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2,2′:6′,2″:6″,6-Trioxytriphenylamine: Synthesis and Properties of the Neutral and Radical Cation

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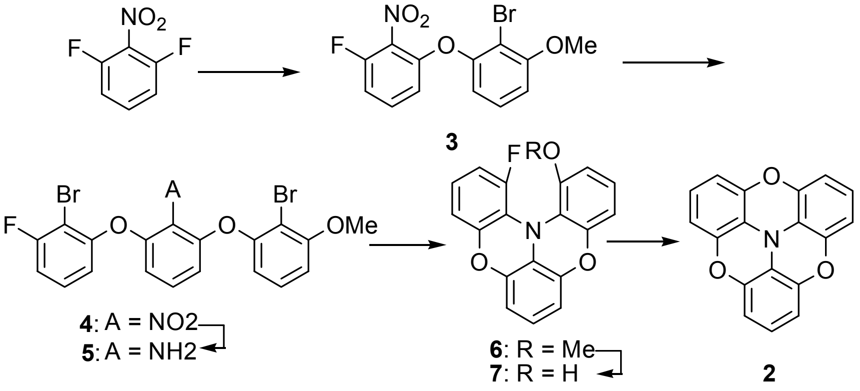

Synthetic Procedures:

Synthesis of 3. NaH (2.64 g, 66.0 mmol, 60% in oil) was washed with *n*-hexane and dried in vacuo. The NaH and dry DMSO (125 ml) were heated at 65 ~ 70 ℃ for 1 h under nitrogen. Then, 2-bromo-3-methoxyphenol (13.4 g, 66.0 mmol) was added and the mixture was stirred for 1 h at the same temperature. After cooling to room temperature, 2,6-difluoronitrobenzene (9.98 g, 62.7 mmol) was added. The mixture was stirred for 2.5 h at 130 °C. The cooled mixture was poured into water, and the aqueous mixture was extracted with dichloromethane. The organic phase was washed with water and brine, dried over Na_2SO_4, filtered, and evaporated. The solid residue was washed with small amount of EtOH and filtered to give **3** as a light brown powder (17.9 g, 83%). Pure sample was obtained by recrystallization from EtOH as a colorless powder; m.p. 145 °C; ^{1}H NMR (400 MHz, [D6]DMSO, 25 °C, TMS): δ = 7.60 (ddd, ^3J(H,H) = 8.7, 8.6, ^4J(H,F) = 6.4 Hz, 1H; CH (F-substituted ring)), 7.46 (dd, ^3J(H,H) = 8.4, 8.3 Hz, 1H; CH (MeO-substituted ring)), 7.35 (ddd, ^3J(H,F) = 8.8, ^3J(H,H) = 8.7, ^4J(H,H) = 1.0 Hz, 1H; CH (F-ring)), 7.09 (dd, ^3J(H,H) = 8.4, ^4J(H,H) = 1.2 Hz, 1H; CH (MeO-ring)), 6.93 (dd, ^3J(H,H) = 8.3, ^4J(H,H) = 1.2 Hz, 1H; CH (MeO-ring)), 6.72 (ddd, ^3J(H,H) = 8.6, ^5J(H,F) = 1.2, ^4J(H,H) = 1.0 Hz, 1H; CH (F-ring)), 3.91 ppm (s, 3H; MeO); ^{13}C NMR (100 MHz, $CDCl_3$, 25 °C, TMS): δ = 157.81, 154.48 (^1J(C,F) = 256.6 Hz), 152.25, 150.12 (^3J(C,F) = 2.5 Hz), 131.80 (^3J(C,F) = 9.1 Hz), 131.37 (^2J(C,F) = 15.6 Hz), 128.91, 114.00, 112.43 (^4J(C,F) = 4.1 Hz), 110.51 (^2J(C,F) = 19.0 Hz), 109.04, 105.49, 56.55 ppm; MS-FAB$^+$ (*m*-NBA:3-nitrobenzyl alcohol): *m*/*z* (%): 344 (100) [M(^{81}Br)+H$^+$], 343 (90) [M(^{81}Br)$^+$], 342 (98) [M(^{79}Br)+H$^+$] , 341 (84) [M(^{79}Br)$^+$] ; IR (KBr): 1541 (NO_2), 1367 cm^{-1} (NO_2); Elemental analysis calcd (%) for **3** ($C_{13}H_9BrFNO_4$): C 45.64, H 2.65, N 4.09; found: C 45.43, H 2.63, N 4.05.

Synthesis of 4. NaH (2.31 g, 57.8 mmol, 60% in oil) washed with *n*-hexane and dried in vacuo was suspended in dry DMSO (100 ml) and the mixture was heated at 65 ~ 70 ℃ for 1 h under nitrogen. 2-Bromo-3-fluorophenol (11.0 g, 57.6 mmol) was added and the mixture was stirred for 1 h at the same temperature. After cooling to room temperature, compound **3** (16.5 g, 48.2 mmol) was added and the mixture was stirred for 3 h at 130 ℃. The reaction mixture was poured into water, extracted with ethyl acetate. The organic phase was washed with water and brine, dried over Na_2SO_4, and filtered. The solvent was removed, and the solid residue was washed with small amount of EtOH and filtered to give **4** as a colorless powder (21.3 g, 86%); m.p. 180 °C; ^{1}H NMR (400 MHz, [D6]DMSO, 25 °C, TMS): δ = 7.54 (ddd, ^3J(H,H) = 8.5, 8.3, ^4J(H,F) = 6.3 Hz, 1H; CH (F-substituted ring)), 7.46 (dd, ^3J(H,H) = 8.4, 8.3 Hz, 1H; CH (central ring)), 7.46 (dd, ^3J(H,H) = 8.5, 8.5 Hz, 1H; CH (MeO-substituted ring)), 7.35 (ddd, ^3J(H,H) = 8.5, ^3J(H,F) = 8.4, ^4J(H,H) = 1.2 Hz, 1H; CH (F-ring)), 7.17 (ddd, ^3J(H,H) = 8.3, ^4J(H,H) = 1.2, ^5J(H,F) = 1.2 Hz, 1H; CH (F-ring)), 7.08 (dd, ^3J(H,H) = 8.4, ^4J(H,H) = 1.2 Hz, 1H; CH (central ring)), 6.92 (dd, ^3J(H,H) = 8.3, ^4J(H,H) = 1.2 Hz, 1H; CH (central ring)), 6.74 (dd, ^3J(H,H) = 8.5, ^4J(H,H) = 0.9 Hz, 1H; CH (MeO-ring)), 6.64 (dd, ^3J(H,H) = 8.5, ^4J(H,H) = 0.9 Hz, 1H; CH (MeO-ring)), 3.91 ppm (s, 3H; MeO); ^{13}C NMR (100 MHz, $CDCl_3$, 25 °C, TMS): δ = 160.42 (^1J(C,F) = 247.7 Hz), 157.86, 153.41 (^3J(C,F) = 3.3 Hz), 152.65, 150.02, 149.29, 134.00, 131.11, 129.04 (^3J(C,F) = 9.9 Hz), 128.87, 116.78 (^4J(C,F) = 3.3 Hz), 114.13, 113.19 (^2J(C,F) = 22.2 Hz), 111.59, 111.39, 108.91, 105.70, 103.64 (^2J(C,F) = 22.2 Hz), 56.66 ppm; MS-FAB$^+$(*m*-NBA): *m*/*z* (%): 516 (49) [M($^{81}Br_2$)+H$^+$], 515 (40) [M($^{81}Br_2$)$^+$], 514 (100) [M(^{81}Br,^{79}Br)+H$^+$], 513 (57) [M(^{81}Br,^{79}Br)$^+$], 512 (48) [M($^{79}Br_2$)+H$^+$], 511 (24) [M($^{79}Br_2$)$^+$]; IR (KBr): 1543 (NO_2), 1373 cm^{-1} (NO_2); Elemental analysis calcd (%) for **4** ($C_{19}H_{12}Br_2FNO_5$): C 44.47, H 2.36, N 2.73; found: C

44.50, H 2.35, N 2.68.

Synthesis of 5. A suspension of **4** (13.5 g, 26.3 mmol), 5% Pd/C (1.89 g), *p*-bromophenol (45.8 g, 265 mmol), and $H_2NNH_2 \cdot H_2O$ (37.2 ml, 767 mmol) in EtOH (700 ml) was refluxed for 2 h under nitrogen. After cooling to room temperature, Pd/C was filtered off and the filtrate was concentrated under reduced pressure and poured into water. The aqueous mixture was extracted with diethyl ether. The organic phase was washed with aq. NaOH (1 M), water, and brine, and dried over $MgSO_4$. The solvent was removed under reduce pressure and the solid residue was recrystallized from EtOH to give **5** as a colorless powder (10.8 g, 85%); m.p. 111 °C; ^{1}H NMR (400 MHz, $CDCl_3$, 25 °C, TMS): δ = 7.24-7.16 (m, 2H), 6.89 (ddd, ^3J(H,F) = 8.2, ^3J(H,H) = 8.1, ^4J(H,H) = 1.2 Hz, 1H; CH (F-substituted ring)), 6.72-6.55 (m, 6H), 4.00 (s, 2H; NH2), 3.94 ppm(s, 3H; MeO); ^{13}C NMR (100 MHz, $CDCl_3$, 25 °C, TMS): δ = 160.33 (^1J(C,F) = 246.0 Hz), 157.60, 155.41 (^3J(C,F) = 3.3 Hz), 154.80, 144.32, 143.42, 130.98, 128.61 (^3J(C,F) = 9.1 Hz), 128.40, 117.06, 115.60, 115.55, 112.95 (^4J(C,F) = 3.3 Hz), 110.84, 110.83 (^2J(C,F) = 22.2 Hz), 106.81, 103.44, 101.22 (^2J(C,F) = 23.0 Hz), 56.57 ppm; MS-FAB$^+$(*m*-NBA): *m*/*z* (%): 486 (39) [M($^{81}Br_2$)+H$^+$], 485 (61) [M($^{81}Br_2$)$^+$], 484 (77) [M(^{81}Br,^{79}Br)+H$^+$], 483 (100) [M(^{81}Br,^{79}Br)$^+$], 482 (39) [M($^{79}Br_2$)+H$^+$], 481 (49) [M($^{79}Br_2$)$^+$]; IR (KBr): 3493 (NH), 3396 cm^{-1}(NH); Elemental analysis calcd (%) for **5** ($C_{19}H_{14}Br_2FNO_3$): C 47.23, H 2.92, N 2.90; found: C

47.46, H 2.94, N 2.83.

Synthesis of 6. A mixture of NaO*t*Bu (5.37 g, 55.9 mmol), $Pd_2(dba)_3 \cdot CHCl_3$ (0.964 g, 0.931 mmol), and $P(t\text{-}Bu)_3$ (283 mg, 1.40 mmol) in dry toluene (38 ml) was stirred for about 15 min at room temperature under nitrogen. A dry toluene solution (330 ml) of compound **5** (9.00 g, 18.6 mmol) was added and the whole mixture was refluxed for 3 h. After cooling to room temperature, the insoluble materials were filtered off and washed with hot toluene. The filtrate was evaporated and the mixture was subjected to silica gel column chromatography with *n*-hexane : ethyl acetate (19 : 1) as an eluent. The oily product was crystallized with *n*-hexane to give **6** as a colorless powder (2.07 g, 35%) ; m.p. 136 °C; ^1H NMR (600 MHz, $CDCl_3$, 25 °C, TMS): δ = 6.93 (t, $^3J(H,H)$ = 8.3 Hz, 1H; CH (MeO-substituted ring)), 6.87-6.79 (m, 2H), 6.77-6.71 (m, 2H), 6.64 (d, $^3J(H,H)$ = 8.3 Hz, 1H; CH (MeO-ring)), 6.62-6.57 (m, 3H), 3.72 ppm (s, 3H; MeO); ^{13}C NMR (150 MHz, $CDCl_3$, 25 °C, TMS): δ = 152.56 ($^1J(C,F)$ = 246.8 Hz), 150.68 ($^5J(C,F)$ = 2.7 Hz), 149.39 ($^3J(C,F)$ = 5.0 Hz), 149.10, 146.65, 146.41, 123.79, 123.28, 123.17, 121.84 ($^3J(C,F)$ = 9.1 Hz), 120.98 ($^2J(C,F)$ = 12.8 Hz), 119.11 ($^4J(C,F)$ = 1.0 Hz), 111.98 ($^4J(C,F)$ = 2.7 Hz), 111.33, 111.15, 111.01 ($^2J(C,F)$ = 20.2 Hz), 109.38, 107.49, 55.55 ppm; MS-FAB$^+$ (*m*-NBA): *m*/*z* (%): 321 (100) [M^+]; Elemental analysis calcd (%) for **6** ($C_{19}H_{12}FNO_3$): C 71.03, H 3.76, N 4.36; found: C 71.06, H 3.64, N 4.35.

Synthesis of 7. Compound **6** (1.22 g, 3.80 mmol) was dissolved in dry CH_2Cl_2 (75 ml) at room temperature under nitrogen. The solution was cooled to -78 ℃, then BBr_3 (1.8 ml, 19.0 mmol) was added. The reaction mixture was slowly warmed up to room temperature and poured into water. The aqueous mixture was extracted with dichloromethane. The organic phase was washed with water and brine, dried over Na_2SO_4. After evaporation of the solvent, the residue was subjected to short silica gel column chromatography with dichloromethane as eluent to give **7** as a crude colorless powder (1.16 g, 99%). This material in solid state or in solution even without base was thermally unstable to give the cyclized product **2** in part. Therefore, this material was used without further purification for the next cyclization reaction; ^1H NMR (400 MHz, $CDCl_3$, 25 °C, TMS): δ = 6.90-6.80 (m, 3H), 6.80-6.72 (m, 2H), 6.63-6.51 (m, 4H), 4.53 ppm (s, 1H, OH); MS-FAB$^+$ (glycerol): *m*/*z* (%): 307 (100) [M^+]; IR (KBr): 3549 cm^{-1} (OH).

Synthesis of 2. To a stirred solution of **7** (1.16 g, 3.77 mmol) in DMF (35 ml) was added K_2CO_3 (0.789 g, 5.71 mmol). The mixture was stirred overnight at room temperature. The reaction mixture was poured into water, extracted with dichloromethane. After usual work-up, the mixture was passed through a silica gel short column with benzene as an eluent. The crude compound was recrystallized from toluene to give pure **2** as pale yellow needles

(1.01 g, 92%). m.p. 291.0-291.5 °C; m.p. 291.5 °C; ^{1}H NMR (400 MHz, C_6D_6, 25 °C, TMS): δ = 6.27 (dd, $^{3}J(H,H)$ = 8.4, 8.4 Hz, 1H; *p*-CH), 6.26 ppm (dd, $^{3}J(H,H)$ = 8.4, $^{4}J(H,H)$ = 1.2 Hz, *m*-CH); ^{13}C NMR (100 MHz, C_6D_6, 25 °C, TMS): δ = 142.67, 123.65, 117.12, 111.44 ppm; MS-FAB^{+} (*m*-NBA): *m*/*z* (%): 287 (100) [M^{+}]; Elemental analysis calcd (%) for **1** ($C_{18}H_9NO_3$): C 75.26, H 3.16, N 4.88; found: C 74.97, H 3.03, N 4.82.

EPR and simulation spectra of 2^+:

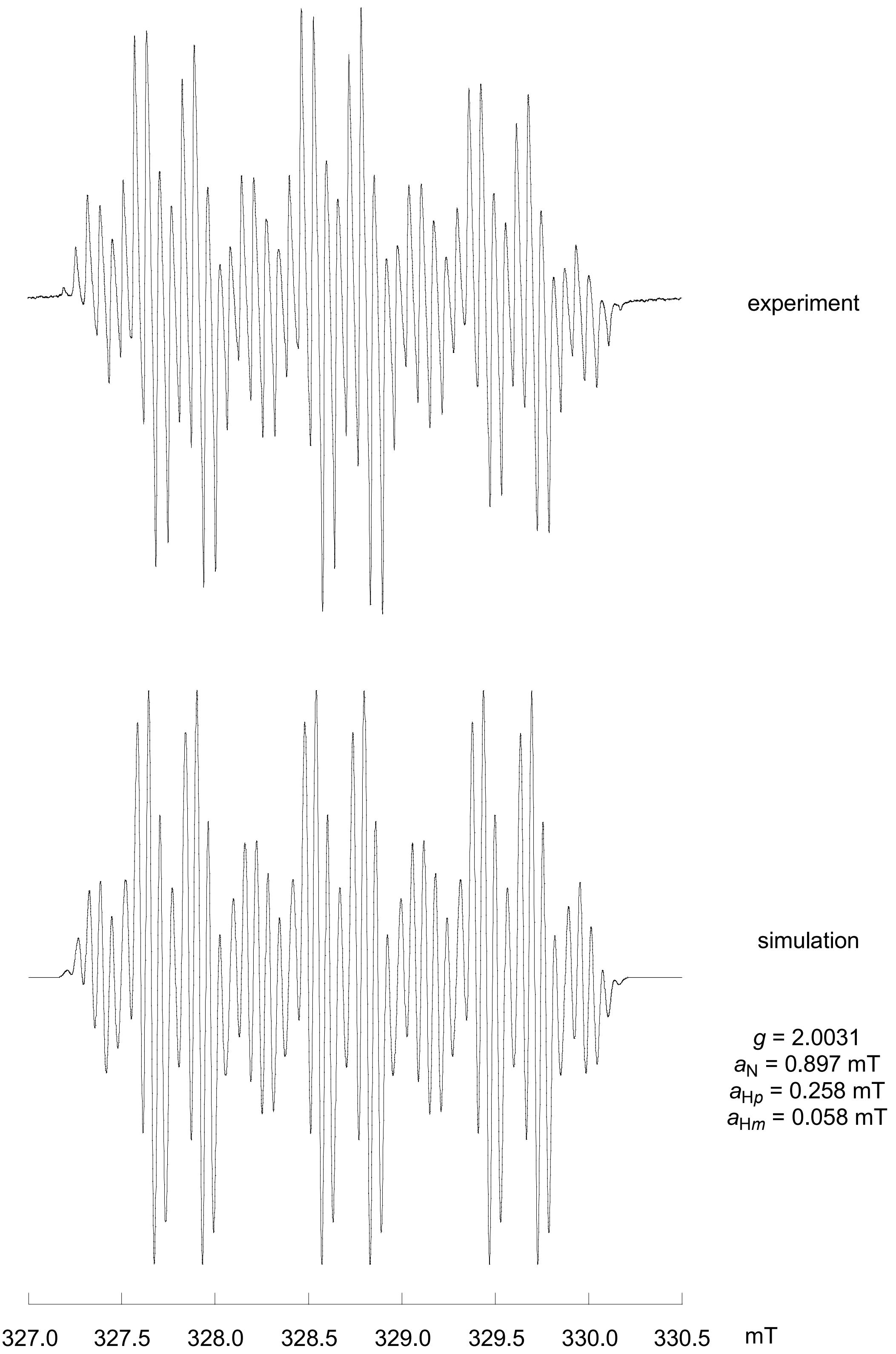

Figure EPR spectra of $\mathbf{1}^+ \cdot PF_6^-$ in butyronitrile at r.t.