Photoredox-catalyzed sulfonylation of alkyl iodides, sulfur dioxide, and electron-deficient alkenes

Shengqing Ye, Danqing Zheng, Jie Wu,* and Guanyinsheng Qiu*

Supporting Information

1. General experimental method (S2-S3).
2. General experimental procedure and characterization data (S4-S11).
3. $^1$H and $^{13}$C NMR spectra of compounds 3 (S12-S59).
General experimental methods:

Unless otherwise stated, all commercial reagents were used as received. All solvents were dried and distilled according to standard procedures. Flash column chromatography was performed using silica gel (60-Å pore size, 32–63μm, standard grade). Analytical thin–layer chromatography was performed using glass plates pre-coated with 0.25 mm 230–400 mesh silica gel impregnated with a fluorescent indicator (254 nm). Thin layer chromatography plates were visualized by exposure to ultraviolet light. Organic solutions were concentrated on rotary evaporators at ~20 Torr at 25–35°C. Nuclear magnetic resonance (NMR) spectra are recorded in parts per million from internal tetramethylsilane on the δ scale. ¹H and ¹³C NMR spectra were recorded in CDCl₃ on a Bruker DRX-400 spectrometer operating at 400 MHz and 100 MHz, respectively. All chemical shift values are quoted in ppm and coupling constants quoted in Hz. High resolution mass spectrometry (HRMS) spectra were obtained on a micrOTOF II Instrument.

General experimental procedure for the photoredox-catalyzed sulfonylation of alkyl iodides 1, sulfur dioxide, and electron-deficient alkenes 2:

\[
\text{Alkyl}^-\text{I} + \overset{\text{DABCO}^\bullet\text{(SO}_2\text{)}_2}{\overset{\text{C}}{\text{R}}\overset{\text{EWG}}{\text{2}}} \xrightarrow{\text{Mes-Acr}^+ (5 \text{ mol }\%)} \overset{\text{(TMS)}_3\text{SiH}, \text{NaOAc, I}_2}{\text{DCE, 15 W blue LED}} \xrightarrow{} \overset{\text{Alkyl}}{\overset{\text{O}}{\overset{\text{S}}{\text{O}}}}\overset{\text{EWG}}{\text{R}} \text{3}
\]

Alkene 2 (0.2 mmol) and DABCO•(SO₂)₂ (0.16 mmol) were combined with NaOAc (0.3 mmol), I₂ (10 mol %) and Mes-Acr⁺ (5 mol %) in a tube. The tube was evacuated and backfilled with N₂ three times before the addition of DCE (3.0 mL), alkyl iodide 1 (0.4 mmol), and (TMS)₃SiH (0.2 mmol). The mixture was then placed around a blue LED (15 W) with a distance of 10 centimeters, and was stirred under blue light irradiation for 48 hours at room temperature. After completion of reaction as indicated by TLC, the mixture was purified directly by flash column chromatography (EtOAc/n-hexane, 1:6) to provide the desired product 3.
Experimental setup:

A typical experimental procedure for the gram-scale reaction of cyclohexyl iodide 1a, DABCO’(SO₂)₂, and (E)-chalcone 2a:

(E)-chalcone 2a (1.040 g, 5.0 mmol) and DABCO•(SO₂)₂ (4.0 mmol) were combined with NaOAc (0.615 g, 7.5 mmol), I₂ (10 mol %) and Mes-Acr⁺ (5 mol %) in a flask. The flask was evacuated and backfilled with N₂ three times before the addition of DCE (60.0 mL), cyclohexyl iodide 1a (2.101 g, 10 mmol), and (TMS)₃SiH (5.0 mmol). The mixture was then placed around a blue LED (15 W) with a distance of 10 centimeters, and was stirred under blue light irradiation for 48 hours at room temperature. After completion of reaction as indicated by TLC, the mixture was purified directly by flash column chromatography (EtOAc/n-hexane, 1:6) to provide the desired product 3a (1.175 g, 66%).

3-(Cyclohexylsulfonyl)-1,3-diphenylpropan-1-one (3a): white solid (50.6 mg, 71%); mp 120–122 °C; ¹H NMR (400 MHz, CDCl₃) δ 7.93 (d, J = 7.4 Hz, 2H), 7.55 (t, J = 7.0 Hz, 3H), 7.43 (t, J = 7.7 Hz, 2H), 7.39 – 7.33 (m, 3H), 5.05 (dd, J = 9.7, 3.2 Hz, 1H), 4.05 (dd, J = 17.9, 3.2 Hz, 1H), 3.83 (dd, J = 17.9, 9.7 Hz, 1H), 2.62 – 2.55 (m, 1H), 2.18 – 1.99 (m, 2H), 1.85 – 1.82 (m, 2H), 1.64 – 1.46 (m, 3H), 1.20 – 1.05 (m, 3H); ¹³C NMR (100
1,3-Diphenyl-3-((tetrahydro-2H-pyran-4-yl)sulfonyl)propan-1-one (3b): white solid (33.7 mg, 47%); mp 107–109 °C; $^1$H NMR (400 MHz, CDCl$_3$) δ 7.93 (d, $J = 7.4$ Hz, 2H), 7.58 – 7.55 (m, 3H), 7.44 (t, $J = 7.7$ Hz, 2H), 7.41 – 7.33 (m, 3H), 5.02 (dd, $J = 9.5$, 3.2 Hz, 1H), 4.09 – 4.00 (m, 3H), 3.83 (dd, $J = 18.0$, 9.5 Hz, 1H), 3.25 – 3.18 (m, 2H), 2.91 – 2.83 (m, 1H), 1.99 – 1.73 (m, 4H); $^{13}$C NMR (100 MHz, CDCl$_3$) δ 194.90, 135.97, 133.70, 133.15, 129.42, 129.14, 128.70, 128.09, 66.47, 65.90, 60.51, 55.32, 37.18, 26.23, 23.47; HRMS (ESI): m/z [M + H]$^+$ calcd for C$_{21}$H$_{25}$O$_3$S$: 357.1519; found: 357.1526.

3-(sec-Butylsulfonyl)-1,3-diphenylpropan-1-one (3c): white solid (46.2 mg, 70%); mp 126–127 °C; $^1$H NMR (400 MHz, CDCl$_3$) δ 7.96 (d, $J = 7.6$ Hz, 2H), 7.59 (t, $J = 6.6$ Hz, 3H), 7.46 (t, $J = 7.4$ Hz, 2H), 7.43 – 7.31 (m, 3H), 5.15 – 5.09 (m, 1H), 4.08 (d, $J = 17.9$ Hz, 1H), 3.91 – 3.81 (m, 1H), 2.67 – 2.63 (m, 1H), 2.09 – 1.97 (m, 1H), 1.61 – 1.50 (m, 1H), 1.37 – 1.26 (m, 3H), 0.94 (t, $J = 7.3$ Hz, 3H); $^{13}$C NMR (100 MHz, CDCl$_3$) δ 195.12, 136.06, 133.59, 133.48, 129.46, 129.41, 128.98, 128.65, 128.08, 60.38, 60.34, 56.03, 55.75, 37.31, 37.20, 23.25, 20.47, 13.27, 10.86, 10.68, 10.25; HRMS (ESI): m/z [M + H]$^+$ calcd for C$_{19}$H$_{23}$O$_3$S$: 331.1362; found: 331.1364.

3-(Methylsulfonyl)-1,3-diphenylpropan-1-one (3d): white solid (23.0 mg, 40%); mp 135–137°C; $^1$H NMR (400 MHz, CDCl$_3$) δ 7.94 (d, $J = 7.2$ Hz, 2H), 7.59 – 7.53 (m, 3H), 7.45 (t, $J = 7.7$ Hz, 2H), 7.41 – 7.36 (m, 3H), 4.95 (dd, $J = 9.5$, 3.5 Hz, 1H), 4.08 (dd, $J = 18.0$, 3.5 Hz, 1H), 3.85 (dd, $J = 18.0$, 9.5 Hz, 1H), 2.69 (s, 3H); $^{13}$C NMR (100 MHz,
CDCl$_3$ δ 194.75, 135.96, 133.73, 133.27, 129.44, 129.25, 129.13, 128.74, 128.11, 64.90, 38.71, 36.68.

3-(Oxetan-3-ylsulfonyl)-1,3-diphenylpropan-1-one (3e): white solid (39.6 mg, 60%); mp 161–162 °C; $^1$H NMR (400 MHz, CDCl$_3$) δ 7.95 (d, J = 7.2 Hz, 2H), 7.59 (t, J = 7.4 Hz, 1H), 7.48 – 7.45 (m, 4H), 7.41 – 7.35 (m, 3H), 4.98 (t, J = 6.9 Hz, 1H), 4.87 – 4.84 (m, 1H), 4.71 (t, J = 7.3 Hz, 1H), 4.39 – 4.18 (m, 3H), 4.08 (dd, J = 18.0, 3.5 Hz, 1H), 3.88 (dd, J = 18.0, 9.5 Hz, 1H); $^{13}$C NMR (100 MHz, CDCl$_3$) δ 194.46, 135.84, 133.86, 131.86, 129.57, 129.43, 129.26, 128.79, 128.12, 69.95, 69.44, 63.38, 53.45, 36.23; HRMS (ESI): m/z [M + H]$^+$ calcd for C$_{18}$H$_{19}$O$_4$S$^+$: 331.0999; found: 331.0998.

3-(Tert-butylsulfonyl)-1,3-diphenylpropan-1-one (3f): white solid (43.4 mg, 70%); mp 149–150 °C; $^1$H NMR (400 MHz, CDCl$_3$) δ $^1$H NMR (400 MHz, CDCl$_3$) δ 7.95 (d, J = 7.4 Hz, 2H), 7.66 – 7.56 (m, 3H), 7.46 (t, J = 7.4 Hz, 2H), 7.39 – 7.31 (m, 3H), 5.22 (d, J = 9.2 Hz, 1H), 4.18 (d, J = 17.9 Hz, 1H), 3.76 (dd, J = 17.9, 9.2 Hz, 1H), 2.52 (dd, J = 9.2, 9.9 Hz, 1H); $^{13}$C NMR (100 MHz, CDCl$_3$) δ 195.22, 136.16, 134.79, 133.79, 133.54, 129.76, 128.81, 128.65, 128.12, 62.19, 59.86, 39.35, 24.19; HRMS (ESI): m/z [M + H]$^+$ calcd for C$_{19}$H$_{23}$O$_3$S$^+$: 311.1362; found: 311.1389.

3-((5-Chloropentyl)sulfonyl)-1,3-diphenylpropan-1-one (3g): white solid (49.9 mg, 66%); mp 121–122 °C; $^1$H NMR (400 MHz, CDCl$_3$) δ 7.94 (d, J = 7.6 Hz, 2H), 7.59 – 7.54 (m, 3H), 7.45 (t, J = 7.5 Hz, 2H), 7.41 – 7.34 (m, 3H), 4.95 (d, J = 9.4 Hz, 1H), 4.08 (d, J = 18.0 Hz, 1H), 3.84 (dd, J = 17.9, 9.5 Hz, 1H), 3.49 (t, J = 6.3 Hz, 2H), 2.84 – 2.66 (m, 2H), 1.84 – 1.69 (m, 4H), 1.51 – 1.44 (m, 2H); $^{13}$C NMR (100 MHz, CDCl$_3$) δ 194.86, 135.95, 133.70, 133.17, 129.41, 129.20, 129.11, 128.71, 128.10, 63.39, 50.31, 44.28, 36.78, 31.75, 25.60, 20.86; HRMS (ESI): m/z [M + H]$^+$ calcd for C$_{20}$H$_{24}$ClO$_3$S$^+$: 379.1129; found: 379.1140.
Ethyl 4-((3-oxo-1-diphenylpropyl)sulfonyl)butanoate (3h): white solid (45.0 mg, 58%); mp 99–100 °C; $^1$H NMR (400 MHz, CDCl$_3$) δ 7.96 (d, J = 7.6 Hz, 2H), 7.60 – 7.56 (m, 3H), 7.47 (t, J = 7.5 Hz, 2H), 7.43 – 7.33 (m, 3H), 4.98 (d, J = 9.4 Hz, 1H), 4.17 – 4.07 (m, 3H), 3.89 – 3.82 (m, 1H), 2.97 – 2.76 (m, 2H), 2.48 – 2.39 (m, 2H), 2.16 – 2.03 (m, 2H), 1.23 (t, J = 7.1 Hz, 3H); $^{13}$C NMR (100 MHz, CDCl$_3$) δ 194.79, 171.91, 135.94, 133.67, 133.02, 129.45, 129.17, 129.06, 128.68, 128.08, 63.41, 60.61, 49.46, 36.72, 32.32, 17.26, 14.09; HRMS (ESI): m/z [M + H]$^+$ calcd for C$_{21}$H$_{25}$O$_5$S$^+$: 389.1417; found: 389.1410.

3-(Isopropylsulfonyl)-1,3-diphenylpropan-1-one (3i): white solid (36.7 mg, 58%); mp 117–118 °C; $^1$H NMR (400 MHz, CDCl$_3$) δ 7.93 (d, J = 7.2 Hz, 2H), 7.59 – 7.53 (m, 3H), 7.43 (t, J = 7.7 Hz, 2H), 7.39 – 7.32 (m, 3H), 5.07 (dd, J = 9.7, 3.2 Hz, 1H), 4.06 (dd, J = 17.9, 3.2 Hz, 1H), 3.83 (dd, J = 18.0, 9.7 Hz, 1H), 2.90 – 2.83 (m, 1H), 1.36 (d, J = 6.8 Hz, 3H), 1.26 (d, J = 7.0 Hz, 3H); $^{13}$C NMR (100 MHz, CDCl$_3$) δ 195.06, 136.04, 133.59, 133.42, 129.42, 128.99, 128.94, 128.65, 128.07, 60.17, 49.99, 37.27, 16.49, 13.57; HRMS (ESI): m/z [M + H]$^+$ calcd for C$_{18}$H$_{21}$O$_3$S$: 317.1206; found: 317.1224.

3-(Butylsulfonyl)-1,3-diphenylpropan-1-one (3j): white solid (47.5 mg, 72%); mp 119–121 °C; $^1$H NMR (400 MHz, CDCl$_3$) δ 7.97 (d, J = 7.4 Hz, 2H), 7.61-7.56 (m, 3H), 7.47 (t, J = 7.7 Hz, 2H), 7.44 – 7.35 (m, 3H), 4.97 (dd, J = 9.6, 3.3 Hz, 1H), 4.13 - 4.07 (m, 1H), 3.90 – 3.83 (m, 1H), 2.75 (m, 2H), 1.96 – 1.56 (m, 2H), 1.51 – 1.17 (m, 2H), 0.89 (t, J = 7.4 Hz, 3H); $^{13}$C NMR (100 MHz, CDCl$_3$) δ 194.94, 136.05, 133.63, 133.34, 129.43, 129.09, 129.03, 128.68, 128.09, 63.19, 50.29, 36.82, 23.51, 21.60, 13.40; HRMS (ESI): m/z [M + H]$^+$ calcd for C$_{19}$H$_{23}$O$_3$S$: 331.1362; found: 331.1378.
3-(Hexylsulfonyl)-1,3-diphenylpropan-1-one (3k): white solid (50.1 mg, 70%); mp 111–112 °C; 
$^1$H NMR (400 MHz, CDCl$_3$) δ 7.93 (d, $J = 7.2$ Hz, 2H), 7.57 – 7.53 (m, 3H), 7.44 (t, $J = 7.7$ Hz, 2H), 7.40 – 7.33 (m, 3H), 4.95 (dd, $J = 9.6$, 3.3 Hz, 1H), 4.07 (dd, $J = 18.0$, 3.4 Hz, 1H), 3.84 (dd, $J = 18.0$, 9.6 Hz, 1H), 2.81 – 2.63 (m, 2H), 1.81 – 1.68 (m, 2H), 1.32 – 1.20 (m, 6H), 0.85 (t, $J = 6.9$ Hz, 3H);
$^{13}$C NMR (100 MHz, CDCl$_3$) δ 194.91, 135.99, 133.62, 133.30, 129.40, 129.06, 129.01, 128.66, 128.07, 63.13, 50.53, 36.77, 31.01, 27.97, 22.15, 21.45, 13.82; HRMS (ESI): m/z [M + H]$^+$ calcd for C$_{21}$H$_{27}$O$_3$S$: 359.1675; found: 359.1681.

3-(Cyclohexylsulfonyl)-3-phenyl-1-(p-tolyl)propan-1-one (3l): white solid (50.3 mg, 68%); mp 130–131 °C; $^1$H NMR (400 MHz, CDCl$_3$) δ 7.83 (d, $J = 8.2$ Hz, 2H), 7.55 (d, $J = 6.7$ Hz, 2H), 7.38 – 7.32 (m, 3H), 7.23 (d, $J = 8.1$ Hz, 2H), 5.04 (dd, $J = 9.7$, 3.2 Hz, 1H), 4.01 (dd, $J = 17.8$, 3.2 Hz, 1H), 3.81 (dd, $J = 17.9$, 9.7 Hz, 1H), 2.63 – 2.55 (m, 1H), 2.38 (s, 3H), 2.18 – 1.99 (m, 2H), 1.85 – 1.82 (m, 2H), 1.64 – 1.49 (m, 3H), 1.20 – 1.05 (m, 3H); $^{13}$C NMR (100 MHz, CDCl$_3$) δ 194.68, 144.47, 133.64, 133.51, 129.40, 129.30, 128.93, 128.85, 128.18, 60.07, 57.88, 36.94, 26.32, 24.93, 24.69, 23.06, 21.59; HRMS (ESI): m/z [M + H]$^+$ calcd for C$_{22}$H$_{27}$O$_3$S$: 371.1675; found: 371.1679.

3-(Cyclohexylsulfonyl)-1-(4-hydroxyphenyl)-3-phenylpropan-1-one (3m): colorless oil (49.1 mg, 66%); $^1$H NMR (400 MHz, DMSO) δ 10.45 (s, 1H), 7.88 (d, $J = 8.7$ Hz, 2H), 7.54 (d, $J = 6.5$ Hz, 2H), 7.45 – 7.20 (m, 3H), 6.84 (d, $J = 8.7$ Hz, 2H), 5.01 – 4.98 (m, 1H), 3.92 – 3.78 (m, 2H), 2.99 – 2.93 (m, 1H), 1.82 – 1.57 (m, 4H), 1.39 – 1.08 (m, 6H); $^{13}$C NMR (100 MHz, DMSO) δ 193.42, 162.44, 133.24, 130.79, 129.87, 128.53, 128.42, 127.65, 115.26, 60.15, 57.20, 36.30, 24.95, 24.70, 24.42, 24.36; HRMS (ESI): m/z [M + H]$^+$ calcd for C$_{21}$H$_{25}$O$_4$S$: 373.1468; found: 373.1474.
3-(Cyclohexylsulfonyl)-1-(4-methoxyphenyl)-3-phenylpropan-1-one (3n): white solid (52.5 mg, 68%); mp 112–113 °C; $^1$H NMR (400 MHz, CDCl$_3$) δ 7.91 (d, $J = 8.9$ Hz, 2H), 7.56 – 7.53 (m, 2H), 7.38 – 7.26 (m, 3H), 6.89 (d, $J = 8.9$ Hz, 2H), 5.04 (dd, $J = 9.7$, 3.2 Hz, 1H), 3.98 (dd, $J = 17.7$, 3.2 Hz, 1H), 3.83 – 3.74 (m, 4H), 2.62–2.54 (m, 1H), 2.18 – 1.99 (m, 2H), 1.84 – 1.81 (m, 2H), 1.63 – 1.46 (m, 3H), 1.19 – 1.07 (m, 3H); $^{13}$C NMR (100 MHz, CDCl$_3$) δ 193.49, 163.78, 133.54, 130.37, 129.39, 129.16, 128.91, 128.82, 113.75, 60.11, 57.86, 55.42, 36.64, 26.30, 24.92, 24.68, 23.06; HRMS (ESI): m/z [M + H]$^+$ calcd for C$_{22}$H$_{27}$O$_4$S$: 387.1625; found: 387.1633.

1-(4-Bromophenyl)-3-(cyclohexylsulfonyl)-3-phenylpropan-1-one (3o): white solid (48.6 mg, 56%); mp 167–169 °C; $^1$H NMR (400 MHz, CDCl$_3$) δ 7.79 (d, $J = 8.6$ Hz, 2H), 7.59 – 7.53 (m, 4H), 7.40 – 7.34 (m, 3H), 5.01 (dd, $J = 9.6$, 3.3 Hz, 1H), 4.02 (dd, $J = 17.9$, 3.4 Hz, 1H), 3.75 (dd, $J = 17.9$, 9.6 Hz, 1H), 2.62 – 2.54 (m, 1H), 2.17 – 1.98 (m, 2H), 1.85 – 1.82 (m, 2H), 1.64 – 1.45 (m, 3H), 1.20 – 1.04 (m, 3H); $^{13}$C NMR (100 MHz, CDCl$_3$) δ 194.25, 134.81, 133.34, 131.99, 129.60, 129.35, 129.05, 128.88, 59.99, 57.92, 37.09, 26.39, 24.94, 24.70, 23.01; HRMS (ESI): m/z [M + H]$^+$ calcd for C$_{21}$H$_{23}$BrO$_3$S$: 435.0624; found: 435.0639.

3-(Cyclohexylsulfonyl)-3-(4-methoxyphenyl)-1-phenylpropan-1-one (3p): colorless oil (44.0 mg, 57%); $^1$H NMR (400 MHz, CDCl$_3$) δ 7.93 (d, $J = 7.24$ Hz, 2H), 7.59 – 7.40 (m, 5H), 6.88 (d, $J = 8.8$ Hz, 2H), 4.99 (dd, $J = 9.8$, 3.1 Hz, 1H), 4.00 (dd, $J = 17.9$, 3.2 Hz, 1H), 3.84 – 3.72 (m, 4H), 2.64 – 2.57 (m, 1H), 2.16 – 2.00 (m, 2H), 1.94 – 1.77 (m, 2H), 1.64 – 1.46 (m, 3H), 1.20 – 1.05 (m, 3H); $^{13}$C NMR (100 MHz, CDCl$_3$) δ 195.25, 136.12, 133.52, 130.52, 128.62, 128.06, 125.14, 114.37, 113.51, 59.38, 57.59, 55.17, 37.06, 26.34, 24.94, 24.70, 22.99; HRMS (ESI): m/z [M + H]$^+$ calcd for C$_{22}$H$_{27}$O$_4$S$: 387.1625; found: 387.1635.
3-((Cyclohexylsulfonyl))-3-(4-nitrophenyl)-1-phenylpropan-1-one (3q): white solid (30.5 mg, 38%); mp 154–156 °C; \(^1\)H NMR (400 MHz, CDCl\(_3\)) \(\delta\) 8.23 (d, \(J = 8.8\) Hz, 2H), 7.92 (d, \(J = 7.3\) Hz, 2H), 7.77 (d, \(J = 8.8\) Hz, 2H), 7.58 (t, \(J = 7.4\) Hz, 1H), 7.46 (t, \(J = 7.7\) Hz, 2H), 5.13 (dd, \(J = 10.0, 3.1\) Hz, 1H), 4.11 (dd, \(J = 18.2, 3.1\) Hz, 1H), 3.85 (dd, \(J = 18.2, 10.0\) Hz, 1H), 2.63–2.55 (m, 1H), 2.16–2.03 (m, 2H), 1.98–1.86 (m, 2H), 1.67–1.51 (m, 2H), 1.25–1.08 (m, 4H); \(^{13}\)C NMR (100 MHz, CDCl\(_3\)) \(\delta\) 194.64, 148.06, 140.87, 135.64, 134.00, 130.59, 128.82, 128.09, 124.05, 59.40, 58.83, 37.49, 26.24, 24.86, 24.70, 23.30; HRMS (ESI): m/z [M + H]\(^+\) calcd for C\(_{21}\)H\(_{24}\)N\(_2\)O\(_5\)S\(_2\): 402.1370; found: 402.1373.

3-((4-Chlorophenyl))-3-(cyclohexylsulfonyl)-1-phenylpropan-1-one (3r): white solid (42.1 mg, 54%); mp 166–168 °C; \(^1\)H NMR (400 MHz, CDCl\(_3\)) \(\delta\) 7.93 (d, \(J = 7.3\) Hz, 2H), 7.59–7.50 (m, 3H), 7.45 (t, \(J = 7.7\) Hz, 2H), 7.35 (d, \(J = 8.5\) Hz, 2H), 5.01 (dd, \(J = 9.9, 3.1\) Hz, 1H), 4.03 (dd, \(J = 18.0, 3.1\) Hz, 1H), 3.78 (dd, \(J = 18.0, 9.9\) Hz, 1H), 2.63–2.56 (m, 1H), 2.14–2.02 (m, 2H), 1.94–1.80 (m, 2H), 1.66–1.45 (m, 4H), 1.18–1.12 (m, 2H); \(^{13}\)C NMR (100 MHz, CDCl\(_3\)) \(\delta\) 194.96, 135.94, 135.01, 133.75, 132.05, 130.77, 129.26, 128.73, 128.09, 59.27, 58.06, 37.20, 26.35, 24.91, 24.70, 23.08; HRMS (ESI): m/z [M + H]\(^+\) calcd for C\(_{21}\)H\(_{24}\)ClO\(_3\)S\(_2\): 391.1129; found: 391.1130.

3-((3-Chlorophenyl))-3-(cyclohexylsulfonyl)-1-phenylpropan-1-one (3s): white solid (36.7 mg, 47%); mp 165–167 °C; \(^1\)H NMR (400 MHz, CDCl\(_3\)) \(\delta\) 7.96 (d, \(J = 7.4\) Hz, 2H), 7.69–7.54 (m, 2H), 7.450–7.46 (m, 3H), 7.38–7.30 (m, 2H), 5.04 (dd, \(J = 9.7, 3.2\) Hz, 1H), 4.08 (dd, \(J = 18.1, 3.2\) Hz, 1H), 3.81 (dd, \(J = 18.1, 9.7\) Hz, 1H), 2.68–2.61 (m, 1H), 2.19–1.88 (m, 4H), 1.69–1.52 (m, 3H), 1.28–1.14 (m, 3H); \(^{13}\)C NMR (100 MHz, CDCl\(_3\)) \(\delta\) 194.85, 135.91, 135.59, 134.89, 133.77, 130.18, 129.40, 129.23, 128.74,

4-(2-(Cyclohexylsulfonyl)ethyl)pyridine \(^2\) (3t): brown solid (36.4 mg, 72%); mp 92–94 °C; \(^1\)H NMR (400 MHz, CDCl\(_3\)) \(\delta\) 8.51 (d, \(J = 5.6\) Hz, 2H), 7.15 (d, \(J = 5.9\) Hz, 2H), 3.18 – 3.10 (m, 4H), 2.83 – 2.75 (m, 1H), 2.14 – 2.11 (m, 2H), 1.92 – 1.88 (m, 2H), 1.71 – 1.46 (m, 3H), 1.29 – 1.16 (m, 3H); \(^{13}\)C NMR (100 MHz, CDCl\(_3\)) \(\delta\) 150.07, 146.96, 123.63, 61.49, 49.22, 26.33, 24.97, 24.86.

((2-(Cyclohexylsulfonyl)sulfonyl)benzene \(^3\)u): white solid (29.0 mg, 46%); mp 138–139 °C; \(^1\)H NMR (400 MHz, CDCl\(_3\)) \(\delta\) 7.95 (d, \(J = 7.5\) Hz, 2H), 7.74 (t, \(J = 7.4\) Hz, 1H), 7.64 (t, \(J = 7.7\) Hz, 2H), 3.58 – 3.53 (m, 2H), 3.38 – 3.33 (m, 2H), 2.96 – 2.89 (m, 1H), 2.24 – 2.12 (m, 2H), 1.99 – 1.95 (m, 2H), 1.78 – 1.51 (m, 3H), 1.35 – 1.18(m, 3H); \(^{13}\)C NMR (100 MHz, CDCl\(_3\)) \(\delta\) 138.30, 134.51, 129.67, 128.00, 62.32, 48.31, 42.33, 25.06, 24.93, 24.88; HRMS (ESI): m/z [M + H]^+ calcd for C_{14}H_{21}O_4S^+: 317.0876; found: 317.0875.

4-(Cyclohexylsulfonyl)-4-phenylbutan-2-one \(^3\)v: white solid (32.3 mg, 55%); mp 86–87 °C; \(^1\)H NMR (400 MHz, CDCl\(_3\)) \(\delta\) 7.50 – 7.48 (m, 2H), 7.42 – 7.36 (m, 3H), 4.85 (dd, \(J = 9.1, 3.9\) Hz, 1H), 3.56 (dd, \(J = 17.9, 3.9\) Hz, 1H), 3.19 (dd, \(J = 17.9, 9.1\) Hz, 1H), 2.60 – 2.53 (m, 1H), 2.14 (d, \(J = 19.4\) Hz, 4H), 2.01 – 1.83 (m, 3H), 1.66 – 1.45 (m, 3H), 1.20 – 1.08 (m, 3H); \(^{13}\)C NMR (100 MHz, CDCl\(_3\)) \(\delta\) 203.52, 133.41, 129.31, 129.02, 128.98, 59.73, 57.93, 41.55, 26.34, 24.95, 24.70, 23.06; HRMS (ESI): m/z [M + H]^+ calcd for C_{16}H_{22}O_5S^+: 295.1362; found: 295.1367.
3-((4-(9H-Carbazol-9-yl)butyl)sulfonyl)-1,3-diphenylpropan-1-one (3w): white solid (65.3 mg, 66%); mp 83–85 °C; $^1$H NMR (400 MHz, CDCl$_3$) $\delta$ 8.08 (d, $J = 7.6$ Hz, 2H), 7.89 (d, $J = 7.4$ Hz, 2H), 7.53 (t, $J = 7.3$ Hz, 1H), 7.45 – 7.36 (m, 6H), 7.30 – 7.20 (m, 7H), 4.82 (d, $J = 9.2$ Hz, 1H), 4.22 (t, $J = 6.3$ Hz, 2H), 4.00 (d, $J = 17.9$ Hz, 1H), 3.76 (dd, $J = 17.9$, 9.5 Hz, 1H), 2.68 – 2.59 (m, 2H), 1.88 – 1.72 (m, 4H); $^{13}$C NMR (100 MHz, CDCl$_3$) $\delta$ 194.72, 140.05, 135.89, 133.64, 132.90, 129.27, 129.10, 128.98, 128.65, 128.04, 125.70, 122.79, 120.36, 118.98, 108.40, 63.65, 50.10, 42.14, 36.66, 27.72, 19.43; HRMS (ESI): m/z [M + H]$^+$ calcd for C$_{31}$H$_{30}$NO$_3$S$^+$: 496.1941; found: 496.1950.

3-(But-3-en-1-ylsulfonyl)-1,3-diphenylpropan-1-one (3x): white solid (36.7mg, 56%); mp 142–143 °C; $^1$H NMR (400 MHz, CDCl$_3$) $\delta$ 7.94 (d, $J = 7.2$ Hz, 2H), 7.59 – 7.53 (m, 3H), 7.45 (t, $J = 7.7$ Hz, 2H), 7.41 – 7.35 (m, 3H), 5.73 – 5.65 (m, 1H), 5.08 – 4.95 (m, 3H), 4.08 (dd, $J = 18.0$, 3.4 Hz, 1H), 3.84 (dd, $J = 18.0$, 9.6 Hz, 1H), 2.90 – 2.73 (m, 2H), 2.60 – 2.40 (m, 2H); $^{13}$C NMR (100 MHz, CDCl$_3$) $\delta$ 194.82, 135.97, 133.76, 133.68, 133.11, 129.45, 129.19, 129.10, 128.70, 128.09, 117.38, 63.57, 49.78, 36.80, 25.75; HRMS (ESI): m/z [M + H]$^+$ calcd for C$_{19}$H$_{21}$O$_3$S$^+$: 329.1206; found: 329.1204.

Reference
$3p$