

A convenient synthesis of bromodifluoromethyl-substituted alkenes

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Abstract

Various functionalized bromodifluoromethyl-substituted alkenes have been prepared by addition of dibromodifluoromethane to functionalized alkenes promoted by a CrCl_3/Fe bimetal redox system, followed by dehydrobromination with $\text{KF}/\text{Al}_2\text{O}_3$.

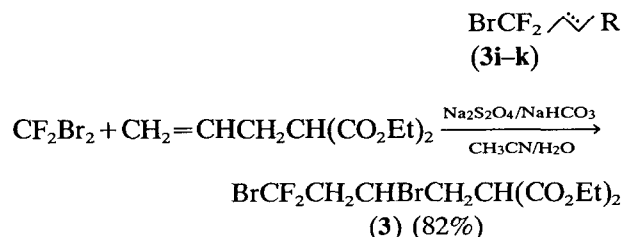
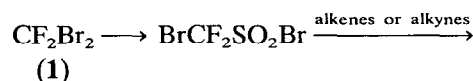
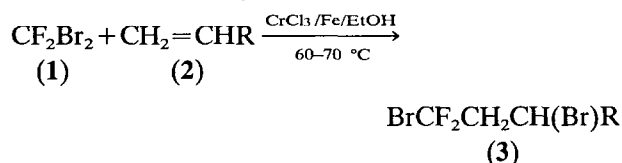
Introduction

In our continuing studies on the application of redox system in organofluorine chemistry and on the synthetic utility of dibromodifluoromethane, we have found that the bimetal redox system CrCl_3/Fe can efficiently promote the addition of dibromodifluoromethane to electron-deficient alkenes to form hydrobromodifluoromethylation products [1]. Subsequent investigation showed that this redox system could also promote the addition of dibromodifluoromethane to electron-rich alkenes to produce 1,3-dibromo-1,1-difluoroalkanes as 1:1 adducts. Later, we found that $\text{KF}/\text{Al}_2\text{O}_3$ was an efficient dehydrobrominating agent which eliminated hydrobromide from such 1,3-dibromo-1,1-difluoroalkanes [2]. Thus the preparation of bromodifluoromethyl-substituted alkenes becomes feasible by utilizing dibromodifluoromethane as the source of the bromodifluoromethyl unit. On dehydrobromination with $\text{KF}/\text{Al}_2\text{O}_3$, 1,3-dibromo-1,1-difluoroalkanes gave the corresponding bromodifluoromethyl-substituted alkenes which are useful building blocks for the introduction of the allylic difluoromethylene fragment into organic molecules [3, 4]. Here, we report the detailed results of such synthetic utility of dibromodifluoromethane and some unexpected reactions.

Results and discussion

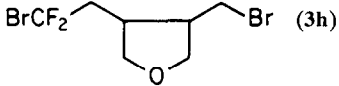
Many initiators, for example, benzoyl peroxide, azobisisobutyronitrile, UV light, $\text{CuCl}/2$ -ethanolamine, AlMe_3 , BEt_3 , $(\text{NH}_4)_2\text{S}_2\text{O}_8/\text{HCO}_2\text{NH}_4$, etc. have been reported as promoting the addition of dibromodifluoromethane (1) to electron-rich alkenes 2, giving 1,3-dibromo-1,1-difluoroalkanes 3 as the 1:1 adduct. Of these initiators, the redox system has distinct advantages when compared with other initiation techniques [5]. In fact, in the presence of the CrCl_3/Fe redox system, alkenes 2 bearing various functional groups such as alkyl, alkenyl, ester, carbonyl and ether groups provide suitable substrates for obtaining 1:1 adducts 3 in good yield. The results are summarized in Table 1. In the case of allyl acetate (2g), some telomerized product was detected, and the yield of the 1:1 adduct was low (Run 7). Diallyl ether (2h) gave the tetrahydrofuran derivative 3h in 78% yield. This result implies that the reaction proceeds via a radical addition pathway. In addition, certain known 1,3-dibromides 3i–k have been synthesized according to the reported procedure [6]. Compound 3l was obtained in 82% yield by the $\text{Na}_2\text{S}_2\text{O}_4/\text{NaHCO}_3$ promoted addition of dibromodifluoromethane to diethyl allylmalonate.

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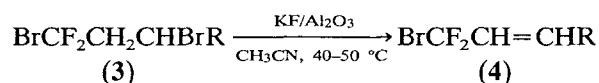
*Author to whom correspondence should be addressed.

TABLE 1. Addition of CF₂Br₂ (1) to alkenes 2^a

Run No.	Alkene 2	Product 3	Yield (%) ^b
1	CH ₂ =CHC ₄ H ₉ (2a)	BrCF ₂ CH ₂ CHBrC ₄ H ₉ (3a)	96
2	CH ₂ =CHC ₆ H ₁₃ (2b)	BrCF ₂ CH ₂ CHBrC ₆ H ₁₃ (3b)	84
3	CH ₂ =CHC ₂ H ₄ CH=CH ₂ (2c)	BrCF ₂ CH ₂ CHBrC ₂ H ₄ CH=CH ₂ (3c)	72
4	CH ₂ =CHC ₂ H ₄ COCH ₃ (2d)	BrCF ₂ CH ₂ CHBrC ₂ H ₄ COCH ₃ (3d)	64
5	CH ₂ =CH(CH ₂) ₈ CO ₂ Me (2e)	BrCF ₂ CH ₂ CHBr(CH ₂) ₈ CO ₂ Me (3e)	64
6	cyclohexene (2f)	2-bromo-1-bromodifluoromethylhexane (3f)	74
7	CH ₂ =CHCH ₂ OAc (2g)	BrCF ₂ CH ₂ CHBrCH ₂ OAc (3g)	30 ^c
8	(CH ₂ =CHCH ₂) ₂ O (2h)	 BrCF ₂ CH ₂ CHBrCH ₂ O (3h)	78
9	CH ₂ =CHCH ₂ Cl (2i)	BrCF ₂ CH ₂ CHBrCH ₂ Cl (3i)	64 ^d
10	CH ₂ =CHPh (2j)	BrCF ₂ CH ₂ CHBrPh (3j)	67 ^d
11	HC≡CPh (2k)	BrCF ₂ CH=CBrPh (3k)	65 ^d

^aMolar ratio of 1/2/CrCl₃/Fe = 1.2–1.5:1:0.2:1.5. Reactions were carried out at 60–70 °C for *c.* 12 h.^bIsolated yields based on alkene 2.^cTelomerized product was also obtained.^dSee ref. 6.

On treatment with KF/Al₂O₃ [7] (*c.* 2.5 equiv. KF) in acetonitrile or *N,N*-dimethylformamide with stirring at 40–50 °C for several hours, these 1,3-dibromides 3 gave the corresponding dehydrobrominated products, i.e. 1-bromodifluoromethyl-alk-1-enes 4. The results are summarized in Table 2.



Dehydrobromination proceeded smoothly to give the corresponding alkenes 4 in good yield. These products were a mixture of *E* and *Z* isomers, with the former

predominating. Thus, treatment of 1,3-dibromo-1,1-difluoromethylheptane (3a) with KF/Al₂O₃ gave such a mixture, the δ_{CF₂} signal of the *E* isomer appearing at –39 ppm in the ¹⁹F NMR while the δ_{CF₂} spectrum of the *Z* isomer appeared at –35 ppm. The *E/Z* ratio agreed well with the result obtained by GC analysis.

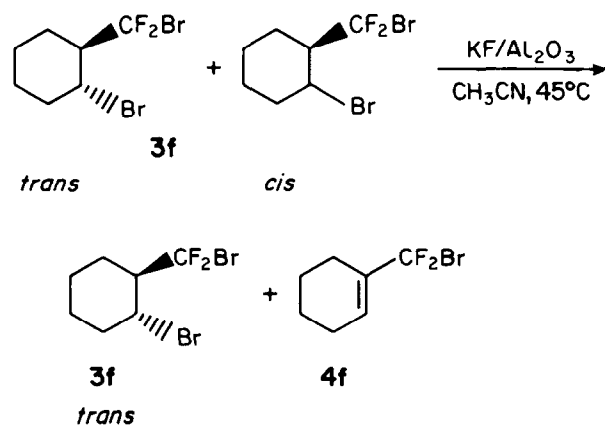
In contrast with the procedure using refluxing triethylamine as the dehydrobrominating agent, the KF/Al₂O₃-promoted dehydrobromination reaction proceeded under much milder conditions and the yields were excellent. Furthermore, the *E/Z* ratio of the products obtained was high (Run Nos. 1–3).

TABLE 2. Dehydrobromination of 1,3-dibromides 3 with KF/Al₂O₃^a

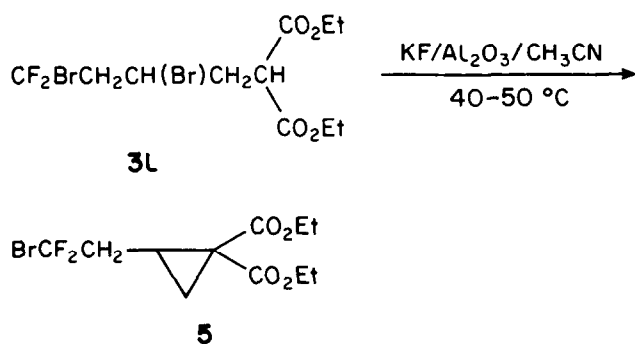
Run No.	1,3-Dibromides 3	Reaction time (h)	Product 4	<i>E/Z</i> ^b	Yield (%) ^c
1	CF ₂ BrCH ₂ CHBrC ₄ H ₉ (3a)	4	CF ₂ BrCH=CHC ₄ H ₉ (4a)	95:5	87
2	3a	4	CF ₂ BrCH=CHC ₄ H ₉ (4a)	94:6	94 ^d
3	3a	28	CF ₂ BrCH=CHC ₄ H ₉ (4a)	1:1	70 ^e
4	CF ₂ BrCH ₂ CHBrC ₆ H ₁₃ (3b)	4	CF ₂ BrCH=CHC ₆ H ₁₃ (4b)	92:8	84
5	CF ₂ BrCH ₂ CHBrC ₂ H ₄ CH=CH ₂ (3c)	4	CF ₂ BrCH=CHC ₂ H ₄ CH=CH ₂ (4c)	88:12	55
6	CF ₂ BrCH ₂ CHBrC ₂ H ₄ Ac (3d)	4	CF ₂ BrCH=CHC ₂ H ₄ Ac (4d)	84:16	74
7	CF ₂ BrCH ₂ CHBr(CH ₂) ₈ CO ₂ Me (3e)	6	CF ₂ BrCH=CH(CH ₂) ₈ CO ₂ Me (4e)	88:12	90
8	2-bromo-1-bromodifluoromethylcyclohexane (3f)	8	1-bromodifluoromethylcyclohexene (4f)	–	40
9	CF ₂ BrCH ₂ CHBrCH ₂ OAc (3g)	4	CF ₂ BrCH=CHCH ₂ OAc (4g)	95:5	65
10	CF ₂ BrCH ₂ CHBrCH ₂ Cl (3i)	5	CF ₂ BrCH=CHCH ₂ Cl (4i)	–	74
11	CF ₂ BrCHCHC ₄ H ₉ (9) 	4	CF ₂ BrCH=CBrC ₄ H ₉ (10)	58:42	87

^aAll reactions were carried out in CH₃CN at 40–50 °C with 2.5 equiv. of KF/Al₂O₃ unless otherwise indicated.^bEstimated by ¹⁹F NMR spectroscopy.^cIsolated yields.^d*N,N*-Dimethylformamide was used as the solvent.^eReaction carried out in refluxing triethylamine.

Functionalities such as the ester, carbonyl, alkenyl and chloromethyl group could tolerate such conditions and did not affect the elimination reaction. For 1-bromodifluoromethyl-2-bromocyclohexane (**3f**), only the *cis* isomer was dehydrobrominated, while the *trans* isomer was unaffected even at 70 °C after 5 h.

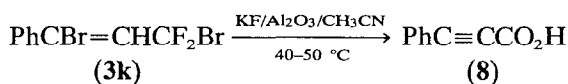
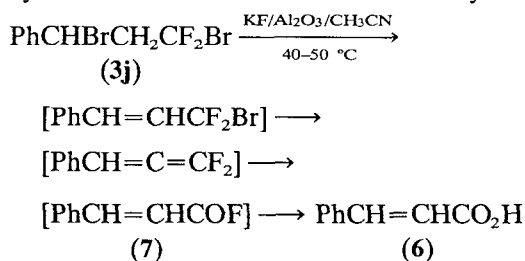


When **31** was dehydrobrominated with $\text{KF}/\text{Al}_2\text{O}_3$, an unexpected product, i.e. diethyl bromodifluoromethylmethyl-1,1-cyclopropanecarboxylate (**5**), was obtained in 92% isolated yield. The structure of compound **5** was confirmed from its ^1H and ^{13}C NMR spectra. The signal from the methylene group of the cyclopropane ring appeared as a doublet at 1.5 ppm ($J=8$ Hz) and integrated for two protons. Under such conditions, the ethyl ester group remained intact. It was interesting to note that no BrCF_2 -substituted alkene could be detected. This result shows that the acidity of the methinic proton in $\text{CH}(\text{CO}_2\text{Et})_2$ is stronger than that of the methinic proton adjacent to the CF_2 group. The carbanion formed underwent nucleophilic reaction with the CHBr to give the corresponding cyclopropane derivative **5**.

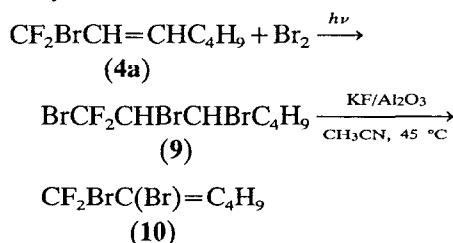


As the bromine atom in bromodifluoromethyl-substituted alkenes is in the allylic position, it is relatively labile under certain conditions. For example, when 1,3-dibromo-1,1-difluoro-3-phenyl-propane (**3j**) was treated with $\text{KF}/\text{Al}_2\text{O}_3$, the α,β -unsaturated carboxylic acid **6** was formed in nearly quantitative yield. (α,β -Unsaturated

carboxylic fluoride **7** is considered to be the intermediate.) Compound **7** was not isolated but its presence could be deduced spectroscopically ($\delta_F/\text{CDCl}_3 = -90$ ppm/ $\text{CF}_3\text{CO}_2\text{H}$; $\nu_{\text{max}} = 1800$ (vs) cm^{-1}). The same result was obtained with the BrCF_2 -substituted vinyl bromide **3k**. However, the bromodifluoromethyl-substituted alkyne could not be obtained in this way.



These bromodifluoromethyl-substituted alkenes react with bromine to give 1,2,3-tribromides in near-quantative yield under UV irradiation. For example, **4a** reacted with bromine giving the 1,2,3-tribromide **9**, and compound **9** could be further dehydrobrominated to the 1,2-dibromo-2-alkene **10** which could not be further dehydrobrominated under these conditions.



In summary, although there are some exceptions, KF supported on alumina in acetonitrile or *N,N*-dimethylformamide has been shown to be a mild dehydrobrominating agent. The simplicity of the experimental procedure, the ready availability of the base and the good yields make this approach a useful route for synthesizing various bromodifluoromethyl-substituted alkenes. Furthermore, such functionalized alkenes bearing an allyl bromine atom are potential CF₂-introducing building blocks in organic synthesis.

Experimental

All boiling points are uncorrected. ^1H NMR spectra were obtained in CCl_4 or CDCl_3 on an EM-360A (60 MHz) or a Bruker AC-300 (300 MHz) spectrometer. ^{19}F NMR spectra were recorded on a Varian EM-360L (56.4 MHz) spectrometer in CCl_4 or CDCl_3 using $\text{CF}_3\text{CO}_2\text{H}$ (TFA) as external standard. Chemical shifts in ppm were positive for upfield shifts. ^{13}C NMR spectra

were recorded on an FX-90Q (22.6 MHz) spectrometer in CDCl_3 . Infrared spectra were obtained from neat liquids on a Shimadzu IR-440 spectrometer. MS spectra were measured on a Finnigan MS-4021 spectrometer. All reagents and solvents were used directly without further purification. In the preparations described below, the product was new where no literature reference is given.

Addition of CF_2Br_2 (1) to alkenes 2. General procedure

The procedure was based on that reported in the literature [1]. A mixture of 50 mmol of CF_2Br_2 (1), 60 mmol of alkene (2), 10 mmol of $\text{CrCl}_3 \cdot 6\text{H}_2\text{O}$ and 75 mmol of iron powder in 100 ml of ethanol was stirred at 60–70 °C for the required time. The reaction was monitored by ^{19}F NMR spectroscopy. After reaction was complete, the resulting mixture was poured into 50 ml of dilute hydrochloric acid (1 N) and extracted with diethyl ether (3 × 30 ml). The combined extract was successively washed with HCl (1 N), water, brine and then dried over Na_2SO_4 . After removal of the solvent, the residue was purified by distillation under reduced pressure to give the pure products 3.

The preparation of compounds 3i–k was based on the method described previously [6]. Compound 3l was prepared as follows [7]. A mixture of diethyl allylmalonate (10 mmol, 2 g), CF_2Br_2 (12 mmol, 2.5 g), $\text{Na}_2\text{S}_2\text{O}_4$ (12 mmol, 2 g), NaHCO_3 (12 mmol, 1 g) in 50 ml of a mixed solvent consisting of CH_3CN and water (3:7) was stirred at 40 °C for c. 1.5 h. The reaction was monitored by ^{19}F NMR spectroscopy. The purifying procedure followed was as described above.

1,3-Dibromo-1,1-difluoroheptane (3a) [6]: Colourless oil, b.p. 95–98 °C/45 mmHg. ^{19}F NMR δ : –34.5 (s, CF_2Br) ppm. ^1H NMR δ : 4.3 (m, 1H, CHBr); 3.05 (m, 2H, CF_2CH_2); 2.2–1.0 (m, 9H, C_4H_9) ppm.

1,3-Dibromo-1,1-difluorononane (3b) [6]: Colourless oil, b.p. 108–110 °C/10 mmHg. ^{19}F NMR δ : –35 (s, CF_2Br) ppm. ^1H NMR δ : 4.1 (m, 1H, CHBr); 3.2–2.6 (m, 2H, CF_2CH_2); 1.8–1.0 (m, 10H, $5 \times \text{CH}_2$); 0.8 (t, $^3J_{\text{HH}} = 2$ Hz, 3H, CH_3) ppm. IR ν_{max} (cm^{-1}): 2900 (s, C–H); 1100 (s, C–F); 670 (s, C–Br).

1,3-Dibromo-1,1-difluorohept-6-ene (3c): Colourless oil, b.p. 108–110 °C/10 mmHg. ^{19}F NMR δ : –35 (s, CF_2Br) ppm. ^1H NMR δ : 6.1–5.7 (m, 1H, $\text{CH}=\text{CH}_2$); 5.3–4.9 (m, 2H, $\text{CH}=\text{CH}_2$); 4.2 (m, 1H, CHBr); 3.4–2.7 (m, 2H, CF_2CH_2); 2.5–1.8 (m, 4H, CH_2CH_2) ppm. IR ν_{max} (cm^{-1}): 1640 (m, C=C); 1200, 1100 (s, C–F). MS m/z (%): 211 ($\text{M}^+ - \text{Br}$, 9.75); 213 ($\text{M}^+ - \text{Br}$, 10.62); 191 (13.16); 193 (13.66); 131 (52.55); 121 (100); 111 (47.37); 81 (34.72). Analysis: Calc. for $\text{C}_7\text{H}_{10}\text{Br}_2\text{F}_2$ (FW 292): C, 28.77; H, 3.42; F, 13.01; Br, 54.79%. Found: C, 28.74; H, 3.62; F, 13.20; Br, 54.80%.

1,3-Dibromo-1,1-difluoroheptan-6-one (3d): b.p. 82–86 °C/2 mmHg, light yellow oil (turns slowly deep brown at room temperature). ^{19}F NMR δ : –35.5 (s, CF_2Br) ppm. ^1H NMR δ : 4.2 (m, 1H, CHBr); 3.4–2.0 (m, 9H, others) ppm. IR ν_{max} (cm^{-1}): 1720 (s, C=O); 1200, 1170 (s, C–F); 640, 540 (s, C–Br). MS m/z (%): 306 (M^+ , 0.29); 308 (M^+ , 0.75); 310 (M^+ , 0.53); 58 (51.10); 43 (Ac^+ , 100). Analysis: Calc. for $\text{C}_7\text{H}_{10}\text{Br}_2\text{F}_2\text{O}$ (FW 308): C, 27.27; H, 3.25; F, 12.34; Br, 51.95%. Found: C, 27.30; H, 3.27; F, 12.19; Br, 51.75%.

Methyl 10,12-dibromo-12,12-difluorotridecanoate (3e): Colourless oil, b.p. 150 °C/1 mmHg. ^{19}F NMR δ : –35 (s, CF_2Br) ppm. ^1H NMR δ : 4.1 (m, 1H, CHBr); 3.65 (s, 3H, OMe); 3.15–2.6 (m, 2H, CF_2CH_2); 2.20 (t, $^3J_{\text{HH}} = 3.5$ Hz, 2H, CH_2CO); 1.8–1.2 (m, 14H, $7 \times \text{CH}_2$) ppm. IR ν_{max} (cm^{-1}): 2900 (s, C–H); 1740 (s, C=O); 1220, 1180 (s, C–F); 660 (s, C–Br). MS m/z (%): 74 ($\text{C}_4\text{H}_7\text{F}^+$, 100); 55 (C_4H_7^+ , 87.96). Analysis: Calc. for $\text{C}_{13}\text{H}_{22}\text{Br}_2\text{F}_2\text{O}_2$ (FW 408): C, 38.24; H, 5.39%. Found: C, 38.25; H, 5.48%.

1-Bromodifluoromethyl-2-bromocyclohexane (3f) [6]: Colourless oil, b.p. 108–110 °C/40 mmHg. ^{19}F NMR δ : –23.5, –32 (AB, CF_2Br , *cis* isomer); –35 (s, CF_2Br , *trans* isomer) ppm. ^1H NMR δ : 4.8–3.7 (m, 1H, CHBr); 3.05 (m, 1H, CHCF_2); 1.9–1.1 (m, 8H, $4 \times \text{CH}_2$) ppm.

2,4-Dibromo-4,4-difluorobutyl acetate (3g): Colourless oil, b.p. 115–118 °C/10 mmHg. ^{19}F NMR δ : –34.8 (s, CF_2Br) ppm. ^1H NMR δ : 4.3 (m, 3H, $\text{CH}(\text{Br})\text{CH}_2\text{O}$); 3.8–2.8 (m, 2H, CH_2); 2.0 (s, 3H, Ac) ppm. IR ν_{max} (cm^{-1}): 1750 (s, C=O); 1240 (s, C–F); 930, 910 (m, C–Br). MS m/z (%): 309 ($\text{M}^+ + 1$, 21.99); 311 ($\text{M}^+ + 1$, 47.58); 313 ($\text{M}^+ + 1$, 30.98); 249 ($\text{M}^+ - \text{OAc}$, 15.82); 251 ($\text{M}^+ - \text{OAc}$, 28.59); 253 ($\text{M}^+ - \text{OAc}$, 13.32); 229 ($\text{M}^+ - \text{Br}$, 27.07); 231 ($\text{M}^+ - \text{Br}$, 33.79); 169 (100); 171 (82.81); 43 (98.44). Analysis: Calc. for $\text{C}_6\text{H}_8\text{Br}_2\text{F}_2\text{O}_2$ (FW 310): C, 23.24; H, 2.58; F, 12.26; Br, 51.61%. Found: C, 23.43; H, 2.49; F, 12.22; Br, 51.47%.

3-Bromomethyl-4-(2'-bromo-2',2'-difluoroethyl)tetrahydrofuran (3h): Colourless oil, b.p. 118–120 °C/20 mmHg. ^{19}F NMR δ : –35.0 (s, CF_2Br) ppm. ^1H NMR δ : 4.30–2.30 (m) ppm. Analysis: Calc. for $\text{C}_7\text{H}_{10}\text{Br}_2\text{F}_2\text{O}$ (FW 308): C, 27.27; H, 3.25; F, 12.34; Br, 51.95%. Found: C, 27.86; H, 3.25; F, 12.47; Br, 51.72%.

1,3-Dibromo-4-chloro-1,1-difluoropentane (3i) [6]: Colourless oil, b.p. 84–85 °C/20 mmHg. ^{19}F NMR δ : –34.5 (s, CF_2Br) ppm. ^1H NMR δ : 4.3 (m, 1H, CHBr); 3.8 (m, CH_2Cl); 3.3–1.8 (m, 2H, CH_2) ppm. IR ν_{max} (cm^{-1}): 1195 (s, C–F); 730 (m, C–Cl).

1,3-Dibromo-1,1-difluoro-3-phenylpropane (3j) [6]: ^{19}F NMR δ : –33.2 (s, CF_2Br) ppm. ^1H NMR δ : 6.93 (s, 5H, Ph); 5.10–4.80 (m, 1H, CHBr); 3.30–2.90 (m, 2H, CH_2CF_2) ppm.

1,3-Dibromo-1,1-difluoro-3-phenylprop-2-ene (3k) [6]: ^{19}F NMR δ : –36 (s, CF_2Br) ppm. ^1H NMR δ : 7.65 (s, 5H, Ph); 7.30–7.00 (m, 1H, CH) ppm.

Diethyl 2,4-dibromo-4,4-difluorobutylmanolate (**3l**): Colourless oil, b.p. 128 °C/1 mmHg. ^{19}F NMR δ : -35.0 (s, CF_2Br) ppm. ^1H NMR δ : 4.20 (q, $^3J_{\text{HH}} = 7$ Hz, 4H, $2 \times \text{OEt}$); 3.8–1.8 (m, 6H, others); 1.36 (t, $^3J_{\text{HH}} = 7$ Hz, 6H, $2 \times \text{OEt}$) ppm. IR ν_{max} (cm^{-1}): 1760, 1740 (s, $\text{C}=\text{O}$); 1200 (vs, $\text{C}-\text{F}$). MS m/z (%): 411 ($\text{M}^+ + 1$, 100); 413 ($\text{M}^+ + 1$, 73.67); 331 (50.34); 333 (21.47). Analysis: Calc. for $\text{C}_{11}\text{H}_{16}\text{Br}_2\text{F}_2\text{O}_4$ (FW 410): C, 32.20; H, 3.90; F, 9.27%. Found: C, 32.45; H, 3.86; F, 9.87%.

Preparation of $\text{KF}/\text{Al}_2\text{O}_3$ [8]

To 250 ml of water was added 20 g of KF (or 34 g of $\text{KF} \cdot 2\text{H}_2\text{O}$) and 30 g of natural alumina. The water was removed on a rotary evaporator at 50–70 °C, and the solid was then dried at 50 °C on a vacuum pump for 2 h until it became powdery. This $\text{KF}/\text{Al}_2\text{O}_3$ corresponded to 7 mmol F/1 g powder.

Dehydrobromination of 1,3-dibromides in the presence of $\text{KF}/\text{Al}_2\text{O}_3$. General procedure

A suspension consisting of 20 ml of acetonitrile or DMF (both commercial samples), 10 mmol of a 1,3-dibromide and 25 mmol of the above $\text{KF}/\text{Al}_2\text{O}_3$ powder was stirred at 40–50 °C for several hours. After the ^{19}F NMR and GC spectra showed that the 1,3-dibromide had been completely consumed, the mixture was filtered off. The filtrate was poured into water and extracted with diethyl ether (3×15 ml). The combined ethereal extracts were washed successively with saturated aq. NaHSO_3 solution, water and brine, and then dried over Na_2SO_4 . After removal of diethyl ether, the residue was distilled under reduced pressure to give the pure products.

1-Bromo-1,1-difluorohept-2-ene (**4a**): Volatile colourless oil, b.p. 78–87 °C/60 mmHg. ^{19}F NMR δ : -39 (s, $2\text{F} \times 5\%$, CF_2Br , *E* isomer); -33.5 (s, $2\text{F} \times 95\%$, CF_2Br , *Z* isomer) ppm. ^1H NMR δ : 6.8–6.6 (m, 2H, $\text{CH}=\text{CH}$); 2.6–2.4 (m, 2H, $\text{CH}_2\text{CH}=\text{}$); 1.8–0.8 (m, 7H, C_3H_7) ppm. IR ν_{max} (cm^{-1}): 2950 (s, $\text{C}-\text{H}$); 1650 (m, $\text{C}=\text{C}$); 1180 (s, $\text{C}-\text{F}$). MS m/z (%): 212 (M^+ , 0.95); 214 (M^+ , 0.95); 133 ($\text{M}^+ - \text{Br}$, 37.61); 83 (CF_2Br^+ , 11.08); 77 ($\text{CF}_2\text{CH}=\text{CH}^+$, 100); 57 (C_4H_9^+ , 11); 53 (C_3H_5^+ , 42.41). Analysis: Calc. for $\text{C}_7\text{H}_{11}\text{BrF}_2$ (FW 213): C, 39.44; H, 5.16; Br, 17.84; F, 37.56%. Found: C, 39.49; H, 5.17; F, 17.28; Br, 37.60%.

1-Bromo-1,1-difluoronon-2-ene (**4b**) [6]: Volatile colourless oil, b.p. 92–95 °C/60 mmHg. ^{19}F NMR δ : -40 (s, $2\text{F} \times 9\%$, CF_2Br , *Z* isomer); -35 (s, $2\text{F} \times 91\%$, CF_2Br , *E* isomer) ppm. ^1H NMR δ : 6.6–5.4 (m, 2H, $\text{CH}=\text{CH}$); 2.1 (m, $\text{CH}_2\text{C}=\text{}$); 1.8–0.8 (m, 11H, C_5H_{11}) ppm.

1-Bromo-1,1-difluorohept-2,6-diene (**4c**): Volatile colourless oil, b.p. 58–62 °C/30 mmHg. ^{19}F NMR δ : -39 (s, $2\text{F} \times 16\%$, CF_2Br , *E* isomer); -34 (s, $2\text{F} \times 84\%$, CF_2Br , *Z* isomer) ppm. ^1H NMR δ : 6.3 (m, 2H, $\text{CH}=\text{CH}$); 5.1–5.0 (m, 3H, $\text{CH}=\text{CH}_2$); 2.3–2.2 (m, 4H,

CH_2CH_2) ppm. IR ν_{max} (cm^{-1}): 1680, 1660 (w, $\text{C}=\text{C}$); 1200 (s, $\text{C}-\text{F}$). MS m/z (%): 211 ($\text{M}^+ + 1$, 7.03); 213 ($\text{M}^+ + 1$, 6.21); 131 ($\text{M}^+ - \text{Br}$, 100). Analysis: Calc. for $\text{C}_7\text{H}_9\text{BrF}_2$ (FW 211): HRMS: 211.9833. Found: HRMS: 211.9876.

1-Bromo-1,1-difluorohept-2-en-6-one (**4d**): Volatile colourless oil, b.p. 78–87 °C/60 mmHg. ^{19}F NMR δ : -36 (s, $2\text{F} \times 12\%$, CF_2Br , *E* isomer); -34 (s, $2\text{F} \times 88\%$, CF_2Br , *Z* isomer) ppm. ^1H NMR δ : 6.5–5.9 (m, 2H, $\text{CH}=\text{CH}$); 3.2–1.8 (m, 7H, others) ppm. IR ν_{max} (cm^{-1}): 1720, 1700 (s, $\text{C}=\text{O}$); 1660 (m, $\text{C}=\text{C}$); 1120, 1160 (s, $\text{C}-\text{F}$). MS m/z (%): 227 ($\text{M}^+ + 1$, 6.34); 229 ($\text{M}^+ + 1$, 6.67); 226 (M^+ , 2.55); 228 (M^+ , 2.2); 211 (3.77); 213 (3.66); 183 ($\text{M}^+ - \text{Ac}$, 1.34); 185 ($\text{M}^+ - \text{Ac}$, 1.28); 147 ($\text{M}^+ - \text{Br}$, 21.57); 103 (13.38); 43 (100). Analysis: Calc. for $\text{C}_7\text{H}_9\text{BrF}_2\text{O}$ (FW 227): HRMS: 226.9880 (^{79}Br); 228.9860 (^{81}Br). Found: HRMS: 226.9850 (^{79}Br); 228.9860 (^{81}Br).

Methyl 11-bromodifluoroundecenoate (**4e**): Colourless oil, b.p. 123–125 °C/1 mmHg. ^{19}F NMR δ : -39 (s, $2\text{F} \times 12\%$, CF_2Br , *E* isomer); -33.5 (s, $2\text{F} \times 88\%$, CF_2Br , *Z* isomer) ppm. ^1H NMR δ : 6.25–6.15 (m, 1H, $\text{CH}=\text{CH}$); 5.90–5.80 (m, 1H, $\text{CH}=\text{CH}$); 3.65 (s, 3H, OMe); 2.3 (t, $^3J_{\text{HH}} = 3.5$ Hz, 2H, CH_2CO); 2.15 (dt, $J_{\text{HH}} = 6$ Hz, 2H, $\text{CH}_2\text{CH}=\text{CH}$); 1.5–1.0 (m, 12H, $6 \times \text{CH}_2$) ppm. IR ν_{max} (cm^{-1}): 2900 (s, $\text{C}-\text{H}$); 1740 (s, $\text{C}=\text{O}$); 1660 (s, $\text{C}=\text{C}$); 1220, 1180 (s, $\text{C}-\text{F}$); 660 (s, $\text{C}-\text{Br}$). MS m/z (%): 327 ($\text{M}^+ + 1$, 1.35); 329 ($\text{M}^+ + 1$, 1.66); 295 ($\text{M}^+ - \text{OMe}$, 1.81); 297 ($\text{M}^+ - \text{OMe}$, 1.43); 307 (7.98); 309 (8.43); 247 (34.61); 175 (46.89); 55 (100). Analysis: Calc. for $\text{C}_{13}\text{H}_{21}\text{BrF}_2\text{O}_2$ (FW 327): C, 47.71; H, 6.42; F, 11.62%. Found: C, 47.62; H, 6.45; F, 11.98%.

Bromodifluoromethylcyclohex-1-ene (**4f**): Volatile colourless oil, b.p. 78–80 °C/60 mmHg. ^{19}F NMR δ : -29.5 (s, CF_2Br) ppm. ^1H NMR δ : 7.2 (s, 1H, $\text{CH}=\text{}$); 2.10 (m, 4H, $\text{CH}_2\text{CH}=\text{CCH}_2$); 1.7 (t, $^3J_{\text{HH}} = 2$ Hz, 4H, CH_2CH_2) ppm. IR ν_{max} (cm^{-1}): 1640 (s, $\text{C}=\text{C}$); 1280 (s, $\text{C}-\text{F}$). Analysis: Calc. for $\text{C}_7\text{H}_9\text{BrF}_2$ (FW 211): C, 39.81; H, 4.27; Br, 37.91%. Found: C, 39.94; H, 4.55; Br, 36.60%.

Bromodifluoromethylallyl acetate (**4g**): Volatile colourless oil, b.p. 77–79 °C/60 mmHg. ^{19}F NMR δ : -36 (s, $2\text{F} \times 5\%$, CF_2Br , *E* isomer); -33.5 (s, $2\text{F} \times 95\%$, CF_2Br , *Z* isomer) ppm. ^1H NMR δ : 6.3 (m, 1H, $\text{CH}=\text{}$); 5.3–4.2 (m, 3H, $\text{CH}_2\text{CH}=\text{}$); 2.0 (s, 3H, Ac) ppm. IR ν_{max} (cm^{-1}): 1750 (s, $\text{C}=\text{O}$); 1710 (w, $\text{C}=\text{C}$); 1220 (s, $\text{C}-\text{F}$). MS m/z (%): 229 ($\text{M}^+ + 1$, 2.14); 231 ($\text{M}^+ + 1$, 1.79); 169 ($\text{M}^+ - \text{OAc}$, 16.23); 171 ($\text{M}^+ - \text{OAc}$, 15.30); 90 (13.03); 44 (100). Analysis: Calc. for $\text{C}_5\text{H}_7\text{BrF}_2\text{O}_2$ (FW 229): C, 31.44; H, 3.06; F, 16.59%. Found: C, 31.52; H, 3.08; F, 16.66%.

1-Bromo-1,1-difluoro-4-chlorobut-2-ene (**4i**): Volatile colourless oil, b.p. 110–115 °C. ^{19}F NMR δ : -31.5 (s, 2F , CF_2Br) ppm. ^1H NMR δ : 6.25 (m, 2H, $\text{CH}=\text{CH}$);

4.15 (m, 2H, CH₂Cl) ppm. IR $\nu_{\max}$ (cm⁻¹): 1720 (s, C=O); 1220 (s, C-F); 740 (s, C-Cl); 660 (s, C-Br). MS m/z (%): 204 (M⁺, 1.51); 169 (M⁺ - Cl, 12.36); 171 (M⁺ - Cl, 10.91); 125 (100); 127 (33.21).

Diethyl 2-bromodifluoromethylmethyl-1,1-cyclopropanedicarboxylate (**5**): Colourless oil, b.p. 120–125 °C/5 mmHg. ¹⁹F NMR δ : -34 (s, CF₂Br) ppm. ¹H NMR δ : 4.2 (q, ³J_{HH} = 7 Hz, 4H, 2×OEt); 2.8–2.1 (m, 3H, CF₂CH₂CH); 1.50 (d, ³J_{HH} = 8 Hz, 2H, cyclo-CH₂); 1.26 (t, ³J_{HH} = 7 Hz, 6H, 2×OEt) ppm. ¹³C NMR δ : 168–167 (s, C=O); 121 (t, ²J_{FC} = 300 Hz, CF₂); 61 (OCH₂); 42.7 (t, ³J_{FC} = 22 Hz, CF₂CH₂); 32 (s, cyclo-C); 21.5 (t, ⁴J_{FC} = 5 Hz, cyclo-CH); 19.6 (cyclo-CH₂); 13.7 (CH₃) ppm. IR $\nu_{\max}$ (cm⁻¹): 1740, 1720 (s, C=O); 1280, 1220 (s, C-F). MS m/z (%): 329 (M⁺ + 1, 100); 331 (M⁺ + 1, 88.42); 283 (M⁺ - OEt, 42.70); 285 (M⁺ - OEt, 49.37); 250 (5.09). Analysis: Calc. for C₁₁H₁₅BrF₂O₄ (FW 328): C, 40.24; H, 4.57; F, 11.59; Br, 24.39%. Found: C, 39.88; H, 4.60; F, 11.97; Br, 24.71%.

1,2,3-Tribromo-1,1-difluoroheptane (**9**): Colourless oil, b.p. 115–117 °C/4 mmHg. ¹⁹F NMR δ : -33.0 (AB, J = 200 Hz, CF₂Br) ppm. ¹H NMR δ : 5.2–3.8 (m, 2H, CHBrCHBr); 2.3–0.8 (m, 9H, C₄H₉) ppm. IR $\nu_{\max}$ (cm⁻¹): 1080 (s, C-F); 690, 680, 655 (m, C-Br). MS m/z (%): 290 (2.10); 211 (23.2); 213 (21.5); 131 (100). Analysis: Calc. for C₇H₁₁Br₃F₂ (FW 373): C, 22.52; H, 2.95; F, 10.19; Br, 66.34%. Found: C, 22.49; H, 2.85; F, 9.98; Br, 66.61%.

1,2-Dibromo-1,1-difluorohept-2-ene (**10**). Volatile colourless oil, b.p. 83–84 °C/15 mmHg. ¹⁹F NMR δ :

-38 (s, 2F×42%, CF₂Br, *E* isomer); -32 (s, 2F×58%, CF₂Br, *Z* isomer) ppm. ¹H NMR δ : 1.6 (t, ³J_{HH} = 7.5 Hz, 1H, CH=); 2.4 (m, 2H, CH₂C=); 1.8–0.9 (m, 4H, CH₂CH₂); 0.8 (t, ³J_{HH} = 2 Hz, 3H, CH₃) ppm. IR $\nu_{\max}$ (cm⁻¹): 1630 (m, C=C); 1100 (s, C-F); 695 (s, C=C). MS m/z (%): 290 (M⁺, 2.15); 292 (M⁺, 3.99); 294 (M⁺, 2.12); 211 (24); 213 (20.8); 131 (100). Analysis: Calc. for C₇H₁₀Br₂F₂ (FW 292): C, 28.77; H, 3.42; F13.01%. Found: C, 28.85; H, 3.35; F, 12.95%.

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