Iodine-mediated construction of polyfunctionalized arylazopyrazoles from β-ketoesters or 2-arylpyrazol-3-ones and arylhydrazines

Rameshwar Prasad Pandit,[a] Sung Hong Kim,[b] and Yong Rok Lee[a]*

[a]School of Chemical Engineering, Yeungnam University, Gyeongsan 712-749, Republic of Korea

yrlee@yu.ac.kr

Phone: 82-53-810-2529. Fax: 82-53-810-4631

[b]Analysis Research Division, Daegu Center, Korea; Basic Science Institute, Daegu 702-701, Republic of Korea

Electronic Supplementary Information (ESI)

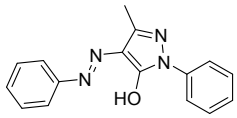
Contents

General Remarks

All the experiments were carried out under nitrogen atmosphere. Merck precoated silica gel plates (Art. 5554) with fluorescent indicator were used for analytical TLC. Flash column chromatography was performed using silica gel 9385 (Merck). Melting points are uncorrected and were determined on Fisher-Johns Melting Point Apparatus. ^{1}H NMR and ^{13}C NMR spectra were recorded on a Varian VNS (600, and 150 MHz, respectively) spectrometer in $CDCl_3$ using δ = 7.24 and 77.00 ppm as solvent chemical shift. Chemical shifts (δ) are expressed in units of ppm and *J* values are given in Hz. Multiplicities are abbreviated as follows; s = singlet, d = doublet, t = triplet, q = quartet, m = multiplet and dd = doublet of doublet, td = triplet of doublet. IR spectra were recorded on ATR-IR (neat), and HRMS was carried out at the Korean Basic Science Institute.

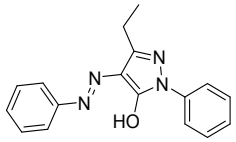
General experimental procedure for the synthesis of arylazopyrazoles and characterization data for the compounds (4a-4v)

To a solution of β-ketoester (0.5 mmol) and arylhydrazine (1.2 mmol) in 1,2-dichloroethane (3.0 mL) was added I_2 (126 mg, 0.25 mmol), acetic acid (0.03 mL, 0.5 mmol) and $AgNO_3$ (8 mg, 10 mol%) and heated the reaction mixture at 70 ^{o}C under nitrogen atmosphere until completion of reaction as indicated by TLC. The volatiles were removed *in vacuo* and the residue was purified by silica gel column chromatography (hexane: ethyl acetate = 30:1) to give desired arylazopyrazoles as solid.



4a

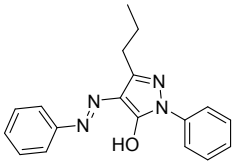
3-Methyl-1-phenyl-4-(phenyldiazenyl)-1*H*-pyrazol-5-ol (4a):[1] Prepared from ethyl 3-oxobutanoate **1a** (65 mg, 0.5 mmol) with phenylhydrazine **(2a**, 130 mg, 1.2 mmol) according to general procedure in 6 h. Orange solid (118 mg, 85%); mp 130-132 °C; ^{1}H NMR (600 MHz, $CDCl_3$): δ = 13.54 (s, 1H), 7.94 (d, *J* = 7.8 Hz, 2H), 7.42-7.37 (m, 6H), 7.19-7.16 (m, 2H), 2.34 (s, 3H); ^{13}C NMR (150 MHz, $CDCl_3$): δ = 157.69, 148.48, 141.07, 137.99, 129.58, 128.84, 128.43, 125.71, 125.05, 118.46, 115.73, 11.72.



4b

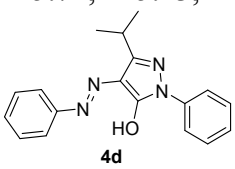
3-Ethyl-1-phenyl-4-(phenyldiazenyl)-1*H*-pyrazol-5-ol (4b):[1] Prepared from ethyl 3-oxopentanoate **1b** (72 mg, 0.5 mmol) with phenylhydrazine **2a** (130 mg, 1.2 mmol) according to general procedure in 6 h. Orange solid (131 mg, 90%); mp 109-111 °C; ^{1}H NMR (600

MHz, $CDCl_3$): δ = 13.58 (s, 1H), 7.95 (dd, *J* = 8.4, 0.6 Hz, 2H), 7.43 – 7.38 (m, 6H), 7.20 – 7.17 (m, 2H), 2.77 (q, *J* = 7.8 Hz, 2H), 1.38 (t, *J* = 7.8 Hz, 3H); ^{13}C NMR (150 MHz, $CDCl_3$): δ = 157.91, 152.96, 141.21, 138.10, 129.66, 128.89, 127.97, 125.71, 125.11, 118.61, 115.76, 20.21, 11.78.



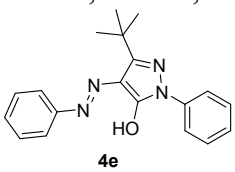
4c

3-Propyl-1-phenyl-4-(phenyldiazenyl)-1*H*-pyrazol-5-ol (4c):[1] Prepared from ethyl 3-oxohexanoate **1c** (79 mg, 0.5 mmol) with phenylhydrazine **2a** (130 mg, 1.2 mmol) according to general procedure in 6 h. Orange solid (136 mg, 89%); mp 120-122 °C; ^1H NMR (600 MHz, $CDCl_3$): δ = 13.60 (s, 1H), 7.95 (dd, *J* = 8.4, 1.2 Hz, 2H), 7.42 – 7.39 (m, 6H), 7.20 – 7.17 (m, 2H), 2.72 (t, *J* = 7.2 Hz, 2H), 1.87 – 1.81 (m, 2H), 1.05 (t, *J* = 7.2 Hz, 3H); ^{13}C NMR (150 MHz, $CDCl_3$): δ = 157.90, 151.93, 141.21, 138.09, 129.67, 128.90, 128.17, 125.74, 125.13, 118.66, 115.78, 28.69, 20.97, 14.06.



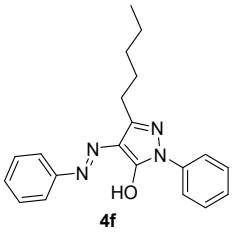
4d

3-Isopropyl-1-phenyl-4-(phenyldiazenyl)-1*H*-pyrazol-5-ol (4d):[1] Prepared from methyl 4-methyl-3-oxopentanoate **1d** (72 mg, 0.5 mmol) with phenylhydrazine **2a** (130 mg, 1.2 mmol) according to general procedure in 5 h. Orange solid (127 mg, 83%); mp 145-147 °C; ^1H NMR (600 MHz, $CDCl_3$): δ = 13.62 (s, 1H), 7.99 – 7.97 (m, 2H), 7.43– 7.40 (m, 6H), 7.20 – 7.17 (m, 2H), 3.21 – 3.15 (m, 1H), 1.42 (d, *J* = 7.2 Hz, 6H); ^{13}C NMR (150 MHz, $CDCl_3$): δ = 158.00, 156.00, 141.25, 138.13, 130.93, 129.63, 129.03, 128.84, 127.43, 125.61, 125.03, 122.80, 118.58, 115.69, 27.68, 20.80.



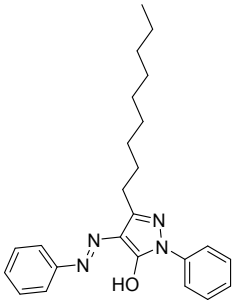
4e

3-(Tert-butyl)-1-phenyl-4-(phenyldiazenyl)-1*H*-pyrazol-5-ol (4e): Prepared from ethyl 4,4-dimethyl-3-oxopentanoate **1e** (86 mg, 0.5 mmol) with phenylhydrazine **2a** (130 mg, 1.2 mmol) according to general procedure in 3 h. Yellow solid (81 mg, 51%); mp 154-156 °C; ^1H NMR (600 MHz, $CDCl_3$): δ = 13.77 (s, 1H), 7.98 (dd, *J* = 8.4, 0.6 Hz, 2H), 7.43 – 7.38 (m, 6H), 7.20 – 7.17 (m, 2H), 1.48 (s, 9H); ^{13}C NMR (150 MHz, $CDCl_3$): δ = 158.22, 157.63, 141.37, 138.17, 129.68, 128.86, 127.23, 125.58, 125.04, 118.59, 115.71, 34.48, 28.84; ATR-IR 2951, 1657, 1592, 1549, 1478, 1259, 1154, 751, 666 cm^{-1}; HRMS (EI) *m*/*z* (M^+) calcd for $C_{19}H_{20}N_4O$: 320.1637; found: 320.1638.



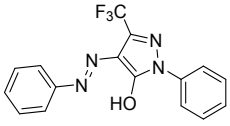
4f

3-Pentyl-1-phenyl-4-(phenyldiazenyl)-1*H*-pyrazol-5-ol (4f):[1] Prepared from methyl 3-oxooctanoate **1f** (86 mg, 0.5 mmol) with phenylhydrazine **2a** (130 mg, 1.2 mmol) according to general procedure in 5 h. Orange solid (147 mg, 88%); mp 95-97 °C; ^{1}H NMR (600 MHz, $CDCl_3$): δ = 13.59 (s, 1H), 7.95 (d, *J* = 7.8 Hz, 2H), 7.43 – 7.38 (m, 6H), 7.20 – 7.17 (m, 2H), 2.72 (t, *J* = 7.8 Hz, 2H), 1.84 – 1.79 (m, 2H), 1.45 – 1.36 (m, 4H), 0.92 (t, *J* = 7.2 Hz, 3H); ^{13}C NMR (150 MHz, $CDCl_3$): δ = 157.87, 152.11, 141.21, 138.09, 129.65, 128.88, 128.14, 125.70, 125.09, 118.62, 115.74, 31.61, 27.20, 26.63, 22.37, 13.99.



4g

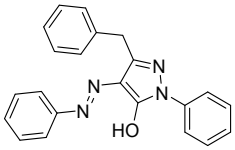
3-Nonyl-1-phenyl-4-(phenyldiazenyl)-1*H*-pyrazol-5-ol (4g): Prepared from methyl 3-oxododecanoate **1g** (114 mg, 0.5 mmol) with phenylhydrazine **2a** (130 mg, 1.2 mmol) according to general procedure in 5 h. Orange red solid (175 mg, 90%); mp 78-80 °C; ^{1}H NMR (600 MHz, $CDCl_3$): δ = 13.59 (s, 1H), 7.97 – 7.95 (m, 1H), 7.42 – 7.38 (m, 7H), 7.20 – 7.17 (m, 2H), 2.73 (t, *J* = 7.8 Hz, 2H), 1.83–1.78 (m, 2H), 1.46 – 1.41 (m, 2H), 1.39 – 1.34 (m, 2H), 1.31 – 1.26 (m, 8H), 0.87 (t, *J* = 6.6 Hz, 3H); ^{13}C NMR (150 MHz, $CDCl_3$): δ = 157.85, 152.09, 141.20, 138.09, 129.63, 128.86, 128.13, 125.68, 125.07, 118.59, 115.73, 31.88, 29.47, 29.40, 29.30, 27.48, 26.65, 22.66, 14.09; ATR-IR 2919, 2850, 1657, 1595, 1544, 1481, 1264, 750 cm^{-1}; HRMS (EI) *m*/*z* (M^+) calcd for $C_{24}H_{30}N_4O$: 390.2420; found: 390.2417.



4h

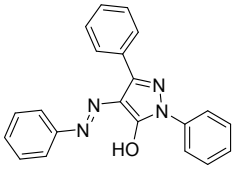
1-Phenyl-4-(phenyldiazenyl)-3-(trifluoromethyl)-1*H*-pyrazol-5-ol (4h): Prepared from ethyl 4,4,4-trifluoro-3-oxobutanoate **1h** (92 mg, 0.5 mmol) with phenylhydrazine **2a** (130 mg, 1.2 mmol) according to general procedure in 3 h. Orange red solid (79 mg, 48%); mp 148-150 °C; ^{1}H NMR (600 MHz, $CDCl_3$): δ = 13.95 (s, 1H), 7.93 – 7.91 (m, 2H), 7.50 – 7.49 (m, 2H), 7.46 – 7.43 (m, 4H), 7.30 – 7.26 (m, 2H); ^{13}C NMR (150 MHz, $CDCl_3$): δ = 157.04, 140.28, 138.24 (q, $J_{C\text{-}F}$ = 39.0 Hz), 137.29, 129.88, 129.08, 128.92, 127.54, 127.34, 126.41, 122.97 (q, $J_{C\text{-}F}$ = 80.4 Hz), 119.52 (q, $J_{C\text{-}F}$ = 269.7 Hz), 119.33, 116.83.

157.04, 138.79 (d, J = 450.00 Hz), 138.24 (q, J = 39.00 Hz), 129.88, 129.09, 128.92, 127.54, 127.34, 126.41, 122.97 (d, J = 81.00 Hz), 120.42, 119.33, 118.62, 116.83; ATR-IR 1661, 1555, 1480, 1237, 1132, 983, 752 cm^{-1}; HRMS (EI) m/z (M^+) calcd for $C_{16}H_{11}F_3N_4O$: 332.0885; found: 332.0887.



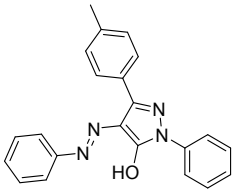
4i

3-Benzyl-1-phenyl-4-(phenyldiazenyl)-1*H*-pyrazol-5-ol (4i):[1] Prepared from methyl 3-oxo-4-phenylbutanoate **1i** (96 mg, 0.5 mmol) with phenylhydrazine **2a** (130 mg, 1.2 mmol) according to general procedure in 6 h. Orange solid (164 mg, 93%); mp 150-152 °C; ^{1}H NMR (600 MHz, $CDCl_3$): δ = 13.44 (s, 1H), 7.87 (dd, J = 8.4, 0.6 Hz, 2H), 7.36 – 7.28 (m, 6H), 7.26 – 7.22 (m, 4H), 7.16 – 7.07 (m, 3H), 3.97 (s, 2H); ^{13}C NMR (150 MHz, $CDCl_3$): δ = 157.70, 150.25, 141.06, 138.02, 137.00, 129.62, 129.10, 128.85, 128.50, 127.56, 126.69, 125.81, 125.16, 118.64, 115.80, 33.19.



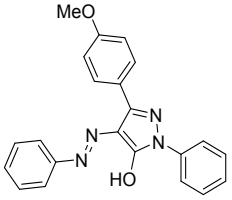
4j

3-Phenyl-1-phenyl-4-(phenyldiazenyl)-1*H*-pyrazol-5-ol (4j):[1] Prepared from ethyl 3-oxo-3-phenylpropanoate **1j** (96 mg, 0.5 mmol) with phenylhydrazine **2a** (130 mg, 1.2 mmol) according to general procedure in 12 h. Orange red solid (161 mg, 95%); mp 157-159 °C; ^{1}H NMR (600 MHz, $CDCl_3$): δ = 13.96 (s, 1H), 8.18 – 8.16 (m, 2H), 8.01 – 7.99 (m, 2H), 7.44 – 7.35 (m, 9H), 7.18 – 7.14 (m, 2H); ^{13}C NMR (150 MHz, $CDCl_3$): δ = 158.12, 146.56, 141.13, 138.04, 130.95, 130.39, 129.78, 129.76, 129.05, 128.94, 128.56, 127.46, 127.30, 126.09, 125.47, 122.82, 118.91, 116.10.



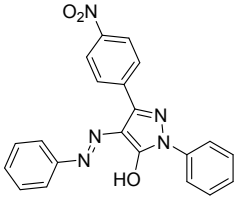
4k

1-Phenyl-4-(phenyldiazenyl)-3-(*p*-tolyl)-1*H*-pyrazol-5-ol (4k):[1] Prepared from ethyl 3-oxo-3-(*p*-tolyl)propanoate **1k** (103 mg, 0.5 mmol) with phenylhydrazine **2a** (130 mg, 1.2 mmol) according to general procedure in 12 h. Red solid (169 mg, 96%); 150-152 °C; ^{1}H NMR (600 MHz, $CDCl_3$): δ = 13.90 (s, 1H), 8.04 (d, J = 7.8 Hz, 2H), 7.98 (dd, J = 8.4, 1.2 Hz, 2H), 7.38 – 7.33 (m, 6H), 7.21 (d, J = 7.8 Hz, 2H), 7.17 – 7.13 (m, 2H), 2.34 (s, 3H); ^{13}C NMR (150 MHz, $CDCl_3$): δ = 158.07, 146.62, 141.18, 139.93, 138.08, 129.71, 129.27, 128.89, 127.55, 127.41, 127.35, 125.94, 125.35, 118.85, 116.01, 21.50.



4l

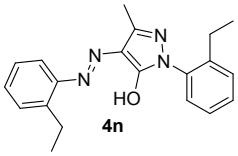
3-(4-methoxyphenyl)-1-phenyl-4-(phenyldiazenyl)-1*H*-pyrazol-5-ol (4l):[1] Prepared from methyl 3-(4-methoxyphenyl)-3-oxopropanoate **1l** (104 mg, 0.5 mmol) with phenylhydrazine **2a** (130 mg, 1.2 mmol) according to general procedure in 12 h. Red solid (177 mg, 96%); mp 172-174 °C; ^{1}H NMR (600 MHz, $CDCl_3$): δ = 13.99 (s, 1H), 8.20 – 8.19 (m, 2H), 8.06 – 8.05 (m, 2H), 7.46 – 7.41 (m, 6H), 7.24 – 7.20 (m, 2H), 7.02 – 7.00 (m, 2H), 3.87 (s, 3H); ^{13}C NMR (150 MHz, $CDCl_3$): δ = 160.96, 158.08, 146.35, 141.22, 138.10, 129.74, 128.91, 127.53, 125.92, 125.33, 123.03, 118.84, 116.00, 114.03, 55.35.



4m

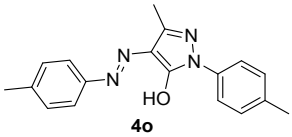
3-(4-Nitrophenyl)-1-phenyl-4-(phenyldiazenyl)-1*H*-pyrazol-5-ol (4m):[1] Prepared from methyl 3-(4-nitrophenyl)-3-oxopropanoate **1m** (111 mg, 0.5 mmol) with phenylhydrazine **2a** (120 mg, 1.2 mmol) according to general procedure in 15 h. Yellow solid (163 mg, 85%); mp 240-242 °C; ^{1}H NMR (600 MHz, $CDCl_3$): δ = 14.11 (s, 1H), 8.44 (d, *J* = 8.4 Hz, 2H), 8.34 (d, *J* = 9.0 Hz, 2H), 8.03 (d, *J* = 7.8 Hz, 2H), 7.48 – 7.46 (m, 6H), 7.28 – 7.26 (m, 2H); ^{13}C NMR (150 MHz, $CDCl_3$): δ = 158.05, 152.61, 143.97, 140.75, 137.73, 136.47, 129.95, 129.08, 127.89, 126.81, 126.69, 126.01, 123.84, 119.06, 116.35.

.



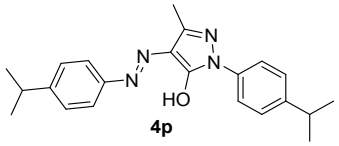
4n

1-(2-Ethylphenyl)-4-((2-ethylphenyl)diazenyl)-3-methyl-1*H*-pyrazol-5-ol (4n): Prepared from ethyl 3-oxobutanoate **1a** (65 mg, 0.5 mmol) with 2-ethylphenylhydrazine **2b** (163 mg, 1.2 mmol) according to general procedure in 6 h. Orange solid (153 mg, 92%); mp 90-92 °C; ^{1}H NMR (600 MHz, $CDCl_3$): δ = 13.86 (s, 1H), 7.84 (d, *J* = 7.8 Hz, 1H), 7.33 – 7.26 (m, 5H), 7.22 (d, *J* = 7.8 Hz, 1H), 7.14 (t, *J* = 7.8 Hz, 1H), 2.73 (q, *J* = 7.8 Hz, 2H), 2.66 (q, *J* = 7.2 Hz, 2H), 2.36 (s, 3H), 1.28 (t, *J* = 7.8 Hz, 3H), 1.17 (t, *J* = 7.8 Hz, 3H); ^{13}C NMR (150 MHz, $CDCl_3$): δ = 158.49, 147.92, 141.42, 138.69, 135.03, 131.33, 129.32, 129.17, 128.97, 128.41, 127.37, 127.36, 126.65, 125.70, 114.68, 24.66, 23.64, 14.39, 13.80, 11.86; ATR-IR 2956, 1655, 1544, 1493, 1253, 1150, 1052, 748 cm^{-1}; HRMS (EI) *m*/*z* (M^+) calcd for $C_{20}H_{22}N_4O$: 334.1794; found: 334.1791.



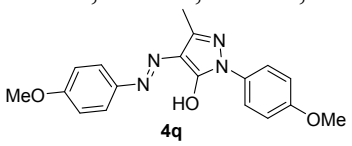
4o

3-Methyl-1-(*p*-tolyl)-4-(*p*-tolyldiazenyl)-1*H*-pyrazol-5-ol (4o): Prepared from ethyl 3-oxobutanoate **1a** (65 mg, 0.5 mmol) with 4-methylphenylhydrazine **2c** (146 mg, 1.2 mmol) according to general procedure in 6 h. Red solid (125 mg, 82%); mp 208-210 °C; ^{1}H NMR (600 MHz, $CDCl_3$): δ = 13.62 (s, 1H), 7.80 (d, *J* = 8.4 Hz, 2H), 7.31 (d, *J* = 8.4 Hz, 2H), 7.21 – 7.19 (m, 4H), 2.35 – 2.34 (m, 9H); ^{13}C NMR (150 MHz, $CDCl_3$): δ = 157.69, 148.30, 138.90, 135.82, 135.68, 134.77, 130.22, 129.42, 118.98, 118.62, 115.78, 21.02, 20.98, 11.78; ATR-IR 2920, 1651, 1551, 1508, 1260, 1151, 812 cm^{-1}; HRMS (EI) *m*/*z* (M^+) calcd for $C_{18}H_{18}N_4O$: 306.1481; found: 306.1483.



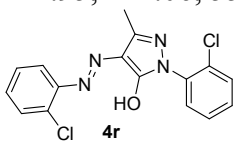
4p

1-(4-Isopropylphenyl)-4-((4-isopropylphenyl)diazenyl)-3-methyl-1*H*-pyrazol-5-ol (4p):[1] Prepared from ethyl 3-oxobutanoate **1a** (65 mg, 0.5 mmol) with 4-isopropylphenylhydrazine **2d** (180 mg, 1.2 mmol) according to general procedure in 6 h. Orange solid (150 mg, 83%); mp 80-82 °C; ^{1}H NMR (600 MHz, $CDCl_3$): δ = 13.55 (s, 1H), 7.76 (d, *J* = 8.4 Hz, 2H), 7.27 (d, *J* = 8.4 Hz, 2H), 7.20 – 7.17 (m, 4H), 2.87 – 2.80(m, 2H), 2.26 (s, 3H), 1.17 (d, *J* = 6.6 Hz, 12H); ^{13}C NMR (150 MHz, $CDCl_3$): δ = 157.64, 148.25, 146.82, 145.77, 139.10, 135.86, 128.05, 127.58, 126.77, 118.71, 115.84, 33.70, 33.67, 23.98, 23.92, 11.74.



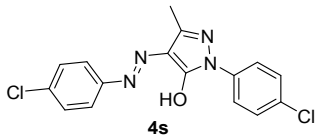
4q

1-(4-Methoxyphenyl)-4-((4-methoxyphenyl)diazenyl)-3-methyl-1*H*-pyrazol-5-ol (4q):[1] Prepared from ethyl 3-oxobutanoate **1a** (65 mg, 0.5 mmol) with 4-methoxyphenylhydrazine **2e** (165 mg, 1.2 mmol) according to general procedure in 6 h. Orange red solid (121 mg, 72%); mp 127-129 °C; ^{1}H NMR (600 MHz, $CDCl_3$): δ = 13.70 (s, 1H), 7.81 (d, *J* = 8.4 Hz, 2H), 7.35 (d, *J* = 9.0 Hz, 2H), 6.94 – 6.92 (m, 4H), 3.81 (s, 6H), 2.32 (s, 3H); ^{13}C NMR (150 MHz, $CDCl_3$): δ = 157.93, 157.47, 157.02, 148.03, 134.80, 131.54, 127.54, 120.39, 117.18, 114.95, 114.06, 55.59, 55.47, 11.74.



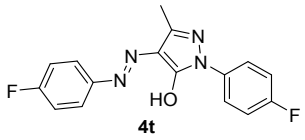
4r

1-(2-Chlorophenyl)-4-((2-chlorophenyl)diazenyl)-3-methyl-1*H*-pyrazol-5-ol (4r): Prepared from ethyl 3-oxobutanoate **1a** (65 mg, 0.5 mmol) with 2-chlorophenylhydrazine **2f** (170 mg, 1.2 mmol) according to general procedure in 12 h. Yellow solid (140 mg, 81%); mp 202-204 °C; ^{1}H NMR (600 MHz, $CDCl_3$): δ = 13.68 (s, 1H), 7.84 (dd, *J* = 8.4, 1.2 Hz, 1H), 7.52 – 7.50 (m, 1H), 7.45 – 7.43 (m, 1H), 7.37 (dd, *J* = 7.8, 1.2 Hz, 1H), 7.36 – 7.31 (m, 3H), 7.10 (td, *J* = 7.8, 1.2 Hz, 1H), 2.36 (s, 3H); ^{13}C NMR (150 MHz, $CDCl_3$): δ = 157.84, 148.52, 137.87, 134.28, 131.86, 130.53, 129.87, 129.85, 129.40, 128.91, 128.06, 127.52, 125.80, 121.83, 115.79, 11.90; ATR-IR 1769, 1668, 1549, 1489, 1245, 1046, 750 cm^{-1}; HRMS (EI) *m*/*z* (M^+) calcd for $C_{16}H_{12}Cl_2N_4O$: 346.0388; found: 346.0387.



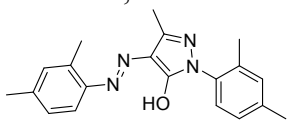
4s

1-(4-Chlorophenyl)-4-((4-Chlorophenyl)diazenyl)-3-methyl-1*H*-pyrazol-5-ol (4s): Prepared from ethyl 3-oxobutanoate **1a** (65 mg, 0.5 mmol) with 4-chlorophenylhydrazine **2g** (170 mg, 1.2 mmol) according to general procedure in 12 h. Orange solid (161 mg, 93%); mp 217-219 °C; ^{1}H NMR (600 MHz, $CDCl_3$): δ =13.50 (s, 1H), 7.90 (d, J = 9.0 Hz, 2H), 7.38 – 7.34 (m, 6H), 2.34 (s, 3H); ^{13}C NMR (150 MHz, $CDCl_3$): δ = 157.66, 148.78, 139.68, 136.52, 131.14, 130.35, 129.83, 128.99, 128.74, 119.56, 116.96, 11.79; ATR-IR 1653, 1548, 1481, 1261, 1148, 817, 502 cm^{-1}; HRMS (EI) m/z (M^+) calcd for $C_{16}H_{12}Cl_2N_4O$: 346.0388; found: 346.0391.



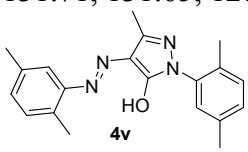
4t

1-(4-Fluorophenyl)-4-((4-fluorophenyl)diazenyl)-3-methyl-1*H*-pyrazol-5-ol (4t): Prepared from ethyl 3-oxobutanoate **1a** (65 mg, 0.5 mmol) with 4-fluorophenylhydrazine **2h** (151 mg, 1.2 mmol) according to general procedure in 12 h. Orange solid (125 mg, 90%); mp 192-194 °C; ^{1}H NMR (600 MHz, $CDCl_3$): δ =13.56 (s, 1H), 7.90-7.88 (m, 2H), 7.39-7.37 (m, 2H), 7.12-7.05 (m, 4H), 2.33 (s, 3H); ^{13}C NMR (150 MHz, $CDCl_3$): δ = 160.61 (d, $J_{C\text{-}F}$ = 244.5 Hz), 160.01 (d, $J_{C\text{-}F}$ =243.0 Hz), 157.53, 148.50, 137.37, 134.16, 128.33, 120.25 (d, $J_{C\text{-}F}$ = 7.5 Hz), 117.26 (d, $J_{C\text{-}F}$ = 9.0 Hz), 116.62 (d, $J_{C\text{-}F}$ = 24.0 Hz), 115.62 (d, $J_{C\text{-}F}$ = 22.5 Hz), 11.75; ATR-IR 1662, 1556, 1501, 1214, 823 cm^{-1}; HRMS (EI) m/z (M^+) calcd for $C_{16}H_{12}F_2N_4O$: 314.0979; found: 314.0977.



4u

1-(2,4-Dimethylphenyl)-4-((2,4-dimethylphenyl)diazenyl)-3-methyl-1*H*-pyrazol-5-ol (4u):[1] Prepared from ethyl 3-oxobutanoate **1a** (65 mg, 0.5 mmol) with 2,4-dimethylphenylhydrazine **2i** (163 mg, 1.2 mmol) according to general procedure in 6 h. Orange solid (128 mg, 77%); mp 130-132 °C; ^{1}H NMR (600 MHz, $CDCl_3$): δ = 13.80 (s, 1H), 7.67 (d, J = 8.4 Hz, 1H), 7.19 (d, J = 8.4 Hz, 1H), 7.09 – 7.08 (m, 2H), 7.05 (d, J = 7.8 Hz, 1H), 6.99 (s, 1H), 2.35 (s, 3H), 2.33 (s, 3H), 2.32 (s, 3H), 2.32 (s, 3H), 2.25 (s, 3H); ^{13}C NMR (150 MHz, $CDCl_3$): δ = 158.40, 147.78, 138.41, 137.10, 135.38, 135.00, 133.03, 131.71, 131.65, 128.10, 127.25, 126.67, 125.22, 114.43, 21.12, 20.94, 18.25, 16.67, 11.84.



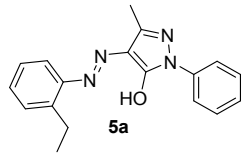
4v

1-(2,5-Dimethylphenyl)-4-((2,5-dimethylphenyl)diazenyl)-3-methyl-1*H*-pyrazol-5-ol (4v):[1] Prepared from ethyl 3-oxobutanoate **1a** (65 mg, 0.5 mmol) with 2,5-dimethylphenylhydrazine **2j** (163 mg, 1.2 mmol) according to general procedure in 6 h. Orange solid (133 mg, 80%); mp 100-102 °C; ^{1}H NMR (600 MHz, $CDCl_3$): δ = 13.75 (s, 1H),

7.60 (s, 1H), 7.17 (d, *J* = 7.8 Hz, 1H), 7.13 (s, 1H), 7.08 – 7.06 (m, 2H), 6.91 (d, *J* = 7.8 Hz, 1H), 2.38 (s, 3H), 2.37 (s, 3H), 2.32 (s, 3H), 2.32 (s, 3H), 2.24 (s, 3H); ^{13}C NMR (150 MHz, $CDCl_3$): δ = 158.22, 147.97, 139.06, 137.37, 136.39, 135.32, 132.06, 130.93, 130.91, 129.41, 128.35, 127.22, 126.40, 122.40, 114.78, 21.28, 20.78, 17.93, 16.31, 11.89.

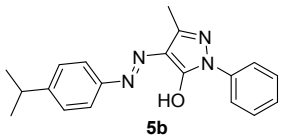
General experimental procedure for the synthesis of arylazopyrazoles and characterization data for arylazopyrazoles (5a-5h)

To a solution of 5-methyl-2-phenyl-2,4-dihydro-3*H*-pyrazol-3-one **3a** (87 mg, 0.5 mmol) and arylhydrazine (0.6 mmol) in 1,2-dichloroethane (3.0 mL) was added I_2 (126 mg, 0.25 mmol), acetic acid (0.03 mL, 0.5 mmol) and $AgNO_3$ (8 mg, 10 mol%) and heated the reaction mixture at 70 ^{o}C under nitrogen atmosphere until completion of reaction as indicated by TLC. The volatiles were removed *in vacuo* and the residue was purified by silica gel column chromatography (hexane: ethyl acetate = 30:1) to give desired products as solid.



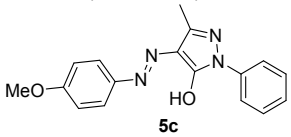
5a

4-((2-Ethylphenyl)diazenyl)-3-methyl-1-phenyl-1*H*-pyrazol-5-ol (5a):[1] Prepared from 5-methyl-2-phenyl-2,4-dihydro-3*H*-pyrazol-3-one **3a** (87 mg, 0.5 mmol) with 2-ethylphenylhydrazine **2b** (81 mg, 0.6 mmol) according to general procedure in 6 h. Orange solid (146 mg, 96%); mp 107-109 °C; ^{1}H NMR (600 MHz, $CDCl_3$): δ = 13.85 (s, 1H), 7.95 – 7.93 (m, 2H), 7.79 (d, *J* = 7.8 Hz, 1H), 7.43 – 7.40 (m, 2H), 7.29 (t, *J* = 7.2 Hz, 1H), 7.23 (d, *J* = 7.2 Hz, 1H), 7.20 – 7.18 (m, 1H), 7.15 (td, *J* = 7.2, 0.6 Hz, 1H), 2.77 (q, *J* = 7.2 Hz, 2H), 2.37 (s, 3H), 1.34 (t, *J* = 7.2 Hz, 3H); ^{13}C NMR (150 MHz, $CDCl_3$): δ = 157.92, 148.50, 138.67, 138.00, 131.34, 129.15, 128.93, 127.40, 125.81, 125.18, 118.79, 114.79, 23.69, 13.82, 11.81.



5b

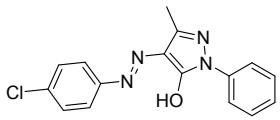
4-((4-Isopropylphenyl)diazenyl)-3-methyl-1-phenyl-1*H*-pyrazol-5-ol (5b):[1] Prepared from 5-methyl-2-phenyl-2,4-dihydro-3*H*-pyrazol-3-one **3a** (87 mg, 0.5 mmol) with 4-isopropylphenylhydrazine **2d** (90 mg, 0.6 mmol) according to general procedure in 5 h. Orange solid (148 mg, 93%); mp 80-82 °C; ^{1}H NMR (600 MHz, $CDCl_3$): δ = 13.56 (s, 1H), 7.89 (d, *J* = 8.4 Hz, 2H), 7.35 (t, *J* = 7.8 Hz, 2H), 7.29 (t, *J* = 8.4 Hz, 2H), 7.21 – 7.18 (m, 2H), 7.13 (t, *J* = 7.2 Hz, 1H), 2.88 – 2.83 (m, 1H), 2.29 (s, 3H), 1.19 (d, *J* = 6.6 Hz, 6H); ^{13}C NMR (150 MHz, $CDCl_3$): δ = 157.87, 148.51, 147.00, 139.07, 138.11, 128.89, 127.97, 127.64, 127.04, 125.07, 122.77, 118.57, 115.91, 33.73, 23.93, 23.86, 11.79.



5c

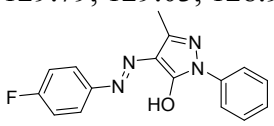
4-((4-Methoxyphenyl)diazenyl)-3-methyl-1-phenyl-1*H*-pyrazol-5-ol (5c):[1] Prepared from 5-methyl-2-phenyl-2,4-dihydro-3*H*-pyrazol-3-one **3a** (87 mg, 0.5 mmol) with 4-methoxyphenylhydrazine **2e** (83 mg, 0.6 mmol) according to general procedure in 10 h. Orange red solid (103 mg, 67%); mp 105-107 °C; ^{1}H NMR (600 MHz, $CDCl_3$): δ = 13.71 (s, 1H), 7.94 (d, *J* = 8.4 Hz, 2H), 7.42 – 7.36 (m, 5H), 6.93 (d, *J* = 8.4 Hz, 2H), 3.82 (s, 3H), 2.34 (s, 3H); ^{13}C NMR (150 MHz, $CDCl_3$): δ = 158.03, 148.37, 138.16, 134.76, 128.89, 126.09, 125.03, 118.58, 117.26, 115.27, 114.98, 114.88, 114.37, 55.61, 11.78.

.



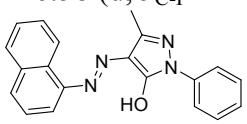
5d

4-((4-Chlorophenyl)diazenyl)-3-methyl-1-phenyl-1H-pyrazol-5-ol (5d):[1] Prepared from 5-methyl-2-phenyl-2,4-dihydro-3*H*-pyrazol-3-one **3a** (87 mg, 0.5 mmol) with 4-chlorophenylhydrazine **2g** (85 mg, 0.6 mmol) according to general procedure in 12 h. Orange solid (148 mg, 95%); mp 132-134 °C; ^{1}H NMR (600 MHz, $CDCl_3$): δ = 13.56 (s, 1H), 7.92 (d, *J* = 8.4 Hz, 2H), 7.41 (t, *J* = 7.8 Hz, 2H), 7.37 – 7.34 (m, 4H), 7.20 (t, *J* = 7.2 Hz, 1H), 2.34 (s, 3H); ^{13}C NMR (150 MHz, $CDCl_3$): δ = 157.72, 148.48, 139.80, 137.92, 130.92, 129.79, 129.03, 128.94, 125.27, 118.57, 116.89, 11.79.



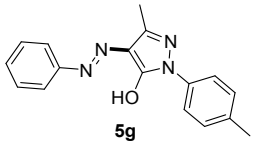
5e

4-((4-Fluorophenyl)diazenyl)-3-methyl-1-phenyl-1H-pyrazol-5-ol (5e):[1] Prepared from 5-methyl-2-phenyl-2,4-dihydro-3*H*-pyrazol-3-one **3a** (87 mg, 0.5 mmol) with 4-fluorophenylhydrazine **2h** (76 mg, 0.6 mmol) according to general procedure in 12 h. Orange solid (134 mg, 91%); mp 103-105 °C; ^{1}H NMR (600 MHz, $CDCl_3$): δ = 13.60 (s, 1H), 7.93 (d, *J* = 8.4 Hz, 2H), 7.42 – 7.37 (m, 4H), 7.19 (td, *J* = 7.8, 1.2 Hz, 1H), 7.10 (t, *J* = 8.4 Hz, 2H), 2.34 (s, 3H); ^{13}C NMR (150 MHz, $CDCl_3$): δ = 160.54 (d, $J_{C\text{-}F}$ = 244.5 Hz), 157.76, 148.44, 137.97, 137.45 (d, $J_{C\text{-}F}$ = 3.0 Hz), 128.91, 128.51, 125.18, 118.53, 117.20 (d, $J_{C\text{-}F}$ = 7.5 Hz), 116.58 (d, $J_{C\text{-}F}$ = 24.0), 11.76.



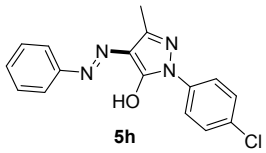
5f

3-Methyl-4-(naphthalen-1-yldiazenyl)-1-phenyl-1*H*-pyrazol-5-ol (5f):[1] Prepared from 5-methyl-2-phenyl-2,4-dihydro-3*H*-pyrazol-3-one **3a** (87 mg, 0.5 mmol) with 1-naphthalenyl hydrazine **2i** (95 mg, 0.6 mmol) according to general procedure in 10 h. Orange red solid (136 mg, 83%); mp 198-200 °C; ^{1}H NMR (600 MHz, $CDCl_3$): δ = 14.56 (s, 1H), 8.08 (d, *J* = 9.0 Hz, 1H), 7.98 (d, *J* = 8.4 Hz, 2H), 7.94 (d, *J* = 7.8 Hz, 1H), 7.90 (d, *J* = 8.4 Hz, 1H), 7.71 (d, *J* = 8.4 Hz, 1H), 7.63 – 7.60 (m, 1H), 7.56 – 7.53 (m, 2H), 7.44 (t, *J* = 7.8 Hz, 2H), 7.23 – 7.20 (m, 1H), 2.42 (s, 3H); ^{13}C NMR (150 MHz, $CDCl_3$): δ = 158.08, 148.55, 137.97, 136.04, 134.06, 129.89, 128.99, 128.83, 127.11, 126.61, 126.03, 125.93, 125.32, 123.16, 119.39, 118.82, 111.35, 11.87.



5g

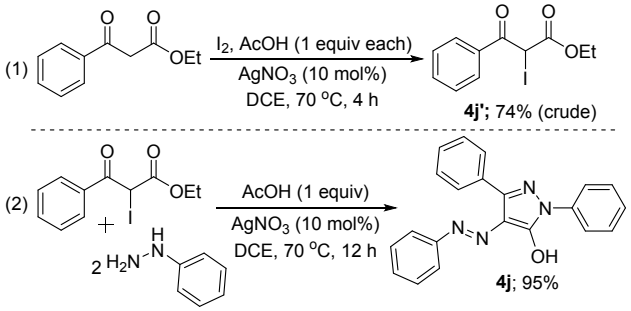
3-Methyl-4-(phenyldiazenyl)-1-(*p*-tolyl)-1*H*-pyrazol-5-ol (5g): Prepared from 5-methyl-2-(*p*-tolyl)-2,4-dihydro-3*H*-pyrazol-3-one **3b** (94 mg, 0.5 mmol) with phenylhydrazine **2a (**65 mg, 0.6 mmol) according to general procedure in 6 h. Red solid (141 mg, 97%); mp 185-187 °C; ^{1}H NMR (600 MHz, $CDCl_3$): δ = 13.58 (s, 1H), 7.81 – 7.80 (m, 2H), 7.42 – 7.38 (m, 4H), 7.22 – 7.17 (m, 3H), 2.35 (s, 6H); ^{13}C NMR (150 MHz, $CDCl_3$): δ = 157.58, 148.37, 141.19, 135.60, 134.86, 129.65, 129.43, 128.62, 125.71, 118.62, 115.78, 20.98, 11.77; ATR-IR 1769, 1650, 1509, 1339, 1256, 753 cm^{-1}; HRMS (EI) *m*/*z* (M^+) calcd for $C_{17}H_{16}N_4O$: 292.1324; found: 292.1322.



5h

1-(4-Chlorophenyl)-3-methyl-4-(phenyldiazenyl)-1*H*-pyrazol-5-ol (5h): Prepared from 2-(4-chlorophenyl)-5-methyl-2,4-dihydro-3*H*-pyrazol-3-one (104 mg, 0.5 mmol) with phenylhydrazine **2a (**65 mg, 0.6 mmol) according to general procedure in 6 h. Orange red solid (148 mg, 95%); mp 186-188 °C; ^{1}H NMR (600 MHz, $CDCl_3$): δ = 13.52 (s, 1H), 7.92 (d, *J* = 8.4 Hz, 2H), 7.43 – 7.39 (m, 4H), 7.36 (d, *J* = 9.0 Hz, 2H), 7.21 – 7.19 (m, 1H), 2.35 (s, 3H); ^{13}C NMR (150 MHz, $CDCl_3$): δ = 157.74, 148.87, 141.03, 136.66, 130.22, 129.71, 128.96, 128.24, 126.00, 119.56, 115.89, 11.79; ATR-IR 1769, 1653, 1547, 14891343, 1269, 1151, 748 cm^{-1}; HRMS (EI) *m*/*z* (M^+) calcd for $C_{16}H_{13}ClN_4O$: 312.0778; found: 312.0778.

Mechanistic Investigation



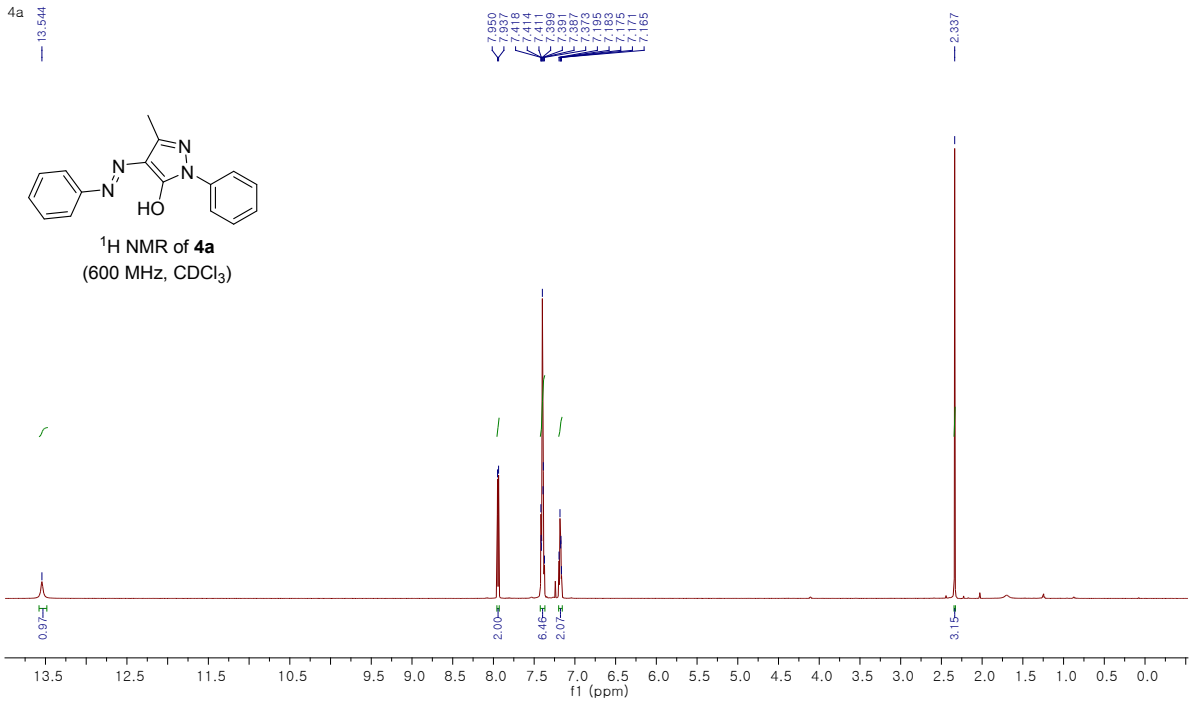
To a solution of ethyl benzoyl acetate (192 mg, 1.0 mmol) in 1,2-dichloroethane (5.0 mL) was added I_2 (252 mg, 1.0 mmol), acetic acid (0.06 mL, 1.0 mmol) and $AgNO_3$ (16 mg, 10 mol%) and heated the reaction mixture at 70 °C for 4 h under nitrogen atmosphere. After cooling the reaction mixture, water (50 mL) was added. The mixture was extracted with diethyl ether (15 mL x 3), the combined organic layers were dried over anhydrous Na_2SO_4, and excess solvent was removed under reduced pressure to give crude product (320 mg) (purification by column chromatography was inappropriate regarding instability of the iodinated intermediates). The yield of **4j'** (236 mg, 74%) was determined by the analysis of ^{1}H NMR of the crude sample. The characterization data of the major iodinated compound is

as follows: ^{1}H NMR (600 MHz, $CDCl_3$) δ = 7.95 (d, *J* = 7.8 Hz, 2H), 7.58 (dd, *J* = 7.8, 7.2, Hz, 1H), 7.45 (dd, *J* = 7.8, 7.2 Hz, 2H), 5.92 (s, 1H), 4.22 (q, *J* = 6.6 Hz, 2H), 1.21 (t, *J* = 7.2 Hz, 3H); ^{13}C NMR (150 MHz, $CDCl_3$) δ = 189.16, 166.43, 134.05, 130.49, 129.03, 128.84, 128.51, 126.53, 63.27, 23.88, 13.75.

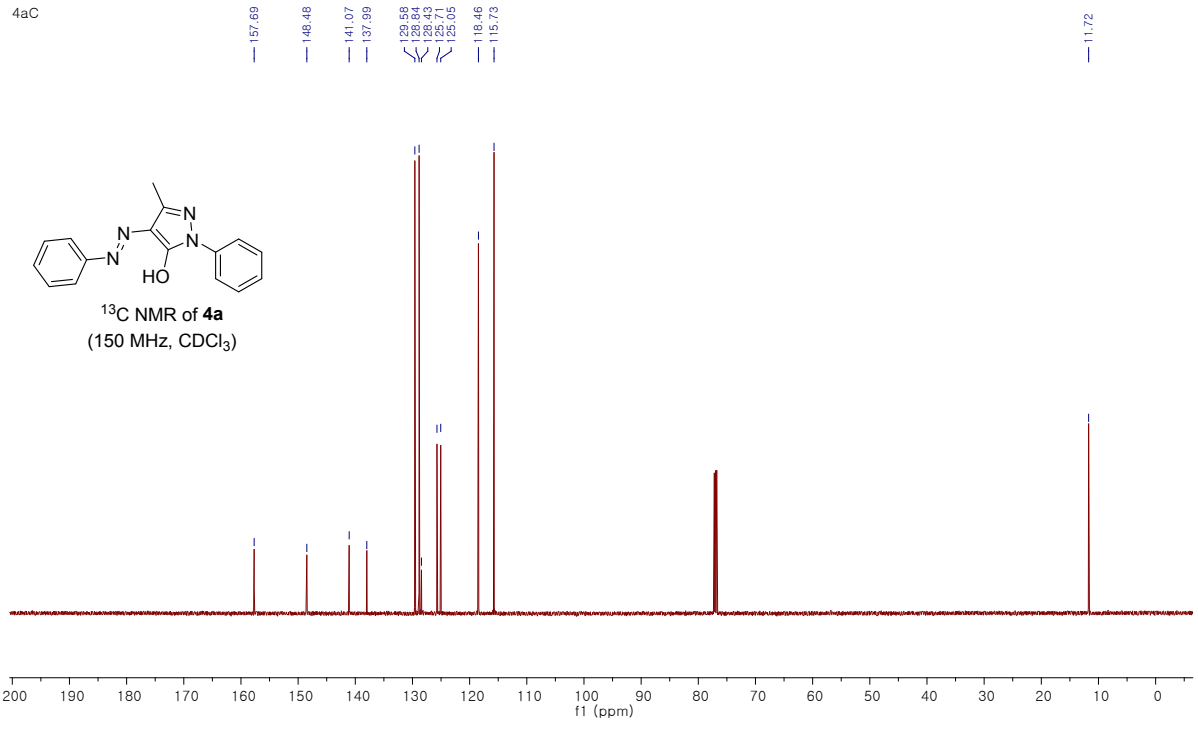
To a solution of crude sample (100 mg, 0.23 mmol) in 1,2-dichloroethane (3.0 mL) was added acetic acid (0.01 mL, 0.25 mmol), $AgNO_3$ (4 mg, 10 mol%), phenyl hydrazine (60 mg, 0.55 mmol) and heated the reaction mixture at 70 ^{o}C under nitrogen atmosphere for 12 h. After cooling the reaction mixture, the excess solvent was removed under reduced pressure and purified by column chromatography to give the desired arylazopyrazole **4j** in 95% yield (77 mg).

Reference

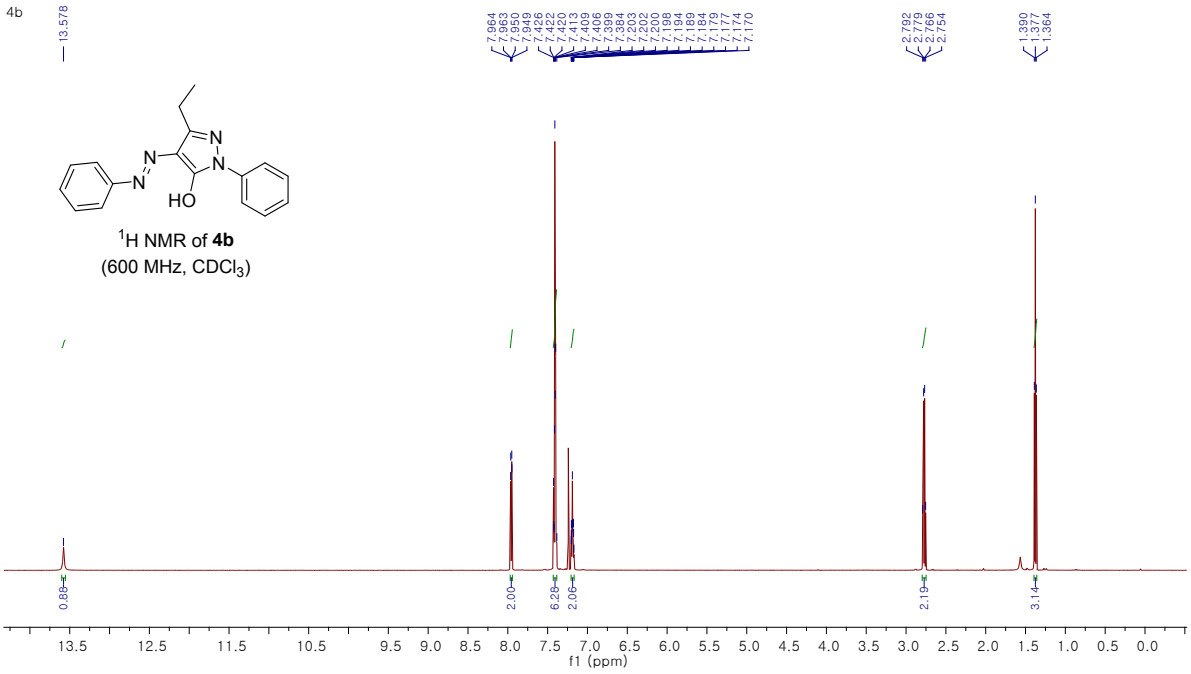
1. R. P. Pandit and Y. R. Lee, *Adv. Synth. Catal.*, 2015, **357**, 2657.



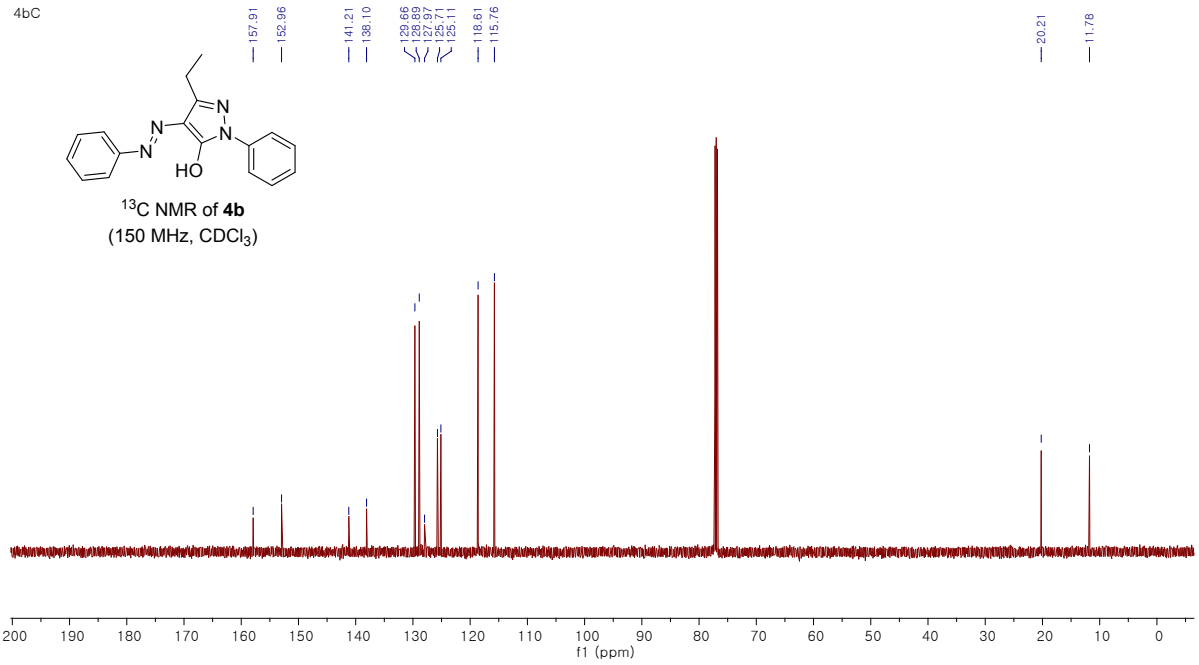
^{1}H NMR of **4a**
(600 MHz, $CDCl_3$)



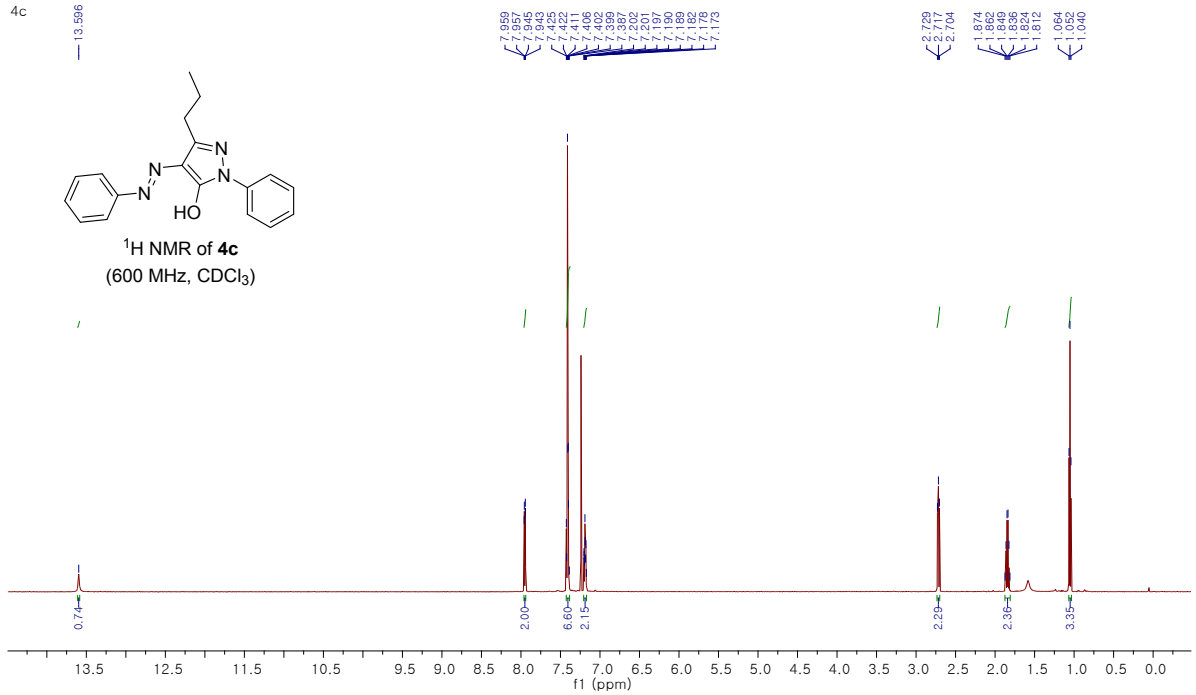
^{13}C NMR of **4a**
(150 MHz, $CDCl_3$)



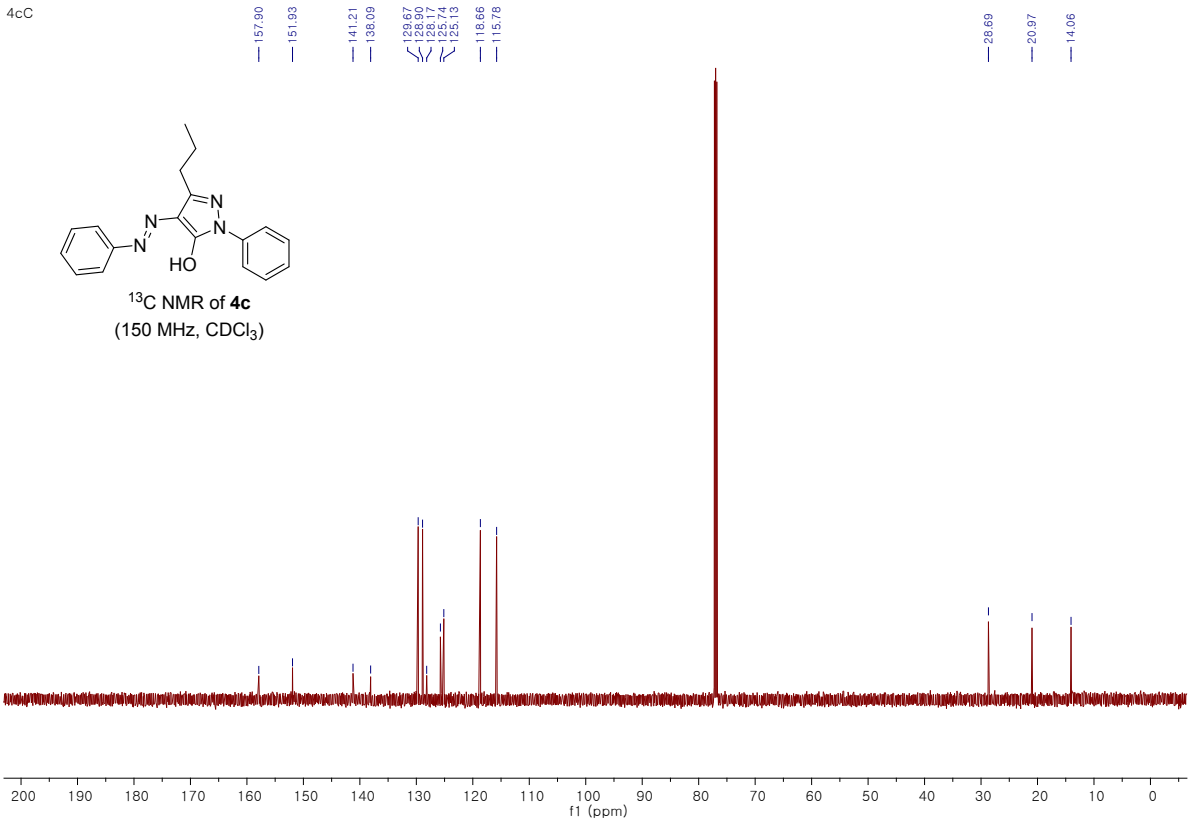
^{1}H NMR of **4b**
(600 MHz, $CDCl_3$)



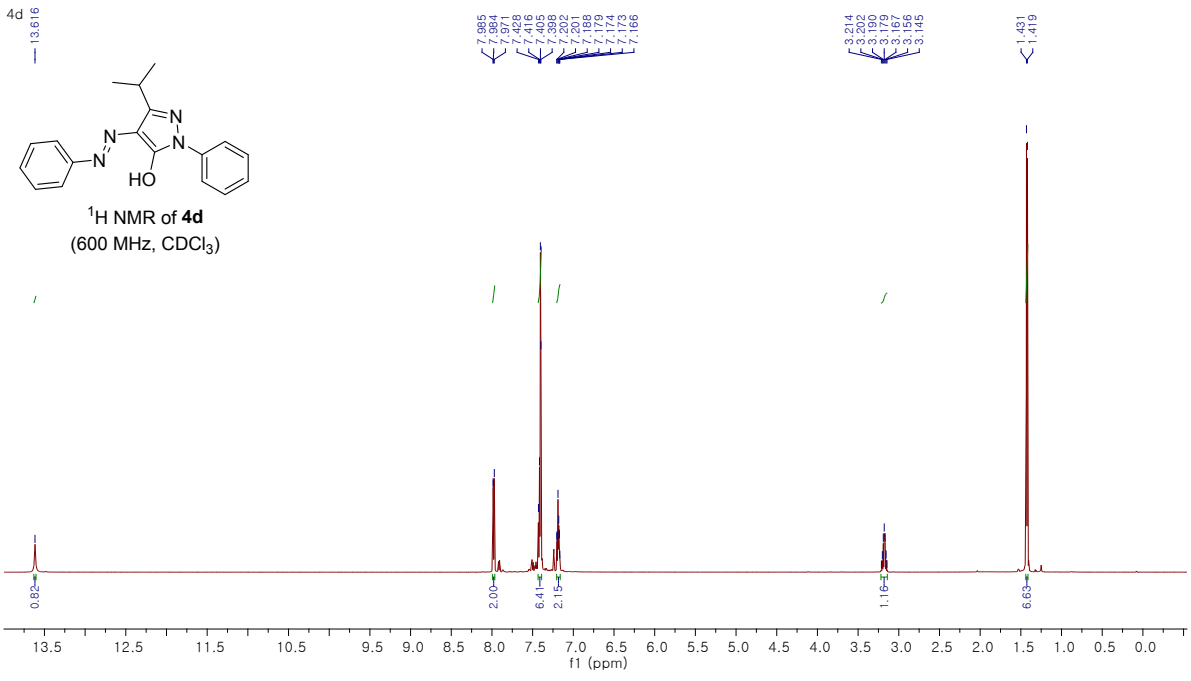
^{13}C NMR of **4b**
(150 MHz, $CDCl_3$)



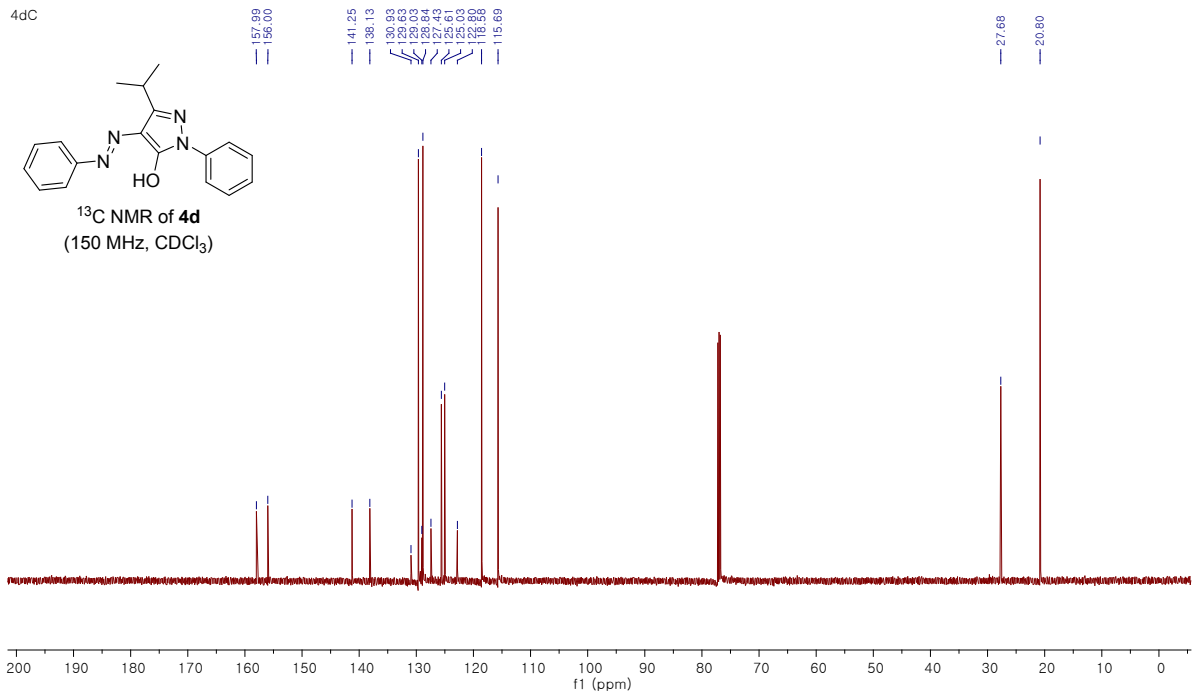
^{1}H NMR of **4c**
(600 MHz, $CDCl_3$)



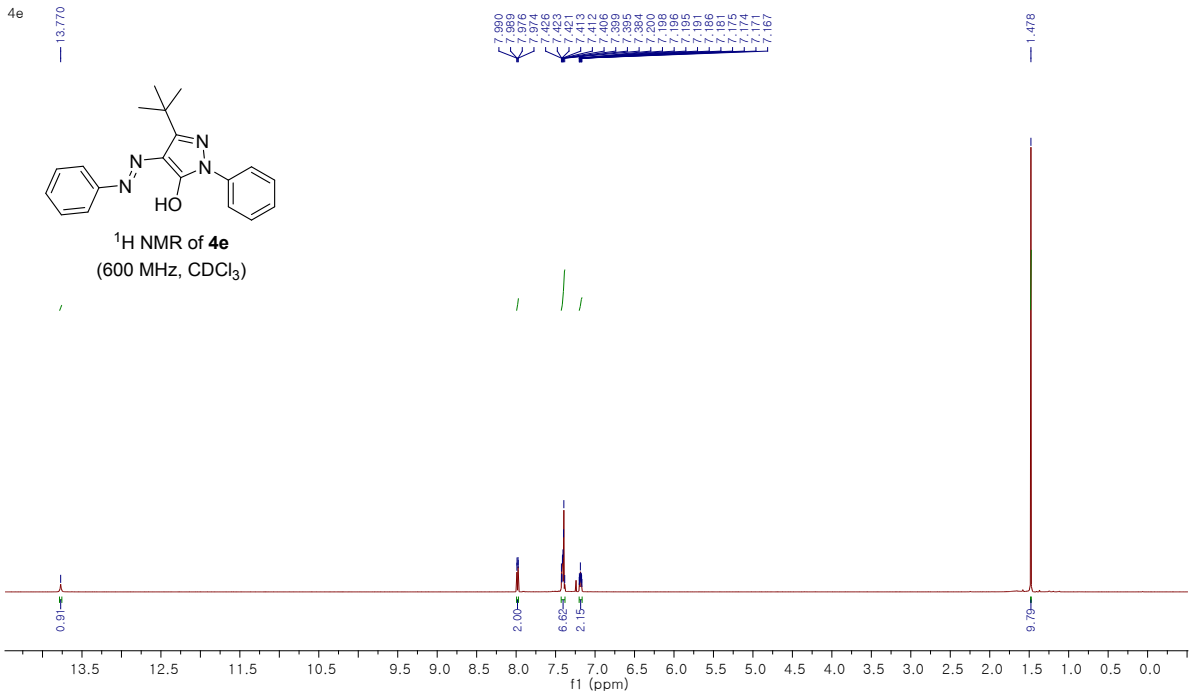
^{13}C NMR of **4c**
(150 MHz, $CDCl_3$)



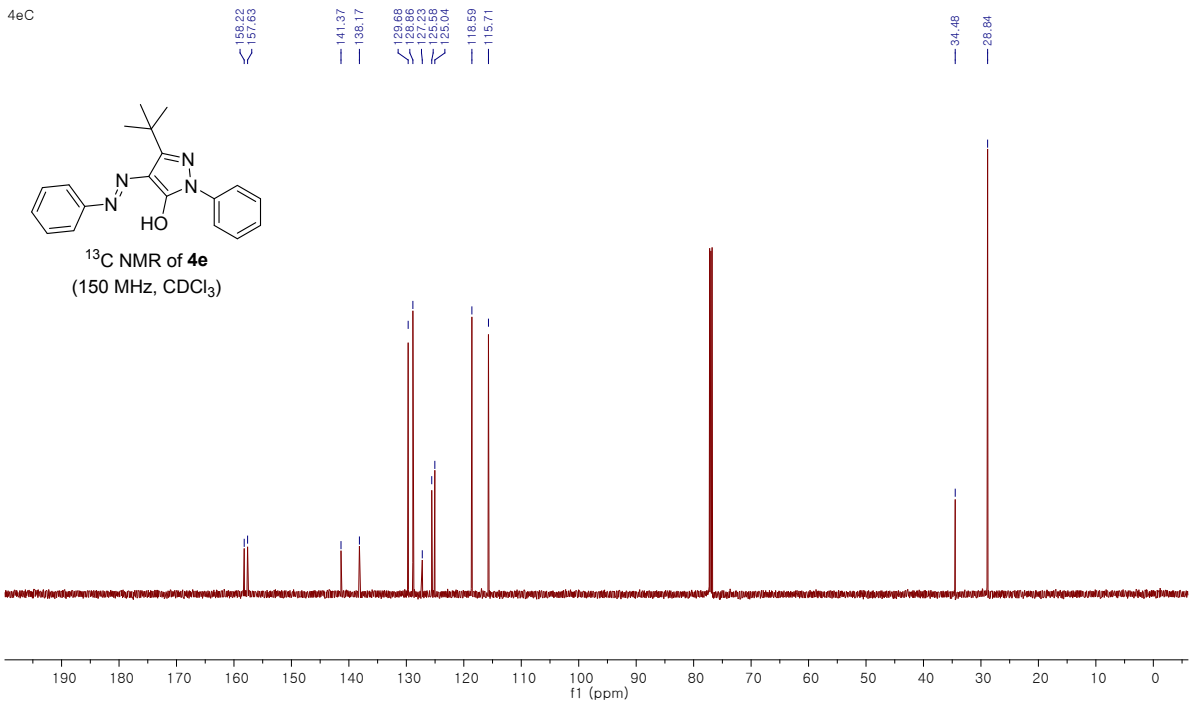
^{1}H NMR of **4d**
(600 MHz, $CDCl_3$)



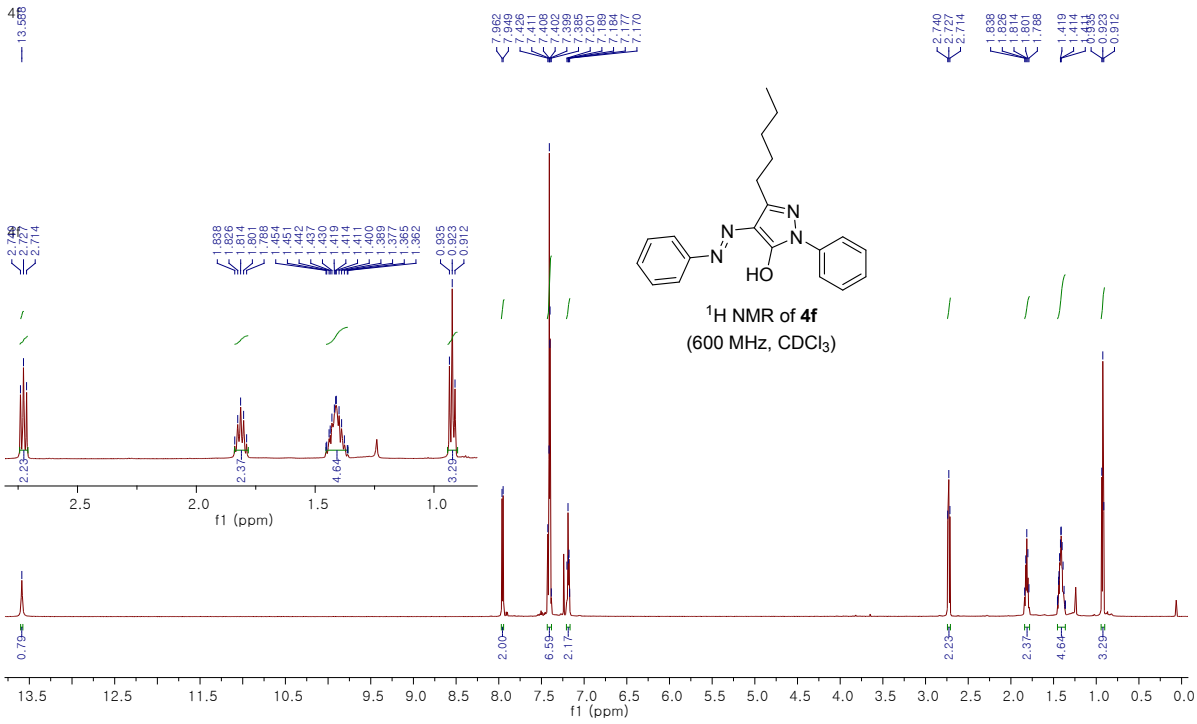
^{13}C NMR of **4d**
(150 MHz, $CDCl_3$)



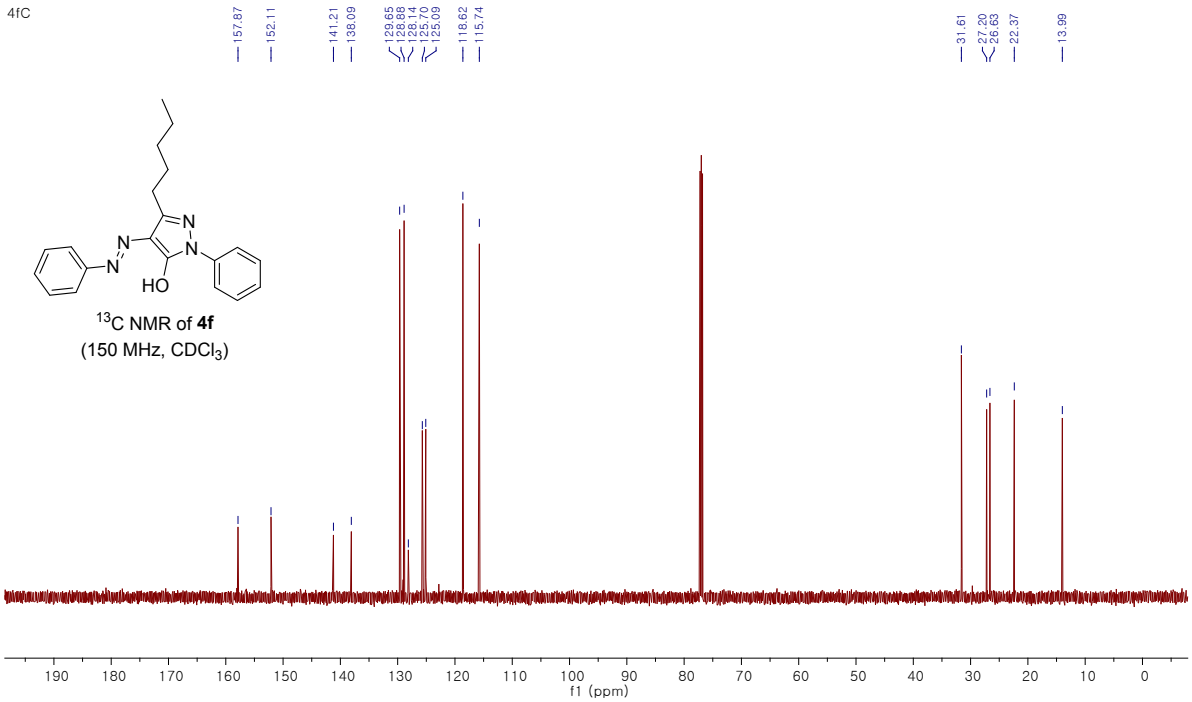
^{1}H NMR of **4e**
(600 MHz, $CDCl_3$)



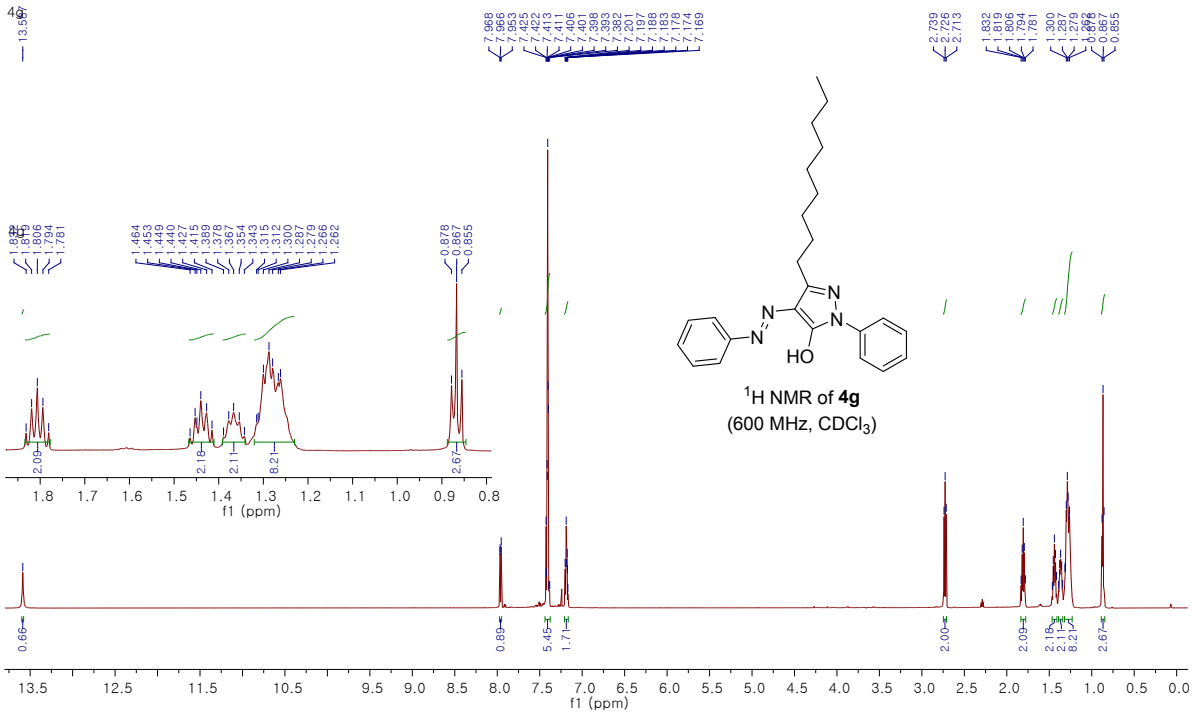
^{13}C NMR of **4e**
(150 MHz, $CDCl_3$)



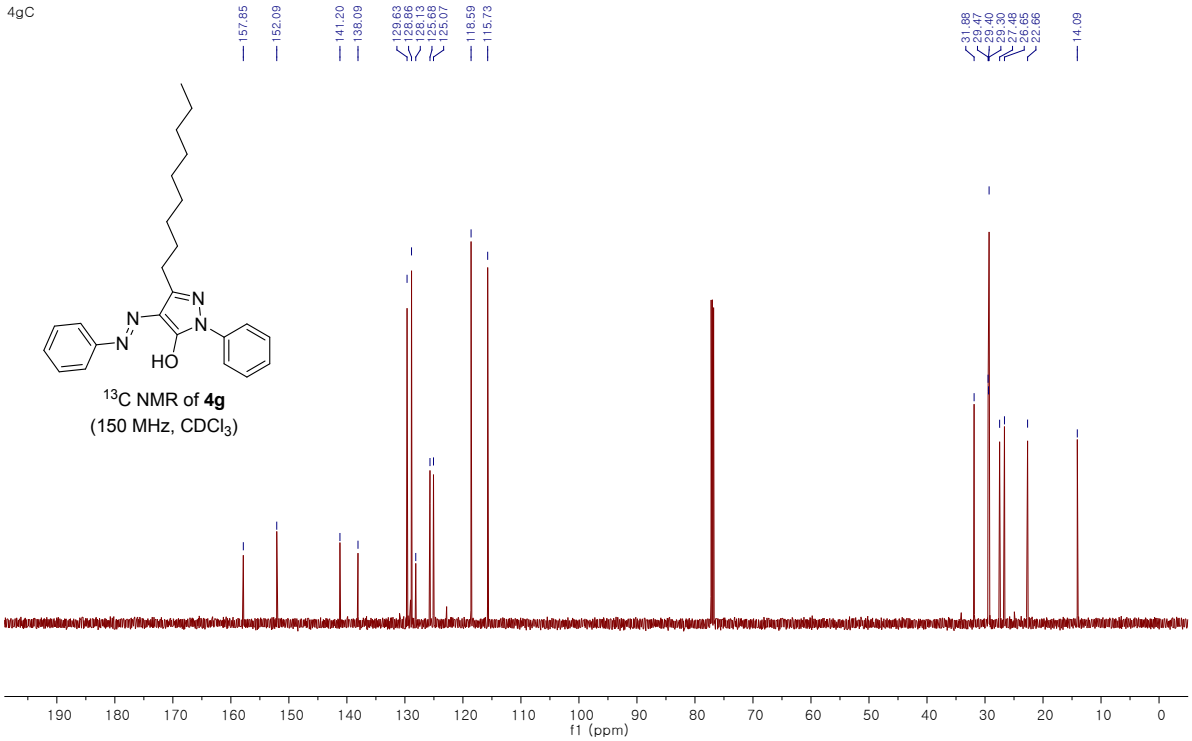
^{1}H NMR of **4f**
(600 MHz, $CDCl_3$)



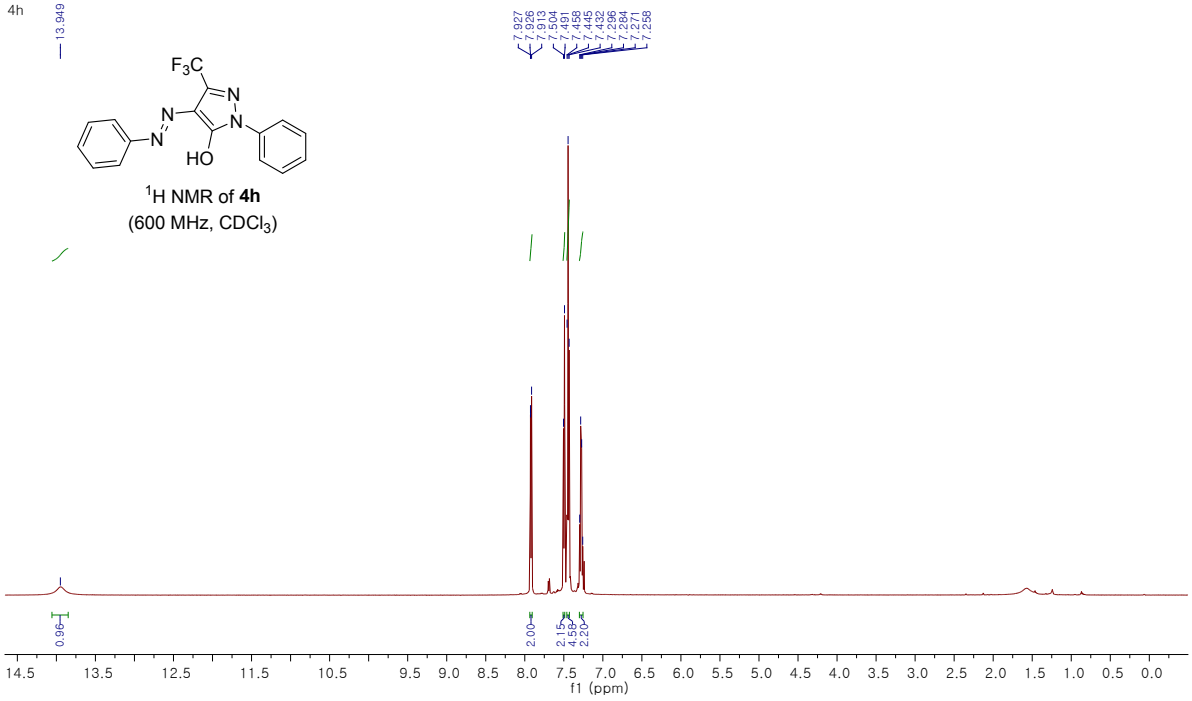
^{13}C NMR of **4f**
(150 MHz, $CDCl_3$)



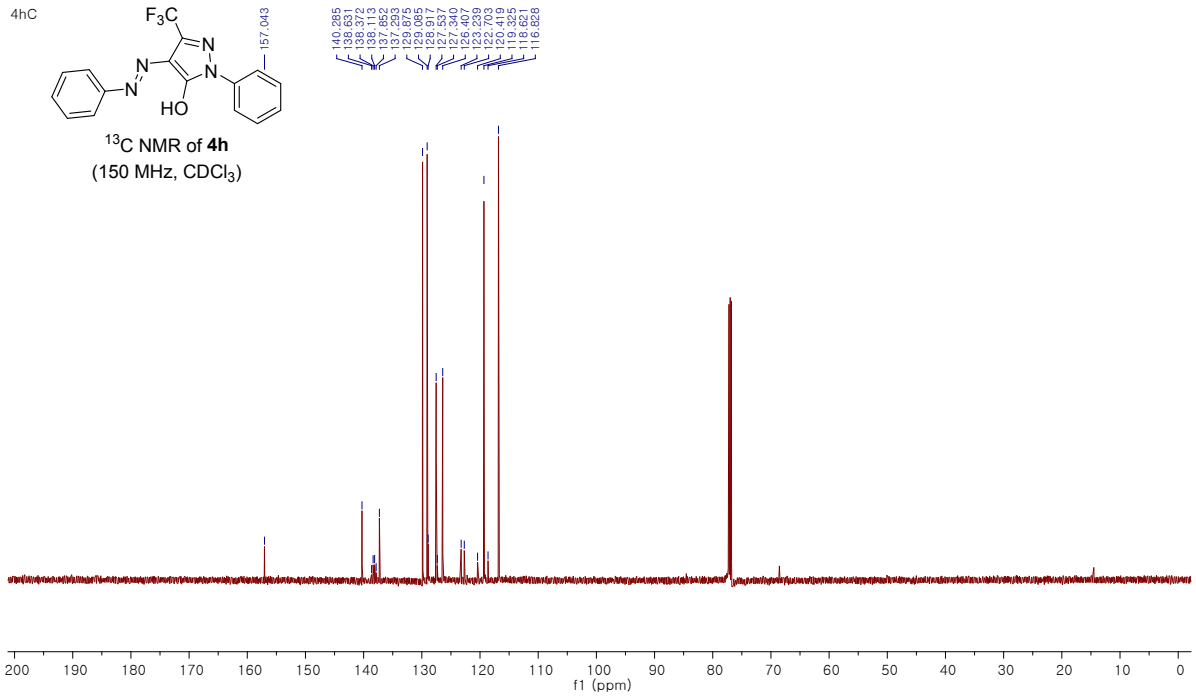
^{1}H NMR of **4g**
(600 MHz, $CDCl_3$)



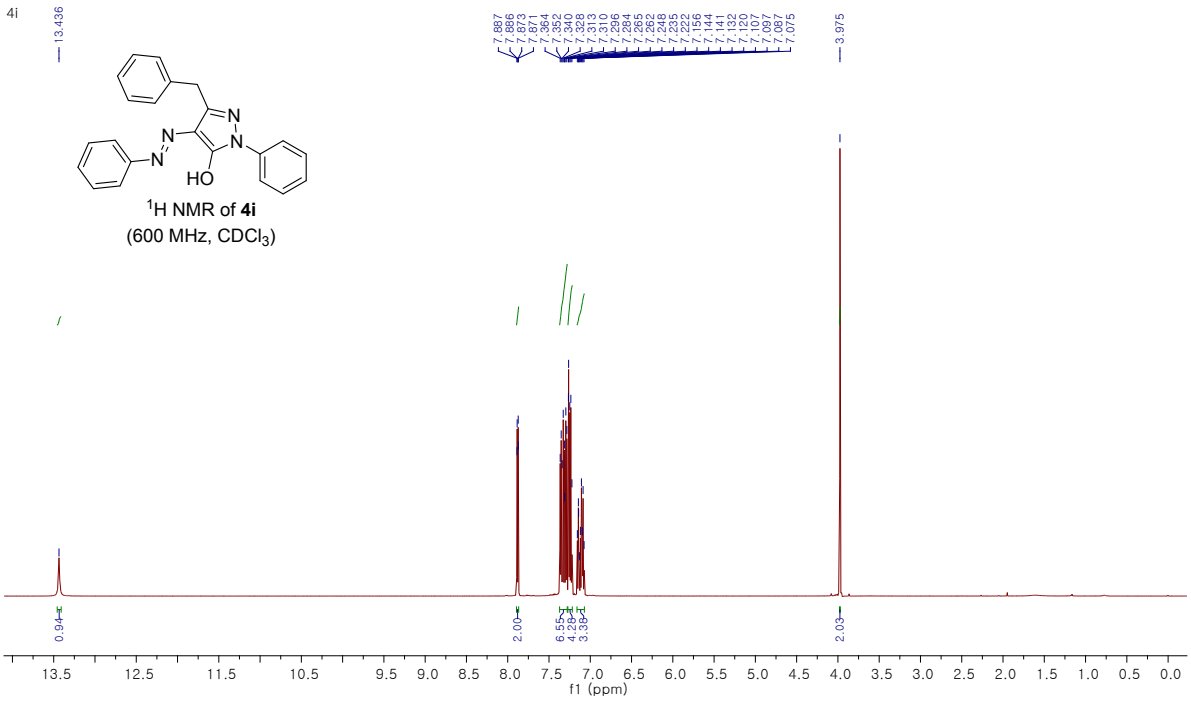
^{13}C NMR of **4g**
(150 MHz, $CDCl_3$)

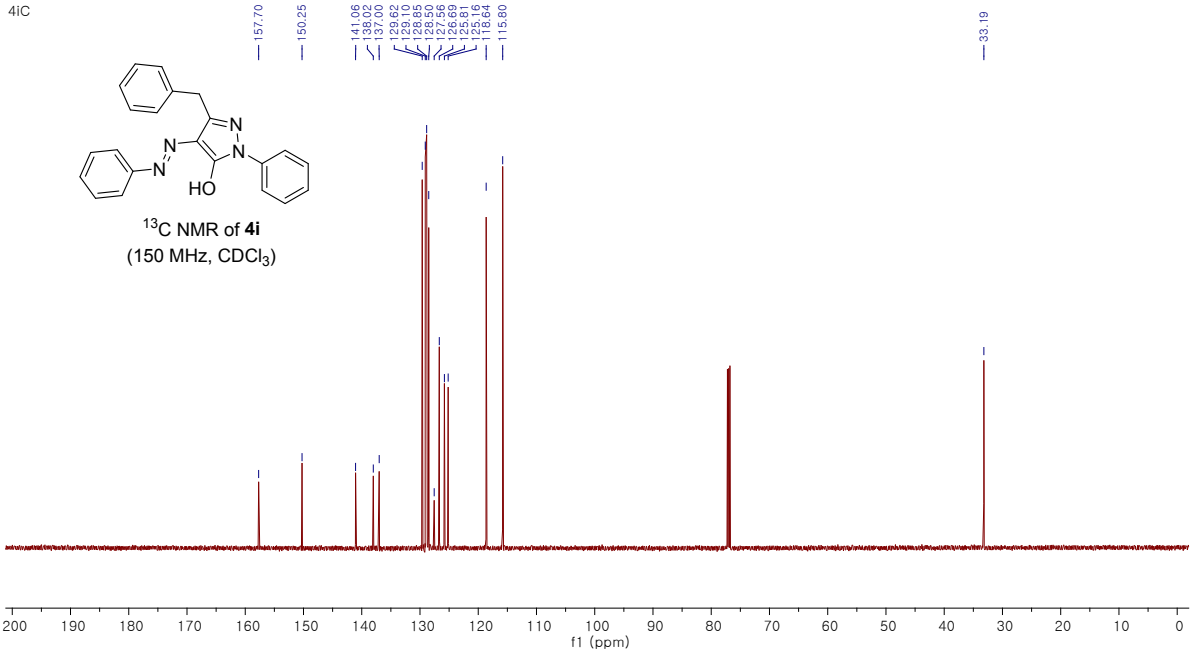


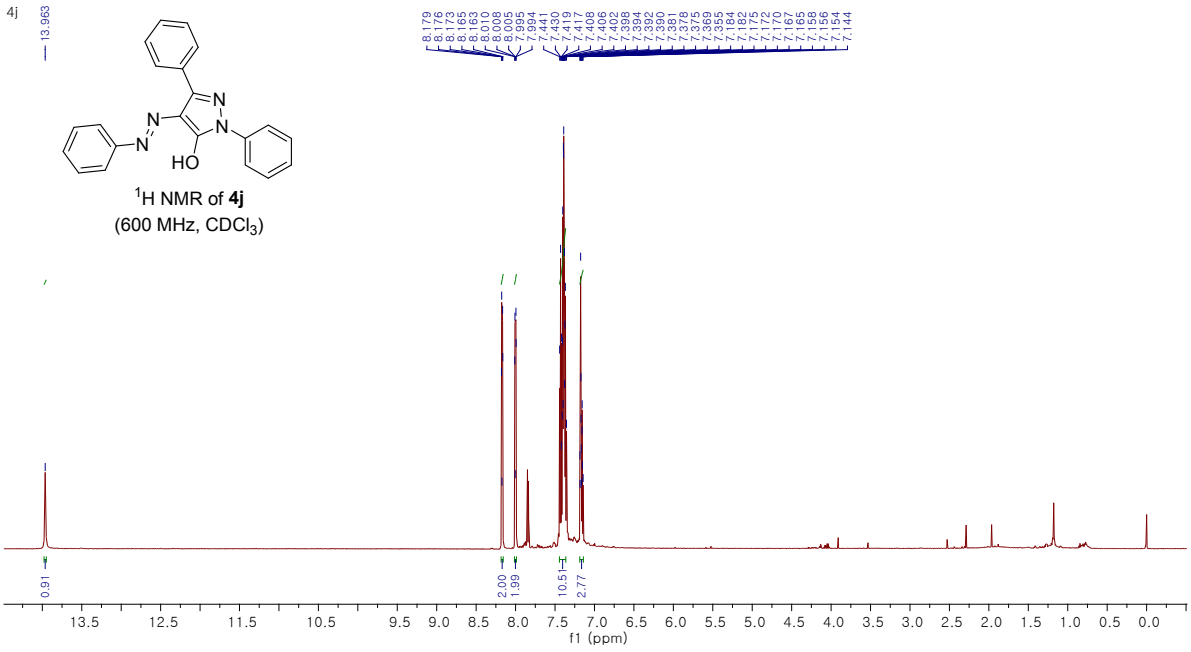
^{1}H NMR of **4h**
(600 MHz, $CDCl_3$)



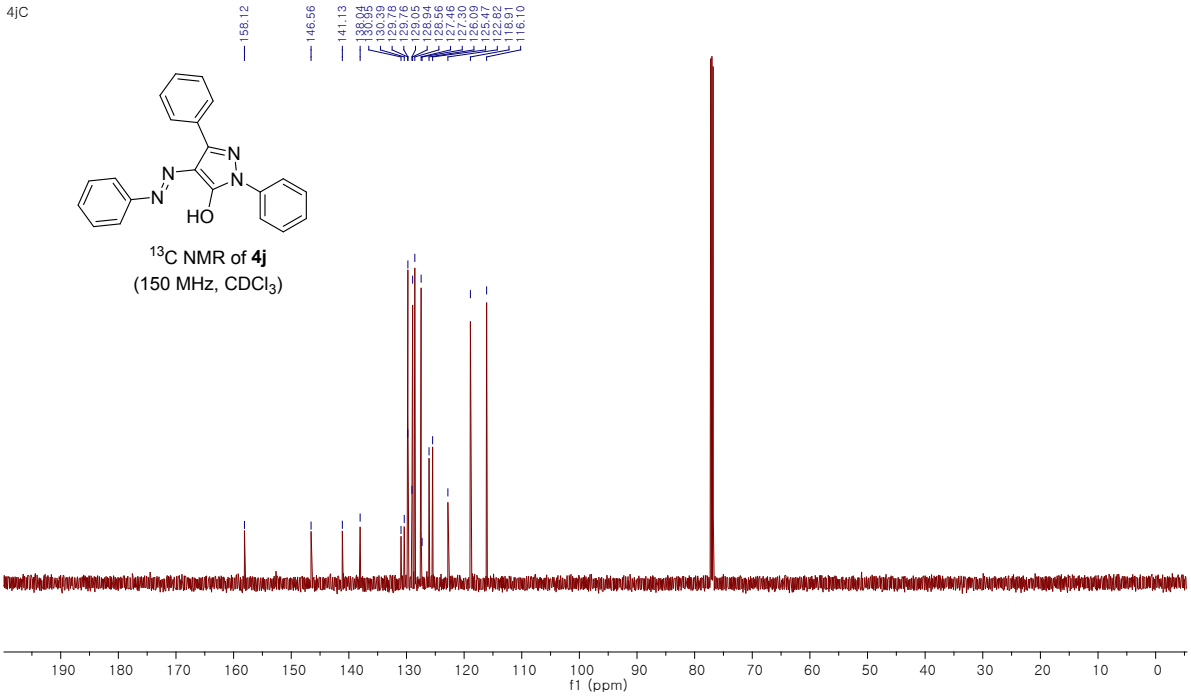
^{13}C NMR of **4h**
(150 MHz, $CDCl_3$)


4i
13.436
7.887
7.886
7.873
7.871
7.364
7.352
7.340
7.328
7.313
7.310
7.296
7.284
7.265
7.262
7.248
7.235
7.222
7.156
7.144
7.141
7.132
7.120
7.107
7.097
7.087
7.075
3.975
HO
^{1}H NMR of **4i**
(600 MHz, $CDCl_3$)
0.94
2.00
6.55
4.22
3.38
2.03
f1 (ppm)

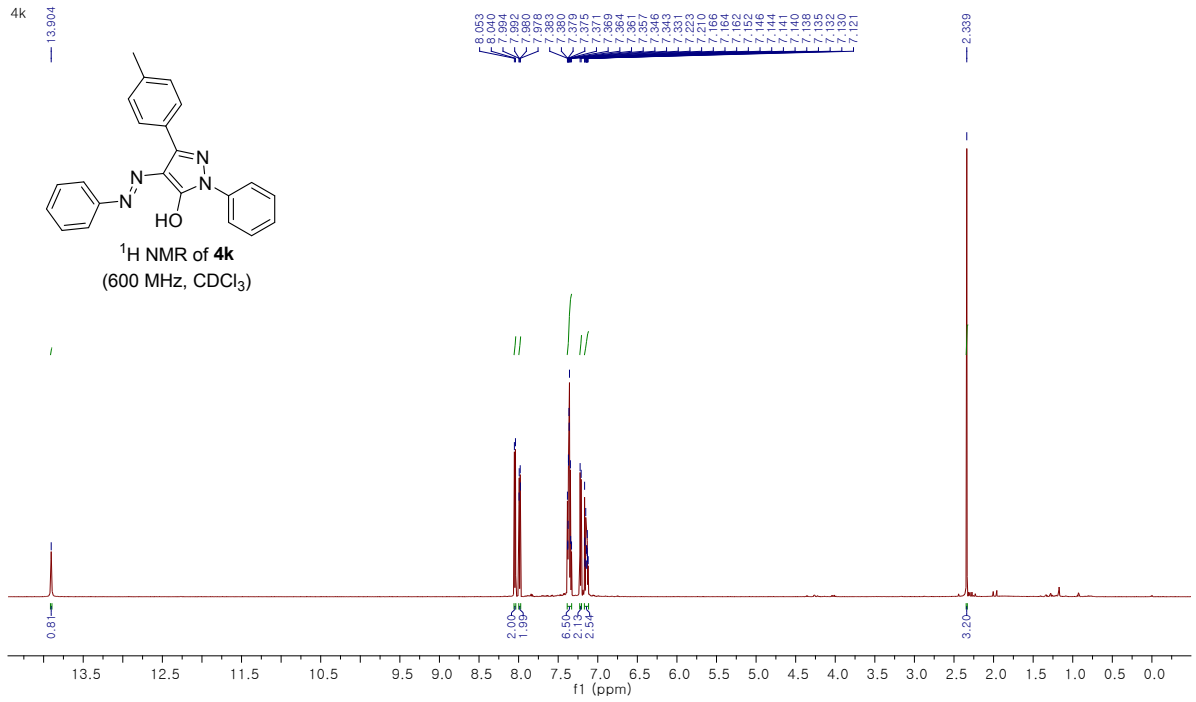

4iC
157.70
150.25
141.06
138.02
137.00
129.62
129.10
128.85
128.50
127.56
126.69
125.81
125.16
118.64
115.80
33.19
HO
^{13}C NMR of **4i**
(150 MHz, $CDCl_3$)
f1 (ppm)



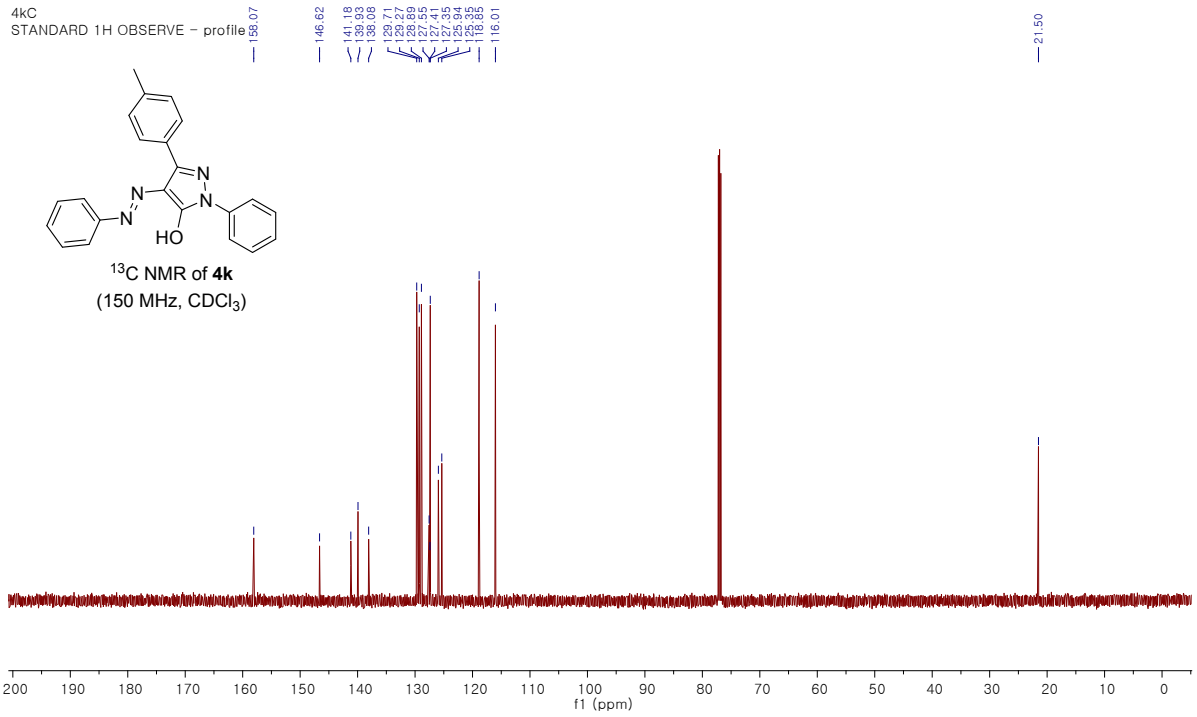
^{1}H NMR of **4j**
(600 MHz, $CDCl_3$)



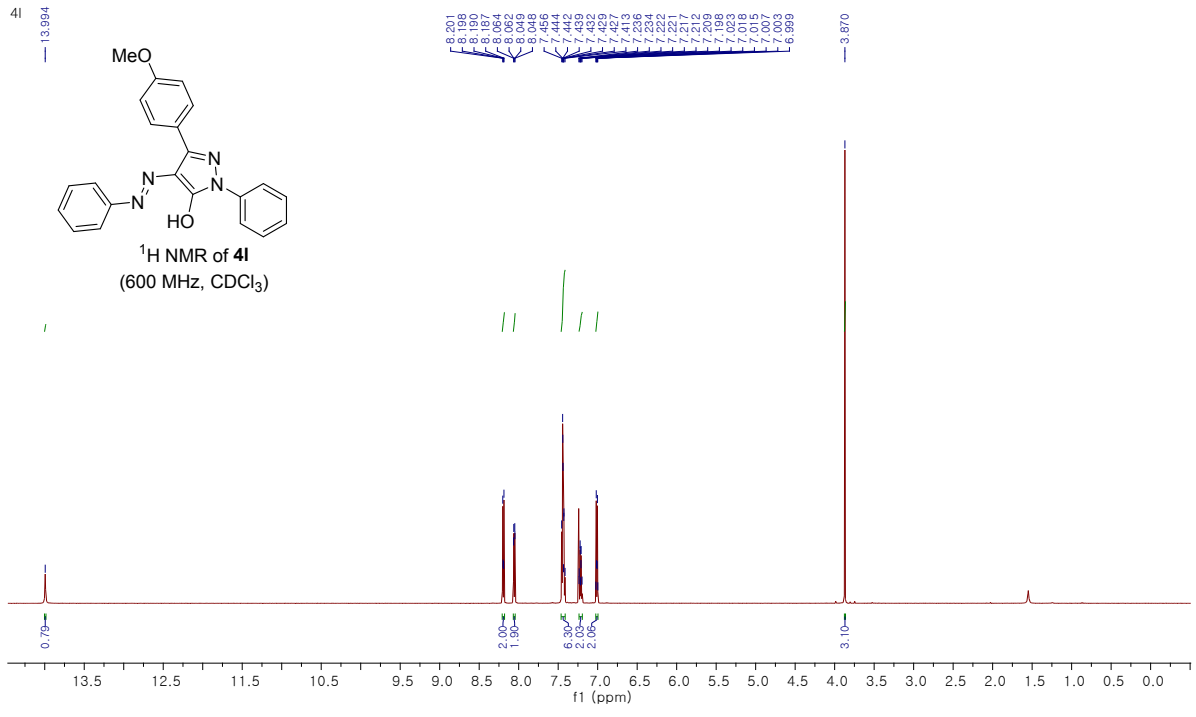
^{13}C NMR of **4j**
(150 MHz, $CDCl_3$)



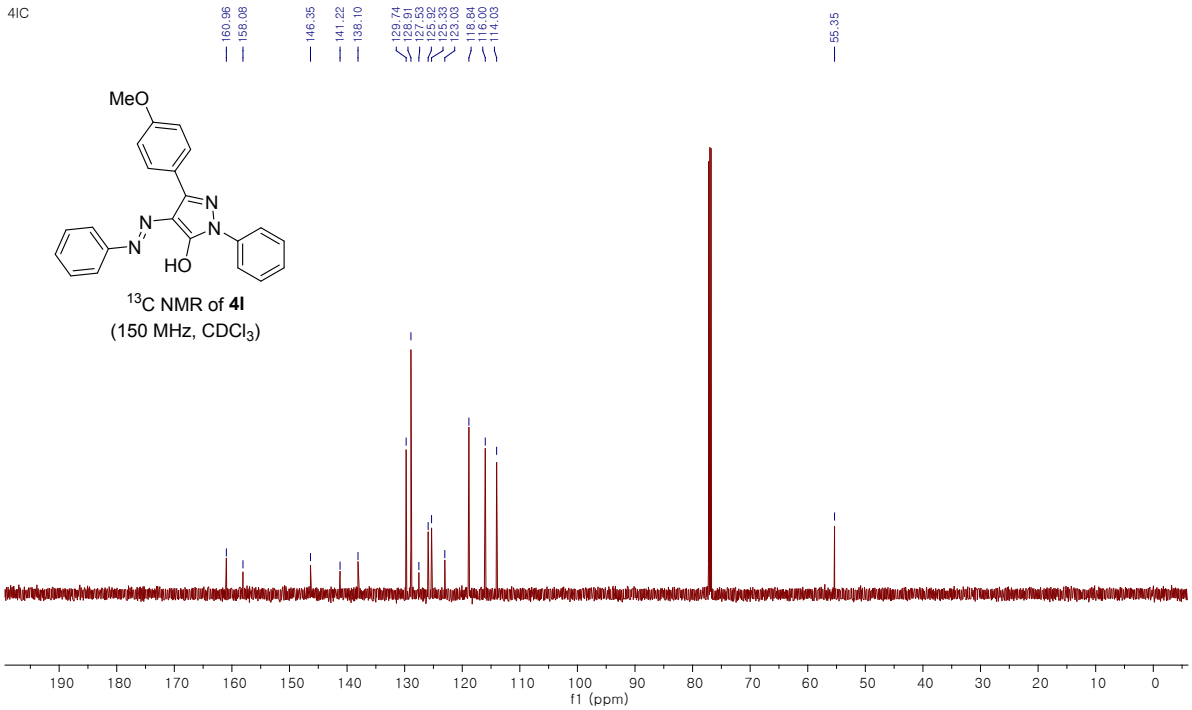
^{1}H NMR of **4k**
(600 MHz, $CDCl_3$)



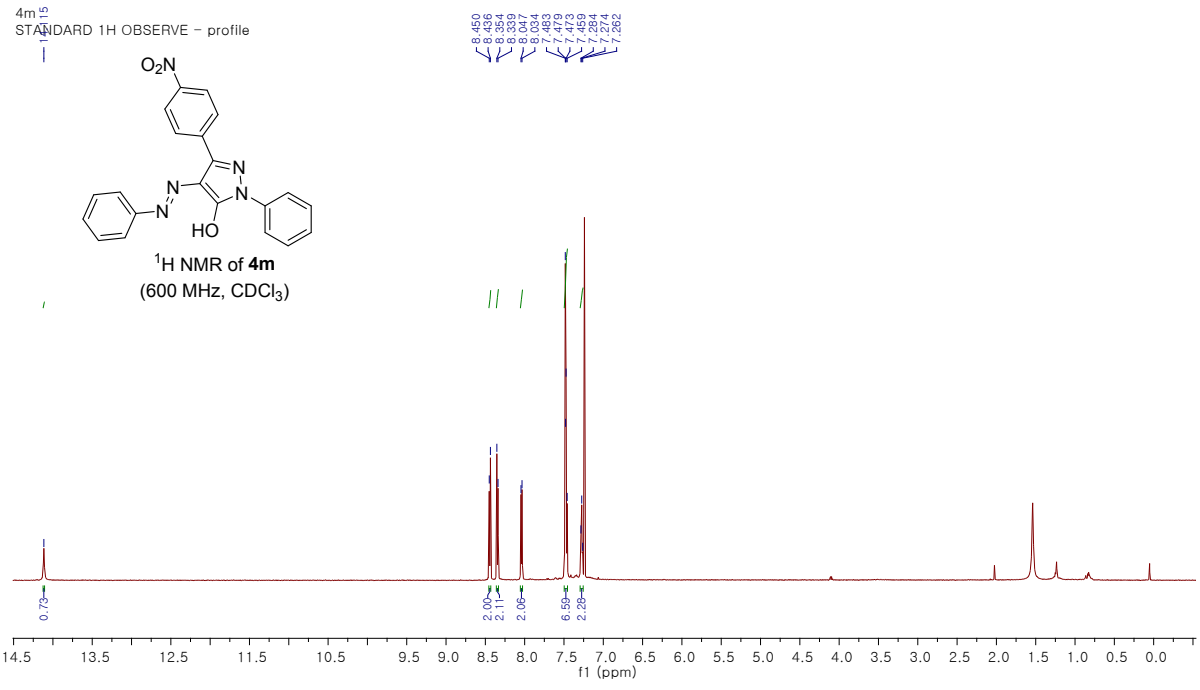
^{13}C NMR of **4k**
(150 MHz, $CDCl_3$)



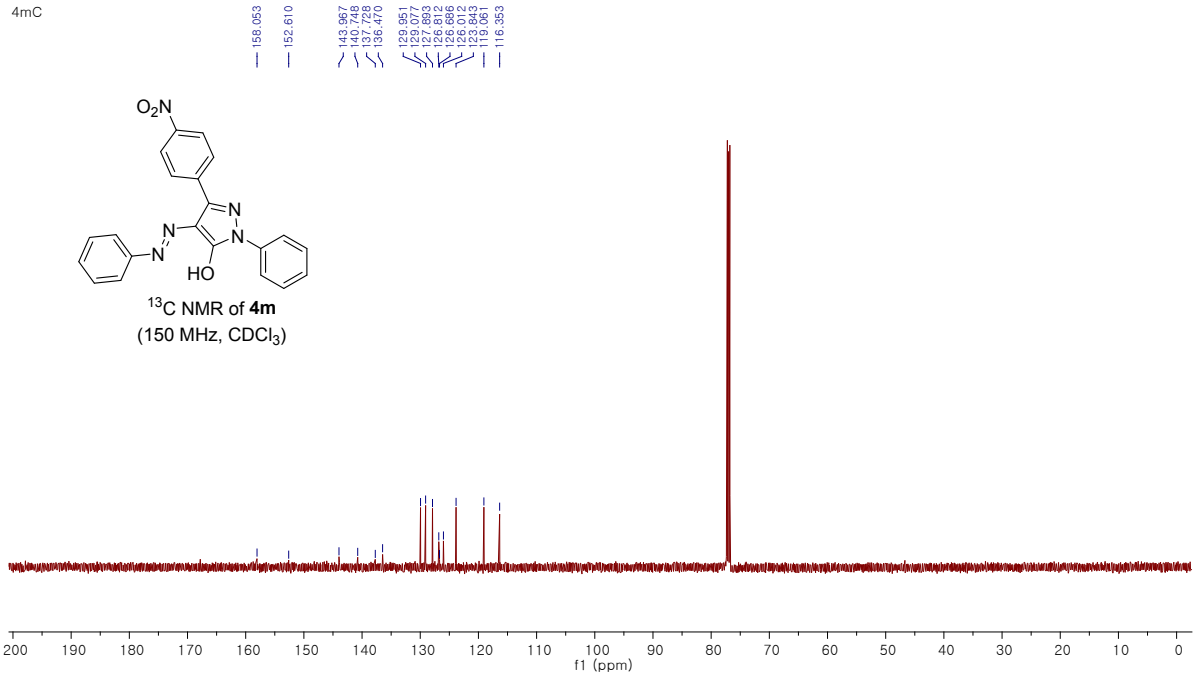
^{1}H NMR of **4l**
(600 MHz, $CDCl_3$)



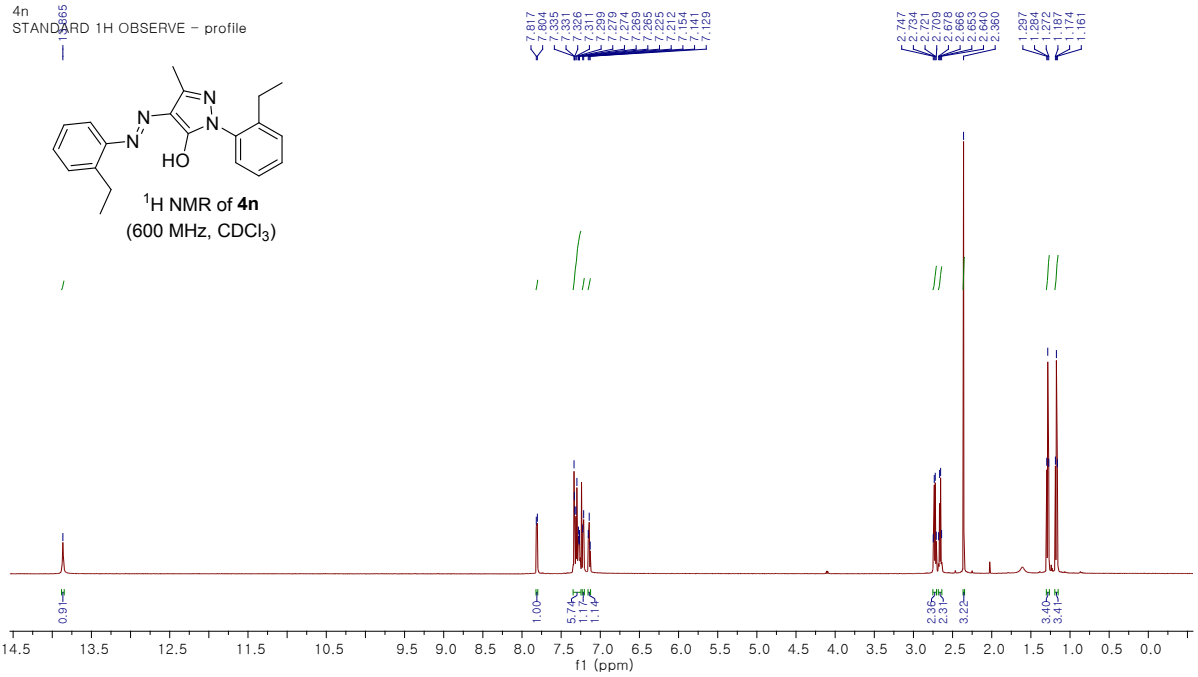
^{13}C NMR of **4l**
(150 MHz, $CDCl_3$)



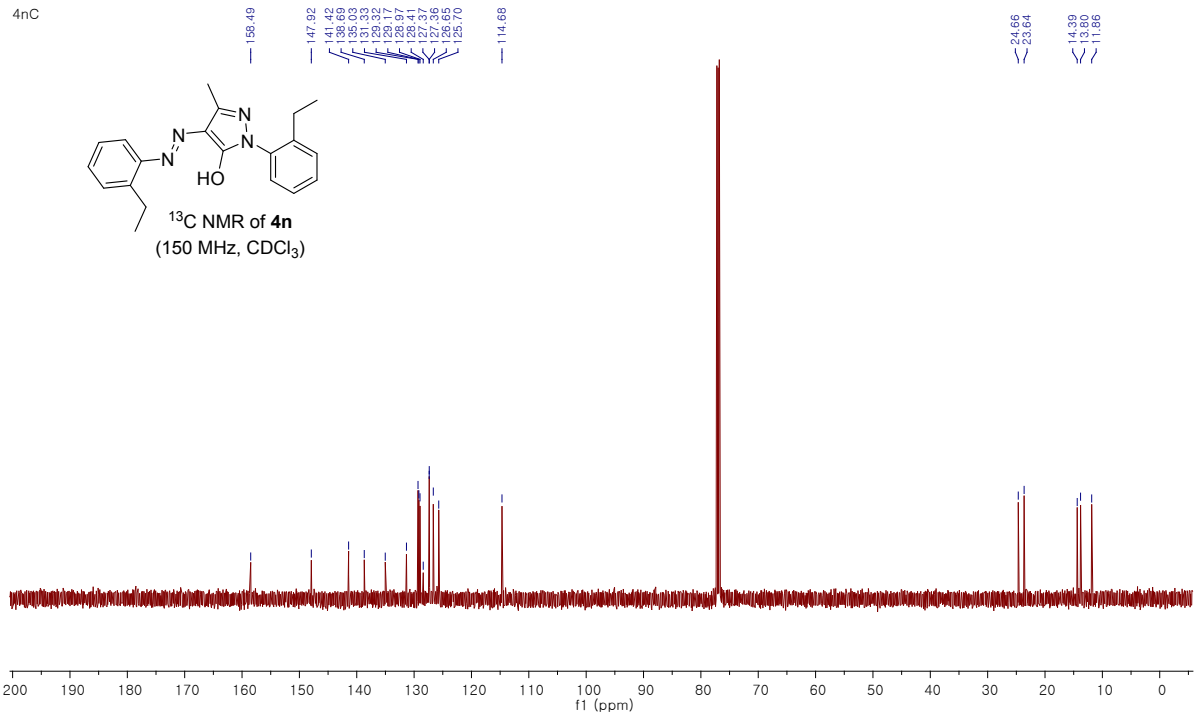
^{1}H NMR of **4m**
(600 MHz, $CDCl_3$)



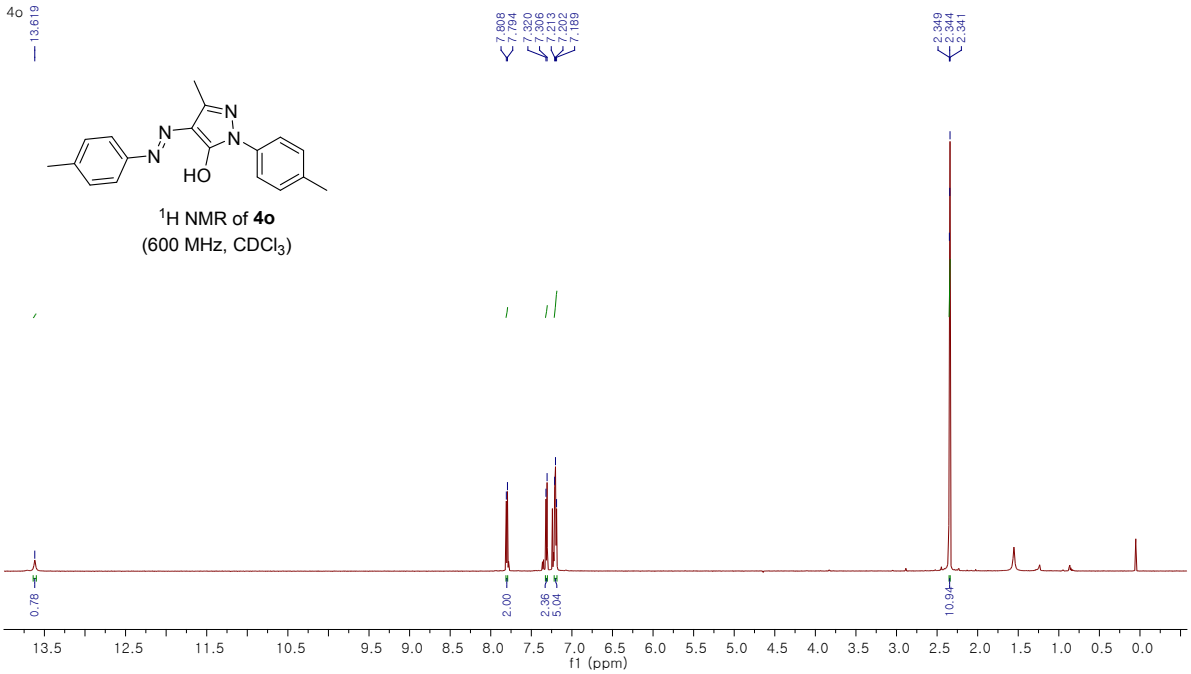
^{13}C NMR of **4m**
(150 MHz, $CDCl_3$)



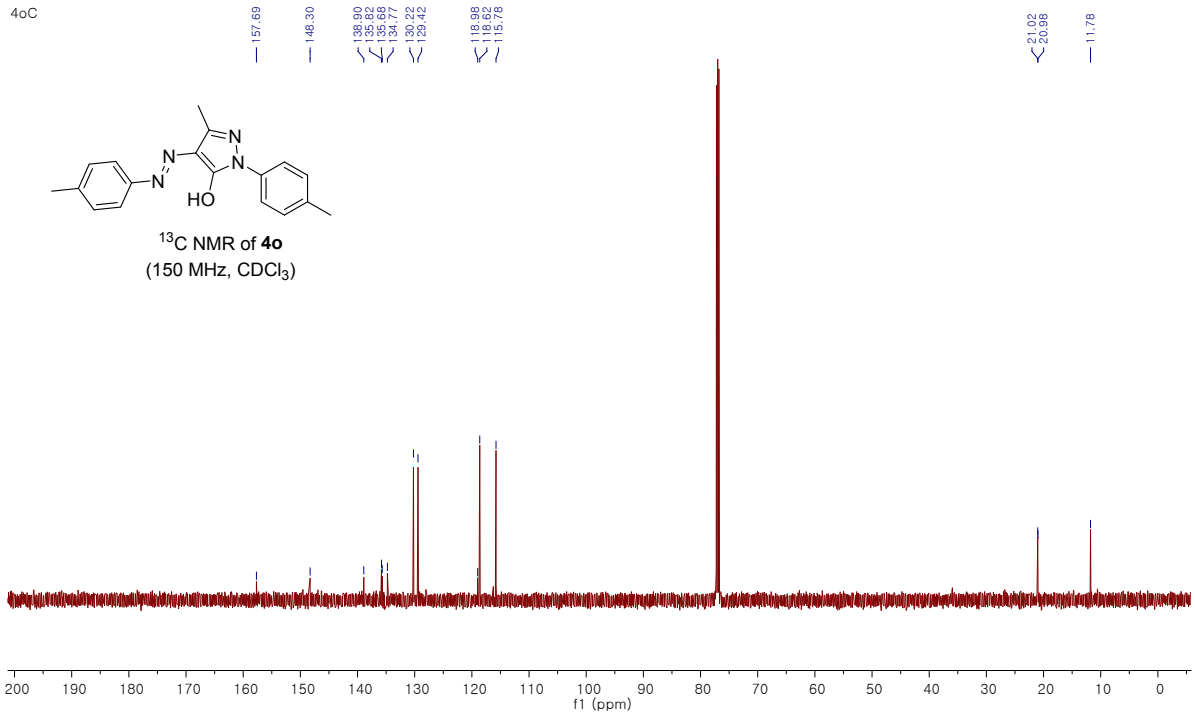
^{1}H NMR of **4n**
(600 MHz, $CDCl_3$)



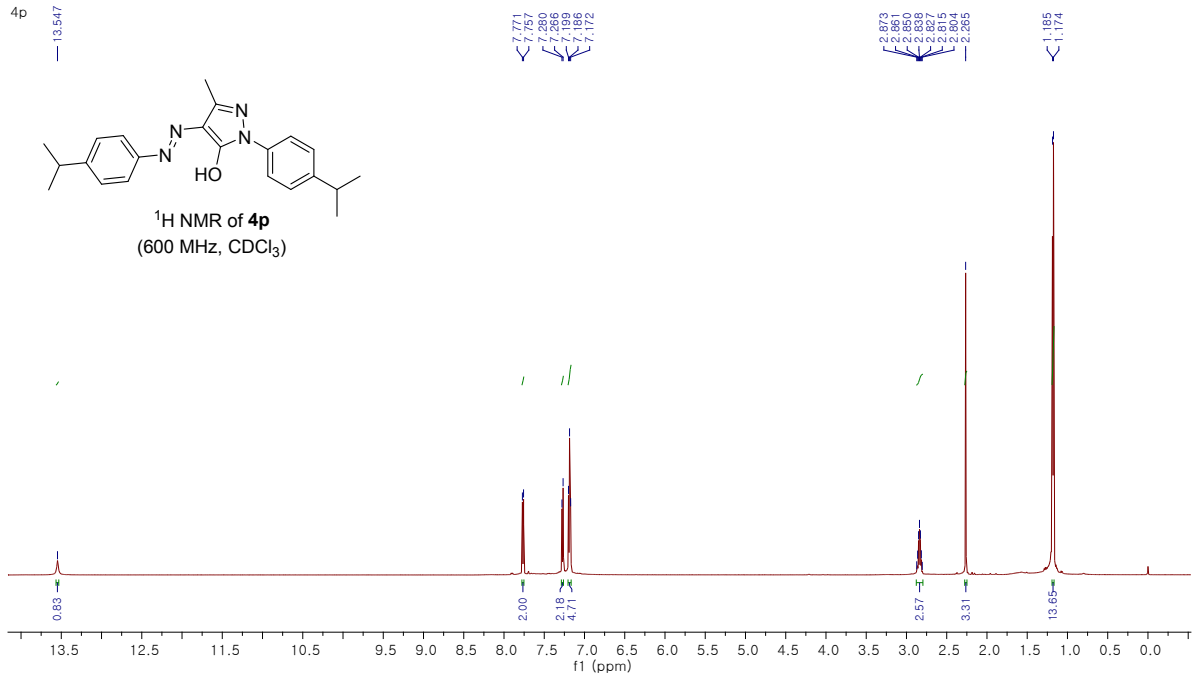
^{13}C NMR of **4n**
(150 MHz, $CDCl_3$)



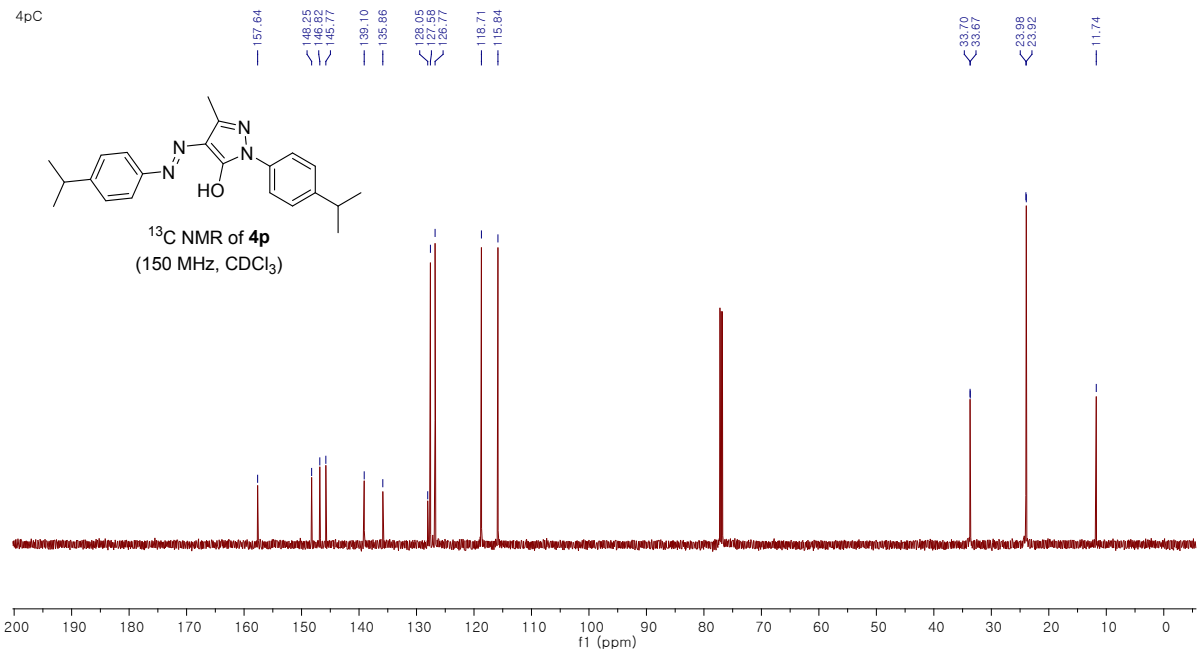
^{1}H NMR of **4o**
(600 MHz, $CDCl_3$)



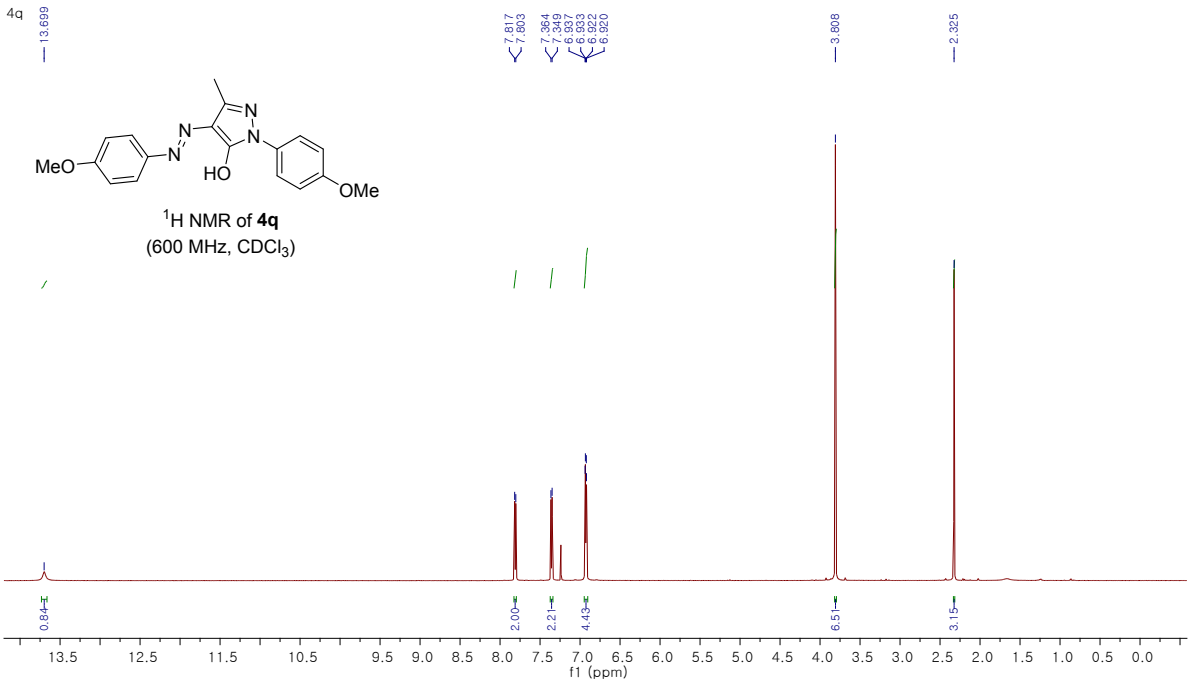
^{13}C NMR of **4o**
(150 MHz, $CDCl_3$)



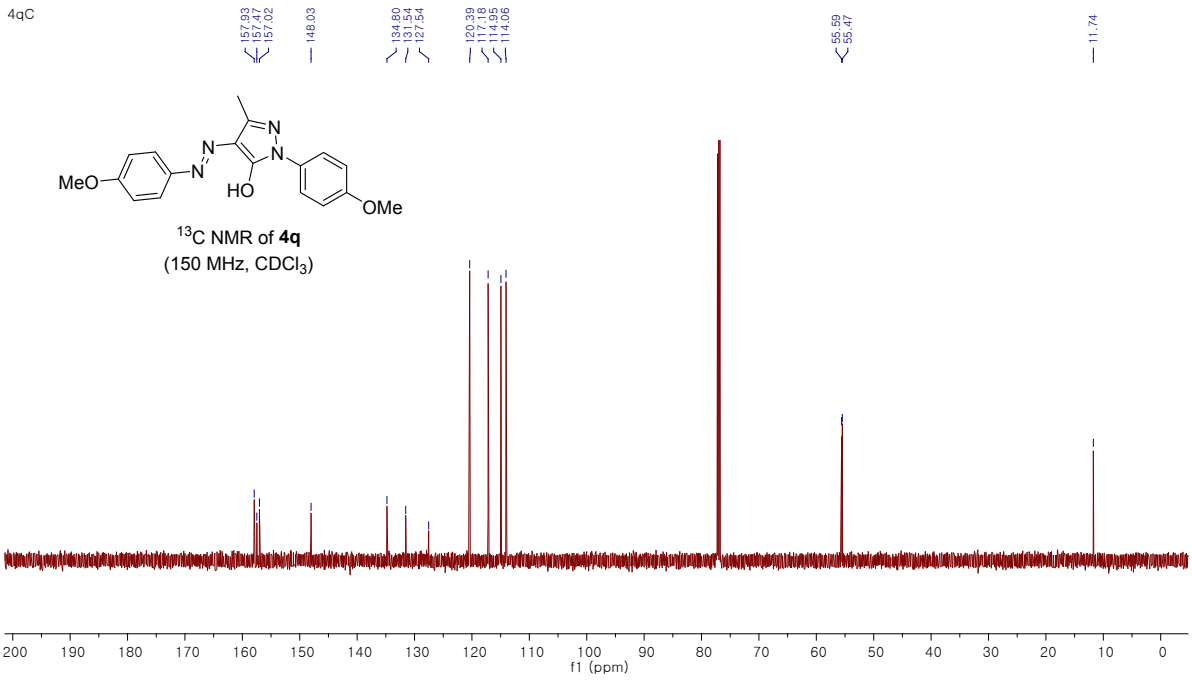
^{1}H NMR of **4p**
(600 MHz, $CDCl_3$)



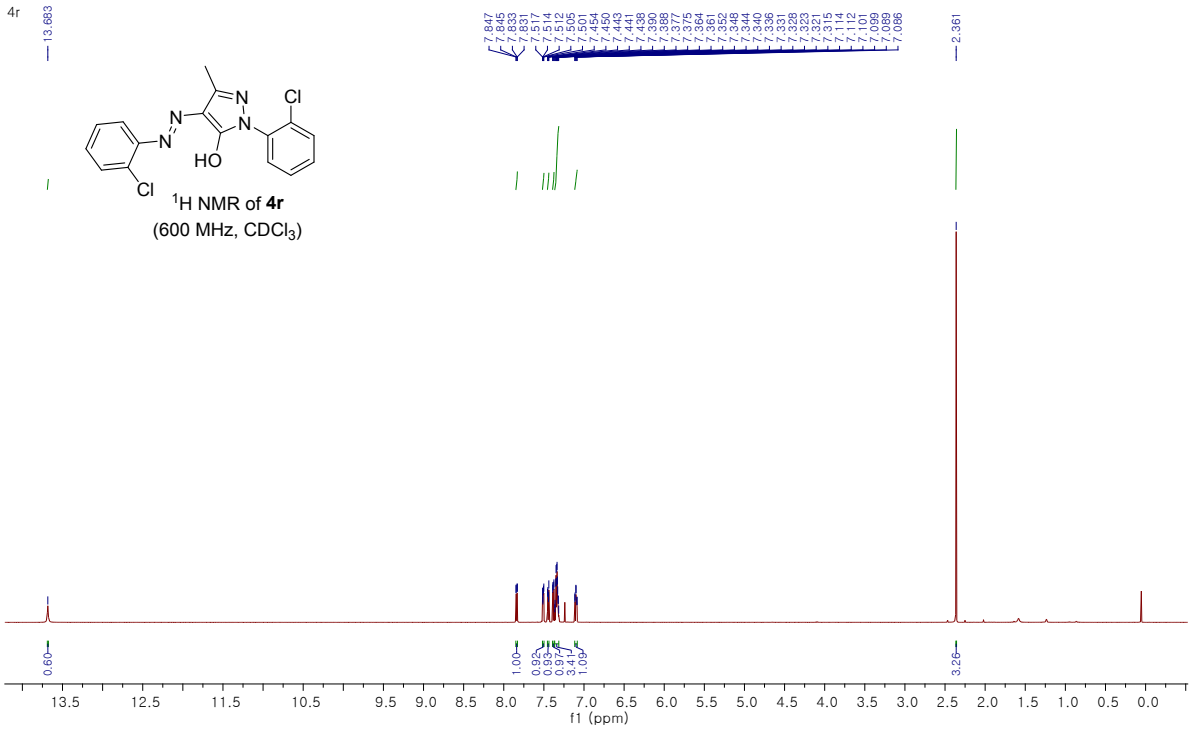
^{13}C NMR of **4p**
(150 MHz, $CDCl_3$)



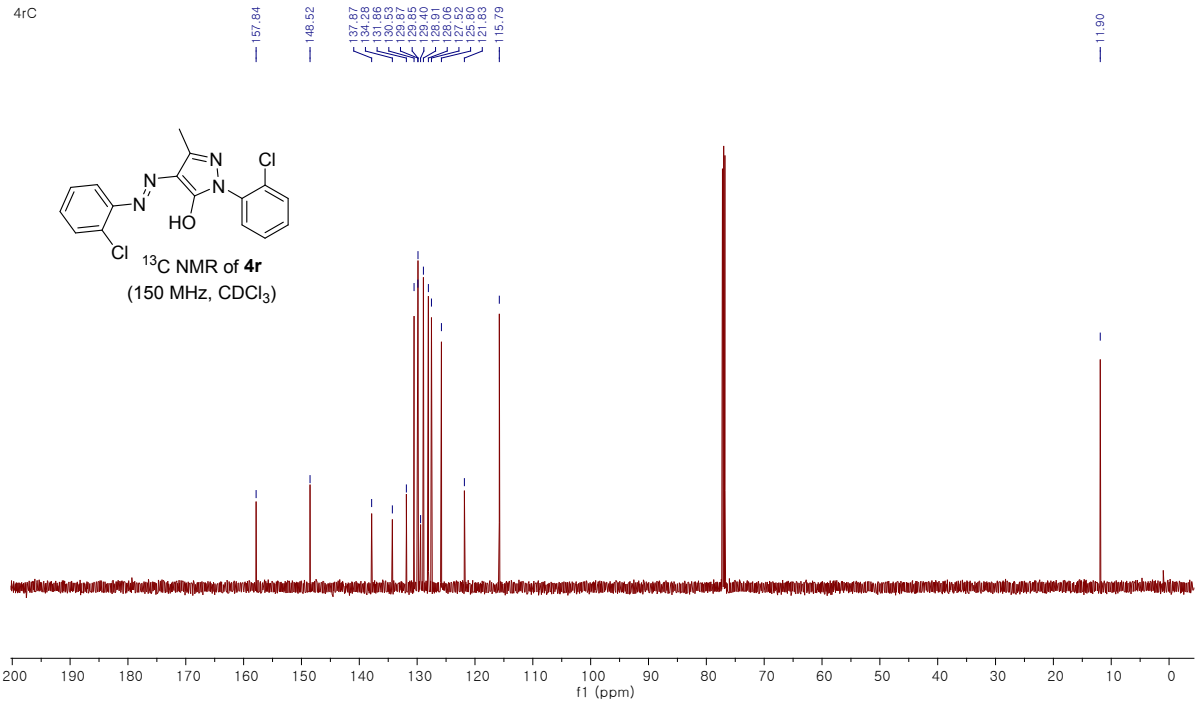
^{1}H NMR of **4q**
(600 MHz, $CDCl_3$)



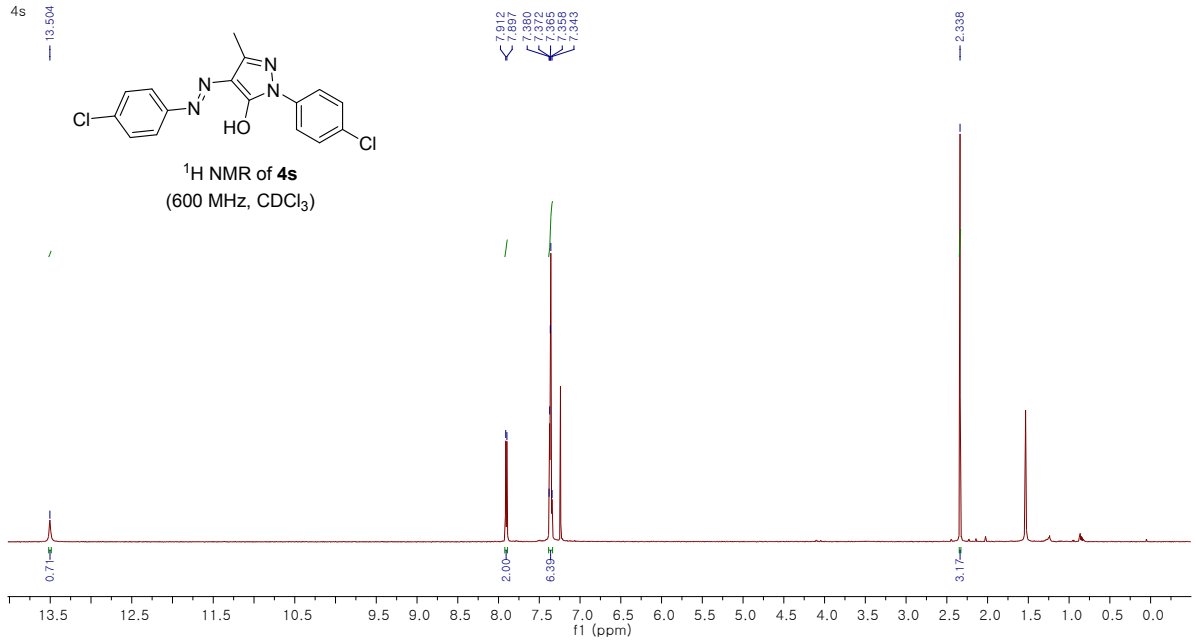
^{13}C NMR of **4q**
(150 MHz, $CDCl_3$)



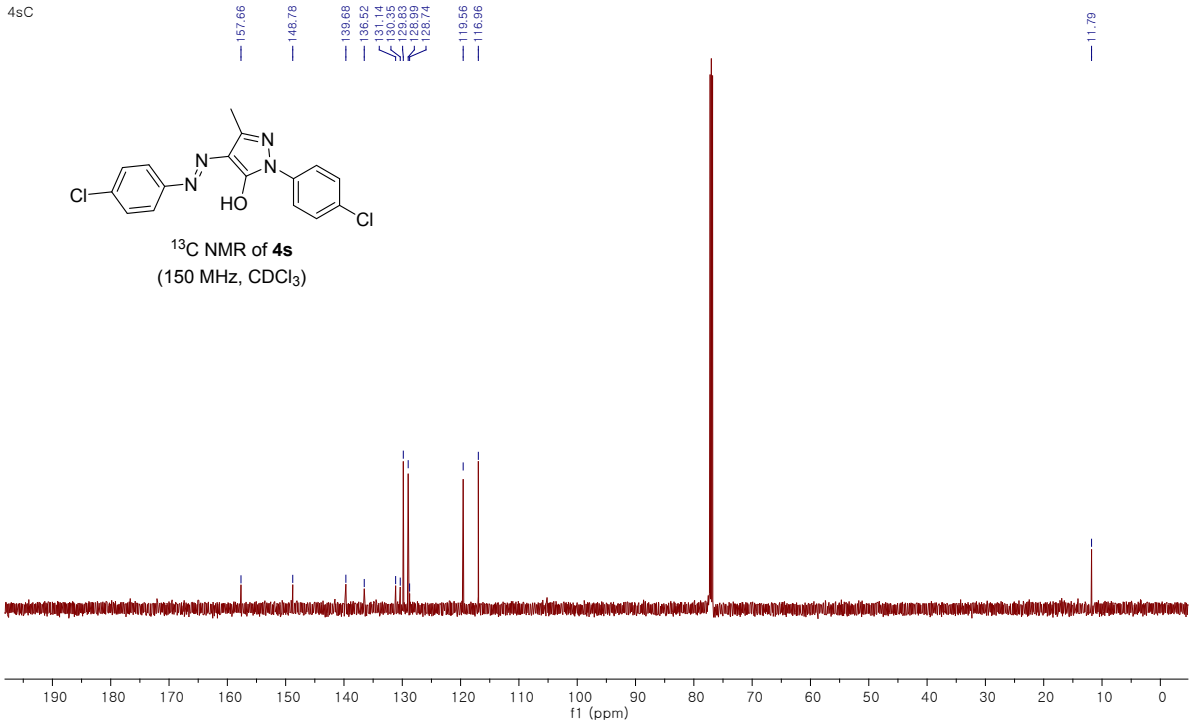
^{1}H NMR of **4r**
(600 MHz, $CDCl_3$)



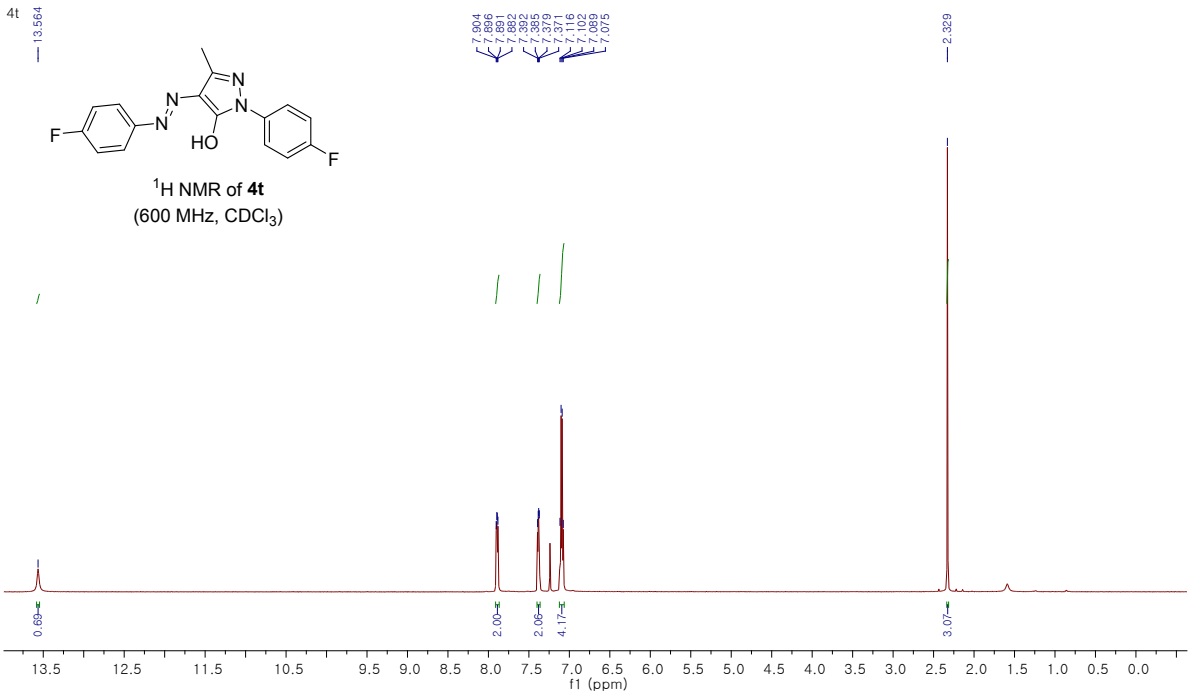
^{13}C NMR of **4r**
(150 MHz, $CDCl_3$)



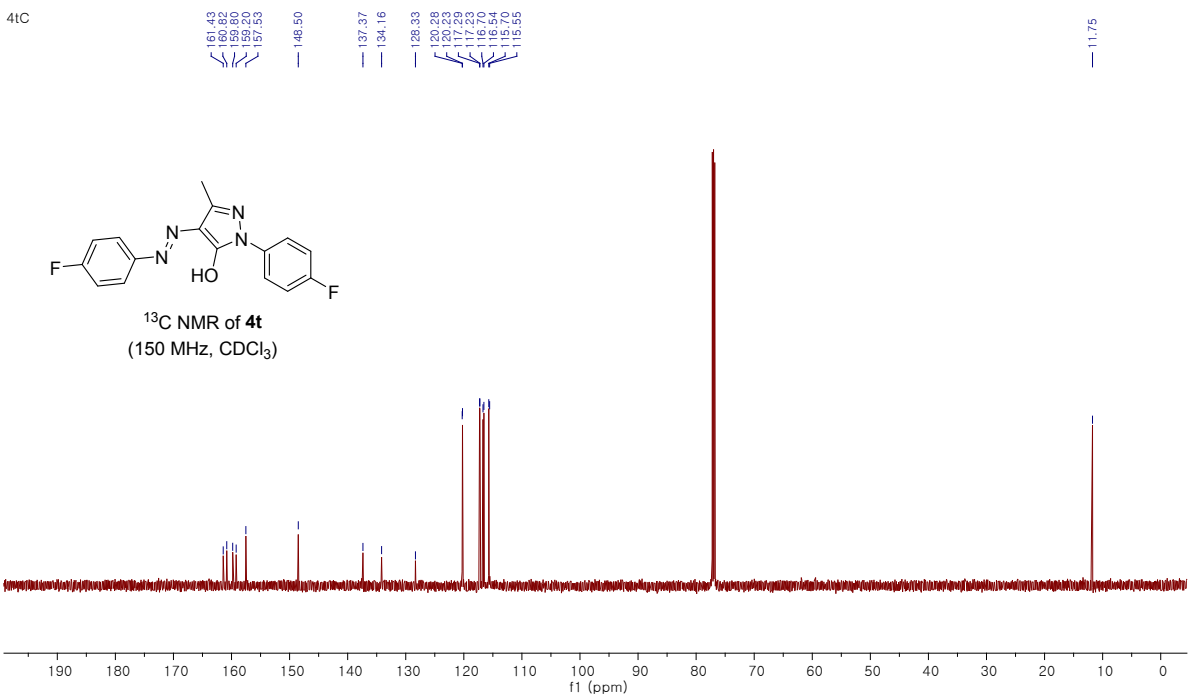
^{1}H NMR of **4s**
(600 MHz, $CDCl_3$)



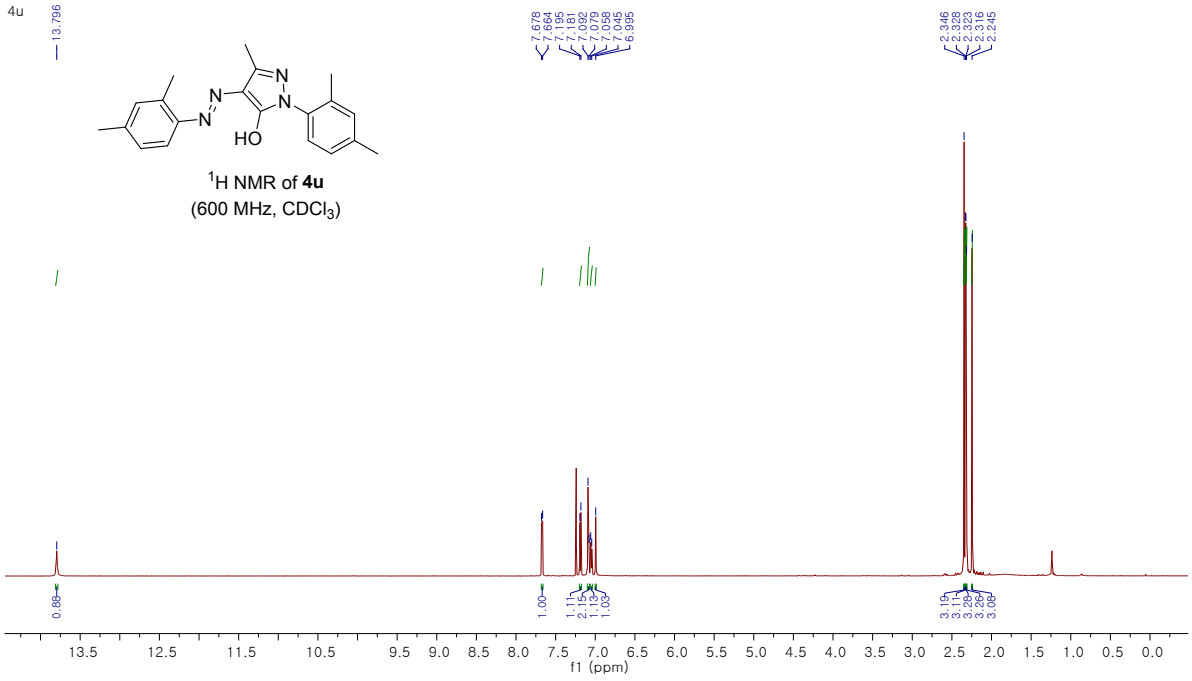
^{13}C NMR of **4s**
(150 MHz, $CDCl_3$)



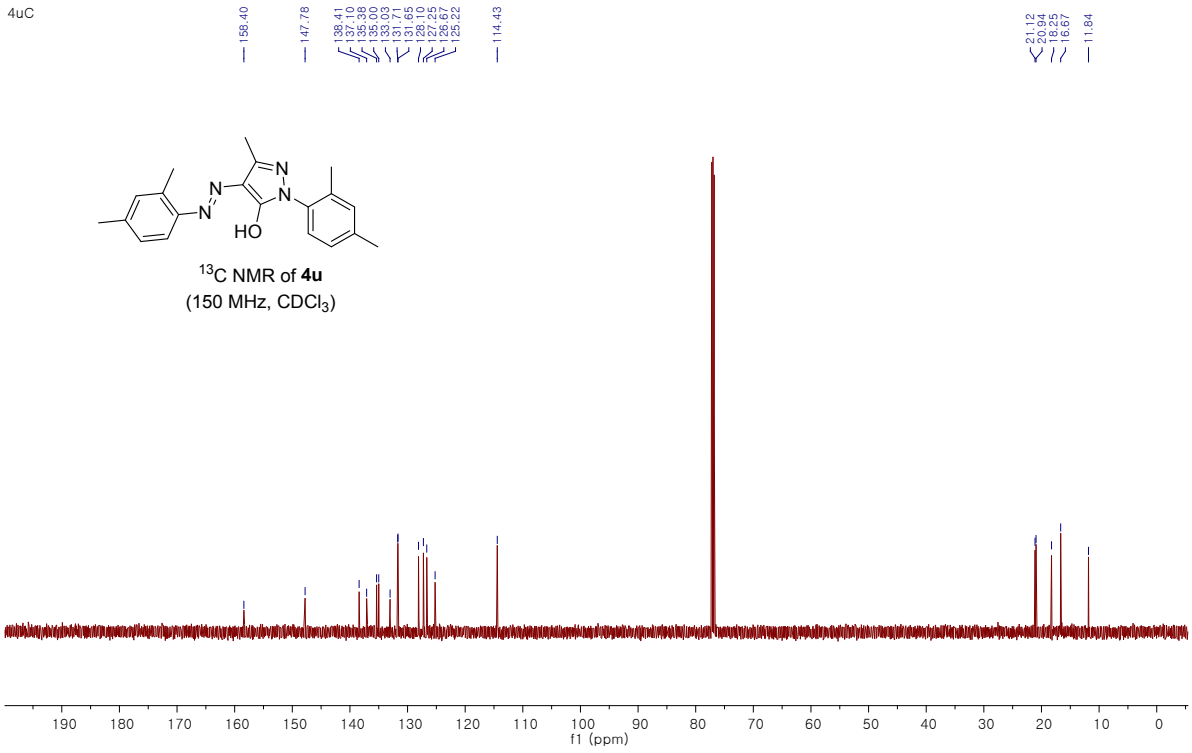
^{1}H NMR of **4t**
(600 MHz, $CDCl_3$)



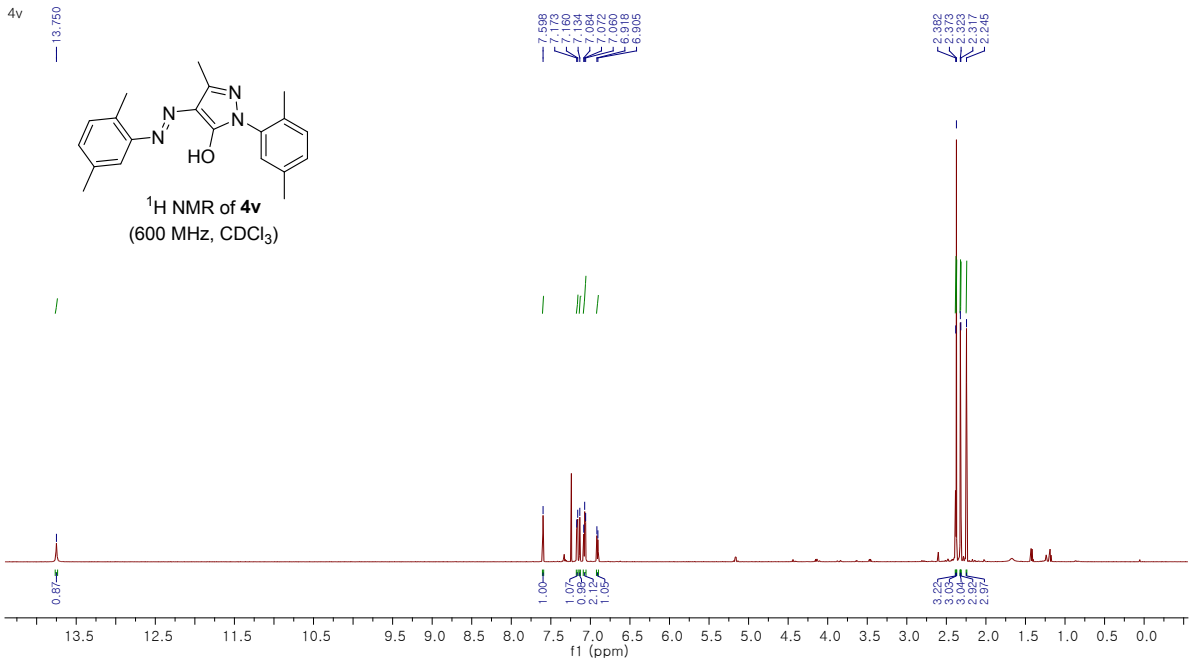
^{13}C NMR of **4t**
(150 MHz, $CDCl_3$)



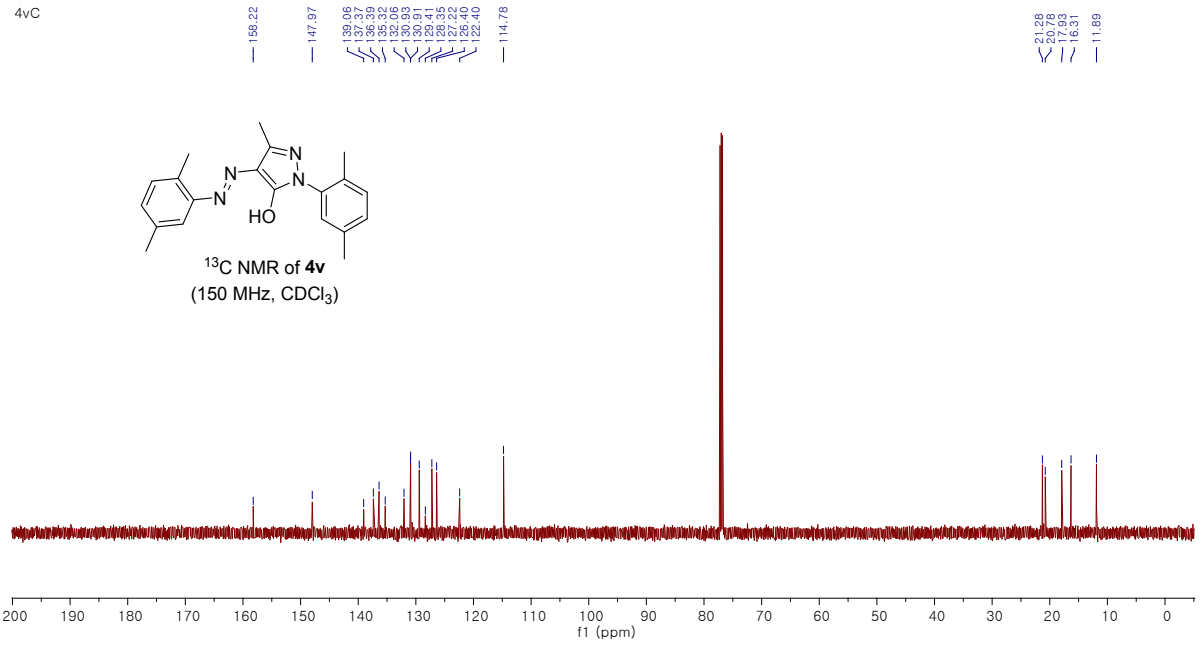
^{1}H NMR of **4u**
(600 MHz, $CDCl_3$)



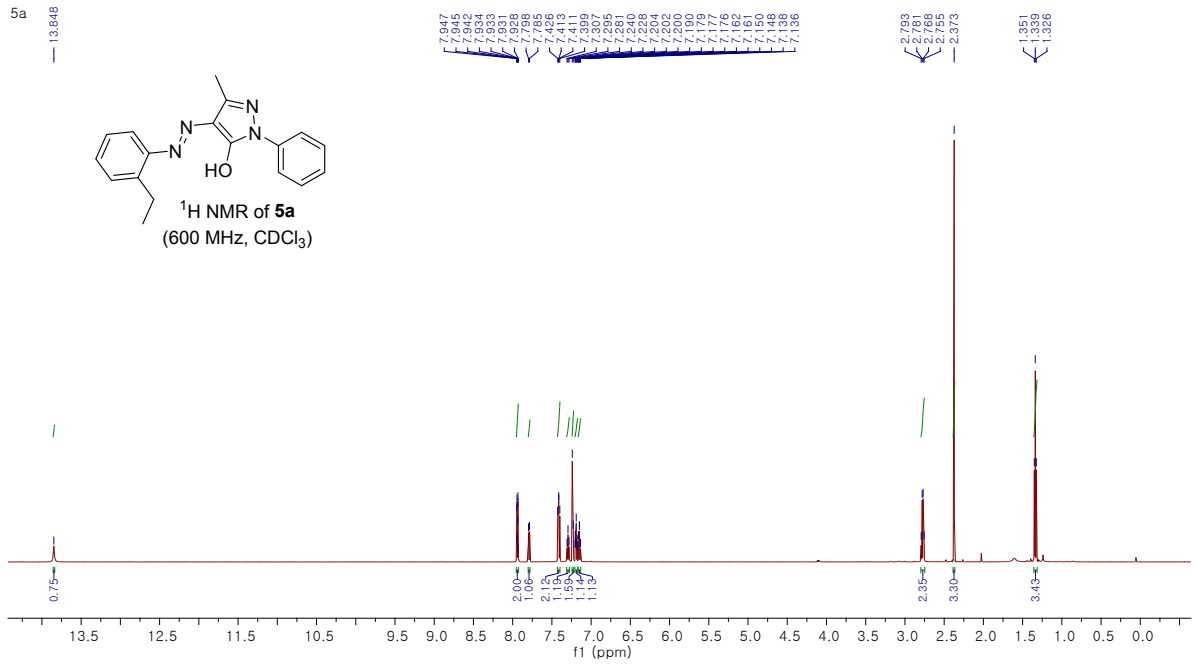
^{13}C NMR of **4u**
(150 MHz, $CDCl_3$)



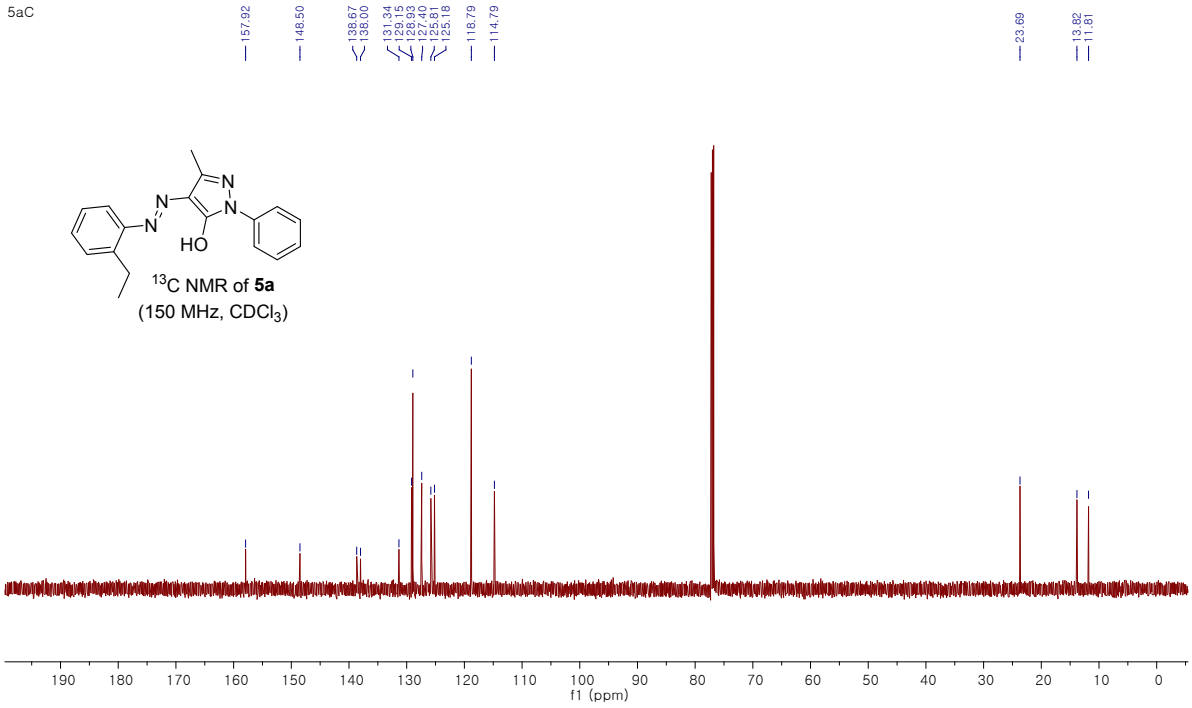
^{1}H NMR of **4v**
(600 MHz, $CDCl_3$)



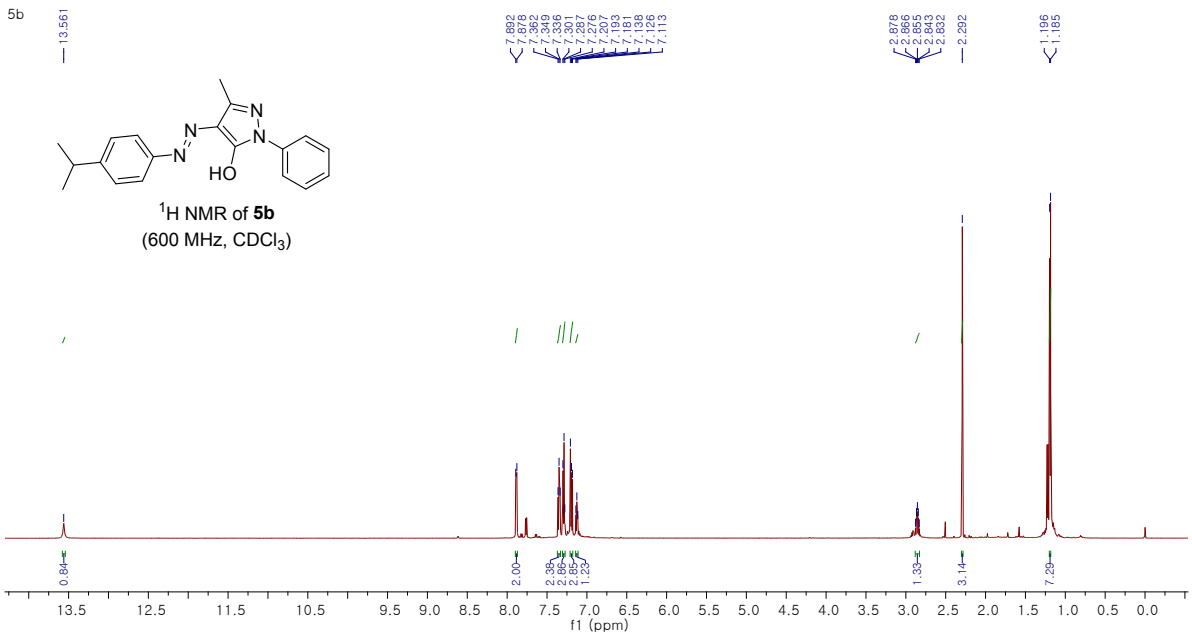
^{13}C NMR of **4v**
(150 MHz, $CDCl_3$)



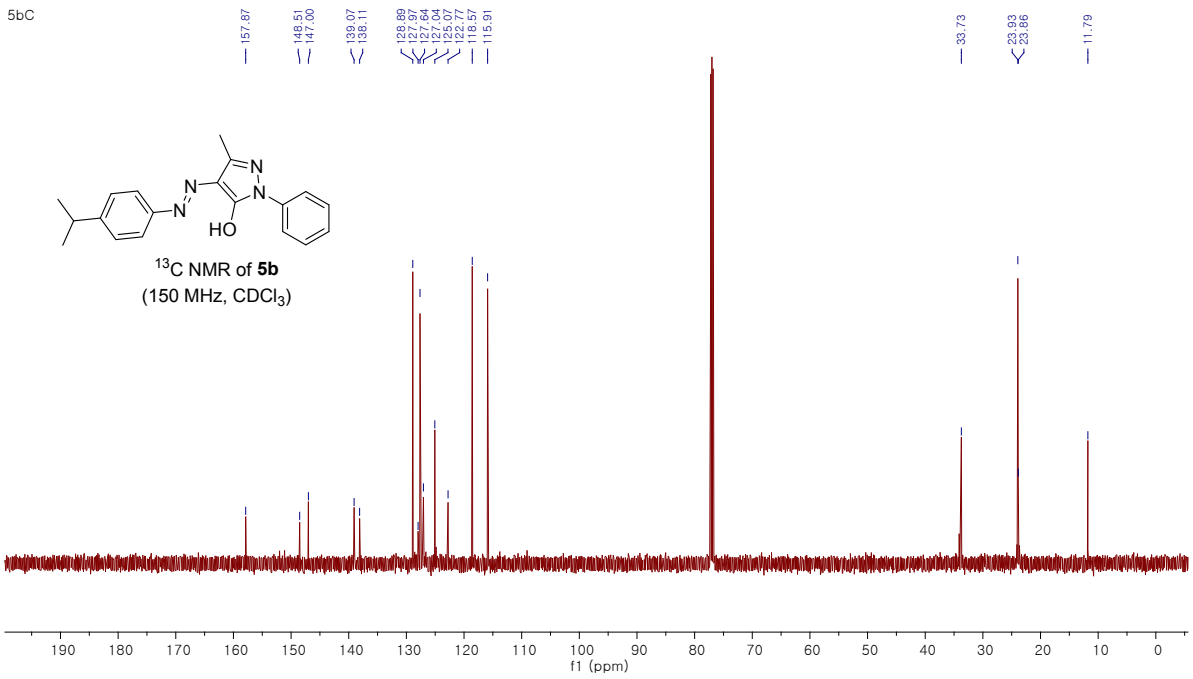
^{1}H NMR of **5a**
(600 MHz, $CDCl_3$)



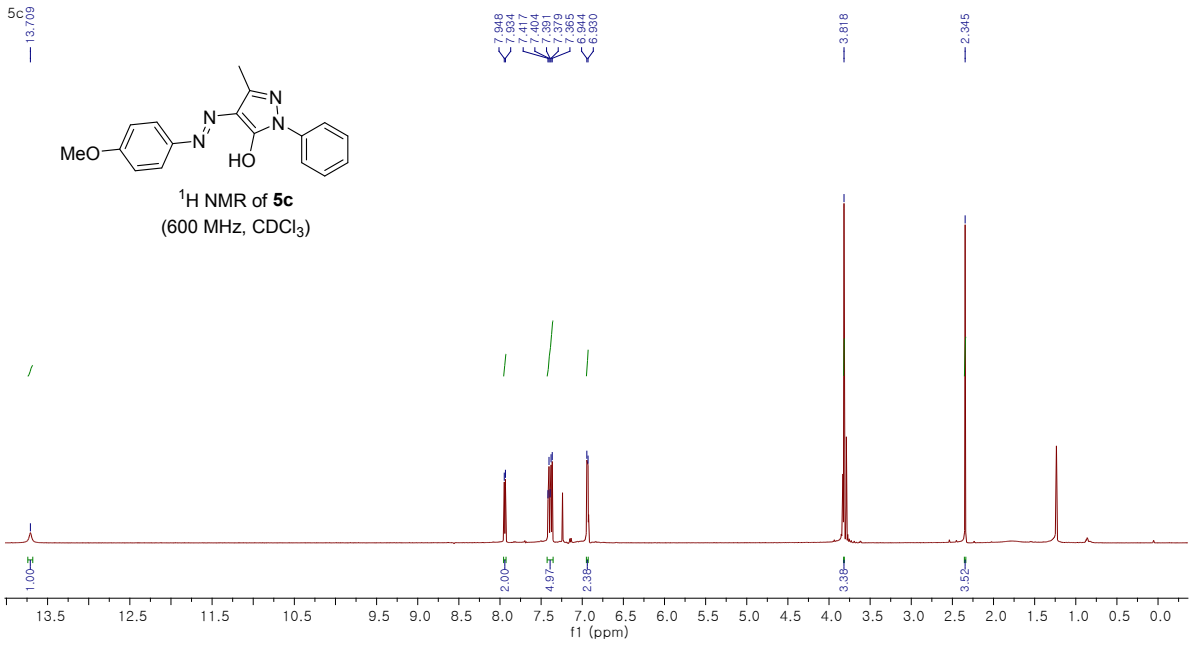
^{13}C NMR of **5a**
(150 MHz, $CDCl_3$)



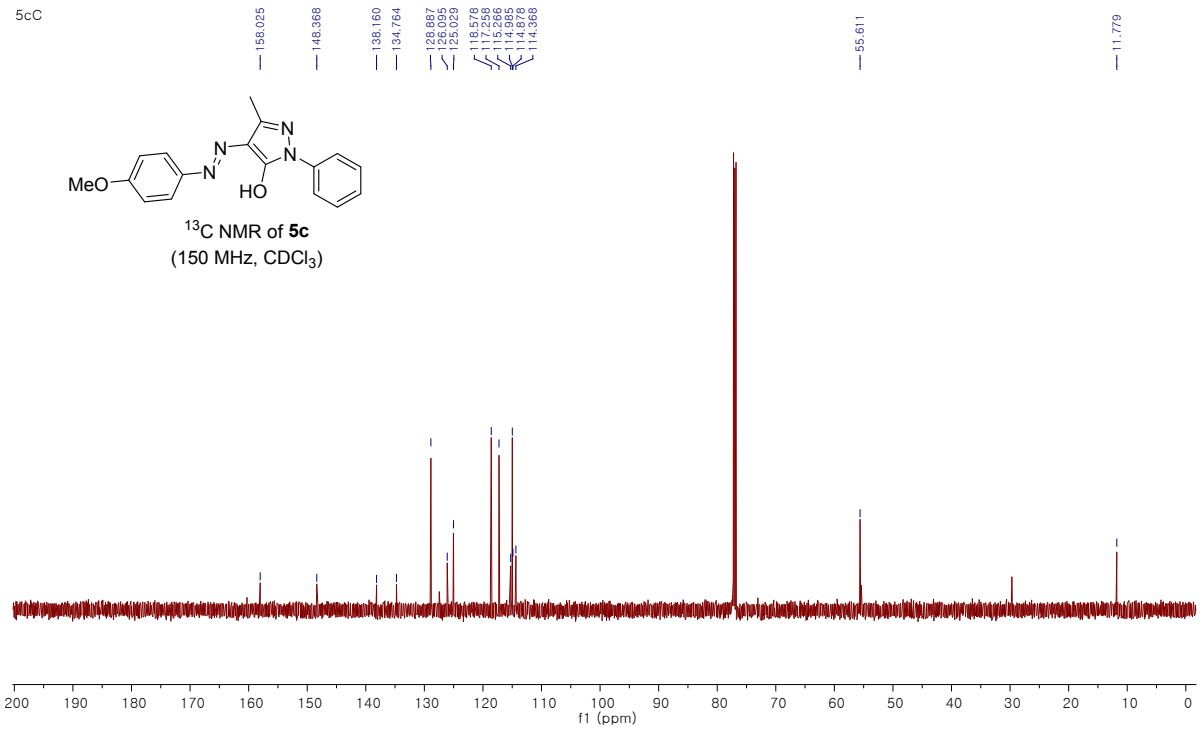
^{1}H NMR of **5b**
(600 MHz, $CDCl_3$)



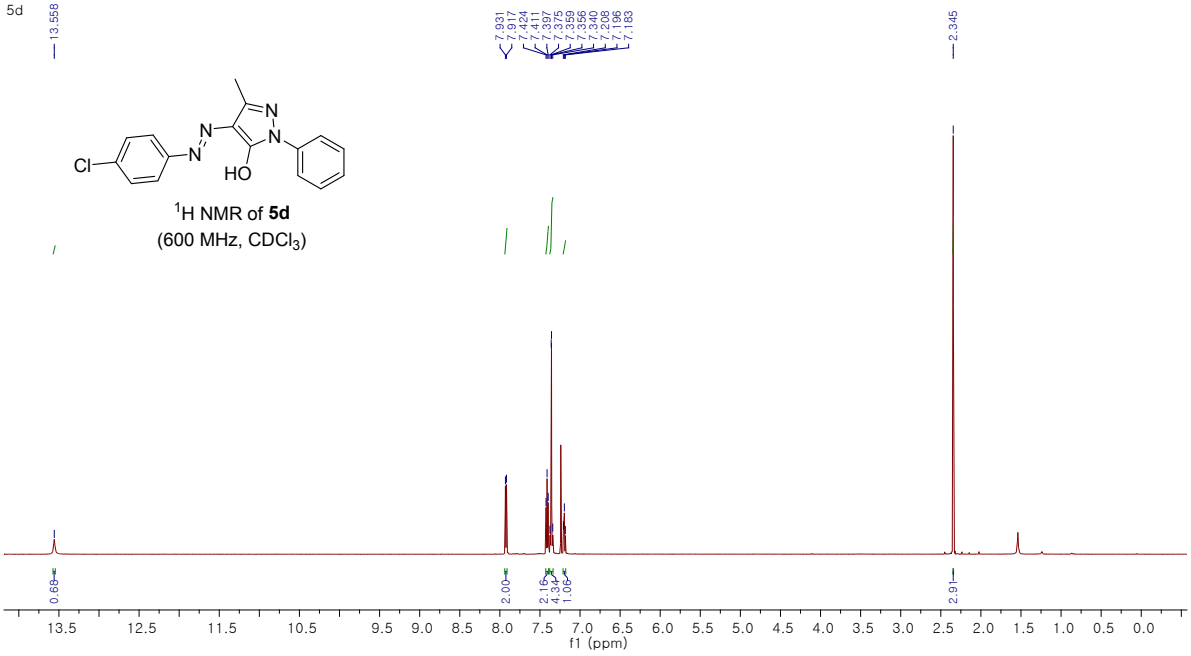
^{13}C NMR of **5b**
(150 MHz, $CDCl_3$)



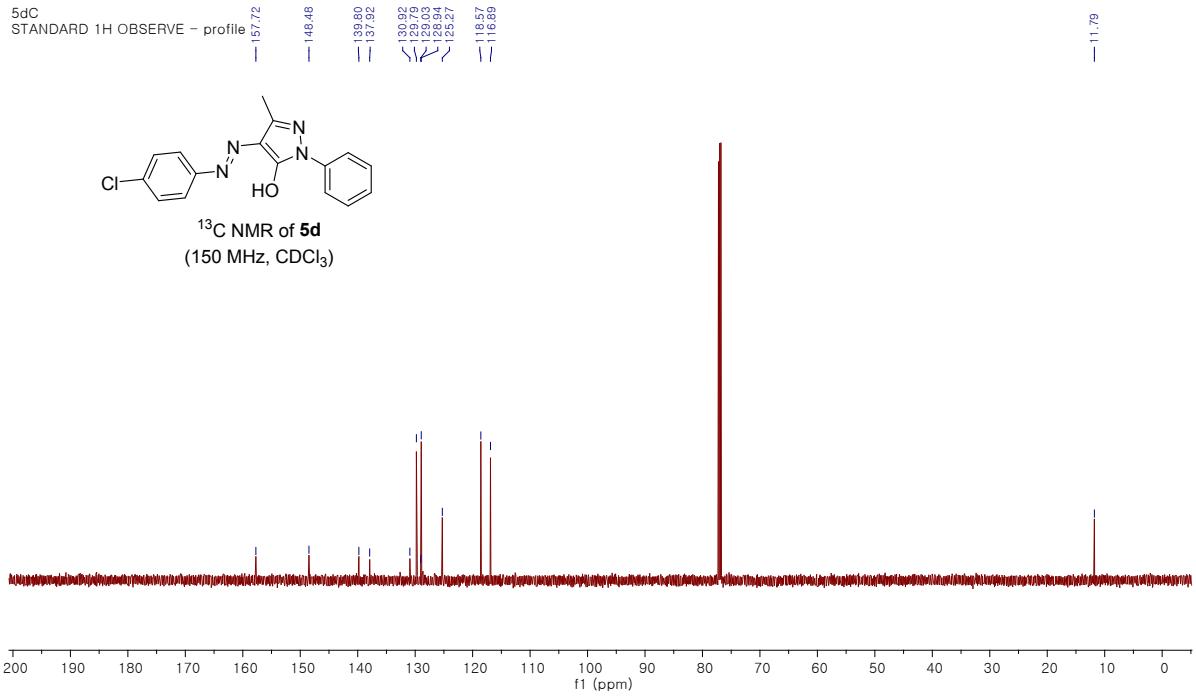
^{1}H NMR of **5c**
(600 MHz, $CDCl_3$)



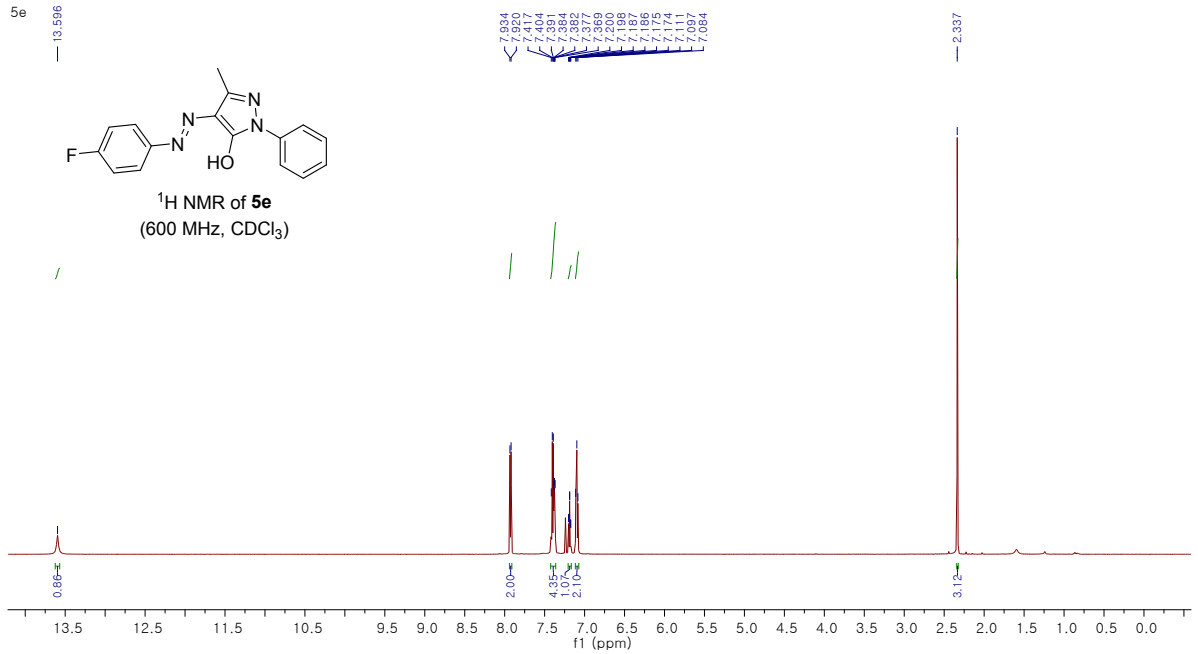
^{13}C NMR of **5c**
(150 MHz, $CDCl_3$)



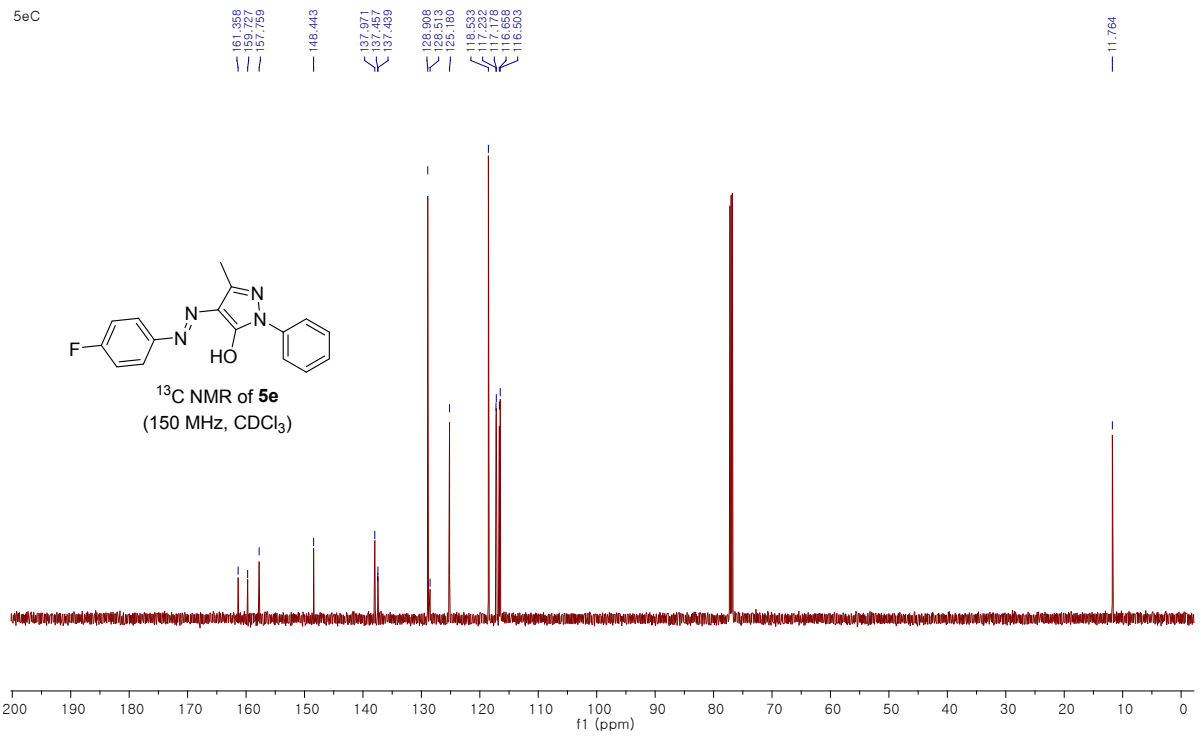
^{1}H NMR of **5d**
(600 MHz, $CDCl_3$)



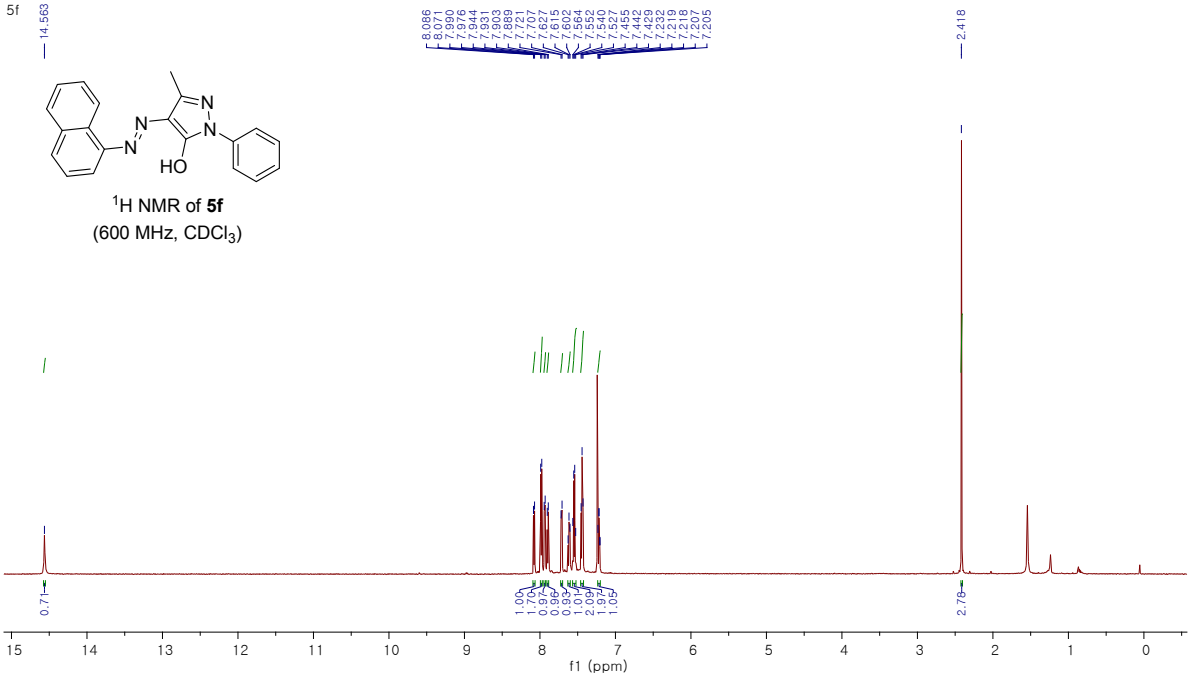
^{13}C NMR of **5d**
(150 MHz, $CDCl_3$)



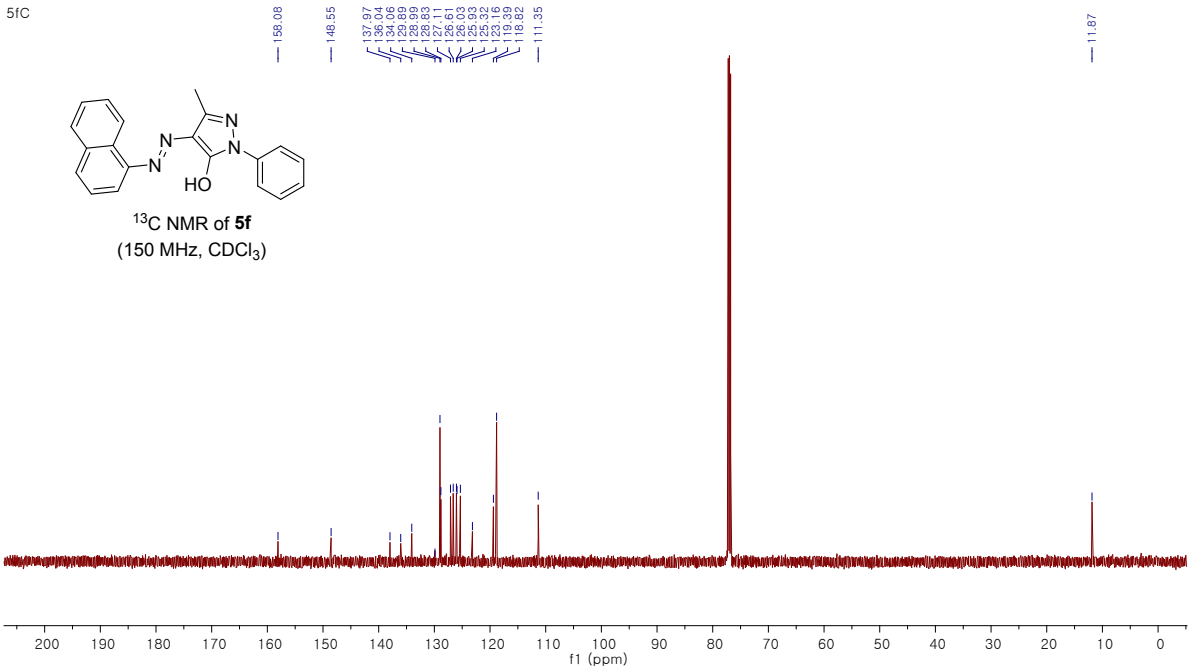
^{1}H NMR of **5e**
(600 MHz, $CDCl_3$)



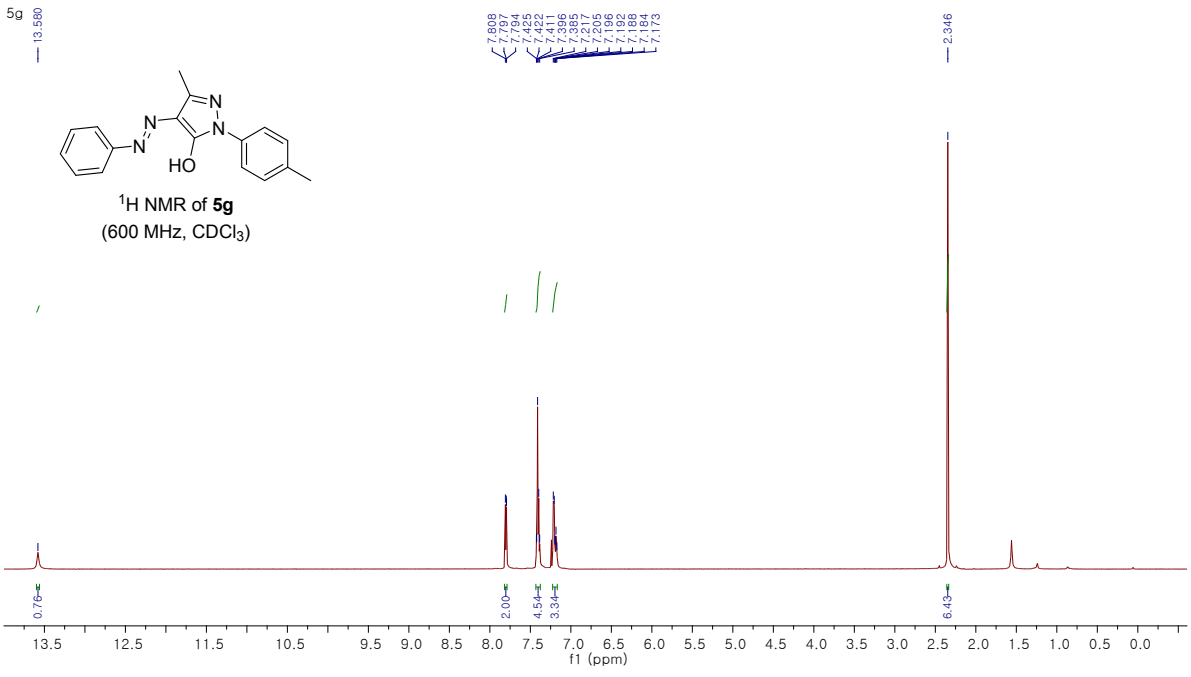
^{13}C NMR of **5e**
(150 MHz, $CDCl_3$)



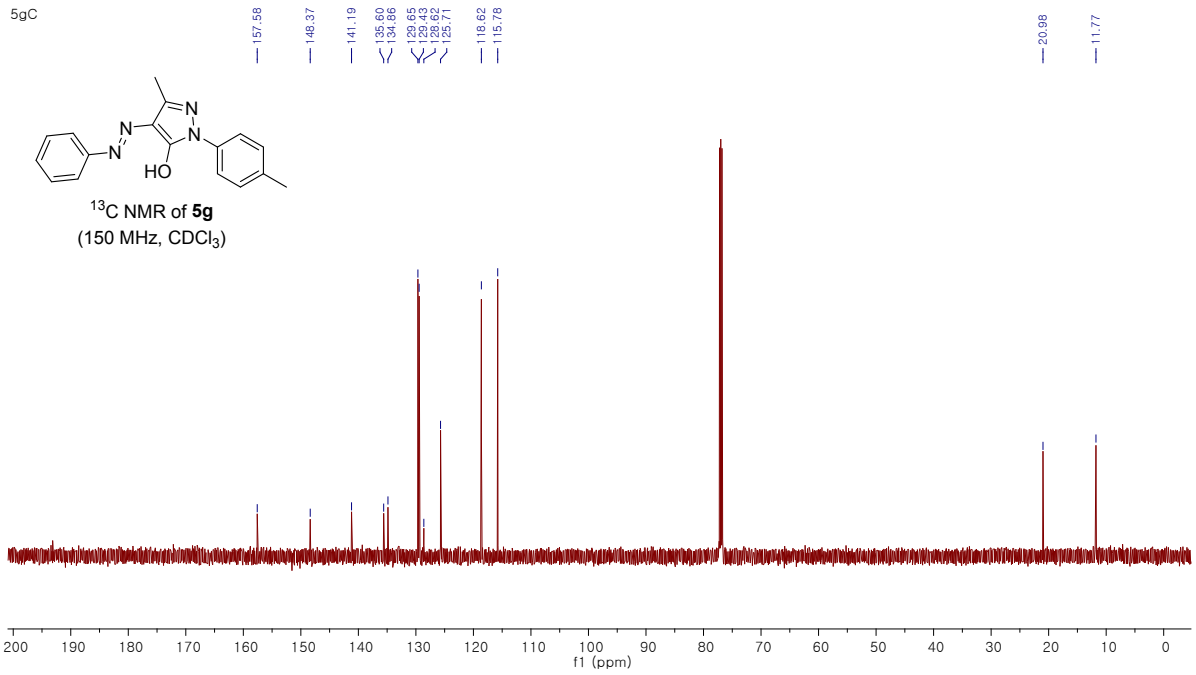
^{1}H NMR of **5f**
(600 MHz, $CDCl_3$)



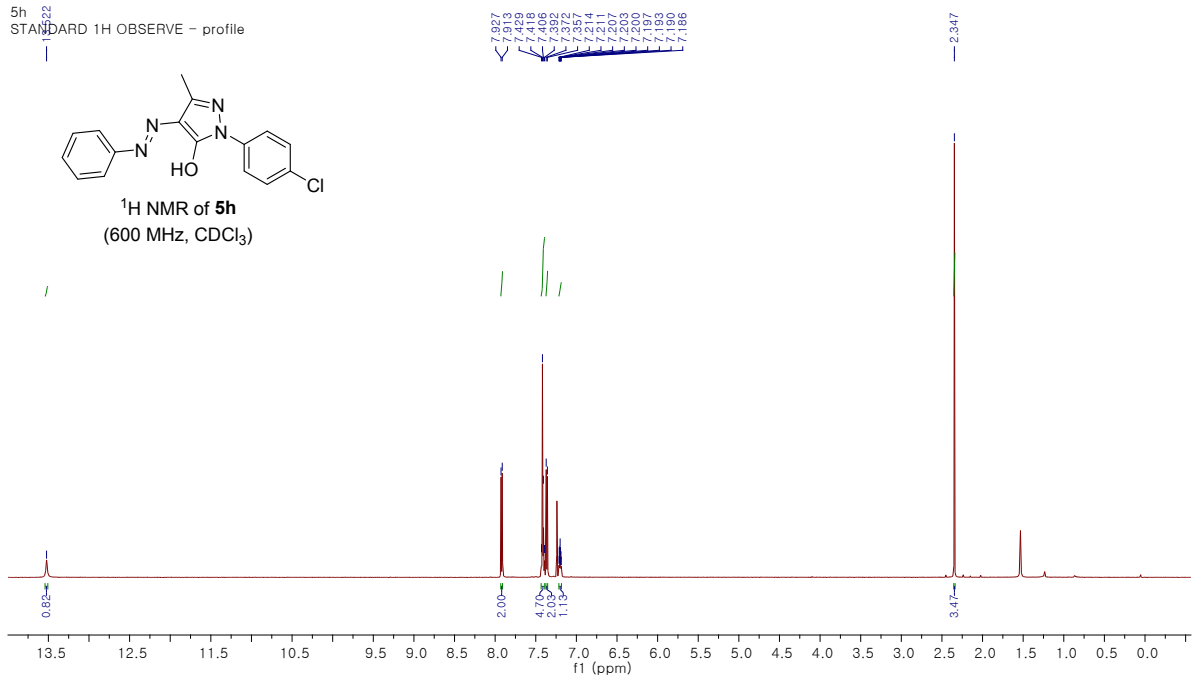
^{13}C NMR of **5f**
(150 MHz, $CDCl_3$)



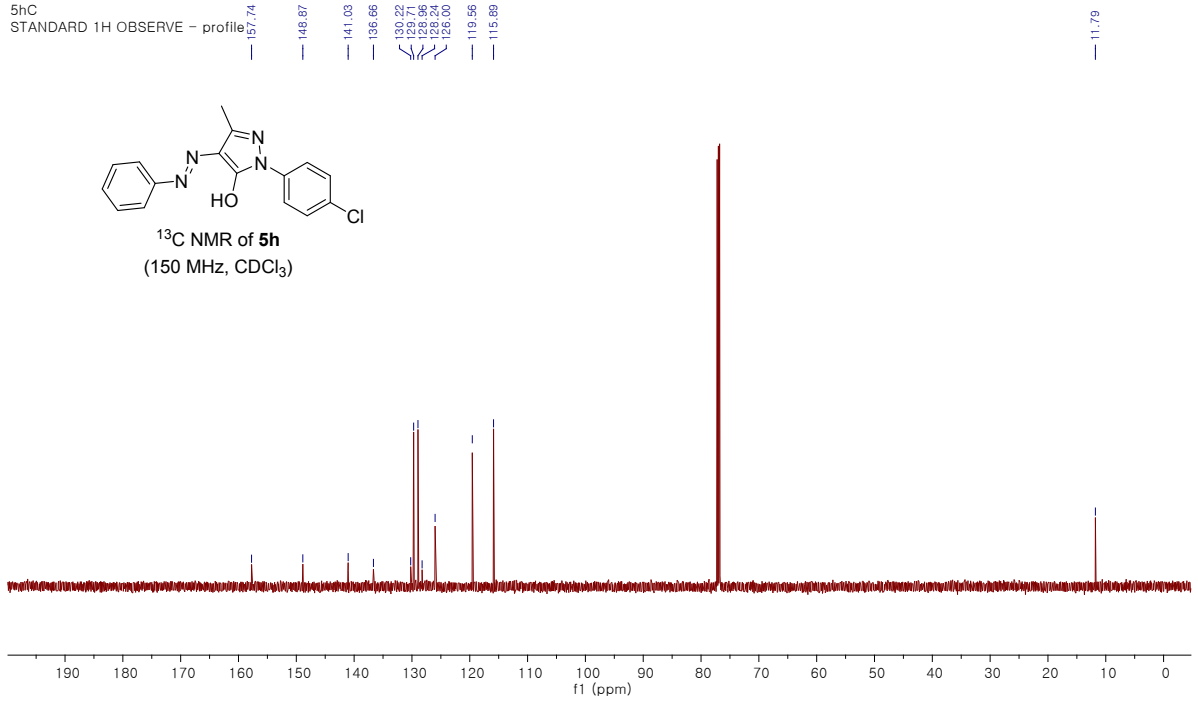
^{1}H NMR of **5g**
(600 MHz, $CDCl_3$)



^{13}C NMR of **5g**
(150 MHz, $CDCl_3$)

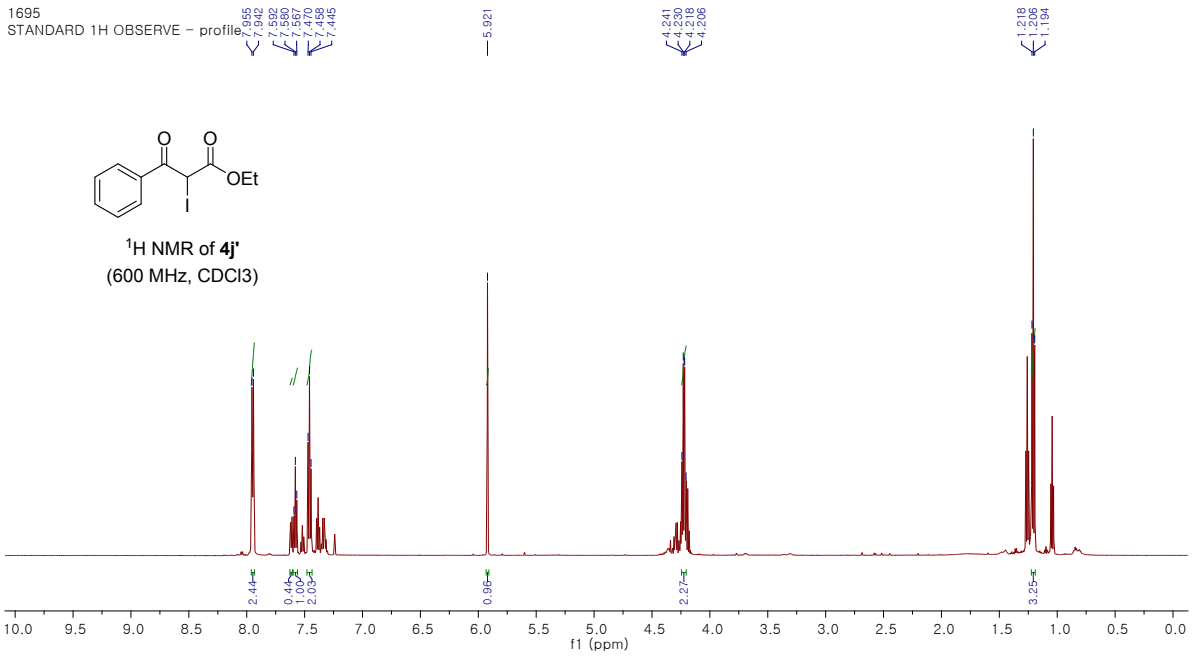


^{1}H NMR of **5h**
(600 MHz, $CDCl_3$)

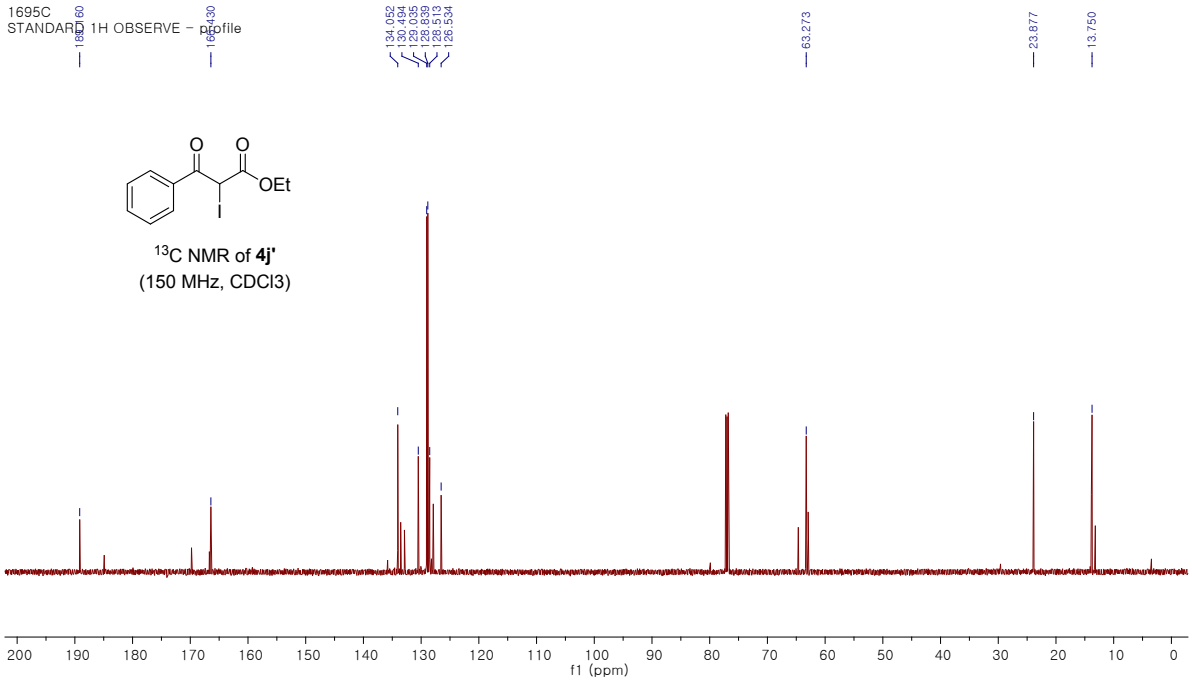


^{13}C NMR of **5h**
(150 MHz, $CDCl_3$)

NMR spectra of crude sample **4j'**



^{1}H NMR of **4j'**
(600 MHz, CDCl3)



^{13}C NMR of **4j'**
(150 MHz, CDCl3)