Supporting Information for

Metal-free aerobic oxidative coupling of amines
in dimethyl sulfoxide via a radical pathway

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General Information

CDCl₃ and CD₃SOCD₃ were purchased from Cambridge Isotope Laboratory Inc; CH₃SOCH₃ was purchased from Aldrich, Acros, Alfa Aesar, TCI, and the yields in DMSO from different sources were the same; tetrahydrothiophene 1-oxide (THTO) was purchased from Alfa Aesar; all amines purchased from Aldrich or Alfa Aesar were distilled and stored at 4°C; and all other chemicals were purchased from Aldrich or Alfa Aesar unless otherwise noted and used as received. ¹H NMR spectra were recorded on a Bruker AVII⁺-400 spectrometer at ambient temperature. GC-MS results were obtained by the Agilent 7890A/5975C GC/MSD system equipped with the DB-17MS (30m, 0.25mm, 0.25μm) column.

NMR spectra were measured on Bruker ARX 400 (¹H at 400 MHz, ¹³C at 100 MHz), Bruker ARX 500 (¹H at 500 MHz, ¹³C at 126 MHz) nuclear magnetic resonance spectrometers. Data for ¹H-NMR spectra are reported as follows: chemical shift (ppm, referenced to TMS; s = singlet, d = doublet, t = triplet, q = quartet, dd = doublet of doublets, dt = doublet of triplets, dm = doublet of multiplet, ddd = doublet of doublet of doublets, td = triplet of doublet of doublets, m = multiplet), coupling constant (Hz), and integration. Data for ¹³C-NMR are reported in terms of chemical shift (ppm) relative to residual solvent peak (Acetone [(CD₃)₂CO]: 2.05 ppm).

General procedure for the aerobic oxidative coupling reactions

In a typical experiment, one atmosphere oxygen is pressurized to a 45 ml Schlenk flask containing amines and solvents. After the reaction mixture is heated for 24 hours, the solution is diluted with methanol to 25 mL and characterized by GC and GC-MS.

For the homo-coupling reactions: Benzylamine 0.065 g (0.6 mmol) and DMSO (1 mL) were added into a Schlenk flask with a high vacuum valve (V = 45 mL) fitting in a Radleys parallel synthesis station.¹ The sample was subjected to three freeze-pump-thaw cycles and then filled with 1 atm O₂. The solution was stirred vigorously and heated at 105 °C for 24 hours.

To obtain the GC results, after it was cooled down to room temperature, the solution was diluted with methanol to 25.00 mL for GC test. The imine products were independently synthesized by condensation of aldehydes and amines, and used as standards for GC measurements.

To obtain the isolated products, the reaction mixture was cooled to room temperature, quenched by water, and extracted with ethyl acetate. The organic phase was dried over Na₂SO₄, filtrated and concentrated. The residue was purified by flash column chromatography on silica gel to afford the final product.² The compounds of P1, P4, P5, P6 can be found in the ref. S3. The compounds of P2 and P3 can be found in the
ref. S4. The compound of P7 can be found in the ref. S5. The compound of P8 can be found in the ref. S6. The compounds of P9, P10, P11 can be found in the ref. S7.

**For the cross-coupling reactions:** benzyamine 0.065 g (0.60 mmol), 1.8 mmol of aliphatic amine and 1.0 mL of DMSO were used instead. The compounds of P12, P13, P14, P15, P16, can be found in the ref. S7.

**For the oxidative coupling reactions of aromatic amines:** 0.5 mmol of aromatic amines, 1.5 mmol of KOH, 1mL of DMSO, 1 atm oxygen were used instead. The solution was stirred vigorously and heated at 90 °C for 48 hours. The reaction mixture was cooled to room temperature, quenched by water, and extracted with ethyl acetate. The organic phase was dried over Na₂SO₄, filtrated and concentrated. The residue was purified by flash column chromatography (PE/EA 200:1) on silica gel to afford the final product. The corresponding spectral data can be found in the supporting information of our previous report. S2 The compounds of P17, P18, P19, P20 can be found in the ref. S8.

**Reference**


Table 1S. Solvent Effect of Oxidation of Benzylamine

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<th>Entry</th>
<th>Solvent</th>
<th>T (°C)</th>
<th>Gas</th>
<th>C (%)b</th>
<th>Y (%)b</th>
<th>Rc</th>
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a Reaction conditions: benzylamine 0.6 mmol, solvent 1 ml, Pgas = 1 atm, 24 hours. THTO = tetrahydrothiophene 1-oxide, THTO2 = sulfolane, THS = tetrahydrothiophene. b C = conversion, Y = yield, GC results. c R = n (sulfone) / n (imine). d 42% of PhCH2NHCHO was detected.

We observed no radical signals by mixing benzyl amine and DMSO at 25 °C (Figure 1S, a). However, after heating the solution (0.6 M benzyl amine in DMSO) under 1 atmosphere of oxygen at 110 °C for 7 hours, we observed a weak radical signal (anisotropic g-value equals 2.004) by EPR method (Figure 1S, b). Meanwhile, 7% of N-benzylidene-1-benzylamine was formed.

Figure 1S. X-band EPR spectrum of radicals formed in DMSO after adding benzylamine. Experimental details: 77 K, frequency 9.0851 GHz, microwave power 1 mW. (a) red: 7 hours at 25 °C; (b) black: 7 hours at 110 °C.
Scheme S1. Proposed mechanism for synthesis of azo compounds.
Experimental and Spectral Data

**P1**

Colorless oil. $^1$H NMR (CDCl$_3$, 400MHz): $\delta$ 4.80 (s, 2H), 7.19-7.32 (m, 1H), 7.32-7.33 (m, 4H), 7.37-7.41 (m, 3H), 7.76-7.78 (m, 2H), 8.36 (s, 1H). $^{13}$C NMR (CDCl$_3$, 100MHz): $\delta$ 65.1, 127.1, 128.1, 128.4, 128.6, 128.7, 130.8, 136.3, 139.4, 162.0.\(^1\)

**P2**

White solid, m. p. = 82-84 ºC. $^1$H NMR (CDCl$_3$, 400MHz): $\delta$ 2.32 (s, 3H), 2.36 (s, 3H), 4.75 (s, 2H), 7.13 (d, $J$ = 7.8 Hz, 2H), 7.20-7.22 (m, 4H), 7.32 (d, $J$ = 8.4 Hz, 2H), 7.39 (d, $J$ = 8.4 Hz, 2H), 7.71 (d, $J$ = 8.4 Hz, 2H), 8.32 (s, 1H). $^{13}$C NMR (CDCl$_3$, 100MHz): $\delta$ 21.2, 21.6, 64.9, 128.1, 128.4, 129.3, 129.4, 133.8, 136.5, 136.6, 141.0, 161.7.\(^2\)

**P3**

White solid, m. p. = 62-63 ºC. $^1$H NMR (CDCl$_3$, 400MHz): $\delta$ 4.77 (s, 2H), 7.29-7.23 (m, 2H), 7.32 (d, $J$ = 8.4 Hz, 2H), 7.39 (d, $J$ = 8.4 Hz, 2H), 7.65 (d, $J$ = 8.4 Hz, 2H), 8.34 (s, 1H). $^{13}$C NMR (CDCl$_3$, 100MHz): $\delta$ 64.2, 128.7, 129.0, 129.3, 129.5, 132.9, 134.5, 136.9, 137.6, 160.9.\(^2\)

**P4**

Colorless oil. $^1$H NMR (CDCl$_3$, 400MHz): $\delta$ 3.76 (s, 3H), 3.79 (s, 3H), 4.70 (s, 2H), 6.86 (d, $J$ = 8.6 Hz, 2H), 6.90 (d, $J$ = 8.7 Hz, 2H), 7.23 (d, $J$ = 8.6 Hz, 2H), 7.70 (d, $J$ = 8.7 Hz, 2H), 8.28 (s, 1H). $^{13}$C NMR (CDCl$_3$, 100MHz): $\delta$ 55.3, 55.4, 64.5, 114.0, 114.1, 129.2, 129.3, 129.9, 131.8, 158.7, 161.0, 161.8.\(^1\)

**P5**

Light yellow oil. $^1$H NMR (CDCl$_3$, 400MHz): $\delta$ 4.75 (s, 2H), 6.99-7.04 (m, 2H), 7.06-7.10 (m, 2H), 7.26-7.30 (m, 2H), 7.74-7.77 (m, 2H), 8.32 (s, 1H). $^{13}$C NMR (CDCl$_3$, 100MHz): $\delta$ 64.2, 115.3, 115.5, 115.7, 115.9, 129.5, 129.6, 130.2, 130.3, 132.5, 135.07, 135.10, 160.6, 160.9, 163.26, 163.3, 165.8.\(^1\)

**P6**


Light yellow oil. $^1$H NMR (CDCl$_3$, 400MHz): $\delta$ 2.38 (s, 3H), 2.49 (s, 3H), 4.81 (s, 2H), 7.14-7.30 (m, 7H), 7.90-7.92 (m, 1H), 8.65 (s, 1H). $^{13}$C NMR (CDCl$_3$, 100MHz): $\delta$ 19.4, 19.5, 63.4, 126.2, 126.3, 127.2, 127.8, 128.4, 130.2, 130.3, 130.9, 134.4, 136.2, 137.7, 137.8, 160.6.  

![Diagram of P7](image1)

White solid, m. p. = 157-158 °C. $^1$H NMR (CDCl$_3$, 400MHz): $\delta$ 5.55 (s, 1H), 7.06-7.08 (m, 2H), 7.16-7.20 (m, 2H), 7.24-7.28 (m, 4H), 7.31-7.37 (m, 7H), 7.39-7.43 (m, 3H), 7.74-7.76 (m, 2H). $^{13}$C NMR (CDCl$_3$, 100MHz): $\delta$ 70.0, 126.8, 127.7, 127.9, 128.1, 128.47, 128.54, 128.6, 128.9, 130.2, 136.9, 140.0, 145.0, 167.0. 

![Diagram of P8](image2)

Light yellow solid, m. p. = 157-158 °C. $^1$H NMR (CDCl$_3$, 400MHz): $\delta$ 4.93 (s, 2H), 7.00-6.94 (m, 2H), 7.05 (dd, $J = 4.8, 3.8$ Hz, 1H), 7.22 (dd, $J = 4.9, 1.2$ Hz, 1H), 7.31 (d, $J = 3.5$ Hz, 1H), 7.39 (d, $J = 5.0$ Hz, 1H), 8.40 (s, 1H). $^{13}$C NMR (CDCl$_3$, 100MHz): $\delta$ 58.6, 124.9, 125.3, 127.0, 127.5, 129.0, 131.0, 141.7, 142.2, 155.5. 

![Diagram of P9](image3)

Yellow oil. $^1$H NMR (CDCl$_3$, 400MHz): $\delta$ 4.75 (s, 2H), 6.26-6.27 (m, 1H), 6.33-6.34 (m, 1H), 6.45-6.47 (m, 1H), 6.77-6.78 (m, 1H), 7.36-7.37 (m, 1H), 7.50 (s, 1H), 8.11 (m, 1H). $^{13}$C NMR (CDCl$_3$, 100MHz): $\delta$ 56.9, 107.9, 110.4, 111.7, 114.5, 142.3, 145.0, 151.3, 151.5, 151.9. 

![Diagram of P10](image4)

Yellow oil. $^1$H NMR (CDCl$_3$, 400 MHz): $\delta$ 8.67 (d, $J = 4.8$ Hz, 1H), 8.59 (d, $J = 4.9$ Hz, 1H), 8.57 (s, 1H), 8.09 (d, $J = 7.9$ Hz, 1H), 7.75 (td, $J = 7.7$ and 1.6 Hz, 1H), 7.68 (td, $J = 7.7$ and 1.8 Hz, 1H), 7.42 (d, $J = 7.8$ Hz, 1H), 7.33 (ddd, $J = 7.4, 4.9$ and 1.0 Hz, 1H), 7.29 (s, 1H), 5.03 (d, $J = 0.6$ Hz, 2H). $^{13}$C NMR (CDCl$_3$, 100 MHz): $\delta$ 66.7, 121.6, 122.2, 122.5, 125.0, 136.6, 136.8, 149.5, 149.6, 154.5, 158.9, 164.0.
Yellow oil. $^1$H NMR (CDCl$_3$, 400 MHz): $\delta$ 0.88 (t, $J = 6.7$ Hz, 2H), 1.28-1.35 (m, 8H), 1.66-1.73 (m, 2H), 3.59 (t, $J = 7.0$ Hz, 1H), 7.36-7.41 (m, 3H), 7.70-7.74 (m, 2H), 8.26 (s, 1H). $^{13}$C NMR (CDCl$_3$, 100 MHz): $\delta$ 14.2, 22.8, 27.5, 29.3, 31.1, 32.0, 61.9, 128.1, 128.7, 130.5, 136.6, 160.8.$^5$

Light yellow oil. $^1$H NMR (CDCl$_3$, 400MHz): $\delta$ 0.89 (t, $J = 6.8$ Hz, 3H), 1.29-1.38 (m, 6H), 1.66-1.73 (m, 2H), 3.61 (t, $J = 7.1$ Hz, 2H), 7.39 (s, 1H), 7.41 (d, $J = 3.0$ Hz, 2H), 7.70-7.73 (m, 2H), 8.26 (s, 1H). $^{13}$C NMR (CDCl$_3$, 100MHz): $\delta$ 14.19, 22.74, 27.16, 31.02, 31.80, 61.94, 128.13, 128.67, 130.53, 136.52, 160.79.$^5$

Light yellow oil. $^1$H NMR (CDCl$_3$, 400MHz): $\delta$ 1.30 (s, 2H), 7.36-7.40 (m, 3H), 7.72-7.74 (m, 2H), 8.27 (s, 1H). $^{13}$C NMR (CDCl$_3$, 100MHz): $\delta$ 29.9, 57.3, 128.0, 128.6, 130.3, 137.3, 155.3.$^5$

Light yellow oil. $^1$H NMR (CDCl$_3$, 400MHz): $\delta$ 1.20-1.42 (m, 3H), 1.54-1.75 (m, 5H), 1.80-1.85 (m, 2H), 3.14-3.22 (m, 1H), 7.36-7.38 (m, 3H), 7.70-7.73 (m, 2H), 8.29 (s, 1H). $^{13}$C NMR (CDCl$_3$, 100MHz): $\delta$ 24.9, 25.8, 34.5, 70.1, 128.1, 128.6, 130.4, 136.7, 158.6.$^5$

Light yellow oil. $^1$H NMR (CDCl$_3$, 400MHz): $\delta$ 1.61-1.75 (m, 4H), 1.85-1.95 (m, 4H), 3.72-3.78 (m, 1H), 7.37-7.39 (m, 3H), 7.70-7.73 (m, 2H), 8.28 (s, 1H). $^{13}$C NMR (CDCl$_3$, 100MHz): $\delta$ 24.75, 34.50, 71.83, 128.00, 128.49, 130.22, 136.62, 158.49.$^5$

Orange solid, m. p. = 65-66 °C. $^1$H NMR (CDCl$_3$, 400MHz): $\delta$ 7.47-7.51 (m, 4H), 7.85-7.88 (m, 4H). $^{13}$C NMR (CDCl$_3$, 100MHz): $\delta$ 150.8, 137.2, 129.4, 124.2.$^6$

Orange solid, m. p. = 184-185 °C. $^1$H NMR (CDCl$_3$, 400MHz): $\delta$ 7.45-7.54 (m, 6H), 7.91-7.94 (m, 4H). $^{13}$C NMR (CDCl$_3$, 100MHz): $\delta$ 152.7, 131.0, 129.1, 122.9.$^6$