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Decarboxylation of fluorosulfones for the preparation fluoroalkylidene precursors

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ABSTRACT

The synthesis of fluorosulfones by alkylation of fluoroacetate derivatives is reported. Their decarboxylation reaction under Krapcho conditions is a convenient process to prepare fluorosulfones as reagents for fluoroalkene synthesis.

Presentation of the Caen's group

The fluorine group of the UMR CNRS 6507 at the ENSICAEN, University of Caen, is managed by the Professor Thierry Lequeux since 1996, and Dr Emmanuel Pfund since 2006. The works of the group are focused on the synthesis of enzyme inhibitors and peptide mimics. To design new medicinal drugs the main objective is the development of new tools to allow short and rapid synthesis of fluoroorganic compounds containing a fluoroalkenes bridge or a difluorophosphonate unit. The two major topics are: (1) New applications of the Julia–Kocienski fluoroolefination reaction and (2) Rapid synthesis of difluoromethylphosphonates as phosphate mimics.

(1) Julia–Kocienski Fluoroolefination: a convenient one-step synthesis of fluoroethylidene derivatives.

Since many years, the group was focused on a straightforward synthesis of fluoro-olefins, and we described a modification of the Julia–Kocienski olefination to prepare, in only one step, fluoroalkylidene derivatives from a fluoroalkylbenzothiazolylsulfone and aldehydes or ketones. This method is general and was used to introduce other functional groups, to prepare peptide isosteres in few steps.

(2) Difluoromethylenephosphonate as mimics of phosphates.

The synthesis of difluoromethylphosphonates is becoming difficult due to environmental protective laws restricting the use of HCFCs and CFCs as starting chemicals. To circumvent this limitation, the group developed a sustainable fluorosulfide, which avoids the use of such reagents. This sulfide involves in the synthesis of enzyme inhibitors allows an easy access to fluorinated hydroxyphosphonates that are building blocks for the synthesis of acyclic nucleosides.

1. Introduction

New generations of modified pheromones, herbicides and medicines, which contain a fluoroolefin moiety present a better bioactivity than the original non-fluorinated compounds [1]. In this field, fluorinated peptide mimics represent an important class and it has been established that the fluorinated carbon–carbon double bond acts as a surrogate of an amide bond of a natural peptide [2].

The synthesis of monofluoroalkenes has mainly been achieved by elimination reactions on suitable substituted fluoroalkene precursors [3], modification of fluorovinyl sulfones, *gem*-bromofluoroalkenes, or fluoroalkenoates [4], as well as by methods that directly form the C=C(F) bond. Wittig-type methods are often applied for the synthesis of terminal fluoroalkenes, α-fluoro-α,β-unsaturated esters, as well as 1-fluoro-1-arylmethylidene derivatives. Recently, the Julia–Kocienski reaction has emerged as an attractive one-step method for fluoroalkene synthesis (Scheme 1) [5].

We, and others have described the Julia–Kocienski fluoroolefination of carbonyl compounds to prepare fluoroalkylidene derivatives in one step, from fluoroalkylbenzothiazolyl- or *N*-phenyltetrazolylsulfones and aldehydes or ketones (equation 1)

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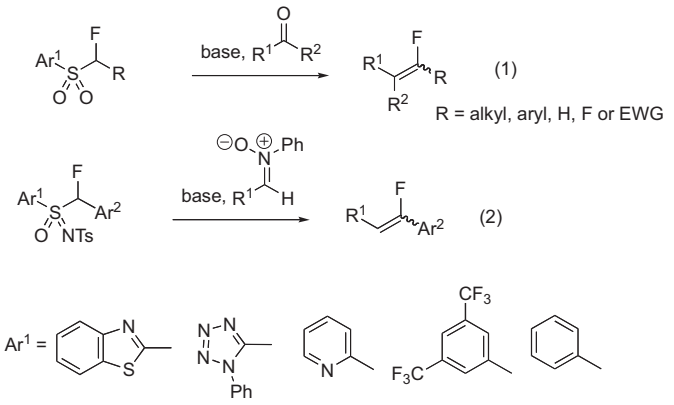
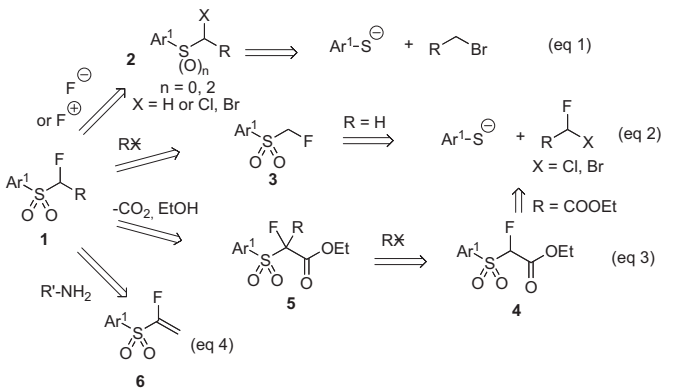


Scheme 1. One-step synthesis of fluoroalkenes.

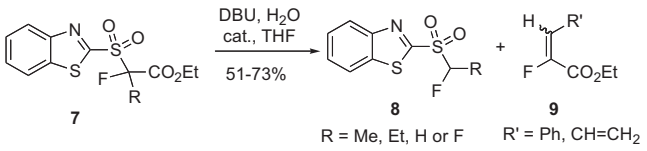
[6]. This olefination has proven an efficient way for the synthesis of α-fluoro-α,β-unsaturated esters, sulfones, nitriles, amides, and aryls from corresponding fluorosulfones [5d]. Recently, Hu introduced a modified method for monofluoroalkene synthesis using fluorosulfoximines and nitrones (Eq. (2) [7].

The Julia–Kocienski reaction is efficient and represents the most direct route to build non-conjugated fluoroalkylidene derivatives, as exemplified by a recent one step synthesis of allylamines [8]. However, the main limitation of this reaction is the synthesis of the starting reagents bearing an alkyl chain or a functionalized alkyl chain. For that reason different approaches for their synthesis have been reported in the literature (Scheme 2). These include the synthesis of fluoroalkylsulfones **1** by fluorination of the corresponding sulfones or α-halo-sulfides **2** (Eq. (1)) [6,9], by alkylation of the corresponding monofluorosulfone **3**, prepared from CH_2FCl (Eq. (2)) [10], and by aza-Michael addition of amines onto fluorovinylsulfones **6** (Eq. (4)) [8]. Interestingly, direct electrophilic fluorination of benzothiazolyl sulfones was reported to be low yielding [6b]. In a previous paper, we reported a complementary approach, which consists of preparing fluoroalkylsulfones **1** (Ar = benzothiazole) by alkylation of a sulfonylester derivative **4**, followed a decarbethoxylation reaction (Eq. (3)) [11,12].

During this study, it was noticed that the yield of the decarbethoxylation step, which required reflux conditions, decreased with increasing size of the alkyl chain [12]. In addition, undesired sulfone elimination leading to fluoroacrylates **9** was observed with allylic and benzylic substrates (Scheme 3). In this process, the formation of the difluoromethylsulfone (R=F) and the fluoromethylsulfone (R=H) were the most facile reactions and occur already at 20 °C, probably due to the high inductive effect of the fluoromethylene and the difluoromethylene groups.



Scheme 2. Synthesis of fluoroalkylsulfone.



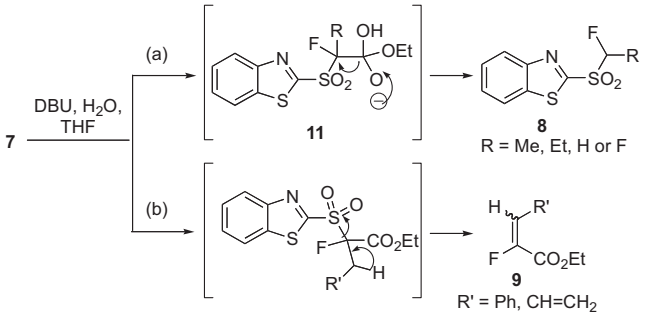
Scheme 3. Decarbethoxylation of sulfonylester derivatives.

In this paper, we report our recent progress for the synthesis of alkylated fluorosulfones related to structure **1**, in which an extended reaction scope is demonstrated both for the alkylation and decarboxylation reactions. In particular, alternative conditions have been developed, that allowed the exclusive decarboxylation of benzyl and allyl-substituted substrates and avoided the formation of acrylate derivatives **9**.

2. Results and discussion

The benzothiazolylsulfone **10** was synthesized according to the literature procedure [11], by alkylation of the mercaptobenzothiazole with ethyl bromofluoroacetate followed by the oxidation of the corresponding sulfide. We reported the alkylation of fluorosulfone **10**, in the presence of DBU, with reactive halides such as iodomethane, benzyl bromide and allyl iodide, in moderate to good yields (Table 1, entries 1,7,10) [12a]. This work was extended to other alkylhalides to afford sulfones **7a–j**. The alkylation reaction using primary alkyl iodides afforded the sulfones **7a–d** in good yield after 2–3 h under stirring at 20 °C (entries 1, 2, 4, 5). In order to avoid using iodoalkanes as reagents, the reaction was also investigated with bromoalkanes. However, reaction with ethyl bromide did not reach completion under the same conditions (not shown). Nevertheless, addition of a catalytic amount of Bu_4NI led to the alkylated sulfone in an equally good 79% yield (entry 3). With a β-substituted iodoalkane (entry 6) low yield was observed even after 16 h under stirring at room temperature. Substituted benzylbromide derivatives gave good yields (entries 8–9). Interestingly, the reaction with allyl bromide was higher-yielding compared to using allyl iodide (entries 10, 11). When substituted allyl bromides were involved the alkylation reaction proceeded smoothly and from 3- and 4-bromobutene a mixture of *E*/*Z* butenylsulfones (entries 12, 13) was obtained following a SN_2 and SN_2' pathway. Alkylation of **10** in the presence of Cs_2CO_3 was not efficient and observed yields were lower and did not exceed 50%.

With an improved alkylation method in hand, the decarboxylation reaction was investigated next (Table 2). Decarboxylation of fluorosulfones **7** mediated by DBU and a small amount of water (Table 2, Method A) is thought to proceed by attack of hydroxide on the ester function, to afford the tetrahedral intermediate **11** (Scheme 4). Subsequent elimination, either directly (as shown), or via the corresponding ester saponification product, leads to alkylsulfones **8** after *in situ* protonation (path a) [12,13]. This

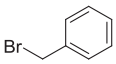
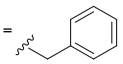
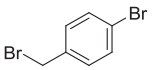
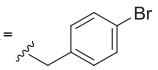
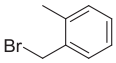
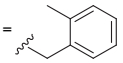
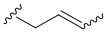
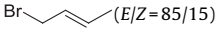
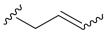


Scheme 4. Synthesis of the decarboxylated sulfone.

Table 1
Alkylation of the benzothiazole derivative.

10 **7a-j**

.

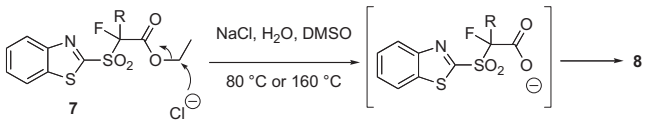
Entry	RX (1.2 equiv.)	Conditions	Product	Yield (%)
1	MeI	1 h, r.t.	**7a**, R = Me	92[a]
2	EtI	2 h, r.t.	**7b**, R = Et	79
3	EtBr	Bu_4NI (5 mol%), 4 h, r.t.		79
4	*n*-BuI	3 h, r.t.	**7c**, R = *n*-Bu	84
5	$C_{12}H_{25}I$ (2 equiv.)	3 h, r.t.	**7d**, R = $C_{12}H_{25}$	72
6	 (2.5 equiv.)	16 h, r.t.	**7e**, R = 	41
7		2 h, r.t.	**7f**, R = 	93[a]
8		2 h, r.t.	**7g**, R = 	77
9		2 h, r.t.	**7h**, R = 	67
10		X = I, 1 h, r.t.	**7i**, R = 	63[a]
11		X = Br, 2 h, r.t.		69
12		2 h, r.t.	**7j**, R = 	88 (*E*/*Z* = 80/20)
13	 (*E*/*Z* = 85/15)	2 h, r.t.	**7j**, R = 	60 (*E*/*Z* = 80/20)

[a] See [12a].

decarboxylation method works well for the unsubstituted substrate **10** (entry 1), but yields decrease rapidly with increasing steric bulk of the substituent, with no conversion at all in case of a butyl group (entries 2–4). Furthermore, in the case of allyl and benzyl substituents, an alternative base-induced desulfonylation process was observed leading to the corresponding α,β-unsaturated esters **9** (entries 6, 9) [14]. Presumably, this elimination process became competitive by the stabilization of the resulting products through conjugation.

To avoid this competitive desulfonylation reaction, decarboxylation of sulfone **7** under neutral Krapcho conditions (Scheme 5) appeared more attractive. In addition, as the reaction proceeds by nucleophilic attack of the chloride ion on the ester ethyl group, as opposed to the carbonyl group, this method was expected to be less susceptible to steric hindrance caused by bulky R-groups.

First, experiments were conducted to determine temperature and reaction time to reach completion. Decomposition of the



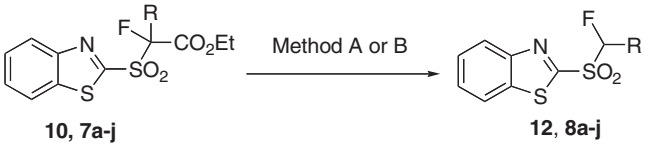
Scheme 5. Decarbethoxylation reaction under Krapcho conditions.

starting sulfone was observed at 190 °C (oil bath). At 130 °C the reagent and product appeared to be stable and the reaction reached completion after 8 h under stirring. Under these conditions, the corresponding fluoromethyl and ethyl sulfones **12** and **8a** were isolated in 54% and 81% yields, respectively (Table 2, entries 1 and 2). DMF as solvent was investigated but a complex mixture was obtained. Experiments with sodium chloride or lithium chloride led to the same yields, and the optimum amount of the chloride source was determined to be 2 equivalents. Water is necessary to the reaction: an experiment under strictly anhydrous conditions led to a moderate yield (<50%), and the optimum amount of water was established to be 10 equivalents (not shown). From the unsubstituted substrate **10**, Method A still provided the best yield in the decarboxylation (entry 1) [12].

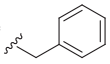
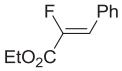
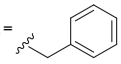
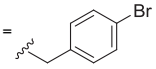
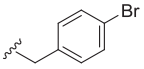
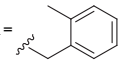
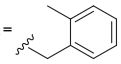
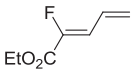
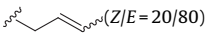
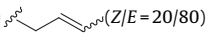
Substrates containing a larger alkyl chain, such as ethyl, butyl and dodecyl, gave the corresponding decarboxylation products **8b–d**, but a longer reaction time is required, and the yield erodes slightly with the chain length (entries 3–5). Nevertheless, reasonable yields were obtained, which represents a significant improvement compared to Method A.

Significantly, when benzyl and allyl substituents (entries 6–10) were investigated, no competitive sulfone elimination to give the acrylate derivatives **9** was observed, and the corresponding decarboxylation products **8f–j** were obtained in moderate to good yields. Sulfones **8**, **12** have already proven to be excellent reagents for the synthesis of fluoroalkylidenes [6].

Table 2
Scope of the decarboxylation reaction.



10, 7a-j **12, 8a-j**

Entry	R=	Method A[a]		Method B[c]	
		Product	Yield (%)	Product	Reaction time yield (%)
1	**10**, R = H	**12**, R = H	77[b]	**12**, R = H	8 h 54
2	**7a**, R = Me	**8a**, R = Me	52	**8a**, R = Me	8 h 81
3	**7b**, R = Et	**8b**, R = Et	33[b]	**8b**, R = Et	16 h 71
4	**7c**, R = *n*-Bu	**8c**, R = *n*-Bu	0	**8c**, R = *n*-Bu	16 h 65
5	**7d**, R = $C_{12}H_{25}$			**8d**, R = $C_{12}H_{25}$	16 h 53
6	**7f**, R = 		**9a**, 68(*Z*/*E* = 98:2)[b]	**8f**, R = 	16 h 62
7	**7g**, R = 			**8g**, R = 	16 h 40
8	**7h**, R = 			**8h**, R = 	16 h 70
9	**7i**, R = 		**9b**, 27 (*Z*/*E* = 86:14)[b]	**8i**, R = 	16 h 51
10	**7j**, R =  (*Z*/*E* = 20/80)			**8j**, R =  (*Z*/*E* = 20/80)	8 h 58

[a] Method A: DBU (1.7 equiv), H_2O catalytic, AcOEt, 50–70 °C, 16 h.
[b] Reported by [12a].
[c] Method B: NaCl (2 equiv), H_2O (10 equiv.), DMSO, 130 °C.

3. Conclusion

In conclusion, we report a significantly improved procedure for the synthesis of fluoroalkylsulfones, which are fluoroalkylidene precursors. This work is based on the alkylation of the easily available sulfonylester **10**, followed by its decarboxylation under Krapcho conditions to afford a variety of fluorosulfones in good yield. In addition, under these neutral decarboxylation conditions no competitive desulfonylation reaction was observed, which greatly increases the scope of the method to prepare a variety of heterocyclic fluorosulfones.

4. Experimental

4.1. General

All commercially available reagents were obtained from Aldrich and used as received. All glassware was dried overnight at 120 °C and cooled to room temperature under a continuous nitrogen flow. THF was dried using a solvent generator from "Innovative Technologies Inc.". HPLC grade ethyl acetate was used without further purification. Flash column chromatography was realized using silica gel 60 (40–63 μm) (Merck). Thin layer chromatography was performed using pre-coated TLC-sheets Alugram® SIL G/UV_{254} plates, on which the spots were visualized by UV-irradiation and/or by $KMnO_4$ solution. NMR spectra were recorded on a 300 MHz or 400 MHz apparatus in deuterated solvent at 25 °C. ^{19}F NMR spectral lines are with respect to the internal references $CFCl_3$. All chemical shifts are reported in δ parts per million (ppm) and coupling constants are in hertz (Hz). High-resolution mass data were recorded on a high-resolution mass spectrometer in the EI or ESI mode.

4.2. General procedure for the formation of alkylated sulfones 7a–j

To fluorosulfone **10**, dissolved in dry THF (0.07 M), alkylhalide (1.2 equiv.) and DBU (1.4 equiv.) were consecutively added dropwise. The reaction mixture was stirred at 20 °C, then quenched with saturated aqueous NH_4Cl and extracted with CH_2Cl_2. The combined organic layers were washed with brine and dried over anhydrous $MgSO_4$, filtered and concentrated under reduced pressure. The residue was purified by column chromatography,

and all compounds were obtained as solids after dissolution in CH_2Cl_2, followed by slow evaporation of the solvent.

4.2.1. Ethyl 2-(2-benzothiazolylsulfonyl)-2-fluoropropanoate (7a) [12a]

The general procedure was followed from **10** (1.50 g, 4.95 mmol), iodomethane (0.37 mL, 5.93 mmol, 1.2 equiv.), DBU (1.03 mL, 6.92 mmol, 1.4 equiv.) and THF (75 mL). The reaction mixture was stirred for 1 h. Column chromatography: pentane/AcOEt, 90:10. Yield of **7a** (mp 64–66 °C) as white crystals: 1.44 g, 92%. ^{1}H NMR (300 MHz, $CDCl_3$) δ 8.28–8.26 (m, 1H), 8.04–8.02 (m, 1H), 7.69–7.61 (m, 2H), 4.41–4.30 (m, 2H, $OC\underline{H}_2CH_3$), 2.17 (d, 3H, $^3J_{HF}$ 21.4 Hz), 1.28 (t, 3H, $^3J_{HH}$ 6.95 Hz, $OCH_2C\underline{H}_3$). ^{13}C NMR (75 MHz, $CDCl_3$) δ 163.2 (d, $^2J_{CF}$ 24.3 Hz, C=O), 160.3, 152.6, 137.9, 128.6, 127.9, 125.9, 122.2, 105.5 (d, $^1J_{CF}$ 233.3 Hz), 63.9 ($O\underline{C}H_2CH_3$), 17.8 (d, $^2J_{CF}$ 19.9 Hz), 13.8 ($OCH_2\underline{C}H_3$). ^{19}F NMR (282 MHz, $CDCl_3$) δ − 148.1 (q, 1F, $^3J_{HF}$ 21.4 Hz).

4.2.2. Ethyl 2-(benzothiazol-2-ylsulfonyl)-2-fluorobutanoate (7b) [12a]

The general procedure was followed from **10** (200 mg, 0.66 mmol), iodoethane (0.064 mL, 0.79 mmol, 1.2 equiv.), DBU (0.14 mL, 0.92 mmol, 1.4 equiv.) and THF (10 mL). The reaction mixture was stirred for 2 h. Column chromatography: pentane/AcOEt, 90:10. Yield of **7b** (mp 62–64 °C) as white crystals: 173 mg, 79%. ^{1}H NMR (300 MHz, $CDCl_3$) δ 8.29–8.26 (m, 1H), 8.06–8.03 (m, 1H), 7.70–7.61 (m, 2H), 4.43–4.33 (m, 2H, $OC\underline{H}_2CH_3$), 2.82–2.46 (m, 2H, $C\underline{H}_2CH_3$), 1.31 (t, 3H, $^3J_{HH}$ 7.1 Hz, $OCH_2C\underline{H}_3$), 1.08 (t, 3H, $^3J_{HH}$ 7.4 Hz, $CH_2C\underline{H}_3$). ^{13}C NMR (75 MHz, $CDCl_3$) δ 162.6 (d, $^2J_{CF}$ 25 Hz, C=O), 160.9, 152.7, 137.9, 128.6, 127.9, 126.0, 122.3, 108.4 (d, $^1J_{CF}$ 235.8 Hz), 63.8 ($O\underline{C}H_2CH_3$), 24.6 (d, $^2J_{CF}$ 19.9 Hz, $\underline{C}H_2CH_3$), 13.9 ($OCH_2\underline{C}H_3$), 7.0 (d, $^3J_{CF}$ 3.6 Hz, $CH_2\underline{C}H_3$). ^{19}F NMR δ − 158.9 (dd, $^3J_{HF}$ 37.6 Hz, $^3J_{HF}$ 11.8 Hz).

4.2.3. Ethyl 2-(2-benzothiazolylsulfonyl)-2-fluorohexanoate (7c)

The general procedure was followed with **10** (150 mg, 0.49 mmol), iodobutane (0.068 mL, 0.59 mmol, 1.2 equiv.), DBU (0.10 mL, 0.69 mmol, 1.4 equiv.) and THF (7.5 mL). The reaction mixture was stirred for 3 h. Column chromatography: pentane/AcOEt, 90:10. Yield of **7c** (mp 106–108 °C) as white crystals: 178 mg, 84%. IR (neat) 2960 (w), 1765 (s), 1348 (s), 1211 (s), 1162 (s) cm^{-1}. ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.27–8.25 (m, 1H), 8.048.02 (m, 1H), 7.687.60 (m, 2H), 4.424.31 (m, 2H, $OC\underline{H}_2CH_3$), 2.742.57 (m, 1H, $C\underline{H}_2CH_2CH_2CH_3$), 2.522.42 (m, 1H, $C\underline{H}_2CH_2CH_2CH_3$), 1.661.47 (m, 2H, $CH_2C\underline{H}_2CH_2CH_3$), 1.451.36 (m, 2H, $CH_2CH_2C\underline{H}_2CH_3$), 1.30 (t, 3H, $^3J_{HH}$ 7 Hz, $OCH_2C\underline{H}_3$), 0.92 (t, 3H, $^3J_{HH}$ 7 Hz, $CH_2CH_2CH_2C\underline{H}_3$) ^{13}C NMR (100 MHz, $CDCl_3$) δ 162.7 (d, $^2J_{CF}$ 25.3 Hz, C=O), 160.9, 152.6, 137.9, 128.5, 127.8, 125.9, 122.2, 108.1 (d, $^1J_{CF}$ 235.2 Hz), 63.7 ($O\underline{C}H_2CH_3$), 30.3 (d, $^2J_{CF}$ 19.4 Hz, $\underline{C}H_2CH_2CH_2CH_3$), 24.7 ($CH_2\underline{C}H_2CH_2CH_3$), 22.2 ($CH_2CH_2\underline{C}H_2CH_3$), 13.8 ($OCH_2\underline{C}H_3$), 13.6 ($CH_2CH_2CH_2\underline{C}H_3$). ^{19}F NMR (282 MHz, $CDCl_3$) δ − 157.0 (dd, 1F, $^3J_{HF}$ 38.7 Hz, $^3J_{HF}$ 12.9 Hz). MS (ESI+) m/z (%) 360.2 ((M+H)$^+$, 100). HRMS (MS+) for $C_{15}H_{18}FNO_4S_2Na$ (M+Na)$^+$ calcd 382.0553, found 382.0559.

4.2.4. Ethyl 2-(benzothiazol-2-ylsulfonyl)-2-fluorotetradecanoate (7d)

The general procedure was followed with **10** (200 mg, 0.66 mmol), iodododecane (0.33 mL, 1.32 mmol, 2 equiv.), DBU (0.14 mL, 0.92 mmol, 1.4 equiv.) and THF (10 mL). The reaction mixture was stirred for 3 h. Column chromatography: pentane/AcOEt, 95:5. Yield of **7d** (mp 68–70 °C) as white crystals: 224 mg, 72%. IR (neat) 2919 (m), 1750 (s), 1462 (m), 1356 (s), 1164 (s) cm^{-1}. ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.29–8.26 (m, 1H), 8.05–8.03 (m, 1H), 7.69–7.62 (m, 2H), 4.41–4.33 (m, 2H, $OC\underline{H}_2CH_3$), 2.65 (dddd, 1H, $^3J_{HF}$ 38.1 Hz, $^2J_{HH}$ 14.6 Hz, $^3J_{HH}$ 11.5 Hz, $^3J_{HH}$ 4.8 Hz), 2.46 (1H, dddd, $^2J_{HH}$ 14.6 Hz, $^3J_{HF}$ 10.9 Hz, $^3J_{HH}$ 9.8 Hz, $^3J_{HH}$ 5.0 Hz), 1.59–1.50 (m, 2H), 1.31 (t, 3H, $^3J_{HH}$ 7.2 Hz, $OCH_2C\underline{H}_3$), 1.25 (m, 18H), 0.88 (3H, t, $^3J_{HH}$ 6.8 Hz, $(CH_2)_{11}C\underline{H}_3$). ^{13}C NMR (100 MHz, $CDCl_3$) δ 162.8 (d, $^2J_{CF}$ 25.4 Hz, C=O), 160.9, 152.7, 137.9, 128.5, 127.8, 126.0, 122.2, 108.1 (d, $^1J_{CF}$ 235.2 Hz), 63.7 ($O\underline{C}H_2CH_3$), 31.9, 30.6 (d, $^2J_{CF}$ 19.9 Hz), 29.6 (2 C), 29.5, 29.3, 29.08, 29.05, 22.65, 22.62, 22.61, 14.1 ($(CH_2)_{11}\underline{C}H_3$), 13.9 ($OCH_2\underline{C}H_3$). ^{19}F NMR (376 MHz, $CDCl_3$) δ − 156.7 (dd, 1F, $^3J_{HF}$ 38.1 Hz, $^3J_{HF}$ 10.9 Hz). MS (ESI+) m/z (%) 472.3 ((M+H)$^+$, 100). HRMS (MS+) for $C_{23}H_{35}FNO_4S_2$ (M+H)$^+$ calcd 472.1992, found 472.1971.

4.2.5. Ethyl 2-(benzothiazol-2-ylsulfonyl)-2-fluoro-4-methylpentanoate (7e)

The general procedure was followed with **10** (500 mg, 1.65 mmol), 1-iodo-2-methylpropane (0.48 mL, 4.12 mmol, 2.5 equiv.), DBU (0.35 mL, 2.31 mmol, 1.4 equiv.) and THF (25 mL). The reaction mixture was stirred for 16 h. Column chromatography: pentane/AcOEt, 90:10. Yield of **7e** (mp 76 °C) as white crystals: 243 mg, 41%. IR (neat) 2963 (w), 1761 (s), 1459 (m), 1347 (s), 1316 (m), 1227 (s), 1151 (s) cm^{-1}. ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.29–8.27 (m, 1H), 8.06–8.03 (m, 1H), 7.69–7.62 (m, 2H), 4.44–4.31 (m, 2H, $OC\underline{H}_2CH_3$), 2.63 (ddd, 1H, $^3J_{HF}$ 40.9 Hz, $^2J_{HH}$ 14.7 Hz, $^3J_{HH}$ 6.8 Hz, $C\underline{H}_2CH(CH_3)_2$), 2.39 (ddd, 1H, $^2J_{HH}$ 14.7 Hz, $^3J_{HF}$ 8.2 Hz, $^3J_{HH}$ 6.8 Hz, $C\underline{H}_2CH(CH_3)_2$), 1.88 (1 H, tqq, $^3J_{HH}$ 6.8 Hz, $^3J_{HH}$ 6.8 Hz, $^3J_{HH}$ 6.8 Hz, $CH_2C\underline{H}(CH_3)_2$), 1.31 (t, 3H, $^3J_{HH}$ 14.3 Hz, $OCH_2C\underline{H}_3$), 1.00–0.97 (m, 6H, $CH_2CH(C\underline{H}_3)_2$). ^{13}C NMR (100 MHz, $CDCl_3$) δ 163.0 (d, $^2J_{CF}$ 25.4 Hz, C=O), 160.7, 152.6, 137.9, 128.5, 127.8, 126.0, 122.2, 108.3 (d, $^1J_{CF}$ 237.6 Hz), 63.7 ($O\underline{C}H_2CH_3$), 38.0 (d, $^2J_{CF}$ 19.1 Hz), 24.7, 23.0, 22.9 (d, $^4J_{CF}$ 2.2 Hz), 13.8 ($OCH_2\underline{C}H_3$). ^{19}F NMR (376 MHz, $CDCl_3$) δ −155.3 (dd, 1F, $^3J_{HF}$ 40.9 Hz, $^3J_{HF}$ 8.2 Hz). MS (ESI+) (m/z) 360.1 ((M+H)$^+$, 100%), 200.0 (66%), 182.0 (93%). HRMS (MS+) for $C_{15}H_{19}FNO_4S_2$ (M+H)$^+$ Calcd. 360.0740; Found. 360.0742.

4.2.6. Ethyl 2-(2-benzothiazolylsulfonyl)-2-fluoro-3-phenylpropanoate (7f) [12a]

The general procedure was followed with **10** (1.00 g, 3.3 mmol), benzylbromide (0.47 mL, 3.96 mmol, 1.2 equiv.), DBU (0.68 mL, 4.62 mmol, 1.4 equiv.) and THF (50 mL). The reaction mixture was stirred for 2 h. Column chromatography: pentane/AcOEt, 90:10. Yield of **7f** (mp 86–88 °C) as white crystals: 1.12 g, 86%. ^{1}H NMR (300 MHz, $CDCl_3$) δ 8.30–8.28 (m, 1H), 8.08–8.05 (m, 1H), 7.71–7.63 (m, 2H), 7.23–7.28 (m, 5H), 4.28–4.17 (m, 2H, $OC\underline{H}_2CH_3$), 3.90 (dd, 1H, $^3J_{HF}$ 38.7 Hz, $^2J_{HH}$ 14.6, $C\underline{H}_2Ph$), 3.82 (dd, 1H, $^2J_{HH}$ 14.6 Hz, $^3J_{HF}$ 12.9 Hz, $C\underline{H}_2Ph$), 1.16 (t, 3H, $^3J_{HH}$ 6.95 Hz, $OCH_2C\underline{H}_3$). ^{13}C NMR δ (75 MHz, $CDCl_3$) δ 161.8 (C=O, $^2J_{CF}$ 25.4 Hz), 160.7, 152.7, 137.9, 130.6, 130.3 (2 C),128.7 (2 C), 128.6, 128.1, 127.9, 126.0, 122.3, 107.2 (d, $^1J_{CF}$ 237.7 Hz), 63.6 ($O\underline{C}H_2CH_3$), 36.7 (d, $^2J_{CF}$ 18.80 Hz), 13.7 ($OCH_2\underline{C}H_3$). ^{19}F NMR (282 MHz, $CDCl_3$) δ − 155.0 (dd, 1F, $^3J_{HF}$ 38.7 Hz, $^3J_{HF}$ 12.9 Hz).

4.2.7. Ethyl 2-(benzothiazol-2-ylsulfonyl)-3-(4-bromophenyl)-2-fluoropropanoate (7g)

The general procedure was followed with **10** (200 mg, 0.66 mmol), 4-Bromobenzylbromide (198 mg, 0.79 mmol, 1.2 equiv.), DBU (0.14 mL, 0.92 mmol, 1.4 equiv.) and THF (10 mL). The reaction mixture was stirred for 2 h. Column chromatography: pentane/AcOEt, 90:10. Yield of **7 g** (mp 126–128 °C) as white crystals: 240 mg, 77%. IR (neat) 2360 (s), 2341 (s), 1750 (m), 1354 (m), 1162 (m), 1012 (m) cm^{-1}. ^{1}H NMR (300 MHz, $CDCl_3$) δ 8.30–8.27 (m, 1H), 8.08–8.03 (m, 1H), 7.72–7.63 (m, 2H), 7.43 (d, 2H, $^3J_{HH}$ 8.4 Hz), 7.12 (d, 2H, $^3J_{HH}$ 8.4 Hz), 4.29–4.18 (m, 2H, $OC\underline{H}_2CH_3$), 3.85 (dd, 1H, $^3J_{HF}$ 38.7 Hz, $^2J_{HH}$ 12.3 Hz, $C\underline{H}_2Ph$), 3.77 (dd, 1H, $^3J_{HF}$ 12.9 Hz, $^2J_{HH}$ 12.3 Hz, $C\underline{H}_2Ph$). 1.18 (t, 3H, $^3J_{HH}$ 7.0 Hz, $OCH_2C\underline{H}_3$). ^{13}C NMR (75 MHz, $CDCl_3$) δ 161.8 (d, $^2J_{CF}$ 24.9 Hz, C=O), 160.5, 152.7, 137.9, 132.0, 131.9, 129.6, 128.7, 128.0, 126.0, 122.4,

122.3, 106.8 (d, $^{1}J_{CF}$ 238.6 Hz), 63.8 ($O\underline{C}H_2CH_3$), 36.1 (d, $^{2}J_{CF}$ 18.8 Hz, $\underline{C}H_2Ph$) 13.8 ($OCH_2\underline{C}H_3$). ^{19}F NMR (282 MHz, $CDCl_3$) δ − 155.4 (dd, 1F, $^{3}J_{HF}$ 38.7 Hz, $^{3}J_{HF}$ 12.9 Hz). MS (ESI+) *m/z* (%) 474 ($(M-^{81}Br)^+$, (53)), 472 ($(M-^{79}Br)^+$, 52). HRMS (MS+) for $C_{18}H_{16}FNO_4S_2{}^{79}Br$ $(M+H)^+$ calcd, 471.9688 found. 471.9692.

4.2.8. Ethyl 2-(benzothiazol-2-ylsulfonyl)-2-fluoro-3-o-tolylpropanoate (7h)

The general procedure was followed with **10** (400 mg, 1.30 mmol), 2-Methylbenzylbromide (0.21 mL, 1.58 mmol, 1.2 equiv.), DBU (0.28 mL, 1.84 mmol, 1.4 equiv.) and THF (20 mL). The reaction mixture was stirred for 2 h. Column chromatography: pentane/AcOEt, 90:10.Yield of **7 h** (mp 112–114 °C) as white crystals: 359 mg, 67%. IR (neat) 2360 (s), 2341 (s), 1747 (m), 1164 (m), 1353 (m), 1160 (s) cm^{-1}. ^{1}H NMR (300 MHz, $CDCl_3$) δ 8.31–8.27 (m, 1H), 8.07–8.04 (m, 1H), 7.71–7.62 (m, 2H), 7.18–7.08 (m, 4H), 4.34–4.19 (m, 2H, $O\underline{C}H_2CH_3$), 4.12–3.96 (m, 2H, $C\underline{H}_2Ph$), 2.30 (s, 3H, Ph-$C\underline{H}_3$), 1.17 (t, 3H, $^{3}J_{HH}$ 7.1 Hz, $OCH_2C\underline{H}_3$). ^{13}C NMR (75 MHz, $CDCl_3$) δ 162.2 (d, $^{2}J_{CF}$ 24.9 Hz, C=O), 160.9, 152.7, 138.1, 137.8, 130.8, 130.3 (d, $^{4}J_{CF}$ 1.2 Hz), 129.3, 128.6, 128.1, 127.9, 126.1, 125.9, 122.3, 107.9 (d, $^{1}J_{CF}$ 239.4 Hz), 63.7 ($OCH_2\underline{C}H_3$), 33.3 (d, $^{2}J_{CF}$ 19 Hz, $\underline{C}H_2Ph$), 19.7 (d, $^{5}J_{CF}$ = 3.3 Hz, Ph-$\underline{C}H_3$), 13.7 ($O\underline{C}H_2CH_3$). ^{19}F NMR (282 MHz, $CDCl_3$) δ − 155.1 (dd, 1F, $^{3}J_{HF}$ 33.3 Hz, $^{3}J_{HF}$ 15.0 Hz). MS (ESI+) *m/z* (%) 430.2 ($(M+Na)^+$, 14), 408.2 ($(M+H)^+$, 5). HRMS (MS+) for $C_{19}H_{18}FNO_4S_2Na$ $(M+Na)^+$ calcd, 430.0553, found. 430.0554

4.2.9. Ethyl 2-(2-benzothiazolylsulfonyl)-2-fluoro-4-pentenoate (7i) [12a]

The general procedure was followed with **10** (800 mg, 2.64 mmol), allyl bromide (0.27 mL, 3.16 mmol, 1.2 equiv.), DBU (0.55 mL, 3.69 mmol, 1.4 equiv.) and THF (40 mL). The reaction mixture was stirred for 2 h. Column chromatography (Pentane/AcOEt, 90:10. Yield of **7i** (mp 84–86 °C) as white crystals: 340 mg, 69%. ^{1}H NMR (300 MHz,$CDCl_3$) δ 8.30–8.27 (m, 1H), 8.07–8.04 (m, 1H), 7.71–7.62 (m, 2H), 5.75–5.66 (m, 1H, $CH_2C\underline{H}{=}CH_2$), 5.36–5.28 (m, 2H, $CH_2CH{=}C\underline{H}_2$), 4.37 (q, 2H, $^{3}J_{HH}$ 7.3 Hz, $O\underline{C}H_2CH_3$), 3.50–3.21 (m, 2H, $C\underline{H}_2CH{=}CH_2$), 1.30 (t, 3H, $^{3}J_{HH}$ 7.3 Hz, $OCH_2C\underline{H}_3$). ^{13}C NMR (75 MHz, $CDCl_3$) δ 162.1 (d, $^{2}J_{CF}$ 25.4 Hz, C=O), 160.7, 152.7, 138.0, 128.6, 127.9, 126.7 ($CH_2\underline{C}H{=}CH_2$), 126.0, 122.7 ($CH_2CH{=}\underline{C}H_2$), 122.3, 106.8 (d, $^{1}J_{CF}$ 236.6 Hz), 63.8 ($O\underline{C}H_2CH_3$), 35.3 (d, $^{2}J_{CF}$ 18.8 Hz, ($\underline{C}H_2CH{=}CH_2$)), 13.9 ($OCH_2\underline{C}H_3$). ^{19}F NMR (282 MHz, $CDCl_3$) δ − 156.7 (dd, 1F, $^{3}J_{HF}$ 34.4 Hz, $^{3}J_{HF}$ 12.9 Hz).

4.2.10. Ethyl 2-(benzothiazol-2-ylsulfonyl)-2-fluorohex-4-enoate (7j)

The general procedure was followed with **10** (300 mg, 0.99 mmol), 3-Bromo-but-1-ene (0.12 mL, 1.19 mmol, 1.2 equiv.) or crotylbromide (0.12 mL, 1.19 mmol, 1.2 equiv.), DBU (0.21 mL, 1.38 mmol, 1.4 equiv.) and THF (15 mL). The reaction mixture was stirred for 2 h. Column chromatography: pentane/AcOEt, 90:10. Yield of **7j** as a mixture of (*E*)- and (*Z*)-alkenes in a ratio of 80/20 as white crystals: *m* = 310 mg, 88%. IR (neat) 2920 (w), 1469 (m), 1339 (s), 1315 (m), 1216 (m), 1156 (s) cm^{-1}. ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.29–8.27 (m, 1H), 8.06–8.03 (m, 1H), 7.69–7.62 (m, 2H), 5.83–5.70 (m, 1H, $CH_2CH{=}C\underline{H}CH_3$), 5.35–5.27 (m, 1H, $CH_2C\underline{H}{=}CHCH_3$), 4.39–4.30 (m, 2H, $O\underline{C}H_2CH_3$), 3.58–3.14 (m, 2H, $C\underline{H}_2CH{=}CHCH_3$), 1.68–1.67 (m, 3H, $CH_2CH{=}CHC\underline{H}_3$), 1.30 (t, 3H, $OCH_2C\underline{H}_3$, $^{3}J_{HH}$ 7.3 Hz). ^{13}C NMR (100 MHz, $CDCl_3$) δ 161.9 (d, $^{2}J_{CF}$ 24.6 Hz), 160.5, 152.4, 137.6, 133.5 ($CH_2CH{=}\underline{C}HCH_3$, *E*), 131.5 ($CH_2CH{=}\underline{C}HCH_3$, *Z*), 128.3, 127.5, 125.7, 121.9, 118.6 (d, $^{3}J_{CF}$ 2.4 Hz, $CH_2\underline{C}H{=}CHCH_3$), 106.8 (d, $^{1}J_{CF}$ 236 Hz), 63.5 ($O\underline{C}H_2CH_3$, *Z*), 63.4 ($O\underline{C}H_2CH_3$, *E*), 34.0 (d, $^{2}J_{CF}$ 19 Hz, $\underline{C}H_2CH{=}CHCH_3$), 17.8 ($CH_2CH{=}C\underline{H}CH_3$, *E*), 13.6 ($OCH_2\underline{C}H_3$, *E*), 13.5 ($OCH_2\underline{C}H_3$, *Z*), 12.8 ($CH_2CH{=}C\underline{H}CH_3$, *Z*). ^{19}F NMR (376 MHz, $CDCl_3$) δ–156.4 (dd, 1F, $^{3}J_{HF}$ 36.8 Hz, $^{3}J_{HF}$ 9.5 Hz, *Z*),–156.5 (dd, 1F, $^{3}J_{HF}$ 36.8 Hz, $^{3}J_{HF}$ 10.9 Hz, *E*). MS (ESI+) (*m/z*) 358.1 ($(M+H)^+$, 34), 200.0 (31), 182.0 (100). HRMS (MS+) for $C_{15}H_{17}FNO_4S_2$ $(M+H)^+$ calcd. 358.0583, found 358.0594.

4.3. General procedure for the formation of decarboxylated sulfones 13 and 8a–j

The sulfone (**10**, **7a**–**j**) was dissolved in DMSO (0.75 M), then NaCl (2 equiv.) and H_2O (10 equiv.) were added. The resulting mixture was stirred for 8 h or 16 h at 130 °C. DMSO was removed under high vacuum and the residue was dissolved in CH_2Cl_2. The organic phase was washed with brine, dried over $MgSO_4$, and concentrated under reduced pressure. The residue was purified by column chromatography.

4.3.1. 2-(Fluoromethylsulfonyl)benzothiazole (12) [6a,12a]

The general procedure was followed with **10** (250 mg, 0.82 mmol), DMSO (1.1 mL), NaCl (96 mg, 1.64 mmol) and H_2O (0.15 mL, 8.2 mmol). Column chromatography: pentane/AcOEt, 90:10. The product was obtained after dissolution in CH_2Cl_2 followed by slow evaporation of the solvent. Yield of **12** (mp 144–146 °C) as white crystals: 103 mg, 54%). ^{1}H NMR (300 MHz, $CDCl_3$) δ 8.28–8.25 (m, 1H), 8.07–8.04 (m, 1H), 7.71–7.62 (m, 2H), 5.60 (d, 2H, $^{2}J_{HF}$ 47.3 Hz). ^{13}C NMR (75 MHz, $CDCl_3$) δ 162.2, 152.7, 137.3, 128.5, 128.0, 125.8, 122.4, 90.6 (d, $^{1}J_{CF}$ 223.4 Hz). ^{19}F NMR (282 MHz, $CDCl_3$) δ − 211.1 (t, 1F, $^{2}J_{HF}$ 47.3 Hz).

4.3.2. 2-(2-Fluoroethylsulfonyl)benzothiazole (8a) [6,12a]

The general procedure was followed with **7a** (250 mg, 0.79 mmol), DMSO (1.05 mL), NaCl (92 mg, 1.58 mmol) and H_2O (0.14 mL, 7.90 mmol). Column chromatography: pentane/AcOEt, 90:10. The product was obtained after dissolution in CH_2Cl_2 followed by slow evaporation of the solvent. Yield of **8a** (mp 76–78 °C) as a white crystals: 156 mg, 81%. ^{1}H NMR (300 MHz, $CDCl_3$) δ 8.29–8.26 (m, 1H), 8.06–8.03 (m, 1H), 7.70–7.60 (m, 2H), 5.84 (dq, 1H, $^{2}J_{HF}$ 48.0 Hz, $^{3}J_{HH}$ 6.5 Hz, $C\underline{H}_2F$), 1.91 (dd, 3H, $^{3}J_{HF}$ 25.8 Hz, $^{3}J_{HH}$ 6.5 Hz, $C\underline{H}_3$). ^{13}C NMR (75 MHz, $CDCl_3$) δ 162.0, 152.8, 137.4, 128.4, 127.8, 125.8, 122.3, 99.4 (d, $^{1}J_{CF}$ 220 Hz), 13.0 (d, $^{2}J_{CF}$ 19.9 Hz, $\underline{C}H_3$). ^{19}F NMR (282 MHz, $CDCl_3$) δ − 171.8 (dq, 1F, $^{2}J_{HF}$ 48.0 Hz, $^{3}J_{HF}$ 25.8 Hz).

4.3.3. 2-(1-Fluoropropylsulfonyl)benzothiazole (8b) [6,12a]

The general procedure was followed with **7b** (157 mg, 0.47 mmol), DMSO (0.63 mL), NaCl (55.3 mg, 0.95 mmol) and H_2O (0.085 mL, 4.7 mmol). Column chromatography: pentane/AcOEt, 90:10. The product was obtained after dissolution in CH_2Cl_2 followed by slow evaporation of the solvent. Yield of **8b** (mp 100–102 °C) as white crystals: 87.2 mg, 71%. ^{1}H NMR (300 MHz, $CDCl_3$) δ 8.26–8.23 (m, 1H), 8.04–8.01 (m, 1H), 7.68–7.58 (m, 2H), 5.61 (ddd, 1H, $^{2}J_{HF}$ 49.4 Hz, $^{3}J_{HH}$ 9.3 Hz, $^{3}J_{HH}$ 3.6 Hz, C$\underline{H}$F), 2.45–2.04 (m, 2H, $C\underline{H}_2CH_3$), 1.21 (t, 3H, $^{3}J_{HH}$ 7.5 Hz, $CH_2C\underline{H}_3$). ^{13}C NMR (75 MHz, $CDCl_3$) δ 162.5, 152.7, 137.3, 128.3, 127.7, 125.6, 122.3, 103.1 (d, $^{1}J_{CF}$ 222.0 Hz), 20.8 (d, $^{2}J_{CF}$ 19.6 Hz, $\underline{C}H_2CH_3$), 8.8 (d, $^{3}J_{CF}$ 3.9 Hz, $CH_2\underline{C}H_3$). ^{19}F NMR (282 MHz, $CDCl_3$) δ − 179.4 (ddd, 1F, $^{2}J_{HF}$ 49.4 Hz, $^{3}J_{HF}$ 33.3 Hz, $^{3}J_{HF}$ 16.1 Hz).

4.3.4. 2-(2-Fluoropentanylsulfonyl)benzothiazole (8c)

The general procedure was followed with **7c** (302 mg, 0.84 mmol), DMSO (1.12 mL), NaCl (98 mg, 1,68 mmol) and H_2O (0.15 mL, 8,40 mmol). Column chromatography: pentane/AcOEt, 90:10. The product was obtained after dissolution in CH_2Cl_2 followed by slow evaporation of the solvent. Yield of **8c** (mp 84–86 °C) as white crystals: 157 mg, 65%. IR (neat) 2955 (w), 2359 (m), 1468 (m), 1228 (s), 1160 (s) cm^{-1}. ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.28–8.26 (m, 1H), 8.05–8.03 (m, 1H), 7.68–7.61 (m, 2H), 5.67 (ddd, 1H, $^{2}J_{HF}$ 51.8 Hz, $^{3}J_{HH}$ 10 Hz, $^{3}J_{HH}$ 3.5 Hz, C$\underline{H}$F), 2.39–2.11 (m, 2H, $C\underline{H}_2CH_2CH_2CH_3$), 1.71–1.58 (m, 2H, $CH_2C\underline{H}_2CH_2CH_3$), 1.49–1.40

(m, 2H, $CH_2CH_2C\underline{H}_2CH_3$), 0.96 (t, 3H, $^3J_{HH}$ 7 Hz, $CH_2CH_2CH_2C\underline{H}_3$). ^{13}C NMR (100 MHz, $CDCl_3$) δ 162.6, 152.8, 137.4, 128.3, 127.8, 125.7, 122.3, 102.3 (d, $^1J_{CF}$ 221 Hz), 26.5 (d, $^2J_{CF}$ 18.5 Hz, $\underline{C}H_2CH_2CH_2CH_3$), 26.4 ($CH_2\underline{C}H_2CH_2CH_3$), 22.0 ($CH_2CH_2\underline{C}H_2CH_3$), 13.6 ($CH_2CH_2CH_2\underline{C}H_3$). ^{19}F NMR (282 MHz, $CDCl_3$) δ − 178.1 (ddd, $^2J_{HF}$ 51.8 Hz, $^3J_{HF}$ 34.0 Hz, $^3J_{HF}$ 17.2 Hz). MS (ESI+) *m/z* (%) 288.1 ($(M+H)^+$, 15). HRMS (MS+) for $C_{12}H_{15}FNO_2S_2$ $(M+H)^+$ calcd 288.0523, found 288.0526.

4.3.5. 2-(1-Fluorotridecylsulfonyl)benzothiazole (8d)

The general procedure was followed with **7d** (396 mg, 0.84 mmol), DMSO (1.12 mL), NaCl (98 mg, 1.68 mmol) and H_2O (0.15 mL, 8.4 mmol). Column chromatography: pentane/AcOEt, 95:5. The product was obtained after dissolution in CH_2Cl_2 followed by slow evaporation of the solvent. Yield of **8d** (mp 86 °C) as white crystals: 177 mg, 53%. IR (neat) 2917 (s), 2848 (w), 1468 (m), 1351 (s), 1318 (w), 1160 (s) cm^{-1}. ^1H NMR (400 MHz, $CDCl_3$) δ 8.30–8.27 (m, 1H), 8.06–8.04 (m, 1H), 7.70–7.62 (m, 2H), 5.66 (ddd, 1H, $^2J_{HF}$ 49.0 Hz, $^3J_{HH}$ 9.9 Hz, $^3J_{HH}$ 3.1 Hz, C$\underline{H}$F), 2.37–2.09 (m, 2H), 1.73–1.52 (m, 2H), 1.45–1.22 (m, 18H), 0.89 (t, 3H, $^3J_{HH}$ 6.8 Hz, $(CH_2)_{11}C\underline{H}_3$). ^{13}C NMR (100 MHz, $CDCl_3$) δ 162.6, 152.9, 137.5, 128.3, 127.8, 125.8, 122.3, 102.3 (d, $^1J_{CF}$ 222.5 Hz), 31.9, 29.6, 29.5, 29.4, 29.3, 29.2, 28.9, 26.8 (d, $^2J_{CF}$ 19.2 Hz), 24.4 (d, $^3J_{CF}$ 2.2 Hz), 22.7, 14.1 ($(CH_2)_{11}\underline{C}H_3$). ^{19}F NMR (376 MHz, $CDCl_3$) δ − 177.8 (ddd, 1F, $^2J_{HF}$ 49.0 Hz, $^3J_{HF}$ 36.8 Hz, $^3J_{HF}$ 16.4 Hz). MS (ESI+)(*m/z*) 400.3 ($(M+H)^+$, 100), 200.0 (26), 182.0 (69). HRMS (MS+) for $C_{20}H_{31}FNO_2S_2$ $(M+H)^+$ calcd. 400.1780, found 400.1765.

4.3.6. 2-(2-Fluorophenylethylsulfonyl)benzothiazole (8f)

The general procedure was followed with **7f** (200 mg, 0.5 mmol), DMSO (0.67 mL), NaCl (59.4 mg, 1 mmol) and H_2O (0.09 mL, 5 mmol). Column chromatography: pentane/AcOEt, 90:10. The product was obtained after dissolution in CH_2Cl_2 followed by slow evaporation of the solvent. Yield of **8f** (mp 106–108 °C) as white crystals: 99.7 mg, 62%. IR (neat) 2943 (w), 1759 (w), 1340 (s), 1153 (s), 1077 (s) cm^{-1}. ^1H NMR (400 MHz, $CDCl_3$) δ 8.23–8.21 (m, 1H), 8.01–7.99 (m, 1H), 7.64–7.57 (m, 2H), 7.32–7.22 (m, 5H), 5.79 (ddd, 1H, $^2J_{HF}$ 47.3 Hz, $^3J_{HH}$ 10.5 Hz, $^3J_{HH}$ 2.5 Hz, C$\underline{H}$F), 3.65 (ddd, 1H, $^3J_{HF}$ 38.7 Hz, $^2J_{HH}$ 14.9 Hz, $^3J_{HH}$ 2.5 Hz, C$\underline{H}_2$Ph), 3.42 (ddd, 1H, $^3J_{HF}$ 17.2 Hz, $^2J_{HH}$ 14.9 Hz, $^3J_{HH}$ 10.5 Hz, C$\underline{H}_2$Ph). ^{13}C NMR (100 MHz, $CDCl_3$) δ 162.2, 152.8, 137.4, 133.0, 129.5, 128.9, 128.4, 127.9, 127.8, 125.8, 122.3, 102.2 (d, $^1J_{CF}$ 225.5 Hz), 33.2 (d, $^2J_{CF}$ 19.4 Hz, $\underline{C}H_2$Ph). ^{19}F NMR (282 MHz, $CDCl_3$) δ − 178.0 (ddd, 1F, $^2J_{HF}$ 47.3 Hz, $^3J_{HF}$ 38.7 Hz, $^3J_{HF}$ 17.2 Hz). MS (ESI+) *m/z* (%) 344.0 ($(M+Na)^+$, 100), 322.0 ($(M+H)^+$, 69). HRMS (MS+) for $C_{15}H_{12}FNO_2S_2Na$ $(M+Na)^+$ calcd 344.0186, found 344.0190.

4.3.7. 2-(2-(4-Bromophenyl)-1-fluoroethylsulfonyl) benzothiazole (8g)

The general procedure was followed with **7g** (151 mg, 0.32 mmol), DMSO (0.44 mL), NaCl (37 mg, 0.64 mmol) and H_2O (0.058 mL, 3.2 mmol). Column chromatography: pentane/AcOEt, 90:10. The product was obtained after dissolution in CH_2Cl_2 followed by slow evaporation of the solvent. Yield of **8g** (mp 136–138 °C) as white crystals: 50,4 mg, 40%. IR (neat) 2360 (s), 2341 (s), 1466 (m), 1342 (s), 1155 (s), 1012 (m) cm^{-1}. ^1H NMR (300 MHz, $CDCl_3$) δ 8.27–8.24 (m, 1H), 8.07–8.04 (m, 1H), 7.70–7.61 (m, 2H), 7.47 (d, 2H, $^3J_{HH}$ 8.4 Hz), 7.18 (d, 2H, $^3J_{HH}$ 8.4 Hz), 5.79 (ddd, 1H, $^2J_{HF}$ 48.4 Hz, $^3J_{HH}$ 10.2 Hz, $^3J_{HH}$ 2.4 Hz, C$\underline{H}$F), 3.60 (ddd, 1H, $^3J_{HF}$ 38.7 Hz, $^2J_{HH}$ 14.9 Hz, $^3J_{HH}$ 2.3 Hz, C$\underline{H}_2$Ph), 3.39 (ddd, 1H, $^3J_{HF}$ 17.2 Hz, $^2J_{HH}$ 14.9 Hz, $^3J_{HH}$ 10.2 Hz, CH_2Ph). ^{13}C NMR (75 MHz, $CDCl_3$) δ 162.0, 152.8, 137.4, 132.0, 131.9, 131.2, 128.5, 127.9, 125.8, 122.3, 121.9, 101.7 (d, $^1J_{CF}$ 224.7 Hz), 32.8 (d, $^2J_{CF}$ 19.4 Hz, $\underline{C}H_2$Ph). ^{19}F NMR (282 MHz, $CDCl_3$) δ − 177.2 (ddd, $^2J_{HF}$ 48.4, $^3J_{HF}$ 38.7 Hz, $^3J_{HF}$ 17.2 Hz). MS (ESI+) (*m/z*) 400.0 ($(M+H)^+$, 49), 182 (100). HRMS (MS+) for $C_{15}H_{12}FNO_2S_2Br$ $(M+H)^+$ calcd 399.9477, found 399.9483.

4.3.8. 2-(1-Fluoro-2-o-tolylethylsulfonyl)benzothiazole (8h)

The general procedure was followed with **7 h** (178.5 mg, 0.439 mmol), DMSO (0.60 mL), NaCl (51.3 g, 0.88 mmol) and H_2O (0.08 mL, 4.4 mmol). Column chromatography: pentane/AcOEt, 90:10. The product was obtained after dissolution in CH_2Cl_2 followed by slow evaporation of the solvent. Yield of **8 h** (mp 120–122 °C) as white crystals: 102.3 mg, 70%. IR (neat) 2360 (s), 2341 (s), 1466 (m), 1343 (m), 1155 (s) cm^{-1}. ^1H NMR (300 MHz, $CDCl_3$) δ 8.28–8.26 (m, 1H), 8.07–8.04 (m, 1H), 7.71–7.61 (m, 2H), 7.26–7.15 (m, 4H), 5.80 (ddd, 1H, $^2J_{HF}$ 47.3 Hz, $^3J_{HH}$ 10.5 Hz, $^3J_{HH}$ 2.1 Hz, C$\underline{H}$F), 3.69 (ddd, 1H, $^3J_{HF}$ 39.8 Hz, $^2J_{HH}$ 15.6 Hz, $^3J_{HH}$ 2.1 Hz, C$\underline{H}_2$Ph), 3.44 (ddd, 1H, $^3J_{HF}$ 16.1 Hz, $^2J_{HH}$ 15.6 Hz, $^3J_{HH}$ 10.5 Hz, C$\underline{H}_2$Ph), 2.39 (s, 3H, Ph-C$\underline{H}_3$). ^{13}C NMR (75 MHz, $CDCl_3$) δ 162.3, 152.8, 137.4, 137.0, 131.4, 130.8, 130.3, 128.4, 127.9, 126.4, 125.8, 122.3, 101.9 (d, $^1J_{CF}$ 224.7 Hz), 30.4 (d, $^2J_{CF}$ 19.6 Hz, $\underline{C}H_2$Ph), 19.5 (d, $^5J_{CF}$ 1.1 Hz, Ph-$\underline{C}H_3$). ^{19}F NMR (282 MHz, $CDCl_3$) δ − 177.3 (ddd, $^2J_{HF}$ 47.3 Hz, $^3J_{HF}$ 39.8 Hz, $^3J_{HF}$ 16.1 Hz). MS (ESI+) (*m/z*) 336.1 ($(M+H)^+$, 14), 332.3 (17), 331.3 (77), 241.1 (20). HRMS (MS+) for $C_{16}H_{14}FNO_2S_2Na$ $(M+Na)^+$ calcd. 358.0342, found. 358.0342.

4.3.9. 2-(1-Fluorobut-3-enylsulfonyl)benzothiazole (8i)

The general procedure was followed with **7i** (154 mg, 0.45 mmol), DMSO (0.60 mL), NaCl (53 mg, 0.90 mmol) and H_2O (0.08 mL, 4.45 mmol). Column chromatography: pentane/AcOEt, 90:10. The product was obtained after dissolution in CH_2Cl_2 followed by slow evaporation of the solvent. Yield of **8i** (mp 92–94 °C) as white crystals: 62 mg, 51%. IR (neat) 2960 (w), 2360 (s), 2342 (s), 1464 (m), 1337 (m), 1318 (m), 1154 (m) cm^{-1}. ^1H NMR (400 MHz, $CDCl_3$) δ 8.27–8.25 (m, 1H), 8.05–8.03 (m, 1H), 7.68–7.60 (m, 2H), 5.92–5.82 (m, 1H, $CH_2C\underline{H}{=}CH_2$), 5.71 (ddd, 1H, $^2J_{HF}$ 47.3 Hz, $^3J_{HH}$ 9.54 Hz, $^3J_{HH}$ 3.5 Hz, C$\underline{H}$F), 5.35–5.28 (m, 2H, $CH_2CH{=}C\underline{H}_2$), 3.15–2.86 (m, 2H, $C\underline{H}_2CH{=}CH_2$). ^{13}C NMR (100 MHz, $CDCl_3$) δ 162.2, 152.8, 137.4, 128.7 (d, $^3J_{CF}$ 1.9 Hz, $CH_2\underline{C}H{=}CH_2$), 128.4, 127.8, 125.7, 122.3, 120.9 ($CH_2CH{=}\underline{C}H_2$), 101.2 (d, $^1J_{CF}$ 223.5 Hz), 31.5 (d, $^2J_{CF}$ 19.4 Hz, $\underline{C}H_2CH{=}CH_2$). ^{19}F NMR (282 MHz, $CDCl_3$) δ − 178.0 (ddd, 1F, $^2J_{HF}$ 47.3 Hz, $^3J_{HF}$ 34.4 Hz, $^3J_{HF}$ 17.2 Hz). MS (ESI+) *m/z* (%) 272.1 ($(M+H)^+$, 6). HRMS (MS+) for $C_{11}H_{10}FNO_2S_2Na$ $(M+Na)^+$ calcd. 294.0029, found 294.0034.

4.3.10. 2-(1-Fluoropent-3-enylsulfonyl)benzothiazole (8j)

The general procedure was followed with **7j** (300 mg 0.84 mmol), DMSO (1.12 mL), NaCl (98 mg, 1.68 mmol) and H_2O (0.15 mL, 8.40 mmol). Column chromatography: pentane/AcOEt, 90:10. The product was obtained after dissolution in CH_2Cl_2 followed by slow evaporation of the solvent. Yield of **8j** as a mixture of (*E*)- and (*Z*)-alkenes in a ratio of 80/20 as white crystals: 138 mg, 58%. IR (neat) 2989 (w), 1769 (s), 1460 (m), 1317 (m), 1347 (s), 1265 (m), 1217 (s), 1140 (m) cm^{-1}. ^1H NMR (400 MHz, $CDCl_3$) δ 8.29–8.26 (m, 1H), 8.06–8.04 (m, 1H), 7.70–7.61 (m, 2H), 5.82–5.56 (m, 2H), 5.51–5.43 (m, 1H, $CH_2C\underline{H}{=}CHCH_3$), 3.08–2.78 (m, 2H, $C\underline{H}_2CH{=}CHCH_3$), 1.72–1.69 (m, 3H, $CH_2CH{=}CHC\underline{H}_3$). ^{13}C NMR (100 MHz, $CDCl_3$) δ 162.4, 152.8, 137.4, 132.1 ($CH_2CH{=}\underline{C}HCH_3$, *E*), 130.4 ($CH_2CH{=}\underline{C}HCH_3$, *Z*), 128.4, 127.8, 125.8, 122.3, 121.1 (d, $^3J_{CF}$ 2.4 Hz, $CH_2\underline{C}H{=}CHCH_3$, *E*), 120.1 (d, $^3J_{CF}$ 2.4 Hz, $CH_2\underline{C}H{=}CHCH_3$, *Z*), 101.63 (d, $^1J_{CF}$ 223.3 Hz, *E*), 101.55 (d, $^1J_{CF}$ 224.1 Hz, *Z*), 30.5 (d, $^2J_{CF}$ 19.9 Hz, $\underline{C}H_2CH{=}CHCH_3$, *E*), 25.0 (d, $^2J_{CF}$ 19.9 Hz, $\underline{C}H_2CH{=}CHCH_3$, *Z*), 18.0 ($CH_2CH{=}CH\underline{C}H_3$, *E*), 13.0 ($CH_2CH{=}CH\underline{C}H_3$, *Z*). ^{19}F NMR (376 MHz, $CDCl_3$) δ − 177.61 (ddd, 1F, $^2J_{HF}$ 47.7 Hz, $^3J_{HF}$ 34.1 Hz, $^3J_{HF}$ 16.4 Hz, *Z*), −177.7 (ddd, 1F, $^2J_{HF}$ 47.7 Hz, $^3J_{HF}$ 34.1 Hz, $^3J_{HF}$ 16.4 Hz, *E*). MS (ESI+) (*m/z*) 286.1 ($(M+H)^+$, 95), 200.0 (14), 182.0 (100). HRMS (MS+) for $C_{12}H_{12}FNO_2S_2$ $(M+H)^+$ calcd. 286.0372, found 286.0367.

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