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A New Iron-Catalyzed Arylation of Aroyl Cyanides - An Efficient Preparation of Polyfunctionalized Diaryl Ketones.

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General All reactions were carried out under an nitrogen atmosphere in dried glassware. Elemental analyses were carried out on a Heraeus CHN-Rapid-Elementanalyzer in the microanalytical laboratories of the Department Chemie, Ludwig-Maximilians-Universität Munich. All starting materials were purchased from commercial sources and used without further purification.

4-Ethoxycarbonylbenzoyl chloride was obtained by known procedure (generation of the Grignard-species[1], quenching with CO_2[2], reaction with $SOCl_2$[3]). THF was continously refluxed and freshly distilled from sodium benzophenone ketyl under nitrogen. Dichloromethane was continously refluxed and freshly distilled from calcium hydride under nitrogen. Freshly destilled acetonitrile was kept under nitrogen and over 4Å MS. Preparative chromatography was performed on silicagel 60 (0.040-0.063 mm) from Merck. Yields refer to isolated yields of compounds estimated to be > 95 % pure as determined by ^{1}H-NMR, capillary GC and combustion analysis (new compounds).

Preparation of Aroyl Cyanides by the Method of Olah[4].

Preparation of **benzoyl cyanide** (**1a**):

Under a nitrogen atmosphere tin(IV) chloride (1.09 g, 4.21 mmol) was slowly added at room temperature to a stirred solution of benzoyl chloride (2.81 g, 20.0 mmol) and cyanotrimethylsilane

(2.13 g, 21 mmol) in dry dichloromethane (50 mL). After 2.5 h of stirring at room temperature the conversion was complete (as indicated by TLC). The reaction mixture was poured onto ice-cold water (150 mL) and extracted with dichloromethane (2 × 150 ml). The combined organic layers were washed with ice-cold water (2 × 150 ml), dried ($MgSO_4$) and concentrated *in vacuo*. After additional destillation of the residue (24.0 mbar, 113 °C) the product **1a** was obtained as a colorless solid (2.34 g, 18.0 mmol, 90 %). **mp:** 30 – 32 °C. The spectral data obtained were in accordance with those described in the literature.[5]

^{1}H-NMR (300 MHz, $CDCl_3$): δ = 8.15 (d, J=8.8 Hz, 2H), 7.85-7.77 (m, 1H), 7.61 (t, J=7.5 Hz, 2H). **^{13}C-NMR** (75 MHz, $CDCl_3$): δ = 165.8, 137.0, 132.9, 130.1, 129.7, 129.4, 128.4, 112.6.

Preparation of **4-methoxybenzoyl cyanide** (**1c**):

Under a nitrogen atmosphere tin(IV) chloride (2.63 g, 10.0 mmol) was slowly added at room temperature to a stirred solution of 4-methoxybenzoyl chloride (5.12 g, 30.0 mmol) and cyanotrimethylsilane (3.64 g, 36.0 mmol) in dry dichloromethane (80 mL). After 2.5 h of stirring at room temperature the conversion was complete (as indicated by TLC). The reaction mixture was poured onto ice-cold water (150 mL) and extracted with dichloromethane (2 × 150 ml). The combined organic layers were washed with ice-cold water (2 × 150 ml), dried ($MgSO_4$) and concentrated *in vacuo*. After additional destillation of the residue (1.5 mbar, 98 °C) the product **1c** was obtained as a colorless solid (4.15 g, 25.8 mmol, 86 %). **mp:** 56 – 58 °C. The spectral data obtained were in accordance with those described in the literature.[6]

^{1}H-NMR (300 MHz, $CDCl_3$): δ = 8.05 (d, J=9.0 Hz, 2H), 6.98 (d, J=9.0 Hz, 2H), 3.88 (s, 3H). **^{13}C-NMR** (75 MHz, $CDCl_3$): δ = 167.0, 166.4, 133.6, 131.9, 127.2, 115.3, 113.9, 113.4, 56.3.

Preparation of Aroyl Cyanides by the Method of Normant[7].

Preparation of **4-chlorobenzoyl cyanide** (**1b**):

Under a nitrogen atmosphere 4-chlorobenzoyl chloride (17.50 g, 0.1 mol) was slowly added at room temperature to a stirred suspension of copper(I) cyanide (17.71 g, 0.2 mol) in dry acetonitrile (70 mL). After 30 min of refluxing the resulting clear solution was cooled to room temperature and concentrated *in vacuo*. The residue was washed with ether, filtrated and concentrated *in vacuo* again. After additional destillation (3.5 mbar, 84 °C) the product **1b** was obtained as a colorless solid (15.73 g, 95.0 mmol, 95 %). **mp:** 40 – 42 °C. The spectral data obtained were in accordance with those described in the literature.[6]

^{1}H-NMR (300 MHz, $CDCl_3$): δ = 8.08 (d, *J*=8.8 Hz, 2H), 7.58 (d, *J*=8.8 Hz, 2H). **^{13}C-NMR** (75 MHz, $CDCl_3$): δ = 166.5, 143.9, 131.7, 131.5, 129.9, 112.4.

Preparation of **4-ethoxycarbonylbenzoyl cyanide** (**1d**):

Under a nitrogen atmosphere 4-ethoxycarbonylbenzoyl chloride (5.32 g, 25.0 mmol) was slowly added at room temperature to a stirred suspension of copper(I) cyanide (4.48 g, 50.0 mmol) in dry acetonitrile (70 mL). After 20 min of refluxing the resulting clear solution was cooled to room temperature and concentrated *in vacuo*. The residue was washed with ether, filtrated and concentrated *in vacuo* again. After additional destillation (0.12 mbar, 85 °C) the product **1d** was obtained as a colorless solid (3.55 g, 17.5 mmol, 70 %). **mp:** 64 – 65 °C.

^{1}H-NMR (300 MHz, $CDCl_3$): δ = 8.27-15 (m, 4H), 4.48-438 (m, 2H), 1.42 (dt, *J*=7.1, 2.65 Hz, 3H). **^{13}C-NMR** (75 MHz, $CDCl_3$): δ = 167.4, 164.9, 137.5, 136.0, 131.2, 130.5, 130.3, 130.0, 112.6, 62.0, 14.2. **MS** (70 eV, EI): 203 ([M^+], 31), 177 (44), 158 (100), 149 (19), 130 (24), 102 (19), 76 (15), 50 (50). **HRMS** (EI): calcd. for $C_{11}H_9NO_3$ [M^+-H]: 203.0582, found: 203.0575. **IR** (KBr): 2986 (m), 2224 (w), 1724 (s), 1684 (s), 1409 (m), 1281 (vs), 1199 (m), 1107 (s), 982 (m), 717 (s). **Anal** calcd. for $C_{11}H_9NO_3$: C: 65.02, H: 4.46, N: 6.89, found: C: 64.66, H: 4.33, N: 6.48.

Preparation of **(6-chloro-3-pyridinyl)(oxo)acetonitrile** (**4**):
Under a nitrogen atmosphere 6-chloronicotinoyl chloride (17.60 g, 0.1 mol) was slowly added at room temperature to a stirred suspension of copper(I) cyanide (17.71 g, 0.2 mol) in dry acetonitrile (70 mL). After 30 min of refluxing the resulting clear solution was cooled to room temperature and concentrated *in vacuo*. The residue was washed with ether, filtrated and concentrated *in vacuo* again. After additional destillation (1.8 mbar, 95 °C) the product **4** was obtained as a colorless solid (9.33 g, 56.0 mmol, 56 %). **mp:** 72 – 74 °C. **^{1}H-NMR** (600 MHz, $CDCl_3$): δ = 9.14 (d, J=2.2 Hz, 1H), 8.32 (dd, J=8.6, 2.6 Hz, 1H), 7.59 (d, J=8.6 Hz, 1H). **^{13}C-NMR** (150 MHz, $CDCl_3$): δ = 165.5, 159.5, 152.1, 139.1, 128.0, 125.4, 111.8. **MS** (70 eV, EI): 166 ([M^+], 100), 142 (24), 140 (90), 138 (42), 112 (33), 76 (20). **HRMS** (EI): calcd. for $C_7H_3ClN_2O$ [M^+-H]: 165.9934, found: 165.9937. **IR** (KBr): 3435 (w), 2227 (m), 1678 (vs), 1582 (vs), 1465 (m), 1378 (vs), 1245 (vs), 1024 (m), 978 (vs), 755 (m). **Anal** calcd. for $C_7H_3ClN_2O$: C: 50.48, H: 1.82, Cl: 21.28 N: 16.82, found: C: 50.43, H: 1.85, Cl: 21.78 N: 16.56.

Typical Procedures for Acylation.

Method A: A dry and nitrogen flushed 50 mL flask, equipped with a stirring bar and a rubber septum was charged with dry THF (10 mL), the aroyl cyanide (2.0 mmol) and iron(III) acetylacetonate (35 mg, 0.1 mmol). The solution was cooled to 0 °C and a solution of arylmagnesium halide (2.4 mmol) was slowly added via syringe during 25 min. At the end of the addition, the reaction mixture was quenched with aq. NH_4Cl (10 mL), diluted with water (25 mL) and extracted with Et_2O (3 × 25 mL). The combined organic layers were washed with aq. $NaHCO_3$ (10 mL), brine (2 × 20 mL), dried ($MgSO_4$), concentrated *in vacuo* and the residue was purified by flash chromatography on silica gel.

Method B: A dry and nitrogen flushed 10 mL flask, equipped with a stirring bar and a rubber septum, was charged with dry THF (5 mL) and a functionalized aryl iodine (2.4 mmol). The solution was cooled to –20 °C and *iso*-propylmagnesium chloride (1.9 mL, 1.4 M in THF, 2.6 mmol) was slowly added. The reaction mixture was stirred at this temperature until the exchange reaction was complete (checked by GC-analysis of reaction aliquots). The resulting solution was then transferred dropwise during 25 min via canula into a second nitrogen flushed 50 mL flask, which contained a solution of aroyl cyanide (2.0 mmol) and iron(III) acetylacetonate (35 mg, 0.1 mmol) in dry THF (10 mL) stirred at -10 °C. After the end of the addition the reaction mixture was quenched with aq. NH_4Cl (10 mL), diluted with water (25 mL) and extracted with Et_2O (3 × 25 mL). The combined organic layers were washed with aq. $NaHCO_3$ (10 mL), brine (2 × 20 mL), dried ($MgSO_4$), concentrated *in vacuo* and the residue was purified by flash chromatography on silica gel.

Preparation of **benzophenone** (**3a**):

Prepared according to **TP A** from benzoyl cyanide (263 mg, 2.00 mmol) and phenylmagnesium chloride (1.40 mL, 1.7 M in THF, 2.4 mmol). Standard workup and column chromatographic purification (SiO_2, pentane: ether = 49 : 1) afforded **3a** as a colorless solid (306 mg, 1.68 mmol, 84 %). **mp:** 48 – 49 °C. The product was identical to authentic material (Aldrich) by ^{1}H-NMR, and ^{13}C-NMR.

^{1}H-NMR (300 MHz, $CDCl_3$): δ = 7.74 (d, *J*=6.0 Hz, 4H), 7.51 (t, *J*=6.0 Hz, 2H), 7.40 (t, *J*=6.0 Hz, 4H). **^{13}C-NMR** (75 MHz, $CDCl_3$): δ = 197.1, 138.0, 132.8, 130.4, 128.7.

Preparation of **4-ethoxycarbonylbenzophenone** (**3b**):

Prepared according to **TP B** from benzoyl cyanide (263 mg, 2.00 mmol) and ethyl 4-iodobenzoate (663 mg, 2.4 mmol). Standard workup and column chromatographic purification (SiO_2, pentane: ether = 47 : 3) afforded **3b** as a colorless solid (407 mg, 1.60 mmol, 80 %). **mp:** 54 – 55 °C. The spectral data obtained were in accordance with those described in the literature.[8]

^{1}H-NMR (300 MHz, $CDCl_3$): δ = 8.08 (d, *J*=8.7 Hz, 2H), 7.78–7.71 (m, 4H), 7.52 (t, *J*=7.5 Hz, 1H), 7.44 (t, *J*=7.5 Hz, 2H), 4.35 (q, *J*=7.2 Hz, 2H), 1.34 (t, *J*=7.2 Hz, 3H). **^{13}C-NMR** (75 MHz, $CDCl_3$): δ = 195.2, 166.3, 141.6, 137.4, 134.0, 133.3, 130.5, 130.1, 129.8, 128.8, 61.8, 14.7.

Preparation of **4-cyanobenzophenone**(**3c**):

Prepared according to **TP B** from benzoyl cyanide (263 mg, 2.00 mmol) and 4-iodobenzonitrile (550 mg, 2.4 mmol). Standard workup and column chromatographic purification (SiO_2, pentane: ether = 23 : 2) afforded **3c** as a colorless solid (323 mg, 1.56 mmol, 78 %). **mp:** 113 – 114 °C. The spectral data obtained were in accordance with those described in the literature.[8]

^{1}H-NMR (300 MHz, $CDCl_3$): δ = 7.80 (d, *J*=9.0 Hz, 2H), 7.72 (d, *J*=9 Hz, 4H), 7.56 (t, *J*=6.0 Hz, 1H), 7.44 (t, *J*=6.0 Hz, 2H). **^{13}C-NMR** (75 MHz, $CDCl_3$): δ = 195.4, 141.6, 136.7, 133.7, 132.6, 130.6, 130.4, 129.0, 118.4, 116.1.

Preparation of **4-chloro-4'-ethoxycarbonylbenzophenone** (**3d**):

Prepared according to **TP B** from 4-chlorobenzoyl cyanide (331 mg, 2.00 mmol) and ethyl 4-iodobenzoate (663 mg, 2.4 mmol). Standard workup and column chromatographic purification (SiO_2, pentane: ether = 23 : 2) afforded **3d** as a colorless solid (427 mg, 1.48 mmol, 74 %). **mp:** 97 – 99 °C.

^{1}H-NMR (300 MHz, $CDCl_3$): δ = 8.15 (d, *J*=8.9 Hz, 2H), 7.83-7.71 (m, 4H), 7.47 (d, *J*=8.4 Hz, 2H), 4.47 (q, *J*=7.1 Hz, 2H), 1.42 (t, *J*=7.1 Hz, 3H). **^{13}C-NMR** (75 MHz, $CDCl_3$): δ = 195.2, 166.1, 141.2, 139.9, 135.7, 134.2, 131.9, 130.0, 129.9, 129.2, 61.9, 14.7.

MS (70 eV, EI): 288 ([M^+], 34), 243 (46), 177 (44), 141 (36), 139 (100), 111 (29), 76 (21). **HRMS** (EI): calcd. for $C_{16}H_{13}ClO_3$ [M^+-H]: 288.0553, found: 288.0534. **IR** (KBr): 3420 (w), 3094 (w), 2984 (m), 2935 (w), 1717 (vs), 1650 (vs), 1587 (vs), 1568 (m), 1484 (m), 1369 (m), 1279 (vs), 1106 (vs), 1093 (vs), 738 (vs). **Anal** calcd. for $C_{16}H_{13}ClO_3$: C: 66.56, H: 4.54, Cl: 12.28, found: C: 66.70, H: 4.61, Cl: 12.26.

Preparation of **4-chloro-4'-methoxybenzophenone**(**3e**):

Prepared according to **TP A** from 4-chlorobenzoyl cyanide (331 mg, 2.00 mmol) and 4-methoxyphenylmagnesium bromide (2.16 mL, 0.9 M in THF, 2.4 mmol). Standard workup and column chromatographic purification (SiO_2, pentane: ether = 19 : 1) afforded **3e** as a colorless solid (439 mg, 1.78 mmol, 89 %). **mp:** 119 – 120 °C.

^{1}H-NMR (300 MHz, $CDCl_3$): δ = 7.78 (d, *J*=8.9 Hz, 2H), 7.69 (d, *J*=8.4 Hz, 2H), 7.43 (d, *J*=8.9 Hz, 2H), 6.95 (d, *J*=8.8 Hz, 2H), 3.87 (s, 3H). **^{13}C-NMR** (75 MHz, $CDCl_3$): δ = 194.2, 163.3, 138.2, 138.5, 132.4, 131.1, 129.8, 128.5, 113.6, 55.5. **MS** (70 eV, EI): 246 ([M^+], 86), 211 (16), 135 (100), 77 (16). **HRMS** (EI): calcd. for $C_{14}H_{11}ClO_2$ [M^+–H]: 246.0448, found: 246.0414. **IR** (KBr): 3436 (w), 2936 (w), 1640 (vs), 1604 (vs), 1509 (m), 1417 (m), 1398 (m), 1307 (m), 1291 (m), 1256 (vs), 1116 (m), 855 (vs), 760 (vs). **Anal** calcd. for $C_{14}H_{11}ClO_2$: C: 68.16, H: 4.49, Cl: 14.37, found: C: 68.27, H: 4.37, Cl: 14.32.

Preparation of **4-cyano-4'-methoxybenzophenone**(**3f**):

Prepared according to **TP B** from 4-methoxybenzoyl cyanide (324 mg, 2.00 mmol) and 4-iodobenzonitrile (550 mg, 2.4 mmol). Standard workup and column chromatographic purification (SiO_2, pentane: ether = 4 : 1) afforded **3f** as a colorless solid (399 mg, 1.68 mmol, 84 %). **mp:** 130 – 132 °C.

^{1}H-NMR (600 MHz, $CDCl_3$): δ = 7.83-7.75 (m, 6H), 6.97 (d, *J*=8.6 Hz, 2H), 3.89 (s, 3H). **^{13}C-NMR** (150 MHz, $CDCl_3$): δ = 193.7, 164.9, 142.1, 132.6, 132.1, 129.9, 129.0, 118.1, 115.2, 113.9, 55.6. **MS** (70 eV, EI): 237 ([M^+], 8), 135 (100), 102 (19), 92 (17). **HRMS** (EI): calcd. for $C_{15}H_{11}NO_2$ [M^+-H]: 237.0790, found: 237.0813. **IR** (KBr): 3435 (m), 2932 (w), 2232 (s), 1642 (vs), 1599 (vs), 1263 (vs), 766 (s). **Anal** calcd. for $C_{15}H_{11}NO_2$: C:

75.94, H: 4.67, N: 5.90, found: C: 75.74, H: 4.75, N: 5.99.

Preparation of **4,4'-dimethoxybenzophenone**(**3g**):

Prepared according to **TP A** from 4-methoxybenzoyl cyanide (324 mg, 2.00 mmol) and 4-methoxyphenylmagnesium bromide (2.16 mL, 0.9 M in THF, 2.4 mmol). Standard workup and column chromatographic purification (SiO_2, pentane: ether = 4 : 1) afforded **3g** as a colorless solid (475 mg, 1.96 mmol, 98 %). **mp:** 138 – 139 °C. The product was identical to authentic material (Aldrich) by ^{1}H-NMR, and ^{13}C-NMR.

^{1}H-NMR (300 MHz, $CDCl_3$): δ = 7.78 (d, *J*=9.3 Hz, 4H), 6.96 (d, *J*=8.9 Hz, 4H), 3.88 (s, 6H). **^{13}C-NMR** (75 MHz, $CDCl_3$): δ = 194.4, 162.8, 132.2, 130.8, 113.5, 55.5.

Preparation of **4,4'-diethoxycarbonylbenzophenone** (**3h**):

Prepared according to **TP B** from 4-ethoxycarbonylbenzoyl cyanide (406 mg, 2.00 mmol) and ethyl 4-iodobenzoate (663 mg, 2.4 mmol). Standard workup and column chromatographic purification (SiO_2, pentane: ether = 9 : 1) afforded **3h** as a colorless solid (444 mg, 1.36 mmol, 68 %).**mp:** 85 – 86 °C.

^{1}H-NMR (600 MHz, $CDCl_3$): δ = 8.01 (d, *J*=8.4 Hz, 4H), 7.77 (d, *J*=8.4 Hz, 4H), 4.35 (q, *J*=7.2 Hz, 4H), 1.36 (t, *J*=7.2 Hz, 6H). **^{13}C-NMR** (150 MHz, $CDCl_3$): δ = 195.4, 165.7, 140.5, 134.6, 129.8, 129.6, 61.5, 14.3. **MS** (70 eV, EI): 326 ([M^+], 52), 298 (28), 281 (100), 253 (24), 177 (32), 149 (18), 104 (10), 76 (34), 65 (66), 43 (62). **HRMS** (EI): calcd. for $C_{19}H_{18}O_5$ [M^+-H]: 326.1154, found: 326.1184. **IR** (KBr): 3421 (m), 2983 (m), 1716 (vs), 1651 (vs), 1503 (w), 1406 (m), 1277 (vs), 1105 (vs), 1020 (m), 936 (s), 719 (s). **Anal** calcd. for $C_{19}H_{18}O_5$: C: 69.93, H: 5.56, found: C: 69.66, H: 5.57.

Preparation of **4,2'-diethoxycarbonylbenzophenone** (**3i**):

Prepared according to **TP B** from 4-ethoxycarbonylbenzoyl cyanide (406 mg, 2.00 mmol) and ethyl 2-iodobenzoate (663 mg, 2.4 mmol). Standard workup and column chromatographic purification (SiO_2, pentane: ether = 4 : 1) afforded **3i** as a colorless solid (431 mg, 1.32 mmol, 66 %).

^{1}H-NMR (600 MHz, $CDCl_3$): δ = 8.08 (d, *J*=8.4 Hz, 3H), 7.80 (d, *J*=8.4 Hz, 2H), 7.69-7.55 (m, 2H), 7.39 (d, *J*=7.1 Hz, 1H), 4.39 (q, *J*=7.5 Hz, 2H), 4.08 (q, *J*=7.1 Hz, 2H), 1.39(t, *J*=7.1 Hz, 3H), 1.07 (t, *J*= 7.5 Hz, 3H). **^{13}C-NMR** (150 MHz, $CDCl_3$): δ = 196.3, 165.8, 165.7, 141.2, 140.4, 134.1, 132.5, 130.2, 129.9, 129.7, 129.4, 129.1, 127.6, 61.6, 61.4, 14.3, 13.7. **MS** (70 eV, EI): 326 ([M^+], 8), 281 (32), 209 (15), 177 (100), 149 (72). **HRMS** (EI): calcd. for $C_{19}H_{18}O_5$ [M^+-H]: 326.1154, found: 326.1159. **IR** (KBr): 3440 (w), 2982 (m), 2938 (w), 1716 (vs), 1681 (vs), 1445 (m), 1407 (s), 1367 (s), 1275 (vs), 1104 (vs), 1018 (s), 933 (s), 769 (s), 727 (s). **Anal** calcd. for $C_{19}H_{18}O_5$: C: 69.93, H: 5.56, found: C: 69.36, H: 5.67.

Preparation of **4-ethoxycarbonyl-4'-methoxybenzophenone**(**3j**):
Prepared according to **TP A** from 4-ethoxycarbonylbenzoyl cyanide (406 mg, 2.00 mmol) and 4-methoxyphenylmagnesium bromide (2.16 mL, 0.9 M in THF, 2.4 mmol). Standard workup and column chromatographic purification (SiO_2, pentane: ether = 4 : 1) afforded **3g** as a colorless solid (472 mg, 1.66 mmol, 83 %). **mp:** 86 – 88 °C.

^{1}H-NMR (300 MHz, $CDCl_3$): δ = 8.13 (d, *J*=8.4 Hz, 2H), 7.84-7.75 (m, 4H), 6.96 (d, *J*=9.0 Hz, 2H), 4.41 (q, *J*=7.2 Hz, 2H), 3.89 (s, 3H), 1.42 (t, *J*= 7.2 Hz, 3H). **^{13}C-NMR** (75 MHz, $CDCl_3$): δ = 195.2, 166.3, 164.0, 142.4, 133.5, 133.0, 130.0, 129.8, 114.1, 97.3, 61.8, 55.9, 14.7. **MS** (70 eV, EI): 284 ([M^+], 42), 239 (11), 135 (100). **HRMS** (EI): calcd. for $C_{17}H_{16}O_4$ [M^+-H]: 284.1049, found: 284.1041. **IR** (KBr): 3437 (m), 2987 (w), 1720 (s), 1647 (vs), 1602 (vs), 1445 (m), 1312 (s), 1280 (vs), 1269 (vs) 1182 (s), 1152 (s), 1127 (vs), 1114 (s), 1105 (s), 1020 (s), 935 (s), 748 (s). **Anal** calcd. for $C_{17}H_{16}O_4$: C: 71.82, H: 5.67, found: C: 71.82, H: 5.76.

Preparation of **4-ethoxycarbonyl-4′-cyanobenzophenone**(**3k**): Prepared according to **TP B** from 4-ethoxycarbonylbenzoyl cyanide (406 mg, 2.00 mmol) and 4-iodobenzonitrile (550 mg, 2.4 mmol). Standard workup and column chromatographic purification (SiO_2, pentane: ether = 4 : 1) afforded **3k** as a colorless solid (397 mg, 1.42 mmol, 71 %). **mp:** 110 – 112 °C.

^{1}H-NMR (300 MHz, $CDCl_3$): δ= 8.11 (d, *J*=8.4 Hz, 2H), 7.81 (d, *J*=7.8 Hz, 2H), 7.84 – 7.77 (m, 4H), 4.34 (q, *J*=7.2 Hz, 2H), 1.36 (t, *J*= 7.2 Hz, 3H). **^{13}C-NMR** (75 MHz, $CDCl_3$): δ= 194.7, 165.9, 140.9, 140.1, 134.8, 133.1, 132.7, 130.6, 130.1, 118.2, 116.6, 62.0, 14.6. **MS** (70 eV, EI): m/z (%): 279 (M^+, 42), 251 (33), 234 (100), 177 (95), 149 (67), 130 (88), 102 (62), 76 (33). **HRMS** (EI): calcd. for $C_{17}H_{13}NO_3$ [M^+–H]: 279.0895, found: 279.0892. **IR** (KBr): 3408 (m), 2989 (m), 2228 (s), 1715 (vs), 1655 (vs), 1407 (s), 1365 (s), 1278 (vs), 1102 (vs), 1019 (vs), 931 (s), 870 (s), 855 (s). **Anal** calcd. for $C_{17}H_{13}NO_3$: C: 73.11, H: 4.69, N: 5.02, found: C: 72.85, H: 4.68, N: 5.14.

Preparation of **2-ethoxycarbonyl-5(4-methoxybenzoyl)furane**(**3l**): Prepared according to **TP B** from 4-methoxybenzoyl cyanide (324 mg, 2.00 mmol) and 2-ethoxycarbonyl-5-iodofurane (532 mg, 2.4 mmol). Standard workup and column chromatographic purification (SiO_2, pentane: ether = 43 : 7) afforded **3l** as a yellow oil (428 mg, 1.56 mmol, 78 %).

^{1}H-NMR (300 MHz, $CDCl_3$): δ = 8.09 (d, *J*=9.0 Hz, 2H), 7.21 (d, *J*=3.6 Hz, 1H), 7.18 (d, *J*=3.6 Hz, 1H), 6.93 (d, *J*=9.0 Hz, 2H), 4.50 (q, *J*=7.2 Hz, 2H), 3.83 (s, 3H), 1.34 (t, *J*=7.2 Hz, 3H). **^{13}C-NMR** (75 MHz, $CDCl_3$): δ = 195.4, 164.4, 156.6, 154.6, 147.0, 132.6, 129.3, 119.6, 118.7, 114.3, 62.0, 55.9, 14.7. **MS** (70 eV, EI): m/z (%): 274 ([M^+], 86), 201 (38), 135 (100). **HRMS** (EI): calcd. for $C_{15}H_{14}O_5$ [M^+–H]: 274.0841, found: 274.0842. **IR** (film):

3076 (w), 2981 (m), 2841 (w), 2048 (w), 1731 (vs), 1644 (s), 1600 (vs), 1573 (s), 1444 (m), 1276 (vs), 1223 (s), 1186 (s), 1167 (s), 885 (s). **Anal** calcd. for $C_{15}H_{14}O_5$: C: 65.69, H: 5.15, found:
C: 65.91, H: 5.33.

Preparation of **(6-chloro-3-pyridinyl)(phenyl)methanone**(**5a**):
Prepared according to **TP A** from (6-chloro-3-pyridinyl)(oxo)acetonitrile (332 mg, 2.00 mmol) and phenylmagnesium chloride (1.40 mL, 1.7 M in THF, 2.4 mmol). Standard workup and column chromatographic purification (SiO_2, pentane: ether = 93 : 7) afforded **5a** as a colorless solid (343 mg, 1.58 mmol, 79 %). **mp:** 36 - 37 °C.
^{1}H-NMR (300 MHz, $CDCl_3$): δ = 8.75 (d, *J*=1.8 Hz, 1H), 8.08 (dd, *J*=8.0, 2.2 Hz, 1H), 7.80-7.74 (m, 2H), 7.63 (t, *J*=7.5 Hz, 1H), 7.55-7.43 (m, 3H). **^{13}C-NMR** (75 MHz, $CDCl_3$): δ = 193.5, 154.9, 151.1, 139.8, 136.4, 133.4, 132.0, 129.9, 128.7, 124.3. **MS** (70 eV, EI): 217 ([M^+], 43), 182 (100), 140 (26), 105 (60), 77 (28). **HRMS** (EI): calcd. for $C_{12}H_8ClNO$ [M^+–H]: 217.0294, found: 217.0283. **IR** (KBr): 3308 (w), 3059 (w), 2855 (w), 1662 (vs), 1581 (vs), 1598 (vs), 1448 (vs), 1358 (vs), 1318 (vs), 1280 (vs), 1158 (vs), 1136 (m), 1105 (vs), 922 (vs), 744 (vs), 706 (vs). **Anal** calcd for $C_{12}H_8ClNO$: C: 66.22, H: 3.70, Cl: 16.29, N: 6.44, found: C: 66.46, H: 3.79, Cl: 16.18, N: 6.48.

Preparation of **ethyl 4-[(6-chloro-3-pyridinyl)carbonyl]benzoate** (**5b**):
Prepared according to **TP B** from (6-chloro-3-pyridinyl)(oxo)acetonitrile (332 mg, 2.00 mmol) and ethyl 4-iodobenzoate (663 mg, 2.4 mmol). Standard workup and column chromatographic purification (SiO_2, pentane: ether = 17 : 3) afforded **5b** as a colorless solid (434 mg, 1.50 mmol, 75 %). **mp:** 83 - 84 °C.
^{1}H-NMR (300 MHz, $CDCl_3$): δ = 8.74 (d, *J*=1.8 Hz, 1H), 8.16 (d, *J*=8.9 Hz, 2H), 8.08 (dd, *J*=8.4, 2.2 Hz, 1H), 7.81 (d, *J*=8.4 Hz, 2H), 7.48 (d, *J*=8.8 Hz, 1H), 4.40 (q, *J*=7.1 Hz, 2H), 1.40 (t,

J=7.1 Hz, 3H). **^{13}C-NMR** (75 MHz, $CDCl_3$): δ = 193.0, 165.4, 155.4, 151.2, 139.7, 139.7, 134.5, 131.4, 129.8, 129.6, 124.4, 61.6, 14.2. **MS** (70 eV, EI): 289 ([M^+], 13), 246 (31), 244 (100), 218 (51), 217 (35), 216 (48), 177 (62), 140 (45). **HRMS** (EI): calcd. for $C_{15}H_{12}ClNO_3$ [M^+–H]: 289.0506, found: 289.0525. **IR** (KBr): 3420 (w), 3048 (m), 2984 (w), 1968 (w), 1716 (vs), 1652 (vs), 1575 (vs), 1461 (m), 1283 (vs), 1109 (vs), 745 (vs). **Anal** calcd. for $C_{15}H_{12}ClNO_3$: C: 62.19, H: 4.17, Cl: 12.24, N: 4.83, found: C: 62.23, H: 4.23, Cl: 12.30, N: 4.78.

Preparation of **(6-chloro-3-pyridinyl)(4-methoxyphenyl)methanone** (**5c**):

Prepared according to **TP A** from (6-chloro-3-pyridinyl)(oxo)acetonitrile (332 mg, 2.00 mmol) and 4-methoxyphenylmagnesium bromide (2.16 mL, 0.9 M in THF, 2.4 mmol). Standard workup and column chromatographic purification (SiO_2, pentane: ether = 17 : 3) afforded **5c** as a colorless solid (425 mg, 1.72 mmol, 86 %). **mp:** 139 - 140 °C.

^{1}H-NMR (300 MHz, $CDCl_3$): δ = 8.71 (d, *J*=1.8 Hz, 1H), 8.03 (dd, *J*=8.0, 2.2 Hz, 1H), 7.79 (d, *J*=8.8 Hz, 2H), 7.45 (d, *J*=8.0 Hz, 1H), 6.97 (d, *J*=8.9 Hz, 2H), 3.89 (s, 3H). **^{13}C-NMR** (75 MHz, $CDCl_3$): δ = 192.1, 164.0, 154.4, 150.7, 139.6, 132.6, 132.4, 129.1, 124.2, 114.0, 55.5. **MS** (70 eV, EI): 247 ([M^+], 29), 135 (100). **HRMS** (EI): calcd. for $C_{13}H_{10}ClNO_2$ [M^+–H]: 247.0400, found: 247.0419. **IR** (KBr): 3430 (w), 2925 (w), 1637 (vs), 1602 (vs), 1578 (m), 1448 (m), 1296 (vs), 1275 (vs), 1182 (m), 1157 (vs), 1105 (vs), 1022 (vs), 846 (vs), 766 (vs). **Anal** calcd. for $C_{13}H_{10}ClNO_2$: C: 63.04, H: 4.07, Cl: 14.31, N: 5.66, found: C: 63.09, H: 4.01, Cl: 14.33, N: 5.55.

References and Notes:

[1] L. Boymond, M. Rottländer, G. Cahiez, P. Knochel, *Angew. Chem. Int. Ed.* **1998**, *37*, 1701.

[2] D. J. Sheeran, J. D. Arenivar, M. Orchin, *J. Organomet. Chem.* **1986**, *316*, 139.

[3] F. Effenberger, G. Epple, J. K. Eberhard, U. Bühler, E. Sohn, *Chem. Ber.* **1983**, *116*, 1183.

[4] G. A. Olah, M. Arvanaghi, G. K. S. Prakash, *Synthesis* **1983**, 636.

[5] R. A. Aitken, N. Karodia, *Eur. J. Org. Chem.* **1999**, 251.

[6] H. Härle, J. C. Jochims, *Chem. Ber.* **1986**, *119*, 1400.

[7] J. F. Normant, C. Piechucky, *Bull. Soc. Chim. Fr* **1972**, *6*, 2402.

[8] R. D. Rieke, W. R. Klein, T.-C. Wu, *J. Org. Chem.* **1993**, *58*, 2492.