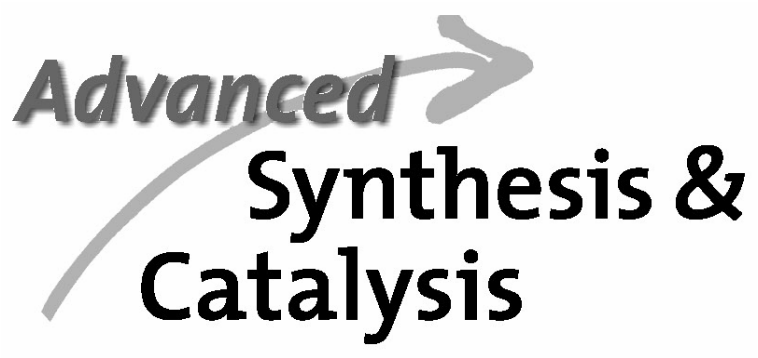

Supporting Information

Supporting Information

Ligand-Free Copper-Catalyzed *N*-Arylation of Nitrogen Nucleophiles

*Arkaitz Correa and Carsten Bolm**

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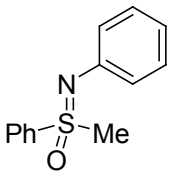
General information: All reagents were purchased from commercial suppliers and used without further purification. All experiments were carried out under argon. Flash chromatography was carried out with Merck silica gel 60 (63-200 mesh). Analytical TLC was performed with Merck silica gel 60 F_{254} plates, and the products were visualized by UV detection. ^{1}H NMR and ^{13}C NMR (300 or 400 MHz and 75 or 100 MHz, respectively) spectra were recorded in $CDCl_3$. Chemical shifts (δ) are reported in ppm using TMS as internal standard, and spin-spin coupling constants (J) are given in Hz.

General procedure for *N*-arylation of nitrogen nucleophiles: An oven-dried tube was charged with *N*-nucleophile (1.0 equiv), Cu_2O (0.10 equiv) and Cs_2CO_3 (2.0 equiv). Under an argon atmosphere the aryl halide (1.5 equiv) was added followed by dry DMF (1 mL). The tube was sealed under argon and the mixture was heated to 100 ºC. After stirring at 100 ºC for 18 h, the heterogeneous mixture was cooled to room temperature and diluted with dichloromethane. The resulting solution was directly filtered through a pad of silica gel and concentrated to yield the product, which was purified by silica gel chromatography to yield the *N*-arylated product. The identity and purity of the products was confirmed by ^{1}H and ^{13}C NMR spectroscopic analysis.

***N*-Phenyl-*S*-methyl-*S*-phenylsulfoximine[1] (3).** Following the general procedure using *rac*-*S*-methyl-*S*-phenylsulfoximine (100 mg, 0.64 mmol) and either iodobenzene (0.11 mL, 0.97 mmol) or bromobenzene (0.10 mL, 0.97 mmol) provided 140 mg (95% yield) of the coupling product as a white solid after purification by flash chromatography (1:1 pentane/ethyl acetate) of the crude brown oil.



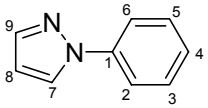
Mp: 101-102 ºC (Lit.[1] mp 100-101 ºC).

^{1}H-NMR (300 MHz, $CDCl_3$) δ 7.91-7.95 (m, 2H), 7.39-7.51 (m, 3H), 6.99-7.10 (m, 4H), 6.78-6.84 (m, 1H), 3.15 (s, 3H).

^{13}C-NMR (75 MHz, $CDCl_3$) δ 145.2 (C), 139.3 (C), 133.3 (CH), 129.6 (CH), 129.0 (CH), 128.6 (CH), 123.3 (CH), 121.6 (CH), 45.9 (CH_3).

All spectral data correspond to those given in the literature.[1]

1-Phenyl-1*H*-pyrazole[2] (4a). Following the general procedure using 1*H*-pyrazole (100 mg, 1.44 mmol) and either iodobenzene (0.24 mL, 2.16 mmol) or bromobenzene (0.23 mL, 2.16 mmol) provided 204 mg (98% yield) of the coupling product as a yellowish oil after purification by flash chromatography (1:1 pentane/ethyl acetate) of the crude brown oil.



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[1] G. Y. Cho, P. Rémy, J. Jansson, C. Moessner, C. Bolm, *Org. Lett.* **2004**, *6*, 3293.

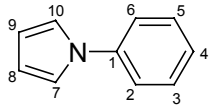
[2] H.-J. Cristau, P. P. Cellier, J.-F. Spindler, M. Taillefer, *Org. Lett.* **2004**, *6*, 695.

^{1}H-NMR (400 MHz, $CDCl_3$) δ 7.91 (dd, J^3 = 2.5 Hz, J^4 = 0.5 Hz, 1H, H-7), 7.68-7.72 (m, 3H, H-2,6,9), 7.41-7.46 (m, 2H, H-3,5), 7.25-7.29 (m, 1H, H-4), 6.45 (dd, J^3 = 2.5 Hz, J^3 = 1.8 Hz, 1H, H-8).

^{13}C-NMR (100 MHz, $CDCl_3$) δ 141.0 (C-9), 140.1 (C-1), 129.4 (C-3,5), 126.7 (C-7), 126.4 (C-4), 119.2 (C-2,6), 107.6 (C-8).

All spectral data correspond to those given in the literature.[2]

1-Phenyl-1*H*-pyrrole[3] (5). Following the general procedure using 1*H*-pyrrole (100 mg, 1.49 mmol) and iodobenzene (0.25 mL, 2.23 mmol) provided 199 mg (93% yield) of the coupling product as a white solid after purification by flash chromatography (pentane) of the crude oil.



Mp: 58-59 ºC (Lit.[3] mp 62 ºC).

^{1}H-NMR (300 MHz, $CDCl_3$) δ 7.35-7.43 (m, 4H, H-2,3,5,6), 7.19-7.24 (m, 1H, H-4), 7.07-7.09 (m, 2H, H-7,10), 6.33-6.35 (m, 2H, H-8,9).

^{13}C-NMR (75 MHz, $CDCl_3$) δ 140.8 (C-1), 129.6 (C-3,5), 125.7 (C-4), 120.6 (C-2,6), 119.4 (C-7,10), 110.5 (C-8,9).

All spectral data correspond to those given in the literature.[3]

1-Phenyl-1*H*-[1,2,4]triazole[3] (6). Following the general procedure using 1*H*-[1,2,4]triazole (100 mg, 1.45 mmol) and iodobenzene (0.24 mL, 2.17 mmol) provided 161 mg (76% yield) of the coupling product as a white solid after purification by flash chromatography (pentane) of the crude oil.

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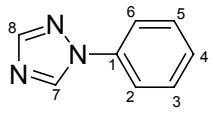
[3] H.-J. Cristau, P. P. Cellier, J.-F. Spindler, M. Taillefer, *Chem. Eur. J.* **2004**, *10*, 5607.



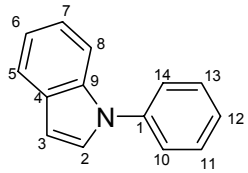
Mp: 47-48 ºC (Lit.[3] mp 46 ºC).

^{1}H-NMR (400 MHz, $CDCl_3$) δ 8.58 (br s, 1H, H-8), 8.11 (br s, 1H, H-7), 7.66-7.69 (m, 2H, H-2,6), 7.47-7.52 (m, 2H, H-3,5), 7.36-7.41 (m, 1H, H-4).

^{13}C-NMR (100 MHz, $CDCl_3$) δ 152.5 (C-7), 140.8 (C-8), 136.9 (C-1), 129.7 (C-3,5), 128.1 (C-4), 119.9 (C-2,6).

All spectral data correspond to those given in the literature.[3]

1-Phenyl-1*H*-indole[3] (7). Following the general procedure using 1*H*-indole (100 mg, 0.85 mmol) and iodobenzene (0.14 mL, 1.28 mmol) provided 156 mg (95% yield) of the coupling product as a yellow oil after purification by flash chromatography (pentane) of the crude oil.



^{1}H-NMR (300 MHz, $CDCl_3$) δ 7.65-7.69 (m, 1H), 7.52-7.56 (m, 1H), 7.40-7.46 (m, 4H), 7.27-7.31 (m, 1H), 7.10-7.25 (m, 2H), 6.65 (dd, J^3 = 3.3 Hz, J^5 = 0.7 Hz, 1H).

^{13}C-NMR (75 MHz, $CDCl_3$) δ 139.9 (C-1), 135.9 (C-7), 129.7 (C-2,6), 129.5 (C-12), 128.1 (C-14), 126.5 (C-4), 124.5 (C-3,5), 122.5 (C-9), 121.3 (C-11), 120.5 (C-10), 110.7 (C-8), 103.7 (C-13).

All spectral data correspond to those given in the literature.[3]

1-Phenyl-1*H*-benzimidazole[4] (8). Following the general procedure using 1*H*-benzimidazole (100 mg, 0.83 mmol) and iodobenzene (0.14 mL, 1.24 mmol) provided

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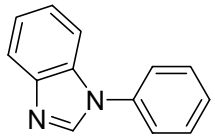
[4] Y.-X. Xie, S.-F. Pi, J. Wang, D.-L. Yin, J.-H. Li. *J. Org. Chem.* **2006**, *71*, 8324.

139 mg (86% yield) of the coupling product as a colorless oil after purification by flash chromatography (1:1 pentane/ethyl acetate) of the crude oil.

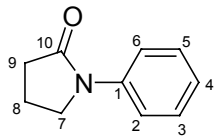


^{1}H-NMR (300 MHz, $CDCl_3$) δ 8.12 (br s, 1H), 7.87-7.90 (m, 1H), 7.41-7.58 (m, 6H), 7.30-7.36 (m, 2H).

^{13}C-NMR (75 MHz, $CDCl_3$) δ 144.2 (C), 142.5 (C), 136.4 (C), 130.1 (CH), 128.0 (CH), 124.0 (CH), 123.7 (CH), 122.8 (CH), 120.6 (CH), 110.5 (CH).

All spectral data correspond to those given in the literature.[4]

1-Phenyl-pyrrolidin-2-one[3] (9). Following the general procedure using pyrrolidin-2-one (100 mg, 1.17 mmol) and iodobenzene (0.19 mL, 1.75 mmol) provided 130 mg (64% yield) of the coupling product as a yellowish solid after purification by flash chromatography (1:1 n-pentane/ethyl acetate) of the crude oil.



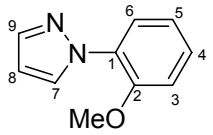
Mp: 66-67 ºC (Lit.[3] mp 68 ºC).

^{1}H-NMR (300 MHz, $CDCl_3$) δ 7.58-7.62 (m, 2H, H-3,5), 7.32-7.39 (m, 2H, H-2,6), 7.10-7.16 (m, 1H, H-4), 3.85 (t, J = 7.0 Hz, 2H, H-7), 2.60 (t, J = 8.0 Hz, 2H, H-9), 2.09-2.19 (m, 2H, H-8).

^{13}C-NMR (75 MHz, $CDCl_3$) δ 174.2 (C-10), 139.4 (C-1), 128.8 (C-3,5), 124.5 (C-4), 119.9 (C-2,6), 48.8 (C-7), 32.8 (C-8), 18.0 (C-9).

All spectral data correspond to those given in the literature.[3]

1-(2-Methoxyphenyl)-1*H*-pyrazole[5] (4b). Following the general procedure using 1*H*-pyrazole (50 mg, 0.72 mmol) and either 2-iodoanisole (0.14 mL, 1.08 mmol) or 2-bromoanisole (0.13 mL, 1.08 mmol) provided 116 mg (94% yield) and 125 mg (99% yield), respectively, of the coupling product as a colorless oil after purification by flash chromatography (1:1 pentane/ethyl acetate) of the crude oil.

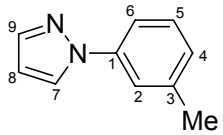


^{1}H-NMR (400 MHz, $CDCl_3$) δ 8.01 (d, J = 2.2 Hz, 1H), 7.68-7.72 (m, 2H), 7.23-7.28 (m, 1H), 6.99-7.05 (m, 2H), 6.39-6.40 (m, 1H), 3.81 (s, 3H).

^{13}C-NMR (100 MHz, $CDCl_3$) δ 151.2 (C), 139.9 (CH), 131.5 (CH), 129.7 (C), 127.9 (CH), 125.2 (CH), 121.1 (CH), 112.3 (CH), 106.2 (CH), 55.9 (CH_3).

All spectral data correspond to those given in the literature.[5]

1-(3-Methylphenyl)-1*H*-pyrazole[6] (4c). Following the general procedure using 1*H*-pyrazole (50 mg, 0.72 mmol) and 3-iodotoluene (0.14 mL, 1.08 mmol) provided 138 mg (98% yield) of the coupling product as a yellowish oil after purification by flash chromatography (pentane) of the crude oil.



^{1}H-NMR (400 MHz, $CDCl_3$) δ 7.87 (d, J^3 = 2.5 Hz, 1H), 7.70 (d, J^3 = 1.4 Hz, 1H), 7.53 (s, 1H), 7.42-7.45 (m, 1H), 7.29 (t, J = 7.8 Hz, 1H), 7.06 (d, J = 7.4 Hz, 1H), 6.42 (t, J = 2.2 Hz, 1H), 2.54 (s, 3H).

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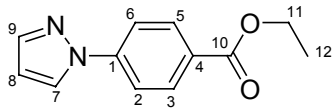
[5] T. Asaumi, N. Chatani, T. Matsuo, F. Kakiuchi, S. Murai, *J. Org. Chem.* **2003**, *68*, 7538.

[6] T.-H. Kwon, H. S. Cho, M. K. Kim, J.-W. Kim, J.-J. Kim, K. H. Lee, S. J. Park, I.-S. Shin, H. Kim, D. M. Shin, Y. K. Chung, J.-I. Hong, *Organometallics* **2005**, *24*, 1578.

^{13}C-NMR (100 MHz, $CDCl_3$) δ 140.9 (CH), 140.1 (C), 139.4 (C), 129.2 (CH), 127.2 (CH), 126. 8 (CH), 119.9 (CH), 116.2 (CH), 107.5 (CH), 21.6 (CH_3).

All spectral data correspond to those given in the literature.[6]

4-Pyrazol-1-yl-benzoic acid ethylester[7] (4d). Following the general procedure using 1*H*-pyrazole (50 mg, 0.72 mmol) and 4-iodobenzoic acid ethylester (0.18 mL, 1.08 mmol) provided 177 mg (99% yield) of the coupling product as a white solid after purification by flash chromatography (dichloromethane) of the crude oil.



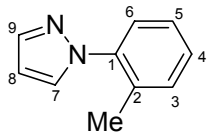
Mp: 63-64 ºC (Lit.[7] mp 66 ºC).

^{1}H-NMR (400 MHz, $CDCl_3$) δ 8.14 (d, J = 8.8 Hz, 2H, H-3,5), 8.11 (d, J = 2.2 Hz, 1H, H-7), 7.75-7.78 (m, 3H, H-2,6,9), 6.47-6.48 (m, 1H, H-3), 4.38 (q, J = 7.2 Hz, 2H, H-11), 1.40 (t, J = 7.2, 3H, H-12).

^{13}C-NMR (100 MHz, $CDCl_3$) δ 165.7 (C-10), 143.1 (C-1), 141.8 (C-9), 131.0 (C-3,5), 128.0 (C-4), 126.8 (C-7), 118.2 (C-5,6), 108.4 (C-8), 61.1 (C-11), 14.5 (C-12).

All spectral data correspond to those given in the literature. [7]

1-(2-Tolyl)-1*H*-pyrazole[8] (4e). Following the general procedure using 1*H*-pyrazole (50 mg, 0.72 mmol) and 2-bromotoluene (0.13 mL, 1.08 mmol) provided 104 mg (91% yield) of the coupling product as a yellowish oil after purification by flash chromatography (pentane) of the crude oil.



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[7] M. Taillefer, N. Xia, A. Ouani, *Angew. Chem.* **2007**, *119*, 952; *Angew. Chem., Int. Ed.* **2007**, *46*, 934.

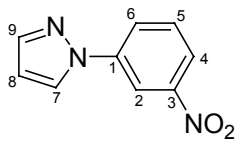
[8] H.-J. Cristal, P. P. Cellier, J.-F. Spindler, M. Taillefer, *Eur. J. Org. Chem.* **2004**, 695.

^{1}H-NMR (300 MHz, $CDCl_3$) δ 7.72 (d, J^3 = 1.5 Hz, 1H, H-9), 7.59 (dd, J^3 = 2.3 Hz, J^4 = 0.7 Hz, 1H, H-7), 7.23-7.34 (m, 4H, H-2,3,4,5), 6.42-6.43 (m, 1H, H-8), 2.24 (s, 3H, CH_3).

^{13}C-NMR (75 MHz, $CDCl_3$) δ 140.3 (C-9), 140.0 (C-1), 133.7 (C-6), 131.3 (C-5), 130.5 (C-7), 128.4 (C-2), 126.5 (C-4), 126.2 (C-3), 106.2 (C-8), 18.1 (CH_3).

All spectral data correspond to those given in the literature. [8]

1-(3-Nitrophenyl)-1*H*-pyrazole[8] (4f). Following the general procedure using 1*H*-pyrazole (50 mg, 0.72 mmol) and 2-bromotoluene (218 mg, 1.08 mmol) provided 134 mg (98% yield) of the coupling product as a yellowish solid after purification by flash chromatography (pentane) of the crude oil.



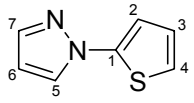
Mp: 93-94 ºC (Lit.[8] mp 94 ºC).

^{1}H-NMR (300 MHz, $CDCl_3$) δ 8.55 (t, J^4 = 2.2 Hz, 1H, H-6), 8.02-8.12 (m, 3H, H-2,4,7), 7.76 (d, J^3 = 1.8 Hz, 1H, H-9), 7.62 (t, J^3 = 8.2 Hz, 1H, H-3), 6.54 (dd, J^3 = 2.5 Hz, J^3 = 1.7, 1H, H-8).

^{13}C-NMR (75 MHz, $CDCl_3$) δ 148.9 (C-5), 142.1 (C-9), 140.9 (C-1), 130.4 (C-3), 126.9 (C-7), 124.3 (C-2), 120.6 (C-4), 113.6 (C-6), 108.8 (C-8).

All spectral data correspond to those given in the literature. [8]

1-(2-Thienyl)-1*H*-pyrazole[8] (4g). Following the general procedure using 1*H*-pyrazole (50 mg, 0.72 mmol) and 2-bromothiophene (0.104 mL, 1.08 mmol) provided 103 mg (95% yield) of the coupling product as an orange oil after purification by flash chromatography (pentane) of the crude oil.

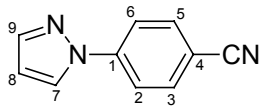


^{1}H-NMR (400 MHz, $CDCl_3$) δ 7.79 (d, J^3 = 2.5 Hz, 1H, H-6), 7.65 (d, J^3 = 1.6 Hz, 1H, H-8), 6.92-7.02 (m, 3H, H-3,4,5), 6.41 (t, J^3 = 2.2 Hz, 1H, H-7).

^{13}C-NMR (100 MHz, $CDCl_3$) δ 143.7 (C-1), 141.1 (C-8), 128.0 (C-3), 126.0 (C-6), 120.1 (C-4), 113.9 (C-5), 107.7 (C-7).

All spectral data correspond to those given in the literature. [8]

1-(4-Cyanophenyl)-1*H*-pyrazole[8] (4h). Following the general procedure using 1*H*-pyrazole (50 mg, 0.72 mmol) and 4-chlorobenzonitrile (148 mg, 1.08 mmol) provided 119 mg (98% yield) of the coupling product as a white solid after purification by flash chromatography (pentane) of the crude oil.



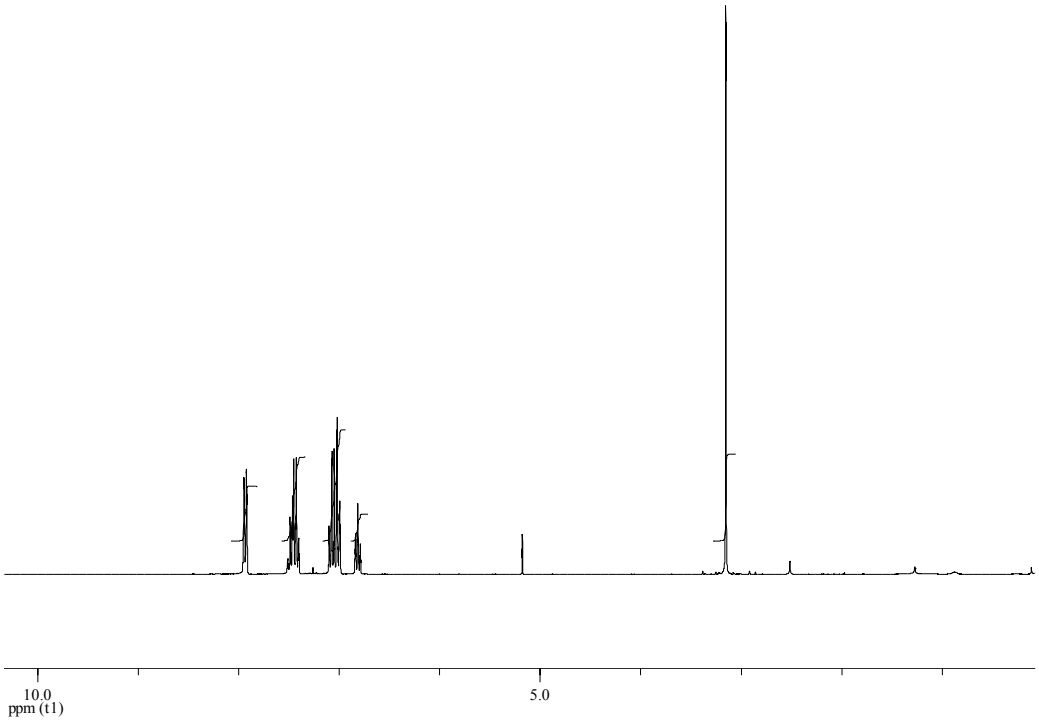
Mp: 87-88 ºC (Lit.[8] mp 87.5 ºC).

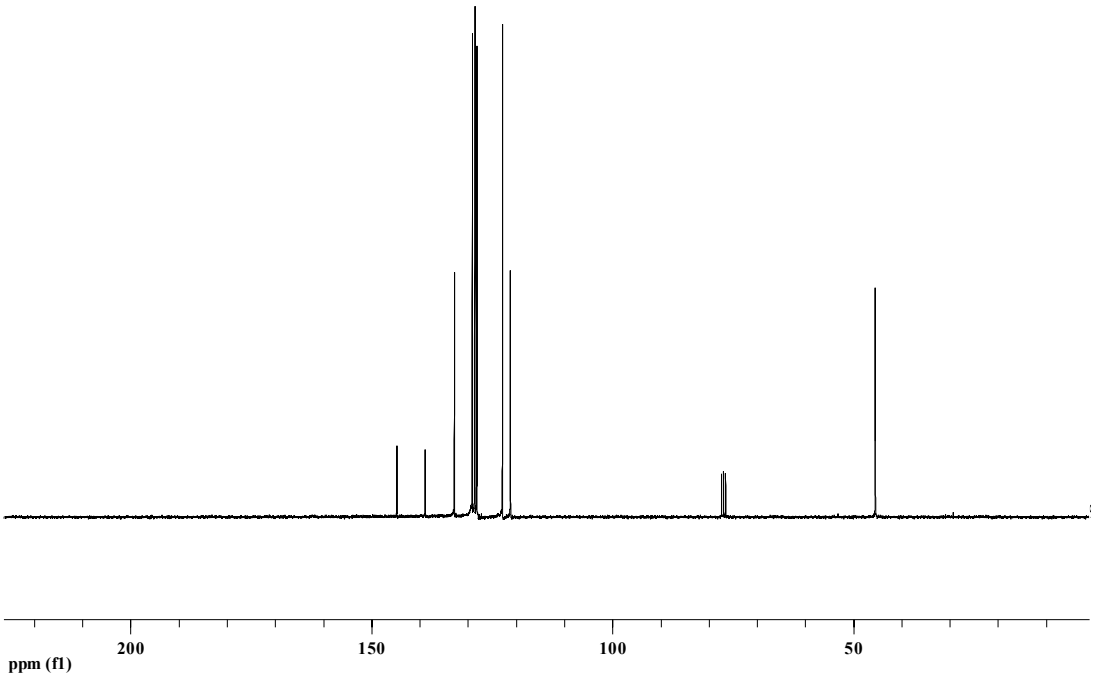
^{1}H-NMR (400 MHz, $CDCl_3$) δ 7.98 (dd, J^3 = 2.5 Hz, J^4 = 0.5 Hz, 1H, H-7), 7.83-7.85 (m, 2H, H-3,5), 7.73-7.77 (m, 3H, H-2,6,9), 6.53 (dd, J^3 = 2.5 Hz, J^3 = 1.7 Hz, 1H, H-8).

^{13}C-NMR (100 MHz, $CDCl_3$) δ 142.9 (C-1), 142.4 (C-9), 133.6 (C-3,5), 126.8 (C-7), 118.9 (C-2,6), 118.4 (CN), 109.5 (C-4), 109.0 (C-8).

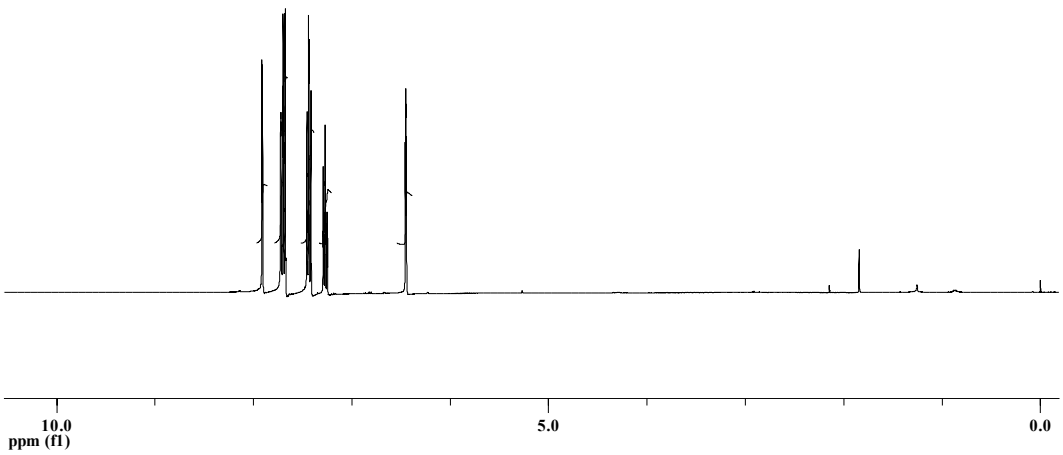
All spectral data correspond to those given in the literature. [8]

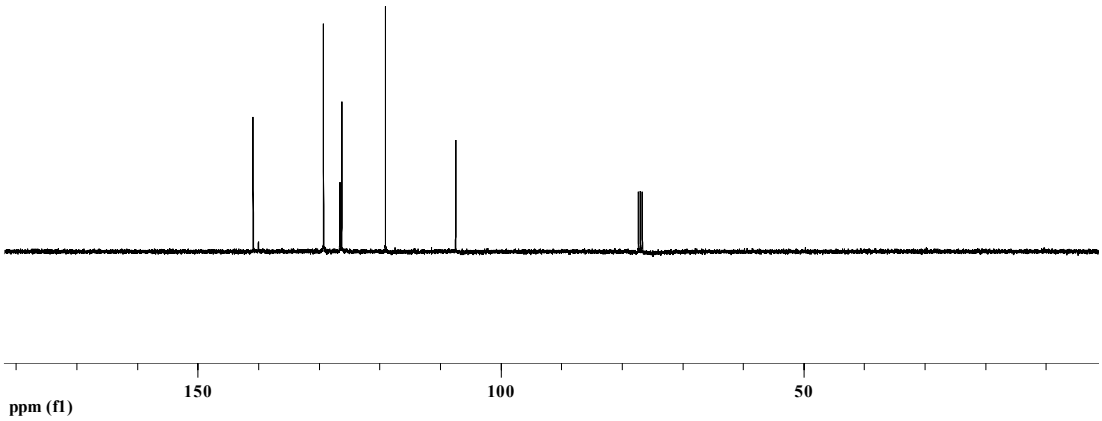
_N_-Phenyl-_S_-methyl-_S_-phenylsulfoximine



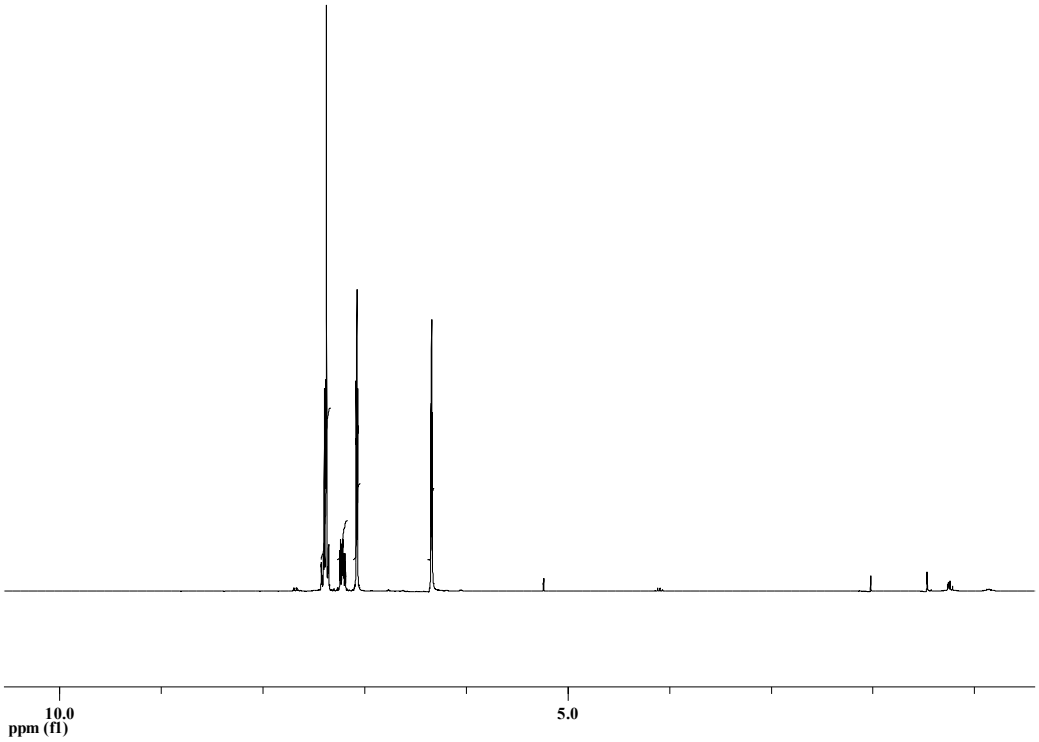


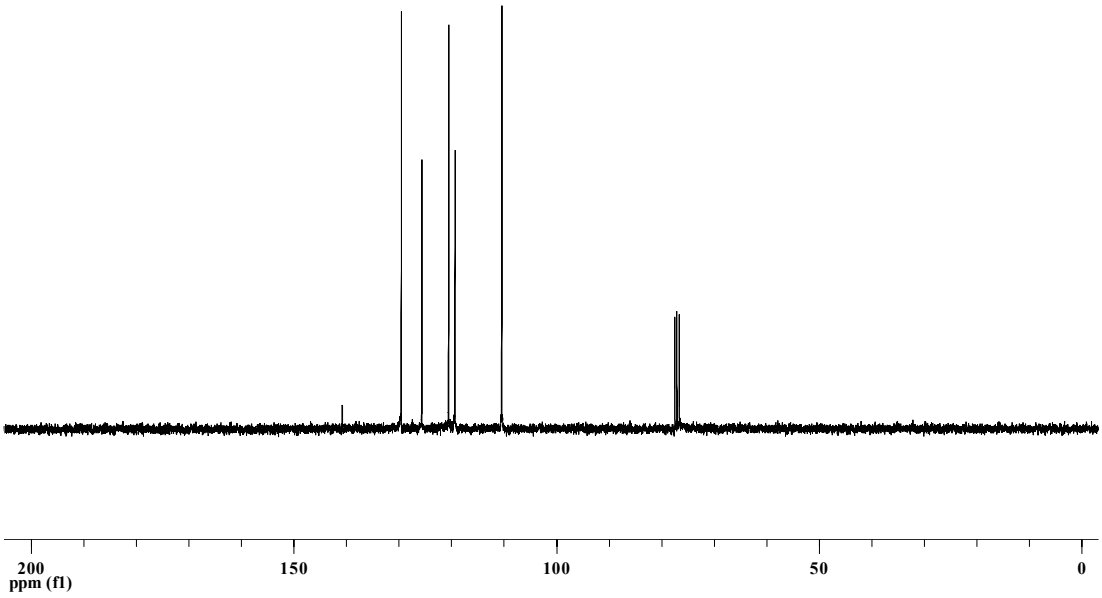
1-Phenyl-1*H*-pyrazole



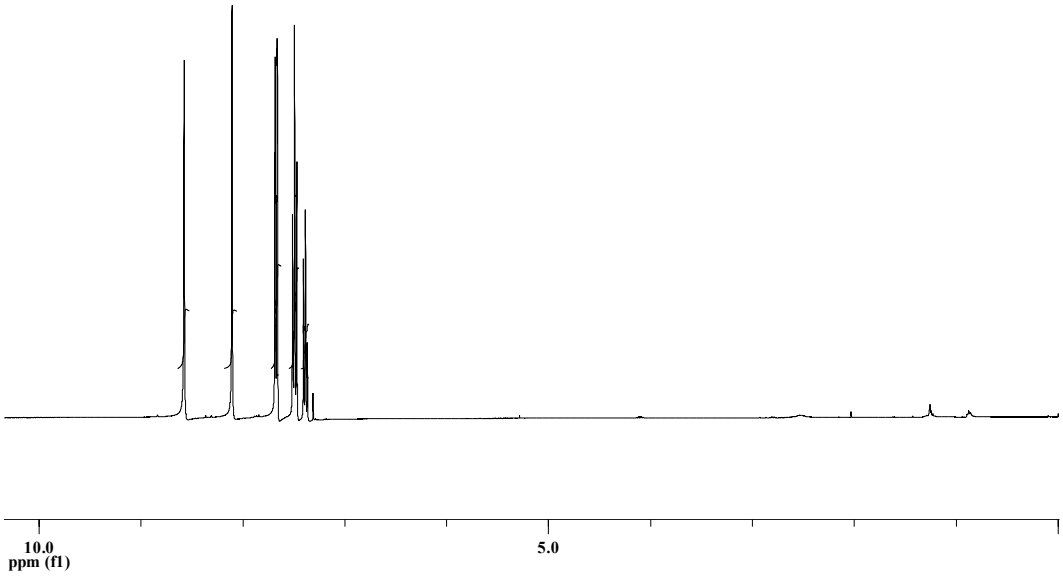


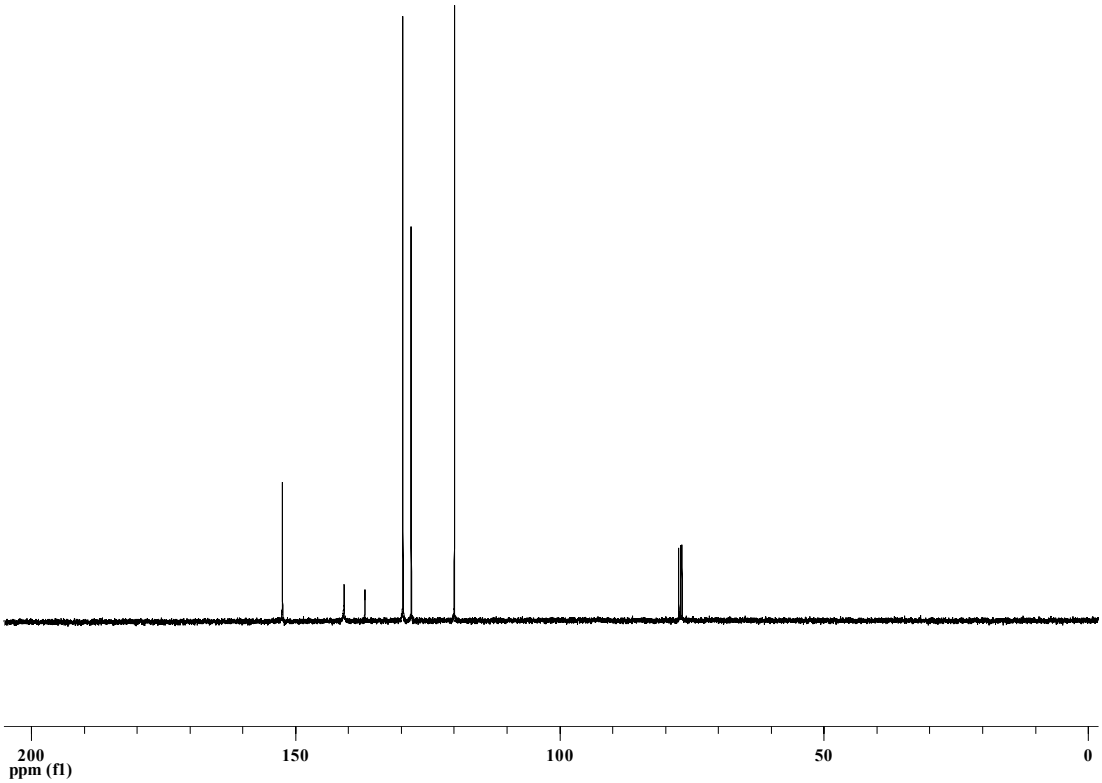
1-Phenyl-1*H*-pyrrole



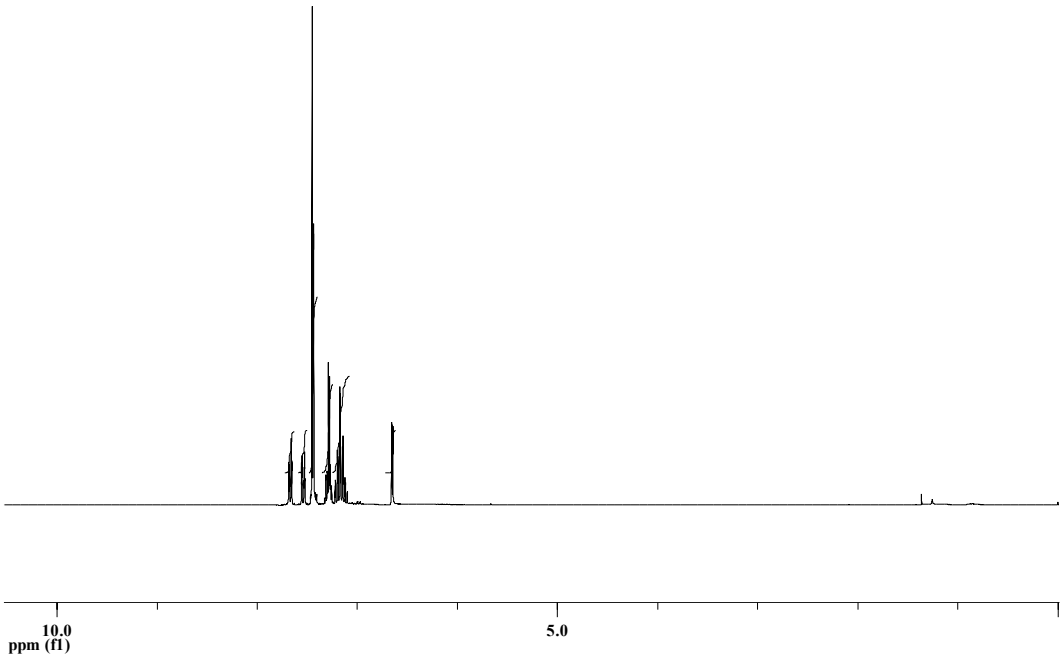


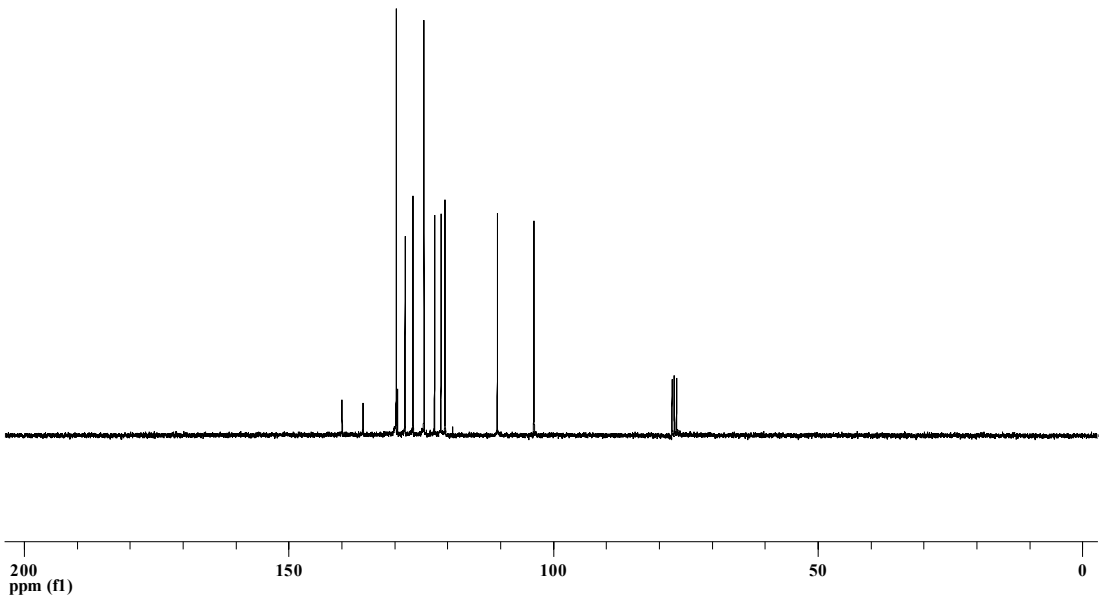
1-Phenyl-1*H*-[1,2,4]triazole



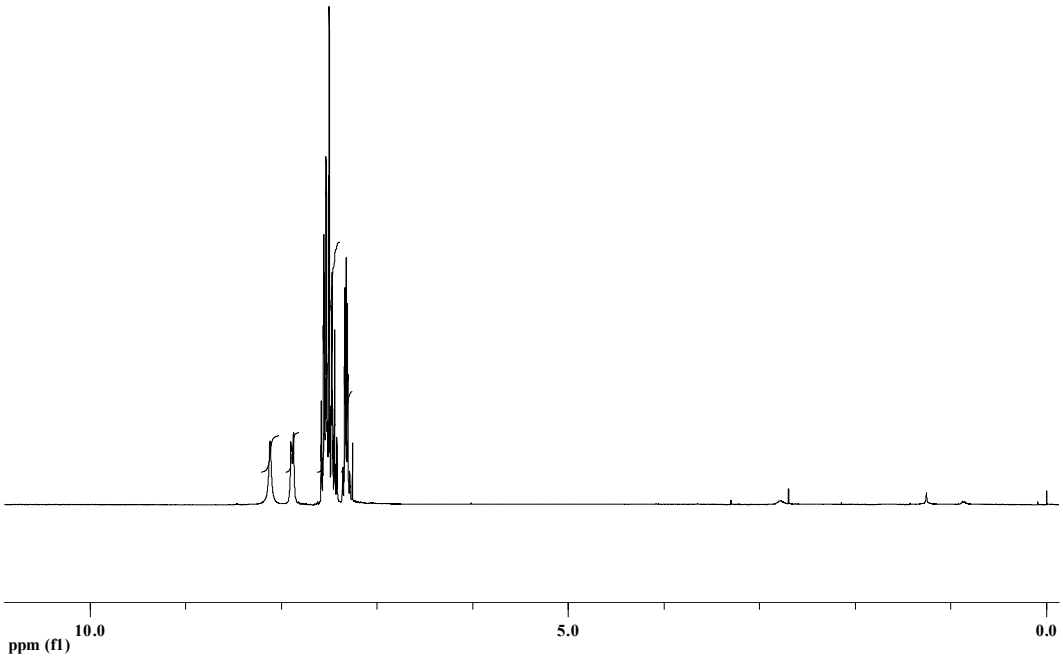


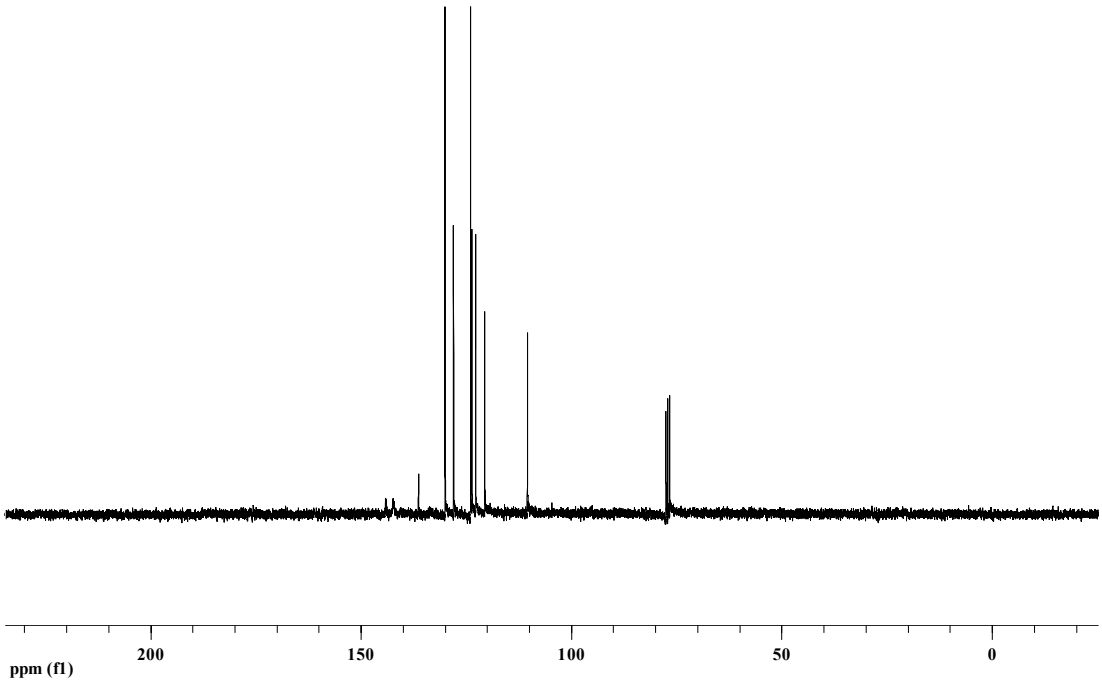
1-Phenyl-1*H*-indole



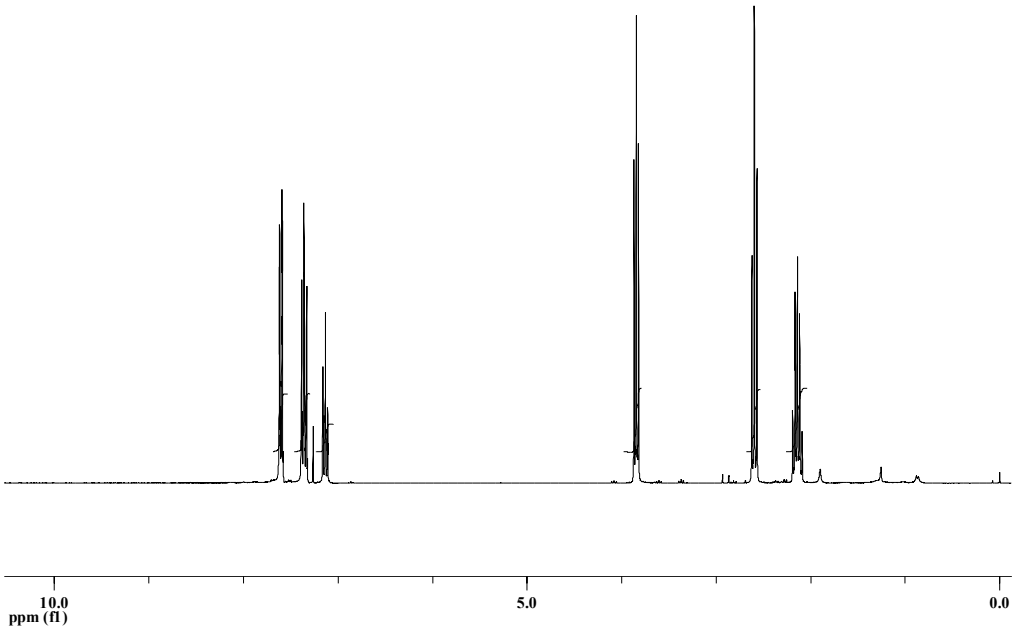


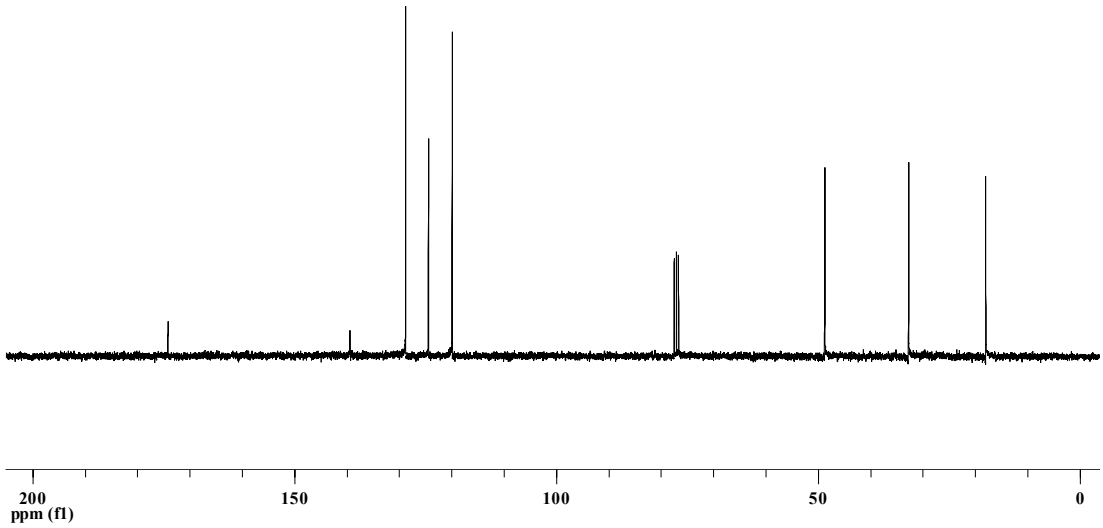
1-Phenyl-1*H*-benzimidazole



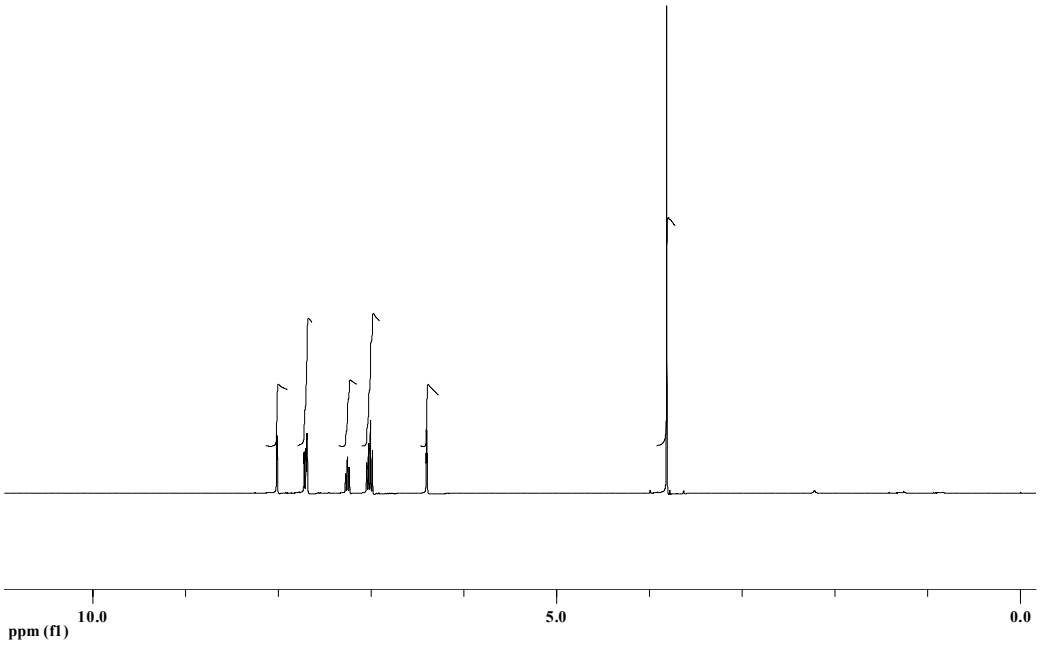


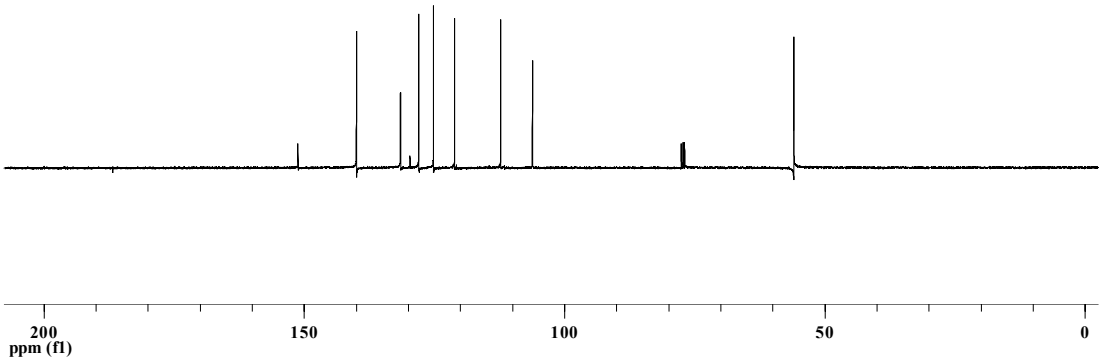
1-Phenyl-pyrrolidin-2-one



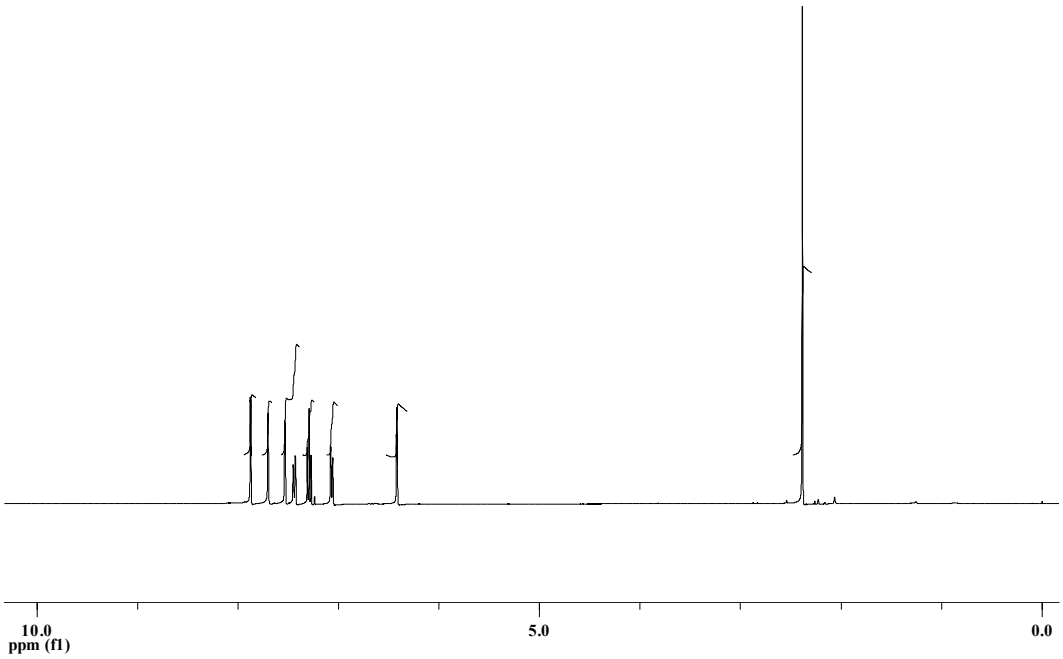


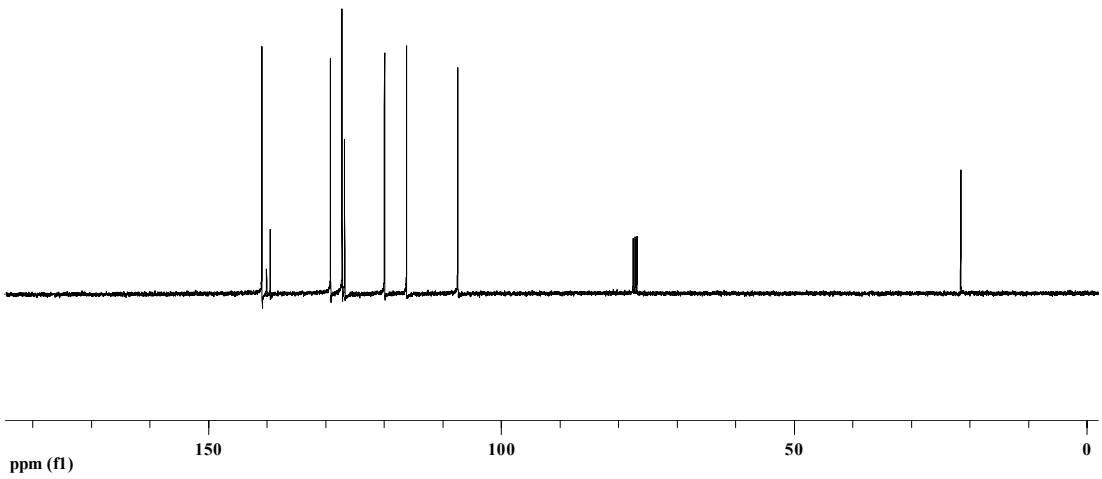
1-(2-Methoxyphenyl)-1*H*-pyrazole



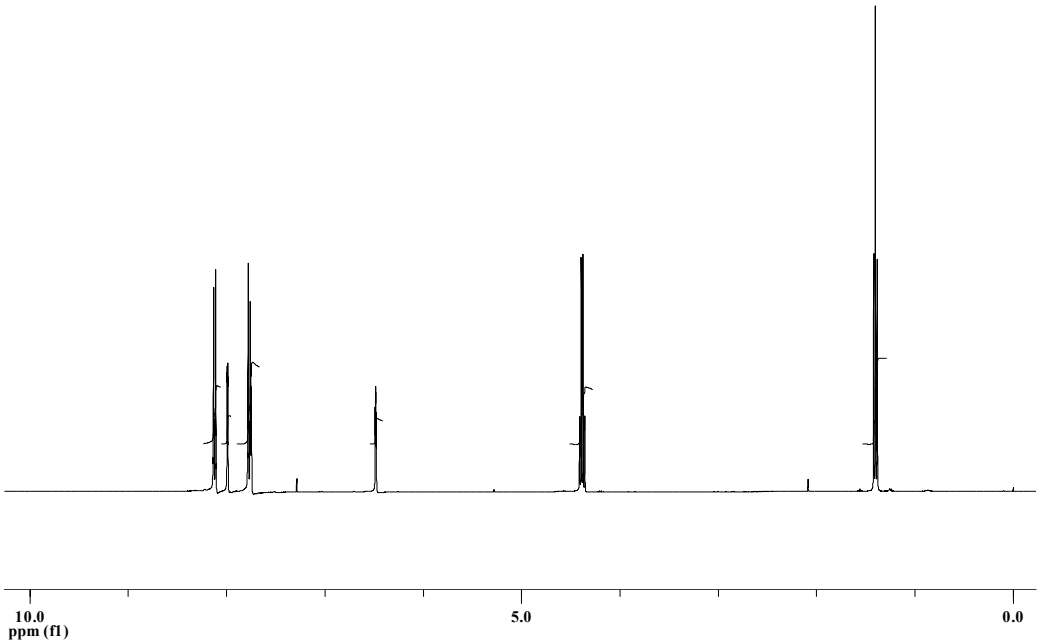


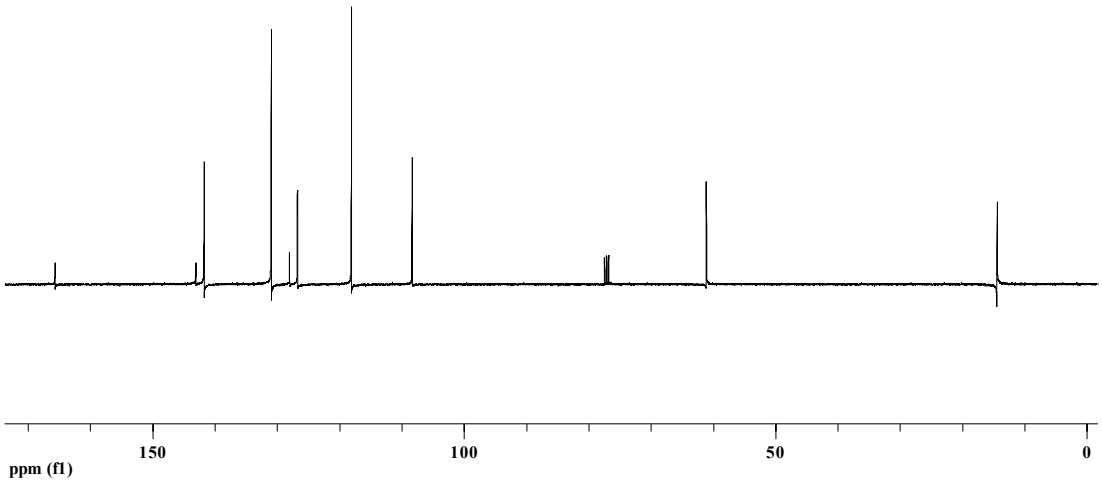
1-(3-Methylphenyl)-1*H*-pyrazole



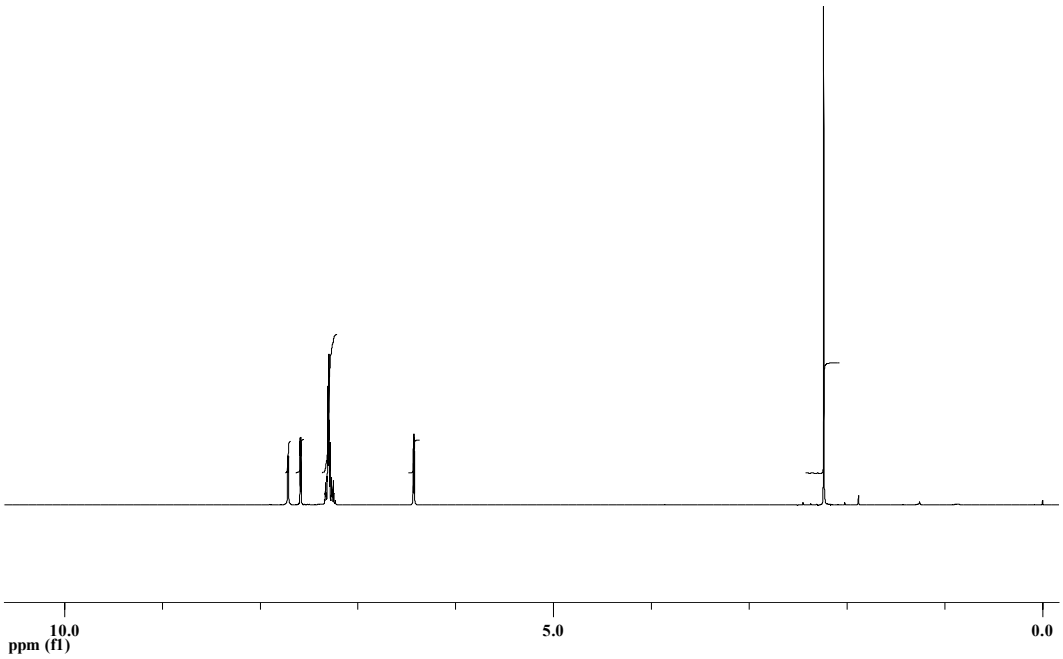


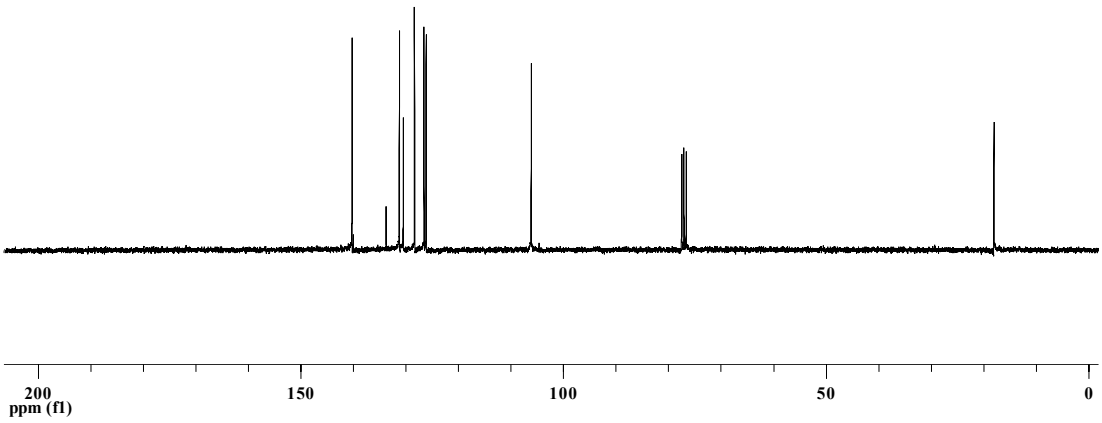
4-Pyrazol-1-yl-benzoic acid ethylester



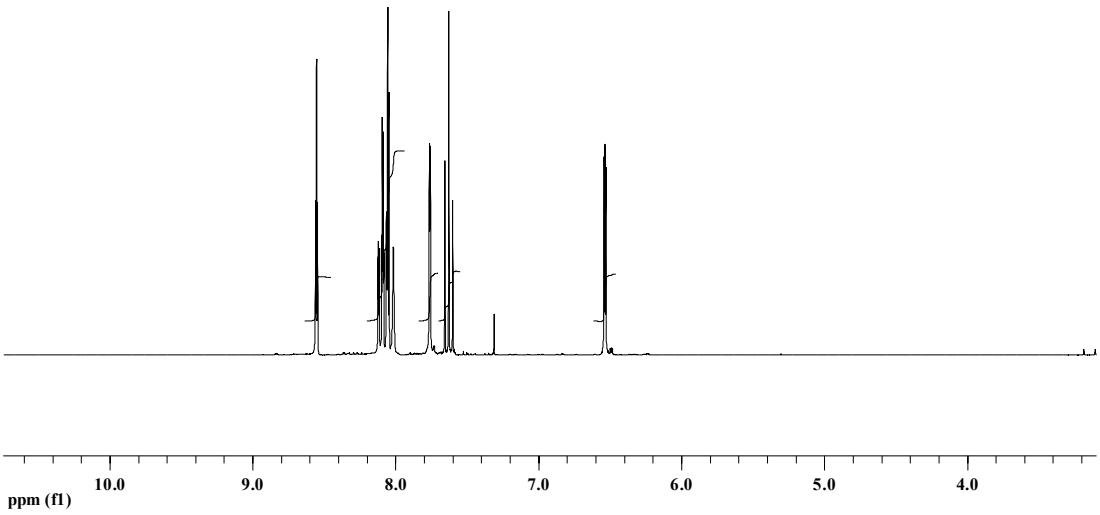


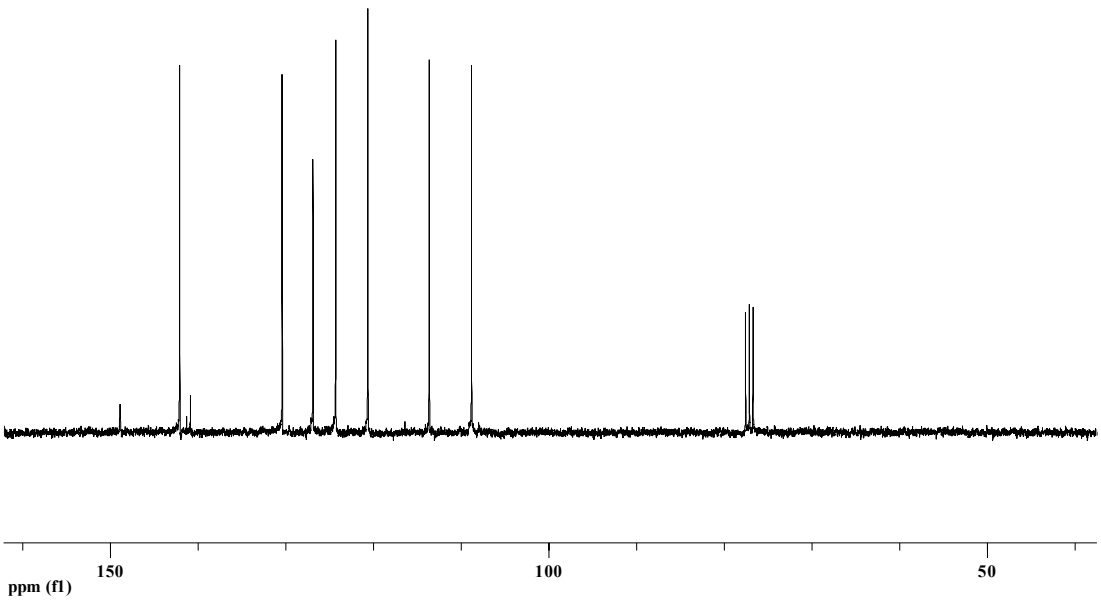
1-(2-Tolyl)-1*H*-pyrazole



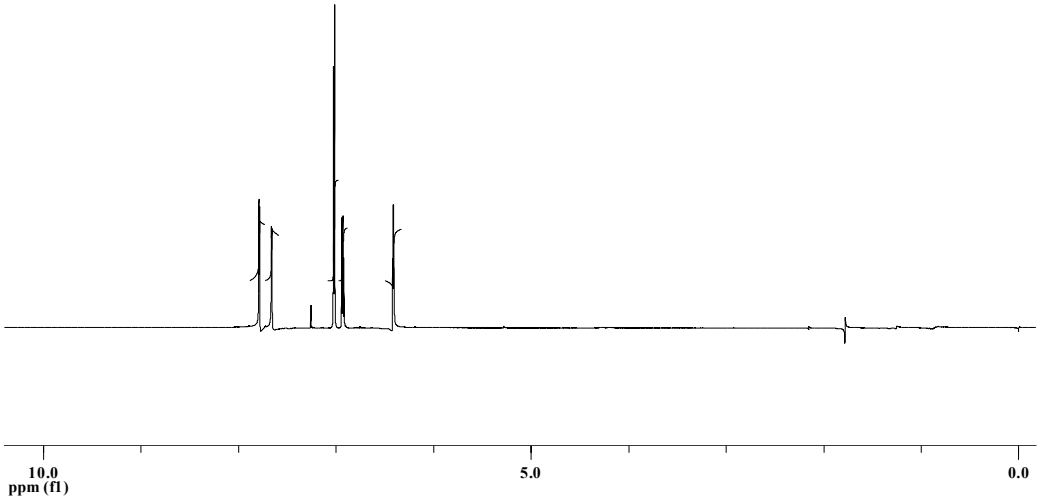


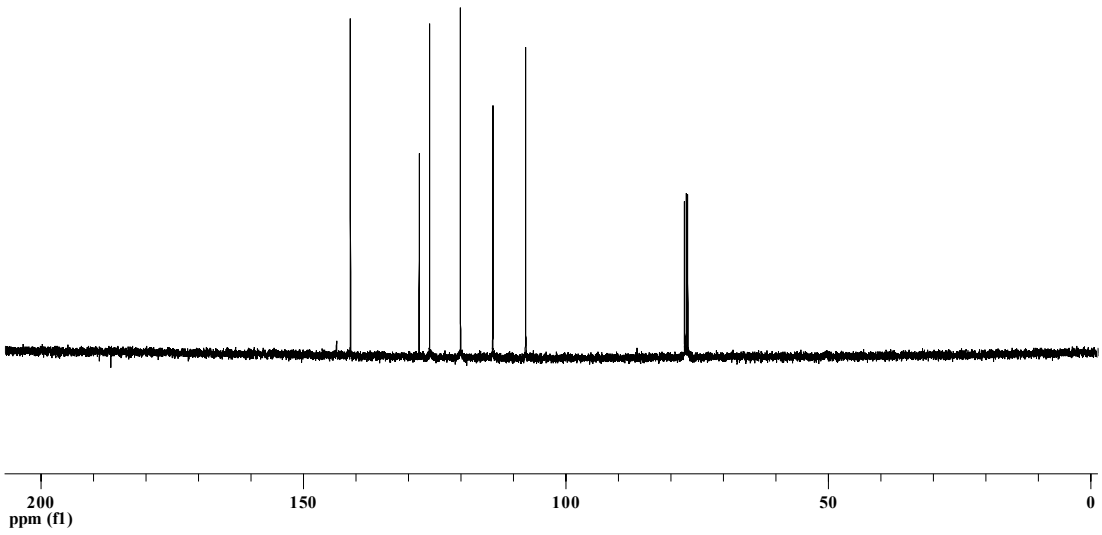
1-(3-Nitrophenyl)-1*H*-pyrazole





1-(2-Thienyl)-1*H*-pyrazole





1-(4-Cyanophenyl)-1*H*-pyrazole