Supporting Information

Transition Metal-Free Synthesis of α-Aryl Ketones via Oxyallyl Cation Capture with Arylboronic Acids

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1. General Information

All the commercial reagents were used as such without further purification. All solvents were used as commercial anhydrous grade without further purification. The flash column chromatography was carried out over silica gel (230-400 mesh). $^1$H and $^{13}$C NMR spectra were recorded on a Bruker Avance-400 MHz spectrometer or Bruker Avance-500 MHz spectrometer. Chemical shifts in $^1$H NMR spectra were reported in parts per million (ppm, $\delta$) downfield from the internal standard Me$_4$Si (TMS, $\delta = 0$ ppm). Chemical shifts in $^{13}$C NMR spectra were reported relative to the central line of the chloroform signal ($\delta = 77.0$ ppm). Peaks were labeled as singlet (s), doublet (d), triplet (t), quartet (q), and multiplet (m). High resolution mass spectra were obtained with a Shimadzu LCMS-IT-TOF mass spectrometer. Chemical yields refer to pure isolated substances.

2. General Procedure for the Synthesis of Substrates and Products

(a) Synthesis of product 3a

To a solution of 1 (0.2 mmol) and 2 (0.4 mmol) in mesitylene (2 mL), TEA (40.4 mg, 0.4 mmol) and (D)-tartaric acid (6 mg, 0.04 mmol) were added. The reaction mixture was then stirred at 110 °C for 24 hours. Upon completion, the reaction mixture was concentrated via rotary evaporation. The crude mixture was purified by flash column chromatography on silica gel to provide the desired product.

(b) Synthesis of $\alpha$-tosyloxy ketones

The following procedure is adapted from the work of Tuncay et al.\(^1\) To the ketone (15.3 mmol, 1.5 equiv.) dissolved in MeCN (20 mL, 0.5 M) was added [hydroxy(tosyloxy)iodo]benzene (4 g, 10.2 mmol, 1 equiv.), and the heterogeneous suspension was sonicated at 50 °C until a homogeneous solution was noted. The MeCN was removed under reduced pressure. The crude products were purified by flash column chromatography, affording the desired $\alpha$-tosyloxyketone 1a-1f.

(c) Synthesis of 2-bromocyclohexanone\(^2\)

A solution of cyclohexanone (1.04 mL, 10.0 mmol) in CH$_2$Cl$_2$ (5 mL) was added dropwise to a solution of $n$-bromosuccinimide (NBS, 2.14 g, 12.0 mmol, 1.2 equiv.) and p-TsOH (190 mg, 1.0
mmol, 0.1 equiv.) in CH$_2$Cl$_2$ (10 mL) at 0 °C. The reaction mixture was then brought to reflux for 4 h. After addition of H$_2$O (10 mL), the organic layer was separated, and the aqueous layer was extracted with CH$_2$Cl$_2$ (3×10 mL). The combined organic layers were washed with saturated aqueous NaHCO$_3$ (20 mL) and brine (20 mL), dried over anhydrous Na$_2$SO$_4$, and concentrated under reduced pressure. Column chromatography on silica gel provided 2-bromocyclohexanone 1g (1.6 g, 90% yield).

3. General Procedure for the Synthesis of Compounds 4-6

(a) Synthesis of 2-(4-bromophenyl)-cyclohexanol 4

To a round bottom flask fitted with stirring bar was added 2-(4-bromophenyl)cyclohexanone 3am (50.6 mg, 0.20 mmol) and methanol (1 mL) to a concentration of 0.2 M. The solution was treated with NaBH$_4$ (15.1 mg, 0.40 mmol) and stirred at room temperature for 2 hours. The reaction was then quenched with saturated NH$_4$Cl, and the aqueous layer was extracted with diethyl ether (3×5 mL). The organic layers were then combined, dried over anhydrous Na$_2$SO$_4$, filtered and concentrated. The crude mixture was purified on silica gel chromatography to give 4 as a while solid (40.8 mg, 80% yield).

(b) Synthesis of 2-(4-bromophenyl)-2-fluorocyclohexan-1-one 5

Under argon atmosphere, to a 10 mL reaction tube charged with a magnetic stirring bar was added 2-(4-bromophenyl)cyclohexanone 4 (50.6 mg, 0.20 mmol), Selectfluor (141.8 mg, 0.40 mmol), p-TsOH (7.6 mg, 0.04 mmol), CH$_2$Cl$_2$ (0.2 mL) and MeCN (0.8 mL). The reaction mixture was stirred at 25 °C until the complete consumption of the starting material (monitored by TLC). The mixture was diluted with ethyl acetate, the resulting organic phase was washed successively with water and brine, dried over Na$_2$SO$_4$, filtered, and concentrated in vacuo. The crude product was purified by flash column chromatography on silica gel (petroleum ether/ethyl acetate) to give 5 as a while solid (46.0 mg, 83% yield).

(c) Synthesis of 7-(4-bromophenyl)oxepan-2-one 6
To a solution of 2-(4-bromophenyl)cyclohexanone 4 (50.6 mg, 0.20 mmol) in 4 mL CH₂Cl₂ was added mCPBA (69 mg, 0.40 mmol) at 0°C. After stirring at rt overnight, the reaction mixture was quenched with 10% K₂CO₃ solution and a saturated aqueous solution of Na₂S₂O₃. The aqueous layer was separated and extracted with CH₂Cl₂. The combined organic layer was dried over MgSO₄, filtered and concentrated under reduced pressure. The resulting crude product was purified by column chromatography (petroleum ether/ethyl acetate) to afford 6 as a colorless solid (47.9 mg, 89%).

4. Control Experiments

<table>
<thead>
<tr>
<th>Entry</th>
<th>Solvent</th>
<th>Additive</th>
<th>Add. Equiv.</th>
<th>Yield (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>mesitylene</td>
<td>(D)-tartaric acid</td>
<td>0.2</td>
<td>74%</td>
</tr>
<tr>
<td>2</td>
<td>mesitylene</td>
<td>(D)-diethyl tartarate</td>
<td>0.2</td>
<td>54%</td>
</tr>
<tr>
<td>3</td>
<td>mesitylene</td>
<td>succinic acid</td>
<td>0.2</td>
<td>68%</td>
</tr>
<tr>
<td>4</td>
<td>mesitylene</td>
<td>HFIP (^a)</td>
<td>-</td>
<td>70%</td>
</tr>
<tr>
<td>5</td>
<td>mesitylene</td>
<td>-</td>
<td>-</td>
<td>52%</td>
</tr>
</tbody>
</table>

\(^a\) Reaction conditions: 1a (0.2 mmol), 2a (0.4 mmol), additive and Et₃N (2 equiv.) in mesitylene (2 mL) at 110 °C for 24 h; \(^b\) mesitylene: HFIP (10:1, V/V); \(^c\) Isolated yield.

5. Unsuccessful Results

\(^a\) Reaction conditions: 1a (0.2 mmol), 2 (0.4 mmol), (D)-tartaric acid (0.04 mmol) and Et₃N (2 equiv.) in mesitylene (2 mL) at 110 °C for 24 h; \(^b\) Pi system is necessary to engage the cationic electrophile.
6. Characterization of Substrates and Products

2-phenylcyclohexan-1-one (3aa)

Colorless oil. R$_f$: 0.43 in 10% ethyl acetate in hexane. The crude mixture was purified by column chromatography on silica gel (petroleum ether/ethyl acetate 25:1). $^1$H NMR (500 MHz, CDCl$_3$) $\delta$: 7.36 (t, $J = 7.5$ Hz, 2H), 7.31-7.27 (m, 1H), 7.17 (d, $J = 7.1$ Hz, 2H), 3.64 (dd, $J = 12.2$, 5.4 Hz, 1H), 2.59-2.45 (m, 2H), 2.33-2.27 (m, 1H), 2.21-2.14 (m, 1H), 2.11-2.00 (m, 2H), 1.91-1.81 (m, 2H); $^{13}$C NMR (126 MHz, CDCl$_3$) $\delta$: 210.4, 138.8, 128.6, 128.4, 127.0, 57.5, 42.3, 35.2, 27.9, 25.4.

2-(2-fluorophenyl)cyclohexan-1-one (3ab)

Colorless oil. R$_f$: 0.45 in 10% ethyl acetate in hexane. The crude mixture was purified by column chromatography on silica gel (petroleum ether/ethyl acetate 25:1). $^1$H NMR (400 MHz, CDCl$_3$) $\delta$: 7.31-7.20 (m, 1H), 7.20-7.08 (m, 2H), 7.09-6.97 (m, 1H), 3.85 (dd, $J = 9.3$, 3.7 Hz, 1H), 2.71-2.37 (m, 2H), 2.33-2.12 (m, 2H), 2.13-1.93 (m, 2H), 1.94-1.69 (m, 2H); $^{13}$C NMR (101 MHz, CDCl$_3$) $\delta$: 208.4, 159.5 (d), 129.7 (d, $J = 4.8$ Hz), 128.5 (d, $J = 8.3$ Hz), 126.1 (d, $J = 14.4$ Hz), 123.9 (d, $J = 3.3$ Hz), 115.2 (d, $J = 22.4$ Hz), 51.0, 42.1, 33.7, 27.4, 25.5; $^{19}$F NMR (376 MHz, CDCl$_3$) $\delta$: -109.56.

2-(2-chlorophenyl)cyclohexan-1-one (3ac)

Colorless oil. R$_f$: 0.45 in 10% ethyl acetate in hexane. The crude mixture was purified by column chromatography on silica gel (petroleum ether/ethyl acetate 25:1). $^1$H NMR (400 MHz, CDCl$_3$) $\delta$: 7.37 (d, $J = 8.0$ Hz, 1H), 7.29-7.17 (m, 3H), 4.10 (dd, $J = 12.7$, 5.3 Hz, 1H), 2.63-2.50 (m, 2H), 2.30-2.17 (m, 2H), 2.08-1.97 (m, 2H), 1.91-1.77 (m, 2H); $^{13}$C NMR (101 MHz, CDCl$_3$) $\delta$: 208.8, 136.7, 134.2, 129.4, 129.4, 128.1, 126.7, 54.0, 42.3, 33.9, 27.6, 25.6.

2-(2-bromophenyl)cyclohexan-1-one (3ad)

Colorless oil. R$_f$: 0.45 in 10% ethyl acetate in hexane. The crude mixture was purified by column chromatography on silica gel (petroleum ether/ethyl acetate 25:1). $^1$H NMR (400 MHz, CDCl$_3$) $\delta$: 7.56 (d, $J = 8.0$ Hz, 1H), 7.31 (t, $J = 7.5$ Hz, 1H), 7.21 (d, $J = 7.7$ Hz, 1H), 7.12 (t, $J = 7.6$ Hz, 1H),
4.12 (dd, J = 12.7, 5.1 Hz, 1H), 2.61-2.48 (m, 2H), 2.35-2.25 (m, 1H), 2.24-2.15 (m, 1H), 2.10-1.96 (m, 2H), 1.95-1.77 (m, 2H); 13C NMR (101 MHz, CDCl₃) δ: 209.0, 138.5, 132.7, 129.6, 128.5, 127.5, 125.3, 56.7, 42.5, 34.3, 27.8, 25.8.

### 2-(o-tolyl)cyclohexan-1-one (3ae)

Colorless oil. Rₚ: 0.43 in 10% ethyl acetate in hexane. The crude mixture was purified by column chromatography on silica gel (petroleum ether/ethyl acetate 25:1). ¹H NMR (400 MHz, CDCl₃) δ: 7.27-7.11 (m, 4H), 3.80 (dd, J = 12.9, 4.9 Hz, 1H), 2.59-2.46 (m, 2H), 2.31-2.19 (m, 5H), 2.11-2.02 (m, 2H), 1.93-1.79 (m, 2H); ¹³C NMR (101 MHz, CDCl₃) δ: 210.0, 137.3, 136.1, 130.3, 127.6, 126.8, 126.0, 53.8, 42.5, 34.2, 27.8, 25.9, 19.7.

### 2-(2-methoxyphenyl)cyclohexan-1-one (3af)

White solid. Rₚ: 0.40 in 10% ethyl acetate in hexane. The crude mixture was purified by column chromatography on silica gel (petroleum ether/ethyl acetate 25:1). ¹H NMR (400 MHz, CDCl₃) δ: 7.23 (t, J = 9.1 Hz, 1H), 7.14-7.07 (m, 1H), 6.98-6.81 (m, 2H), 3.93 (m, 1H), 3.76 (s, 3H), 2.59-2.40 (m, 2H), 2.27-2.10 (m, 2H), 2.10-1.93 (m, 2H), 1.91-1.71 (m, 2H); ¹³C NMR (101 MHz, CDCl₃) δ: 209.9, 156.9, 128.7, 127.9, 127.8, 120.5, 110.5, 55.4, 51.0, 42.3, 33.4, 27.5, 25.7.

### 2-(3-fluorophenyl)cyclohexan-1-one (3ag)

Colorless oil. Rₚ: 0.45 in 10% ethyl acetate in hexane. The crude mixture was purified by column chromatography on silica gel (petroleum ether/ethyl acetate 25:1). ¹H NMR (400 MHz, CDCl₃) δ: 7.33-7.26 (m, 1H), 7.01-6.78 (m, 3H), 3.61 (dd, J = 12.1, 5.5 Hz, 1H), 2.55-2.41 (m, 2H), 2.32-2.13 (m, 2H), 2.04-1.94 (m, 2H), 1.87-1.77 (m, 2H); ¹³C NMR (101 MHz, CDCl₃) δ: 209.7, 162.9 (d, J = 245.2 Hz), 141.3 (d, J = 7.4 Hz), 129.8 (d, J = 8.3 Hz), 124.4 (d, J = 2.8 Hz), 115.6 (d, J = 21.6 Hz), 113.9 (d, J = 21.0 Hz), 57.2, 42.3, 35.1, 26.6, 25.4; ¹⁹F NMR (471 MHz, CDCl₃) δ: -113.48.

### 2-(3-chlorophenyl)cyclohexan-1-one (3ah)

Colorless oil. Rₚ: 0.45 in 10% ethyl acetate in hexane. The crude mixture was purified by column chromatography on silica gel (petroleum ether/ethyl acetate 25:1). ¹H NMR (400 MHz, CDCl₃) δ: 7.25-7.18 (m, 2H), 7.11 (s, 1H), 7.02-6.96 (m, 1H), 3.56 (dd, J = 12.1, 5.4 Hz, 1H), 2.57-2.38 (m, 2H), 2.07-1.93 (m, 2H), 1.94-1.78 (m, 2H); ¹³C NMR (101 MHz, CDCl₃) δ: 209.9, 156.9, 128.7, 127.9, 127.8, 120.5, 110.5, 55.4, 51.0, 42.3, 33.4, 27.5, 25.7.
2H), 2.31-2.08 (m, 2H), 2.04-1.91 (m, 2H), 1.86-1.72 (m, 2H); $^{13}$C NMR (101 MHz, CDCl$_3$) $\delta$: 209.4, 140.7, 134.1, 129.5, 128.7, 127.0, 126.8, 57.0, 42.1, 35.0, 27.7, 25.3.

![3ai](image)

**2-(m-tolyl)cyclohexan-1-one (3ai)**

Colorless oil. R$_F$: 0.42 in 10% ethyl acetate in hexane. The crude mixture was purified by column chromatography on silica gel (petroleum ether/ethyl acetate 25:1). $^1$H NMR (500 MHz, CDCl$_3$) $\delta$: 7.22 (t, $J = 7.5$ Hz, 1H), 7.06 (d, $J = 7.6$ Hz, 1H), 6.94 (d, $J = 8.4$ Hz, 2H), 3.57 (dd, $J = 12.0$, 5.4 Hz, 1H), 2.57-2.39 (m, 2H), 2.34 (s, 3H), 2.29-2.11 (m, 2H), 2.10-1.96 (m, 2H), 1.89-1.75 (m, 2H); $^{13}$C NMR (126 MHz, CDCl$_3$) $\delta$: 210.3, 138.7, 137.8, 129.2, 128.2, 127.6, 125.5, 57.3, 42.1, 34.9, 27.7, 25.2, 21.4.

![3aj](image)

**2-(3-methoxyphenyl)cyclohexan-1-one (3aj)**

Colorless oil. R$_F$: 0.43 in 10% ethyl acetate in hexane. The crude mixture was purified by column chromatography on silica gel (petroleum ether/ethyl acetate 25:1). $^1$H NMR (400 MHz, CDCl$_3$) $\delta$: 7.28 (t, $J = 3.9$ Hz, 1H), 6.83 (dd, $J = 8.0$, 2.2 Hz, 1H), 6.76 (d, $J = 7.6$ Hz, 1H), 6.72 (d, $J = 1.9$ Hz, 1H), 3.82 (s, 3H), 3.61 (dd, $J = 12.0$, 5.4 Hz, 1H), 2.63-2.38 (m, 2H), 2.34-2.23 (m, 1H), 2.22-2.12 (m, 1H), 2.10-1.97 (m, 2H), 1.91-1.77 (m, 2H); $^{13}$C NMR (101 MHz, CDCl$_3$) $\delta$: 210.2, 159.5, 140.3, 129.3, 120.9, 114.5, 112.1, 57.3, 55.1, 42.1, 34.9, 27.7, 25.2.

![3ak](image)

**2-(4-fluorophenyl)cyclohexan-1-one (3ak)**

Colorless oil. R$_F$: 0.45 in 10% ethyl acetate in hexane. The crude mixture was purified by column chromatography on silica gel (petroleum ether/ethyl acetate 25:1). $^1$H NMR (400 MHz, CDCl$_3$) $\delta$: 7.20-6.93 (m, 4H), 3.60 (dd, $J = 11.8$, 5.3 Hz, 1H), 2.64-2.36 (m, 2H), 2.33-2.09 (m, 2H), 2.08-1.91 (m, 2H), 1.90-1.70 (m, 2H); $^{13}$C NMR (101 MHz, CDCl$_3$) $\delta$: 210.1, 161.8 (d, $J = 244.7$ Hz), 134.4 (d, $J = 2.4$ Hz), 130.0 (d, $J = 7.9$ Hz), 115.1 (d, $J = 21.3$ Hz), 56.6, 42.2, 35.4, 27.8, 25.4; $^{19}$F NMR (376 MHz, CDCl$_3$) $\delta$: -116.20.

![3al](image)

**2-(4-chlorophenyl)cyclohexan-1-one (3al)**

Colorless oil. R$_F$: 0.45 in 10% ethyl acetate in hexane. The crude mixture was purified by column chromatography on silica gel (petroleum ether/ethyl acetate 25:1). $^1$H NMR (400 MHz, CDCl$_3$) $\delta$: 7.35-7.24 (m, 2H), 7.11-7.01 (m, 2H), 3.65-3.55 (m, 1H), 2.61-2.38 (m, 2H), 2.34-2.09 (m, 2H), 2.08-1.91 (m, 2H), 1.90-1.70 (m, 2H); $^{13}$C NMR (101 MHz, CDCl$_3$) $\delta$: 210.1, 161.8 (d, $J = 244.7$ Hz), 134.4 (d, $J = 2.4$ Hz), 130.0 (d, $J = 7.9$ Hz), 115.1 (d, $J = 21.3$ Hz), 56.6, 42.2, 35.4, 27.8, 25.4; $^{19}$F NMR (376 MHz, CDCl$_3$) $\delta$: -116.20.
2.09-1.90 (m, 2H), 1.91-1.68 (m, 2H); $^{13}$C NMR (101 MHz, CDCl$_3$) δ: 209.8, 137.2, 132.7, 129.9, 128.5, 56.8, 42.2, 35.2, 27.8, 25.3.

2-(4-bromophenyl)cyclohexan-1-one (3am)$^9$
White solid. R$_f$: 0.45 in 10% ethyl acetate in hexane. The crude mixture was purified by column chromatography on silica gel (petroleum ether/ethyl acetate 25:1). $^1$H NMR (400 MHz, CDCl$_3$) δ: 7.45 (d, $J$ = 8.3 Hz, 2H), 7.01 (d, $J$ = 8.4 Hz, 2H), 3.57 (dd, $J$ = 12.1, 5.3 Hz, 1H), 2.56-2.39 (m, 2H), 2.29-2.11 (m, 2H), 2.04-1.91 (m, 2H), 1.88-1.75 (m, 2H); $^{13}$C NMR (126 MHz, CDCl$_3$) δ: 209.7, 137.7, 131.4, 130.3, 120.8, 56.8, 42.2, 35.2, 27.7, 25.3.

2-(4-methoxyphenyl)cyclohexan-1-one (3an)$^3$
White solid. R$_f$: 0.43 in 10% ethyl acetate in hexane. The crude mixture was purified by column chromatography on silica gel (petroleum ether/ethyl acetate 25:1). $^1$H NMR (400 MHz, CDCl$_3$) δ: 7.15-7.00 (m, 2H), 6.94-6.85 (m, 2H), 3.79 (s, 3H), 3.57 (dd, $J$ = 12.2, 5.4 Hz, 1H), 2.59-2.37 (m, 2H), 2.34-2.08 (m, 2H), 2.07-1.91 (m, 2H), 1.90-1.72 (m, 2H); $^{13}$C NMR (126 MHz, CDCl$_3$) δ: 210.7, 158.4, 130.8, 129.4, 113.8, 56.5, 55.2, 42.2, 35.3, 27.9, 25.4.

2-(4-(tert-butyl)phenyl)cyclohexan-1-one (3ao)$^3$
White solid. R$_f$: 0.40 in 10% ethyl acetate in hexane. The crude mixture was purified by column chromatography on silica gel (petroleum ether/ethyl acetate 25:1). $^1$H NMR (400 MHz, CDCl$_3$) δ: 7.36 (d, $J$ = 7.8 Hz, 2H), 7.08 (d, $J$ = 8.0 Hz, 2H), 3.65-3.54 (m, 1H), 2.57-2.42 (m, 2H), 2.31-2.13 (m, 2H), 2.03 (dd, $J$ = 18.7, 6.7 Hz, 2H), 1.88-1.77 (m, 2H), 1.32 (s, 9H); $^{13}$C NMR (101 MHz, CDCl$_3$) δ: 210.7, 149.6, 135.7, 128.2, 125.4, 57.0, 42.3, 35.2, 34.5, 31.5, 28.0, 25.4.

2-(p-tolyl)cyclohexan-1-one (3ap)$^3$
Colorless oil. R$_f$: 0.45 in 10% ethyl acetate in hexane. The crude mixture was purified by column chromatography on silica gel (petroleum ether/ethyl acetate 25:1). $^1$H NMR (500 MHz, CDCl$_3$) δ: 7.15 (d, $J$ = 7.9 Hz, 2H), 7.04 (d, $J$ = 8.0 Hz, 2H), 3.58 (dd, $J$ = 12.1, 5.4 Hz, 1H), 2.57-2.39 (m, 2H), 2.34 (s, 3H), 2.31-2.11 (m, 2H), 2.10-1.94 (m, 2H), 1.94-1.74 (m, 2H); $^{13}$C NMR (126 MHz, CDCl$_3$) δ: 210.4, 136.4, 135.7, 129.0, 128.3, 57.0, 42.1, 35.0, 34.5, 31.5, 27.8, 25.3, 21.0
2-(4-phenoxophenyl)cyclohexan-1-one (3aq)

Colorless oil. R$_f$: 0.50 in 10% ethyl acetate in hexane. The crude mixture was purified by column chromatography on silica gel (petroleum ether/ethyl acetate 35:1). $^1$H NMR (400 MHz, CDCl$_3$) $\delta$: 7.45-7.28 (m, 2H), 7.18-6.92 (m, 7H), 3.59 (dd, $J = 12.2$, 5.5 Hz, 1H), 2.61-2.38 (m, 2H), 2.35-2.11 (m, 2H), 2.06-1.91 (m, 2H), 1.89-1.74 (m, 2H); $^{13}$C NMR (126 MHz, CDCl$_3$) $\delta$: 210.4, 157.2, 156.1, 133.5, 129.7, 129.7, 123.2, 119.0, 118.6, 56.7, 42.2, 35.4, 27.9, 25.4. HRMS (ESI): m/z [M+H]$^+$ calcd. for [C$_{18}$H$_{19}$O$_2$]: 267.1380, found: 267.1380.

methyl 4-(2-oxocyclohexyl)benzoate (3as)

Colorless oil. R$_f$: 0.43 in 10% ethyl acetate in hexane. The crude mixture was purified by column chromatography on silica gel (petroleum ether/ethyl acetate 25:1). $^1$H NMR (400 MHz, CDCl$_3$) $\delta$: 8.00 (d, $J = 8.3$ Hz, 2H), 7.21 (d, $J = 8.3$ Hz, 2H), 3.90 (s, 3H), 3.67 (dd, $J = 12.2$, 5.5 Hz, 1H), 2.57-2.42 (m, 2H), 2.31-2.14 (m, 2H), 2.08-1.97 (m, 2H), 1.90-1.79 (m, 2H); $^{13}$C NMR (101 MHz, CDCl$_3$) $\delta$: 209.4, 166.9, 144.0, 129.6, 128.7, 128.6, 57.4, 52.0, 42.2, 35.0, 27.7, 25.3.

2-(1,1'-biphenyl)-4-yl)cyclohexan-1-one (3ar)

White solid. R$_f$: 0.55 in 10% ethyl acetate in hexane. The crude mixture was purified by column chromatography on silica gel (petroleum ether/ethyl acetate 35:1). $^1$H NMR (500 MHz, CDCl$_3$) $\delta$: 7.61-7.55 (m, 4H), 7.43 (t, $J = 7.7$ Hz, 2H), 7.34 (t, $J = 7.4$ Hz, 1H), 7.22 (d, $J = 8.2$ Hz, 2H), 3.67 (dd, $J = 12.3$, 5.4 Hz, 1H), 2.59-2.46 (m, 2H), 2.36-2.29 (m, 1H), 2.22-2.15 (m, 1H), 2.11-2.02 (m, 2H), 1.90-1.82 (m, 2H); $^{13}$C NMR (126 MHz, CDCl$_3$) $\delta$: 210.4, 141.0, 139.8, 137.8, 128.9, 128.7, 127.1, 127.1, 57.1, 42.2, 35.2, 27.8, 25.4.

2-(2-isopropylphenyl)cyclohexan-1-one (3at)

Colorless oil. R$_f$: 0.40 in 10% ethyl acetate in hexane. The crude mixture was purified by column chromatography on silica gel (petroleum ether/ethyl acetate 25:1). $^1$H NMR (400 MHz, CDCl$_3$) $\delta$: 7.33 (dd, $J = 7.7$, 1.3 Hz, 1H), 7.31-7.25 (m, 1H), 7.25-7.18 (m, 1H), 7.14 (d, $J = 7.6$ Hz, 1H), 3.92 (dd, $J = 12.7$, 5.4 Hz, 1H), 3.00-2.84 (m, 1H), 2.67-2.45 (m, 2H), 2.37-2.17 (m, 2H), 2.19-2.01 (m, 2H), 1.97-1.80 (m, 2H), 1.32-1.15 (m, 6H); $^{13}$C NMR (126 MHz, CDCl$_3$) $\delta$: 210.2, 146.4,
136.0, 128.3, 127.1, 125.6, 125.3, 53.2, 42.5, 35.3, 29.3, 27.6, 25.9, 24.0, 23.8. HRMS (ESI): m/z [M+H]+ calcd. for [C_{15}H_{21}O]: 217.1587, found: 217.1584.

2-(naphthalen-1-yl)cyclohexan-1-one (3au)

White solid. R_F: 0.39 in 10% ethyl acetate in hexane. The crude mixture was purified by column chromatography on silica gel (petroleum ether/ethyl acetate 25:1). ^1H NMR (400 MHz, CDCl_3) δ: 7.90-7.84 (m, 1H), 7.78 (d, J = 8.2 Hz, 1H), 7.75-7.68 (m, 1H), 7.51-7.42 (m, 3H), 7.36 (d, J = 7.1 Hz, 1H), 4.36 (dd, J = 12.5, 5.3 Hz, 1H), 2.71-2.60 (m, 2H), 2.47-2.38 (m, 1H), 2.36-2.23 (m, 2H), 2.18-2.10 (m, 1H), 2.02-1.88 (m, 2H); ^13C NMR (126 MHz, CDCl_3) δ: 210.0, 135.2, 133.8, 131.8, 129.0, 127.6, 125.9, 125.3, 125.3, 125.3, 123.2, 53.3, 42.6, 34.3, 27.9, 25.9.

2-(anthracen-9-yl)cyclohexan-1-one (3av)

White solid. R_F: 0.55 in 10% ethyl acetate in hexane. The crude mixture was purified by column chromatography on silica gel (petroleum ether/ethyl acetate 35:1). ^1H NMR (400 MHz, CDCl_3) δ: 8.42 (s, 1H), 8.11-7.98 (m, 2H), 7.98-7.82 (m, 2H), 7.56-7.37 (m, 4H), 4.88 (dd, J = 12.3, 6.7 Hz, 1H), 2.98-2.77 (m, 1H), 2.80-2.46 (m, 2H), 2.41-2.28 (m, 2H), 2.26-2.10 (m, 2H), 2.08-1.86 (m, 1H); ^13C NMR (126 MHz, CDCl_3) δ: 209.3, 132.5, 132.0, 130.0, 129.5, 127.5, 125.5, 124.6, 51.3, 41.9, 33.4, 25.7, 25.5.

2-(benzo[d][1,3]dioxol-5-yl)cyclohexan-1-one (3aw)

Colorless oil. R_F: 0.40 in 10% ethyl acetate in hexane. The crude mixture was purified by column chromatography on silica gel (petroleum ether/ethyl acetate 25:1). ^1H NMR (400 MHz, CDCl_3) δ: 6.77 (d, J = 7.9 Hz, 1H), 6.64 (d, J = 1.4 Hz, 1H), 6.58 (dd, J = 7.9, 1.4 Hz, 1H), 5.93 (s, 2H), 3.53 (dd, J = 12.0, 5.3 Hz, 1H), 2.59-2.38 (m, 2H), 2.30-2.08 (m, 2H), 2.03-1.92 (m, 2H), 1.88-1.75 (m, 2H); ^13C NMR (126 MHz, CDCl_3) δ: 210.5, 147.7, 146.5, 132.7, 121.6, 109.1, 108.3, 101.0, 57.2, 42.3, 35.5, 27.9, 25.5.

2-(thiophen-2-yl)cyclohexan-1-one (3ax)

Colorless oil. R_F: 0.30 in 10% ethyl acetate in hexane. The crude mixture was purified by column chromatography on silica gel (petroleum ether/ethyl acetate 20:1). ^1H NMR (400 MHz, CDCl_3) δ:
7.24 (d, J = 5.1 Hz, 1H), 6.99-6.90 (m, 1H), 6.86 (d, J = 3.2 Hz, 1H), 3.92 (dd, J = 11.1, 5.4 Hz, 1H), 2.60-2.53 (m, 1H), 2.50-2.36 (m, 2H), 2.18-1.92 (m, 3H), 1.94-1.73 (m, 2H); 13C NMR (101 MHz, CDCl$_3$) δ: 208.9, 141.1, 126.5, 125.1, 124.4, 52.0, 41.6, 36.2, 27.7, 25.0.

(E)-2-styrylcyclohexanone (3ay) and (E)-2-(2-phenylethylidene)cyclohexanone (3ay') as a mixture (3ay:3ay' = 3.7:1)

White solid. R$_f$: 0.65 in 10% ethyl acetate in hexane. The crude mixture was purified by column chromatography on silica gel (petroleum ether/ethyl acetate 40:1). $^1$H NMR (500 MHz, CDCl$_3$) δ: 7.38 (d, J = 7.5 Hz, 7.4H), 7.32-7.15 (m, 16.1H), 6.78 (t, J = 7.6 Hz, 1H), 6.47-6.35 (m, 7.4H), 3.45 (d, J = 7.6 Hz, 2H), 3.19 (dt, J = 10.4, 6.4 Hz, 3.7H), 2.61 (t, J = 6.0 Hz, 2H), 2.50-2.43 (m, 5.7H), 2.40-2.32 (m, 3.7H), 2.22-2.16 (m, 3.7H), 2.09-2.03 (m, 3.7H), 1.97-1.85 (m, 6.7H), 1.82-1.72 (m, 12.1H); 13C NMR (101 MHz, CDCl$_3$) δ: 211.2, 137.1, 136.6, 131.4, 128.6, 128.5, 127.5, 127.3, 126.3, 126.3, 54.0, 41.7, 40.2, 34.4, 33.9, 27.6, 26.8, 24.4, 23.6, 23.3.

4-methyl-2-phenylcyclohexan-1-one (3ba)

Colorless oil. R$_f$: 0.45 in 10% ethyl acetate in hexane. The crude mixture was purified by column chromatography on silica gel (petroleum ether/ethyl acetate 25:1). $^1$H NMR (400 MHz, CDCl$_3$) δ: 7.37-7.29 (m, 2H), 7.28-7.21 (m, 1H), 7.15-7.07 (m, 2H), 3.64 (dt, J = 13.4, 4.5 Hz, 1H), 2.59-2.45 (m, 2H), 2.26-2.04 (m, 3H), 1.80-1.66 (m, 1H), 1.62-1.46 (m, 1H), 1.11-1.01 (m, 3H); 13C NMR (101 MHz, CDCl$_3$) δ: 210.3, 138.8, 128.7, 128.3, 126.9, 56.7, 43.7, 41.6, 35.7, 32.4, 21.3. HRMS (ESI): m/z [M+H]$^+$ calcd. for [C$_{13}$H$_{17}$O]$^+$: 189.1274, found: 189.1289.

3-phenyltetrahydro-4H-pyran-4-one (3ca)$^{13}$

White solid. R$_f$: 0.25 in 10% ethyl acetate in hexane. The crude mixture was purified by column chromatography on silica gel (petroleum ether/ethyl acetate 20:1). $^1$H NMR (500 MHz, CDCl$_3$) δ: 7.35 (t, J = 7.4 Hz, 2H), 7.32-7.27 (m, 1H), 7.27-7.21 (m, 2H), 4.30-4.20 (m, 2H), 4.03-3.93 (m, 2H), 3.79 (dd, J = 8.7, 6.1 Hz, 1H), 2.71-2.63 (m, 1H), 2.63-2.54 (m, 1H); 13C NMR (126 MHz, CDCl$_3$) δ: 205.7, 134.9, 128.9, 128.6, 127.5, 73.1, 68.5, 58.0, 41.9.
2-phenylcycloheptan-1-one (3da)\textsuperscript{14}

White solid. R\textsubscript{f}: 0.50 in 10% ethyl acetate in hexane. The crude mixture was purified by column chromatography on silica gel (petroleum ether/ethyl acetate 30:1). \textsuperscript{1}H NMR (500 MHz, CDCl\textsubscript{3}) \(\delta: 7.34-7.28\) (m, 2H), 7.27-7.19 (m, 3H), 3.80-3.65 (m, 1H), 2.69 (t, \(J = 12.7\) Hz, 1H), 2.52 (d, \(J = 12.1\) Hz, 1H), 2.21-2.09 (m, 1H), 2.08-1.90 (m, 4H), 1.71-1.55 (m, 1H), 1.53-1.40 (m, 2H); \textsuperscript{13}C NMR (126 MHz, CDCl\textsubscript{3}) \(\delta: 213.4, 140.4, 128.5, 127.8, 126.9, 58.8, 42.7, 32.0, 30.0, 28.5, 25.3.

2-phenylcyclopentadecan-1-one (3ea)\textsuperscript{15}

Colorless oil. R\textsubscript{f}: 0.40 in 20% ethyl acetate in hexane. The crude mixture was purified by column chromatography on silica gel (petroleum ether/ethyl acetate 45:1). \textsuperscript{1}H NMR (400 MHz, CDCl\textsubscript{3}) \(\delta: 7.38-7.16\) (m, 5H), 3.77 (dd, \(J = 9.3, 5.3\) Hz, 1H), 2.55-2.38 (m, 1H), 2.33-2.13 (m, 2H), 1.78-1.66 (m, 1H), 1.66-1.50 (m, 3H), 1.42-1.19 (m, 19H); \textsuperscript{13}C NMR (101 MHz, CDCl\textsubscript{3}) \(\delta: 211.9, 139.5, 128.8, 128.2, 127.1, 58.1, 41.6, 32.3, 27.6, 27.1, 26.9, 26.9, 26.5, 26.5, 26.3, 23.6.

2-phenylpentan-3-one (3fa)\textsuperscript{16}

Colorless oil. R\textsubscript{f}: 0.50 in 20% ethyl acetate in hexane. The crude mixture was purified by column chromatography on silica gel (petroleum ether/ethyl acetate 50:1). \textsuperscript{1}H NMR (400 MHz, CDCl\textsubscript{3}) \(\delta: 7.35-7.29\) (m, 2H), 7.27-7.24 (m, 1H), 7.24-7.19 (m, 2H), 3.81-3.71 (m, 1H), 2.45-2.28 (m, 2H), 1.39 (d, \(J = 7.0\) Hz, 3H), 0.97 (t, \(J = 7.3\) Hz, 3H); \textsuperscript{13}C NMR (101 MHz, CDCl\textsubscript{3}) \(\delta: 211.5, 140.9, 128.8, 127.8, 127.0, 52.7, 34.2, 17.5, 7.9.

cis-2-methyl-6-phenylcyclohexanone (3ha)

Colorless oil. R\textsubscript{f}: 0.43 in 15% ethyl acetate in hexane. The crude mixture was purified by column chromatography on silica gel (petroleum ether/ethyl acetate 25:1). \textsuperscript{1}H NMR (400 MHz, CDCl\textsubscript{3}) \(\delta: 7.36-7.29\) (m, 2H), 7.26-7.22 (m, 1H), 7.15-7.11 (m, 2H), 3.62 (dd, \(J = 12.4, 5.1\) Hz, 1H), 2.64-2.53 (m, 1H), 2.33-2.16 (m, 2H), 2.03-1.86 (m, 3H), 1.56-1.46 (m, 1H), 1.06 (d, \(J = 6.5\) Hz, 3H); \textsuperscript{13}C NMR (101 MHz, CDCl\textsubscript{3}) \(\delta: 211.2, 138.8, 128.7, 128.2, 126.8, 57.7, 45.8, 37.2, 36.3, 25.8, 14.7. HRMS (ESI): \textit{m/z} [M+H]\textsuperscript{+} calcd. for [C\textsubscript{13}H\textsubscript{17}O]: 189.1274, found: 189.1295.
2-(4-bromophenyl)cyclohexan-1-ol (4)
White solid. R<sub>f</sub>: 0.45 in 10% ethyl acetate in hexane. The crude mixture was purified by column chromatography on silica gel (petroleum ether/ethyl acetate 25:1). <sup>1</sup>H NMR (400 MHz, CDCl<sub>3</sub>) δ: 7.48-7.42 (m, 2H), 7.16-7.11 (m, 2H), 3.69-3.54 (m, 1H), 2.46-2.33 (m, 1H), 2.14-2.04 (m, 1H), 1.91-1.70 (m, 3H), 1.61-1.22 (m, 5H); <sup>13</sup>C NMR (101 MHz, CDCl<sub>3</sub>) δ: 142.5, 131.7, 129.6, 120.4, 74.2, 52.6, 34.6, 33.3, 25.9, 25.0.

2-(4-bromophenyl)-2-fluorocyclohexan-1-one (5)
White solid. R<sub>f</sub>: 0.48 in 20% ethyl acetate in hexane. The crude mixture was purified by column chromatography on silica gel (petroleum ether/ethyl acetate 30:1). <sup>1</sup>H NMR (400 MHz, CDCl<sub>3</sub>) δ: 7.53 (d, J = 8.1 Hz, 2H), 7.24 (d, J = 7.9 Hz, 2H), 2.87-2.72 (m, 1H), 2.51-2.27 (m, 3H), 2.13-1.97 (m, 2H), 1.93-1.75 (m, 2H); <sup>13</sup>C NMR (101 MHz, CDCl<sub>3</sub>) δ: 205.6 (d, J = 23.5 Hz), 135.5 (d, J = 22.0 Hz), 131.6, 127.9 (d, J = 7.1 Hz), 123.1 (d, J = 2.7 Hz), 97.8 (d, J = 183.3 Hz), 39.6, 38.4 (d, J = 22.8 Hz), 27.4, 21.7 (d, J = 5.8 Hz); <sup>19</sup>F NMR (376 MHz, CDCl<sub>3</sub>) δ: -146.45.

7-(4-bromophenyl)oxepan-2-one (6)
White solid. R<sub>f</sub>: 0.36 in 10% ethyl acetate in hexane. The crude mixture was purified by column chromatography on silica gel (petroleum ether/ethyl acetate 20:1). <sup>1</sup>H NMR (400 MHz, CDCl<sub>3</sub>) δ: 7.44-7.40 (m, 2H), 7.22-7.18 (m, 2H), 5.20 (d, J = 9.4 Hz, 1H), 2.81-2.71 (m, 2H), 2.11-1.95 (m, 4H), 1.82-1.68 (m, 2H); <sup>13</sup>C NMR (101 MHz, CDCl<sub>3</sub>) δ: 174.5, 139.8, 131.6, 127.5, 121.9, 81.2, 37.5, 34.9, 28.5, 22.7.

5-methyl-2-oxocyclohexyl 4-methylbenzenesulfonate (1b)
Colorless liquid. R<sub>f</sub>: 0.20 in 10% ethyl acetate in hexane. The crude mixture was purified by column chromatography on silica gel (petroleum ether/ethyl acetate 10:1). <sup>1</sup>H NMR (400 MHz, CDCl<sub>3</sub>) δ: 7.83 (d, J = 8.2 Hz, 2H), 7.32 (d, J = 8.1 Hz, 2H), 5.01 (dd, J = 12.6, 6.5 Hz, 1H), 2.53-2.26 (m, 6H), 2.16-1.92 (m, 2H), 1.77-1.53 (m, 1H), 1.45-1.20 (m, 1H), 1.12-0.95 (m, 3H); <sup>13</sup>C NMR (126 MHz, CDCl<sub>3</sub>) δ: 202.4, 144.8, 133.8, 129.7, 127.9, 80.7, 42.3, 39.7, 34.6, 31.0, 21.6, 20.7. HRMS (ESI): m/z [M+H]<sup>+</sup> calcd. for [C<sub>14</sub>H<sub>19</sub>O<sub>4</sub>S]: 283.0999, found: 283.0938.
4-oxotetrahydro-2H-pyran-3-yl 4-methylbenzenesulfonate ($1c$)\textsuperscript{18}

White solid. $R_F$: 0.20 in 10% ethyl acetate in hexane. The crude mixture was purified by column chromatography on silica gel (petroleum ether/ethyl acetate 10:1). $^1$H NMR (400 MHz, CDCl$_3$) $\delta$: 7.84 (d, $J = 8.3$ Hz, 2H), 7.35 (d, $J = 8.1$ Hz, 2H), 4.92 (dd, $J = 9.2$, 6.7 Hz, 1H), 4.30 (ddd, $J = 11.1$, 6.6, 1.3 Hz, 1H), 4.23-4.10 (m, 1H), 3.73-3.56 (m, 2H), 2.72-2.53 (m, 2H), 2.45 (s, 3H); $^{13}$C NMR (101 MHz, CDCl$_3$) $\delta$: 198.4, 145.3, 133.0, 129.8, 128.0, 77.9, 71.0, 68.2, 42.3, 21.7.

2-tosyloxycycloheptanone ($1d$)\textsuperscript{18}

White solid. $R_F$: 0.20 in 10% ethyl acetate in hexane. The crude mixture was purified by column chromatography on silica gel (petroleum ether/ethyl acetate 10:1). $^1$H NMR (400 MHz, CDCl$_3$) $\delta$: 7.83 (d, $J = 8.3$ Hz, 2H), 7.36 (d, $J = 8.2$ Hz, 2H), 5.11-4.93 (m, 1H), 2.65-2.39 (m, 5H), 1.97-1.48 (m, 8H); $^{13}$C NMR (126 MHz, CDCl$_3$) $\delta$: 206.3, 145.0, 133.4, 129.8, 127.9, 84.0, 40.3, 31.2, 27.8, 25.1, 22.6, 21.6.

2-tosyloxycyclopentadecanone ($1e$)\textsuperscript{19}

White solid. $R_F$: 0.30 in 10% ethyl acetate in hexane. The crude mixture was purified by column chromatography on silica gel (petroleum ether/ethyl acetate 15:1). $^1$H NMR (400 MHz, CDCl$_3$) $\delta$: 7.80 (d, $J = 7.3$ Hz, 2H), 7.35 (d, $J = 7.5$ Hz, 2H), 4.72-4.65 (m, 1H), 2.78-2.61 (m, 1H), 2.53-2.30 (m, 4H), 1.87-1.65 (m, 3H), 1.59-1.44 (m, 1H), 1.44-1.01 (m, 20H); $^{13}$C NMR (101 MHz, CDCl$_3$) $\delta$: 207.5, 145.2, 133.1, 129.9, 127.9, 84.1, 37.7, 31.5, 27.3, 26.9, 26.6, 26.5, 26.4, 26.1, 26.1, 25.9, 22.5, 21.7, 21.7.

3-oxopentan-2-yl 4-methylbenzenesulfonate ($1f$)\textsuperscript{18}

White solid. $R_F$: 0.45 in 10% ethyl acetate in hexane. The crude mixture was purified by column chromatography on silica gel (petroleum ether/ethyl acetate 25:1). $^1$H NMR (500 MHz, CDCl$_3$) $\delta$: 7.81 (d, $J = 8.0$ Hz, 2H), 7.37 (d, $J = 8.0$ Hz, 2H), 4.85-4.77 (m, 1H), 2.67-2.53 (m, 2H), 2.46 (s, 3H), 1.35 (d, $J = 7.0$ Hz, 3H), 1.02 (t, $J = 7.2$ Hz, 3H); $^{13}$C NMR (126 MHz, CDCl$_3$) $\delta$: 207.7, 145.3, 133.2, 130.0, 127.9, 80.7, 31.2, 21.6, 17.6, 7.0.
3-methyl-2-oxocyclohexyl 4-methylbenzenesulfonate (1h)

White solid. R<sub>f</sub>: 0.18 in 10% ethyl acetate in hexane. The crude mixture was purified by column chromatography on silica gel (petroleum ether/ethyl acetate 10:1).<sup>1</sup>H NMR (400 MHz, CDCl<sub>3</sub>) δ: 7.84 (d, <i>J</i> = 8.3 Hz, 2H), 7.32 (d, <i>J</i> = 8.1 Hz, 2H), 4.99 (dd, <i>J</i> = 11.3, 6.7 Hz, 1H), 2.45-2.33 (m, 5H), 2.09-2.02 (m, 1H), 1.93-1.87 (m, 1H), 1.83-1.74 (m, 2H), 1.34-1.24 (m, 1H), 1.02 (d, <i>J</i> = 6.5 Hz, 3H); <sup>13</sup>C NMR (101 MHz, CDCl<sub>3</sub>) δ: 203.8, 144.7, 134.0, 129.6, 127.8, 81.8, 44.6, 35.6, 35.1, 23.1, 21.6, 13.8. HRMS (ESI): m/z [M+H]<sup>+</sup> calcd. for [C<sub>14</sub>H<sub>19</sub>O<sub>4</sub>S]<sup>+</sup>: 283.0999, found: 283.1015.
7. References
8. Copies of $^1$H and $^{13}$C NMR Spectra of Substrates and Products

$^1$H NMR spectrum of 3aa in CDCl$_3$

$^{13}$C NMR spectrum of 3aa in CDCl$_3$
$^1$H NMR spectrum of 3ab in CDCl$_3$

3ab

$^{13}$C NMR spectrum of 3ab in CDCl$_3$

3ab
$^1$H NMR spectrum of 3ac in CDCl$_3$

3ac

$^{13}$C NMR spectrum of 3ac in CDCl$_3$

3ac
$^1$H NMR spectrum of 3ad in CDCl$_3$

$^{13}$C NMR spectrum of 3ad in CDCl$_3$
$^1$H NMR spectrum of 3ae in CDCl$_3$

![$^1$H NMR spectrum of 3ae in CDCl$_3$](image1)

$^{13}$C NMR spectrum of 3ae in CDCl$_3$

![$^{13}$C NMR spectrum of 3ae in CDCl$_3$](image2)
$^1$H NMR spectrum of 3af in CDCl$_3$

$^{13}$C NMR spectrum of 3af in CDCl$_3$
$^1$H NMR spectrum of 3ag in CDCl$_3$

$^{13}$C NMR spectrum of 3ag in CDCl$_3$
$^{1}$H NMR spectrum of 3ah in CDCl$_3$

$^{13}$C NMR spectrum of 3ah in CDCl$_3$
**$^1$H NMR spectrum of 3ai in CDCl$_3$**

![H NMR spectrum of 3ai in CDCl$_3$](image)

**$^{13}$C NMR spectrum of 3ai in CDCl$_3$**

![C NMR spectrum of 3ai in CDCl$_3$](image)
$\text{H NMR spectrum of 3aj in CDCl}_3$

$\text{13C NMR spectrum of 3aj in CDCl}_3$
$^1$H NMR spectrum of 3ak in CDCl$_3$

$^{13}$C NMR spectrum of 3ak in CDCl$_3$
$^1$H NMR spectrum of 3al in CDCl$_3$

![H NMR spectrum](image)

$^{13}$C NMR spectrum of 3al in CDCl$_3$

![C NMR spectrum](image)
$^1$H NMR spectrum of 3am in CDCl₃

![H NMR spectrum of 3am](image)

$^{13}$C NMR spectrum of 3am in CDCl₃

![C NMR spectrum of 3am](image)
$^1$H NMR spectrum of 3an in CDCl$_3$

$^{13}$C NMR spectrum of 3an in CDCl$_3$
$^1$H NMR spectrum of 3ao in CDCl$_3$

$^{13}$C NMR spectrum of 3ao in CDCl$_3$
$^1$H NMR spectrum of 3ap in CDCl$_3$

$^{13}$C NMR spectrum of 3ap in CDCl$_3$
$^1$H NMR spectrum of 3aq in CDCl$_3$

3aq

$^{13}$C NMR spectrum of 3aq in CDCl$_3$

3aq
$^1$H NMR spectrum of 3ar in CDCl$_3$

![$^1$H NMR spectrum of 3ar in CDCl$_3$](image)

$^{13}$C NMR spectrum of 3ar in CDCl$_3$

![$^{13}$C NMR spectrum of 3ar in CDCl$_3$](image)
$^1$H NMR spectrum of 3as in CDCl$_3$

$^{13}$C NMR spectrum of 3as in CDCl$_3$
\(^1\)H NMR spectrum of 3at in CDCl\(_3\)

\[^1^3\)C NMR spectrum of 3at in CDCl\(_3\)
$^1$H NMR spectrum of 3au in CDCl$_3$

\[ \text{3au} \]

$^{13}$C NMR spectrum of 3au in CDCl$_3$

\[ \text{3au} \]
$^1$H NMR spectrum of 3av in CDCl$_3$

3av

$^{13}$C NMR spectrum of 3av in CDCl$_3$

3av
$^1$H NMR spectrum of 3aw in CDCl$_3$

$^{13}$C NMR spectrum of 3aw in CDCl$_3$
$^1$H NMR spectrum of 3ax in CDCl$_3$

$^{13}$C NMR spectrum of 3ax in CDCl$_3$
$^1$H NMR spectrum of mixture 3ay and 3ay' in CDCl$_3$

3ay, 3ay' = 3.7:1

$^{13}$C NMR spectrum of mixture 3ay and 3ay' in CDCl$_3$

3ay, 3ay' = 3.7:1
$^1$H NMR spectrum of 3ba in CDCl$_3$

$^{13}$C NMR spectrum of 3ba in CDCl$_3$
$^1$H NMR spectrum of 3ca in CDCl$_3$

$^{13}$C NMR spectrum of 3ca in CDCl$_3$
$^1$H NMR spectrum of 3da in CDCl$_3$

$^{13}$C NMR spectrum of 3da in CDCl$_3$
$^1$H NMR spectrum of 3ea in CDCl$_3$

3ea

$^{13}$C NMR spectrum of 3ea in CDCl$_3$

3ea
$^1$H NMR spectrum of 3fa in CDCl$_3$

$^{13}$C NMR spectrum of 3fa in CDCl$_3$
\(^1H\) NMR spectrum of 3ha in CDCl\(_3\)

\(^{13}C\) NMR spectrum of 3ha in CDCl\(_3\)
\(^1\text{H NMR spectrum of 4 in CDCl}_3\)

\(\text{OH} \quad \text{Br} \quad 4\)

\(^{13}\text{C NMR spectrum of 4 in CDCl}_3\)

\(\text{OH} \quad \text{Br} \quad 4\)
$^1$H NMR spectrum of 5 in CDCl$_3$

$^{13}$C NMR spectrum of 5 in CDCl$_3$
$^1$H NMR spectrum of 6 in CDCl$_3$

$^{13}$C NMR spectrum of 6 in CDCl$_3$
$^1$H NMR spectrum of 1b in CDCl$_3$

$^{13}$C NMR spectrum of 1b in CDCl$_3$
$^1$H NMR spectrum of 1c in CDCl$_3$

$^{13}$C NMR spectrum of 1c in CDCl$_3$
$^1$H NMR spectrum of 1d in CDCl$_3$

$^{13}$C NMR spectrum of 1d in CDCl$_3$
$^1$H NMR spectrum of 1e in CDCl$_3$

$^{13}$C NMR spectrum of 1e in CDCl$_3$
$^{1}H$ NMR spectrum of 1f in CDCl$_3$

$^{13}C$ NMR spectrum of 1f in CDCl$_3$
$^1$H NMR spectrum of 1h in CDCl$_3$

$^{13}$C NMR spectrum of 1h in CDCl$_3$