KIO_3-catalyzed cross dehydrogenative coupling reaction: sulfenylation of phenol and arylamine derivatives in water at room temperature

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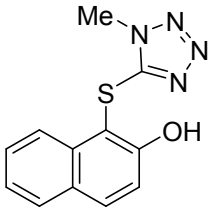
Experimental Section

General Information: Melting points were determined on a unimelt capillary melting point apparatus and reported uncorrectedly. All compounds were fully characterized by spectroscopic data. The NMR spectra were recorded on a Bruker Avance III (^{1}H: 400 MHz, ^{13}C: 101 MHz), chemical shifts (δ) are expressed in ppm, and J values are given in Hz, and DMSO-d_6 was used as solvent. The reactions were monitored by thin layer chromatography (TLC) using silica gel GF254. HRMS (ESI) analysis was measured on a LCMS-IT-TOF instrument. All chemicals and solvents were used as received without further purification unless otherwise stated. IR spectra were recorded on a Thermo Scientific Nicolet 6700 Fourier IR spectrometer (ATIR) in KBr pellet.

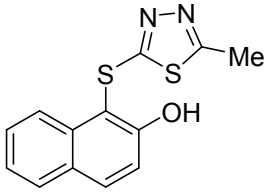
General procedure for preparation of targeted molecules

A mixture of arenes **1** (0.5 mmol), heterocyclic thiols or thiones **2** (0.5 mmol), and KIO_3 (0.1 mmol) in water (2 mL) was stirred at room temperature for 15 h. After the reaction was finished, the mixture was extracted with EtOAc (3 × 10 mL) and then dried over anhydrous sodium sulfate and filtered. After evaporation of the solvent under vacuum, the residue was subjected to flash column chromatography on silica gel to afford products **3-5**

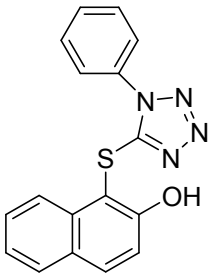
1 Characterization Data



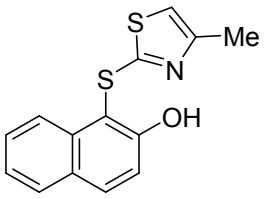
1-((1-methyl-1H-tetrazol-5-yl)thio)naphthalen-2-ol **3a**, eluent: 50% EtOAc/PE, white solid, mp: 209-210 °C, yield 82% (105.8 mg). ^{1}H NMR (400 MHz, DMSO-d_6) δ 10.79 (s, 1H), 8.24 (dd, J = 8.5, 1.0 Hz, 1H), 7.98 (d, J = 8.9 Hz, 1H), 7.90 (d, J = 8.0 Hz, 1H), 7.61 – 7.53 (m, 1H), 7.43 – 7.34 (m, 1H), 7.29 (d, J = 8.9 Hz, 1H), 4.04 (s, 3H). ^{13}C NMR (101 MHz, DMSO-d_6) δ 157.95, 152.99, 135.25, 132.81, 128.60, 128.53, 127.95, 123.59, 123.48, 118.31, 103.80, 33.97. HRMS (ESI) [M-H]$^-$ Calcd for $C_{12}H_9N_4OS$ 257.0503, found 257.0501. IR (KBr) ν 3132, 1619, 1503, 1349, 1285, 814, 750, 701 cm^{-1}.



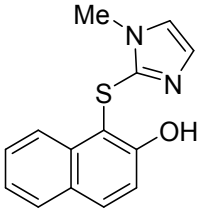
1-((5-methyl-1,3,4-thiadiazol-2-yl)thio)naphthalen-2-ol **3b**, 25% EtOAc/PE, white solid, mp: 183-184 °C, yield 70% (95.9 mg). ^{1}H NMR (400 MHz, DMSO-d_6) δ 11.02 (s, 1H), 8.21 (d, J = 8.5 Hz, 1H), 8.02 (d, J = 8.9 Hz, 1H), 7.89 (d, J = 8.1 Hz, 1H), 7.65 – 7.50 (m, 1H), 7.45 – 7.26 (m, 2H), 2.48 (s, 3H). ^{13}C NMR (101 MHz, DMSO-d_6) δ 168.94, 165.41, 158.53, 135.02, 133.71, 128.82, 128.68, 128.42, 123.77, 123.25, 118.58, 107.05, 15.16. HRMS (ESI) [M-H]$^-$ Calcd for $C_{13}H_9N_2OS_2$ 273.0162, found 273.0160. IR (KBr) ν 3445, 1622, 1387, 1196, 1078, 823, 744, 476 cm^{-1}.



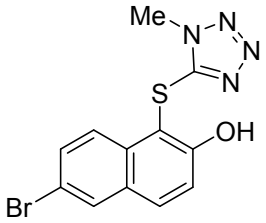
1-((1-phenyl-1H-tetrazol-5-yl)thio)naphthalen-2-ol **3c**, 25% EtOAc/PE, white solid, mp: 119-120 °C, yield 84% (134.4 mg). ^{1}H NMR (400 MHz, DMSO-d_6) δ 10.73 (s, 1H), 8.14 (d, J = 8.5 Hz, 1H), 7.98 (d, J = 8.9 Hz, 1H), 7.89 (d, J = 8.0 Hz, 1H), 7.81 – 7.76 (m, 2H), 7.69 – 7.62 (m, 3H), 7.59 – 7.49 (m, 1H), 7.46 – 7.34 (m, 1H), 7.26 (d, J = 8.9 Hz, 1H). ^{13}C NMR (101 MHz, DMSO-d_6) δ 158.12, 153.84, 135.27, 133.32, 132.99, 130.54, 129.91, 128.51, 128.50, 127.92, 124.66, 123.57, 123.43, 118.34, 103.14. HRMS (ESI) [M-H]$^-$ Calcd for $C_{17}H_{11}N_4OS$ 319.0659, found 319.0650. IR (KBr) ν 3139, 1622, 1500, 1376, 1285, 818, 759, 690 cm^{-1}.



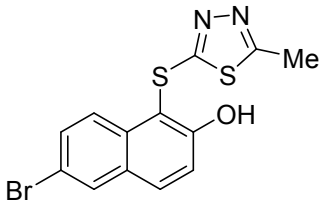
1-((4-methylthiazol-2-yl)thio)naphthalen-2-ol **3d**, 12% EtOAc/PE, white solid, mp: 125-126 °C, yield 67% (91.5 mg). ^{1}H NMR (400 MHz, DMSO-d_6) δ 10.76 (s, 1H), 8.21 (d, J = 8.5 Hz, 1H), 8.02 (d, J = 9.0 Hz, 1H), 7.90 (dd, J = 8.2, 1.3 Hz, 1H), 7.60 – 7.50 (m, 1H), 7.43 – 7.30 (m, 2H), 6.91 (d, J = 1.3 Hz, 1H), 2.27 (s, 3H). ^{13}C NMR (101 MHz, DMSO-d_6) δ 166.24, 158.66, 152.54, 135.32, 133.46, 128.66, 128.63, 128.13, 123.55, 123.43, 118.60, 113.99, 106.73, 16.95. HRMS (ESI) $[M+H]^+$ Calcd for $C_{14}H_{12}NOS_2$ 274.0355, found 274.0364. IR (KBr) ν 3114, 3057, 2922, 1602, 1382, 1208, 1064, 736 cm^{-1}.



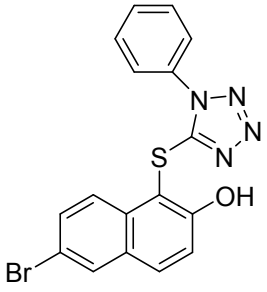
1-((1-methyl-1H-imidazol-2-yl)thio)naphthalen-2-ol **3e**, 25% EtOAc/PE, white solid, mp: 156-157 °C, yield 69% (88.3 mg). ^{1}H NMR (400 MHz, DMSO-d_6) δ 10.78 (s, 1H), 8.54 (d, J = 8.6 Hz, 1H), 7.90 – 7.78 (m, 2H), 7.57 – 7.48 (m, 1H), 7.38 – 7.29 (m, 1H), 7.24 (d, J = 8.8 Hz, 1H), 7.19 (d, J = 1.3 Hz, 1H), 6.87 (d, J = 1.2 Hz, 1H), 3.69 (s, 3H). ^{13}C NMR (101 MHz, DMSO-d_6) δ 166.24, 158.66, 152.54, 135.32, 133.46, 128.66, 128.63, 128.13, 123.55, 123.43, 118.60, 113.99, 106.73, 16.95. HRMS (ESI) $[M-H]^-$ Calcd for $C_{14}H_{11}N_2OS$ 255.0598, found 255.0599. IR (KBr) ν 3424, 2926, 2543, 1615, 1443, 1344, 1281, 1126, 756, 489 cm^{-1}.



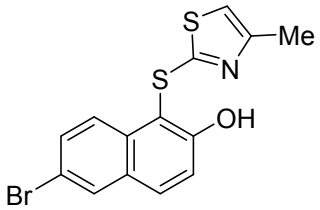
6-bromo-1-((1-methyl-1H-tetrazol-5-yl)thio)naphthalen-2-ol **3f**, 25% EtOAc/PE, white solid, mp: 187-189 °C, yield 80% (134.4 mg). ^{1}H NMR (400 MHz, DMSO-d_6) δ 10.98 (s, 1H), 8.23 – 8.12 (m, 2H), 7.97 (d, J = 9.0 Hz, 1H), 7.67 (dd, J = 9.1, 2.1 Hz, 1H), 7.33 (d, J = 9.0 Hz, 1H), 4.05 (s, 3H). ^{13}C NMR (101 MHz, DMSO-d_6) δ 158.37, 152.80, 134.06, 131.98, 130.66, 130.27, 129.72, 126.09, 119.55, 116.33, 104.26, 33.99. HRMS (ESI) $[M-H]^-$ Calcd for $C_{12}H_8BrN_4OS$ 334.9608, found 334.9608. IR (KBr) ν 3436, 3119, 1487, 1339, 1281, 1193, 1075, 815, 705 cm^{-1}.



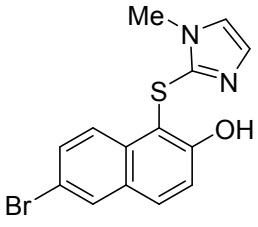
6-bromo-1-((5-methyl-1,3,4-thiadiazol-2-yl)thio)naphthalen-2-ol **3g**, 25% EtOAc/PE, white solid, mp: 182-183 °C, yield 86% (151.3 mg).^{1}H NMR (400 MHz, DMSO-d_6) δ 11.17 (s, 1H), 8.22 (d, J = 2.1 Hz, 1H), 8.19 (d, J = 9.0 Hz, 1H), 8.06 (d, J = 9.0 Hz, 1H), 7.72 (dd, J = 9.0, 2.1 Hz, 1H), 7.43 (d, J = 9.0 Hz, 1H), 2.55 (s, 3H). ^{13}C NMR (101 MHz, DMSO-d_6) δ 168.24, 165.37, 158.85, 133.74, 132.73, 131.04, 130.40, 129.76, 125.67, 119.77, 116.53, 107.23, 15.10. HRMS (ESI) [M-H]$^-$ Calcd for $C_{13}H_8NBr_2OS_2$ 350.9267, found 350.9259. IR (KBr) ν 3432, 2924, 1588, 1385, 1198, 1075, 818, 527 cm^{-1}.



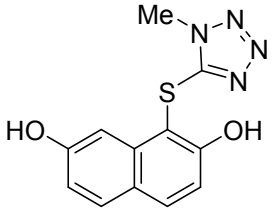
6-bromo-1-((1-phenyl-1H-tetrazol-5-yl)thio)naphthalen-2-ol **3h**, 33% EtOAc/PE, white solid, mp: 188-189 °C, yield 83% (165.2 mg). ^{1}H NMR (400 MHz, DMSO-d_6) δ 10.94 (s, 1H), 8.17 (d, J = 2.1 Hz, 1H), 8.09 (d, J = 9.0 Hz, 1H), 7.96 (d, J = 9.0 Hz, 1H), 7.82 – 7.73 (m, 2H), 7.68 – 7.60 (m, 4H), 7.30 (d, J = 9.0 Hz, 1H). ^{13}C NMR (101 MHz, DMSO-d_6) δ 158.98, 154.08, 134.54, 133.71, 132.65, 131.09, 131.04, 130.65, 130.39, 130.14, 126.59, 125.11, 120.04, 116.74, 104.01. HRMS (ESI) [M-H]$^-$ Calcd for $C_{17}H_{10}BrN_4OS$ 396.9764, found 396.9759. IR (KBr) ν 3429, 3149, 1495, 1395, 1337, 1244, 1072, 809, 693, 482 cm^{-1}.



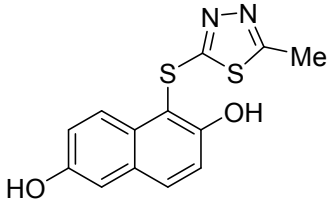
6-bromo-1-((4-methylthiazol-2-yl)thio)naphthalen-2-ol **3i**, 25% EtOAc/PE, white solid, mp: 134-135 °C, yield 68% (119.3 mg). ^{1}H NMR (400 MHz, DMSO-d_6) δ 10.96 (s, 1H), 8.23 – 8.08 (m, 2H), 8.01 (d, J = 9.0 Hz, 1H), 7.71 – 7.58 (m, 1H), 7.39 (d, J = 9.0 Hz, 1H), 6.93 (s, 1H), 2.26 (s, 3H). ^{13}C NMR (101 MHz, DMSO-d_6) δ 165.67, 159.05, 152.62, 134.13, 132.60, 130.87, 130.34, 129.82, 125.94, 119.85, 116.43, 114.15, 107.09, 16.92. HRMS (ESI) [M-H]$^-$ Calcd for $C_{14}H_9BrNOS_2$ 349.9314, found 349.9315. IR (KBr) ν 3103, 2921, 1589, 1379, 1174, 1027, 812, 752 cm^{-1}.



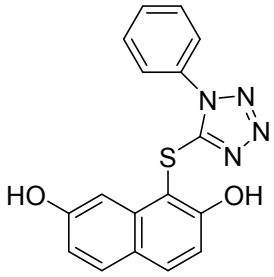
6-bromo-1-((1-methyl-1H-imidazol-2-yl)thio)naphthalen-2-ol **3j**, 33% EtOAc/PE, white solid, mp: 201-202 °C, yield 65% (108.5 mg). ^{1}H NMR (400 MHz, DMSO-d_6) δ 10.82 (s, 1H), 8.49 (d, J = 9.1 Hz, 1H), 8.08 (d, J = 2.1 Hz, 1H), 7.84 (d, J = 9.0 Hz, 1H), 7.63 (dd, J = 9.1, 2.1 Hz, 1H), 7.28 (d, J = 8.9 Hz, 1H), 7.20 (d, J = 1.3 Hz, 1H), 6.87 (d, J = 1.3 Hz, 1H), 3.69 (s, 3H). ^{13}C NMR (101 MHz, DMSO-d_6) δ 157.53, 139.01, 134.08, 130.69, 130.05, 129.97, 129.84, 128.37, 127.03, 123.67, 119.95, 116.20, 109.07, 33.43. HRMS (ESI) $[M+H]^+$ Calcd for $C_{14}H_{12}BrN_2OS$ 234.9848, found 234.9848. IR (KBr) ν 3438, 2924, 2516, 1610, 1482, 1338, 1276, 1133, 934, 811, 742, 690 cm^{-1}.



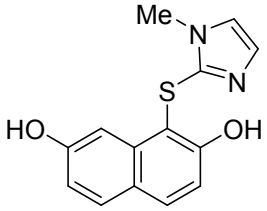
1-((1-methyl-1H-tetrazol-5-yl)thio)naphthalene-2,7-diol **3k**, 50% EtOAc/PE, white solid, mp: 214-215 °C, yield 84% (115.1 mg). ^{1}H NMR (400 MHz, DMSO-d_6) δ 10.62 (s, 1H), 9.94 (s, 1H), 7.81 (d, J = 8.8 Hz, 1H), 7.72 (d, J = 8.8 Hz, 1H), 7.48 (d, J = 2.3 Hz, 1H), 7.03 (d, J = 8.8 Hz, 1H), 6.92 (dd, J = 8.7, 2.4 Hz, 1H), 4.03 (s, 3H). ^{13}C NMR (101 MHz, DMSO-d_6) δ 158.44, 157.42, 153.09, 137.43, 132.64, 130.49, 123.04, 115.71, 114.68, 105.75, 101.80, 33.99. HRMS (ESI) $[M-H]^-$ Calcd for $C_{12}H_9N_4O_2S$ 273.0452, found 273.0452. IR (KBr) ν 3283, 1622, 1525, 1402, 1323, 1210, 826 cm^{-1}.



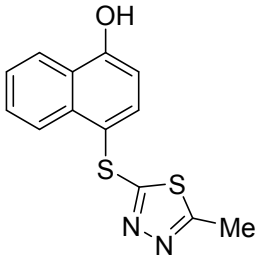
1-((5-methyl-1,3,4-thiadiazol-2-yl)thio)naphthalene-2,6-diol **3l**, 33% EtOAc/PE, white solid, mp: 182-183 °C, yield 85% (123.3 mg). ^{1}H NMR (400 MHz, DMSO-d_6) δ 10.53 (s, 1H), 9.67 (s, 1H), 8.07 (d, J = 9.9 Hz, 1H), 7.81 (d, J = 8.9 Hz, 1H), 7.26 (d, J = 9.0 Hz, 1H), 7.20 – 7.05 (m, 2H), 2.50 (s, 3H). ^{13}C NMR (101 MHz, DMSO-d_6) δ 169.28, 165.26, 156.00, 153.75, 131.85, 130.04, 128.95, 124.84, 120.44, 118.82, 110.28, 107.06, 15.15. HRMS (ESI) $[M-H]^-$ Calcd for $C_{13}H_9N_2O_2S_2$ 289.0111, found 289.0106. IR (KBr) ν 3379, 2923, 1603, 1382, 1195, 1123, 812, 610 cm^{-1}.



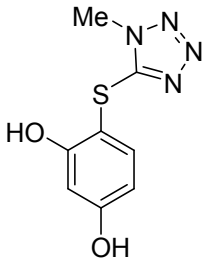
1-((1-phenyl-1H-tetrazol-5-yl)thio)naphthalene-2,7-diol **3m**, 25% EtOAc/PE, white solid, mp: 221-223 °C, yield 80% (134.4 mg). ^{1}H NMR (400 MHz, DMSO-d_6) δ 10.58 (s, 1H), 9.90 (s, 1H), 7.84 – 7.74 (m, 3H), 7.73 – 7.61 (m, 4H), 7.38 (d, J = 2.3 Hz, 1H), 7.01 (d, J = 8.8 Hz, 1H), 6.92 (dd, J = 8.7, 2.3 Hz, 1H). ^{13}C NMR (101 MHz, DMSO-d_6) δ 158.71, 157.41, 153.99, 137.44, 133.37, 132.89, 130.62, 130.46, 130.02, 124.60, 123.06, 115.66, 114.77, 105.69, 101.04. HRMS (ESI) [M-H]$^-$ Calcd for $C_{17}H_{11}N_4O_2S$ 335.0608, found 335.0602. IR (KBr) ν 3371, 3187, 2925, 1629, 1512, 1389, 1311, 1152 cm^{-1}.



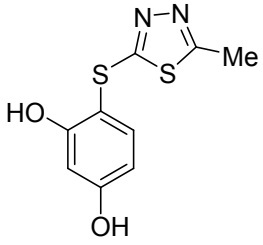
1-((1-methyl-1H-imidazol-2-yl)thio)naphthalene-2,7-diol **3n**, 33% EtOAc/PE, white solid, mp: 201-202 °C, yield 78% (106.1 mg). ^{1}H NMR (400 MHz, DMSO-d_6) δ 10.44 (s, 1H), 9.84 (s, 1H), 7.81 (d, J = 2.4 Hz, 1H), 7.67 (dd, J = 19.9, 8.8 Hz, 2H), 7.19 (d, J = 1.3 Hz, 1H), 6.97 (d, J = 8.8 Hz, 1H), 6.91 – 6.83 (m, 2H), 3.71 (s, 3H). ^{13}C NMR (101 MHz, DMSO-d_6) δ 157.65, 156.86, 139.58, 137.35, 131.27, 130.01, 128.15, 123.44, 123.13, 115.48, 115.24, 106.87, 106.63, 33.43. HRMS (ESI) [M-H]$^-$ Calcd for $C_{14}H_{11}N_2O_2S$ 271.0547, found 271.0140. IR (KBr) ν 3375, 2921, 2600, 1623, 1521, 1456, 1354, 1197, 821, 487 cm^{-1}.



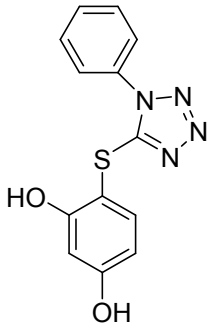
4-((5-methyl-1,3,4-thiadiazol-2-yl)thio)naphthalen-1-ol **3o**, 33% EtOAc/PE, white solid, mp: 193-194 °C, yield 76% (104.1 mg). ^{1}H NMR (400 MHz, DMSO-d_6) δ 11.08 (s, 1H), 8.34 – 8.12 (m, 2H), 7.91 (d, J = 8.0 Hz, 1H), 7.72 – 7.61 (m, 1H), 7.62 – 7.51 (m, 1H), 6.98 (d, J = 8.0 Hz, 1H), 2.49 (s, 3H). ^{13}C NMR (101 MHz, DMSO-d_6) δ 169.86, 165.59, 157.09, 137.42, 134.51, 128.49, 125.84, 125.70, 124.47, 123.14, 114.95, 108.67, 15.13. HRMS (ESI) [M-H]$^-$ Calcd for $C_{13}H_9N_2OS_2$ 273.0162, found 273.0155. IR (KBr) ν 2924, 1570, 1353, 1263, 1097, 828, 756 cm^{-1}.



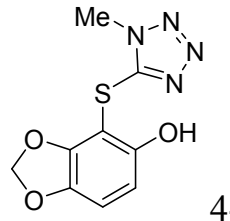
2-((1-methyl-1H-tetrazol-5-yl)thio)benzene-1,3-diol **3p**, 50% EtOAc/PE, white solid, mp: 165-167 °C, yield 75% (84.0 mg). ^{1}H NMR (400 MHz, DMSO-d_6) δ 10.15 (s, 1H), 9.85 (s, 1H), 7.28 (d, J = 8.5 Hz, 1H), 6.49 – 6.36 (m, 1H), 6.36 – 6.20 (m, 1H), 3.95 (s, 3H). ^{13}C NMR (101 MHz, DMSO-d_6) δ 160.91, 159.11, 153.38, 136.76, 108.12, 103.20, 101.60, 33.98. HRMS (ESI) [M-H]$^-$ Calcd for $C_8H_7N_4O_2S$ 223.0295, found 223.0292. IR (KBr) ν 3351, 3285, 1598, 1460, 1287, 1184, 979, 861, 651 cm^{-1}.



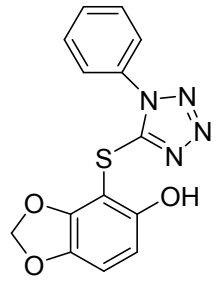
2-((5-methyl-1,3,4-thiadiazol-2-yl)thio)benzene-1,3-diol **3q**, 25% EtOAc/PE, white solid, mp: 213-215 °C, yield 65% (78.0 mg). ^{1}H NMR (400 MHz, DMSO-d_6) δ 10.33 (s, 1H), 10.03 (s, 1H), 7.33 (d, J = 8.4 Hz, 1H), 6.47 (d, J = 2.4 Hz, 1H), 6.33 (dd, J = 8.5, 2.5 Hz, 1H), 2.54 (s, 3H). ^{13}C NMR (101 MHz, DMSO-d_6) δ 171.29, 165.18, 161.80, 159.82, 137.88, 108.56, 104.77, 103.55, 15.23. HRMS (ESI) [M-H]$^-$ Calcd for $C_9H_7N_2O_2S_2$ 238.9954, found 238.9956. IR (KBr) ν 3437, 2924, 1614, 1465, 1389, 1153, 872, 812, 745, 477 cm^{-1}.



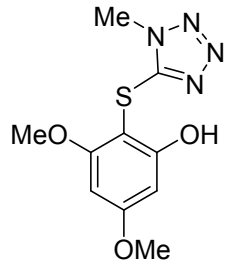
2-((1-phenyl-1H-tetrazol-5-yl)thio)benzene-1,3-diol **3r**, 33% EtOAc/PE, white solid, mp: 201-202 °C, yield 73% (104.4 mg). ^{1}H NMR (400 MHz, DMSO-d_6) δ 10.09 (s, 1H), 9.86 (s, 1H), 7.77 – 7.55 (m, 5H), 7.25 (d, J = 8.5 Hz, 1H), 6.39 (d, J = 2.5 Hz, 1H), 6.29 (dd, J = 8.5, 2.5 Hz, 1H). ^{13}C NMR (101 MHz, DMSO-d_6) δ 161.19, 159.37, 154.51, 137.22, 133.36, 130.51, 129.91, 124.70, 108.02, 103.21, 100.60. HRMS (ESI) [M-H]$^-$ Calcd for $C_{13}H_9N_4O_2S$ 285.0452, found 285.0453. IR (KBr) ν 3411, 3213, 2924, 1593, 1393, 1196, 1114, 841, 772, 696, 531 cm^{-1}.



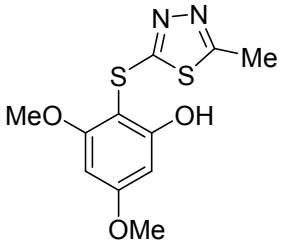
4-((1-methyl-1H-tetrazol-5-yl)thio)benzo[d][1,3]dioxol-5-ol **3s**, 50% EtOAc/PE, white solid, mp: 162-164 °C, yield 83% (104.6 mg). ^{1}H NMR (400 MHz, DMSO-d_6) δ 10.11 (s, 1H), 7.01 (s, 1H), 6.55 (s, 1H), 5.99 (s, 2H), 3.98 (s, 3H). ^{13}C NMR (101 MHz, DMSO-d_6) δ 153.71, 153.06, 150.14, 140.47, 113.49, 102.40, 101.75, 98.13, 34.04. HRMS (ESI) $[M-H]^-$ Calcd for $C_9H_7N_4O_3S$ 251.0244, found 251.0245. IR (KBr) ν 3168, 1614, 1437, 1175, 1029, 930, 831, 702 cm^{-1}.



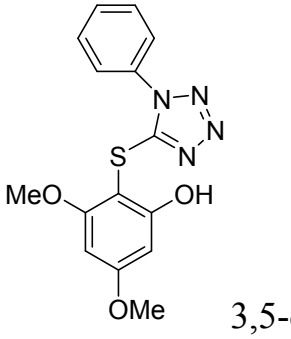
4-((1-phenyl-1H-tetrazol-5-yl)thio)benzo[d][1,3]dioxol-5-ol **3t**, 25% EtOAc/PE, white solid, mp: 160-161 °C, yield 80% (125.6 mg). ^{1}H NMR (400 MHz, DMSO-d_6) δ 10.08 (s, 1H), 7.76 – 7.59 (m, 5H), 7.00 (s, 1H), 6.53 (s, 1H), 5.99 (s, 2H). ^{13}C NMR (101 MHz, DMSO-d_6) δ 154.20, 150.49, 140.39, 133.33, 130.59, 129.93, 124.79, 114.05, 101.75, 101.23, 98.13. HRMS (ESI) $[M+H]^+$ Calcd for $C_{14}H_{11}N_4O_3S$ 315.0546, found 315.0549. IR (KBr) ν 3134, 2924, 1493, 1436, 1246, 1176, 1032, 838, 478 cm^{-1}.



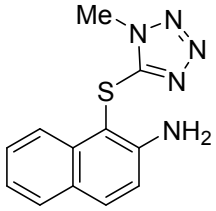
3,5-dimethoxy-2-((1-methyl-1H-tetrazol-5-yl)thio)phenol **3u**, 25% EtOAc/PE, white solid, mp: 144-146 °C, yield 74% (99.2 mg). ^{1}H NMR (400 MHz, DMSO-d_6) δ 10.33 (s, 1H), 6.23 – 6.11 (m, 2H), 3.94 (s, 3H), 3.74 (s, 3H), 3.72 (s, 3H). ^{13}C NMR (101 MHz, DMSO-d_6) δ 162.91, 161.40, 160.29, 153.46, 94.11, 91.92, 90.87, 56.19, 55.36, 33.78. HRMS (ESI) $[M-H]^-$ Calcd for $C_{10}H_{11}N_4O_3S$ 267.0557, found 267.0549. IR (KBr) ν 3114, 1583, 1466, 1287, 1165, 1102, 826, 712 cm^{-1}.



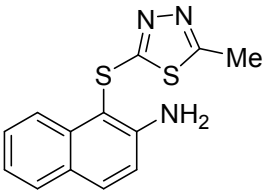
3,5-dimethoxy-2-((5-methyl-1,3,4-thiadiazol-2-yl)thio)phenol **3v**, 33% EtOAc/PE, white solid, mp: 159-160 °C, yield 70% (99.4 mg). ^{1}H NMR (400 MHz, DMSO-d_6) δ 10.44 (s, 1H), 6.38 – 6.05 (m, 2H), 3.77 (s, 3H), 3.76 (s, 3H), 2.53 (s, 3H). ^{13}C NMR (101 MHz, DMSO-d_6) δ 171.22, 164.56, 163.59, 161.67, 160.84, 95.52, 94.12, 90.89, 56.24, 55.38, 15.13. HRMS (ESI) [M-H]$^-$ Calcd for $C_{11}H_{11}N_2O_3S_2$ 283.0217, found 283.0211. IR (KBr) ν 3434, 2926, 1597, 1201, 1099, 816, 476 cm^{-1}.



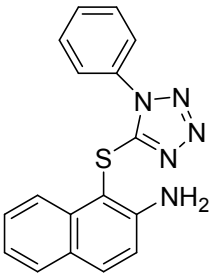
3,5-dimethoxy-2-((1-phenyl-1H-tetrazol-5-yl)thio)phenol **3w**, 25% EtOAc/PE, white solid, mp: 152-153 °C, yield 72% (118.8 mg). ^{1}H NMR (400 MHz, DMSO-d_6) δ 10.27 (s, 1H), 7.75 – 7.56 (m, 5H), 6.12 (d, J = 1.1 Hz, 2H), 3.74 (s, 3H), 3.69 (s, 3H). ^{13}C NMR (101 MHz, DMSO-d_6) δ 163.12, 161.34, 160.35, 154.26, 133.38, 130.39, 129.85, 124.48, 94.07, 90.79, 56.11, 55.33. HRMS (ESI) [M-H]$^-$ Calcd for $C_{15}H_{13}N_4O_3S$ 329.0714, found 329.0707. IR (KBr) ν 3187, 2925, 1600, 1464, 1310, 1162, 1098, 811, 477 cm^{-1}.



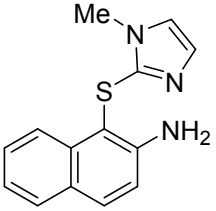
1-((1-methyl-1H-tetrazol-5-yl)thio)naphthalen-2-amine **4a**, 25% EtOAc/PE, white solid, mp: 152-153 °C, yield 91% (117.0 mg). ^{1}H NMR (400 MHz, DMSO-d_6) δ 8.01 (d, J = 8.4 Hz, 1H), 7.81 (d, J = 8.9 Hz, 1H), 7.73 (d, J = 7.8 Hz, 1H), 7.50 – 7.38 (m, 1H), 7.26 – 7.16 (m, 1H), 7.14 (d, J = 8.9 Hz, 1H), 6.27 (s, 2H), 4.02 (s, 3H). ^{13}C NMR (101 MHz, DMSO-d_6) δ 152.96, 151.00, 136.18, 132.48, 128.47, 127.80, 127.19, 122.47, 121.65, 118.45, 94.86, 33.81. [M-H]$^-$ Calcd for $C_{12}H_{10}N_5S$ 256.0662, found 256.0660. IR (KBr) ν 3424, 3327, 1625, 1394, 1282, 1163, 824, 741 cm^{-1}.



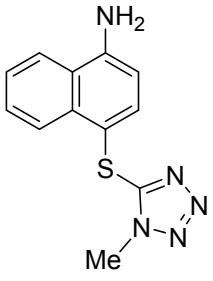
1-((5-methyl-1,3,4-thiadiazol-2-yl)thio)naphthalen-2-amine **4b**, 25% EtOAc/PE, white solid, mp: 185-186 °C, yield 84% (114.7 mg). ^{1}H NMR (400 MHz, DMSO-d_6) δ 8.09 – 7.96 (m, 1H), 7.81 (d, J = 8.9 Hz, 1H), 7.77 – 7.65 (m, 1H), 7.49 – 7.38 (m, 1H), 7.26 – 7.12 (m, 2H), 6.36 (s, 2H), 2.47 (s, 3H). ^{13}C NMR (101 MHz, DMSO-d_6) δ 169.40, 165.55, 150.75, 135.47, 133.06, 128.74, 128.30, 127.31, 122.00, 118.59, 99.83, 15.18. HRMS (ESI) $[M-H]^-$ Calcd for $C_{13}H_{10}N_3S_2$ 272.0322, found 272.0318. IR (KBr) ν 3422, 3321, 2925, 1615, 1386, 1079, 820, 743, 477 cm^{-1}.



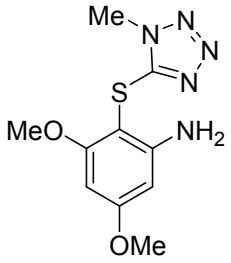
1-((1-phenyl-1H-tetrazol-5-yl)thio)naphthalen-2-amine **4c**, 25% EtOAc/PE, white solid, mp: 182-183 °C, yield 85% (135.6 mg). ^{1}H NMR (400 MHz, DMSO-d_6) δ 7.95 – 7.85 (m, 3H), 7.80 (d, J = 8.9 Hz, 1H), 7.76 – 7.62 (m, 4H), 7.43 – 7.34 (m, 1H), 7.25 – 7.11 (m, 2H), 6.31 (s, 2H). ^{13}C NMR (101 MHz, DMSO-d_6) δ 153.64, 151.33, 136.10, 133.43, 132.57, 130.50, 129.92, 128.39, 127.74, 127.15, 124.68, 122.43, 121.55, 118.51, 94.30. HRMS (ESI) $[M-H]^-$ Calcd for $C_{17}H_{12}N_5S$ 318.0819, found 318.0820. IR (KBr) ν 3461, 3325, 1624, 1500, 1395, 1090, 818, 753, 691 cm^{-1}.



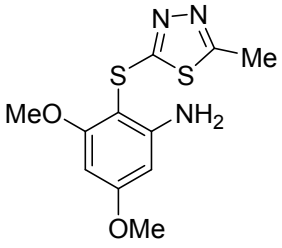
1-((1-methyl-1H-imidazol-2-yl)thio)naphthalen-2-amine **4d**, 20% EtOAc/PE, yellow oil, yield 68% (86.7 mg). ^{1}H NMR (400 MHz, DMSO-d_6) δ 8.40 (d, J = 8.5 Hz, 1H), 7.68 (d, J = 9.0 Hz, 2H), 7.53 – 7.36 (m, 1H), 7.24 – 7.13 (m, 2H), 7.10 – 7.02 (m, 1H), 6.89 (m, 1H), 6.19 (s, 2H), 3.56 (s, 3H). ^{13}C NMR (101 MHz, DMSO-d_6) δ 149.59, 138.27, 135.66, 130.94, 128.30, 128.22, 127.26, 127.13, 124.03, 123.05, 121.39, 118.42, 101.17, 33.44. HRMS (ESI) $[M+H]^+$ Calcd for $C_{14}H_{14}N_3S$ 256.0903, found 256.0902. IR (KBr) ν 3434, 3304, 3186, 2924, 2855, 1616, 1462, 1404, 1124, 819, 749 cm^{-1}.



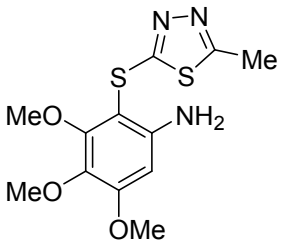
4-((1-methyl-1H-tetrazol-5-yl)thio)naphthalen-1-amine **4e**, 33% EtOAc/PE, white solid, mp: 164-166 °C, yield 73% (93.8 mg). ^{1}H NMR (400 MHz, DMSO-d_6) δ 8.18 (dd, J = 20.7, 8.2 Hz, 2H), 7.72 (d, J = 8.1 Hz, 1H), 7.59 – 7.50 (m, 1H), 7.50 – 7.41 (m, 1H), 6.72 (d, J = 8.0 Hz, 1H), 6.47 (s, 2H), 4.00 (s, 3H). ^{13}C NMR (101 MHz, DMSO-d_6) δ 153.93, 148.77, 137.73, 134.93, 127.51, 125.09, 124.34, 123.31, 123.21, 107.10, 105.41, 33.98. HRMS (ESI) $[M-H]^-$ Calcd for $C_{12}H_{10}N_5S$ 256.0662, found 256.0669. IR (KBr) ν 3426, 3330, 3232, 1631, 1569, 1509, 1439, 1351, 1270, 1072, 761 cm^{-1}.



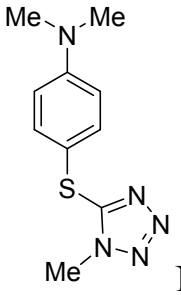
3,5-dimethoxy-2-((1-methyl-1H-tetrazol-5-yl)thio)aniline **4f**, 33% EtOAc/PE, white solid, mp: 151-152 °C, yield 76% (101.5 mg). ^{1}H NMR (400 MHz, DMSO-d_6) δ 6.02 (d, J = 2.5 Hz, 1H), 5.88 (d, J = 2.5 Hz, 1H), 5.73 (s, 2H), 3.94 (s, 3H), 3.71 (s, 3H), 3.69 (s, 3H). ^{13}C NMR (101 MHz, DMSO-d_6) δ 163.13, 161.86, 153.22, 153.09, 91.92, 88.09, 86.39, 55.87, 55.04, 33.69. HRMS (ESI) $[M+H]^+$ Calcd for $C_{10}H_{14}N_5O_2S$ 268.0863, found 268.0876. IR (KBr) ν 3395, 3294, 3199, 2931, 1576, 1459, 1157, 822, 694, 473 cm^{-1}.



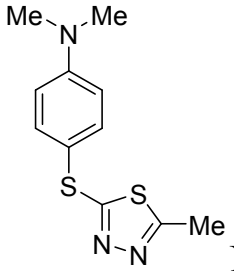
3,5-dimethoxy-2-((5-methyl-1,3,4-thiadiazol-2-yl)thio)aniline **4g**, 33% EtOAc/PE, white solid, mp: 137-138 °C, yield 66% (93.4 mg). ^{1}H NMR (400 MHz, DMSO-d_6) δ 6.04 (d, J = 2.5 Hz, 1H), 5.89 (d, J = 2.5 Hz, 1H), 5.80 (s, 2H), 3.72 (s, 3H), 3.71 (s, 3H), 2.53 (s, 3H). ^{13}C NMR (101 MHz, DMSO-d_6) δ 171.49, 164.88, 163.53, 161.65, 152.93, 91.79, 91.22, 88.11, 55.98, 55.09, 15.17. HRMS (ESI) $[M+H]^+$ Calcd for $C_{11}H_{14}N_3O_2S_2$ 284.0522, found 284.0521. IR (KBr) ν 3427, 3321, 2930, 1582, 1201, 1150, 1079, 472 cm^{-1}.



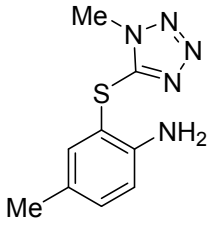
5-(dimethyl-l3-oxidaneyl)-3,4-dimethoxy-2-((5-methyl-1,3,4-thiadiazol-2-yl)thio)aniline **4h**, 50% EtOAc/PE, white solid, mp: 146-147 °C, yield 76% (119.0 mg). ^{1}H NMR (400 MHz, DMSO-d_6) δ 6.24 (s, 1H), 5.55 (s, 2H), 3.71 (s, 3H), 3.69 (s, 3H), 3.58 (s, 3H), 3.32 (s, 3H). ^{13}C NMR (101 MHz, DMSO-d_6) δ 170.72, 165.07, 157.02, 154.47, 148.37, 132.79, 96.01, 94.09, 61.32, 60.78, 55.50, 15.16. HRMS (ESI) $[M+H]^+$ Calcd for $C_{13}H_9N_2OS_2$ 314.0628, found 314.0633. IR (KBr) ν 3435, 3332, 2941, 1633, 1488, 1395, 1245, 1098, 1010, 832, 469 cm^{-1}.



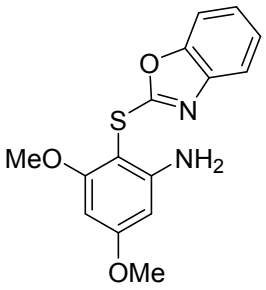
N,N-dimethyl-4-((1-methyl-1H-tetrazol-5-yl)thio)aniline **4i**, 25% EtOAc/PE, white solid, mp: 106-108 °C, yield 82% (96.4 mg). ^{1}H NMR (400 MHz, DMSO-d_6) δ 7.41 (d, J = 8.9 Hz, 2H), 6.73 (d, J = 8.9 Hz, 2H), 3.96 (s, 3H), 2.93 (s, 6H). ^{13}C NMR (101 MHz, DMSO-d_6) δ 153.91, 151.26, 135.52, 112.93, 110.29, 39.75, 33.99. HRMS (ESI) $[M+H]^+$ Calcd for $C_{10}H_{14}N_5S$ 236.0964, found 236.0960. IR (KBr) ν 3439, 2917, 1588, 1506, 1357, 1162, 1076, 814, 708, 524 cm^{-1}.



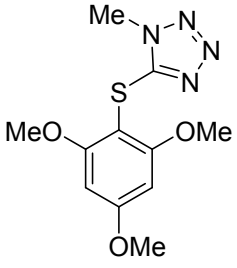
N,N-dimethyl-4-((5-methyl-1,3,4-thiadiazol-2-yl)thio)aniline **4j**, 25% EtOAc/PE, white solid, mp: 126-127 °C, yield 72% (90.4 mg). ^{1}H NMR (400 MHz, DMSO-d_6) δ 7.48 (d, J = 8.9 Hz, 2H), 6.78 (d, J = 8.9 Hz, 2H), 2.97 (s, 6H), 2.56 (s, 3H). ^{13}C NMR (101 MHz, DMSO-d_6) δ 165.27, 151.65, 136.16, 113.50, 113.14, 39.71, 15.92, 15.18. HRMS (ESI) $[M+H]^+$ Calcd for $C_{11}H_{14}N_3S_2$ 252.0624, found 252.0635. IR (KBr) ν 3437, 2923, 1590, 1511, 1373, 1192, 1079, 816 cm^{-1}.



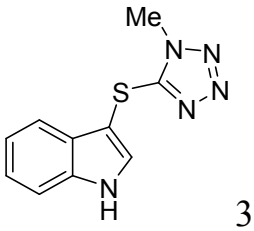
4-methyl-2-((1-methyl-1H-tetrazol-5-yl)thio)aniline **4k**, 33% EtOAc/PE, white solid, mp: 117-118 °C, yield 74% (81.8 mg). ^{1}H NMR (400 MHz, DMSO-d_6) δ 7.19 (d, J = 1.2 Hz, 1H), 7.02 (dd, J = 8.3, 2.1 Hz, 1H), 6.71 (d, J = 8.2 Hz, 1H), 5.40 (s, 2H), 3.97 (s, 3H), 2.14 (s, 3H). ^{13}C NMR (101 MHz, DMSO-d_6) δ 152.67, 148.30, 136.46, 132.78, 125.46, 115.65, 106.70, 33.94, 19.64. HRMS (ESI) $[M+H]^+$ Calcd for $C_9H_{12}N_5S$ 222.0808, found 222.0803. IR (KBr) ν 3468, 3368, 2923, 1618, 1498, 1392, 1163, 832, 704 cm^{-1}.



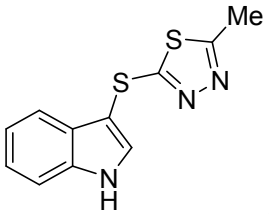
2-(benzo[d]oxazol-2-ylthio)-3,5-dimethoxyaniline **4l**, 33% EtOAc/PE, white solid, mp: 197-199 °C, yield 38% (57.4 mg). ^{1}H NMR (400 MHz, DMSO-d_6) δ 7.62 – 7.43 (m, 2H), 7.34 – 7.13 (m, 2H), 5.99 (s, 2H), 5.80 (s, 2H), 3.67 (s, 6H). ^{13}C NMR (101 MHz, DMSO-d_6) δ 164.96, 161.81, 153.73, 151.09, 141.80, 124.37, 123.68, 118.03, 109.96, 90.48, 55.71. HRMS (ESI) $[M+H]^+$ Calcd for $C_{15}H_{15}N_2O_3S$ 303.0798, found 303.0786. IR (KBr) ν 3434, 2925, 1594, 1458, 1127, 749, 477 cm^{-1}.



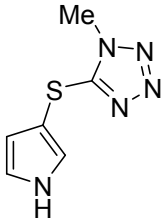
1-methyl-5-((2,4,6-trimethoxyphenyl)thio)-1H-tetrazole **4m**, 25% EtOAc/PE, white solid, mp: 136-137 °C, yield 90% (126.9 mg). ^{1}H NMR (400 MHz, DMSO-d_6) δ 6.33 (s, 2H), 3.96 (s, 3H), 3.83 (s, 3H), 3.76 (s, 6H).^{13}C NMR (101 MHz, DMSO-d_6) δ 163.43, 161.29, 153.29, 93.22, 91.73, 56.35, 55.67, 33.80. HRMS (ESI) $[M+H]^+$ Calcd for $C_{11}H_{15}N_4O_3S$ 283.0859, found 283.0857. IR (KBr) ν 3419, 2931, 1583, 1464, 1224, 1125, 1031, 808, 699, 479 cm^{-1}.



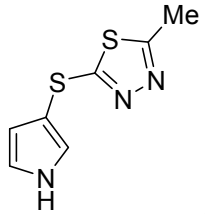
3-((1-methyl-1H-tetrazol-5-yl)thio)-1H-indole **5a**, 33% EtOAc/PE, white solid, mp: 146-147 °C, yield 86% (99.4 mg). ^{1}H NMR (400 MHz, DMSO-d_6) δ 11.83 (s, 1H), 7.92 (d, J = 2.7 Hz, 1H), 7.53 – 7.48 (m, 2H), 7.22 – 7.18 (m, 1H), 7.14 – 7.10 (m, 1H), 4.02 (s, 3H). ^{13}C NMR (101 MHz, DMSO-d_6) δ 153.45, 136.46, 133.07, 128.37, 122.51, 120.58, 118.21, 112.54, 94.10, 34.08. HRMS (ESI) [M-H]$^-$ Calcd for $C_{10}H_8N_5S$ 230.0506, found 230.0503. IR (KBr) ν 3179, 2921, 1421, 1234, 1167, 755, 483 cm^{-1}.



2-((1H-indol-3-yl)thio)-5-methyl-1,3,4-thiadiazole **5b**, 25% EtOAc/PE, white solid, mp: 168-169 °C, yield 93% (114.9 mg). ^{1}H NMR (400 MHz, DMSO-d_6) δ 11.96 (s, 1H), 7.96 (t, J = 2.5 Hz, 1H), 7.55 – 7.52 (m, 2H), 7.24 (t, J = 7.6 Hz, 1H), 7.16 (t, J = 7.6 Hz, 1H), 3.48 (s, 3H). ^{13}C NMR (101 MHz, DMSO-d_6) δ 172.02, 165.37, 136.71, 133.13, 127.54, 122.72, 120.92, 117.96, 112.72, 98.39, 15.16. HRMS (ESI) [M-H]$^-$ Calcd for $C_{11}H_8N_3S_2$ 246.0165, found 246.0163. IR (KBr) ν 3160, 2916, 1428, 1382, 1093, 743, 602, 471 cm^{-1}.

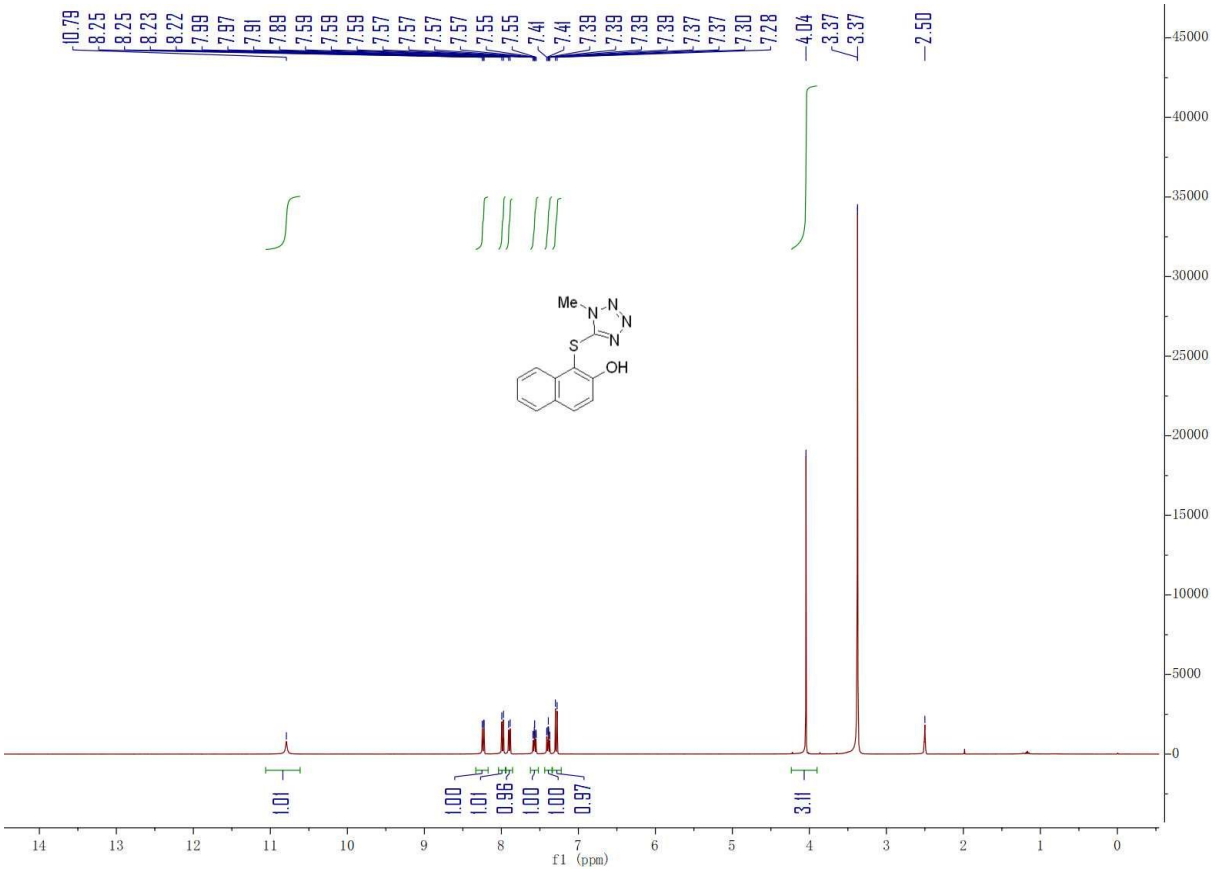


5-((1H-pyrrol-3-yl)thio)-1-methyl-1H-tetrazole **5c**, 25% EtOAc/PE, white solid, mp: 129-130 °C, yield 84% (76.0 mg). ^{1}H NMR (400 MHz, DMSO-d_6) δ 11.73 (s, 1H), 7.48 – 6.87 (m, 1H), 6.68 – 6.42 (m, 1H), 6.27 – 6.03 (m, 1H), 3.95 (s, 3H). HRMS (ESI) [M-H]$^-$ Calcd for $C_6H_6N_5S$ 180.0349, found 180.0349. IR (KBr) ν 3448, 3231, 1390, 1279, 1132, 1079, 748, 610 cm^{-1}.

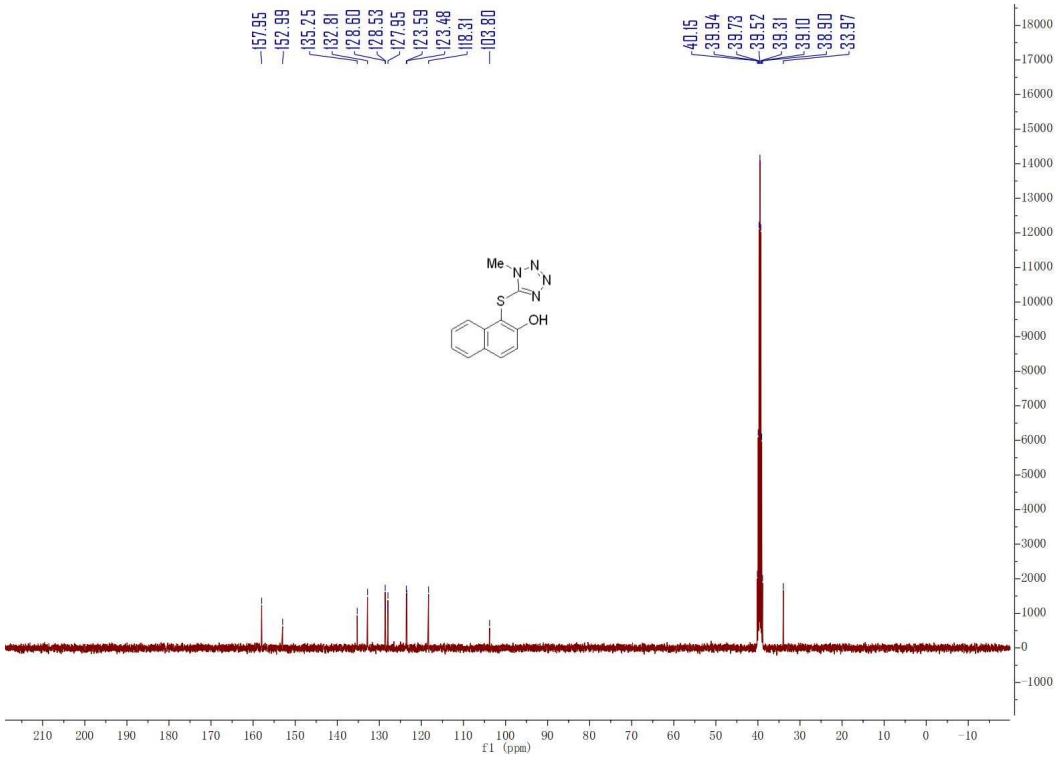


2-((1H-pyrrol-3-yl)thio)-5-methyl-1,3,4-thiadiazole **5d**, 25% EtOAc/PE, white solid, mp: 114-115 °C, yield 82% (80.8 mg). ^{1}H NMR (400 MHz, DMSO-d_6) δ 11.84 (s, 1H), 7.31 – 6.83 (m, 1H), 6.73 – 6.46 (m, 1H), 6.32 – 6.08 (m, 1H), 2.57 (s, 3H). ^{13}C NMR (101 MHz, DMSO-d_6) δ 171.43, 165.98, 124.19, 118.38, 111.91, 110.23, 15.26. HRMS (ESI) [M-H]$^-$ Calcd for $C_7H_6N_3S_2$ 196.0009, found 196.0005. IR (KBr) ν 3187, 2926, 1414, 1197, 1075, 829, 753, 608 cm^{-1}.

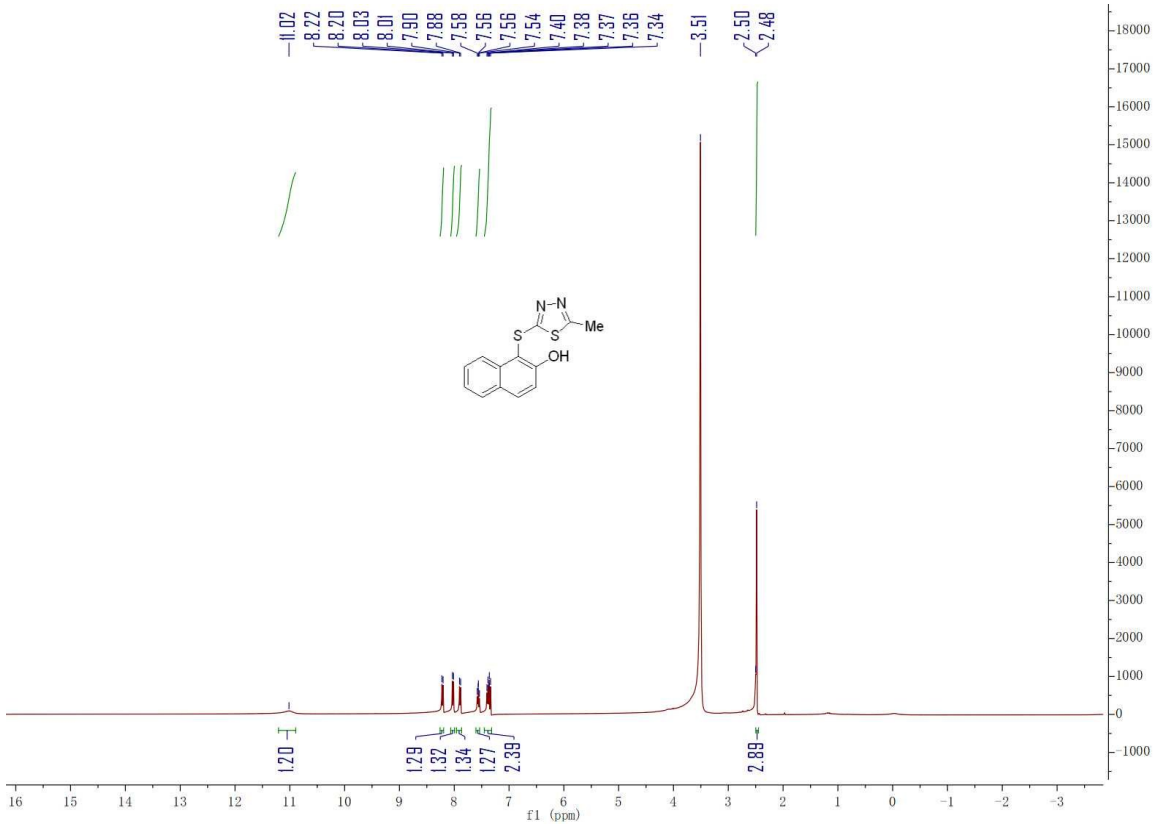
2. NMR Spectra of All Products



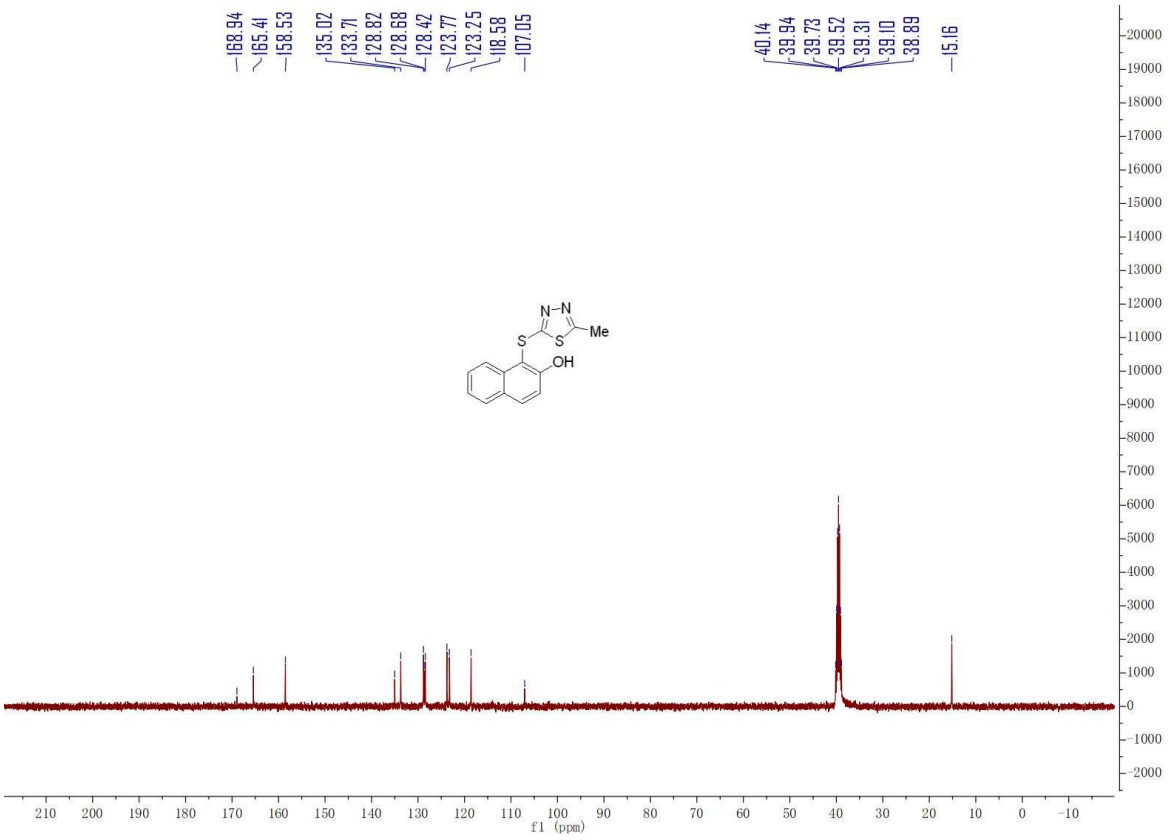
^{1}H NMR of 3a



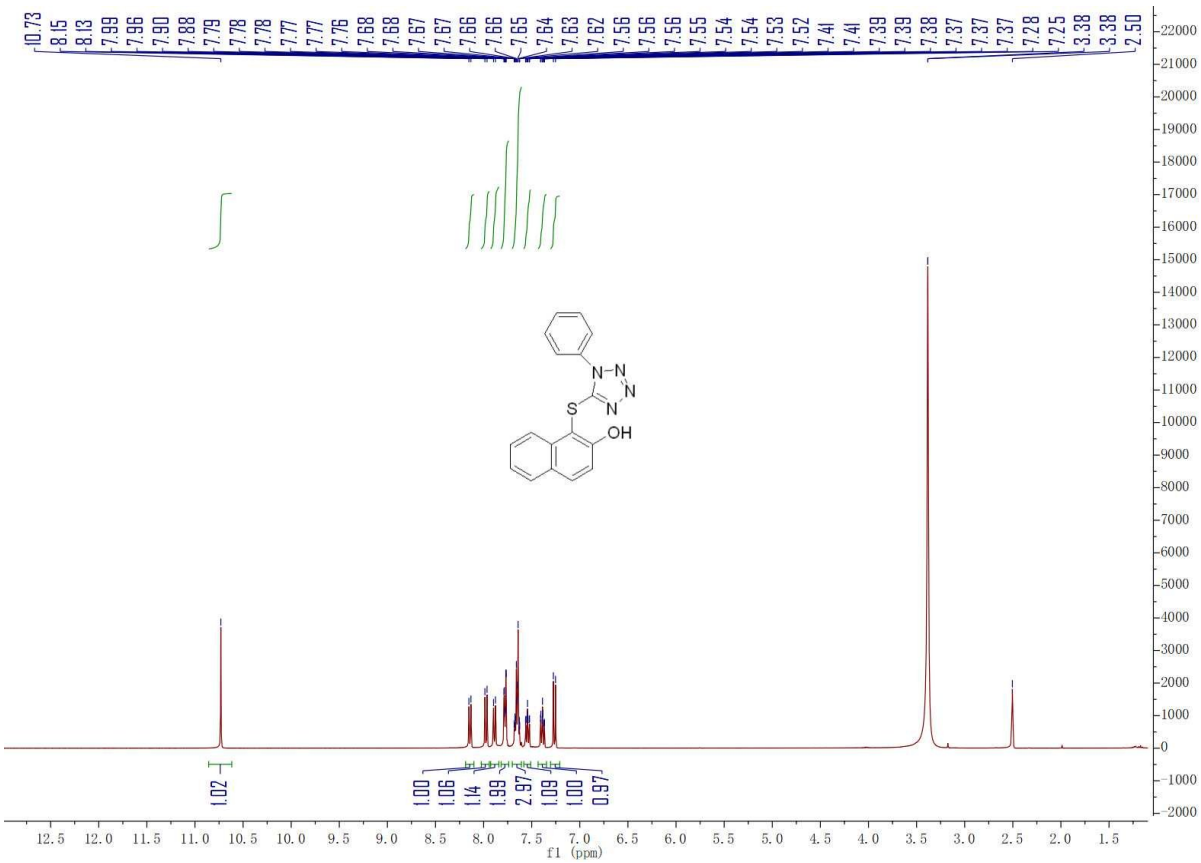
^{13}C NMR of 3a



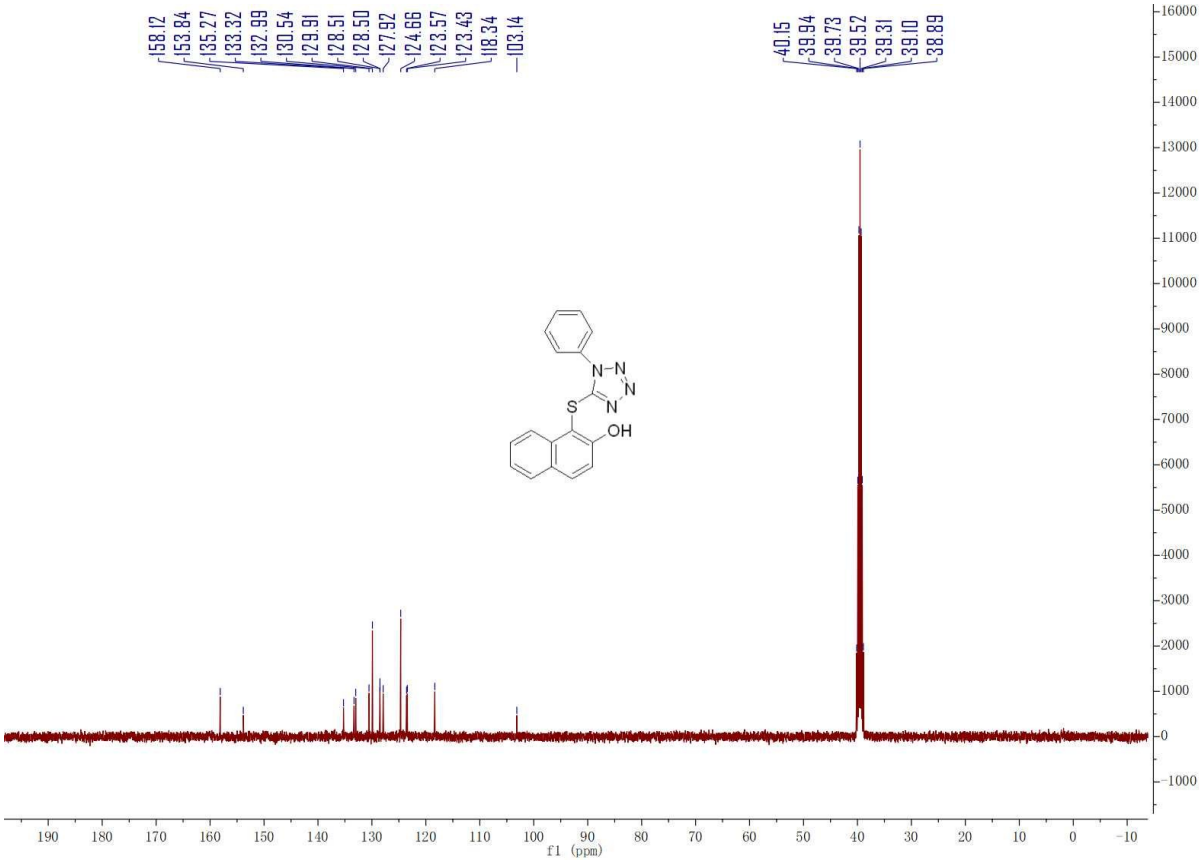
^{1}H NMR of 3b



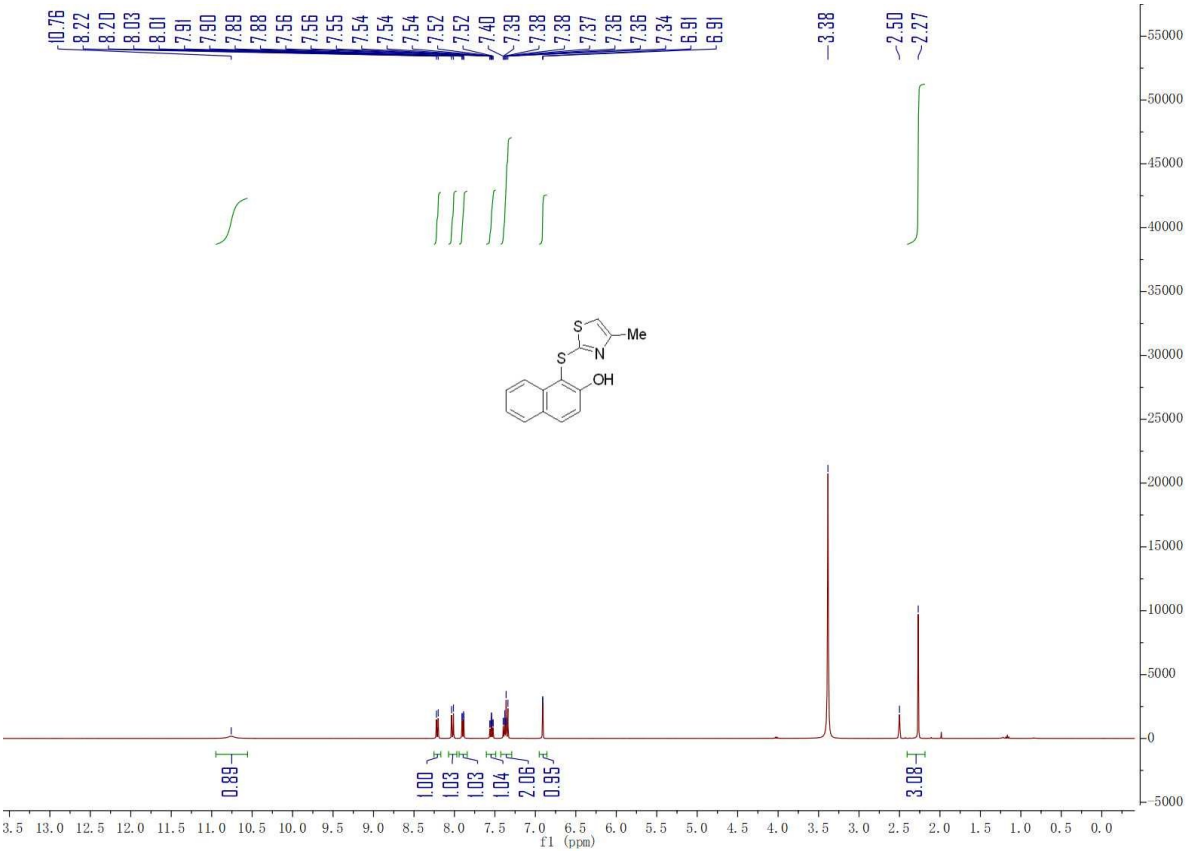
^{13}C NMR of 3b



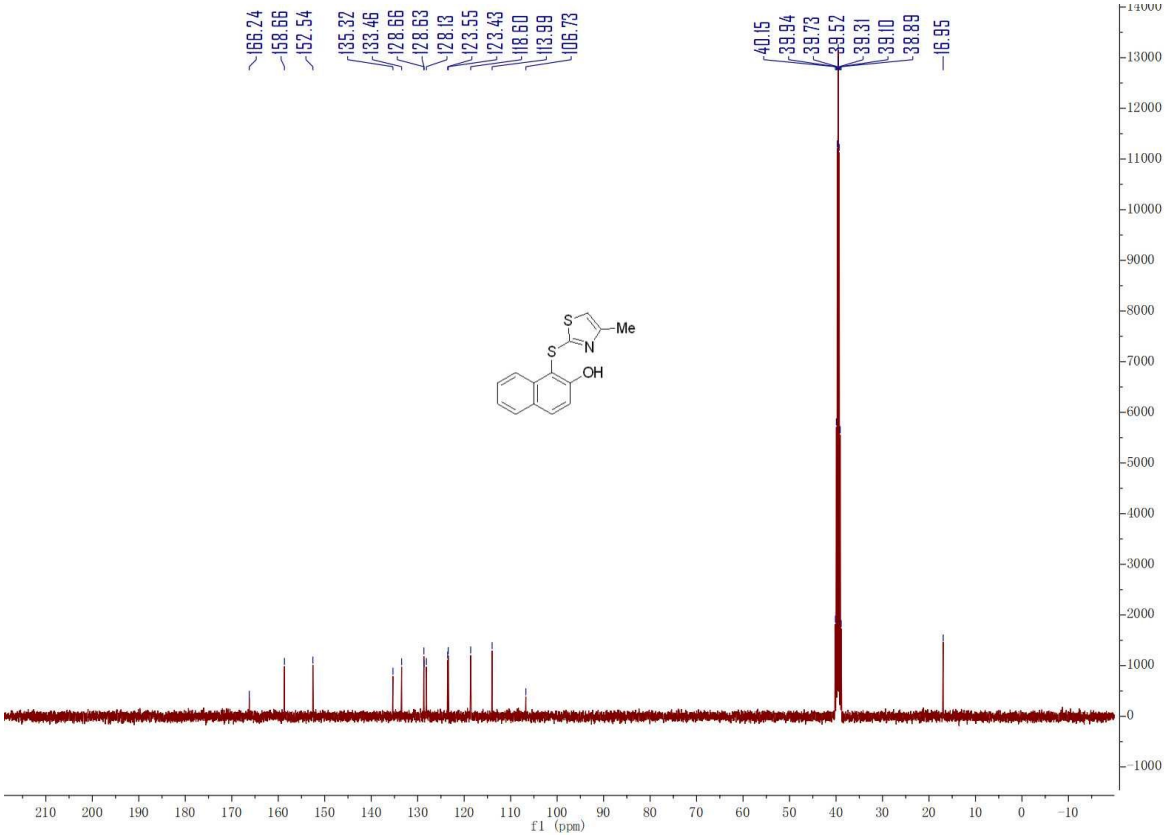
^{1}H NMR of 3c



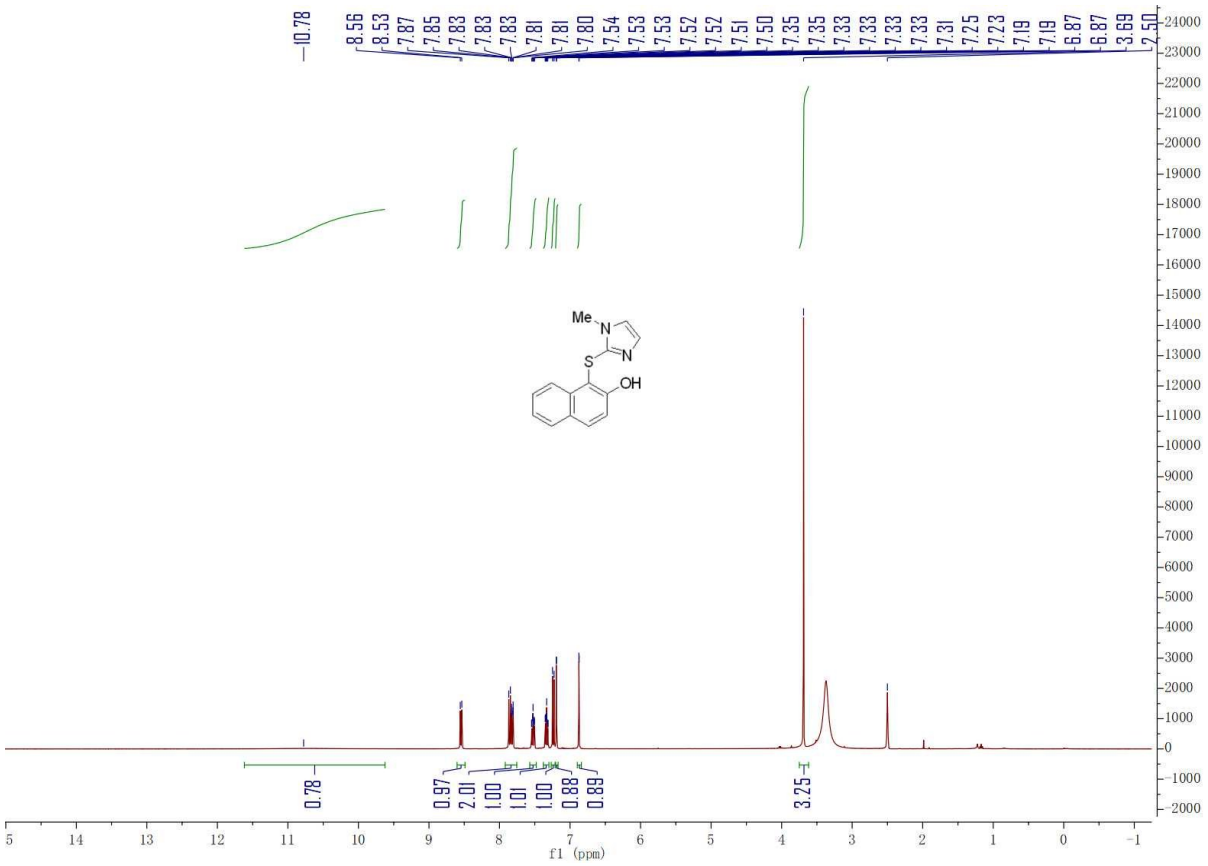
^{13}C NMR of 3c



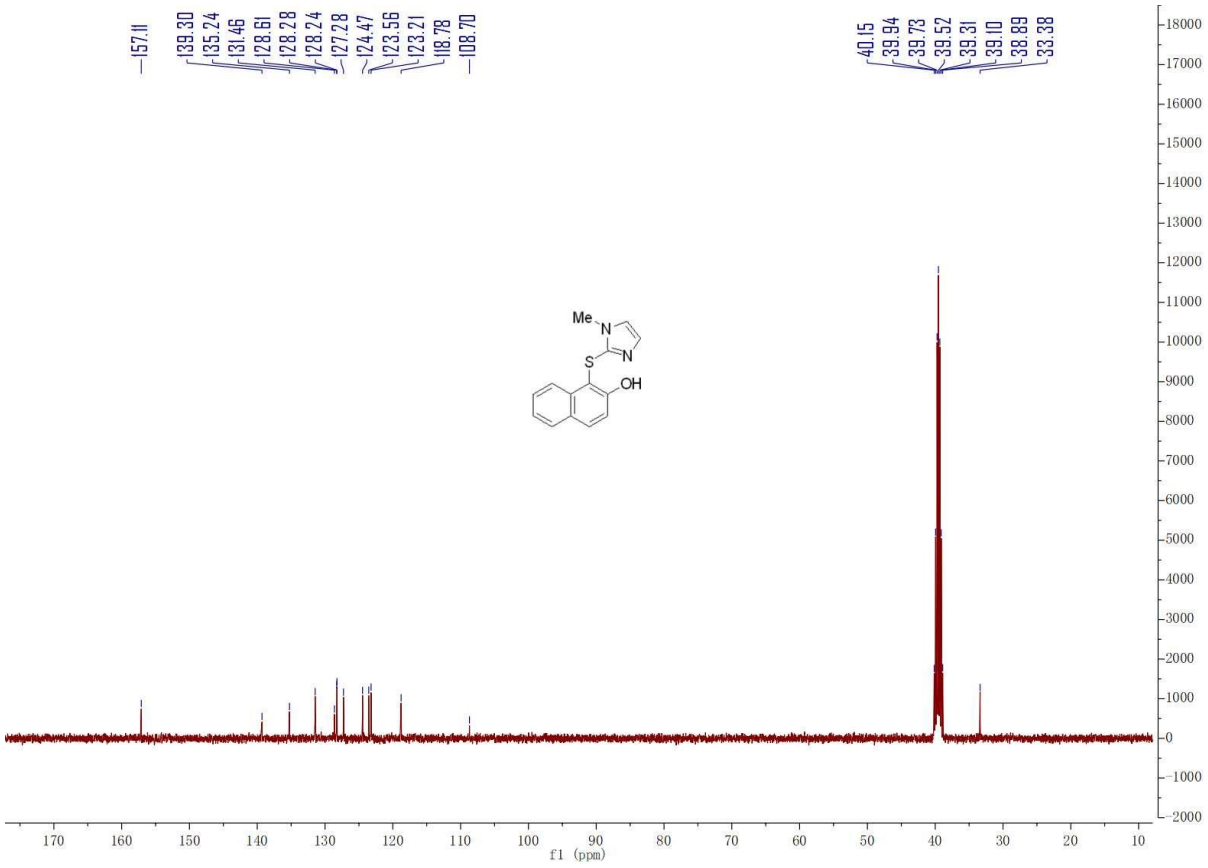
^{1}H NMR of 3d



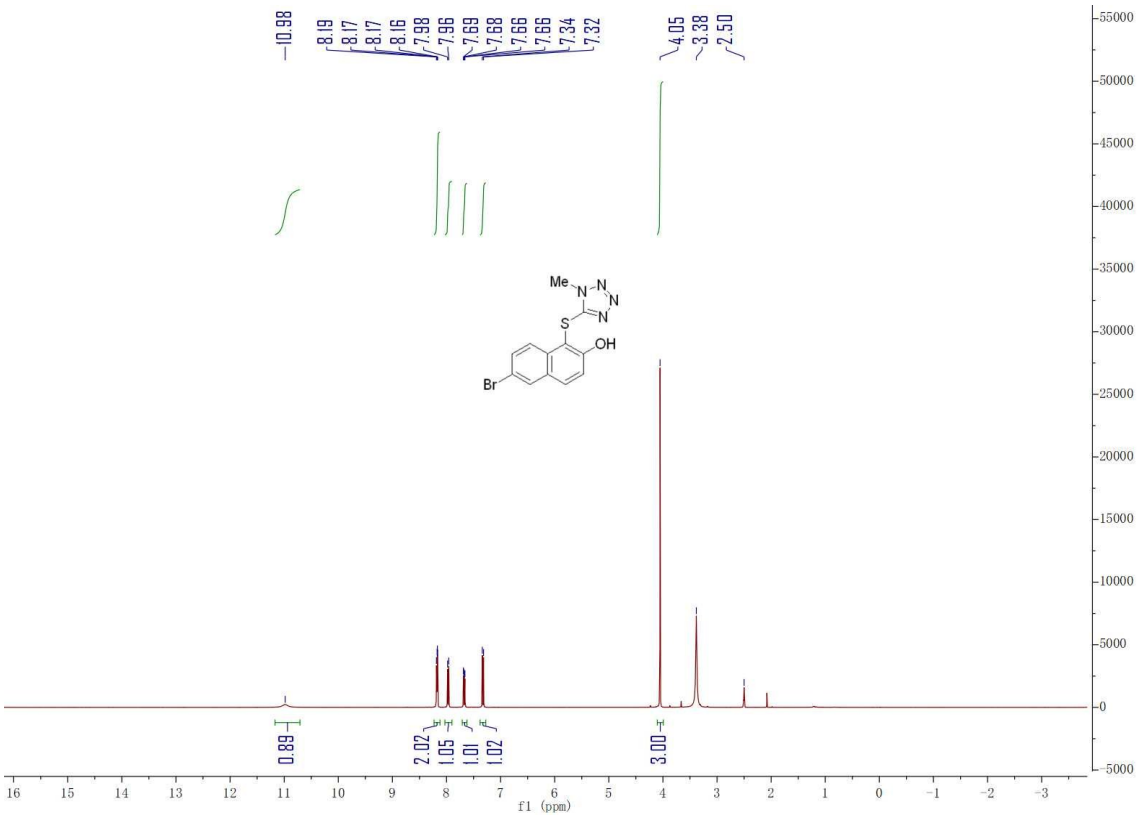
^{13}C NMR of 3d



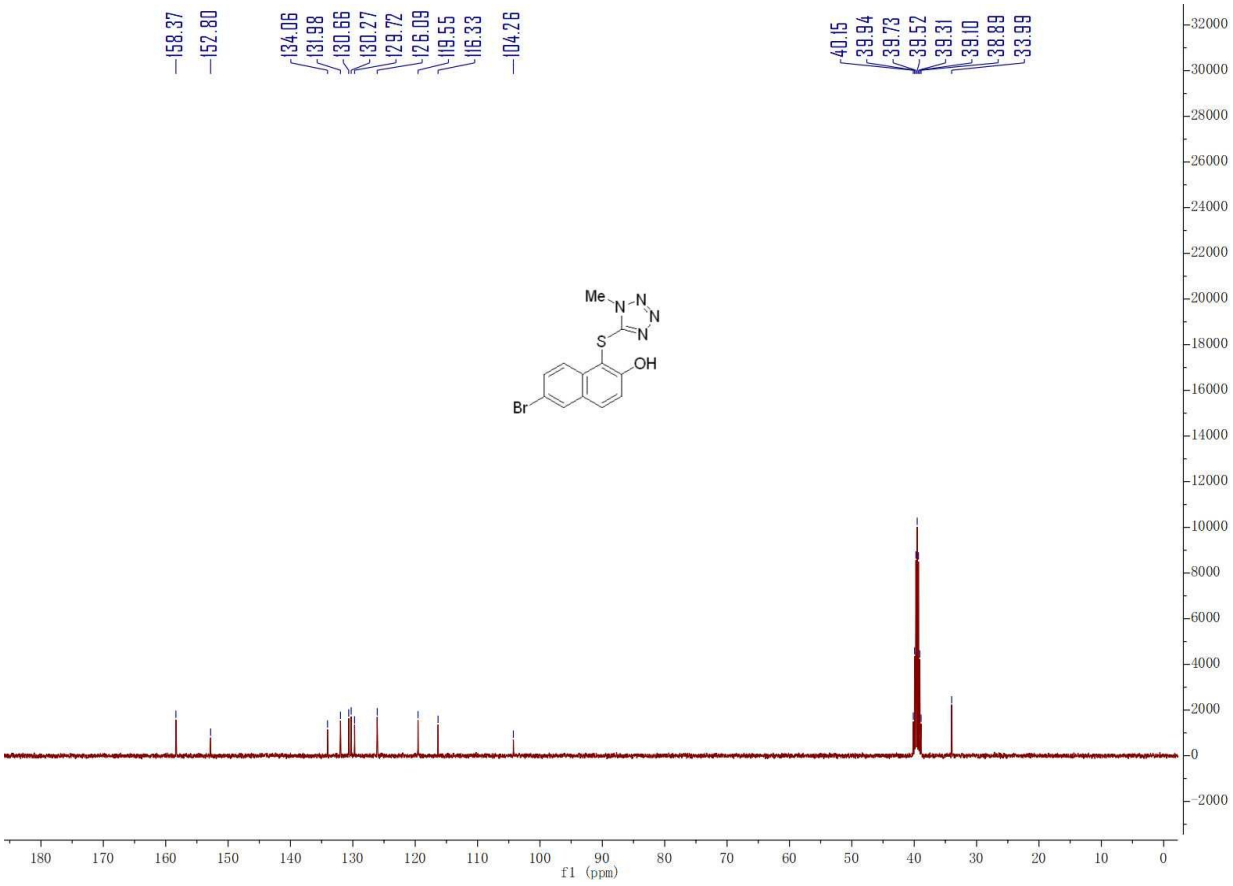
[1]H NMR of 3e



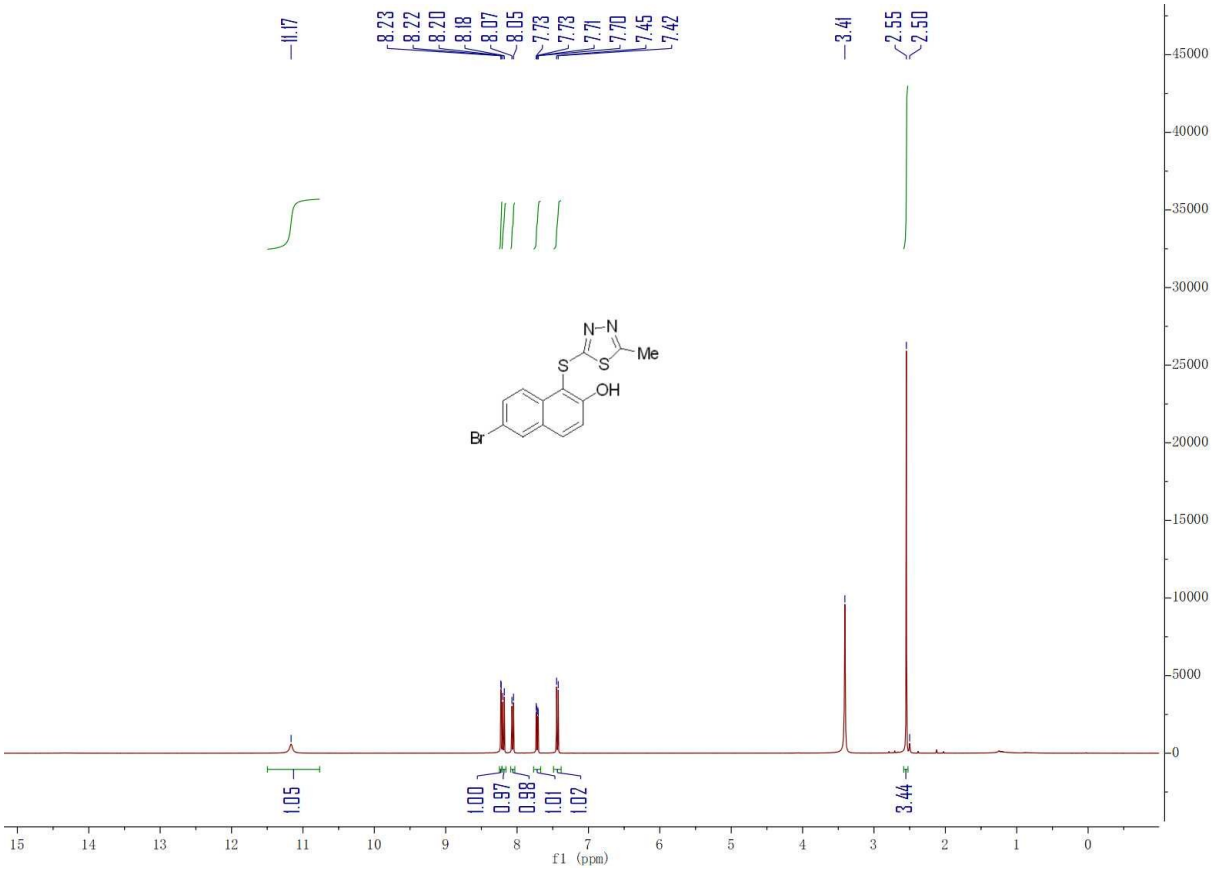
[13]C NMR of 3e



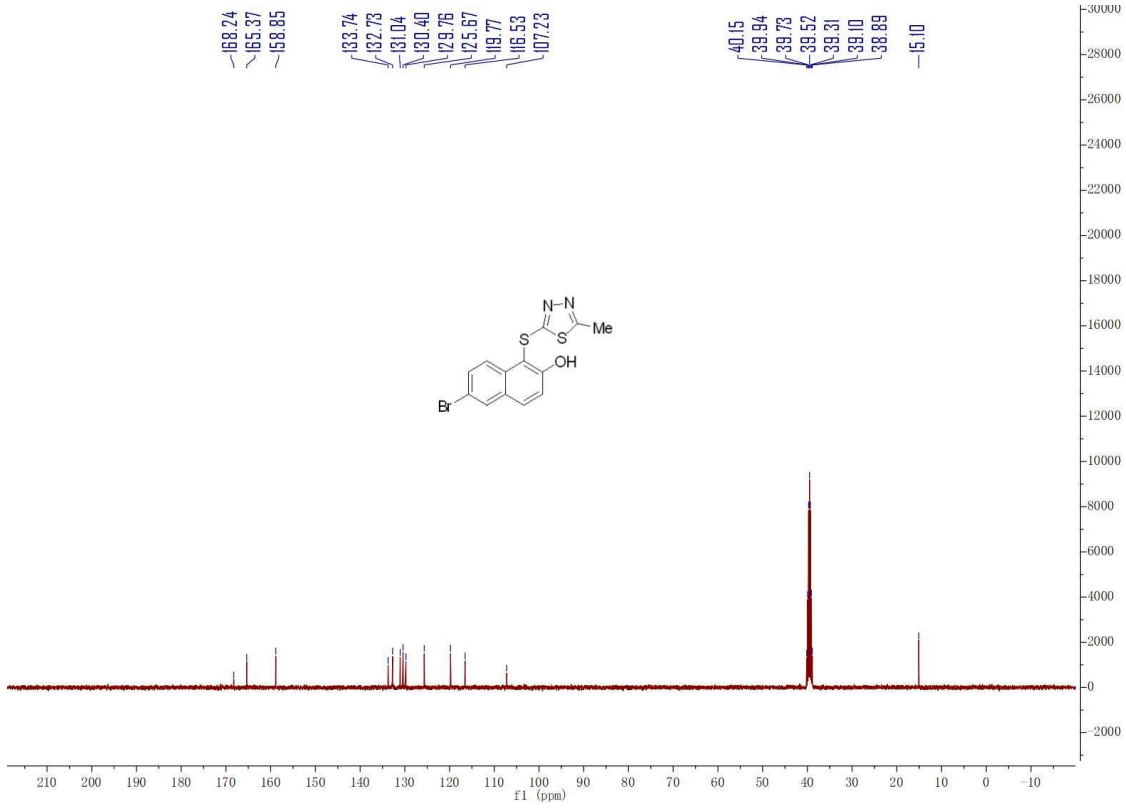
^{1}H NMR of 3f



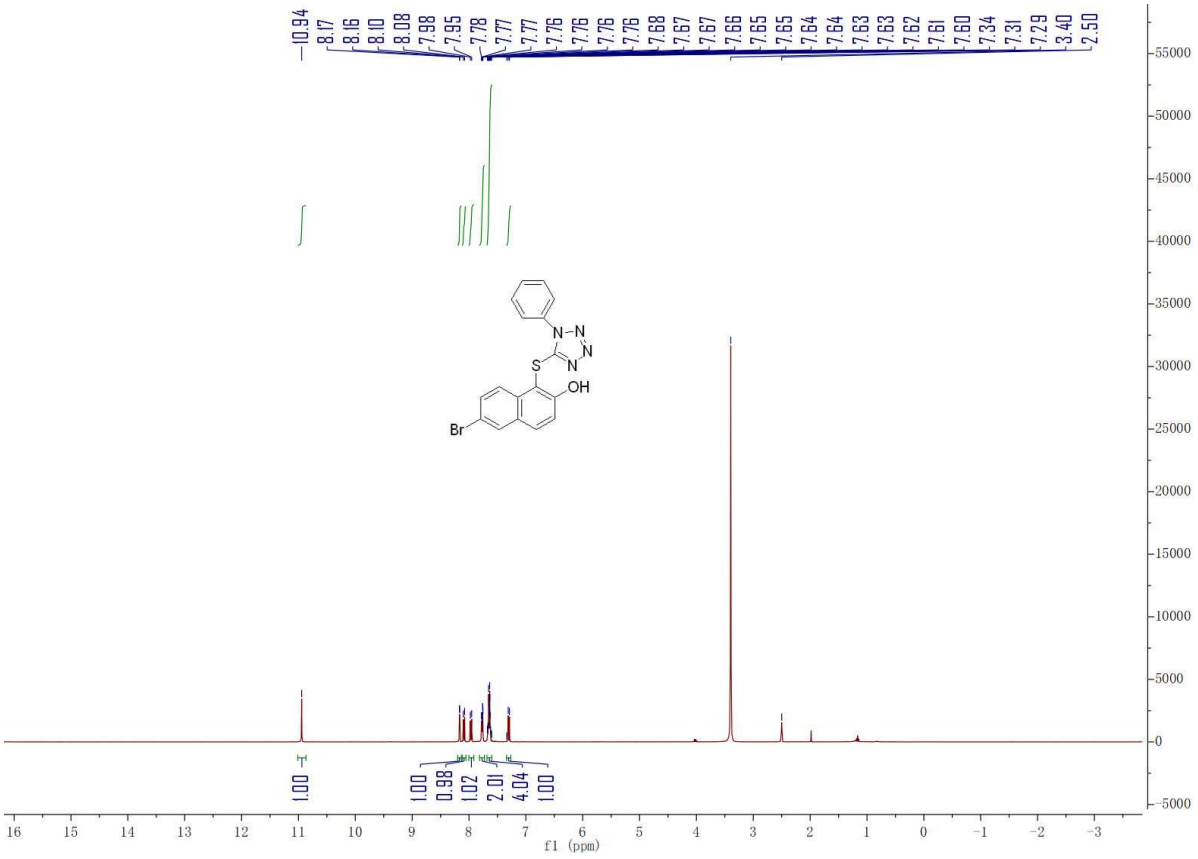
^{13}C NMR of 3f


11.17
8.23
8.22
8.20
8.18
8.07
8.05
7.73
7.73
7.71
7.70
7.45
7.42
3.41
2.55
2.50
N-N
Me
S
S
OH
Br
1.05
1.00
0.97
0.98
1.01
1.02
3.44
f1 (ppm)

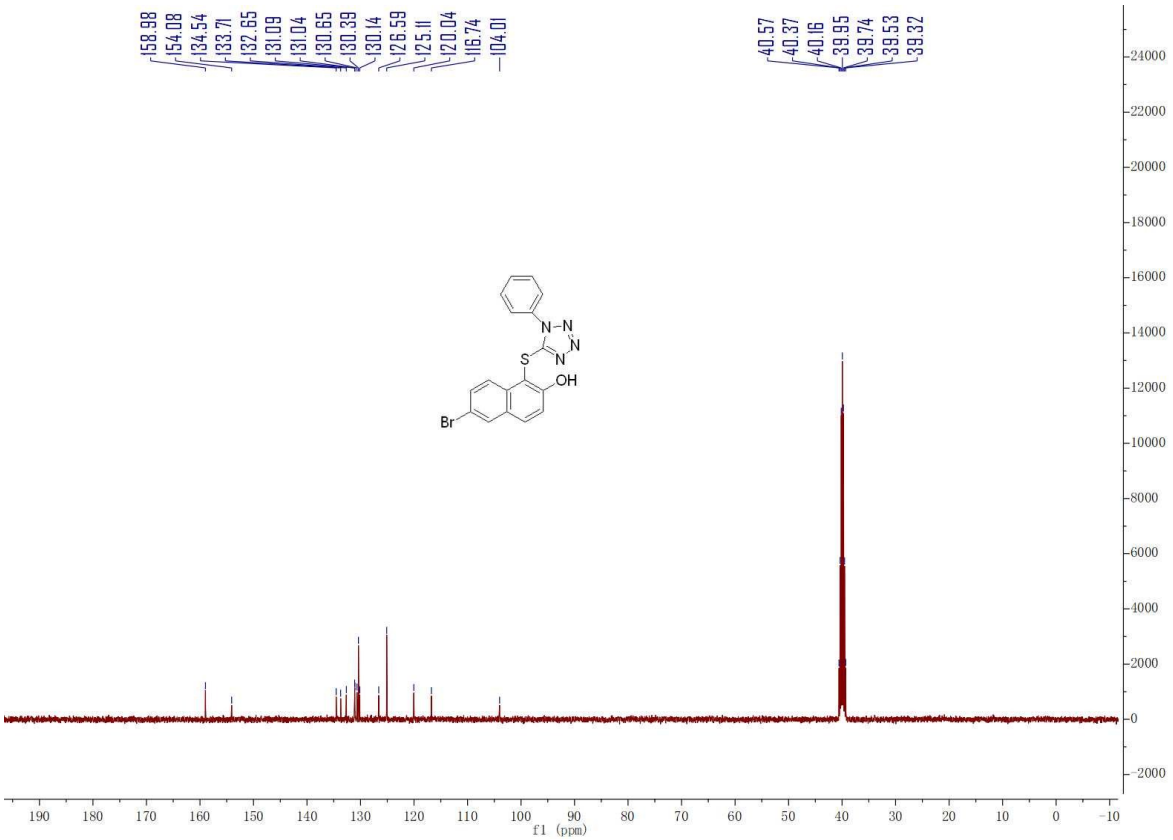
^{1}H NMR of 3g


168.24
165.37
158.85
133.74
132.73
131.04
130.40
129.76
125.67
119.77
116.53
107.23
40.15
39.94
39.73
39.52
39.31
39.10
38.89
15.10
N-N
Me
S
S
OH
Br
f1 (ppm)

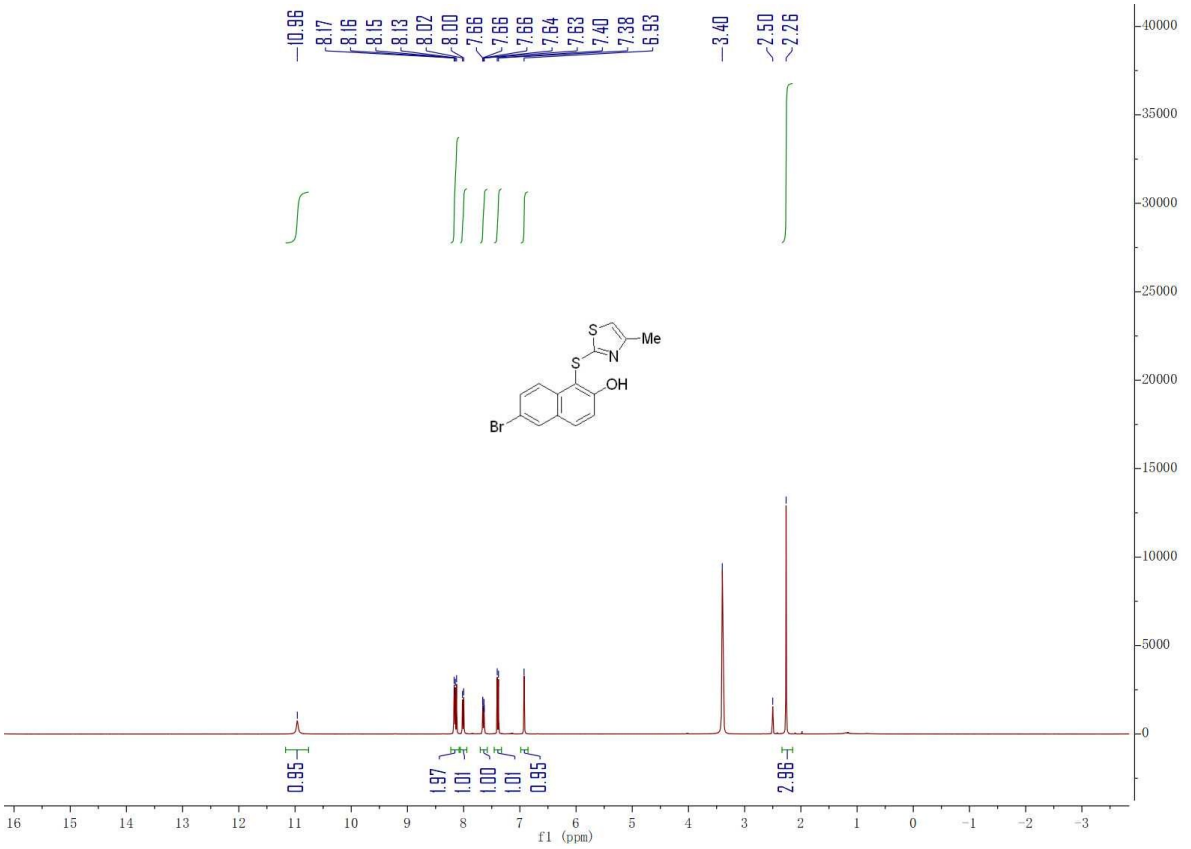
^{13}C NMR of 3g



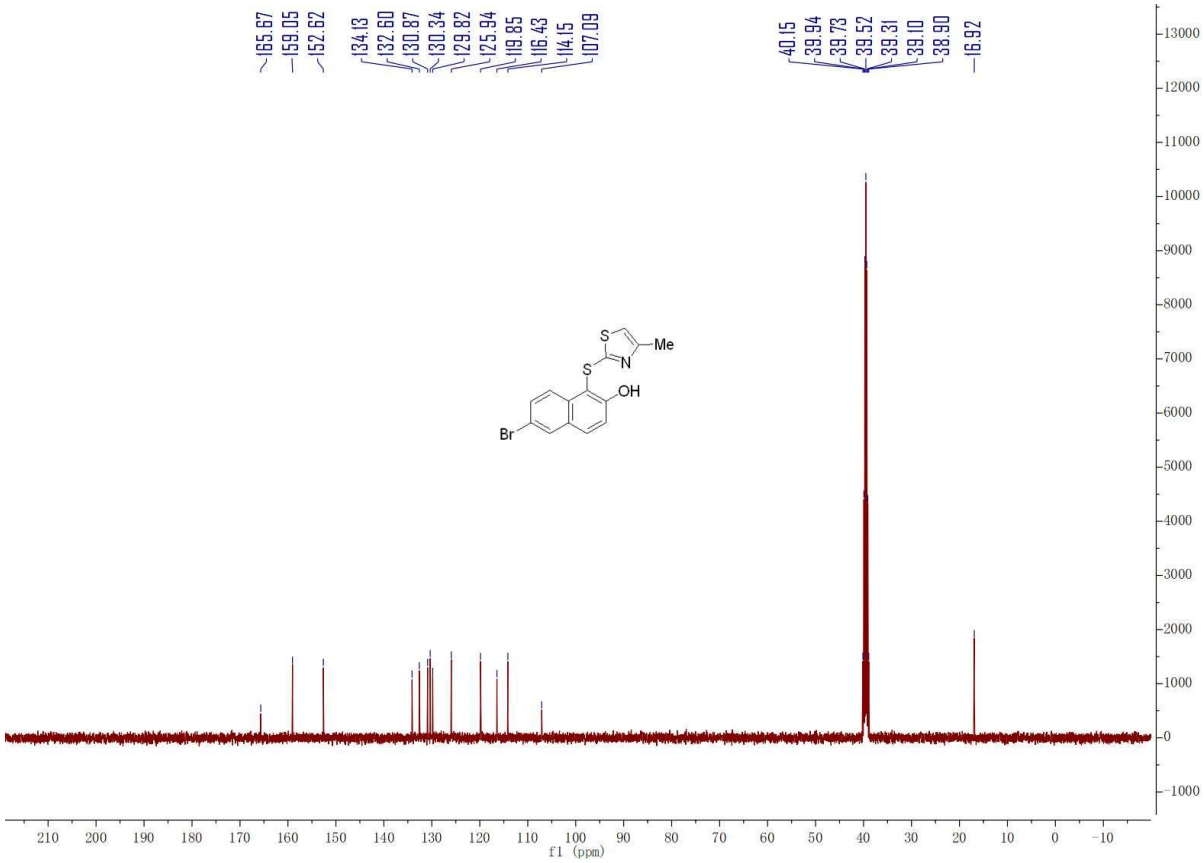
^{1}H NMR of 3h



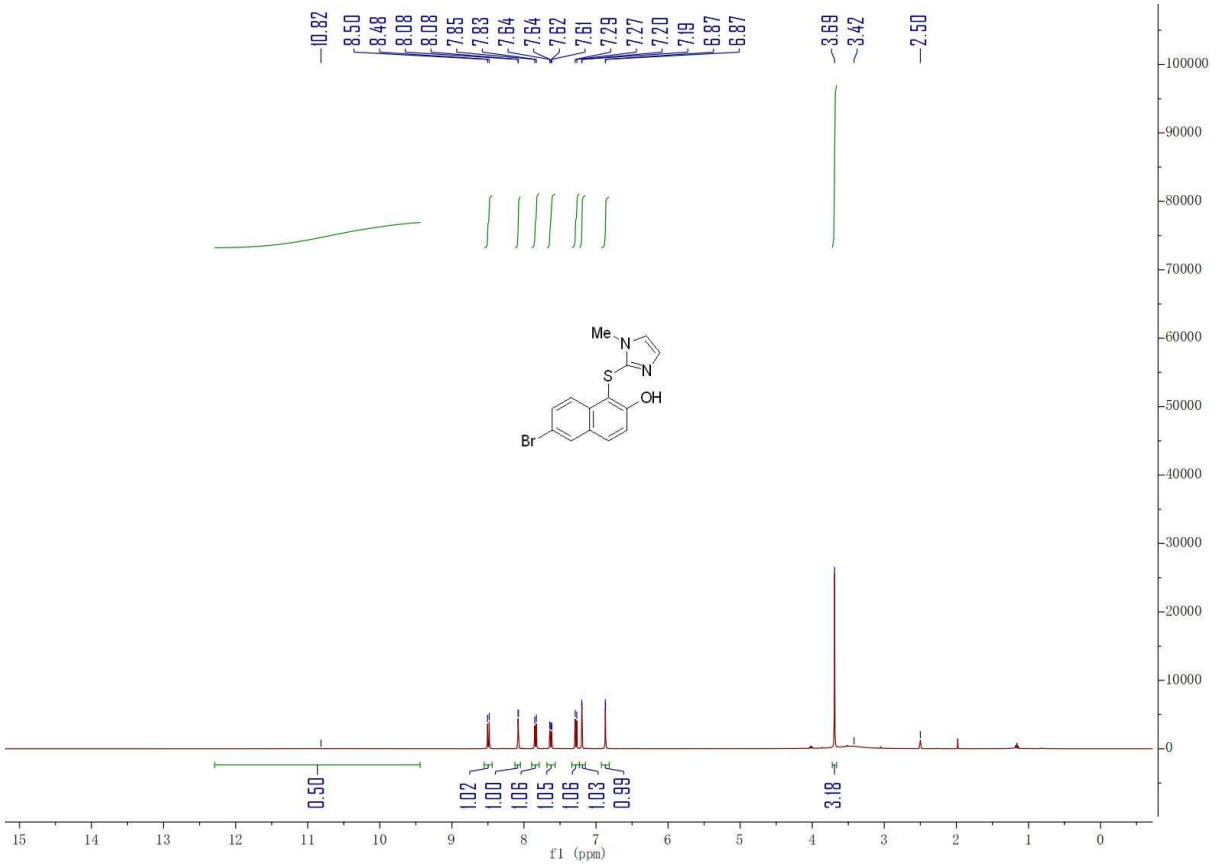
^{13}C NMR of 3h



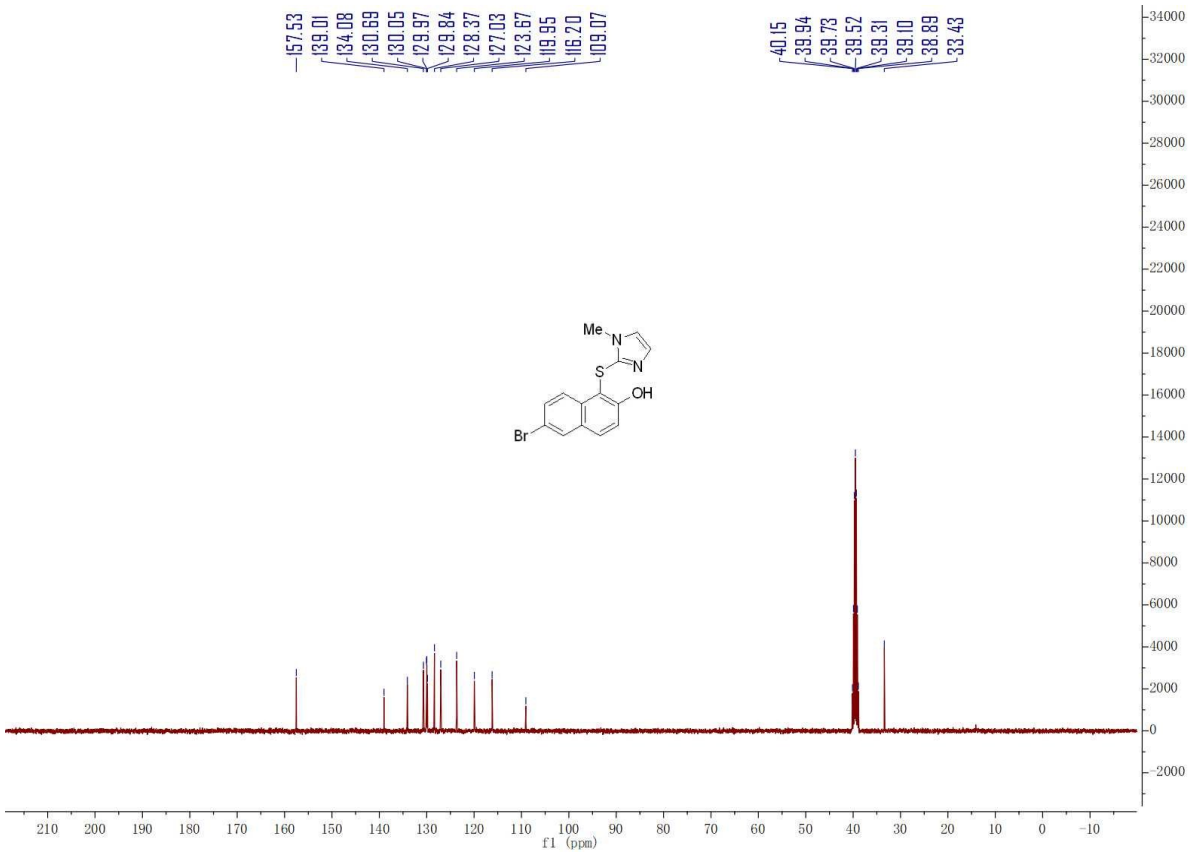
^{1}H NMR of 3i



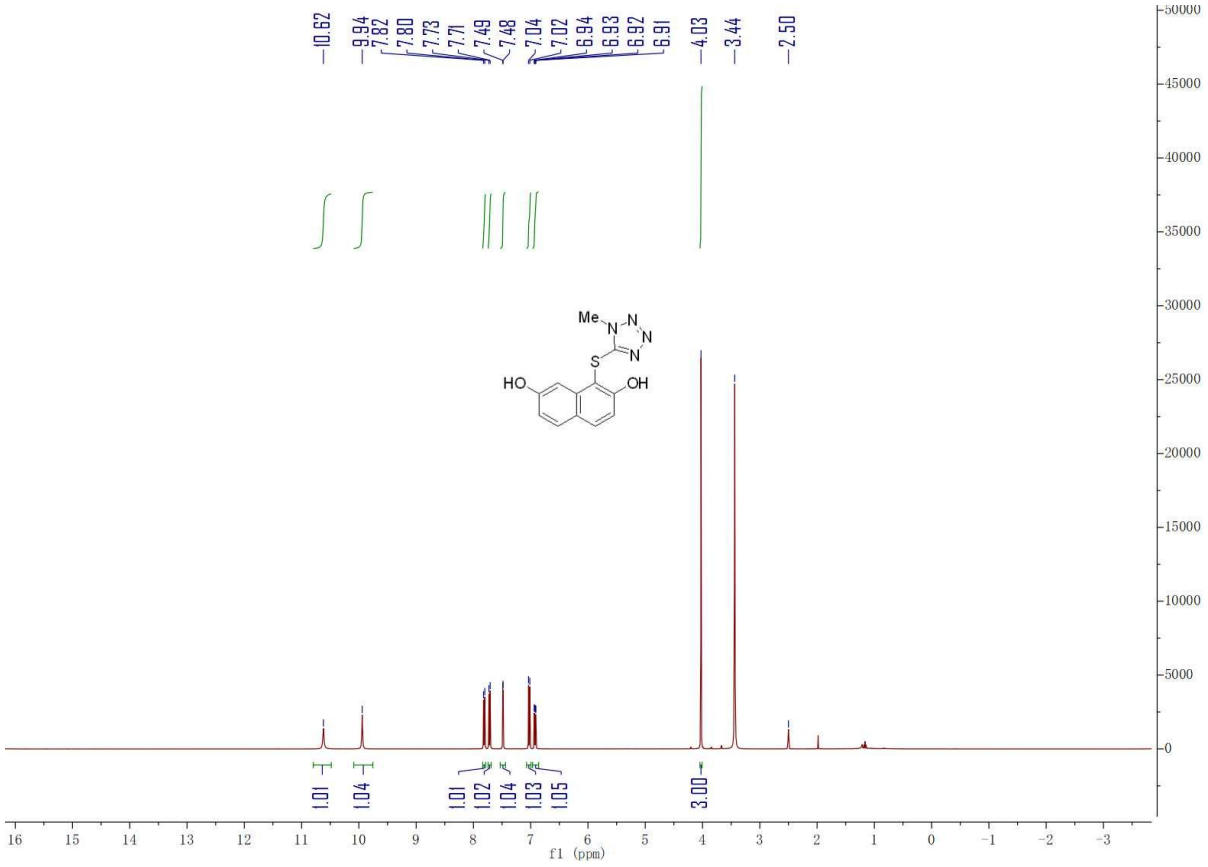
^{13}C NMR of 3i



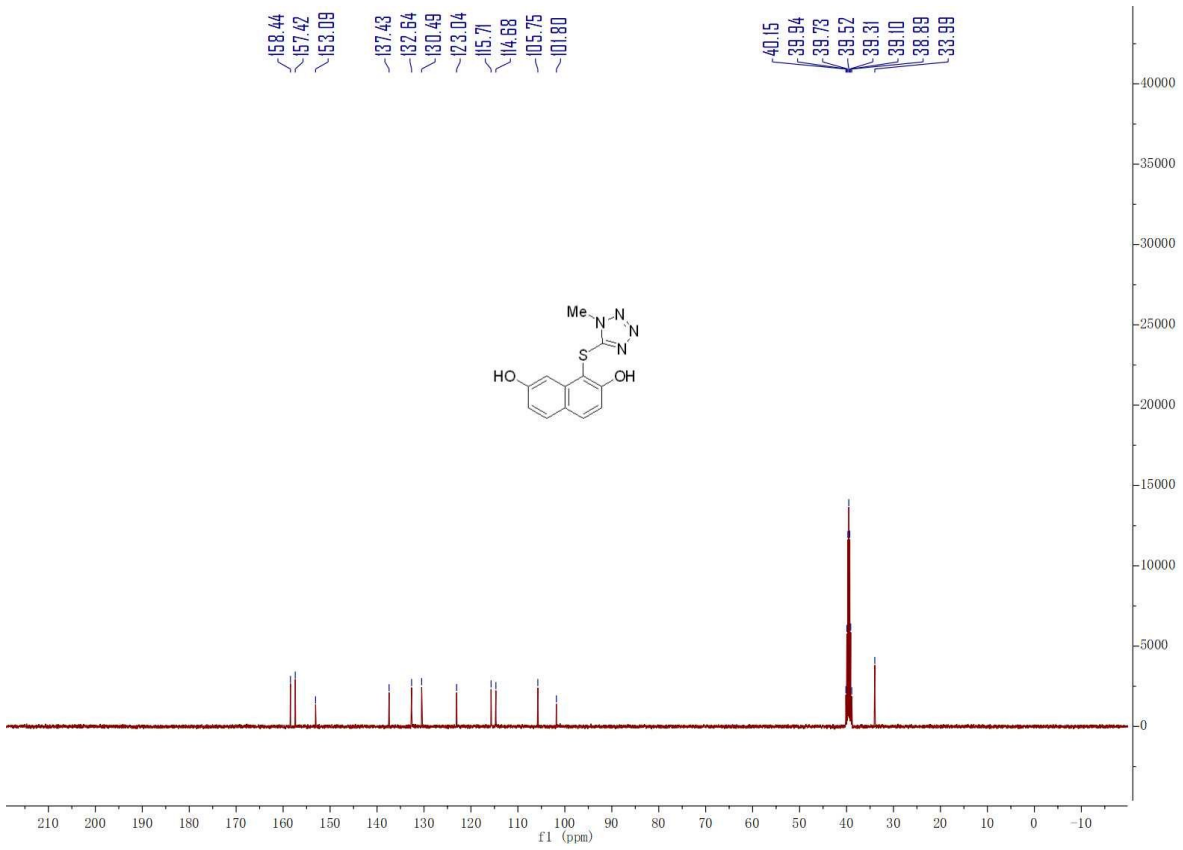
^{1}H NMR of 3j



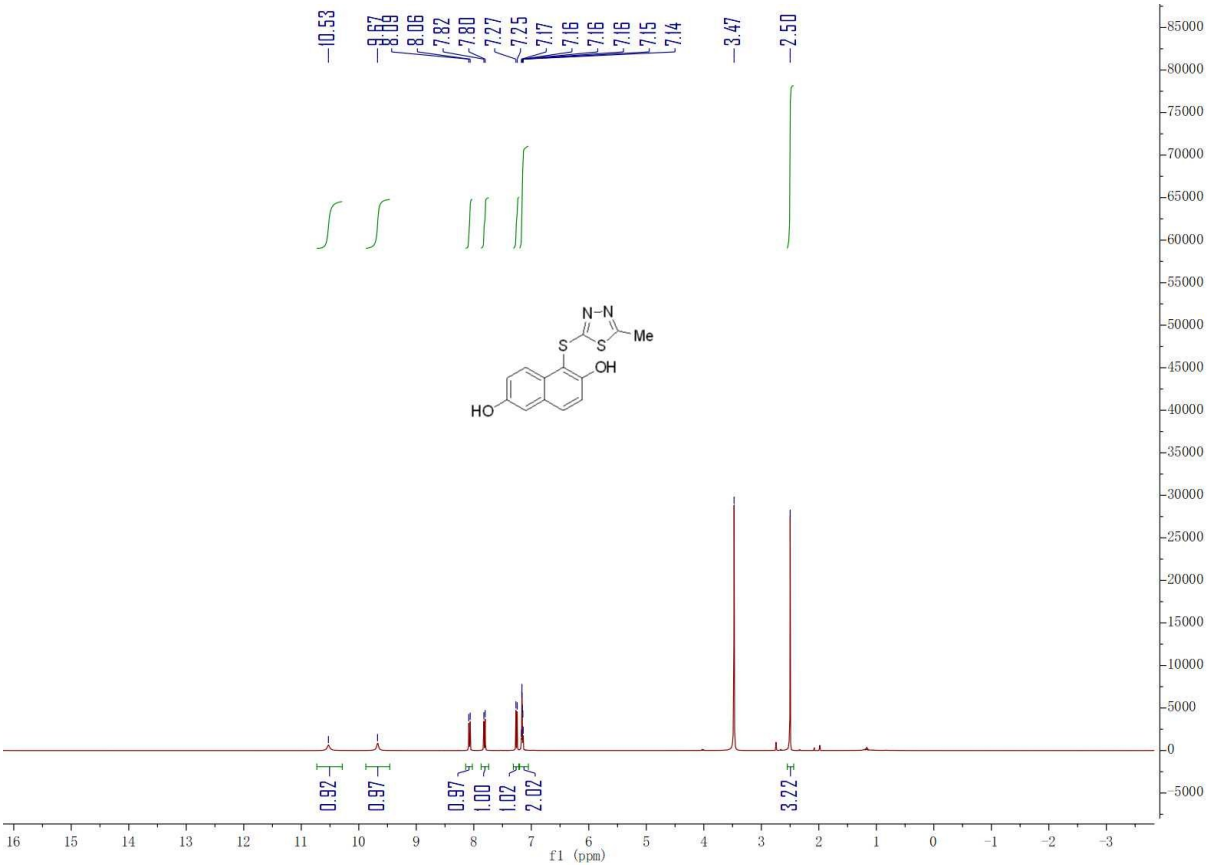
^{13}C NMR of 3j



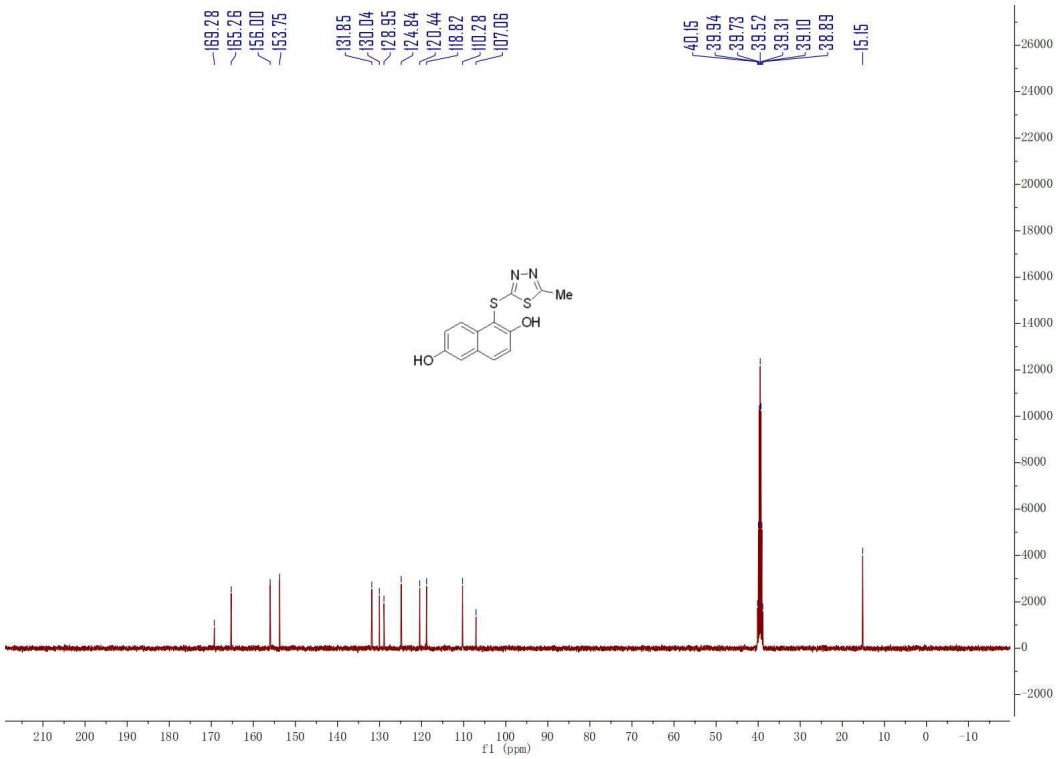
^{1}H NMR of 3k



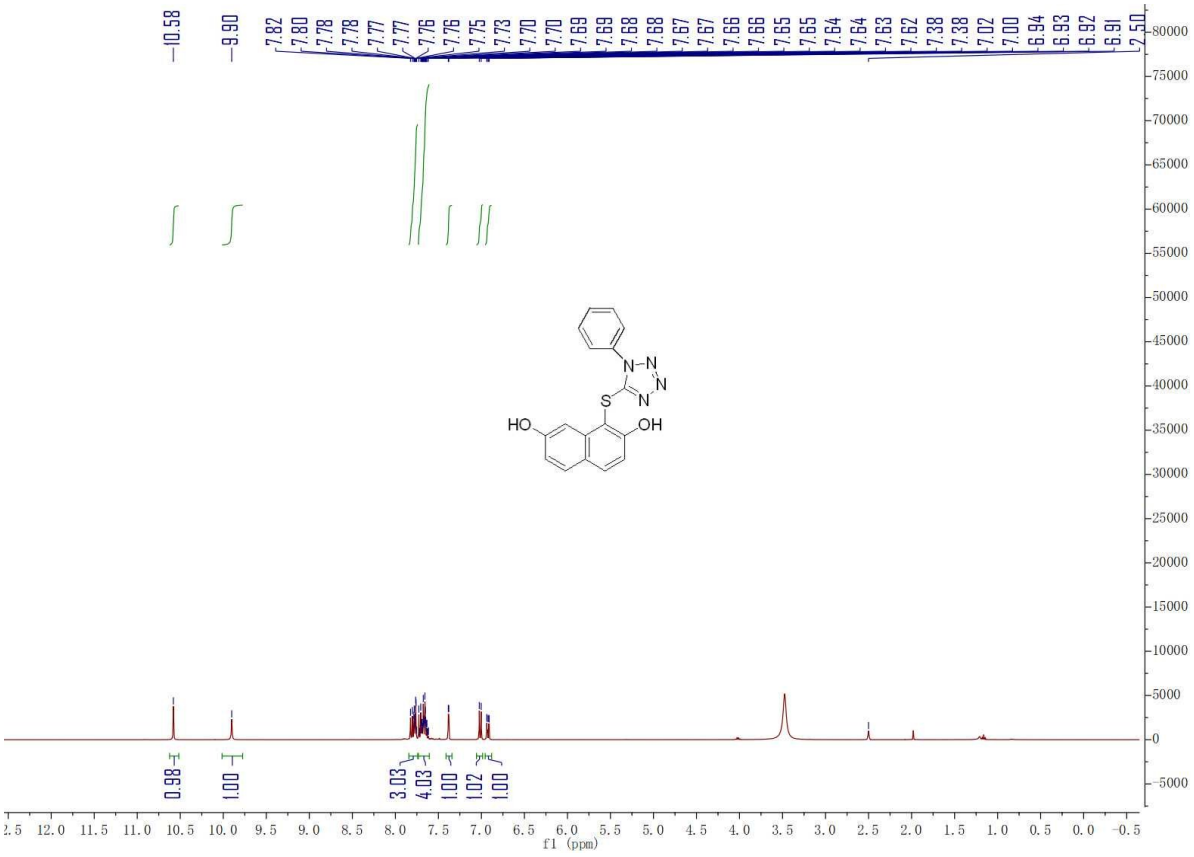
^{13}C NMR of 3k



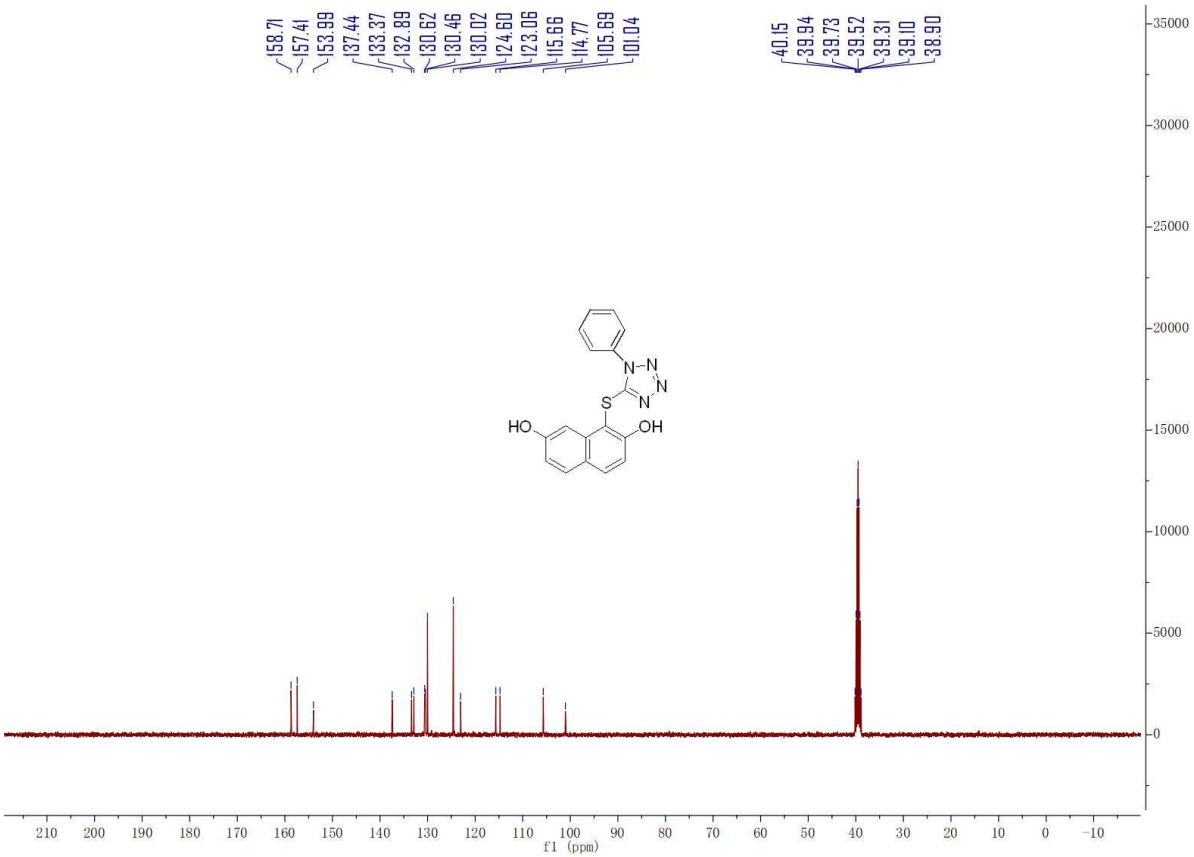
^{1}H NMR of 3l



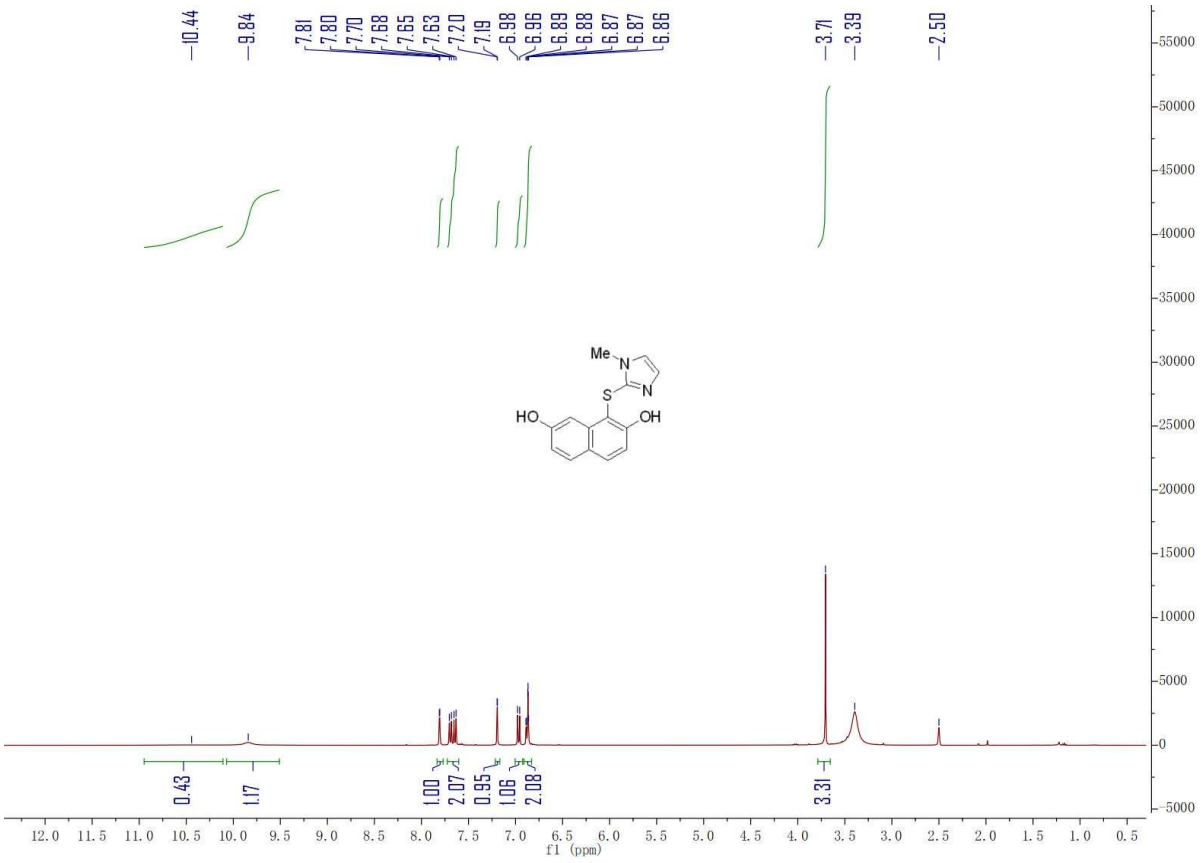
^{13}C NMR of 3l



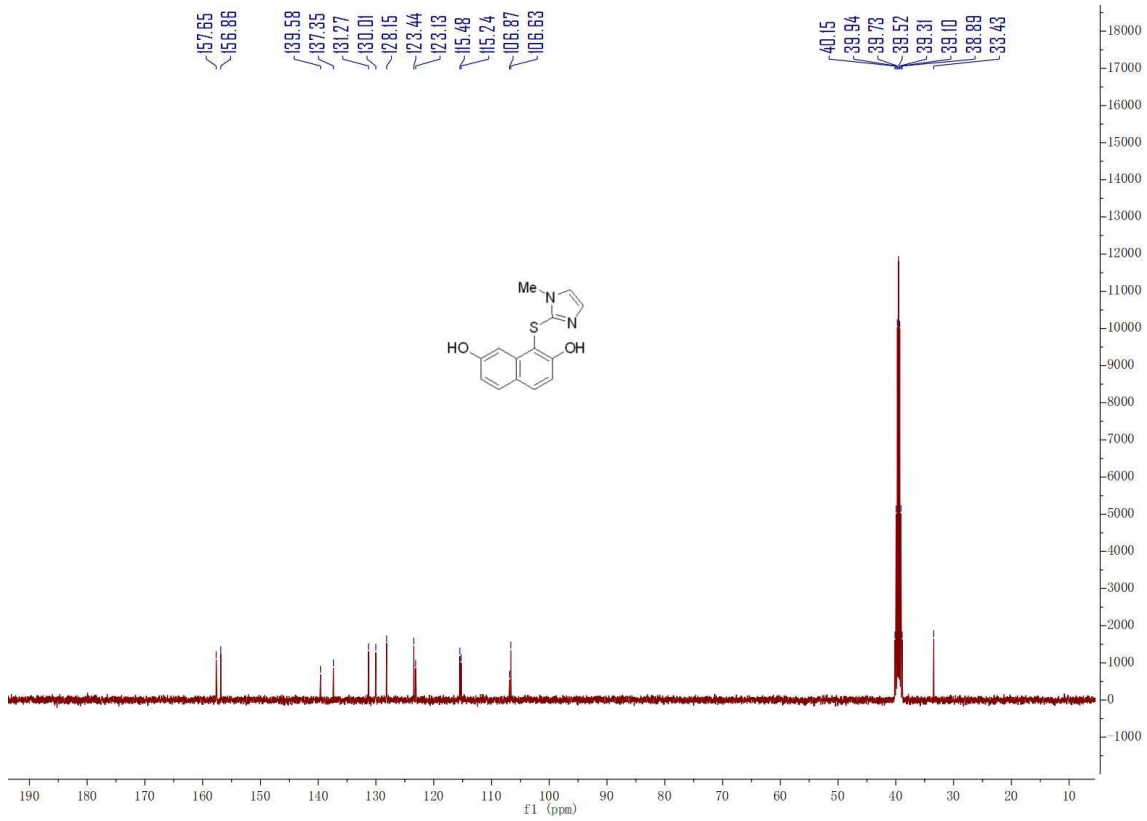
^{1}H NMR of 3m



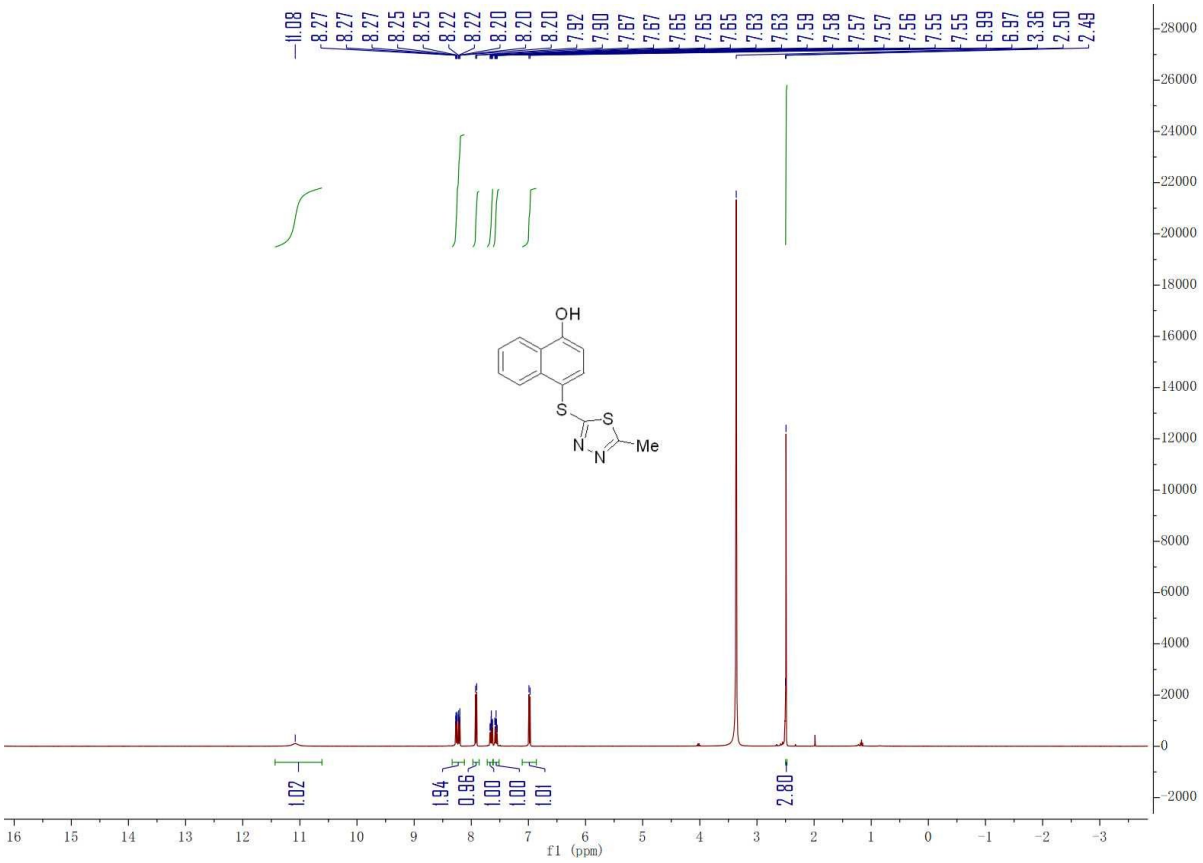
^{13}C NMR of 3m



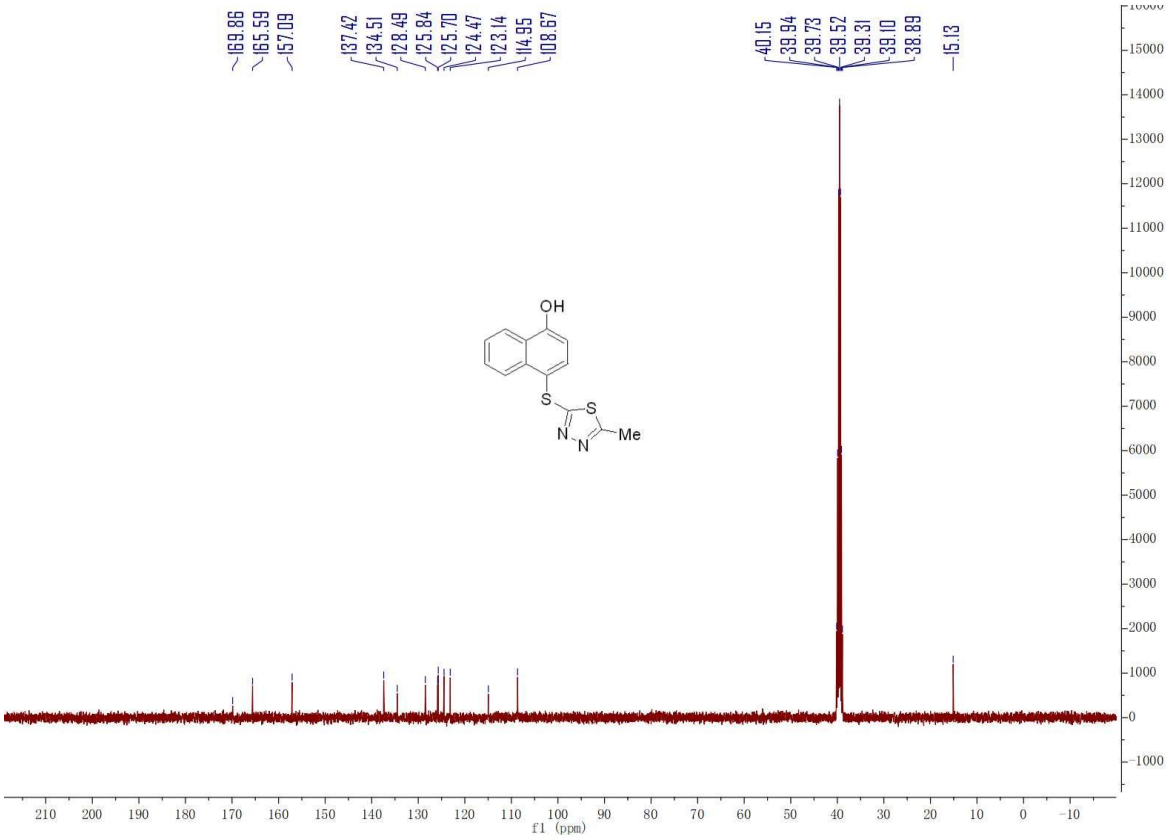
^{1}H NMR of 3n



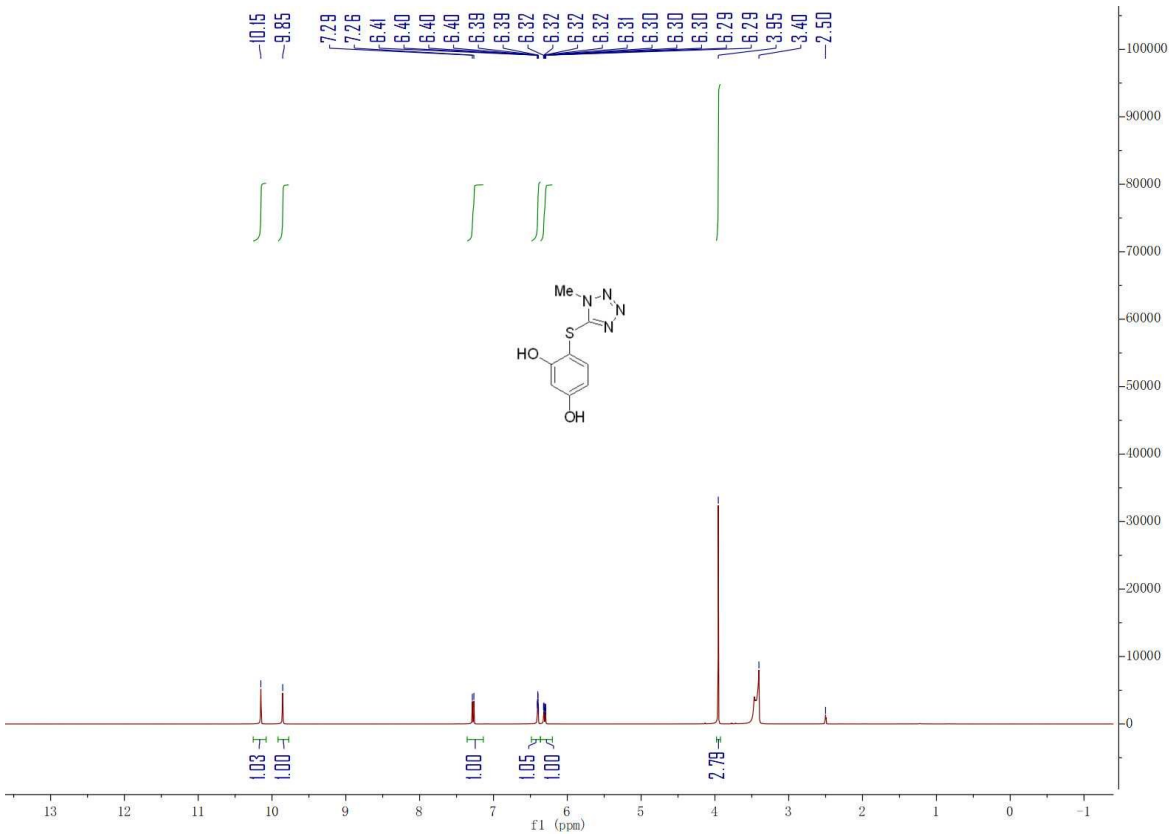
^{13}C NMR of 3n



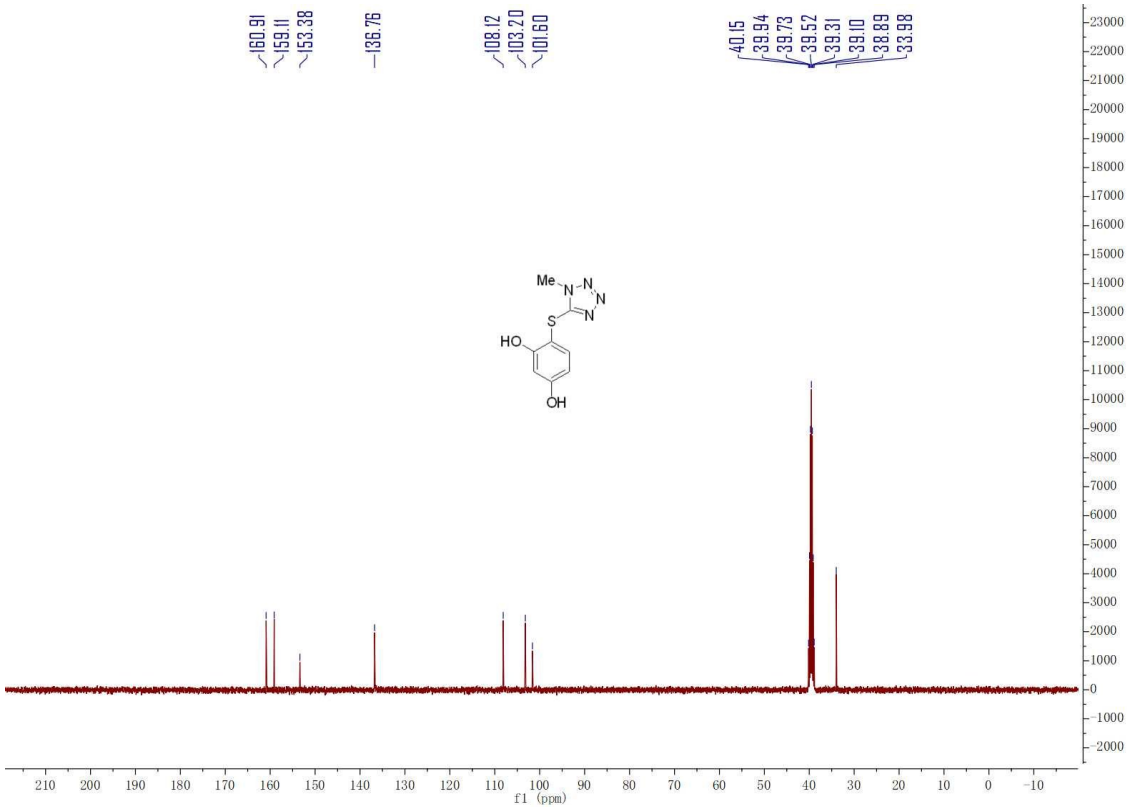
^{1}H NMR of 3o



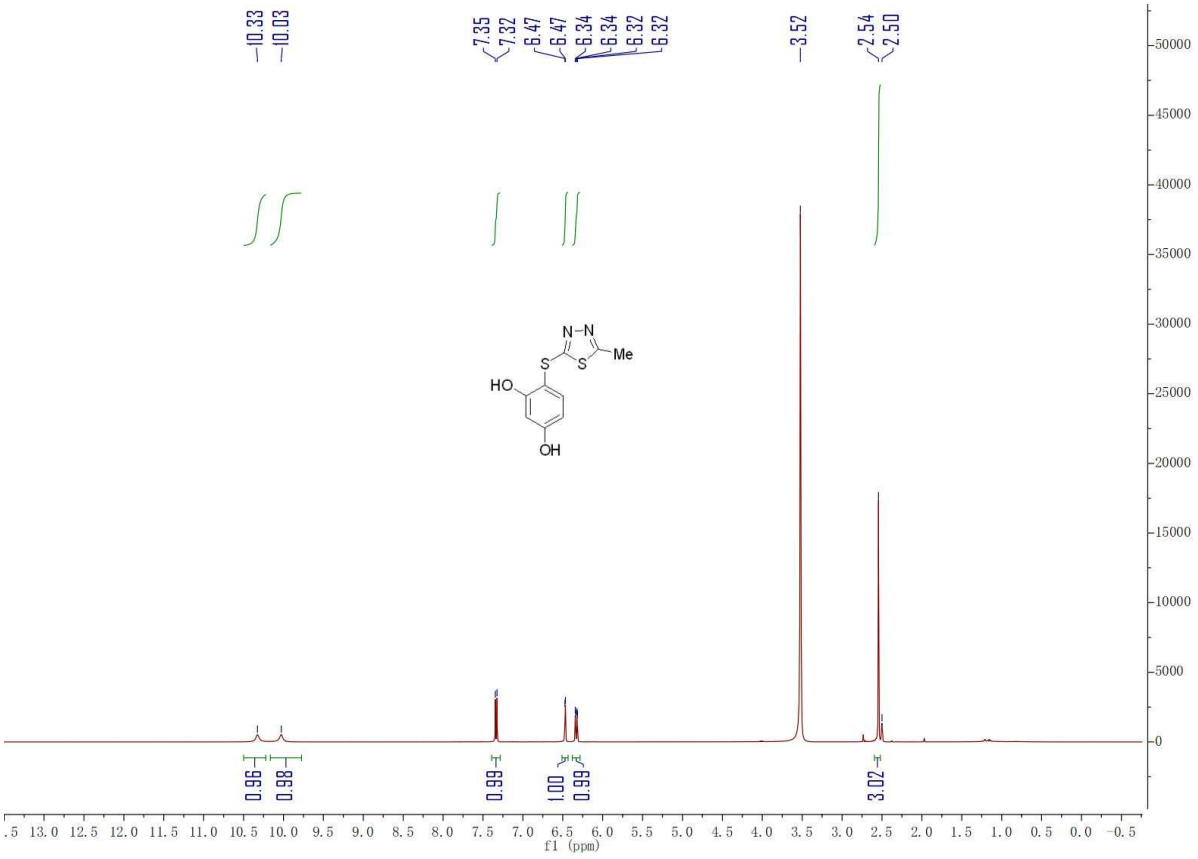
^{13}C NMR of 3o



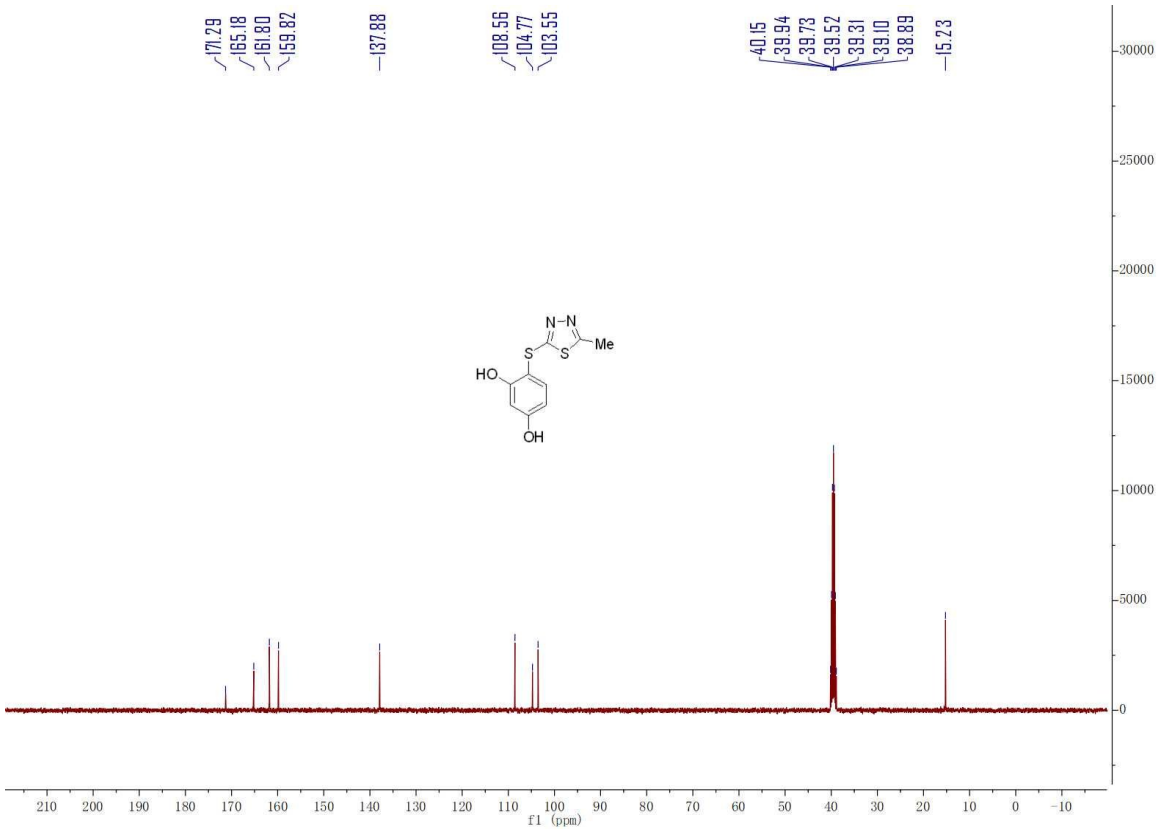
^{1}H NMR of 3p



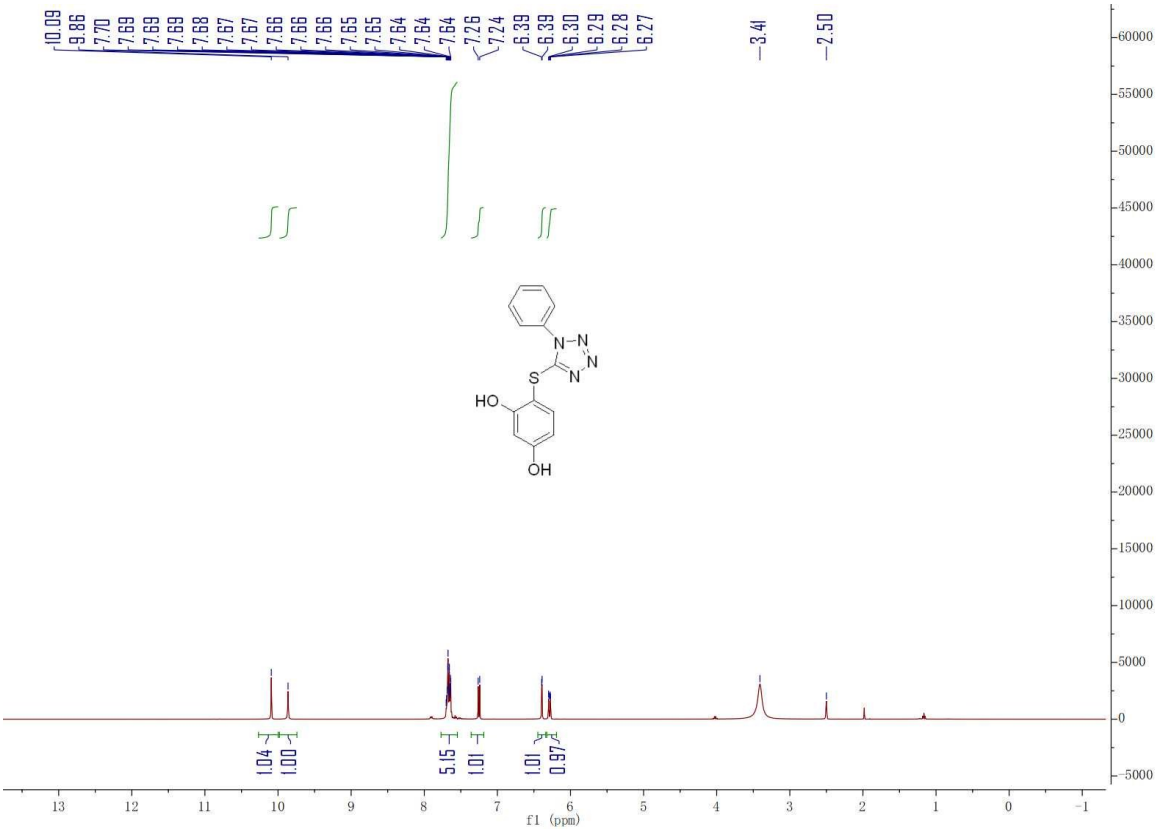
^{13}C NMR of 3p



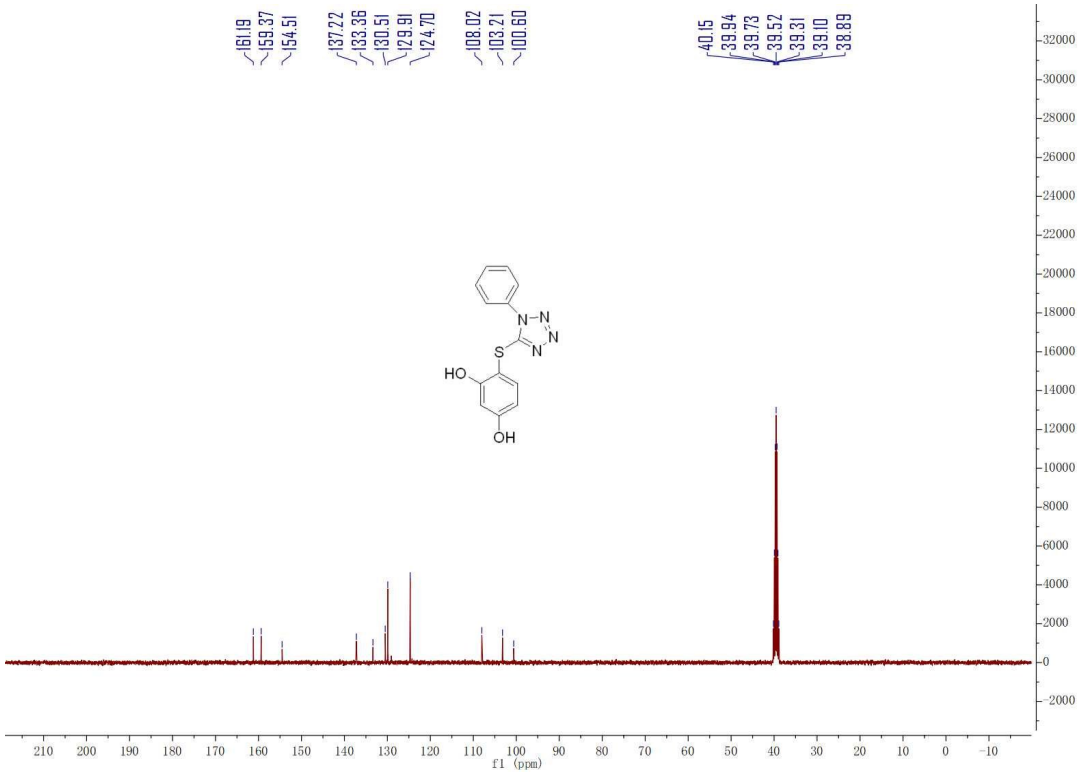
^{1}H NMR of 3q



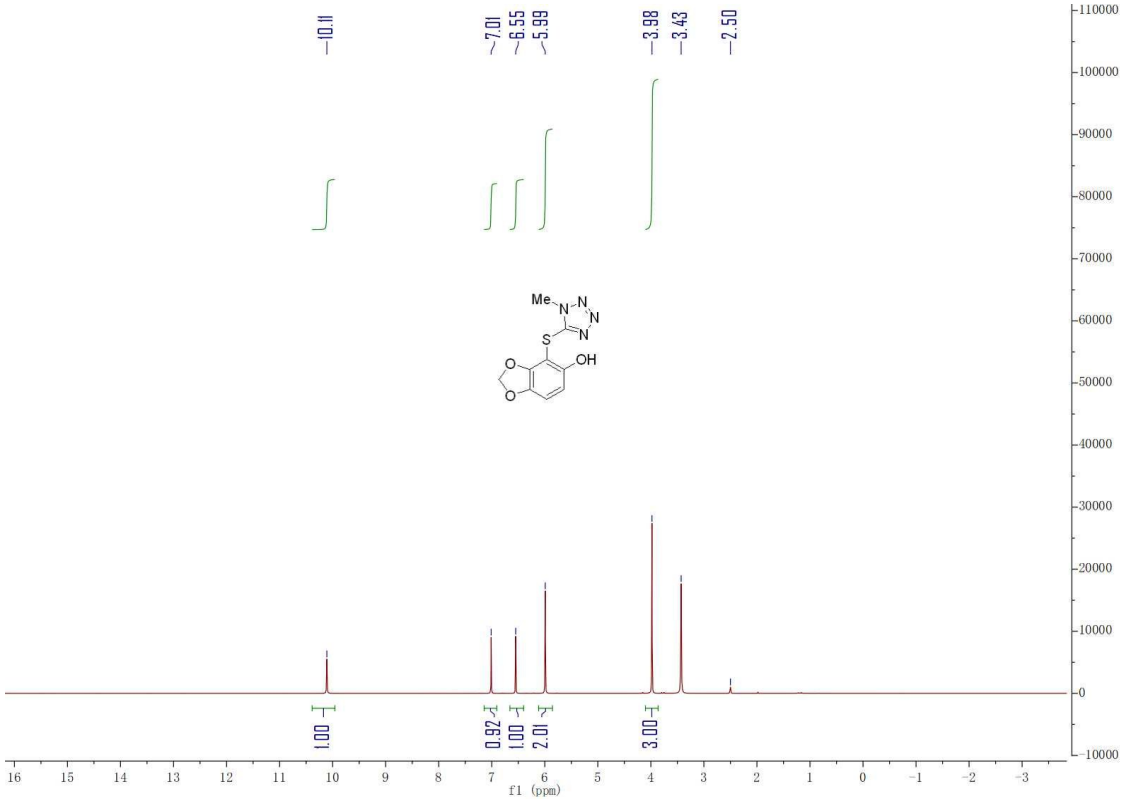
^{13}C NMR of 3q



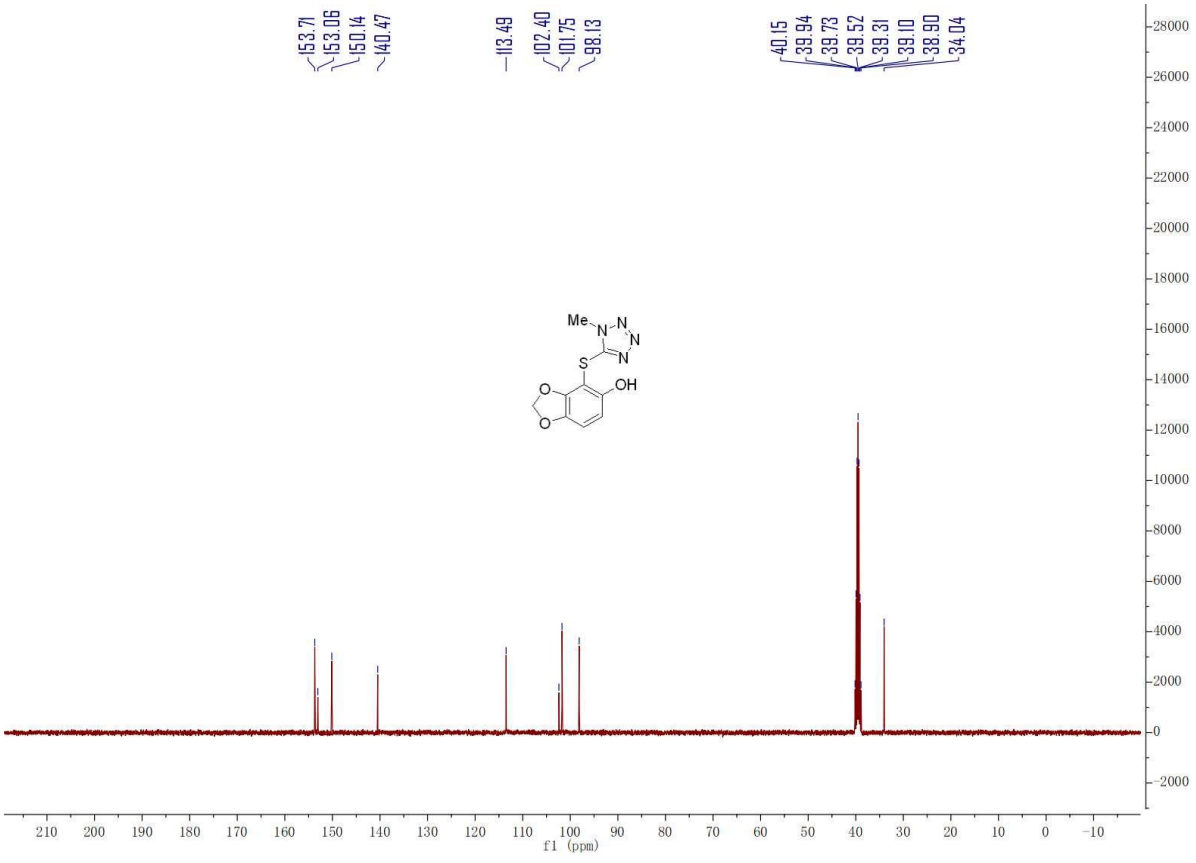
^{1}H NMR of 3r



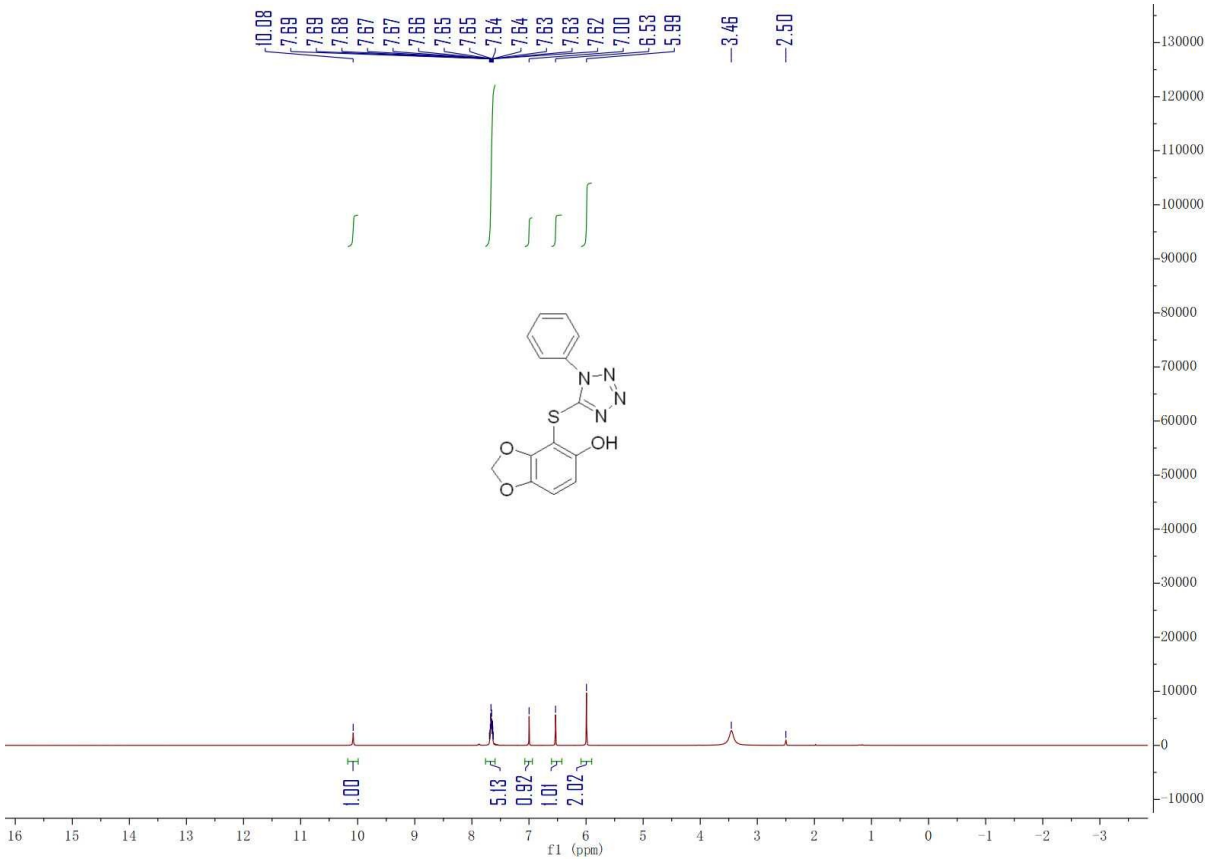
^{13}C NMR of 3r



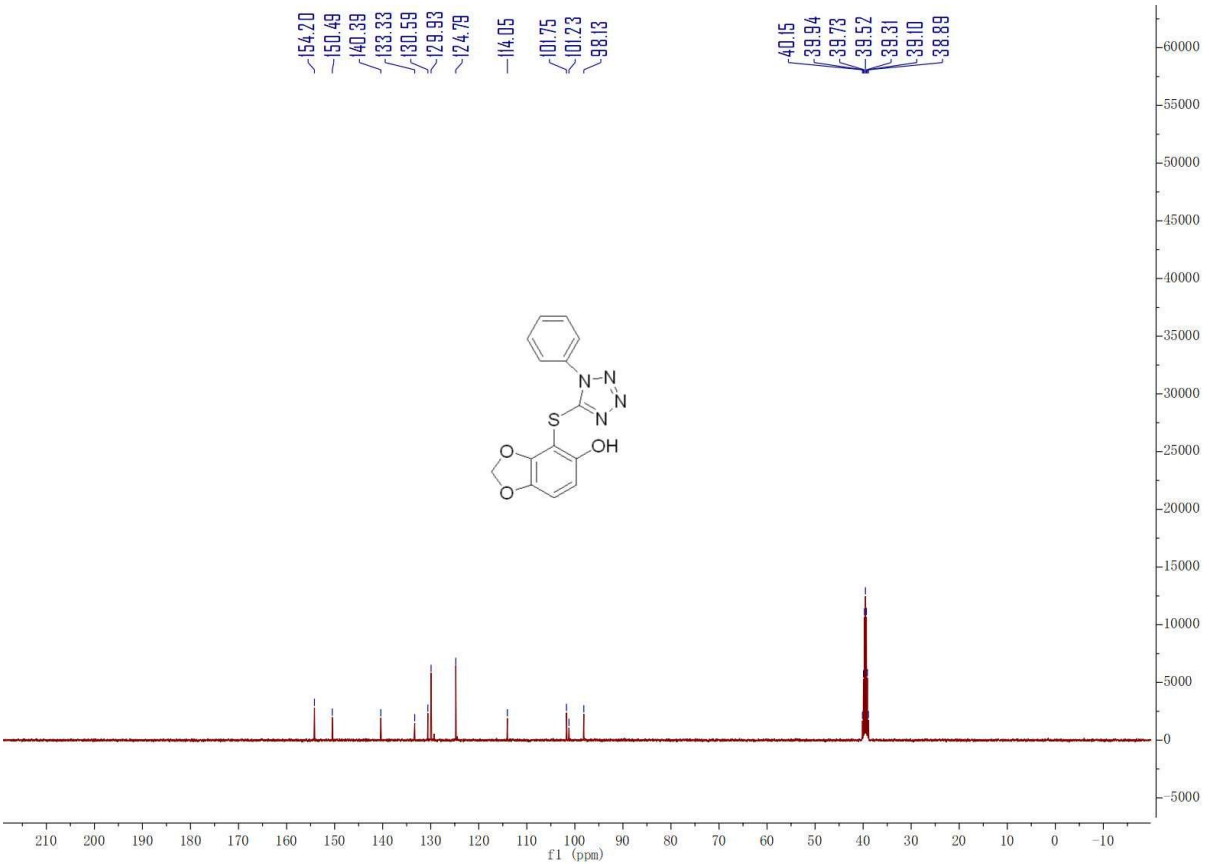
^{1}H NMR of 3s



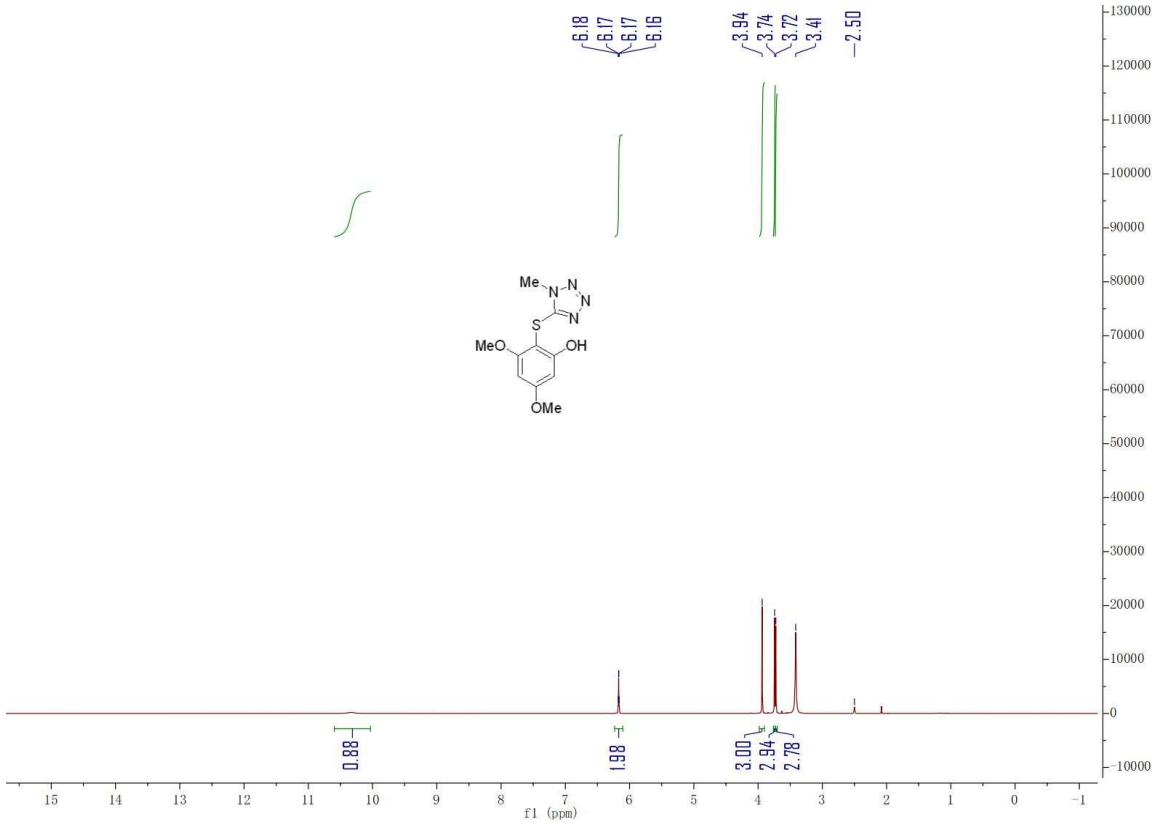
^{13}C NMR of 3s



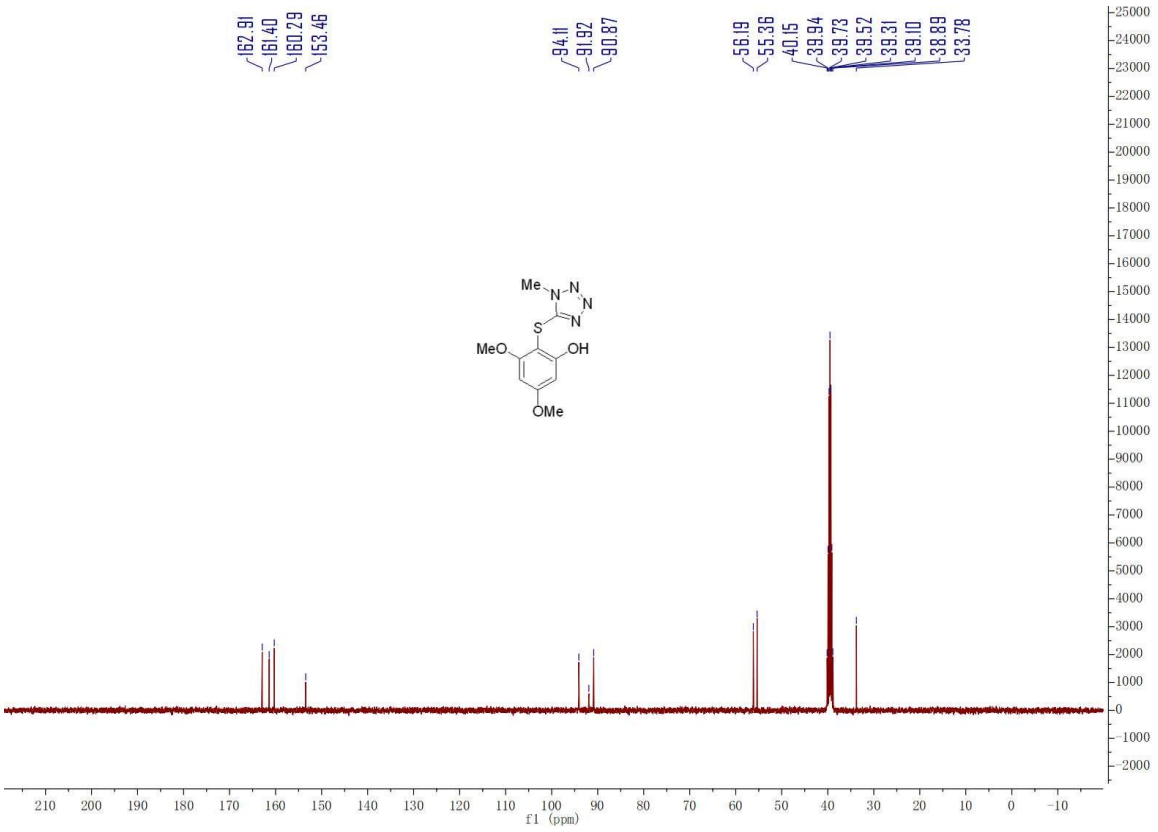
^{1}H NMR of 3t



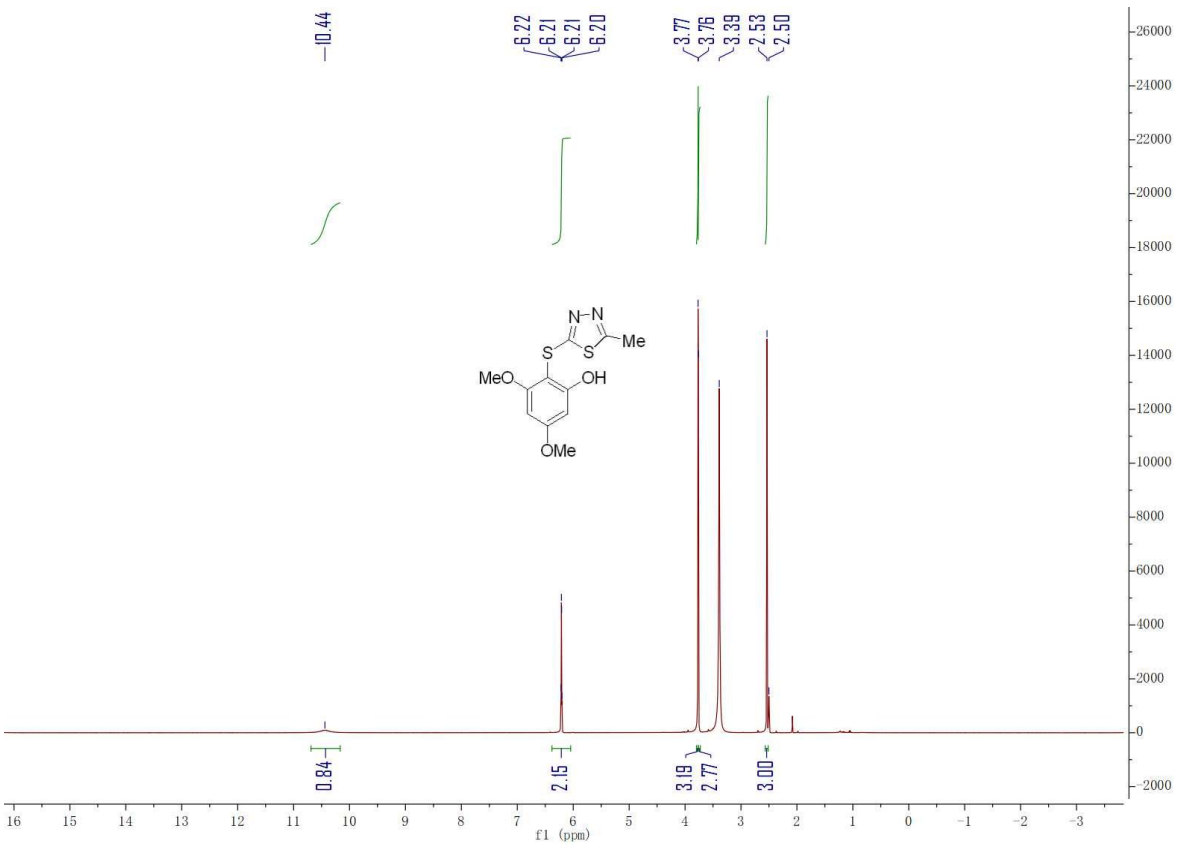
^{13}C NMR of 3t



^{1}H NMR of 3u



^{13}C NMR of 3u



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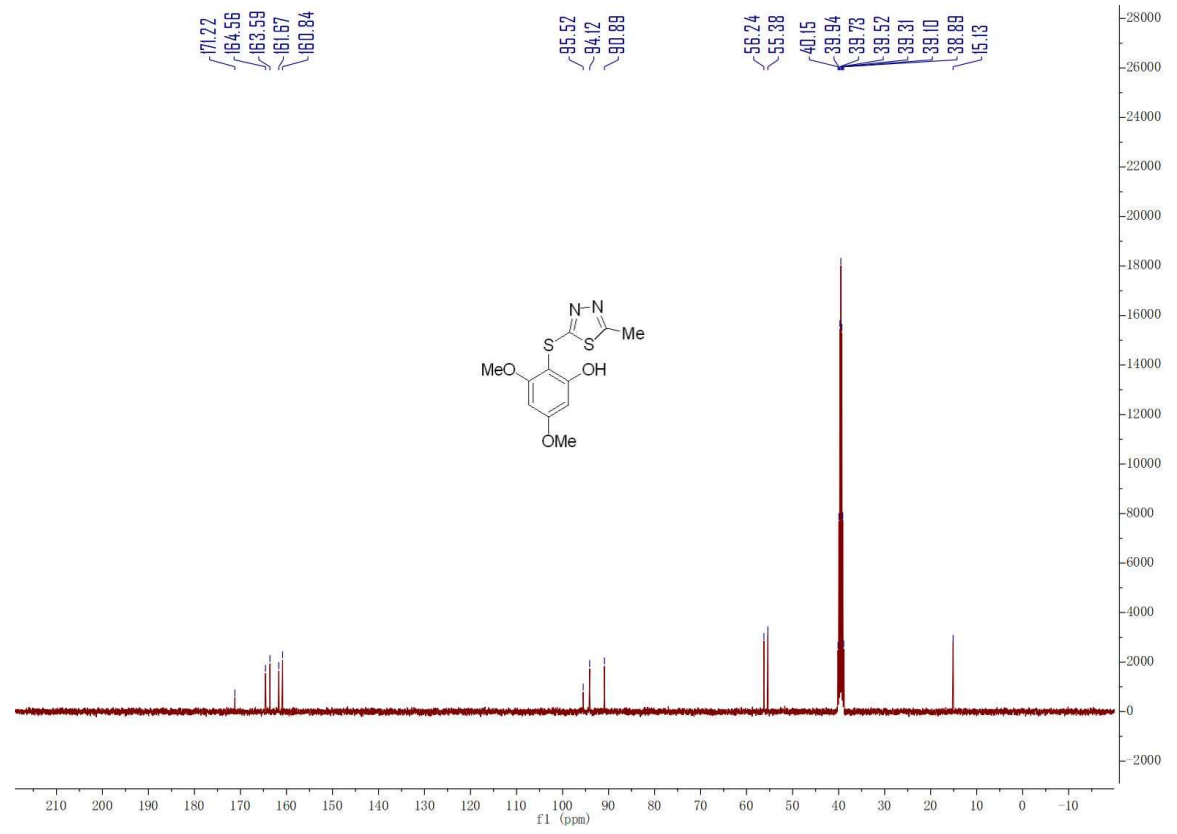
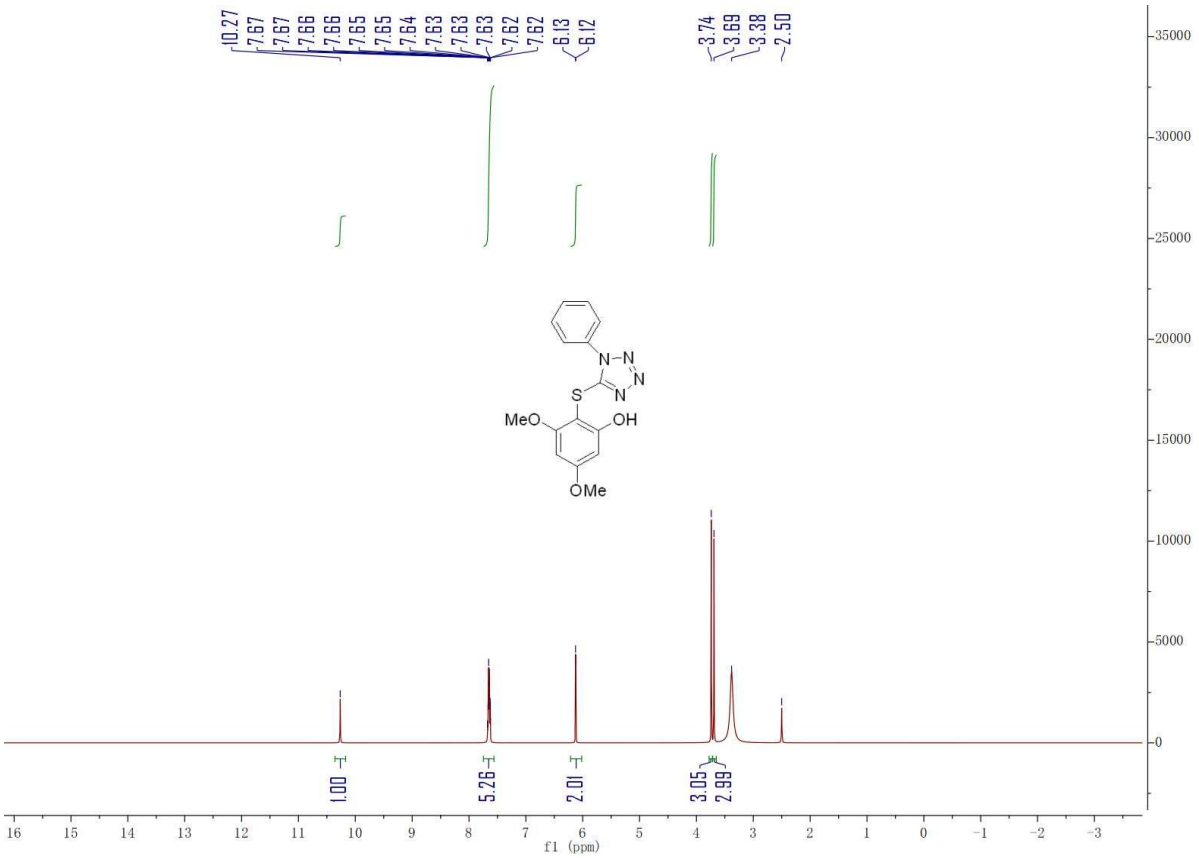


^{13}C NMR of 3v



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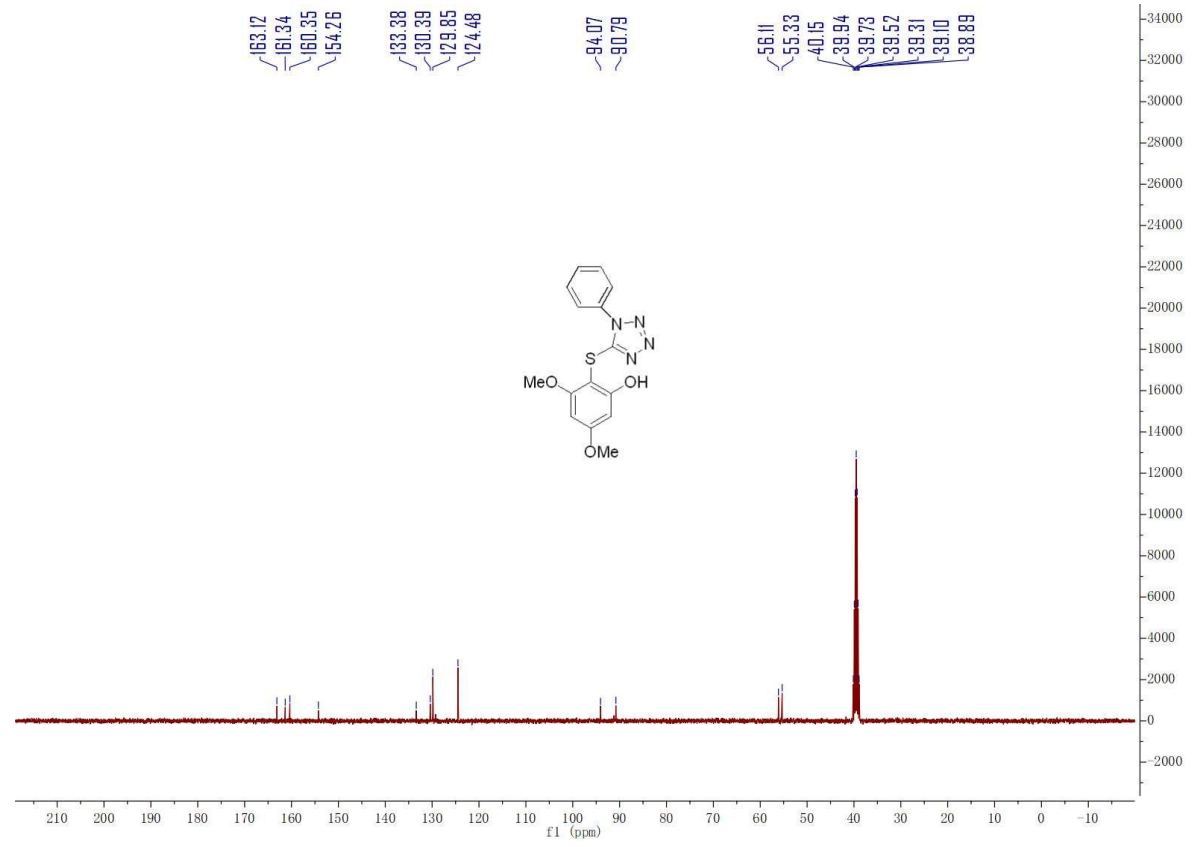
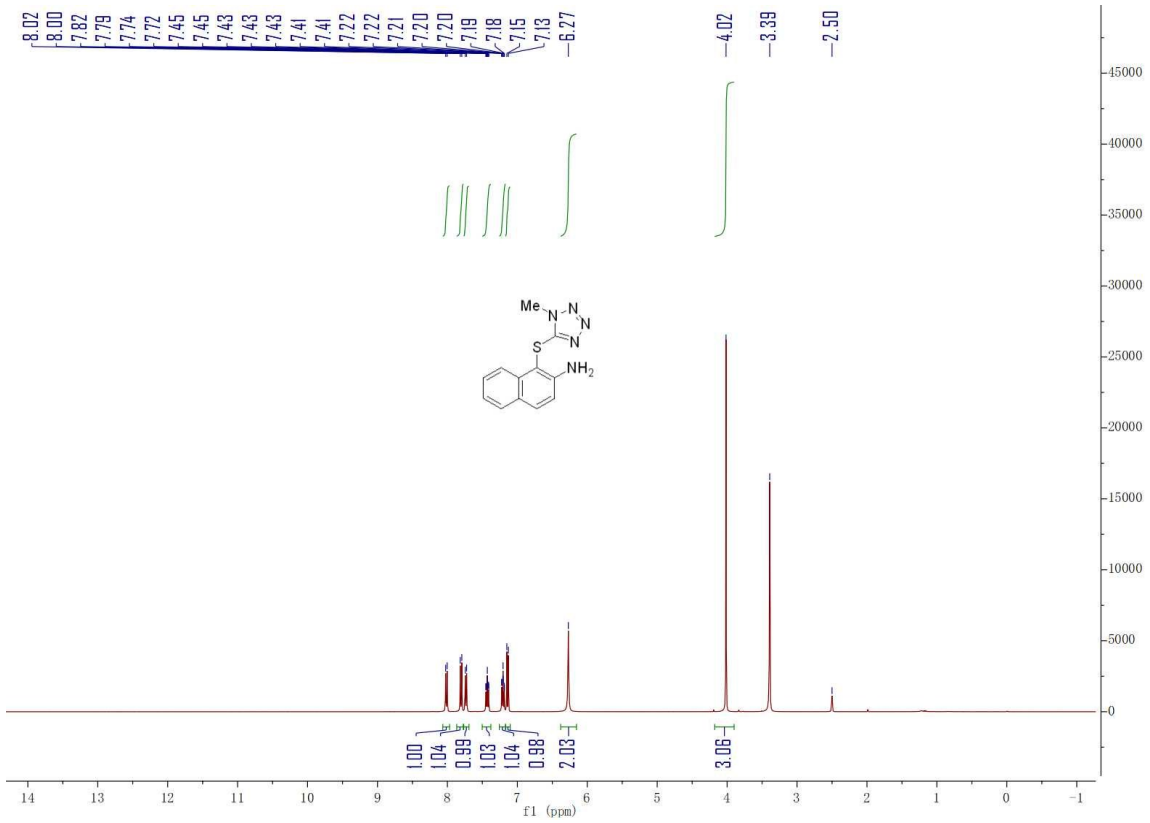
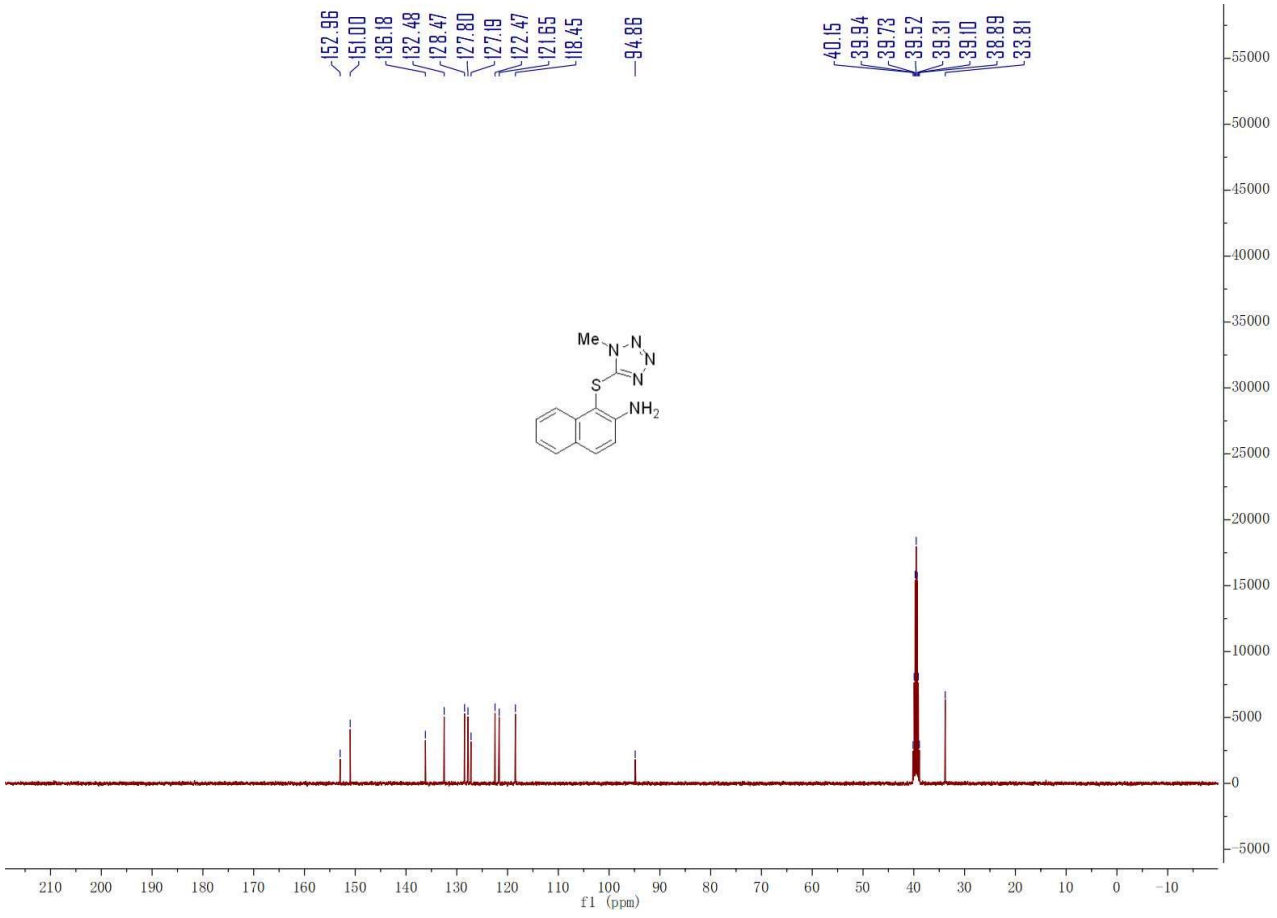


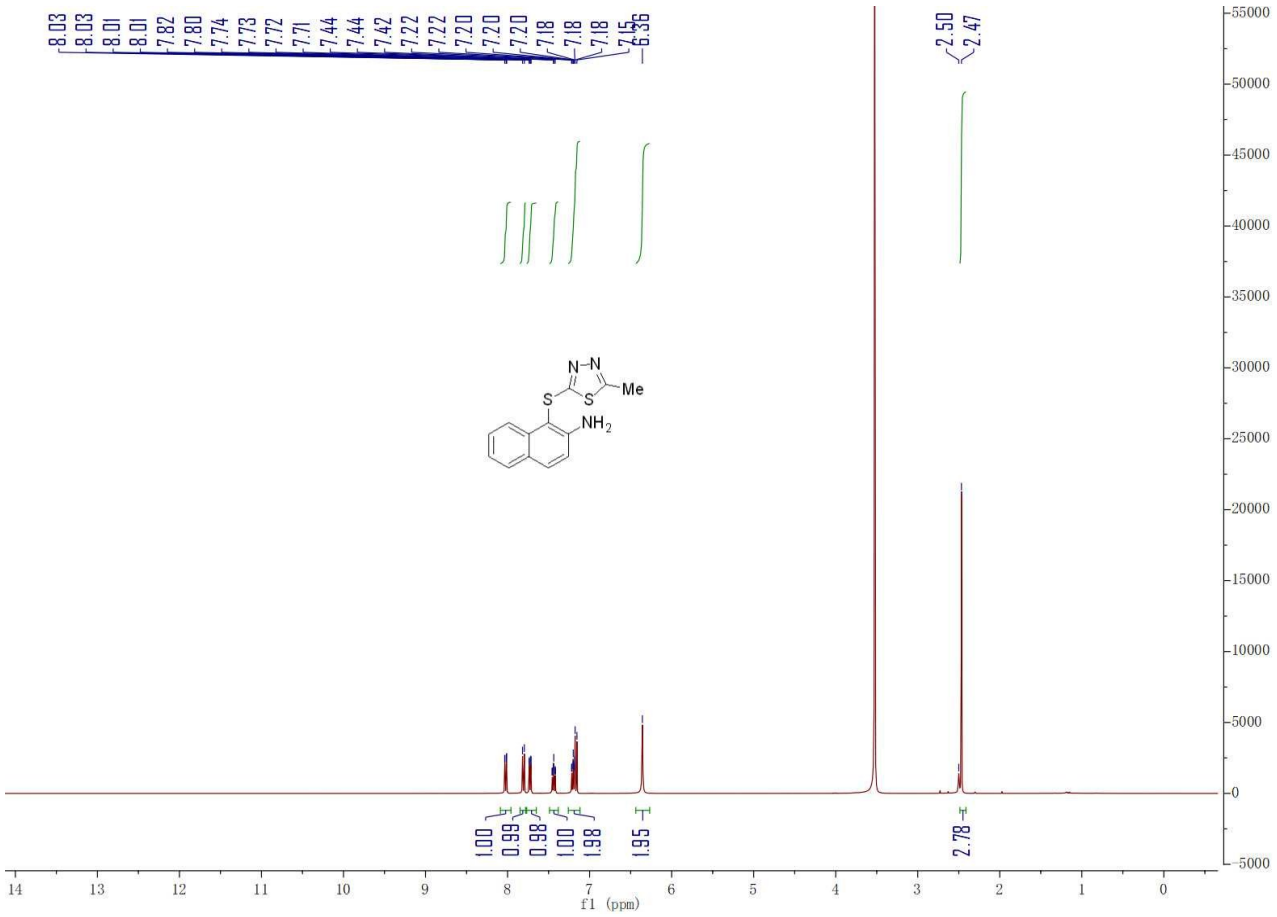
^{13}C NMR of 3w



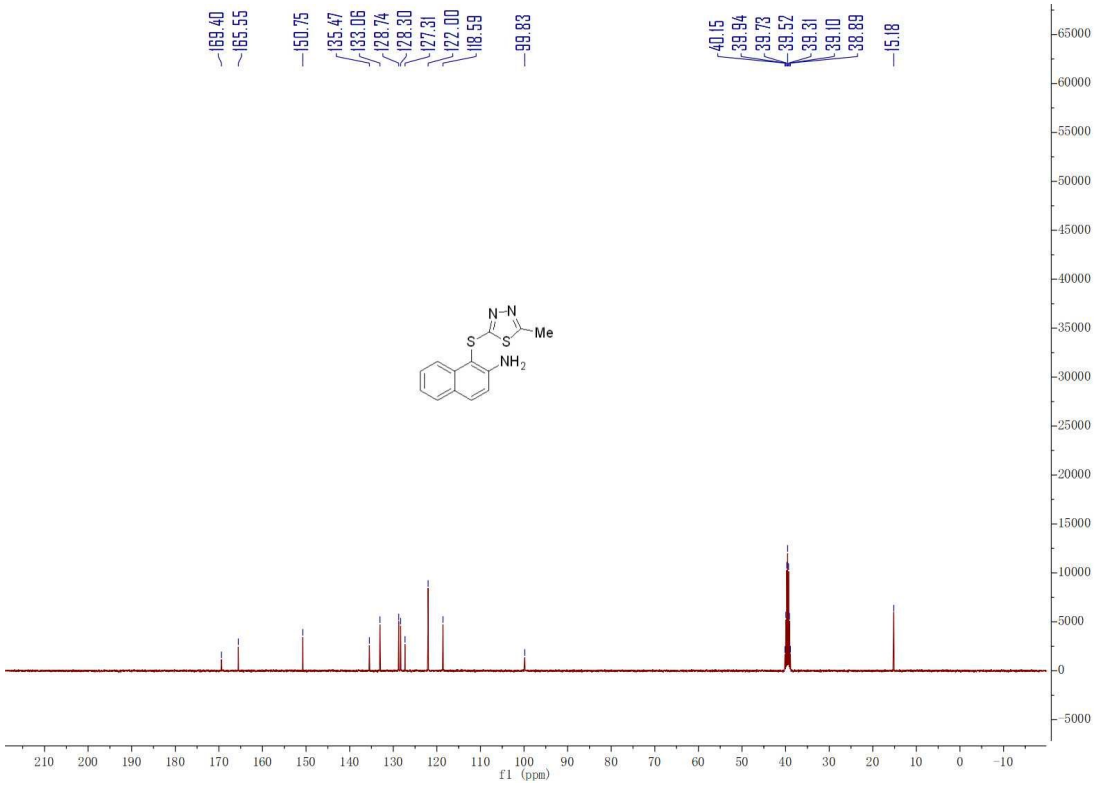
^{1}H NMR of 4a



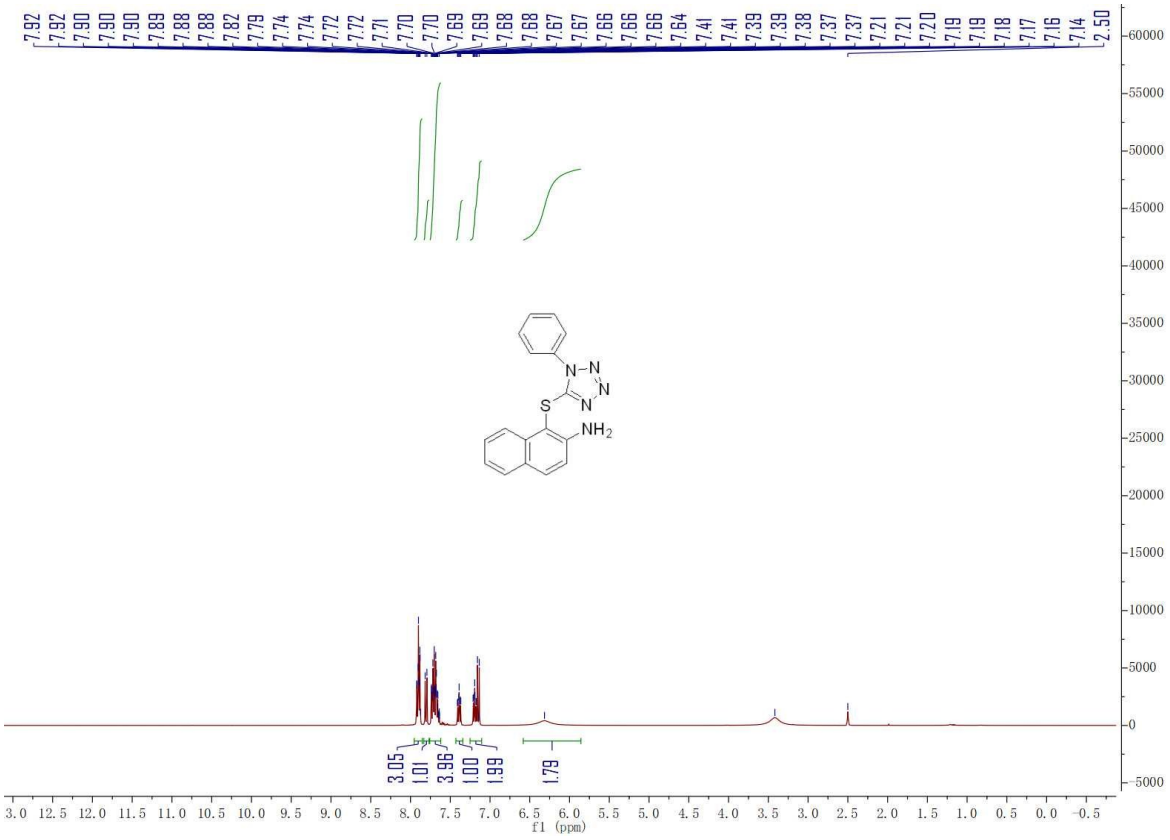
^{13}C NMR of 4a



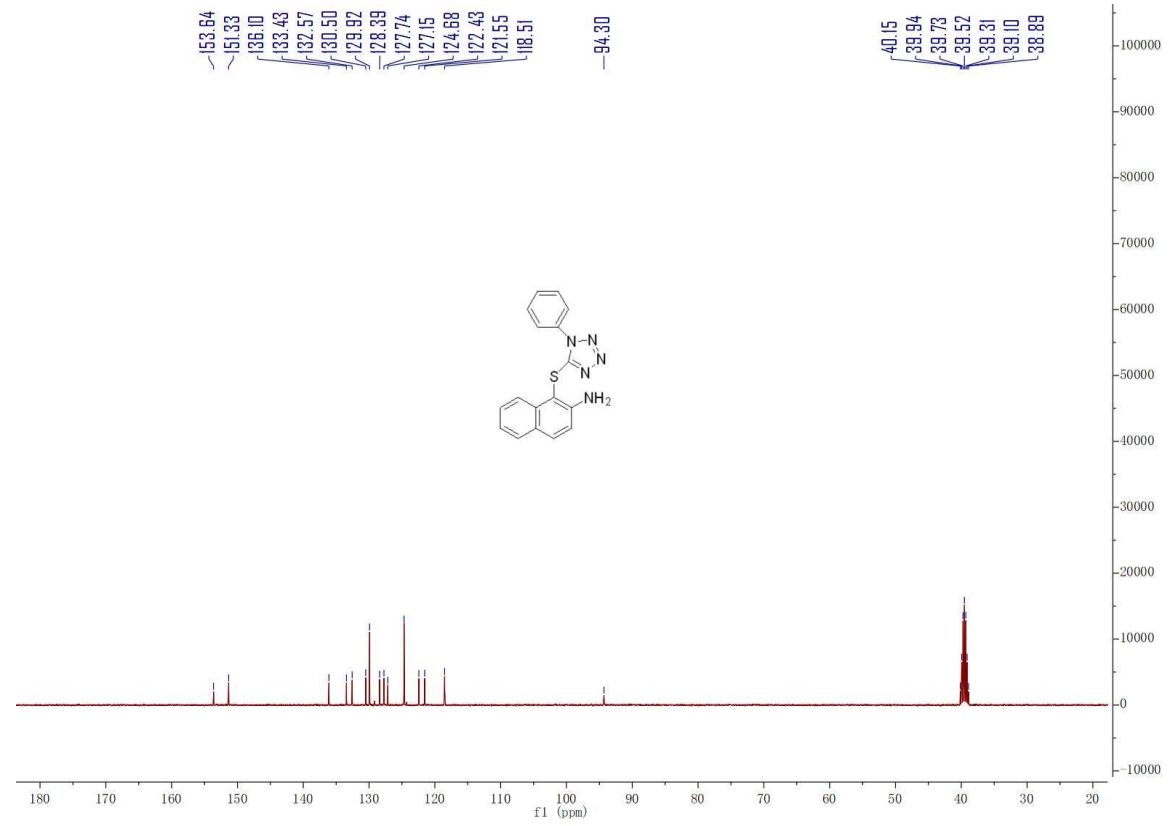
^{1}H NMR of 4b



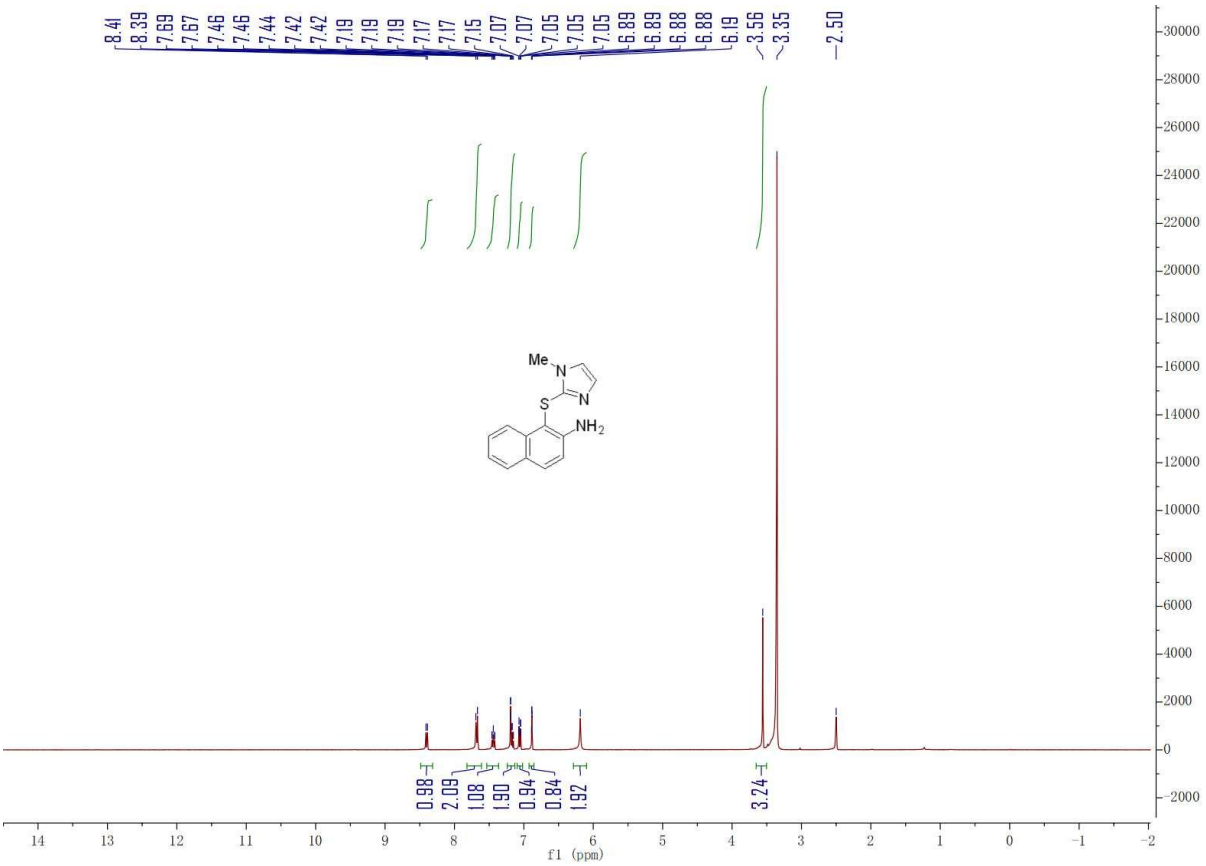
^{13}C NMR of 4b



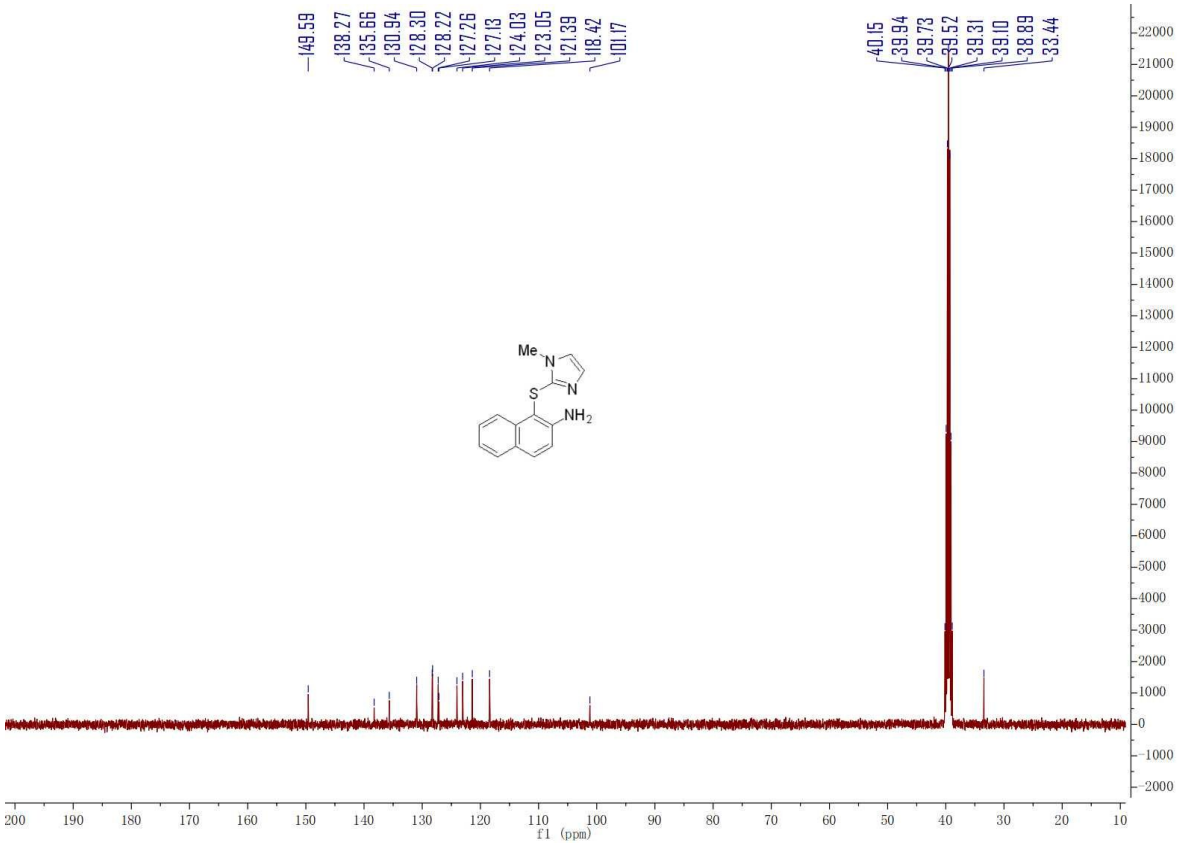
^{1}H NMR of 4c



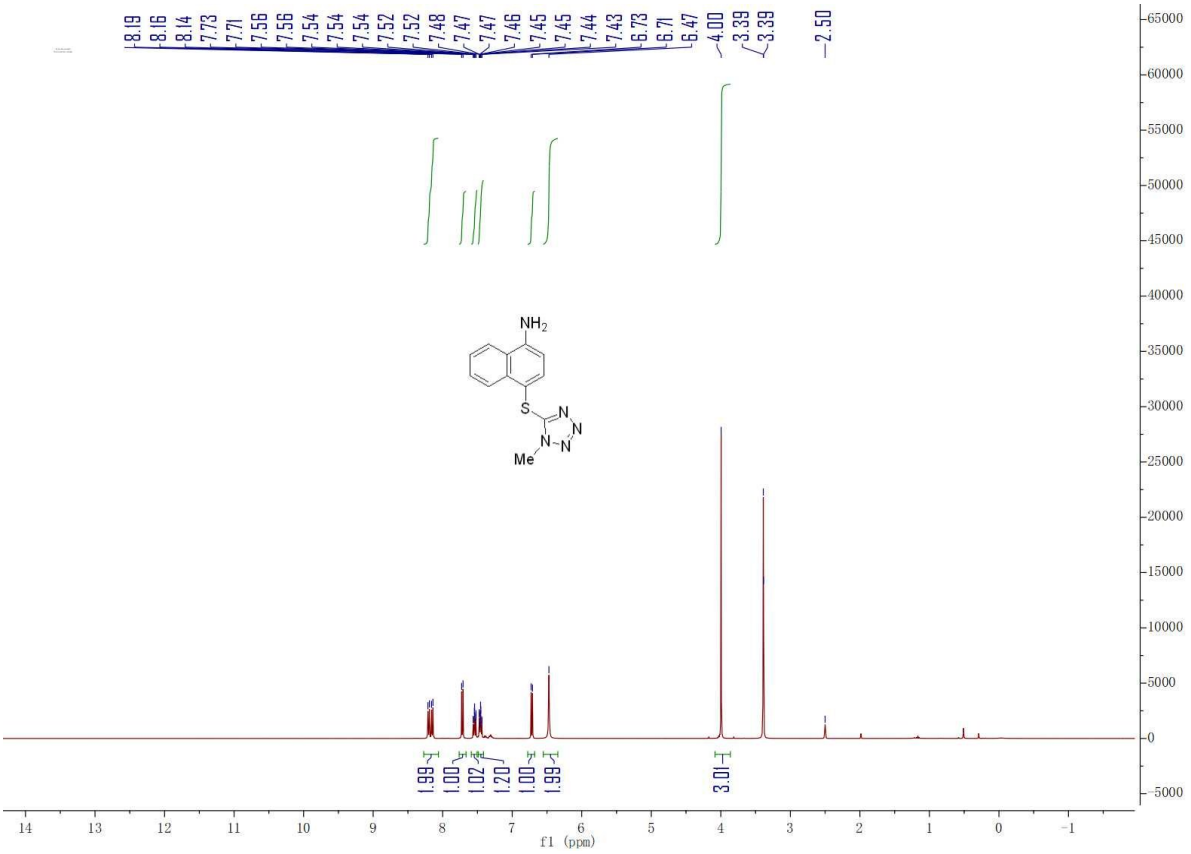
^{13}C NMR of 4c



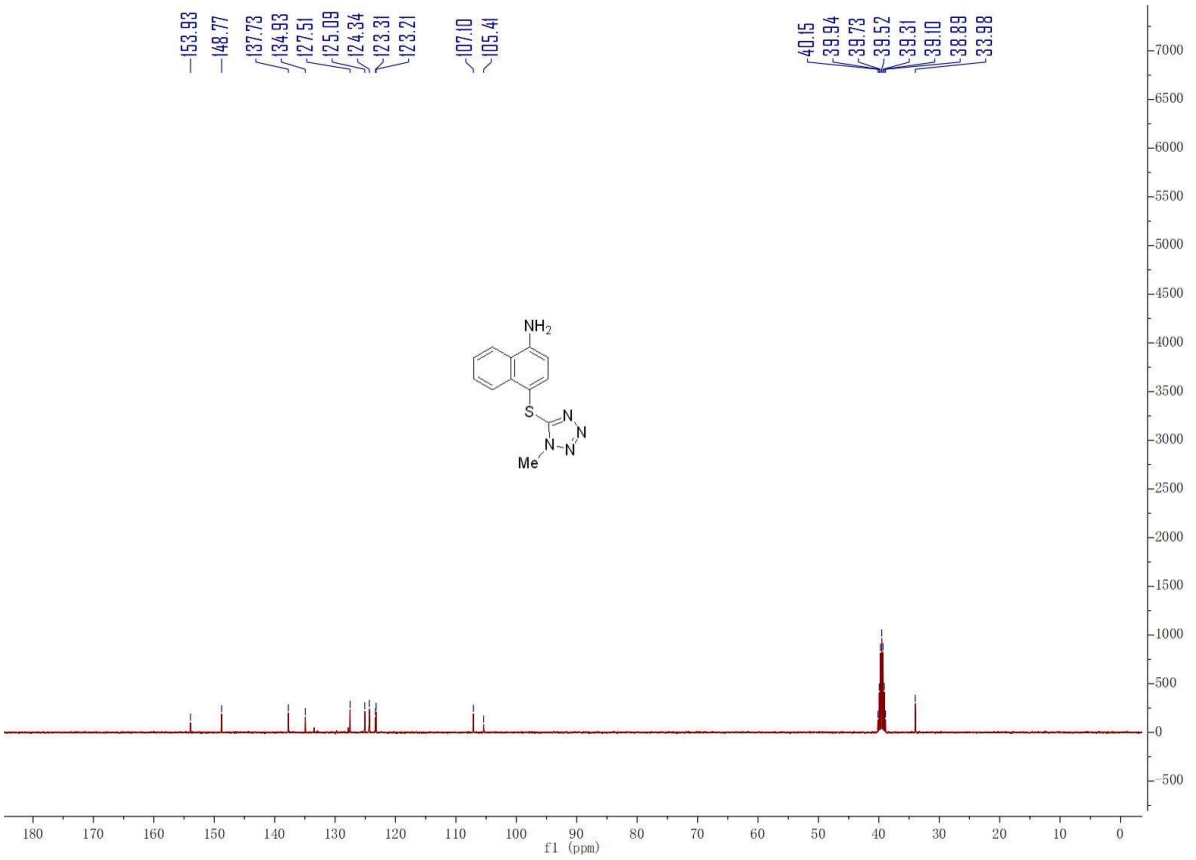
^{1}H NMR of 4d



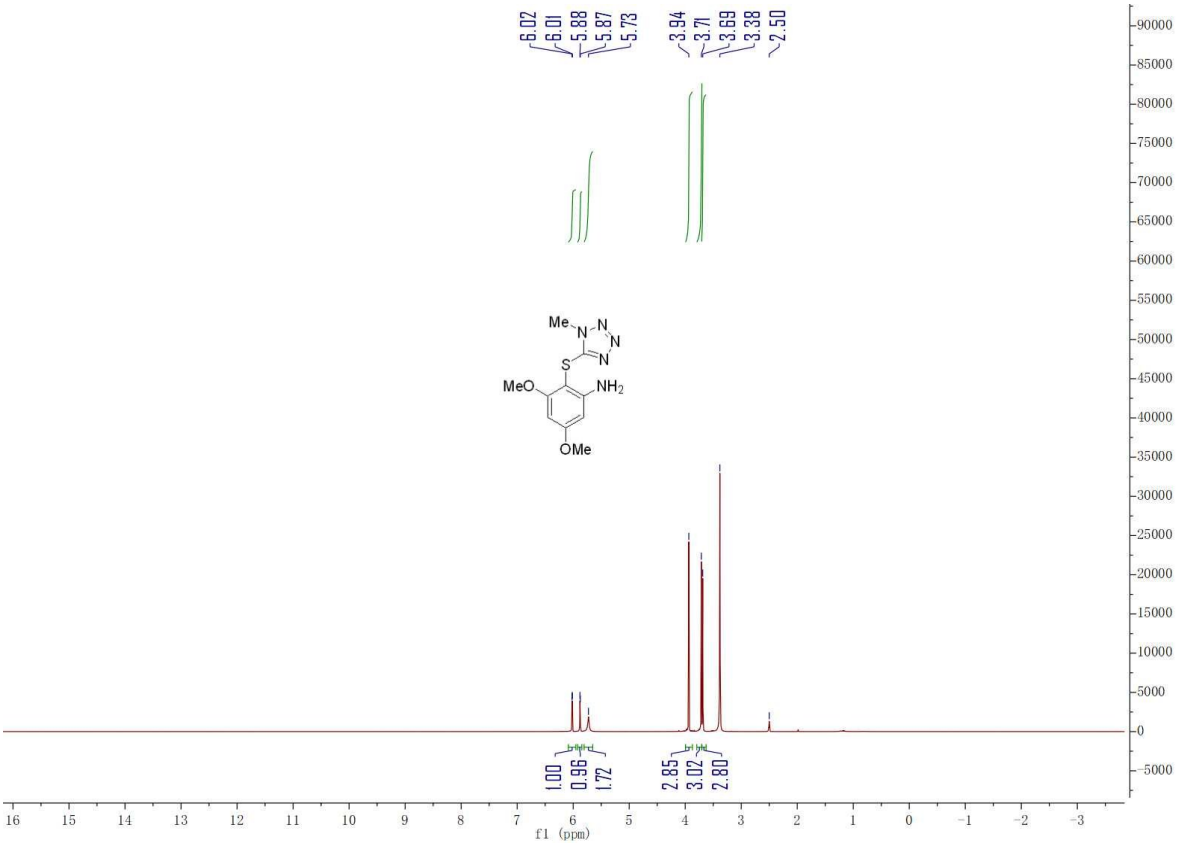
^{13}C NMR of 4d



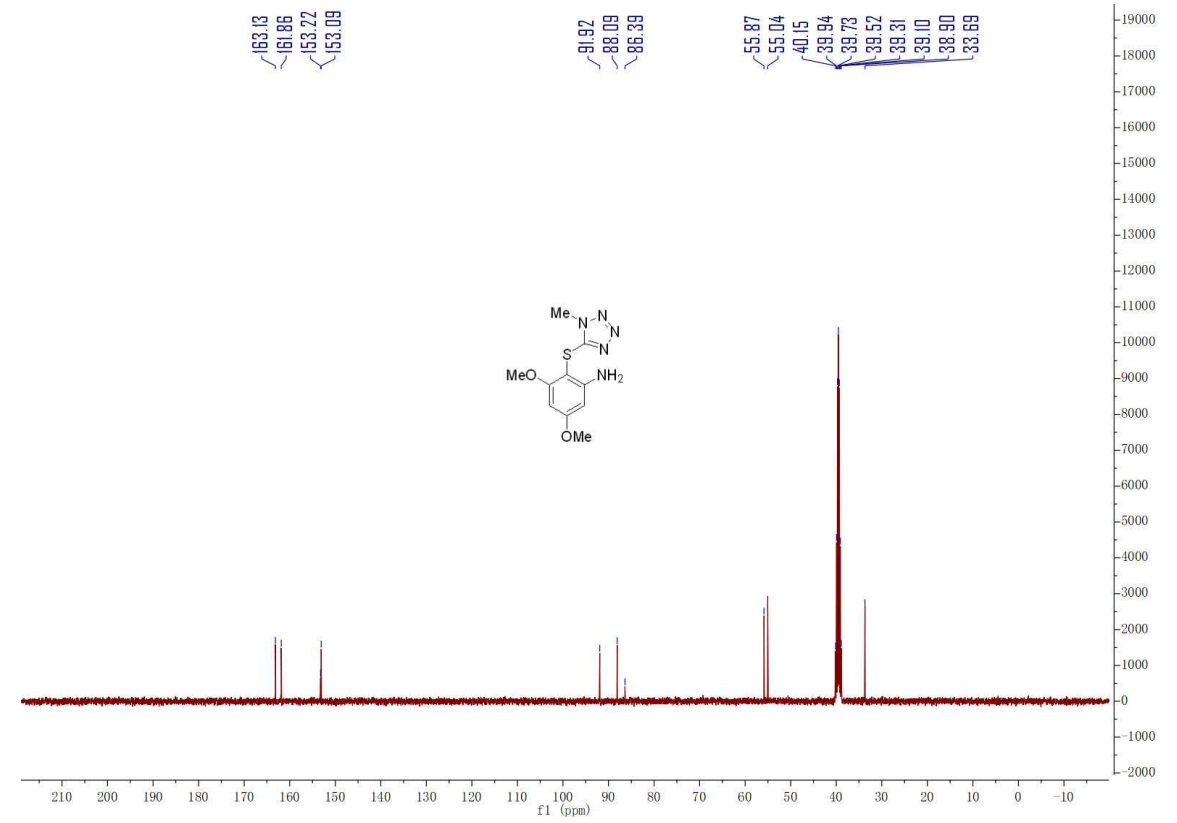
^{1}H NMR of 4e



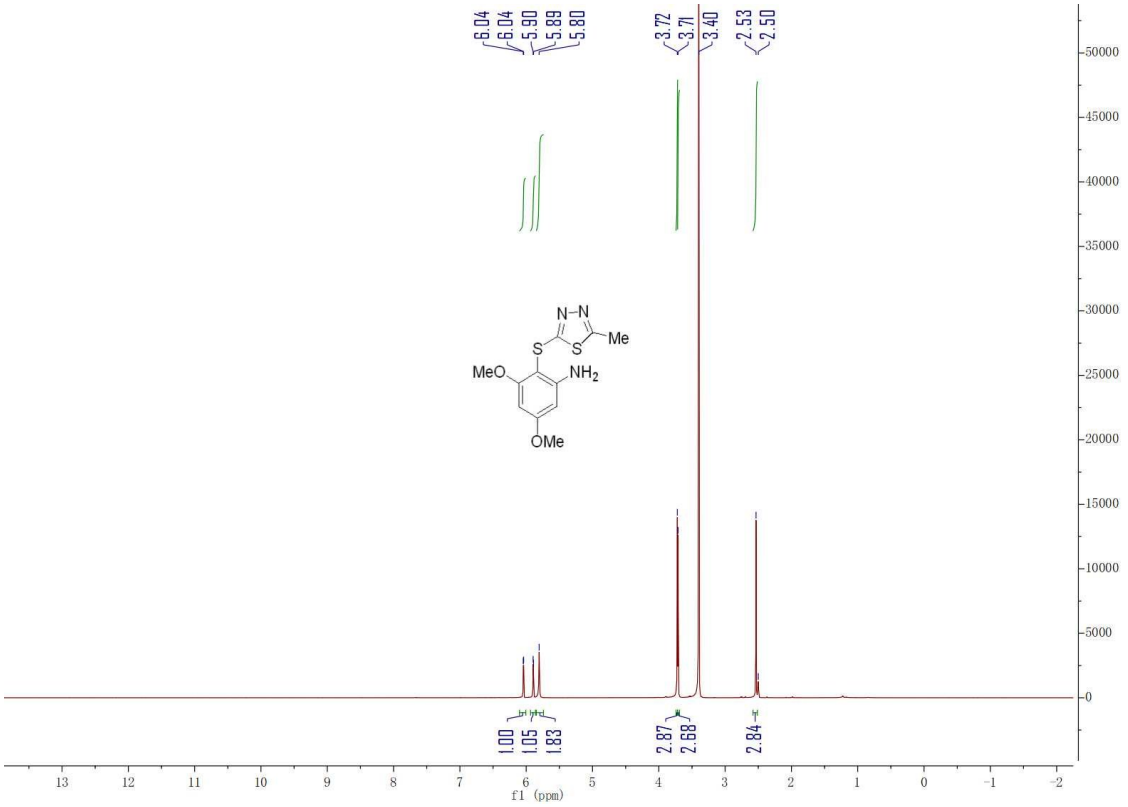
^{13}C NMR of 4e



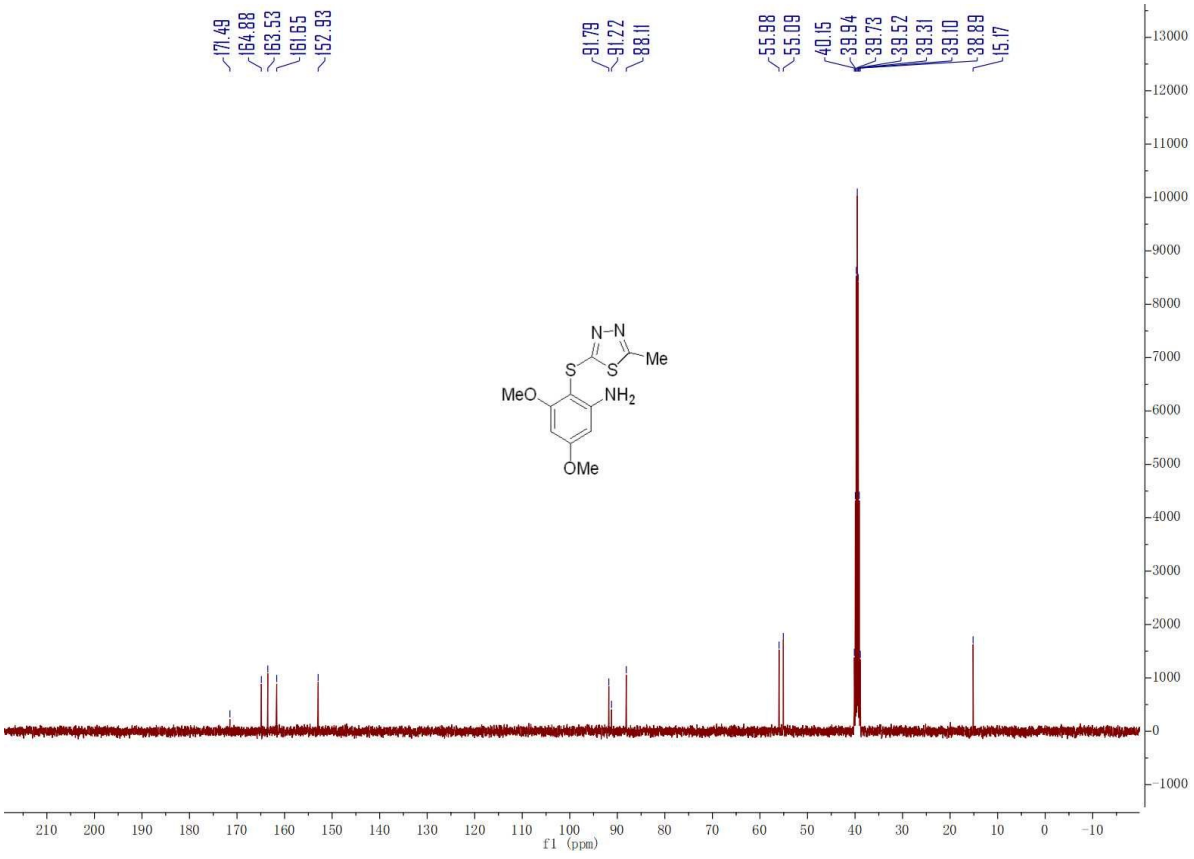
^{1}H NMR of 4f



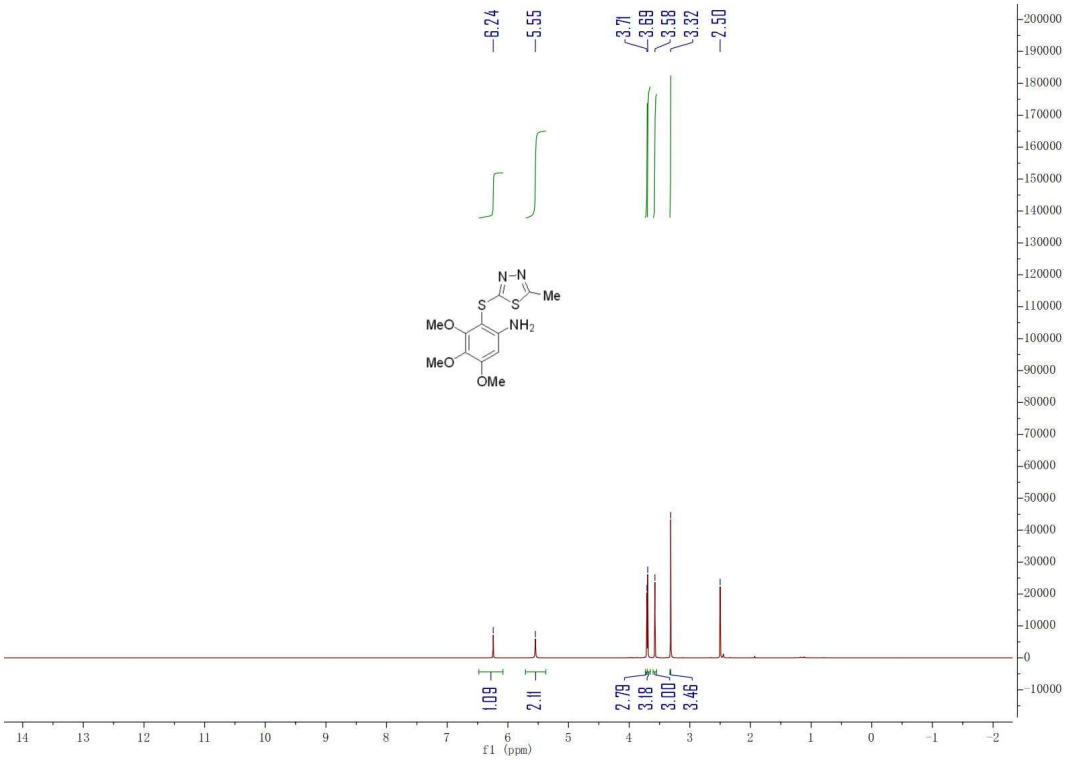
^{13}C NMR of 4f



^{1}H NMR of 4g



^{13}C NMR of 4g



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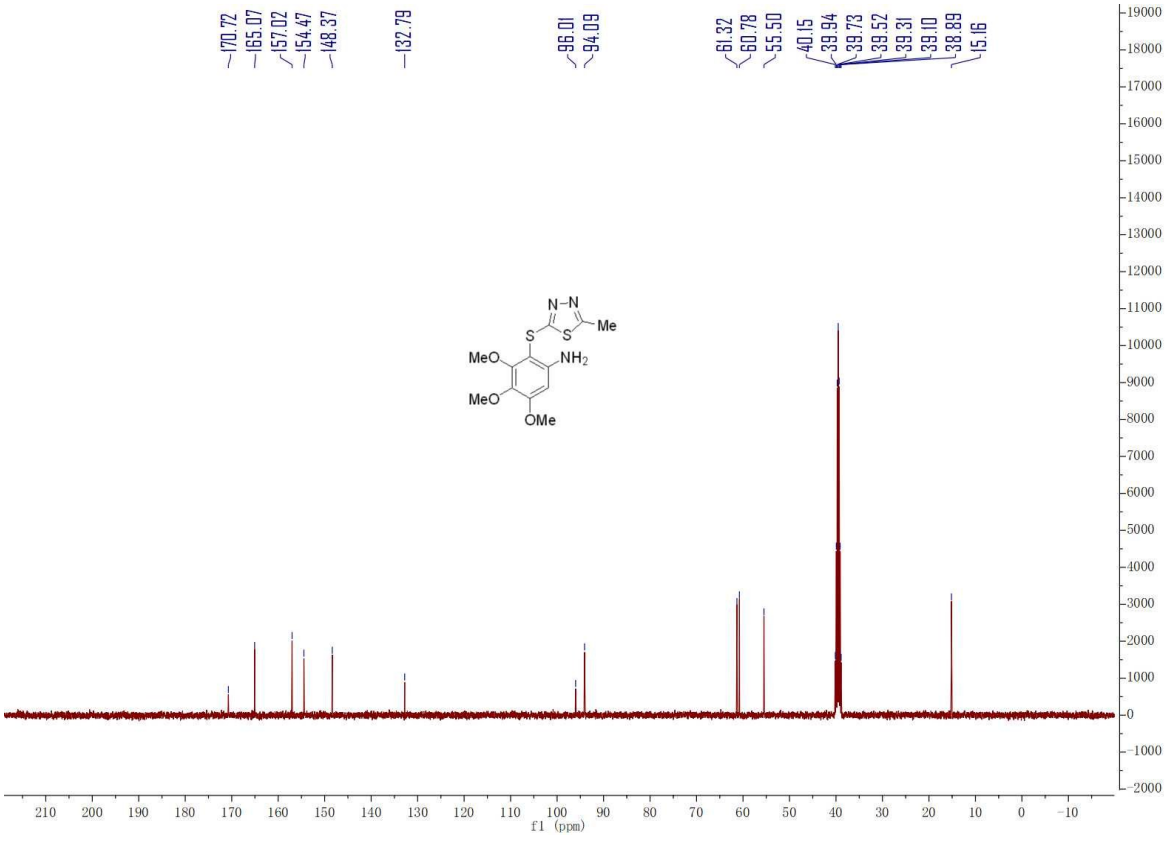

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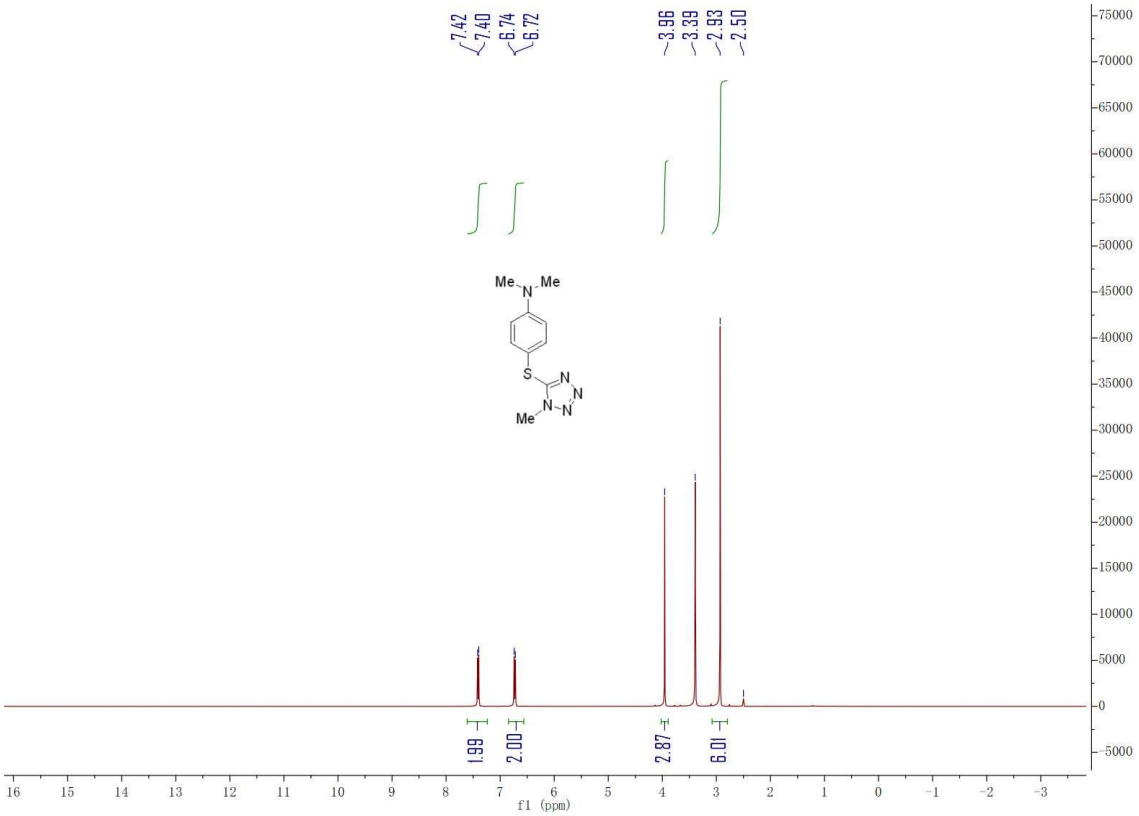
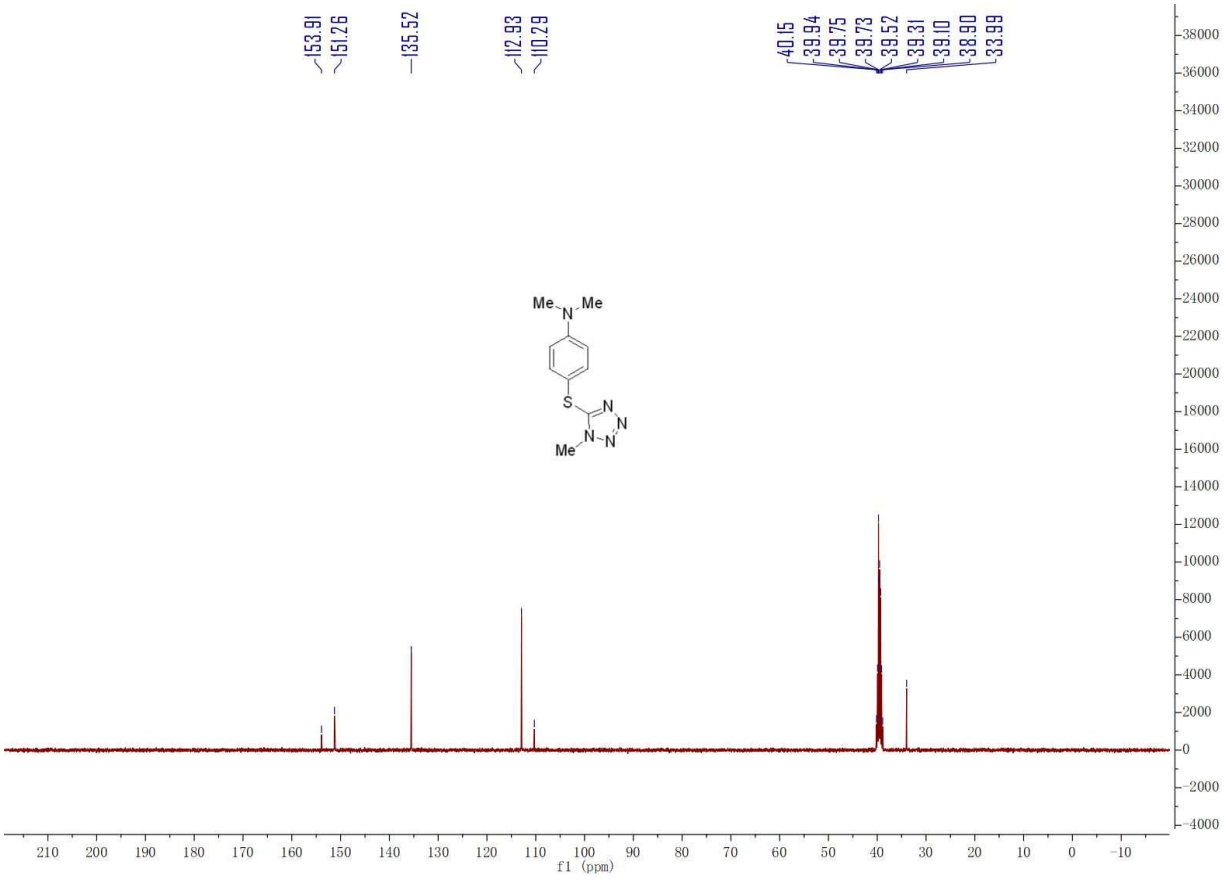
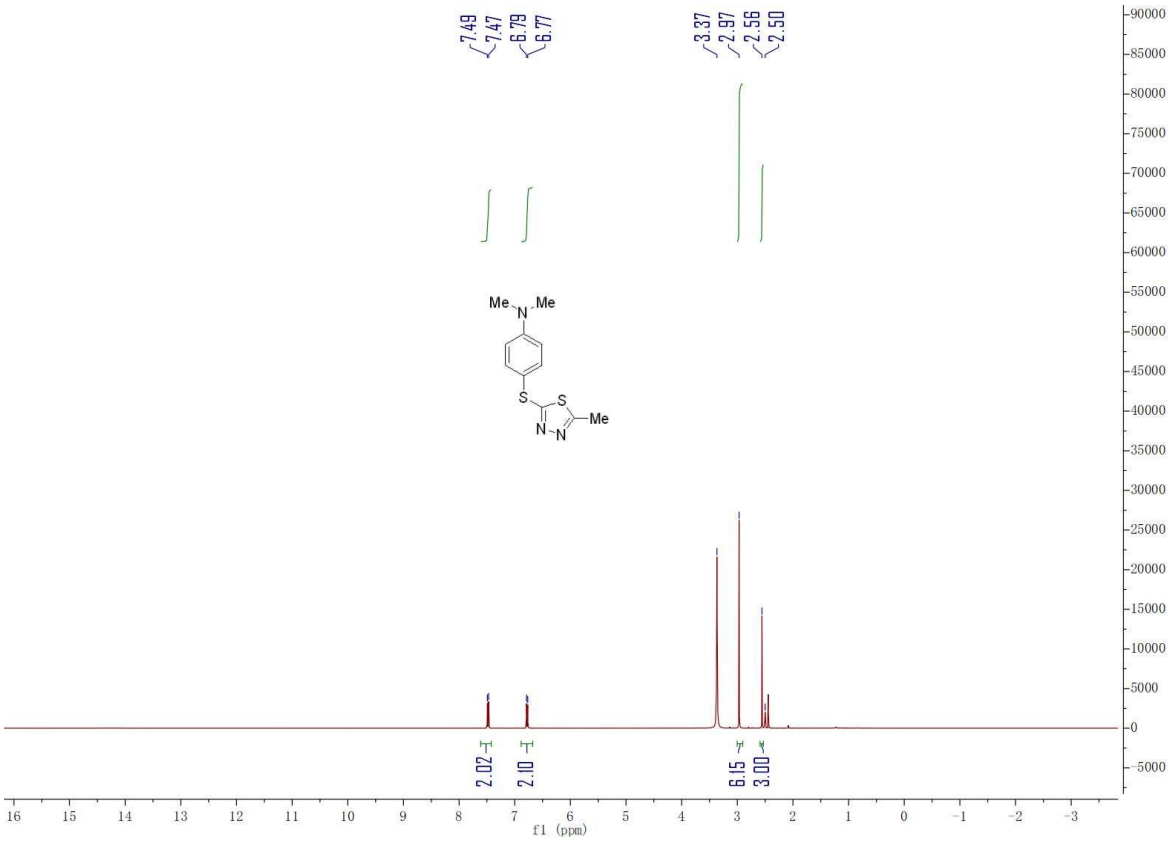


^{1}H NMR of 4i



^{13}C NMR of 4i



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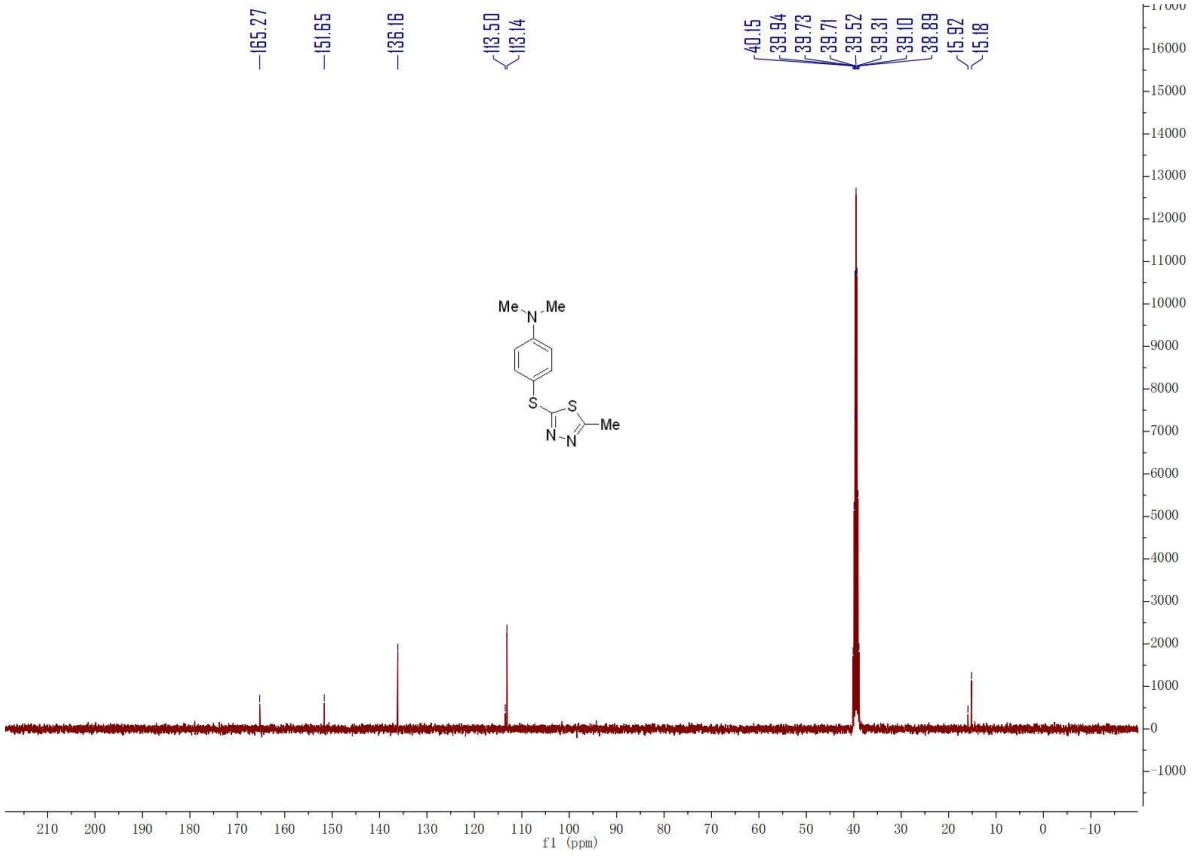

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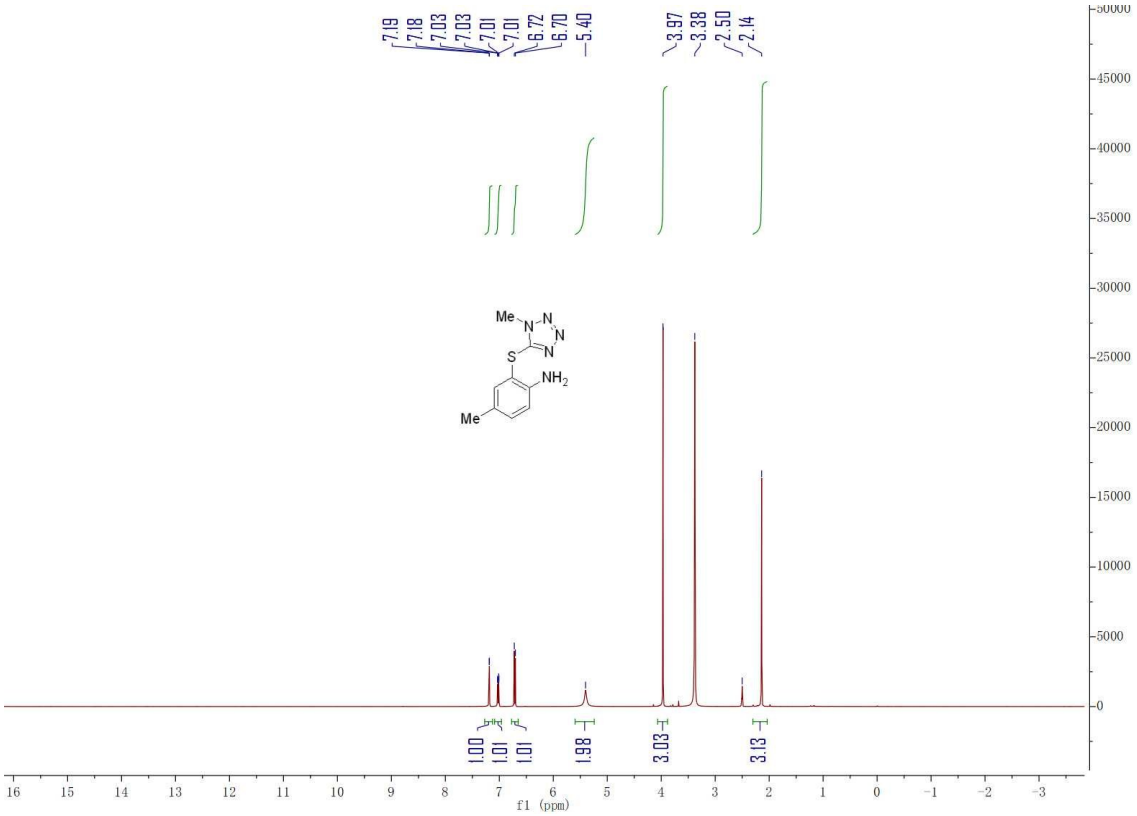

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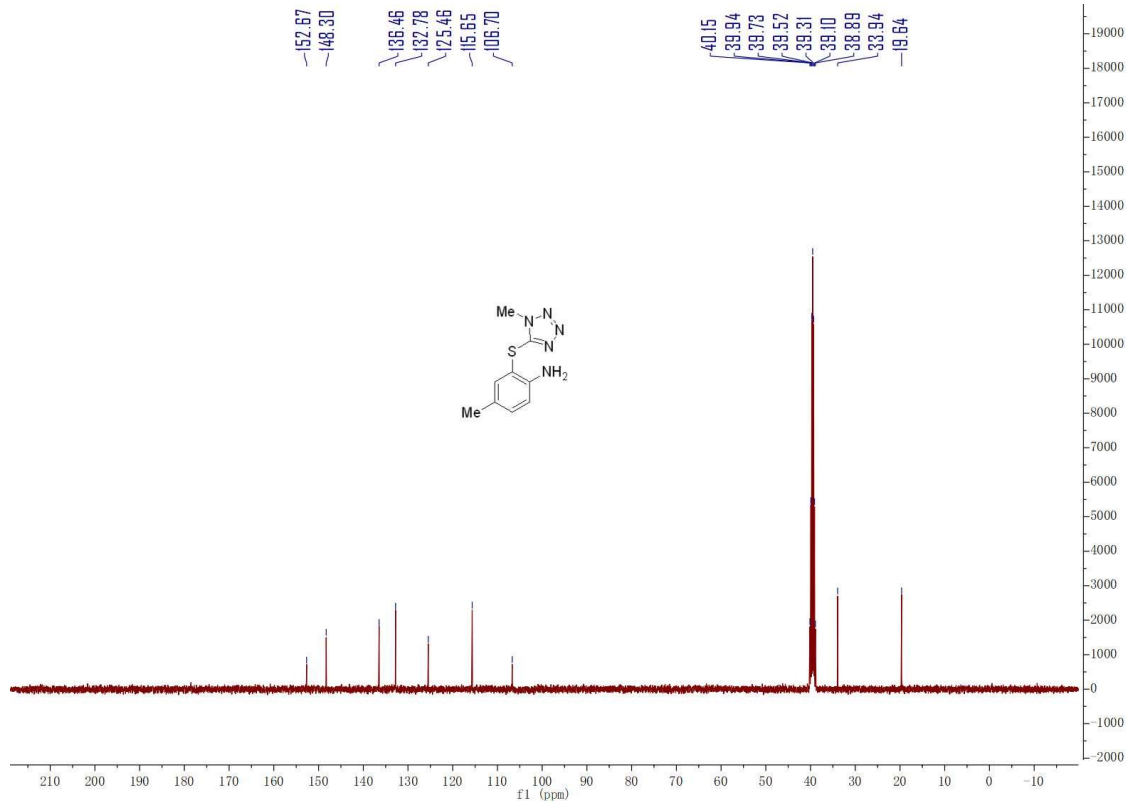

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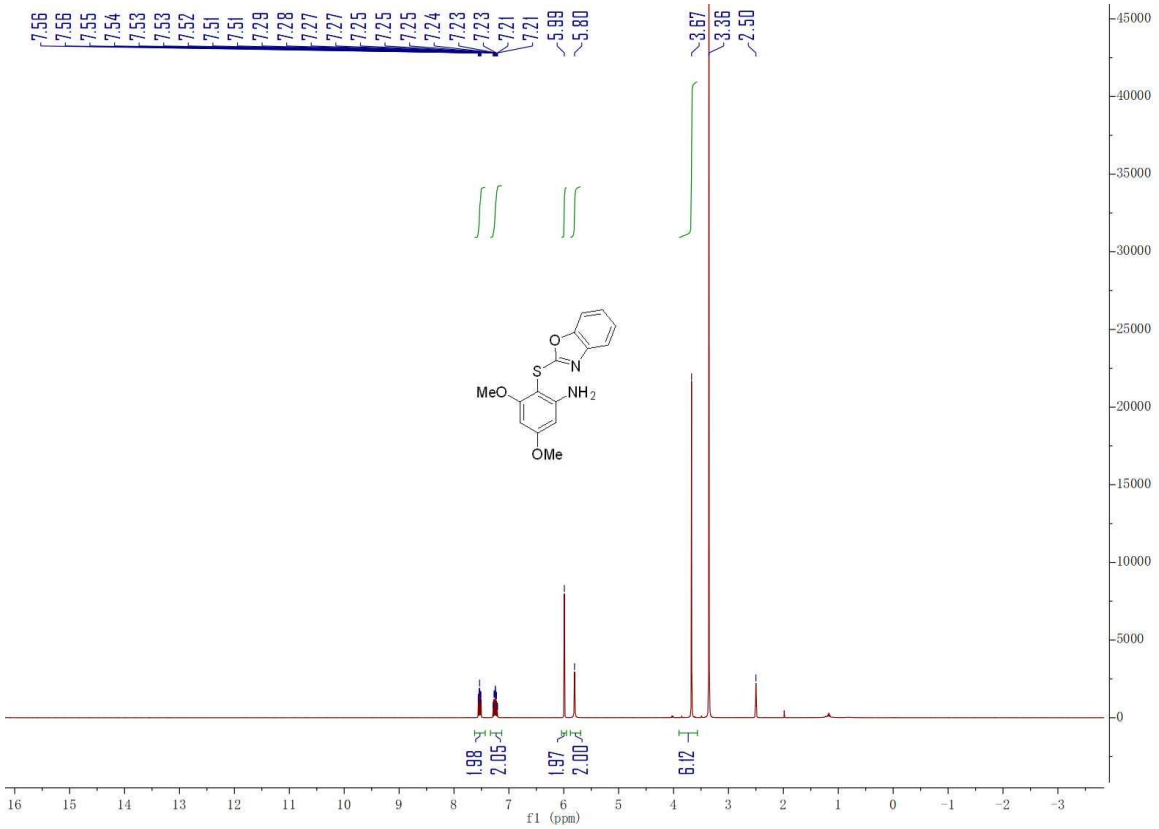

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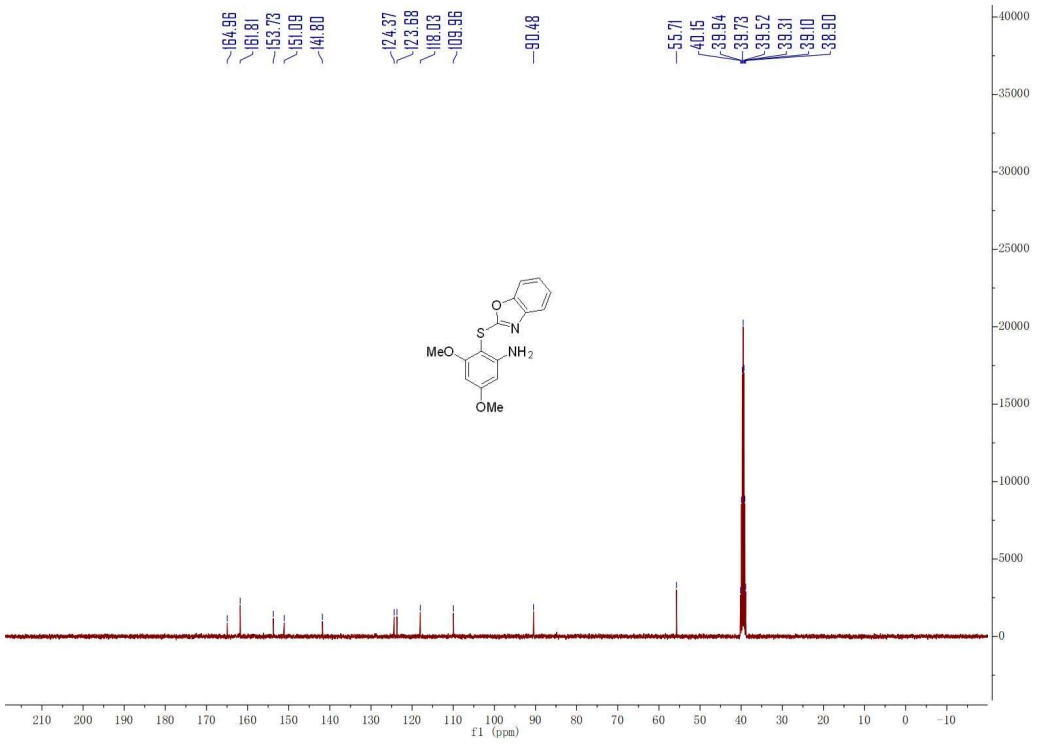

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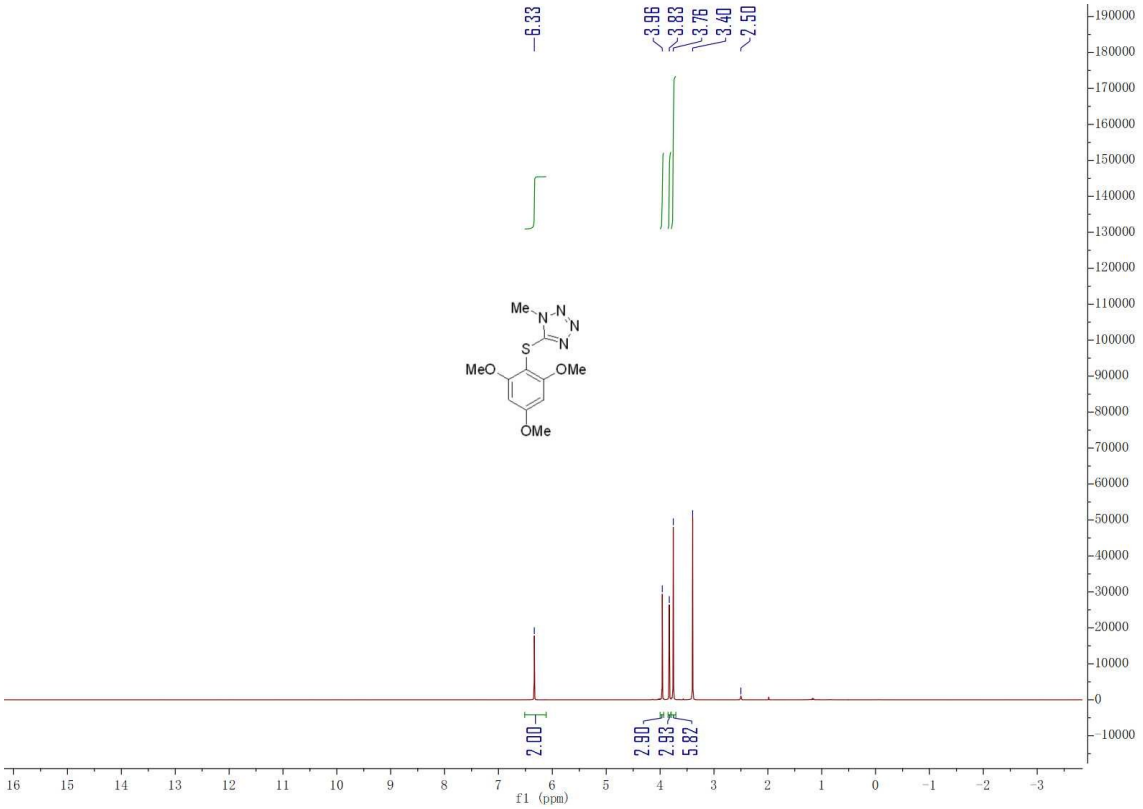
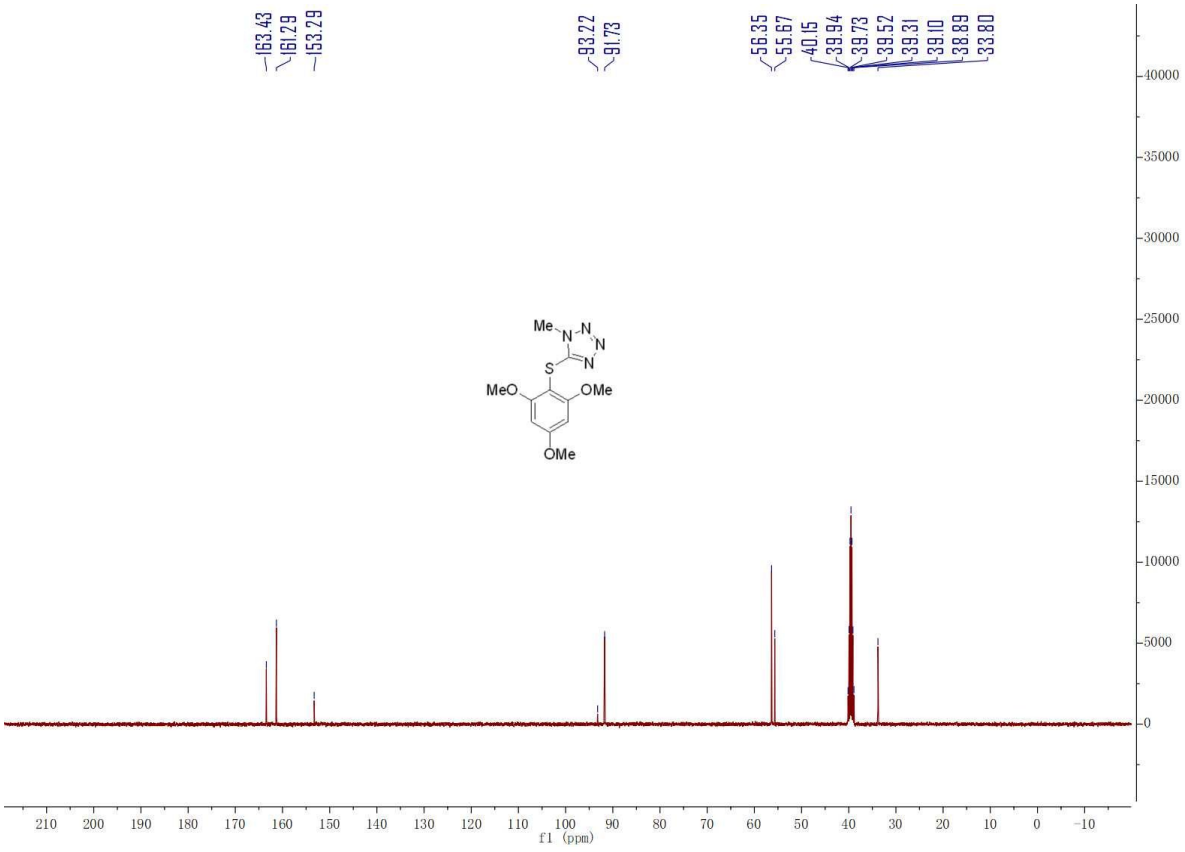
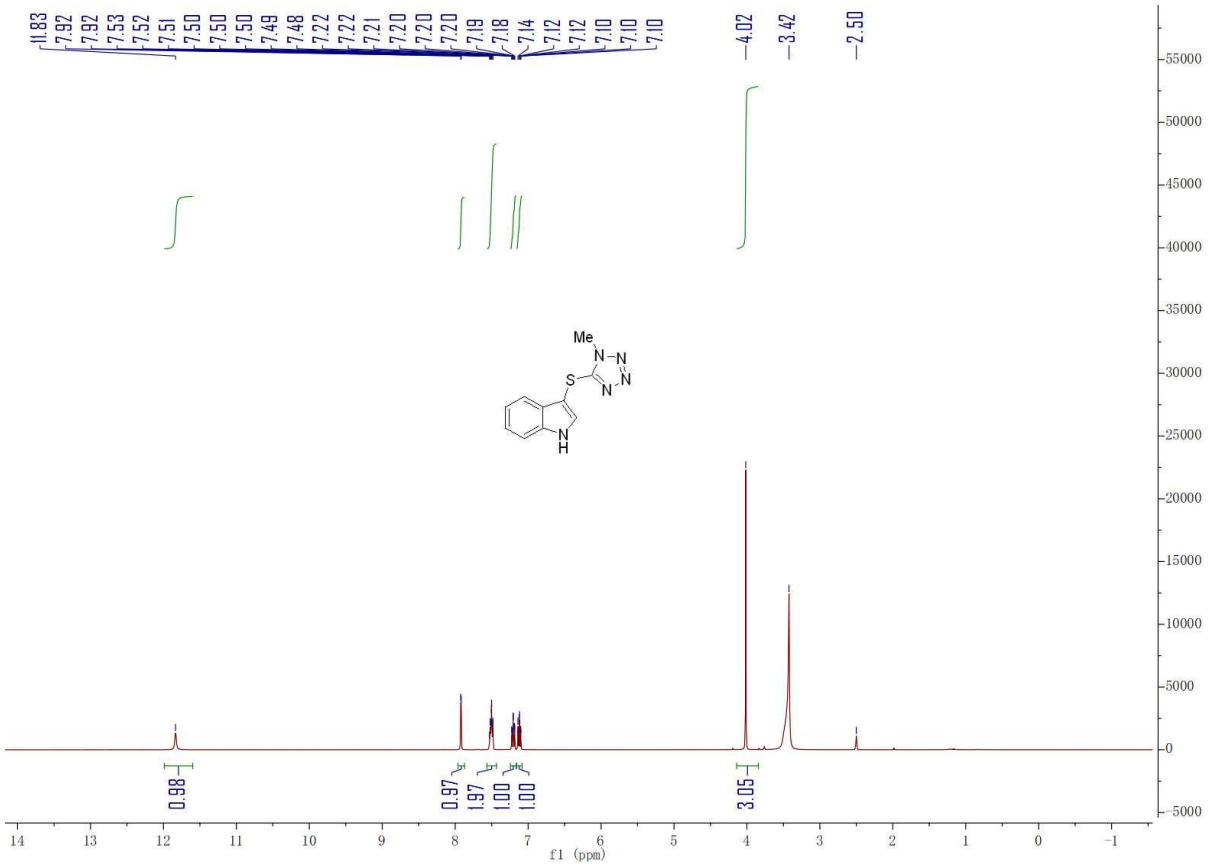


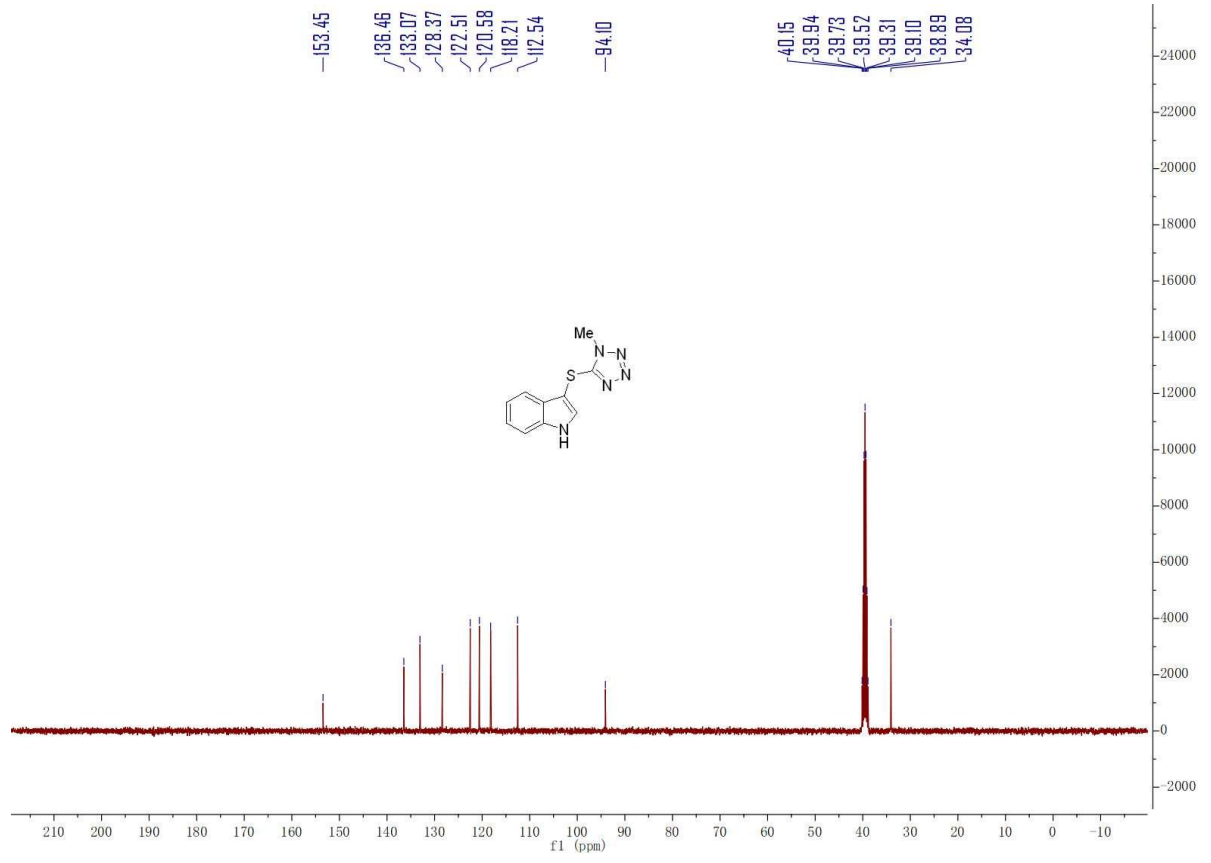
^{1}H NMR of 4m



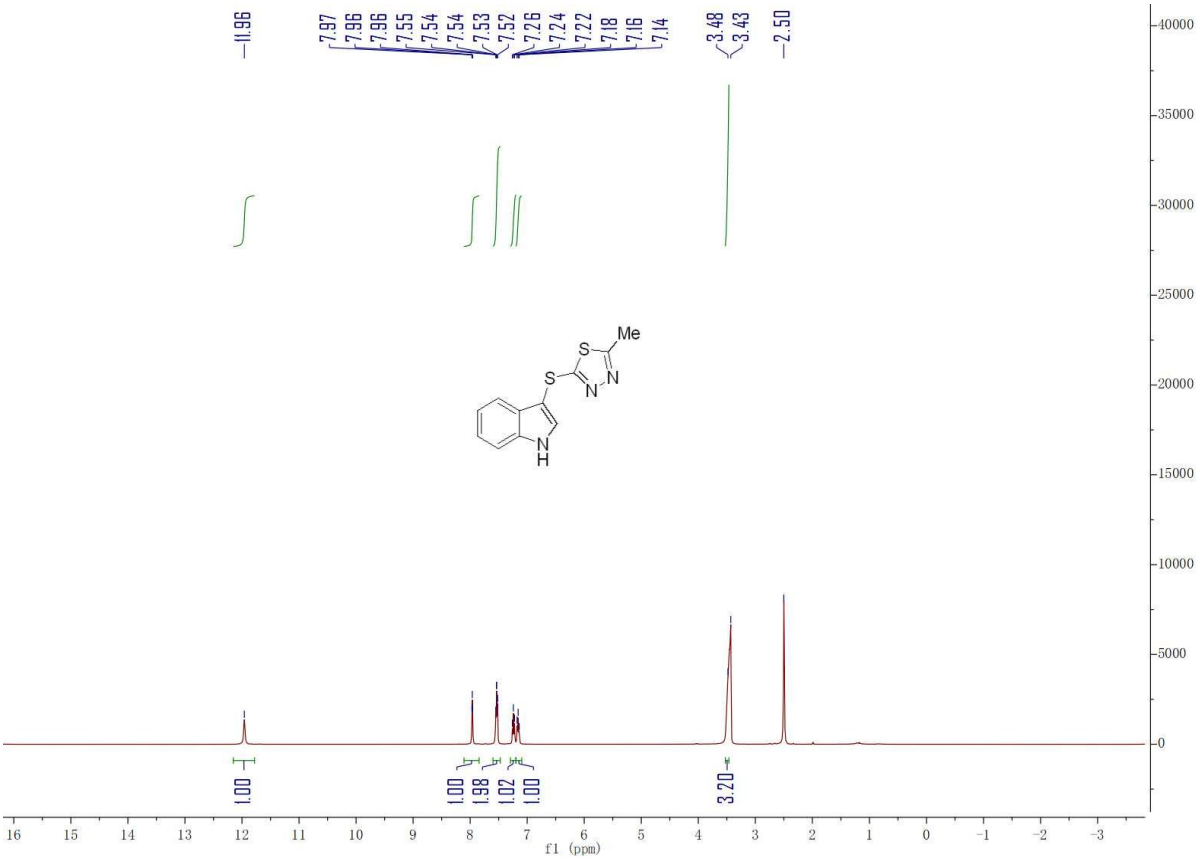
^{13}C NMR of 4m



^{1}H NMR of 5a



^{13}C NMR of 5a



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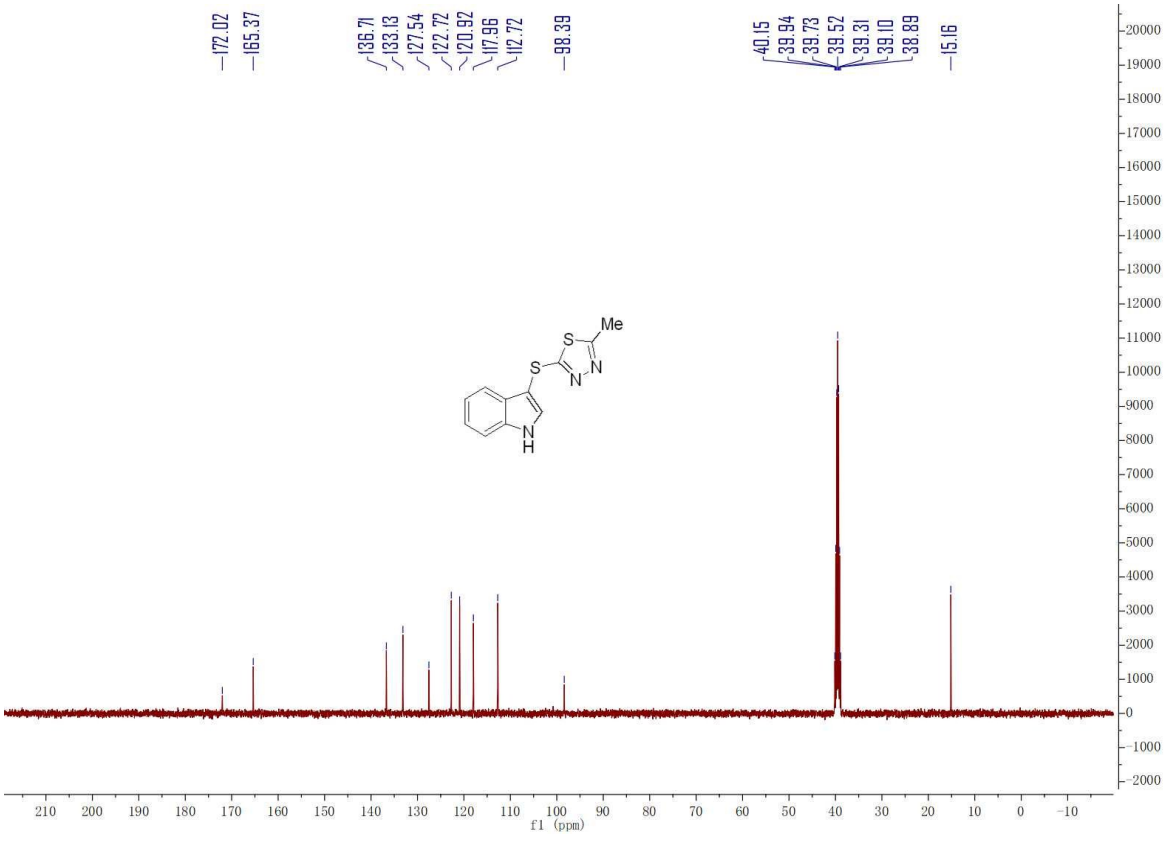
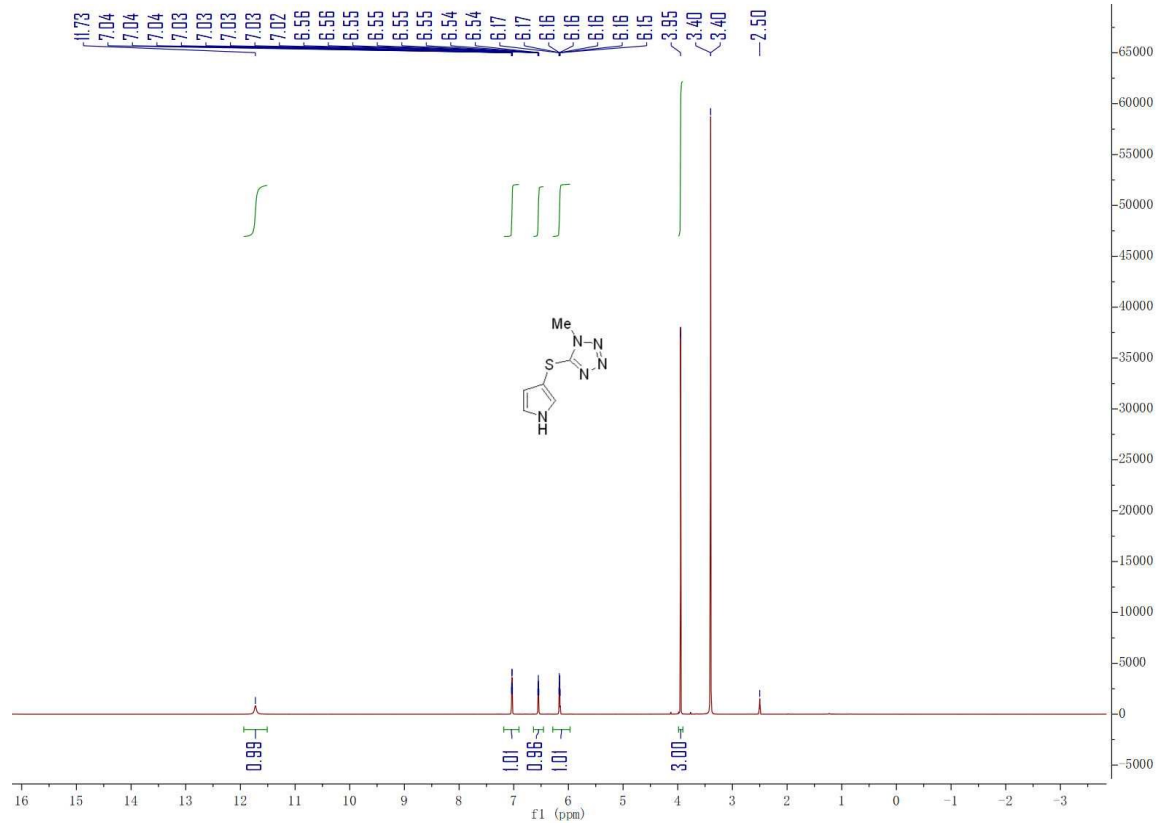


^{13}C NMR of 5b



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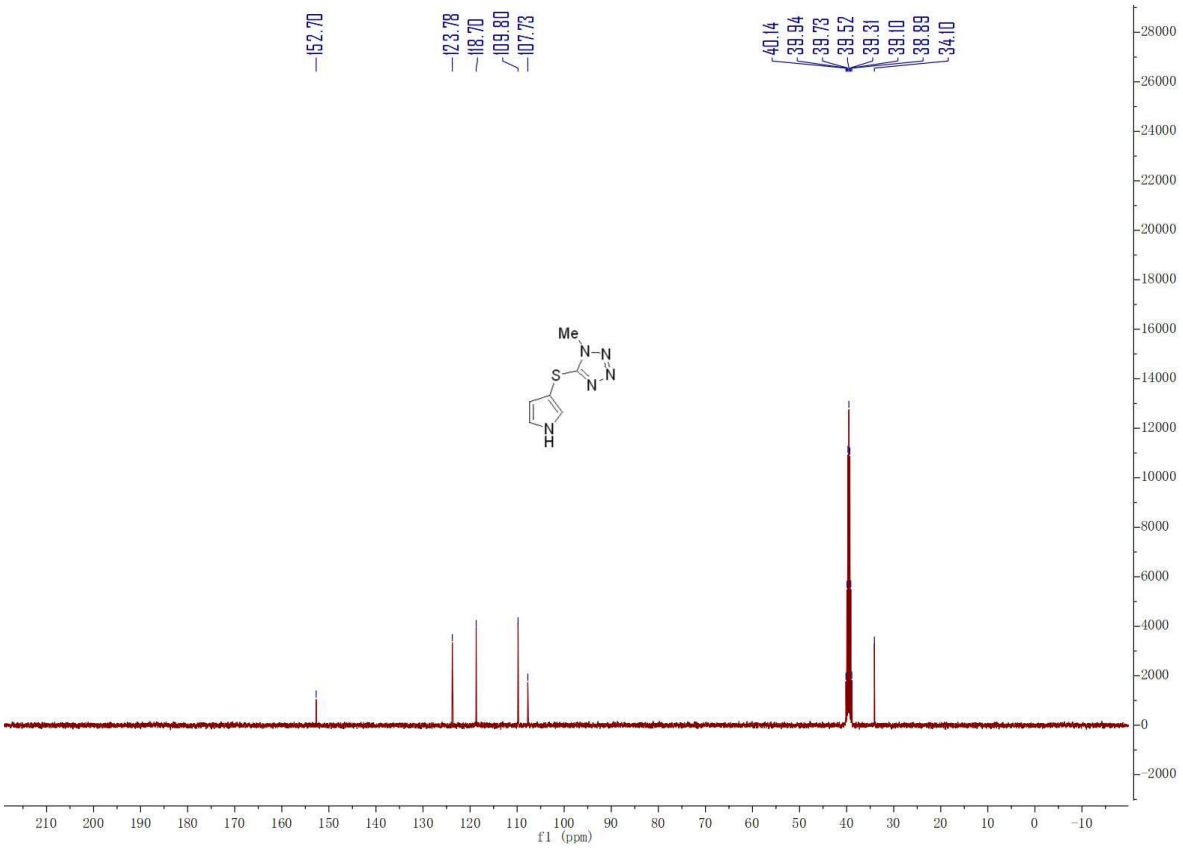

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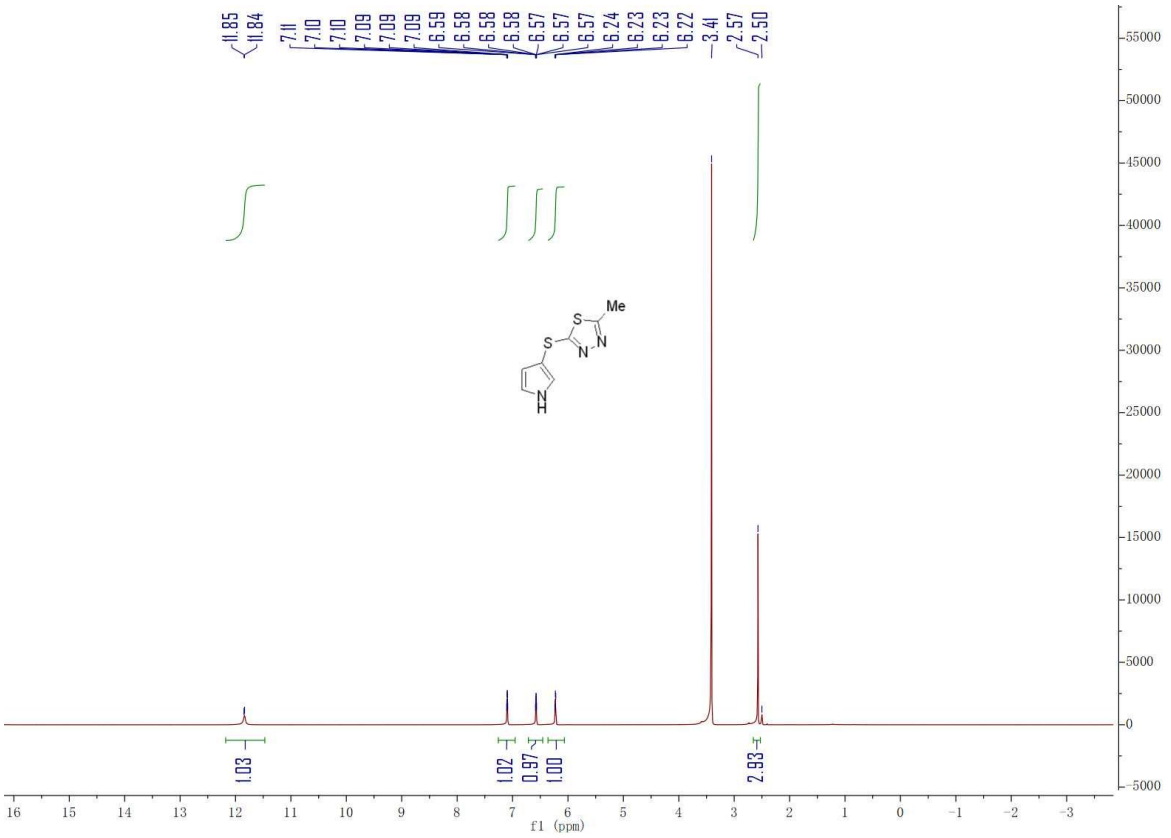
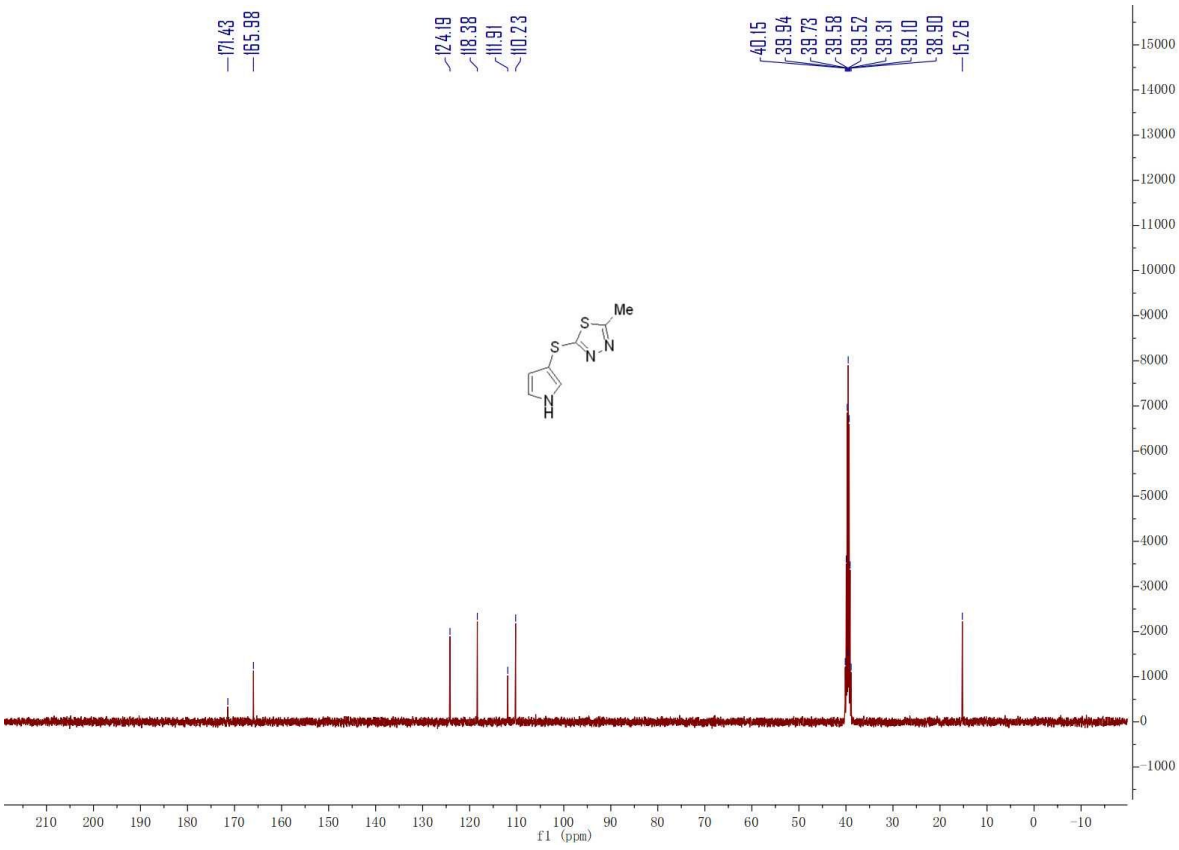


^{1}H NMR of 5d



^{13}C NMR of 5d