)$ 2.35 (6 H, m), 2.2 (3 H, br s), $\delta(H)$ 6.7 (2 H, br s); mass spectrum, m/e (relative intensity) 188 (M^+, 100), 173 (78), 169 (15), 168 (10), 119 (90), 91 (20), 77 (15).

3,5-Dimethylbenzyl fluoroacetate (12): yield 65 mg (14%) of liquid product; decomposes on heating; NMR $\delta(CF_3)$ −77 (br s), $\delta(CH_3)$ 2.3 (6 H, br s), $\delta(CH_2)$ 5.15 (2 H, br s), $\delta(H)$ 6.85 (3 H, br s); mass spectrum, calcd for $C_{11}H_{11}O_2F_3$ m/e 232.0711, found m/e 232.0713; m/e (relative intensity) 232 (M^+, 80), 187 (20), 186 (10), 119 (100), 118 (20), 117 (20), 91 (20), 77 (20), 69 (15).

The effect of the amount of trifluoroacetic acid on the product distribution resulting in the fluorination of **8**, as determined by ^{19}F NMR, is presented in the Table I.

Fluorination of 1,2,3-Trimethylbenzene (13). (A) HF-Catalyzed Fluorination. To a solution of **13** (2 mmol) in methylene chloride (4 mL) was added 2 mmol of xenon difluoride, and under stirring a catalytic amount of hydrogen fluoride was introduced. After the workup, 230 mg of crude reaction mixture was isolated, which after purification by preparative GLC resulted in 105 mg (38%) of a mixture of 1-fluoro-3,4,5-trimethylbenzene (**14**) and 1-fluoro-2,3,4-trimethylbenzene (**15**) in the ratio 1:2. We were unable to separate products **14** and **15**; however, further HF-catalyzed fluorination of 70 mg of this mixture in methylene chloride (2 mL) with 70 mg of xenon difluoride gave 55 mg (70%) of crude product **16**. Purification of **16** by preparative GLC (DDP 12%, Chromosorb Regular 100, T = 140 °C) resulted in 20 mg (25%) of colorless liquid 1,2-difluoro-3,4,5-trimethylbenzene (**16**).

1,2-Difluoro-3,4,5-trimethylbenzene (16): NMR $\delta(F)$ −144 (1 F, dm, J = 24, 12 Hz), −146 (1 F, dm, J = 24, 7.5 Hz), $\delta(CH_3)$ 2.1 (3 H, br s), 2.2 (6 H, br s), $\delta(H)$ 6.7 (1 H, J = 12, 7.5 Hz); mass spectrum, calcd for $C_9H_{10}F_2$ m/e 156.0766, found m/e 156.0770; m/e (relative intensity) 156 (M^+, 65), 155 (25), 141 (100).

HF-catalyzed fluorination of 2 mmol of **13** with 4 mmol of xenon difluoride gave a complex reaction mixture, containing up to ten products.

(B) CF_3COOH-Catalyzed Fluorination. To a solution of **13** (2 mmol) in methylene chloride (8 mL) were added 2 mmol of xenon difluoride and 2 mL of 1 M CF_3COOH in methylene chloride under stirring. After the workup, 260 mg of crude reaction mixture was isolated, which was analyzed by ^{19}F NMR. The relative yields of the products formed are noted in Scheme III. Products were isolated by preparative GLC (SE-30 10%, Chromosorb A 45/60, T = 110–140 °C).

1-(Trifluoromethyl)-2,3,4-trimethylbenzene (17): yield 15 mg (4%) of colorless liquid; NMR $\delta(CF_3)$ −62 (m), $\delta(CH_3)$ 2.25 (6 H, br s), 2.15 (3 H, br s), $\delta(H)$ 6.8 (1 H, d, J = 8 Hz), 7.15 (1 H, d, J = 8 Hz); mass spectrum, calcd for $C_{10}H_{11}F_3$ m/e 188.0813, found m/e 188.0812; m/e (relative intensity) 188 (M^+, 80), 173 (100), 119 (50), 91 (10), 77 (10).

2,6-Dimethylbenzyl trifluoroacetate (18): yield 40 mg (9%) of oily product; decomposes on heating; NMR $\delta(CF_3)$ −77 (m), $\delta(CH_3)$ 2.32 (6 H, br s), $\delta(CH_2)$ 5.28 (2 H, br s), $\delta(H)$ 6.85 (3 H, br s); mass spectrum, calcd for $C_{11}H_{11}O_2F_3$ m/e 232.0711, found m/e 232.0713, m/e (relative intensity) 232 (M^+, 30), 187 (10), 119 (90), 118 (100), 105 (10), 104 (10), 91 (25), 77 (10), 69 (25).

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[13] Yagupolskii, L. M.; Malyushecheva, G. I., *Zh. Obshch. Khim.* **1961**, *35*, 1422–1426.

[14] Gutowsky, H. S.; McCall, D. W.; McGarvey, B. R.; Meyer, L. H. *J. Am. Chem. Soc.* **1952**, *74*, 4809–4817.

1-Fluoro-3,4,5-trimethylbenzene (14) and 1-fluoro-2,3,4-trimethylbenzene (15): yield 75 mg (27%) of a liquid mixture in the ratio of 1:4 **14**/**15**; we were unable to separate the two products; NMR for **14** δ(F) -128.5 (t, J = 9 Hz); NMR for **15** δ(F) -130 ppm (m). Both products were transformed with xenon difluoride in to 1,2-difluoro-3,4,5-trimethylbenzene (**16**).

Registry No. **1**, 95-93-2; **2**, 10585-06-5; **3**, 400-01-1; **4**, 3360-65-4; **5**, 85649-60-1; **6**, 319-92-6; **7**, 3360-61-0; **8**, 108-67-8; **9**, 392-61-0; **10**, 392-69-8; **11**, 3360-56-3; **12**, 52040-88-7; **13**, 526-73-8; **14**, 52547-91-8; **15**, 52547-99-6; **16**, 85649-61-2; **17**, 85649-62-3; **18**, 85649-63-4; XeF_2, 13709-36-9; HF, 7664-39-3; CF_3COOH, 76-05-1; 1,3,4-trimethylbenzene, 95-63-6.

A Simple Method for Predicting Hydration Energies of Organic Cations Derived from Protonation or Alkylation of Neutral Oxygen and Nitrogen Bases

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A simple method is presented for predicting the hydration free energies of certain organic cations on the basis of additive group contributions and an electrostatic component. Approximate hydration effects accompanying protonation or alkylation of various functional groups are tabulated and illustrated with reference to published data on benzylation of adenosine and guanosine in aqueous mixtures.

Qualitative reasoning based on the idea that charge development is facilitated in solvents of high dielectric constant and that small ions are more highly solvated than larger ones, is sometimes useful in rationalizing solvent effects on reaction rates and equilibria.[1] However, it is frequently necessary to consider specific solute-solvent interactions, particularly in polar protic solvents.[2] A good example is provided by the "anomalous" basicity order of the aliphatic amines in water.[3] Electronic factors suggest that amine basicity should increase in the order $NH_4 < MeNH_2 < Me_2NH < Me_3N$, which is indeed that observed in the gas phase and in many organic solvents.[4] However, a different order is observed in aqueous solution, which Arnett et al.[3] demonstrated was due to more effective hydration of the less highly substituted ammonium ions. They attributed this to the greater number of acidic hydrogen atoms in these ions available for hydrogen bonding to the solvent. Specific contributions to hydration energies of this kind seemed to be characteristic of ions arising from the protonation of both nitrogen and oxygen bases[5] and led Arnett, Taft, and their co-workers to propose that "the number and type of hydrogen bond which an onium ion can donate to a basic solvent is a rough first order guide to its solvation behavior".[6]

It has been known for some time that the hydration free energies of neutral organic compounds are approximately additive functions of the groups present,[7] and Hine and Mookerjee (HM) have devised a scheme for estimating them on this basis.[8] We therefore wondered whether this scheme could be extended to organic onium ions by deducing additional group contributions from the available experimental data. This should provide a semiquantitative framework for the discussion of hydration effects in chemical reactions involving organic cations in terms of the functional groups present.

A Model for Cation Hydration

Ionic hydration differs from that of neutral species by the presence of an electrostatic component, ΔG_{el}, associated with the energy of charging the cavity in the solvent in which the ion resides.[9] While numerous workers have attempted to calculate cationic hydration energies, they have focused almost exclusively on those of the metal cations.[9-11] Nevertheless some of the ideas developed should form a useful basis for the model proposed here.

It has been customary to represent the total hydration energy by eq 1, where ΔG_{ne} is the "nonelectrostatic" component,

$$\Delta G^{g \rightarrow H_2O} = \Delta G_{el} + \Delta G_{ne} \qquad (1)$$

ponent, i.e., the hydration energy of the hypothetical discharged ion. This has most often been estimated by comparison with appropriate neutral analogues, the assumption being of course, that the energies of cavity formation and solvent structure making/breaking interactions are similar in species of similar size and shape, regardless of charge. Here we propose a similar idea based on eq 2

$$\Delta G_{ne} = -2.303RT \sum_{i}^{\text{group}} [\log \gamma]_i \qquad (2)$$

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[11] Important exceptions to this statement are described in papers by Aue et al.[12] and Arnett[13] in which hydration free energies of ammonium ions were discussed in terms of the Born equation. In neither work was explicit account of specific solvation attempted.

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