Supplementary Material (ESI) for Green Chemistry

"Green" bromination of ketones with H_2O_2-HBr "on water"

Ajda Podgoršek, Stojan Stavber, Marko Zupan and Jernej Iskra*

Laboratory for Organic and Bioorganic Chemistry, ″Jožef Stefan″ Institute, Jamova 39, 1000 Ljubljana, Slovenia and Faculty of Chemistry and Chemical Technology, University of Ljubljana, Aškerčeva 5, 1000 Ljubljana, Slovenia
jernej.iskra@ijs.si

Table of contents

General

All chemicals were obtained form commercial sources and were used without further purification. Column and thin layer chromatography was carried out using silica gel 60 (0.063-0.200 mm) and silica 60F-245 plates, respectively. ^{1}H and ^{13}C NMR spectra were recorded in $CDCl_3$ using a Varian Inova 300 MHz spectrometer. The chemical shifts (δ) are reported in ppm units relative to TMS as an internal standard for ^{1}H NMR and $CDCl_3$ for ^{13}C NMR spectra. Melting points were determined using a Büchi 535 melting point apparatus. Mass spectra were obtained using an Autospec Q mass spectrometer with electron impact ionization (EI, 70 eV).

Typical reaction procedure for bromination of ketones in aqueous H_2O_2-HBr system

One mmol of substrate was suspended in 0.5 mL of water (in case of performing reaction with additional water) and the flask was covered with an aluminium foil to shield the reaction mixture from light. Then 0.057 mL (0.5 mol equiv.) of 48% aqueous solution of HBr was added and after stirring the mixture at room temperature for 5 minutes 0.051 mL (0.5 mol equiv.) of 30% aqueous solution of H_2O_2 was added. This procedure (0.5 mol equiv. HBr, stirring for 5 minutes, 0.5 mol equiv H_2O_2) was then repeated every 2-3 hours until the appropriate amount of bromide and oxidant had been added (See **Tables 1**, **2**, **3** and **4**). The progress of the reaction was monitored by TLC. After completion of the reaction (8 to 24 hours), the work-up procedure depended on the aggregate state of products.

Work-up procedure for liquid products:

The reaction mixture was first dissolved in 5 mL of appropriate mixture of hexane and ethylacetate (20:1 or 10:1), solid $NaHSO_3$ was then added to reduce any unreacted Br_2 and H_2O_2 and the solution was dried over anhydrous Na_2SO_4. The insoluble material was then filtered off and the organic solvent evaporated under reduced pressure. The crude reaction mixture was then analyzed by ^{1}H NMR spectroscopy. Finally, the products were isolated by column chromatography (SiO_2, hexane/EtOAc) and structure determined by comparison with the literature data.

Work-up procedure for solid products:

The reaction mixture was filtered off and rinsed with 10 mL of water. The crude reaction mixture was then analyzed by ^{1}H NMR spectroscopy. Finally, products were isolated by

column chromatography (SiO_2, hexane/EtOAc) or purified by crystallization and their structures determined by comparison with the literature data.

2-Bromo-2-methylcyclohexane-1,3-dione (3b, Table 2)[1]

126 mg (1.0 mmol) of **3a** was transformed using the following reaction conditions: 0.204 mL (2.0 mmol H_2O_2), 0.114 mL (1.0 mmol) HBr, 0.5 mL H_2O, stirring for 8 h at room temperature; work-up for liquid products. Column chromatography gave 185 mg (90%) of pure product **3b**; δ_H(300 MHz; $CDCl_3$; Me_4Si) 1.67-1.81 (m, 1H, CH_2), 1.82 (s, 3H, CH_3), 2.20-2.34 (m, 1H, CH_2), 2.58 (dt, J 16.2 and 4.9 Hz, 2H, CH_2), 3.36 (ddd, J 16.2, 11.6 and 5.8 Hz, 2H, CH_2); δ_C(76 MHz; $CDCl_3$; Me_4Si) 17.9 (CH_3), 19.2 (CH_2), 35.7 (CH_2), 59.9 (CBr), 201.0 (CO); *m/z* (EI, 70 eV) 206 (2%, M^++2), 204 (2%, M^+), 126 (9%), 97 (64%), 82(24%), 80 (24%), 70 (16%), 55 (100%).

2-Bromo-1,3-diphenylpropane-1,3-dione (5b, Table 2)[2]

224 mg (1.0 mmol) of **5a** was transformed using the following reaction conditions: 0.204 mL (2.0 mmol) H_2O_2, 0.114 mL (1.0 mmol) HBr, 0.5 mL H_2O, stirring for 9 h at room temperature; work-up for solid products. Crystallization from EtOH gave 248 mg (82%) of pure solid product **5b**; mp 88-89 °C; δ_H(300 MHz; $CDCl_3$; Me_4Si) 6.57 (s, 1H, CHBr), 7.45-7.50 (m, 4H, ArH), 7.58-7.63 (m, 2H, ArH), 7.99-8.01 (m, 4H, ArH); δ_C(76 MHz; $CDCl_3$; Me_4Si) 52.6 (CHBr), 129.0 (Ar-C), 129.2 (Ar-C), 133.7 (Ar-C), 134.2 (Ar-C), 188.9 (CO); *m/z* (EI, 70 eV) 304 (0.7%, M^++2), 302 (0.7%, M^+), 223 (37%), 105 (100%), 77 (41%).

2-Bromo-1-phenylbutane-1,3-dione (6b, Table 2)[3]

162 mg (1.0 mmol) of **6a** was transformed using the following reaction conditions: 0.204 mL (2.0 mmol) H_2O_2, 0.114 mL (1.0 mmol) HBr, 0.5 mL H_2O, stirring for 9 h at room temperature; work-up for liquid products. Column chromatography gave 190 mg (79%) of **6b**; δ_H(300 MHz; $CDCl_3$; Me_4Si) 2.46 (s, 3H, CH_3), 5.63 (s, 1H, CHBr), 7.44-7.54 (m, 2H, ArH), 7.58-7.67 (m, 1H, ArH), 7.96-8.00 (m, 2H, ArH); δ_C (76 MHz; $CDCl_3$; Me_4Si) 27.08 (CH_3), 52.86 (CHBr), 128.93 (Ar-C), 129.17 (Ar-C), 133.63 (Ar-C), 134.42 (Ar-C), 189.85 (CO), 198.11 (CO); *m/z* (EI, 70 eV) 242 (0.5%, M^++2), 240 (0.5%, M^+), 200 (5%), 198 (5%), 105 (100%), 77 (40%); and

2,2-dibromo-1-phenylbutane-1,3-dione (6c, Table 2)[4] (16 mg, 5%)

δ_H(300 MHz; $CDCl_3$; Me_4Si) 2.53 (s, 3H, CH_3), 7.45-7.50 (m, 2H, ArH), 7.58-7.64 (m, 1H, ArH), 8.05-8.10 (m, 2H, ArH); δ_C(76 MHz; $CDCl_3$; Me_4Si) 24.7 (CH_3), 68.8 (CBr_2), 128.6 (Ar-C), 130.6 (Ar-C), 130.8 (Ar-C), 134.3 (Ar-C), 185.4 (CO), 191.7 (CO).

Ethyl 1-bromo-2-oxo-cyclopentanecarboxylate (7b, Table 2)[1]

156 mg (1.0 mmol) of **7a** was transformed using the following reaction conditions: 0.204 mL (2.0 mmol) H_2O_2, 0.114 mL (1.0 mmol) HBr, 0.5 mL H_2O, stirring for 8 h at room temperature; work-up for liquid products. Column chromatography gave 200 mg (85%) of pure product **7b**; δ_H(300 MHz; $CDCl_3$; Me_4Si) 1.33 (t, J 7.1 Hz, 3H, CH_3), 2.10-2.23 (m, 2H, CH_2), 2.26-2.39 (m, 1H, CH_2), 2.43-2.62 (m, 2H, CH_2), 2.72-2.83 (m, 1H, CH_2), 4.31 (q, J 7.1 Hz, 2H, CH_2); δ_C(76 MHz; $CDCl_3$; Me_4Si) 13.9 (CH_3), 19.4 (CH_2), 35.1(CH_2), 38.7 (CH_2), 62.1(CH_2), 63.2 (CBr), 166.9 (CO), 205.9 (CO); *m/z* (EI, 70 eV) 236 (7%, M^++2), 234 (7%, M^+), 190 (15 %), 188 (15%), 109 (100%).

Ethyl 2-benzyl-2-bromo-3-oxobutanoate (8b, Table 2)[5]

220 mg (1.0 mmol) of **8a** was transformed using the following reaction conditions: 0.204 mL (2.0 mmol) H_2O_2, 0.228 mL (2.0 mmol) HBr, 0.5 mL H_2O, stirring for 24 h at room temperature; work-up for liquid products. Column chromatography gave 284 mg (95%) of pure product **8b**; δ_H(300 MHz; $CDCl_3$; Me_4Si) 1.21 (t, J 7.10, 3H, CH_3), 2.34 (s, 3H, CH_3), 3.51 (d, J 14.5 Hz, 1H, CH_2), 3.64 (d, J 14.5 Hz, 1H, CH_2), 4.21 (q, J 7.1 Hz, 2H, CH_2), 7.20-7.30 (m, 5H, ArH); δ_C(76 MHz; $CDCl_3$; Me_4Si) 13.7 (CH_3), 26.8 (CH_3), 42.6 (CH_2), 53.4 (CH_2), 63.1 (CBr), 127.5 (Ar-C), 128.1 (Ar-C), 130.4 (Ar-C), 134.6 (Ar-C), 167.1 (CO), 197.7 (CO); *m/z* (EI, 70 eV) 258 (10%), 256 (10%), 219 (35%), 173 (83%), 131 (58%), 91 (35%), 78 (100%).

2-Bromo-cyclooctanone (9b, Table 2)[6]

126 mg (1.0 mmol) of **9a** was transformed using the following reaction conditions: 0.204 mL (2.0 mmol) H_2O_2, 0.125 mL (1.1 mmol) HBr, stirring for 24 h at room temperature; work-up for liquid products. Column chromatography gave 141 mg (69%) of pure product **9b**; δ_H(300 MHz; $CDCl_3$; Me_4Si) 1.11-1.25 (m, 1H, CH_2), 1.35-1.48 (m, 1H, CH_2), 1.50-1.97 (m, 6H,

CH_2), 2.26-2.46 (m, 3H, CH_2), 2.81-2.91 (m, 1H, CH_2), 4.28 (dd, J 10.8 and J 4.6 Hz, 1H, CHBr); δ_C(76 MHz; $CDCl_3$; Me_4Si) 23.9 (CH_2), 25.4 (CH_2), 26.5 (CH_2), 28.7 (CH_2), 32.6 (CH_2), 36.2 (CH_2), 54.3 (CHBr), 208.6 (CO); *m/z* (EI, 70 eV) 125 (4%), 98 (100%), 55 (83%).

α-Bromo-4-methylacetophenone (10b, Table 2)[7]

134 mg (1.0 mmol) of **10a** was transformed using the following reaction reaction conditions: 0.204 mL (2.0 mmol) H_2O_2, 0.125 mL (1.1 mmol) HBr, 0.5 mL H_2O, stirring for 24 h at room temperature; work-up for liquid products. Column chromatography gave 166 mg (78%) of pure solid product **10b**; mp 47-48°C (mp[7] 51-52ºC); δ_H(300 MHz; $CDCl_3$; Me_4Si) 2.43 (s, 3H, CH_3), 4.43 (s, 2H, CH_2), 7.29 (d, J 8.3 Hz, 2H, ArH), 7.88 (d, J 8.3 Hz, 2H, ArH); δ_C(76 MHz; $CDCl_3$; Me_4Si) 21.7 (CH_3), 31.0 (CH_2Br), 129.0 (Ar-C), 129.5 (Ar-C), 131.4 (Ar-C), 145.0 (Ar-C), 190.9 (CO); *m/z* (EI, 70 eV) 214 (4%, M^++2), 212 (4%, M^+), 119 (100%), 105 (15 %), 91 (47 %), 77 (8%), 65 (23%).

2-Bromo-1,2-diphenylethanone (11b, Table 2)[8]

196 mg (1.0 mmol) of **11a** was transformed using the following reaction reaction conditions: 0.204 mL (2.0 mmol) H_2O_2, 0.171 mL (1.5 mmol) HBr, 0.5 mL H_2O, stirring for 24 h at room temperature; work-up for liquid products. Column chromatography gave 242 mg (88%) of pure solid product **11b**; mp 45-46 °C (mp[8] 44-46 °C); δ_H(300 MHz; $CDCl_3$; Me_4Si) 6.39 (s, 1H, CHBr), 7.31-7.58 (m, 8H, ArH), 7.91-8.01 (m, 2H, ArH); δ_C(76 MHz; $CDCl_3$; Me_4Si) 51.0 (CHBr), 128.8 (Ar-C), 129.0 (Ar-C), 129.1 (Ar-C), 133.7 (Ar-C), 134.1 (Ar-C), 135.6 (Ar-C), 191.0 (CO); *m/z* (EI, 70 eV) 276 (0.4%, M^++2), 274 (0.4%, M^+), 195 (7%), 105 (100%), 90 (10%), 77 (20%).

2-Bromo-1,3-diphenylpropan-1-one (12b, Table 2)[9]

210 mg (1.0 mmol) of **12a** was transformed using the following reaction conditions: 0.114 mL (2.0 mmol) H_2O_2, 0.171 mL (1.5 mmol) HBr, 0.5 mL H_2O, stirring for 24 h at room temperature; work-up for liquid products. Column chromatography gave 248 mg (86%) of pure product **12b**; δ_H(300 MHz; $CDCl_3$; Me_4Si) 3.35 (dd, J 14.3 and J 7.1 Hz, 1H, CH_2), 3.67 (dd, J 14.3 and J 7.5 Hz, 1H, CH_2), 5.32 (dd, J 7.5 and J 7.1 Hz , 1H, CHBr), 7.16-7.32 (m, 5H, ArH), 7.39-7.48 (m, 2H, ArH), 7.52-7.59 (m, 1H, ArH), 7.95-7.98 (m, 2H, ArH); δ_C(76

MHz; $CDCl_3$; Me_4Si) 39.4 (CH_2), 46.6 (CHBr), 127.0 (Ar-C), 128.6 (Ar-C), 128.7 (Ar-C), 128.8 (Ar-C), 129.4 (Ar-C), 133.7 (Ar-C), 134.3 (Ar-C), 137.5 (Ar-C), 192.7 (CO); *m/z* (EI, 70 eV) 290 (2%, M^++2), 289 (12%, M^+-H+2), 288 (2%, M^+), 287 (9%, M^+-H), 209 (100%), 131 (11%), 105 (72%), 77 (33%).

2-Bromo-1-phenylpropan-1-one (13b, Table 2)[10]

134 mg (1.0 mmol) of **13a** was transformed using the following reaction conditions: 0.204 mL (2.0 mmol) H_2O_2, 0.228 mL (2.0 mmol) HBr, stirring for 24 h at room temperature; work-up for liquid products. Column chromatography gave 166 mg (78%) of pure product **13b**; δ_H(300 MHz; $CDCl_3$; Me_4Si) 1.91 (d, J 6.6 Hz, 3H, CH_3), 5.30 (q, J 6.6 Hz, 1H, CHBr), 7.49 (t, J 7.4 Hz, 2H, ArH), 7.59 (tt, J 7.4 and 1.5 Hz, 1H, ArH), 8.02 (dd, J 7.4 and 1.5 Hz, 2H, ArH); δ_C(76 MHz; $CDCl_3$; Me_4Si) 20.1 (CH_3), 41.4 (CHBr), 128.7 (Ar-C), 128.9 (Ar-C), 133.7 (Ar-C), 134.0 (Ar-C), 193.3 (CO); *m/z* (EI, 70 eV) 214 (2%, M^++2), 212 (2%, M^+), 105 (100%), 77 (36%).

2-Bromo-2-cyclobutyl-1-phenylethanone (14b, Table 2)[11]

160 mg (1.0 mmol) of **14a** was transformed using the following reaction conditions: 0.204 mL (2.0 mmol) H_2O_2, 0.228 mL (2.0 mmol) HBr, stirring for 24 h at room temperature; work-up for solid products. Crystallization from EtOH gave 182 mg (76%) of pure solid product **14b**; mp 57-58°C (mp[11] 54-55 ºC); δ_H(300 MHz; $CDCl_3$; Me_4Si) 1.80-1.93 (m, 1H, CH_2), 2.34-2.49 (m, 1H, CH_2), 2.71-2.82 (m, 2H, CH_2), 3.08-3.19 (m, 2H, CH_2), 7.42-7.49 (m, 2H, ArH), 7.54 (tt, J 7.4 and 1.5 Hz, 1H, ArH), 8.03 (dd, J 7.4 and 1.5 Hz, 2H, ArH); δ_C(76 MHz; $CDCl_3$; Me_4Si) 16.5 (CH_2), 37.0 (CH_2), 59.6 (CBr), 128.3 (Ar-C), 130.1 (Ar-C), 132.2 (Ar-C), 133.2 (Ar-C), 194.5 (CO); *m/z* (EI, 70 eV) 240 (1%, M^++2), 238 (1%, M^+), 159 (1%), 105 (100%), 77 (35%).

4-Bromononan-5-one (15b, Table 2)[12]

142 mg (1.0 mmol) of **15a** was transformed using the following reaction conditions: 0.204 mL (2.0 mmol) H_2O_2, 0.228 mL (2.0 mmol) HBr, stirring for 24 h at room temperature; work-up for liquid products. Column chromatography gave 176 mg (80%) of pure product **15b**; δ_H(300 MHz; $CDCl_3$; Me_4Si) 0.90-0.97 (m, 6H, CH_3), 1.28-1.66 (m, 6H, CH_2), 1.84-2.04 (m, 2H, CH_2), 2.58-2.78 (m, 2H, CH_2), 4.26 (dd, J 8.1 and 6.0 Hz, 1H, CHBr); δ_C(76

MHz; $CDCl_3$; Me_4Si) 13.4 (CH_3), 13.8 (CH_3), 20.6 (CH_2), 22.2 (CH_2), 26.0 (CH_2), 35.3 (CH_2), 38.6 (CH_2), 53.5 (CHBr), 204.4 (CO); *m/z* (EI, 70 eV) 222 (0.5%, M^++2), 220 (0.5%, M^+), 180 (4%), 178 (4%), 85 (100%), 57 (71%).

3-Bromononan-2-one (16b, Table 2)[13]

142 mg (1.0 mmol) of **16a** was transformed using the following reaction conditions: 0.204 mL (2.0 mmol) H_2O_2, 0.228 mL (1.0 mmol) HBr, stirring for 24 h at room temperature; work-up for liquid products. Column chromatography gave mixture of **16b** (74 mg, 33%); δ_H(300 MHz; $CDCl_3$; Me_4Si) 0.86-0.90 (m, 3H, CH_3), 1.19-1.40 (m, 6H, CH_2), 1.41-1.55 (m, 2H, CH_2), 1.85-2.06 (m, 2H, CH_2), 2.36 (s, 3H, CH_3), 4.23 (dd, J 8.1 and 6.5 Hz, 1H, CHBr); δ_C(76 MHz; $CDCl_3$; Me_4Si) 14.0 (CH_3), 22.4 (CH_2), 27.2 (CH_2), 28.6 (CH_2), 28.9 (CH_2), 31.4 (CH_2), 33.5 (CH_3), 54.4 (CHBr), 202.0 (CO); and

1-Bromo-2-nonanone (16d, Table 2)[14] (32 mg, 14%)

δ_H(300 MHz; $CDCl_3$; Me_4Si) 0.86-0.90 (m, 3H, CH_3), 1.19-1.40 (m, 8H, CH_2), 1.57-1.66 (m, 2H, CH_2), 2.65 (t, 2H, J 7.4 Hz, CH_2), 3.89 (s, 2H, CH_2); δ_C(76 MHz; $CDCl_3$; Me_4Si) 14.0 (CH_3), 22.5 (CH_2), 23.8 (CH_2), 26.0 (CH_2), 28.90 (CH_2), 31.6 (CH_2), 34.3 (CH_2), 39.8 (CH_2Br), 202.1 (CO).

2-Bromo-2,4-dimethylpentan-3-one (17b, Table 2)[15]

114 mg (1.0 mmol) of **17a** was transformed using the following reaction conditions: 0.204 mL (2.0 mmol) H_2O_2, 0.228 mL (2.0 mmol) HBr, stirring for 24 h at room temperature; work-up for liquid products. Column chromatography gave 148 mg (77%) of pure product **17b**; δ_H(300 MHz; $CDCl_3$; Me_4Si) 1.18 (d, J 6.7 Hz, 6H, CH_3), 1.87 (s, 6H, CH_3), 3.45 (sept, J 6.7 Hz, 1H, CH); δ_C(76 MHz; $CDCl_3$; Me_4Si) 29.3 (CH_3), 34.5 (CH_3), 64.5 (CH), 96.0 (CBr), 209.9 (CO); *m/z* (EI, 70 eV) 194 (0.3%, M^++2), 192 (0.3%, M^+), 123 (11%), 121 (11%), 85 (11%), 71 (100%).

1-Bromo-1-phenylpropan-2-one (18b, Table 3)[3]

134 mg (1.0 mmol) of **18b** was transformed using the following reaction conditions: 0.204 mL (2.0 mmol) H_2O_2, 0.228 mL (2.0 mmol) HBr, stirring for 24 h at room temperature; work-up for liquid products. Column chromatography (SiO_2, CH_2Cl_2) gave 187 mg (88%) of

pure product **18b**; δ_H(300 MHz; $CDCl_3$; Me_4Si) 2.30 (s, 3H, CH_3), 5.44 (s, 1H, CHBr), 7.34-7.46 (m, 5H, ArH); δ_C(76 MHz; $CDCl_3$; Me_4Si) 27.1 (CH_3), 57.3 (CHBr), 127.7 (Ar-C), 129.7 (Ar-C), 129.8 (Ar-C), 130.1 (Ar-C), 130.2 (Ar-C), 135.1 (Ar-C), 200.2 (CO); *m/z* (EI, 70 eV) 214 (2%, M^++2), 212 (2%, M^+), 171 (46%), 169 (50%), 133 (100%), 118 (15%), 105 (25%), 90 (43%), 77 (15%).

1-(3-Bromo-4-methoxyphenyl)propan-2-one (19d, Table 3)

164 mg (1.0 mmol) of **19a** was transformed using the following reaction conditions: 0.204 mL (2.0 mmol) H_2O_2, 0.114 mL (1.0 mmol) HBr, 0.5 mL H_2O, stirring for 24 h at room temperature; work-up for liquid products. Column chromatography gave 230 mg (95%) of **19d**; δ_H(300 MHz; $CDCl_3$; Me_4Si) 2.16 (s, 3H, CH_3), 3.62 (s, 2H, CH_2), 3.87 (s, 3H, CH_3), 6.86 (d, J 8.4 Hz, 1H, ArH), 7.10 (dd, J 8.4 and 2.1 Hz, 1H, ArH), 7.38 (d, J 2.1 Hz, 1H, ArH); δ_C(76 MHz; $CDCl_3$; Me_4Si) 29.2 (CH_3), 49.3 (CH_2), 56.1 (CH_3), 111.6 (Ar-C), 112.0 (Ar-C), 127.6 (Ar-C), 129.4 (Ar-C), 134.0 (Ar-C), 154.9 (Ar-C), 205.8 (CO); *m/z* (EI, 70 eV) 244 (30%, M^++2), 242 (30%, M^+), 201 (100%), 199 (100%), 105 (48%), 77 (62%); found: C, 49.51; H, 4.65. $C_{10}H_{11}BrO_2$ requires C, 49.41; H, 4.56%.

4-(3-Bromo-4-methoxyphenyl)butan-2-one (20d, Table 3)[16]

178 mg (1.0 mmol) of **20a** was transformed using the following reaction conditions: 0.204 mL (2.0 mmol) H_2O_2, 0.114 mL (1.0 mmol) HBr, 0.5 mL H_2O, stirring for 24 h at room temperature; work-up for liquid products. Column chromatography gave 246 mg (96%) of **20d**; δ_H(300 MHz; $CDCl_3$; Me_4Si) 2.13 (s, 3H, CH_3), 2.76 (m, 4H, CH_2), 3.85 (s, 3H, CH_3), 6.81 (d, J 8.4 Hz, 1H, ArH), 7.08 (dd, J 8.4 and 2.1 Hz, 1H, ArH), 7.36 (d, J 2.1 Hz, 1H, ArH); δ_C(76 MHz; $CDCl_3$; Me_4Si) 28.3 (CH_3), 30.0 (CH_2), 44.9 (CH_2), 56.1 (CH_3), 111.4 (Ar-C), 111.8 (Ar-C), 128.2 (Ar-C), 132.9 (Ar-C), 134.6 (Ar-C), 154.1 (Ar-C), 207.5 (CO); *m/z* (EI, 70 eV) 258 (57%, M^++2), 256 (57%, M^+), 201 (100%), 199 (100%), 178 (26%), 134 (41%), 121 (65%), 77 (32%).

2-Bromoindane-1-one (21b, Table 4)[17]

132 mg (1.0 mmol) of **21a** was transformed using the following reaction conditions: 0.204 mL (2.0 mmol) H_2O_2, 0.125 mL (1.1 mmol) HBr, stirring for 24 h at room temperature; work-up for solid products. Column chromatography gave 184 mg (87%) of **21b**; mp 37-38

°C (mp[1] 37-38 °C); δ_H(300 MHz; $CDCl_3$; Me_4Si) 3.42 (dd, J 18.1 and 3.2 Hz, 1H, CH_2), 3.84 (dd, J 18.1 and 7.5 Hz, 1H, CH_2), 4.65 (dd, J 7.5 and 3.2 Hz, 1H, CHBr), 7.40-7.46 (m, 2H, ArH), 7.64-7.69 (m, 1H, ArH), 7.81-7.84 (m, 1H, ArH); δ_C(76 MHz; $CDCl_3$; Me_4Si) 37.9 (CH_2), 44.0 (CHBr), 125.0 (Ar-C), 126.4 (Ar-C), 128.2 (Ar-C), 133.5 (Ar-C), 135.9 (Ar-C), 151.1 (Ar-C), 199.5 (CO); *m/z* (EI, 70 eV) 212 (13%, M^++2), 210 (13%, M^+), 131 (100%), 103 (46 %), 77 (28%); and

2,2-Dibromoindane-1-one (21c, Table 4)[17] (11mg, 4%)

mp 133-134 °C (mp[17] 133-134 °C) δ_H(300 MHz; $CDCl_3$; Me_4Si) 4.30 (s, 2H, CH_2), 7.42 (d, J 7.70 Hz, 1H, ArH), 7.51 (t, J 7.7 Hz, 1H, ArH), 7.75 (dt, J 7.7 and 1.2 Hz, 1H, ArH), 7.96 (d, J 7.7 Hz, 1H, ArH); δ_C(76 MHz; $CDCl_3$; Me_4Si) 52.3 (CH_2), 56.8 (CBr_2), 126.0 (Ar-C), 126.6 (Ar-C), 128.7 (Ar-C), 129.0 (Ar-C), 136.9 (Ar-C), 147.1 (Ar-C), 192.7 (CO); *m/z* (EI, 70 eV) 292 (18%, M^++4), 290 (34%, M^++2), 288 (18%, M^+), 211 (95%), 209 (100%), 198 (5%), 196 (5%), 130 (27%), 102 (89%), 89 (18%), 75 (37%).

2-Bromo-1-tetralone (23b, Table 4)[17]

146 mg (1.0 mmol) of **23a** was transformed using the following reaction conditions: 0.204 mL (2.0 mmol) H_2O_2, 0.125 mL (1.1 mmol) HBr, stirring for 24 h at room temperature; work-up for liquid products. Column chromatography gave 203 mg (90%) of pure product **23b**; δ_H(300 MHz; $CDCl_3$; Me_4Si) 2.41-2.60 (m, 2H, CH_2), 2.90 (dt, J 17.2 and J 4.5 Hz, 1H, CH_2), 3.26-3.37 (m, 1H, CH_2), 4.73 (t, J 4.5 Hz, 1H, CHBr), 7.25 (d, J 7.9 Hz, 1H, ArH), 7.34 (t, J 7.9 Hz, 1H, ArH), 7.51 (td, J 7.9 and J 1.5 Hz, 1H, ArH), 8.09 (dd, 1H, 7.9 and 1.4 Hz, 1H, ArH); δ_C(76 MHz; $CDCl_3$; Me_4Si) 26.1 (CH_2), 31.9 (CH_2), 50.4 (CHBr), 127.1 (Ar-C), 128.6 (Ar-C), 128.7 (Ar-C), 129.9 (Ar-C), 134.1 (Ar-C), 142.9 (Ar-C), 190.5 (CO); *m/z* (EI, 70 eV) 226 (18%, M^++2), 224 (18%, M^+), 144 (33%), 118 (100%), 115 (32%), 90 (42%).

Tandem oxidation and bromination of *sec*-alcohol

1.0 mmol of *sec*-alcohol was suspended in 0.5 mL of water and the flask was covered with an aluminum foil. Then 0.057 mL (0.5 mol equiv.) of 48% aqueous solution of HBr was added. After stirring at room temperature for 5 minutes, to the mixture was added 0.051 mL (0.5 mol equiv.) of 30% aqueous solution of H_2O_2. This procedure (0.5 mol equiv. of HBr, stirring for 5 minutes, 0.5 mol equiv. of H_2O_2) were then repeated every four hours until the appropriate amount of HBr and H_2O_2 had been added (**Table 5**). After completion of the reaction the

crude reaction mixture was isolated following the work-up procedure for liquid products and isolated by column chromatography (SiO_2, hexane/EtOAc).

2-Bromocycloheptanone (28b, Table 5)[18]

114 mg (1.0 mmol) of **26** was transformed using the following reaction conditions: 0.408 mL (4.0 mmol) H_2O_2, 0.170 mL (1.5 mmol) HBr, stirring for 10h at room temperature. Column chromatography gave 168 mg (88%) of pure product **28b**; δ_H(300 MHz; $CDCl_3$; Me_4Si) 1.30-1.44 (m, 1H, CH_2), 1.49-2.06 (m, 5H, CH_2), 2.29-2.52 (m, 3H), 2.81-2.90 (m, 1H, CH_2), 4.37 (dd, J 9.6 and 5.1 Hz, 1H, CHBr); δ_C(76 MHz; $CDCl_3$; Me_4Si) 24.9 (CH_2), 26.8 (CH_2), 29.5 (CH_2), 34.2 (CH_2), 39.33 (CH_2), 53.7 (CHBr), 206.2 (CO); *m/z* (EI, 70 eV) 192 (4%, M^++2), 190 (4%, M^+), 149 (3%), 137 (2%), 123 (2%), 111 (45%), 83 (28%), 69 (29%), 55 (100%).

2-Bromopentan-3-one (29b, Table 5)[19]

88 mg (1.0 mmol) of **27** was transformed using the following reaction conditions: 0.408 mL (4.0 mmol) H_2O_2, 0.170 mL (1.5 mmol) HBr, stirring for 10h at room temperature. Column chromatography gave 152 mg (92%) of pure product **29b**; δ_H(300 MHz; $CDCl_3$; Me_4Si) 1.12 (t, J 7.3 Hz, 3H, CH_3), 1.75 (d, J 6.8 Hz, 3H, CH_3), 2.60 (qd, J 7.3 and 17.9 Hz, 1H, CH_2), 2.87 (qd, J 7.3 and 17.9 Hz, 1H, CH_2), 4.43 (q, J 6.8 Hz, 1H, CHBr); δ_C(76 MHz; $CDCl_3$; Me_4Si) 8.1 (CH_3), 20.1 (CH_3), 31.9 (CH_2), 47.2 (CHBr), 205.1 (CO); *m/z* (EI, 70 eV) 166 (20%, M^++2), 164 (20%, M^+), 137 (15%), 135 (15%), 109 (70%), 107 (70%), 84 (63%), 57 (100%).

Determination of concentration of bromine and hydrogen peroxide in H_2O_2-HBr system

1.60 mL (14.0 mmol) of a 48% aqueous solution of HBr and 2.86 mL (28.0 mmol) of a 30% aqueous solution of H_2O_2 were added to 7.0 mL of water. The flask was covered with an aluminium foil and stirred at room temperature. Time dependence of the concentration of bromine and hydrogen peroxide was followed periodically by iodometric titration. Small portions (100 μL) of solution were transferred into 10 mL 0.05 M aqueous solution of potassium iodide. First, the concentration of bromine was determined with instantaneous titration of liberated iodine with 0.05 M aqueous solution of $Na_2S_2O_3$. Then, 0.55 mL of 10% aqueous solution of H_2SO_4 was added and after 30 minutes the liberated iodine was titrated to determine the concentration of hydrogen peroxide.

NMR experiments

Spectrum A: 55 mg (0.25 mmol) of 2-benzyl-3-oxo-butyric acid ethyl ester **8a** was dissolved in 0.8 mL of $CDCl_3$. Spectrum B: 55 mg (0.25 mmol) of **8a** was dissolved in 0.32 mL of DMSO-d_6 and 0.48 mL of D_2O was added. Spectrum C: 55 mg (0.25 mmol) of **8a** was dissolved in 0.32 mL of DMSO-d_6 and 0.48 mL of D_2O and 0.028 mL (0.25 mmol) of 48% aqueous solution of HBr were added. ^1H NMR spectra were recorded in 1 hour time after preparation of samples.

References

1. I. Pravst, M. Zupan and S. Stavber, *Green Chem.,* 2006**, 8**, 1001-1005.
2. J. Košmrlj, M. Kočevar and S. Polanc, *Synth. Commun.,* 1996**, 26 (19)**, 3583-3592.
3. H. Y. Choi and D. Y. Chi, *Org. Lett.,* 2003, ***5* (4)**, 411-414.
4. V. L. Heasley, D. F. Shellhamer, A. E. Chappell, J. M. Cox, D. J. Hill, S. L. McGovern and C. C. Eden, *J. Org. Chem.,* 1998, **63**, 4433-4437.
5. B. Das, K. Venkateswarlu, G. Mahender and I. Mahender, *Tetrahedron Lett.,* 2005, **46**, 3041-3044.
6. D. P. Bauer and R. S. Macomber, *J. Org. Chem.,* 1975, **40 (13)**, 1990-1992.
7. I. J. Borowitz, K. C. Yee, E. Lord and H. Parnes, *J. Am. Chem. Soc.,* 1972, **94 (19)**, 6817-6822.
8. I. Moreno, I. Tellitu, E. Dominguez and R. SanMartin, *Eur.J.Org.Chem.,* 2002, **13**, 2126-2135.
9. F. G. Weber and R. Radeglia, *J. Prak. Chem.,* 1989, **331 (2)**, 212-222.
10. Z. Z. Huang and Y. Tang, *J. Org. Chem.,* 2002, **67 (15)**, 5320-5326.
11. K. Yelekci, X. L. Lu and R. B. Silverman, *J. Am. Chem. Soc.,* 1989**, 111 (3)**, 1138-1140.
12. P. Besse, T. Dokoltchik and H. Veschambre, H., *Tetrahedron: Asymmetry*, 1998, **9**, 4441-4457.
13. G. Cristalli, A. Eleuteri, R. Volpini, S. Vittori, E. Camaioni and G. Lupidi, *J. Med. Chem.,* 1994, **37 (1)**, 201-205.
14. V. Reutrakul, A. Tiensripojamarn, K. Kusamran and S. Nimgirawath, *Chem. Lett.,* 1979, **3**, 209-212.
15. H. O. House and G. A. Frank, *J. Am. Chem. Soc.,* 1965, **30**, 2948-2952.
16. M. Kitamura, M. Yoshida, T. Kikuchi and K. Narasaka, *Synthesis*, 2003, **15**, 2415-2426.
17. B. Šket and M. Zupan, *Synth. Commun.,* 1989, **19 (13-14)**, 2481-2487.
18. C. A. K. Horiuchi, S. Kiji, *Bull. Chem. Soc. Jpn.*, 1997, **70 (2)**, 421-426.
19. U. Berens, H. D. Scharf, *J. Org. Chem.*, 1995, **60**, 5127-5134.