was dried ($MgSO_4$) and concentrated under vacuum to afford the acid **9** (2.80 g, 65% yield), mp 101–103 °C: $[\alpha]_D$ −66.0° (*c* 2.6, $CHCl_3$); ^1H NMR δ 11 (br s, 1 H), 7.43–7.2 (m, 5 H), 6.09 (m, 1 H, 2.5 (m, 3 H), 2.40 (d, 2 H, *J* = 6.7 Hz), 2.23 (m, 2 H), 2.0 (m, 2 H), 1.53 (m, 1 H); ^{13}C ($CDCl_3$) δ 178.3, 142.0, 136.3, 128.2, 126.7, 125.0, 123.1, 40.6, 32.0, 30.1, 28.8, 26.9; IR (KBr) 1702 cm^{-1}; MS (EI) 216 (26, $M^{\cdot+}$), 156 (100). Anal. Calcd for $C_{14}H_{16}O_2$: C, 77.75; H, 7.46. Found: C, 77.40; H, 7.35.

(*S*)-1-[(4-Phenyl-3-cyclohexen-1-yl)acetyl]-4-(2-pyridinyl)piperazine (10). To the acid **9** (4.00 g, 18.5 mmol) in CH_2Cl_2 (65 mL) stirred with cooling on ice–water was added isobutyl chloroformate (2.65 g, 2.52 mL, 19.5 mmol) dropwise. The mixture was stirred at 0 °C for 1 h, and then 1-(2-pyridyl)piperazine (2.84 g, 2.06 mL, 20.3 mmol) was added. After 15 min the cooling bath was removed, and then after 1 h the mixture was diluted with CH_2Cl_2 (100 mL), washed with water (2 × 100 mL), dried ($MgSO_4$), and concentrated under vacuum. The residue (8 g) was chromatographed on silica gel (EtOAc) and recrystallized from hexane (100 mL)/EtOAc (100 mL) to afford pure product **10** (5.78 g, 87%), mp 123–125 °C: $[\alpha]_D$ −46.1° (*c* 2.64, $CHCl_3$); ^1H NMR (300 MHz, $CDCl_3$) δ 8.21 (m, 1 H), 7.58–7.18 (m's, 6 H), 6.68 (m, 2 H), 6.09 (m, 1 H), 3.80 (m, 2 H), 3.65 (s, 4 H), 3.51 (m, 2 H), 2.58–1.80 (m's, 8 H), 1.50 (m, 1 H); ^{13}C NMR ($CDCl_3$) δ 170.8, 159.1, 147.9, 142.0, 137.7, 136.3, 128.2 (2 C), 126.7, 124.9 (2 C), 123.3, 113.9, 107.2, 45.5, 45.4, 41.1, 39.3 (probably 2 C), 32.3, 30.4, 29.2, 26.9; IR (KBr) 1637, 1590 cm^{-1}; MS (EI) 361 (13, $M^{\cdot+}$), 107 (100). Anal. Calcd for $C_{23}H_{27}N_3O$: C, 76.42; H, 7.53; N, 11.55. Found: C, 75.95; H, 7.53; N, 11.55.

(*S*)-1-[2-(4-Phenyl-3-cyclohexen-1-yl)ethyl]-4-(2-pyridinyl)piperazine (1). The amide **9** (5.80 g, 16.0 mmol) in THF (100 mL) and $LiAlH_4$ in Et_2O (1 M, 11 mL, 11 mmol) were mixed and heated under reflux for 4 h. The mixture was cooled and quenched with saturated aqueous Na_2SO_4 (6 mL) and then stirred for 45 min. The mixture was filtered, the residue was washed with THF, and the combined filtrate was concentrated under vacuum. The residue was recrystallized from methyl *tert*-butyl ether to afford pure **1** (4.90 g, 88% yield), mp 113–114 °C: $[\alpha]_D$ −56.7° (*c* 1.0, $CHCl_3$); ^1H NMR (200 MHz, $CDCl_3$) δ 8.21 (m, 1 H), 7.5–7.1 (m, 6 H), 6.68 (m, 2 H), 6.09 (m, 1 H), 3.57 (m, 4 H), 2.58 (m, 4 H), 2.43 (m, 4 H), 2.33 (m, 1 H), 2.0–1.4 (m, 6 H); ^{13}C NMR ($CDCl_3$) δ 159.6, 147.9, 142.2, 137.4, 136.4, 128.2 (2 C), 126.6, 124.9 (2 C), 123.9, 113.2, 107.0, 56.7, 53.2 (2 C), 45.2 (2 C), 33.4, 32.6, 31.7, 29.4, 27.2. Anal. Calcd for $C_{23}H_{29}N_3$: C, 79.50; H, 8.41; N, 12.09. Found: C, 79.67; H, 8.55; N, 12.23. HPLC on a Chiracel OJ column eluted with 9:1 hexane/2-propanol showed the enantiomer ratio to be 96.3:3.7.

Acknowledgment. We thank M. Ohno for providing unpublished data and A. Galan for helpful comments.

Aerosol Fluorination of 1-Chloroadamantane, 2-Chloroadamantane, and Methyl 1-Adamantylacetate: A Novel Synthetic Approach to 1- and 2-Substituted Hydryl-, Methyl-, and (Difluoromethyl)-*F*-adamantanes

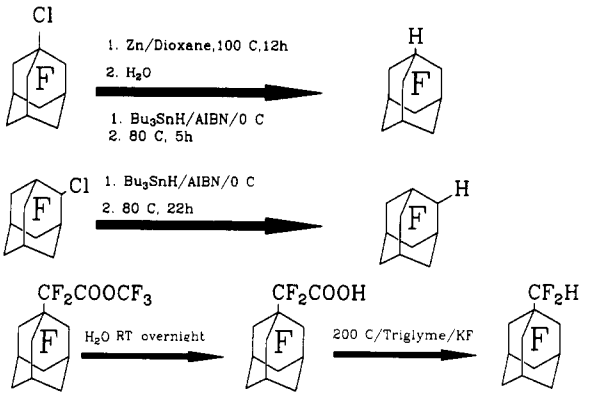
James L. Adcock,* Huimin Luo, and Sharique S. Zuberi

Department of Chemistry, University of Tennessee, Knoxville, Tennessee 37996-1600

Received February 18, 1992

Adamantane has interested chemists for nearly a century. Research based on its unusual chemical and physical properties has led to important advances in several areas of organic chemistry.[1,2] Many adamantane derivatives such as chlorinated adamantanes[3,4] and 1,2-disubstituted adamantanes[5] have been synthesized. However, far fewer highly fluorinated adamantane derivatives are known.[6,7] The synthesis of perfluoroadamantane by aerosol direct fluorination was reported several years ago by our group.[8] However, the extreme stabilities of C–F bonds made it difficult to derivatize. This prompted us to search for a good synthon for other fluorinated adamantane derivatives. Since the application of aerosol direct fluorination to alkyl chlorides has been demonstrated,[9,10] and 1-chloroadamantane and 2-chloroadamantane are commercially available, they were chosen as precursors to make, hopefully, more reactive perfluoroadamantane derivatives. Direct fluorination of carboxylic acid esters has also been shown to produce fluorinated carboxylic acid derivatives.[11] In this paper, we report direct fluorinations of 1-chloroadamantane, 2-chloroadamantane, and methyl 1-adamantylacetate; subsequent syntheses of 1-hydryl-*F*-adamantane, 2-hydryl-*F*-adamantane, 1-methyl-*F*-adamantane, and 2-methyl-*F*-adamantane from the corresponding chloro-*F*-adamantanes and 1-(difluoromethyl)-*F*-adamantane from *F*-1-adamantylacetic acid are also described, proving the utility of our synthons.

Scheme I. Synthesis of 1-Hydryl-*F*-adamantane, 2-Hydryl-*F*-adamantane, and 1-(Difluoromethyl)-*F*-adamantane



Results and Discussion

With the help of spectroscopic techniques (vide infra), the major products (98% by weight) collected from the aerosol direct fluorination of 1-chloroadamantane and 2-chloroadamantane were identified as their corresponding perfluorinated analogues. No chlorine loss or 1,2-chloride shift was observed in either of the compounds. Considering the total rearrangement of tertiary alkyl chlorides in noncyclic systems and partial rearrangements of secondary alkyl chlorides, the lack of a 1,2-chlorine shift is noteworthy if not too surprising. We attribute this lack of a 1,2-chlorine shift to the rigidity of the adamantane skeleton. The percent yields based on the throughput (amounts injected) of 1-chloro-*F*-adamantane and 2-chloro-*F*-adamantane are 59.2% and 50.7%, respectively. The aerosol direct fluorination of methyl 1-adamantyl-

(1) Fort, R. C.; Schleyer, P. v. R. *Chem. Rev.* **1964**, *64*, 277.
(2) Bingham, R. C.; Schleyer, P. v. R. *J. Am. Chem. Soc.* **1971**, *93*, 3189.
(3) Stetter, H.; Krause, M.; Last, W. D. *Chem. Ber.* **1969**, *102*, 3357.
(4) Bach, R. D.; Badher, R. C. *Synthesis* **1979**, 529.
(5) Abdel-Sayed, A. N.; Bauer, L. K. *Tetrahedron* **1988**, *44*, 1873.
(6) Maraschin, N. J.; Catsikis, B. D.; Davis, L. H.; Jarvinen, G.; Lagow, R. J. *J. Am. Chem. Soc.* **1975**, *97*, 513.
(7) Robertson, G.; Liu, E. K. S.; Lagow, R. J. *J. Org. Chem.* **1978**, *43*, 4981.
(8) Adcock, J. L.; Robin, M. L. *J. Org. Chem.* **1983**, *48*, 3128.
(9) Adcock, J. L.; Evans, W. D.; Heller-Grossman, L. *J. Org. Chem.* **1983**, *48*, 4953.
(10) Adcock, J. L.; Evans, W. D. *J. Org. Chem.* **1984**, *49*, 2719.
(11) A comprehensive paper is to be published in this journal.

0022-3263/92/1957-4749$03.00/0

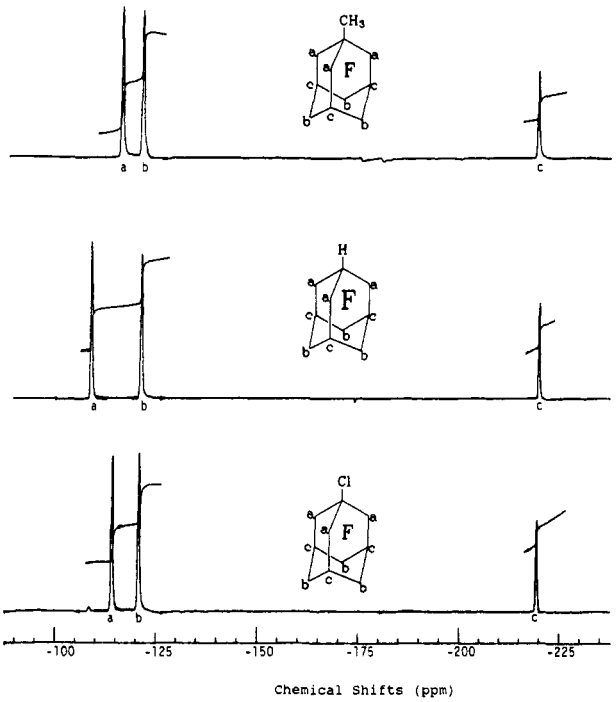


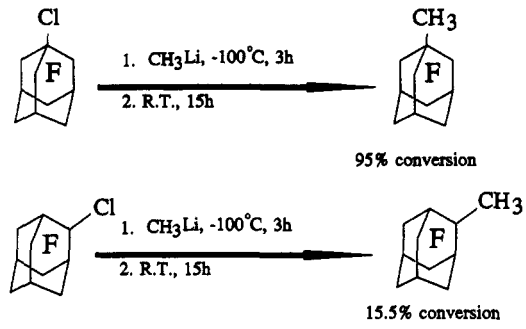
Figure 1. ^{19}F NMR spectra of 1-substituted *F*-adamantanes.

acetate resulted in both *F*-methyl *F*-1-adamantylacetate and the *F*-1-adamantylacetyl fluoride which are too moisture sensitive to be easily isolated.

The relatively good reactivity of both the tertiary 1-chloro-*F*-adamantane and the more resistant secondary 2-chloro-*F*-adamantane made their derivatization feasible. 1-Chloro-*F*-adamantane can be converted to 1-hydryl-*F*-adamantane using zinc metal in 1,4-dioxane as a reducing agent (Scheme I), followed by quenching with water. However, 2-chloro-*F*-adamantane did not react with zinc under the same conditions even with a much longer reaction time. When $(n\text{-Bu})_3SnH$ was used as a reducing agent, both 1-chloro-*F*-adamantane and 2-chloro-*F*-adamantane were readily converted to the corresponding hydryl-*F*-adamantanes although 2-chloro-*F*-adamantane needed a longer reaction time (Scheme I).

The ^{19}F-NMR spectrum of 1-hydryl-*F*-adamantane has three resonances at −108.70, −121.05, and −219.70 ppm (int 6:6:3), the first two are in the CF_2 region and the third is in the CF region. This is in agreement with the structure of 1-hydryl-*F*-adamantane which has three groups of chemically equivalent fluorine atoms and is similar to that of 1-chloro-*F*-adamantane (Figure 1). The ^1H-NMR spectrum of 1-hydryl-*F*-adamantane exhibits a clear heptet at 3.41 ppm (relative to TMS). These NMR results are different from those reported by Lagow who claimed to have isolated 1-hydrylpentadecafluoroadamantane (i.e., 1-hydryl-*F*-adamantane) from the LaMar direct fluorination of adamantane.[6] The sample described by Lagow et al.[6] appears to be a hydrocarbon-contaminated sample of perfluoroadamantane from the reported ^{19}F NMR (CF_2 −121.5 ppm, quintet and CF −223.6 ppm, unresolved) and ^1H NMR (1.75 ppm, broad peak, vs TMS) resonances. These values compare well with our previously reported *F*-adamantane results: CF_2 −121.2 ppm, pentet of intensity 12, and CF as a near symmetrical multiplet of 13 peaks centered at −223.53 ppm of intensity 4.[8] Their reported resonances are also at variance with the ^{19}F NMR and with the ^1H NMR chemical shifts reported in this work for either the 1-hydryl-*F*-adamantane, 3.41 ppm, or the 2-hydryl-*F*-adamantane, 5.15 ppm (doublet), both of which occur at much lower field.

Scheme II. Synthesis of 1-Methyl-*F*-adamantane and 2-Methyl-*F*-adamantane



Infrared spectra show C–H stretching frequencies of 2988 cm^{-1} for 1-hydryl-*F*-adamantane, 2993 cm^{-1} for 2-hydryl-*F*-adamantane, and 3007 cm^{-1} for 1-(difluoromethyl)-*F*-adamantane which are reasonable for such highly fluorinated residues which tend to increase the frequency of the C–H vibrations.[12]

The reaction of 1-chloro-*F*-adamantane with CH_3Li gave a mixture of 1-methyl-*F*-adamantane, 1-chloro-*F*-adamantane, and 1-hydryl-*F*-adamantane (Scheme II). If bromine or iodine was added following CH_3Li and the reaction time increased, almost pure 1-methyl-*F*-adamantane was obtained where 1-chloro-*F*-adamantane and 1-hydryl-*F*-adamantane could not be detected by ^{19}F-NMR. If the system is kept extremely dry, no 1-hydryl-*F*-adamantane is observed by ^{19}F-NMR. The ^{19}F-NMR spectral pattern for 1-hydryl-, 1-methyl-, and 1-chloro-*F*-adamantanes are very similar except that the chemical shifts of three CF_2 groups nearest to the substituent are different in each case (Figure 1). The ^1H-NMR spectrum of 1-methyl-*F*-adamantane showed only one peak at 1.46 ppm.

The reaction of 2-chloro-*F*-adamantane with CH_3Li gave a mixture of 2-methyl-*F*-adamantane (minor), 2-chloro-*F*-adamantane, and 2-hydryl-*F*-adamantane (Scheme II). Unlike 1-chloro-*F*-adamantane, if bromine or iodine was added following CH_3Li and the reaction time increased, the mixture was always obtained but the percentage of 2-methyl-*F*-adamantane increased. The ^1H-NMR spectrum of 2-methyl-*F*-adamantane showed a doublet at 1.66 ppm, J_{HF} 27.83 Hz. Unlike the 1-substituted *F*-adamantanes, the pattern of ^{19}F-NMR spectra for the three 2-substituted *F*-adamantane are different (see Figure 2). The ^{19}F-NMR spectrum of 2-hydryl-*F*-adamantane consists of an AB spectrum (−119.26, −122.00 ppm, J_{ab} = 190 Hz) overlapped with one singlet (−123.22 ppm) in the CF_2 region, one unresolved peak, and two multiplets in the CF and CFH region (int 10:2:1:2). The ^{19}F-NMR spectra of both 2-chloro-*F*-adamantane and 2-methyl-*F*-adamantane (Figure 2) contain no AB spectrum but exhibit a doublet due to two bridgehead fluorine atoms (labeled e or f, respectively) coupled with one fluorine atom (labeled a or d, respectively). The coupling constants J_{ea} of 2-chloro-*F*-adamantane (46.89 Hz) and J_{df} of 2-methyl-*F*-adamantane (36.63 Hz) are noteworthy because they are significantly greater in magnitude than typical vicinal coupling constants. The reason is unknown but may be a through-space back-lobe effect.

The methylation and hydrogenation results clearly indicate that tertiary *F*-adamantyl chlorides are more reactive than the secondary chlorides. This is expected in the case of the reduction of alkyl halides by organotin

(12) Weiblen, D. G. In *Fluorine Chemistry*; Simons, J. H., Ed.; Academic Press: New York, 1954; Vol. 2, pp 449–503.

hydrides which occurs via a free-radical chain mechanism.[13-15] A radical mechanism may also explain the action of bromine and iodine on the alkylation of the 1-chloro-*F*-adamantane. In one reaction of methyllithium with 1-chloro-*F*-adamantane, 1-iodo-*F*-adamantane was obtained but the reaction could not be repeated and may be due to the metalation of the hydryl-*F*-adamantane in the absence of methyl chloride in the medium competing with iodine.[16]

Experimental Section

The perfluorination was carried out on an improved aerosol fluorination reactor, and detailed operating procedures have been described elsewhere.[17] 1-Chloro- and 2-chloroadamantanes were purchased from Lancaster Synthesis and were used as received. 1-Adamantaneacetic acid (Aldrich Chemical) was converted to its ester via a conventional esterification method. The fluorinated products were manipulated on a vacuum line; some purifications were achieved by trap to trap fractionation using slush baths; gas chromatography was used for final purification: Bendix Model 2300, subambient multicontroller, equipped with a QF-1 column, 7-m × $^3/_8$-in. 13% fluorosilicone QF-1 (Analabs) stationary phase on 60–80 mesh, acid-washed chromosorb P conditioned at 225 °C (12 h). The purity of some of the compounds was monitored on a SP 2100 (Supelco) 60-m × 0.25-mm i.d. fused silica capillary column (Hewlett-Packard 5890A). The products were characterized by vapor-phase infrared spectra recorded on a Bio-Rad Spc 3200 spectrometer. The negative chemical ionization (electron attachment) mass spectrum was recorded on a VG.ZAB-EQ mass spectrometer. Samples were introduced into the source via the reference inlet to a pressure of 10^{-6} Torr and diluted with nitrogen gas to 10^{-5}–10^{-4} Torr and bombarded with 70 eV electrons. ^{19}F NMR spectra were determined on a JEOL FX90Q FTNMR spectrometer (using the omniprobe and NM-PVTS1 programmable VT system) in $CFCl_3$ as both solvent and internal standard. Elemental analyses were performed by E+R Microanalytical Laboratory, Inc., Corona NY.

Preparation of the Methyl Ester of 1-Adamantaneacetic Acid. 1-Adamantaneacetic acid (7.8 g; 40.2 mmol) was refluxed in an excess of dry methanol, to which ca. 3 mL of concentrated sulfuric acid had been added, contained in a round-bottomed flask (250 mL) equipped with a Teflon magnetic stir bar, a reflux condenser, and a drying tube. The workup consisted of extracting the product mixture in diethyl ether (ca. 200 mL); washing it with water, and drying it over sodium sulfate. The ester (6.7 g; 32.2 mmol; 80%) was recovered by evaporating the diethyl ether. The product was identified by ^{1}H NMR and IR spectroscopy.

Aerosol Fluorination of 1-Chloroadamantane. In a typical run, 1-chloroadamantane (1.96 g; 11.5 mmol) was fluorinated as a solution in 1,1,2-trichloroethane (6.32 g; 47.4 mmol) over a period of 4.75 h. The detailed fluorination conditions are listed in Table I (1). The reactor product trap was connected to the vacuum line and pumped overnight to effect maximum transfer. Following trap to trap fractionation, 1-chloro-*F*-adamantane (3.0 g; 6.81 mmol) was collected in the −22 °C trap and 1,1,2-trichlorotrifluoroethane (R-113, 5.4 g; 30.9 mmol) in the −78 °C trap. The percent yield of 1-chloro-*F*-adamantane based on injection of 1-chloroadamantane was 59.2% and the percent yield of R-113 based on injection of 1,1,2-trichloroethane was 65.3%. ^{19}F-NMR spectrum of 1-chloro-*F*-adamantane consisted of three peaks at −114.32, −120.98, −219.34 ppm (int 6:6:3), the first two are in the CF_2 region, the last is in the CF region. This is consistent with its structure. The prominent peaks in the mass spectrum were [*m*/*z* (formula, int)] 442 ($C_{10}F_{15}{}^{37}Cl$, 4.3); 440 ($C_{10}F_{15}{}^{35}Cl$, 15.4); 405 ($C_{10}F_{15}$, 100); 386 ($C_{10}F_{14}$, 24.0). The vapor-phase infrared spectrum had bands at 1294 (vs), 1284 (vs), 1011 (m), 978 (m), 959 (vs), 853 (m), 736 (m), 651 (w), 482 (w), cm^{-1}. Anal. Calcd for $C_{10}F_{15}Cl$: C, 27.26; F, 64.69; Cl, 8.02. Found: C, 27.33; F, 64.76; Cl, 7.83.

Table I. Parameters of Aerosol Fluorinations[a]

fluorination reactns	1	2	3
fluorine flow (mL/min)			
module 1-1	8	8	8
module 1-2	50	50	31
module 2-1	38	38	23
module 2-2	6	6	6
helium diluent (mL/min)			
module 1-1	170	170	170
module 1-2	170	170	170
module 2-1	170	170	170
module 2-2	170	170	170
main carrier (He, mL/min)	500	500	500
primary hydrocarbon carrier	55	55	55
secondary hydrocarbon carrier	500	500	500
reaction temp (°C)			
module 1	−8	−10	−4
module 2	−1	0	0
evaporator	102	102	121
injector	105	105	120
hydrocarbon throughput (mmol/h)	2.42	2.68	2.39
ratio (H_2:F_2)	1:2.25	1:2.25	1:2.50

[a] Referring to aerosol fluorinator components described in ref 17.

Aerosol Fluorination of 2-Chloroadamantane. In a typical run, 2-chloroadamantane (1.37 g; 8.04 mmol) was fluorinated as a solution in 1,1,2-trichloroethane (4.36 g; 32.7 mmol) over a period of 3.00 h. The detailed fluorination conditions are listed in Table I (2). Products were transferred to the vacuum line and worked up as described above. 2-Chloro-*F*-adamantane (1.8 g; 4.08 mmol) was collected in the −22 °C trap and R-113 (4.0 g; 22.4 mmol) in the −78 °C trap. The percent yield of 2-chloro-*F*-adamantane based on injection of 2-chloroadamantane was 50.7%, and the percent yield of R-113 based on injection of 1,1,2-trichloromethane was 68.5%. ^{19}F-NMR of 2-chloro-*F*-adamantane had three unresolved peaks at −114.28, −118.17, and −121.34 ppm in the CF_2 region and two peaks at −214.05 and −223.35 ppm in the CF region. This is consistent with its structure. The mass spectrum consisted of the following peaks: [*m*/*z* (formula, int)] 442 ($C_{10}F_{15}{}^{37}Cl$, 11.0); 440 ($C_{10}F_{15}{}^{35}Cl$, 12.4); 405 ($C_{10}F_{15}$, 100); 386 ($C_{10}F_{14}$, 98.6); 367 ($C_{10}F_{13}$, 25.5); 336 (C_9F_{12}, 15.8); 317 (C_9F_{11}, 32.4). The vapor-phase infrared spectrum showed bands at 1234 (vs), 1276 (vs), 984 (m), 970 (s), 958 (s), 872 (w), 828 (w), 668 (vw), 652 (vw) cm^{-1}. Anal. Calcd for $C_{10}F_{15}Cl$: C, 27.26; F, 64.69; Cl, 8.02. Found: C, 27.45; F, 64.72; Cl, 8.30.

Aerosol Fluorination of Methyl 1-Adamantylacetate. Methyl 1-adamantylacetate (3.2 g; 15.38 mmol) was fluorinated over a period of 6.14 h. The detailed fluorination conditions are listed in Table I (3). The crude product was transferred onto a vacuum line and fractionated. The *F*-methyl *F*-1-adamantylacetate and *F*-1-adamantylacetyl fluoride were recovered from the −22 and −45 °C vacuum line traps (1.0 g; 1.6 mmol; 11%). The ^{19}F NMR spectra of the products showed the expected five different kinds of fluorine atoms: −59.40, −98.24, −109.39, −121.08, −219.40 ppm.[18]

Synthesis of 1-Hydryl-*F*-adamantane: Method A. 1-Chloro-*F*-adamantane (1.6 g; 3.63 mmol) contained in a round-bottomed flask (100 mL) equipped with a Teflon magnetic stir bar and a reflux condenser was allowed to react with zinc metal (0.23 g; 3.63 mmol) in the presence of 1,4-dioxane. The reaction mixture was refluxed for 12 h followed by continuous stirring at room temperature for an additional 12 h. Some solid material separated out on standing at room temperature. This was filtered off and identified as the starting material. The addition of distilled water to the 1,4-dioxane solution resulted in the precipitation of a white solid which was recovered and air dried. The white solid was further purified by sublimation to yield a white crystalline solid which was identified as 1-hydryl-*F*-adamantane (0.62 g; 1.52 mmol; 42%).

(13) Menapace, L. W.; Kuivila, H. G. *J. Am. Chem. Soc.* **1964**, *86*, 3047.
(14) Carlsson, D. J.; Ingold, K. U. *J. Am. Chem. Soc.* **1968**, *90*, 1055, 7047.
(15) Kuivila, H. G. *Synthesis* **1970**, 499.
(16) Adcock, J. L.; Renk, E. B. *J. Org. Chem.* **1979**, *44*, 3431–3433.
(17) Adcock, J. L.; Cherry, M. L. *Ind. Eng. Chem. Res.* **1987**, *26*, 208.

(18) Neither product could be easily isolated because of their fluoride ion sensitivity and hygroscopic nature. The mixture was used immediately for the synthesis of 1-(difluoromethyl)-*F*-adamantane.

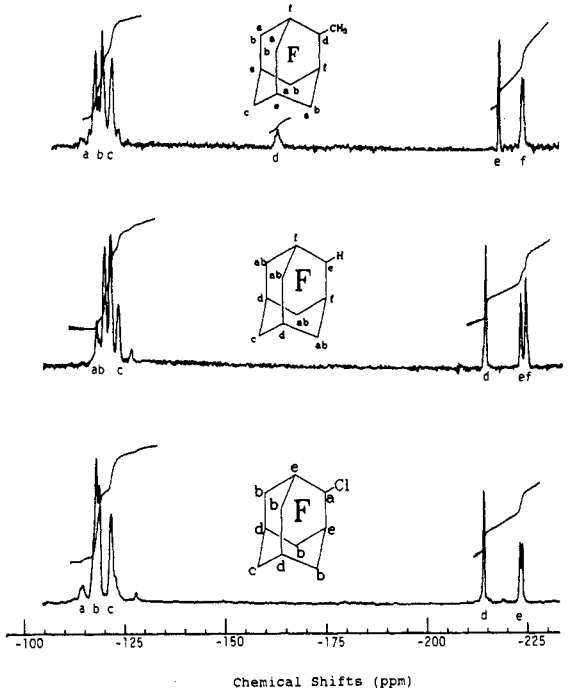


Figure 2. ^{19}F NMR spectra of 2-substituted *F*-adamantanes.

Method B. 1-Chloro-*F*-adamantane (0.5 g, 1.1 mmol) and azobis(isobutyronitrile) (AIBN, 0.4 mg, as a radical initiator) were loaded into a Pyrex ampule covered with a rubber septum. The ampule was cooled to 0 °C, and $(n\text{-Bu})_3SnH$ (0.4 mL, 1.49 mmol) was injected by syringe under nitrogen. After the reaction mixture was heated at 80 °C while standing for 5 h, it was connected to a vacuum line. A total of 0.22 g of product was collected after vacuum-line fractionation as a white solid in the −22 °C trap. The yield was 49%.

Both products from methods A and B were identical. The ^{19}F NMR spectrum of 1-hydryl-*F*-adamantane had two peaks at −108.70 and −121.05 in the CF_2 region and one peak at −219.70 ppm in the CF region (int 6:3:3). The ^1H NMR spectrum had a clear heptet at 3.41 ppm (relative to TMS, $^3J_{HF}$ = 5.61 Hz). The mass spectrum showed the following peaks: [*m*/*z* (formula, int)] 407 ($^{13}CC_9F_{15}H$, 1.9); 406 ($C_{10}F_{15}H$, 12.1); 405 ($C_{10}F_{15}$, 6.5); 387 ($^{13}CC_9F_{14}$, 12.8); 386 ($C_{10}F_{14}$, 100); 367 ($C_{10}F_{13}$, 1.6).

The vapor-phase infrared spectrum had bands at 2988 (vw), 1329 (vs), 1294 (s), 1272 (s), 1138 (s), 1106 (w), 1000 (s), 938 (s), 733 (w), 650 (w), 622 (w) cm^{-1}. Anal. Calcd for $C_{10}F_{15}H$: C, 29.58; F, 70.17; H, 0.25. Found: C, 29.73; F, 70.35; H, 0.31.

Synthesis of 2-Hydryl-*F*-adamantane. 2-Chloro-*F*-adamantane (0.5 g; 1.13 mmol) and AIBN (0.4 mg) were loaded into a Pyrex ampule covered with a rubber septum. The ampule was cooled to 0 °C; $(n\text{-Bu})_3SnH$ (0.4 mL; 1.49 mmol) was then added under nitrogen. The reaction mixture was heated to 80 °C for 22 h followed by trap to trap vacuum line fractionation. The 2-hydryl-*F*-adamantane (0.25 g; 0.61 mmol; 54%) was recovered as a white solid in the −22 °C trap. The ^{19}F-NMR spectrum of 2-hydryl-*F*-adamantane consisted of an AB spectrum (ν_a = −119.26 ppm, ν_b = −122.00 ppm, J_{ab} = 190 Hz) overlapped with a singlet (−123.22 ppm) in the CF_2 region and three more peaks at −214.59, −223.35, and −224.66 ppm in the CF and CFH region. The ^1H-NMR spectrum had one doublet at 5.15 ppm; J_{HF} = 48.83 Hz. The mass spectrum had peaks: [*m*/*z* (formula, int)] 405 ($C_{10}F_{15}$, 0.9); 387 ($^{13}CC_9F_{14}$, 10.8); 386 ($C_{10}F_{14}$, 100). The vapor-phase infrared spectrum showed bands at 2993 (vw), 1348 (w), 1298 (vs), 1275 (s), 1227 (w), 1203 (w), 1030 (w), 994 (m), 983 (s), 967 (vs), 936 (s), 855 (vw), 725 (w) cm^{-1}. Anal. Calcd for $C_{10}F_{15}H$: C, 29.58; F, 70.17; H, 0.25. Found: C, 29.83; F, 70.13; H, 0.45.

Synthesis of 1-Methyl-*F*-adamantane. 1-Chloro-*F*-adamantane (0.5 g, 1.1 mmol) and diethyl ether (1 mL) were placed in a 100-mL flask capped with a septum. An ether solution of CH_3Li (0.85 mL) was injected through the septum into the solution cooled to −100 °C. The reactants were stirred at this temperature for 3 h, warmed slowly to room temperature, and stirred for an additional 15 h. The reaction flask was connected to the vacuum line. Following trap to trap fractionation, a white solid was collected in the −22 °C trap. GC and ^{19}F-NMR of this solid indicated that it was composed of 1-methyl-*F*-adamantane (95%), 1-chloro-*F*-adamantane (2.7%), and 1-hydryl-*F*-adamantane (2.0%). The ^{19}F-NMR spectrum of 1-methyl-*F*-adamantane had three unresolved peaks at −116.09, −121.13, and −219.37 ppm (int 6:6:3); the first two are in the CF_2 region and the last is in the CF region. The mass spectrum of 1-methyl-*F*-adamantane had peaks: [*m*/*z* (formula, int)] 421 ($^{13}CC_{10}F_{15}H_3$, 16); 420 ($C_{11}F_{15}H_3$, 100); 381 ($C_{11}F_{13}H_2$, 19); 380 ($C_{11}F_{13}H$, 26). The vapor-phase infrared spectrum of 1-methyl-*F*-adamantane had absorption bands at 2994 (vw), 2967 (vw), 1298 (s), 1283 (vs), 1118 (w), 1083 (m), 1054 (w), 1033 (m), 990 (s), 937 (m), 923 (m), 846 (m), 651 (w) cm^{-1}. Anal. Calcd for $C_{11}F_{15}H_3$: C, 31.37; F, 67.67; H, 0.96. Found: C, 31.53; F, 67.60; H, 1.10.

Synthesis of 2-Methyl-*F*-adamantane. 2-Chloro-*F*-adamantane (0.5 g, 1.1 mmol) and diethyl ether (1 mL) were placed in a 100-mL flask capped with a septum. An ether solution of CH_3Li (0.85 mL) was injected through the septum at −100 °C. The reactants were stirred at this temperature for 3 h, warmed to room temperature, and stirred for another 15 h. Finally, the reaction flask was connected to the vacuum line and pumped. Following trap to trap fraction, white solid was collected in the −22 °C trap. GC and ^{19}F-NMR of this solid indicated that it was composed of 2-methyl-*F*-adamantane (15.5%), 2-chloro-*F*-adamantane (31.9%), and 2-hydryl-*F*-adamantane (52.7%). The ^{19}F-NMR spectrum of 2-methyl-*F*-adamantane consisted of peaks at −117.65, −119.27, −121.58, −162.82, −217.90, and −223.85 ppm; the first three are in the CF_2 region, and the last three are in the CF region. The mass spectrum of 2-methyl-*F*-adamantane had peaks: [*m*/*z* (formula, int)] 420 ($C_{11}F_{15}H_3$, 1.5); 401 ($C_{11}F_{14}H_3$, 4.5); 400 ($C_{11}F_{14}H_2$, 15); 381 ($C_{11}F_{13}H_2$, 15.5); 380 ($C_{11}F_{13}H$, 100). The vapor-phase infrared spectrum of 2-methyl-*F*-adamantane had absorption bands at 2980 (vw), 1294 (vs), 1272 (s), 1217 (vw), 1161 (vw), 1129 (w), 1095 (w), 1081 (w), 1048 (w), 1019 (m), 996 (w), 979 (s), 964 (vs), 923 (m), 655 (w), 636 (vw) cm^{-1}. Anal. Calcd for $C_{11}F_{15}H_3$: C, 31.37; F, 67.67; H, 0.96. Found: C, 31.61; F, 67.42; H, 0.90.

Synthesis of 1-(Difluoromethyl)-*F*-adamantane. A mixture of *F*-methyl *F*-1-adamantylacetate and *F*-1-adamantylacetyl fluoride (1.0 g) was dissolved in an excess of distilled water and left overnight at 22 °C. The white solid which formed was extracted with $CFCl_3$ and the solvent evaporated to yield ca. 1.0 g of *F*-1-adamantylacetic acid. *F*-1-Adamantylacetic acid (1.0 g; 0.0016 mmol) was decarboxylated in the presence of triglyme (3 mL) and potassium fluoride (0.1 g) in a round-bottomed flask (100 mL) heated to ca. 180–200 °C and equipped with a Teflon magnetic stir bar and a reflux condenser. 1-(Difluoromethyl)-*F*-adamantane sublimed out onto the reflux condenser as a white solid. The solid was removed, dissolved in $CFCl_3$, and washed with water to remove traces of triglyme. The fluorocarbon layer was separated out, and the $CFCl_3$ was evaporated to yield a white crystalline solid (0.5 g; 0.0010 mmol; 62%). The ^{19}F-NMR spectrum consisted of three peaks at −111.96, −121.05, and −121.16 ppm in the CF_2 region and one peak at −219.80 ppm in the CF region. The ^1H-NMR spectrum had one triplet at 6.27 ppm, and J_{FH} is equal to 51.04 Hz which was expected. The mass spectrum had peaks: [*m*/*z* (formula, int)] 457 ($^{13}CC_{10}F_{17}H$, 18.9); 456 ($C_{11}F_{17}H$, 100); 436 ($C_{11}F_{16}$, 38.0); 405 ($C_{10}F_{15}$, 24.6); 386 ($C_{10}F_{14}$, 28.4); 367 ($C_{10}F_{13}$, 11.4). HRMS calcd for $C_{11}F_{17}H$ 455.9807, found 455.9803 (exact mass). The vapor-phase infrared spectrum had bands at the following positions: 3007 (vw), 1396 (w), 1378 (w), 1298 (vs), 1286 (vs), 1141 (m), 1029 (m), 969 (s) cm^{-1}.

Registry No. 1-Adamantaneacetic acid, 4942-47-6; methyl 1-adamantylacetate, 27174-71-6; 1-chloroadamantane, 935-56-8; 1-chloroperfluoroadamantane, 142422-08-0; 2-chloroadamantane, 7346-41-0; 2-chloroperfluoroadamantane, 142422-09-1; perfluoromethyl (perfluoro-1-adamantyl)acetate, 82829-41-2; (perfluoro-1-adamantyl)acetyl fluoride, 107406-39-3; 1-hydroxyperfluoroadamantane, 54767-15-6; 2-hydrylperfluoroadamantane, 142422-10-4; 1-methylperfluoroadamantane, 142422-11-5; 2-methylperfluoroadamantane, 142422-12-6; 1-(difluoromethyl)-perfluoroadamantane, 142422-13-7.