

Electronic Supplementary Information

Facile synthesis of functionalized 6-cyano-2-oxa-7-azabicyclo[4.1.0]hept-3-en-1-yl acetate : a catalyst free approach to access the pyran fused 2-acetoxy-NH-aziridines

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Content	Page Numbers
Materials and method	S2
Experimental procedures	S3-S4
Spectral data	S5-S12
¹ H and ¹³ C NMR spectra of all compounds	S13-S56

Materials and Method

^1H -NMR and ^{13}C -NMR spectral analysis were carried out on Bruker-Advance Digital 300 MHz and 75 MHz instruments where tetramethylsilane (TMS) was used as internal standard. Infrared spectra were recorded in KBr pellets in reflection mode on a Perkin Elmer RX-1 FTIR spectrophotometer. High Resolution Mass Spectra were obtained using a QTOFMICRO YA263 mass spectrometer. Elemental analyses were done using an autoanalyzer. Suitable single crystals of compound 2a, 2h, 2j and 3b were mounted on a Bruker-AXS SMART APEX II diffractometer equipped with a graphite monochromator. All the reactions were monitored by thin layer chromatography carried out on Merck aluminum-blocked silica gel plates coated with silica gel G under UV light and also by exposure to iodine vapour for detection. Melting points were recorded on a Köfler Block apparatus and are uncorrected. Synthetic grade chemicals from Sigma-Aldrich, Spectrochem and E-Merck were used for carrying out the organic reactions. For column chromatography Spectrochem 100-200 mesh silica gel was used. All the organic solvents, used in the reaction, were distilled and dried over Na_2SO_4 .

Experimental procedures

General procedure for the synthesis of 4-H-pyrans.

Triethylamine (1 drop) was added to a solution of aromatic aldehydes (2 mmol), malononitrile (2 mmol), and 1,3-diketones (2 mmol) in EtOH (5 ml) and the reaction mixture was refluxed for 15 min. The precipitate that formed was filtered off, washed with water (5×10 ml) and EtOH (3×5 ml), and finally recrystallized from EtOH. The crystallized pure compounds were then subjected for the synthesis of chromeno[2,3-*b*]azirin-1a(1*H*)-yl acetates.

General procedure for the synthesis of spiropyrans.

Triethylamine (1 drop) was added to a solution of ninhydrin (2 mmol), malononitrile (2 mmol), and 1,3-diketones (2 mmol) in EtOH (5 ml) and the reaction mixture was refluxed for 15 min. The precipitate that formed was filtered off, washed with water (5×10 ml) and EtOH (3×5 ml), and finally recrystallized from EtOH. The crystallized pure compounds were then subjected for the synthesis of chromeno[2,3-*b*]azirin-1a(1*H*)-yl acetates.

General procedure for the synthesis of 6-cyano-2-oxa-7-azabicyclo[4.1.0]hept-3-en-1-yl acetate (2).

To a stirring suspension of 2-amino-3-cyano-4-*H*-pyrans (1 mmol) in 3 ml of DCM, 1.1 mmol of PIDA was added and stirring was continued at r.t. After the total consumption of the starting material, indicated by TLC (20-40 % ethyl acetate in petroleum ether), the reaction mixture was directly subjected for column chromatography (15- 30% ethyl acetate in petroleum ether) to afford the pure product. Same procedure was applied in case of 2-amino-3-cyano-spiropyrans. The isolated products were characterized by spectral (¹H NMR, ¹³C NMR, IR, HRMS), and X-ray crystallographic analysis.

General procedure for the synthesis of 6-cyano-2-oxa-7-azabicyclo[4.1.0]hept-3-en-1-yl carboxylate (3):

To a stirring mixture of 2-amino-3-cyano-4*H*-pyrans (1 mmol), triethylamine (2 mmol) and carboxylic acids (2 mmol) in 3 ml of DCM, 1.1 mmol of PIDA was added and stirring was continued at r.t. After the total consumption of the starting material, indicated by TLC (20-40% ethyl acetate in petroleum ether), the reaction mixture was directly subjected for column chromatography (15-30% ethyl acetate in petroleum ether) to afford the pure product. The isolated products were characterized by spectral (¹H NMR, ¹³C NMR, IR, HRMS), and X-ray crystallographic analysis.

7a-cyano-7-(4-nitrophenyl)-6-oxo-3,4,5,6,7,7a-hexahydrochromeno[2,3-b]azirin-1a(1H)-yl acetate (2a). Yield: (0.340g, 92%); Off-white solid; m.p. 190-192 °C; IR (KBr): cm^{-1} ; 3300, 3158, 2932, 2243, 1787, 1647, 1515, 1371, 1348, 1240, 1165, 1097, 995, 918, 862, 733, 597, 519; δ_{H} (300 MHz; CDCl_3 ; Me_4Si): δ 1.99-2.06 (m, 2H), 2.26-2.35 (m, 5H), 2.45 (s, 1H), 2.55 (d, $J=5.4$ Hz, 2H), 4.42 (s, 1H), 7.39 (d, $J=8.4$ Hz, 2H), 8.17 (d, $J=8.7$ Hz, 2H); δ_{C} (75 MHz; CDCl_3 ; Me_4Si): δ 20.1, 20.4, 28.0, 36.3, 36.8, 39.4, 42.6, 87.9, 109.6, 115.4, 123.8, 128.8, 144.3, 147.5, 166.1, 167.1, 195.8; HRMS (ESI-TOF) m/z Calcd for $[\text{C}_{18}\text{H}_{15}\text{N}_3\text{O}_6+\text{H}]^+$: 370.1034, found: 370.1032.

7a-cyano-6-oxo-7-phenyl-3,4,5,6,7,7a-hexahydrochromeno[2,3-b]azirin-1a(1H)-yl acetate (2b). Yield: (0.288g, 89%); Off white solid; m.p. 132-134 °C; IR (KBr): cm^{-1} ; 3175, 2963, 2238, 1791, 1631, 1372, 1238, 1229, 1152, 1100, 1063, 936, 870, 730, 700, 608, 519; δ_{H} (300 MHz; mixture of CDCl_3 and DMSO-d_6 ; Me_4Si): δ 1.81 (d, $J=4.8$ Hz, 2H), 2.00-2.10 (m, 5H), 2.33 (d, $J=3.6$ Hz, 2H), 4.12 (d, $J=11.7$ Hz, 1H), 4.44 (bs, 1H), 7.00-7.10 (m, 5H); δ_{C} (75 MHz; mixture of CDCl_3 and DMSO-d_6 ; Me_4Si): δ 19.9, 20.3, 27.9, 35.8, 36.8, 53.4, 88.1, 109.8, 116.2, 127.2, 127.6, 128.2, 137.4, 165.5, 167.2, 195.7; HRMS (ESI-TOF) m/z Calcd for $[\text{C}_{18}\text{H}_{16}\text{N}_2\text{O}_4+\text{H}]^+$: 325.1183, found: 325.1188.

7a-cyano-7-(furan-2-yl)-6-oxo-3,4,5,6,7,7a-hexahydrochromeno[2,3-b]azirin-1a(1H)-yl acetate (2c). Yield: (0.264g, 84%); Off-white solid; m.p. 126-128 °C; IR (KBr): cm^{-1} ; 3133, 2955, 2935, 2240, 1784, 1633, 1373, 1169, 1101, 1072, 949, 879, 745, 606, 519; δ_{H} (300 MHz; CDCl_3 ; Me_4Si): δ 1.92-1.98 (m, 2H), 2.19 (s, 3H), 2.29-2.51 (m, 5H), 4.63 (s, 1H), 6.16 (d, $J=3$ Hz, 1H), 6.28 (t, $J=2.4$ Hz, 1H), 7.29 (d, $J=0.6$ Hz, 1H); δ_{C} (75 MHz; CDCl_3 ; Me_4Si): δ 20.0,

20.4, 27.9, 33.4, 35.6, 36.8, 52.6, 87.6, 108.0, 110.6, 115.8, 142.7, 149.6, 165.2, 167.4, 195.6; HRMS (ESI-TOF) m/z Calcd for $[C_{16}H_{14}N_2O_5+H]^+$: 315.0975, found: 315.0981.

7a-cyano-7-(4-methoxyphenyl)-6-oxo-3,4,5,6,7,7a-hexahydrochromeno[2,3-*b*]azirin-1a(1*H*)-yl acetate (2d). Yield: (0.318g, 90%); White solid; m.p. 162-164 °C; IR (KBr): cm^{-1} ; 3244, 2958, 2237, 1782, 1666, 1644, 1513, 1371, 1234, 1166, 1101, 1069, 994, 930, 878, 605, 518; δ_H (300 MHz; $CDCl_3$; Me_4Si): δ 2.00-2.03 (m, 2H), 2.24-2.38 (m, 6H), 2.55 (d, $J=5.1$ Hz, 2H), 3.77 (s, 3H), 4.44 (s, 1H), 6.86 (d, $J=7.5$ Hz, 2H), 7.12 (d, $J=8.1$ Hz, 2H); δ_C (75 MHz; $CDCl_3$; Me_4Si): δ 19.9, 20.2, 27.7, 36.7, 36.8, 38.1, 54.9, 55.0, 87.9, 110.2, 114.0, 114.1, 116.0, 128.2, 128.3, 128.4, 128.5, 128.6, 159.0, 165.1, 167.1, 195.6; HRMS (ESI-TOF) m/z Calcd for $[C_{19}H_{18}N_2O_5+H]^+$: 355.1288, found: 355.1294.

6-(4-bromophenyl)-6a-cyano-5-oxo-1,3,4,5,6,6a-hexahydro-1aH-cyclopenta[5,6]pyrano[2,3-*b*]azirin-1a-yl acetate (2e). Yield: (0.350g, 90%); Off-white solid; m.p. 176-178 °C; IR (KBr): cm^{-1} ; 3262, 2935, 2249, 1794, 1707, 1499, 1409, 1375, 1227, 1094, 1001, 930, 870, 742, 730, 647, 604, 521, 503; δ_H (300 MHz; $CDCl_3$; Me_4Si): δ 2.29 (s, 3H), 2.45-2.48 (m, 2H), 2.68-2.700 (m, 3H), 4.18 (s, 1H), 7.13 (d, $J=8.1$ Hz, 2H), 7.50 (d, $J=7.8$ Hz, 2H); δ_C (75 MHz; $CDCl_3$; Me_4Si): δ 20.4, 25.6, 33.5, 38.0, 38.7, 90.6, 113.2, 115.4, 122.6, 129.9, 130.0, 131.9, 132.0, 132.1, 133.3, 167.0, 177.7, 201.0; HRMS (ESI-TOF) m/z Calcd for $[C_{17}H_{13}BrN_2O_4+Na]^+$: 410.9951, found: 410.9955.

7a-cyano-4,4-dimethyl-7-(3-nitrophenyl)-6-oxo-3,4,5,6,7,7a-hexahydrochromeno[2,3-*b*]azirin-1a(1*H*)-yl acetate (2f). Yield: (0.354g, 89%); White solid; m.p. 150-152 °C; IR (KBr): cm^{-1} ; 3235, 2956, 2249, 1794, 1668, 1644, 1531, 1371, 1351, 1158, 1098, 943, 919, 876, 727, 674, 617; δ_H (300 MHz; $CDCl_3$; Me_4Si): δ 1.02 (s, 3H), 1.07 (s, 3H), 2.16 (d, $J=3$ Hz, 2H), 2.21 (s, 3H), 2.40 (s, 3H), 4.39 (s, 1H), 7.47 (t, $J=7.9$ Hz, 1H), 7.61 (d, $J=7.8$ Hz, 1H), 7.93 (s,

1H), 8.08 (d, $J=8.1$ Hz, 1H); δ_C (75 MHz; $CDCl_3$; Me_4Si): δ 20.0, 27.8, 31.6, 36.1, 38.8, 41.2, 50.4, 87.7, 108.1, 115.1, 122.4, 122.5, 129.2, 134.2, 138.8, 148.1, 164.1, 166.7, 195.4; HRMS (ESI-TOF) m/z Calcd for $[C_{20}H_{19}N_3O_6+H]^+$: 398.1347, found: 398.1331.

7a-cyano-6-oxo-7-(thiophen-2-yl)-7a,8-dihydro-6H-chromeno[3',4':5,6]pyrano[2,3-*b*]azirin-8a(7H)-yl acetate (2g). Yield: (0.289g, 76%); Pale yellow solid; m.p. 136-138 °C; IR (KBr): cm^{-1} ; 3238, 2925, 2246, 1787, 1724, 1710, 1631, 1380, 1157, 1099, 1039, 759, 705; δ_H (300 MHz; $CDCl_3$; Me_4Si): δ 2.34 (s, 3H), 2.73 (s, 1H), 5.04 (s, 1H), 7.02-7.05 (m, 1H), 7.16 (d, $J=3.3$ Hz, 1H), 7.26-7.36 (m, 3H), 7.60 (t, $J=7.2$ Hz, 1H), 7.83 (d, $J=6.9$ Hz, 1H); δ_C (75 MHz; $CDCl_3$; Me_4Si): δ 20.4, 36.5, 37.1, 88.9, 100.3, 113.5, 115.3, 116.8, 123.0, 124.4, 125.8, 127.1, 133.0, 137.6, 152.6, 154.4, 158.7, 159.9, 167.1, 170.9; Anal. Calcd for $C_{19}H_{12}N_2O_5S$: C 60.00; H 3.18; N 7.36%. Found: C 60.02; H 3.16; N 7.34%.

7a-cyano-7-(4-methoxyphenyl)-6-oxo-7a,8-dihydro-6H-chromeno[3',4':5,6]pyrano[2,3-*b*]azirin-8a(7H)-yl acetate (2h). Yield: (0.364g 90%); Off-white solid; m.p. 192-194 °C; IR (KBr): cm^{-1} ; 3258, 2844, 2248, 1806, 1726, 1638, 1610, 1509, 1380, 1249, 1183, 1161, 1112, 1100, 1023, 946, 763, 720, 568, 541; δ_H (300 MHz; $CDCl_3$; Me_4Si): δ 2.32 (s, 3H), 2.62 (s, 1H), 3.80 (s, 3H), 4.64 (s, 1H), 6.90 (d, $J=8.7$ Hz, 2H), 7.20-7.36 (m, 4H), 7.59 (t, $J=7.8$ Hz, 1H), 7.83 (d, $J=7.7$ Hz, 1H); δ_C (75 MHz; $CDCl_3$; Me_4Si): δ 20.4, 37.3, 39.9, 55.3, 88.9, 100.5, 113.6, 114.4, 115.7, 116.7, 122.8, 124.3, 127.7, 129.0, 132.7, 152.6, 155.0, 159.6, 160.0, 167.1; HRMS (ESI-TOF) m/z Calcd for $[C_{22}H_{16}N_2O_6+H]^+$: 405.1081, found: 405.1090.

7-(4-bromophenyl)-7a-cyano-6-oxo-7a,8-dihydro-6H-chromeno[3',4':5,6]pyrano[2,3-*b*]azirin-8a(7H)-yl acetate (2i). Yield: (0.398g, 88%); Off-white solid; m.p. 168-170 °C; IR (KBr): cm^{-1} ; 3310, 3069, 3051, 2926, 2241, 1768, 1712, 1645, 1489, 1384, 1241, 1163, 1108, 1024, 965, 920, 868, 762, 564, 501; δ_H (300 MHz; $CDCl_3$; Me_4Si): δ 2.26 (s, 3H), 2.62 (s, 1H),

4.52 (s, 1H), 7.12 (d, $J=8.1$ Hz, 2H), 7.19-7.29 (m, 2H), 7.43 (d, $J=8.4$ Hz, 2H), 7.53 (t, $J=7.8$ Hz, 1H), 7.77 (d, $J=7.8$ Hz, 1H); δ_C (75 MHz; $CDCl_3$; Me_4Si): δ 20.0, 36.5, 39.9, 88.4, 99.5, 113.2, 114.9, 116.4, 122.1, 122.5, 124.1, 129.3, 129.4, 131.7, 132.6, 134.4, 152.2, 154.9, 159.7, 166.7; HRMS (ESI-TOF) m/z Calcd for $[C_{21}H_{13}BrN_2O_5+H]^+$: 453.0081, found: 453.0079.

7a-cyano-7-isopropyl-6-oxo-7a,8-dihydro-6H-chromeno[3',4':5,6]pyrano[2,3-*b*]azirin-8a(7H)-yl acetate (2j). Yield: (0.289g, 85%); White solid; m.p. 174-176 °C; IR (KBr): cm^{-1} ; 3208, 2960, 2243, 1779, 1698, 1632, 1394, 1176, 1112, 1097, 1056, 979, 940, 878, 757; δ_H (300 MHz; $DMSO-d_6$; Me_4Si): δ 0.92 (d, $J=5.4$ Hz, 3H), 1.11 (d, $J=5.7$ Hz, 3H), 2.26 (s, 3H), 2.48 (s, 1H), 3.31 (s, 1H), 6.34 (s, 1H), 7.36-7.45 (m, 2H), 7.68 (t, $J=7.7$ Hz, 1H), 7.75 (d, $J=7.8$ Hz, 1H); δ_C (75 MHz; $DMSO-d_6$; Me_4Si): δ 19.3, 20.2, 20.6, 29.8, 31.5, 88.7, 101.6, 113.8, 116.8, 117.7, 122.9, 125.1, 133.4, 152.1, 155.5, 160.9, 168.4; HRMS (ESI-TOF) m/z Calcd for $[C_{18}H_{16}N_2O_5+H]^+$: 341.1132, found: 341.1137.

7a-cyano-7-isopropyl-4-methyl-6-oxo-7,7a-dihydro-6H-pyrano[3',4':5,6]pyrano[2,3-*b*]azirin-1a(1H)-yl acetate (2k). Yield: (0.256g, 84%); White solid; m.p. 178-180 °C; IR (KBr): cm^{-1} ; 3236, 2956, 2248, 1781, 1714, 1598, 1398, 1251, 1169, 1090, 953, 883, 669; δ_H (300 MHz; $CDCl_3$; Me_4Si): δ 0.91 (d, $J=6.9$ Hz, 3H), 1.18 (d, $J=6.9$ Hz, 3H), 2.15 (s, 3H), 2.18 (s, 3H), 2.49 (s, 1H), 2.56-2.63 (m, 1H), 3.31 (d, $J=6.3$ Hz, 1H), 5.72 (s, 1H); δ_C (75 MHz; $CDCl_3$; Me_4Si): δ 18.8, 19.7, 20.1, 20.3, 29.4, 33.4, 38.3, 87.7, 98.5, 98.9, 117.0, 159.9, 161.6, 162.9, 167.3; HRMS (ESI-TOF) m/z Calcd for $[C_{15}H_{16}N_2O_5+H]^+$: 305.1132, found: 305.1149.

7-(4-bromophenyl)-7a-cyano-4-methyl-6-oxo-7,7a-dihydro-6H-pyrano[3',4':5,6]pyrano[2,3-*b*]azirin-1a(1H)-yl acetate (2l). Yield: (0.358g, 86%); pale yellow solid; m.p. 170-172 °C; IR (KBr): cm^{-1} ; 3241, 3120, 2245, 1794, 1727, 1694, 1594, 1170, 1158, 1100, 503; δ_H (300 MHz; $CDCl_3$; Me_4Si): δ 2.22 (s, 3H), 2.28 (s, 3H), 2.50 (s, 1H), 4.43 (s, 1H), 5.85 (s, 1H), 7.16 (d,

$J=8.4$ Hz, 2H), 7.49 (d, $J=8.1$ Hz, 2H); δ_C (75 MHz; CDCl_3 ; Me_4Si): δ 19.8, 20.3, 37.0, 39.7, 88.3, 96.8, 98.7, 115.4, 122.4, 129.7, 132.0, 134.7, 159.7, 162.6, 167.0; HRMS (ESI-TOF) m/z Calcd for $[\text{C}_{18}\text{H}_{13}\text{BrN}_2\text{O}_5+\text{H}]^+$: 438.9900, found: 438.9864.

7a-cyano-7-(4-cyanophenyl)-4-methyl-6-oxo-7,7a-dihydro-6H-pyrano[3',4':5,6]pyrano[2,3-b]azirin-1a(1H)-yl acetate (2m). Yield: (0.320g, 88%); Off-white solid; m.p. 184-186 °C; IR (KBr): cm^{-1} ; 3229, 2928, 2243, 2221, 1784, 1707, 1599, 1446, 1386, 1239, 1167, 1156, 1103, 1038, 916, 867, 827, 757, 578, 552; δ_H (300 MHz; CDCl_3 ; Me_4Si): δ 2.17 (s, 3H), 2.23 (s, 3H), 2.57 (s, 1H), 4.41 (s, 1H), 5.81 (s, 1H), 7.34 (d, $J=8.1$ Hz, 2H), 7.59 (d, $J=8.1$ Hz, 2H); δ_C (75 MHz; CDCl_3 ; Me_4Si): δ 19.5, 20.0, 36.4, 40.0, 87.9, 96.0, 98.4, 111.8, 114.7, 118.2, 128.6, 132.2, 140.7, 159.6, 161.4, 162.6, 166.6; HRMS (ESI-TOF) m/z Calcd for $[\text{C}_{19}\text{H}_{13}\text{N}_3\text{O}_5+\text{H}]^+$: 364.0928, found: 364.0922.

7a-cyano-1',3',6-trioxo-1,1',3,3',4,5,6,7a-octahydro-1aH-spiro[chromeno[2,3-b]azirine-7,2'-inden]-1a-yl acetate (2n). Yield: (0.333g, 88%); Off-white solid; m.p. 190-192 °C; IR (KBr): cm^{-1} ; 3247, 2967, 2939, 2249, 1790, 1752, 1713, 1665, 1644, 1369, 1249, 1214, 1174, 1106, 1044, 1031, 942, 907, 773, 648, 609; δ_H (300 MHz; mixture of CDCl_3 and DMSO-d_6 ; Me_4Si): δ 1.96-1.99 (m, 2H), 2.17 (s, 3H), 2.22 (d, $J=5.1$ Hz, 2H), 2.46-2.61(m, 2H), 5.84 (s, 1H), 7.88-7.99 (m, 4H); δ_C (75 MHz; DMSO-d_6 ; Me_4Si): δ 19.6, 20.1, 27.7, 35.3, 35.5, 54.0, 86.7, 109.8, 113.1, 123.3, 123.5, 135.9, 136.2, 140.6, 140.7, 166.3, 169.8, 193.9, 195.6, 195.8; HRMS (ESI-TOF) m/z Calcd for $[\text{C}_{20}\text{H}_{14}\text{N}_2\text{O}_6+\text{H}]^+$: 379.0925, found: 379.0926.

6a-cyano-1',3',5-trioxo-1,1',3',4,5,6a-hexahydro-1aH,3H-spiro[cyclopenta[5,6]pyrano[2,3-b]azirine-6,2'-inden]-1a-yl acetate (2o). Yield: (0.313g, 86%); Off-white solid; m.p. 216-218 °C; IR (KBr): cm^{-1} ; 3231, 2935, 2243, 1788, 1751, 1715, 1697, 1649, 1589, 1440, 1373, 1285, 1235, 1158, 1040, 910, 881, 863, 828, 764, 647, 614; δ_H (300 MHz; DMSO-d_6 ; Me_4Si): δ 2.16 (s,

3H), 2.29 (s, 1H), 2.38 (s, 1H), 2.57-2.77 (m, 2H), 6.79 (s, 1H), 8.04 (s, 4H); δ_C (75 MHz; DMSO- d_6 ; Me $_4$ Si): δ 20.2, 21.1, 26.3, 31.2, 32.7, 34.9, 55.0, 89.2, 101.6, 112.0, 113.5, 120.4, 124.1, 124.3, 132.6, 135.8, 137.7, 138.1, 141.0, 141.2, 166.9, 172.1, 181.2, 188.9, 193.1, 195.3, 200.6, 200.7; HRMS (ESI-TOF) m/z Calcd for [C $_{19}$ H $_{12}$ N $_2$ O $_6$ +H] $^+$: 365.0768, found: 365.0774.

7-(2-chlorophenyl)-7a-cyano-6-oxo-3,4,5,6,7,7a-hexahydrochromeno[2,3-b]azirin-1a(1H)-yl acetate (2p). Yield: (0.337g, 94%); White solid; m.p. 142-144 °C; IR (KBr):cm $^{-1}$; 3217, 2956, 2937, 2244, 1788, 1668, 1626, 1474, 1432, 1372, 1234, 1175, 1102, 1064, 997, 871, 768, 738, 618, 459; δ_H (300 MHz; CDCl $_3$; Me $_4$ Si): δ 1.90-1.98 (m, 2H), 2.18 (s, 3H), 2.24 (t, $J=6.2$ Hz, 2H), 2.36 (s, 1H), 2.50 (t, $J=5.3$ Hz, 2H), 5.06 (s, 1H), 6.87 (d, $J=7.5$ Hz, 1H), 7.04-7.16 (m, 2H), 7.38 (d, $J=7.8$ Hz, 1H); δ_C (75 MHz; CDCl $_3$; Me $_4$ Si): δ 19.8, 20.1, 27.5, 34.4, 35.2, 36.5, 87.8, 110.6, 115.6, 126.2, 128.5, 128.8, 129.4, 133.7, 134.3, 165.5, 166.9, 195.1; HRMS (ESI-TOF) m/z Calcd for [C $_{18}$ H $_{15}$ ClN $_2$ O $_4$ +H] $^+$: 359.0793, found: 359.0799.

7a-cyano-7-(furan-2-yl)-6-oxo-7a,8-dihydro-6H-chromeno[3',4':5,6]pyrano[2,3-b]azirin-8a(7H)-yl acetate (2q). Yield: (0.313g, 86%); Pale yellow solid; m.p. 142-144 °C; IR (KBr):cm $^{-1}$; 3251, 2932, 2245, 1781, 1707, 1635, 1611, 1391, 1375, 1158, 1100, 926, 785, 608, 449; δ_H (300 MHz; CDCl $_3$; Me $_4$ Si): δ 2.33 (s, 3H), 2.80 (s, 1H), 4.91 (s, 1H), 6.40 (d, $J=4.1$ Hz, 2H), 7.31-7.36 (m, 2H), 7.40 (s, 1H), 7.60 (t, $J=7.8$ Hz, 1H), 7.80-7.83 (m, 1H); δ_C (75 MHz; CDCl $_3$; Me $_4$ Si): δ 20.4, 34.9, 35.9, 88.3, 98.1, 108.9, 110.9, 113.5, 115.3, 116.8, 122.8, 124.5, 133.1, 143.1, 148.3, 152.6, 154.8, 159.9, 167.3; HRMS (ESI-TOF) m/z Calcd for [C $_{19}$ H $_{12}$ N $_2$ O $_6$ +Na] $^+$: 387.0588, found: 387.0623.

7a-cyano-7-(4-nitrophenyl)-6-oxo-7a,8-dihydro-6H-chromeno[3',4':5,6]pyrano[2,3-b]azirin-8a(7H)-yl acetate (2r). Yield: (0.377g, 90%); Off-white solid; m.p. 222-224 °C; IR (KBr):cm $^{-1}$; 3419, 2924, 2259, 1698, 1634, 1520, 1347, 1164, 1107, 1050, 1025, 758, 504, 450; δ_H (300

MHz; mixture of CDCl₃ and DMSO-d₆; Me₄Si): δ 2.22 (s, 3H), 4.57 (s, 1H), 5.83 (s, 1H), 7.19-7.28 (m, 2H), 7.43-7.54 (m, 4H), 7.76 (d, *J*=8.1 Hz, 1H), 8.09 (d, *J*=8.7 Hz, 1H); δ_C (75 MHz; mixture of CDCl₃ and DMSO-d₆; Me₄Si): δ 18.9, 25.2, 40.2, 64.9, 93.8, 104.1, 118.3, 120.0, 121.3, 127.8, 128.3, 129.3, 134.0, 137.8, 148.8, 152.3, 157.2, 160.4, 164.9, 172.0; HRMS (ESI-TOF) *m/z* Calcd for [C₂₁H₁₃N₃O₇+H]⁺: 420.0826, found: 420.0832.

7a-cyano-7-(4-nitrophenyl)-6-oxo-3,4,5,6,7,7a-hexahydrochromeno[2,3-b]azirin-1a(1H)-yl cyclohexanecarboxylate (3a); Yield: (0.175g, 40%); White solid; m.p. 208 °C; IR (KBr):cm⁻¹; 3310, 2942, 2921, 2854, 2247, 1773, 1663, 1643, 1515, 1370, 1348, 1169, 1095, 731, 525; δ_H (300 MHz; DMSO-d₆; Me₄Si): δ 1.27-2.58 (m, 17H), 4.51 (s, 1H), 5.91 (s, 1H), 7.49 (d, *J*=8.4 Hz, 2H), 8.19 (d, *J*=8.1 Hz, 2H) ; δ_C (75 MHz; DMSO-d₆; Me₄Si): δ 20.3, 24.7, 24.9, 25.5, 28.0, 28.3, 28.7, 35.6, 36.9, 41.8, 88.3, 109.4, 116.2, 123.8, 129.6, 146.4, 147.2, 166.7, 172.5, 196.1; Anal. Calcd for C₂₃H₂₃N₃O₆: C 63.15; H 5.30; N 9.61%. Found: C 63.12; H 5.32; N 9.64%.

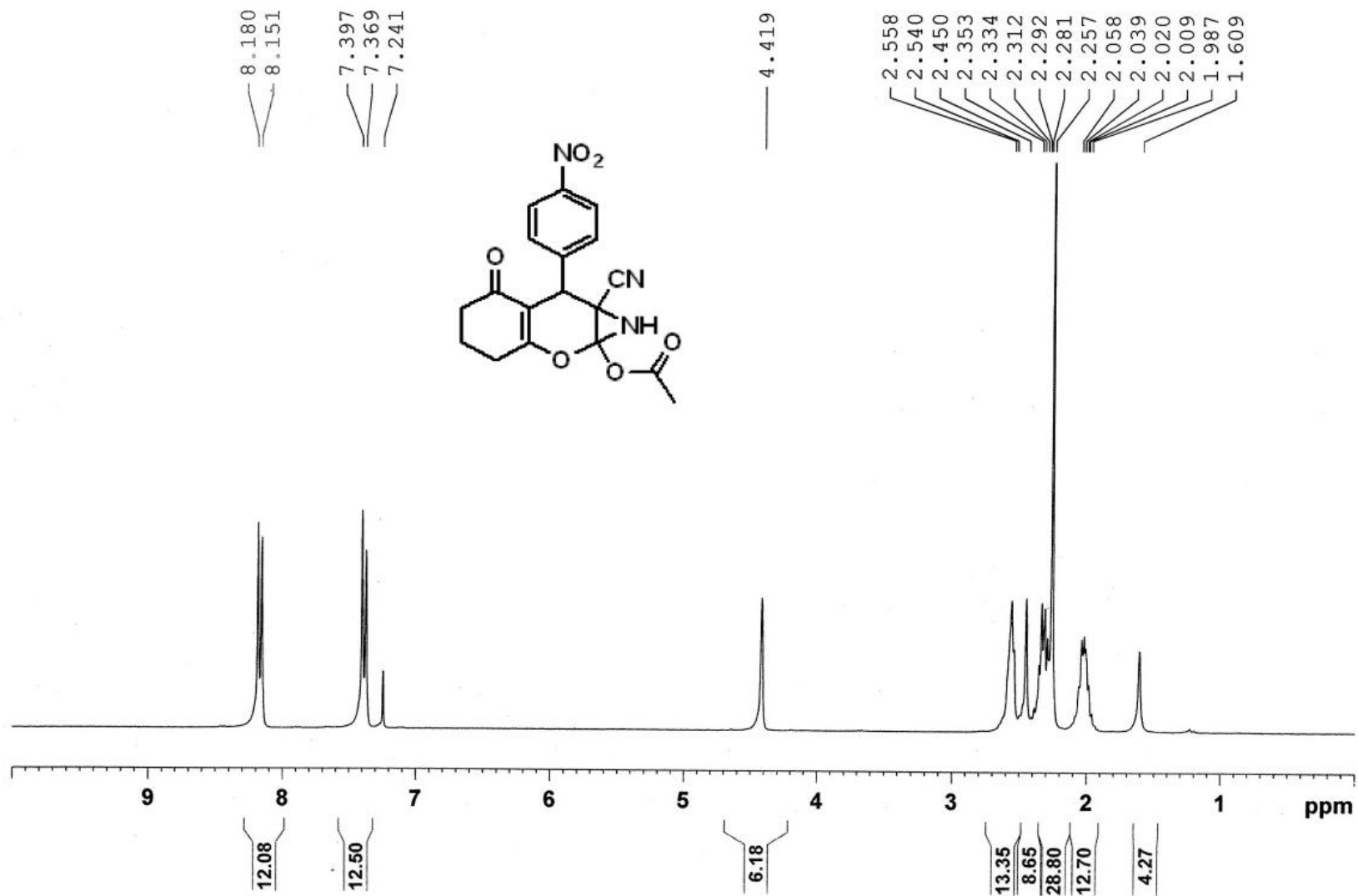
7a-cyano-7-(4-nitrophenyl)-6-oxo-3,4,5,6,7,7a-hexahydrochromeno[2,3-b]azirin-1a(1H)-yl 2-phenylacetate (3b). Yield: (0.111g, 25%); White solid; m.p. 204-206 °C; IR (KBr):cm⁻¹; 3114, 2956, 2243, 1788, 1653, 1632, 1515, 1375, 1347, 1236, 1091, 995, 706, 526; δ_H (300 MHz; DMSO-d₆; Me₄Si): δ 2.02 (s, 2H), 2.27-2.55 (m, 5H), 3.83 (s, 2H), 4.41 (s, 1H), 7.30-7.39 (m, 7H), 8.17 (d, *J*=8.7 Hz, 2H); δ_C (75 MHz; DMSO-d₆; Me₄Si): δ 15.3, 23.2, 31.5, 32.0, 34.5, 35.6, 83.3, 104.8, 110.6, 119.1, 123.1, 124.05, 124.1, 124.6, 126.6, 139.5, 142.7, 161.4, 163.4, 191.0; Anal. Calcd for C₂₄H₁₉N₃O₆: C 64.72; H 4.30; N 9.43%. Found: C 64.74; H 4.32; N 9.40%.

7a-cyano-7-(4-nitrophenyl)-6-oxo-3,4,5,6,7,7a-hexahydrochromeno[2,3-b]azirin-1a(1H)-yl 2,2-diphenylacetate (3c). Yield: (0.115g, 22%); White solid; m.p. 162-164 °C; IR (KBr):cm⁻¹; 3138, 2922, 2242, 1781, 1657, 1629, 1237, 1093, 1345, 1237, 1210, 1039, 995, 937, 755, 705, 694, 624, 617; δ_H (300 MHz; mixture of CDCl₃ and DMSO-d₆; Me₄Si): δ 1.96 (d, *J*=6.6 Hz,

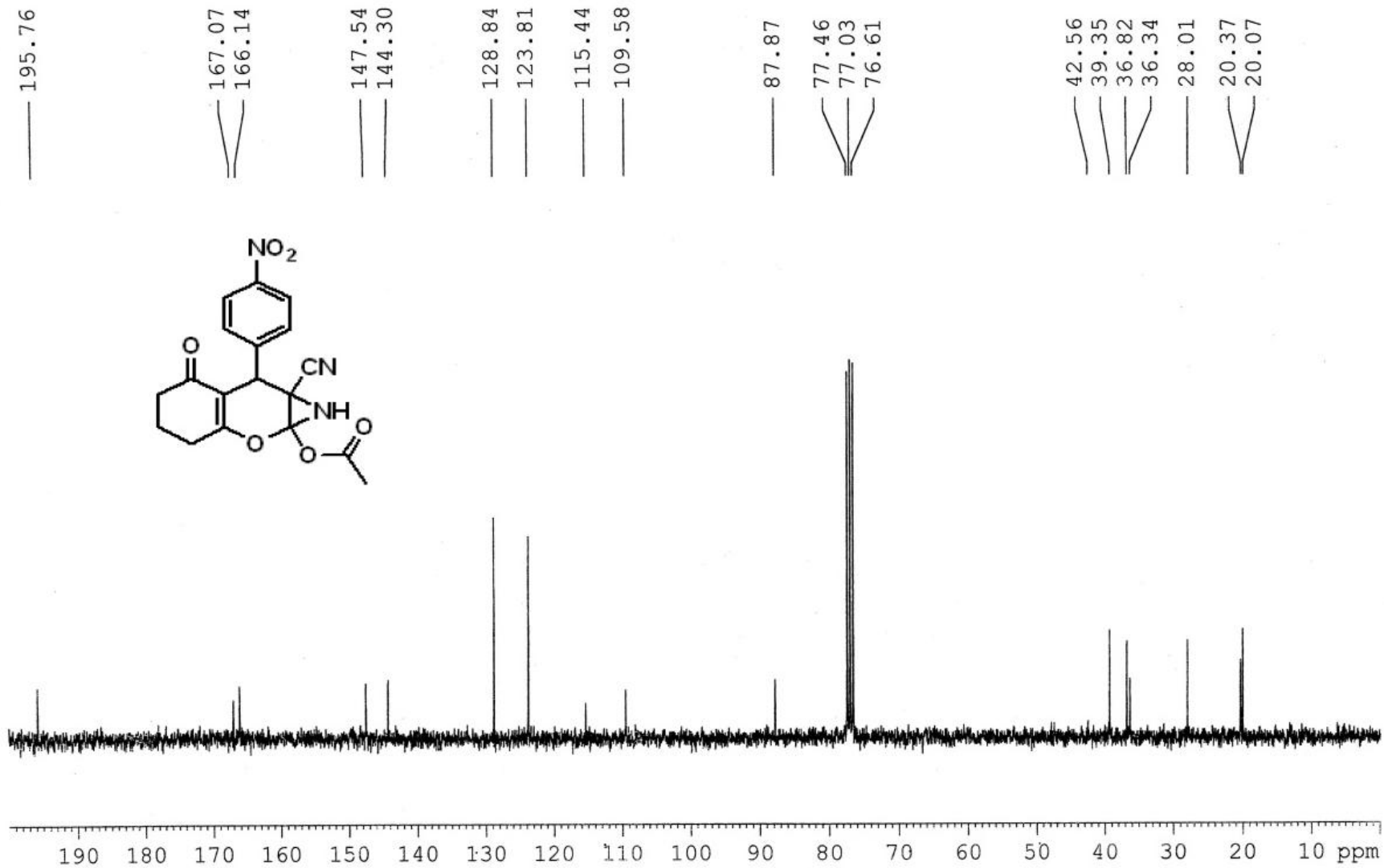
2H), 2.24 (t, $J=6.3$ Hz, 2H), 2.488 (s, 2H), 4.32 (s, 1H), 4.88 (s, 1H), 5.14 (s, 1H), 7.27-7.37 (m, 12H), 8.10 (d, $J=8.4$ Hz, 2H); δ_C (75 MHz; mixture of $CDCl_3$ and $DMSO-d_6$; Me_4Si): δ 19.9, 27.9, 29.5, 35.3, 36.7, 56.1, 88.4, 109.4, 115.6, 123.4, 127.7, 128.3, 128.4, 128.5, 128.56, 128.6, 128.7, 128.8, 136.7, 145.0, 147.1, 166.3, 169.3, 195.9; Anal. Calcd for $C_{30}H_{23}N_3O_6$: C 69.09; H 4.45; N 8.06%. Found: C 69.08; H 4.42; N 8.08%.

7a-cyano-7-(4-nitrophenyl)-6-oxo-7a,8-dihydro-6H-chromeno[3',4':5,6]pyrano[2,3-b]azirin-8a(7H)-yl cyclohexanecarboxylate (3r). Yield: (0.171g, 35%); White solid; m.p. 168-170 °C; IR (KBr): cm^{-1} ; 3166, 2936, 2245, 1779, 1706, 1631, 1520, 1384, 1351, 1237, 1166, 1104, 1055, 768, 568; δ_H (300 MHz; $DMSO-d_6$; Me_4Si): δ 1.12-1.83 (m, 10H), 2.50 (s, 1H), 4.86 (s, 1H), 6.25 (s, 1H), 7.27-7.57 (m, 5H), 7.66-7.69 (m, 5H), 7.68 (d, $J=7.8$ Hz, 1H), 8.08 (d, $J=8.1$ Hz, 2H); δ_C (75 MHz; $DMSO-d_6$; Me_4Si): δ 24.7, 24.8, 25.5, 28.3, 28.6, 35.7, 41.8, 89.3, 100.0, 113.7, 115.6, 117.0, 123.1, 124.0, 125.3, 129.9, 131.3, 133.7, 145.1, 147.6, 152.4, 155.3, 160.0, 172.5; HRMS (ESI-TOF) m/z Calcd for $[C_{26}H_{21}N_3O_7+Na]^+$: 510.1272, found: 510.1208. Anal. Calcd for $C_{26}H_{21}N_3O_7$: C 64.06; H 4.34; N 8.62%. Found: C 64.04; H 4.32; N 8.64%.

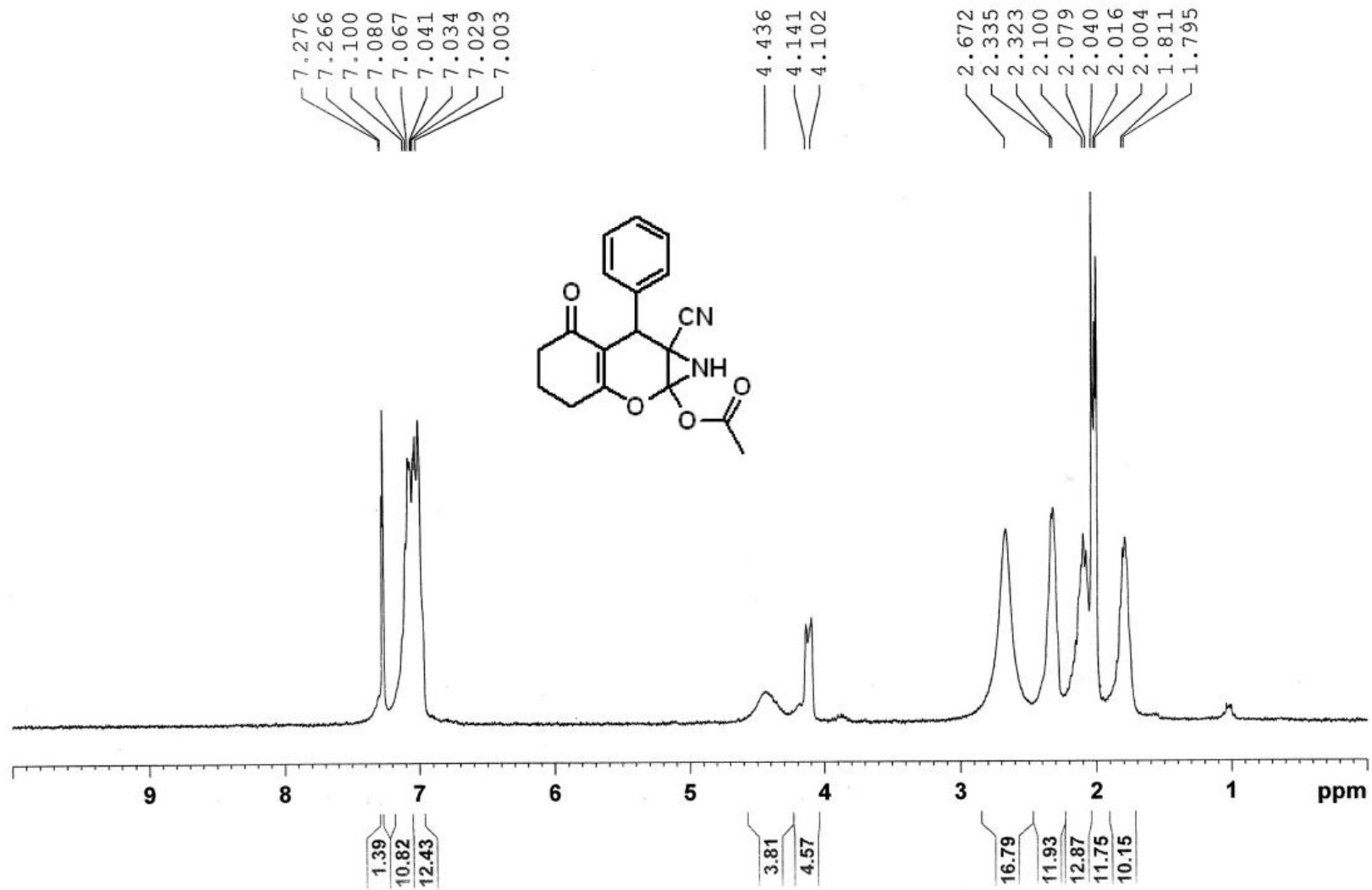
Spectra (^1H NMR and ^{13}C NMR):



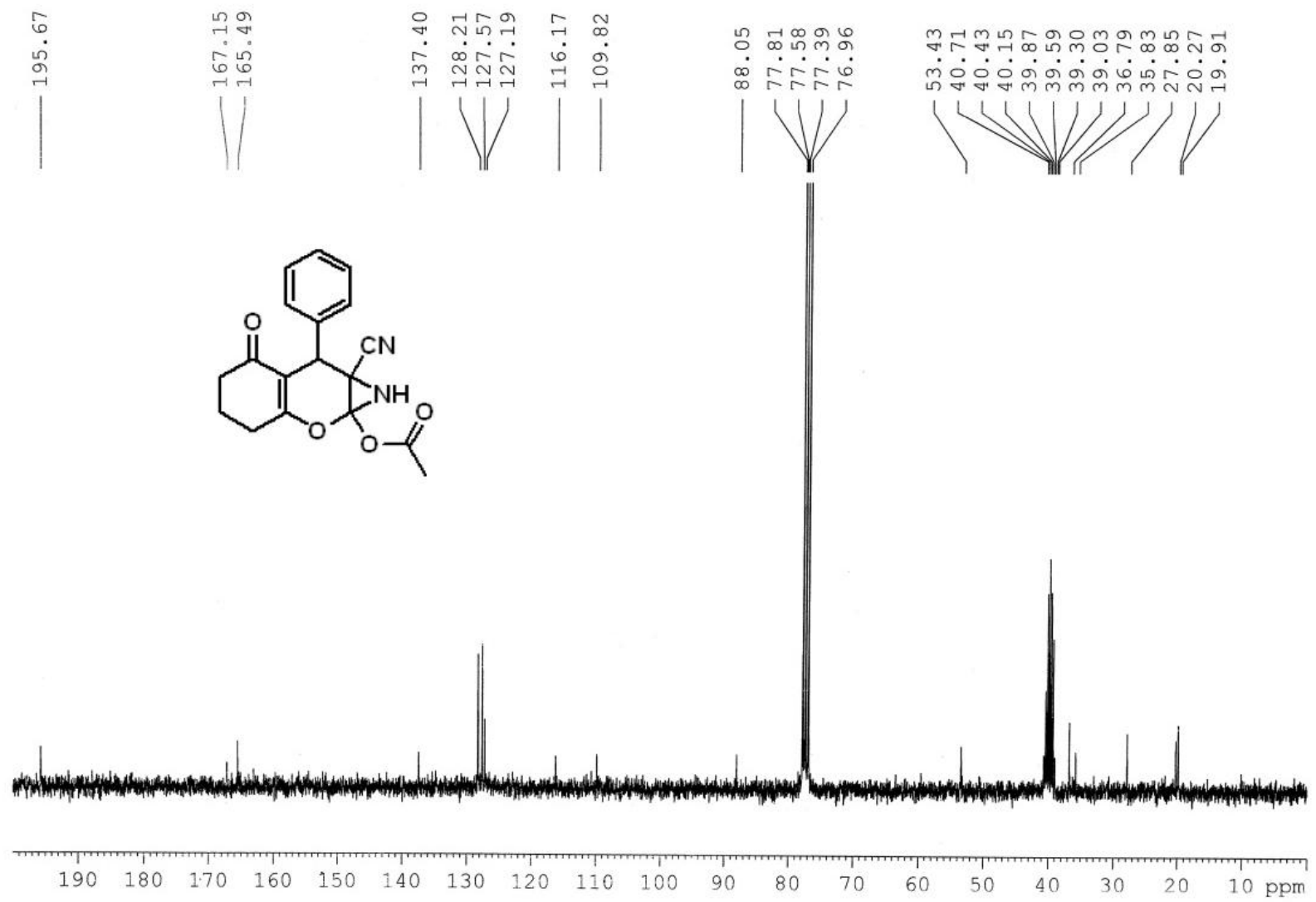
^1H NMR of 2a



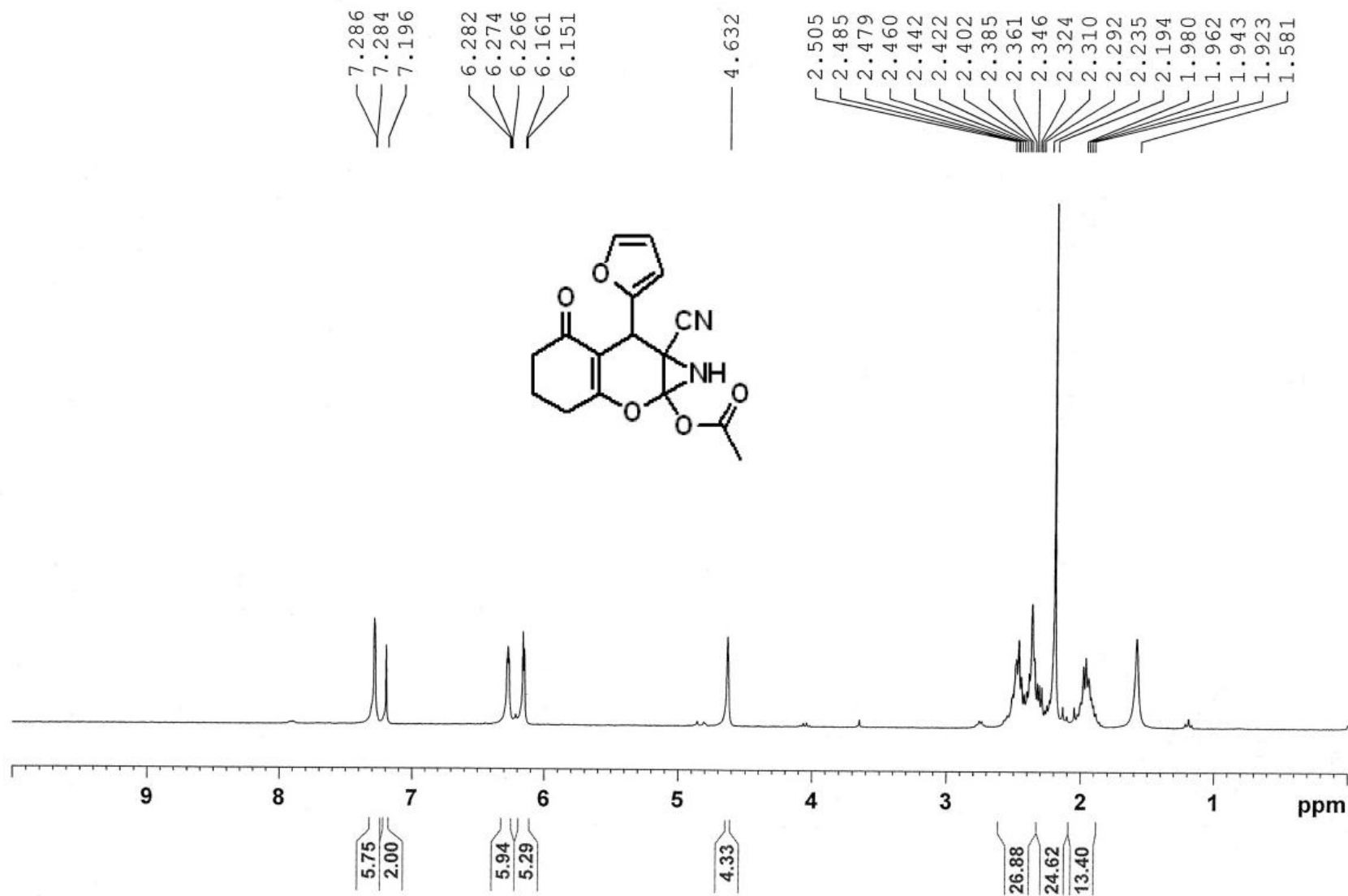
^{13}C NMR of 2a



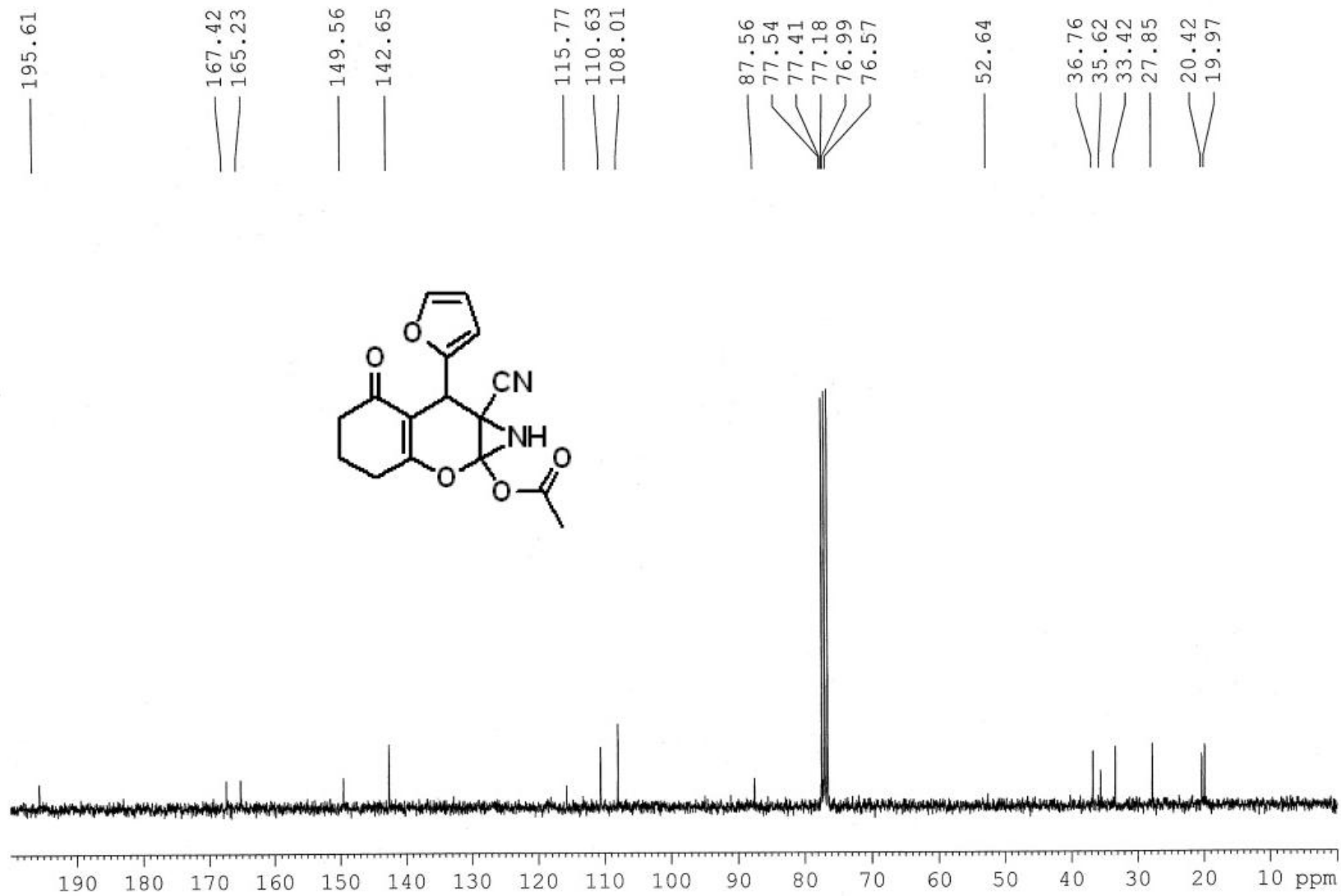
^1H NMR of 2b



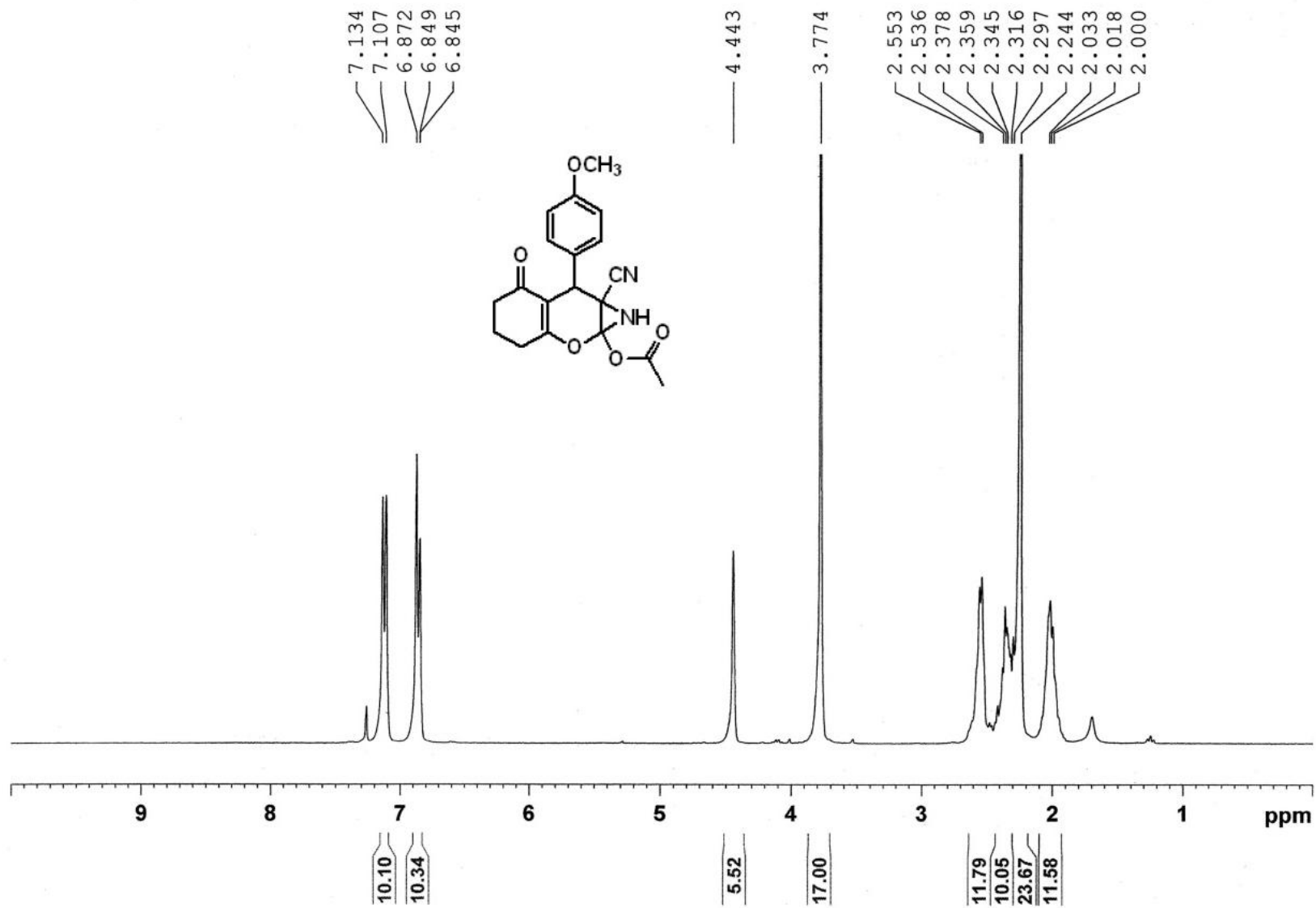
¹³C NMR of 2b



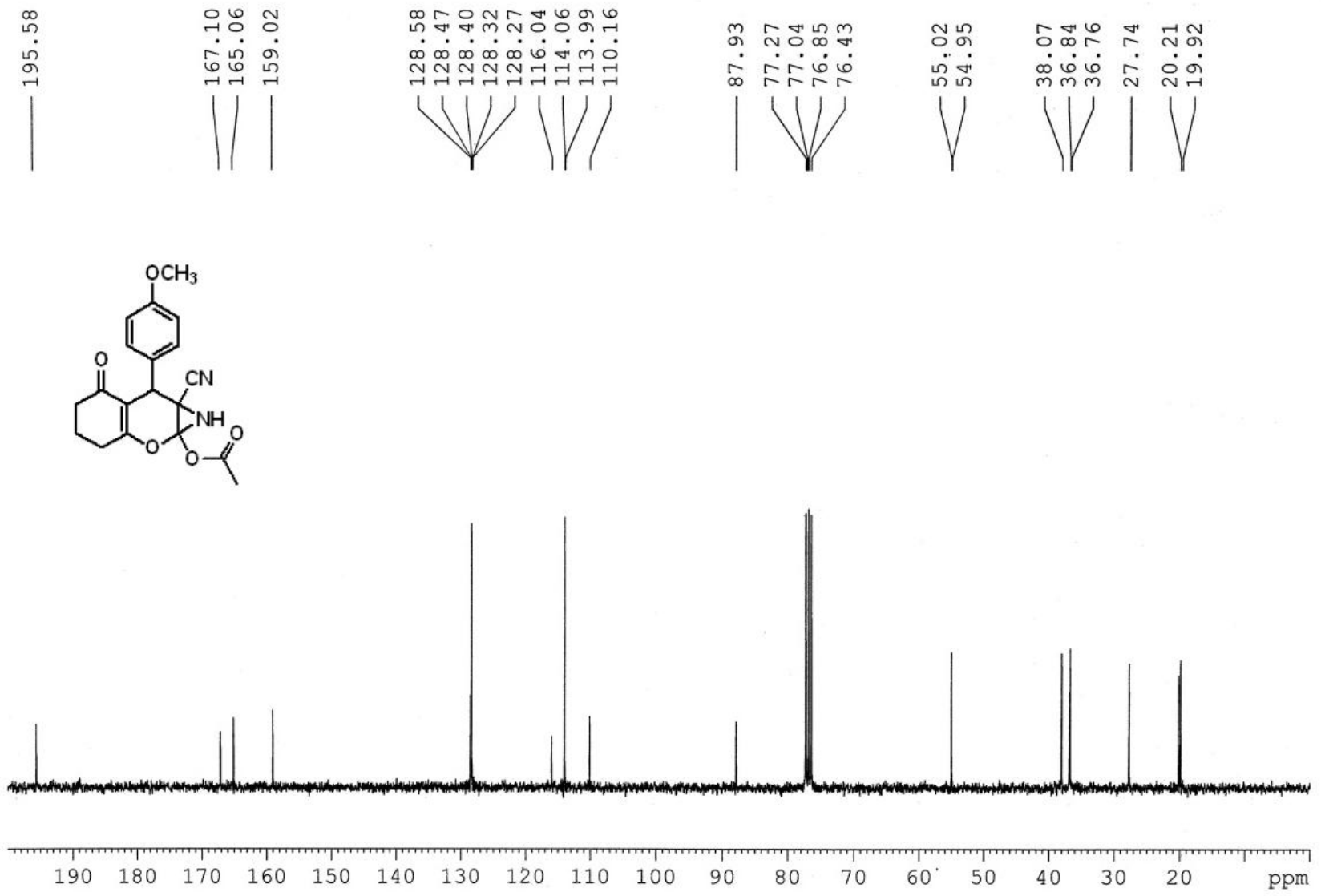
¹H NMR of 2c



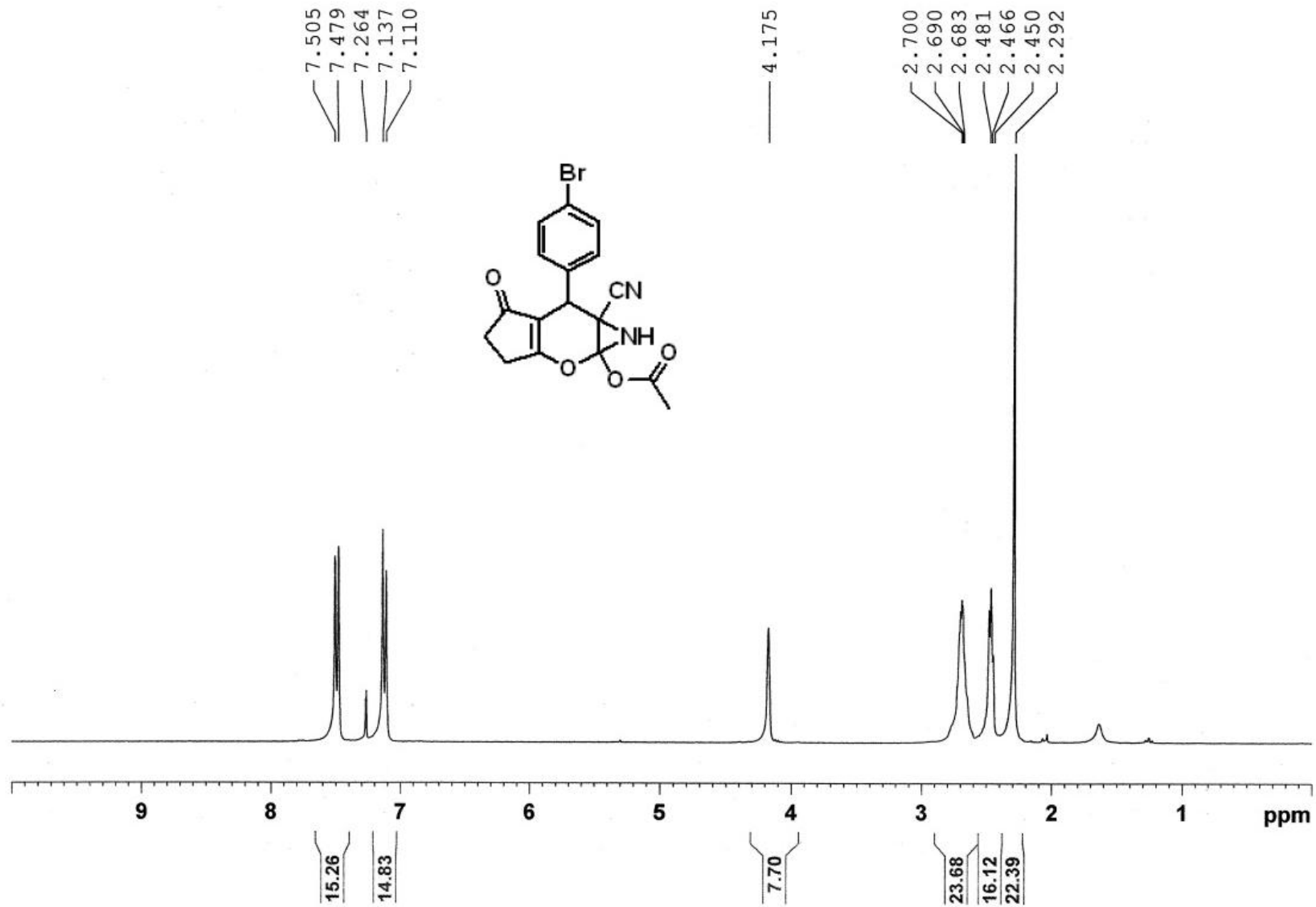
^{13}C NMR of 2c



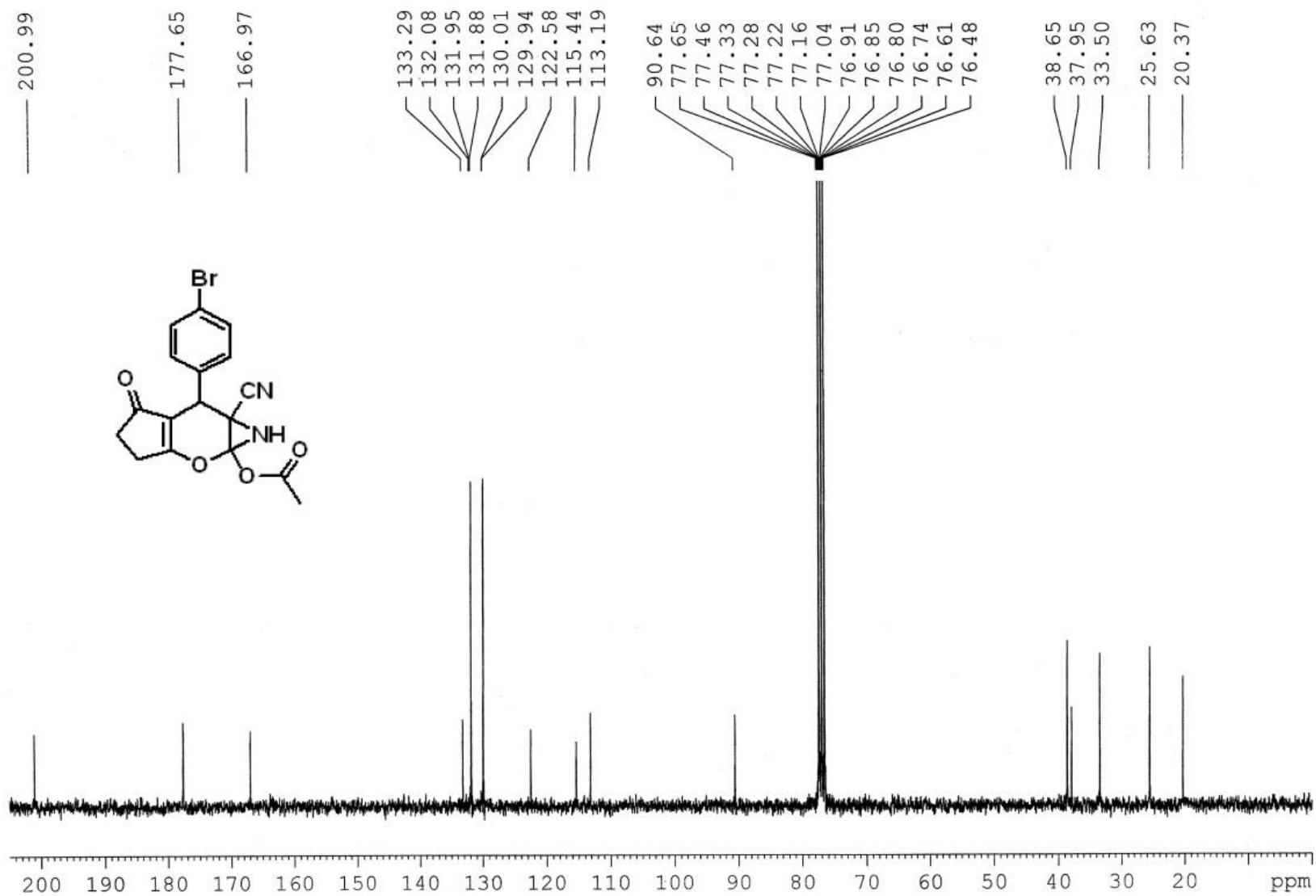
¹H NMR of 2d



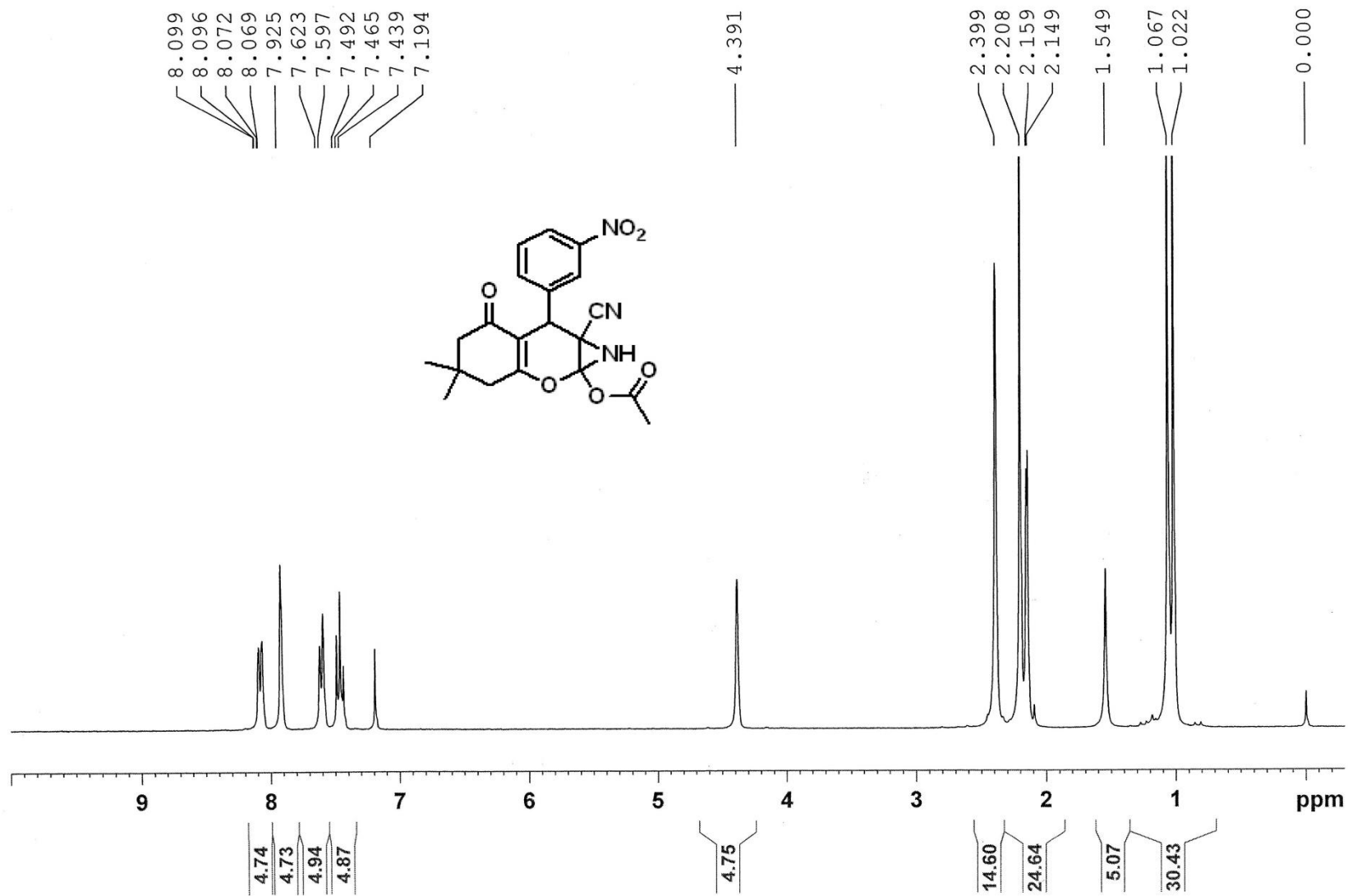
¹³C NMR of 2d



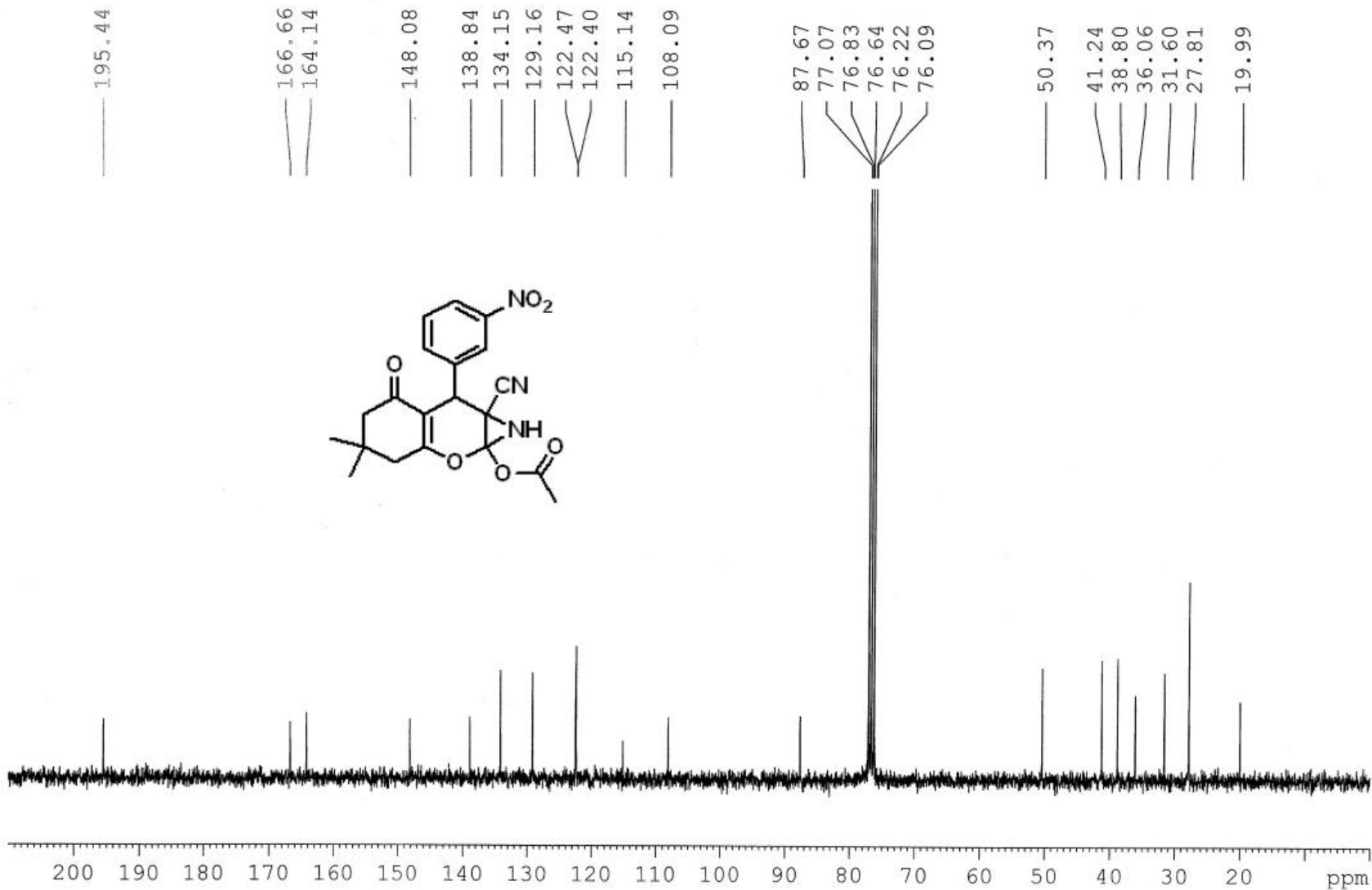
$^1\text{H NMR}$ of 2e



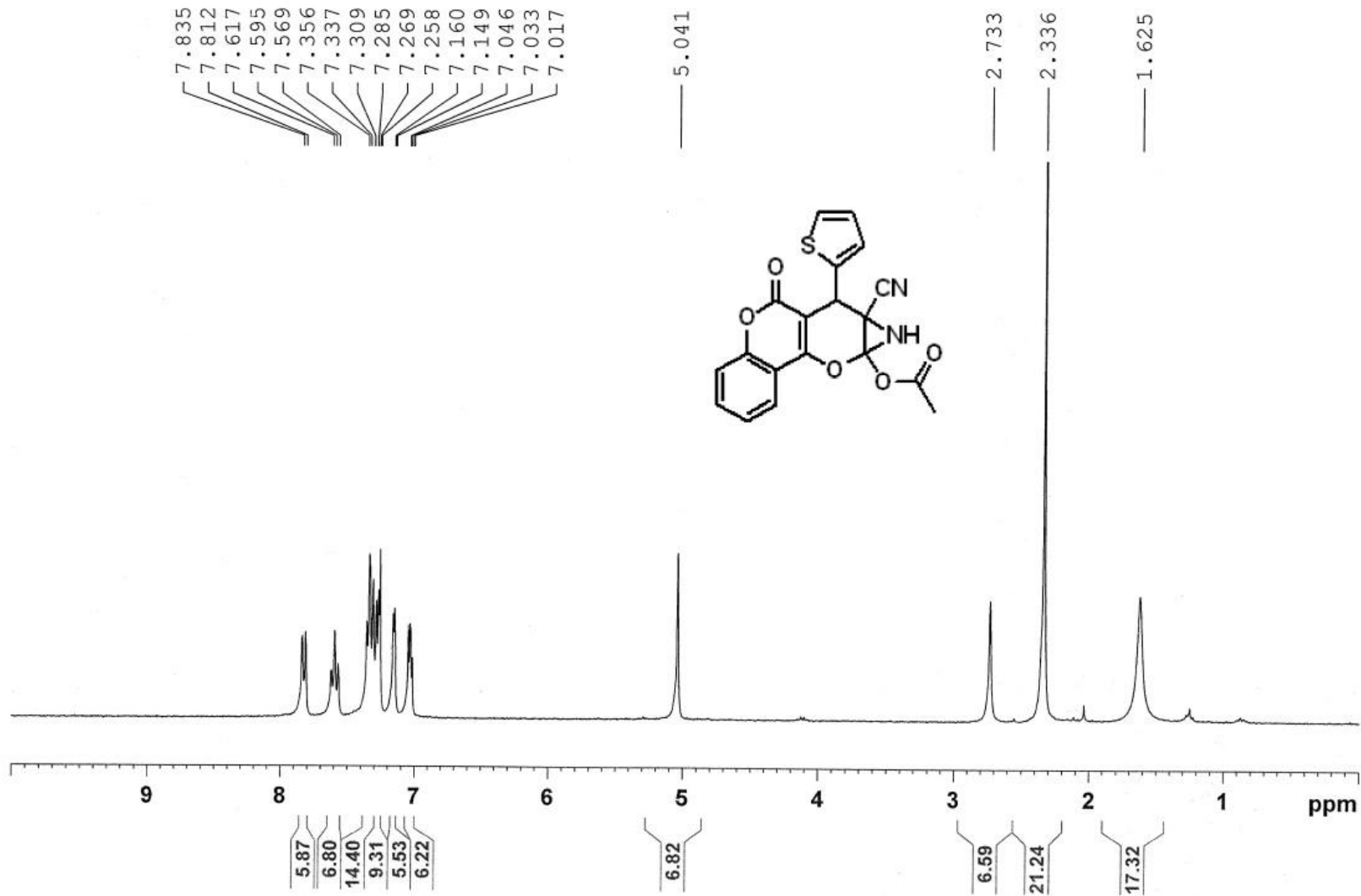
^{13}C NMR of 2e



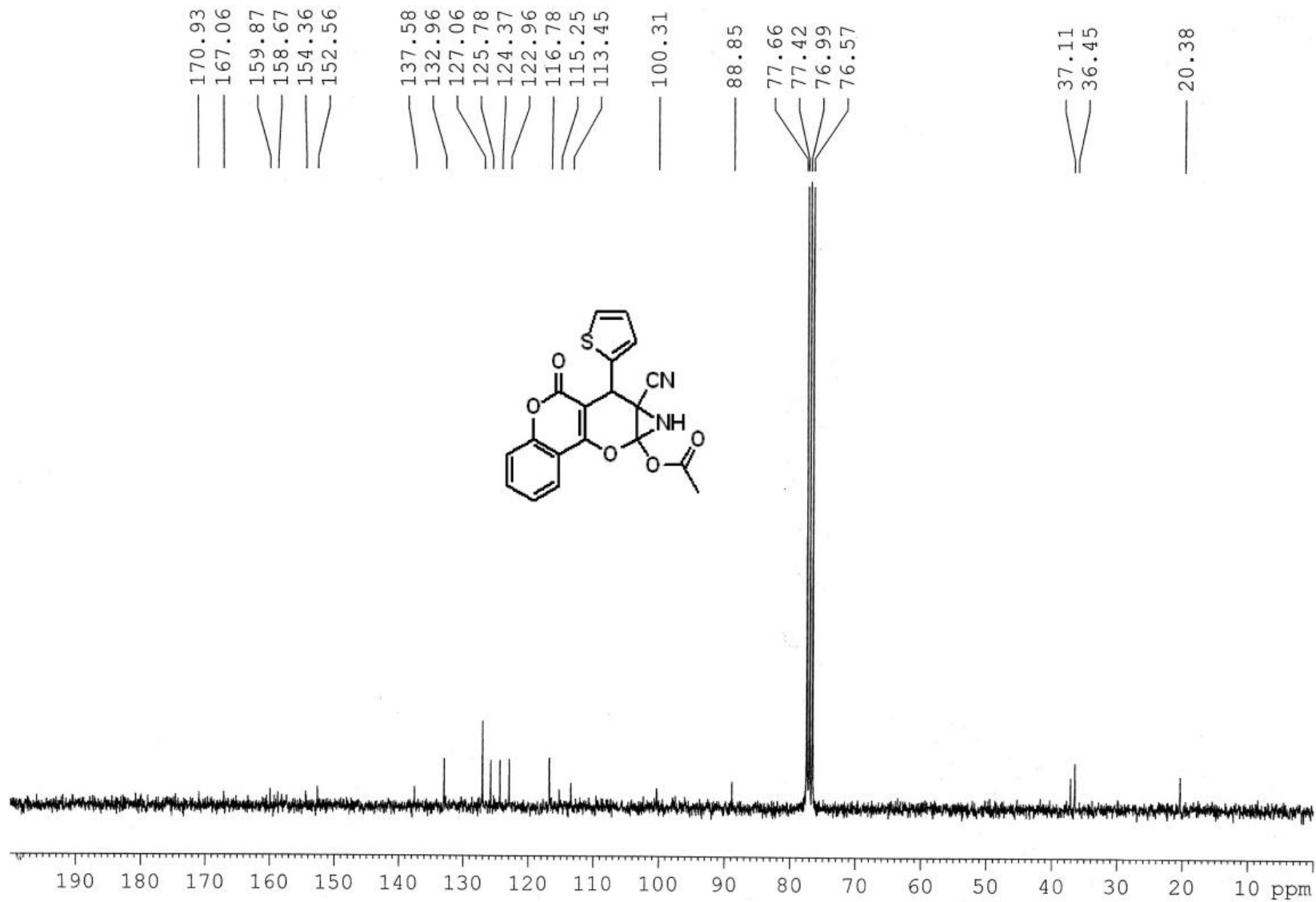
¹H NMR of 2f



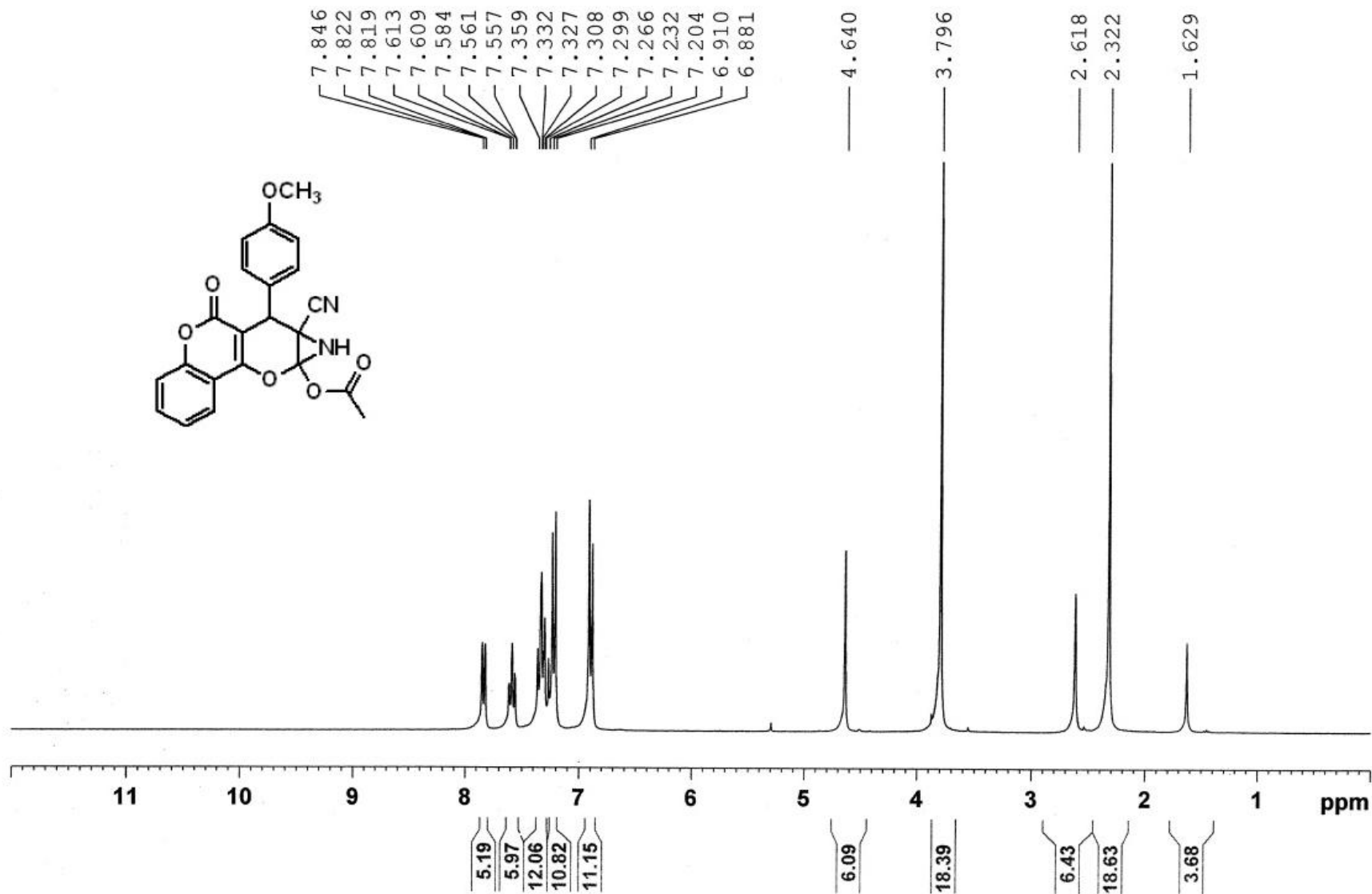
¹³C NMR of 2f



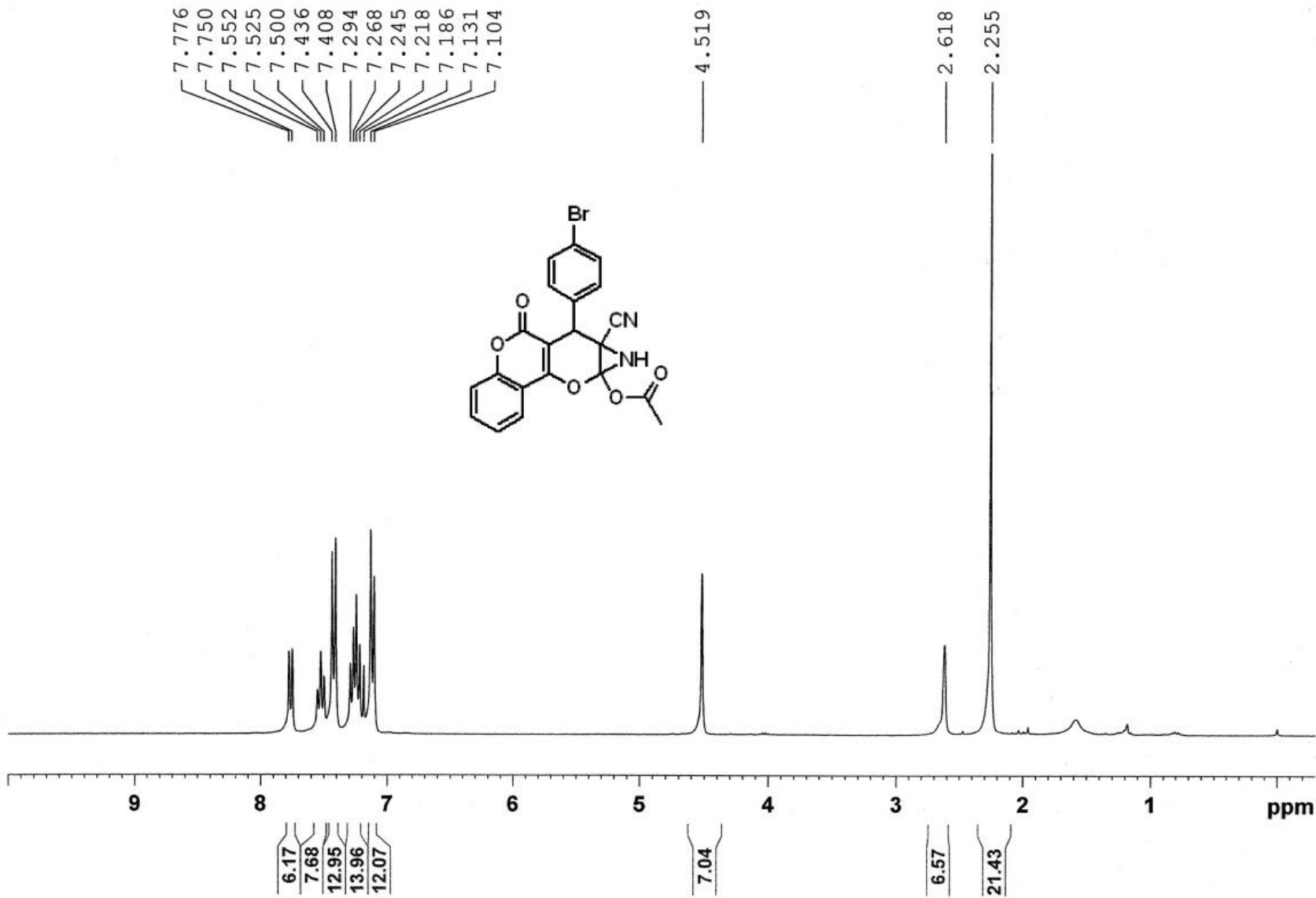
¹H NMR of 2g



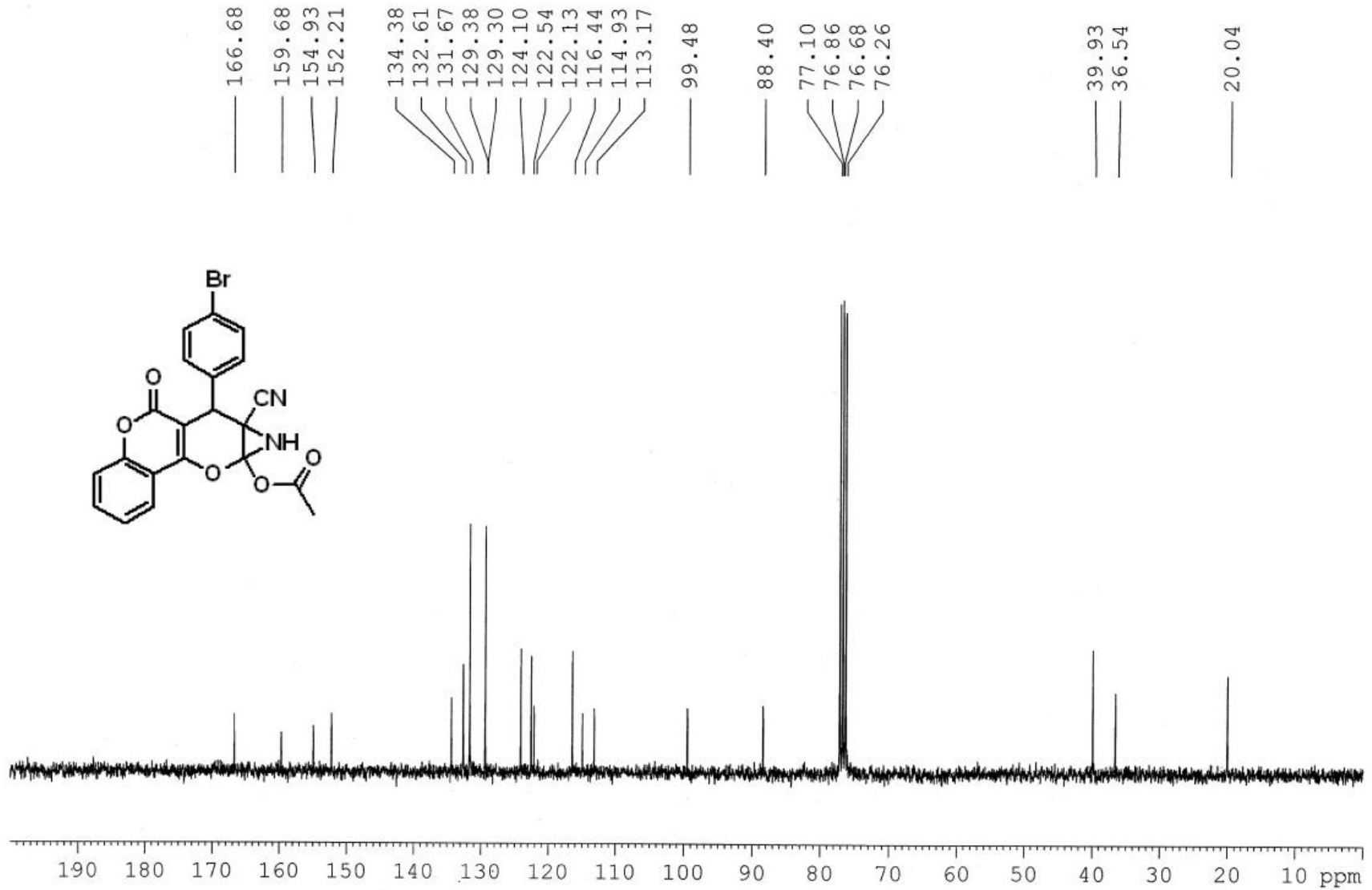
^{13}C NMR of 2g



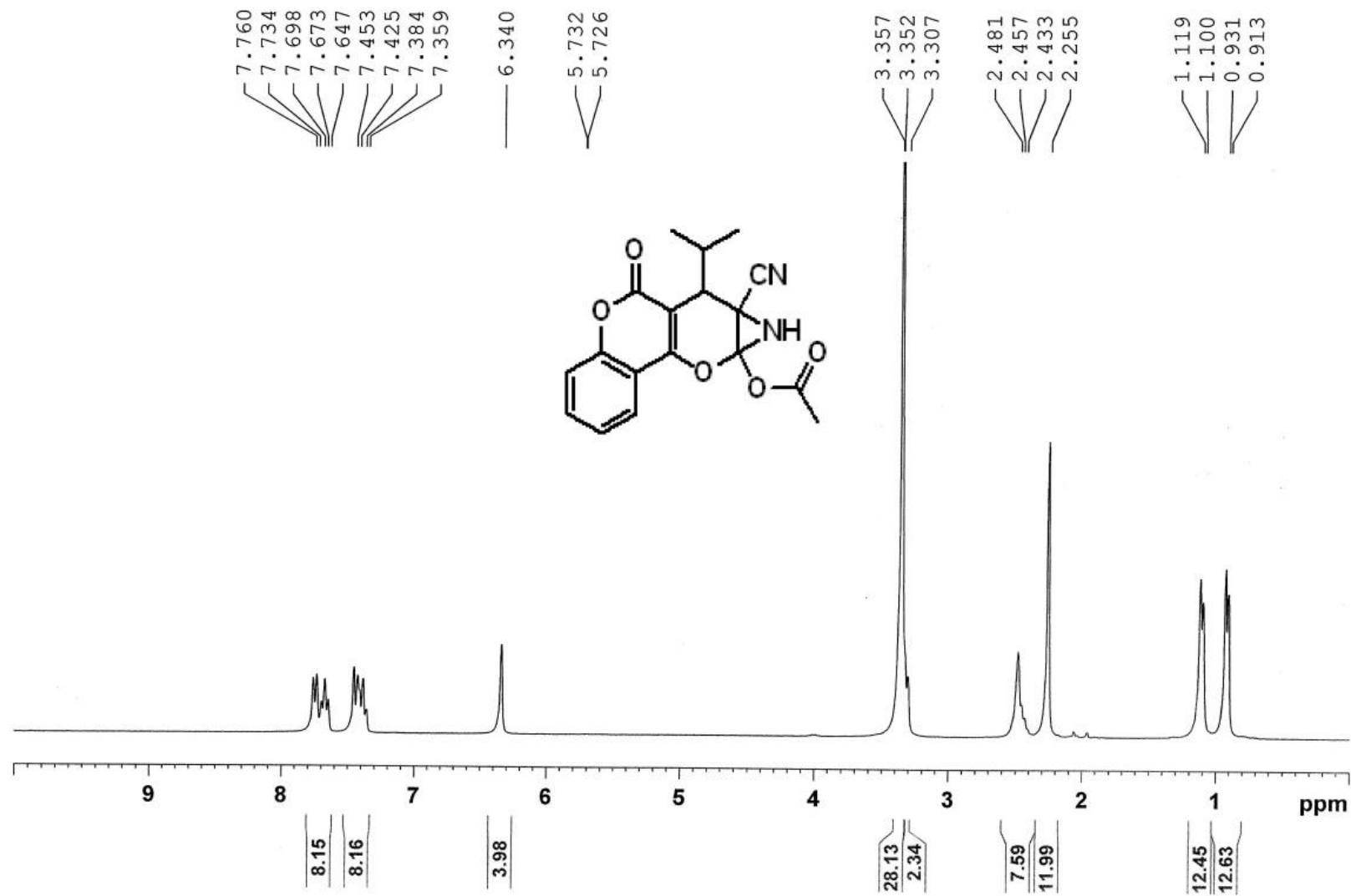
¹H NMR of 2h



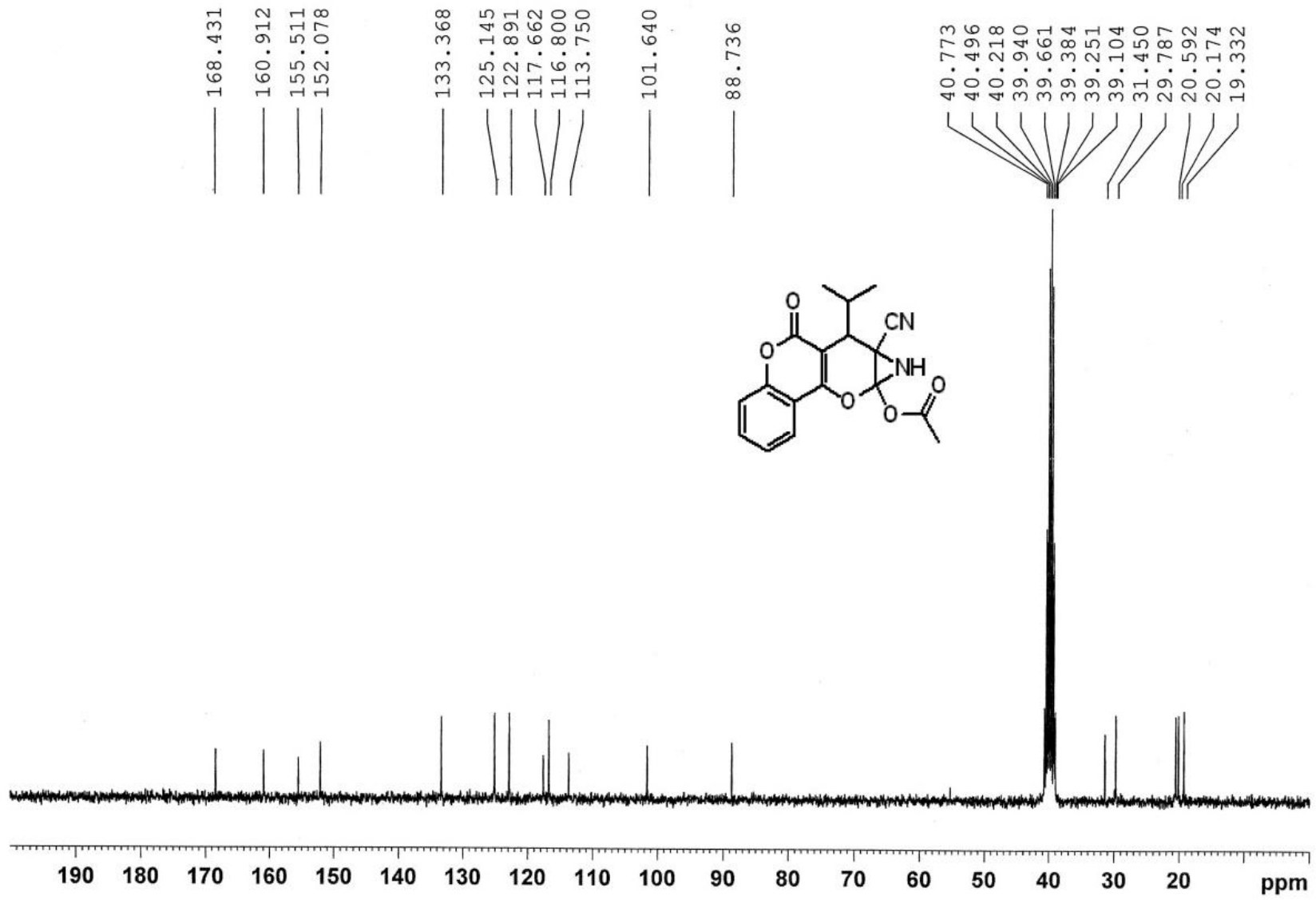
¹H NMR of 2i



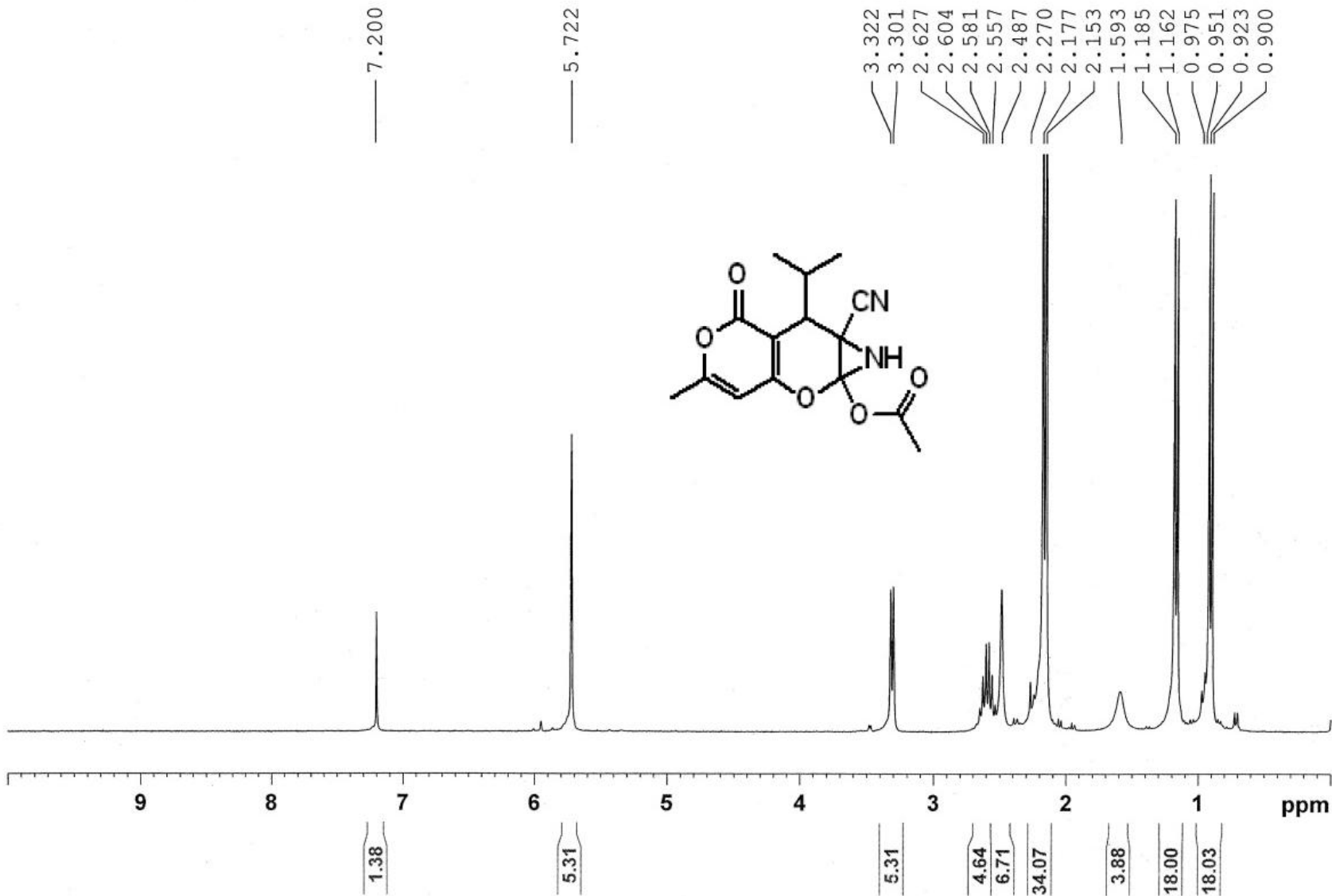
¹³C NMR of 2i



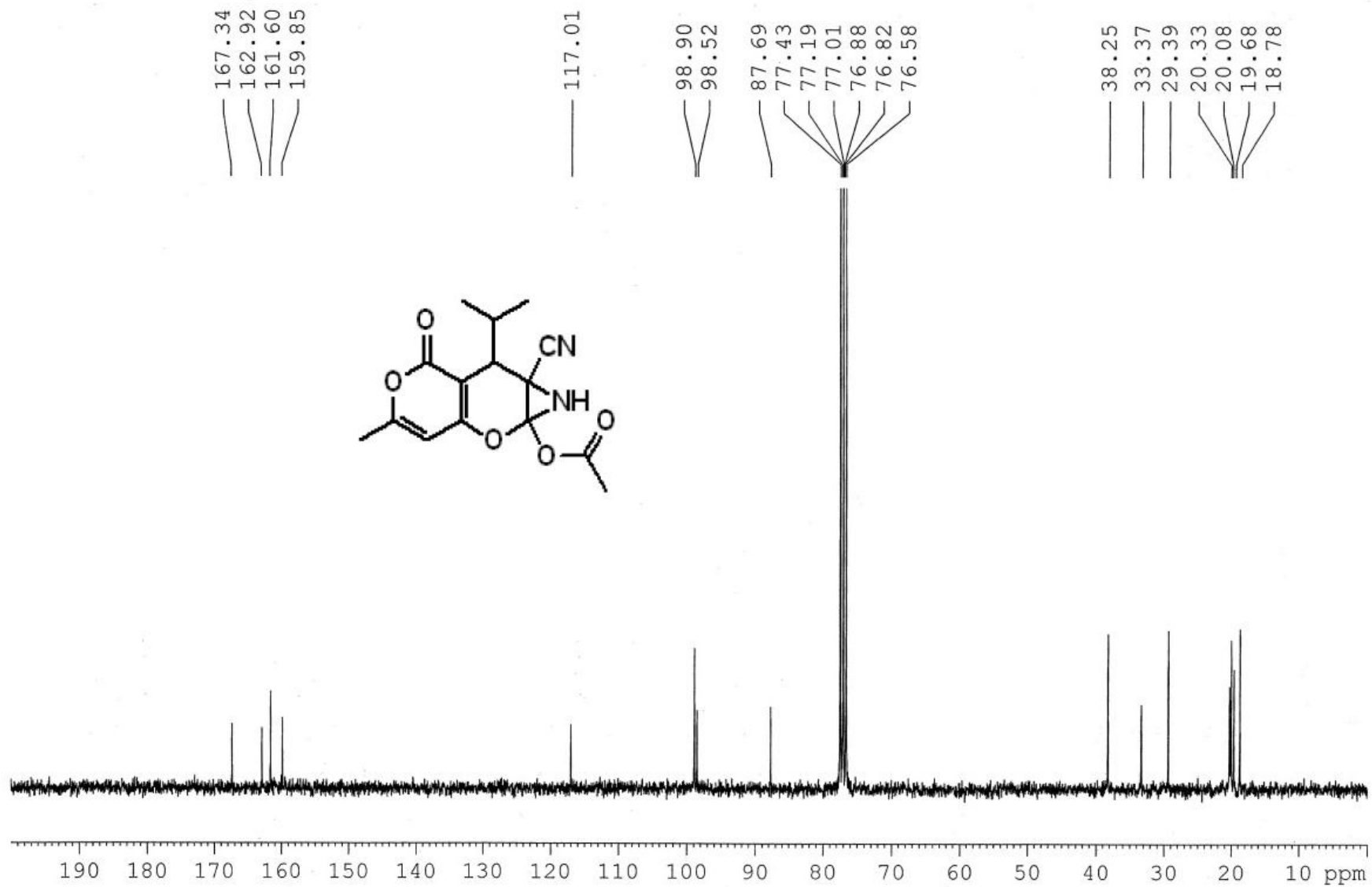
¹H NMR of 2j



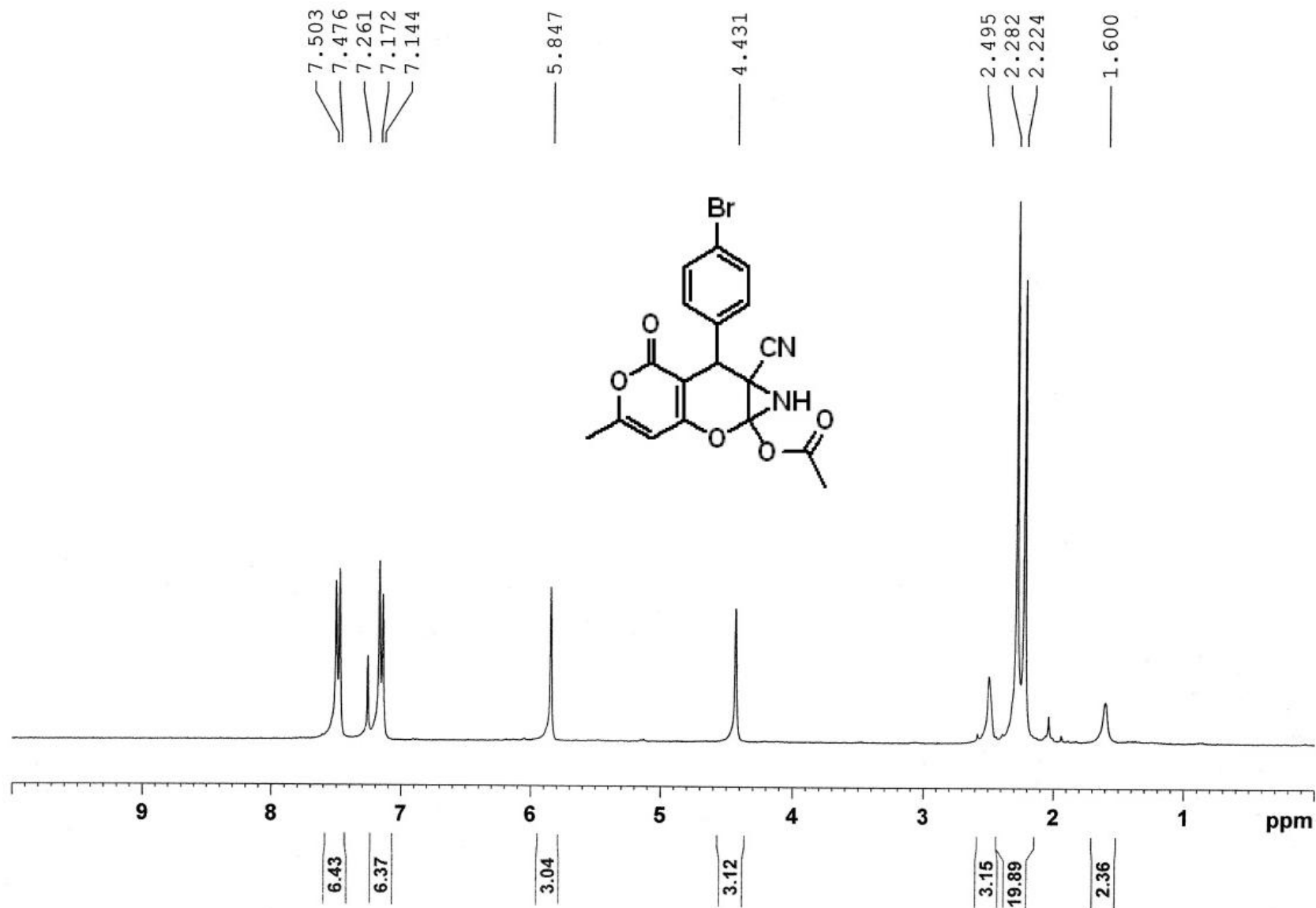
¹³C NMR of 2j



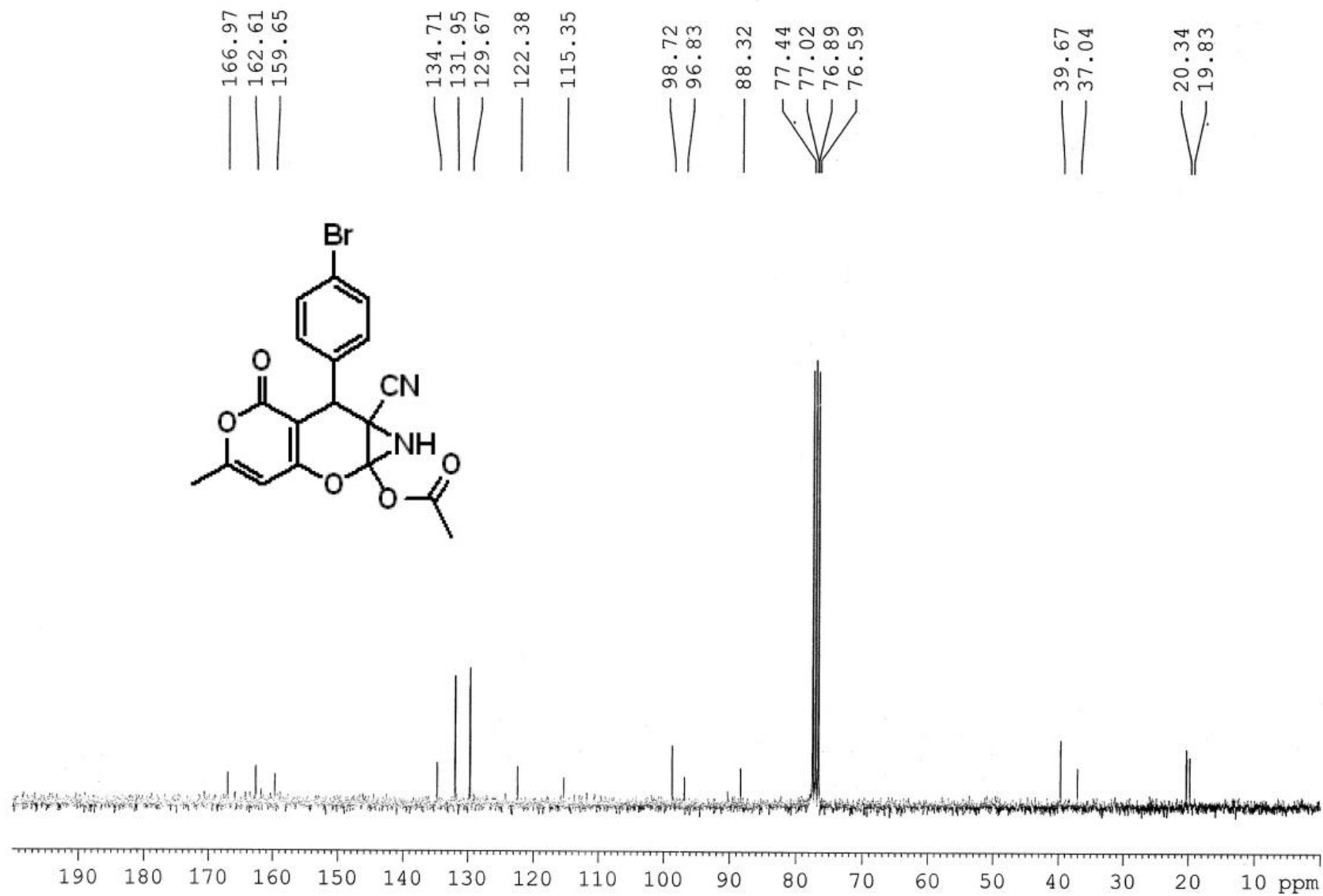
¹H NMR of 2k



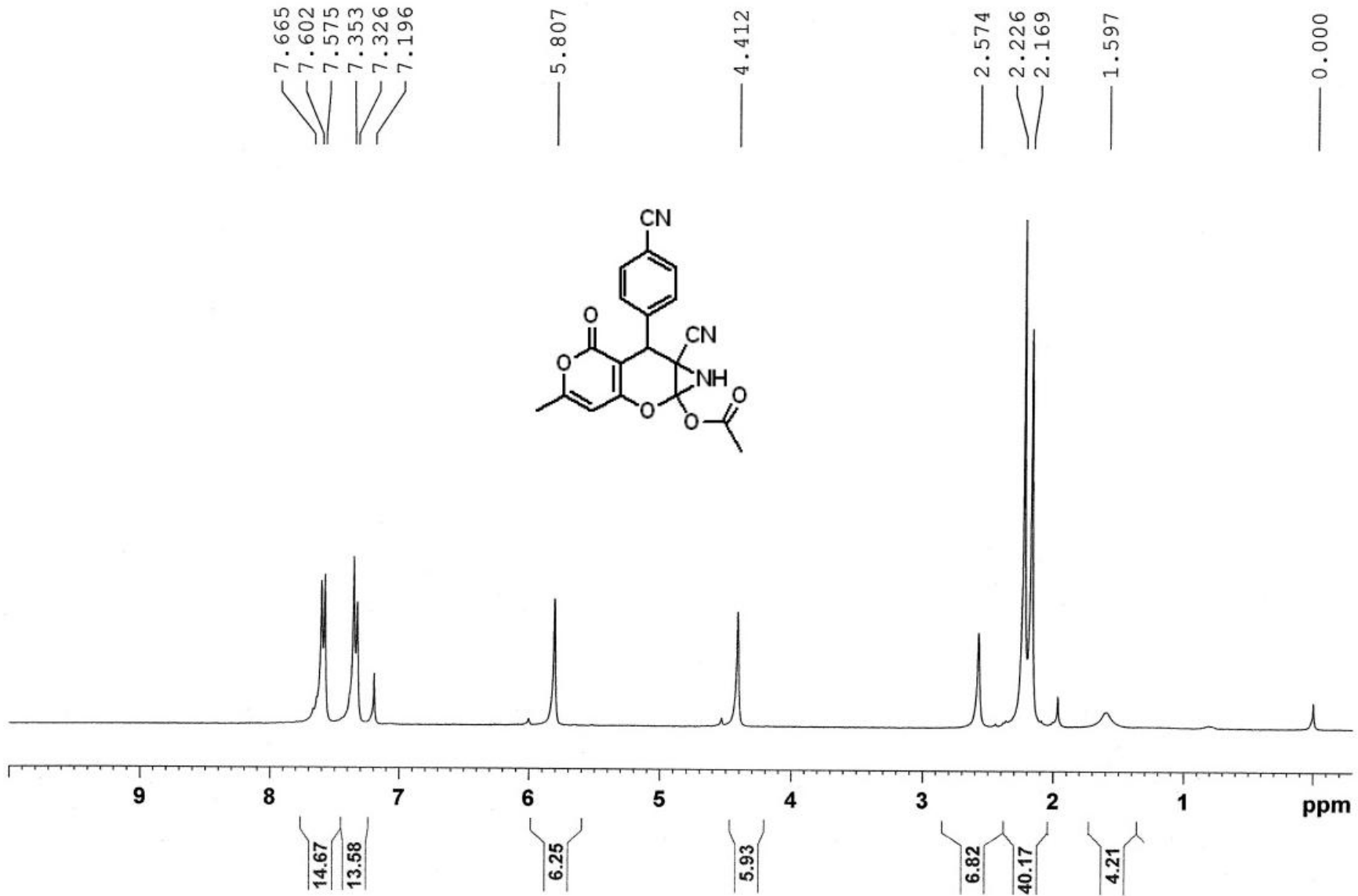
¹³C NMR of 2k



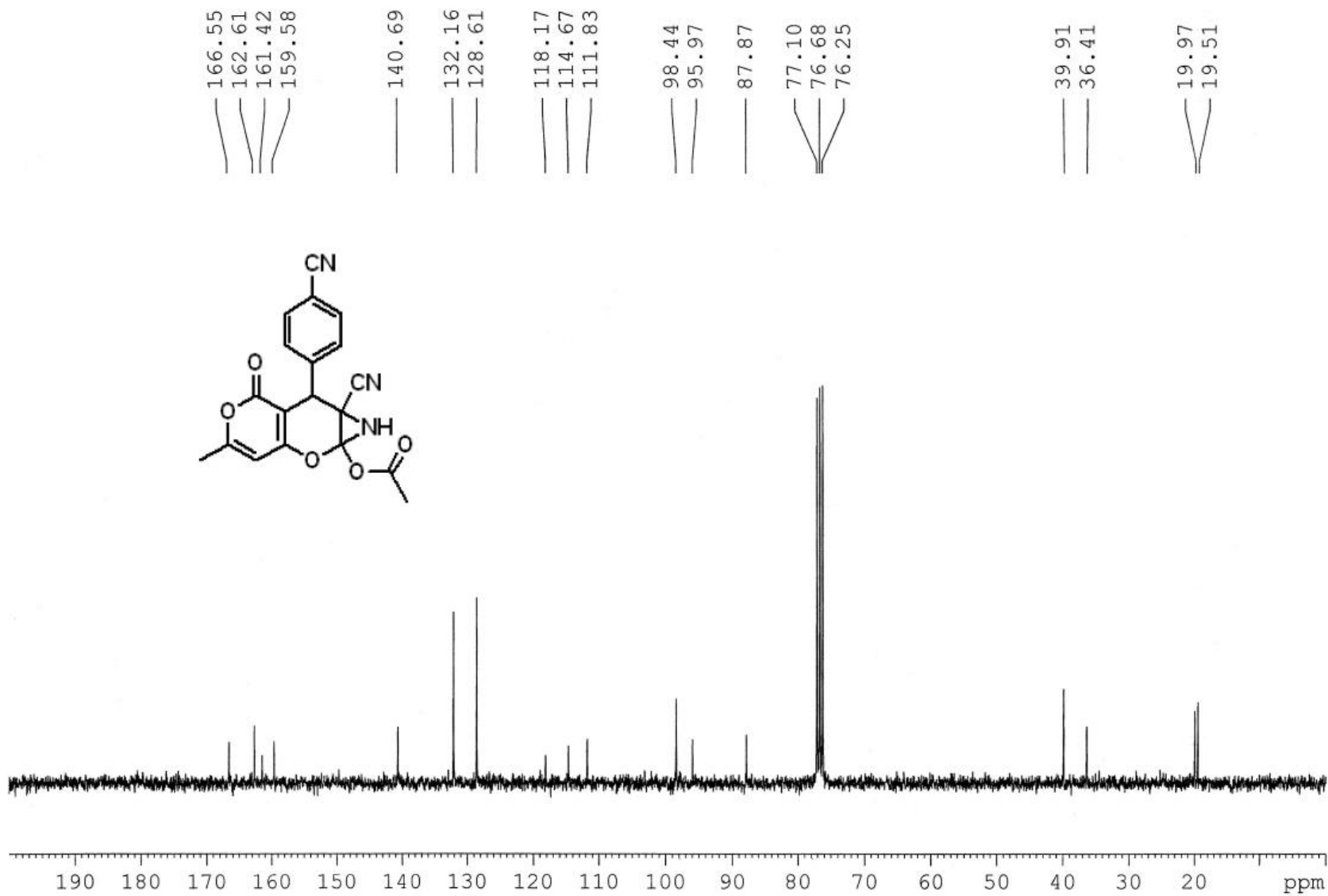
¹H NMR of 2l



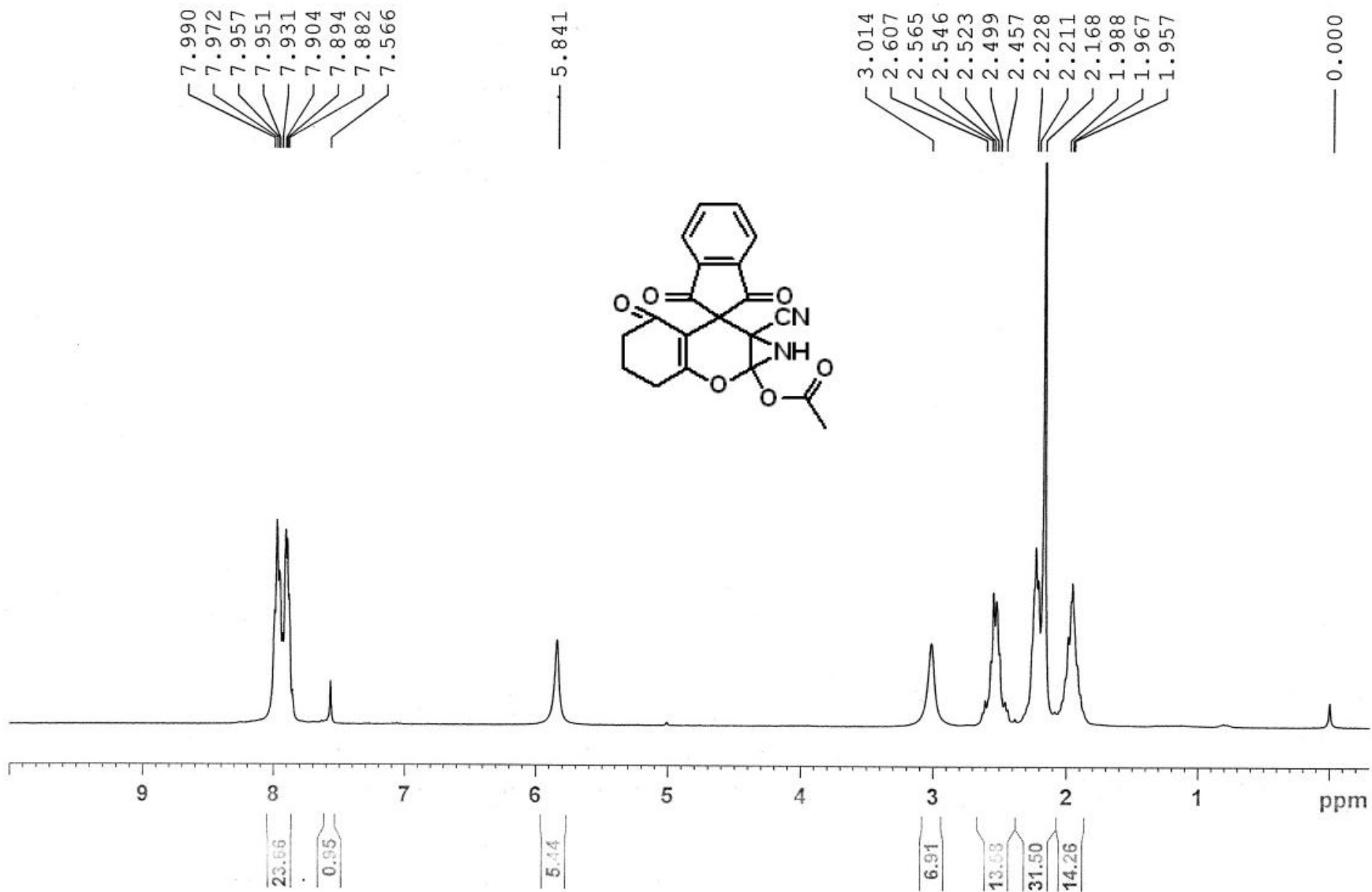
^{13}C NMR of 21



¹H NMR of 2m



^{13}C NMR of 2m



¹H NMR of 2n

195.80
195.60
193.89

169.83
166.33

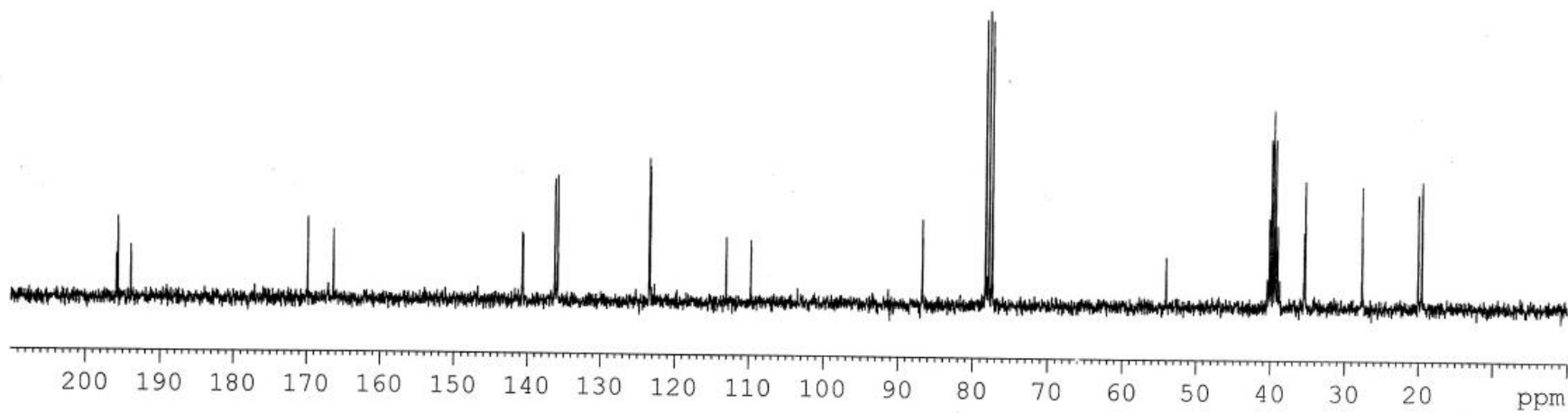
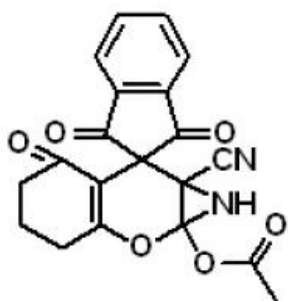
140.70
140.59
136.24
135.87

123.45
123.33

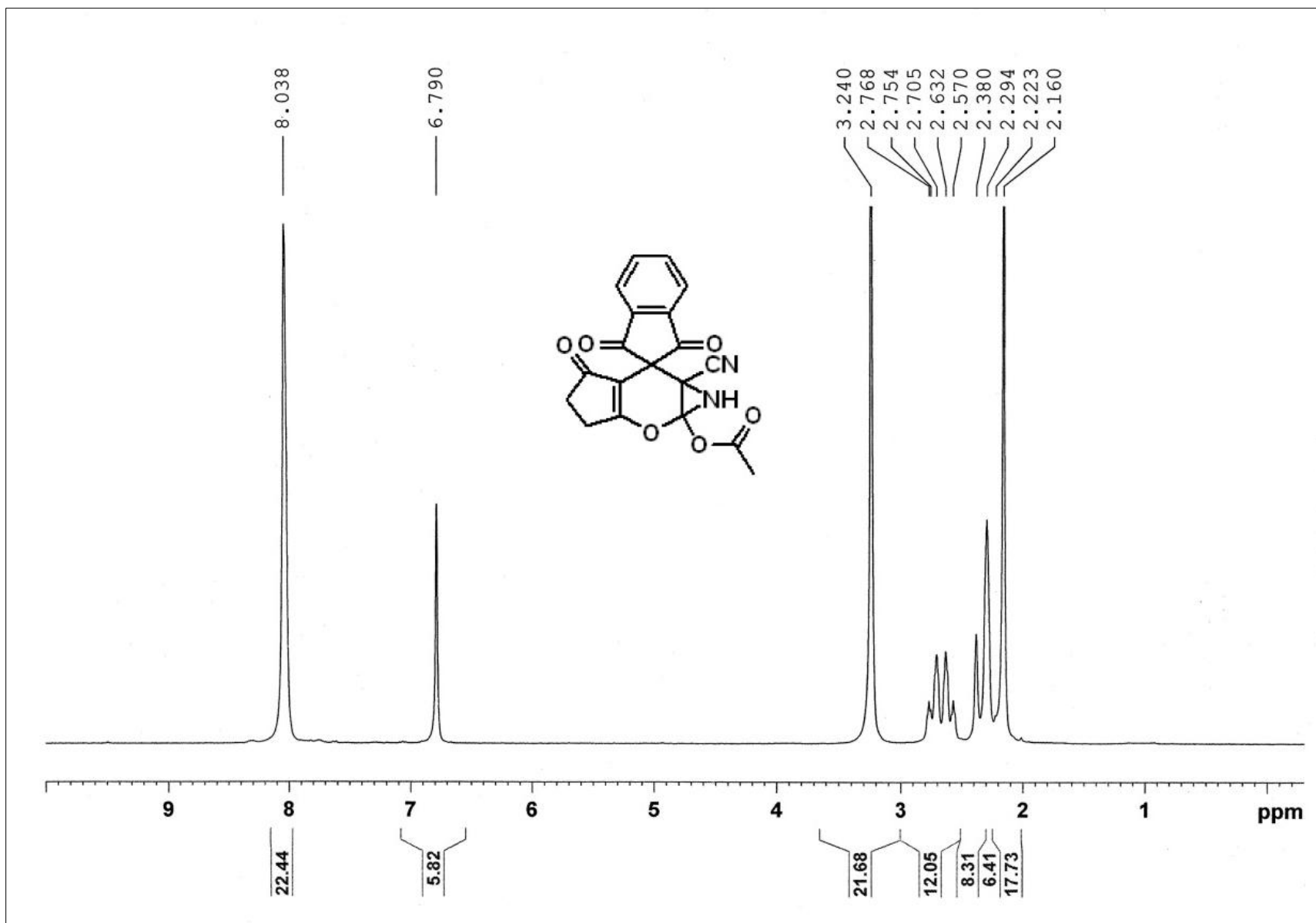
113.10
109.75

86.70
78.26
78.02
77.83
77.40

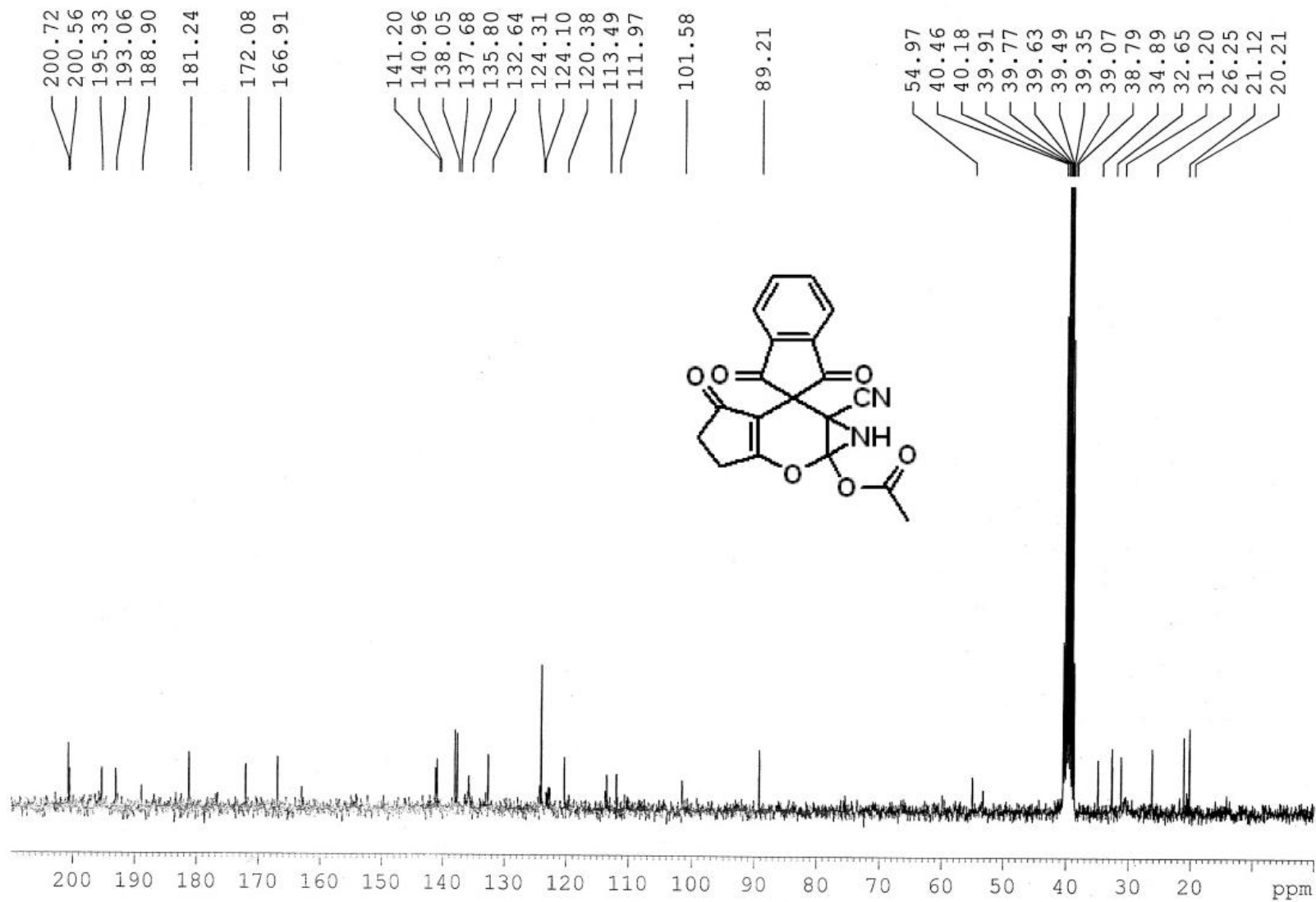
54.04
40.48
40.21
39.94
39.66
39.38
39.10
38.82
35.51
35.34
27.65
20.10
19.61



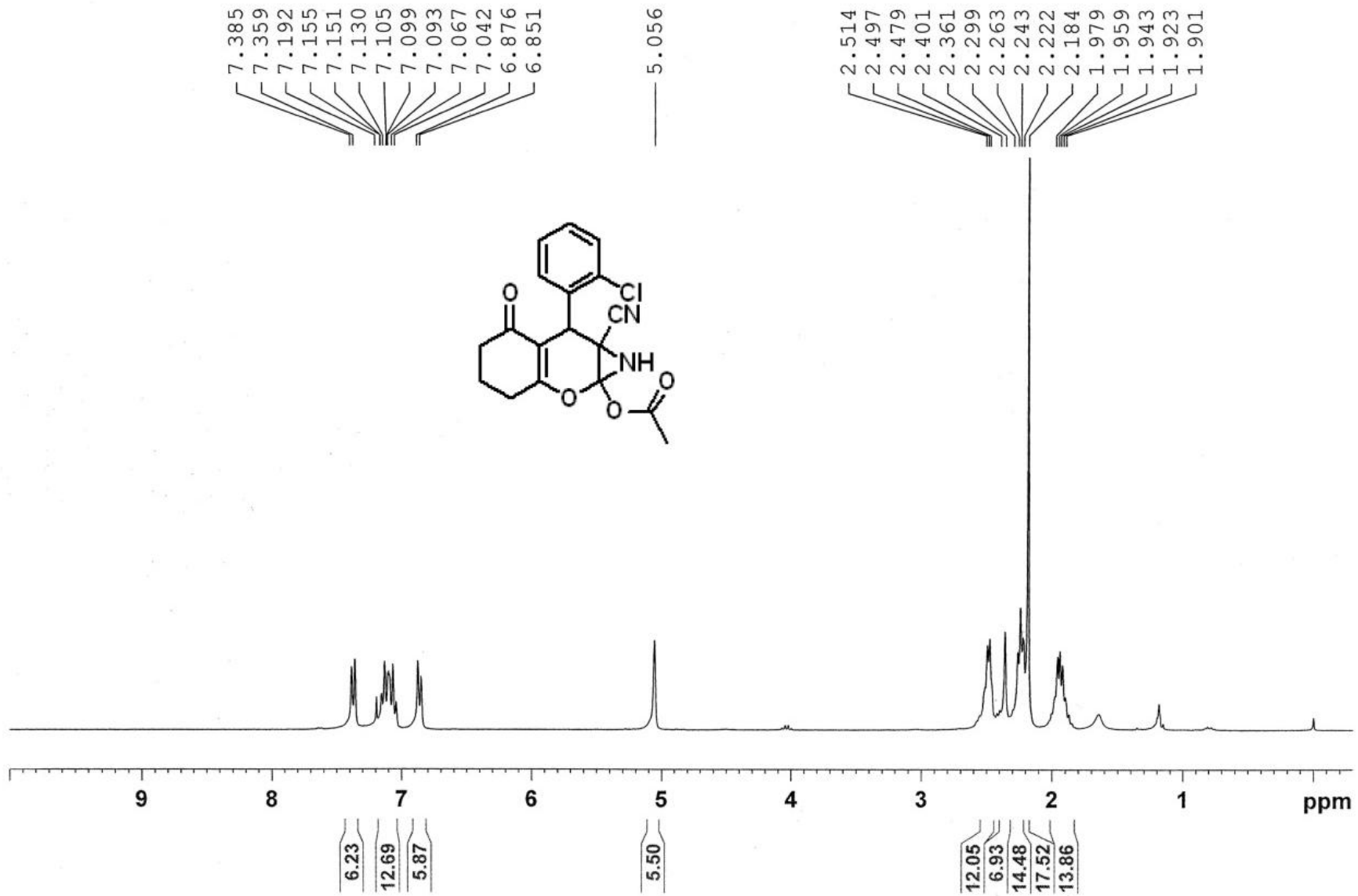
¹³C NMR of 2n



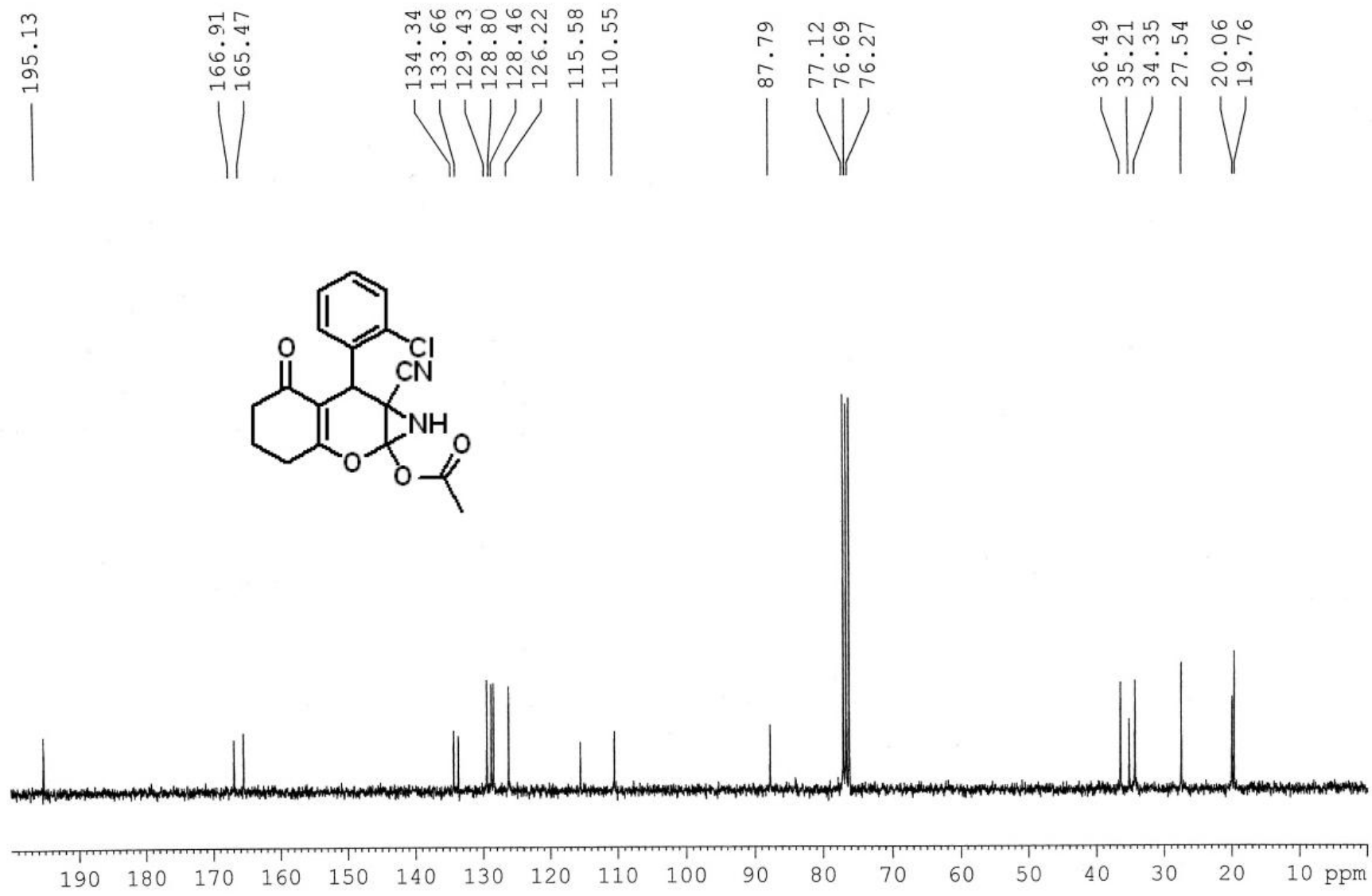
¹H NMR of 2o



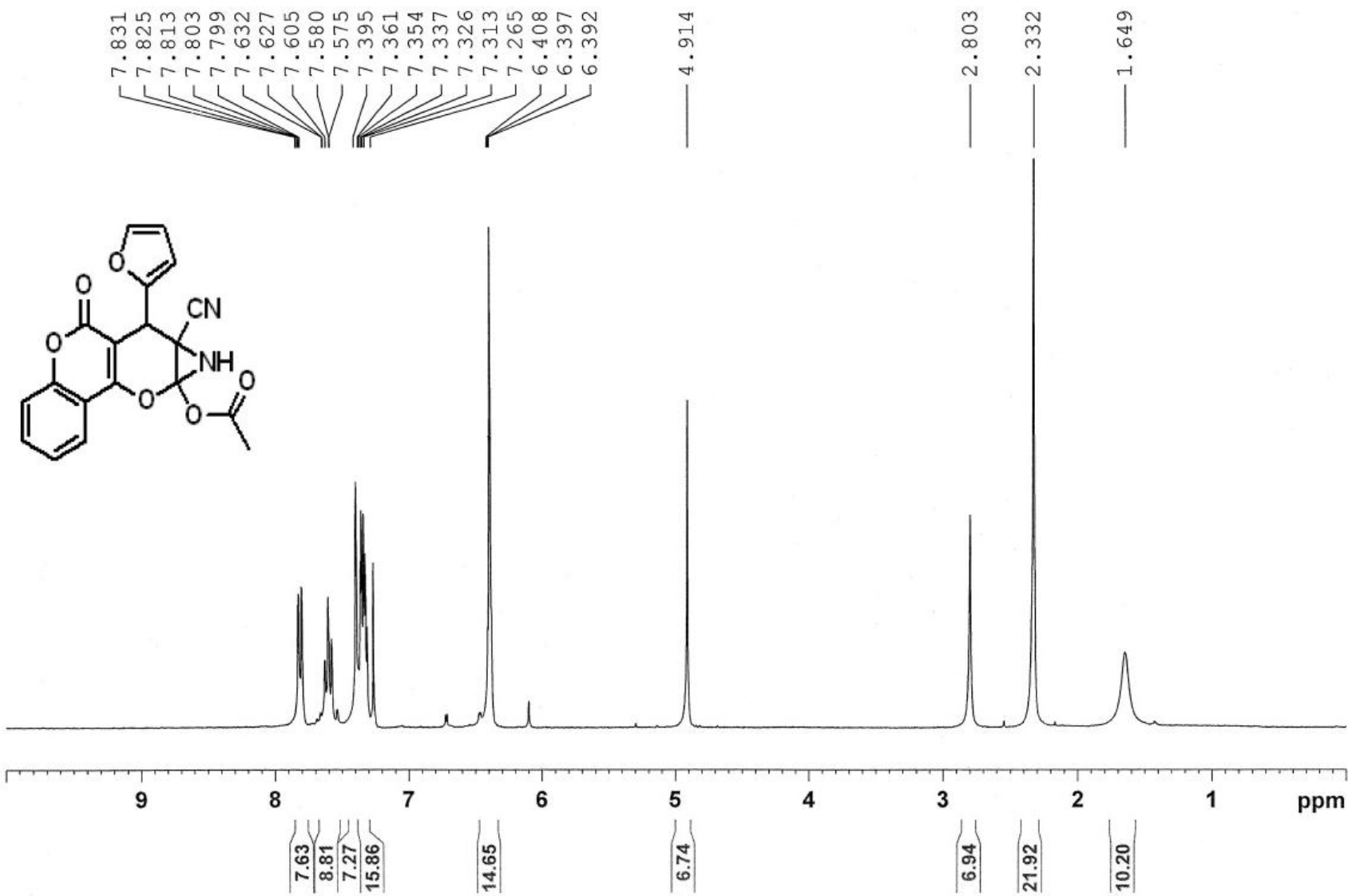
¹³C NMR of **2o**



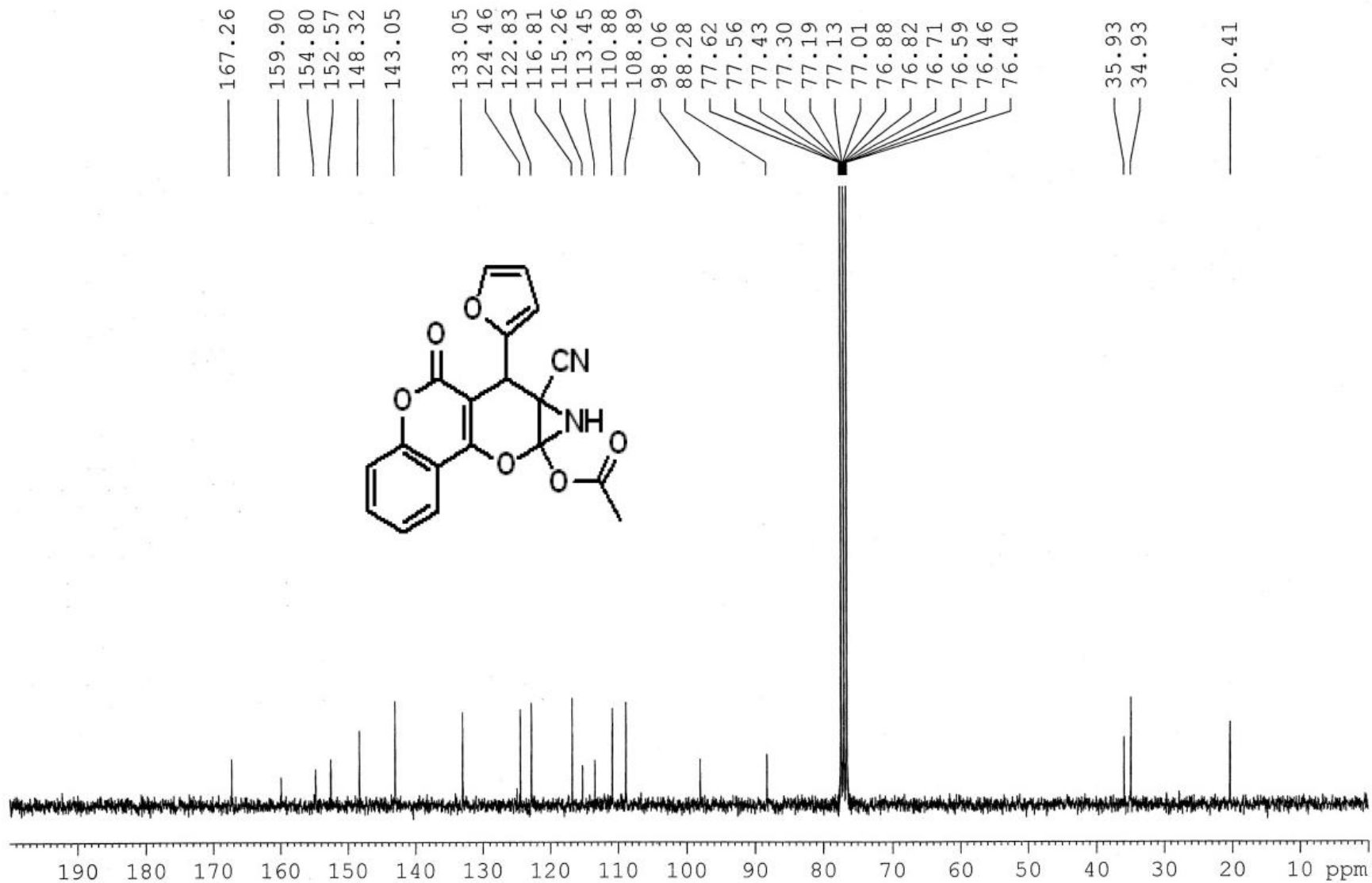
¹H NMR of 2p



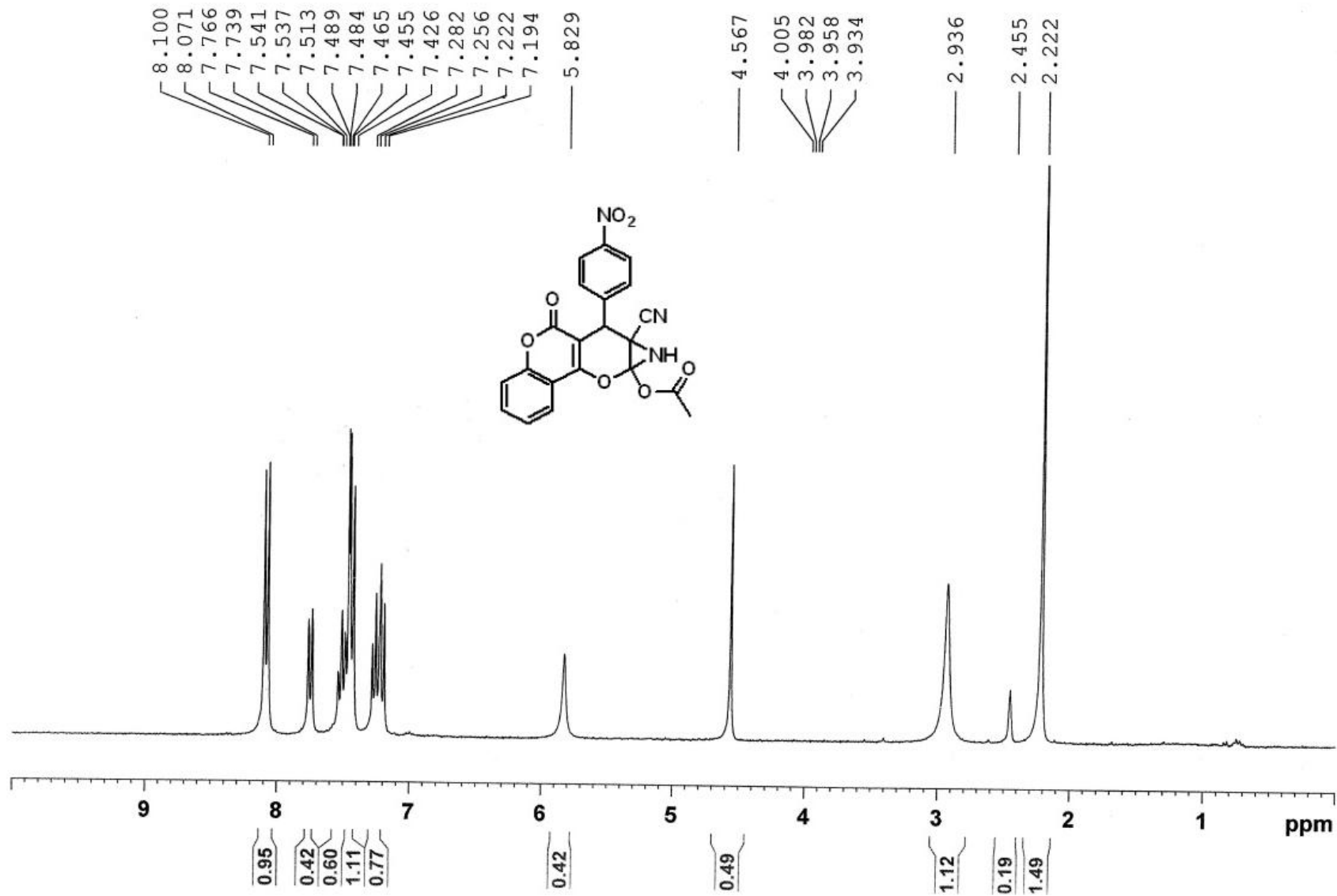
¹³C NMR of 2p



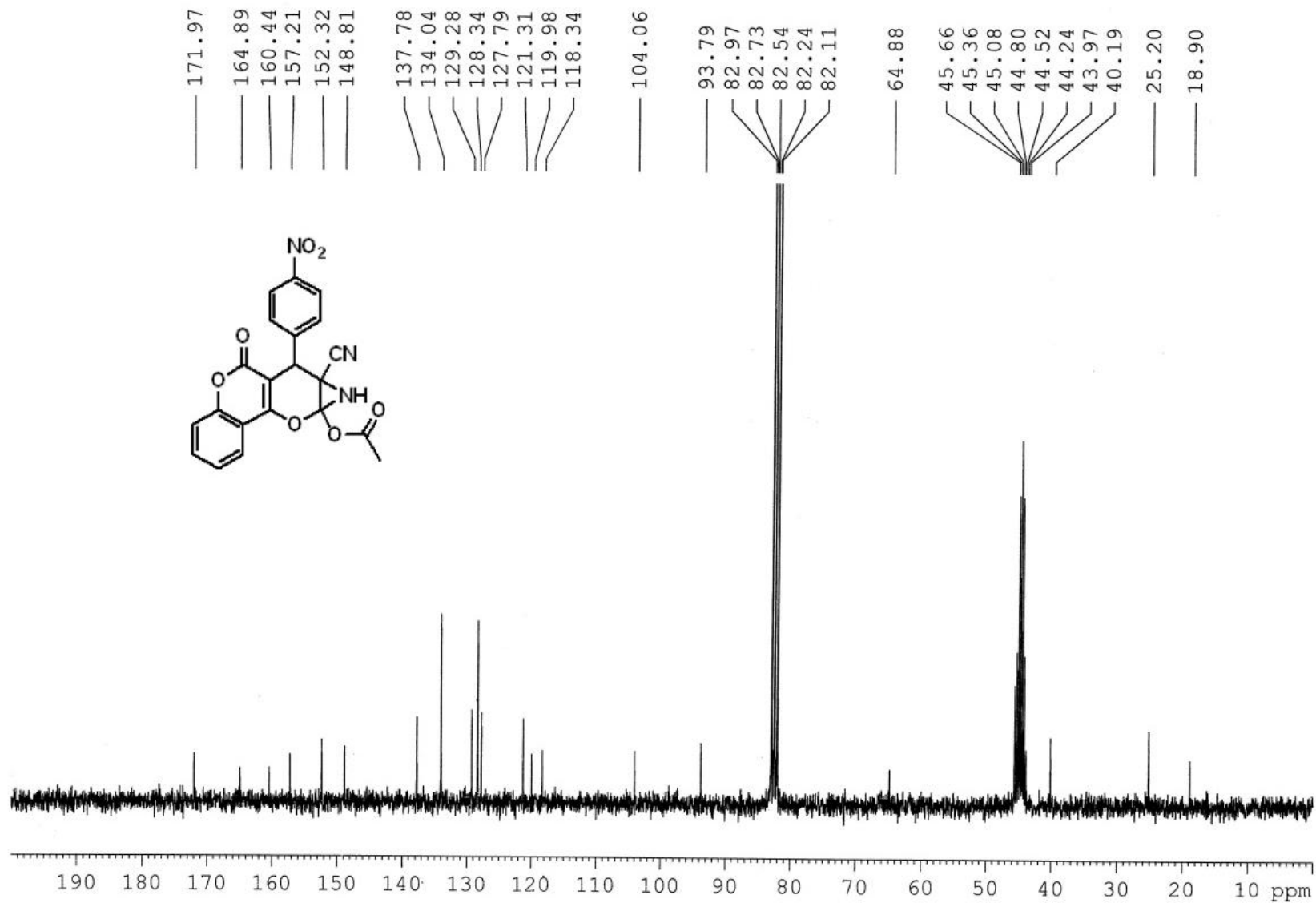
¹H NMR of 2q



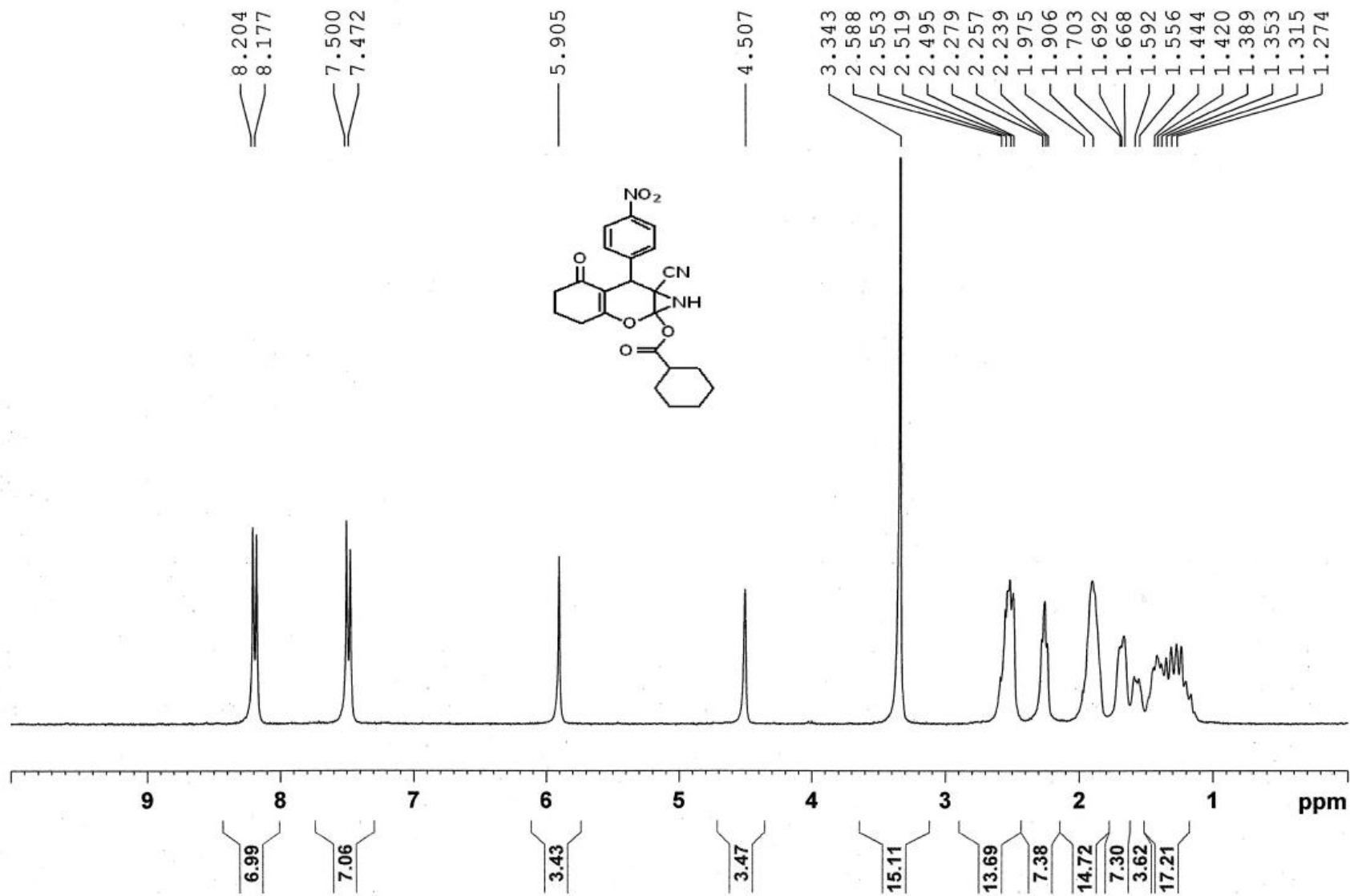
¹³C NMR of 2q



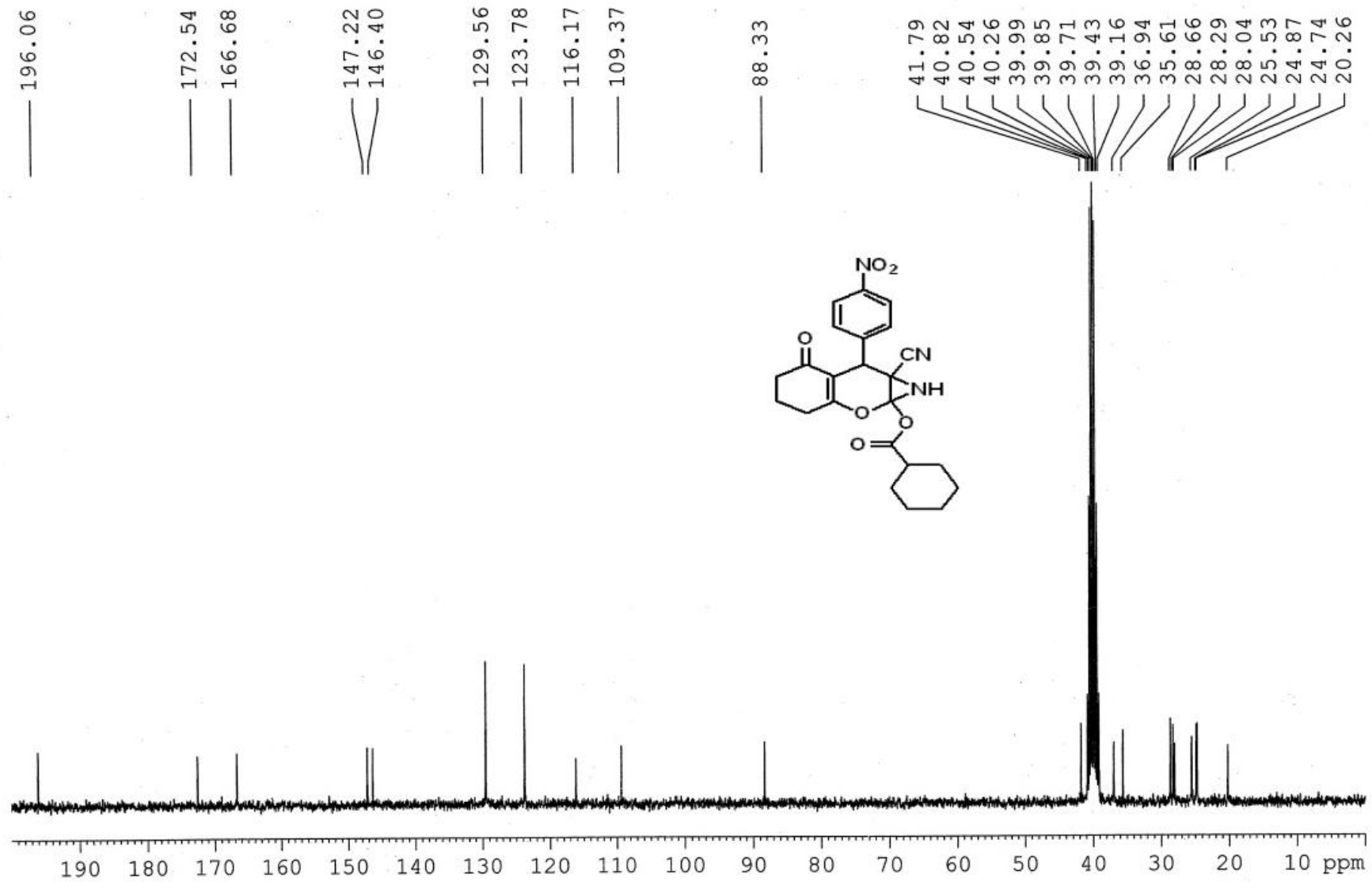
¹H NMR of 2r



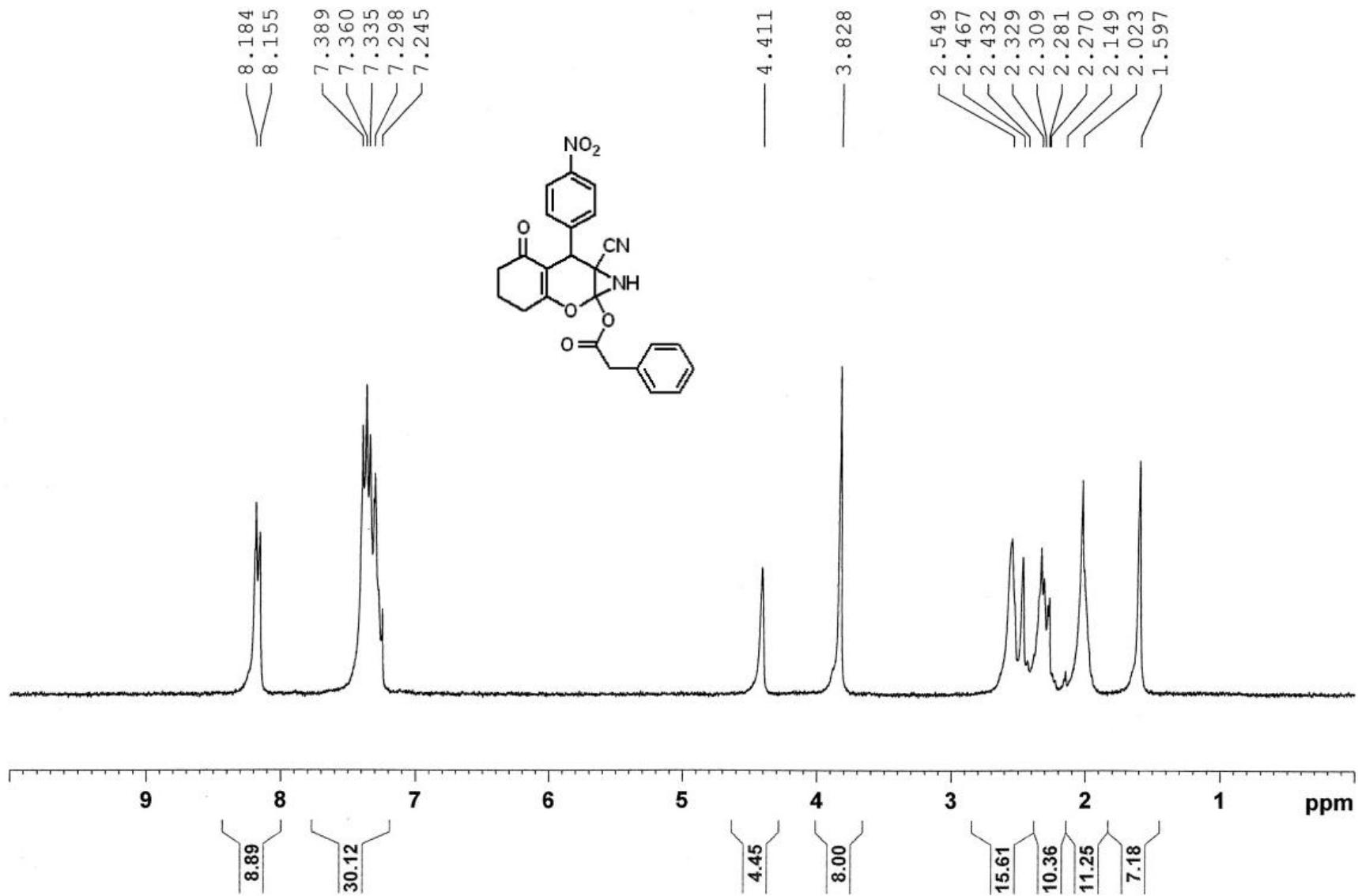
¹³C NMR of 2r



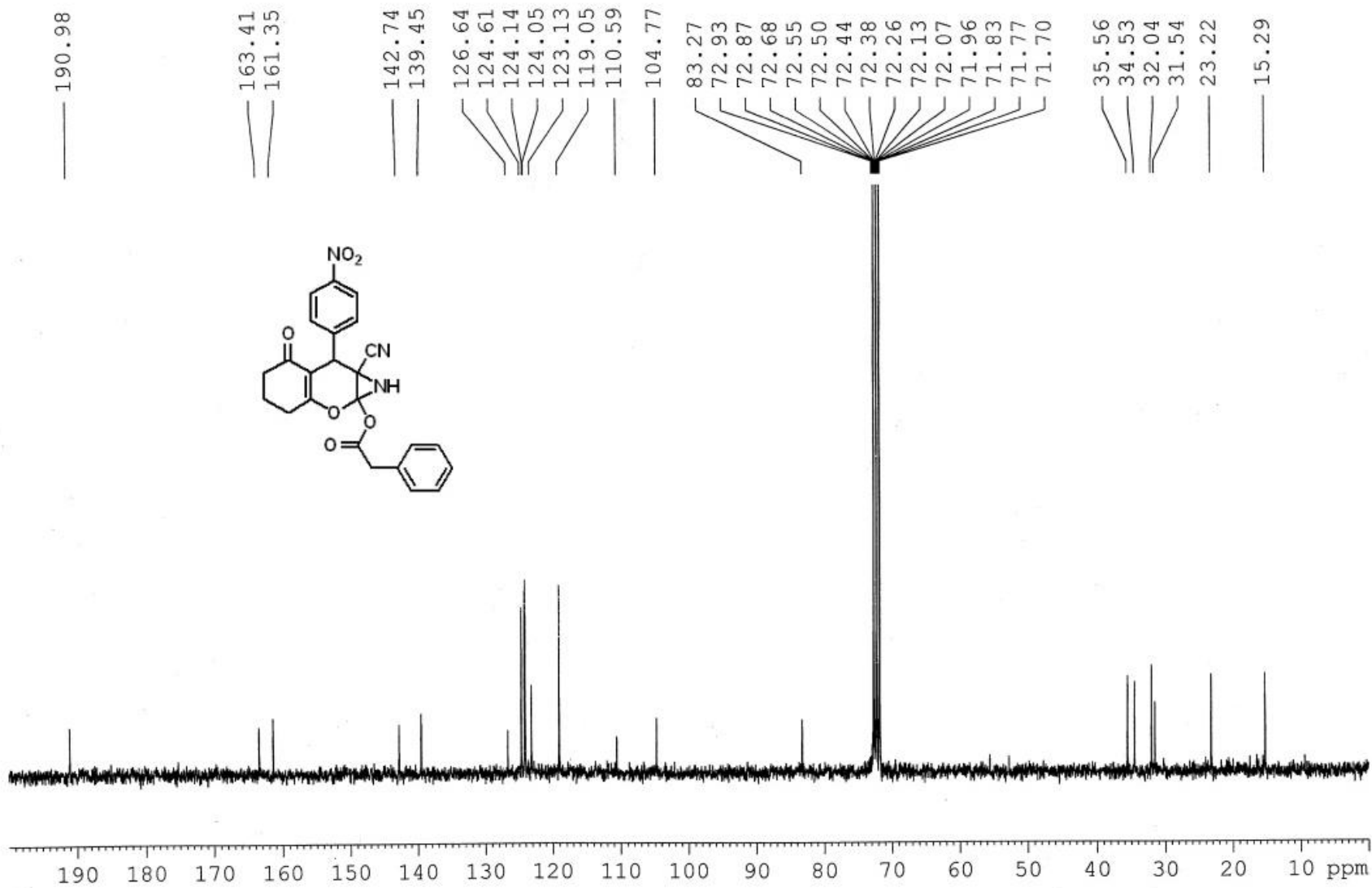
¹H NMR of 3a



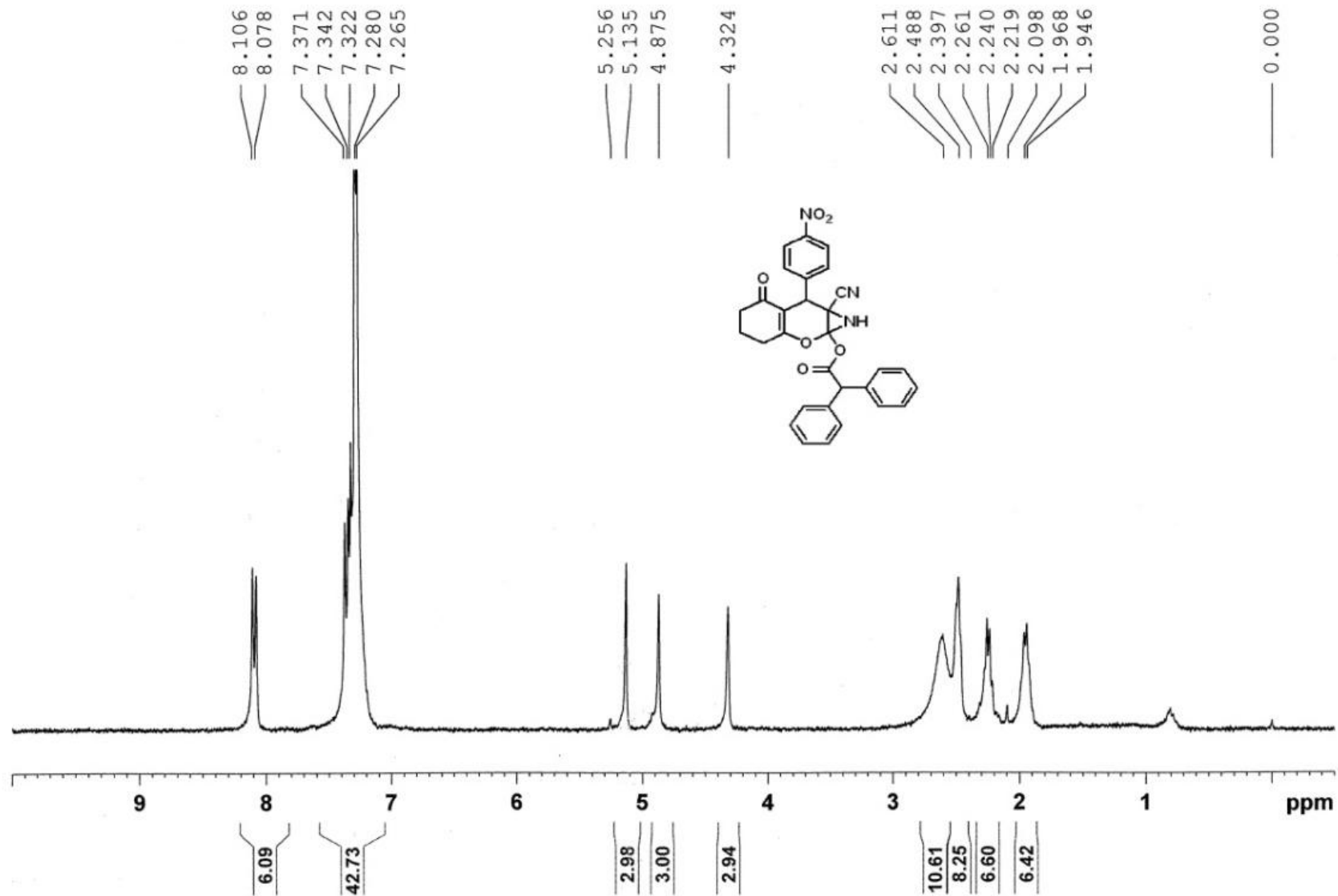
¹³C NMR of 3a



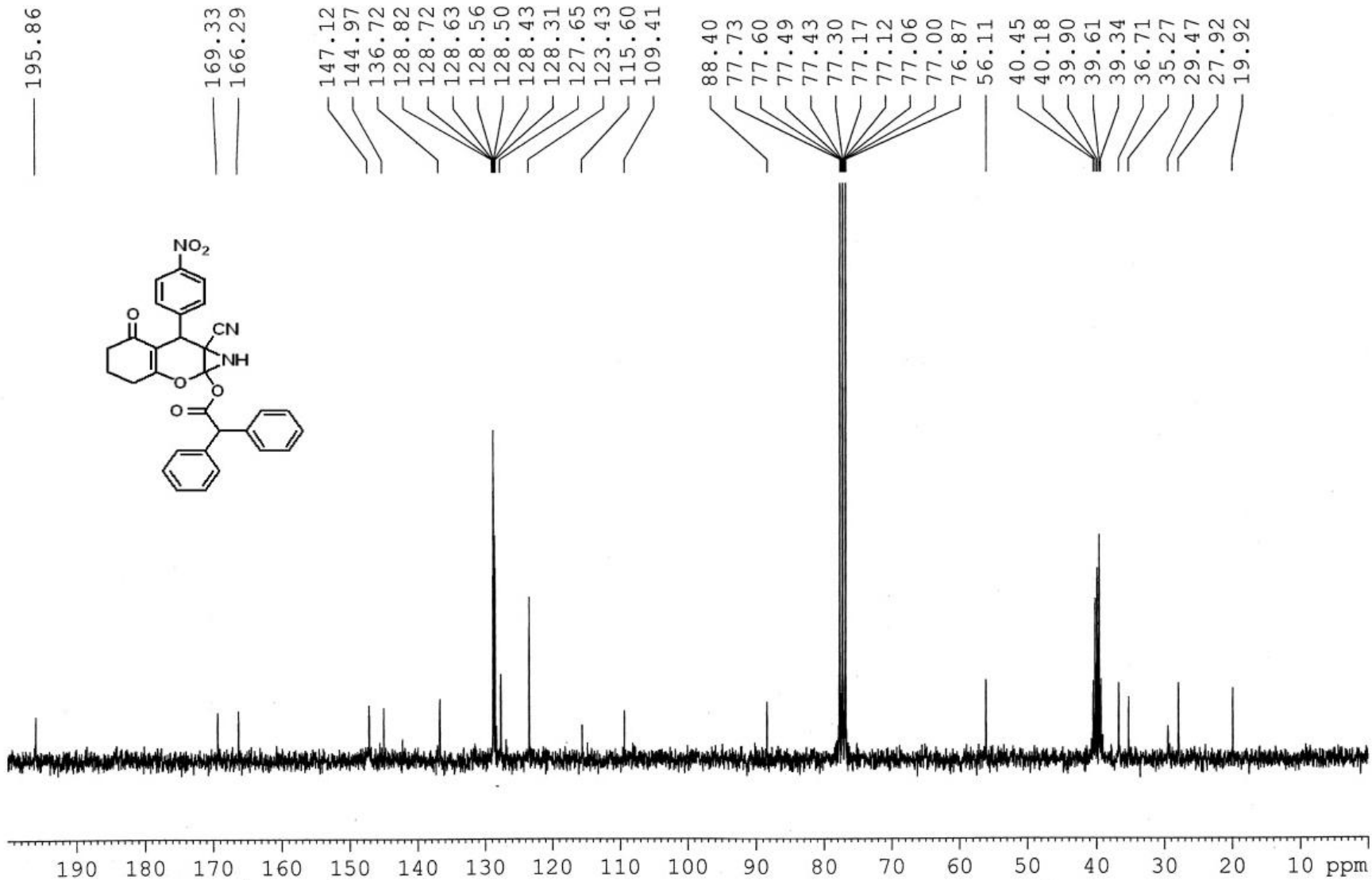
¹H NMR of 3b



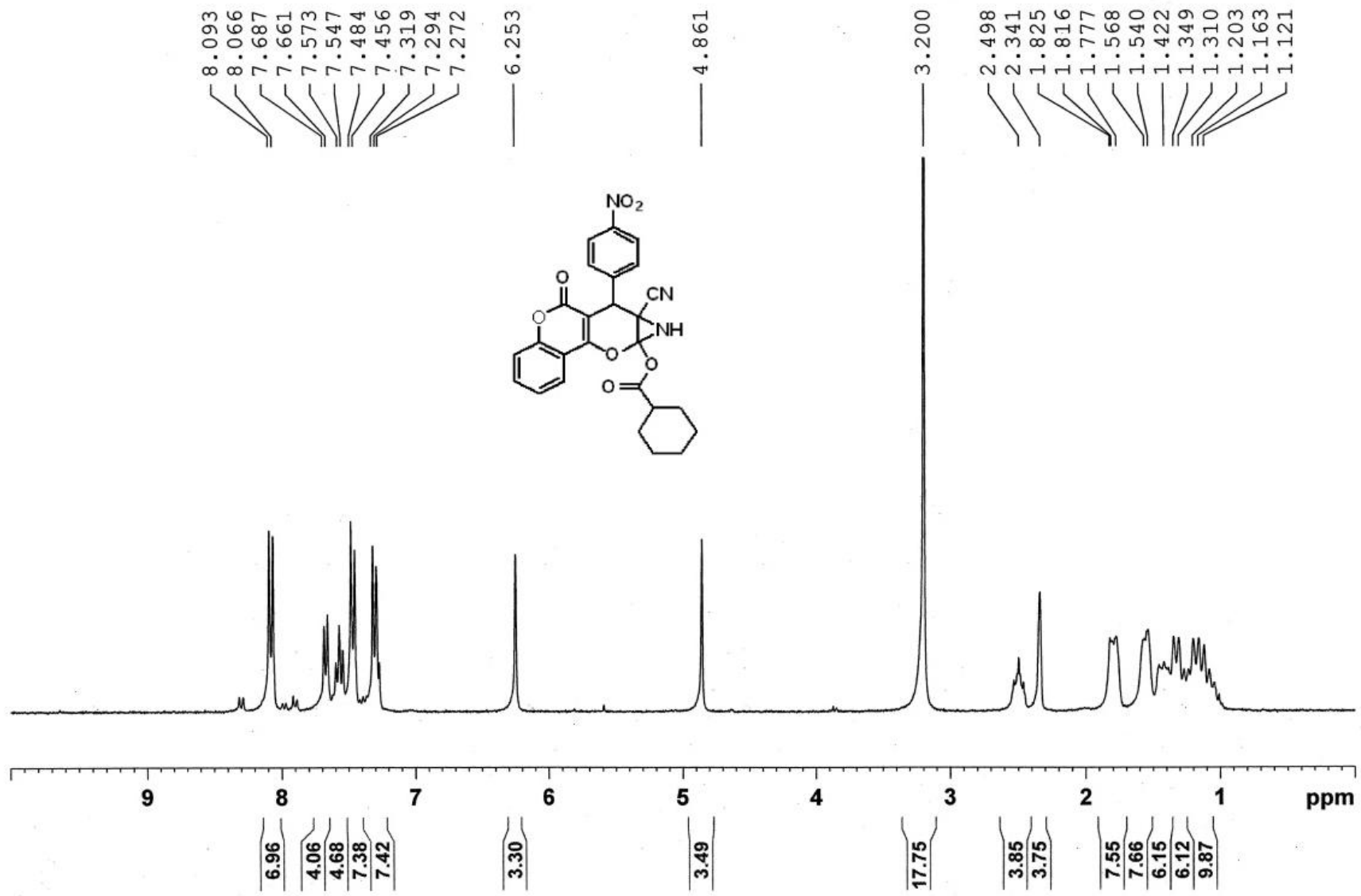
¹³C NMR of 3b



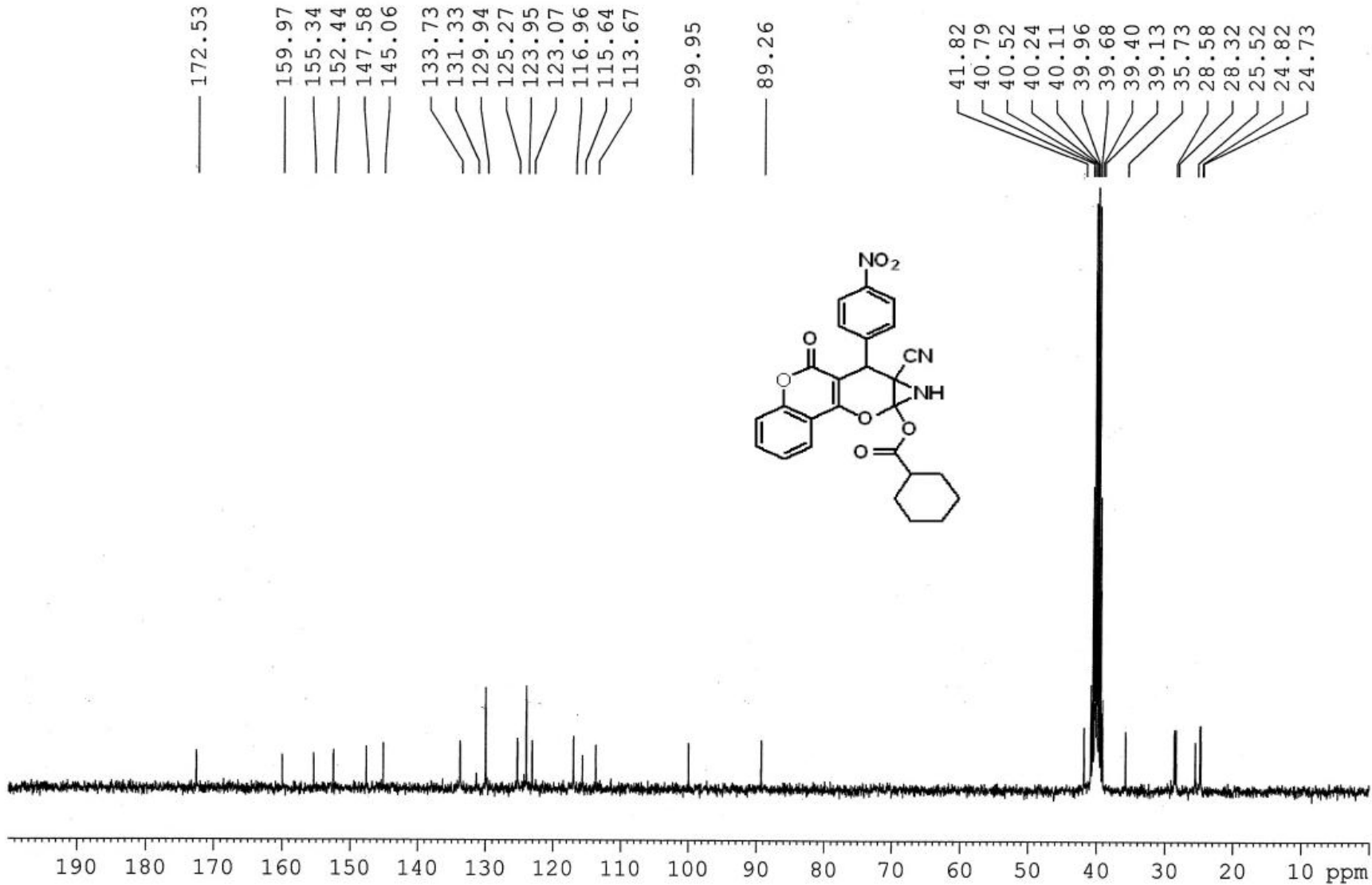
^1H NMR of 3c



¹³C NMR of 3c



¹H NMR of 3r



¹³C NMR of 3r