Direct Synthesis of Polysubstituted Quinoline Derivatives by InBr₃-Promoted Dimerization of 2-Ethynylaniline Derivatives

Supporting Information

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Experimental Section

General Methods. All reactions were carried out under an Ar atmosphere, unless otherwise stated. Methanol was freshly distilled from Mg/I₂ prior to use. Reactions were monitored by thin-layer chromatography (TLC) of reaction aliquots. Analytical TLC was carried out on silica gel 60 F₂₅₄ (MERCK), and compounds were detected by UV light. Column chromatography was performed using Silica gel 60 (Merck). ¹H NMR spectra were measured at 500 MHz and using tetramethylsilane as an internal standard. ¹³C NMR spectra were measured at 125 MHz using tetramethylsilane or the center of peak of chloroform (77.0 ppm) as an internal standard. HRMS were measured using NBA (3-nitrobenzylalcohol) as a matrix.

General procedure for the preparation of trimethylsilylethynylaniline 1. To a suspension of powdered CuI (19 mg, 0.10 mmol) in piperidine (1.5 mL) was added a solution of trimethylsilylacetylene (236 mg, 2.4 mmol) in piperidine (1.5 mL) via a syringe, and the resulting mixture was stirred for 2.5 h at room temperature. A piperidine solution (3 mL) of 2-iodoaniline (2 mmol) and PdCl₂(PPh₃)₂ (70 mg, 0.10 mmol) was also stirred for the same period of time. The latter solution was then added to the former solution via a cannula. The resulting mixture was stirred at room temperature and monitored by TLC until the starting material had been consumed. The reaction was quenched by adding a saturated aqueous solution of NaHCO₃. The aqueous layer was extracted with CHCl₃, the organic phase was dried over anhydrous Na₂SO₄, filtered, and evaporated under reduced pressure. The crude product was purified by silica gel column chromatography (hexane : AcOEt = 9:1), followed by recrystallization.

2-(Trimethylsilylethynyl)aniline¹ (1a): 62% yield; pale yellow oil; IR (neat) 2139 cm⁻¹; ¹H NMR (500 MHz, CDCl₃) δ 0.24 (s, 9H), 4.03 (brs, 2H), 6.65 (td, 1H, *J* = 7.8, 1.2 Hz), 6.69 (d, 1H, *J* = 7.8 Hz), 7.09 (td, 1H, *J* = 7.8, 1.5 Hz), 7.27 (td, 1H, *J* = 7.8, 1.2 Hz); ¹³C NMR (125 MHz, CDCl₃) δ 0.1, 99.8, 101.7, 108.1, 114.4, 118.0, 129.9, 132.3, 147.8; MS (FAB): *m/z* 189 (M⁺, 100%).

4-Methyl-2-(trimethylsilylethynyl)aniline² (1b): 80% yield; brown needles from CH₂Cl₂-hexane; mp: 52-53 °C; ¹H NMR (500 MHz, CDCl₃) δ 0.24 (s, 9H), 2.18 (s, 3H), 4.08 (brs, 2H), 6.58 (d, 1H, *J* = 7 Hz), 6.91 (d, 1H, *J* = 8 Hz), 7.10 (s, 1H); ¹³C NMR (125 MHz, CDCl₃) δ 0.2, 20.2, 99.4, 102.1, 107.9, 114.4, 127.0, 130.8, 132.3, 145.9; MS (FAB): *m/z* 203 (M⁺, 100%).

4,5-Dimethyl-2-(trimethylsilylethynyl)aniline (1c): 75% yield; brown needles from CH₂Cl₂-hexane; mp: 74-75 °C; ¹H NMR (500 MHz, CDCl₃) δ 0.24 (s, 9H), 2.09 (s, 3H), 2.15 (s, 3H), 4.02 (brs, 2H), 6.49 (s, 1H), 7.05 (s, 1H); ¹³C NMR (125 MHz, CDCl₃) δ 0.2, 18.6, 20.0, 98.7, 102.2, 105.4, 115.8, 125.9, 132.8, 138.9, 146.3; MS (FAB): *m/z* 217 (M⁺, 100%); HRMS (FAB): Calcd for C₁₃H₁₉NSi: 217.1287, Found: 217.1276.

4-Fluoro-2-(trimethylsilylethynyl)aniline (1d): 65% yield; brown oil; ¹H NMR (500 MHz, CDCl₃) δ 0.26 (s, 9H), 4.08 (brs, 2H), 6.59 (dd, 1H, *J* = 8.5 Hz, 3 Hz), 6.83 (td, 1H, *J* = 8.5 Hz, 3 Hz), 6.97 (dd, 1H, *J* = 8.5 Hz, 3 Hz); ¹³C NMR (125 MHz, CDCl₃) δ 0.0, 100.7 (d, *J* = 1.9 Hz), 100.8, 108.5 (d, *J* = 9.7 Hz), 115.2 (d, *J* = 8.5 Hz), 117.1 (d, *J* = 22.9 Hz), 117.8 (d, *J* = 22.9 Hz), 144.7, 155.1 (d, *J* = 234.7 Hz); MS (FAB): *m/z* 207 (M⁺, 100%); HRMS (FAB): Calcd for C₁₁H₁₄FNSi: 207.0880, Found: 207.0866.

4-Cyano-2-(trimethylsilylethynyl)aniline⁴ (1e): 70% yield; pale yellow needles from CH₂Cl₂-hexane; mp: 103-104 °C (lit.⁴ 106 °C); ¹H NMR (500 MHz, CDCl₃) δ 0.24 (s, 9H), 4.79 (brs, 2H), 6.65 (d, 1H, *J* = 8 Hz), 7.29 (d, 1H, *J* = 8 Hz), 7.52 (s, 1H); ¹³C NMR (125 MHz, CDCl₃) δ -0.15, 99.0, 99.6, 102.0, 107.9, 113.8, 119.3, 133.3, 136.5, 151.5; MS (FAB): *m/z* 215 (M⁺+H, 100%).

4-Nitro-2-(trimethylsilylethynyl)aniline³ (1f): 60% yield; yellow needles from CH₂Cl₂-hexane; mp: 127.5-128.0 °C; ¹H NMR (500 MHz, CDCl₃) δ 0.26 (s, 9H), 5.01 (brs, 2H), 6.64 (d, 1H, *J* = 9.5 Hz), 7.97 (dd, 1H, *J* = 9.5 Hz, 2.5 Hz), 8.19 (d, 1H, *J* = 2.5 Hz); ¹³C NMR (125 MHz, CDCl₃) δ -0.14, 98.9, 102.2, 106.9, 112.8, 126.1, 128.9, 138.1, 153.3; MS (FAB): *m/z* 235 (M⁺+H, 100%).

General procedure for the preparation of 2-(ethynyl)anilines 2. To a methanol solution (3 mL) of trimethylsilylethynylaniline (1 mmol), a 1 M aqueous solution of potassium hydroxide (1 mL) was added and the resulting mixture was stirred at room temperature and monitored by TLC until the starting material had been consumed. After removing methanol, the product was extracted with CHCl₃. The combined organic phases were dried over anhydrous Na₂SO₄, filtered, and evaporated under reduced pressure. The crude product was purified by silica gel column chromatography (hexane : AcOEt = 9:1), followed by recrystallization.

2-Ethynylaniline⁵ (2a): 90% yield; yellow oil; ¹H NMR (500 MHz, CDCl₃) δ 3.34 (s, 1H), 4.23 (brs, 2H), 6.67 (m, 2H), 7.13 (t, 1H, *J* = 7.5 Hz), 7.31 (d, 1H, *J* = 7.5); ¹³C NMR (125 MHz, CDCl₃) δ 80.6, 82.5, 106.6, 114.3, 117.8, 130.1, 132.6, 148.5; MS (FAB): *m/z* 117 (M⁺, 100%).

4-Methyl-2-ethynylaniline⁵ (2b): 91% yield; yellow oil; ¹H NMR (500 MHz, CDCl₃) δ 2.19 (s, 3H), 3.35 (s, 1H), 4.09 (brs, 2H), 6.58 (d, 1H, *J* = 8.5 Hz), 6.93 (d, 1H, *J* = 8.5 Hz), 7.13 (s, 1H); ¹³C NMR (125MHz, CDCl₃) δ 20.1, 80.8, 82.1, 106.5, 114.5, 126.9, 130.9, 132.6, 146.2; MS (FAB): *m/z* 131 (M⁺, 100%).

4,5-Dimethyl-2-ethynylaniline (2c): 90% yield; colorless needles from CH₂Cl₂-hexane; mp: 64-65 °C; ¹H NMR (500 MHz, CDCl₃) δ 2.09 (s, 3H), 2.15 (s, 3H), 3.31 (s, 1H), 4.04 (brs, 2H), 6.47 (s, 1H), 7.07 (s, 1H); ¹³C NMR (125 MHz, CDCl₃) δ 18.5, 19.9, 80.9, 81.6, 104.0, 115.9, 125.9, 132.9, 139.1, 146.5; MS (FAB): *m/z* 145 (M⁺, 100%); HRMS (FAB): Calcd for C₁₀H₁₁N: 145.0891, Found: 145.0891.

4-Fluoro-2-ethynylaniline (2d): 85% yield; yellow oil; ¹H NMR (500 MHz, CDCl₃) δ 3.40 (s, 1H), 4.12 (brs, 2H), 6.60 (dd, 1H, *J* = 9 Hz, 4.5 Hz), 6.86 (td, 1H, *J* = 9 Hz, 3 Hz), 7.01 (dd, 1H, *J* = 9 Hz, 3 Hz); ¹³C NMR (125 MHz, CDCl₃) δ 79.7, 83.2, 107.1 (d, *J* = 9.5 Hz), 115.2 (d, *J* = 7.7 Hz), 117.3 (d, *J* = 22.9 Hz), 118.1 (d, *J* = 23.9 Hz), 145.0, 154.0 (d, *J* = 233.7 Hz); MS (FAB): *m/z* 136 (M⁺+H, 100%); HRMS (FAB): Calcd for C₈H₇FN: 136.0563, Found: 136.0563.

4-Cyano-2-ethynylaniline⁵ (2e): 92% yield; colorless solids from CH₂Cl₂-hexane; mp 104-106 °C (lit.⁵ 105-106 °C); ¹H NMR (500 MHz, CDCl₃) δ 3.43 (s, 1H), 4.80 (brs, 2H), 6.66 (d, 1H, *J* = 8.5 Hz), 7.33 (d, 1H, *J* = 8.5 Hz), 7.55 (s, 1H); ¹³C NMR (125 MHz, CDCl₃) δ 78.2, 84.2, 99.8, 106.7, 114.0, 119.2, 133.6, 136.9, 151.8; MS (FAB): *m/z* 142 (M⁺+H, 100%).

4-Nitro-2-ethynylaniline⁶ (2f): 88% yield; brown needles from CH₂Cl₂-hexane; mp: 125-126 °C; ¹H NMR (500 MHz, CDCl₃) δ 3.45 (s, 1H), 5.00 (brs, 2H), 6.66 (d, 1H, *J* = 9 Hz), 8.02 (dd, 1H, *J* = 9 Hz, 2.5 Hz), 8.22 (d, 1H, *J* = 2.5 Hz); ¹³C NMR (125 MHz, CDCl₃) δ 78.1, 84.3, 105.7, 113.0, 126.4, 129.3, 138.3, 153.5; MS (FAB): *m/z* 163 (M⁺+H, 100%).

General procedure for the intermolecular cyclization of 2. To a 10 mL reaction flask under argon containing freshly distilled methanol (0.6 mL), 2-(ethynyl)aniline **2** (140 mg, 0.600 mmol) and InBr₃

(212 mg, 0.600 mmol) were added. The resulting mixture was refluxed and monitored by TLC until the starting material had been consumed. After the usual work-up, the crude product was purified by silica gel column chromatography (hexane : AcOEt = 7:3) to afford the polysubstituted quinoline **3** in a yield as described in Table 2.

2-(4-Methyl-2-quinolinyl)aniline⁷ (3a): pale yellow plate from CH₂Cl₂-hexane; mp: 78-79 °C; ¹H NMR (500 MHz, CDCl₃) δ 2.74 (s, 3H), 6.14 (brs, 2H), 6.80 (m, 2H), 7.19 (t, 1H, *J* = 8 Hz), 7.52 (t, 1H, *J* = 8 Hz), 7.67 (m, 3H), 7.96 (d, 1H, *J* = 8 Hz), 8.03 (d, 1H, *J* = 8 Hz); ¹³C NMR (125 MHz, CDCl₃) δ 19.0, 117.3, 117.4, 121.1, 121.8, 123.6, 125.9, 126.5, 129.3, 129.4, 129.8, 130.1, 144.7, 146.7, 147.4, 158.9; MS (FAB): *m/z* 235 (M⁺+H, 100%); HRMS (FAB): Calcd for C₁₆H₁₅N₂: 235.1235, Found: 235.1237; Anal: Calcd for C₁₆H₁₄N₂: C, 82.02; H, 6.02; N, 11.96, Found: C, 81.73; H, 6.16; N, 11.77.

2-(4,6-Dimethyl-2-quinolinyl)-4-methylaniline (3b): yellow needles from CH₂Cl₂-hexane; mp: 146-147 °C; ¹H NMR (500 MHz, CDCl₃) δ 2.32 (s, 3H), 2.55 (s, 3H), 2.70 (s, 3H), 5.88 (brs, 2H), 6.70 (d, 1H, *J* = 8 Hz), 6.99 (d, 1H, *J* = 8 Hz), 7.46 (s, 1H), 7.48 (dd, 1H, *J* = 8 Hz, 1.5 Hz), 7.60 (s, 1H), 7.71 (s, 1H), 7.92 (d, 1H, *J* = 8 Hz); ¹³C NMR (125 MHz, CDCl₃) δ 19.0, 20.6, 21.8, 117.3, 121.2, 122.1, 122.6, 126.3, 126.4, 129.1, 130.0, 130.7, 131.3, 135.6, 143.9, 144.7, 145.2, 158.1; MS (FAB): *m/z* 263 (M⁺+H, 100%); HRMS (FAB): Calcd for C₁₈H₁₉N₂: 263.1548, Found: 263.1550; Anal: Calcd for C₁₈H₁₈N₂: C, 82.41; H, 6.92; N, 10.68, Found: C, 82.02; H, 7.23; N, 10.58.

2-(4,6,7-Trimethyl-2-quinolinyl)-4,5-dimethylaniline (3c): yellow needles from CH₂Cl₂-hexane; mp: 182.5-183.0 °C; ¹H NMR (500 MHz, CDCl₃) δ 2.22 (s, 3H), 2.24 (s, 3H), 2.44 (s, 3H), 2.45 (s, 3H), 2.68 (s, 3H), 5.96 (brs, 2H), 6.60 (s, 1H), 7.43 (s, 1H), 7.55 (s, 1H), 7.66 (s, 1H), 7.78 (s, 1H); ¹³C NMR (125 MHz, CDCl₃) δ 18.9, 19.0, 19.7, 20.2, 20.3, 118.6, 119.9, 120.1, 123.0, 124.8, 125.3, 128.8, 130.3, 135.3, 138.6, 139.0, 143.3, 145.2, 145.9, 158.1; MS (FAB): *m/z* 291 (M⁺+H, 100%); HRMS (FAB): Calcd for C₂₀H₂₃N₂: 291.1861, Found: 291.1858; Anal: Calcd for C₂₀H₂₂N₂: C, 82.72; H, 7.64; N, 9.65, Found: C, 82.72; H, 7.84; N, 9.77.

2-(6-Fluoro-4-methyl-2-quinolinyl)-4-fluoroaniline (3d): yellow solids from CH₂Cl₂-hexane; mp: 116-117 °C; ¹H NMR (500 MHz, CDCl₃) δ 2.69 (s, 3H), 5.88 (brs, 2H), 6.83 (dd, 1H, *J* = 9 Hz, 4 Hz), 6.93 (td, 1H, *J* = 9 Hz, 2.5 Hz), 7.35 (dd, 1H, *J* = 9 Hz, 2.5 Hz), 7.45 (td, 1H, *J* = 9 Hz, 2.5 Hz), 7.56

(m, 2H), 8.01 (dd, 1H, $J = 9$ Hz, 4 Hz); ^{13}C NMR (125 MHz, CDCl_3) δ 19.2, 107.3 (d, $J = 21.9$ Hz), 115.3 (d, $J = 23.9$ Hz), 117.0 (d, $J = 22$ Hz), 118.1 (d, $J = 6.7$ Hz), 119.3 (d, $J = 24.8$ Hz), 121.4, 121.9 (d, $J = 6.7$ Hz), 127.3 (d, $J = 9.7$ Hz), 131.7 (d, $J = 9.5$ Hz), 143.5 (d, $J = 32.4$ Hz), 144.5 (d, $J = 5.8$ Hz), 154.6, 156.4, 157.1, 160.4 (d, $J = 246$ Hz); MS (FAB): m/z 271 ($\text{M}^+\text{+H}$, 100%); HRMS (FAB): Calcd for $\text{C}_{16}\text{H}_{13}\text{F}_2\text{N}_2$: 271.1047, Found: 271.1058; Anal: Calcd for $\text{C}_{16}\text{H}_{12}\text{F}_2\text{N}_2$: C, 71.10; H, 4.48; N, 10.24, Found: C, 71.10; H, 4.48; N, 10.36.

2-(6-Cyano-4-methyl-2-quinolinyl)-4-cyanoaniline (3e): yellow needles from CH_2Cl_2 -hexane; mp: 294-295 °C; ^1H NMR (500 MHz, $\text{DMSO}-d_6$) δ 2.77 (s, 3H), 6.93 (d, 1H, $J = 9$ Hz), 7.50 (d, 1H, $J = 9$ Hz), 8.04 (d, 1H, $J = 9$ Hz), 8.22 (m, 2H), 8.38 (s, 1H), 8.67 (s, 1H); ^{13}C NMR (125 MHz, $\text{DMSO}-d_6$) δ 17.8, 95.7, 108.0, 116.8, 116.9, 118.5, 119.8, 120.9, 125.2, 129.8, 130.1, 130.5, 133.1, 134.4, 145.9, 146.7, 152.3, 158.9; MS (EI): m/z 284 (M^+ , 100%), MS (FAB): m/z 285 ($\text{M}^+\text{+H}$, 100%); HRMS (FAB): Calcd for $\text{C}_{18}\text{H}_{13}\text{N}_4$: 285.1140, Found: 285.1146.

2-(4-Methyl-6-nitro-2-quinolinyl)-4-nitroaniline⁸ (3f): yellow solids; mp: 242-243 °C; ^1H NMR (500 MHz, $\text{DMSO}-d_6$) δ 2.58 (s, 3H), 6.51 (brs, 2H), 6.83 (d, 1H, $J = 9$ Hz), 6.93 (d, 1H, $J = 2.5$ Hz), 8.08 (dd, 1H, $J = 9$ Hz, 2.5 Hz), 8.27 (d, 1H, $J = 9$ Hz), 8.51 (dd, 1H, $J = 9$ Hz, 2.5 Hz), 8.85 (s, 1H), 9.06 (d, 1H, $J = 2.5$ Hz); ^{13}C NMR (125 MHz, $\text{DMSO}-d_6$) δ 14.9, 113.2, 119.5, 121.3, 122.1, 125.7, 126.6, 127.0, 130.7, 131.1, 135.4, 144.7, 145.4, 148.8, 152.9, 154.7; MS (FAB): m/z 325 ($\text{M}^+\text{+H}$, 100%); HRMS (FAB): Calcd for $\text{C}_{16}\text{H}_{13}\text{N}_4\text{O}_4$: 325.0937, Found: 325.0940.

Procedure for the intermolecular cyclization of 2a in $\text{MeOH}-d_4$. To an NMR tube equipped with a screw cap containing methanol- d_4 (0.75 mL) under argon, 2-ethynylaniline (**2a**, 87.8 mg, 0.750 mmol) and InBr_3 (265 mg, 0.750 mmol) were added. The resulting mixture was refluxed and monitored by NMR until the starting material had been consumed. After the usual work-up, the crude product was purified by silica gel column chromatography (hexane : $\text{AcOEt} = 7:3$) to afford **3a-d** in 63% (55 mg) yield.

d_4 -2-(4-Methyl-2-quinolinyl)aniline (3a-d): yellow needles from CH_2Cl_2 -hexane; mp: 77-78 °C; ^1H NMR (500 MHz, CDCl_3) δ 6.18 (brs, 2H), 6.80 (m, 2H), 7.19 (m, 1H), 7.52 (t, 1H, $J = 8$ Hz), 7.67 (m, 2H), 7.95 (d, 1H, $J = 8$ Hz), 8.05 (d, 1H, $J = 8$ Hz); ^{13}C NMR (125 MHz, CDCl_3) δ 18.5 (m, CD_3), 117.2, 117.3, 120.7 (t, $J_{\text{C-D}} = 24.8$ Hz), 121.6, 123.5, 125.8, 126.5, 129.2, 129.3, 129.7, 130.1, 144.5,

146.7, 147.4, 158.9; MS (FAB): m/z 239 ($M^+ + H$, 100%); HRMS (FAB): Calcd for $C_{16}H_{11}D_4N_2$: 239.1486, Found: 239.1477.

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X-ray data for 3a

ORTEP drawing of the quinoline **3a**

Table 1. Crystal data and structure refinement for (3a).

Identification code	quinoline 3a	
Empirical formula	C ₁₆ H ₁₄ N ₂	
Formula weight	234.29	
Temperature	273(2) K	
Wavelength	0.71073 Å	
Crystal system	Orthorhombic	
Space group	Pbca	
Unit cell dimensions	a = 9.7558(9) Å	a = 90°.
	b = 9.0365(9) Å	b = 90°.
	c = 26.814(3) Å	g = 90°.
Volume	2363.8(4) Å ³	
Z	8	
Density (calculated)	1.152 Mg/m ³	
Absorption coefficient	0.069 mm ⁻¹	
F(000)	868	
Crystal size	0.50 x 0.30 x 0.30 mm ³	
Theta range for data collection	1.52 to 28.30°.	
Index ranges	-12<=h<=9, -11<=k<=12, -35<=l<=34	
Reflections collected	12610	
Independent reflections	2763 [R(int) = 0.0300]	
Completeness to theta = 28.30°	94.1 %	
Absorption correction	Empirical	
Refinement method	Full-matrix least-squares on F ²	
Data / restraints / parameters	2763 / 0 / 164	
Goodness-of-fit on F ²	1.050	
Final R indices [I>2sigma(I)]	R1 = 0.0539, wR2 = 0.2075	
R indices (all data)	R1 = 0.0635, wR2 = 0.2384	
Largest diff. peak and hole	0.506 and -0.455 e.Å ⁻³	

Table 2. Atomic coordinates ($\times 10^4$) and equivalent isotropic displacement parameters ($\text{\AA}^2 \times 10^3$) for **3a**. $U(\text{eq})$ is defined as one third of the trace of the orthogonalized U^{ij} tensor.

	x	y	z	$U(\text{eq})$
N(1)	9790(1)	1369(1)	3918(1)	18(1)
N(2)	11959(1)	-582(2)	3995(1)	25(1)
C(1)	7389(2)	2024(2)	4083(1)	18(1)
C(2)	6966(2)	1037(2)	3697(1)	17(1)
C(3)	8817(2)	2140(2)	4180(1)	18(1)
C(4)	7961(1)	304(2)	3436(1)	18(1)
C(5)	10408(2)	-413(2)	3280(1)	17(1)
C(6)	6469(2)	2872(2)	4377(1)	20(1)
C(7)	9273(2)	3059(2)	4571(1)	21(1)
C(8)	10130(2)	-868(2)	2792(1)	19(1)
C(9)	11630(2)	-932(2)	3509(1)	19(1)
C(10)	9375(2)	482(2)	3555(1)	16(1)
C(11)	12150(2)	-2380(2)	2770(1)	22(1)
C(12)	8361(2)	3860(2)	4850(1)	23(1)
C(13)	5476(2)	790(2)	3584(1)	22(1)
C(14)	10977(2)	-1840(2)	2535(1)	21(1)
C(15)	12477(2)	-1919(2)	3245(1)	21(1)
C(16)	6944(2)	3771(2)	4749(1)	22(1)

Table 3. Bond lengths [Å] and angles [°] for **3a**.

N(1)–C(10)	1.3242(19)
N(1)–C(3)	1.3712(19)
N(2)–C(9)	1.3800(19)
C(1)–C(6)	1.419(2)
C(1)–C(2)	1.427(2)
C(1)–C(3)	1.422(2)
C(2)–C(4)	1.367(2)
C(2)–C(13)	1.502(2)
C(3)–C(7)	1.409(2)
C(4)–C(10)	1.424(2)
C(5)–C(8)	1.399(2)
C(5)–C(9)	1.421(2)
C(5)–C(10)	1.488(2)
C(6)–C(16)	1.367(2)
C(7)–C(12)	1.368(2)
C(8)–C(14)	1.388(2)
C(9)–C(15)	1.407(2)
C(11)–C(15)	1.378(2)
C(11)–C(14)	1.394(2)
C(12)–C(16)	1.412(2)
C(10)–N(1)–C(3)	118.21(13)
C(6)–C(1)–C(2)	123.89(13)
C(6)–C(1)–C(3)	118.57(13)
C(2)–C(1)–C(3)	117.53(13)
C(4)–C(2)–C(1)	117.91(13)
C(4)–C(2)–C(13)	120.80(14)
C(1)–C(2)–C(13)	121.28(14)
N(1)–C(3)–C(7)	117.57(14)
N(1)–C(3)–C(1)	123.15(14)

C(7)-C(3)-C(1)	119.26(14)
C(2)-C(4)-C(10)	121.25(14)
C(8)-C(5)-C(9)	118.02(14)
C(8)-C(5)-C(10)	119.52(13)
C(9)-C(5)-C(10)	122.25(13)
C(16)-C(6)-C(1)	120.78(14)
C(12)-C(7)-C(3)	120.85(15)
C(14)-C(8)-C(5)	122.31(14)
N(2)-C(9)-C(5)	121.88(14)
N(2)-C(9)-C(15)	118.95(14)
C(5)-C(9)-C(15)	118.99(13)
N(1)-C(10)-C(4)	121.91(14)
N(1)-C(10)-C(5)	119.09(13)
C(4)-C(10)-C(5)	118.93(13)
C(15)-C(11)-C(14)	120.05(15)
C(7)-C(12)-C(16)	120.12(15)
C(8)-C(14)-C(11)	119.14(15)
C(11)-C(15)-C(9)	121.42(14)
C(6)-C(16)-C(12)	120.40(14)

Symmetry transformations used to generate equivalent atoms:

Table 4. Anisotropic displacement parameters ($\text{\AA}^2 \times 10^3$) for **3a**. The anisotropic displacement factor exponent takes the form: $-2p^2 [h^2 a^* U^{11} + \dots + 2 h k a^* b^* U^{12}]$

	U^{11}	U^{22}	U^{33}	U^{23}	U^{13}	U^{12}
N(1)	16(1)	18(1)	19(1)	2(1)	0(1)	0(1)
N(2)	16(1)	37(1)	23(1)	-3(1)	-5(1)	5(1)
C(1)	18(1)	18(1)	17(1)	5(1)	1(1)	0(1)
C(2)	16(1)	18(1)	19(1)	5(1)	-1(1)	1(1)
C(3)	18(1)	17(1)	18(1)	3(1)	1(1)	-1(1)
C(4)	17(1)	20(1)	18(1)	1(1)	-2(1)	0(1)
C(5)	14(1)	16(1)	21(1)	1(1)	0(1)	-2(1)
C(6)	18(1)	22(1)	21(1)	4(1)	2(1)	3(1)
C(7)	21(1)	21(1)	21(1)	2(1)	0(1)	-2(1)
C(8)	18(1)	20(1)	20(1)	3(1)	-1(1)	-1(1)
C(9)	14(1)	22(1)	20(1)	3(1)	0(1)	-3(1)
C(10)	15(1)	18(1)	16(1)	3(1)	-1(1)	-1(1)
C(11)	18(1)	19(1)	29(1)	0(1)	7(1)	-1(1)
C(12)	27(1)	22(1)	21(1)	-1(1)	1(1)	-2(1)
C(13)	16(1)	23(1)	25(1)	0(1)	-2(1)	1(1)
C(14)	22(1)	22(1)	19(1)	0(1)	2(1)	-2(1)
C(15)	14(1)	24(1)	26(1)	3(1)	0(1)	0(1)
C(16)	25(1)	21(1)	21(1)	1(1)	4(1)	3(1)

Table 5. Hydrogen coordinates ($\times 10^4$) and isotropic displacement parameters ($\text{\AA}^2 \times 10^{-3}$) for **3a**.

	x	y	z	U(eq)
H(2A)	11418	-35	4169	30
H(2B)	12706	-911	4125	30
H(4)	7710	-323	3177	22
H(6)	5532	2815	4316	25
H(7)	10205	3123	4641	25
H(8)	9351	-506	2633	23
H(11)	12713	-3053	2605	26
H(12)	8676	4463	5106	28
H(13A)	5113	1639	3414	32
H(13B)	4983	639	3890	32
H(13C)	5379	-68	3375	32
H(14)	10764	-2127	2211	25
H(15)	13274	-2267	3394	26
H(16)	6329	4327	4936	27

D:\A\+KA-262-1H.als
Single Pulse Experiment

D:\A\+KA-262-1H.als
COMNT Single Pulse Experiment
DATIM 3-AUG-2004 14:46:23
OBNUC 1H
EXMOD single pulse.exp
OBFKQ 500.00 MHz
OBSEF 162.00 KHz
OBFIN 416.0 Hz
POINT 16384
FREOU 7507.5 Hz
SCANS 8
ACQFM 2.182 sec
PD 4.000 sec
PM1 6.8 us
IRNUC 1H
CTEMP 24.5 c
SLVNT CDCL3
EXREF 7.24 ppm
BF 1.00 Hz
RGAIN 11

1a

D:\A\+KA-231-gen-1H.als
 COMNT Single Pulse Experiment
 DATIM 21-MAY-2004 16:56:59
 OBNUC 1H
 EXMOD single_pulse.exp
 OBFRQ 500.00 MHz
 OBSEF 162.00 KHz
 OBFIN 416.0 Hz
 POINT 16384
 FREOU 7507.5 Hz
 SCANS 8
 ACQTM 2.182 sec
 PD 4.000 sec
 PM1 6.8 us
 IRNUC 1H
 CTEMP 24.8 c
 SLVNT CDCL3
 EXREF 7.24 ppm
 BF 1.00 Hz
 RGAIN 14

D:\A\+KA-230-1H.als
Single Pulse Experiment

D:\A\+KA-230-1H.als
 COMNT Single Pulse Experiment
 DATIM 24-MAY-2004 18:41:29
 OBNUC 1H
 EXMOD single_pulse.exp
 OBFRQ 500.00 MHz
 OBSET 162.00 KHz
 OBFIN 416.0 Hz
 POINT 16384
 FREQU 7507.5 Hz
 SCANS 8
 ACQTM 2.182 sec
 PD 4.000 sec
 PM1 6.8 us
 IRNUC 1H
 CTMP 23.1 c
 SLVNT CDCL3
 EXREF 7.24 ppm
 BF 1.00 Hz
 RGAIN 13

1c

D:\A'+\KA-251-1H.als
 Single Pulse Experiment
 1-JUL-2004 18:19:26
 EXMOD single pulse.exp
 OBFRQ 500.00 MHz
 OBSET 162.00 KHz
 OBFIN 416.0 Hz
 POINT 16384
 FREOU 7507.5 Hz
 SCANS 8
 ACQTM 2.182 sec
 PD 4.000 sec
 PW1 6.8 us
 IRNUC 1H
 CTEMP 25.0 C
 SLVNT CDCL3
 EXREF 7.24 ppm
 BF 1.00 Hz
 RGAIN 12

1d

DFILE D:\A\+ \KA-263-1H.als
 COMNT Single Pulse Experiment
 DATIM 3-AUG-2004 15:02:42
 OBNUC 1H
 EXMOD single pulse.exp
 OBFRQ 500.00 MHz
 OBSET 162.00 KHz
 OBFIN 416.0 Hz
 POINT 16384
 FREQU 7507.5 Hz
 SCANS 8
 ACQTM 2.182 sec
 PD 4.000 sec
 PW1 6.8 us
 IRNUC 1H
 CTEMP 24.6 c
 SLVNT CDCL3
 EXREF 7.24 ppm
 BF 1.00 Hz
 RGAIN 11

DFILE E:\A\KA-492-1H.als
 COMNT Single Pulse Experiment
 DATIM 6-JAN-2006 19:15:47
 OBNUC 1H
 EXMOD single_pulse.exp
 OBFRQ 500.00 MHz
 OBSET 162.00 KHz
 OBFIN 416.0 Hz
 POINT 16384
 FREQU 7507.5 Hz
 SCANS 8
 ACQTM 2.182 sec
 PD 4.000 sec
 PW1 7.5 us
 IRNUC 1H
 CTEMP 16.2 C
 SLVNT CDCL3
 EXREF 7.24 ppm
 BF 1.00 Hz
 RGAIN 12

1f

E:\A\KA-447-1H.als
Single Pulse Experiment

DFILE E:\A\KA-447-1H.als
 COMNT Single Pulse Experiment
 DATIM 14-NOV-2005 23:37:40
 OBNUC 1H
 EXMOD single_pulse.exp
 OBFRQ 500.00 MHz
 OBSET 162.00 KHz
 OBFIN 416.0 Hz
 POINT 16384
 FREQU 7507.5 Hz
 SCANS 8
 ACQTM 2.182 sec
 PD 4.000 sec
 PW1 7.5 us
 IRNUC 1H
 CTEMP 23.4 C
 SIVNT CDCL3
 EXREF 7.24 ppm
 BF 1.00 Hz
 RGAIN 14

2a

E:\^A\KA-485-Me-1H.als
Single Pulse Experiment

DFILE E:\^A\KA-485-Me-1H.als
COMNT Single Pulse Experiment
DATIM 17-DEC-2005 17:39:39
OBNUC 1H
EXMOD single_pulse.exp
OBFRQ 500.00 MHz
OBSET 162.00 KHz
OBFIN 416.0 Hz
POINT 16384
FREQU 7507.5 Hz
SCANS 16
ACQTM 2.182 sec
PD 4.000 sec
PWL 7.5 us
IRNUC 1H
CTEMP 20.9 C
SLVNT CDCL3
EXREF 0.00 ppm
BF 1.00 Hz
RGAIN 11

2b

DFILE E:\A\KA-484-Dimethyl-1H.als
 COMNT Single Pulse Experiment
 DATIM 17-DEC-2005 17:15:09
 OBNUC 1H
 EXMOD single_pulse.exp
 OBFRQ 500.00 MHz
 OBSET 162.00 KHz
 OBFIN 416.0 Hz
 POINT 16384
 FREQ 7507.5 Hz
 SCANS 16
 ACQTM 2.182 sec
 PD 4.000 sec
 PUL 7.5 us
 IRNUC 1H
 CTEMP 20.9 C
 SLVNT CDCL3
 EXREF 0.00 ppm
 BF 1.00 Hz
 RGAIN 9

2c

Single Pulse Experiment

DEFILE E:\A\KA-483-F-1H.als
 COMNT Single Pulse Experiment
 DATIM 17-DEC-2005 16:56:32
 OBNUC 1H
 EXMOD single_pulse.exp
 OBFRO 500.00 MHz
 OBSET 162.00 KHz
 OBFIN 416.0 Hz
 POINT 16384
 FREQU 7507.5 Hz
 SCANS 16
 ACQTM 2.182 sec
 PD 4.000 sec
 PM1 7.5 us
 IRNUC 1H
 CTEMP 20.7 C
 SLVNT CDCL3
 EXREF 0.00 ppm
 BF 1.00 Hz
 RGAIN 11

2d

SINGLE PULSE EXPERIMENT

DEFILE E:\AKA-4/b-1h.ais
 COMNT Single Pulse Experiment
 DATIM 7-DEC-2005 10:53:31
 OBNUC 1H
 EXMOD single_pulse.exp
 OBFRQ 500.00 MHz
 OBSET 162.00 KHz
 OBFIN 416.0 Hz
 POINT 16384
 FREQU 7507.5 Hz
 SCANS 8
 ACQTM 2.182 sec
 PD 4.000 sec
 PM1 7.5 us
 IRNUC 1H
 CTEMP 19.9 c
 SLVNT CDCL3
 EXREF 7.24 ppm
 BF 1.00 Hz
 RGAIN 14

2e

Single Pulse Experiment

DEFILE E:\A\KA-494-1H.als
 COMNT Single Pulse Experiment
 DATIM 7-JAN-2006 11:15:26
 OBNUC 1H
 EXMOD single_pulse.exp
 OBFREQ 500.00 MHz
 OBSET 162.00 KHz
 OBFIN 416.0 Hz
 POINT 16384
 FREQU 7507.5 Hz
 SCANS 8
 ACQTM 2.182 sec
 PD 4.000 sec
 PW1 7.5 us
 IRNUC 1H
 CTEMP 15.6 C
 SLVNT CDCL3
 EXREF 7.24 ppm
 BF 1.00 Hz
 RGAIN 17

D:\AKA-373-mono-1H.als
 Single Pulse Experiment
 1-NOV-2005 20:58:50
 1H
 single_pulse.exp
 500.00 MHz
 162.00 KHz
 416.0 Hz
 16384
 7507.5 Hz
 8
 2.182 sec
 4.000 sec
 7.5 us
 1H
 22.2 c
 CDCl3
 7.24 ppm
 1.00 Hz
 17
 RGAIN

3a

Single Pulse Experiment

DFILE E:\A\KA-486-1H.als
 COMNT Single Pulse Experiment
 DATIM 21-DEC-2005 12:49:41
 OBNUC 1H
 EXMOD single_pulse.exp
 OBFRQ 500.00 MHz
 OBSET 162.00 KHz
 OBFIN 416.0 Hz
 POINT 16384
 FREQ 7507.5 Hz
 SCANS 16
 ACQTM 2.182 sec
 PD 4.000 sec
 PW1 7.5 us
 IRNUC 1H
 CTEMP 18.9 C
 SLVNT CDCL3
 EXREF 0.00 ppm
 BF 1.00 Hz
 RGAIN 13

E:\A\KA-487-1-1H.als
Single Pulse Experiment

FILE E:\A\KA-487-1-1H.als
 COMNT Single Pulse Experiment
 DATIM 21-DEC-2005 17:26:53
 OBNUC 1H
 EXMOD single_pulse.exp
 OBFRQ 500.00 MHz
 OBSET 162.00 KHz
 OBFIN 416.0 Hz
 POINT 16384
 FREQ 7507.5 Hz
 SCANS 32
 ACQTM 2.182 sec
 PD 4.000 sec
 PM1 7.5 us
 IRNUC 1H
 CTEMP 19.8 C
 SLVNT CDCL3
 EXREF 0.00 ppm
 BF 1.00 Hz
 RGAIN 13

D:\AKA-281-mono-1H.als
Single Pulse Experiment

DFILE
 COMNT
 DATIM
 OBNUC
 EXMOD
 OBFRQ
 OBSET
 OBFIN
 POINT
 FREQU
 SCANS
 ACQTM
 PD
 PW1
 IRNUC
 CTEMP
 SLVNT
 EXREF
 BF
 RGAIN

D:\AKA-281-mono-1H.als
 Single Pulse Experiment
 1-NOV-2005 21:35:40
 1H
 single_pulse_exp
 500.00 MHz
 162.00 KHz
 416.0 Hz
 16384
 7507.5 Hz
 8
 2.182 sec
 4.000 sec
 7.5 us
 1H
 23.0 c
 CDCL3
 7.24 ppm
 1.00 Hz
 17

3d

E:\A\KA-477-hatena-1H.als
Single Pulse Experiment

DFILE E:\A\KA-477-hatena-1H.als
 COMNT Single Pulse Experiment
 DATIM 14-DEC-2005 22:31:43
 OBNUC 1H
 EXMOD single_pulse.exp
 OBFRQ 500.00 MHz
 OBSET 162.00 KHz
 OBFIN 416.0 Hz
 POINT 16384
 FREQU 7507.5 Hz
 SCANS 8
 ACQTM 2.182 sec
 PD 4.000 sec
 PW1 7.5 us
 IRNUC 1H
 CTEMP 19.3 C
 SLVNT DMSO
 EXREF 2.49 ppm
 BF 1.00 Hz
 RGAIN 17

DEFILE E:\KA-495-4-1H.als
COMNT Single Pulse Experiment
DATIM 13-JAN-2006 11:45:58
OBNUC 1H
EXMOD single pulse.exp
OBFRO 500.00 MHz
OBSET 162.00 KHz
OBFIN 416.0 Hz
POINT 16384
FREQU 7507.5 Hz
SCANS 16
ACQTM 2.182 sec
PD 4.000 sec
PWL 7.5 us
IRNUC 1H
CTEMP 17.0 C
SLVNT DMSO
EXREF 2.49 ppm
BF 1.00 Hz
RGAIN 17

DEFILE E:\KA-471-3-1H.als
 COMNT Single Pulse Experiment
 DATIM 17-JAN-2006 20:06:39
 OBNUC 1H
 EXMOD single_pulse.exp
 OBFRQ 500.00 MHz
 OBSET 162.00 KHz
 OBFIN 416.0 Hz
 POINT 16384
 FREQU 7507.5 Hz
 SCANS 32
 ACQTM 2.182 sec
 PD 4.000 sec
 PW1 7.5 us
 IRNUC 1H
 CTEMP 20.0 C
 SLVNT CDCL3
 EXREF 7.24 ppm
 BF 1.00 Hz
 RGAIN 18

3a-d