# Supplementary Material (ESI) for Chemical Communications


# Supporting information

## An Iron-catalysed Chemo- and Regioselective Tetrahydrofuran Synthesis

Gerhard Hilt,* Patrick Bolze and Iris Kieltsch

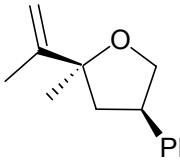
*Fachbereich Chemie, Philipps-Universität Marburg, Hans-Meerwein-Straße, 35043 Marburg, Germany*

## 1. General procedure (GP)

In a Schlenk tube under nitrogen atmosphere $FeCl_2$ (0.2 mmol), $PPh_3$ (0.1 mmol), NHC-Ligand[1] (0.1 mmol), (or the preformed $FeCl_2$(dppe) complex) zinc dust (1.4 mmol) and $NEt_3$ were suspended in $CH_3CN$ (1 ml) and heated until boiling. After 5 min agitation the alkene (5 mmol) and styrene epoxide (1 mmol) were added. The mixture was stirred at 60°C for 4h and filtered through a pad of silica by using $Et_2O$ (100 ml) as eluent. After evaporation under reduced pressure the crude product was purified by flash chromatography.

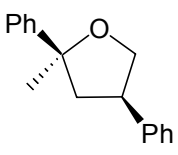
## 2. Analytic Data

### a) 2-Isopropenyl-2-methyl-4-phenyltetrahydrofuran (Table 1, entry 1)




**FC** (Silica, pentane:$CH_2Cl_2$ = 1:1), $R_f$ = 0.43. Main diastereomer: **$^1$H NMR** (300 MHz, $CDCl_3$): $\delta$ = 1.65 (s, 3H), 2.06 (s, 2H), 2.33 (t, 1H, *J* = 11.6 Hz), 2.50 (dd, 1H, *J* = 12.3, 8.0 Hz), 3.74-3.88 (m, 1H), 4.00 (dd, 1H, *J* = 10.0, 8.3 Hz), 4.52 (t, 1H, *J* = 7.8 Hz), 5.02 (s, 1H), 5.32 (s, 1H), 7.42-7.60 (m, 5H). **$^{13}$C NMR** (125 MHz, $CDCl_3$): $\delta$ = 19.2, 26.7, 44.6, 45.2, 74.1, 85.6, 108.1, 126.5, 127.3, 128.4, 140.9, 150.0. Further resolved signals of the minor diastereomer: **$^1$H NMR** (300 MHz, $CDCl_3$): $\delta$ = 1.70 (s, 3H), 2.03 (s, 2H), 2.73 (dd, 1H, *J* = 12.3, 7.3 Hz), 3.59-3.72 (m, 1H), 4.09 (t, 1H, *J* = 8.6 Hz), 4.52 (t, 1H, *J* = 8.3 Hz), 5.10 (s, 1H), 5.32 (s, 1H). **$^{13}$C NMR** (125 MHz, $CDCl_3$): $\delta$ = 19.2, 26.4, 44.7, 45.3, 73.6, 86.0, 109.5, 126.4, 127.2, 128.4, 141.7, 148.8. **MS (EI):** m/z (%): 202 ($M^+$, 4), 187 (100), 161 (18), 157 (21), 142 (10), 129 (12), 117 (34), 104 (8), 91 (23), 77 (10), 69 (74). **HRMS (EI):** $C_{14}H_{18}O$, calculated m/z = 202.1358, found m/z = 202.1362.

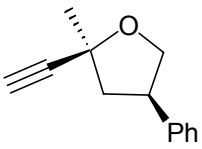
### b) 2-Methyl-2,4-diphenyltetrahydrofuran (Table 1, entry 2)




**FC** (Silica, pentane:$CH_2Cl_2$ = 1:1), $R_f$ = 0.41. Main diastereomer: **$^1$H NMR** (300 MHz, $CDCl_3$): $\delta$ = 1.73 (s, 3H), 2.43 (dd, 1H, *J* = 10.6, 12.3 Hz), 2.76 (dd, 1H, *J* = 8.0, 12.3 Hz), 3.72-3.89 (m, 1H), 3.82 (dd, 1H, *J* = 10.0, 8.3 Hz), 4.52 (t, 1H, *J* = 7.8 Hz), 7.30-7.65 (m, 10H). **$^{13}$C NMR** (125 MHz, $CDCl_3$): $\delta$ = 30.5, 45.7, 47.9, 74.4, 124.4, 126.4, 126.6, 127.3, 128.2, 128.4, 140.8, 148.9. Further resolved signals of the minor diastereomer: **$^1$H NMR** (300 MHz, $CDCl_3$): $\delta$ = 1.78 (s, 3H), 2.32 (t, 1H, *J* = 11.8 Hz), 2.84 (dd, 1H, *J* = 12.2, 7.2 Hz,), 3.34-3.50 (m, 1H), 4.10 (t, 1H, *J* = 8.8 Hz), 4.46 (t, 1H, *J* = 8.3 Hz). **$^{13}$C NMR** (125 MHz, $CDCl_3$): $\delta$ = 30.1, 44.5, 48.2, 73.9, 124.6, 126.5, 126.5, 127.2, 128.1, 128.5, 141.6, 147.6. **MS (EI):** m/z (%): 238 ($M^+$, 1), 223 (100),

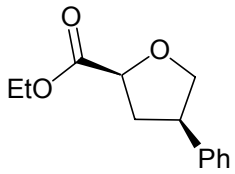
208 (3), 193 (17), 178 (7), 165 (3), 130 (5), 117 (34), 105 (86), 91 (21), 77 (22), 65 (5), 51 (6). **HRMS (EI):** $C_{17}H_{18}O$, calculated m/z = 238.1358, found m/z = 238.1360.

### c) 2-(1-Ethynyl)-2-methyl-4-phenyltetrahydrofuran (Table 1, entry 3)



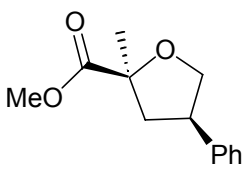

**FC** (Silica, pentane:$CH_2Cl_2$ = 2:3), $R_f$ = 0.32. Main diastereomer: **$^1$H NMR** (300 MHz, $CDCl_3$): $\delta$ = 1.58 (3H), 1.86 (dd, 1H, *J* = 12.3, 10.3 Hz), 2.56 (dd, 1H, *J* = 12.1, 7.5 Hz), 2.39 (s, 1H), 3.64-3.77 (m, 1H), 3.80 (d, 1H, *J* = 8.6 Hz), 4.18 (dd, 1H, *J* = 9.0, 7.7 Hz), 7.12-7.20 (m, 5H). **$^{13}$C NMR** (125 MHz, $CDCl_3$): $\delta$ = 27.5, 45.1, 49.0, 71.1, 74.2, 76.8, 86.7, 126.6, 127.1, 128.5, 140.4. Further resolved signals of the minor diastereomer: **$^1$H NMR** (300 MHz, $CDCl_3$): $\delta$ = 1.54 (3H), 2.32 (dd, 2H, *J* = 10.0, 8.6 Hz), 2.45 (s, 1H), 3.32-3.47 (m, 1H), 3.80-3.85 (m, 1H), 4.28 (t, 1H, *J* = 8.3 Hz). **$^{13}$C NMR** (125 MHz, $CDCl_3$): $\delta$ = 28.5, 45.1, 48.0, 71.3, 74.6, 76.2, 87.6, 126.7, 127.5, 128.5, 142.0. **MS (EI):** m/z (%): 186 ($M^+$, 8), 171 (3), 156 (33), 141 (100), 128 (13), 115 (29), 103 (8), 91 (21), 77 (12), 65 (8), 51 (9). **HRMS (EI):** $C_{13}H_{14}O$, calculated m/z = 186.1045, found m/z = 186.1049.

### d) Ethyl 4-phenyltetrahydro-2-furancarboxylate (Table 1, entry 4)



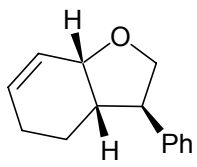

**FC** (Silica, pentane:$CH_2Cl_2$ = 2:3), $R_f$ = 0.22. Main diastereomer: **$^1$H NMR** (300 MHz, $CDCl_3$): $\delta$ = 1.31 (t, 3H, *J* = 7.2 Hz), 2.08-2.23 (m, 1H), 2.71-2.84 (m, 1H), 3.40-3.60 (m, 1H), 3.95 (t, 1H, *J* = 9.1 Hz), 4.25 (q, 2H, *J* = 7.0 Hz), 4.30 (t, 1H, *J* = 8.0 Hz), 4.62 (t, 1H, *J* = 8.2 Hz), 7.21-7.39 (m, 5H). **$^{13}$C NMR** (125 MHz, $CDCl_3$): $\delta$ = 14.1, 38.2, 45.1, 61.0, 75.2, 77.3, 126.9, 127.3, 128.6, 139.8, 172.9. Further resolved signals of the minor diastereomer: **$^1$H NMR** (300 MHz, $CDCl_3$): $\delta$ = 2.32-2.45 (m, 1H), 2.46-2.58 (m, 1H), 3.90 (t, 1H, *J* = 8.0 Hz), 4.24 (q, 2H, *J* = 7.4 Hz), 4.43 (t, 1H, *J* = 8.0 Hz), 4.71 (dd, 1H, *J* = 8.6, 4.3 Hz). **$^{13}$C NMR** (125 MHz, $CDCl_3$): $\delta$ = 43.7, 75.4, 77.2, 126.7, 127.1, 128.6, 141.1, 173.0. **MS (EI):** m/z (%): 220 ($M^+$,5), 202 (8), 147 (100), 129 (47), 120 (21), 115 (19), 91 (95), 77 (11), 65 (5), 51 (5). **HRMS (EI):** $C_{17}H_{18}O$, calculated m/z = 220.1099, found m/z = 220.1099.

### e) Methyl 2-methyl-4-phenyltetrahydro-2-furancarboxylate (Table 1, entry 5)



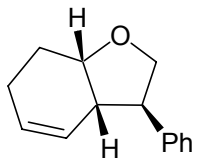

**FC** (Silica, pentane:$CH_2Cl_2$ = 1:1), $R_f$ = 0.40. Main diastereomer: **$^1$H NMR** (300 MHz, $CDCl_3$): $\delta$ = 1.75 (s, 3H), 2.55 (dd, 1H, *J* = 12.3, 8.6 Hz), 2.66 (dd, 1H, *J* = 12.9, 10.0 Hz), 3.64-3.80 (m, 1H), 3.97 (s, 3H), 4.07 (dd, 1H, *J* = 10.3, 8.6 Hz), 4.51 (t, 1H, *J* = 7.8 Hz), 7.38-7.56 (m, 5H). **$^{13}$C NMR** (125 MHz, $CDCl_3$): $\delta$ = 25.2, 44.0, 44.5, 52.2, 75.2, 83.5, 126.7, 127.2, 128.5, 139.5, 175.4. Further resolved signals of the minor diastereomer: **$^1$H NMR** (300 MHz, $CDCl_3$): $\delta$ = 1.79 (s, 3H), 2.16 (dd, 1H, *J* = 12.8, 10.8 Hz), 3.03 (dd, 1H, *J* = 12.8, 7.5 Hz), 4.12 (t, 1H, *J* = 8.5 Hz), 4.56 (t, 1H, *J* = 8.3 Hz). **$^{13}$C NMR** (125 MHz, $CDCl_3$): $\delta$ = 24.3, 44.6, 45.1, 52.2, 75.2, 126.6, 127.0, 141.0, 175.2. **MS (EI):** m/z (%): 220 (M+,1), 161 (100), 143 (4), 131 (5), 115 (8), 91 (16), 77 (6), 65 (4), 51 (4). **HRMS (EI):** $C_{13}H_{14}O$, calculated m/z = 220.1099, found m/z =220.1094.

**f) 3-Phenyl-2,3,3a,4,5,7a-hexahydrobenzo[*b*]furan (4)**



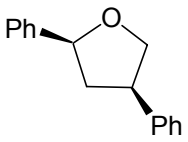

**FC** (Silica, pentane:$CH_2Cl_2$ = 1:2), $R_f$ = 0.41. **$^1$H NMR** (300 MHz, $CDCl_3$): $\delta$ = 1.65-1.79 (m, 1H), 1.94-2.06 (m, 1H), 2.07-2.11 (m, 1H), 2.25-2.39 (m, 1H), 2.51-2.64 (m, 1H), 3.36 (q, 1H, *J* = 7.6 Hz), 3.99 (t, 1H, *J* = 8.3 Hz), 4.48 (t, 1H, *J* = 8.3 Hz), 4.65-4.72 (m, 1H), 5.98-6.07 (m, 1H), 6.09-6.18 (m, 1H), 7.38-7.57 (m, 5H). **$^{13}$C NMR** (125 MHz, $CDCl_3$): $\delta$ = 22.4, 23.3, 45.3, 49.5, 73.9, 75.2, 126.5, 126.8, 127.5, 128.6, 130.3, 142.3. **MS (EI):** m/z (%): 200 ($M^+$, 100), 170 (14), 155 (29), 141 (25), 132 (45), 129 (37), 115 (36), 104 (47), 91 (97), 79 (76), 77 (41), 65 (19), 51 (16). **HRMS (EI):** $C_{14}H_{16}O$, calculated m/z = 200.1201, found m/z = 200.1199.

**g) 3-Phenyl-2,3,3a,6,7,7a-hexahydrobenzo[*b*]furan (5)**



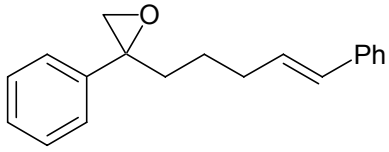

**FC** (Silica, pentane:$CH_2Cl_2$ = 1:2), $R_f$ = 0.31. **$^1$H NMR** (300 MHz, $CDCl_3$): $\delta$ = 1.65-1.79 (m, 1H), 1.94-2.06 (m, 1H), 2.07-2.11 (m, 1H), 2.25-2.39 (m, 1H), 2.51-2.64 (m, 1H), 3.36 (q, 1H, *J* = 7.6 Hz), 3.99 (t, 1H, *J* = 8.3 Hz), 4.48 (t, 1H, *J* = 8.3 Hz), 4.65-4.72 (m, 1H), 5.98-6.07 (m, 1H), 6.09-6.18 (m, 1H), 7.38-7.57 (m, 5H). **$^{13}$C NMR** (125 MHz, $CDCl_3$): $\delta$ = 22.4, 23.3, 45.3, 49.5, 73.9, 75.2, 126.5, 126.8, 127.5, 128.6, 130.3, 142.3. **MS (EI):** m/z (%): 200 ($M^+$, 100), 170 (14), 155 (29), 141 (25), 132 (45), 129 (37), 115 (36), 104 (47), 91 (97), 79 (76), 77 (41), 65 (19), 51 (16). **HRMS (EI):** $C_{14}H_{16}O$, calculated m/z = 200.1201, found m/z = 200.1204.

**h) 2,4-Diphenyltetrahydrofuran[2] 6°a,b**



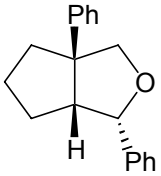

**FC** (Silica, pentane:$CH_2Cl_2$ = 1:1), $R_f$ = 0.40. Main diastereomer: **$^1$H NMR** (300 MHz, $CDCl_3$): $\delta$ = 2.03 (q, 1H, *J* = 10.5 Hz), 2.70-2.84 (m, 1H), 3.84-3.96 (m, 1H), 4.02 (t, 1H, *J* = 8.5 Hz), 4.37 (t, 1H, *J* = 8.2 Hz), 5.08 (dd, 1H, *J* = 10.2, 5.8 Hz), 7.20-7.47 (m, 10H). **$^{13}$C NMR** (125 MHz, $CDCl_3$): $\delta$ = 43.7, 46.0, 75.0, 81.8, 125.6, 126.6, 127.2, 127.3, 128.4, 128.6, 141.6, 142.6. Further resolved signals of the minor diastereomer: **$^1$H NMR** (300 MHz, $CDCl_3$): $\delta$ = 2.33 (ddd, 1H, *J* = 12.6, 8.3, 6.0 Hz), 2.48 (dt, 1H, *J* = 12.6, 7.6 Hz), 3.47-3.59 (m, 1H), 3.95 (t, 1H, *J* = 8.3 Hz), 4.47 (t, 1H, *J* = 8.0 Hz), 5.24 (dd, 1H, *J* = 7.0, 6.0 Hz). **$^{13}$C NMR** (125 MHz, $CDCl_3$): $\delta$ = 42.6, 44.3, 75.1, 80.5, 125.4, 126.6, 127.1, 127.3, 128.3, 128.6, 142.0, 143.5. **MS (EI):** m/z (%): 224 ($M^+$, 37), 193 (100), 179 (53), 165 (13), 146 (30), 133 (35), 117 (94), 105 (46), 91 (54), 77 (36), 65 (19), 51 (14). **HRMS (EI):** $C_{16}H_{16}O$, calculated m/z = 224.1201, found m/z = 224.1204. The spectroscopic data is in accordance with published data.[2]

**i) 2-Phenyl-2-(5-phenyl-pent-enyl)-oxirane (7)**




The starting material for the intramolecular reaction was synthesised adapting known procedures for the ozonolysis,[3] the Wittig type reaction[4] and the epoxide formation.[5]

**j) 1,3a-Diphenyl-hexahydrocyclopenta[*c*]furan (8)**



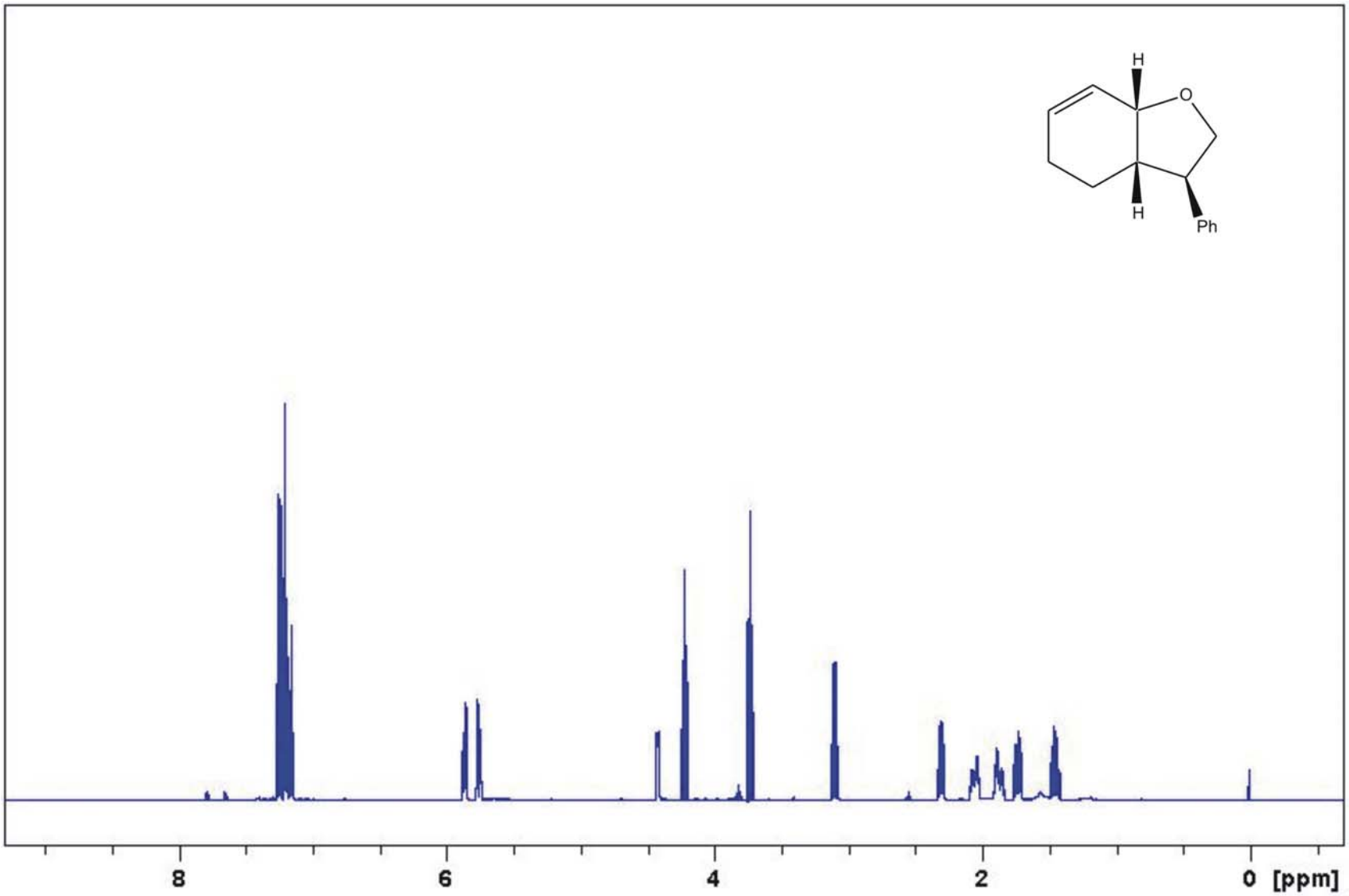

**FC** (Silica, EtOAc:pentane: = 1:15), $R_f$ = 0.30. Main diastereomer: **$^1$H NMR** (300 MHz, $CDCl_3$): $\delta$ = 1.73-2.09 (m, 6H), 2.68-2.79 (m, 1H), 3.75 (d, 1H, *J* = 9.0 Hz), 4.20 (d, 1H, *J* = 9.0 Hz), 4.45 (d, 1H, *J* = 7.6 Hz), 7.08-7.40 (m, 10H). **$^{13}$C NMR** (125 MHz, $CDCl_3$): $\delta$ = 25.0, 30.9, 37.7, 60.2, 60.7, 80.8, 88.8, 125.7, 125.8, 125.9, 127.3, 128.3, 128.4, 142.0, 148.8. **MS (EI):** m/z (%):264 ($M^+$, 25), 234 (37), 191 (17), 173 (17), 158 (100), 143 (80), 129 (72), 115 (67), 105 (35), 91 (95), 77 (41), 67 (18), 51 (15).

## Literature

[1] As NHC-ligand precursor 1,3-bis-(2,4,6-trimethylphenyl)imidazolium chloride was used, see: A. J. Arduengo, R. Krafczyk, R. Schmutzler, H. A. Craig, J. R. Goerlich, W. J. Marshal, M. Unverzagt, *Tetrahedron* 1999, **55**, 14523.
[2] A. D. Rodríguez, O. M. Cóbar, O. L. Padilla, *J. Nat. Prod.* 1997, **60**, 915; N. D. Buezo, I. Alonso, J. C. Carreto, *J. Am. Chem. Soc.* 1998, **120**, 7129.
[3] J.-L. Hsu, J.-M. Fang, *J. Org. Chem.* 2001, **66**, 8573.
[4] G. A. Molander, C. del Pozo Losada, *Tetrahedron* 1998, **54**, 5819.
[5] J. A. Ciaccio, A. L. Drahus, R. M. Meis, C. T. Tingle, M. Smrtka, R. Geneste, Synth. Commun. 2003, 33, 2135.

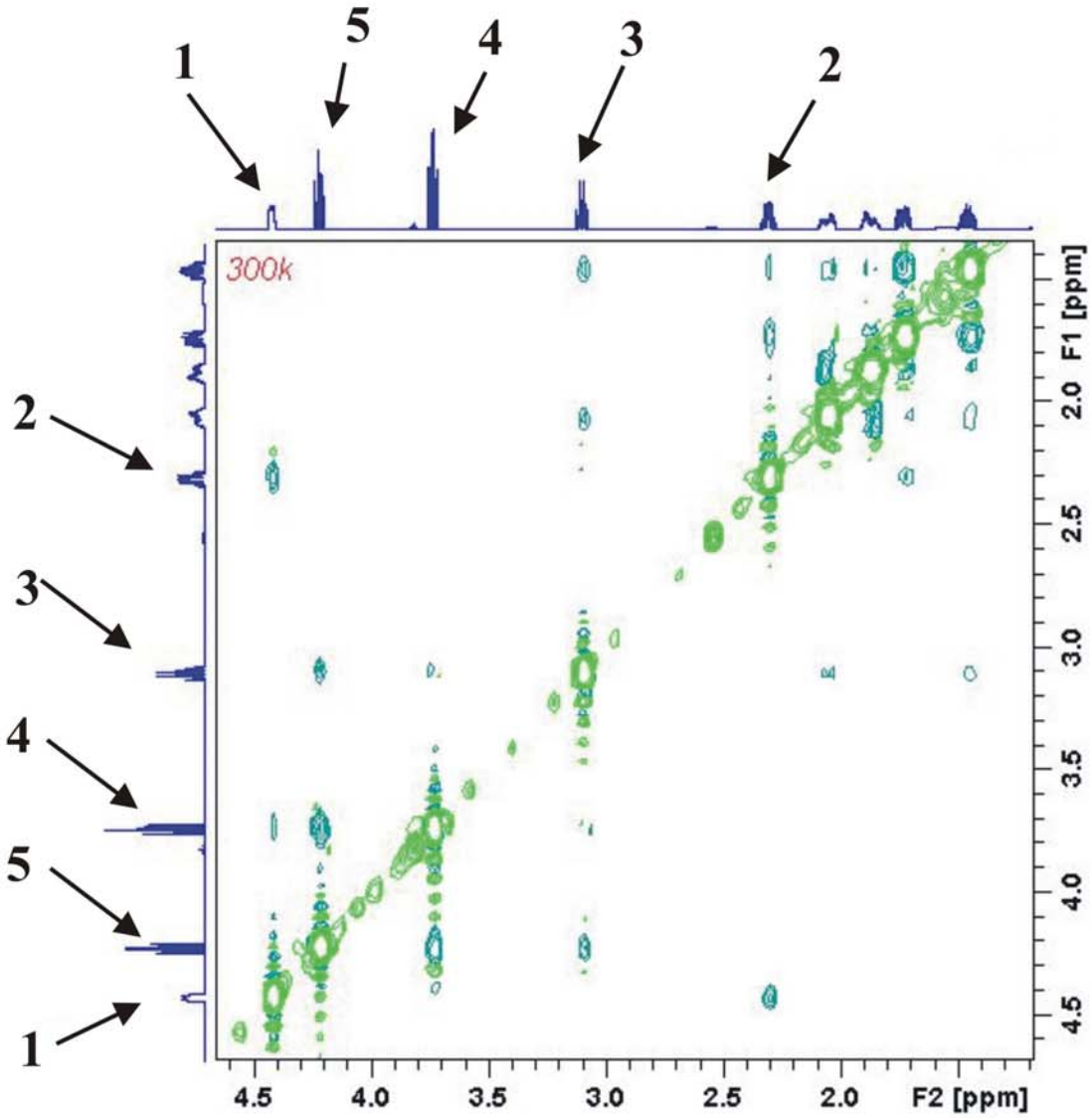
# Supplementary Material (ESI) for Chemical Communications

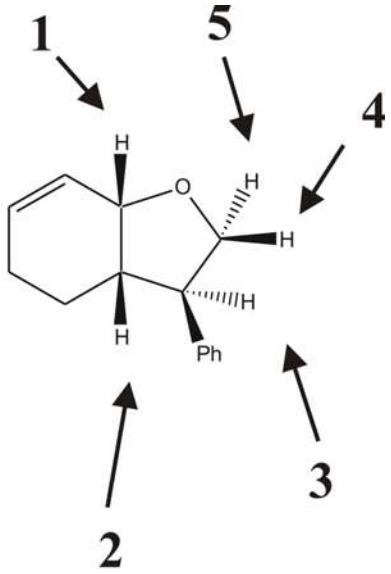

$^1$H NMR spectrum of compound **4**:



# Supplementary Material (ESI) for Chemical Communications

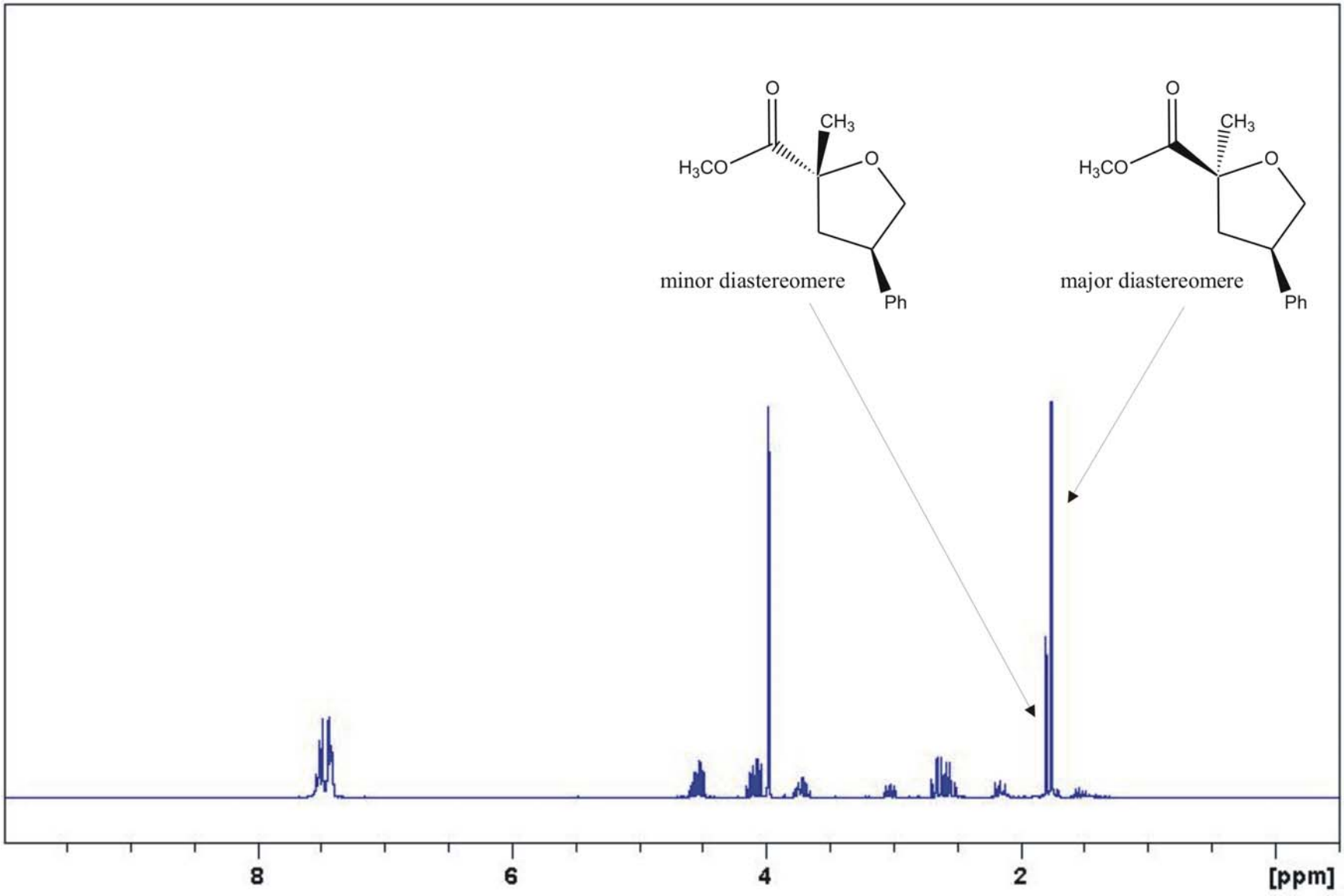

Part of the NOESY spectrum of compound **4**:



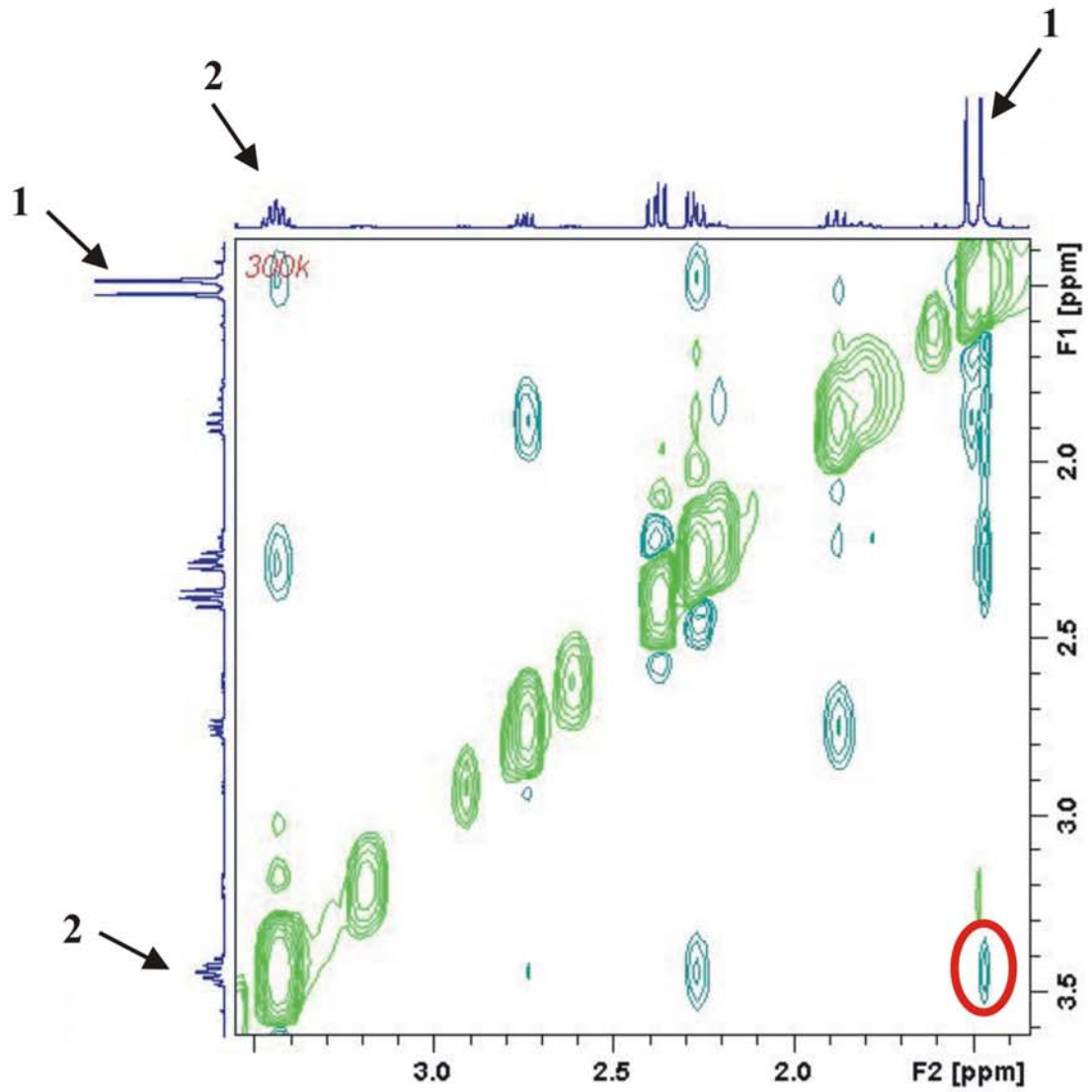
# Supplementary Material (ESI) for Chemical Communications

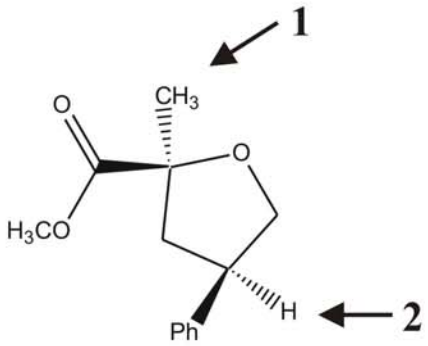

$^1$H NMR spectrum of the compound of type **3** in Table 1, entry 5:



# Supplementary Material (ESI) for Chemical Communications


Part of the NOESY spectrum of compound of type **3** in Table 1, entry 5:

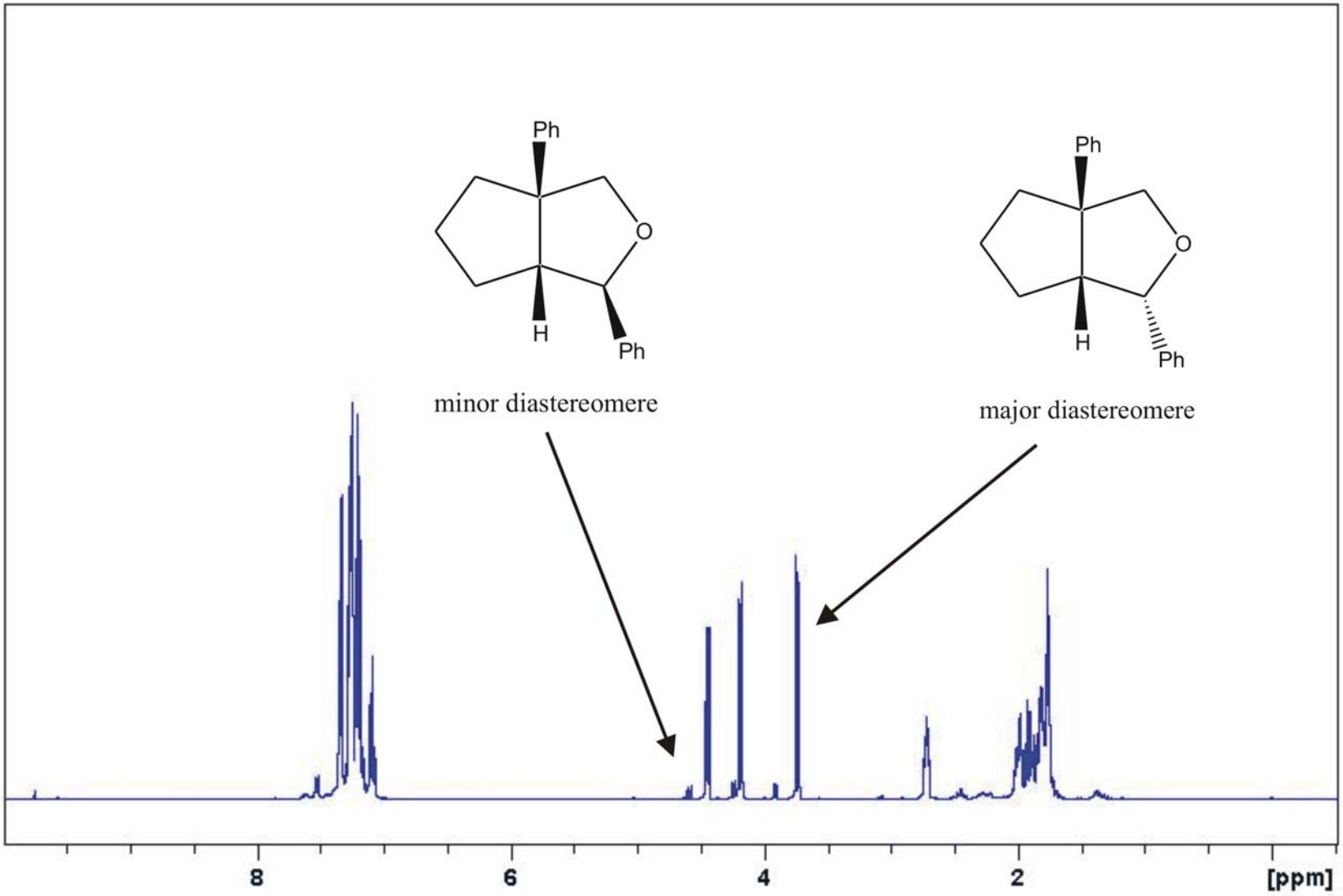



major Diastereomere

# Supplementary Material (ESI) for Chemical Communications


$^1$H NMR spectrum of the compound **8** (93 : 7 ratio of diastereomers):



# Supplementary Material (ESI) for Chemical Communications


NOESY spectrum of compound **8**: