Electronic Supplementary Information

Rhodium(I)-Catalyzed One-Pot Synthesis of Dialkyl Ketone from Methanol and Alkene through Directed sp^3 C-H Bond Activation of N-Methylamine

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General Information

Flash column chromatography was performed using E. Merck 230-400 mesh silica gel. Column chromatography were monitored by analytical thin-layer chromatography (TLC) carried out on 0.25 mm E. Merck silica gel plates (60 F-254) using UV light as a visualizing agent *p*-anisaldehyde solution, and heat as developing agent. Gas chromatographic analyses were performed on a Donam DS 6200 instrument with FID detector and a Hewlett Packard HP-5 capillary column. Low-resolution mass spectra were measured on a Hewlett-Packard HP G1800A GCD system equipped with a Hewlett Packard HP-5 capillary column. NMR spectra were recorded in $CDCl_3$ on a Bruker Advance DPX 250 (^{1}H NMR, 250 MHz; ^{13}C NMR, 62.9 MHz) and a Bruker Advance II DPX 400 (^{1}H NMR, 400 MHz; ^{13}C NMR, 100 MHz) spectrometers, and the chemical shift was expressed in ppm relative to TMS. Infrared (IR) spectra were recorded on Nicolet Impact 400 spectrometer. Elemental Analysis (EA) was obtained from the Organic Chemistry Research Center, Sogang University, Seoul, Korea. High-resolution mass spectrometry was performed by the National Center for Inter-University Facilities, Seoul National University, Seoul, Korea.

Materials

$(PPh_3)_3RhCl$ (**2**) was prepared as described in the literature.[1] Methanol and olefins used in the experiments were purchased from commercial sources. Toluene was distilled from sodium/benzophenone under nitrogen atmosphere prior to use.

Typical procedure for the reaction of methanol and norbornene (1a) (Table 1, entry 1)

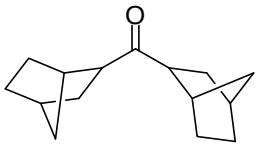
A screw-capped pressure vial (1 mL) was charged with 32.0 mg (1 mmol) of methanol, 46 mg (0.05 mmol) of $(PPh_3)_3RhCl$ (**2**), 32 mg (0.3 mmol) of 2-amino-4-picoline (**3**), 12 mg (0.1 mmol) of benzoic acid (**4**), 564 mg (6 mmol) of norbornene (**1a**) and 50 mg of toluene. The reaction mixture was stirred for

[1] J. A. Osborn, G. Wilkinson, In *Reagents for Transition Metal Complex and Organometallic Synthesis*: R. Angelich, Ed.; Wiley: New York, 1989; Vol. **28**, pp. 90-91.

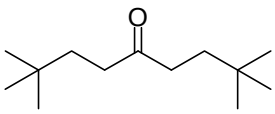
24 h in an oil bath that was preheated at 150 ^{o}C. After cooling to room temperature, the organic layer was purified by column chromatography (SiO_2, *n*-hexane : ethyl acetate = 20 : 1) to afford 185 mg (85%) of dinorbornyl ketone (**5a**).

Formation of aminal (*N,N'*-bis(4-methyl-2-pyridinyl)methandiamine) from formaldehyde and 2-amino-4-picoline (3), and the subsequent reaction of the resulting aminal and norbornene (1a) in the presence of $RhCl(PPh_3)_3$ (2) and benzoic acid (4). Paraformaldehyde (0.9 g, 0.03 mmol), polymeric form of formaldehyde, was added to 2-amino-4-picoline (**3**) (2 equiv.) at room temperature over 4Å molecular sieve. On standing at room temperature for 1 day, white solid was formed. It was dissolved in methylene chloride and filtered. The resulting solution was concentrated and dried *in-vacuo* to give aminal as a white solid (74%, 5.09 g). When the reaction of the resulting aminal and norbornene (**1a**, 3 mmol based on aminal) was carried out in toluene at 150 ^{o}C for 24 h in the presence of $(PPh_3)_3RhCl$ (**2**, 5mol% based on aminal) and benzoic acid (**4**), dinorbornyl ketone (**5a**) was not determined in the final reaction mixture.

Aminal (*N,N'*-bis(4-methyl-2-pyridinyl)methandiamine): ^{1}H NMR (250 MHz, $CDCl_3$): δ8.06 (d, *J* = 5.1 Hz, 2H, in pyridine), 6.78 (s, 2H, in pyridine), 6.49 (d, *J* = 5.1 Hz, 2H, in pyridine), 5.54 (s, 4H, -$NHCH_2NH$-), 2.20 (s, 6H, CH_3 in pyridine). ^{13}C NMR (62.9 MHz, $CDCl_3$): δ158.0, 148.9, 147.5, 116.1, 109.2, 60.6, 21.6. IR ($CDCl_3$): 3060, 3002, 2918, 1601, 1555, 1488, 1434, 1351, 1306, 1251, 1193, 1178, 953, 889, 802, 749 cm^{-1}. HRMS (FAB^{+}) calcd for $C_{14}H_{17}N_4$ ([MCH^{+}]) 241.1375, found 241.1453. Anal calcd for $C_{13}H_{16}N_4$: C, 68.39; H, 7.06; N, 24.54. Found: C, 67.47; H, 6.83; N, 21.51.

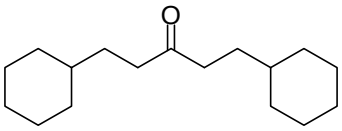


Dinorbornyl ketone (**5a**).[2] ^{1}H NMR (400 MHz, $CDCl_3$): δ2.60-2.24 (m), 2.01-1.00 (m). ^{13}C NMR (62.9 MHz, $CDCl_3$): δ214.1, 213.8, 53.4, 52.8, 41.4, 40.1, 36.4, 36.0, 33.6, 32.9, 30.3, 30.0, 29.0, 24.9. MS: *m/z* (%): 218 (M^{+}, 11), 151 (33), 123 (27), 95 (99), 80 (8), 67 (15), 41 (6), 18 (22). IR ($CDCl_3$): 2950, 2868, 1701, 1452, 1363, 1310, 1098 cm^{-1}. Registry number: 17610-50-3

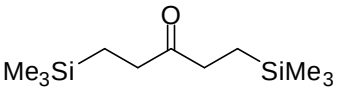


[2] M. L. N. Rao and M. Periasamy, *Journal of Organometallic Chemistry* 1998, **553**, 91; C. Narayana and M. Periasamy, *Tetrahedron Letters* 1985, **26**, 6361.

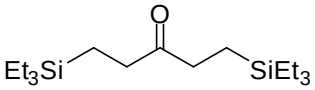
2,2,8,8-Tetramethyl-5-nonanone (**5b**).[3] ^{1}H NMR (400 MHz, $CDCl_3$): δ2.40 (t, *J* = 6.0 Hz, 4H), 1.49 (t, *J* = 6.0 Hz, 4H), 0.88 (s, 18H). ^{13}C NMR (100 MHz, $CDCl_3$): δ212.6 (CO), 38.7, 37.7, 30.2, 29.3. MS: *m/z* (%): 198 (M^+, 1), 183 (27), 141 (18), 113 (99), 85 (31), 57 (48), 43 (18), 41 (18), 18 (16). IR ($CDCl_3$): 2955, 2866, 1713, 1474, 1365 cm^{-1}. Registry number: 5709-95-5



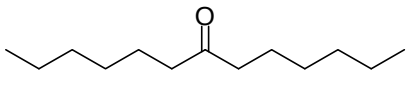
1,5-Dicyclohexyl-3-pentanone (**5c**).[4] ^{1}H NMR (400 MHz, $CDCl_3$): δ2.41 (t, *J* = 7.8 Hz, 4H), 1.69-162 (m, 10H), 1.48 (q, 4H), 1.25-1.11 (m, 8H), 0.91-0.82 (m, 4H). ^{13}C NMR (100 MHz, $CDCl_3$): δ212.1 (CO), 40.3, 37.2, 33.1, 31.2, 26.5, 26.2. MS: *m/z* (%): 250 (M^+, 3), 155 (36), 149 (10), 139 (27), 137 (16), 121 (62), 110 (8), 97 (52), 96 (99), 95 (32), 94 (19), 93 (11), 83 (11), 79 (11), 71 (16), 69 (19), 67 (18), 58 (10), 55 (41), 41 (24). IR ($CDCl_3$): 2922, 2850, 1713, 1448, 1367 cm^{-1}. Registry number: 62221-44-7



1,5-Bis(trimethylsilyl)-3-pentanone (**5d**).[5] ^{1}H NMR (400 MHz, $CDCl_3$): δ2.39 (m, 4H), 0.77 (m, 4H), -0.004 (s, 18H, $SiMe_3$). ^{13}C NMR (100 MHz, $CDCl_3$): δ212.9 (CO), 36.4, 10.4, -1.8. MS: *m/z* (%): 230 (M^+, 2), 157 (31), 147 (99), 73 (84), 45 (8), 18 (10). IR ($CDCl_3$): 2953, 2895, 1719, 1415, 1248, 1187, 978, 834, 755, 691 cm^{-1}. Registry number: 18053-95-7



1,5-Bis(triethylsilyl)-3-pentanone (**5e**). ^{1}H NMR (400 MHz, $CDCl_3$): δ2.38 (m, 4H), 0.95 (t, *J* = 8.0 Hz, 18H, -Si($CH_2C\underline{H}_3$)$_3$), 0.79 (m, 4H), 0.54 (q, 12H, -Si($C\underline{H}_2CH_3$)$_3$). ^{13}C NMR (100 MHz, $CDCl_3$): δ213.1 (CO), 36.3, 7.3, 5.2, 3.0. MS: *m/z* (%): 314 (M^+, 1), 286 (16), 285 (63), 217 (21), 190 (18), 189 (99), 169 (10), 161 (29), 115 (57), 87 (66), 86 (16), 72 (11), 59 (27). IR ($CDCl_3$): 2952, 2909, 2874, 1719, 1457, 1415, 1238, 1186, 1016, 733 cm^{-1}. HRMS (EI+) calcd for $C_{17}H_{38}OSi_2$ ([MNa^+]) 337.2461, found 337.2354. Anal calcd for $C_{17}H_{38}OSi_2$: C, 64.89; H, 12.17; Found: C, 64.80; H, 12.11.



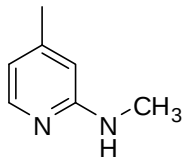
7-Tridecanone (**5f**).[4] ^{1}H NMR (400 MHz, $CDCl_3$): δ2.40 (t, *J* = 7.4 Hz, 4H), 1.57-1.52 (m, 4H), 1.32-1.27

[3] C.-H. Jun, C. W. Moon, S.-G. Lim and H. Lee, *Org. Lett*. 2002, **4**, 1595; C.-H. Jun, D.-Y. Lee, Y.-H. Kim and H. Lee, *Organometallics* 2001, **20**, 2928; C.-H. Jun, K.-Y. Chung and J.-B. Hong, *Org. Lett*. 2001, **3**, 785.

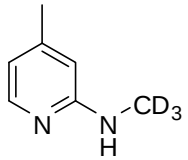
[4] H. C. Brown and M. W. Rathke, *J. Am. Chem. Soc*. 1967, **89**, 2738.

[5] C. P. Lenges, P. S. White and M. Brookhart, *J. Am. Chem. Soc*. 1998, **120**, 6965.

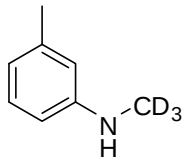
(m, 12H), 0.89-0.86 (m, 6H). ^{13}C NMR (100 MHz, $CDCl_3$): δ212.1 (CO), 43.0, 31.9, 29.2, 24.2, 22.5, 14.1. MS: *m/z* (%): 198 (M^+, 1), 141 (7), 128 (7), 113 (41), 85 (23), 71 (19), 58 (26), 43 (35), 28 (21), 18 (99). IR ($CDCl_3$): 2953, 2929, 2848, 1704, 1469 cm^{-1}. Registry number: 462-18-0



2-Methylamino-4-methylpyridine (**8**).[6] ^{1}H NMR (250 MHz, $CDCl_3$): δ7.96 (d, *J* = 5.2 Hz, 1H, in pyridine), 6.41 (d, *J* = 5.0 Hz, 1H, in pyridine), 6.19 (s, 1H, in pyridine), 4.81 (br s, 1H, NH), 2.95 (d, 3H, NHC<u>H</u>$_3$), 2.22 (s, 3H, CH_3 in pyridine). ^{13}C NMR (62.9 MHz, $CDCl_3$): δ159.9, 148.4, 147.8, 114.3, 106.4, 29.2, 21.3. MS: *m/z* (%): 122 (M^+, 99), 121 (49), 94 (30), 93 (79), 92 (25), 66 (16), 65 (10), 39 (6). IR ($CDCl_3$): 3423, 3286, 2921, 1615, 1568, 1525, 1413, 1384, 1286, 1241, 1183, 1082, 976, 914, 797 cm^{-1}. HRMS (EI+) calcd for $C_7H_{10}N_2$ ([M^+]) 122.0845, found 122.0844. Registry number: 45699-12-5



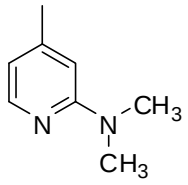
N-d-4-Methyl-2-pyridinamine (**8**-d_3). ^{1}H NMR (250 MHz, $CDCl_3$): δ7.96 (d, *J* = 5.2 Hz, 1H, in pyridine), 6.43 (d, *J* = 5.2 Hz, 1H, in pyridine), 6.20 (s, 1H, in pyridine), 4.52 (br s, 1H, NH), 2.24 (s, 3H, CH_3 in pyridine). ^{13}C NMR (62.9 MHz, $CDCl_3$): δ160.0, 148.6, 147.9, 114.5, 106.5, 21.4. MS: *m/z* (%): 125 (M^+, 99), 124 (13), 123 (32), 96 (15), 95 (21), 94 (79), 92 (30), 92 (18), 80 (15), 65 (17), 64 (10), 31 (12), 28 (33), 18 (86), 17 (22). IR ($CDCl_3$): 3275, 1615, 1564, 1488, 1288, 1182, 1033, 984, 959, 914, 865, 796 cm^{-1}. HRMS (EI+) calcd for $C_7H_7D_3N_2$ ([M^+]) 125.1027, found 125.1029. Anal calcd for $C_7H_7D_3N_2$: C, 67.16; H, 10.46; N, 22.38; Found: C, 67.17; H, 9.83; N, 21.17.



N-d-3-Methylaniline (**11**-d_3). ^{1}H NMR (250 MHz, $CDCl_3$): δ7.11 (t, *J* = 8.1 Hz, 1H), 6.54 (d, *J* = 7.5 Hz, 1H), 6.42 (s, 1H), 3.59 (br s, 1H, NH), 2.28 (s, 3H, CH_3). ^{13}C NMR (62.9 MHz, $CDCl_3$): δ149.5, 139.1, 129.2, 118.2, 113.3, 109.7, 21.8. MS: *m/z* (%): 124 (M^+, 99), 109 (5), 92 (10), 77 (8), 60 (5). IR ($CDCl_3$): 3410, 3041, 2918, 1605, 1589, 1509, 1490, 1329, 1308, 1265, 1182, 1168, 1147, 1037, 990, 858, 769, 692

[6] A. R. Katritzky, S. Rachwal and B. Rachwal, *J. Chem. Soc., Perkin Trans 1,* 1987, 805.

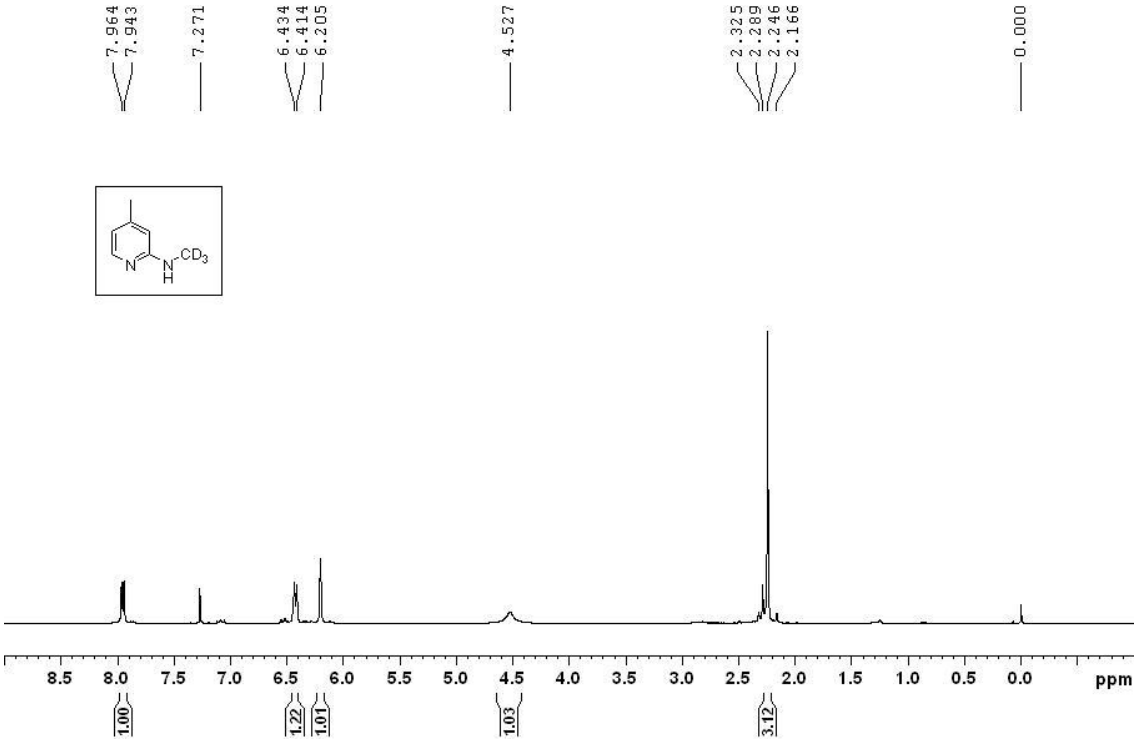
cm^{-1}. HRMS (EI+) calcd for $C_8H_8D_3N$ ([M^+]) 122.1078, found 124.1077. Anal calcd for $C_8H_8D_3N$: C, 77.36; H, 11.36; N, 11.28; Found: C, 77.39; H, 11.15; N, 11.48.



2-Dimethylamino-4-methylpyridine (**12**).[7] ^{1}H NMR (400 MHz, $CDCl_3$): δ8.03 (d, *J* = 5.2 Hz, 1H, in pyridine), 6.38 (d, *J* = 4.8 Hz, 1H, in pyridine), 6.31 (s, 1H, in pyridine), 3.05 (s, 6H, -N($C\underline{H}_3$)$_2$), 2.24 (s, 3H, CH_3 in pyridine). ^{13}C NMR (100 MHz, $CDCl_3$): δ159.8, 148.0, 147.6, 113.2, 106.3, 38.2, 21.5. MS: *m/z* (%): 136 (M^+, 59), 122 (67), 121 (99), 108 (14), 107 (70), 94 (35), 93 (95), 92 (52), 80 (13), 66 (20), 65 (22), 44 (10), 39 (10), 28 (19), 18 (10). IR ($CDCl_3$): 3011, 2921, 1717, 1608, 1414, 1355, 1310, 1273, 1225, 1162, 1103, 1062, 1019, 984, 797 cm^{-1}. Registry number: 20173-72-2

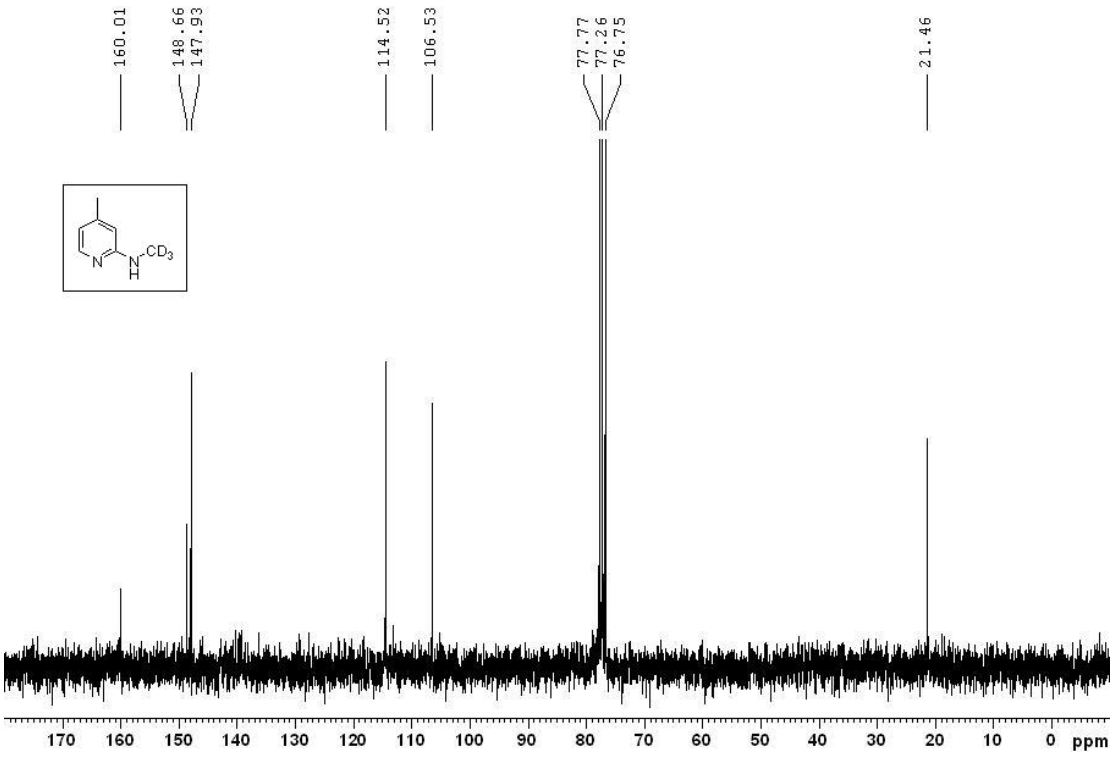
^{1}H and ^{13}C NMR spectra of new compound

^{1}H NMR of Compound **8-d_3**

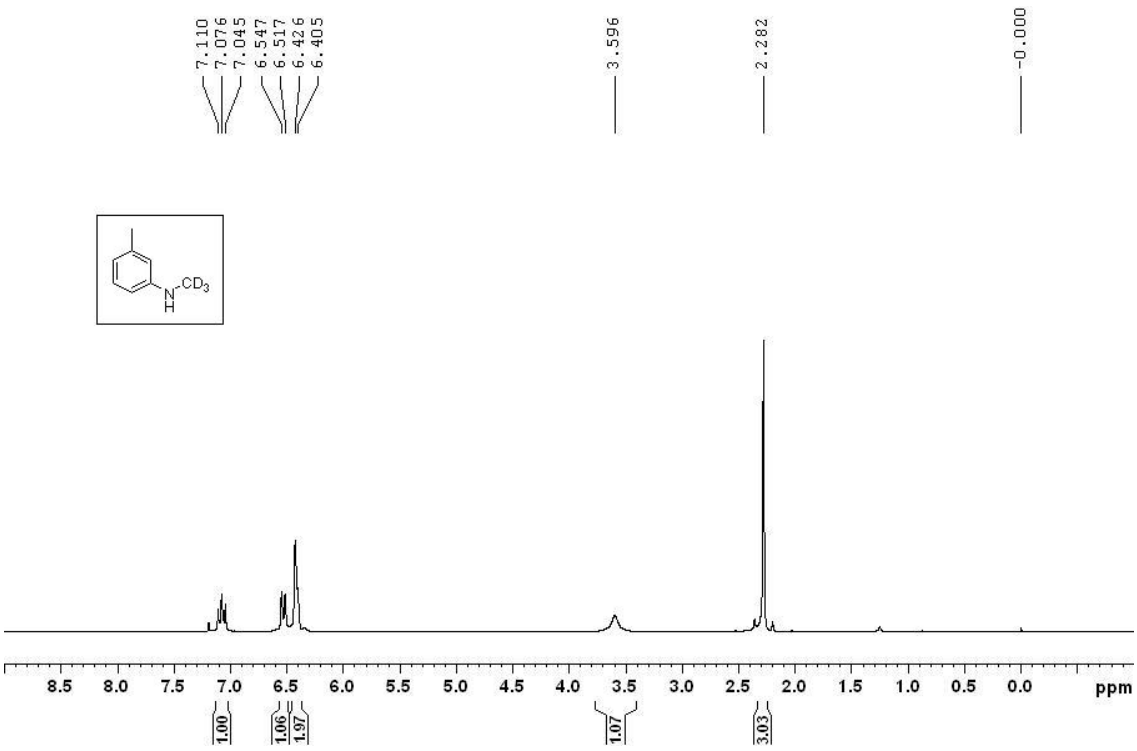


[7] C. Chen, K. M. Wilcoxen, C. Q. Huang, Y.-F. Xie, J. R. McCarthy, T. R. Webb, Y.-F. Zhu, J. Saunders, X.-J. Liu, T.-K. Chen, H. Bozigian and D. E. Grigoriadis, *J. Med. Chem.* 2004, **47**, 4787; C. P. Whittle, *Tetrahedron Letters* 1968, **9**, 3689.

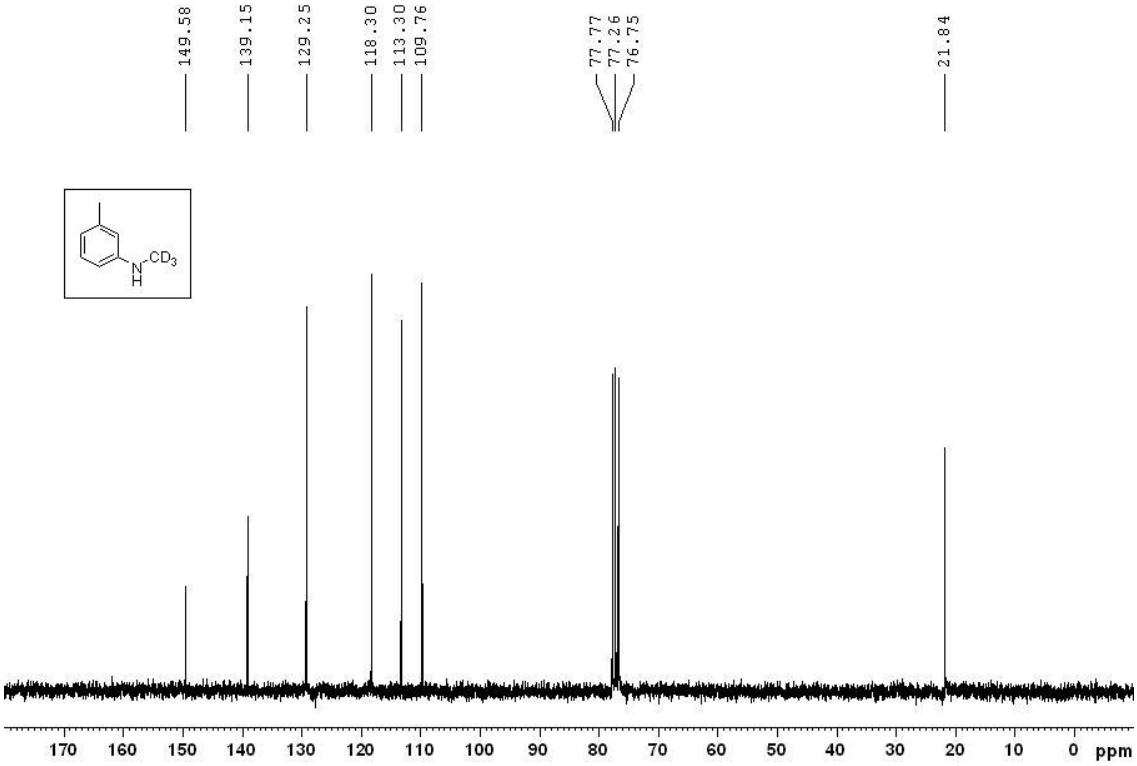
^{13}C NMR of Compound **8-d$_3$**



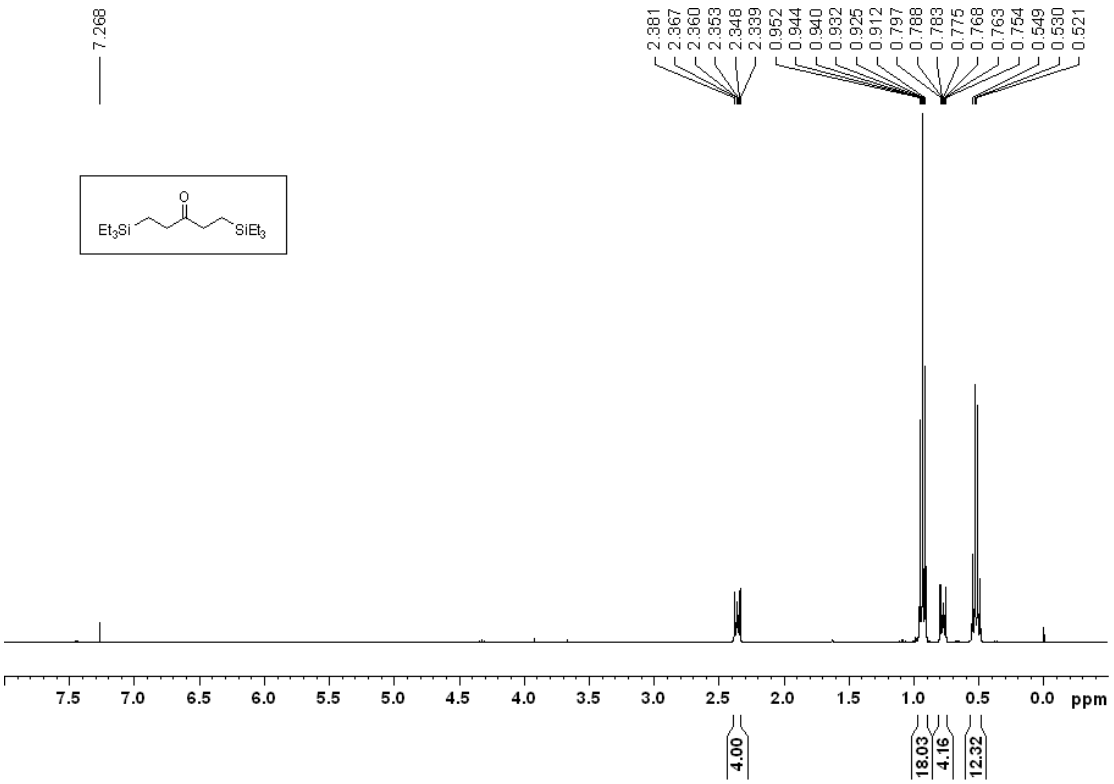
^{1}H NMR of Compound **11-d$_3$**



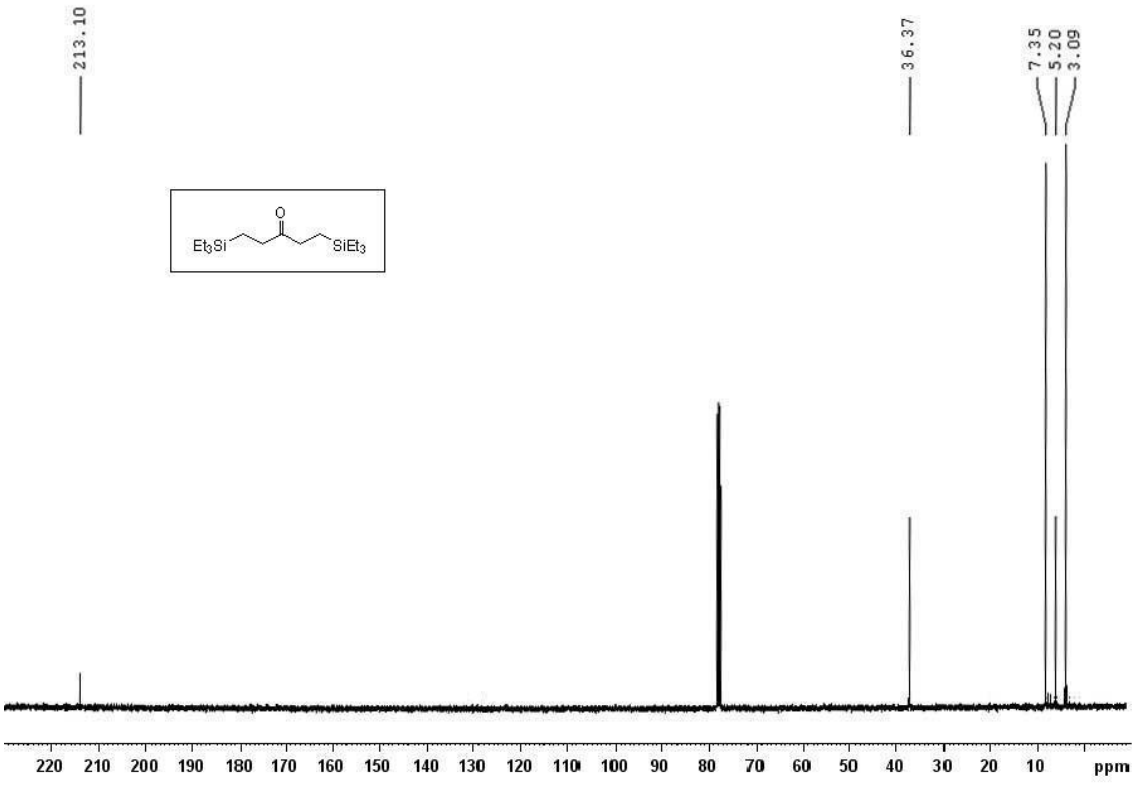
^{13}C NMR of Compound **11-d$_3$**



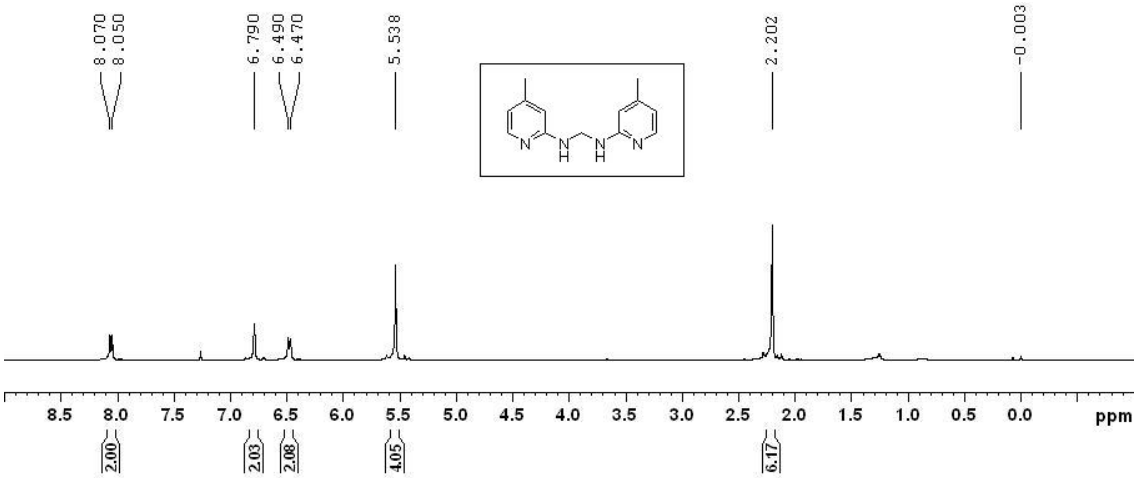
^{1}H NMR of Compound **5e**



^{13}C NMR of Compound **5e**



^{1}H NMR of aminal, *N*,*N'*-bis(4-methyl-2-pyridinyl)methandiamine, from paraformaldehyde and 2-amino-4-picoline (**3**)



^{13}C NMR of aminal, *N*,*N*'-bis(4-methyl-2-pyridinyl)methandiamine