Tetrahedron 64 (2008) 7419–7425

Contents lists available at ScienceDirect

Tetrahedron

journal homepage: www.elsevier.com/locate/tet

# α-Fluorination of β-ketosulfones by Selectfluor™ F–TEDA–$BF_4$

Hossein Loghmani-Khouzani [a,*], Mohammad R. Poorheravi [a], Majid M.M. Sadeghi [a], Lorenzo Caggiano [b], Richard F.W. Jackson [b]

[a] Department of Chemistry, University of Isfahan, Isfahan 81746-73441, Iran
[b] Department of Chemistry, The University of Sheffield, Dainton Building, Sheffield S3 7HF, UK

ARTICLE INFO

*Article history:*
Received 18 February 2008
Received in revised form 21 April 2008
Accepted 8 May 2008
Available online 13 May 2008

*Keywords:*
Fluorination
Selectfluor™
β-Ketosulfones
Difluoromethylene

ABSTRACT

Attempted fluorination of β-ketosulfides using Selectfluor™ resulted only in the isolation of the corresponding diaryl disulfides, presumed to arise by decomposition of an unstable fluorinated intermediate. However, fluorination of β-ketosulfones using Selectfluor™ under anhydrous conditions does allow the isolation of both mono-and difluorinated products in moderate to good yields.



## 1. Introduction

Introduction of fluorine atoms into an organic molecule is a common strategy in the field of medicinal chemistry, because it can result in a dramatic enhancement in biological activity.[1] Selective introduction of the difluoromethyl group ($CHF_2$) has also attracted interest since this group can behave as a lipophilic isostere of the hydroxyl group (OH), as well as a hydrogen-bond donor.[2–7] Compounds containing the $CHF_2$ group are widely used as anaesthetics, for example, desflurane and isoflurane.[8,9] Examples of the incorporation of the group into other biologically active molecules include its use in enzyme inhibitors,[10,11] sugar analogues,[12,13] pesticides[14,15] and herbicides.[16] Other applications of compounds containing the difluoromethyl group have been reported, including its incorporation into liquid crystals[17] and in fluorinated polymers.[18]

Several methods are available to introduce a difluoromethyl group into organic substrates. For example, reactions of fluorinated nucleophiles including (difluoromethyl)-dimethylphenylsilane,[20,21] (chlorodifluoromethyl)trimethyl-silane, or difluoromethylphenylsulfone[22] have been reported. As an alternative, modification of the existing framework by deoxofluorination of aldehydes, either directly using a variety of electrophilic reagents ($SeF_4$, DAST, or $SF_4$),[23,24] or indirectly by fluorination of 1,2- or 1,3-dithianes using $BrF_3$ and other in situ-generated halogen fluorides, is possible.[25,26] Nucleophilic fluorination of *gem*-bistriflates using TBAF has also been employed.[27] Other possibilities include radical addition of $CF_2Br_2$ to double bonds,[28] $S_{RN}1$ reaction between a nucleophile and $CHF_2Cl$[29,30] and hydrogenation of terminal 1,1-difluoroalkenes.[13]

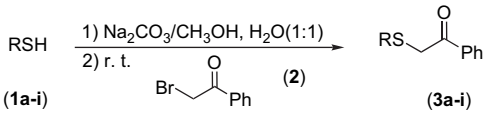
In the context of our work, Ar–$COCF_2$S–Ar′ have been shown to possess interesting anti-HIV-1 activity as non-nucleoside reverse transcriptase (RT) inhibitors (NNRTIs).[31] Methods to prepare Ar–$COCF_2$S–Ar′ derivatives are limited. α-(Alkylthio)-α,α-difluoroacetophenone analogues have been prepared by electrochemical fluorination of α-(phenylthio)-acetophenone,[32] oxidative desulfurization–fluorination of orthothioesters[33] and electrophilic *gem*-difluorination of α-(alkylthio)acetophenone derivatives with *N*-fluoropyridinium salts.[34] Halogenation of β-ketosulfones using potassium halide and hydrogen peroxide has been reported.[35] By using this method α,α-dihalo-β-ketosulfones have been prepared in high yields, but this method cannot be applied to the preparation of fluorinated sulfones. In this paper, we report a solution to this problem via the α-fluorination of β-ketosulfones using Selectfluor™, a convenient electrophilic NF fluorinating agent.[19]

## 2. Results and discussion

In continuation of our previous research on fluorination of α-hydrogen activated compounds,[36,37] a series of β-ketosulfides **3a–i** were prepared by reaction of arylthiols with α-bromoacetophenone in the presence of $Na_2CO_3$ (Scheme 1) using literature methods.[38] Times and yields of the reactions for compounds **3a–i** are summarized in Table 1.

* Corresponding author. Tel.: +98 311 7932722; fax: +98 311 6689732.
*E-mail addresses:* h.log119@sci.ui.ac.ir, loghmani_h@yahoo.com (H. Loghmani-Khouzani).

0040-4020/$ – see front matter © 2008 Elsevier Ltd. All rights reserved.
doi:10.1016/j.tet.2008.05.034



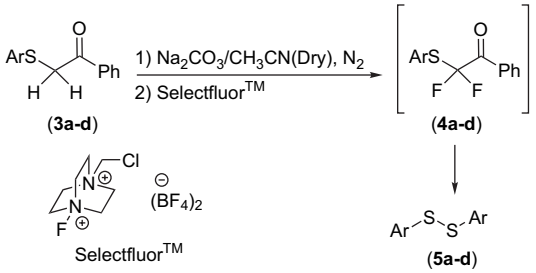

**Scheme 1.** Preparation of β-ketosulfides from reaction of arylthiols with α-bromoacetophenone.

**Table 1**
Preparation of β-ketosulfides **3a–f**

| Compound | R | Time (min) | Yield[a] (%) |
|---|---|---|---|
| **3a** | Ph | 60 | 88 |
| **3b** | 4-Br–$C_6H_4$ | 45 | 93 |
| **3c** | 4-Me–$C_6H_4$ | 40 | 96 |
| **3d** | 2-Naphthyl | 55 | 86 |
| **3e** | $PhCH_2$ | 30 | 100 |
| **3f** | 4-$MeOC_6H_4CH_2$ | 30 | 100 |
| **3g** | 2-Furylmethyl | 35 | 97 |
| **3h** | *c*-$C_6H_{11}$ | 45 | 78 |
| **3i** | $C_6H_{13}$ | 55 | 88 |

[a] Isolated yields.

It has been reported that α-fluorosulfides decompose significantly during isolation and purification.[39–41] In the event, attempted fluorination of the β-ketosulfides **3a–d** using Selectfluor™ resulted only in the isolation of the corresponding diaryl sulfanes **5a–d** (Scheme 2, Table 2). GC–MS analysis prior to purification showed the presence of the desired products **4a–d**, and the debenzoylated products $ArSCF_2H$, in addition to the isolated diaryl disulfides **5a–d**. When the β-ketosulfides **3a–d** were subjected to the same conditions, in the absence of Selectfluor™, the starting materials were recovered. This evidence suggests that the β-ketosulfides are indeed fluorinated, through a Pummerer mechanism,[42] and then decompose to disulfides (see Supplementary data). In view of these disappointing results, fluorination of the other substrates was not attempted.




**Scheme 2.** Attempted fluorination of β-ketosulfides using Selectfluor™/$Na_2CO_3$.

**Table 2**
Diaryl disulfides **5a–d** produced by attempted fluorination of β-ketosulfides **3a–d**

| Compound | Ar | Yield[a] (%) |
|---|---|---|
| **5a** | Ph | 88 |
| **5b** | 4-Br–$C_6H_4$ | 83 |
| **5c** | 4-Me–$C_6H_4$ | 87 |
| **5d** | 2-Naphthyl | 91 |

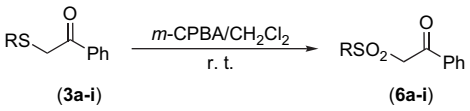
[a] Isolated yields.

To enhance the activation of the methylene group adjacent to the sulfur atom, and also to help stabilise the products, the α-(arylthio)acetophenones **3a–i** were each oxidized to the corresponding β-ketosulfones (**6a–i**) with *m*-CPBA and 1-(phenylsulfonyl)propan-2-one **6j**, which were purchased from the Merck Company. The results are given in Table 3 and Scheme 3.

**Table 3**
Oxidation β-ketosulfides **3a–i** by *m*-CPBA

| Compound | R | Time (min) | Yield[a] (%) |
|---|---|---|---|
| **6a** | Ph | 30 | 78 |
| **6b** | 4-Br–$C_6H_4$ | 25 | 80 |
| **6c** | 4-Me–$C_6H_4$ | 25 | 81 |
| **6d** | 2-Naphthyl | 20 | 83 |
| **6e** | $PhCH_2$ | 50 | 62 |
| **6f** | 4-$MeOC_6H_4CH_2$ | 45 | 73 |
| **6g** | 2-Furylmethyl | 55 | 56 |
| **6h** | *c*-$C_6H_{11}$ | 65 | 76 |
| **6i** | $C_6H_{13}$ | 60 | 85 |

[a] Isolated yields.



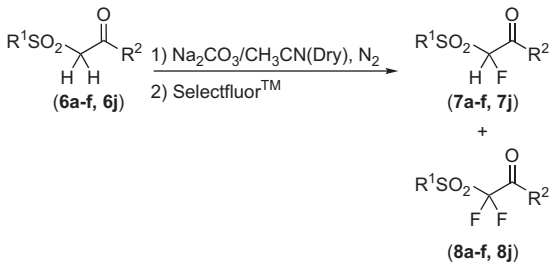

**Scheme 3.** Oxidation of β-ketosulfides by *m*-CPBA.

Fluorination of β-ketosulfones **6a–j** was carried out using Selectfluor™ in the presence of sodium carbonate in dry acetonitrile, under an inert atmosphere. Monofluoro β-ketosulfones **7a–d** and difluoro β-ketosulfones, **8a–f**, **8j** were obtained. In all cases difluoro derivatives were the main products even when 1 equiv of Selectfluor™ was used. No fluorinated products were isolated from reaction of the sulfones **6g**, **6h** and **6i**. The fluorinated products decomposed upon prolonged exposure to the atmosphere, but were perfectly stable when stored under inert, dry conditions. The yields and conditions of these reactions are given in Table 4 and Scheme 4.

**Table 4**
Preparation of fluorinated β-ketosulfones

| Substrate **6** | $R^1$ | $R^2$ | Monofluoro product **7** | Yield[a,b] (%) | Difluoro product **8** | Yield[a] (%) |
|---|---|---|---|---|---|---|
| **6a** | Ph | Ph | **7a** | 8 | **8a** | 45[c] |
| **6b** | 4-Br–$C_6H_4$ | Ph | **7b**[c] | 11 | **8b** | 48 |
| **6c** | 4-Me–$C_6H_4$ | Ph | **7c** | 10 | **8c** | 41 |
| **6d** | 2-Naphthyl | Ph | **7d** | 10 | **8d** | 52 |
| **6e**[e] | $PhCH_2$ | Ph | **7e** | 0 | **8e**[d] | 86 |
| **6f** | 4-$MeOC_6H_4CH_2$ | Ph | **7f** | 0 | **8f** | 73 |
| **6j** | Ph | $CH_3$ | **7j** | 0 | **8j** | 30 |

[a] Isolated yields.
[b] Low yields of the products are due to less reactivity of α-hydrogens of the substrate. Similar results have been reported for this reaction under different conditions.[40]
[c] This compound was obtained in low yield and was not possible to characterize completely.
[d] This compound has been prepared previously using fluorine gas, in 15% yield.[43]
[e] Only difluoro β-ketosulfone was obtained.




**Scheme 4.** Fluorination of β-ketosulfones by Selectfluor™.

Successful fluorination of 1-(phenylsulfonyl)propan-2-one **6j** to give the corresponding 1,1′-difluoro derivative **8j**, albeit in modest yield, does suggest that the procedure is applicable to fluorination

of substrates with additional sites for enolisation. Fluorination of **6j** with $FClO_3$/NaH to give **7j** and **8j** has been reported previously,[44] but no characterization data for the product of bis-fluorination, **8j**, were included.

In the $^1H$ NMR spectra of the substrate β-ketosulfones **6a–j**, the methylene protons appeared in the range of 4.39–4.85 ppm, but in the monofluorinated products **7a–f** the protons appear in the range 6.3–6.6 ppm. The coupling between F and H ($^2J_{HF}$ 48.0 Hz) clearly shows that there is no keto–enol equilibrium and the compounds are entirely in the keto-form.

## 3. Experimental

### 3.1. General

Melting points were determined using a Linkam HF591 heating stage, used in conjunction with a TC92 controller, and are uncorrected. NMR spectra were recorded using either a Bruker DRX500, 400 or 250 machines at room temperature. $^1H$ and $^{13}C$ NMR spectra were measured using deuterochloroform as solvent and chemical shifts were measured relative to residual solvent or $CFCl_3$ as an internal standard for $^{19}F$ NMR and are expressed in parts per million (δ). Mass spectra were obtained using a MicroMass LCT machine in ES or EI mode. Infrared spectra were measured on a Perkin Elmer Paragon 100 FT-IR spectrophotometer. Abbe Refractometer (ATAGO) Model AD-13.

All reaction solvents used were of HPLC grade or distilled; petroleum ether refers to the fraction, which boils in the range 40–60 °C. TLC plates were visualized by UV light (254 nm). All organic extracts were dried over magnesium sulfate. All compounds were supplied by either the Lancaster Synthesis or the Aldrich Chemical Company and were used without further purification.

### 3.2. Typical procedure for preparation of β-keto-sulfides (3b–i)

#### 3.2.1. 1-Phenyl-2-(phenylthio)ethanone (*3a*)

Benzenethiol (103 μL, 1.0 mL) was added dropwise to a stirred solution of α-bromoacetophenone (154.6 mg, 1.0 mmol) in methanol (10 mL) and water (10 mL) and stirred for 1 h. The reaction was monitored by TLC and showed the complete disappearance of starting materials. The reaction mixture was poured into 100 mL of 1 M HCl containing 50 g of crushed ice. The product was filtered under vacuum and washed with 10 mL ice-cold methanol and 10 mL water. Recrystallisation from methanol and filtration gave compound **3a** (0.20 g, 88%); mp 52–53 °C (lit.[45,46] mp 51–53 °C from ethanol); $^1H$ NMR (500 MHz, $CDCl_3$) δ 4.25 (s, 2H), 7.19 (dd, *J* 2.3 and 7.8 Hz, 1H), 7.25 (t, *J* 7.8 Hz, 2H), 7.37 (dd, *J* 1.6 and 7.3 Hz, 2H), 7.43 (t, *J* 7.8 Hz, 2H), 7.54 (t, *J* 7.8 Hz, 1H) and 7.91 (dd, *J* 1.3 and 8.4 Hz, 2H); $^{13}C$ NMR (126 MHz, $CDCl_3$) δ 41.2 ($CH_2$), 127.1, 128.7, 129.1, 129.1, 130.4, 133.5, 134.9, 135.4 and 194.0 (C=O); IR (KBr, $cm^{-1}$) 3123, 2935, 1668 (C=O), 1568, 1552, 1526, 1434, 1399, 1121, 1137 and 1066; HRMS (EI) Found: $M^+$, 228.0464. $C_{14}H_{12}OS$ requires $M^+$, 228.0601; LRMS *m*/*z* (EI): 228 ($M^+$, 60%) and 105 (100%). Elemental analysis: Found (%): C, 73.45; H, 5.21; S, 14.12. Calcd for $C_{14}H_{12}OS$: C, 73.65; H, 5.30; S, 14.04.

#### 3.2.2. 2-(4-Bromophenylthio)-1-phenylethanone (*3b*)

Recrystallized from methanol (93%); mp 85–86 °C (lit.[45] mp 82–84 °C from diethyl ether); $^1H$ NMR (500 MHz, $CDCl_3$) δ 4.17 (s, 2H), 7.16–7.24 (m, 2H), 7.30–7.35 (m, 2H), 7.38–7.44 (m, 2H), 7.50 (t, *J* 7.5 Hz, 1H) and 7.85 (dd, *J* 8.5 and 1.3 Hz, 2H); $^{13}C$ NMR (126 MHz, $CDCl_3$) δ 41.0 ($CH_2$), 28.6, 128.7, 132.0, 132.1, 133.6, 133.9, 135.2 and 193.6; IR (KBr, $cm^{-1}$) 3111, 2891, 1694 (C=O), 1596, 1451, 1380 and 1201; HRMS (EI) Found: $M^+$, 306.9728. $C_{14}H_{11}BrOS$ requires $M^+$, 306.9730; LRMS *m*/*z* (EI): 308 ($M^+$, 23%) and 105 (100%). Elemental analysis: Found (%): C, 54.41; H, 3.50; S, 10.55. Calcd for $C_{14}H_{11}BrOS$: C, 54.74; H, 3.61; S, 10.44.

#### 3.2.3. 2-(p-Tolylthio)-1-phenylethanone (*3c*)

Recrystallized from methanol (96%); mp 38–39 °C (lit.[45] mp 36–37 °C from ethanol); $^1H$ NMR (500 MHz, $CDCl_3$) δ 2.28 (s, 3H), 4.18 (s, 2H), 7.06 (d, *J* 7.8 Hz, 2H), 7.37 (d, *J* 7.8 Hz, 2H), 7.43 (t, *J* 7.3 Hz, 2H), 7.54 (td, *J* 1.3 and 6.8 Hz, 1H) and 7.91 (dd, *J* 1.3 and 4.3 Hz, 2H); $^{13}C$ NMR (126 MHz, $CDCl_3$) δ 21.1 ($CH_3$), 41.8 ($CH_2$), 128.6, 128.7, 129.8, 130.9, 131.4, 131.5, 133.3, 135.5, 137.4 and 194.1 (C=O); IR (KBr, $cm^{-1}$) 3144, 2968, 1692 (C=O), 1578, 1562, 1546, 1434, 1389, 1125, 1146 and 1077; HRMS (EI) Found: $M^+$, 242.1454. $C_{15}H_{14}OS$ requires $M^+$, 242.1467; LRMS *m*/*z* (EI): 242 ($M^+$, 21%) and 105 (100%). Elemental analysis: Found (%): C, 74.44; H, 5.34; S, 13.12. Calcd for $C_{15}H_{14}OS$: C, 74.34; H, 5.82; S, 13.23.

#### 3.2.4. 2-(Naphthalene-3-ylthio)-1-phenylethanone (*3d*)

Recrystallized from methanol (86%); mp 96.5–97 °C, (lit.[47] mp 98–100 °C from methanol); $^1H$ NMR (500 MHz, $CDCl_3$) δ 4.38 (s, 2H), 7.46–7.53 (m, 5H), 7.59 (t, *J* 7.5 Hz, 1H), 7.77–7.82 (m, 3H), 7.84 (d, *J* 1.6 Hz, 1H) and 7.97 (dd, *J* 8.5 and 1.3 Hz, 2H); $^{13}C$ NMR (126 MHz, $CDCl_3$) δ 41.1 ($CH_2$), 125.6, 126.1, 126.6, 127.3, 127.7, 127.9, 128.6, 128.7, 128.7, 132.1, 133.5, 133.6, 135.4 and 194.0 (C=O); IR (KBr, $cm^{-1}$) 3063, 2970, 1663 (C=O), 1585, 1492, 1268, 1127, 935, 816 and 600; HRMS (EI) Found: $M^+$, 278.1405. $C_{18}H_{14}OS$ requires $M^+$, 278.1507; LRMS *m*/*z* (EI): 278 ($M^+$, 21%) and 105 (100%). Elemental analysis: Found (%): C, 77.32; H, 4.76; S, 11.59. Calcd for $C_{18}H_{14}OS$: C, 77.67; H, 5.07; S, 11.52.

#### 3.2.5. 2-(Benzylthio)-1-phenylethanone (*3e*)

Recrystallized from ethanol (100%); mp 82 °C; $^1H$ NMR (400 MHz, $CDCl_3$) δ 3.67 (s, 2H), 3.76 (s, 2H), 7.32–7.42 (m, 5H), 7.47 (t, *J* 7.7 Hz, 2H), 7.58 (t, *J* 7.5 Hz, 1H) and 7.94 (d, *J* 8.1 Hz, 2H); $^{13}C$ NMR (101 MHz, $CDCl_3$) δ 35.8, 36.0, 127.3, 128.5, 128.6, 128.7, 129.3, 133.3, 135.3, 137.3 and 194.4 (C=O); IR (KBr, $cm^{-1}$) 3103, 3021, 2943, 2883, 1670 (C=O), 1582, 1453, 1399, 1330, 1200, 1150, 1066, 752, 640 and 582; HRMS (EI) Found: $M^+$, 242.0763. $C_{15}H_{14}OS$ requires $M^+$, 242.0765; LRMS *m*/*z* (EI): 242 ($M^+$, 35%) and 105 (100%). Elemental analysis: Found (%): C, 73.61; H, 5.68; S, 13.41. Calcd for $C_{15}H_{14}OS$: C, 73.34; H, 5.82; S, 13.23.

#### 3.2.6. 2-(4-Methoxybenzylthio)-1-phenylethanone (*3f*)

Recrystallized from ethanol (100%); mp 42 °C; $^1H$ NMR (500 MHz, $CDCl_3$) δ 3.66 (s, 2H), 3.72 (s, 2H), 3.78 (s, 3H), 7.94 (d, *J* 7.2, 2H), 7.56 (t, *J* 7.4 Hz, 1H), 7.45 (t, *J* 7.7 Hz, 2H), 7.28 (d, *J* 8.6 Hz, 2H) and 6.85 (d, *J* 8.6 Hz, 2H); $^{13}C$ NMR (101 MHz, $CDCl_3$) δ 35.6, 35.9, 55.3, 113.9, 128.6, 128.7, 129.3, 130.3, 133.3, 135.5, 158.8 and 194.5 (C=O); IR (KBr, $cm^{-1}$) 3093, 2953, 2889, 1675 (C=O), 1584, 1456, 1389, 1340, 1200, 1156, 1069, 753, 641 and 582; HRMS (EI) Found: $M^+$, 242.0844. $C_{16}H_{16}O_2S$ requires $M^+$, 242.0936. Elemental analysis: Found (%): C, 70.66; H, 5.79; S, 11.92. Calcd for $C_{16}H_{16}O_2S$: C, 70.56; H, 5.92; S, 11.77.

#### 3.2.7. 2-((Furan-2-yl)methylthio)-1-phenylethanone (*3g*)

Recrystallized from ethanol (97%); mp 67–68 °C (ethanol) (lit.[48] mp 67.5 °C from ethanol); $^1H$ NMR (400 MHz, $CDCl_3$) δ 3.78 (s, 2H), 3.79 (s, 2H), 6.26 (d, *J* 2.9 Hz, 1H), 6.31 (dd, *J* 3.2 and 1.9 Hz, 1H), 7.37–7.41 (m, 1H), 7.47 (t, *J* 7.6 Hz, 2H), 7.59 (ddd, *J* 8.5, 2.3 and 1.2 Hz, 1H) and 7.95 (dd, *J* 8.5 and 1.1 Hz, 2H); $^{13}C$ NMR (101 MHz, $CDCl_3$) δ 28.3, 36.3, 108.6, 110.4, 128.6, 128.6, 133.3, 135.4, 142.4, 150.4 and 194.2 (C=O); IR (KBr, $cm^{-1}$) 3103, 2942, 2884, 1671 (C=O), 1598, 1582, 1506, 1454, 1399, 1330, 1302, 1258, 1200, 1148 and 1065; HRMS (EI) Found: $M^+$, 232.0564. $C_{13}H_{12}O_2S$ requires $M^+$, 232.0558; LRMS *m*/*z* (EI): 232 ($M^+$, 62%) and 105 (100%). Elemental analysis: Found (%): C, 66.97; H, 4.98; S, 14.11. Calcd for $C_{13}H_{12}O_2S$: C, 67.22; H, 5.21; S, 13.77.

*3.2.8. 2-(Cyclohexylthio)-1-phenylethanone (**3h**)*

Bp 154–155 °C (lit.[49] 153–155 °C); IR (Neat, $cm^{-1}$) 3102, 2901, 2878, 1710 (C=O), 1565, 1334, 1120, 1054, 845; HRMS (EI) Found: $M^+$, 234.1108. $C_{14}H_{18}OS$ requires $M^+$, 234.0992; LRMS *m/z* (EI): 234 ($M^+$, 94%); $n_D^{20}$=1.5698 (lit.[49] $n_D^{20}$=1.5705). Elemental analysis: Found (%): C, 71.53; H, 7.45; S, 13.76. Calcd for $C_{14}H_{18}OS$: C, 71.75; H, 7.74; S, 13.68.

*3.2.9. 2-(Hexylthio)-1-phenylethanone (**3i**)*

Bp 156 °C (lit.[49] 155 °C); IR (Neat, $cm^{-1}$) 3091, 2943, 2793, 1714 (C=O), 1555, 1354, 1134, 1050, 824; HRMS (EI) Found: $M^+$, 236.1205. $C_{14}H_{20}OS$ requires $M^+$, 236.1198; LRMS *m/z* (EI): 236 ($M^+$, 72%); $n_D^{20}$=1.5402 (lit.[49] $n_D^{20}$=1.5391). Elemental analysis: Found (%): C, 71.23; H, 8.78; S, 13.61. Calcd for $C_{14}H_{20}OS$: C, 71.14; H, 8.53; S, 13.57.

### 3.3. Typical procedure for the attempted fluorination of β-ketosulfides (5a–d)

*3.3.1. 1,2-Diphenyldisulfane (**5a**)*

Sodium carbonate (212 mg, 2.1 mmol) was added to a stirred solution of 1-phenyl-2-(phenylthio)ethanone (228 mg, 1.0 mmol) in dry acetonitrile under $N_2$ and stirred for 2 h. Selectfluor™ (715 mg, 2.1 mmol) was then added and left to stir overnight. The reaction was monitored by TLC and showed the complete disappearance of starting materials. The reaction was quenched by the addition of water and was extracted with $CH_2Cl_2$, separated, dried with anhydrous $MgSO_4$, concentrated under reduced pressure and purified by flash silica gel chromatography [petroleum ether/EtOAc (95:5)] to afford the disulfide **5a** (88%); $R_f$ 0.6, mp 59 °C (ethanol) (lit.[50] mp 58–60 °C from ethanol); $^1$H NMR (500 MHz, $CDCl_3$) $\delta$ 7.14–7.17 (m, 6H), 7.39–7.45 (m, 4H); $^{13}$C NMR (126 MHz, $CDCl_3$) $\delta$ 127.0, 127.3, 128.9, 138.7; IR (KBr, $cm^{-1}$) 3072, 1552, 1385, 1287, 1267, 1176, 1106, 894, 623; HRMS (EI) Found: $M^+$, 218.0436. $C_{12}H_{10}OS_2$ requires $M^+$, 218.0425; LRMS *m/z* (EI): 218 (65%, $M^+$), 109 (M−SPhS, 100%); CI$^+$: $[MNH_4]^+$, 236. Elemental analysis: Found (%): C, 66.08; H, 4.76; S, 29.46. Calcd for $C_{10}H_{12}OS_2$: C, 66.01; H, 4.62; S, 29.37.

*3.3.2. 1,2-Bis(4-bromophenyl)disulfane (**5b**)*

Yield 83%; mp 94–95 °C (ethanol) (lit.[51] mp 95 °C from ethanol); $^1$H NMR (500 MHz, $CDCl_3$) $\delta$ 7.34–7.40 (m, 4H), 7.43–7.50 (m, 4H); $^{13}$C NMR (126 MHz, $CDCl_3$) $\delta$ 121.5, 129.4, 132.2, 135.7; IR (KBr, $cm^{-1}$) 3056, 1550, 1466, 1341, 1238, 903, 543, 450; HRMS (EI) Found: $M^+$, 376.0334. $C_{12}H_8Br_2S_2$ requires $M^+$, 376.0231; LRMS *m/z* (EI): 376 (23%, $M^+$), 312 (M−S, 4%), 189 (45%), 108 (100%); CI$^+$: $[MNH_4]^+$, 394. Elemental analysis: Found (%): C, 38.03; H, 2.04; S, 17.23. Calcd for $C_{12}H_8Br_2S_2$: C, 38.32; H, 2.14; S, 17.05.

*3.3.3. 1,2-Di-p-tolyldisulfane (**5c**)*

Yield 87%, mp 45–47 °C (ethanol) (lit.[52] mp 43–46 °C from ethanol); $^1$H NMR (500 MHz, $CDCl_3$) $\delta$ 2.87 (s, 3H), 7.21–7.32 (d, 4H), 7.63–7.80 (m, 4H); $^{13}$C NMR (126 MHz, $CDCl_3$) $\delta$ 45.8, 119.6, 126.7, 123.2, 131.3; IR (KBr, $cm^{-1}$) 3097, 2943, 1544, 1455, 1367, 1266, 9023, 533; HRMS (EI) Found: $M^+$, 246.0504. $C_{14}H_{14}S_2$ requires $M^+$, 246.0498; LRMS *m/z* (EI): 246 (89%, $M^+$), 214 (M−S, 16%); CI$^+$: $[MNH_4]^+$, 260. Elemental analysis: Found (%): C, 68.43; H, 5.87; S, 26.23. Calcd for $C_{14}H_{14}S_2$: C, 68.25; H, 5.73; S, 26.03.

*3.3.4. 1,2-Di(naphthalen-2-yl)disulfane (**5d**)*

Yield 91%; mp 140 °C ($CH_2Cl_2$); $^1$H NMR (250 MHz, $CDCl_3$) $\delta$ 7.46–7.53 (m, 4H), 7.62 (dd, *J* 8.6 and 1.9 Hz, 2H), 7.77–7.83 (m, 6H) and 7.99 (d, *J* 1.3 Hz, 2H); $^{13}$C NMR (63 MHz, $CDCl_3$) $\delta$ 125.6, 126.2, 126.5, 126.7, 127.4, 127.8, 129.0, 130.8, 131.5 and 132.2; IR (KBr, $cm^{-1}$) 3087, 1597, 1550, 1451, 1150, 1074, 918, 700, 626 and 451; HRMS (EI) Found: $M^+$, 318.1006. $C_{20}H_{14}S_2$ requires $M^+$, 318.1104; LRMS *m/z* (EI): 318 ($M^+$, 47%) and 254 (M−$S_2$, 11%). Elemental analysis: Found (%): C, 75.22; H, 4.33; S, 20.23. Calcd for $C_{20}H_{14}S_2$: C, 75.43; H, 4.43; S, 20.14.

### 3.4. Typical procedure for preparation of β-ketosulfones (6a–i)

*3.4.1. 1-Phenyl-2-(phenylsulfonyl)ethanone (**6a**)*

*m*-CPBA (0.517 g, 3 mmol) was added to a stirred solution of 1-phenyl-2-(phenylthio)ethanone (0.228 g, 1 mmol) in $CH_2Cl_2$ (20 mL) at 0 °C and stirring was continued for 30 min. Saturated aqueous sodium sulfite solution (50 mL) was added and the mixture was stirred for a further 1 h at room temperature. The $CH_2Cl_2$ layer was washed with water (50 mL), dried ($MgSO_4$), filtered, and concentrated under reduced pressure. Flash chromatography on silica gel using ethyl acetate/petrol ether (30:70) afforded the sulfone **6a** (0.201 g, 78%); mp 92–93 °C (methanol) (lit.[53,54] 93–94 °C from methanol); $^1$H NMR (500 MHz, $CDCl_3$) $\delta$ 4.74 (s, 2H), 7.48–7.51 (m, 2H), 7.55–7.60 (m, 2H), 7.64–7.59 (m, 1H), 7.66–7.71 (m, 1H), 7.94 (dd, *J* 8.5 and 1.3 Hz, 2H) and 7.90 (dd, *J* 8.5 and 1.3 Hz, 2H); $^{13}$C NMR (126 MHz, $CDCl_3$) $\delta$ 63.4 ($CH_2$), 128.5, 128.8, 129.2, 129.3, 134.2, 134.4, 135.7, 138.7 and 187.9 (C=O); IR (KBr, $cm^{-1}$) 3070, 2999, 1672 (C=O), 1569, 1582, 1428, 1446, 1317, 1152, 1131, 1084 and 1026; HRMS (EI) Found: $M^+$, 260.1231. $C_{14}H_{12}O_3S$ requires $M^+$, 260.1301; LRMS *m/z* (EI): 260 ($M^+$, 1%), 196 (M−$SO_2$, 12%) and 105 (100%). Elemental analysis: Found (%): C, 64.78; H, 4.87; S, 12.12. Calcd for $C_{14}H_{12}O_3S$: C, 64.60; H, 4.65; S, 12.32.

*3.4.2. 2-(4-Bromophenylsulfonyl)-1-phenylethanone (**6b**)*

Yield 80%; mp 122 °C (ethanol) (lit.[54] 122–123 °C from ethanol); $^1$H NMR (500 MHz, $CDCl_3$) $\delta$ 4.73 (s, 2H), 7.50 (t, *J* 7.9 Hz, 2H), 7.64 (ddd, *J* 8.7, 2.5 and 1.3 Hz, 1H), 7.69–7.72 (m, 2H), 7.76 (d, *J* 8.7 Hz, 2H) and 7.93 (dd, *J* 8.5 and 1.3 Hz, 2H); $^{13}$C NMR (126 MHz, $CDCl_3$) $\delta$ 63.3, 128.9, 129.2, 129.8, 130.2, 132.5, 134.5, 136.6, 137.6 and 187.9; IR (KBr, $cm^{-1}$) 3097, 2914, 1702 (C=O), 1557, 1321, 1121, 1025, 820 and 769; HRMS (EI) Found: $M^+$, 338.9791. $C_{14}H_{12}BrO_3S$ requires $M^+$, 338.9691; LRMS *m/z* (EI): 339 ($M^+$, 4%), 274 (M−$SO_2$, 23%) and 105 (100%). Elemental analysis: Found (%): C, 49.77; H, 3.35; S, 9.68. Calcd for $C_{14}H_{12}BrO_3S$: C, 49.50; H, 3.25; S, 9.45.

*3.4.3. 1-Phenyl-2-tosylethanone (**6c**)*

Yield 81%; mp 92–93 °C (ethanol) (lit.[53,54] mp 93–94 °C from ethanol); $^1$H NMR (500 MHz, $CDCl_3$) $\delta$ 2.78 (s, 3H), 4.72 (s, 2H), 7.51 (t, *J* 7.8, Hz, 2H), 7.54 (ddd, *J* 8.7, 2.38 and 1.2 Hz, 1H), 7.70–7.73 (m, 2H), 7.77 (d, *J* 8.7 Hz, 2H) and 7.83 (dd, *J* 8.5 and 1.3 Hz, 2H); $^{13}$C NMR (126 MHz, $CDCl_3$) $\delta$ 42.3, 63.3, 128.9, 129.2, 129.7, 130.2, 132.6, 134.4, 136.6, 137.7 and 187.8 (C=O); IR (KBr, $cm^{-1}$) 3086, 2904, 1701 (C=O), 1555, 1311, 1120, 1029, 821 and 770; HRMS (EI) Found: $M^+$, 274.0321. $C_{15}H_{14}O_3S$ requires $M^+$, 274.0231; LRMS *m/z* (EI): 274 ($M^+$, 9%) and 210 (M−$SO_2$, 23%). Elemental analysis: Found (%): C, 65.45; H, 4.98; S, 11.56. Calcd for $C_{15}H_{14}O_3S$: C, 65.67; H, 5.14; S, 11.69.

*3.4.4. 2-(Naphthalen-2-ylsulfonyl)-1-phenylethanone (**6d**)*

Yield 83%; mp 131 °C (ether) (lit.[45,53–55] 89 °C from ethanol); $^1$H NMR (500 MHz, $CDCl_3$) $\delta$ 4.81 (s, 2H), 7.46 (m, 2H), 7.61 (m, 2H), 7.67–7.72 (m, 1H), 7.87 (dd, *J* 8.7 and 1.91 Hz, 1H), 7.96 (tt, *J* 8.7 and 6.1 Hz, 5H) and 8.46 (d, *J* 1.6 Hz, 1H); $^{13}$C NMR (126 MHz, $CDCl_3$) $\delta$ 63.6 ($CH_2$), 122.9, 127.7, 128.0, 128.8, 129.9, 129.5, 129.5, 129.6, 130.6, 132.0, 134.3, 135.5, 135.6, 135.7 and 188.0 (C=O); IR (KBr, $cm^{-1}$) 3068, 2988, 2941, 1667 (C=O), 1597, 1451, 1311, 1274, 1227, 1150, 1075, 1003, 669 and 918; HRMS (EI) Found: $M^+$, 310.1096. $C_{14}H_{11}O_3S$ requires $M^+$, 310.1043; LRMS *m/z* (EI): 310 ($M^+$, 23%), 264 (M−$SO_2$, 32%) and 105 (100%). Elemental analysis: Found (%): C, 69.38; H, 4.32; S, 10.48. Calcd for $C_{14}H_{11}O_3S$: C, 69.66; H, 4.55; S, 10.33.

*3.4.5. 2-(Benzylsulfonyl)-1-phenylethanone (**6e**)*

Yield 62%; mp 111–113 °C (ethanol) (lit.[54] mp 112–113 °C from ethanol); $^1$H NMR (400 MHz, $CDCl_3$) $\delta$ 4.39 (s, 2H), 4.56 (s, 2H),

7.45–7.38 (m, 3H), 7.53 (td, *J* 12.1 and 5.48 Hz, 4H), 7.66 (t, *J* 7.5 Hz, 1H) and 7.97 (dd, *J* 8.5 and 1.1 Hz, 2H); $^{13}$C NMR (101 MHz, $CDCl_3$) $\delta$ 56.6, 59.8, 129.1, 131.3, 133.1, 134.2, 135.6, 136.3, 148.5, 152.8 and 201.5 (C=O); IR (KBr, $cm^{-1}$) 3098, 2988, 1703 (C=O), 1351, 1279, 1135 and 903; HRMS (EI) Found: $M^+$, 274.0783. $C_{15}H_{14}O_3S$ requires $M^+$, 274.0755; LRMS *m*/*z* (EI): 274 ($M^+$, 33%) and 91 (100%). Elemental analysis: Found (%): C, 65.49; H, 5.44; S, 11.78. Calcd for $C_{15}H_{14}OS$: C, 65.67; H, 5.14; S, 11.69.

*3.4.6. 2-(4-Methoxybenzylsulfonyl)-1-phenylethanone (**6f**)*

Recrystallized from ethanol (73%); mp 53 °C; $^1$H NMR (500 MHz, $CDCl_3$) $\delta$ 3.78 (s, 3H), 4.09 (s, 2H), 4.22 (s, 2H), 6.88 (d, *J* 8.5 Hz, 2H), 7.24 (d, *J* 8.5 Hz, 2H), 7.47 (t, *J* 7.7 Hz, 2H), 7.61 (t, *J* 7.4 Hz, 1H) and 7.90 (d, *J* 7.4 Hz, 2H); $^{13}$C NMR (101 MHz, $CDCl_3$) $\delta$ 55.3, 57.1, 57.6, 114.4, 120.9, 128.7, 128.9, 131.7, 134.3, 136.1, 159.9 and 192.6 (C=O); IR (KBr, $cm^{-1}$) 3107, 2973, 2876, 1704 (C=O), 1574, 1455, 1378, 1353, 1210, 1145, 1078, 755, 634 and 576; HRMS (EI) Found: $M^+$, 304.0887. $C_{16}H_{16}O_4S$ requires $M^+$, 304.0689. Elemental analysis: Found (%): C, 63.12; H, 5.27; S, 10.82. Calcd for $C_{16}H_{16}O_2S$: C, 63.14; H, 5.30; S, 10.54.

*3.4.7. 2-((Furan-2-yl)methylsulfonyl)-1-phenylethanone (**6g**)*

Yield 56%; mp 92 °C (ethanol); $^1$H NMR (400 MHz, $CDCl_3$) $\delta$ 4.53 (s, 2H), 4.67 (s, 2H), 6.43 (dd, *J* 3.2 and 1.9 Hz, 1H), 6.61 (d, *J* 3.5 Hz, 1H), 7.47 (dd, *J* 1.9 and 1.0 Hz, 1H), 7.53 (t, *J* 7.8 Hz, 2H), 7.67 (t, *J* 7.5 Hz, 1H) and 7.97 (dd, *J* 8.5 and 1.2 Hz, 2H); $^{13}$C NMR (101 MHz, $CDCl_3$) $\delta$ 53.2, 57.4, 111.7, 113.2, 129.0, 129.9, 134.7, 139.8, 145.5, 158.7 and 198.7 (C=O); IR (KBr, $cm^{-1}$) 3113, 2953, 2854, 1691 (C=O), 1598, 1583, 1506, 1454, 1309, 1330, 1275, 1258, 1200, 1148, 1065, 750, 686 and 543; HRMS (EI) Found: $M^+$, 264.3204. $C_{13}H_{12}O_4S$ requires $M^+$, 264.3201; *m*/*z* ($CI^+$): 282 ($(M+NH_4)^+$, 100%) and 201 ($(MH-SO_2)$, 30%). Elemental analysis: Found (%): C, 59.28; H, 4.48; S, 12.11. Calcd for $C_{13}H_{12}O_4S$: C, 59.08; H, 4.58; S, 12.13.

*3.4.8. 2-(Cyclohexylsulfonyl)-1-phenylethanone (**6h**)*

Yield 76%; mp 74 °C (ethanol); $^1$H NMR (500 MHz, $CDCl_3$) $\delta$ 3.10–4.67 (m, 11H), 4.84 (s, 2H), 7.55 (t, *J* 8.1 Hz, 2H), 7.74 (ddd, *J* 8.1, 2.5 and 1.3 Hz, 1H) and 7.89–7.94 (m, 2H); $^{13}$C NMR (126 MHz, $CDCl_3$) $\delta$ 15.1, 17.2, 36.0, 49.1, 51.5, 70.2, 128.2, 131.4, 139.4, 150.5 and 188.6; IR (KBr, $cm^{-1}$) 3111, 2914–2875, 1705 (C=O), 1657, 1311, 1111, 1035, 826 and 708; HRMS (EI) Found: $M^+$, 266.1054. $C_{14}H_{18}O_3S$ requires $M^+$, 266.1078; LRMS *m*/*z* (EI): 266 ($M^+$, 94%) and 202 ($M-SO_2$, 34%). Elemental analysis: Found (%): C, 63.51; H, 6.93; S, 12.44. Calcd for $C_{14}H_{18}O_3S$: C, 63.13; H, 6.81; S, 12.04.

*3.4.9. 2-(Hexylsulfonyl)-1-phenylethanone (**6i**)*

Yield 85%; mp 63 °C (ethanol); $^1$H NMR (500 MHz, $CDCl_3$) $\delta$ 2.80 (t, *J* 7.3 Hz, 3H), 3.10–3.81 (m, 8H), 4.21 (t, *J* 8.4 Hz, 2H), 4.85 (s, 2H), 7.55 (t, *J* 8.1 Hz, 2H), 7.62 (ddd, *J* 8.3, 2.5 and 1.3 Hz, 1H) and 7.75–7.81 (m, 2H); $^{13}$C NMR (126 MHz, $CDCl_3$) $\delta$ 18.2, 27.2, 38.3, 41.1, 46.5, 56.8, 71.2, 126.7, 130.4, 133.3, 140.5 and 187.8; IR (KBr, $cm^{-1}$) 3101, 2910, 2775, 1708 (C=O), 1655, 1300, 1100, 1025, 816 and 728; HRMS (EI) Found: $M^+$, 268.1134. $C_{14}H_{20}O_3S$ requires $M^+$, 268.1168; LRMS *m*/*z* (EI): 268 ($M^+$, 91%) and 204 ($M-SO_2$, 44%). Elemental analysis: Found (%): C, 62.36; H, 7.43; S, 12.02. Calcd for $C_{14}H_{18}O_3S$: C, 62.66; H, 7.51; S, 11.95.

### 3.5. Typical procedure for fluorination of β-ketosulfones (7a–d, 8a–f, 8j)

*3.5.1. 2-(Benzylsulfonyl)-2,2-fluoro-1-phenylethanone (**8e**)*

$Na_2CO_3$ (0.233 g, 2.2 mmol) was added to a stirred solution of 2-(benzylsulfonyl)-1-phenylethanone (0.274 g, 1 mmol) in dry acetonitrile (15 mL) at room temperature under $N_2$ and stirred for 2 h. Selectfluor™ (0.782 g, 2.2 mmol) was added and stirring was continued overnight at room temperature. The reaction was monitored by TLC and deemed complete by the disappearance of starting materials. The reaction was quenched by the addition of water and was extracted with $CH_2Cl_2$ (3×20 mL). The organic layers were separated and dried ($MgSO_4$), filtered and concentrated under reduced pressure. The residue was purified by flash chromatography on silica gel eluting with ethyl acetate/petrol ether (30:70) to afford the fluorinated product **8e** (86%); $R_f$ 0.8 (EtOAc/pet. ether 30:70); mp 91 °C (ethanol); $^1$H NMR (500 MHz, $CDCl_3$) $\delta$ 4.59 (s, Ph–$CH_2$–$SO_2$–, 2H), 7.43–7.49 (m, 5H), 7.54–7.61 (m, 2H), 7.70 (ddd, *J* 7.5, 2.6 and 1.5 Hz, 1H) and 8.13 (dd, *J* 8.6 and 1.2 Hz, 2H); $^{13}$C NMR (126 MHz, $CDCl_3$) $\delta$ 56.4 (Ph–$CH_2$–$SO_2$–), 116.9 (t, *J* 302.7 Hz, $CF_2$), 123.7, 128.9, 129.1, 129.7, 130.7, 131.6, 131.7, 135.6 and 184.4 (C=O); $^{19}$F NMR (235 MHz, $CDCl_3$) $\delta$ −102.7 (s, 2F, $CF_2$); IR (KBr, $cm^{-1}$) 3101, 2989, 1711 (C=O), 1551, 1454, 1345, 1234, 1141, 902, 771 and 745; HRMS (EI) Found: $M^+$, 310.0432. $C_{15}H_{12}F_2O_3S$ requires $M^+$, 310.0408; LRMS *m*/*z* ($EI^+$): 310 ($M^+$, 2%), 226 ($M-SO_2$, 3%), 105 (50%) and 91 (100%). Elemental analysis: Found (%): C, 58.11; H, 4.01; S, 10.45. Calcd for $C_{15}H_{12}F_2O_3S$: C, 58.06; H, 3.90; S, 10.33.

*3.5.2. 2-Fluoro-1-phenyl-2-(phenylsulfonyl)ethanone (**7a**) and 2,2-difluoro-1-phenyl-2-(phenylsulfonyl)ethanone (**8a**)*

Following the typical procedure for fluorination of β-ketosulfones, the monofluoro product **7a** was obtained in 8% yield; $^1$H NMR (500 MHz, $CDCl_3$) $\delta$ 6.36 (d, *J* 48.0 Hz, 1H), 7.44–7.50 (m, 2H), 7.58–7.60 (m, 5H), 7.63–7.71 (m 1H) and 8.01–8.08 (m, 2H); $^{13}$C NMR (126 MHz, $CDCl_3$) $\delta$ 100.2 (d, *J* 285.7 Hz, CFH), 121.3, 123.1, 123.6, 124.3, 126.6, 127.1, 128.2, 130.1 and 181.5 (C=O); $^{19}$F NMR (235 MHz, $CDCl_3$) $\delta$ −181.1 (d, *J* 48.0 Hz, F, CF); IR (KBr, $cm^{-1}$) 3102, 2899, 1679 (C=O), 1556, 1445, 1324, 1227, 932 and 865; HRMS (EI) Found: $M^+$, 278.1332. $C_{14}H_{11}FO_3S$ requires $M^+$, 278.1345; LRMS *m*/*z* (EI): 278 ($M^+$, 97%) and 105 (7%). Elemental analysis: Found (%): C, 60.23; H, 4.04; S, 11.67. Calcd for $C_{14}H_{11}FO_3S$: C, 60.42; H, 3.98; S, 11.52, and the difluoro product **8a** in 45% yield; mp 78 °C (toluene/hexane); $^1$H NMR (500 MHz, $CDCl_3$) $\delta$ 7.54–7.58 (m, 2H), 7.62–7.68 (m, 5H), 7.70–7.78 (m, 1H) and 8.13–8.19 (m, 2H); $^{13}$C NMR (126 MHz, $CDCl_3$) $\delta$ 116.5 (t, *J* 301.1 Hz, $CF_2$), 128.8, 129.3, 129.6, 129.8, 130.6, 131.8, 132.5, 136.0 and 184.0 (C=O); $^{19}$F NMR (235 MHz, $CDCl_3$) $\delta$ −102.8 (s, 2F, $CF_2$); IR (KBr, $cm^{-1}$) 3093, 2909, 1687 (C=O), 1550, 1451, 1355, 1239, 944 and 872; LRMS *m*/*z* (EI): 296 ($M^+$, 100%), 156 (4%) and 105 (4%). Elemental analysis: Found (%): C, 56.45; H, 3.22; S, 10.92. Calcd for $C_{14}H_{10}F_2O_3S$: C, 56.75; H, 3.40; S, 10.82.

*3.5.3. 2-(4-Bromophenylsulfonyl)-2,2-difluoro-1-phenylethanone (**8b**)*

Following the typical procedure for fluorination of β-ketosulfones, the difluoro product **8b** was obtained in 48% yield; $^1$H NMR (500 MHz, $CDCl_3$) $\delta$ 7.58 (t, *J* 7.7 Hz, 2H), 7.79 (ddd, *J* 8.6, 2.3 and 1.3 Hz, 1H), 7.88–7.93 (m, 2H), 7.98 (d, *J* 8.6 Hz, 2H) and 8.04 (dd, *J* 8.6 and 1.3 Hz, 2H); $^{13}$C NMR (126 MHz, $CDCl_3$) $\delta$ 87.5, 116.2 (t, *J* 301.8 Hz, $CF_2$), 128.9, 130.6, 130.7, 131.5, 132.0, 133.0, 135.5 and 184.0 (C=O); $^{19}$F NMR (235 MHz, $CDCl_3$) $\delta$ −102.7 (s, 2F, $CF_2$); IR (KBr, $cm^{-1}$) 3093, 3050, 2897, 2832, 1716 (C=O), 1553, 1437, 1366, 1246, 925, 866 and 824; HRMS (EI) Found: $M^+$, 375.1902. $C_{14}H_9BrF_2O_3S$ requires $M^+$, 375.1075; LRMS *m*/*z* (EI): 375 ($M^+$, 8%), 311 ($M-SO_2$, 6%), 127 (100%) and 105 (75%). Elemental analysis: Found (%): C, 44.78; H, 2.35; S, 8.70. Calcd for $C_{14}H_9BrF_2O_3S$: C, 44.82; H, 2.42; S, 8.55.

*3.5.4. 2-Fluoro-1-phenyl-2-tosylethanone (**7c**) and 2,2-difluoro-1-phenyl-2-tosylethanone (**8c**)*

Following the typical procedure for fluorination of β-ketosulfones, the monofluoro product **7c** was obtained in 10% yield; mp 78–81 °C (ethanol); $^1$H NMR (500 MHz, $CDCl_3$) $\delta$ 2.92 (s, 3H), 6.32 (d, *J* 48.9 Hz, 1H), 7.54 (t, *J* 7.7 Hz, 2H), 7.60 (ddd, *J* 8.7, 2.3 and 1.2 Hz, 1H), 7.10–7.18 (m, 2H), 7.67 (d, *J* 8.7 Hz, 2H) and 7.91 (dd, *J* 8.5 and 1.3 Hz, 2H); $^{13}$C NMR (126 MHz, $CDCl_3$) $\delta$ 78.9, 100.3 (d, *J* 48.9 Hz, CF), 130.1, 130.4, 130.8, 131.3, 132.3, 133.7, 136.5, 139.1 and 184.4

(C=O); $^{19}$F NMR (235 MHz, $CDCl_3$) $\delta$ −102.7 (d, *J* 48.9 Hz, F, CFH); IR (KBr, $cm^{-1}$) 3097, 2879, 1705 (C=O), 1546, 1455, 1314, 1237, 922 and 855; HRMS (EI) Found: $M^+$, 292.0632. $C_{15}H_{13}FO_3S$ requires $M^+$, 292.0645; LRMS *m*/*z* (EI): 292 ($M^+$, 94%) and 293 (27%). Elemental analysis: Found (%): C, 61.76; H, 4.54; S, 11.07. Calcd for $C_{15}H_{13}FO_3S$: C, 61.63; H, 4.48; S, 10.97, and the difluoro product **8c** in 41% yield; mp 71 °C (ethanol); $^1$H NMR (500 MHz, $CDCl_3$) $\delta$ 2.93 (s, 3H), 7.61 (t, *J* 7.5 Hz, 2H), 7.68 (ddd, *J* 8.5, 2.5 and 1.2 Hz, 1H), 7.82–7.84 (m, 2H), 7.87 (d, *J* 8.5 Hz, 2H) and 8.1 (dd, *J* 8.5 and 1.2 Hz, 2H); $^{13}$C NMR (126 MHz, $CDCl_3$) $\delta$ 78.9, 111.4 (t, *J* 301.3 Hz, $CF_2$), 130.7, 131.2, 131.8, 132.2, 132.9, 133.2, 134.6, 139.8 and 182.3 (C=O); IR (KBr, $cm^{-1}$) 3092, 2912, 1713 (C=O), 1550, 1301, 1110, 1009, 830 and 760; HRMS (EI) Found: $M^+$, 310.0543. $C_{15}H_{12}F_2O_3S$ requires $M^+$, 310.0502; LRMS *m*/*z* (EI): 310 ($M^+$, 100%), 311 (23%) and 246 ($M-SO_2$, 8%). Elemental analysis: Found (%): C, 58.32; H, 3.98; S, 10.56. Calcd for $C_{15}H_{12}F_2O_3S$: C, 58.06; H, 3.90; S, 10.33.

### 3.5.5. 2-Fluoro-2-(naphthalen-2-ylsulfonyl)-1-phenylethanone (**7d**) and 2,2-difluoro-2-(naphthalen-2-ylsulfonyl)-1-phenylethanone (**8d**)

Following the typical procedure for fluorination of β-keto-sulfones, the monofluoro product **7d** was obtained in 10% yield; mp 136 °C; $^1$H NMR (500 MHz, $CDCl_3$) $\delta$ 6.40 (d, *J* 48.0 Hz, 1H, CFH), 7.53–7.62 (m, 2H), 7.70–7.64 (m, 2H), 7.73 (ddd, *J* 8.3, 7.0 and 1.3 Hz, 1H), 7.83 (ddd, *J* 8.6, 2.0 and 1.0 Hz, 1H), 8.01–8.15 (m, 5H) and 8.47 (d, *J* 1.8 Hz, 1H); $^{13}$C NMR (126 MHz, $CDCl_3$) $\delta$ 100.5 (d, *J* 232.3 Hz, F, CFH), 123.6, 127.9, 128.1, 128.8, 129.6, 129.7, 129.8, 130.1, 131.6, 132.0, 132.5, 134.0, 135.0, 136.0 and 186.6 (C=O); $^{19}$F NMR (235 MHz, $CDCl_3$) $\delta$ −179.0 (d, *J* 48.0 Hz, 1F, CFH); IR (KBr, $cm^{-1}$) 3104, 3066, 2924, 2839, 1731 (C=O), 1545, 1437, 1363, 1236, 934, 853 and 811; HRMS (EI) Found: $M^+$, 328.1042. $C_{18}H_{13}FO_3S$ requires $M^+$, 328.1060; LRMS *m*/*z* (EI): 328 ($M^+$, 5%), 264 ($M-SO_2$, 2%), 127 (100%) and 105 (85%). Elemental analysis: Found (%): C, 65.66; H, 4.01; S, 9.87. Calcd for $C_{18}H_{13}FO_3S$: C, 65.84; H, 3.99; S, 9.76, and the difluoro product **8d** in 52% yield; mp 142 °C (ether); $^1$H NMR (500 MHz, $CDCl_3$) $\delta$ 7.54 (dd, *J* 8.3 and 7.5 Hz, 2H), 7.69–7.72 (m, 2H), 7.75 (ddd, *J* 8.3, 6.9 and 1.3 Hz, 1H), 7.96–8.00 (m, 2H), 8.05 (dd, *J* 11.7 and 8.2 Hz, 2H), 8.20 (td, *J* 2.3 and 1.1 Hz, 2H) and 8.62 (d, *J* 1.5 Hz, 1H); $^{13}$C NMR (126 MHz, $CDCl_3$) $\delta$ 116.7 (t, *J* 301.4 Hz, 2F, $CF_2$), 124.3, 128.1, 128.1, 128.9, 129.4, 129.7, 129.9, 130.5, 130.8, 132.0, 134.0, 135.4, 136.4 and 183.8 (C=O); $^{19}$F NMR (235 MHz, $CDCl_3$) $\delta$ −102.6 (s, 2F); IR (KBr, $cm^{-1}$) 3100, 3055, 1746 (C=O), 1545, 1492, 1436, 1361, 1245, 954, 843 and 817; HRMS (EI) Found: $M^+$, 346.1132. $C_{18}H_{12}F_2O_3S$ requires $M^+$, 346.1211; LRMS *m*/*z* (EI): 346 ($M^+$, 3%), 264 ($M-SO_2$, 2%), 127 (65%) and 105 (100%). Elemental analysis: Found (%): C, 62.32; H, 3.59; S, 9.57. Calcd for $C_{18}H_{12}F_2O_3S$: C, 62.42; H, 3.49; S, 9.26.

### 3.5.6. 2,2-Difluoro-2-(4-methoxybenzylsulfonyl)-1-phenylethanone (**8f**)

Following the typical procedure for fluorination of β-keto-sulfones, the difluoro product **8f** was obtained in 73% yield, recrystallized from ethanol; mp 92 °C; $^1$H NMR (500 MHz, $CDCl_3$) $\delta$ 3.88 (s, 3H), 4.21 (s, 2H), 6.96 (d, *J* 8.3 Hz, 2H), 7.35 (d, *J* 8.3 Hz, 2H), 7.52 (t, *J* 7.5 Hz, 2H), 7.68 (t, *J* 7.5 Hz, 1H) and 7.98 (d, *J* 7.5 Hz, 2H); $^{13}$C NMR (101 MHz, $CDCl_3$) $\delta$ 56.3, 57.8, 108.7 (t, *J* 301.3 Hz, $CF_2$), 115.2, 121.5, 128.9, 129.3, 131.9, 135.3, 136.8, 160.1 and 190.2 (C=O); $^{19}$F NMR (235 MHz, $CDCl_3$) $\delta$ −134.3 (s, 2F, $CF_2$); IR (KBr, $cm^{-1}$) 3877, 2982, 2923, 1706 (C=O), 1566, 1455, 1365, 1350, 1201, 1145 and 1097; HRMS (EI) Found: $M^+$, 340.0645. $C_{16}H_{14}F_2O_4S$ requires $M^+$, 340.0683. Elemental analysis: Found (%): C, 56.71; H, 4.34; S, 9.56. Calcd for $C_{16}H_{14}F_2O_4S$: C, 56.46; H, 4.14; S, 9.42.

### 3.5.7. 1,1-Difluoro-1-(phenylsulfonyl)propan-2-one (**8j**)

Following the typical procedure for fluorination of β-keto-sulfones, the difluoro product **8j** (30%) was isolated as an oil; $^1$H NMR (500 MHz, $CDCl_3$) $\delta$ 2.49 (s, 3H), 7.58 (t, *J* 7.8 Hz, 2H), 7.73 (t, *J* 6.3 Hz, 1H) and 7.90 (d, *J* 7.8 Hz, 2H); $^{13}$C NMR (101 MHz, $CDCl_3$) $\delta$ 27.4, 114.4 (t, *J* 300.21 Hz, $CF_2$), 129.6, 130.6, 135.9, 136.4 and 191.8 (C=O); $^{19}$F NMR (235 MHz, $CDCl_3$) $\delta$ −110.7 (s, 2F, $CF_2$); IR (KBr, $cm^{-1}$) 3037, 2973, 2906, 1714 (C=O), 1566, 1450, 1355, 1345, 1211, 1155 and 1087; HRMS (EI) Found: $M^+$, 234.0234. $C_9H_8F_2O_3S$ requires $M^+$, 234.0265. Elemental analysis: Found (%): C, 46.32; H, 3.34; S, 13.56. Calcd for $C_9H_8F_2O_3S$: C, 46.15; H, 3.44; S, 13.69.

## Acknowledgements

We thank the Department of Chemistry, University of Isfahan, Iran, for financial support and the Department of Chemistry, The University of Sheffield, UK, for $^1$H, $^{13}$C and $^{19}$F, NMR, HRMS and GC–mass spectra.

## Supplementary data

Supplementary data associated with this article can be found in the online version, at doi:10.1016/j.tet.2008.05.034.

## References and notes

1. Mogi, R.; Morisaki, K.; Hu, J. B.; Prakash, G. K. S.; Olah, G. A. *J. Fluorine Chem.* **2007**, *128*, 1098–1103.
2. Brigaud, T.; Laurent, E. *Tetrahedron Lett.* **1990**, *31*, 2287–2290.
3. Zhu, L. G.; Li, Y.; Ni, C. F.; Hu, J. B.; Beier, P.; Wang, Y.; Prakash, G. K. S.; Olah, G. A. *J. Fluorine Chem.* **2007**, *128*, 1241–1247.
4. Zhang, L. J.; Li, Y.; Hu, J. B. *J. Fluorine Chem.* **2007**, *128*, 755–761.
5. Yudin, A. K.; Prakash, G. K. S.; Deffieux, D.; Bradley, M.; Bau, R.; Olah, G. A. *J. Am. Chem. Soc.* **1997**, *119*, 1572–1581.
6. Erickson, J. A.; McLoughlin, J. I. *J. Org. Chem.* **1995**, *60*, 1626–1631.
7. Sasson, R.; Hagooly, A.; Rozen, S. *Org. Lett.* **2003**, *5*, 769–771.
8. Rozov, L. A.; Huang, C.; Halpern, D. F.; Vernice, G. G. U.S. Patent 5,283,372, 1994.
9. Halpern, D. F.; Robin, M. L. U.S. Patent 4,996,371, 1991.
10. Chen, Y.; Freskos, J. N.; Gasiecki, A. F.; Grapperhaus, M. L.; Hansen, D. W., Jr.; Heintz, R. M.; Khanna, I. K.; Kolodziej, S. A.; Mantegani, S.; Massa, M. A.; McDonald, J. J.; Mischke, D. A.; Nagy, M. A.; Perrone, E.; Schmidt, M. A.; Spangler, D. P.; Talley, J. J.; Trivedi, M.; Wynn, T. A.; Becker, D. P.; Rico, J. G. WO/2004/000811, 2003.
11. Parker, M. F.; McElhone, K. E.; Mate, R. A.; Bronson, J. J.; Gai, Y.; Bergstrom, C. P.; Marcin, L. R.; Macor, J. E. WO/2003/053912, 2003.
12. Kaneko, S.; Yamazaki, T.; Kitazume, T. *J. Org. Chem.* **1993**, *58*, 2302–2312.
13. Houlton, J. S.; Motherwell, W. B.; Ross, B. C.; Tozer, M. J.; Williams, D. J.; Slawin, A. M. Z. *Tetrahedron* **1993**, *49*, 8087–8106.
14. Otaka, K.; Oohira, D.; Takaoka, D. WO/2004/006677, 2004.
15. Markl, M.; Schaper, W.; Ort, O.; Jakobi, H.; Braun, R.; Krautstrunk, G.; Sanft, U.; Bonin, W.; Stark, H.; Pasenok, S.; Cabrera, I. WO/2000/007998, 2000.
16. Goure, W. F.; Leschinsky, K. L.; Wratten, S. J.; Chupp, J. P. *J. Agric. Food Chem.* **1991**, *39*, 981–986.
17. Kondou, T.; Matsui, S.; Miyazawa, K.; Takeuchi, H.; Kubo, Y.; Takeshita, F.; Nakagawa, E. WO/1998/13324, 1998.
18. *Fluorine-Containing Molecules: Structure, Reactivity, Synthesis and Applications*; Liebman, J. F., Greenberg, A., Dolbier, W. R., Jr., Eds.; VCH: New York, NY, 1988.
19. Lal, G. S.; Pez, G. P.; Syvret, R. G. *Chem. Rev.* **1996**, *96*, 1737–1755.
20. Stahly, G. P. *J. Fluorine Chem.* **1989**, *43*, 53–66.
21. Prakash, G. K. S.; Hu, J. B.; Mathew, T.; Olah, G. A. *Angew. Chem., Int. Ed.* **2003**, *42*, 5216–5219.
22. Prakash, G. K. S.; Hu, J. B.; Ying, W.; Olah, G. A. *Angew. Chem., Int. Ed.* **2004**, *43*, 5203–5206.
23. Middleton, W. J. *J. Org. Chem.* **1975**, *40*, 574–578.
24. Olah, G. A.; Nojima, M.; Kerekes, I. *J. Am. Chem. Soc.* **1974**, *96*, 925–927.
25. Sondej, S. C.; Katzenellenbogen, J. A. *J. Org. Chem.* **1986**, *51*, 3508–3513.
26. Olah, G. A.; Chambers, R. D.; Prakash, G. K. S. *Synthetic Fluorine Chemistry*; John Wiley: New York, NY, 1992.
27. García Martínez, A.; Barcina, J. O.; Rys, A. Z.; Subramanian, L. R. *Tetrahedron Lett.* **1992**, *33*, 7787–7788.
28. Gonzalez, J.; Foti, C. J.; Elsheimer, S. *J. Org. Chem.* **1991**, *56*, 4322–4325.
29. Hine, J.; Porter, J. J. *J. Am. Chem. Soc.* **1960**, *82*, 6178–6181.
30. Langlois, B. R. *J. Fluorine Chem.* **1988**, *41*, 247–261.
31. Umemoto, T.; Tomizawa, G. *Bull. Chem. Soc. Jpn.* **1986**, *59*, 3625–3629.
32. Furuta, S.; Kuroboshi, M.; Hiyama, T. *Bull. Chem. Soc. Jpn.* **1998**, *71*, 1939–1951.
33. Takeda, S.; Kaneko, Y.; Eto, H.; Tokizawa, M.; Sato, S.; Yoshida, K.; Namiki, S.; Ogawa, M. *Chem. Pharm. Bull.* **2000**, *48*, 1097–1100.
34. Pedersen, O. S.; Pedersen, E. B. *Synthesis* **2000**, 479–495.
35. Suryakiran, N.; Prabhakar, P.; Reddy, T. S.; Mahesh, K. C.; Rajesh, K.; Venkateswarlu, Y. *Tetrahedron Lett.* **2007**, *48*, 877–881.
36. Butler, P.; Golding, B. T.; Laval, G.; Loghmani-Khouzani, H.; Ranjbar-Karimi, R.; Sadeghi, M. M. *Tetrahedron* **2007**, *63*, 11160–11166.

37. Sadeghi, M. M.; Loghmani-Khouzani, H.; Ranjbar-Karimi, R.; Golding, B. T. *Tetrahedron Lett.* **2006**, *47*, 2455–2457.
38. Bradsher, C. K.; Brown, F. C.; Grantham, R. J. *J. Am. Chem. Soc.* **1954**, *76*, 114–115.
39. Lal, G. S. *J. Org. Chem.* **1993**, *58*, 2791–2796.
40. Zupan, M. *J. Fluorine Chem.* **1976**, *8*, 305–309.
41. Eto, H.; Kaneko, Y.; Takeda, S.; Tokizawa, M.; Sato, S.; Yoshida, K.; Namiki, S.; Ogawa, M.; Maebashi, K.; Ishida, K.; Matsumoto, M.; Asaoka, T. *Chem. Pharm. Bull.* **2001**, *49*, 173–182.
42. Furuta, S.; Kuroboshi, M.; Hiyama, T. *Tetrahedron Lett.* **1995**, *36*, 8243–8246.
43. Toyota, A.; Ono, Y.; Chiba, J.; Sugihara, T.; Kaneko, C. *Chem. Pharm. Bull.* **1996**, *44*, 703–708.
44. Takeuchi, Y.; Ogura, H.; Kanada, A.; Koizumi, T. *J. Org. Chem.* **1992**, *57*, 2196–2199.
45. Ratts, K. W. *J. Org. Chem.* **1972**, *37*, 848–851.
46. Kenny, W. J.; Walsh, J. A.; Davenport, D. A. *J. Am. Chem. Soc.* **1961**, *83*, 4019–4022.
47. Guss, C. O.; Wilgus, H. S., III. *J. Org. Chem.* **1959**, *24*, 1011–1012.
48. Schulte, K. E.; Vonweissenborn, V.; Kwon, S. K. *Eur. J. Med. Chem.* **1978**, *13*, 25–31.
49. Long, L. M. *J. Am. Chem. Soc.* **1946**, *68*, 2159–2161.
50. Trost, B. M. *Chem. Rev.* **1978**, *78*, 363–382.
51. Yiannios, C. N.; Karabinos, J. V. *J. Org. Chem.* **1963**, *28*, 3246–3248.
52. Wallace, T. J.; Schriesheim, A. *Tetrahedron* **1965**, *21*, 2271–2280.
53. Back, T. G.; Collins, S.; Kerr, R. G. *J. Org. Chem.* **1983**, *48*, 3077–3084.
54. Amel, R. T.; Marek, P. J. *J. Org. Chem.* **1973**, *38*, 3513–3516.
55. Ratts, K. W.; Yao, A. N. *J. Org. Chem.* **1966**, *31*, 1185–1188.