Novel Introduction of a Tetrafluoroethylene (-CF_2CF_2-) Unit into Organic Molecules

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Abstract: The reductive coupling of 4-bromo-3,3,4,4-tetrafluorobut-1-ene with 2.4 equivalents of various carbonyl compounds proceeded very smoothly in the presence of 2.4 equivalents of MeLi/LiBr-free at –78 °C for two hours, giving the corresponding adducts in high to excellent yields. On the other hand, triethyl(1,1,2,2-tetrafluorobut-3-enyl)silane, which could be prepared by treatment of 4-bromo-3,3,4,4-tetrafluorobut-1-ene and chlorotriethylsilane with magnesium at 0 °C for three hours, reacted with some aldehydes in the presence of 1 mol% of tetrabutylammonium fluoride, the desired adducts being obtained in good to high yields.

Key words: tetrafluoroethylene, MeLi/LiBr-free, triethyl(1,1,2,2-tetrafluorobut-3-enyl)silane, reductive coupling

The incorporation of a fluorine-containing fragment into organic molecules can have a significant influence on the material characteristics or biological activity of the molecules by affecting their physicochemical and/or pharmacological properties.[1] While the incorporation of terminal perfluorinated moieties has been extensively studied,[2] the introduction of an internal perfluoroalkylene unit, e.g. **1** (Figure 1, n >2) is relatively rare.

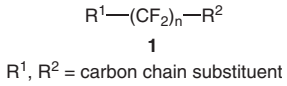

Figure 1 Internal perfluoroalkylene unit (n >2)

In 1998, DiMagno and co-workers proposed a general strategy for enhancing molecular recognition based on increasing 'polar hydrophobicity', which could be achieved by replacing polar hydrophilic groups with polar hydrophobic groups, e.g., a CHOH group in carbohydrates with a CF_2 group. It was found that the hexafluoropyranose **2** shown in Figure 2, has a tenfold increase in transport across the red blood cell membrane, compared to glucose due to enhanced affinity for the transporter protein.[3]

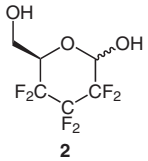

Figure 2 DiMagno's partially fluorinated hexapyranose

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This observation prompted several chemists to investigate heavily fluorinated sugars (Figure 3). For example, the asymmetric synthesis of the tetrafluoropyranose **3** and **4** was achieved by Linclau et al.[4] Very recently, Gouverneur and co-workers have also reported the synthesis of tetrafluorinated *C*-nucleosides **5**.[5]

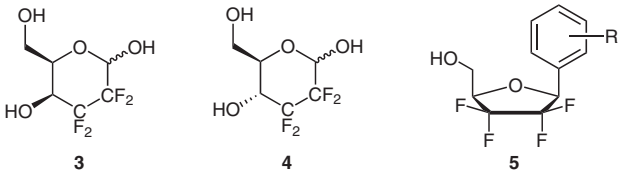
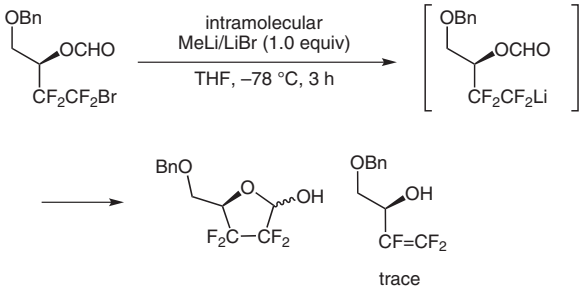
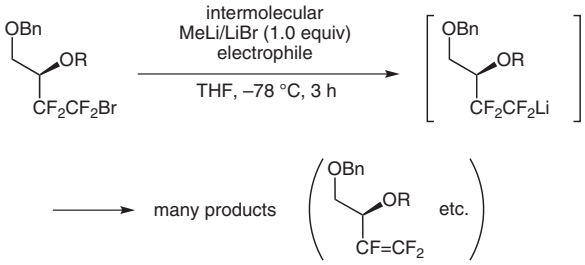


Figure 3 Tetrafluorinated carbohydrate or *C*-nucleoside analogues

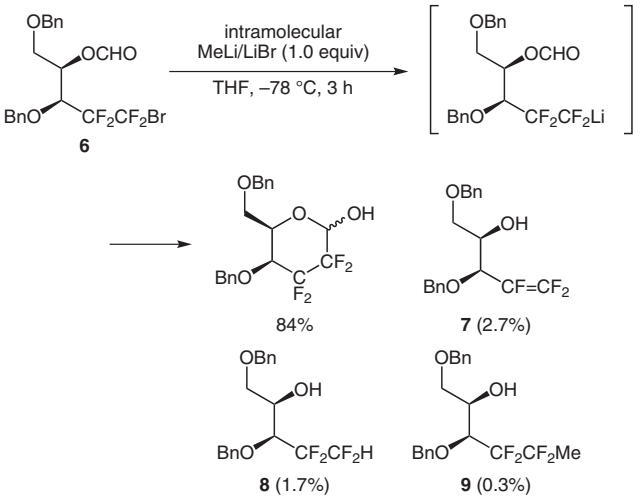
In the syntheses of these heavily fluorinated sugars, however, intramolecular cyclization (Equation 1) was required because fluoride elimination from the in situ generated polyfluoroalkyllithium species proceeded significantly in the intermolecular coupling reaction (Equation 2).[6] Even in the intramolecular cyclization of the formate derivative **6**, β-elimination product **7**, reduction product **8**, as well as methylated product **9** were also observed (Equation 3).[4]



Equation 1

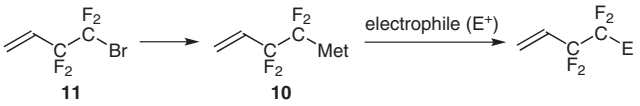


Equation 2



Equation 3

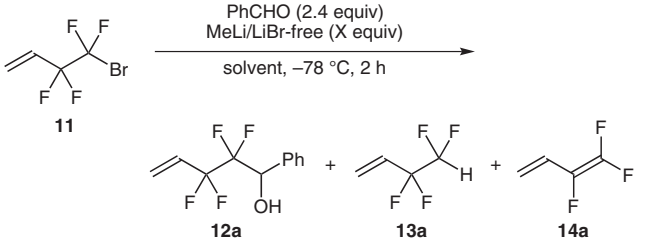
Such a synthetic difficulty in the synthesis of molecules having a perfluoroalkylene unit, especially a tetrafluoroethylene unit, prompted us to re-investigate the intermolecular nucleophilic addition of (tetrafluoroalkyl)metal species **10**, derived from commercially available 4-bromo-3,3,4,4-tetrafluorobut-1-ene (**11**), with various electrophiles in detail (Scheme 1).



Scheme 1 Intended program

Gassman et al. have already reported the reductive coupling of perfluoroalkyl iodide with various aldehydes, ketones, and esters.[2d] Our initial studies on the reductive coupling of 4-bromo-3,3,4,4-tetrafluorobut-1-ene (**11**) and benzaldehyde were carried out by examining their reaction conditions (Table 1). Thus, treatment of **11** and 2.4 equivalents of benzaldehyde with 1.2 equivalents of methyllithium/lithium bromide in diethyl ether at –78 °C for two hours did not give any of the desired product **12a**; the starting bromide **11** was recovered quantitatively (entry 1). The use of lithium bromide free methyllithium (MeLi/LiBr-free) instead brought about a slight increase in the yield, the desired alcohol **12a** being obtained in only 15% yield, together with 1% of the reduction product **13a**, although a large amount of the starting material still remained unreacted (entry 2). Switching the solvent from diethyl ether to tetrahydrofuran improved the yield of **12a** from 15 to 59% (entry 3). Although the prolonged reaction time as well as the addition of Lewis acid did not lead to satisfactory results (entries 4 and 5), the use of 2.4 equivalents of MeLi/LiBr-free resulted in a complete consumption of the starting material, the desired adduct **12a** being obtained almost quantitatively (entry 6). In this case, the employment of MeLi/LiBr-free was found to be crucial because the reaction in the presence of 2.4 equivalents of MeLi/LiBr in tetrahydrofuran gave **12a** in only 50% yield, together with 5% of **13a** (Entry 7). Additionally, when butyllithium was used instead of MeLi/LiBr-free, the yield of **12a** was decreased from 95 to 79% (entry 8). Increasing the reaction temperature also led to a decrease in the yield of **12a** and β-elimination product **14a** was afforded as a byproduct (entry 9).

Table 1 Investigation of the Reaction Conditions



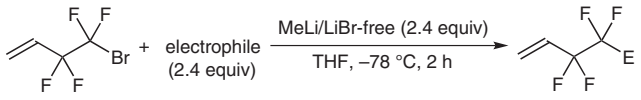
Entry	MeLi/LiBr-free (equiv)	Solvent	Yield[a] (%) 12a	13a	14a	Recovered[a] (%) of **11**
1	1.2[b]	Et_2O	trace	0	0	97
2	1.2	Et_2O	15	1	0	81
3	1.2	THF	59	5	0	33
4	1.2[c]	THF	47	4	0	45
5	1.2[d]	THF	12	trace	0	85
6	2.4	THF	95	trace	0	0
7	2.4[b]	THF	50	5	0	36
8	2.4[e]	THF	79	7	0	0
9[f]	2.4[f]	THF	68	0	9	8

[a] Determined by ^{19}F NMR.
[b] Commercially available MeLi/LiBr (Et_2O soln) was used.
[c] Stirred for 4 h.
[d] $BF_3{\cdot}OEt_2$ (2.4 equiv) was used.
[e] *n*-BuLi (hexane soln) was used instead of MeLi/LiBr-free.
[f] Carried out at –40 °C.

With the optimum reaction conditions in hand (Table 1, entry 6), we next investigated the reaction of **11** with various electrophiles. The results are summarized in Table 2. As shown in entries 2–4, the position of the substituent on the benzene ring of the aldehyde did not influence the reaction at all. Additionally, aldehydes having an electron-donating group, such as Me, OMe, on the benzene ring could participate well in the coupling reaction (entries 2 and 5), whereas an electron-withdrawing group, such as CF_3, CN, or NO_2, on the benzene ring of the aromatic aldehydes led to a significant decrease in the yield (entries 7–9). Other aldehydes, like furfural as well as cinnamaldehyde, were also found to be good electrophiles, the corresponding alcohols being afforded in high yields (entries 10 and 11). As described in entries 12–15, treatment of **11** with various aliphatic aldehydes, such as propanal, heptanal, cyclohexanecarboxaldehyde, and pivalaldehyde, furnished the coupling products, **12l–o** in excellent yields. Furthermore, the reaction with various ketones took place very smoothly to give the corresponding alcohols **12p**,**q** in

good to high yields (entries 16 and 17). The non-activated imine, such as *N*-benzylbenzaldehyde imine, was found to be less reactive in this reaction, none of the desired product was afforded at all. However, the use of boron trifluoride–diethyl ether complex as a Lewis acid led to a significant improvement of the yield, the desired amine being obtained in 40% yield (entry 18). On the other hand, the reductive coupling with a chiral sulfinimine proceeded very smoothly to give the corresponding amine in good yield as a diastereomeric mixture in a ratio of 90:10 of (*R*s,*S*)/(*R*s,*R*).[7]

Table 2 The Reductive Coupling of **11** with Various Electrophiles



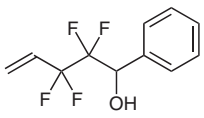
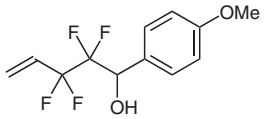
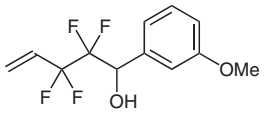
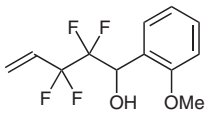
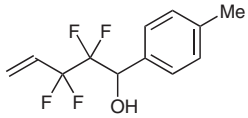
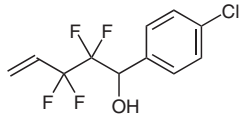
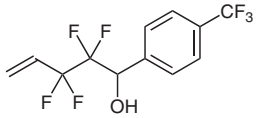
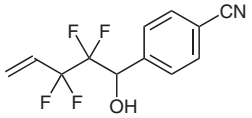
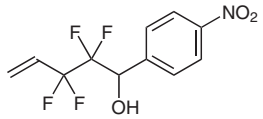
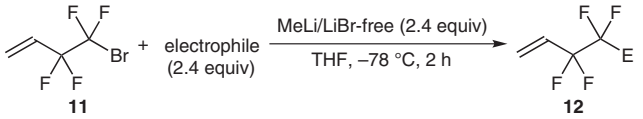
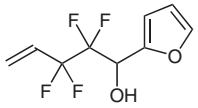
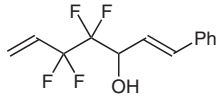
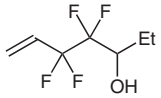
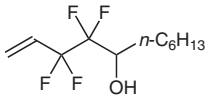
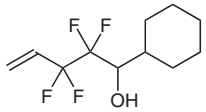
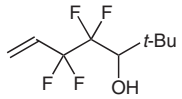
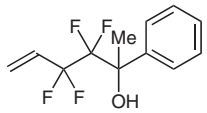
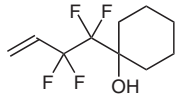
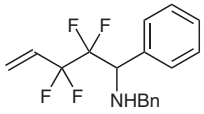
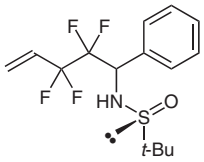
Entry	Product	Yield[a] (%)	
		^{19}F NMR	Isolated
1	 **12a**	95	86
2	 **12b**	quant.	77
3	 **12c**	quant.	78
4	 **12d**	77	63
5	 **12e**	89	80
6	 **12f**	69	63
7	 **12g**	–	37
8	 **12h**	35	30
9	 **12i**	trace	

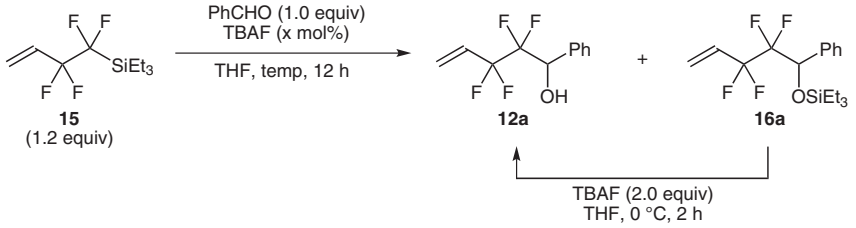
Table 2 The Reductive Coupling of **11** with Various Electrophiles (continued)



Entry	Product	Yield[a] (%)	
		^{19}F NMR	Isolated
10	 **12j**	84	77
11	 **12k**	95	74
12	 **12l**	97	57[b]
13	 **12m**	87	61
14	 **12n**	quant.	78
15	 **12o**	95	84
16	 **12p**	64	56
17	 **12q**	quant.	78
18	 **12r**	40[c]	34
19	 **12s**	70	61[d]

[a] In all cases, the products were isolated after treatment of the crude materials with excess $NaBH_4$ in order to reduce the unreacted electrophile.
[b] The low isolated yield was due to the high volatility of the product.
[c] $BF_3{\cdot}OEt_2$ (2.4 equiv) was used.
[d] Diastereomeric ratio: (*Rs*,*S*)/(*Rs*,*R*) 90:10.

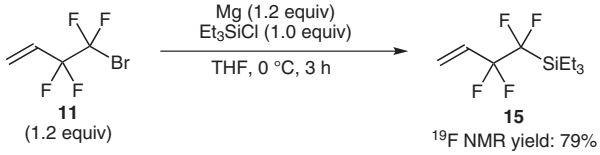
Table 3 Investigation of the Reaction Conditions



Entry	TBAF (mol%)	Temp (°C)	Yield[a] (%) of **12a** and **16a**
1	1.0	r.t.	78
2	1.0	0	91 (89)[b]
3	1.0	–20	70
4	0.5	0	66

[a] Determined by ^{19}F NMR.
[b] Isolated yield of **12a** after treatment of the resultant mixture of **12a** and **16a** with 2.0 equiv of TBAF.

Next our interest was directed toward triethyl(1,1,2,2-tetrafluorobut-3-enyl)silane (**15**) as an another reagent for the introduction of the tetrafluoroethylene unit because of the accumulated studies on the coupling reaction of trimethyl(trifluoromethyl)silane with various carbonyl compounds in the presence of a catalytic amount of fluoride ion.[8] After several attempts, a synthetic method was established; thus, treatment of 1.2 equivalents of **11** with 1.0 equivalents of chlorotriethylsilane in the presence of 1.2 equivalents of magnesium in tetrahydrofuran at 0 °C for three hours gave the desired product **15** in 79% ^{19}F NMR yield (Scheme 2).



Scheme 2 Preparation of triethyl(1,1,2,2-tetrafluorobut-3-enyl)silane

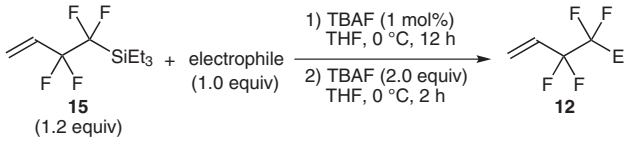
We next examined the fluoride-catalyzed nucleophilic addition of **15** with various carbonyl compounds. Thus, treatment of 1.2 equivalents of **15** and 1.0 equivalents of benzaldehyde with 1 mol% of tetrabutylammonium fluoride at room temperature for 12 hours gave the corresponding alcohol **12a** and the silyl ether **16a** in 78% combined yield (Table 3, entry 1). As shown in entry 2, decreasing the temperature from room temperature to 0 °C led to a significant improvement in the yield, the desired material was obtained in 91% yield. Without isolation, treatment of the reaction mixture with 2.0 equivalents of tetrabutylammonium fluoride in tetrahydrofuran at 0 °C for two hours resulted in smooth desilylation, the alcohol **12a** was obtained in 89% isolated yield over two steps. On the other hand, the reaction at –20 °C or 0.5 mol% loading of tetrabutylammonium fluoride were found to be fruitless (entries 3 and 4).

With the optimal reaction conditions (Table 3, entry 2), we continued the investigation of the coupling reaction using various electrophiles. The results are summarized in Table 4.

As shown in entries 4–6, the aromatic aldehydes with an electron-withdrawing group, such as Cl, CF_3, and CN, on the benzene ring, were found to be good electrophiles in the reaction, the desired alcohols **12f–h**, being obtained in high yields. On the other hand, an electron-donating group, such as OMe and Me, on the benzene ring led to a significant decrease of the yield (entries 2 and 3). Especially, the reaction with anisaldehyde proceeded very sluggishly and any trace of the desired product was not detected at all. An aliphatic aldehyde was somewhat less reactive and the desired product was obtained in moderate yield even when the reaction was carried out at room temperature (entry 8). Furthermore, various ketones are also less reactive (entries 9–12). Even an aryl ketone having a strongly electron-withdrawing group, such as a NO_2 group, on the benzene ring afforded the product in moderate yield (entry 10). Acid chloride, as well as ester, did not give any products at all (entries 13 and 14).

As synthetic applications of the coupling products **12**, the carbon elongation at the other side of tetrafluoroethylene unit was carried out (Scheme 3). Thus, treatment of **12a** and **12l** with excess ozone in dichloromethane at –78 °C for three hours, followed by the addition of dimethyl sulfide into the reaction mixture, gave tetrafluorinated furanose derivatives **17a** and **17l** as a diastereomeric mixture in 67% and 64% yields, respectively. Thus-obtained furanose derivatives were subjected to an excess amount of Grignard reagent in tetrahydrofuran at reflux temperature for 12 hours, the corresponding unsymmetric 1,4-diols **18a** and **18l** were obtained 85 and 96% yields, respectively.[9]

Table 4 The Fluoride-Catalyzed Nucleophilic Addition



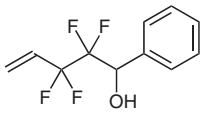
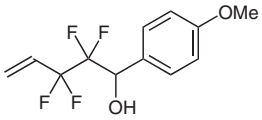
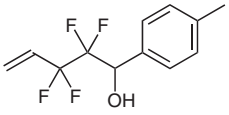
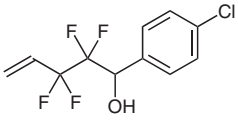
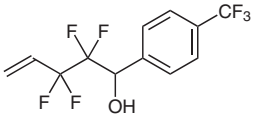
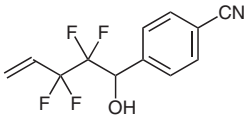
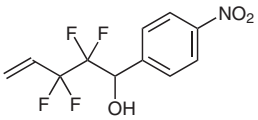
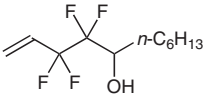
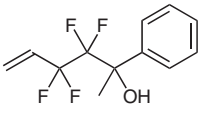
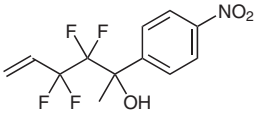
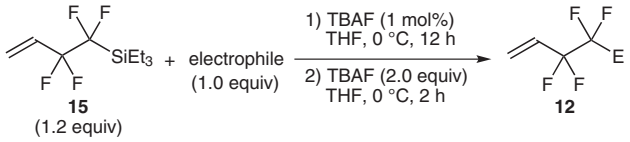
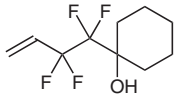
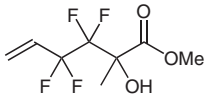
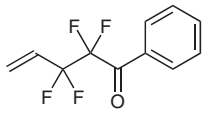
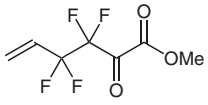
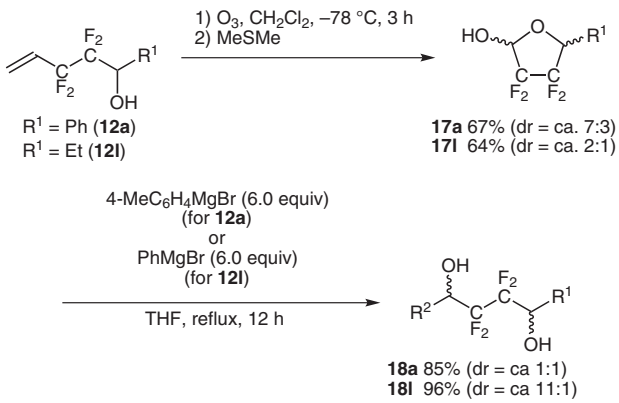
Entry	Product	Yield (%)	
		^{19}F NMR	Isolated
1	 **12a**	89	82
2	 **12b**	–[a]	–[a]
3	 **12e**	65	56
4	 **12f**	96	84
5	 **12g**	74	58
6	 **12h**	88	62
7	 **12i**	22	21
8	 **12m**	52	42[b]
9	 **12p**	0	0
10	 **12t**	41	37

Table 4 The Fluoride-Catalyzed Nucleophilic Addition (continued)



Entry	Product	Yield (%)	
		^{19}F NMR	Isolated
11	 **12q**	5	–
12	 **12u**	0	0
13[c]	 **12v**	0	0
14[c]	 **12w**	0	0

[a] Not determined.
[b] Carried out at r.t.
[c] Carried out in the presence of 1.2 equiv of TBAF.



Scheme 3 Synthetic applications of **12a** and **12l**

In summary, we have demonstrated the reductive coupling of **11** with various electrophiles in the presence of MeLi/LiBr-free. As a result, various carbonyl compounds could participate in the reaction very well to give the corresponding adducts **12** in high to excellent yields. We also synthesized the tetrafluoroethylene unit containing silyl compound **15** as a novel synthetic reagent. Though **15** is much less reactive than the lithium reagent, the reaction with aromatic aldehydes with an electron-withdrawing group, such as CF_3 and CN, took place very smoothly, compared with the reaction with the lithium reagent. Thus-obtained tetrafluorinated alcohols **12** could be converted into unsymmetric 1,4-diols via ozonolysis and followed by a Grignard reaction.

In this way, we have established novel synthetic approaches to various types of molecules having a tetrafluoroethylene unit.

Infrared spectra were taken on a Jasco FT/IR-4100typeA spectrophotometer as film on a NaCl plate. ^{1}H and ^{13}C NMR spectra were measured with a Bruker DRX-500 NMR spectrometer and a Jeol JNM- AL 400 NMR spectrometer in $CDCl_3$ soln with TMS as an internal reference. A Jeol JNM-EX90A (84.21 MHz) FT-NMR spectrometer and a Jeol JNM-AL 400 NMR spectrometer were used for determining the yield of the products with hexafluorobenzene (C_6F_6). ^{19}F NMR (376.05 MHz) spectra were measured with a Jeol JNM-AL 400 NMR spectrometer in $CDCl_3$ soln with $CFCl_3$ as an internal standard. ^{31}P NMR (161.70 MHz) spectra were measured with a Jeol JNM-AL 400 NMR spectrometer in $CDCl_3$ soln with Ph_3P as an external standard. ^{13}C and ^{31}P NMR spectra were proton decoupled. HRMS were taken on a Hitachi M-80B mass spectrometer by EI, CI, and FAB methods.

All chemicals were of reagent grade and, if necessary, were purified in the usual manner prior to use. TLC was performed on aluminum sheets coated with Merck silica gel 60 F_{254} plates, and column chromatography was carried out using Wacogel C-200 as adsorbent.

2,2,3,3-Tetrafluoro-1-phenylpent-4-en-1-ol (12a); Typical Procedure

To a soln of **11** (0.062 g, 0.3 mmol) in THF (0.6 mL) was added benzaldehyde (0.073 mL, 0.072 mmol) at –78 °C. After ca. 10 min,

to this mixture was added dropwise 1.06 M MeLi/LiBr-free (0.75 mL, 0.72 mmol) and the mixture was stirred at this temperature for 2 h. The reaction was quenched with aq NH_4Cl and then it was extracted with Et_2O (3 ×). The combined organic layers were dried (anhyd Na_2SO_4), then filtered, and concentrated in vacuo. The residue was dissolved in EtOH, and to this mixture was added excess $NaBH_4$ at 0 °C. The soln was allowed to reach r.t., and stirred for several hours. The reaction was quenched with aq NH_4Cl and it was extracted with EtOAc (3 ×). The combined organic layers were dried (anhyd Na_2SO_4), then filtered and concentrated in vacuo. The residue was purified by column chromatography (silica gel, hexane–EtOAc, 5:1) to give the corresponding alcohol **12a** (0.062 g, 0.26 mmol, 86%).

IR (neat): 3423, 3068, 3037, 2925, 1958, 1814, 1707, 1650, 1496, 1456, 1420, 1238, 1180, 1105, 1010, 968, 848, 811 cm^{-1}.

^1H NMR ($CDCl_3$): δ = 2.51 (br s, 1 H), 5.16 (dd, *J* = 16.66, 6.39 Hz, 1 H), 5.66 (d, *J* = 11.47 Hz, 1 H), 5.85 (dm, *J* = 17.38 Hz, 1 H), 6.01 (ddt, *J* = 11.47, 17.38, 11.47 Hz, 1 H), 7.39–7.47 (m, 5 H).

^{13}C NMR ($CDCl_3$): δ = 71.74–72.25 (m), 113.01 (q, *J* = 33.6 Hz), 115.04–116.00 (m), 117.61–118.48 (m), 123.43–123.62 (m), 126.89 (t, *J* = 24.00 Hz), 128.04, 128.36, 129.18, 135.18.

^{19}F NMR ($CDCl_3$, $CFCl_3$): δ = –112.98 (dd, *J* = 263.61, 11.47 Hz, 1 F), –113.91 (dd, *J* = 263.61, 11.47 Hz, 1 F), –120.10 (d, *J* = 274.01 Hz, 1 F), –127.63 (dd, *J* = 274.01, 16.66 Hz, 1 F).

HRMS (FAB): *m*/*z* [M^+] calcd for $C_{11}H_{10}F_4O$: 234.0668; found: 234.0667.

2,2,3,3-Tetrafluoro-1-(4-methoxyphenyl)pent-4-en-1-ol (12b)
IR (neat): 3449, 3006, 2938, 2842, 1614, 1587, 1515, 1465, 1444, 1420, 1305, 1253, 1178, 1108, 1031, 986, 969, 842 cm^{-1}.

^1H NMR ($CDCl_3$): δ = 2.63 (s, 1 H), 3.81 (s, 3 H), 5.08 (ddd, *J* = 14.82, 7.19, 2.80 Hz, 1 H), 5.65 (d, *J* = 11.75 Hz, 1 H), 5.83 (dt, *J* = 17.38, 2.20 Hz, 1 H), 6.00 (ddt, *J* = 11.75, 17.38, 11.75 Hz, 1 H), 6.91 (d, *J* = 8.79 Hz, 2 H), 7.37 (d, *J* = 7.99 Hz, 2 H).

^{13}C NMR ($CDCl_3$): δ = 55.23, 71.33–71.84 (m), 112.60–113.50 (m), 114.07 (d, *J* = 5.02 Hz), 115.17–115.98 (m), 118.08 (td, *J* = 33.08, 11.55 Hz), 123.41 (t, *J* = 9.94 Hz), 126.98 (t, *J* = 23.95 Hz), 129.31, 160.18.

^{19}F NMR ($CDCl_3$, $CFCl_3$): δ = –113.01 (dd, *J* = 263.61, 11.75 Hz, 1 F), –113.98 (dd, *J* = 263.61, 11.75 Hz, 1 F), –120.51 (dd, *J* = 273.39, 4.87 Hz, 1 F), –127.60 (dd, *J* = 273.39, 14.82 Hz, 1 F).

HRMS (FAB): *m*/*z* [M^+] calcd for $C_{12}H_{12}F_4O_2$: 264.0773; found: 264.0769.

2,2,3,3-Tetrafluoro-1-(3-methoxyphenyl)pent-4-en-1-ol (12c)
IR (neat): 3444, 3006, 2942, 2840, 1934, 1712, 1659, 1603, 1492, 1467, 1438, 1420, 1261, 1184, 1105, 987, 908 cm^{-1}.

^1H NMR ($CDCl_3$): δ = 2.62 (br s, 1 H), 3.81 (s, 3 H), 5.10 (dd, *J* = 17.06, 6.79 Hz, 1 H), 5.66 (d, *J* = 11.19 Hz, 1 H), 5.85 (dt, *J* = 16.79, 2.2 Hz, 1 H), 6.01 (ddt, *J* = 11.80, 17.39, 11.80 Hz, 1 H), 6.91–6.94 (m, 1 H), 7.02 (d, *J* = 7.59 Hz, 2 H), 7.30 (t, *J* = 7.79 Hz, 1 H).

^{13}C NMR ($CDCl_3$): δ = 55.23, 71.89 (dd, *J* = 28.92, 23.19 Hz), 112.47–113.51 (m), 114.81–115.97 (m), 117.57–118.45 (m), 120.43, 123.50 (t, *J* = 9.49 Hz), 126.92 (t, *J* = 24.00 Hz), 129.34, 136.63, 159.51.

^{19}F NMR ($CDCl_3$, $CFCl_3$): δ = –113.02 (dd, *J* = 263.61, 11.80 Hz, 1 F), –114.00 (dd, *J* = 263.61, 11.80 Hz, 1 F), –119.99 (d, *J* = 273.39 Hz, 1 F), –127.68 (dt, *J* = 273.39, 17.06 Hz, 1 F).

HRMS (FAB): *m*/*z* [M^+] calcd for $C_{12}H_{12}F_4O_2$: 264.0773; found: 264.0777.

2,2,3,3-Tetrafluoro-1-(2-methoxyphenyl)pent-4-en-1-ol (12d)
IR (neat): 3451, 3008, 2944, 2843, 1708, 1650, 1603, 1590, 1495, 1465, 1442, 1420, 1356, 1289, 1248, 1181, 1118, 1026, 987, 857, 829, 809 cm^{-1}.

^1H NMR ($CDCl_3$): δ = 3.65 (br s, 1 H), 3.86 (s, 3 H), 5.42 (dd, *J* = 19.57, 6.39 Hz, 1 H), 5.65 (d, *J* = 11.80 Hz, 1 H), 5.87 (dt, *J* = 17.38, 2.2 Hz, 1 H), 6.07 (ddt, *J* = 11.80, 17.38, 11.80 Hz, 1 H), 6.93–7.03 (m, 2 H), 7.33–7.38 (m, 2 H).

^{13}C NMR ($CDCl_3$): δ = 55.69, 68.90 (dd, *J* = 28.92, 23.09 Hz), 111.20, 112.77–113.62 (m), 115.25–116.20 (m), 117.74–118.74 (m), 123.07–123.26 (m), 127.30 (t, *J* = 24.00 Hz), 129.83 (d, *J* = 1.61 Hz), 130.13, 157.69.

^{19}F NMR ($CDCl_3$, $CFCl_3$): δ = –113.46 (dd, *J* = 260.98, 12.41 Hz, 1 F), –115.12 (ddd, *J* = 258.72, 11.80, 4.89 Hz, 1 F), –120.06 (dt, *J* = 270.76, 6.21 Hz, 1 F), –127.93 (dd, *J* = 270.76, 19.57 Hz, 1 F).

HRMS (FAB): *m*/*z* [M^+] calcd for $C_{12}H_{12}F_4O_2$: 264.0773; found: 264.0773.

2,2,3,3-Tetrafluoro-1-(4-methylphenyl)pent-4-en-1-ol (12e)
IR (neat): 3433, 3032, 2925, 1914, 1650, 1616, 1516, 1420, 1244, 1181, 1110, 1010, 986, 910, 837, 785, 760, 734, 705, 491 cm^{-1}.

^1H NMR ($CDCl_3$): δ = 2.40 (s, 3 H), 2.73 (br s, 1 H), 5.09 (dd, *J* = 17.24, 7.19 Hz, 1 H), 5.66 (d, *J* = 11.12 Hz, 1 H), 5.86 (dd, *J* = 17.28, 2.00 Hz, 1 H), 6.027 (ddt, *J* = 11.12, 17.28, 11.12 Hz, 1 H), 7.22 (d, *J* = 8.39 Hz, 2 H), 7.35 (d, *J* = 7.99 Hz, 2 H).

^{13}C NMR ($CDCl_3$): δ = 21.12, 71.78 (dd, *J* = 28.92, 22.29 Hz), 112.66–113.49 (m), 115.03–115.97 (m), 117.66–118.45 (m), 123.39 (t, *J* = 9.94 Hz), 126.96 (t, *J* = 23.95 Hz), 127.91, 129.05, 130.36, 132.17 (d, *J* = 1.71 Hz), 139.08.

^{19}F NMR ($CDCl_3$, $CFCl_3$): δ = –113.02 (dd, *J* = 263.61, 11.12 Hz, 1 F), –113.95 (dd, *J* = 263.61, 11.12 Hz, 1 F), –120.30 (dt, *J* = 273.39, 6.02 Hz, 1 F), –127.62 (dd, *J* = 273.01, 17.24 Hz, 1 F).

HRMS (FAB): *m*/*z* [M^+] calcd for $C_{12}H_{12}F_4O$: 248.0824; found: 248.0822.

1-(4-Chlorophenyl)-2,2,3,3-tetrafluoropent-4-en-1-ol (12f)
IR (neat): 3433, 2925, 1911, 1650, 1599, 1493, 1420, 1237, 1181, 1111, 1015, 969, 849, 828, 783, 733, 682 cm^{-1}.

^1H NMR ($CDCl_3$): δ = 3.01 (s, 1 H), 4.97 (dd, *J* = 16.66, 7.59 Hz, 1 H), 5.54 (d, *J* = 10.87 Hz, 1 H), 5.72 (dt, *J* = 17.28, 2.6 Hz, 1 H), 5.87 (ddt, *J* = 10.87, 17.28, 10.87 Hz, 1 H), 7.22 (s, 4 H).

^{13}C NMR ($CDCl_3$): δ = 71.32 (dd, *J* = 28.92, 23.19 Hz), 112.33–113.49 (m), 114.85–115.97 (m), 117.94 (q, *J* = 34.1 Hz), 123.75 (t, *J* = 9.89 Hz), 126.64 (t, *J* = 24.00 Hz), 128.53, 129.39, 133.54 (d, *J* = 1.61 Hz), 135.09.

^{19}F NMR ($CDCl_3$, $CFCl_3$): δ = –112.77 (dd, *J* = 263.61, 10.87 Hz, 1 F), –113.61 (dd, *J* = 263.61, 10.87 Hz, 1 F), –120.02 (dd, *J* = 276.02, 7.14 Hz, 1 F), –127.23 (dd, *J* = 273.39, 16.66 Hz, 1 F).

HRMS (FAB): *m*/*z* [M^+] calcd for $C_{11}H_9ClF_4O$: 268.0278; found: 268.0280.

2,2,3,3-Tetrafluoro-1-[4-(trifluoromethyl)phenyl]pent-4-en-1-ol (12g)
IR (neat): 3619, 3434, 2925, 1623, 1420, 1326, 1246, 1171, 1133, 1069, 1019, 979, 858, 789, 477 cm^{-1}.

^1H NMR ($CDCl_3$): δ = 2.60 (br s, 1 H), 5.25 (dd, *J* = 16.86, 6.79 Hz, 1 H), 5.70 (d, *J* = 11.55 Hz, 1 H), 5.87 (dd, *J* = 16.89, 2.4 Hz, 1 H), 6.02 (ddt, *J* = 11.55, 16.89, 11.55 Hz, 1 H), 7.63 (dd, *J* = 25.58, 8.39 Hz, 4 H).

^{13}C NMR ($CDCl_3$): δ = 71.45 (dd, *J* = 28.92, 23.09 Hz), 112.18–113.59 (m), 114.71–116.06 (m), 117.28–118.54 (m), 122.55,

124.03 (td, J = 9.14, 1.61 Hz), 125.26 (q, J = 3.58 Hz), 126.50 (t, J = 24.00 Hz), 128.48, 131.31 (q, J = 32.53 Hz), 138.81.

^{19}F NMR ($CDCl_3$, $CFCl_3$): δ = –63.25 (s, 3 F), –112.70 (dd, J = 263.61, 11.55 Hz, 1 F), –113.49 (dd, J = 263.61, 11.55 Hz, 1 F), –119.41 (dd, J = 273.39, 7.52 Hz, 1 F), –127.35 (ddd, J = 270.76, 16.86, 4.89 Hz, 1 F).

HRMS (FAB): m/z [M$^+$] calcd for $C_{12}H_9F_7O$: 302.0542; found: 302.0552.

1-(4-Cyanophenyl)-2,2,3,3-tetrafluoropent-4-en-1-ol (12h)
IR (neat): 3434, 2927, 2234, 1931, 1727, 1650, 1612, 1506, 1420, 1241, 1177, 1108, 1011, 989, 859, 834, 789, 736, 703, 568 cm^{-1}.

^{1}H NMR ($CDCl_3$): δ = 3.00 (br s, 1 H), 5.24 (dd, J = 14.21, 5.99 Hz, 1 H), 5.70 (d, J = 11.40 Hz, 1 H), 5.86 (dt, J = 17.38, 2.00 Hz, 1 H), 6.02 (ddt, J = 11.40, 17.38, 11.40 Hz, 1 H), 7.59 (d, J = 7.99 Hz, 2 H), 7.67 (d, J = 7.19 Hz, 2 H).

^{13}C NMR ($CDCl_3$): δ = 71.18 (dd, J = 28.92, 23.19 Hz), 112.12–113.487 (m), 114.65–115.97 (m), 117.23–118.14 (m), 118.39, 124.02 (t, J = 9.54 Hz), 126.45 (t, J = 23.95 Hz), 128.84, 131.96, 140.36.

^{19}F NMR ($CDCl_3$, $CFCl_3$): δ = –112.99 (dd, J = 31.96, 11.40 Hz, 2 F), –119.17 (d, J = 270.76 Hz, 1 F), –126.91 (dd, J = 276.02, 14.21 Hz, 1 F).

HRMS (FAB): m/z [M + H]$^+$ calcd for $C_{12}H_{10}F_4NO$: 260.0698; found: 260.0703.

2,2,3,3-Tetrafluoro-1-(4-nitrophenyl)pent-4-en-1-ol (12i)
IR (neat): 3493, 3116, 2928, 2858, 1709, 1650, 1608, 1524, 1421, 1350, 1318, 1242, 1180, 1109, 1014, 988, 862, 833, 795, 728, 698, 485 cm^{-1}.

^{1}H NMR ($CDCl_3$): δ = 3.08 (br s, 1 H), 5.32 (dd, J = 14.45, 6.79 Hz, 1 H), 5.71 (d, J = 11.40 Hz, 1 H), 5.90 (dt, J = 17.38, 14.99 Hz, 1 H), 6.02 (ddt, J = 11.40, 17.38, 11.40 Hz, 1 H), 7.65 (d, J = 8.79 Hz, 2 H), 8.22 (d, J = 8.79 Hz, 2 H).

^{13}C NMR ($CDCl_3$): δ = 71.09 (dd, J = 28.92, 23.09 Hz), 112.05–113.54 (m), 114.58–116.02 (m), 117.16–118.50 (m), 123.33, 124.20 (t, J = 9.49 Hz), 126.31 (t, J = 23.95 Hz), 127.94, 128.55, 129.06, 141.99 (d, J = 1.61 Hz), 148.26.

^{19}F NMR ($CDCl_3$, $CFCl_3$): δ = –112.91 (dd, J = 17.30, 11.40 Hz, 2 F), –119.08 (dd, J = 276.02, 7.14 Hz, 1 F), –126.82 (dd, J = 280.53, 14.45 Hz, 1 F).

HRMS (FAB): m/z [M + H]$^+$ calcd for $C_{11}H_{10}F_4NO_3$: 280.0599; found: 280.0599.

2,2,3,3-Tetrafluoro-1-(furan-2-yl)pent-4-en-1-ol (12j)
IR (neat): 3409, 2926, 1650, 1503, 1421, 1237, 1187, 1150, 1111, 1014, 981, 926, 887, 802, 745, 597, 478 cm^{-1}.

^{1}H NMR ($CDCl_3$): δ = 2.57 (d, J = 7.59 Hz, 1 H), 5.17 (quint, J = 7.99 Hz, 1 H), 5.66 (d, J = 11.22 Hz, 1 H), 5.84 (dd, J = 17.18, 2.00 Hz, 1 H), 5.98 (ddt, J = 11.22, 17.18, 11.22 Hz, 1 H), 6.41 (dd, J = 3.20, 2.00 Hz, 1 H), 6.50 (d, J = 3.20 Hz, 1 H), 7.46 (d, J = 2.00 Hz, 1 H).

^{13}C NMR ($CDCl_3$): δ = 65.55 (dd, J = 28.92, 24.00 Hz), 66.99 (dd, J = 28.11, 23.90 Hz), 109.79 (t, J = 3.31 Hz), 111.075, 111.53 (q, J = 1.67 Hz), 112.20, 112.52, 112.85, 114.73–115.661 (m), 117.65 (td, J = 33.48, 2.51 Hz), 122.07 (t, J = 9.94 Hz), 123.65 (t, J = 9.89 Hz), 125.15–125.96 (m), 127.09–127.66 (m), 142.11–142.25 (m), 143.27 (dd, J = 10.74, 4.92 Hz), 144.24 (dd, J = 9.04, 4.12 Hz), 147.93–148.04 (m).

^{19}F NMR ($CDCl_3$, $CFCl_3$): δ = –113.67 (dd, J = 263.61, 11.22 Hz, 1 F), –115.18 (dd, J = 266.24, 11.22 Hz, 1 F), –122.01 (dt, J = 270.76, 7.34 Hz, 1 F), –126.49 (dd, J = 270.76, 17.18 Hz, 1 F).

HRMS (FAB): m/z [M$^+$] calcd for $C_9H_8F_4O_2$: 224.0460; found: 224.0458.

4,4,5,5-Tetrafluoro-1-phenylhepta-1,6-dien-3-ol (12k)
IR (neat): 3397, 3029, 2924, 1653, 1578, 1496, 1450, 1420, 1237, 1184, 1109, 1010, 967, 863 cm^{-1}.

^{1}H NMR ($CDCl_3$): δ = 2.47 (d, J = 5.20 Hz, 1 H), 4.77 (td, J = 14.53, 6.79 Hz, 1 H), 5.70 (d, J = 11.70 Hz, 1 H), 5.89 (dt, J = 17.29, 2.00 Hz, 1 H), 6.07 (ddt, J = 11.70, 17.29, 11.70 Hz, 1 H), 6.29 (dd, J = 15.79, 6.79 Hz, 1 H), 6.81 (d, J = 15.79 Hz, 1 H), 7.29–7.32 (m, 1 H), 7.36 (t, J = 7.39 Hz, 2 H), 7.43 (d, J = 7.19 Hz, 2 H).

^{13}C NMR ($CDCl_3$): δ = 71.18 (dd, J = 27.31, 24.8 Hz), 112.68–113.44 (m), 115.17–115.99 (m), 117.65–118.53 (m), 121.86 (d, J = 3.21 Hz), 123.67 (t, J = 9.54 Hz), 126.97 (t, J = 23.95 Hz), 126.82, 128.45, 128.65, 135.58 (d, J = 32.23 Hz).

^{19}F NMR ($CDCl_3$, $CFCl_3$): δ = –113.22 (dd, J = 258.72, 11.70 Hz, 1 F), –113.96 (dd, J = 263.61, 7.14 Hz, 1 F), –122.46 (dd, J = 273.39, 7.14 Hz, 1 F), –126.48 (dd, J = 273.01, 14.53 Hz, 1 F).

HRMS (FAB): m/z [M$^+$] calcd for $C_{13}H_{12}F_4O$: 260.0824; found: 260.0825.

3,3,4,4-Tetrafluorohept-6-en-3-ol (12l)
This compound is so volatile that it could not be isolated in a pure form. The isolated mixture contained **12l** and a small amount of EtOAc.

^{1}H NMR ($CDCl_3$): δ = 1.02 (t, J = 7.39 Hz, 3 H), 1.50–1.70 (m, 1 H), 1.71–1.89 (m, 1 H), 2.86 (d, J = 7.19 Hz, 1 H), 3.92 (dt, 16.85, 7.59 Hz, 1 H), 5.63 (d, J = 11.70 Hz, 1 H), 5.82 (dt, J = 17.38, 2.20 Hz, 1 H), 6.01 (ddt, J = 17.38, 11.70, 11.70 Hz, 1 H).

^{13}C NMR ($CDCl_3$): δ = 9.93, 71.54 (dd, J = 28.11, 23.19 Hz), 113.16–119.50 (m, 2 C), 123.51 (t, J = 9.89 Hz), 127.54 (t, J = 23.95 Hz).

^{19}F NMR ($CDCl_3$): δ = –128.12 (dd, J = 273.39, 16.85 Hz, 1 F), –122.94 (dd, J = 273.39, 7.14 Hz, 1 F), –114.07 (ddd, J = 268.50, 263.61, 11.70 Hz, 2 F).

HRMS (CI): m/z [M + H]$^+$ calcd for $C_7H_{11}F_4O$: 187.0746; found: 187.0750.

3,3,4,4-Tetrafluoroundec-1-en-5-ol (12m)
IR (neat): 3389, 2961, 2931, 2860, 1467, 1420, 1261, 1188, 1097, 1015, 981, 958, 869, 803, 730, 460 cm^{-1}.

^{1}H NMR ($CDCl_3$): δ = 0.87–0.91 (m, 3 H), 1.30–1.35 (m, 11 H), 4.04 (dd, J = 15.99, 7.19 Hz, 1 H), 5.68 (d, J = 10.79 Hz, 1 H), 5.87 (dt, J = 17.58, 2.00 Hz, 1 H), 6.04 (ddt, J = 11.22, 17.38, 11.22 Hz, 1 H).

^{13}C NMR ($CDCl_3$): δ = 13.96 (d, J = 2.41 Hz), 22.55 (d, J = 1.61 Hz), 28.95 (d, J = 1.61 Hz), 29.34, 31.65 (d, J = 1.71 Hz), 70.00 (dd, J = 27.31, 23.90 Hz), 112.86–114.04 (m), 115.34–116.58 (m), 117.82–119.12 (m), 123.26 (t, J = 9.89 Hz), 127.20 (t, J = 24.4 Hz).

^{19}F NMR ($CDCl_3$, $CFCl_3$): δ = –113.92 (t, J = 10.91 Hz, 2 F), –122.84 (dd, J = 273.39, 7.14 Hz, 1 F), –128.41 (dd, J = 276.02, 14.67 Hz, 1 F).

HRMS (FAB): m/z [M + H]$^+$ calcd for $C_{11}H_{19}F_4O$: 243.1374; found: 243.1377.

1-Cyclohexyl-2,2,3,3-tetrafluoropent-4-en-1-ol (12n)
IR (neat): 3607, 3443, 2930, 2856, 2673, 1651, 1453, 1420, 1304, 1256, 1193, 1105, 986, 958, 933, 918, 896, 873, 847, 794, 731, 676, 458 cm^{-1}.

^{1}H NMR ($CDCl_3$): δ = 1.14–1.44 (m, 5 H), 1.66 (s, 2 H), 1.82 (dd, J = 24.38, 13.19 Hz, 5 H), 3.89 (d, J = 20.37 Hz, 1 H), 5.67 (d,

J = 11.60 Hz, 1 H), 5.88 (dt, J = 17.38, 2.4 Hz, 1 H), 6.04 (ddt, J = 11.60, 17.38, 11.60 Hz, 1 H).

^{13}C NMR ($CDCl_3$): δ = 25.92 (d, J = 14.86 Hz), 26.33, 30.14 (d, J = 1.71 Hz), 38.04, 72.93 (dd, J = 27.31, 21.49 Hz), 113.12 (dd, J = 36.55, 33.03 Hz), 114.32 (t, J = 33.03 Hz), 115.61 (dd, J = 35.54, 33.03 Hz), 116.87 (t, J = 33.03 Hz), 118.09 (dd, J = 35.54, 33.03 Hz), 119.44 (d, J = 66.16 Hz), 123.26 (t, J = 9.49 Hz), 127.16 (t, J = 24.4 Hz).

^{19}F NMR ($CDCl_3$, $CFCl_3$): δ = –114.77 (dd, J = 22.19, 11.60 Hz, 2 F), –120.65 (d, J = 275.64 Hz, 1 F), –125.59 (dd, J = 273.01, 20.37 Hz, 1 F).

HRMS (FAB): m/z $[M + H]^+$ calcd for $C_{11}H_{17}F_4O$: 241.1217; found: 241.1204.

4,4,5,5-Tetrafluoro-2,2-dimethylhept-6-en-3-ol (12o)
IR (neat): 3609, 3490, 2964, 2880, 1714, 1651, 1483, 1469, 1420, 1371, 1266, 1238, 1188, 1112, 985, 959, 909, 885, 796, 758, 733, 721, 449 cm^{-1}.

^{1}H NMR ($CDCl_3$): δ = 1.08 (s, 9 H), 1.92 (d, J = 8.39 Hz, 1 H), 3.76 (dd, J = 24.42, 7.59 Hz, 1 H), 5.66 (d, J = 10.82 Hz, 1 H), 5.86 (dt, J = 17.58, 2.00 Hz, 1 H), 6.05 (ddt, J = 10.82, 17.58, 10.82 Hz, 1 H).

^{13}C NMR ($CDCl_3$): δ = 26.48, 26.53 (t, J = 1.66 Hz), 35.33, 53.37, 74.98 (dd, J = 28.11, 21.49 Hz), 113.17 (t, J = 33.89 Hz), 115.13–115.99 (m), 117.70–118.48 (m), 120.62 (t, J = 31.83 Hz), 123.07 (t, J = 9.54 Hz), 127.40 (t, J = 24.35 Hz).

^{19}F NMR ($CDCl_3$, $CFCl_3$): δ = –114.16 (dd, J = 261.35, 10.82 Hz, 1 F), –115.22 (dd, J = 261.35, 10.82 Hz, 1 F), –115.78 (d, J = 273.39, Hz, 1 F), –128.90 (dd, J = 273.39, 24.42 Hz, 1 F).

HRMS (FAB): m/z $[M + H]^+$ calcd for $C_9H_{15}F_4O$: 215.1061; found: 215.1059.

3,3,4,5-Tetrafluoro-2-phenylhex-5-en-2-ol (12p)
IR (neat): 3611, 3484, 3095, 3063, 3031, 3004, 2946, 1958, 1905, 1815, 1713, 1650, 1605, 1497, 1449, 1419, 1382, 1350, 1236, 1182, 1114, 1029, 1012, 980, 915, 810, 762, 728, 700, 671, 649, 623 cm^{-1}.

^{1}H NMR ($CDCl_3$): δ = 1.82 (s, 3 H), 2.58 (s, 1 H), 5.51 (d, J = 12.00 Hz, 1 H), 5.70 (dt, J = 17.19, 2.4 Hz, 1 H), 5.89 (ddt, J = 12.00, 17.19, 12.00 Hz, 1 H), 7.36–7.42 (m, 3 H), 7.59 (d, J = 7.59 Hz, 2 H).

^{13}C NMR ($CDCl_3$): δ = 25.01, 75.74 (d, J = 49.6 Hz), 113.24–114.25 (m), 115.74–116.85 (m), 118.24–119.43 (m), 126.25, 127.48, 127.71, 127.99 (d, J = 13.25 Hz).

^{19}F NMR ($CDCl_3$, $CFCl_3$): δ = –107.93 (dd, J = 263.61, 12.00 Hz, 1 F), –109.87 (dd, J = 263.61, 12.00 Hz, 1 F), –118.29 (d, J = 276.02 Hz, 1 F), –119.56 (d, J = 275.64 Hz, 1 F).

HRMS (FAB): m/z $[M + Na]^+$ calcd for $C_{12}H_{12}F_4NaO$: 271.0722; found: 271.0721.

1-(1,1,2,2-Tetrafluorobut-3-enyl)cyclohexanol (12q)
IR (neat): 3677, 3606, 3465, 3108, 3056, 2941, 2865, 2673, 1914, 1703, 1651, 1452, 1419, 1383, 1358, 1322, 1291, 1255, 1182, 1109, 975, 912, 879, 870, 847, 824, 778, 737, 693, 636, 502 cm^{-1}.

^{1}H NMR ($CDCl_3$): δ = 1.16–1.26 (m, 1 H), 1.58–1.85 (m, 10 H), 5.62 (d, J = 11.70 Hz, 1 H), 5.81 (dt, J = 17.38, 2.2 Hz, 1 H), 6.07 (ddt, J = 11.70, 17.38, 11.70 Hz, 1 H).

^{13}C NMR ($CDCl_3$): δ = 20.47, 25.15, 30.25–30.35 (m), 41.94, 74.42 (td, J = 23.54, 1.71 Hz), 113.64–114.73 (m), 116.13–117.30 (m), 118.62–119.86 (m), 122.17 (t, J = 9.94 Hz), 128.17 (t, J = 23.95 Hz).

^{19}F NMR ($CDCl_3$, $CFCl_3$): δ = –110.88 (d, J = 11.70 Hz, 2 F), –125.029 (s, 2 F).

HRMS (FAB): m/z $[M^+]$ calcd for $C_{10}H_{14}F_4O$: 226.0981; found: 226.0975.

***N*-Benzyl-2,2,3,3-tetrafluoro-1-phenylpent-4-enylamine (12r)**
IR (neat): 3364, 3086, 3064, 3027, 2929, 2843, 1957, 1646, 1602, 1584, 1494, 1471, 1454, 1416, 1358, 1329, 1267, 1226, 1207, 1157, 1090, 972, 960, 912, 867, 827, 797, 750, 694, 633, 580 cm^{-1}.

^{1}H NMR ($CDCl_3$): δ = 1.94 (s, 1 H), 3.37 (d, J = 13.19 Hz, 1 H), 3.60 (d, J = 13.19 Hz, 1 H), 4.06 (dd, J = 17.45, 9.59 Hz, 1 H), 5.39 (d, J = 11.12 Hz, 1 H), 5.62 (d, J = 17.38 Hz, 1 H), 5.85 (ddt, J = 11.12, 17.38, 11.12 Hz, 1 H), 7.11–7.24 (m, 10 H).

^{13}C NMR ($CDCl_3$): δ = 50.75, 61.79 (dd, J = 25.70, 20.58 Hz), 113.19 (t, J = 33.48 Hz), 114.33 (t, J = 32.63 Hz), 115.67 (t, J = 33.94 Hz), 116.88 (td, J = 32.68, 3.31 Hz), 118.16 (t, J = 33.89 Hz), 119.42 (t, J = 33.03 Hz), 127.19, 127.49 (t, J = 24.00 Hz), 128.22–128.55 (m), 129.09, 134.35, 134.96, 139.14, 161.90.

^{19}F NMR ($CDCl_3$, $CFCl_3$): δ = –112.38 (dd, J = 260.98, 11.12 Hz, 1 F), –113.41 (dd, J = 260.98, 11.12 Hz, 1 F), –116.47 (dt, J = 270.76, 4.89 Hz, 1 F), –123.80 (dd, J = 270.76, 17.45 Hz, 1 F).

HRMS (FAB): m/z $[M + H]^+$ calcd for $C_{18}H_{18}F_4N$: 324.1377; found: 324.1368.

(*R*)-*N*-(2,2,3,4-Tetrafluoro-1-phenylpent-4-enyl)-2-methylpropane-2-sulfinamide (12s)
Obtained as a mixture of diastereomers, ratio 90:10. A part of the major isomer could be isolated in a pure form, however, the minor isomer could not be obtained in a pure form. For the minor isomer, only identified peaks in the NMR spectra are shown.

Major Isomer (*Rs*,*S*)
White solid; mp 83 °C.

IR (KBr): 3423, 3321, 2963, 1458, 1419, 1367, 1222, 1185, 1098, 1073, 1007, 982, 960, 875, 847, 828, 802, 745, 730, 719, 701, 642, 543, 485, 433 cm^{-1}.

^{1}H NMR ($CDCl_3$): δ = 1.22 (s, 9 H), 3.69 (d, J = 7.19 Hz, 1 H), 4.88 (td, J = 13.47, 7.59 Hz, 1 H), 5.58 (d, J = 11.25 Hz, 1 H), 5.73 (d, J = 17.38 Hz, 1 H), 5.84 (ddt, J = 11.25, 17.38, 11.25 Hz, 1 H), 7.36 (d, J = 2.40 Hz, 5 H).

^{13}C NMR ($CDCl_3$): δ = 22.70, 56.85, 60.26 (dd, J = 24.00, 21.49 Hz), 112.79 (t, J = 34.69 Hz), 113.54 (t, J = 33.89 Hz), 115.28 (t, J = 34.34 Hz), 116.10 (t, J = 33.88 Hz), 117.76 (t, J = 34.29 Hz), 118.65 (t, J = 33.88 Hz), 123.81 (t, J = 9.54 Hz), 126.39 (t, J = 24.4 Hz), 128.30, 128.80, 129.11, 134.91 (d, J = 4.22 Hz).

^{19}F NMR ($CDCl_3$, $CFCl_3$): δ = –112.41 (t, J = 11.25 Hz, 2 F), –117.65 (dd, J = 273.39, 13.47 Hz, 1 F), –120.42 (dd, J = 273.01, 13.47 Hz, 1 F).

Minor Isomer (*Rs*,*R*)
^{19}F NMR ($CDCl_3$, $CFCl_3$): δ = –112.14 (d, J = 7.98 Hz, 2 F), –119.51 (dd, J = 270.76, 13.54 Hz, 1 F), –120.53 (dd, J = 270.76, 13.54 Hz, 1 F).

HRMS (FAB): m/z $[M + H]^+$ calcd for $C_{15}H_{20}F_4NOS$: 338.1203; found: 338.1207.

Triethyl(1,1,2,2-tetrafluorobut-3-en-1-yl)silane (15)
To a soln of Mg (0.087 g, 3.6 mmol) in THF (7.2 mL) was added a Et_3SiCl (0.543 g, 3.6 mmol) at 0 °C. After ca. 5 min, to this mixture was added dropwise **11** (0.620 g, 3.0 mmol) and it was stirred at this temperature for 3 h. To the mixture was added excess hexane (30 mL) and then it was filtered; it was then concentrated in vacuo (79% by ^{19}F NMR). The residue was purified by column chromatography (silica gel, hexane only) to give **15**.

IR (neat): 3108, 2960, 2884, 2742, 1912, 1653, 1461, 1419, 1383, 1243, 1091, 1029, 981, 955, 919, 889, 802, 741, 604, 579, 491, 408 cm^{-1}.

^1H NMR ($CDCl_3$): δ = 0.84 (t, *J* = 7.59 Hz, 6 H), 1.04 (t, *J* = 7.59 Hz, 9 H), 5.65 (q, *J* = 11.63 Hz, 1 H), 5.81 (d, *J* = 17.29 Hz, 1 H), 5.99 (ddt, *J* = 11.63, 17.29, 11.63 Hz, 1 H).

^{13}C NMR ($CDCl_3$): δ = 1.41, 6.64 (d, *J* = 11.65 Hz), 115.09 (t, *J* = 31.43 Hz), 117.51 (t, *J* = 31.43 Hz), 119.92 (t, *J* = 31.43 Hz), 121.17 (t, *J* = 51.25 Hz), 123.03–123.22 (m), 123.86 (t, *J* = 51.25 Hz), 126.04, 126.87 (t, *J* = 25.65 Hz).

^{19}F NMR ($CDCl_3$, $CFCl_3$): δ = –110.99 (d, *J* = 11.63 Hz, 2 F), –122.05 (s, 2 F).

HRMS (EI^+): *m/z* [M^+] calcd for $C_{10}H_{18}F_4Si$: 242.1114; found: 242.1110.

3,3,4,5-Tetrafluoro-2-(4-nitrophenyl)hex-5-en-2-ol (12t); Typical Procedure

To a soln of **15** (0.087 g, 0.36 mmol) in THF (0.3 mL) was added 4-nitroacetophenone (0.050 g, 0.030 mmol) at 0 °C. After ca. 10 min, to this mixture was added dropwise 0.1 M TBAF (0.03 mL, 1 mol%) and it was stirred at this temperature for 12 h. The reaction was quenched with H_2O and then it was extracted with Et_2O (3 ×). The combined organic layers were dried (anhyd Na_2SO_4), then filtered, and concentrated in vacuo. To the residue was added 1.0 M TBAF (0.60 mL, 0.6 mmol) at 0 °C. The mixture was stirred for 2 h and quenched with H_2O and then it was extracted with Et_2O (3 ×). The combined organic layers were dried (anhyd Na_2SO_4), filtered, and concentrated in vacuo. The residue was purified by column chromatography (silica gel, hexane–EtOAc, 5:1) to give the corresponding alcohol **12t** (0.033 g, 0.11 mmol, 37%).

IR (neat): 3517, 3117, 3002, 2923, 2853, 1649, 1606, 1523, 1459, 1419, 1351, 1296, 1263, 1236, 1186, 1117, 1076, 1014, 980, 920, 856, 807, 754, 737, 704, 477 cm^{-1}.

^1H NMR ($CDCl_3$): δ = 1.82 (s, 3 H), 2.77 (s, 1 H), 5.57 (d, *J* = 11.90 Hz, 1 H), 5.70 (dt, *J* = 17.18, 2.4 Hz, 1 H), 5.93 (ddt, *J* = 11.90, 17.18, 11.90 Hz, 1 H), 7.76 (d, *J* = 8.79 Hz, 2 H), 8.20 (dt, *J* = 9.59, 2.2 Hz, 2 H).

^{13}C NMR ($CDCl_3$): δ = 25.18–25.27 (m), 29.65, 75.72 (t, *J* = 25.65 Hz), 113.14–113.87 (m), 115.68–116.39, 118.18–118.98, 122.82, 122.93 (d, *J* = 1.61 Hz), 123.01, 127.25 (t, *J* = 21.89 Hz), 146.89 (d, *J* = 2.51 Hz), 147.58.

^{19}F NMR ($CDCl_3$, $CFCl_3$): δ = –109.32 (dd, *J* = 263.61, 11.90 Hz, 1 F), –110.88 (ddd, *J* = 258.72, 11.90, 4.89 Hz, 1 F), –119.07 (dd, *J* = 278.28, 4.89 Hz, 1 F), –120.48 (d, *J* = 278.28 Hz, 1 F).

HRMS (FAB): *m/z* [M + H]$^+$ calcd for $C_{12}H_{12}F_4NO_3$: 294.0753; found: 294.0757.

3,3,4,4-Tetrafluoro-5-phenyltetrahydrofuran-2-ol (17a); Typical Procedure

The alcohol **12a** (4.5 mmol) was dissolved in CH_2Cl_2 (15 mL) and cooled to –78 °C. Then the argon in the flask was replaced with O_3, and the mixture was stirred at this temperature for 3 h. The reaction was quenched with Me_2S, and extracted with EtOAc (3 ×). The mixture was filtered, and the thus obtained filtrate was concentrated in vacuo. The residue was purified by column chromatography (silica gel, hexane–EtOAc, 2: 1) to give the corresponding tetrahydrofuran as an isomeric mixture in a ratio of ca. 7:3.

^1H NMR ($CDCl_3$): δ = 3.31–3.36 (m, 1 H), 5.30–5.46 (m, 1 H), 5.60–5.64 (m, 1 H), 7.39–7.49 (m, 5 H).

^{19}F NMR ($CDCl_3$): δ = –137.26 to –120.05 (m, 4 F).

HRMS: *m/z* [M^+] calcd for $C_{10}H_8F_4O_2$: 236.0460; found: 236.0459.

5-Ethyl-3,3,4,4-tetrafluorotetrahydrofuran-1-ol (17l)

Isolated as an isomeric mixture in a ratio of ca. 2:1.

^1H NMR ($CDCl_3$): δ = 1.04 (t, *J* = 7.59 Hz, 3 H), 1.65–1.83 (m, 2 H), 3.87–4.27 (m, 2 H), 5.36 (d, *J* = 6.39 Hz, 1 H).

^{19}F NMR ($CDCl_3$, $CFCl_3$): δ = –135.17 (dd, 241.80, 16.92 Hz, 1 F), –130.07 (dd, *J* = 241.80, 4.89 Hz, 1 F), –128.13 (dd, *J* = 246.31, 7.52 Hz, 1 F), –119.28 (d, *J* = 239.17 Hz, 1 F).

HRMS (EI): *m/z* [M + H]$^+$ calcd for $C_6H_9F_4O_2$ 189.0539; found: 189.0539.

2,2,3,3-Tetrafluoro-1-(4-methylphenyl)-4-phenylbutane-1,4-diol (18a); Typical Procedure

To a soln of **17a** (0.1 mmol) in THF (0.5 mL) was dropwise added 0.55 M 4-MeC_6H_4MgBr in THF [0.73 mL, 4.0 equiv which was prepared from 4-bromotoluene (2.0 mmol) and Mg (2.0 mmol) at r.t. for 1 h] at r.t. Then the mixture was stirred at reflux overnight. The reaction was quenched with sat. NH_4Cl and after separation of the two layers, the aqueous soln was washed with Et_2O (2 ×) and the combined organic layers were washed with brine, dried (Na_2SO_4), and concentrated in vacuo. The resulting mixture was purified by column chromatography (silica gel, hexane–EtOAc, 2:1) to obtain the corresponding diol.

^1H NMR ($CDCl_3$): δ = 1.64 (s, 1 H), 2.32 (d, *J* = 39.17 Hz, 3 H), 3.11 (d, *J* = 44.76 Hz, 1 H), 5.23 (t, *J* = 17.98 Hz, 1 H), 6.72 (d, *J* = 8.39 Hz, 1 H), 7.04 (d, *J* = 7.99 Hz, 1 H), 7.15–7.26 (m, 1 H), 7.36–7.41 (m, 3 H).

^{19}F NMR ($CDCl_3$): δ = –127.64 (ddd, *J* = 19.55, 80.85, 276.02 Hz, 2 F), –116.93 (dd, *J* = 56.03, 275.64 Hz, 2 F).

HRMS: *m/z* [M + Na]$^+$ calcd for $C_{17}H_{16}F_4NaO_2$: 351.0984; found: 351.0977.

2,2,3,3-Tetrafluoro-1-phenylhexane-1,4-diol (18l)

Isolated with dr 11:1.

IR (neat): 3347, 3037, 2979, 2942, 2884, 1496, 1457, 1313, 1237, 1202, 1175, 1114, 1029, 989, 911, 884, 822, 789, 732, 699, 612, 489 cm^{-1}.

^1H NMR ($CDCl_3$): δ = 1.04 (t, *J* = 7.59 Hz, 3 H), 1.60–1.88 (m, 2 H), 3.85 (d, *J* = 6.30 Hz, 1 H), 3.89–3.99 (m, 1 H), 4.43 (d, *J* = 4.00 Hz, 1 H), 5.04 (d, *J* = 21.29 Hz, 1 H), 7.26–7.45 (m, 5 H).

^{13}C NMR ($CDCl_3$): δ = 10.27, 22.60–22.70 (m), 71.93 (dd, *J* = 52.11, 28.11 Hz), 72.88 (t, *J* = 72.89 Hz), 113.35–120.10 (m, 2 C), 128.48, 128.65, 129.51, 135.06.

^{19}F NMR ($CDCl_3$, $CFCl_3$): δ = –127.97 (ddt, *J* = 278.28, 21.29, 7.33 Hz, 1 F), –127.52 (ddt, *J* = 275.64, 14.67, 7.33 Hz, 1 F), –119.12 (ddt, *J* = 275.64, 12.41, 6.30 Hz, 1 F), –117.31 (d, *J* = 276.02 Hz, 1 F).

HRMS (EI): *m/z* [M^+] calcd for $C_{12}H_{14}F_4O_2$: 266.0930; found: 266.0933.

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