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Reaction of β-fluorinated vinamidinium salts with Grignard reagents and reducing agents New facile and efficient route to fluorinated allylamines

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Abstract

β-Fluorinated vinamidinium salts (**1**) readily reacted with a series of Grignard reagents in tetrahydrofuran, followed by the action of reducing agents at room temperature, to produce stereospecifically the corresponding fluorinated allylamines (**4** and **5**) in good to excellent yields.

Keywords: Vinamidinium salts; Grignard reactions/reagents; Reduction; Enamines; Allylamines; Fluorine and compounds

1. Introduction

Vinamidinium (1,5-diazapentadienium) salts, vinylogs of amidinium compounds, have widely been utilized in organic synthesis since they have unique and versatile reactivities [1]. Many types of vinamidinium salts appended with various substituents have hitherto been developed and used as potent three-carbon building blocks for the synthesis of acyclic and cyclic organic compounds [1–14]. In contrast to such extensive works, there are only a few reports on the fluorine-containing vinamidinium salts [13–17], which should be useful synthons for synthesizing fluorinated compounds of biological and material interest. In our continuing studies in this area, we recently succeeded in preparing the vinamidinium salts with fluorine substituents, such as fluoro [18], trifluoromethyl [19] and polyfluoroalkoxy [20] at the β carbon. These salts were successfully applied to the synthesis of fluorinated heterocycles [19,21,22], β-aminoacroleins [23], dienamino carbonyl compounds and aromatic compounds [24]. A focus of our research interest has been addressed to studies for the scope and limitation of the synthetic utility of these fluorine-containing vinamidinium salts. Very recently, we have reported that β-fluoro and β-polyfluoroalkoxy vinamidinium salts react smoothly with a variety of Grignard reagents to give the corresponding α,β-unsaturated aldehydes [25,26]. Herein we would like to report the reactions of these β-fluorinated vinamidinium salts with Grignard reagents followed by treatment with reducing agents. The results demonstrated that the reactions constitute a new facile and efficient route to β-fluorinated allylic amines which are useful synthons for the synthesis of various organofluorine compounds [27].

2. Results and discussion

We previously proposed a possible mechanism for the reaction of 1,5-diaza-1,1,5,5-tetraethyl-3-fluoro-1,3-pentadienium iodide (β-fluoro vinamidinium salt) (**1A**) with Grignard reagents, followed by acidic workup, leading to the formation of α-fluoro-α,β-unsaturated aldehydes **3** via an intermediate enamine **X** [25] (Scheme 1). In fact, the existence of the intermediate had strongly been suggested by the ^{19}F NMR spectra of the reaction mixtures in all cases, where the resonance appeared as doublet of doublets ($J = 31-34$ and 10–31 Hz) at around -70 ppm (upfield from the external standard of CF_3COOH). This peak shifted to around -57 ppm corresponding to the final product **3** by the treatment with aqueous acid. Attempts to isolate this intermediate before acidic workup were unsuccessful; **X** was entirely converted to **3** during the isolation by column

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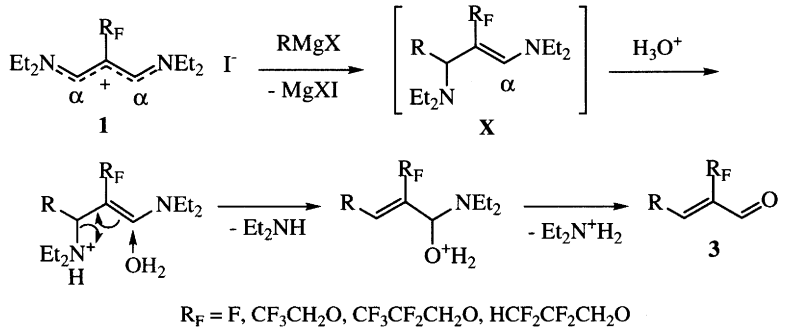
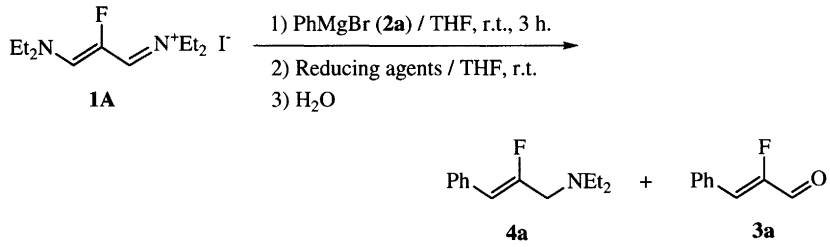


R_F = F, CF_3CH_2O, $CF_3CF_2CH_2O$, $HCF_2CF_2CH_2O$

Scheme 1.



Scheme 2.

chromatography (silica gel or aluminum oxide [activated, basic]/hexane).

In the present study, we planned to make further synthetic use of this enamine intermediate before acidic workup, assuming that the in situ reduction of the intermediate **X** with hydride-reducing reagents would provide very useful fluorinated allylic amines.

We first treated the reaction mixture, resulting from the reaction of **1A** with phenylmagnesium bromide **2a** (2.2 equiv.) in tetrahydrofuran (THF) at room temperature for 3 h, with a variety of hydride-reducing agents under various conditions (Scheme 2). The results are summarized in Table 1. The treatment of the reaction mixture with 1.1 equiv. of diisobutylaluminum hydride (DIBAL) as the reducing agent in THF at room temperature for 1 h and then with water gave α-fluorocinnamaldehyde **3a**, a hydrolysis product of the enamine, in 98% yield as sole product (Entry 1). Prolongation of the reaction time (24 h) produced the desired allylamine, *N,N*-diethyl-2-fluoro-3-pheny-2*Z*-propenylamine (**4a**), in a low yield (10%) along with **3a** (Entry 2). Furthermore, the use of an excess amount of DIBAL increased the yield of **4a** (Entries 3 and 4). The best result was obtained from the reaction with 4.0 equiv. of DIBAL for 24 h, affording **4a** in 90% yield without formation of **3a** (Entry 5). The quenching with 10% hydrochloric acid, instead of water, gave a hydrochloride salt of the amine **4a**.

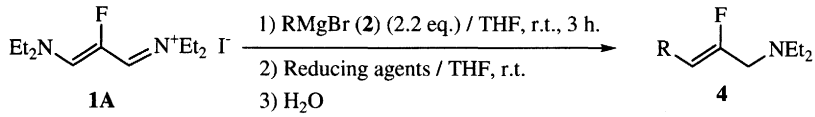
Table 1
Reaction of **1A** with phenylmagnesium bromide (**2a**) and reducing agents under various conditions

Entry	Reducing reagent (eq.)	Time (h)	Yield[a]/% of	
			4a	**3a**
1	DIBAL (1.0)	1	0	98
2	DIBAL (1.0)	24	10	79
3	DIBAL (3.0)	24	79	19
4	DIBAL (4.0)	3	51	48
5	DIBAL (4.0)	24	90	0
6	BH_3·THF (1.0)	3	67	13
7	BH_3·THF (1.0)	24	97	0
8	$NaBH_4$ (1.0)	24	24	55
9	$LiAlH_4$ (1.0)	24	57	42

[a] Determined by ^{19}F NMR.

Borane-THF complex was also employable as the reducing agent. Thus, 1.0 equiv. of borane-THF complex gave **4a** in 67% (with 13% of **3a**) for 3 h and in 97% yields (without **3a**) for 24 h (Entries 6 and 7). Other reducing agents, such as sodium borohydride and lithium aluminum hydride (1.0 equiv.), yielded a mixture of **3a** and **4a** even if the reactions were carried out for 24 h (Entries 8 and 9).

We next examined the synthesis of various fluorinated allylamines **4** according to the previous described methodology. The vinamidinium salt **1A** was allowed to react with a variety of Grignard reagents (2.2 equiv.) in THF at ambient temperature for 3 h, followed by treatment with DIBAL (4.0 equiv.) or borane-THF complex (1.0 equiv.) at room temperature for 24 h (Entries 5 and 7) (Scheme 3). The results are summarized in Table 2. Both reducing agents could participate nicely in the reactions using all Grignard reagents



Scheme 3.

Table 2
Results of the reaction of **1A** with various Grignard reagents-reducing agents

Entry	**R**MgX (**2**)	Reducing agent	Yield[a]/% of **4**	
10	PhMgBr (**2a**)	DJBAL	(**4a**)	85
11		BH_3·THF		92
12	*p*-$CH_3OC_6H_4MgBr$ (**2b**)	DIBAL	(**4b**)	88
13		BH_3·THF		82
14	*p*-$CH_3C_6H_4MgBr$ (**2c**)	DIBAL	(**4c**)	93
15		BH_3·THF		94
16	α-NaphthylMgBr (**2d**)	DIBAL	(**4d**)	83
17		BH_3·THF		88
18	BuMgBr (**2e**)	DIBAL	(**4e**)	71
19		BH_3·THF		60
20	$C_6H_5CH_2MgCl$ (**2f**)	DIBAL	(**4f**)	74
21		BH_3·THF		43
22	*i*-PrMgBr (**2g**)	DIBAL	(**4g**)	50
23		BH_3·THF		40
24	*t*-BuMgCl (**2h**)	DIBAL	(**4h**)	(5)[b]

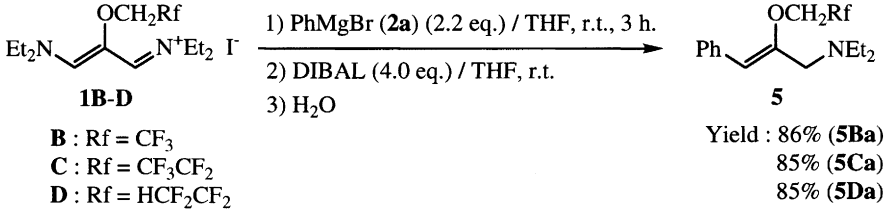
[a] Isolated yields.
[b] ^{19}F NMR yie1d.

except *t*-butylmagnesium chloride. Thus, DIBAL reacted smoothly with the mixture from aromatic Grignard reagents **2a–d** to give the corresponding arylated fluoroallylamines **4a–d** in high yields (83–93%) (Entries 10, 12, 14 and 16). Similarly, borane-THF complex led to satisfactory results (82–94 yield) (Entries 11, 13, 15 and 17). The reaction of both reducing agents with the mixture from primary and secondary alkyl Grignard reagents **2e–g** also gave the corresponding alkylated fluoroallylamine **4e–g** in good to moderate yields (Entries 18–23). However, tertiary alkyl Grignard reagent, *t*-butylmagnesium chloride (**2h**), gave the product **4h** only in low NMR yield along with an unidentified product, large amounts of the starting material **1A** being left unchanged (Entry 24). The low yield of **4h** is mainly due to low reactivity of **2h** toward **1A** [25]. In all these reactions, the allylamines **4** thus obtained were only one stereoisomer having the *Z* configuration, which was unambiguously determined on the basis of the magnitudes of vicinal H–F couplings in ^1H and ^{19}F NMR spectra [28].

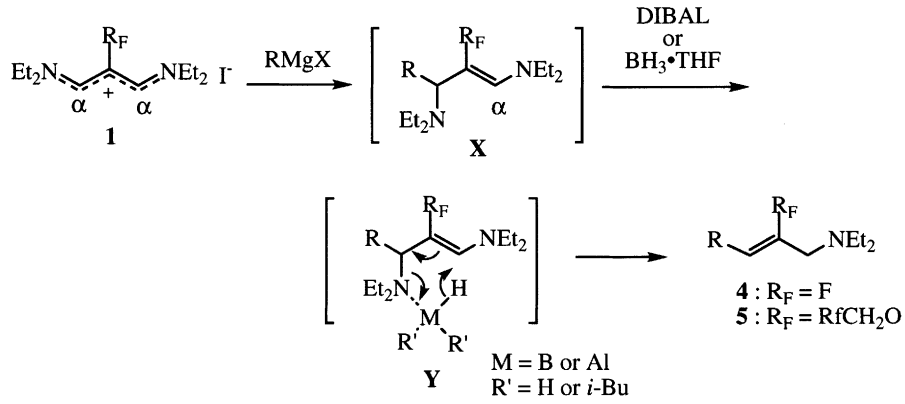
We also synthesized polyfluoroalkoxylated allylamines **5** by the reaction of DIBAL with the reaction mixture from β-polyfluoroalkoxylated vinamidinium salts **1B–D** and Grignard reagent **2a** (Scheme 4). Thus, 1,5-diaza-1,1,5,5-tetraethyl-3-(2,2,2-trifluoroethoxy)-1,3-pentadienium iodide (β-trifluoroethoxy vinamidinium salt) (**1B**) was treated with 2.2 equiv. of phenylmagnesium bromide (**2a**) in THF at room temperature for 3 h and then with 4.0 equiv. of DIBAL at the same temperature for 24 h to afford *N,N*-diethyl-3-phenyl-2-(2,2,2-trifluoroethoxy)-2*Z*-propenylamine (**5Ba**) in 86% yield. The reaction with other vinamidinium salts having 2,2,3,3,3-pentafluoropropoxy (**1C**) and 2,2,3,3-tetrafluoropropoxy group (**1D**) at the β carbon proceeded smoothly to give the corresponding polyfluoroalkoxylated allylic amines (**5Ca**, **5Da**) in good yields. The chain length and number of fluorine of the polyfluoroalkoxy group did not affect the yields of the allylamines **5**. The products **5** consisted of single isomers but their stereochemistry has yet to be determined.

The following mechanism is anticipated for the formation of the allylamines **4** and **5** (Scheme 5). The intermediate enamine **X** resulting from the attack of Grignard reagent on the α carbon of **1** may react with reducing agent through a six-membered ring transition state **Y**, in which the reductive deamination occurs via an S_N2' like process to afford the allylamine. This mechanism was verified by the reaction using a deuterated reducing agent. Thus, the reaction mixture prepared from **1A** and **2a** was similarly treated with borane-d_3-THF complex to give the corresponding α-deuterated allylamine 6 in 87% yield (Scheme 6).

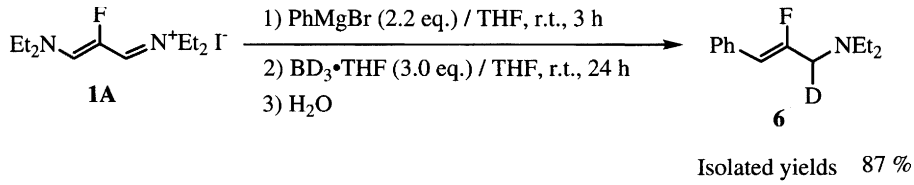
The predominant formation of the *Z*-isomer may be explained by an S_N2' displacement of the diethylamino group for the most stable conformer of the six-membered



Scheme 4.



Scheme 5.

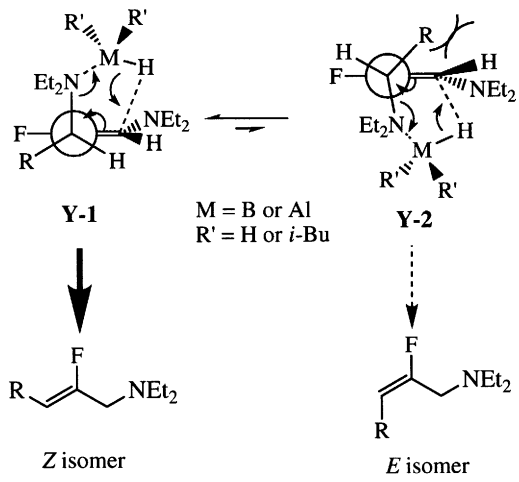


Scheme 6.

ring transition state **Y**. The conformer **Y-1** should be more stable than the other **Y-2**, which has a 1,3-allylic strain (Scheme 7). Therefore, the reaction proceeds preferentially via **Y-2**, leading to the *Z* isomer.

3. Conclusion

In the present study, we have shown that β-fluoro (**1A**) and β-polyfluoroalkoxy vinamidinium salts (**1B–D**) react with Grignard reagents to generate the intermediate enamines, which can be transformed by the action of reducing agents, such as DIBAL and borane–THF complex, into fluorinated allylamines in good yields. This reaction can serve as a facile and efficient route to the fluorinated allylamines, and also substantiates the utility of these vinamidinium salts as fluorine-containing three-carbon building blocks in organic fluorine synthesis.



Scheme 7.

4. Experimental

4.1. Measurement and materials

Infrared spectra (IR) were measured in a liquid film or KBr disk method with a Shimadzu FTIR-8200PC spectrophotometer. ^{1}H and ^{13}C NMR spectra were obtained with a Bruker DRX500 (500 MHz for ^{1}H and 125 MHz for ^{13}C) spectrometer in a chloroform-d ($CDCl_3$) solution with tetramethylsilane (TMS) as an internal reference. A JEOL JNM EX90 (84.10 MHz) spectrometer was used to measure ^{19}F NMR spectra in $CDCl_3$ with trichlorofluoromethane (CCl_3F) as an internal reference. ^{19}F NMR yield was calculated from the peak area ratio of a sample to benzotrifluoride (BTF) as an internal standard. Mass spectra (MS) and high resolution mass spectra (HRMS) were taken on a Hitachi M-80B, Shimadzu QP-1000 and/or JEOL JMS-700 mass spectrometer. Melting points were obtained on a Mettler FP5 melting point determination apparatus and are uncorrected. The elemental analyses of the products gave satisfactory results.

β-Fluoro (**1A**) and β-polyfluoroalkoxy vinamidinium salts **1B–D** were prepared according to the method reported by us [18,20]. All chemicals are of reagent grade and, if

necessary, were purified by a conventional manner before use. Tetrahydrofuran (THF) was distilled with sodium benzophenone kethyl and stored under argon. All reactions were carried out under an atmosphere of argon.

*4.2. Reaction of vinamidinium salts **1** with Grignard reagents and reducing agents: synthesis of fluorinated allylamines **4** and **5***

The typical procedure is as follows. To a solution of the vinamidinium salt **1A** (0.328 g, 1.0 mmol) in THF (3 ml) was gradually added 2.2 equiv. of phenylmagnesium bromide in THF (2.3 ml) at 0°C and then the mixture was stirred at room temperature for 3 h under an atmosphere of argon. DIBAL (1.0 M solution in hexane (4.0 ml)) was added to the reaction mixture and the whole was stirred at room temperature for 24 h. The reaction mixture was poured on ice-water and then extracted with dichloromethane (20 ml × 4). The organic layers were washed with a brine (30 ml), dried over anhydrous sodium sulfate, and concentrated in vacuo. The residue was purified by silica-gel column chromatography (hexane-benzene (50:50)) to give *N,N*-diethyl-2-fluoro-3-pheny-2*Z*-propenylamine (**4a**) (0.176 g, 85% yield) as a colorless liquid. When the reaction mixture was treated with 10% hydrochloric acid instead of ice-water, the hydrochloride salt of **4a** was isolated as a white solid after column chromatography (benzene and then ethanol).

The other reactions employing **1A**, **1B–D**, various Grignard reagents, DIBAL and borane–THF complex were carried out in the same way as cited above.

5. *N,N*-diethyl-2-fluoro-3-pheny-2*Z*-propenylamine (4a)

^{1}H NMR ($CDCl_3$) δ 1.32 (t, $J = 7.3$ Hz, 6H), 2.87 (dq, $J = 13.0, 7.3$ Hz, 2H), 2.94 (dq, $J = 13.0, 7.3$ Hz, 2H), 3.64 (d, $J = 22.0$ Hz, 2H), 5.81 (d, $J = 38.0$ Hz, 1H), 7.25–7.37 (m, 3H), 7.49–7.53 (m, 2H); ^{13}C NMR ($CDCl_3$) δ 9.20, 54.16, 59.08 (d, $J = 25.5$ Hz), 114.94 (d, $J = 7.6$ Hz), 128.03, 128.42, 128.79 (d, $J = 7.4$ Hz), 131.87 (d, $J = 3.1$ Hz), 152.55 (d, $J = 266.5$ Hz); ^{19}F NMR ($CDCl_3$) δ −101.87 (dt, $J = 38.0, 22.0$ Hz, 1F); IR (neat) 3059 (w), 3004 (w), 2982 (m), 2943 (m), 2885 (w), 2388 (vs), 2284 (m), 1685 (w) cm^{-1}; MS *m/e* (relative intensity) 207 (M^+, 21), 192 (30), 136 (11), 135 (100), 115 (18), 58 (20); HRMS (EI) found: *m/z* 207.1407; calculated for $C_{13}H_{18}FN$: M, 207.1423.

6. *N,N*-diethyl-2-fluoro-3-(4-methoxyphenyl)-2*Z*-propenylamine (4b)

M.p. 84–86°C; ^{1}H NMR ($CDCl_3$) δ 1.33 (t, $J = 7.2$ Hz, 6H), 2.79–3.04 (m, 4H), 3.65 (d, $J = 22.1$ Hz, 2H), 3.82 (s, 3H), 5.76 (d, $J = 38.5$ Hz, 1H), 6.83–6.93 (m, 2H), 7.41–7.51 (m, 2H); ^{19}F NMR ($CDCl_3$) δ −104.88 (dt, $J = 38.5$, 22.1 Hz, 1F); IR (KBr) 2978 (m), 2932 (m), 2878 (m), 2939 (m), 2731 (s), 2658 (s), 2584 (m), 2492 (m), 2434 (m), 1689 (w); MS *m/e* (relative intensity) 237 (M^+, 31), 222 (12), 166 (12), 165 (100); HRMS (EI) found: *m/z* 237.1511; calculated for $C_{14}H_{20}FNO$: M, 237.1529.

7. *N,N*-diethyl-2-fluoro-3-(4-methylphenyl)-2*Z*-propenylamine (4c)

M.p. 60–61°C; ^{1}H NMR ($CDCl_3$) δ 1.33 (t, $J = 7.3$ Hz, 6H), 2.35 (s, 3H), 2.88 (dq, $J = 12.8, 7.3$ Hz, 2H), 2.96 (dq, $J = 12.8, 7.3$ Hz, 2H), 3.66 (d, $J = 22.0$ Hz, 2H), 5.78 (d, $J = 38.5$ Hz, 1H), 7.16 (d, $J = 8.3$ Hz, 2H), 7.40 (d, $J = 8.3$ Hz, 2H); ^{13}C NMR ($CDCl_3$) δ 9.38, 21.23, 54.33, 59.21 (d, $J = 25.5$ Hz), 114.99 (d, $J = 8.2$ Hz), 128.27, 128.83 (d, $J = 7.6$ Hz), 129.12 (d, $J = 3.1$ Hz), 138.21 (d, $J = 2.0$ Hz), 152.11 (d, $J = 265.3$ Hz); ^{19}F NMR ($CDCl_3$) δ −102.92 (dt, $J = 38.5, 22.0$ Hz, 1F); IR (KBr) 2297 (m), 2978 (m), 2951 (m), 2889 (w), 2380 (vs), 2326 (vs), 2280 (vs), 1686 (m) cm^{-1}; MS *m/e* (relative intensity) 221 (M^+, 17), 206 (19), 192 (2), 150 (12), 149 (100), 129 (11), 86 (5), 58 (15). HRMS (EI) found: *m/z* 221.1572; calculated for $C_{14}H_{20}FN$: M, 221.1580.

8. *N,N*-diethyl-2-fluoro-3-(4-methylphenyl)-2*Z*-propenylamine hydrochloride (4c·HCl)

M.p. 58 ∼ 60°C; ^{1}H NMR ($CDCl_3$) δ 1.50 (t, $J = 7.25$ Hz, 6H), 3.15 (s, 3H), 3.28 (q, $J = 7.25$ Hz, 4H), 4.10 (d, $J = 20.0$ Hz, 2H), 6.24 (d, $J = 39.01$ Hz, 1H), 7.07 ∼ 7.51 (m, 4H), 9.45–9.55 (m, 1H); ^{13}C NMR ($CDCl_3$) δ 9.3, 21.0, 47.4, 51.8 (d, $J = 27.48$ Hz), 128 (d, $J = 2.26$ Hz), 116.6 (d, $J = 5.66$ Hz), 128.9 (d, $J = 7.29$ Hz), 129.1, 138.1 (d, $J = 1.76$ Hz), 147.8 (d, $J = 262.8$ Hz); ^{19}F NMR ($CDCl_3$) δ −106.19 (dt, $J = 39.01, 20.0$ Hz, 1F); IR (KBr) 3340 (w), 2889 (w), 2384 (s), 1686 (m), 1450 (s), 1393 (s), 1366 (m), 1342 (s), 1157 (vs), 1110 (m), 1049 (s), 810 (s), 760 (m) cm^{-1}; MS (EI) *m/z* (relative intensity) 221 (M^+, 22), 206 (19), 150 (11), 149 (100), 129 (9), 86 (6); MS (SIMS) found: 479.3021, calculated for $C_{28}H_{42}$ ^{35}Cl F_2N_2 ($2M^+$-^{35}Cl): 479.3004.

9. *N,N*-diethyl-2-fluoro-3-(α-naphtyl)-2*Z*-propenylamine (4d)

^{1}H NMR ($CDCl_3$) δ 1.33 (t, $J = 7.3$ Hz, 6H), 2.85–3.02 (m, 4H), 3.72 (d, $J = 21.5$ Hz, 2H), 6.50 (d, $J = 35.5$ Hz, 1H), 7.40–7.96 (m, 7H); ^{13}C NMR ($CDCl_3$) δ 9.24, 54.26, 59.13 (d, $J = 26.0$ Hz), 112.13 (d, $J = 9.7$ Hz), 123.65, 125.23, 125.83, 126.43, 127.43 (d, $J = 8.3$ Hz), 128.02, 128.22, 128.56 (d, $J = 6.8$ Hz), 131.07, 133.45, 153.23 (d, $J = 265.2$ Hz); ^{19}F NMR ($CDCl_3$) δ −103.19 (dt,

J = 35.5, 21.5 Hz, 1F); IR (neat) 3051 (vs), 2936 (s), 2873 (m), 2819 (m), 2630 (w), 1686 (m); MS *m/z* (relative intensity) 257 (M^+, 23), 242 (11), 228 (6), 186 (21), 185 (100), 165 (31), 128 (60). HRMS *m/z* found: 257.1567; calculated for $C_{17}H_{20}FN$: 257.1580.

10. *N,N*-diethyl-2-fluoro-2*Z*-heptenylamine hydrochloride (4e·HCl)

^{1}H NMR ($CDCl_3$) δ 0.91 (t, J = 7.00 Hz, 3H), 1.28–1.43 (m, 4H), 1.50 (t, J = 7.50 Hz, 6H), 2.18 (dt, J = 7.50, 6.75 Hz, 2H), 3.20 (q, J = 7.50 Hz, 4H), 3.90 (d, J = 19.50 Hz, 2H), 5.31 (dt, J = 36.00, 7.50 Hz, 1H), 9.55–9.65 (m, 1H); ^{13}C NMR ($CDCl_3$) δ 9.38, 13.43, 21.93, 23.33 (d, J = 4.52 Hz), 30.40, 30.43, 47.45 (d, J = 28.00 Hz), 118.36 (d, J = 13.20 Hz), 148.30 (d, J = 251.5 Hz); ^{19}F NMR ($CDCl_3$) δ −111.67 (dt, J = 36.00, 7.50 Hz, 1F); IR (neat) 3420 (m), 295 (vs), 2932 (vs), 2862 (s), 2484 (s), 1705 (m), 1632 (w), 1466 (s), 1119 (w), 883 (w); HRMS (FAB) found: *m/z* 411.3308; calculated for $C_{22}H_{46}$ $^{35}ClF_2N_2$ ($2M^+$-^{35}Cl): 411.3317.

11. *N,N*-diethyl-2-fluoro-4-phenyl-2*Z*-butenylamine (4f)

^{1}H NMR ($CDCl_3$) δ 1.33 (t, J = 7.3 Hz, 6H), 2.87 (dq, J = 12.8, 7.3 Hz, 2H), 2.94 (dq, J = 12.8, 7.3 Hz, 2H), 3.52 (d, J = 7.5 Hz, 2H), 3.58 (d, J = 21.0 Hz, 2H), 5.21 (dt, J = 35.0, 7.5 Hz, 1H), 7.15–7.38 (m, 5H); ^{13}C NMR ($CDCl_3$) δ 9.31, 30.08 (d, J = 5.2 Hz), 54.34, 58.11 (d, J = 26.4 Hz), 114.70 (d, J = 14.8 Hz), 126.40, 128.40 (d, J = 52.9 Hz), 139.08, 152.50 (d, J = 256.0 Hz); ^{19}F NMR ($CDCl_3$) δ −108.76 (dt, J = 35.0, 21.0 Hz, 1F); IR (neat) 3063 (w), 3028 (w), 3005 (w), 2982 (m), 2943 (m), 2854 (w), 2388 (vs), 2284 (m), 1697 (w); MS *m/e* (relative intensity) 221 (M^+, 14), 207 (15), 206 (100), 149 (42), 129 (54), 128 (11), 103 (12), 91 (10), 58 (50); HRMS (EI) found: *m/z* 221.1572; calculated for $C_{14}H_{20}FN$: 221.1580.

12. *N,N*-diethy-2-fluoro-4-phenyl-2*Z*-butenylamine hydrochloride (4f·HCl)

M.p.66 ∼ 68°C; ^{1}H MNR ($CDCl_3$) δ 1.46 (t, J = 7.25 Hz, 6H), 3.19 (q, J = 7.25 Hz, 4H), 3.51 (d, J = 7.50 Hz, 2H), 3.92 (d, J = 19.5 Hz, 2H), 5.54 (dt, J = 35.5, 7.5 Hz, 1H), 7.13 ∼ 7.33 (m, 5H); ^{13}C NMR ($CDCl_3$) δ 9.4, 30.0 (d, J = 4.36 Hz), 47.6, 50.4 (d, J = 27.7 Hz), 117.1 (d, J = 13.1 Hz), 126.5, 128.0, 138.0, 148.7 (d, J = 253.4 Hz); ^{19}F NMR ($CDCl_3$) δ −110.97 (dt, J = 35.5, 19.5 Hz, 1F); IR (KBr) 3395 (w) 2974 (s), 2923 (s), 2492 (vs), 1705 (m), 1454 (s), 1392 (s), 1218 (w), 1164 (m), 975 (m), 949 (m), 934 (m), 829 (m), 737 (s), 702 (s) cm^{-1}; MS (SIMS) found: 479.3009, calculated for $C_{28}H_{42}$$^{35}ClF_2N_2$ ($2M^+$-^{35}Cl): 479.3004.

13. *N,N*-diethyl-2-fluoro-4-methyl-2*Z*-pentenylammonium Iodide (2g)

^{1}H NMR ($CDCl_3$) δ 1.05 (d, J = 7.25 Hz, 6H), 1.56 (t, J = 7.25 Hz, 6H), 2.83 (dq, J = 7.25, 2.50 Hz, 1H), 3.28 (q, J = 7.25 Hz, 4H), 3.89 (d, J = 19.50 Hz, 2H), 5.24 (dd, J = 37.30, 9.25 Hz, 1H); ^{13}C NMR ($CDCl_3$) δ 9.56, 22.20, 24.38 (d, J = 3.14 Hz), 48.04, 51.31 (d, J = 28.17 Hz), 126.12 (d, J = 12.32 Hz), 146.23 (d, J = 250.87 Hz); ^{19}F NMR ($CDCl_3$) δ −112.28 (dt, J = 37.30, 19.5 Hz, 1F); IR (neat) 3402 (m), 3209 (w), 2927 (vs), 2873 (s), 2642 (s), 2484 (m), 1705 (m), 1616 (w), 1292 (s); HRMS (FAB) found: *m/z* 475.2376; calculated for $C_{20}H_{42}F_2IN_2$: 2M-I, 475.2362.

14. *N,N*-diethyl-2-(2,2,2-trifluoroethoxy)-3-phenyl-2*Z*-propenylamine (5Ba)

^{1}H NMR ($CDCl_3$) δ 1.30 (t, J = 7.00 Hz, 6H), 2.86–3.00 (m, 4H), 3.56 (s, 2H), 4.00 (q, J = 8.60 Hz, 2H), 6.07 (s, 1H), 7.27 (m, 1H), 7.33 (m, 2H), 7.48 (m, 2H); ^{13}C NMR ($CDCl_3$) δ 9.07, 53.58, 60.53, 67.32 (q, J = 35.07 Hz), 121.54, 123.01 (q, J = 278.54 Hz), 127.97, 128.43, 129.01, 132.99, 148.22; ^{19}F NMR ($CDCl_3$) δ −75.19 (t, J = 8.8 Hz, 3F); IR (neat) 3005 (w), 2982 (w), 2947 (w), 2392 (m), 2353 (m), 2284 (m), 1660 (w), 1450 (w), 1281 (m), 1165 (s); MS *m/e* (relative intensity) 287 (M^+, 26), 272 (37), 258 (4), 204 (4), 155 (15); HRMS *m/z* found: 287.1487; calculated for $C_{15}H_{20}F_3NO$: 287.1497. *N,N*-diethyl-2-(2,2,3,3,3-pentafluoropropoxy)-3-phenyl-2*Z*-propenylamine (5Ca) ^{1}H NMR ($CDCl_3$) δ 1.35 (t, J = 7.0 Hz, 6H), 3.03 (q, J = 7.0 Hz, 4H), 3.7 (s, 2H), 4.27 (t, J = 13.20 Hz, 2H), 6.15 (s, 1H), 7.07–7.55 (m, 5H); ^{19}F NMR ($CDCl_3$) δ −83.93 (s, 3F), −124.25 (t, J = 13.20 Hz, 2F); MS *m/e* (relative intensity) 337 (M^+, 25), 322 (36), 246 (6), 115 (12); HRMS *m/z* found: 337.1462. Calculated for $C_{16}H_{20}F_5NO$: 337.1465.

15. *N,N*-diethyl-2-(2,2,3,3,-tetrafluoropropoxy)-3-phenyl-2*Z*-propenylamine (5Da)

^{1}H NMR ($CDCl_3$) δ 1.32 (t, J = 7.0 Hz, 6H), 3.02 (q, J = 7.0 Hz, 4H), 3.67 (s, 2H), 4.27 (m, 2 H), 5.93 (tt, J = 52.8, 6.1 Hz, 1H), 6.03 (s, 1H), 7.08–7.60 (m, 5H); ^{19}F NMR ($CDCl_3$) δ −125.12 (m, 2F), −138.80 (dm, J = 52.8 Hz, 2F); MS *m/e* (relative intensity) 319 (M^+, 22), 304 (36), 247 (100), 115 (12); HRMS *m/z* found: 319.1558. Calculated for $C_{16}H_{21}F_4NO$: 319.1559.

16. *N,N*-diethyl-1-deuterio-2-fluoro-3-phenyl-2*Z*-propenylamine (6)

^{1}H NMR ($CDCl_3$) δ 1.32 (t, J = 7.30 Hz, 6H), 2.87 (dq, J = 12.8, 7.3 Hz, 2H), 2.95 (dq, J = 12.8, 7.3 Hz, 2H), 3.63 (d, J = 21.5 Hz, 1H), 5.81 (d, J = 38.0 Hz, 1H), 7.25–7.56

(m, 5H); ^{13}C NMR ($CDCl_3$) δ 9.28, 54.18, 58.80 (q, $J = 22.3$ Hz), 115.01 (d, $J = 7.8$ Hz), 128.12, 128.51, 128.86 (d, $J = 7.8$ Hz), 131.92 (d, $J = 2.4$ Hz), 152.61 (d, $J = 266.5$ Hz); ^{19}F NMR ($CDCl_3$) δ −102.03 (dd, $J = 38.0$, 21.5 Hz, 1F); IR (neat) 3055 (m), 3001 (m), 2982 (m), 2943 (m), 2885 (w), 1790 (vs); MS *m/e* (relative intensity) 208 (M^+, 20), 193 (30), 154 (26), 137 (11), 136 (100), 116 (17), 94 (38); HRNS *m/z* found: 208.1465. Calculated for $C_{13}H_{17}DFN$: 208.1485.

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