Supporting information

O-difluoromethylation of 1,3-diones with S-difluoromethyl sulfonium salt

Chun-Bo Yue\textsuperscript{a,b}, Jin-Hong Lin\textsuperscript{b}, Ji Cai\textsuperscript{b}, Cheng-Pan Zhang\textsuperscript{b}, Gang Zhao\textsuperscript{b}, Ji-Chang Xiao\textsuperscript{b,*} and HengFeng Li\textsuperscript{a,*}

\textsuperscript{a}School of Materials Science and Engineering, Central South University, 932 south Lushan road, Changsha 410083, China
\textsuperscript{b}Key Laboratory of Organofluorine Chemistry, Shanghai Institute of Organic Chemistry, Chinese Academy of Sciences 345 Lingling Road, Shanghai 200032, China.

Table of Contents

Supporting information ................................................................................................................... S1
1. General Information .................................................................................................................... S2
2. The Procedure for the Synthesis of compound 3 ................................................................... S2
3. The Procedure for O-difluoromethylation ........................................................................... S3
4. The procedure for the preparation of compound D-5e ........................................................... S7
5. The O-difluoromethylation of compound D-5e ................................................................... S8
6. The trap of difluorocarbene ................................................................................................. S11
7. The determination of the configuration of product 6l ............................................................ S12
8. Copies of \textsuperscript{1}H NMR, \textsuperscript{19}F NMR and \textsuperscript{13}C NMR Spectra of compounds 3 and 6 ................. S14
9. Copies of \textsuperscript{1}H NMR, \textsuperscript{19}F NMR, \textsuperscript{13}C NMR and \textsuperscript{2}D NMR of compound D-5e and D-6e ........ S35
1. General Information

$^1$H, $^{13}$C and $^{19}$F NMR spectra were detected on a 500 MHz, 400 MHz or 300 MHz NMR spectrometer. Data for $^1$H NMR, $^{13}$C NMR and $^{19}$F NMR were recorded as follows: chemical shift ($\delta$, ppm), multiplicity (s = singlet, d = doublet, t = triplet, m = multiplet, q = quartet, coupling constants in Hz). Mass spectra were obtained on GC-MS or LC-MS (ESI). High resolution mass data were recorded on a high resolution mass spectrometer in the EI or ESI mode.

2. The Procedure for the Synthesis of compound 3

\[
\begin{align*}
\text{S} & \quad \text{H} \\
\text{O} & \quad \text{C} \\
\text{F} & \quad \text{S}
\end{align*}
\]

Into the solution of thiophenol (32.18 g, 292.5 mmol), THF (30 mL) and H$_2$O (5 mL) was added sodium hydroxide (30 g, 0.75 mol). HCF$_2$Cl was bubbled into the system slowly at room temperature for 4 h. After the resulting mixture was further stirred for 2 h, the solid was removed by filtration. Into the filtrate were added water (30 mL) and THF (50 mL). THF phase was separated, and the aqueous phase was extracted with THF (30 mL $\times$ 2). The organic phase was combined and dried over anhydrous magnesium sulfate. After filtration, the solvent was removed by concentration in vacuo to afford II as a slightly yellow liquid (35.67 g, 78%).

Into the solution of compound II (35.67 g, 229.3 mmol) in DCM (20 mL) was added the saturated solution of 3-chloroperbenzoic acid (46 g, 261.3 mmol) in DCM dropwise at -20 °C. The resulting mixture was further stirred at this temperature for 10 min. Saturated sodium carbonate (50 mL) was added into the reaction system. The mixture was extracted with DCM (50 mL $\times$ 3). The combined organic phase was dried over anhydrous magnesium sulfate. After filtration, the solvent was removed by concentration in vacuo, and the residue was subjected to flash column chromatography with the use of hexane/ethyl acetate (23 : 2) as eluent to afford the product III (30.43 g, 75%).

Into the solution of compound III (4.0 g, 22.7 mmol) and $m$-xylene (2.65 g, 25 mmol) in diethyl ether (20 mL) was added the solution of trifluoromethanesulfonic anhydride (7.0 g, 25 mmol) in diethyl ether (50 mL) dropwise at -78 °C under N$_2$ atmosphere for 2 h. The resulting reaction mixture was further stirred for 20 min. Two phases were observed. The upper layer phase was discarded. The residue was washed with diethyl ether (40 mL $\times$ 3), and was then dissolved in DCM (50 mL). Into the DCM solution was added aqueous solution of sodium tetrafluoroborate (1 M, 100 mL). The resulting mixture was stirred for 2 min, and then the aqueous phase was discarded (anion metathesis). This anion metathesis procedure was further repeated twice. The organic phase was dried over anhydrous magnesium sulfate. After filtration, the solvent was
removed by concentration to give a white solid product 3 (4.3 g, 53 %).

(Difluoromethyl)(phenyl)sulfane[1], 78 %, 1H NMR (400 MHz, CDCl\textsubscript{3}) \(\delta\) 7.59 (dd, \(J = 7.7, 1.2\) Hz, 2 H), 7.47 – 7.33 (m, 3 H), 6.83 (td, \(J = 57.0\) 0.5Hz, 1 H). 19F NMR (376 MHz, CDCl\textsubscript{3}) \(\delta\) -91.39 (d, \(J = 57.0\) Hz, 2 F).

((Difluoromethyl)sulfinyl)benzene[1], 75 %, 1H NMR (400 MHz, CDCl\textsubscript{3}) \(\delta\) 7.71 (d, \(J = 7.7\) Hz, 2 H), 7.62 – 7.57 (m, 3 H), 6.02 (t, \(J = 55.4\) Hz, 1 H). 19F NMR (376 MHz, CDCl\textsubscript{3}) \(\delta\) -119.25 (dd, \(J = 55.4, 13.0\) Hz, 2 F).

(Difluoromethyl)(2,4-dimethylphenyl)(phenyl) sulfonium tetrafluoroborate, white solid, 53 %, 1H NMR (400 MHz, CDCl\textsubscript{3}) \(\delta\) 8.07 (t, \(J = 52.9\) Hz, 1 H), 7.85 (d, \(J = 8.0\) Hz, 2 H), 7.80 (t, \(J = 7.4\) Hz, 1H), 7.72 (dd, \(J = 17.2, 8.6\) Hz, 3 H), 7.40 (d, \(J = 8.6\) Hz, 1 H), 7.34 (s, 1 H), 2.60 (s, 3 H), 2.43 (s, 3 H). 19F NMR (376 MHz, CDCl\textsubscript{3}) \(\delta\) -99.45 (dd, \(J = 53.0, 3.4\) Hz, 2 F), -151.44 (s, 1F), -151.49 (s, 3F). 13C NMR (126 MHz, CDCl\textsubscript{3}) \(\delta\) 147.88 (s), 143.52 (s), 135.59 (s), 134.28 (s), 131.86 (s), 131.71 (s), 131.37 (s), 130.53 (s), 118.74 (t, \(J = 298.2\) Hz), 118.34 (s), 112.90 (s), 21.62 (s), 19.99 (s).HRMS (ESI) Calecd for C\textsubscript{15}H\textsubscript{15}F\textsubscript{2}S\textsuperscript{+} [M-BF\textsubscript{4}]\textsuperscript{−} : 265.0857, Found: 265.0857. IR: 3389, 3058, 1601, 1583, 1476, 1446, 1438, 1377, 1275, 1234, 1100, 1033, 814, 738,715, 689, 552, 542, 533, 521, 496 cm\textsuperscript{-1}.

3. The Procedure for O-difluoromethylation

Into a mixture of salt 3 (53.6 mg, 0.15 mmol), 1,3-cyclohexanedione (5a, 11.2 mg, 0.1 mmol) and potassium carbonate (20.8 mg, 0.15 mmol) were added the deionized water (2.9 mg, 0.16 mmol) and dry DCM (1.5 mL) under N\textsubscript{2} atmosphere. The resulting mixture was stirred at room temperature for 2 h. The solvent was removed by concentration, and the residue was subjected to flash column chromatography with the use of n-pentane/ether (3 : 2) as eluent to afford the pure product 6a (85%).
3-(Difluoromethoxy)cyclohex-2-enone\textsuperscript{[4]}, 85 \%, \textsuperscript{1}H NMR (400 MHz, CDCl\textsubscript{3}) \(\delta\) 6.50 (t, \(J = 72.0\) Hz, 1 H), 5.52 (s, 1 H), 2.49 (t, \(J = 6.2\) Hz, 2 H), 2.36 (t, \(J = 6.7\) Hz, 2 H), 2.02 (p, \(J = 6.4\) Hz, 2 H). \textsuperscript{19}F NMR (376 MHz, CDCl\textsubscript{3}) \(\delta\) -85.26 (d, \(J = 72.0\) Hz, 2 F).

3-(Difluoromethoxy)-2-methylcyclohex-2-enone\textsuperscript{[4]}, 70 \%, \textsuperscript{1}H NMR (400 MHz, CDCl\textsubscript{3}) \(\delta\) 6.52 (t, \(J = 73.4\) Hz, 1 H), 2.63-2.60 (m, 2 H), 2.46 – 2.34 (m, 2 H), 2.10 – 1.90 (m, 2 H), 1.75 (t, \(J = 1.7\) Hz, 3 H). \textsuperscript{19}F NMR (376 MHz, CDCl\textsubscript{3}) \(\delta\) -80.10 (d, \(J = 73.4\) Hz, 2 F).

3-(Difluoromethoxy)-5,5-dimethylcyclohex-2-enone\textsuperscript{[4]}, 86 \%, \textsuperscript{1}H NMR (400 MHz, CDCl\textsubscript{3}) \(\delta\) 6.50 (t, \(J = 72.1\) Hz, 1 H), 5.53 (s, 1 H), 2.34 (s, 2 H), 2.22 (s, 2 H), 1.07 (s, 6 H). \textsuperscript{19}F NMR (376 MHz, CDCl\textsubscript{3}) \(\delta\) -85.29 (d, \(J = 72.0\) Hz, 2 F).

3-(Difluoromethoxy)-5-methylcyclohex-2-enone\textsuperscript{[4]}, 71 \%, \textsuperscript{1}H NMR (400 MHz, CDCl\textsubscript{3}) \(\delta\) 6.50 (t, \(J = 72.0\) Hz, 1 H), 5.51 (s, 1 H), 2.58 – 2.39 (m, 2 H), 2.33 – 2.17 (m, 2 H), 2.08-2.01 (m, 1 H), 1.09 (d, \(J = 6.3\) Hz, 3 H). \textsuperscript{19}F NMR (376 MHz, CDCl\textsubscript{3}) \(\delta\) -84.69 (dd, \(J = 173.6, 72.0\) Hz, 1 F), -85.93 (dd, \(J = 173.6, 71.0\) Hz, 1 F).
5-(Difluoromethoxy)-1,6-dihydro-[1,1'-biphenyl]-3(2H)-one, 76%, $^1$H NMR (400 MHz, CDCl$_3$) $\delta$ 7.40 – 7.24 (m, 5 H), 6.53 (t, $J = 72.0$ Hz, 1 H), 5.63 (s, 1 H), 3.48 – 3.23 (m, 1 H), 2.87 – 2.32 (m, 4 H). $^{19}$F NMR (282 MHz, CDCl$_3$) $\delta$ -84.88 (dd, $J = 173.1$, 72.3 Hz 1 F), -86.54 (dd, $J = 173.0$, 70.9 Hz, 1 F).

3-(Difluoromethoxy)cyclopent-2-enone, 0.3 mmol scale was used, 76%, $^1$H NMR (400 MHz, CDCl$_3$) $\delta$ 6.55 (t, $J = 71.6$ Hz, 1 H), 5.55 (s, 1 H), 2.87 – 2.65 (m, 2 H), 2.61 – 2.42 (m, 2 H). $^{19}$F NMR (376 MHz, CDCl$_3$) $\delta$ -86.79 (d, $J = 71.5$ Hz, 2 F).

3-(Difluoromethoxy)-2-methylcyclopent-2-enone, 69%, $^1$H NMR (400 MHz, CDCl$_3$) $\delta$ 6.66 (t, $J = 72.2$ Hz, 1 H), 2.81 – 2.75 (m, 2 H), 2.55 – 2.50 (m, 2 H), 1.68 (t, $J = 1.9$ Hz, 3 H). $^{19}$F NMR (376 MHz, CDCl$_3$) $\delta$ -81.33 (d, $J = 72.3$ Hz, 2 F).

3-(Difluoromethoxy)-2-ethylcyclopent-2-enone, 84%, $^1$H NMR (400 MHz, CDCl$_3$) $\delta$ 6.65 (t, $J = 72.3$ Hz, 1 H), 2.83 – 2.65 (m, 2 H), 2.64 – 2.43 (m, 2 H), 2.18 (q, $J = 7.6$ Hz, 2 H), 1.00 (t, $J = 7.6$ Hz, 3 H). $^{19}$F NMR (376 MHz, CDCl$_3$) $\delta$ -81.39 (d, $J = 72.3$ Hz, 2 F).

2-Bromo-3-(difluoromethoxy)cyclopent-2-enone, 79%, $^1$H NMR (400 MHz, CDCl$_3$) $\delta$ 6.83 (t, $J = 70.9$ Hz, 1 H), 3.07 – 2.87 (m, 2 H), 2.78 – 2.61 (m, 2 H). $^{19}$F NMR (376 MHz, CDCl$_3$) $\delta$ -81.48 (d, $J = 70.9$ Hz, 2 F).
2-(4-Chlorophenyl)-3-(difluoromethoxy)-1H-inden-1-one, Red solid, 77 %, M.P.: 71.8 °C, $^1$H NMR (400 MHz, CDCl$_3$) $\delta$ 7.56 (d, $J = 8.3$ Hz, 2 H), 7.53 (d, $J = 7.3$ Hz, 1 H), 7.45 (t, $J = 7.5$ Hz, 1 H), 7.40 (d, $J = 8.1$ Hz, 2 H), 7.37 – 7.27 (m, 2 H), 6.64 (t, $J = 72.4$ Hz, 1 H). $^{19}$F NMR (376 MHz, CDCl$_3$) $\delta$ -81.35 (d, $J = 72.4$ Hz, 2 F). $^{13}$C NMR (126 MHz, CDCl$_3$) $\delta$ 192.73 (s), 163.91 (t, $J = 2.9$ Hz), 138.78 (s), 134.72 (s), 133.77 (s), 130.64 (s), 130.43 (s), 130.25 (s), 128.92 (s), 126.90 (s), 122.75 (s), 119.64 (t, $J = 1.4$ Hz), 117.69 (s), 114.60 (t, $J = 264.0$ Hz). HRMS (EI) Calcd for C$_{16}$H$_9$F$_2$O$_2$Cl, [M]$^+$: 306.0259, Found: 306.0254. IR (KBr): 3060, 1715, 1588, 1491, 1457, 1364, 1309, 1123, 1074, 1036, 913, 756, 698, 597, 511 cm$^{-1}$.

3-(Difluoromethoxy)-2-phenyl-1H-inden-1-one, Red solid, 76 %, M.P.: 97.8 °C, $^1$H NMR (400 MHz, CDCl$_3$) $\delta$ 7.56– 7.53 (m, 3 H), 7.47 – 7.41 (m, 3 H), 7.38 – 7.30 (m, 3 H), 6.65 (t, $J = 72.1$ Hz, 1 H). $^{19}$F NMR (376 MHz, CDCl$_3$) $\delta$ -80.67 (d, $J = 72.1$ Hz, 2 F). $^{13}$C NMR (126 MHz, CDCl$_3$) $\delta$ 193.09 (s), 163.75 (t, $J = 2.9$ Hz), 139.12 (s), 133.62 (s), 130.27 (s), 130.24 (s), 129.47 (s), 128.69 (s), 128.68 (s), 128.46 (s), 122.58 (s), 119.45 (t, $J = 1.0$ Hz), 118.20 (s), 114.51 (t, $J = 263.3$ Hz). HRMS (EI) Calcd for C$_{16}$H$_{10}$F$_2$O$_2$: [M]$^+$: 272.0649, Found: 272.0648. IR (KBr): 3072, 1712, 1620, 1589, 1490, 1458, 1370, 1321, 1299, 1216, 1086, 1033, 1014, 947,872, 829, 793,764,741, 724, 629, 461 cm$^{-1}$.

(Z)-3-(Difluoromethoxy)-1,3-diphenylprop-2-en-1-one, wite solid, 79 %. M.P.: 72.6 °C. Only Z-isomer was observed before isolation. But after isolation, both Z- and $E$- isomers were observed. $Z:E = 76:24$, Characterization data of Z-isomer. $^1$H NMR (400 MHz, CDCl$_3$) $\delta$ 7.99 – 7.94 (m, 2 H), 7.80 – 7.72 (m, 2 H), 7.62 (tt, $J = 7.3$, 1.3 Hz, 1 H), 7.51 – 7.41 (m, 5 H), 7.03 (s, 1 H), 6.89 (t, $J =$
75.3 Hz, 1 H). 19F NMR (376 MHz, CDCl3) δ -82.20 (d, J = 75.2 Hz, 2 F). 13C NMR (126 MHz, CDCl3) δ 188.80 (s), 157.12 (s), 138.20 (s), 133.93 (s), 133.20 (s), 131.38 (s), 128.90 (s), 128.69 (s), 128.41 (s), 127.16 (s), 116.81 (t, J = 261.6 Hz), 109.80 (s). HRMS (EI) Calcd for C16H12F2O2, [M]+: 274.0805, Found: 274.0804, IR (KBr): 3061, 1665, 1599, 1574, 1493, 1448, 1351, 1271, 1213, 1119, 1055, 913, 846, 769, 689, 591 cm⁻¹.

(Z)-4-(Difluoromethoxy)pent-3-en-2-one. 0.3 mmol scale was used, colorless oil, 30%. Only Z-isomer was observed before isolation. But after isolation, both Z- and E- isomers were observed. Z : E = 82 : 18, 1H NMR (400 MHz, CDCl3) δ 6.60 (t, J = 73.8 Hz, 1 H), 5.45 (s, 1 H), 2.32 (s, 3 H), 2.11 (s, 3 H). 19F NMR (376 MHz, CDCl3) δ -81.74 (d, J = 73.8 Hz, 2 F). 13C NMR (126 MHz, CDCl3) δ 196.67 (s), 156.17 (t, J = 2.4 Hz), 115.35 (s), 114.61 (t, J = 261.6 Hz), 31.34 (s), 20.41 (s). HRMS (EI) Calcd for C6H8F2O2, [M]+: 150.0492, Found: 150.0497. IR (KBr): 2921, 2849, 1725, 1639, 1562, 1544, 1509, 1460, 1188, 799, 763, 750, 688, 659 cm⁻¹.

(Z)-5-(Difluoromethoxy)-2,2,6,6-tetramethylhept-4-en-3-one, 0.3 mmol scale was used, colorless oil, 68%. 1H NMR (400 MHz, CDCl3) δ 6.82 (t, J = 76.0 Hz, 1 H), 6.06 (s, 1 H), 1.17 (s, 9 H), 1.14 (s, 9 H). 19F NMR (376 MHz, CDCl3) δ -81.98 (d, J = 76.0 Hz, 2 F). 13C NMR (126 MHz, CDCl3) δ 204.01 (s), 168.89 (t, J = 2.5 Hz), 116.65 (t, J = 259.3 Hz), 103.21 (s), 44.26 (s), 37.98 (s), 27.88 (s), 26.47 (s). HRMS (EI) Calcd for C12H20F2O2, [M]+: 234.1431, Found: 234.1434. IR (KBr): 2962, 1260, 1188, 1149, 1084, 1021, 799, 763, 750, 688, 659 cm⁻¹.

4. The procedure for the preparation of compound D-5e

Into a mixture of 5-phenylcyclohexane-1,3-dione (377 mg, 2 mmol) and potassium carbonate (277mg, 2mmol) was added deuterated water (1.5mL) under N2 atmosphere. The resulting mixture was stirred at room temperature for 20 min. Dry THF (5 mL) and a solution of deuterium bromide in D2O (2 M, 0.5 mL) were added to quench the reaction. Two phases were observed. The upper layer phase was dried over anhydrous magnesium sulfate. After filtration, the solvent was
removal by concentration to give partially deuterated 5-phenylcyclohexane-1,3-dione.

The deuteration of the above partially deuterated 5-phenylcyclohexane-1,3-dione was repeated twice to afford the final deuterated 5-phenylcyclohexane-1,3-dione (D-5e) (331 mg, 88% yield, 80% deuterated).

Poor solubility of D-5e in CDCl₃ was observed. The ¹H NMR spectrum of D-5e in D-DMSO reveals that only enolate form was observed. The characterization data of D-5e in D-DMSO is shown as follows. ¹H NMR (400 MHz, DMSO) δ 7.31 – 7.24 (m, 4 H), 7.23 – 7.17 (m, 1 H), 5.24 (s, 0.4 H), 3.31 – 3.23 (m, 1 H), 2.59 – 2.52 (m, 2 H), 2.38 – 2.32 (m, 2 H). ¹³C NMR (126 MHz, DMSO) δ 187.43 (br), 172.41 (s). 144.03 (s), 128.91 (s), 127.35 (s), 127.01 (s), 103.68 (t, J = 20.3 Hz), 39.21 (s), 25.59 (s), 21.48 (s). IR (KBr): 2922, 2348, 1622, 1555, 1371, 1247, 1187, 1141, 1099, 1060, 996, 862, 834, 752, 696, 555, 489 cm⁻¹, HRMS (EI) Calcd for C₁₂H₁₀D₂O₂: 189.0900, Found: 189.0893; C₁₂H₁₁DO₂: 190.0963, Found: 190.0966.

5. The O-difluoromethylation of compound D-5e
(1) O-difluoromethylation without water

Into the mixture of D-5e (18.8 mg, 0.1 mmol), salt 3 (54.3 mg, 0.15 mmol) and potassium carbonate (20.7 mg 0.15 mmol) was added dry DCM (1.5 mL) under N₂ atmosphere. The resulting mixture was stirred at room temperature for 6 h. The solvent was removed by concentration, and the residue was subjected to flash column chromatography with the use of n-pentane/ether (3:2) to afford the product D-6e (84% yield, 16% deuterated).

---
(2) \(O\)-difluoromethylation in the presence of \(\text{D}_2\text{O}\)

Into the mixture of \(\text{D}-5\text{e}\) (18.8 mg, 0.1 mmol), salt 3 (54.5 mg, 0.15 mmol) and potassium carbonate (20.6 mg 0.15 mmol) were added \(\text{D}_2\text{O}\) (3 mg, 0.15 mmol) and dry DCM (1.5 mL) under \(\text{N}_2\) atmosphere. The resulting mixture was stirred for 2 h. The solvent was removed by concentration, and the residue was subjected to flash column chromatography to afford the product \(\text{D}-6\text{e}\) (82 % yield, 55 % deuterated).
Scheme 2 $^{19}\text{F}$ NMR spectra of the reaction mixture with the use of trifluoromethylbenzene as an internal standard.

$^1\text{H}$ NMR (400 MHz, CDCl$_3$) δ 7.38-7.33 (m, 2 H), 7.31 – 7.18 (m, 3 H), 6.54 (t, $J = 71.8$, Hz, 0.45 H), 5.63 (s, 0.15 H), 3.44 – 3.35 (m, 1 H), 2.80 – 2.55 (m, 4 H). $^{19}\text{F}$ NMR (376 MHz, CDCl$_3$) δ -85.33 (dt, $J = 173.8$, 10.8 Hz, 1 F), -86.85 (dt, $J = 173.8$, 10.8 Hz, 1 F). $^{13}\text{C}$ NMR (126 MHz, CDCl$_3$) δ 197.61 (s), 168.73 (t, $J = 3.1$ Hz), 141.75 (s), 128.97 (s), 127.40 (s), 126.62 (s), 113.66 (tt, $J = 259.9$, 33.8 Hz), 107.96 (t, $J = 24.6$ Hz), 43.56 (s), 38.90 (s), 35.43 (s). $^2\text{D}$ NMR (61 MHz, CH$_2$Cl$_2$) δ 6.57 (t, $J = 10.9$ Hz, 1 D), 5.62 (s, 1.15 D). IR (KBr):1672, 1612, 1496, 1454, 1427, 1374, 1341, 1299, 1189,1128, 1079, 971, 910, 795, 757, 699, 628, 470cm$^{-1}$. HRMS (EI) Calcd for C$_{13}$H$_{10}$D$_2$F$_2$O$_2$: 239.0868, Found: 239.0872, C$_{13}$H$_{10}$D$_2$F$_2$O$_2$: 240.0931, Found: 240.0929.
6. The trap of difluorocarbene

Into a mixture of D-5e (18.8 mg, 0.1 mmol), salt 3 (54.4 mg, 0.15 mmol) and potassium carbonate (20.6 mg 0.15 mmol) were added 2,3-dimethyl-2-butene (11.8 mg, 0.14 mmol) and dry DCM (1.5 mL) under N2 atmosphere. The resulting mixture was stirred for 6 h. The yields of compounds 6e and 7 were determined by 19F NMR with the use of trifluoromethylbenzene as an internal standard (the spectrum is shown as follows).

Scheme 3 19F NMR spectra of the reaction mixture with the use of trifluoromethylbenzene as an internal standard.
7. The determination of the configuration of product 6l
NOE spectrum of 61
8. Copies of $^1$H NMR, $^{19}$F NMR and $^{13}$C NMR Spectra of compounds 3 and 6
$^{19}$F NMR

$^{1}$H NMR
$^{19}$F NMR

$^{1}$H NMR

S20
$^1$H NMR

$^{19}$F NMR
$^{1}H$ NMR

$^{19}F$ NMR
$\text{Me}\quad\text{Me}$

$\text{OCF}_2\text{H}$

$^\text{13}C\text{ NMR}$

$\text{Me}\quad\text{Me}$

$\text{OCF}_2\text{H}$

$^\text{1}H\text{ NMR}$

$\text{tBu}\quad\text{tBu}$

$\text{OCF}_2\text{H}$

$^\text{1}H\text{ NMR}$
9. Copies of $^1$H NMR, $^{19}$F NMR, $^{13}$C NMR and $^2$D NMR of compound D-5e and D-6e