Copper(II) accelerated azide-alkyne cycloaddition reaction using mercaptopyridine-based triazole ligands

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Supporting information

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Experimental section

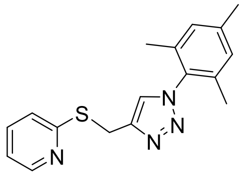
General methods

Commercially available reagents and solvents were used as received. Propargylated mercaptopyridines[1] and mesityl azide[2] were synthesized as reported in the literature. Synthesis of all metal complexes was performed under air. Solvents were dried by standard methods and distilled under nitrogen. IR spectra were recorded on a Bruker Alpha FT-IR/ATR spectrometer. Melting points were determined on a Fisher-Johns apparatus and are uncorrected. NMR spectra were obtained with a Bruker Ascend (400 MHz) spectrometer. Elemental analyses were obtained with a Thermo Finnegan CHNSO-1112 apparatus and a Perkin Elmer Series II CHNS/O 2400 instruments. X-Ray diffraction analyses were collected in an Agilent Gemini Diffractometer using Mo Kα radiation (l = 0.71073 Å). Data were integrated, scaled, sorted, and averaged using the CrysAlisPro software package. The structures we solved using direct methods, using SHELX 2014 and refined by full matrix least squares against F^2.[3] All non hydrogen atoms were refined anisotropically.

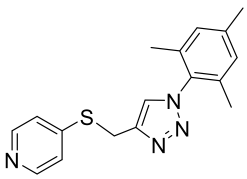
Catalytic trials

General procedure for the Suzuki-Miyarura coupling of aryl chlorides and boronic acids.

Monotriazole preparation. A mixture of the appropriate alkyne (0.1 mmol), mesityl azide (0.11 mmol), and complex **1** (2.5 mol%) were suspended in 5 mL of methanol in a 10 mL glass vial equipped with a small stirring bar. The mixture was then irradiated for 30 min at 60°C using an irradiation power of 30 W. After cooling down to room temperature, the solvent was removed under vacuum and the residue was extracted with 5 mL of DCM and filtered and dried. The residue was washed with petroleum ether to furnish the mono-triazoles as white or yellow solids.

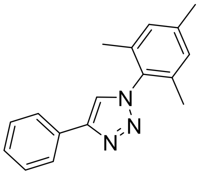


The general procedure afforded the triazole **A** as yellow solid in 89% yield (193 mg, 0.623 mmol). m.p. = 158-160 °C. ^{1}H-NMR (CDCl$_3$, 400 MHz): δ = 1.90 (s, 6H, C*H*$_3$), 2.35 (s, 3H, C*H*$_3$), 4.63 (s, 2H, C*H*$_2$), 6.97 (s, 2H, Ar*H*), 6.99-7.03 (m, 1H, Ar*H*), 7.23 (d, J = 7.5 Hz, 1H, Ar*H*), 7.48-7.52 (m, 1H, Ar*H*), 7.54 (s, 1H, Tz*H*), 8.46 (m, 1H, ArH). ^{13}C-NMR (CDCl$_3$, 100 MHz): δ = 17.5, 24.8, 30.9, 121.7, 122.4, 124.5, 129.0, 133.5, 135.1, 136.1, 139.9, 145.3, 149.4, 158.0. FT-IR/ATR *ν* max cm^{-1}: 3121, 2957, 2925, 2856, 1725, 1602, 1484, 1446, 1372, 1331, 1270, 1213, 1151, 1122, 1071, 1025, 1005, 956, 942, 864. Found: C, 65.53; H 5.89, N 17.98; calc. for: C$_{17}$H$_{18}$N$_4$S C, 65.78; H, 5.85, N 18.05.

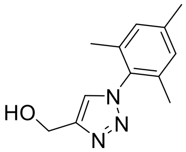


The general procedure afforded the triazole **B** as orange solid in 91% yield (198 mg, 0.637 mmol). m.p. = 172-174 °C. ^{1}H-NMR (CDCl$_3$, 400 MHz): δ = 1.94 (s, 6H, C*H*$_3$), 2.41 (s, 3H, *CH*$_3$), 4.51 (s, 2H, C*H*$_2$), 7.04 (s, 2H, Ar*H*), 7.27 (d, *J* = 8.4 Hz, 2H, Ar*H*), 7.60 (s, 1H, Tz*H*), 8.59 (bs, 1H, Ar*H*). ^{13}C-NMR (CDCl$_3$, 100 MHz): δ = 17.1, 21.0, 26.0, 124.4, 125.6, 128.8, 129.0, 132.0, 133.2, 134.8, 136.8, 140.1, 143.5. FT-

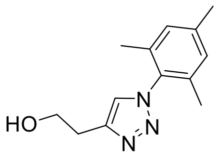
IR/ATR *ν* max cm-1: 3138, 2956, 2911, 2874, 1757, 1621, 1489, 1312, 1307, 1296, 1265, 1218, 1177, 1039, 966, 951, 904, 889. Found: C, 66.02; H 5.49, N 18.34; calc. for: $C_{17}H_{18}N_4S$ C, 65.78; H, 5.85, N 18.05.



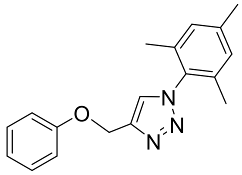
The general procedure afforded the triazole **C** in 99% (261 mg, off white solid). ^{1}H-NMR ($CDCl_3$, 400 MHz): ^{1}H NMR (400 MHz, $CDCl_3$, ppm): δ = 7.93 (d, *J* = 7.0 Hz, 1H, ArH), 7.84 (s, 1H, CH_{tz}), 7.49-7.44 (m, 2H, ArH), 7.39-7.34 (m, 1H, ArH) 7.01 (s, 2H, ArH), 2.37 (s, 3H, CH_3), 2.02 (s, 6H, CH_3). ^{13}C NMR (100 MHz, $CDCl_3$): δ = 147.7, 140.2, 135.2, 133.6, 130.6, 129.2, 129.0, 128.4, 125.8, 121.6, 21.2, 17.4. Spectroscopy data is consistent with the literature.[4]



The general procedure afforded the triazole **D** in 95% (206 mg, clear oil). ^{1}H-NMR ($CDCl_3$, 400 MHz): δ = 1.92 (s, 6H, CH_3). 2.34 (s, 3H, CH_3), 4.25 (s, 1H, OH), 4.90 (bs, 2H, CH2), 6.97 (s, 2H, CH_{ar}), 7.62 (s, 1H, CH_{tz}). ^{13}C-NMR ($CDCl_3$, 100 MHz): δ = 17.2, 21.1, 56.3, 123.8, 129.1, 133.4, 135.0, 140.0, 147.8. Spectroscopy data is consistent with the literature.[5]

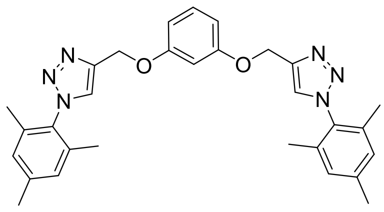


The general procedure afforded the triazole **E** in 97% (224 mg, off white solid). ^{1}H-NMR ($CDCl_3$, 400 MHz): δ = 1.92 (s, 6H, $2CH_3$), 2.34 (s, 3H, CH_3), 3.07 (t, *J* = 6.0 Hz, 2H, CH_2), 4.25 (brs, 1H, OH), 6.99 (s, 2H, CH_{ar}), 7.62 (s, 1H, CH_{tz}). ^{13}C-NMR ($CDCl_3$, 100MHz): δ = 17.2, 21.1, 28.7, 61.6, 123.5, 129.0, 133.5, 135.1, 139.9, 145.4 Spectroscopy data is consistent with the literature.[5]

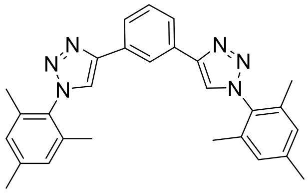


The general procedure afforded the triazole **F** in 96% (282 mg, white solid). m.p. = 156-158 ºC. ^{1}H-NMR ($CDCl_3$, 400 MHz): δ = 1.82 (s, 6H, CH_3), 2.26 (s, 3H, CH_3), 5.24 (s, 2H, CH_2), 6.87 (s, 2H, Ar*H*), 6.88-6.91 (m, 1H, ArH), 6.93 (d, *J* = 8.4 Hz, 2H, Ar*H*), 7.21 (t, *J* = 8.4 Hz, 2H, Ar*H*), 7.54 (s, 1H, Tz*H*). ^{13}C-NMR ($CDCl_3$, 100 MHz): δ = 17.4, 21.2, 62.4, 115.1, 121.4, 124.6, 129.2, 129.6, 133.5, 135.1, 1401.1, 144.3, 158.3. FT-IR/ATR *ν* max cm-1: 3118, 2941, 2931, 2867, 1722, 1643, 1481, 1398, 1315, 1288, 1244, 1212, 1134, 1039, 943, 921, 900, 877. Found: C, 73.21; H 6.49, N 14.30; calc. for: $C_{18}H_{19}N_3O$ C, 73.69; H, 6.53, N 14.32.

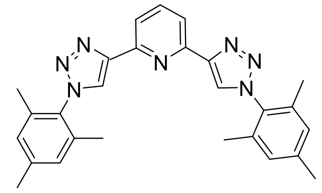
Bis-triazole preparation. A mixture of the appropriate alkyne (0.1 mmol), mesityl azide (0.22 mmol), and complex **1** (5 mol%) were suspended in 5 mL of methanol in a 10 mL glass vial equipped with a small stirring bar. The mixture was then irradiated for 30 min at 60°C using an irradiation power of 30 W. After cooling down to room temperature, the solvent was removed under vacuum and the residue was extracted with 5 mL of DCM and filtered. The residue was washed with petroleum ether to furnish the bis-triazoles as white or yellow solids.



The general procedure afforded the triazole **G** in 87% (442 mg, beige solid). m. p. = 171-173 °C. ^{1}H-NMR (CDCl$_3$, 400 MHz): δ = 1.86 (s, 12H, C*H*$_3$), 2.26 (s, 6H, *CH*$_3$), 5.22 (s, 4H, C*H*$_2$), 6.56-6.59 (m, 2H, Ar*H*), 6.63 (t, *J* = 7.8 Hz, 1H, ArH), 6.90 (s, 4H, Ar*H*), 7.12 (t, *J* = 8.4 Hz, 1H, Ar*H*), 7.57 (s, 2H, Tz*H*). ^{13}C-NMR (CDCl$_3$, 100 MHz): δ = 17.4, 21.2, 62.4, 102.7, 107.9, 124.7, 129.2, 130.1, 133.5, 135.1, 140.2, 144.1, 159.6. IR/ATR *v* max cm-1: 3109, 2987, 2913, 2871, 1746, 1687, 1412, 1401, 1321, 1277, 1219, 1188, 1166, 943, 921, 871. Found: C, 71.01; H 6.12, N 16.30; calc. for: $C_{30}H_{32}N_6O_2$ C, 70.84; H, 6.34, N 16.52.

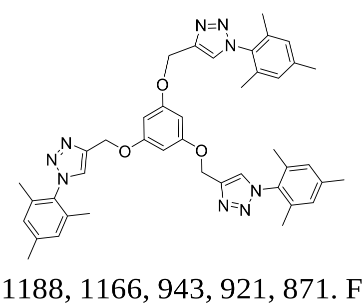


The general procedure afforded the triazole **H** in 96% (175 mg, white solid). ^{1}H-NMR (CDCl$_3$, 400 MHz): δ = 8.47 (s, 1H, ArH), 8.00 (s, 2H, CH$_{tz}$), 7.94 (dd, 4 *J* = 1.3 Hz, 3 *J* = 7.7 Hz, 2H, ArH), 7.57 (t, 3 *J* = 7.8 Hz, 1H, ArH), 7.05 (s, 4H, ArH), 2.38 (s, 6H, CH$_3$), 2.02 (s, 12H, CH$_3$). ^{13}C-NMR (100 MHz, CDCl$_3$): δ 147.6, 140.8, 135.6, 134.1, 132.0, 130.1, 129.6, 125.9, 123.4, 122.7, 21.4, 17.6. Spectroscopy data is consistent with the literature.[6]



The general procedure afforded the triazole **I** in 93% (184 mg, white solid). ^{1}H-NMR (CDCl$_3$, 400 MHz): δ = 8.28 (s, 2H, CH$_{tz}$), 8.19 (d, *J* = 7.8 Hz, 2H, PyH), 7.96 (t, 3 *J* = 7.8 Hz, 1H, Py-H), 7.03, (s, 4H, ArH), 2.36 (s, 6H, CH$_3$), 2.00 (s, 12H, CH$_3$); ^{13}C-NMR (100 MHz, CDCl$_3$): δ = 150.3, 148.2, 140.3, 137.9, 135.1, 133.5, 129.1, 124.4, 119.2, 20.9, 17.1. Spectroscopy data is consistent with the literature.[7]

Tris-triazole preparation. A mixture of the appropriate alkyne (0.1 mmol), mesityl azide (0.33 mmol), and complex **1** (5 mol%) were suspended in 5 mL of methanol in a 10 mL glass vial equipped with a small stirring bar. The mixture was then irradiated for 45 min at 60°C using an irradiation power of 30 W. After cooling down to room temperature, the solvent was removed under vacuum and the residue was extracted with 5 mL of DCM and filtered. The residue was washed with petroleum ether to furnish the respective tris-triazole as a white solid.



The general procedure afforded the triazole **J** in 83% (601 mg, white solid). m.p. = 192-194 °C. ^{1}H-NMR (CDCl$_3$, 400 MHz): δ = 1.87 (s, 18H, C*H*$_3$), 2.27 (s, 9H, *CH*$_3$), 5.19 (s, 6H, C*H*$_2$), 6.30 (s, 3H, Ar*H*), 6.90 (s, 6H, Ar*H*), 7.60 (s, 3H, Tz*H*). ^{13}C-NMR (CDCl$_3$, 100 MHz): δ = 17.4, 21.2, 62.4, 95.6, 124.8, 129.2, 133.5, 135.1, 140.2, 143.9, 160.3. IR/ATR *v* max cm-1: 3109, 2987, 2913, 2871, 1746, 1687, 1412, 1401, 1321, 1277, 1219, 1188, 1166, 943, 921, 871. Found: C, 69.45; H 6.72, N 17.70; calc. for: $C_{42}H_{45}N_9O_3$ C, 69.69; H, 6.27, N 17.41.

References:

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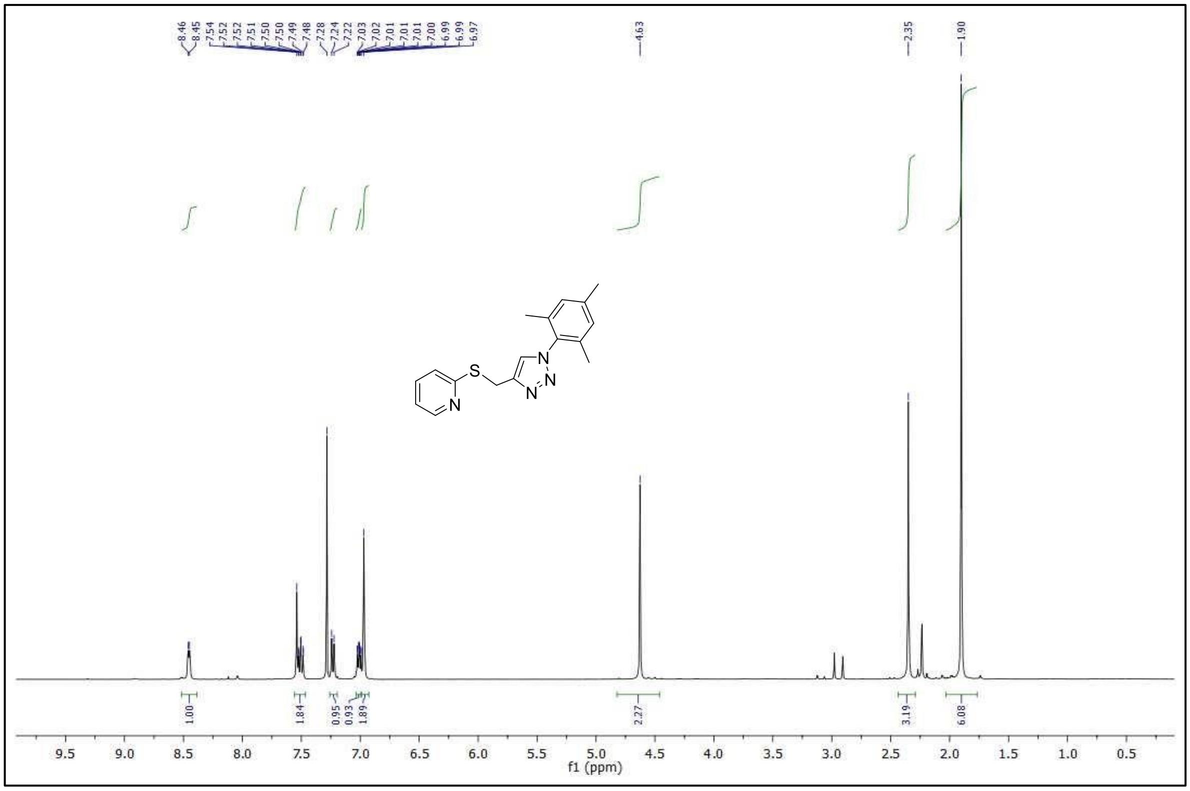

Figure S1. ^{1}H NMR (400 MHz) spectrum for **A** in $CDCl_3$.

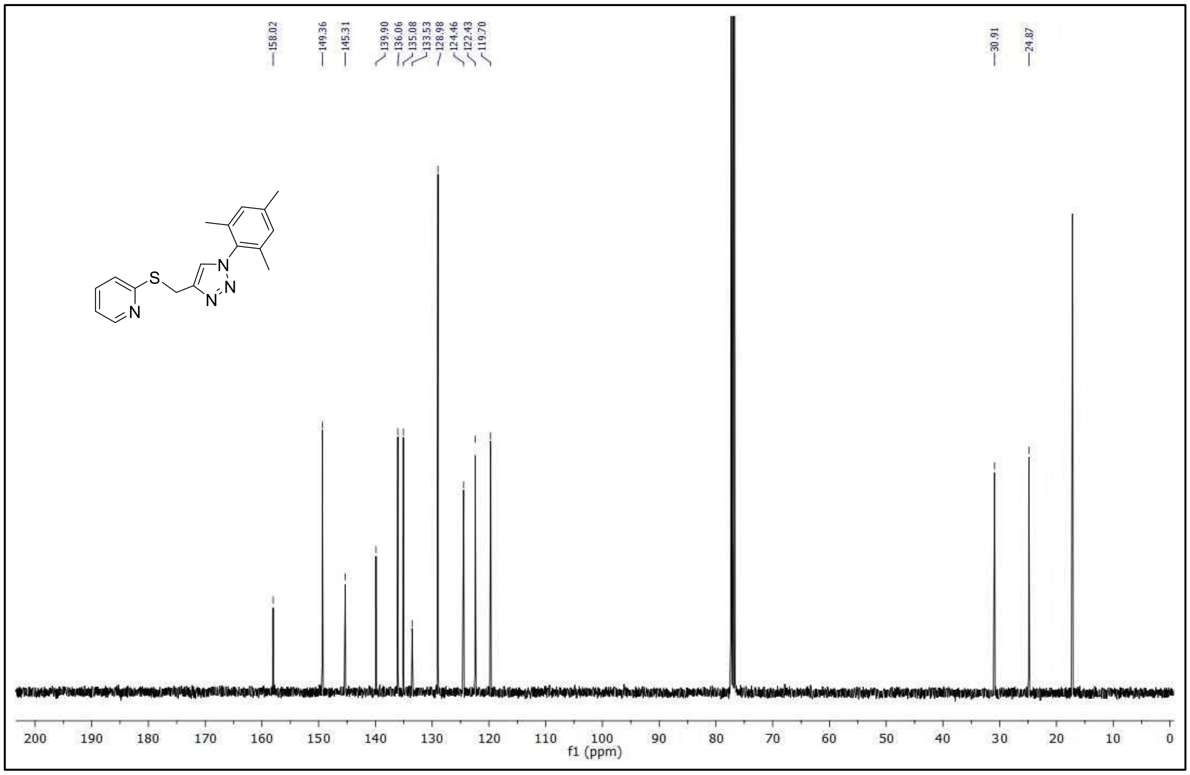

Figure S2. ^{13}C NMR (100 MHz) spectrum for **A** in $CDCl_3$

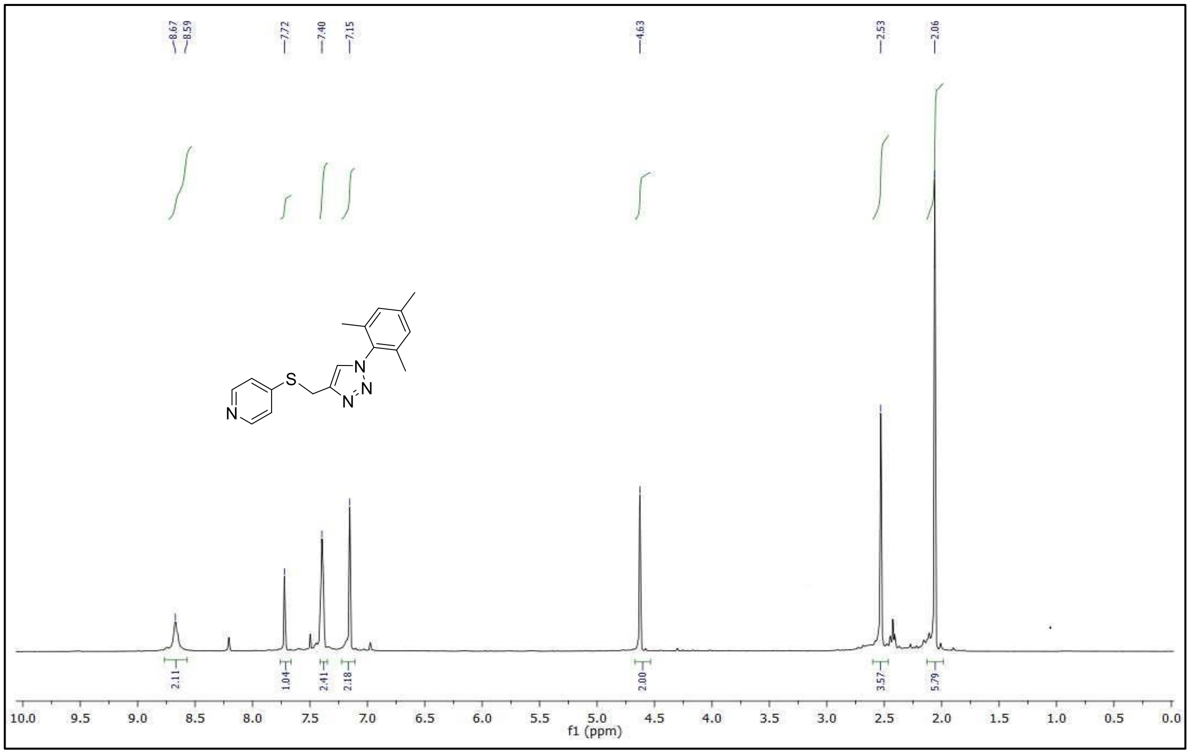

Figure S3. ^{1}H NMR (400 MHz) spectrum for **B** in $CDCl_3$.

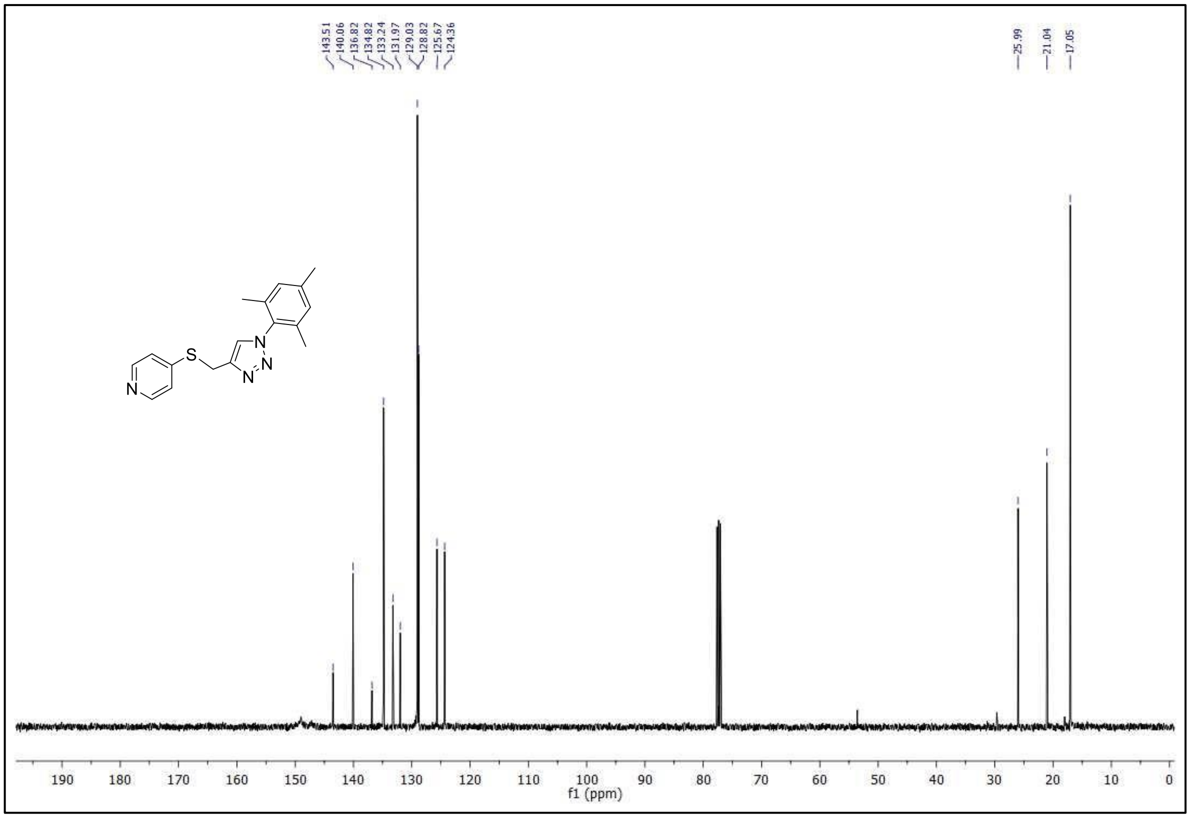

Figure S4. ^{13}C NMR (100 MHz) spectrum for **B** in $CDCl_3$

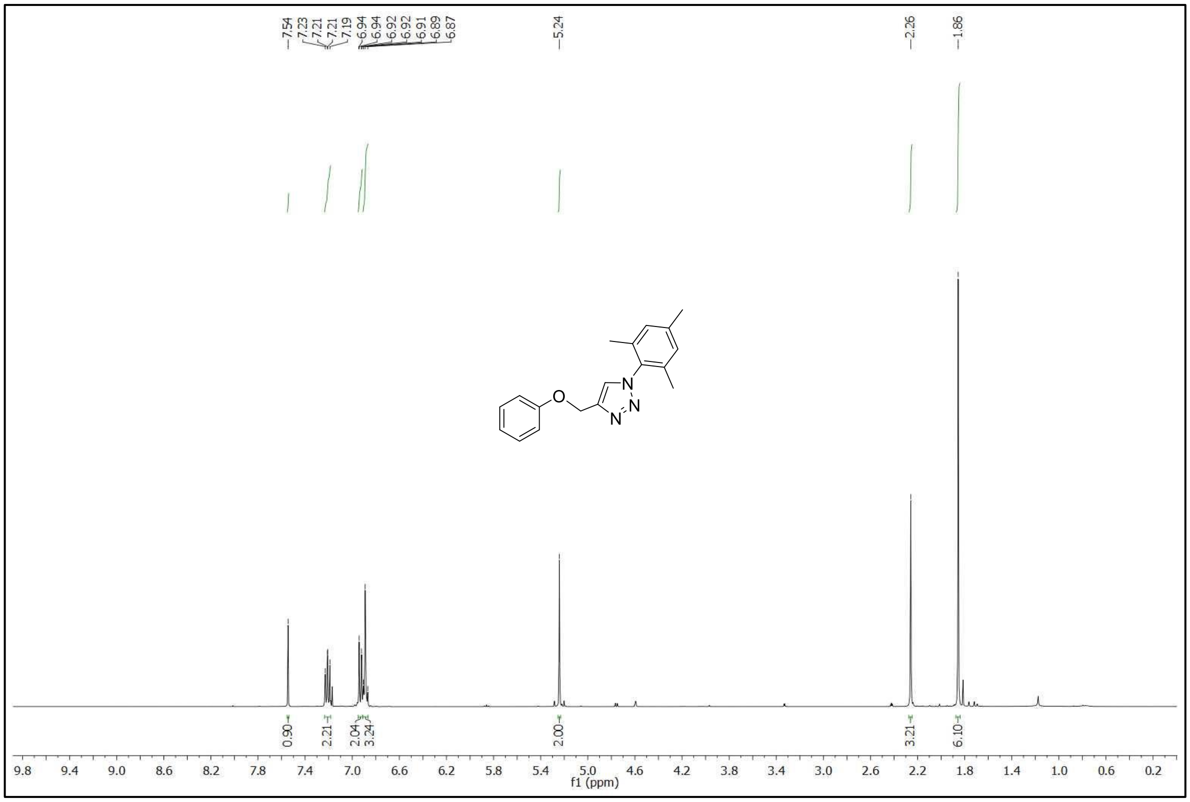

Figure S5. ^{1}H NMR (400 MHz) spectrum for **F** in $CDCl_3$.

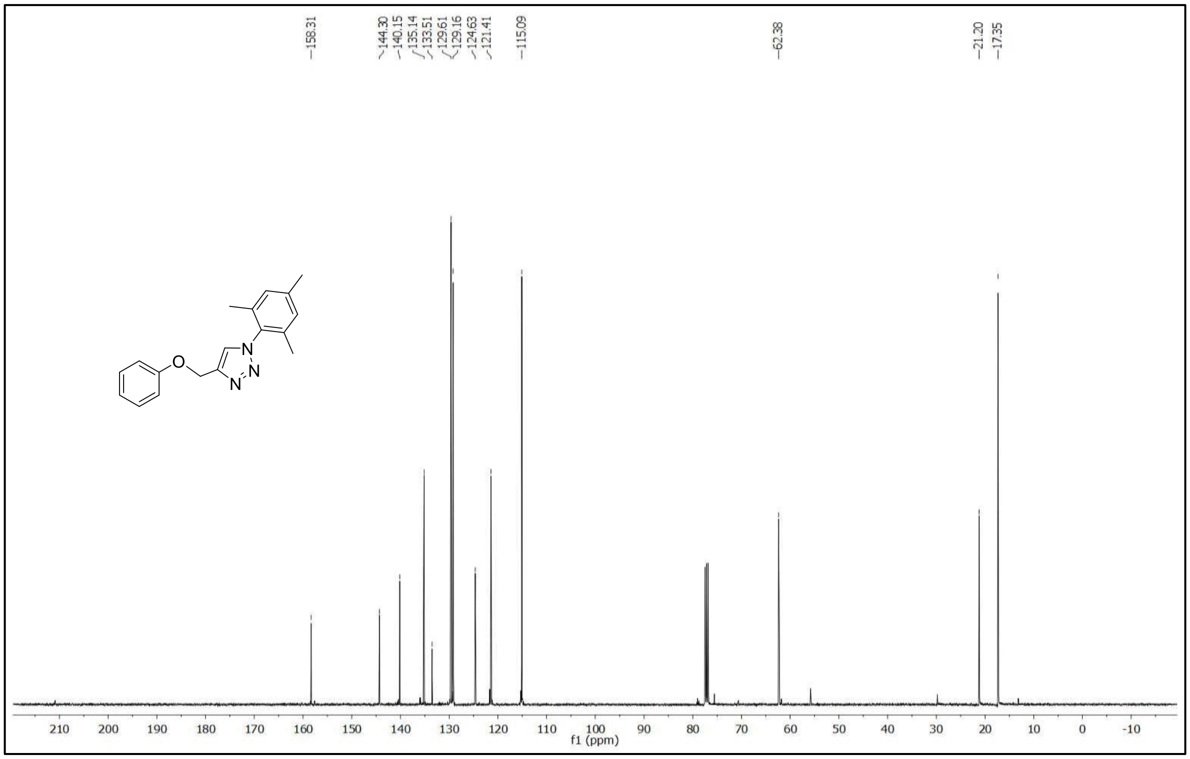

Figure S6. ^{13}C NMR (100 MHz) spectrum for **F** in $CDCl_3$

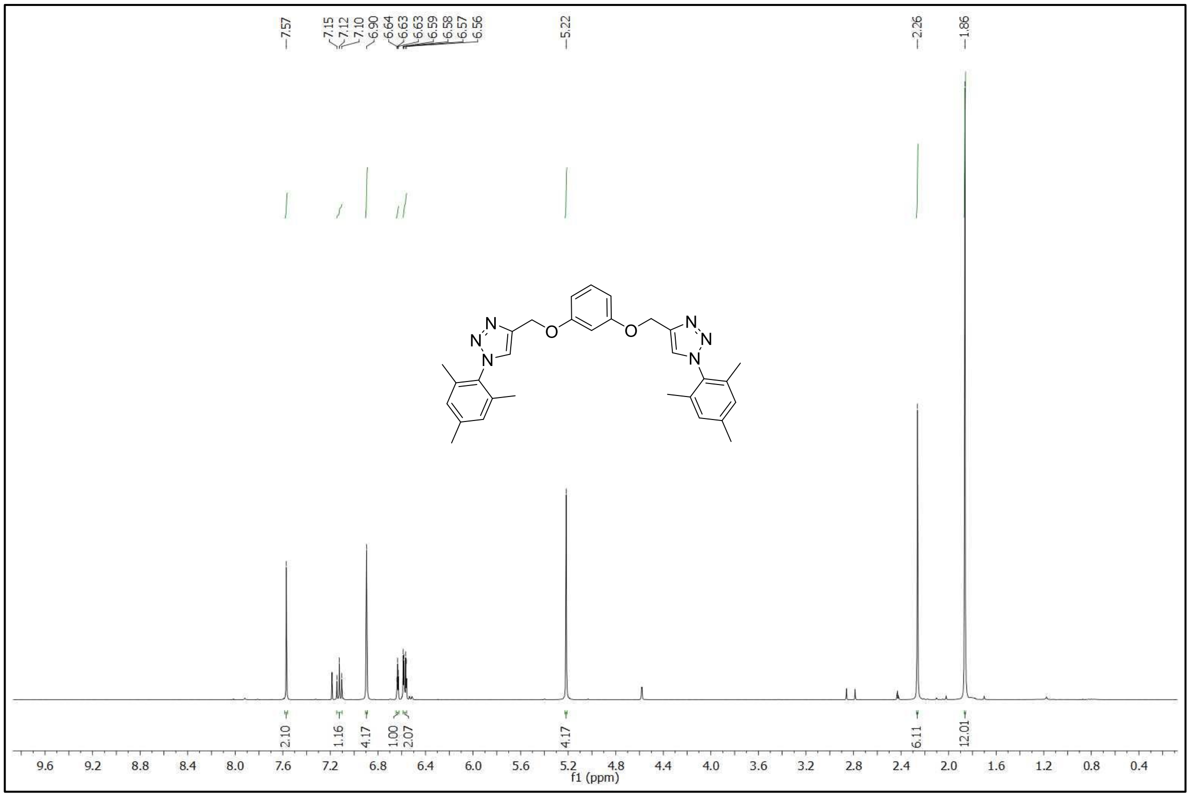

Figure S7. ^{1}H NMR (400 MHz) spectrum for **G** in $CDCl_3$.

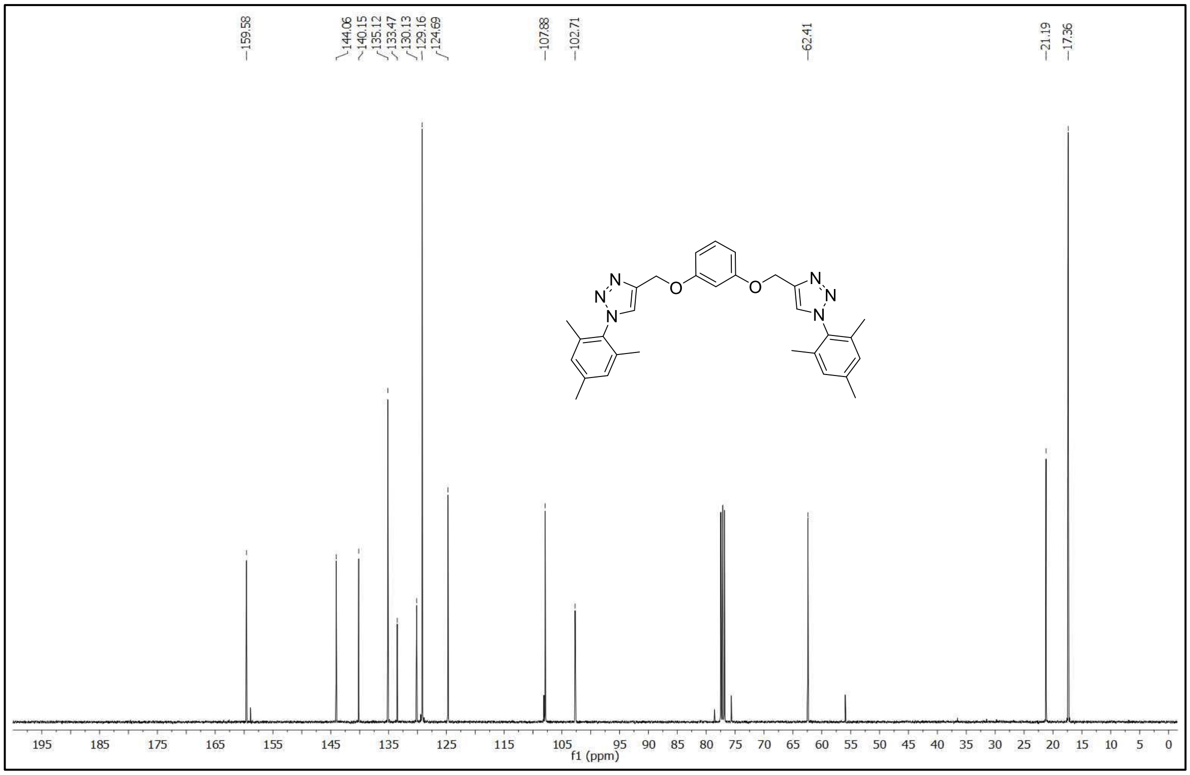

Figure S8. ^{13}C NMR (100 MHz) spectrum for **G** in $CDCl_3$

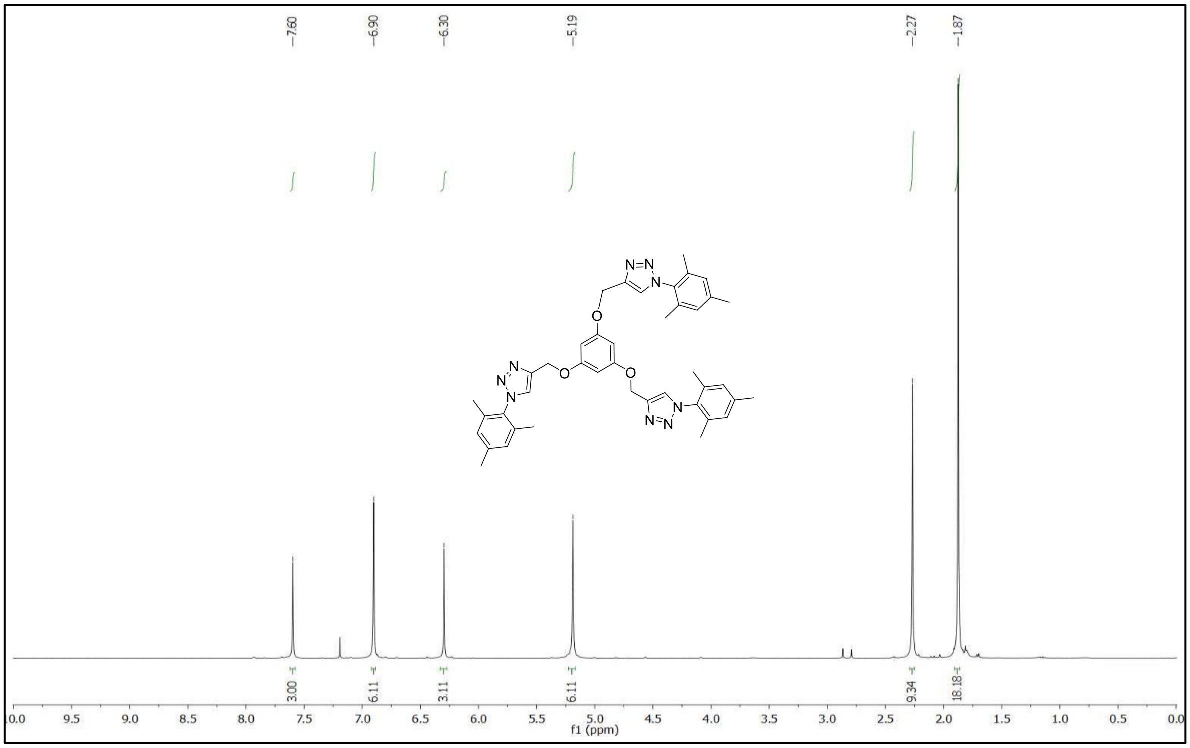

Figure S9. ^{1}H NMR (400 MHz) spectrum for **J** in CDCl$_{3.}$

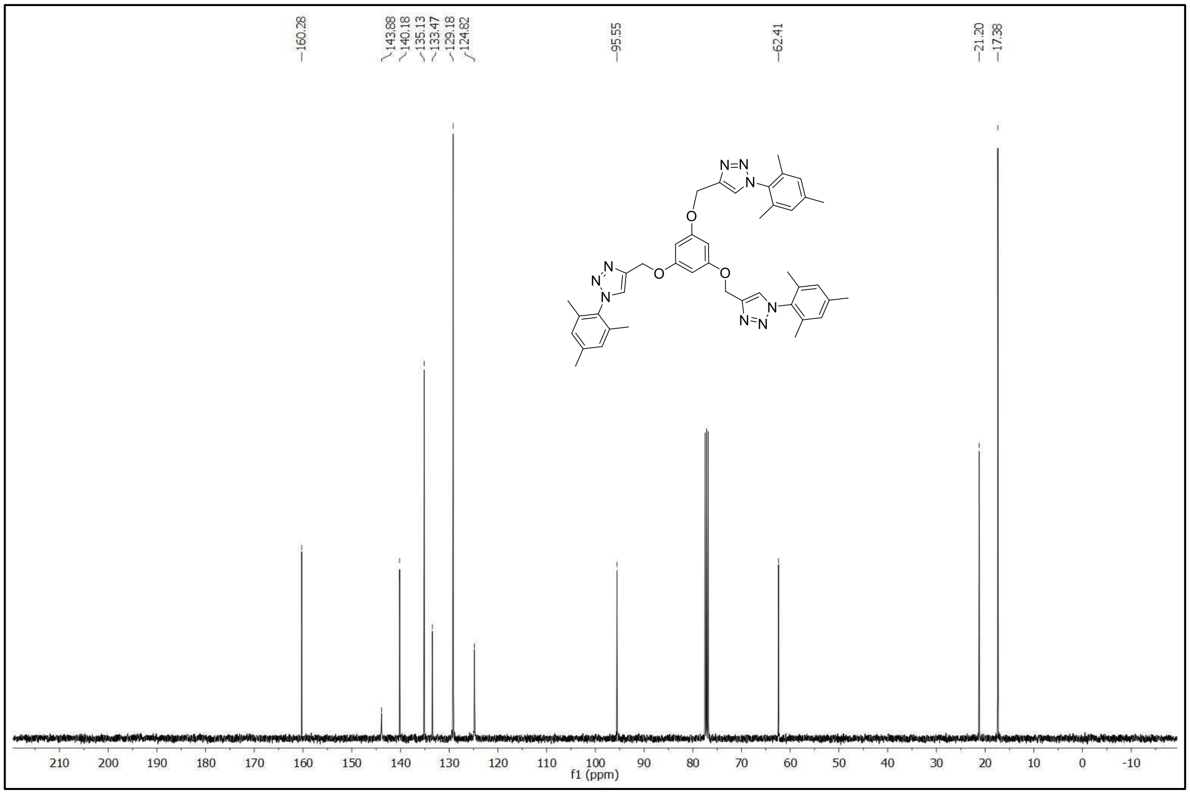

Figure S10. ^{13}C NMR (100 MHz) spectrum for **J** in CDCl$_3$