One-pot stereoselective synthesis of perfluoroalkylated (*E*)-allylic alcohols mediated by $Ti(OPr^i)_4$ and Ph_3P [1]

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Synthesis of perfluoroalkylated (*E*)-allylic alcohols by the 'one-pot' reaction of equimolar amounts of aldehyde, 3-bromo-1,1,1-trifluoroacetone (or α-bromoalkyl perfluoroalkyl ketone), triphenylphosphine and titanium(IV) isopropoxide is described. The reductive olefination products were obtained in good yields exclusively in *E*-form. Thus this methodology provides a very convenient synthesis of perfluoroalkylated (*E*)-allylic alcohols and the widespread use of these allylic alcohols is quite important in organic synthesis. They are interesting fluorinated building blocks, not easily available by existing synthetic methods. A possible mechanism for the explanation of formation of reductive olefinic products and the stereochemical results is proposed.

Introduction

Titanium-containing compounds have emerged as synthetically useful reagents in organic synthesis in recent years.[2] Among them, titanium(IV) isopropoxide occupies an important position, particularly in asymmetric synthesis. The well known Sharpless asymmetric epoxidation is carried out by using titanium(IV) isopropoxide as a catalyst.[3] It was combined with BINOL as a catalyst in the Mukaiyama aldol condensation [4a] and used as a Lewis acid for catalyzed cyclopropanation of allylic alcohols.[4b] A number of catalytic and stoichiometric titanium-mediated hydrosilylations of carbonyl compounds have been reported applying to the reduction of esters,[5] lactones [6] and to the conversion of amides to aldehydes.[7]

Allylic alcohols are employed as useful building blocks in many synthetic applications, particularly in the synthesis of biologically active compounds [8] and may undergo a lot of useful organic transformations.[9] A number of methods for the preparation of allylic alcohols are known,[10] but multiple steps are necessary or else the starting materials are not commercially available. Recently a new stereoselective method for the preparation of allylic alcohols by using nickel-catalyzed alkylative cyclization of ynals or coupling of aldehydes, alkynes and organozincs has been reported.[11] However, the synthesis of perfluoroalkylated allylic alcohols [12a–e] and difluoro species [12e–h] is still limited. The Grignard reaction between vinyl bromides and trifluoroacetaldehyde gave α-trifluoromethylated allylic alcohols, but ultrasonic irradiation was found to be necessary.[12a] The reduction of α-hydroxy alkynes, which were prepared by the reaction of trifluoroacetaldehyde with alkynyllithium compounds, gave α-trifluoromethylated allylic alchhols.[12b] Another route to α-trifluoromethylated allylic alcohols was by using a Wittig-type reaction.[12c,d] Thus the literature methods for the preparation of the title compounds mainly lack convenience and the starting materials had to be prepared in advance.

One-pot synthesis has attracted much interest in recent years because it provides a simple and efficient entry to compounds by including two or more transformations in a single operation to increase the complexity of a product starting from commercially available, relatively simple precursors.[13] In our laboratory, 'one-pot' carbon–carbon double-bond formation has been attained between α-bromo carboxylic derivatives (esters, amides and nitriles) and aldehydes in the presence of n-Bu_3-P(As) and catalyst (Pd,[14,15] Zn,[16–19] Cd [20]). α,β-Unsaturated esters,[14,16,17,20] amides [15,18] and nitriles [19] were formed. The geometry of the newly formed double bond in the product was exclusively or predominantly *E* in esters and amides. This reaction greatly simplifies the traditional Wittig reaction into a stereospecific alkenylation methodology and compresses the three steps of a Wittig reaction into a one-step, one-pot synthesis.[14,21] Therefore efforts to develop an effective 'one-pot' method for the preparation of allylic alcohols, especially fluoro species, have attracted much attention. Herein we report a novel reductive olefination mediated by $Ti(OPr^i)_4$ and Ph_3P and its application to the 'one-pot' stereoselective synthesis of perfluoroalkylated (*E*)-allylic alcohols.

Table 1 Preparation of perfluoroalkylated allylic alcohols [a] mediated by $Ti(OPr^i)_4$ and Ph_3P

Compound	R	Yield (%) [b]
3a	C_6H_5	90
3b	4-$CH_3C_6H_4$	99
3c	4-FC_6H_4	87
3d	4-ClC_6H_4	77
3e	4-$CH_3OC_6H_4$	54
3f	4-$NO_2C_6H_4$	55
3g	3-BrC_6H_4	71
3h	3-ClC_6H_4	78
3i	2-BrC_6H_4	95
3j	*E*-$C_6H_5CH{=}CH$	81
3k	2,4-$Cl_2C_6H_3$	64
3l	Piperonyl	51

[a] All reactions were carried out neat at 80 °C for 24 h, using 1.0 equiv. each of $Ti(OPr^i)_4$, Ph_3P, 3-bromo-1,1,1-trifluoroacetone **2** and aldehyde **1**. [b] Isolated yields. All new compounds were characterized by microanalyses, IR, NMR and mass spectroscopy.

Results and discussion

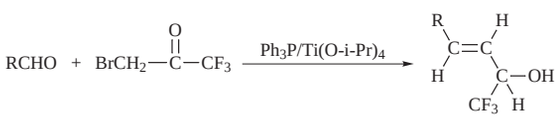
The reaction is carried out neat. On heating equivalent amounts of aldehyde **1**, 3-bromo-1,1,1-trifluoroacetone **2**, triphenylphosphine and titanium(IV) isopropoxide at 80 °C for 24 h, after work-up, reductive olefinic products **3** were obtained in good yields exclusively as the *E*-form (Scheme 1). The results are summarized in Table 1.

As an extension of this method a number of substrates **4**

Table 2 Substituted allylic alcohols prepared[a]

Compound	R	R^1	R_f	Reaction		Yield (%)[b]
				Temp. (*T*/°C)	Time (*t*/h)	
5a	C_6H_5	CH_3	CF_3	100	22	72
5b	3-ClC_6H_4	CH_3	CF_3	100	22	60
5c	3-ClC_6H_4	n-Pr	CF_3	100	22	90
5d	4-$CH_3OC_6H_4$	n-Pr	CF_3	100	22	42
5e	2-BrC_6H_4	CH_3	C_2F_5	90	24	67
5f	4-$CH_3OC_6H_4$	CH_3	C_2F_5	90	24	91
5g	*E*-$C_6H_4CH{=}CH$	CH_3	C_2F_5	90	24	99
5h	2,4-$Cl_2C_6H_3$	CH_3	C_2F_5	90	24	79
5i	C_6H_5	CH_3	n-C_3F_7	110	22	87
5j	4-FC_6H_4	CH_3	n-C_3F_7	110	22	80
5k	2-BrC_6H_4	CH_3	n-C_3F_7	110	22	65
5l	4-$CH_3OC_6H_4$	CH_3	n-C_3F_7	110	22	78

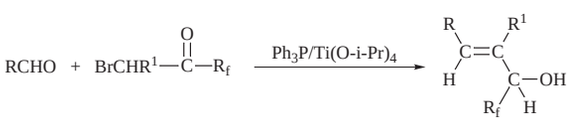
[a] All reactions were carried out neat using 1.0 equiv. each of $Ti(OPr^i)_4$, Ph_3P, bromoalkyl perfluoroalkylketone **4** and aldehyde **1**. [b] Isolated yields. All new compounds were characterized by microanalyses, IR, NMR and mass spectroscopy. The configurations of the products were determined by NOESY spectra showing that the CH(OH)(R_f) group is *cis* (*Z*) with respect to C*H*=C. Therefore the double bond in compounds **5** is in the *E*-configuration.



1 **2** **3**

Scheme 1

were investigated. All reactions proceed well giving substituted allylic alcohols **5** solely as the *E*-isomers (Scheme 2).

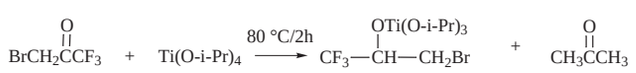


1 **4** **5**

Scheme 2

The results are summarized in Table 2. Unfortunately, attempts to extend this reaction to aliphatic aldehydes failed. A resinous product was obtained, and purified product was hard to isolate.

In order to elucidate the reaction mechanism we did the following experiments: 1. 3-Bromo-1,1,1-trifluoroacetone **2** was shown to react with titanium(IV) isopropoxide by independent experiment. When **2** reacted with titanium(IV) isopropoxide at 80 °C for 2 h, tetraalkoxide **6** was isolated and characterized,[22] and it further reacted with 4-chlorobenzaldehyde in the presence of Ph_3P to give the desired product **3d**. Acetone was also isolated and characterized (see Scheme 3).

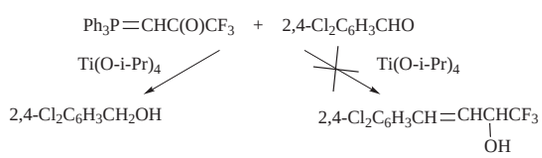


2 **6**

Scheme 3

2. In the absence of titanium(IV) isopropoxide, no olefination occurred under the same conditions. Thus, a possible mechanism involving triphenylphosphine attack on 3-bromo-1,1,1-trifluoroacetone **2** to give the enolate, followed by aldol condensation, transferring the $Ph_3\overset{+}{P}Br$ onto the hydroxylic oxygen, followed by elimination of HBr from cation **7**, and a Meerwein–Ponndorf–Verley 1,2-reduction of the enone product, seems to be discounted. If the above mentioned mechanism is correct, the olefination product should be obtained in the absence of titanium(IV) isopropoxide.

3. (Trifluoroacetylmethylene)triphenylphosphorane (Wittig olefination ylide) did not react with aldehydes in the presence of titanium(IV) isopropoxide to give allylic alcohols, but instead the aldehyde was reduced by titanium(IV) isopropoxide to afford the corresponding alcohol (57%) (Scheme 4). Thus a mechanism *via* Wittig ylide seems to be unreasonable.



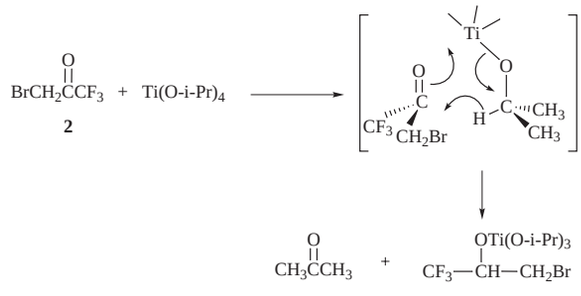
Scheme 4

4. Attempts to carry out the reductive olefination by use of fluorine-free α-bromo ketone $BrCH_2C(O)Ph$ **11** instead of **2** were unsuccessful. There is a competing reaction of titanium(IV) isopropoxide between **2** (or **11**) and an aldehyde. In the fluorine-containing case, the reaction of titanium(IV) isopropoxide with **2** takes place smoothly since **2** is more reactive than an aldehyde due to the strong electron-withdrawing effect of the CF_3 group, while in the fluorine-free case the aldehyde is more reactive than bromo ketone **11**. Thus the reductive olefination failed when **11** was used as substrate.

5. Other halophilic reagents, such as n-Bu_3P (89% yield of **3a**), n-Bu_3As (92% yield of **3a**) and n-Bu_3Sb (68% yield of **3a**), can also be used in this reaction instead of Ph_3P by combination with $Ti(OPr^i)_4$.

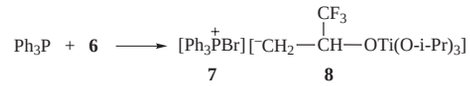
Thus, the tentative hypothesis shown in Schemes 5, 6, and 7 appears to be consistent with the information currently available.

The reaction is postulated to be initiated by a Meerwein–Ponndorf–Verley-like reduction of 3-bromo-1,1,1-trifluoroacetone **2** with titanium(IV) isopropoxide[23] to give **6** (Scheme 5). A halophilic reaction occurred between intermediate **6** and



2 **6**

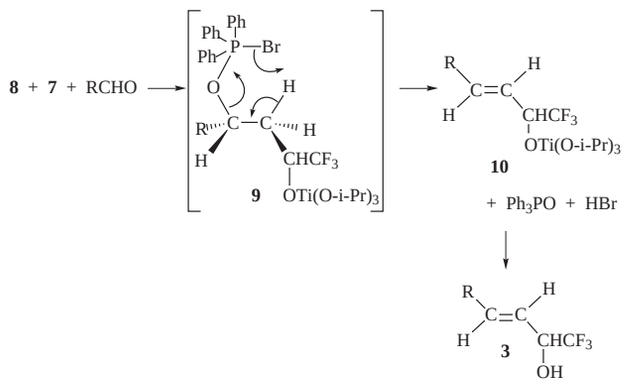
Scheme 5



Scheme 6

triphenylphosphine, forming ion-pair **7** and **8** (Scheme 6) which was analogous to that reported in the literature.[24] It might be stabilized by the strongly electron-withdrawing trifluoromethyl group.

Subsequently the active species **7** and **8** reacted with aldehyde thereby forming a six-membered intermediate **9**. After elimination of triphenylphosphine oxide and HBr the intermediate **10** was formed, which on hydrolysis gave the product **3** (Scheme 7).



Scheme 7

Intermediate **9** is similar to that reported in the literature[25] in which it was shown to be present by an HBr-cleavage experiment. It is different to the Mitsunobu reaction[26] since no bromoalkane was obtained.

The intermediate **9**, in which the $CHCF_3[OTi(OPr^i)_3]$ group is located *anti* with respect to the R group, is a favorable configuration energetically and, after elimination of triphenylphosphine oxide and HBr, leads to the above *E*-isomer. Thus the stereochemical results can be rationalized.

The most intriguing aspect is that the sequence of reactions proceeds *via* Meerwein–Ponndorf–Verley reduction of $BrCH_2COCF_3$ first, and then the product reacts with Ph_3P since the bromofluoro compound is more reactive than aldehydes.

These studies provide a very convenient synthesis of perfluoroalkylated (*E*)-allylic alcohols efficiently and stereoselectively, and the widespread use of these allylic alcohols is quite important in organic synthesis. They are interesting fluorinated building blocks, not easily available by existing synthetic methods, and would be expected to be useful intermediates for the synthesis of fluorine-containing biologically active compounds.

Experimental

Bps and mps are uncorrected. The IR spectra of liquid products as films and of solid products as KCl disks were taken on a Digilab FTS-20E spectrometer. ^{1}H NMR spectra were recorded on a Bruker AM-300 (300 MHz) spectrometer (δ-values in ppm from tetramethylsilane, in $CDCl_3$; *J* -values are given in Hz). ^{19}F NMR spectra were taken on a Varian EM-360 (60 MHz) spectrometer (δ in ppm from external trifluoroacetic acid, in $CDCl_3$, positive for upfield shifts). Mass spectra were measured on a Finnigan GC-MS-4021 mass spectrometer. High resolution mass spectrometry data were obtained on a Finnigan-Mat 8430 high-resolution mass spectrometer. Extracts were dried over anhydrous sodium sulfate.

3-Bromo-1,1,1-trifluoroacetone 2

This was obtained from Aldrich Chemical Company.

Ethyl 2,2,2-trifluoroethyl ketone and butyl trifluoromethyl ketone

These were prepared according to the method reported.[27]

Ethyl pentafluoroethyl ketone and ethyl heptafluoropropyl ketone

These were prepared according to the method reported.[28]

Bromofluoro ketones

These were prepared according to the method reported.[29]

General procedure for the preparation of trifluoroalkylated allylic alcohols 3

Into a mixture of 3-bromo-1,1,1-trifluoroacetone **2** (1 mmol), an aldehyde **1** (1 mmol) and triphenylphosphine (1 mmol) in a capped vessel under nitrogen was injected titanium(IV) isopropoxide (1 mmol). After having been stirred at 80 °C for 24 h, the reaction mixture was treated with 5% hydrochloric acid (10 ml) and extracted with diethyl ether (3 × 20 ml). The organic layer was washed with water (3 × 10 ml), dried and evaporated to remove the solvent. The residue was chromatographed on silica gel, and eluted with petroleum ether (60–90 °C)–ethyl acetate (95 : 5) to give the product. Yields are given in Table 1.

1,1,1-Trifluoro-4-phenylbut-3-en-2-ol 3a. Bp 114–115 °C/2.5 mmHg. (Lit.,[12a] bp 76–77 °C/1 mmHg); ν_{max}/cm^{-1}: 3390, 3060, 1650, 1500, 1450, 1360, 1270, 1170, 1070, 1050 and 970; δ_H 7.44–7.28 (m, 5H), 6.86 (d, *J* 16.0, 1H), 6.20 (dd, *J* 16.0, 6.5, 1H), 4.65–4.61 (m, 1H), 2.38 (br s, 1H); δ_F + 1.4 (s); *m*/*z* 202 (M^+ 57%), 133 (100), 115 (32), 113 (39), 105 (15), 103 (19), 91 (18), 77 (23).

1,1,1-Trifluoro-4-(4-methylphenyl)but-3-en-2-ol (3b). Bp 110 °C/2.5 mmHg; ν_{max}/cm^{-1}: 3390, 1660, 1610, 1510, 1270, 1170, 1130, 1040 and 970; δ_H 7.31 (d, *J* 8.1, 2H), 7.15 (d, *J* 8.1, 2H), 6.82 (d, *J* 16.0, 1H), 6.15 (dd, *J* 16.0, 6.7, 1H), 4.63–4.59 (m, 1H), 2.35 (s, 3H), 2.25 (br s, 1H); δ_F +1.6 (s); *m*/*z* 216 (M^+, 30), 147 (100), 129 (35), 117 (12), 115 (23), 105 (27), 91 (27), 77 (11), 55 (50) [Found: C, 61.32; H, 5.02. $C_{11}H_{11}F_3O$ (216.20) requires C, 61.11; H, 5.13%].

1,1,1-Trifluoro-4-(4-fluorophenyl)but-3-en-2-ol (3c). Bp 102–104 °C/2.6 mmHg; ν_{max}/cm^{-1}: 3400, 3040, 1660, 1600, 1510, 1270, 1230, 1180, 1160 and 1130; δ_H 7.43–7.36 (m, 2H), 7.08–6.99 (m, 2H), 6.83 (d, *J* 16.0, 1H), 6.12 (dd, *J* 16.0, 6.4, 1H), 4.66–4.60 (m, 1H), 2.43 (d, *J* 5.4, 1H); δ_F +1.4 (s, 3F), +35.0 (s, 1F); *m*/*z* 221 (M^+ + 1, 38), 220 (M^+, 43), 151 (100), 133 (80), 109 (72), 103 (52), 101 (53), 75 (47), 69 (46), 55 (77) [Found: C, 54.25; H, 3.97. $C_{10}H_8F_4O$ (220.17) requires C, 54.55; H, 3.66%].

4-(4-Chlorophenyl)-1,1,1-trifluorobut-3-en-2-ol (3d). Bp 112 °C/2.5 mmHg; ν_{max}/cm^{-1}: 3580, 3430, 3050, 2980, 1650, 1590, 1490, 1400, 1360, 1260, 1170, 1130, 1010 and 970; δ_H 7.37–7.30 (m, 4H), 6.82 (d, *J* 16.0, 1H), 6.17 (dd, *J* 16.0, 6.3, 1H), 4.67–4.61 (m, 1H), 2.40 (d, *J* 5.8, 1H); δ_F +1.4 (s); *m*/*z* 238 (M^+ + 2, 17), 236 (M^+, 52), 201 (12), 169 (34), 167 (100), 149 (26), 132 (17), 103 (24) [Found: C, 50.86; H, 3.31. $C_{10}H_8ClF_3O$ (236.62) requires C, 50.76; H, 3.41%].

1,1,1-Trifluoro-4-(4-methoxyphenyl)but-3-en-2-ol (3e). Bp 120 °C/2 mmHg; ν_{max}/cm^{-1}: 3500, 2930, 1600, 1580, 1500, 1260, 1180, 1130 and 1030; δ_H 7.37–7.26 (m, 2H), 6.93–6.85 (m, 2H), 6.78 (d, *J* 16.0, 1H), 6.05 (dd, *J* 16.0, 6.8, 1H), 4.65–4.55 (m, 1H), 3.82 (s, 3H), 2.51 (s, 1H); δ_F +1.5 (s); *m*/*z* 232 (M^+, 64), 163 (100), 145 (30), 121 (30), 91 (24), 77 (17), 55 (48) [Found: C, 57.00; H, 4.58. $C_{11}H_{11}F_3O_2$ (232.20) requires C, 56.90; H, 4.77%].

1,1,1-Trifluoro-4-(4-nitrophenyl)but-3-en-2-ol (3f). Mp: 103–104 °C; ν_{max}/cm^{-1}: 3400, 1600, 1510, 1340, 1270, 1170, 1130, 976

and 860; δ_H 8.23–8.19 (m, 2H), 7.59–7.55 (m, 2H), 6.97 (d, 1H, *J* 16.0), 6.38 (dd, *J* 16.0, 5.6, 1H), 4.90–4.60 (m, 1H), 2.88 (s, 1H); δ_F +1.0 (s) *m*/*z* 247 (M^+, 24), 178 (100), 132 (44), 103 (24), 77 (19), 51 (14) [Found: C, 48.47; H, 3.21; N, 5.62. $C_{10}H_8F_3NO_3$ (247.17) requires C, 48.59; H, 3.26; N, 5.67%].

4-(3-Bromophenyl)-1,1,1-trifluorobut-3-en-2-ol (3g). Bp 105 °C/2 mmHg; ν_{max}/cm^{-1}: 3500, 1570, 1270, 1180, 1130 and 970; δ_H 7.60–7.10 (m, 4H), 6.80 (d, *J* 16.0, 1H), 6.20 (dd, *J* 16.0, 6.3, 1H), 4.70–4.60 (m, 1H), 2.88 (s, 1H); δ_F +1.3 (s); *m*/*z* 282 (M^+ + 2, 39), 280 (M^+, 41), 213 (76), 211 (30), 132 (100), 103 (37), 77 (31), 51 (24) [Found: C, 42.80; H, 3.12. $C_{10}H_8BrF_3O$ (281.07) requires C, 42.73; H, 2.87%].

4-(3-Chlorophenyl)-1,1,1-trifluorobut-3-en-2-ol (3h). Bp 110 °C/2 mmHg; ν_{max}/cm^{-1}: 3400, 1600, 1570, 1470, 1270, 1180, 1130 and 970; δ_H 7.50–7.20 (m, 4H), 6.80 (dd, *J* 16.0, 0.8, 1H), 6.20 (dd, *J* 16.0, 6.3, 1H), 4.70–4.55 (m, 1H), 2.75 (s, 1H); δ_F +1.3 (s); *m*/*z* 236 (M^+, 72), 201 (23), 167 (100), 149 (39), 132 (26), 103 (40), 77 (18), 69 (14), 55 (25) [Found: C, 50.27; H, 3.60. $C_{10}H_8ClF_3O$ (236.62) requires C, 50.76; H, 3.41%].

4-(2-Bromophenyl)-1,1,1-trifluorobut-3-en-2-ol (3i). Bp 81 °C/2.5 mmHg; ν_{max}/cm^{-1}: 3580, 3410, 1470, 1440, 1260, 1170, 1130, 1020 and 970; δ_H 7.59–7.52 (m, 2H), 7.33–7.14 (m, 3H), 6.16 (dd, *J* 15.9, 6.3, 1H), 4.72–4.67 (m, 1H), 2.41 (d, *J* 5.4, 1H); δ_F +1.4 (s); *m*/*z* 282 (M^+ + 2, 24), 280 (M^+, 24), 213 (30), 211 (30), 201 (33), 133 (72), 131 (100), 102 (36), 77 (34), 69 (37), 51 (20) [Found: C, 42.98; H, 2.72. $C_{10}H_8BrF_3O$ (281.07) requires C, 42.73; H, 2.87%].

1,1,1-Trifluoro-6-phenylhexa-3,5-dien-2-ol (3j). Bp 118 °C/2.5 mmHg; ν_{max}/cm^{-1}: 3320, 3020, 1640, 1450, 1260, 1180, 1120, 1040 and 990; δ_H 7.43–7.28 (m, 5H), 6.84–6.76 (m, 1H), 6.69–6.60 (m, 2H), 5.80 (dd, *J* 15.7, 6.6, 1H), 4.59–4.55 (m, 1H), 2.24 (d, *J* 5.1, 1H); δ_F +1.7 (s); *m*/*z* 229 (M^+ + 1, 13), 228 (M^+, 19), 159 (41), 141 (28), 130 (57), 129 (63), 115 (55), 102 (20), 92 (70), 91 (100), 77 (18) [Found: C, 63.10; H, 4.59. $C_{12}H_{11}F_3O$ (228.21) requires C, 63.16; H, 4.86%].

4-(2,4-Dichlorophenyl)-1,1,1-trifluorobut-3-en-2-ol (3k). Bp 110 °C/2 mmHg; ν_{max}/cm^{-1}: 3500, 2900, 1470, 1260, 1180, 1110, 1020 and 970; δ_H 7.50–7.00 (m, 4H), 6.20 (dd, *J* 16.0, 6.0, 1H), 4.85–4.65 (m, 1H), 2.70 (s, 1H); δ_F +1.4 (s); *m*/*z* 270 (M^+, 45), 235 (12), 201 (100), 159 (52), 141 (44), 131 (25), 113 (33), 102 (23), 77 (43) [Found: C, 43.99; H, 2.52. $C_{10}H_7Cl_2F_3O$ (271.07) requires C, 44.31; H, 2.60%].

1,1,1-Trifluoro-4-piperonylbut-3-en-2-ol (3l). Bp 100 °C/2 mmHg; ν_{max}/cm^{-1}: 3430, 2950, 1600, 1500, 1490, 1450, 1250, 1170 and 1130; δ_H 7.10–6.50 (m, 4H), 5.90 (s, 2H), 5.80 (dd, *J* 15.9, 6.8, 1H), 4.59–4.42 (m, 1H), 2.53 (s, 1H); δ_F +1.5 (s); *m*/*z* 246 (M^+, 100), 177 (74), 147 (51), 135 (19), 119 (28), 91 (33), 55 (13) [Found: M^+, 246.0488. $C_{11}H_9F_3O_3$ requires M, 246.0504].

General procedure for the preparation of substituted allylic alcohols 5

The procedure is similar with that of the preparation of compounds **3** and the reaction times and temperatures and yields are listed in Table 2.

1,1,1-Trifluoro-3-methyl-4-phenylbut-3-en-2-ol (5a). Bp 90 °C/1 mmHg; ν_{max}/cm^{-1} 3390, 1500, 1450, 1270, 1170, 1130, 760 and 700; δ_H 7.52–7.20 (m, 5H), 6.71 (s, 1H), 4.57 (q, *J* 7.0, 1H), 2.60 (s, 1H), 2.00 (s, 3H); δ_F −0.7 (s); *m*/*z* 216 (M^+, 62%), 147 (100), 129 (86), 115 (32), 91 (44) [Found: C, 60.80; H, 5.09. $C_{11}H_{11}F_3O$ (216.20) requires C, 61.11; H, 5.13%]; NOESY spectrum showed that the CH(OH)(CF_3) group is *cis* (*Z*) with respect to 4-H.

4-(3-Chlorophenyl)-1,1,1-trifluoro-3-methylbut-3-en-2-ol (5b). Bp 90 °C/1 mmHg; ν_{max}/cm^{-1} 3420, 1600, 1570, 1480, 1270, 1170 and 1120; δ_H 7.40–7.10 (m, 4H), 6.63 (s, 1H), 4.53 (q, *J* 7.0, 1H), 2.59 (s, 1H), 1.95 (s, 3H); δ_F −1.0 (s); *m*/*z* 250 (M^+, 59), 197 (13), 181 (100), 163 (50), 146 (32), 125 (31), 115 (52) [Found: C, 52.66; H, 4.13. $C_{11}H_{10}ClF_3O$ (250.65) requires C, 52.71; H, 4.02%].

4-(3-Chlorophenyl)-1,1,1-trifluoro-3-propylbut-3-en-2-ol (5c). Bp 100 °C/1 mmHg; ν_{max}/cm^{-1}: 3420, 1600, 1570, 1470, 1270, 1170, 1130 and 780; δ_H 7.40–7.10 (m, 4H), 6.74 (s, 1H), 4.58 (q, *J* 6.5, 1H), 2.52–2.12 (m, 3H), 1.60–1.45 (m, 2H), 0.92 (t, *J* 7.5, 3H); δ_F −0.7 (s); *m*/*z* 278 (M^+, 100), 261 (21), 225 (52), 209 (63), 167 (39), 151 (33), 115 (77) [Found: C, 56.35; H, 5.22. $C_{13}H_{14}ClF_3O$ (278.70) requires C, 56.03; H,5.06%].

1,1,1-Trifluoro-4-(4-methoxyphenyl)-3-propylbut-3-en-2-ol (5d). Bp 90 °C/1 mmHg; ν_{max}/cm^{-1}: 3460, 2960, 2880, 1610, 1510, 1470, 1250, 1170 and 1130; δ_H 7.30–7.20 (m, 2H), 6.90–6.80 (m, 2H), 6.69 (s, 1H), 4.53 (q, *J* 7.0, 1H), 3.82 (s, 3H), 2.60–2.20 (m, 3H), 1.60–1.40 (m, 2H), 0.94 (t, *J* 7.3, 3H); δ_F −0.8 (s); *m*/*z* 274 (M^+, 100), 245 (63), 227 (28), 177 (94), 205 (49), 146 (52) [Found: C, 61.08; H, 6.24. $C_{14}H_{17}F_3O_2$ (274.28) requires C, 61.31; H,6.25%].

1-(2-Bromophenyl)-4,4,5,5,5-pentafluoro-2-methylpent-1-en-3-ol (5e). Bp 80 °C/1 mmHg; ν_{max}/cm^{-1}: 3440, 1560, 1470, 1440, 1210, 119, 1130 and 1025; δ_H 7.65–7.10 (m, 4H), 6.70 (s, 1H), 4.67–4.77 (m, 1H), 2.62 (d, *J* 3.8 1H), 1.87 (s, 3H); δ_F 4.5 (s, 3F), 46.5 (d, *J* 8.8, 1F), 48.0 (d, *J* 14.0, 1F); *m*/*z* 344 (M^+, 7), 227 (51), 146 (100), 131 (37), 115 (48) [Found: C, 41.41; H, 2.73. $C_{12}H_{10}BrF_5O$ (345.11) requires C, 41.76; H, 2.92%].

4,4,5,5,5-Pentafluoro-1-(4-methoxyphenyl)-2-methylpent-1-en-3-ol (5f). Bp 85 °C/1 mmHg; ν_{max}/cm^{-1}: 3460, 1610, 1580, 1510, 1450, 1250, 1180 and 840; δ_H 7.30–7.20 (m, 2H), 6.95–6.85 (m, 2H), 6.57 (s, 1H), 4.60 (dd, *J* 9.4,15.8, 1H), 3.80 (s, 3H), 2.82 (s, 1H), 1.95 (d, *J* 1.3, 3H); δ_F 4.5 (s, 3F), 46.5 (d, *J* 9.4, 1F), 47.7 (d, *J* 15.8, 1F); *m*/*z* 296 (M^+, 49), 279 (9), 177 (100), 159 (36), 121 (20) [Found: C, 52.95; H, 3.92. $C_{13}H_{13}F_5O_2$ (296.24) requires C, 52.71; H, 4.42%].

1,1,1,2,2-Pentafluoro-4-methyl-7-phenylhepta-4,6-diene-3-ol (5g). Bp 120 °C/1 mmHg; ν_{max}/cm^{-1}: 3440, 1490, 1450, 1210, 1190, 1130, 970 and 750; δ_H 7.55–7.20 (m, 5H), 7.00 (dd, *J* 10.9, 15.6, 1H), 6.63 (d, *J* 15.6, 1H), 6.35 (d, *J* 10.9, 1H), 4.55 (dd, *J* 8.6, 16.3, 1H), 2.84 (s, 1H), 1.95 (s, 3H); δ_F 4.5 (s, 3F), 46.5 (d, *J* 8.6, 1F), 48.3 (d, *J* 16.3, 1F); *m*/*z* 292 (M^+, 15), 276 (21), 173 (41), 143 (41), 115 (48), 105 (57), 91 (76), 43 (100) [Found: C, 57.10; H, 4.00. $C_{14}H_{13}F_5O$ (292.25) requires C, 57.54; H, 4.48%].

1-(2,4-Dichlorophenyl)-4,4,5,5,5-pentafluoro-2-methylpent-1-en-3-ol (5h). Bp 100 °C/1 mmHg; ν_{max}/cm^{-1}: 3430, 1590, 1550, 1470, 1210, 1190, 1130 and 820; δ_H 7.39 (d, *J* 2.0, 1H), 7.30–7.10 (m, 2H), 6.65 (s, 1H), 4.69 (dd, *J* 9.1, 15.7, 1H), 2.78 (s, 1H), 1.83 (d, *J* 1.3, 3H); δ_F 4.3 (s, 3F), 46.3 (d, *J* 9.1, 1F), 47.7 (d, *J* 15.7, 1F); *m*/*z* 334 (M^+, 14), 215 (100), 197 (17), 180 (36), 145 (27), 115 (44). [Found: C, 42.76; H, 2.45. $C_{12}H_9Cl_2F_5O$ (335.10) requires C, 43.01; H, 2.71%].

4,4,5,5,6,6,6-Heptafluoro-2-methyl-1-phenylhex-1-en-3-ol (5i). Bp 65 °C/1 mmHg; ν_{max}/cm^{-1}: 3410, 1490, 1450, 1230, 1120 and 940; δ_H 7.45–7.20 (m, 5H), 6.68 (s, 1H), 4.73 (dd, *J* 8.0, 17.1, 1H), 2.80 (s, 1H), 2.00 (d, *J* 0.66, 3H); δ_F 3.5 (t, 3F), 42.9–44.2 (m, 1F), 44.9–46.2 (m, 1F), 49.0 (s, 2F); *m*/*z* 316 (M^+, 7), 234 (18), 219 (46), 181 (47), 147 (100), 129 (50), 43 (31) [Found: C, 49.66; H, 3.52. $C_{13}H_{11}F_7O$ (316.22) requires C, 49.38; H, 3.51%]. NOESY spectrum showed that the CH(OH)(C_3F_7) group is *cis* (*Z*) with respect to 1-H.

4,4,5,5,6,6,6-Heptafluoro-1-(4-fluorophenyl)-2-methylhex-1-en-3-ol (5j). Bp 54 °C/ 1 mmHg; ν_{max}/cm^{-1}: 3420, 1600, 1510, 1450, 1230, 1190, 1120 and 740; δ_H 7.40–7.15 (m, 2H), 7.10–6.95 (m, 2H), 6.62 (s, 1H), 4.70 (dd, *J* 7.8, 17.0, 1H), 2.75 (s, 1H), 1.95 (s, 3H); δ_F 3.6 (s, 3F), 37.0 (s, 1F), 42.9–44.2 (m, 1F), 45.1–46.4 (m, 1F), 48.0 (s, 2F); *m*/*z* 165 (100), 147 (34), 109 (15) [Found: C, 46.65; H, 3.00. $C_{13}H_{10}F_8O$ (334.21) requires C, 46.72; H, 3.02%].

1-(2-Bromophenyl)-4,4,5,5,6,6,6-heptafluoro-2-methylhex-1-en-3-ol (5k). Bp 70 °C/1 mmHg; ν_{max}/cm^{-1}: 3450, 1560, 1470, 1440, 1225, 1180, 1115 and 750; δ_H 7.60–7.55 (d, *J* 8.0, 1H), 7.40–7.20 (m, 2H), 7.15–7.05 (m, 1H), 6.69 (s, 1H), 4.78 (dd, *J* 7.6, 17.3, 1H), 2.72 (s, 1H), 1.86 (d, *J* 0.66, 3H); δ_F 3.5 (s, 3F), 42.9–44.2 (m, 1F), 45.1–46.4 (m, 1F), 48.0 (s, 2F); *m*/*z* 195 (0.65), 146 (100), 131 (33), 115 (36) [Found: C, 39.54; H, 2.59. $C_{13}H_{10}BrF_7O$ (395.11) requires C, 39.52; H, 2.55%].

4,4,5,5,6,6,6-Heptafluoro-1-(4-methoxyphenyl)-2-methylhex-1-en-3-ol (5l). Bp 80 °C/1 mmHg; ν_{max}/cm^{-1}: 3460, 1610, 1580, 1510, 1225, 1180, 1110 and 740; δ_H 7.35–7.15 (m, 2H), 6.90–6.80 (m, 2H), 6.56 (s, 1H), 4.68 (dd, *J* 7.8, 17.1, 1H), 3.80 (s, 3H), 3.02 (s, 1H) 1.96 (d, *J* 1.0, 3H); δ_F 3.5 (t, 3F), 42.9–44.2 (m, 1F), 45.1–46.4 (m, 1F), 48.5 (s, 2F); *m*/*z* 177 (100), 159 (33), 121 (19), 69 (12) [Found: C, 48.52; H, 3.85. $C_{14}H_{13}F_7O_2$ (346.24) requires C, 48.57; H, 3.78%].

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