N-alkylation of organonitrogen compounds catalyzed by methylene-linked bis-NHC half-sandwich ruthenium complexes

Zakaria Moutaoukil,[a] Emmanuel Serrano-Díez,[a] Isidro G. Collado,[a] Manuel Jiménez-Tenorio*[b] and José Manuel Botubol-Ares*[a]

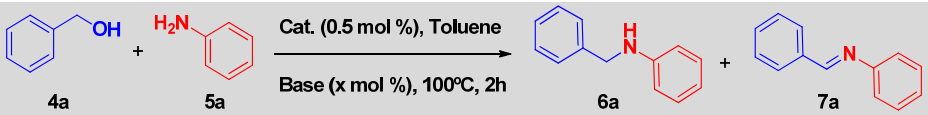
[a]University of Cadiz, Departamento de Química Orgánica-INBIO, Facultad de Ciencias, Torre Sur, 4º planta, 11510, Puerto Real, Cádiz

[b]University of Cadiz, Departamento de Ciencias de los Materiales e Ingeniería Metalúrgica y Química Inorgánica-INBIO, Facultad de Ciencias, Torre Norte, 1º planta, 11510, Puerto Real, Cádiz

josemanuel.botubol@uca.es

1. Optimization of reaction conditions

Table S1. Initial Screening of Reaction Conditions for *N*-alkylation of Aniline with Benzyl Alcohol[a]

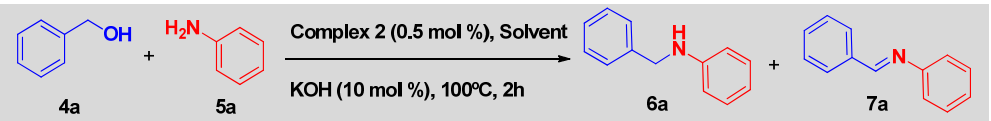


4a 5a 6a 7a

entry	catalyst (mol %)	base (mol %)	yield 6a (%)[b]	yield 7a (%)[b]
1	**1** (0.5)	K_2CO_3 (10)	10	31
2	**2** (0.5)	K_2CO_3 (10)	18	48
3	**3** (0.5)	K_2CO_3 (10)	11	44
4	**1** (0.5)	KO*i*Pr (10)	70	14
5	**2** (0.5)	KO*i*Pr (10)	82	7
6	**3** (0.5)	KO*i*Pr (10)	75	9
7	**1** (0.5)	NaOH (10)	93	5
8	**2** (0.5)	NaOH (10)	89	8
9	**3** (0.5)	NaOH (10)	85	11
10	**1** (0.5)	^{t}BuOK (10)	80	18
11	**2** (0.5)	^{t}BuOK (10)	92	7
12	**3** (0.5)	^{t}BuOK (10)	85	14
13	**1** (0.5)	KOH (10)	93	5
14	**2** (0.5)	KOH (10)	>99	-
15	**3** (0.5)	KOH (10)	96	2
16	-	KOH (10)	-	5
17	**2** (0.5)	-	-	-

[a]Unless noted otherwise, reactions were carried out with aniline (1.0 mmol), benzyl alcohol (1.0 mmol), base (10 mol %) and Ru cat. (0.5 mol %) in 2 mL of toluene at 100 ºC. [b]Determined by GC-MS after 2h.

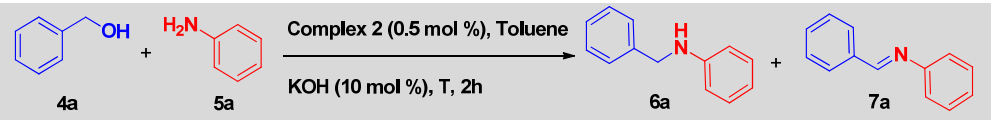
Table S2. Solvent Screening for *N*-alkylation of Aniline with Benzyl Alcohol Using Complex **2**[a]



entry	solvent	yield 6a (%)[b]	yield 7a (%)[b]
1	toluene	>99	-
2	*p*-xylene	>99	-
3	1,4-dioxane	78	3
4	DMF	-	3
5	^{t}BuOH	49	30
6	-	98	2

[a]Unless noted otherwise, reactions were carried out with aniline (1.0 mmol), benzyl alcohol (1.0 mmol), KOH (10 mol %) and complex **2** (0.5 mol %) in 2 mL of solvent at 100 ºC. [b]Determined by GC-MS after 2h.

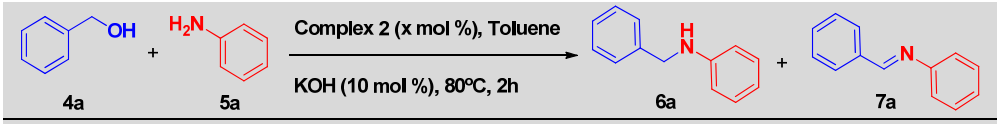
Table S3. Temperature Optimization for *N*-alkylation of Aniline with Benzyl Alcohol Using Complex **2**[a]



entry	T (ºC)	yield 6a (%)[b]	yield 7a (%)[b]
1	100	>99	-
2	80	>99	-
3	60	75	25

[a]Unless noted otherwise, reactions were carried out with aniline (1.0 mmol), benzyl alcohol (1.0 mmol), KOH (10 mol %) and complex **2** (0.5 mol %) in 2 mL of toluene. [b]Determined by GC-MS after 2h.

Table S4. Optimization of the Amount of Complex **2** for *N*-alkylation of Aniline with Benzyl Alcohol[a]



entry	cat 2 (mol %)	yield 6a (%)[b]	yield 7a (%)[b]	TON[c]	TOF (h^{-1})[d]
1	0.5	>99	-	198	99
2	0.1	94	5	940	470
3[e]	0.1	6	78	60	30
4	0.05	90	10	1800	900

[a]Unless noted otherwise, reactions were carried out with aniline (2.0 mmol), benzyl alcohol (2.0 mmol), KOH (10 mol %) in 2 mL of toluene at 80ºC. [b]Determined by CG-MS after 2h. [c]Turnover number (moles of aniline converted to **6a** per mole of catalyst). [d]Turnover frequency (moles of aniline converted to **6a** per mole of catalyst per hour). [e]The reaction was carried out at 60ºC.

2. General method for the *N*-alkylation of amines with alcohols. Characterization data for compounds 6a-p, 8a-q, 9, 10a-b and 11.

The corresponding primary alcohols (1.0 mmol) and amines (1.0 mmol) were added to a solution of the ruthenium catalyst **2** (0.001 mmol, 0.8 mg) and KOH (0.1 mmol, 5.6 mg) in degassed toluene (2 mL) under argon. The reaction mixture was stirred at 80 ºC for 2 h and then evaluated by TLC and GC-MS. The reaction mixture was cooled to room temperature and the solvent evaporated under reduced pressure. The resulting crude product was purified by column chromatography on silica gel using mixtures of hexanes and ethyl acetate as eluents to afford the corresponding *N*-alkylated products.

***N*-benzylaniline (6a).**[1] Pale yellow solid, mp 38-40 ºC (181.2 mg, 99% isolated yield) (flash chromatography 5% ethyl acetate/petroleum ether). ^{1}H NMR (400 MHz, $CDCl_3$): δ 4.06 (br s, N*H*), 4.33 (s, 2H), 6.65 (d, *J* = 8.1 Hz, 2H), 6.72 (tt, *J* = 7.3, 1.1 Hz, 1H), 7.15-7.19 (m, 2H), 7.27-7.38 (m, 5H) ppm. ^{13}C NMR (100 MHz, $CDCl_3$): δ 148.1, 139.4, 129.2 (2C), 128.6 (2C), 127.4 (2C), 127.2, 117.5, 112.8 (2C), 48.2 ppm.

***N*-(2-methylbenzyl)aniline (6b).**[2] Yellow oil (173.6 mg, 88%) (flash chromatography 5% ethyl acetate/petroleum ether). ^{1}H NMR (400 MHz, $CDCl_3$): δ 2.38 (s, 3H), 3.90 (br s, N*H*), 4.28 (s, 2H), 6.65 (d, *J* = 7.6 Hz, 2H), 6.73 (tt, *J* = 7.3, 1.1 Hz, 1H), 7.17-7.22 (m, 5H), 7.34 (d, *J* = 6.6 Hz, 1H) ppm. ^{13}C NMR (100 MHz, $CDCl_3$): δ 148.2, 136.9, 136.2, 130.3, 129.2 (2C), 128.1, 127.3, 126.0, 117.3, 112.6 (2C), 46.2, 18.8 ppm.

***N*-(3-methylbenzyl)aniline (6c).**[3] White solid, mp 42-44 ºC (189.4 mg, 96%) (flash chromatography 40% ethyl acetate/petroleum ether). ^{1}H NMR (400 MHz, $CDCl_3$): δ 2.35 (s, 3H), 4.07 (br s, N*H*), 4.28 (s, 2H), 6.64 (d, *J* = 8.6 Hz, 2H), 6.72 (tt, *J* = 7.3, 1.1 Hz, 1H), 7.09 (d, *J* = 8.1 Hz, 1H), 7.16-7.23 (m, 5H) ppm. ^{13}C NMR (100 MHz, $CDCl_3$): δ 148.1, 139.3, 138.1, 129.1 (2C), 128.4, 128.2, 127.9, 124.5, 117.4, 112.7 (2C), 48.2, 21.3 ppm.

***N*-(4-methylbenzyl)aniline (6d).**[4] White solid, mp 42-44 ºC (177.5 mg, 90%) (flash chromatography 5% ethyl acetate/petroleum ether). ^{1}H NMR (400 MHz, $CDCl_3$): δ 2.45 (s, 3H), 4.36 (s, 2H), 6.72 (d, *J* = 8.2 Hz, 2H), 6.82 (tt, *J* = 7.3, 1.1 Hz, 1H), 7.24-7.29 (m, 4H), 7.35 (d, *J* = 8.2 Hz, 2H) ppm. ^{13}C NMR (100 MHz, $CDCl_3$): δ 148.2, 136.8, 136.3, 129.3 (2C), 129.2 (2C), 127.5 (2C), 117.5, 112.8 (2C), 48.1, 21.1 ppm.

***N*-(4-fluorobenzyl)aniline (6e).**[4] Yellow oil (199.2 mg, 99%) (flash chromatography 5% ethyl acetate/petroleum ether). ^{1}H NMR (400 MHz, $CDCl_3$): δ 4.06 (br s, N*H*), 4.38 (s, 2H), 6.74 (d, *J* = 7.5 Hz, 2H), 6.82 (tt, *J* = 7.5, 1.1 Hz, 1H), 7.15 (d, *J* = 8.7 Hz, 2H), 7.32 (dd, *J* = 8.7, 7.5 Hz, 2H), 7.41-7.46 (m, 2H) ppm. ^{13}C NMR (100 MHz, $CDCl_3$): δ 162.0 (d, $J_{C\text{-}F}$ = 245.0 Hz), 147.9, 135.0 (d, $J_{C\text{-}F}$ = 3.1 Hz), 129.3 (2C), 129.0 (d, $J_{C\text{-}F}$ = 8.0 Hz, 2C), 117.7, 115.4 (d, $J_{C\text{-}F}$ = 21.4 Hz, 2C), 112.9 (2C), 47.6 ppm. ^{19}F NMR (376 MHz, $CDCl_3$): δ - 115.6 ppm.

***N*-(4-chlorobenzyl)aniline (6f).**[4] Yellow oil (204.6 mg, 94%) (flash chromatography 5% ethyl acetate/petroleum ether). ^{1}H NMR (400 MHz, $CDCl_3$): δ 4.33 (s, 2H), 6.65 (d, *J* = 7.7 Hz, 2H), 6.79 (tt, *J* = 7.3, 1.1 Hz, 1H), 7.20-7.26 (m, 2H), 7.34 (m, 4H) ppm. ^{13}C NMR (100 MHz, $CDCl_3$): δ 147.8, 138.0, 132.8, 129.3 (2C), 128.73 (2C), 128.67 (2C), 117.8, 112.9 (2C), 47.6 ppm.

***N*-benzylpyridin-2-amine (6g).**[3] White solid, mp 94-96 ºC (182.4 mg, 99%) (flash chromatography 25% ethyl acetate/petroleum ether). ^{1}H NMR (400 MHz, $CDCl_3$): δ 4.51 (d, *J* = 5.8 Hz, 2H), 5.02 (br s, N*H*), 6.37 (d, *J* = 8.4 Hz, 1H), 6.59 (ddd, *J* = 7.1, 5.2, 0.9 Hz, 1H), 7.24-7.43 (m, 6H), 8.10 (d, *J* = 5.2 Hz, 1H) ppm. ^{13}C NMR (100 MHz, $CDCl_3$): δ 158.6, 148.1, 139.1, 137.4, 128.6 (2C), 127.3 (2C), 127.2, 113.1, 106.7, 46.3 ppm.

***N*-(4-methylbenzyl)pyridin-2-amine (6h).**[5] White solid, mp 74-76 ºC (182.4 mg, 92%) (flash chromatography 25% ethyl acetate/petroleum ether). ^{1}H NMR (400 MHz, $CDCl_3$): δ 2.32 (s, 3H), 4.41 (d, *J* = 5.7 Hz, 2H), 5.01 (br s, N*H*), 6.33 (d, *J* = 8.6 Hz, 1H), 6.54 (ddd, *J* = 7.2, 5.0, 0.9 Hz, 1H), 7.12 (d, *J* = 7.8 Hz, 2H), 7.22 (d, *J* = 7.8 Hz, 2H), 7.36 (ddd, *J* = 8.6, 7.2, 1.9 Hz, 1H), 8.05 (d, *J* = 5.0 Hz, 1H) ppm. ^{13}C NMR (100 MHz, $CDCl_3$): δ 158.6, 148.0, 137.4, 136.7, 136.0, 129.2 (2C), 127.3 (2C), 112.9, 106.6, 46.0, 21.0 ppm.

***N*-(4-methoxybenzyl)pyridin-2-amine (6i).**[5] White solid, mp 128-131 ºC (212.1 mg, 99%) (flash chromatography 35% ethyl acetate/petroleum ether). ^{1}H NMR (500 MHz, $CDCl_3$): δ 3.79 (s, 3H), 4.41 (d, *J* = 5.4 Hz, 2H), 4.97 (br s, N*H*), 6.36 (dt, *J* = 8.4, 1.0 Hz, 1H), 6.57 (ddd, *J* = 7.2, 5.1, 1.0 Hz, 1H), 6.85-6.88 (m, 2H), 7.26-7.29 (m, 2H), 7.39 (ddd, *J* = 8.4, 7.2, 1.9 Hz, 1H), 8.08 (ddd, *J* = 5.1, 1.9, 1.0 Hz, 1H) ppm. ^{13}C NMR (125 MHz, $CDCl_3$): δ 158.8, 158.6, 148.0, 137.4, 131.1, 128.6 (2C), 113.9 (2C), 113.0, 106.7 55.2, 45.7 ppm.

***N*-(4-chlorobenzyl)pyridin-2-amine (6j).**[1] White solid, mp 104-106 ºC (216.5 mg, 99%) (flash chromatography 30% ethyl acetate/petroleum ether). ^{1}H NMR (400 MHz, $CDCl_3$): δ 4.46 (d, *J* = 6.0 Hz, 2H), 5.04 (br s, N*H*), 6.33 (d, *J* = 8.4 Hz, 1H), 6.58 (ddd, *J* = 7.1, 5.1, 0.9 Hz, 1H), 7.25-7.29 (m, 4H), 7.38 (ddd, *J* = 8.4, 7.1, 1.9 Hz, 1H), 8.07 (d, *J* = 5.1 Hz, 1H) ppm. ^{13}C NMR (100 MHz, $CDCl_3$): δ 158.4, 148.1, 137.8, 137.5, 132.8, 128.7 (2C), 128.6 (2C), 113.3, 106.8, 45.5 ppm.

***N*-(Benzo[1,3]dioxol-5-ylmethyl)aniline (6k).**[6] White solid, mp 78-80 ºC (184.1 mg, 81%) (flash chromatography 5% ethyl acetate/petroleum ether). ^{1}H NMR (400 MHz, $CDCl_3$): δ 3.98 (br s, N*H*), 4.23 (s, 2H), 5.94 (s, 2H), 6.61-6.65 (m, 2H), 6.72 (tt, *J* = 7.6, 1.1 Hz, 1H), 6.77 (d, *J* = 7.6 Hz, 1H), 6.82-6.85 (m, 1H), 6.86-6.88 (m, 1H), 7.18 (dd, *J* = 8.6, 7.2 Hz, 2H) ppm. ^{13}C NMR (100 MHz, $CDCl_3$): δ 148.0, 147.9, 146.7, 133.3, 129.2 (2C), 120.6, 117.6, 112.8 (2C), 108.3, 108.0, 101.0, 48.1 ppm.

***N*-(3-((*tert*-butyldimethylsilyl)oxy)benzyl)aniline (6l).**[7] Colourless oil (163.0 mg, 52%) (flash chromatography 3% ethyl acetate/petroleum ether). ^{1}H NMR (400 MHz, $CDCl_3$): δ 0.15 (s, 6H), 0.95 (s, 9H), 4.27 (s, 2H), 6.65 (d, *J* = 7.7 Hz, 2H), 6.70-6.77 (m, 2H), 6.83 (s, 1H), 6.95 (d, *J* = 7.7 Hz, 1H), 7.12-7.21 (m, 3H), ppm. ^{13}C NMR (100 MHz, $CDCl_3$): δ 155.9, 147.3, 140.4, 129.6, 129.3, 120.6, 119.4, 119.0, 118.2, 113.5, 48.6, 25.7, 18.2, -4.42 ppm.

***N*-phenethylaniline (6m).**[8] Colourless oil (193.3 mg, 98%) (flash chromatography 5% ethyl acetate/petroleum ether). ^{1}H NMR (400 MHz, $CDCl_3$): δ 3.03 (t, *J* = 7.0 Hz, 2H), 3.51 (t, *J* = 7.0 Hz, 2H), 3.73 (br s, N*H*), 6.75 (d, *J* = 8.7 Hz, 2H), 6.87 (tt, *J* = 7.3, 1.1 Hz, 1H), 7.29-7.41 (m, 5H), 7.46 (dd, *J* = 8.0, 6.6 Hz, 2H) ppm. ^{13}C NMR (100 MHz, $CDCl_3$): δ 147.9, 139.2, 129.2 (2C), 128.7 (2C), 128.5 (2C), 126.3, 117.3, 112.8 (2C), 44.9, 35.3 ppm.

***N*-(cyclopropylmethyl)aniline (6n).**[4] Yellow oil (145.7 mg, 99%) (flash chromatography 5% ethyl acetate/petroleum ether). ^{1}H NMR (400 MHz, $CDCl_3$): δ 0.32 (dt, *J* = 5.9, 4.4 Hz, 2H), 0.60-0.67

(m, 2H), 1.12-1.24 (m, 1H), 3.04 (d, *J* = 6.9 Hz, 2H), 3.73 (br s, N*H*), 6.70 (d, *J* = 7.4 Hz, 2H), 6.79 (tt, *J* = 7.4, 1.1 Hz, 1H), 7.21-7.31 (m, 2H) ppm. ^{13}C NMR (100 MHz, $CDCl_3$): δ 148.4, 129.2 (2C), 117.3, 112.8 (2C), 49.1, 10.9, 3.4 (2C) ppm.

***N*-ethylpyridin-2-amine (6o).**[9] White solid, mp 78-80 ºC (120.9 mg, 99%) (flash chromatography 10% ethyl acetate/petroleum ether). ^{1}H NMR (400 MHz, $CDCl_3$): δ 1.24 (t, *J* = 7.2 Hz, 3H), 3.28 (quint, *J* = 7.2 Hz, 2H), 4.45 (br s, N*H*), 6.35 (d, *J* = 8.6 Hz, 1H), 6.54 (ddd, *J* = 7.2, 5.1, 1.0 Hz, 1H), 7.40 (ddd, *J* = 8.6, 7.2, 1.8 Hz, 1H), 8.06 (dd, *J* = 5.1, 1.8 Hz, 1H) ppm. ^{13}C NMR (100 MHz, $CDCl_3$): δ 158.8, 148.2, 137.4, 112.7 106.3, 36.9, 14.8 ppm.

***N*-methylpyridin-2-amine (6p).**[10] Yellow oil (56.2 mg, 52%) (flash chromatography 50% ethyl acetate/petroleum ether). ^{1}H NMR (400 MHz, $CDCl_3$): δ 2.91 (d, *J* = 4.0 Hz, 3H), 4.64 (br s, N*H*), 6.39 (dt, *J* = 8.4, 1.0 Hz, 1H), 6.57 (ddd, *J* = 7.2, 5.1, 0.9 Hz, 1H), 7.44 (ddd, *J* = 8.4, 7.2, 1.9 Hz, 1H), 8.06 (ddd, *J* = 5.1, 1.9, 0.9 Hz, 1H) ppm. ^{13}C NMR (100 MHz, $CDCl_3$): δ 159.5, 147.4, 137.9, 112.6, 106.3, 29.1 ppm.

***N*-benzyl-2-bromoaniline (8a).**[3] Yellow oil (222.8 mg, 85%) (flash chromatography 5% ethyl acetate/petroleum ether). ^{1}H NMR (400 MHz, $CDCl_3$): δ 4.41 (d, *J* = 5.7 Hz, 2H), 4.76 (br s, N*H*), 6.56-6.63 (m, 2H), 7.13 (ddd, *J* = 8.5, 7.4, 1.5 Hz, 1H), 7.27-7.32 (m, 1H), 7.33-7.39 (m, 4H), 7.45 (dd, *J* = 7.9, 1.5 Hz, 1H) ppm. ^{13}C NMR (100 MHz, $CDCl_3$): δ 144.8, 138.6, 132.4, 128.7 (2C), 128.4, 127.3, 127.2 (2C), 117.9, 111.6, 109.6, 48.0 ppm.

***N*-benzyl-3-bromoaniline (8b).**[11] Colourless oil (259.5 mg, 99%) (flash chromatography 10% ethyl acetate/petroleum ether). ^{1}H NMR (400 MHz, $CDCl_3$): δ 4.00 (br s, N*H*), 4.21 (s, 2H), 6.46 (ddd, *J* = 8.0, 1.9, 0.9 Hz, 1H), 6.72 (t, *J* = 1.9 Hz, 1H), 6.79 (ddd, *J* = 8.0, 1.9, 0.9 Hz, 1H), 6.95 (t, *J* = 8.0 Hz, 1H), 7.23-7.33 (m, 5H) ppm. ^{13}C NMR (100 MHz, $CDCl_3$): δ 149.2, 138.6, 130.4, 128.6 (2C), 127.34 (2C), 127.31, 123.1, 120.1, 115.3, 111.4, 47.9 ppm.

***N*-benzyl-4-bromoaniline (8c).**[11] White solid, mp 52-54 ºC (215.0 mg, 82%) (flash chromatography 10% ethyl acetate/petroleum ether). ^{1}H NMR (400 MHz, $CDCl_3$): δ 4.08 (br s, N*H*), 4.31 (s, 2H), 6.51 (d, *J* = 8.7 Hz, 2H), 7.25 (d, *J* = 8.7 Hz, 2H), 7.27-7.41 (m, 5H) ppm. ^{13}C NMR (100 MHz, $CDCl_3$): δ 147.0, 138.8, 131.9 (2C), 128.7 (2C), 127.4 (2C), 127.3, 114.4 (2C), 109.1, 48.2 ppm.

***N*-benzyl-4-chloroaniline (8d).**[11] Colourless oil (213.3 mg, 98%) (flash chromatography 5% ethyl acetate/petroleum ether). ^{1}H NMR (400 MHz, $CDCl_3$): δ 4.32 (s, 2H), 6.57 (d, *J* = 8.9 Hz, 2H), 7.14 (d, *J* = 8.9 Hz, 2H), 7.28-7.40 (m, 5H) ppm. ^{13}C NMR (100 MHz, $CDCl_3$): δ 146.6, 138.9, 129.0 (2C), 128.6 (2C), 127.36 (2C), 127.32, 122.0, 113.9 (2C), 48.3 ppm.

4-(benzylamino)benzonitrile (8e).[12] White solid, mp 62-64 ºC (202.0 mg, 97%) (flash chromatography 10% ethyl acetate/petroleum ether). ^{1}H NMR (400 MHz, $CDCl_3$): δ 4.37 (s, 2H), 4.60 (br s, N*H*), 6.54-6.63 (m, 2H), 7.28-7.37 (m, 5H), 7.38-7.44 (m, 2H) ppm. ^{13}C NMR (100 MHz, $CDCl_3$): δ 151.0, 137.8, 133.7 (2C), 128.8 (2C), 127.7, 127.3 (2C), 120.3, 112.4 (2C), 99.1, 47.5 ppm.

***N*-benzyl-4-methylaniline (8f).**[4] Yellow oil (195.3 mg, 99%) (flash chromatography 5% ethyl acetate/petroleum ether). ^{1}H NMR (400 MHz, $CDCl_3$): δ 2.36 (s, 3H), 3.98 (br s, N*H*), 4.39 (s, 2H),

6.66 (d, *J* = 8.3 Hz, 2H), 7.10 (d, *J* = 8.3 Hz, 2H), 7.38 (m, 1H), 7.42-7.51 (m, 4H) ppm. ^{13}C NMR (100 MHz, $CDCl_3$): δ 145.8, 139.6, 129.6 (2C), 128.4 (2C), 128.1, 127.4 (2C), 127.0, 112.9 (2C), 48.5, 20.3 ppm.

***N*-benzylnaphthalen-1-amine (8g).**[1] Brown solid, mp 58-60 ºC (231.0 mg, 99%) (flash chromatography 5% ethyl acetate/petroleum ether). ^{1}H NMR (500 MHz, $CDCl_3$): δ 4.52 (s, 2H), 4.84 (br s, N*H*), 6.69 (dd, *J* = 7.4, 1.2 Hz,1H), 7.32-7.54 (m, 9H), 7.84-7.89 (m, 2H) ppm. ^{13}C NMR (100 MHz, $CDCl_3$): δ 143.0, 139.0, 134.2, 128.65 (2C), 128.64, 127.7 (2C), 127.3, 126.6, 125.7, 124.7, 123.3, 119.9, 117.7, 104.8, 48.6 ppm.

***N*-benzylquinolin-2-amine (8h).**[13] Yellow solid, mp 91-93 ºC (231.9 mg, 99%) (flash chromatography 20% ethyl acetate/petroleum ether). ^{1}H NMR (400 MHz, $CDCl_3$): δ 4.75 (d, *J* = 5.5 Hz, 2H), 5.26 (br s, N*H*), 6.61 (d, *J* = 8.9 Hz, 1H), 7.23-7.39 (m, 4H), 7.41-7.46 (m, 2H), 7.54-7.65 (m, 2H), 7.78-7.82 (m, 2H) ppm. ^{13}C NMR (100 MHz, $CDCl_3$): δ 156.6, 147.9, 139.3, 137.2, 129.4, 128.5 (2C), 127.6 (2C), 127.3, 127.1, 126.1, 123.4, 122.0, 111.2, 45.7 ppm.

***N*-benzylpyrimidin-2-amine (8i).**[5] White solid, mp 74-76 ºC (183.4 mg, 99%) (flash chromatography 25% ethyl acetate/petroleum ether). ^{1}H NMR (400 MHz, $CDCl_3$): δ 4.63 (d, *J* = 5.7 Hz, 2H), 6.44 (t, *J* = 4.8 Hz, 1H), 6.67 (br s, N*H*), 7.23-7.40 (m, 5H), 8.08 (br s, 2H) ppm. ^{13}C NMR (100 MHz, $CDCl_3$): δ 162.2, 157.8 (2C), 139.0, 128.4 (2C), 127.5 (2C), 127.1, 110.4, 45.4 ppm.

***N*-benzylbenzo[*d*]thiazol-2-amine (8j).**[14] White solid, mp 154-156 ºC (209.2 mg, 99%) (flash chromatography 20% ethyl acetate/petroleum ether). ^{1}H NMR (400 MHz, $CDCl_3$): δ 4.64 (s, 2H), 6.37 (br s, N*H*), 7.08 (dt, *J* = 7.6, 1.2 Hz, 1H), 7.23-7.43 (m, 6H), 7.45 (dd, *J* = 8.2, 1.2 Hz, 1H), 7.57 (dd, *J* = 7.9, 1.2 Hz, 1H) ppm. ^{13}C NMR (100 MHz, $CDCl_3$): δ 167.6, 152.2, 137.4, 130.4 (2C), 128.8, 127.8 (2C), 127.6, 126.0, 121.6, 120.8, 118.9, 49.4 ppm.

(*E*)-*N*-benzyl-4-styrylaniline (8k).[15] White solid, mp 88−90 °C (171.2 mg, 60%) (flash chromatography 3% ethyl acetate/petroleum ether). ^{1}H NMR (400 MHz, $CDCl_3$): δ 4.36 (s, 2H), 6.64 (d, *J* = 8.5 Hz, 2H), 6.89 (d, *J* = 16.3 Hz, 1H), 7.01 (d, *J* = 16.3 Hz, 1H), 7.16-7.22 (m, 1H), 7.27-7.39 (m, 9H), 7.44-7.47 (m, 2H) ppm. ^{13}C NMR (100 MHz, $CDCl_3$): δ 147.7, 139.1, 138.0, 128.7 (2C), 128.6 (2C), 128.5 (2C), 127.7 (2C), 127.4, 127.3 (2C), 127.2, 126.7, 126.0 (2C), 124.5, 112.9, 48.1 ppm.

Dibenzylamine (8l).[4] Colourless oil (148.0 mg, 75%) (flash chromatography 20% ethyl acetate/petroleum ether). ^{1}H NMR (400 MHz, $CDCl_3$): δ 1.57 (br s, N*H*), 3.74 (s, 4H), 7.16-7.28 (m, 10H) ppm. ^{13}C NMR (100 MHz, $CDCl_3$): δ 140.3 (2C), 128.4 (4C), 128.1 (4C), 126.9 (2C), 53.2 (2C) ppm.

***N*-benzyl-1-phenylethanamine (8m).**[4] Colourless oil (171.1 mg, 81%) (flash chromatography 5% ethyl acetate/petroleum ether). ^{1}H NMR (500 MHz, $CDCl_3$): δ 1.39 (d, *J* = 6.6 Hz, 3H), 1.64 (br s, N*H*), 3.62 (d, *J* = 13.1 Hz, 1H), 3.69 (d, *J* = 13.1 Hz, 1H), 3.84 (q, *J* = 6.6 Hz, 1H), 7.28-7.43 (m, 10H) ppm. ^{13}C NMR (125 MHz, $CDCl_3$): δ 145.5, 140.6, 128.4 (2C), 128.3 (2C), 128.1 (2C), 126.9, 126.8, 126.7 (2C), 57.5, 51.6, 24.5 ppm.

***N*-benzylcyclohexanamine (8n).**[16] Pale yellow oil (153.4 mg, 81%) (flash chromatography petroleum ether/ethyl acetate/Et_3N 4:1:0.05). ^{1}H NMR (400 MHz, $CDCl_3$): δ 1.11-1.23 (m, 5H),

1.61-1.66 (m, 1H), 1.73-1.82 (m, 2H), 1.88-1.92 (m, 2H), 2.43-2.50 (m, 1H), 3.76 (s, 2H), 7.19-7.22 (m, 1H), 7.27-7.31 (m, 4H) ppm. ^{13}C NMR (100 MHz, $CDCl_3$): δ 141.1, 128.3 (2C), 128.1 (2C), 126.8, 55.9, 50.5, 33.0 (2C), 25.9, 24.9 (2C) ppm.

1-benzylpyrrolidine (8o).[4] Yellow oil (132.2 mg, 82%) (flash chromatography 2% MeOH/DCM). ^{1}H NMR (500 MHz, $CDCl_3$): δ 1.76-1.78 (m, 4H), 2.51-2.54 (m, 4H), 3.63 (s, 2H), 7.22-7.34 (m, 5H) ppm. ^{13}C NMR (125 MHz, $CDCl_3$): δ 138.7, 128.9 (2C), 128.1 (2C), 126.9, 60.4, 53.9 (2C), 23.2 (2C) ppm.

1-(4-methoxybenzyl)pyrrolidine (8p).[17] Pale yellow oil (118.6 mg, 62%) (flash chromatography petroleum ether/ethyl acetate/Et_3N 7:1:0.2). ^{1}H NMR (400 MHz, $CDCl_3$): δ 1.74-1.80 (m, 4H), 2.47-2.51 (m, 4H), 3.55 (s, 2H), 3.79 (s, 3H), 6.81-6.88 (m, 2H), 7.24 (d, *J* = 8.6 Hz, 2H) ppm. ^{13}C NMR (100 MHz, $CDCl_3$): δ 158.6, 130.0 (2C), 128.2, 113.5 (2C), 60.0, 55.2, 54.0 (2C), 23.4 (2C) ppm.

1-benzylpiperidine (8q).[4] Light orange oil (61.3 mg, 35%) (flash chromatography petroleum ether/ethyl acetate/Et_3N 4:1:0.05). ^{1}H NMR (400 MHz, $CDCl_3$): δ 1.41-1.46 (m, 2H), 1.56-1.61 (m, 4H), 2.40 (br s, 4H), 3.50 (s, 2H), 7.30-7.31 (m, 3H), 7.35-7.39 (m, 2H) ppm. ^{13}C NMR (100 MHz, $CDCl_3$): δ 138.0, 129.4 (2C), 128.1 (2C), 127.0, 63.6, 54.3 (2C), 25.7 (2C), 24.2 ppm.

***N*-phenylpyrrolidine (9)**.[18] Colourless oil (75.1 mg, 51%) (flash chromatography 5% ethyl acetate/petroleum ether). ^{1}H NMR (400 MHz, $CDCl_3$): δ 2.02-2.08 (m, 4H), 3.31-3.37 (m, 4H), 6.63 (d, *J* = 7.7 Hz, 2H), 6.71 (t, *J* = 7.7 Hz, 1H), 7.25-7.31 (m, 2H) ppm. ^{13}C NMR (100 MHz, $CDCl_3$): δ 147.9, 129.1 (2C), 115.4, 111.6 (2C), 47.6 (2C), 25.4 (2C) ppm.

1,2,3,4-Tetrahydroquinoxaline (10a).[19] Yellow solid, mp 99-101 ºC (41.6 mg, 31%) (flash chromatography 15% ethyl acetate/petroleum ether). ^{1}H NMR (400 MHz, $CDCl_3$) δ 3.41 (s, 4H), 6.47-6.52 (m, 2H), 6.56-6.60 (m, 2H) ppm. ^{13}C NMR (100 MHz, $CDCl_3$) δ 133.6 (2C), 118.8 (2C), 114.7 (2C), 41.4 (2C) ppm.

1,4-dihydroquinoxaline (10b).[20] Amorphous yellow solid (66.1 mg, 50%) (flash chromatography 15% ethyl acetate/petroleum ether). ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.74–7.81 (m, 2H), 8.08–8.15 (m, 2H), 8.84 (s, 2H) ppm. ^{13}C NMR (100 MHz, $CDCl_3$): δ 145.0 (2C), 143.0 (2C), 130.1 (2C), 129.5 (2C) ppm.

Indole (11).[21] The title compound was prepared according to the general procedure using 2-aminophenethyl alcohol (2744.0 mg, 20 mmol) and was purified by flash chromatography (10% ethyl acetate/petroleum ether) to yield the title compound (2319.6 mg, 99% isolated yield) as a white solid, mp 52-53 ºC. ^{1}H NMR (400 MHz, $CDCl_3$): δ 6.57 (ddd, *J* = 3.1, 2.0, 1.0 Hz, 1H), 7.13 (ddd, *J* = 8.1, 7.1, 1.1 Hz, 1H), 7.18-7.23 (m, 2H), 7.40 (ddd, *J* = 8.1, 1.8, 8.0 Hz, 1H), 7.66 (ddd, *J* = 8.1, 1.8, 0.8 Hz, 1H), 8.12 (br s, N*H*) ppm. ^{13}C NMR (100 MHz, $CDCl_3$): δ 135.7, 127.8, 124.1, 122.0, 120.7, 119.8, 111.0, 102.6 ppm.

3. General method for the *N*-alkylation of amides with alcohols. Characterization data for compounds 13a-h.

The corresponding primary alcohols (1.0 mmol) and amides (1.0 mmol) were added to a solution of the ruthenium catalyst **2** (0.005 mmol, 3.86 mg) and KOH (0.1 mmol, 5.6 mg) in degassed *p*-

xylene (2 mL) under argon. The reaction mixture was stirred at 140 ºC for 16 h and then evaluated by TLC and GC-MS. The mixture was cooled to room temperature. The reaction crude was purified by silica gel column using petroleum ether and ethyl acetate mixtures to afford compounds **13a-h**.

***N*-benzylbenzamide (13a**).[22] White solid, mp 99-101 ºC (209.1 mg, 99%) (flash chromatography 50% ethyl acetate/petroleum ether).[1]H NMR (400 MHz, $CDCl_3$): δ 4.60 (d, *J* = 5.8 Hz, 2H), 6.76 (br s, 1H), 7.25-7.34 (m, 5H), 7.39 (tt, *J* = 8.4, 1.4 Hz, 2H), 7.45-7.50 (m, 1H), 7.77-7.80 (m, 2H) ppm. ^{13}C NMR (100 MHz, $CDCl_3$): δ167.4, 138.2, 134.3, 131.4, 128.6 (2C), 128.4 (2C), 127.8 (2C), 127.4, 126.9 (2C), 44.0 ppm.

***N*-(4-fluorobenzyl)benzamide (13b)**.[22] White solid, mp 113-115 ºC (226.9 mg, 99%) (flash chromatography 50% ethyl acetate/petroleum ether). ^{1}H NMR (500 MHz, $CDCl_3$): δ 4.53 (d, *J* = 5.8 Hz, 2H), 6.95-7.00 (m, 3H), 7.25 (dd, *J* = 8.5, 5.5 Hz, 2H), 7.37 (t, *J* = 7.7 Hz, 2H), 7.47 (tt, *J* = 7.7, 1.1 Hz, 1H), 7.78 (d, *J* = 7.0 Hz, 2H) ppm. ^{13}C NMR (125 MHz, $CDCl_3$): δ167.4, 162.0 (d, $J_{C\text{-}F}$ = 245.5 Hz), 134.12, 134.06 (d, $J_{C\text{-}F}$ = 3.3 Hz), 131.5, 129.3 (d, $J_{C\text{-}F}$ = 8.1 Hz), 128.4 (2C), 126.9 (2C), 115.4 (d, $J_{C\text{-}F}$ = 21.5 Hz), 43.2 ppm. ^{19}F NMR (376 MHz, $CDCl_3$): δXX ppm.

***N*-(4-methoxybenzyl)benzamide (13c).**[22] White solid, mp 95-96º (219.6 mg, 91%) (flash chromatography 55% ethyl acetate/petroleum ether). ^{1}H NMR (400 MHz, $CDCl_3$): δ3.76 (s, 3H), 4.51 (d, *J* = 5.6 Hz, 2H), 6.84 (m, 3H), 7.23 (d, *J* = 8.8 Hz, 2H), 7.26-7.41 (m, 2H), 7.42-7.51 (m, 1H), 7.69-7.90 (m, 2H) ppm. ^{13}C NMR (100 MHz, $CDCl_3$): δ167.3, 158.8, 134.3, 131.3, 130.3, 129.1 (2C), 128.4 (2C), 126.9 (2C), 113.9 (2C), 55.2, 43.4 ppm.

***N*-(cyclopropylmethyl)benzamide (13d).**[23] White solid, mp 77-79 ºC (173.5 mg, 99%) (flash chromatography 50% ethyl acetate/petroleum ether). ^{1}H NMR (400 MHz, $CDCl_3$): δ0.19-0.27 (m, 2H), 0.47-0.55 (m, 2H), 0.98-1.09 (m, 1H), 3.28 (t, *J* = 6.4 Hz, 2H), 6.50 (br s, 1H), 7.39 (d, *J* = 7.6 Hz, 2H), 7.46 (t, *J* = 7.6 Hz, 1H), 7.77 (d, *J* = 7.6 Hz, 2H) ppm. ^{13}C NMR (100 MHz, $CDCl_3$): δ167.4, 134.7, 131.2, 128.4 (2C), 126.8 (2C), 44.8, 10.7, 3.4 ppm.

***N*-pentylbenzamide (13e).**[24] Pale yellow oil (141.5 mg, 74%) (flash chromatography 40% ethyl acetate/petroleum ether). ^{1}H NMR (400 MHz, $CDCl_3$): δ0.88 (t, *J* = 6.8 Hz, 3H), 1.27-1.39 (m, 4H), 1.54-1.64 (m, 2H), 3.37-3.44 (m, 2H), 6.38 (br s, 1H), 7.38 (t, *J* = 7.4 Hz, 2H), 7.42-7.51 (m, 1H), 7.75 (d, *J* = 7.4 Hz, 2H) ppm. ^{13}C NMR (100 MHz, $CDCl_3$): δ167.5, 134.8, 131.2, 128.4 (2C), 126.8 (2C), 40.0, 29.3, 29.1, 22.3, 13.9 ppm.

***N*-benzyl-4-methoxybenzamide (13f).**[22] White solid, mp 126-128 ºC (224.4 mg, 96%) (flash chromatography 50% ethyl acetate/petroleum ether). ^{1}H NMR (400 MHz, $CDCl_3$): δ3.82 (s, 3H), 4.59 (d, *J* = 5.7 Hz, 2H), 6.62 (br s, 1H), 6.88 (d, *J* = 8.8 Hz, 2H), 7.24-7.34 (m, 5H), 7.76 (d, *J* = 8.8 Hz, 2H) ppm. ^{13}C NMR (100 MHz, $CDCl_3$): δ167.0, 162.2, 138.5, 128.8 (2C), 128.7 (2C), 127.8 (2C), 127.4, 126.6, 113.7 (2C), 55.4, 44.0 ppm.

***N*-benzylisonicotinamide (13g).**[25] White solid, mp 85-87 ºC (210.1 mg, 99%) (flash chromatography 60% ethyl acetate/petroleum ether). ^{1}H NMR (400 MHz, $CDCl_3$): δ 4.60 (d, *J* = 5.7 Hz, 2H), 6.96 (br s, 1H), 7.23-7.39 (m, 5H), 7.55-7.61 (m, 2H), 8.53-8.70 (m, 2H) ppm. ^{13}C NMR (100 MHz, $CDCl_3$): δ165.4, 150.4 (2C), 141.4, 137.5, 128.8, 127.85 (2C), 127.79 (2C), 120.9 (2C), 44.2 ppm.

***N*-benzylpropionamide (13h)**.[26] White solid, mp 50-52 ºC (161.6 mg, 99%) (flash chromatography 50% ethyl acetate/petroleum ether). ^{1}H NMR (400 MHz, $CDCl_3$): δ 1.18 (t, *J* = 7.6 Hz, 3H), 2.25 (q, *J* = 7.6 Hz, 2H), 4.44 (d, *J* = 5.7 Hz, 2H), 5.75 (br s, 1H), 7.25-7.36 (m, 5H) ppm. ^{13}C NMR (100 MHz, $CDCl_3$): δ 173.6, 138.4, 128.7 (2C), 127.8 (2C), 127.5, 43.6, 29.7, 9.8 ppm.

4. General method for the *N*-alkylation of sulfonamides with alcohols. Characterization data for compounds 15a-j.

The corresponding primary alcohols (1 mmol) and sulfonamides (1 mmol) were added to a solution of the ruthenium catalyst **2** (0.025 mmol, 19.3 mg) and KOH (0.1 mmol, 5.6 mg) in degassed *p*-xylene (2 mL) under argon. The reaction mixture was stirred at 140 ºC for 16 h and then evaluated by TLC and GC-MS. The mixture was cooled to room temperature. The reaction crude was purified by silica gel column using petroleum ether and ethyl acetate mixtures to afford compounds **15a-j**.

***N*-benzylbenzenesulfonamide (15a)**.[27] White solid, mp 78-80 ºC (205.2 mg, 83%) (flash chromatography 20% ethyl acetate/petroleum ether). ^{1}H NMR (400 MHz, $CDCl_3$): δ 4.15 (d, *J* = 6.2 Hz, 2H), 4.79 (t, *J* = 6.2 Hz, 1H), 7.16-7.22 (m, 2H), 7.23-7.29 (m, 3H), 7.47-7.55 (m, 2H), 7.56-7.61 (m, 1H), 7.85-7.90 (m, 2H) ppm. ^{13}C NMR (100 MHz, $CDCl_3$): δ 139.9, 136.1, 132.7, 129.1 (2C), 128.7 (2C), 127.9, 127.8 (2C), 127.1 (2C), 47.3 ppm.

***N*-(4-methoxybenzyl)benzenesulfonamide (15b)**.[28] White solid, mp 105-107 ºC (133.1 mg, 48%) (flash chromatography 30% ethyl acetate/petroleum ether). ^{1}H NMR (400 MHz, $CDCl_3$): δ 3.76 (s, 3H), 4.06 (d, *J* = 6.1 Hz, 2H), 4.71 (t, *J* = 6.1 Hz, 1H), 6.78 (d, *J* = 8.8 Hz, 2H), 7.08 (d, *J* = 8.8 Hz, 2H), 7.47-7.52 (m, 2H), 7.54-7.61 (m, 1H), 7.84-7.89 (m, 2H) ppm. ^{13}C NMR (100 MHz, $CDCl_3$): δ 159.3, 139.9, 132.6, 129.2 (2C), 129.1 (2C), 128.1, 127.1 (2C), 114.0 (2C), 55.3, 46.8 ppm.

***N*-(4-chlorobenzyl)benzenesulfonamide (15c)**.[28] White solid, mp 112-114 ºC (183.1 mg, 65%) (flash chromatography 20% ethyl acetate/petroleum ether). ^{1}H NMR (400 MHz, $CDCl_3$): δ 4.10 (d, *J* = 6.3 Hz, 2H), 5.00 (t, *J* = 6.3 Hz, 1H), 7.12 (d, *J* = 8.4 Hz, 2H), 7.22 (d, *J* = 8.4 Hz, 2H), 7.50 (dd, *J* = 8.3, 6.9 Hz, 2H), 7.56-7.62 (m, 1H), 7.84 (d, *J* = 8.3 Hz, 2H) ppm. ^{13}C NMR (100 MHz, $CDCl_3$): δ 139.8, 134.8, 133.7, 132.8, 129.16, 129.15, 128.8, 127.0, 46.5 ppm.

***N*-(pentyl)benzenesulfonamide (15d)**.[29] Yellow oil (122.7 mg, 54%) (flash chromatography 10% ethyl acetate/petroleum ether). ^{1}H NMR (400 MHz, $CDCl_3$): δ 0.82 (t, *J* = 6.8 Hz, 3H), 1.19-1.26 (m, 4H), 1.43 (quint, *J* = 7.0 Hz, 2H), 2.93 (td, *J* = 7.0, 6.2 Hz, 2H), 4.58 (t, *J* = 6.2 Hz, 1H), 7.47-7.59 (m, 3H), 7.85-7.88 (m, 2H) ppm. ^{13}C NMR (100 MHz, $CDCl_3$): δ 140.0, 132.5, 129.0 (2C), 127.0 (2C), 43.2, 29.2, 28.6, 22.1, 13.8 ppm.

***N*-Benzyl-4-methylbenzenesulfonamide (15e)**.[27] White solid, mp 161-163 ºC (224.7 mg, 86%) (flash chromatography 20% ethyl acetate/petroleum ether). ^{1}H NMR (400 MHz, $CDCl_3$) δ 2.45 (s, 3H), 4.13 (d, *J* = 6.2 Hz, 2H), 4.96 (br s, 1H), 7.19−7.23 (m, 2H), 7.25−7.34 (m, 5H), 7.77 (t, *J* = 8.2 Hz, 2H) ppm. ^{13}C NMR (100 MHz, $CDCl_3$): δ 143.4, 136.8, 136.3, 129.7 (2C), 128.6, 127.80 (2C), 127,77 (2C), 127.1, 47.2, 21.5 ppm.

***N*-Benzyl-3-methoxybenzenesulfonamide (15f)**.[30] White solid, mp 80-81 ºC (210.8 mg, 76%) (flash chromatography 25% ethyl acetate/petroleum ether). ^{1}H NMR (400 MHz, $CDCl_3$): δ 3.82

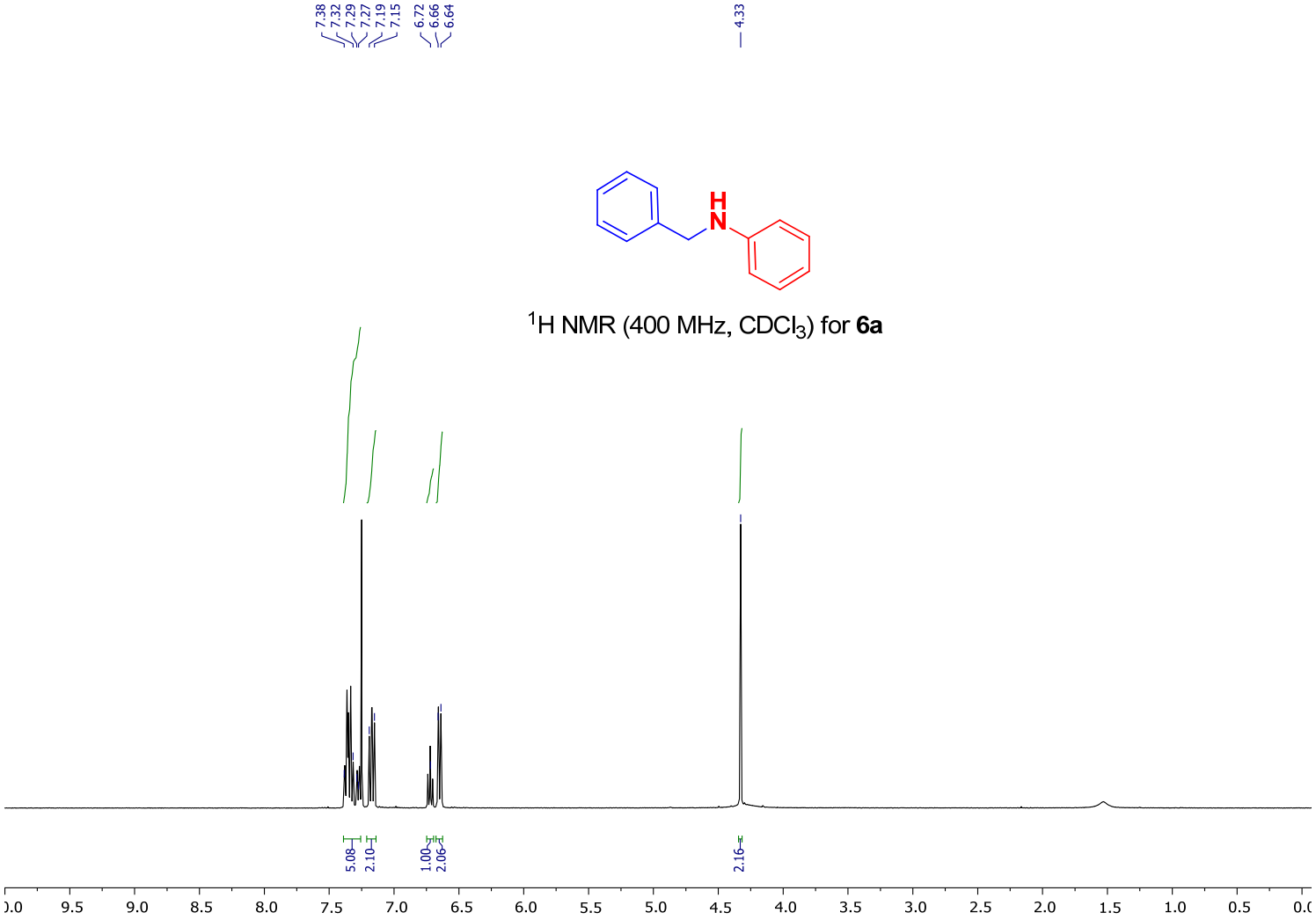
(s, 3H), 4.15 (d, *J* = 6.2 Hz, 2H), 5.24 (t, *J* = 6.2 Hz, 1H), 7.10 (ddd, *J* = 8.0, 2.6, 1.1 Hz, 1H), 7.19-7.30 (m, 5H), 7.38 (t, *J* = 1.8, Hz, 1H), 7.41 (d, *J* = 8.0, Hz, 1H), 7.46 (ddd, *J* = 8.0, 1.8, 1.1 Hz, 1H) ppm. ^{13}C NMR (100 MHz, $CDCl_3$): δ 159.8, 140.9, 136.2, 130.1, 128.5 (2C), 127.76 (2C), 127.74, 119.15, 119.12, 111.6, 55.5, 47.2 ppm.

***N*-Benzyl-(phenyl)methanesulfonamide (15g)**.[31] White solid, mp 145-146 ºC (235.2 mg, 90%) (flash chromatography 20% ethyl acetate/petroleum ether). ^{1}H NMR (400 MHz, $CDCl_3$): δ 4.05 (d, *J* = 6.1 Hz, 2H), 4.12 (s, 2H), 4.43 (t, *J* = 6.1 Hz, 1H), 7.18-7.29 (m, 10H) ppm. ^{13}C NMR (100 MHz, $CDCl_3$): δ 136.8, 130.6 (2C), 129.2, 128.80 (2C), 128.78 (2C), 128.7, 128.1, 128.0 (2C), 59.4, 47.6 ppm.

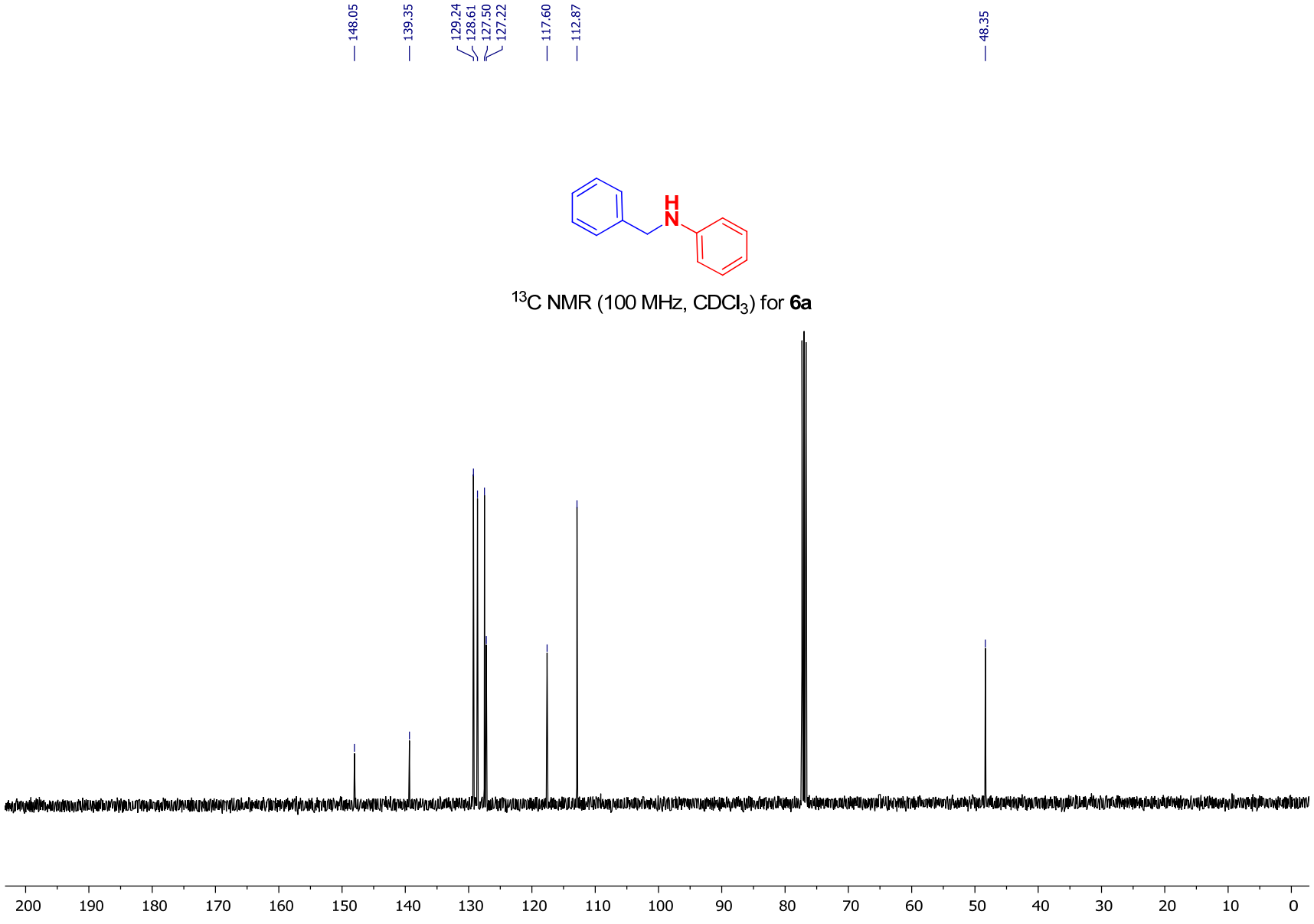
***N*-Benzylmethanesulfonamide (15h)**.[27] White solid, mp 58-61 ºC (157.4 mg, 85%) (flash chromatography 20% ethyl acetate/petroleum ether). ^{1}H NMR (400 MHz, $CDCl_3$): δ 2.82 (s, 3H), 4.29 (d, *J* = 6.2 Hz, 2H), 4.96 (br s, 1H), 7.38-7.27 (m, 5H) ppm. ^{13}C NMR (100 MHz, $CDCl_3$): δ 136.7, 128.8 (2C), 128.0, 127.8 (2C), 47.1, 41.0 ppm.

***N*-(4-(diethylamino)benzyl)-4-methoxybenzenesulfonamide (15i)**. The title compound was prepared according to the general procedure using 4-methoxybenzenesulfonamide (3744.0 mg, 20 mmol) and 4-(diethylamino)benzyl alcohol (3580.0 mg, 20 mmol) and was purified by flash chromatography (20% ethyl acetate/petroleum ether) to yield the title compound (250.9 mg, 72% isolated yield) as a white solid, mp 83-85 ºC. ^{1}H NMR (400 MHz, $CDCl_3$): δ 1.12 (t, *J* = 7.2 Hz, 6H), 3.30 (q, *J* = 7.2 Hz, 4H), 3.86 (s, 3H), 3.97 (d, *J* = 5.9 Hz, 2H), 4.62 (br s, 1H), 6.54 (d, *J* = 8.8 Hz, 2H), 6.95 (d, *J* = 8.8 Hz, 2H), 6.98 (d, *J* = 8.8 Hz, 2H), 7.79 (d, *J* = 8.8 Hz, 2H) ppm. ^{13}C NMR (100 MHz, $CDCl_3$): δ 162.7, 147.3, 131.5, 129.2 (4C), 122.3, 114.1 (2C), 111.6 (2C), 55.5, 46.9, 44.2 (2C), 12.4 (2C) ppm. IR (film): 3271, 2976, 1615, 1524, 1314, 1258, 1147, 1042, 890, 837, 802, 557 cm^{-1}. HRMS (ESI/TOF) *m/z*: calcd for $C_{18}H_{25}SO_3N_2$ ($[M+H]^+$), 349.1586; found, 349.1609.

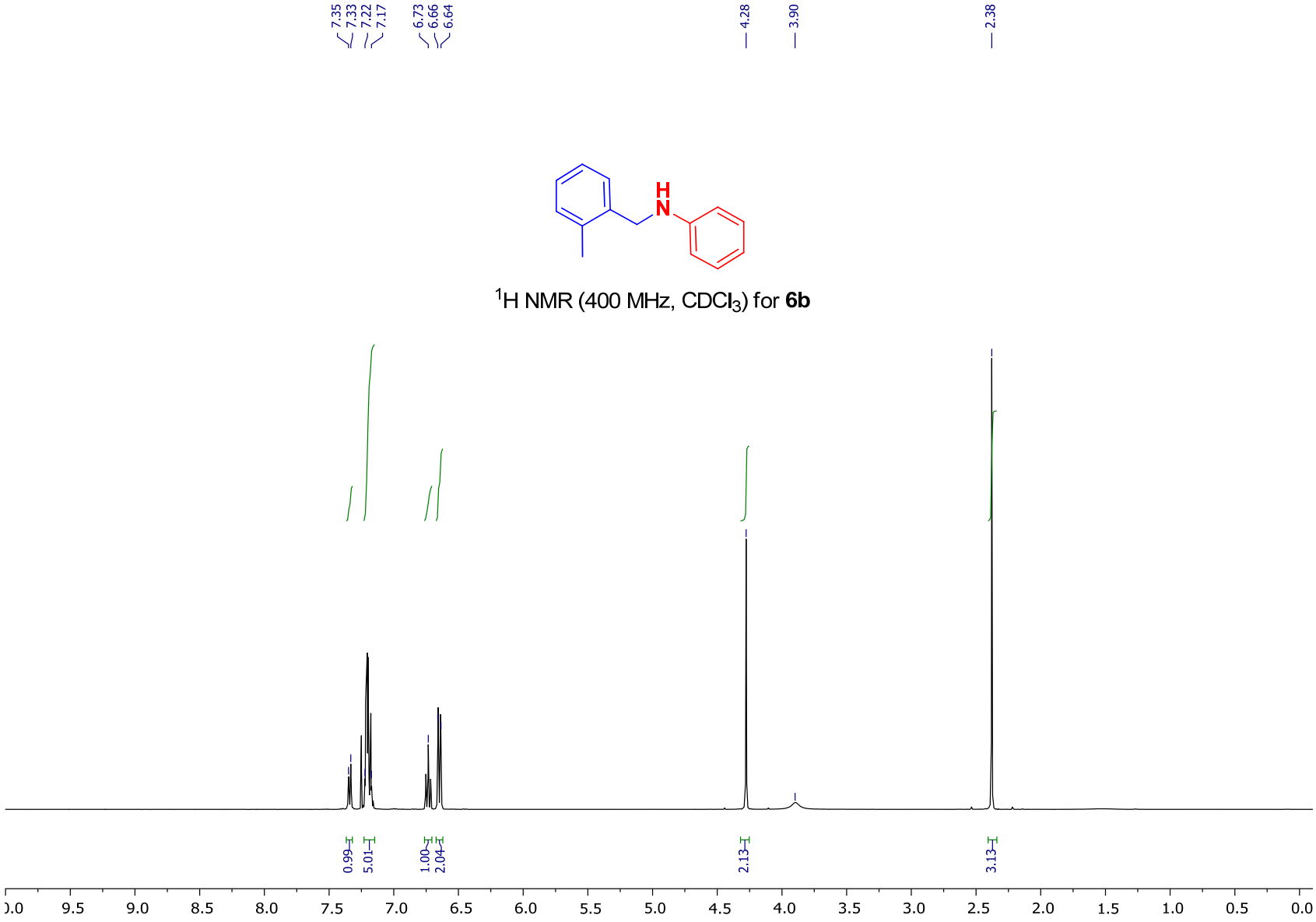
5. NMR spectrum



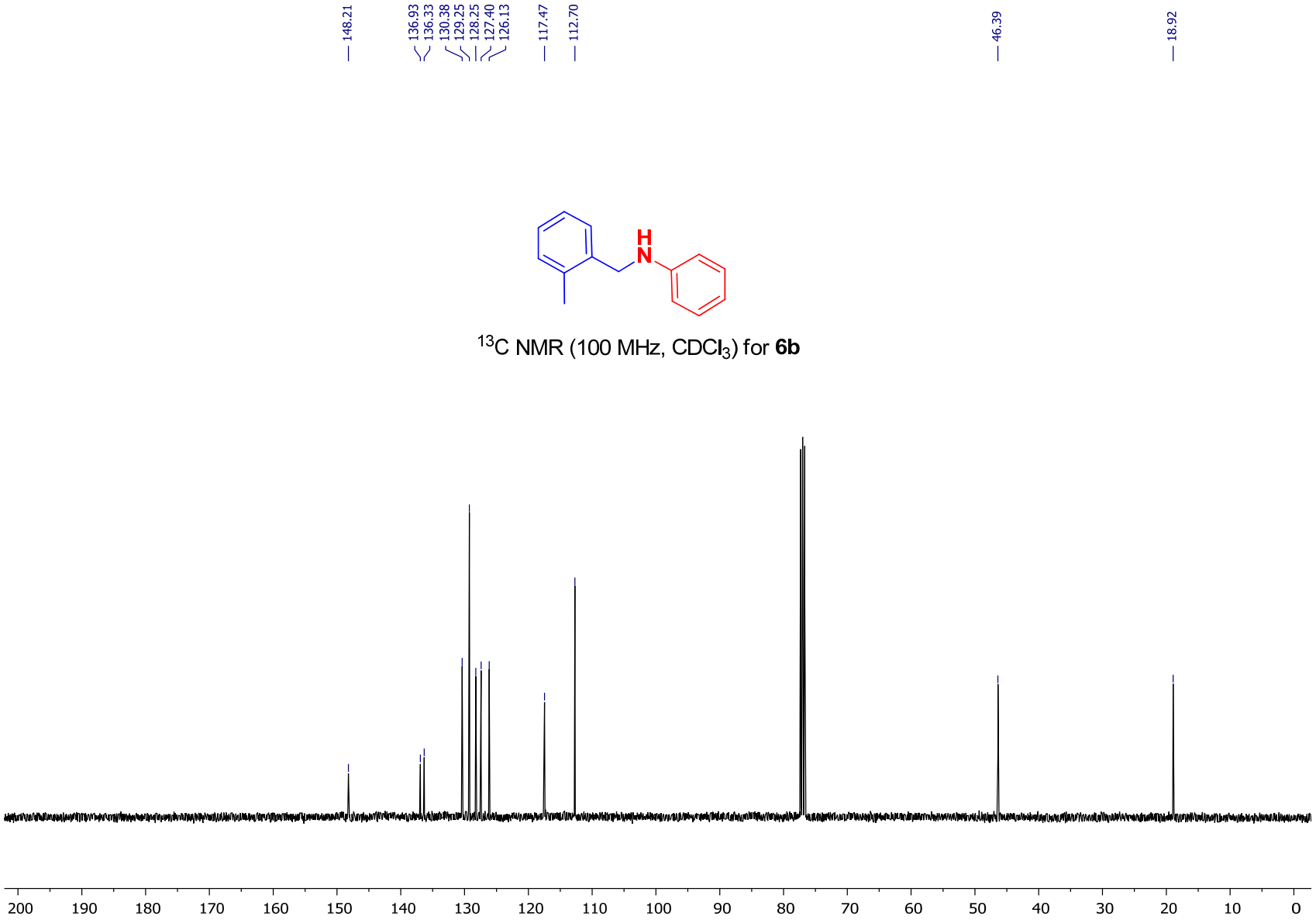
^{1}H NMR (400 MHz, $CDCl_3$) for **6a**



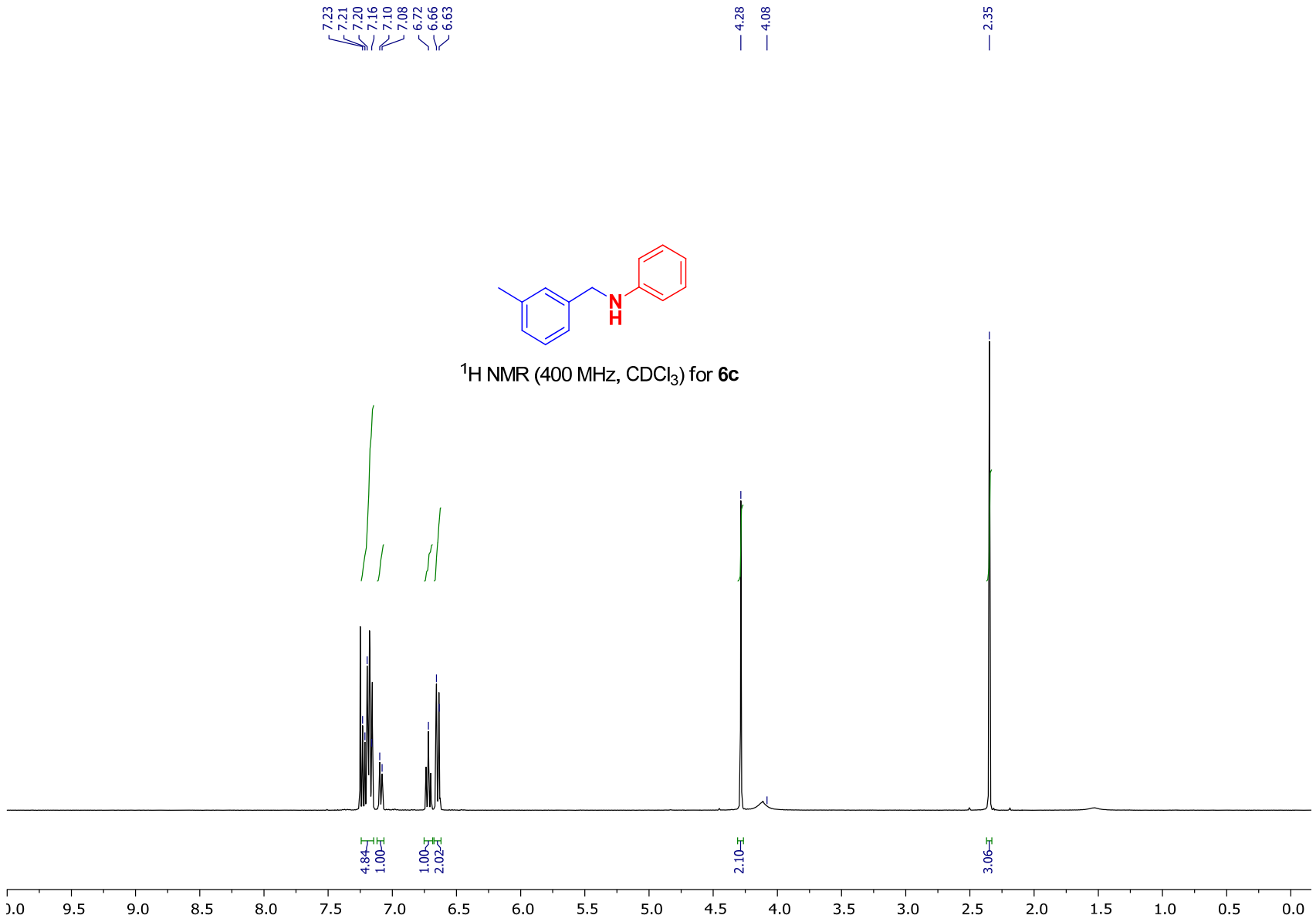
^{13}C NMR (100 MHz, $CDCl_3$) for **6a**



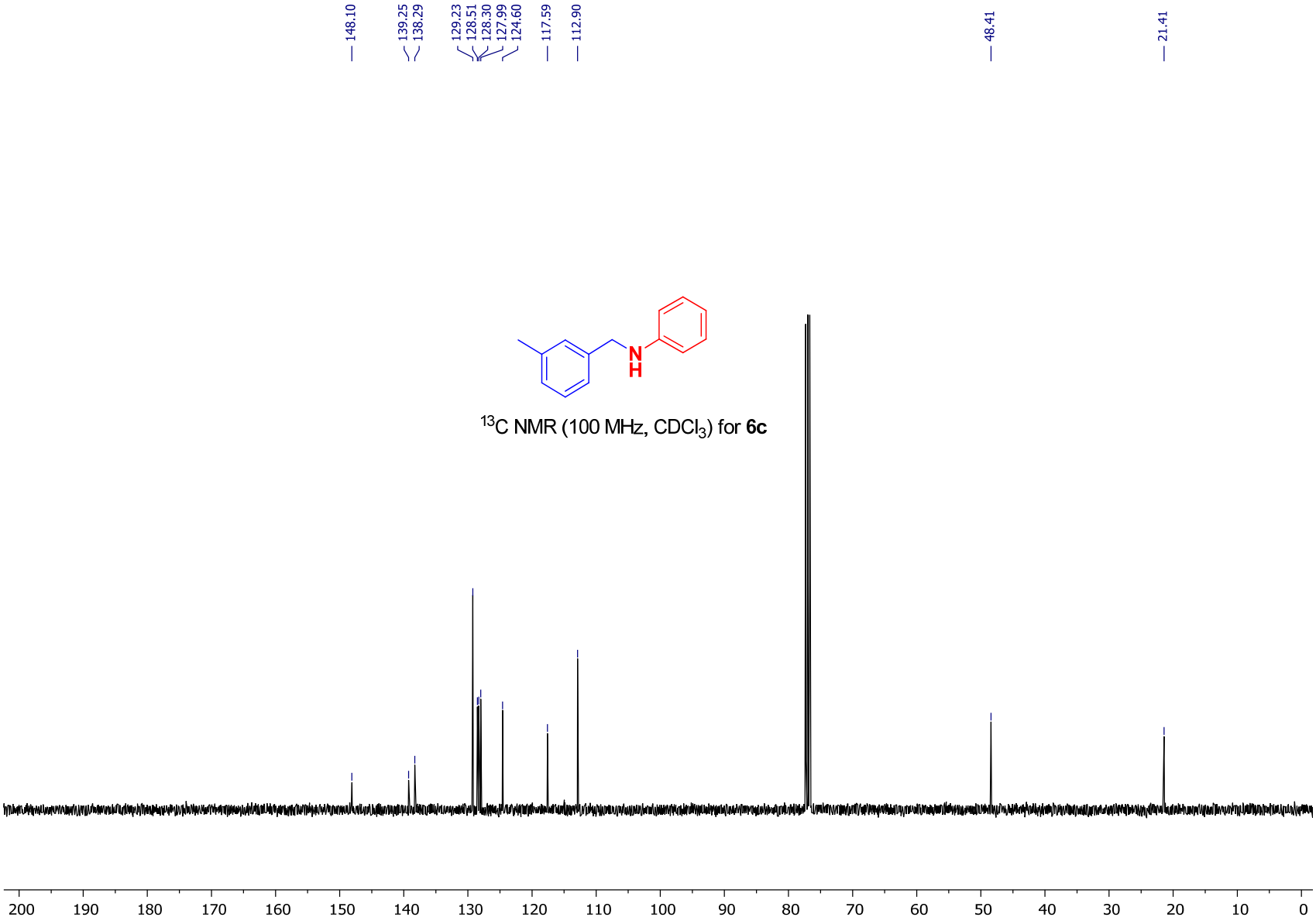
^{1}H NMR (400 MHz, $CDCl_3$) for **6b**



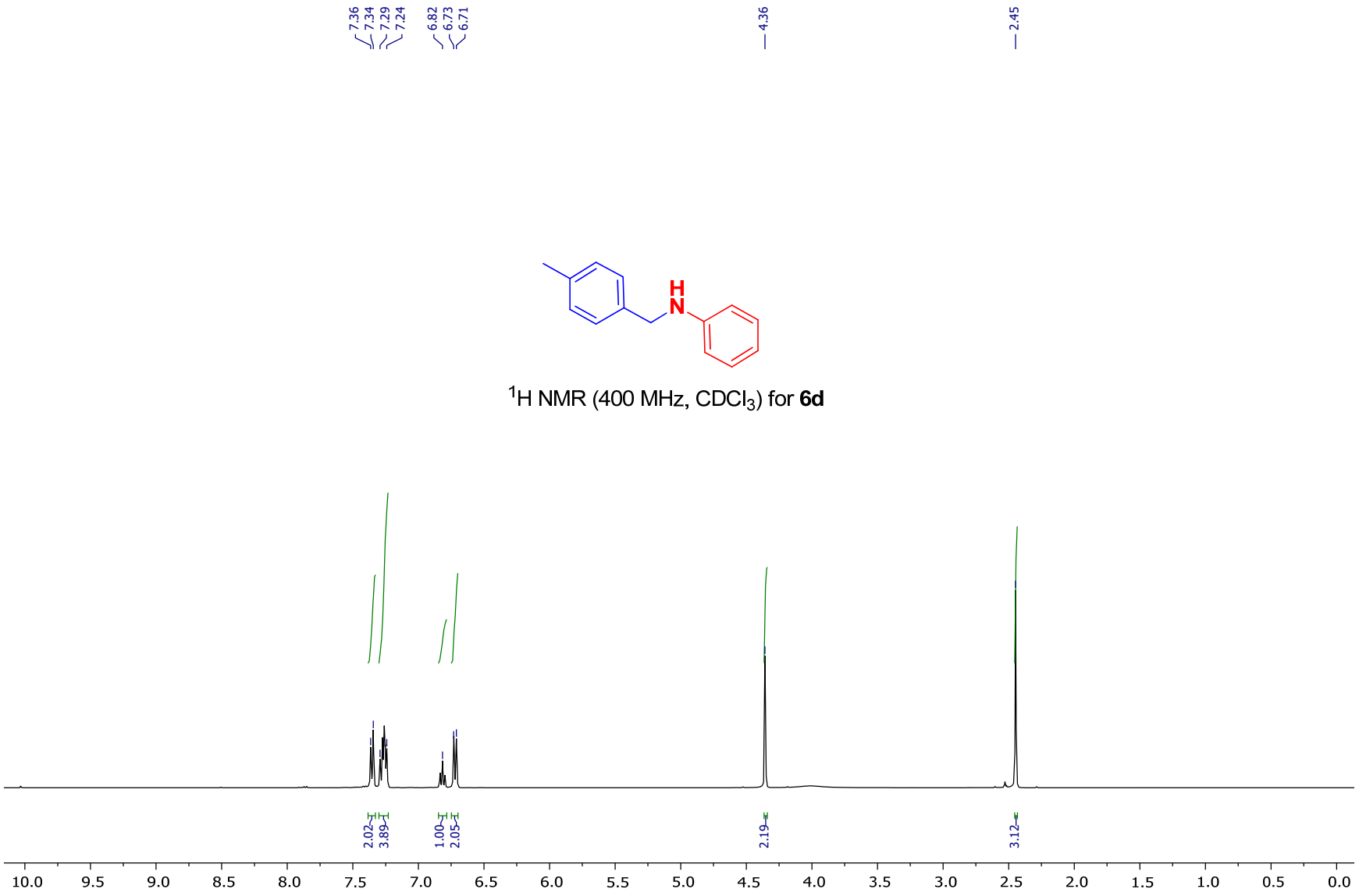
^{13}C NMR (100 MHz, $CDCl_3$) for **6b**



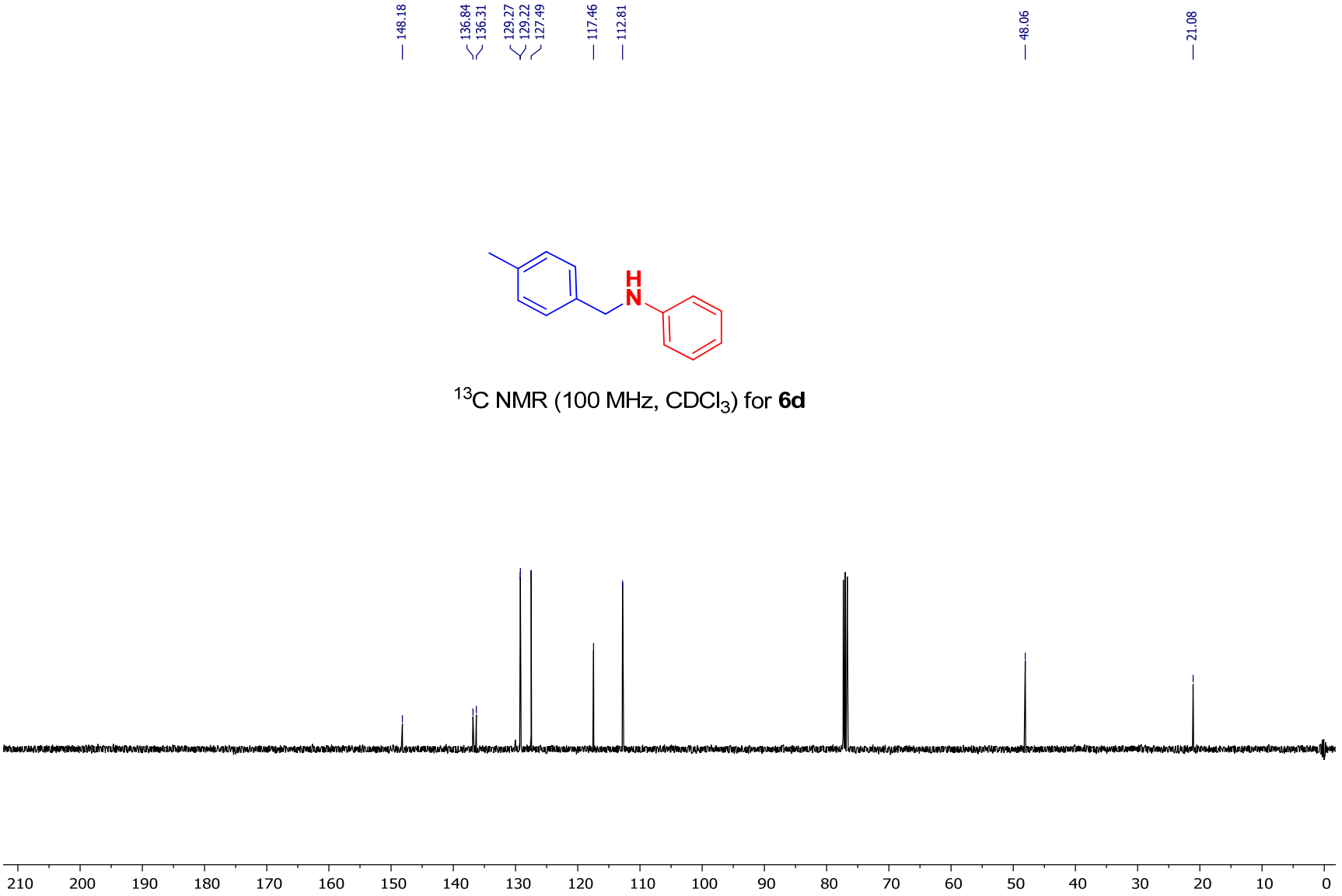
^{1}H NMR (400 MHz, $CDCl_3$) for **6c**



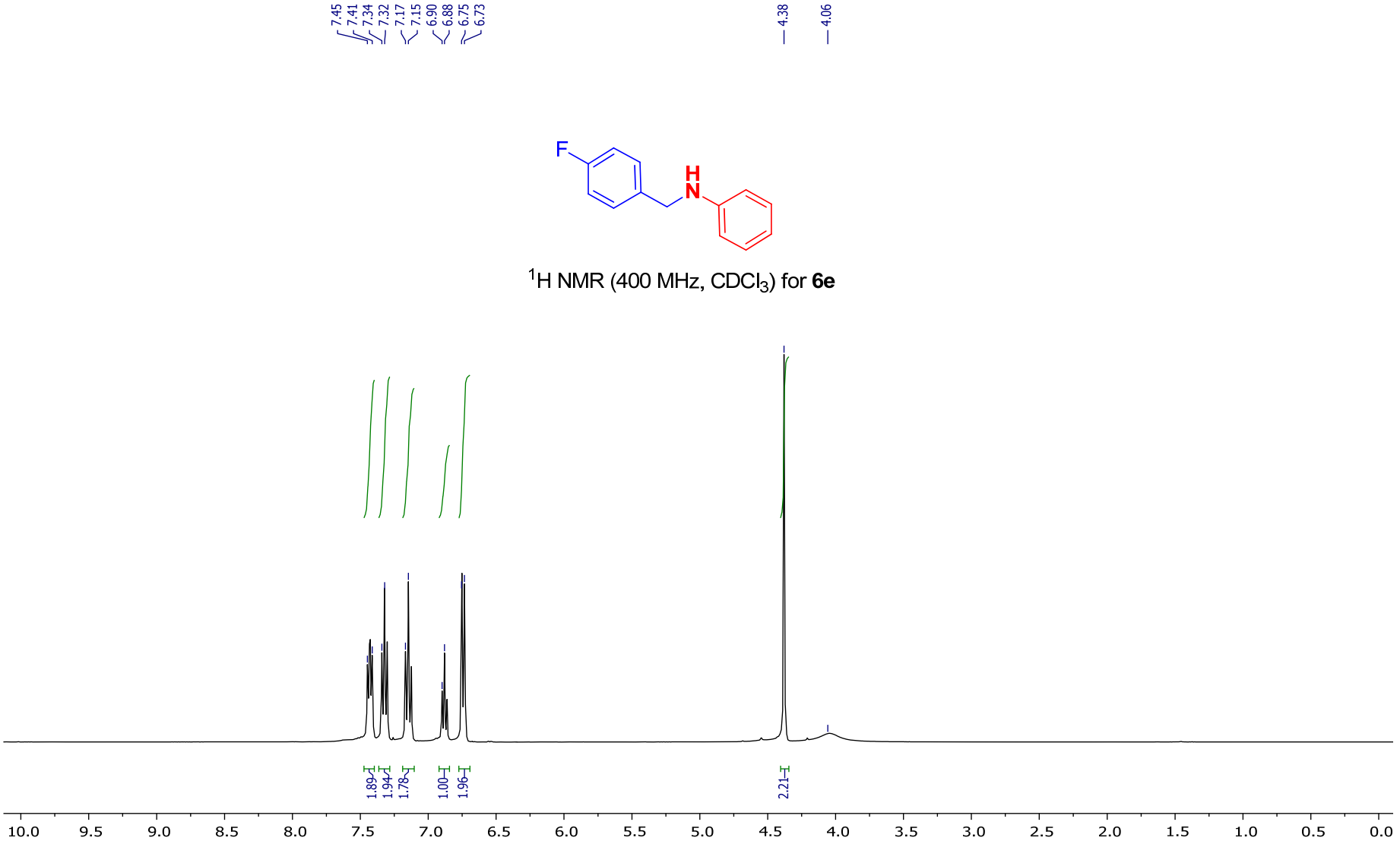
^{13}C NMR (100 MHz, $CDCl_3$) for **6c**



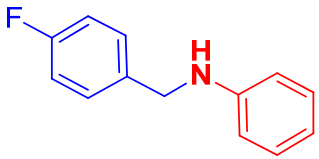
^{1}H NMR (400 MHz, $CDCl_3$) for **6d**



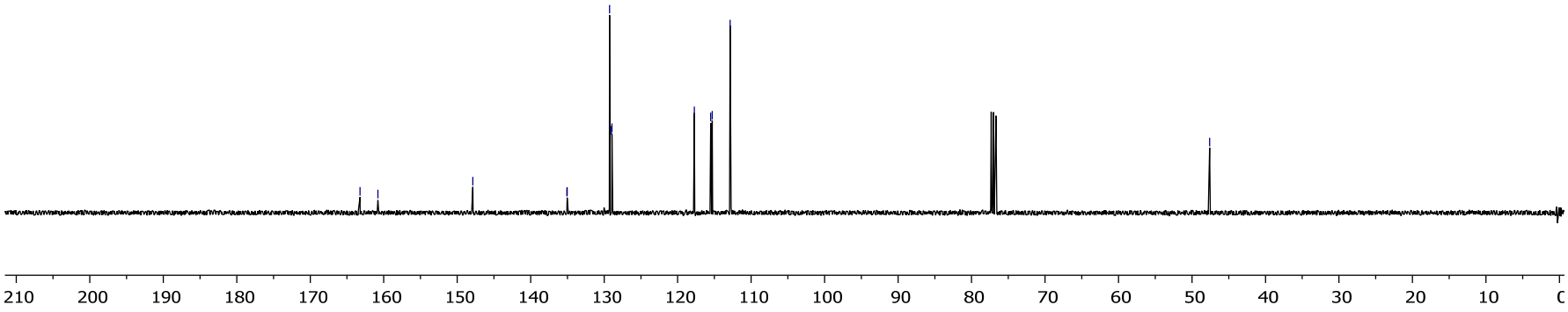
^{13}C NMR (100 MHz, $CDCl_3$) for **6d**

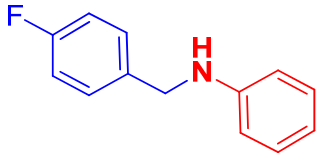


^{1}H NMR (400 MHz, $CDCl_3$) for **6e**

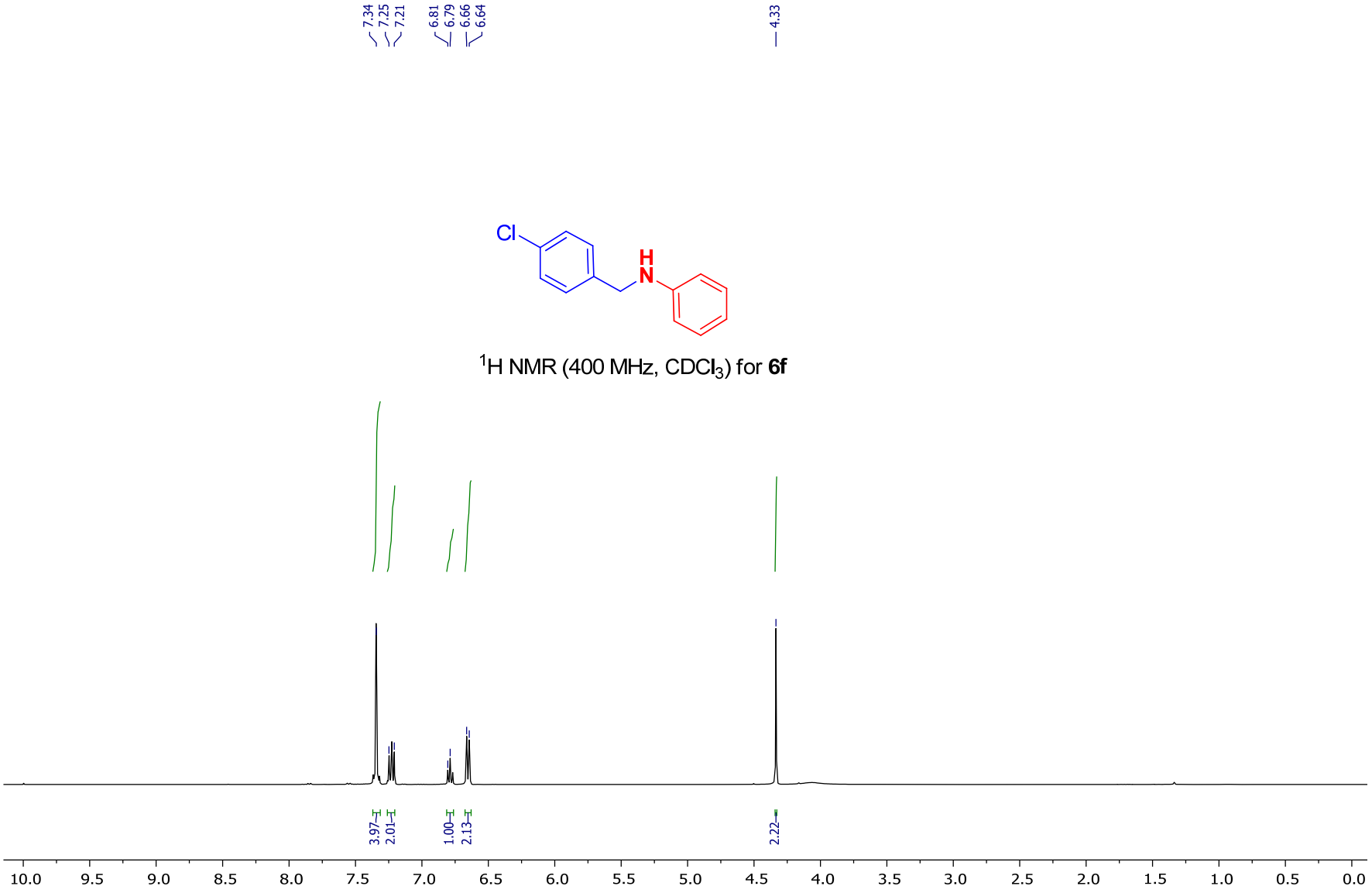


^{13}C NMR (100 MHz, $CDCl_3$) for **6e**

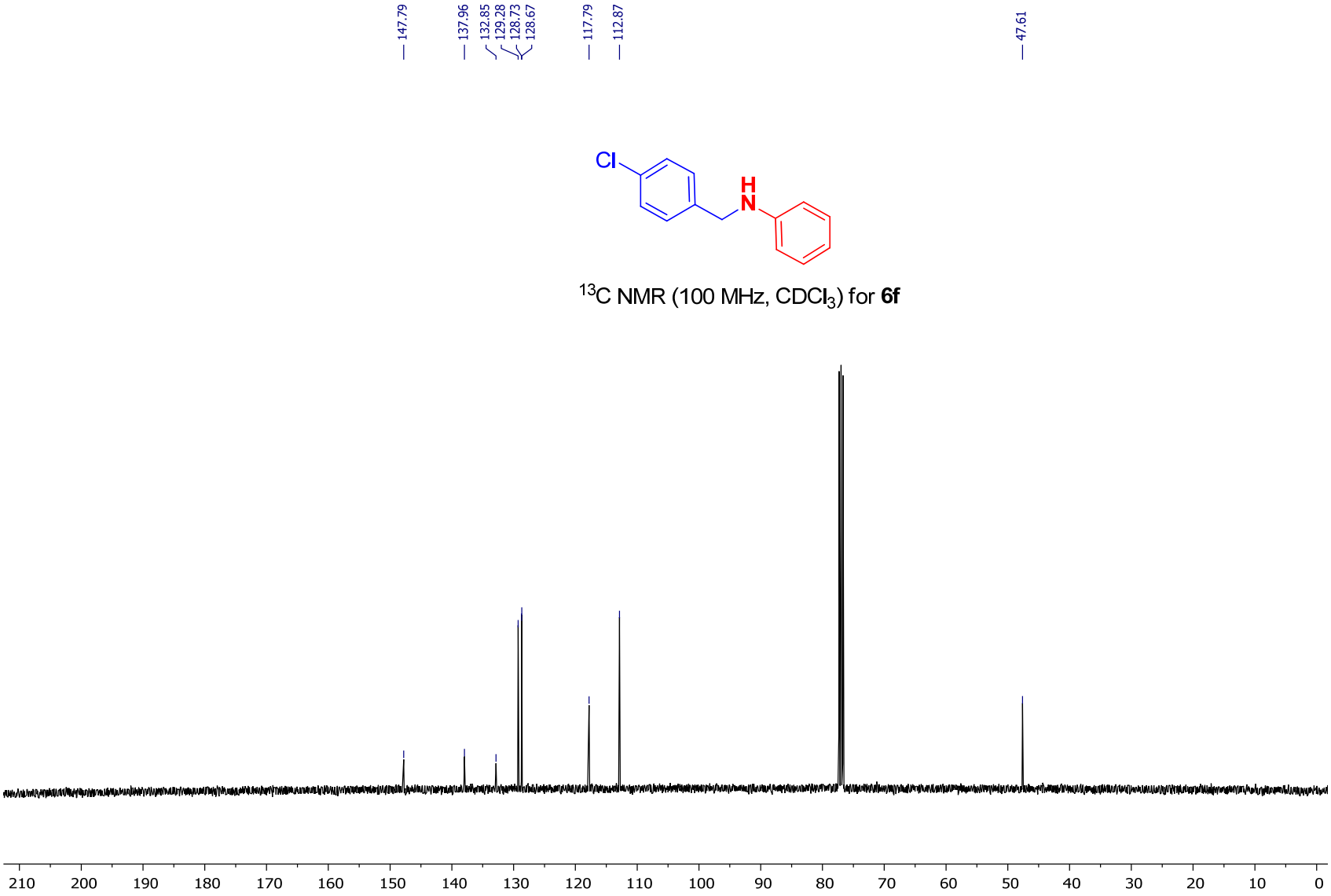




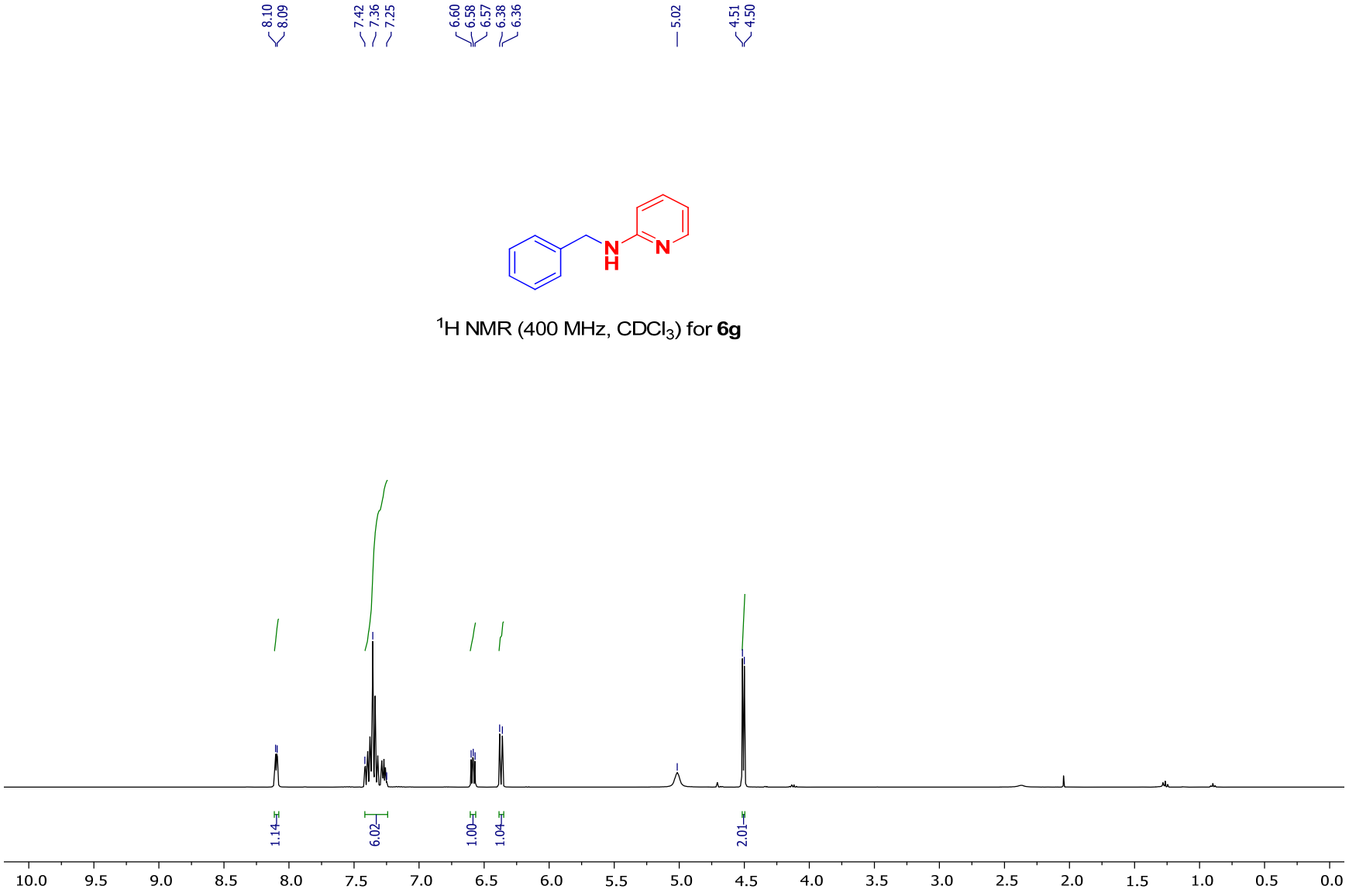
^{19}F NMR (376 MHz, $CDCl_3$) for **6e**



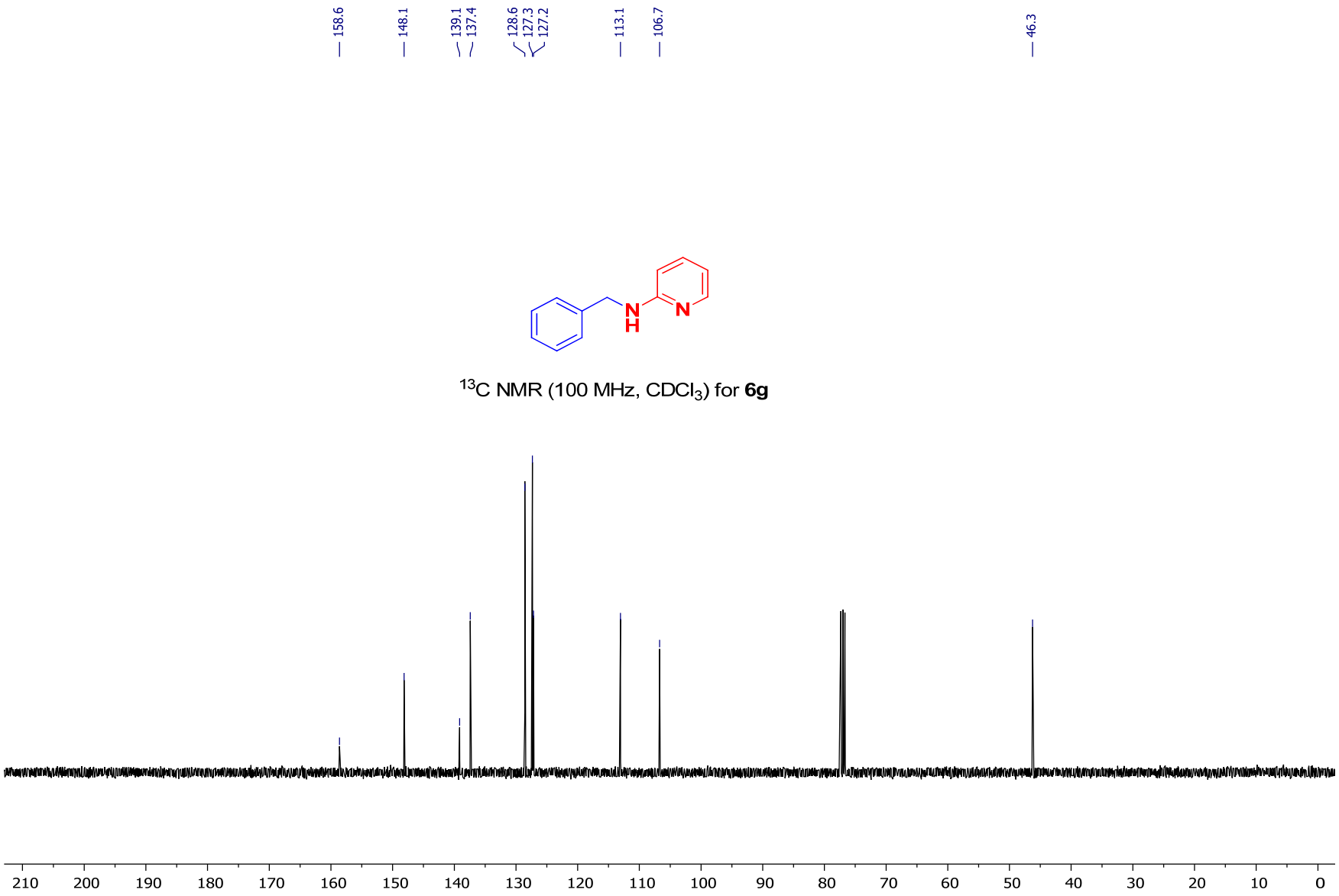
^{1}H NMR (400 MHz, $CDCl_3$) for **6f**



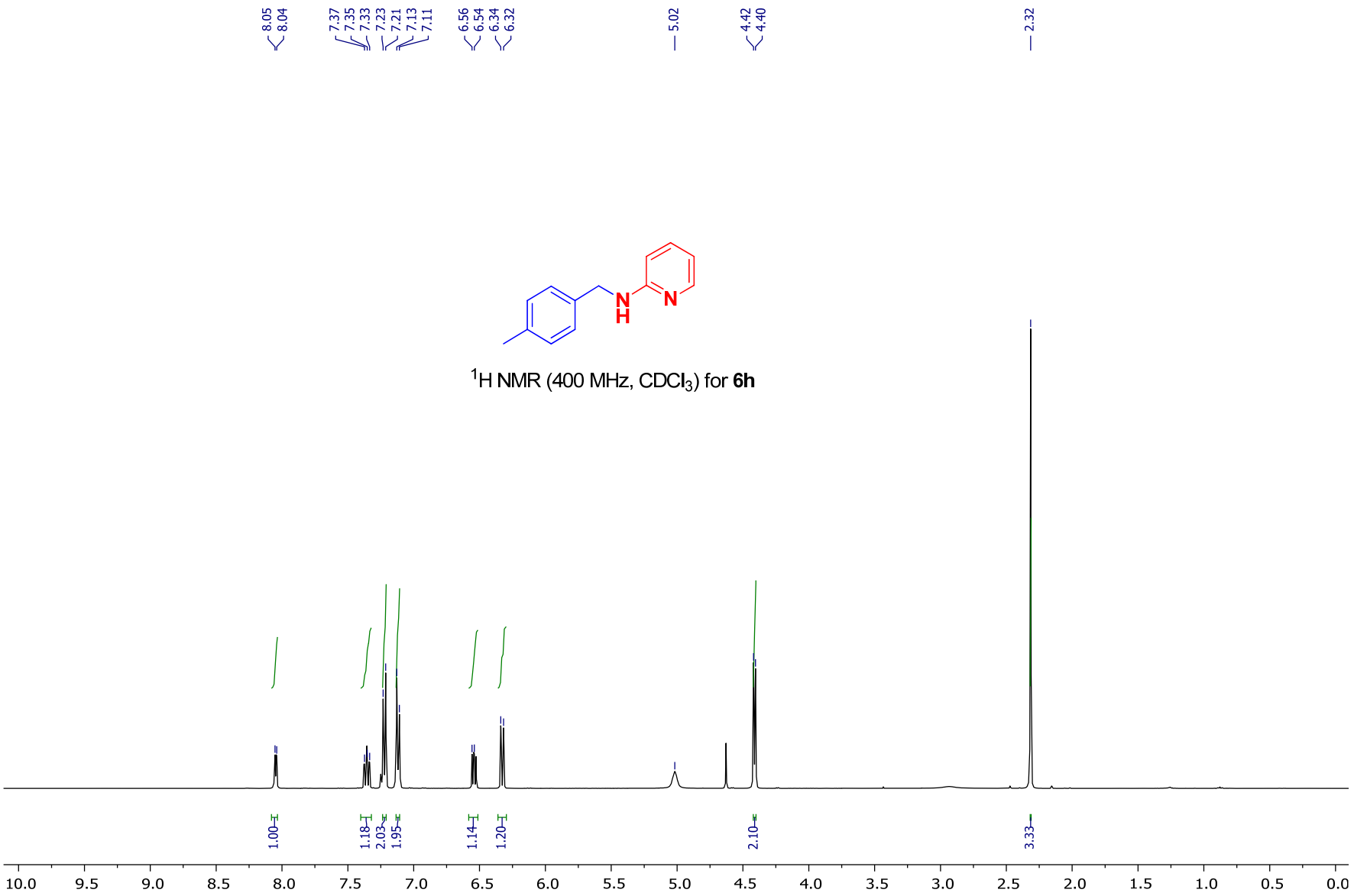
^{13}C NMR (100 MHz, $CDCl_3$) for **6f**



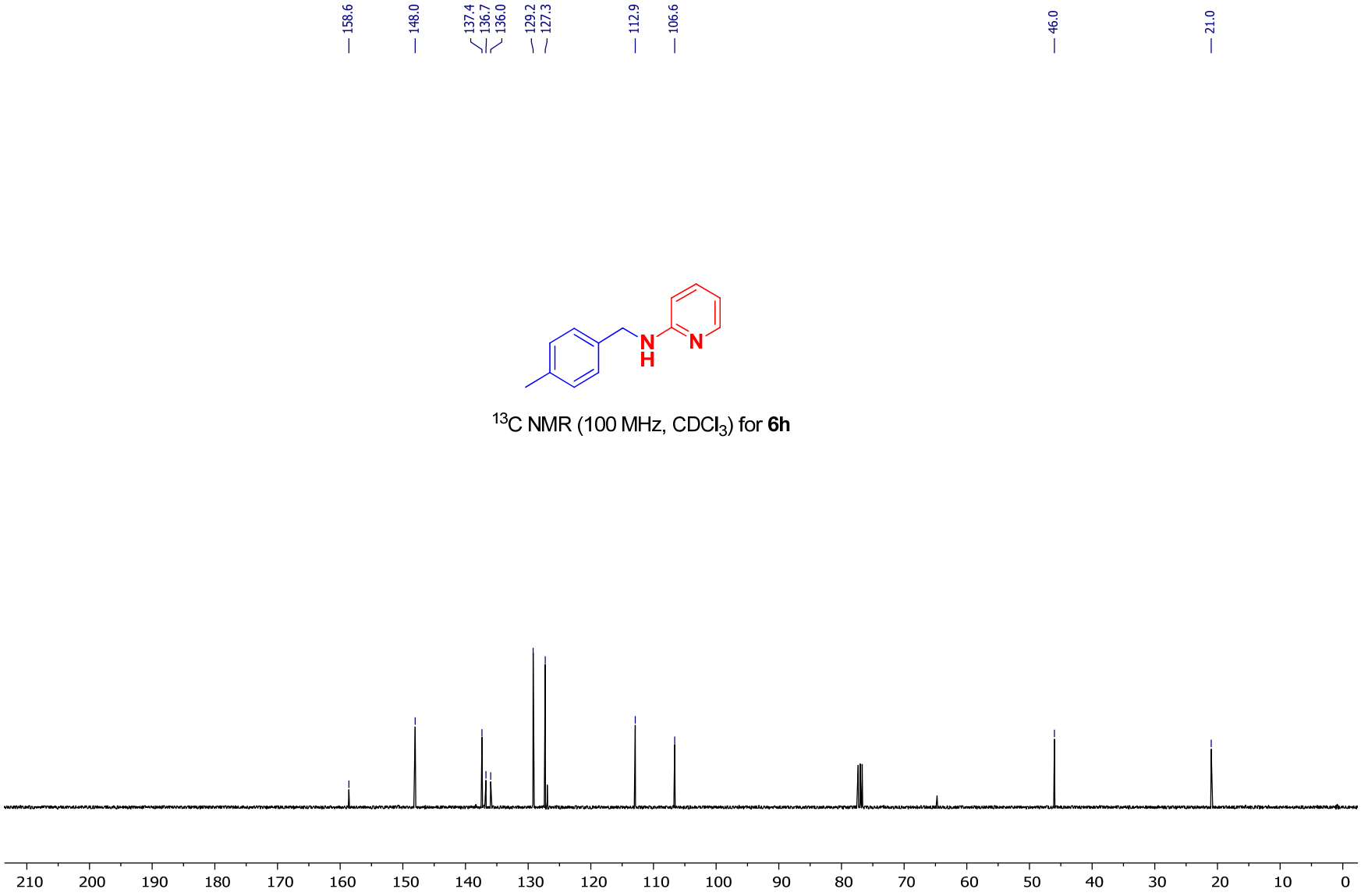
^{1}H NMR (400 MHz, $CDCl_3$) for **6g**



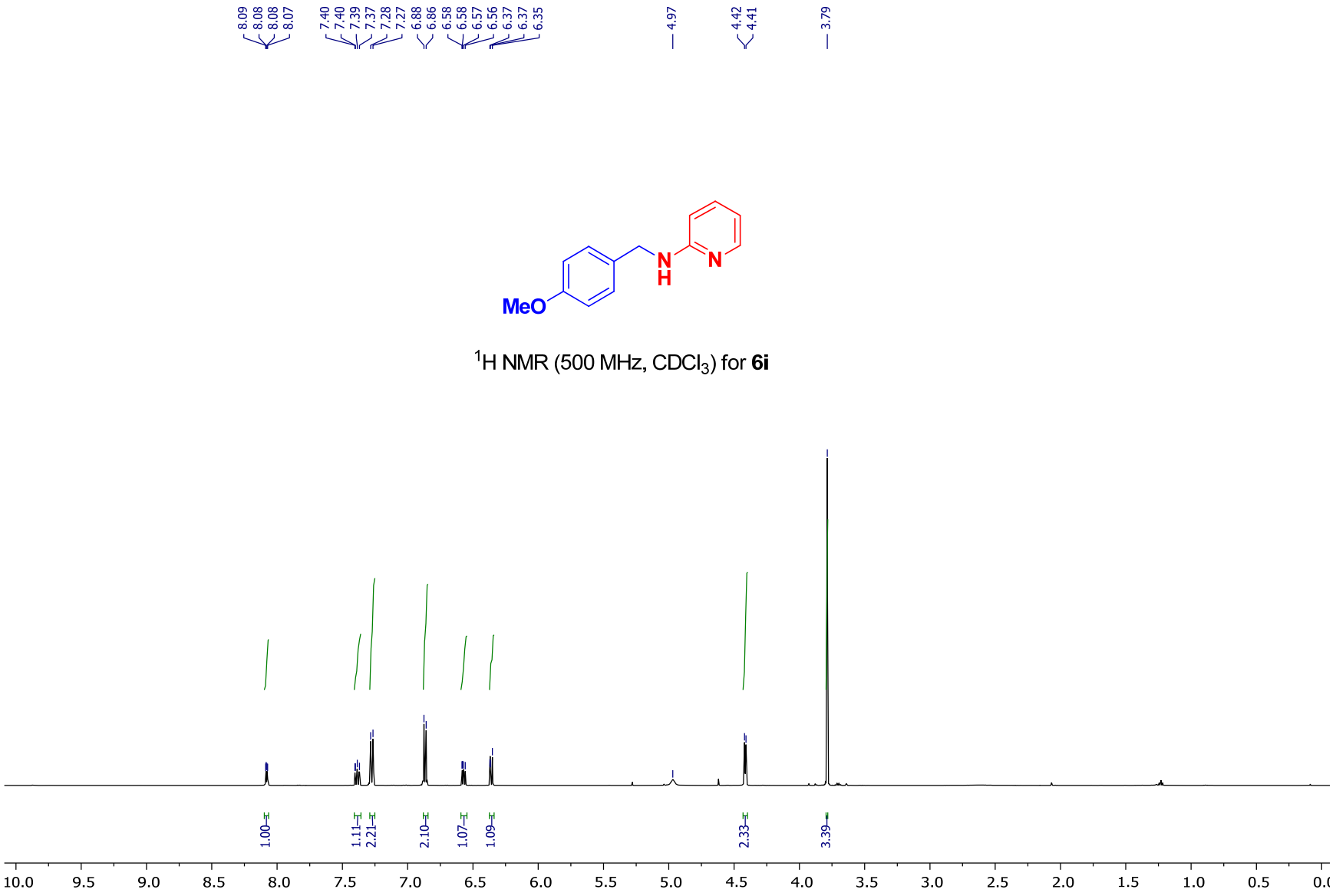
^{13}C NMR (100 MHz, $CDCl_3$) for **6g**



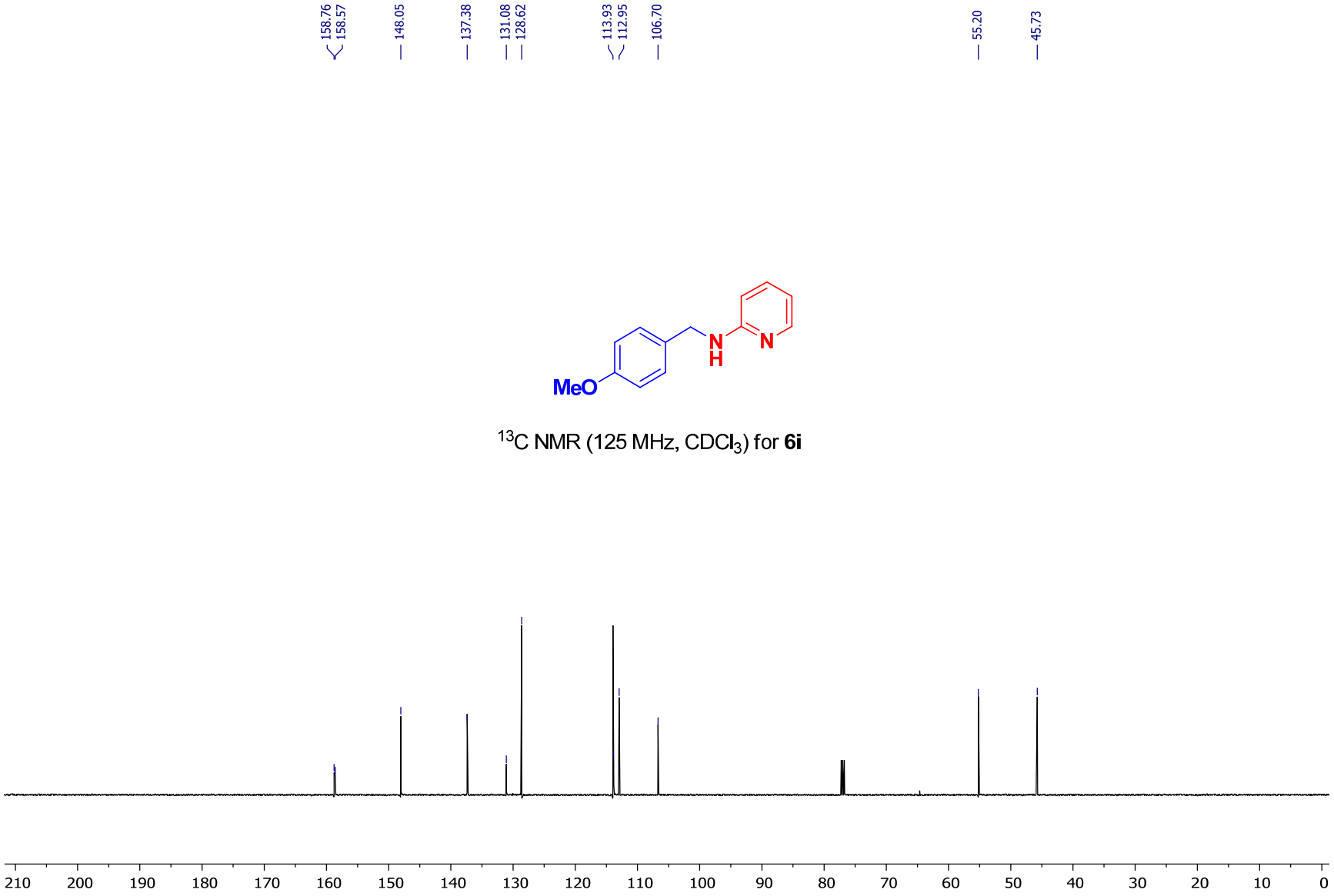
^{1}H NMR (400 MHz, $CDCl_3$) for **6h**



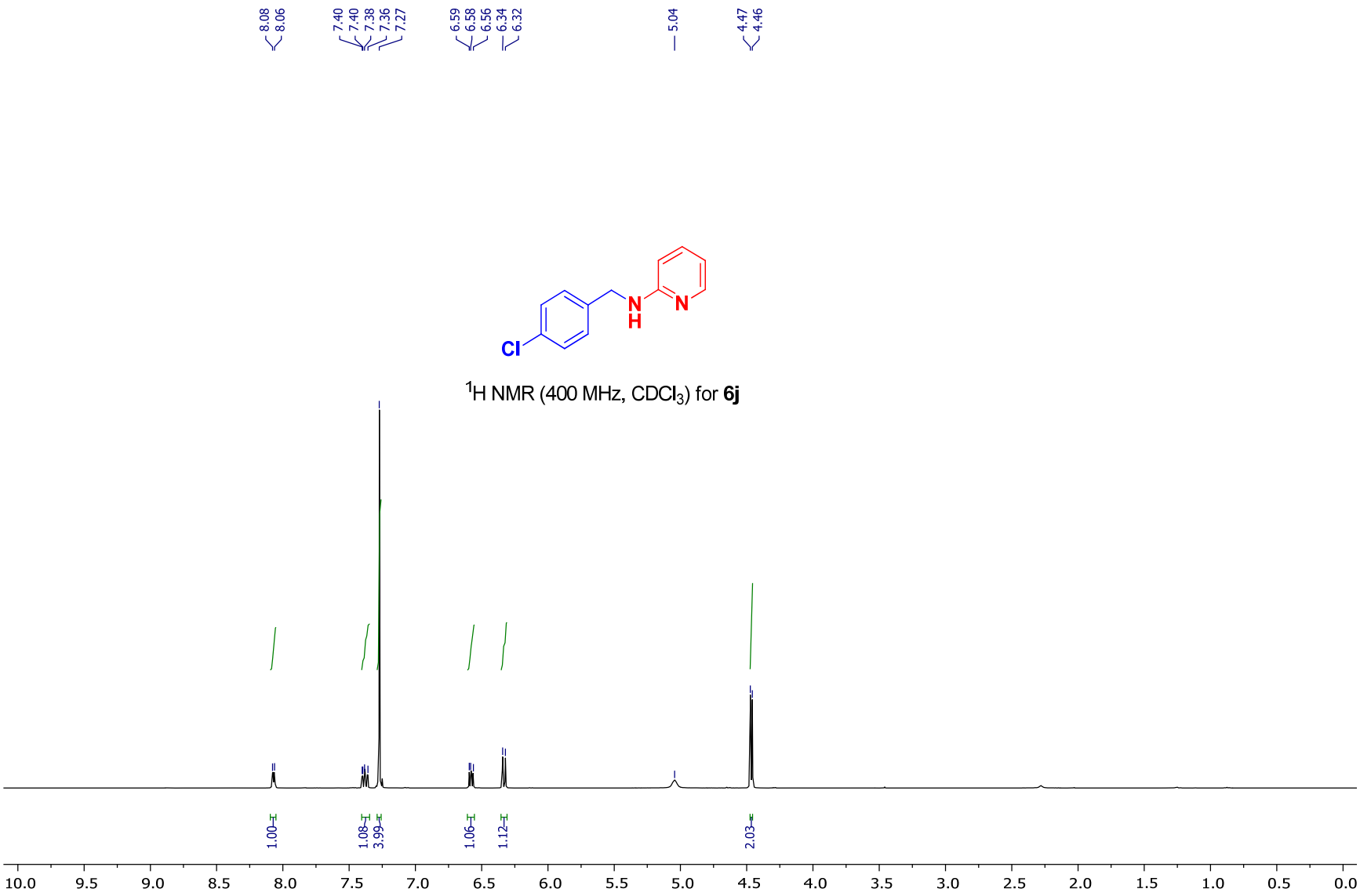
^{13}C NMR (100 MHz, $CDCl_3$) for **6h**



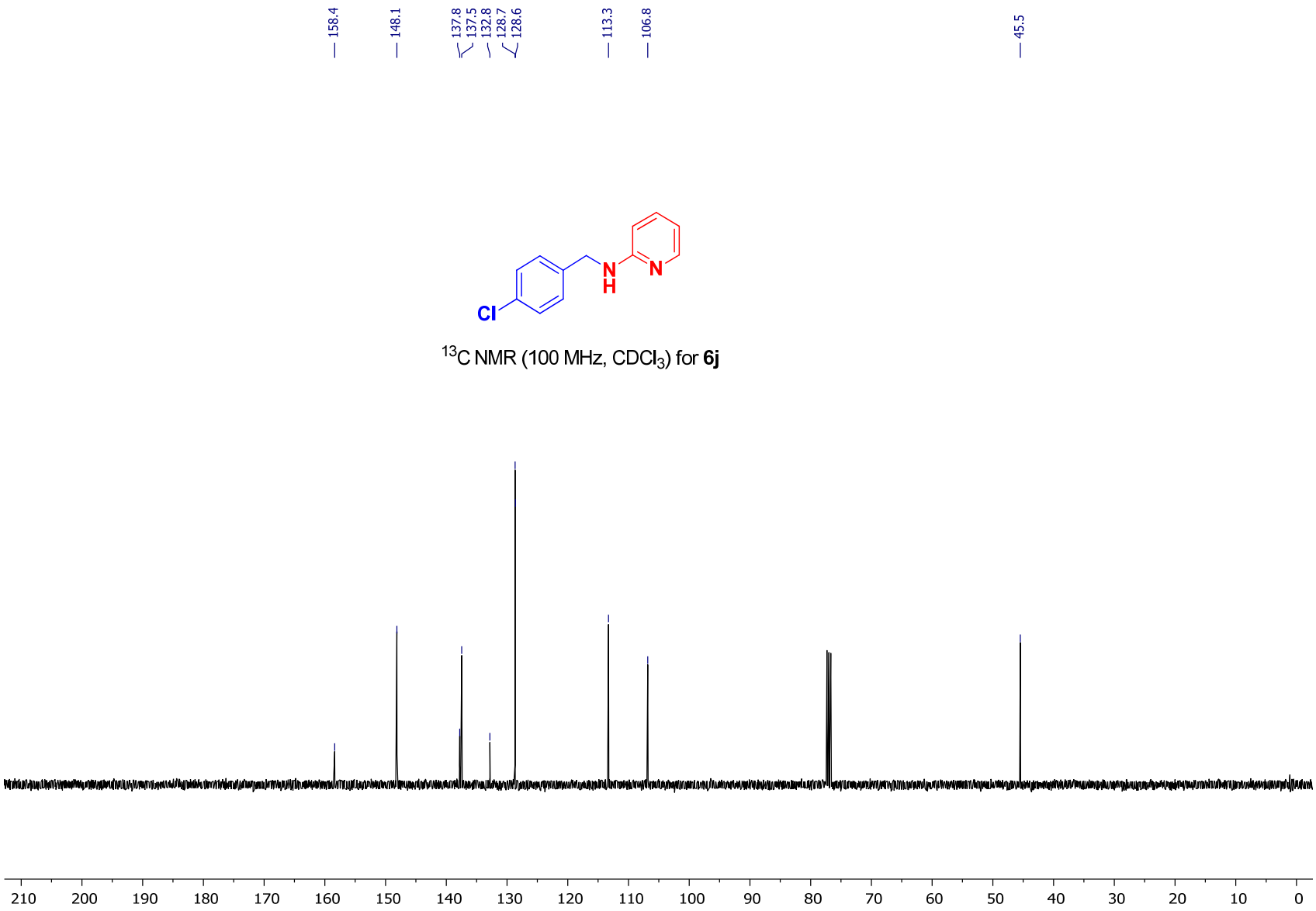
^{1}H NMR (500 MHz, $CDCl_3$) for **6i**



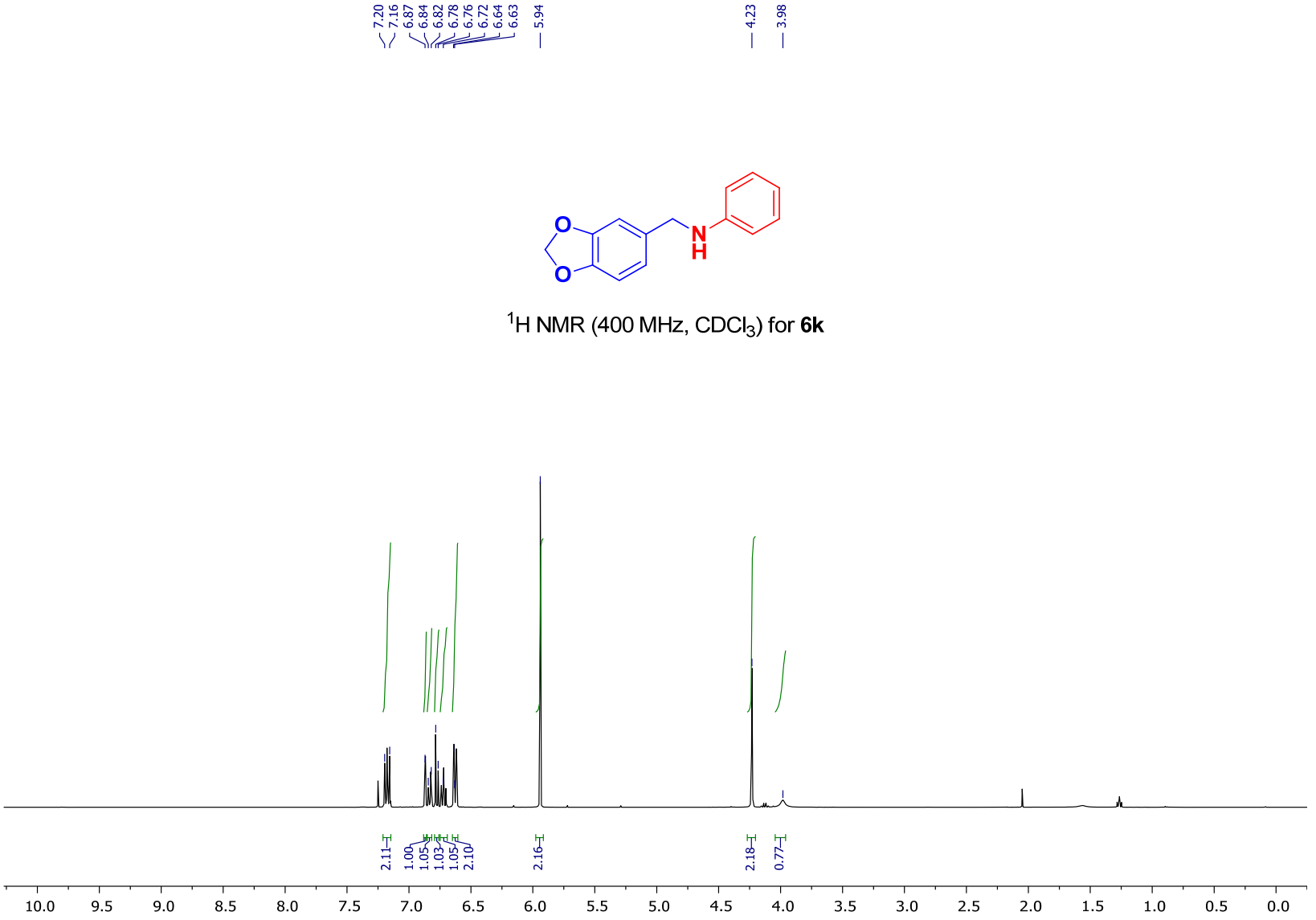
^{13}C NMR (125 MHz, $CDCl_3$) for **6i**



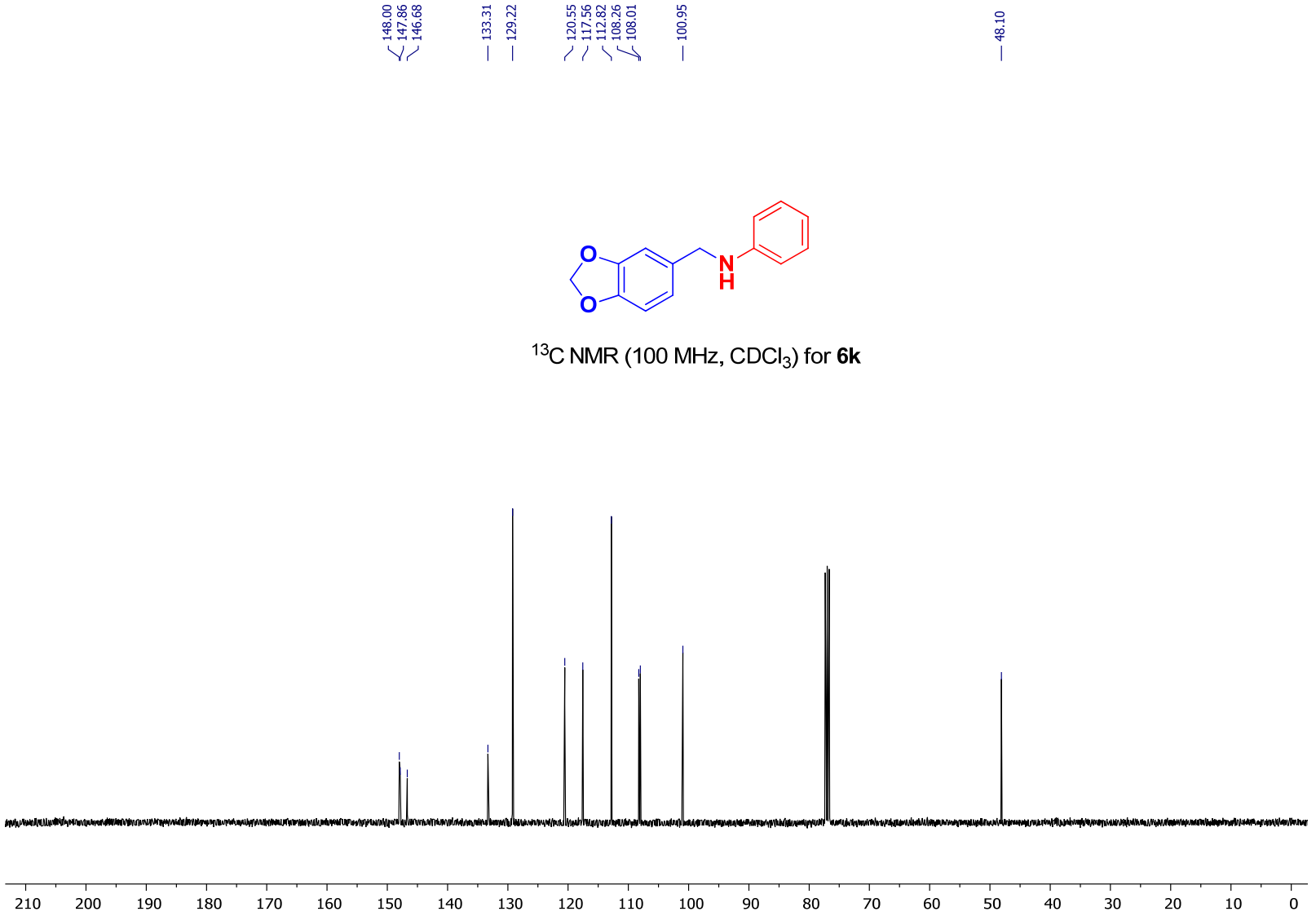
^{1}H NMR (400 MHz, $CDCl_3$) for **6j**



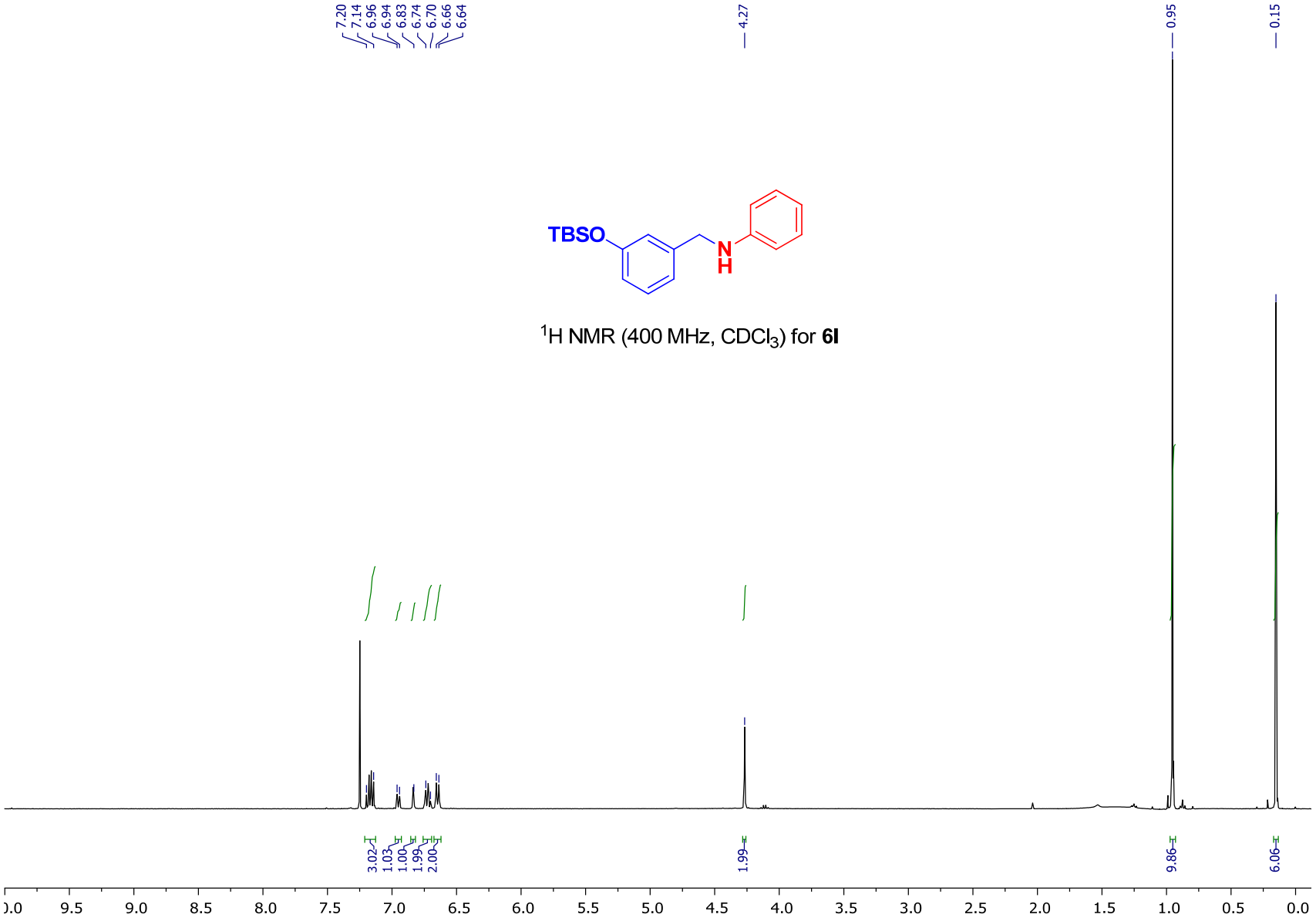
^{13}C NMR (100 MHz, $CDCl_3$) for **6j**



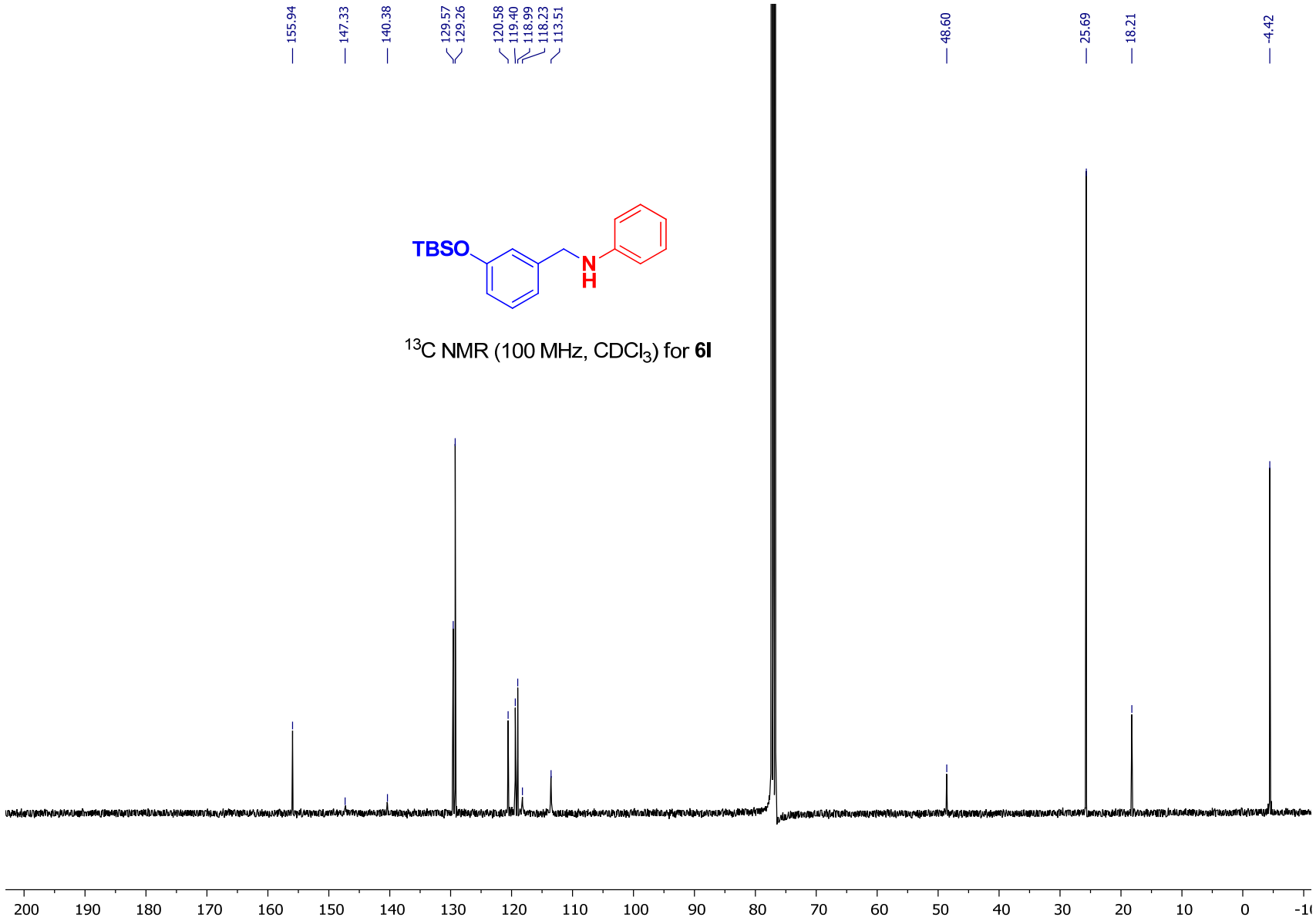
^{1}H NMR (400 MHz, $CDCl_3$) for **6k**



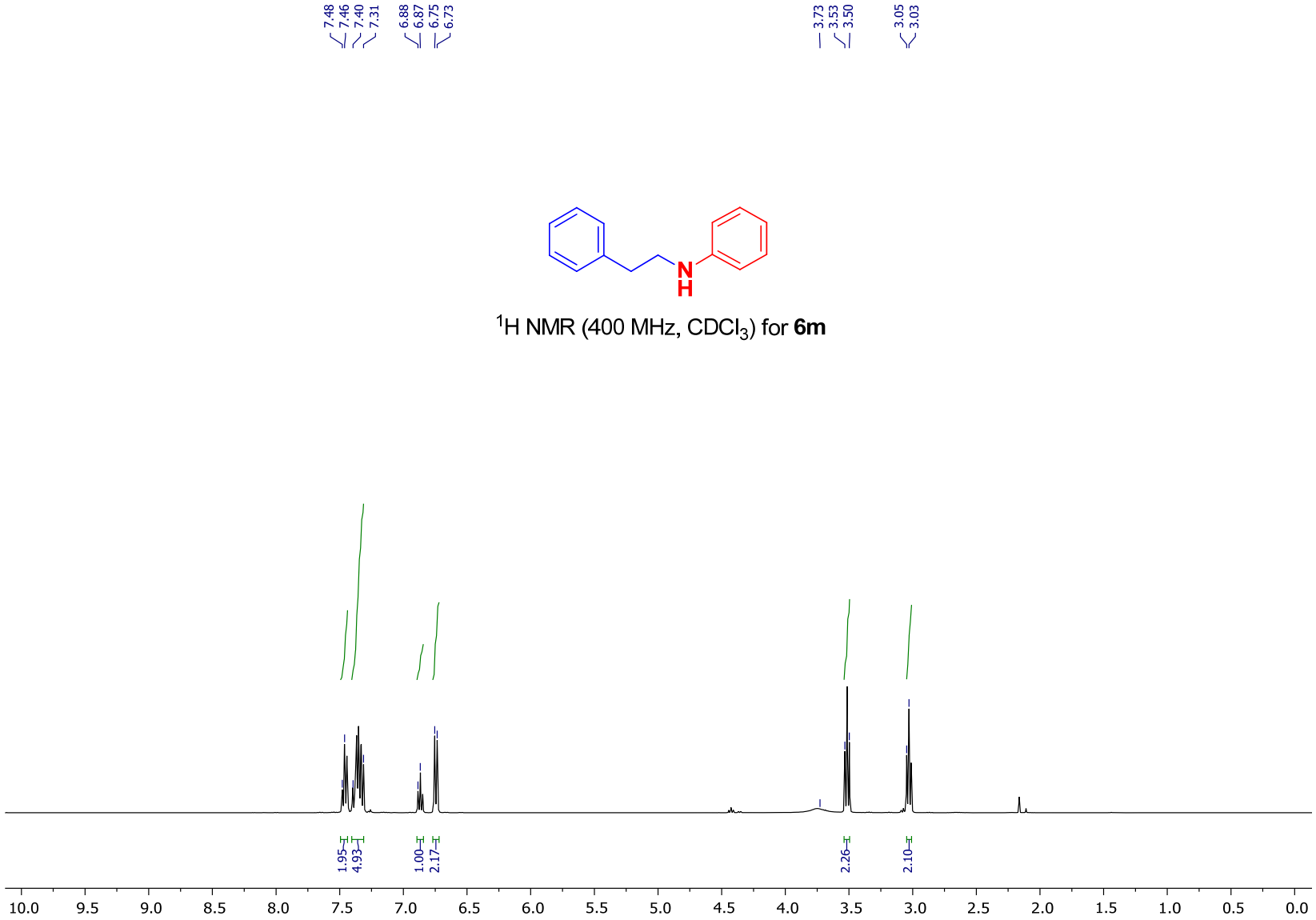
^{13}C NMR (100 MHz, $CDCl_3$) for **6k**



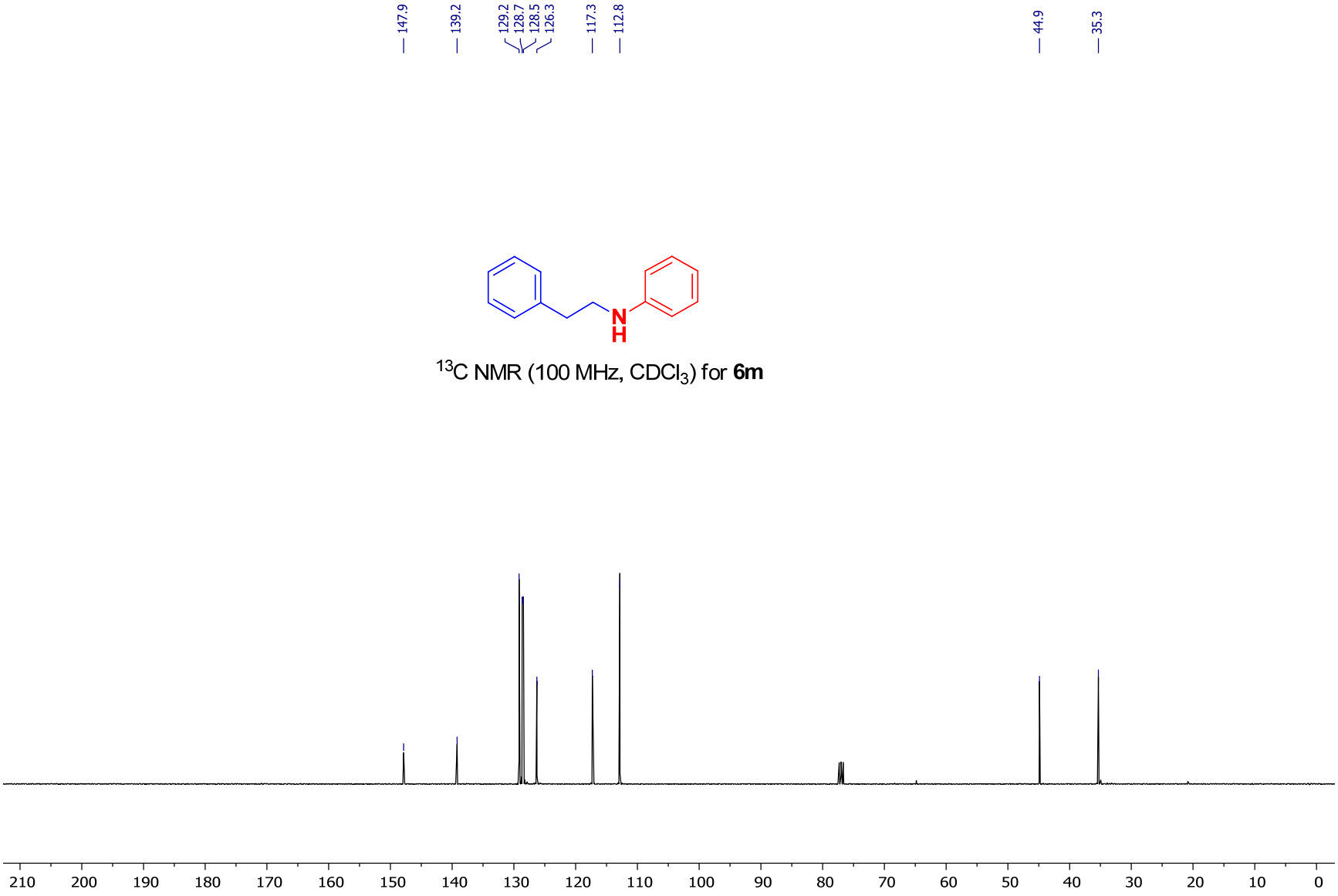
^{1}H NMR (400 MHz, $CDCl_3$) for **6l**



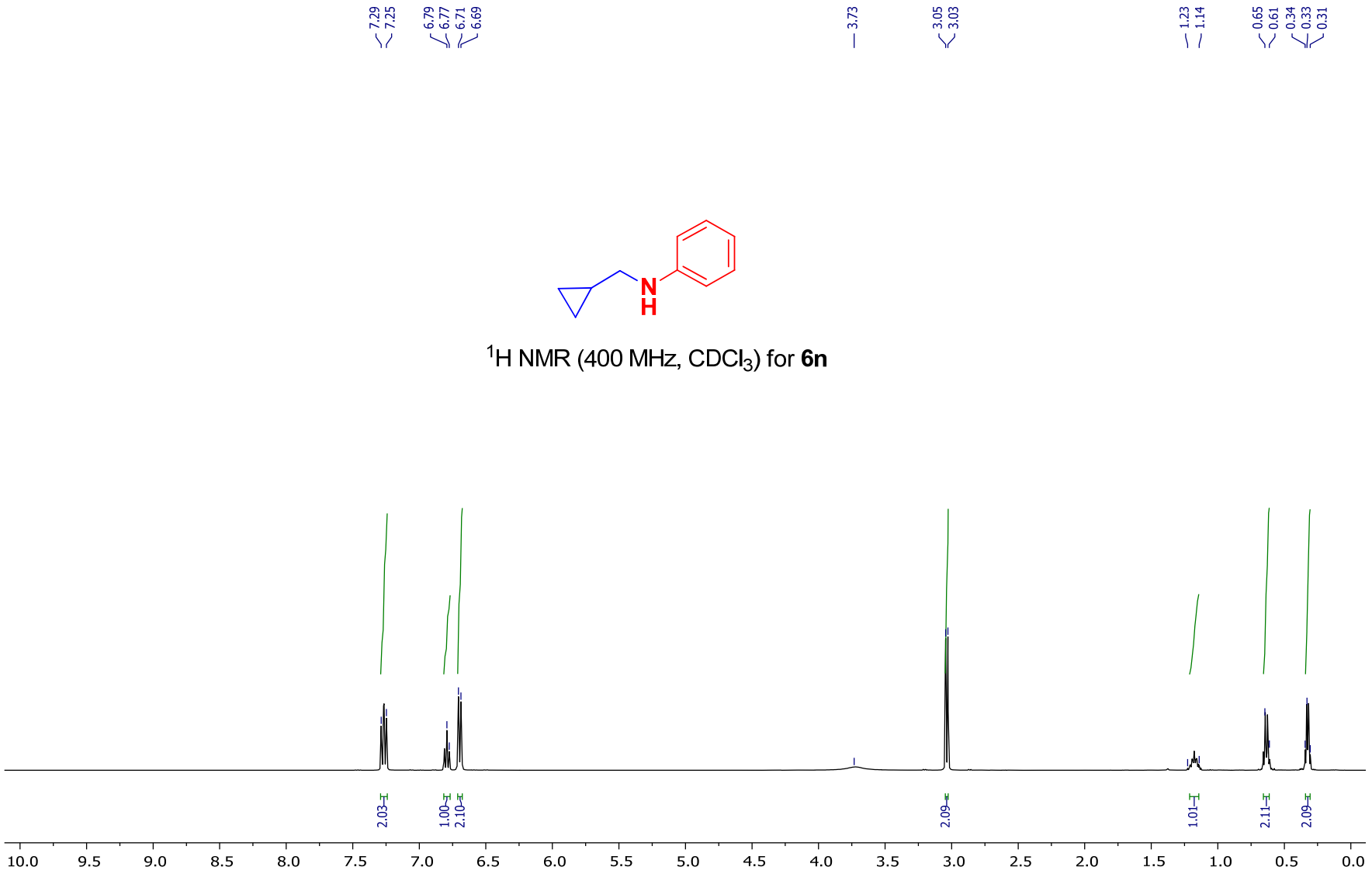
^{13}C NMR (100 MHz, $CDCl_3$) for **6l**



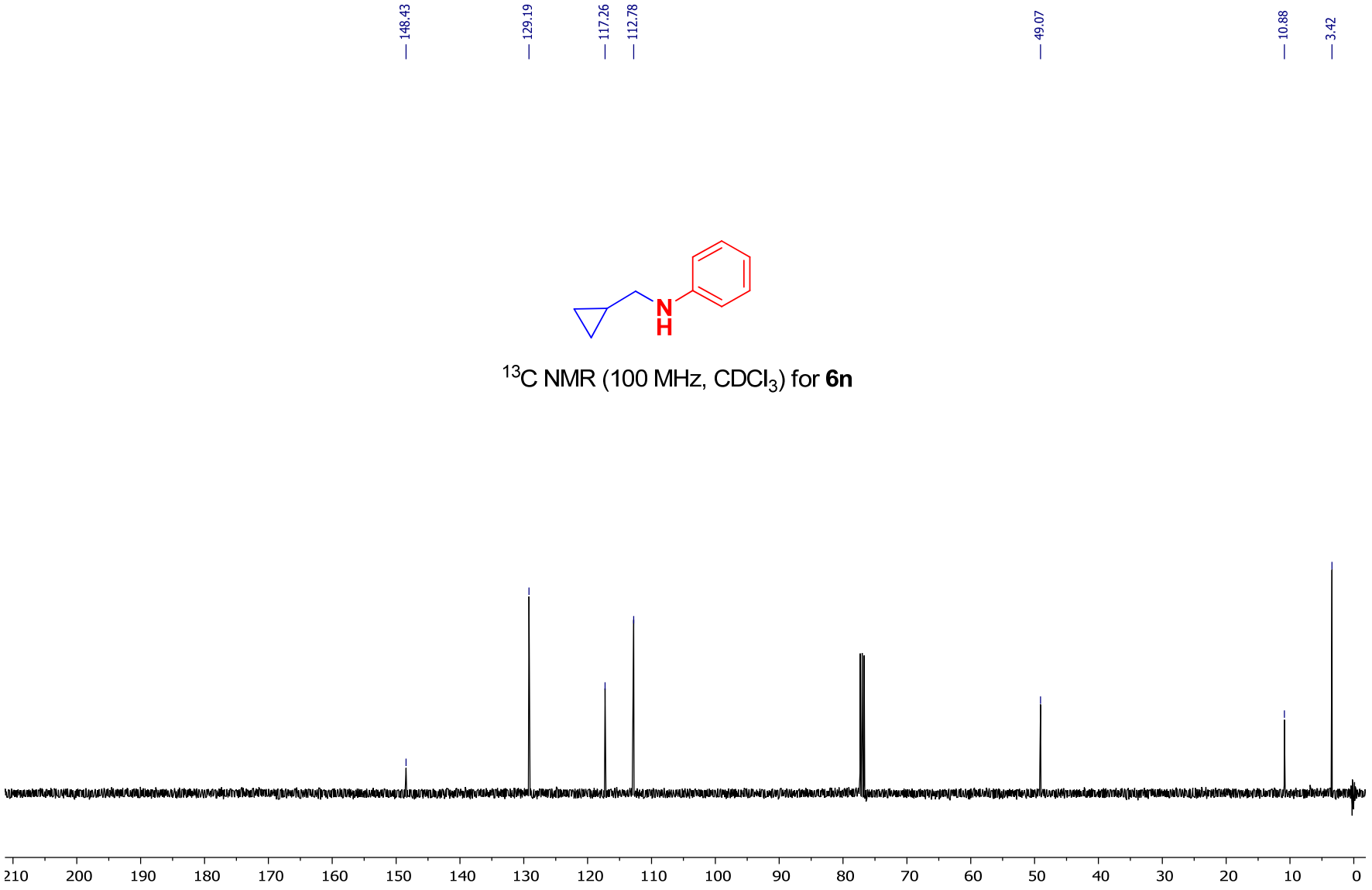
^{1}H NMR (400 MHz, $CDCl_3$) for **6m**



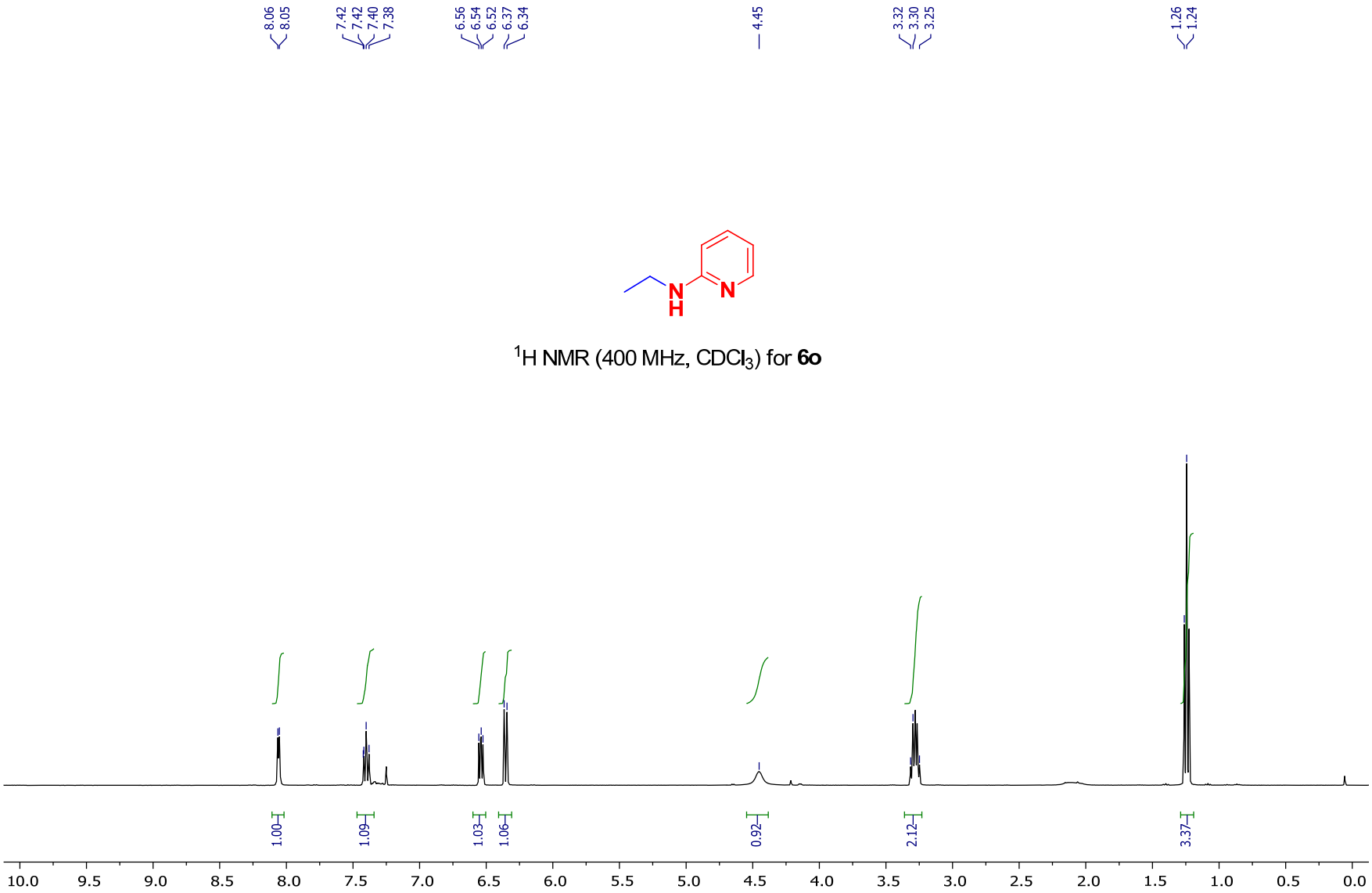
^{13}C NMR (100 MHz, $CDCl_3$) for **6m**



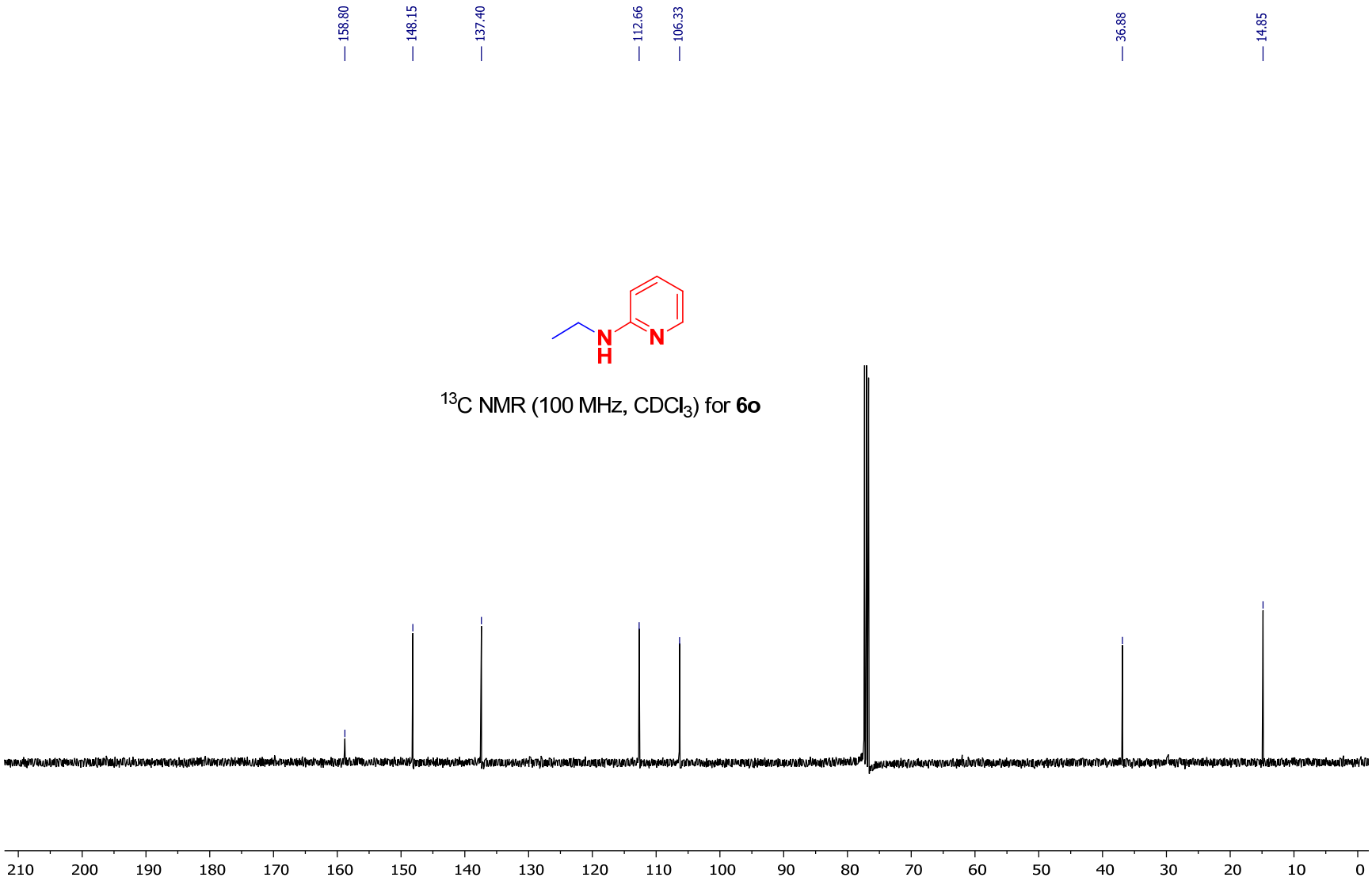
^{1}H NMR (400 MHz, $CDCl_3$) for **6n**



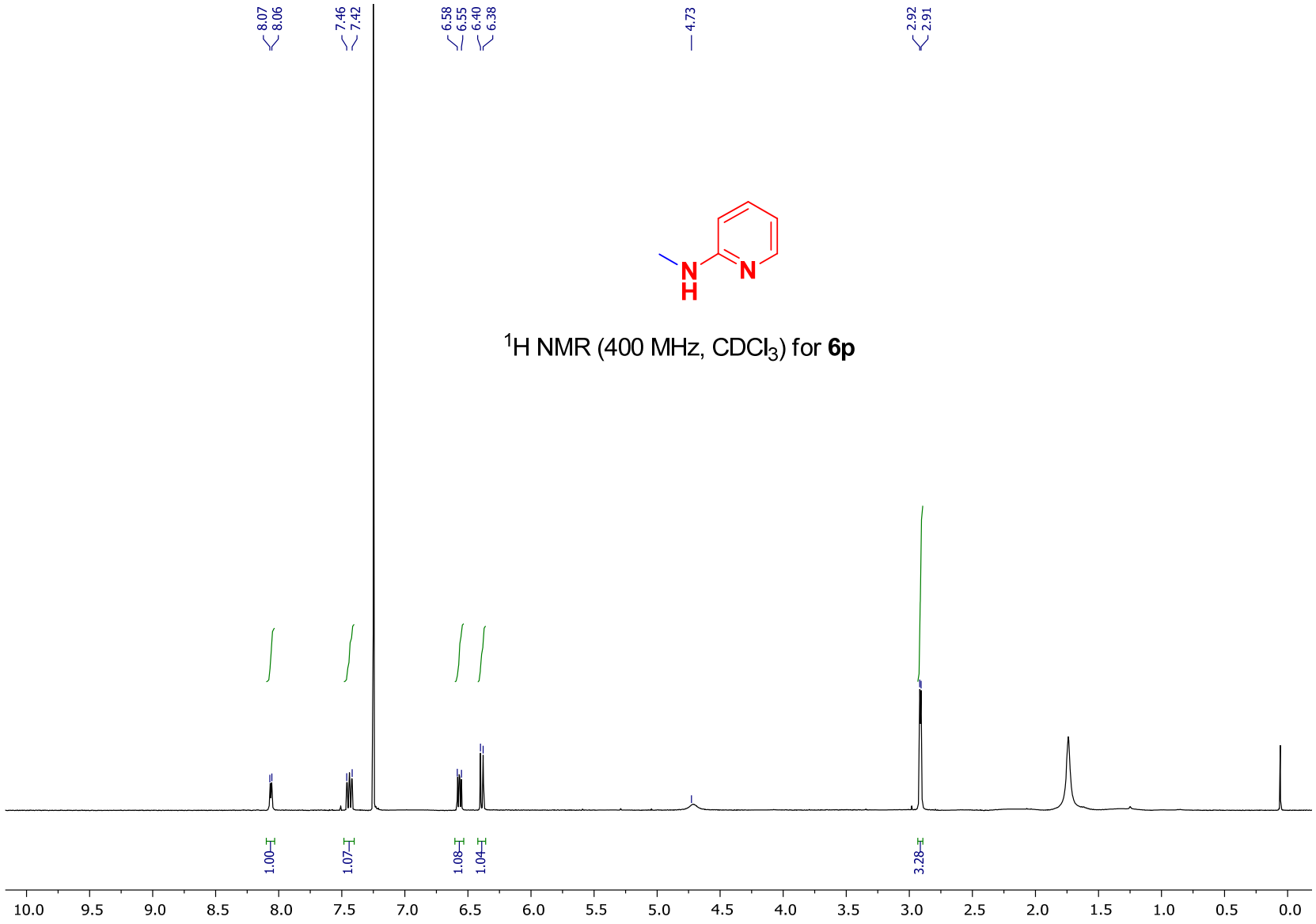
^{13}C NMR (100 MHz, $CDCl_3$) for **6n**



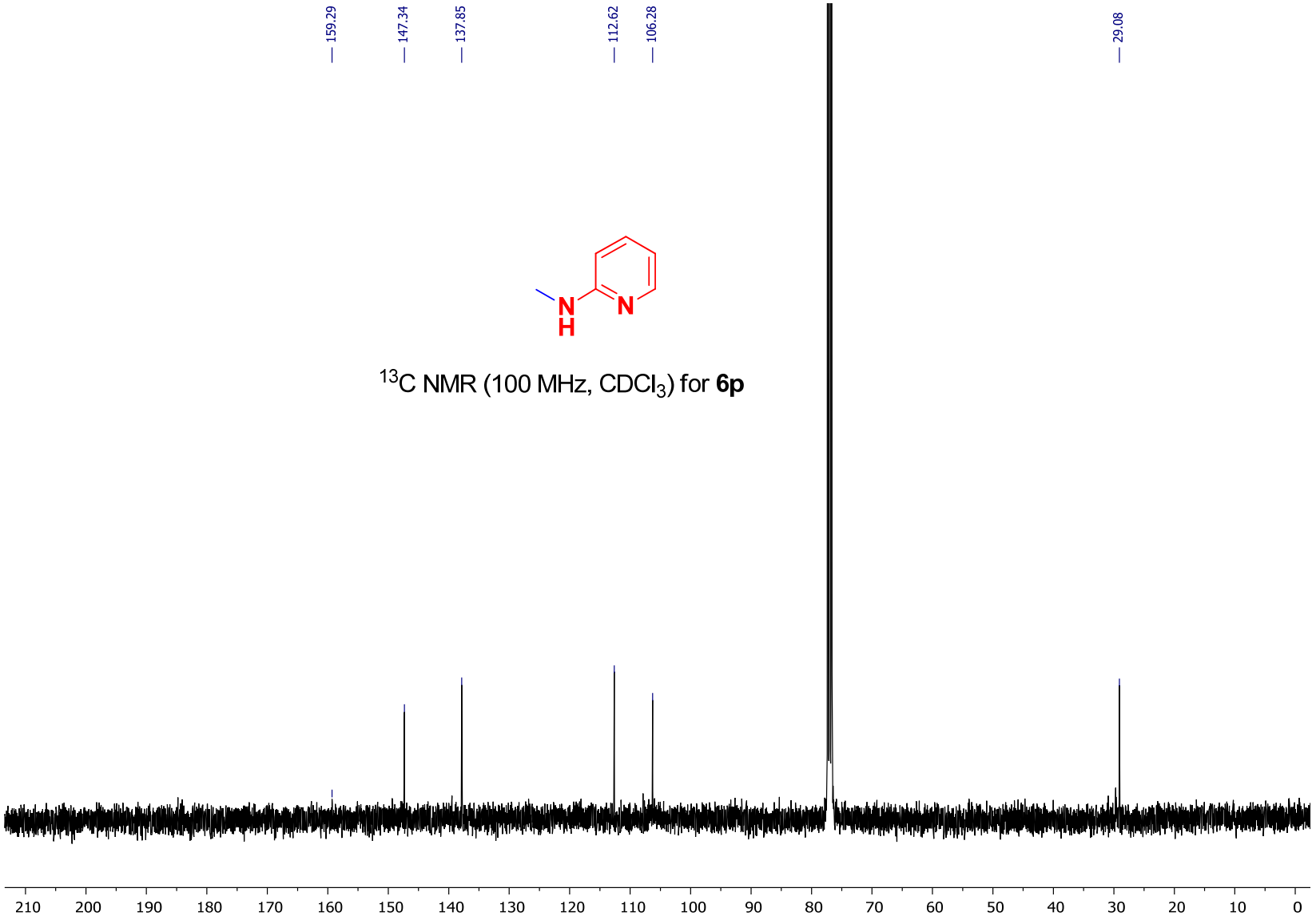
^{1}H NMR (400 MHz, $CDCl_3$) for **6o**



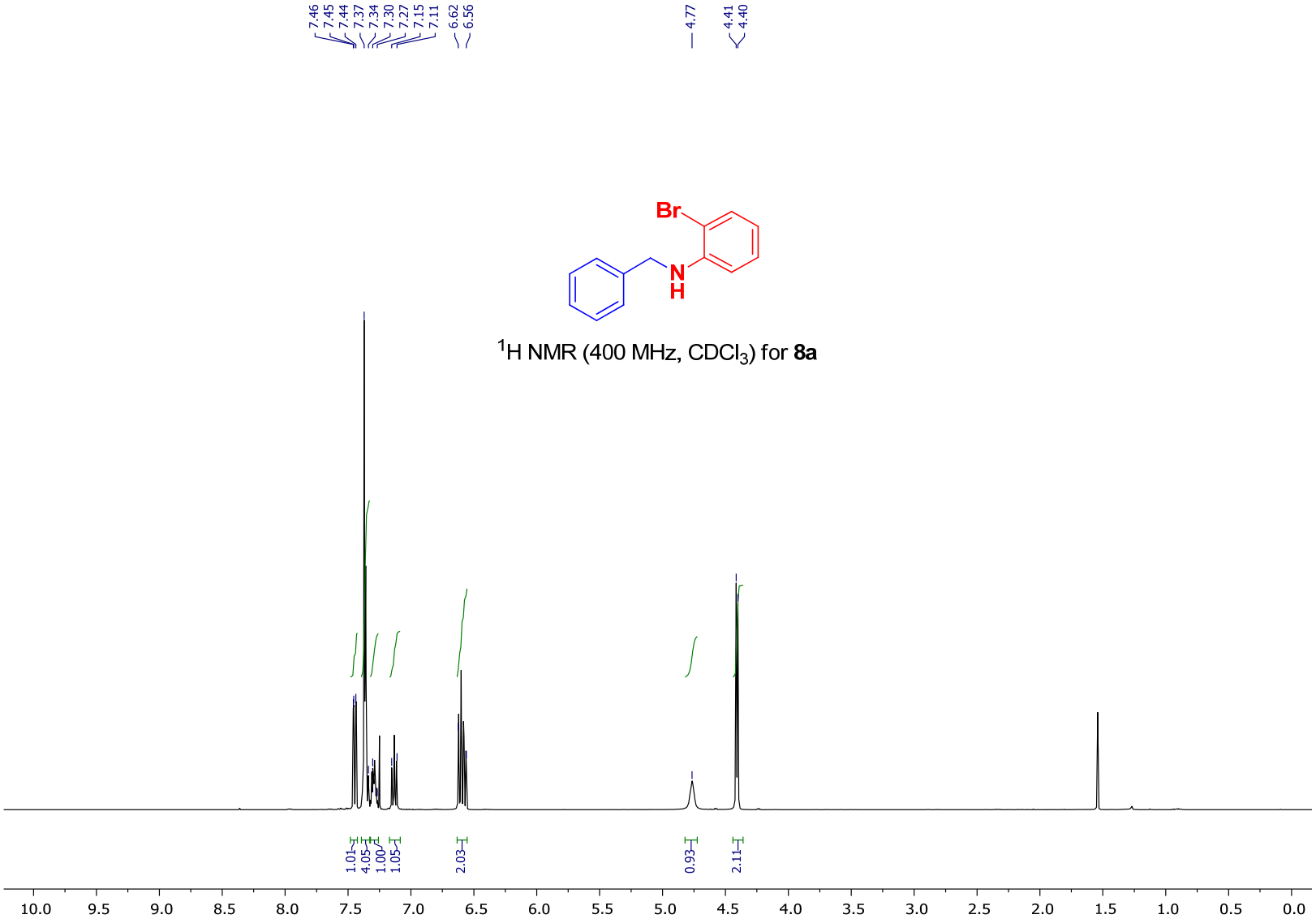
^{13}C NMR (100 MHz, $CDCl_3$) for **6o**



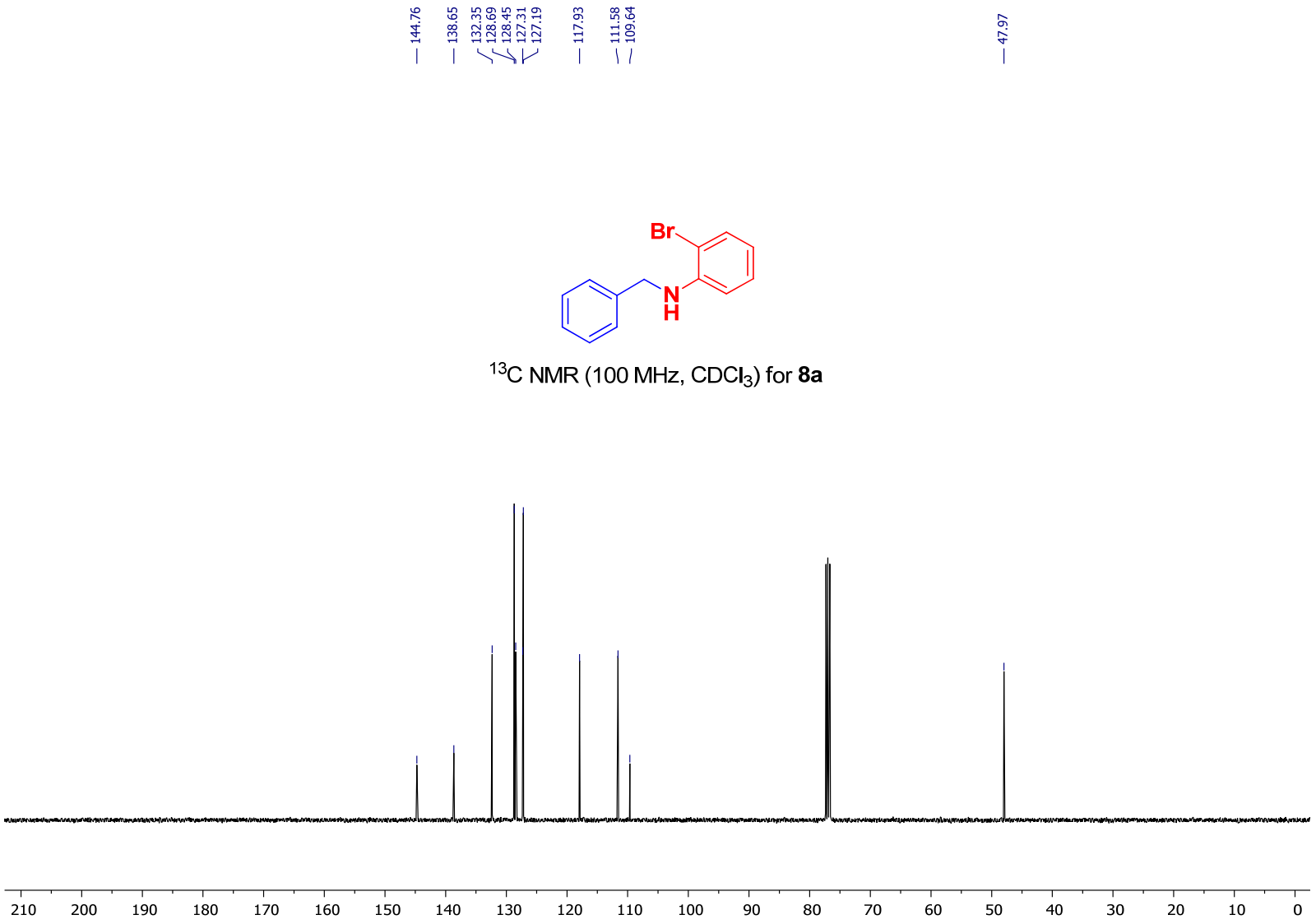
^{1}H NMR (400 MHz, $CDCl_3$) for **6p**



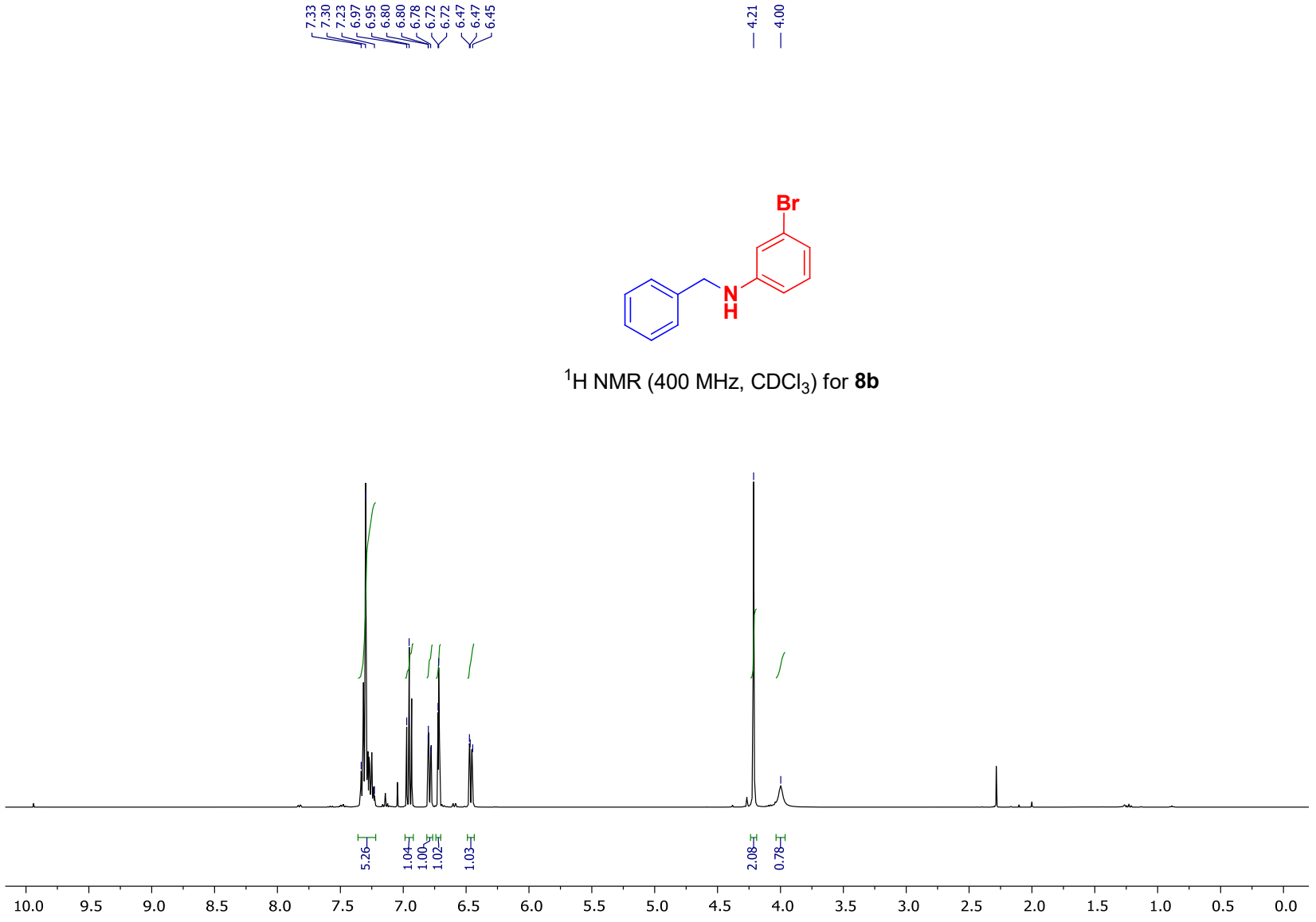
^{13}C NMR (100 MHz, $CDCl_3$) for **6p**



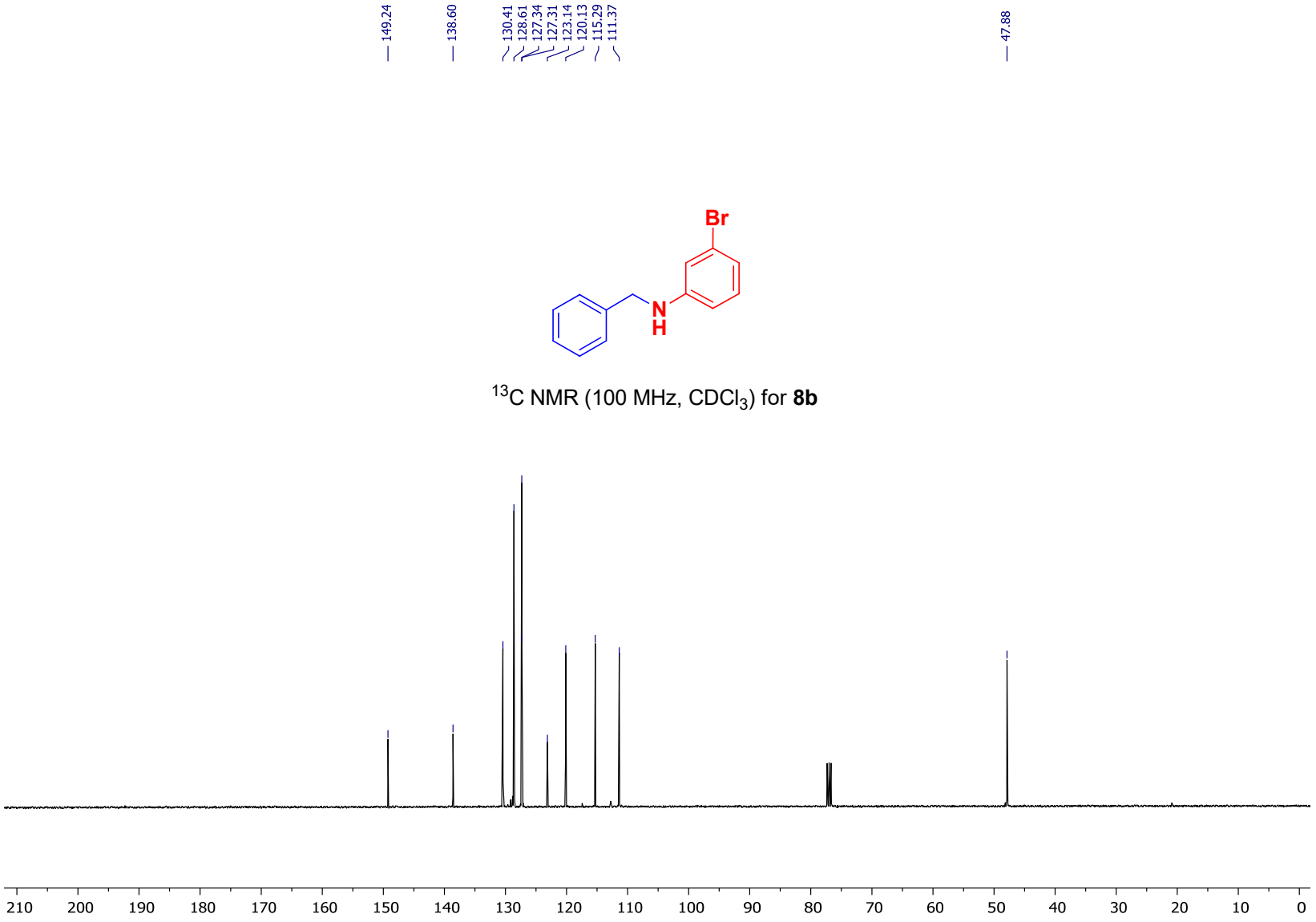
^{1}H NMR (400 MHz, $CDCl_3$) for **8a**



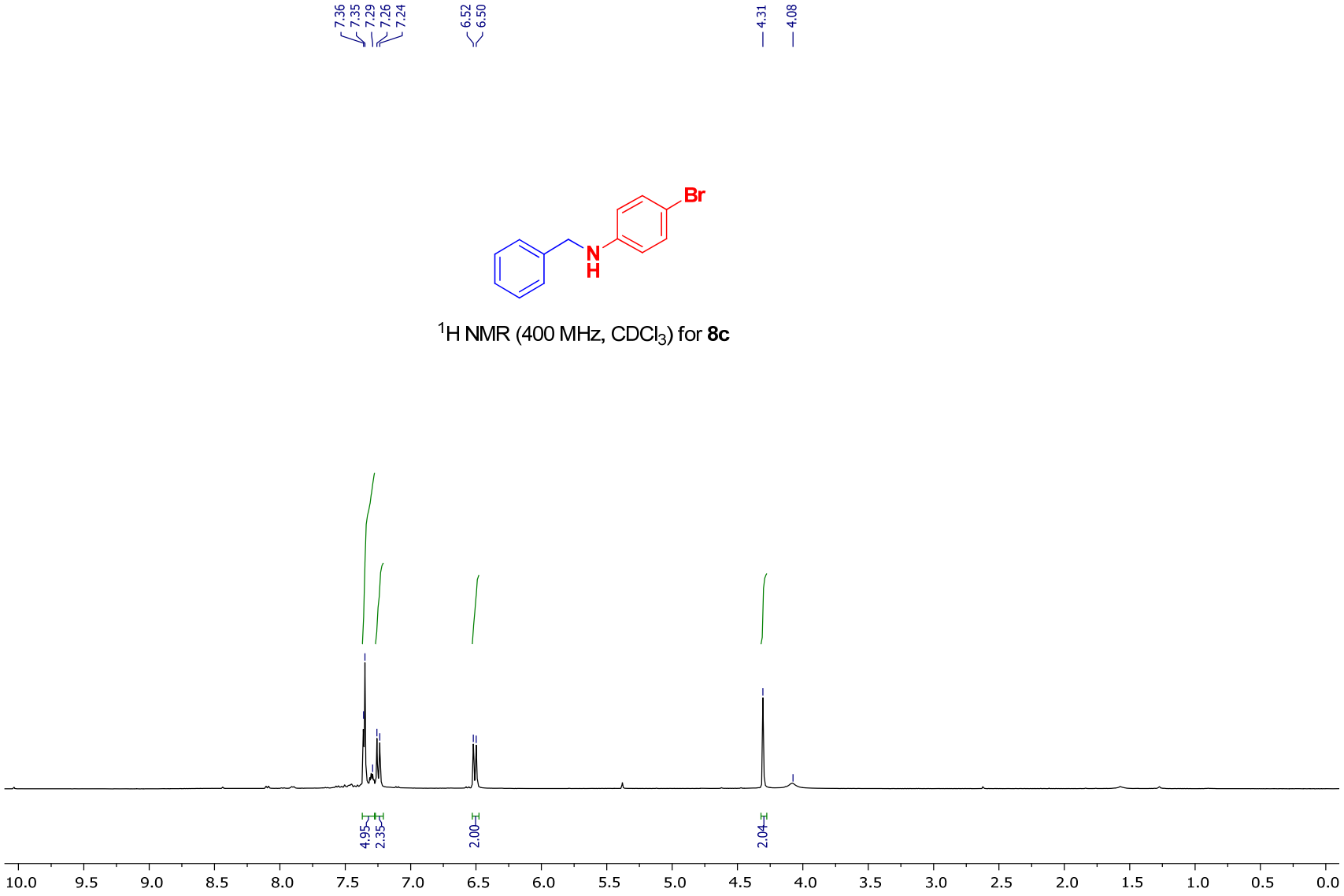
^{13}C NMR (100 MHz, $CDCl_3$) for **8a**



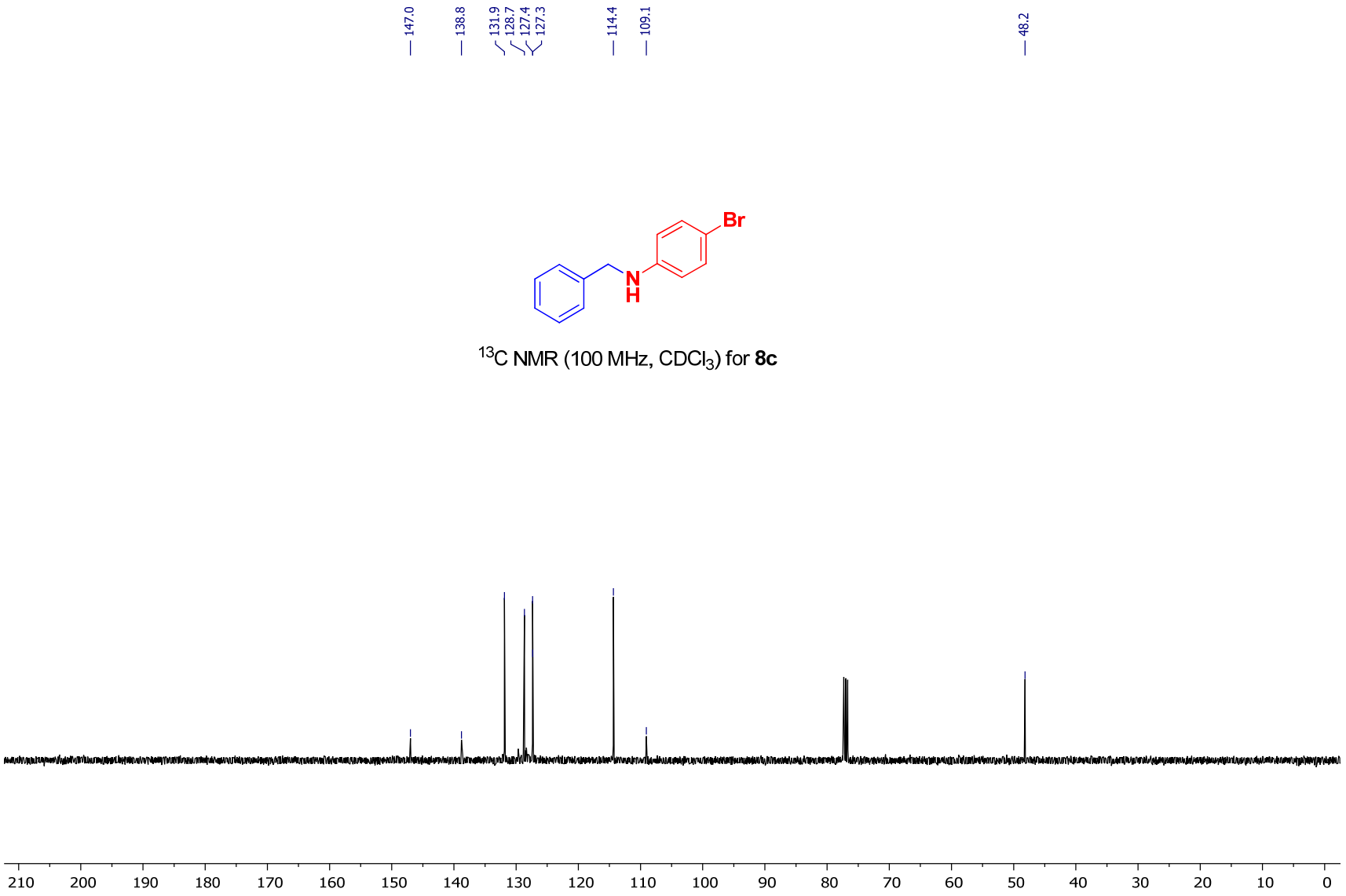
^{1}H NMR (400 MHz, $CDCl_3$) for **8b**



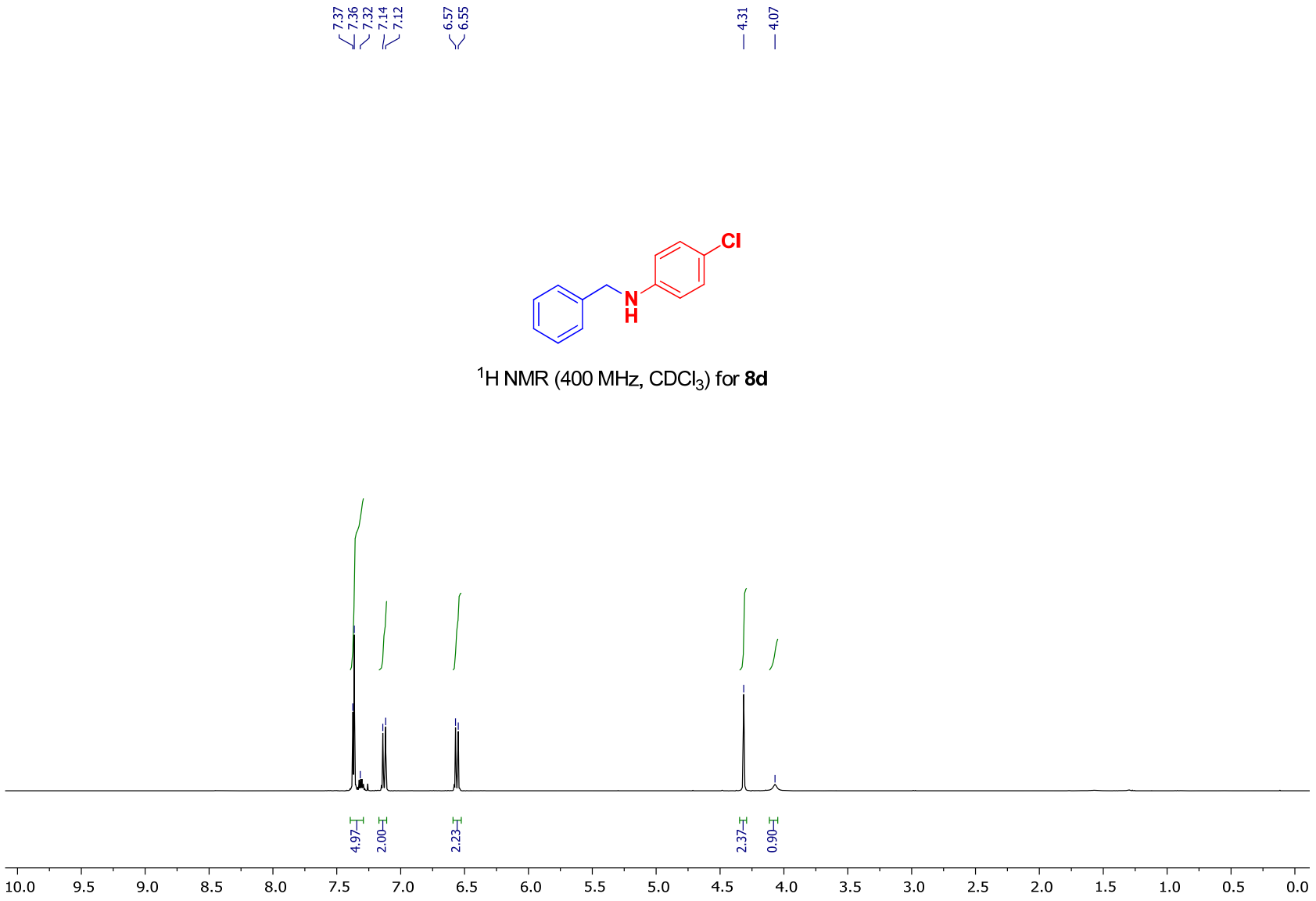
^{13}C NMR (100 MHz, $CDCl_3$) for **8b**



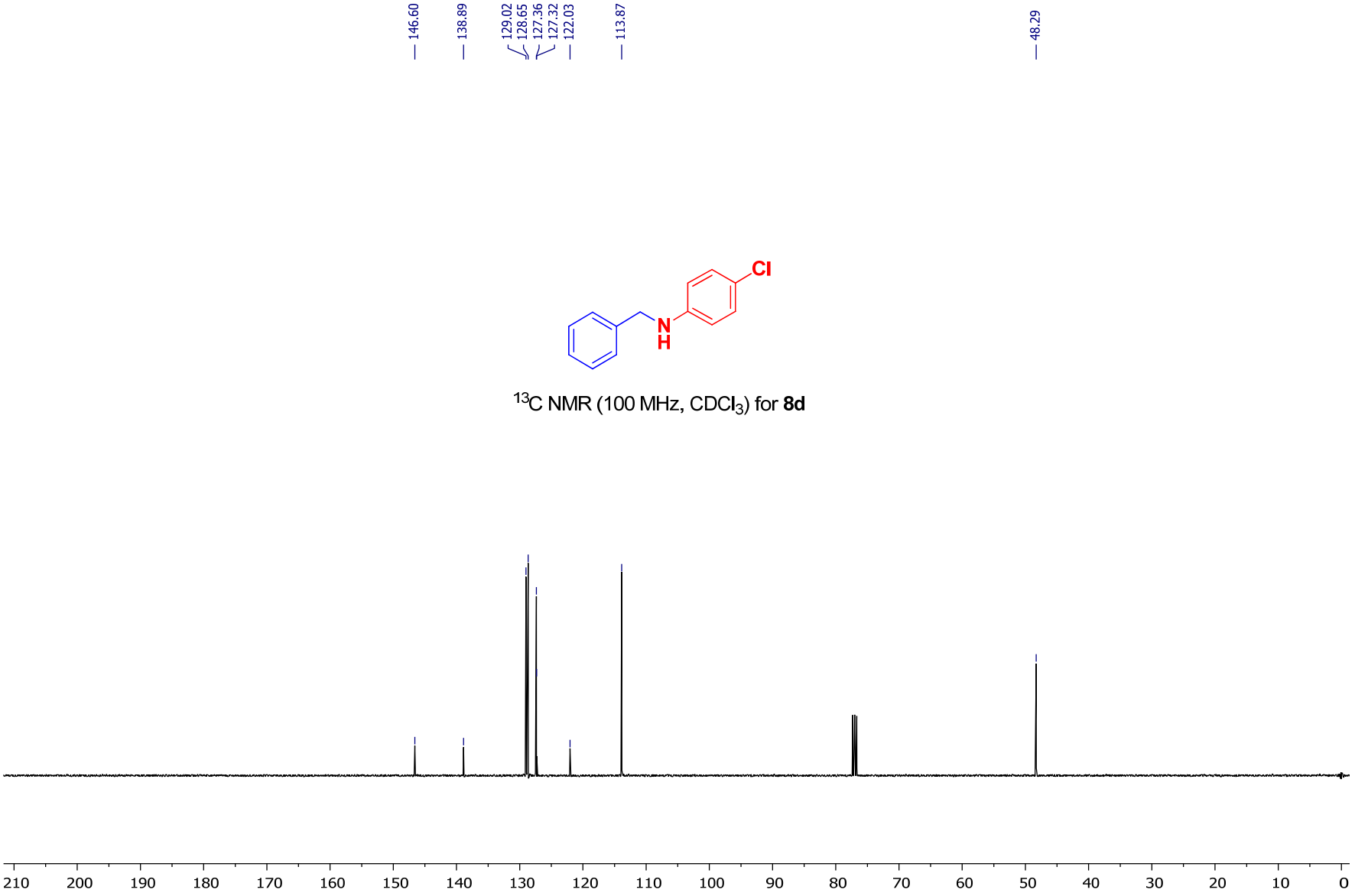
^{1}H NMR (400 MHz, $CDCl_3$) for **8c**



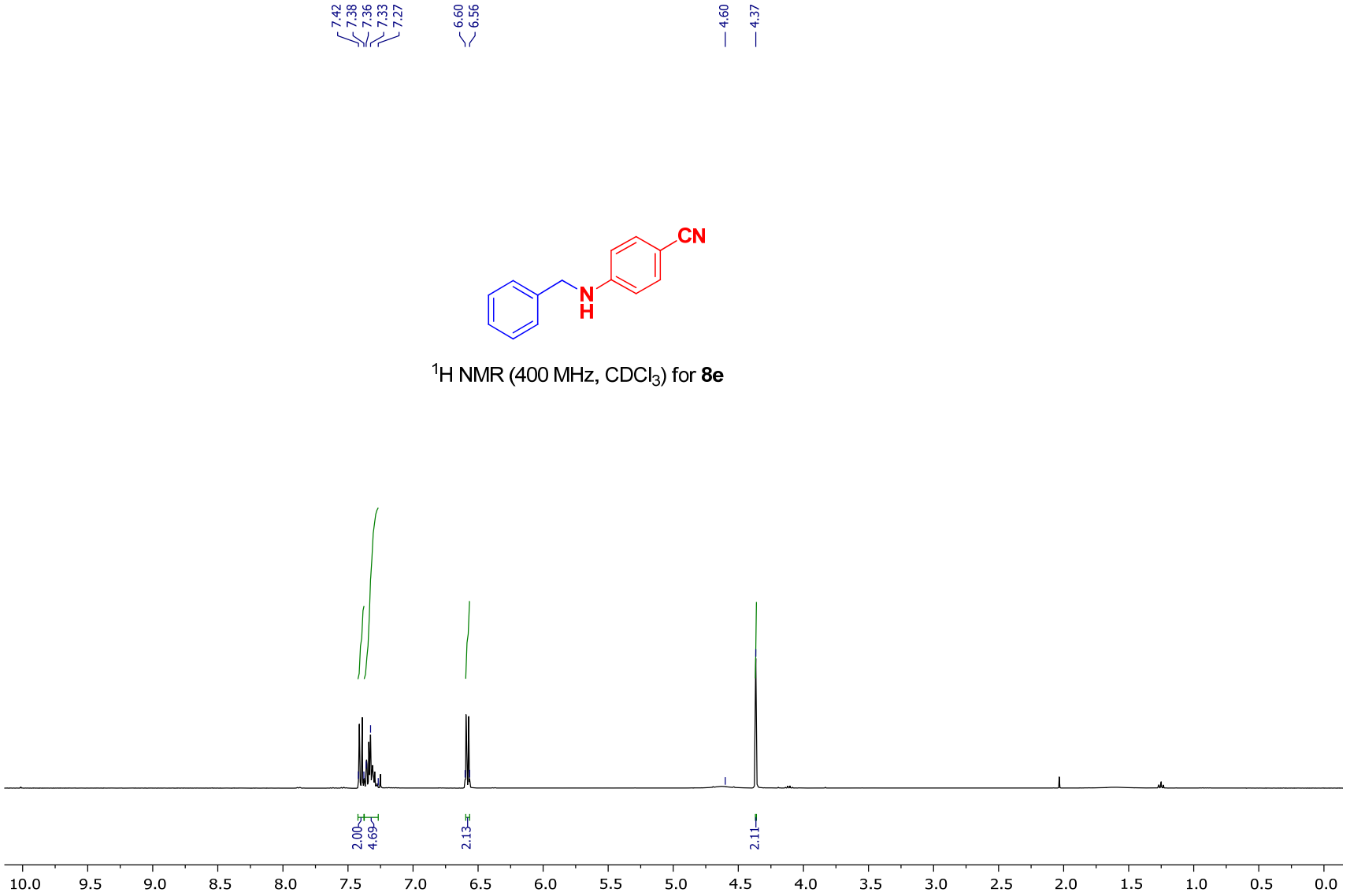
^{13}C NMR (100 MHz, $CDCl_3$) for **8c**



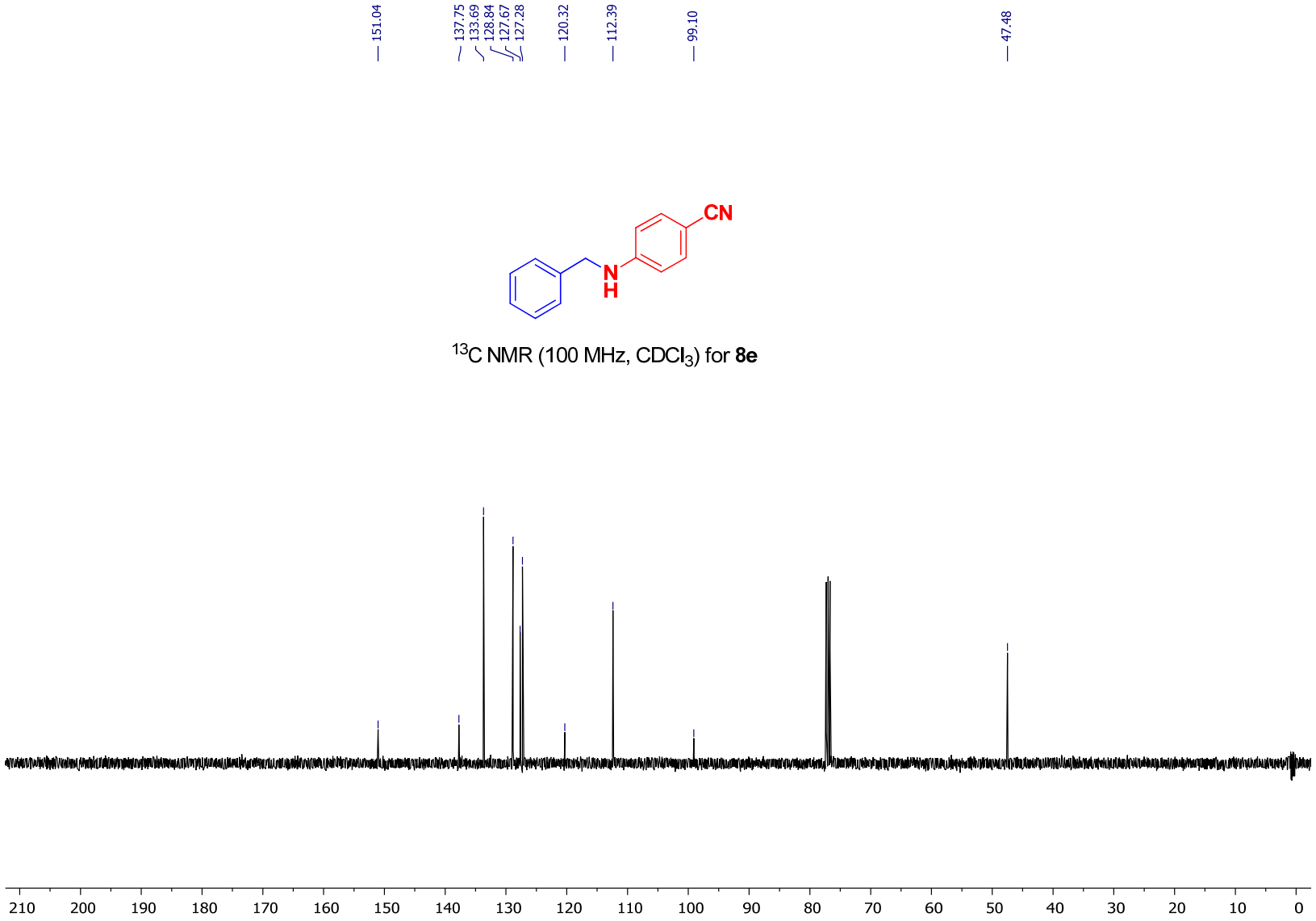
^{1}H NMR (400 MHz, $CDCl_3$) for **8d**



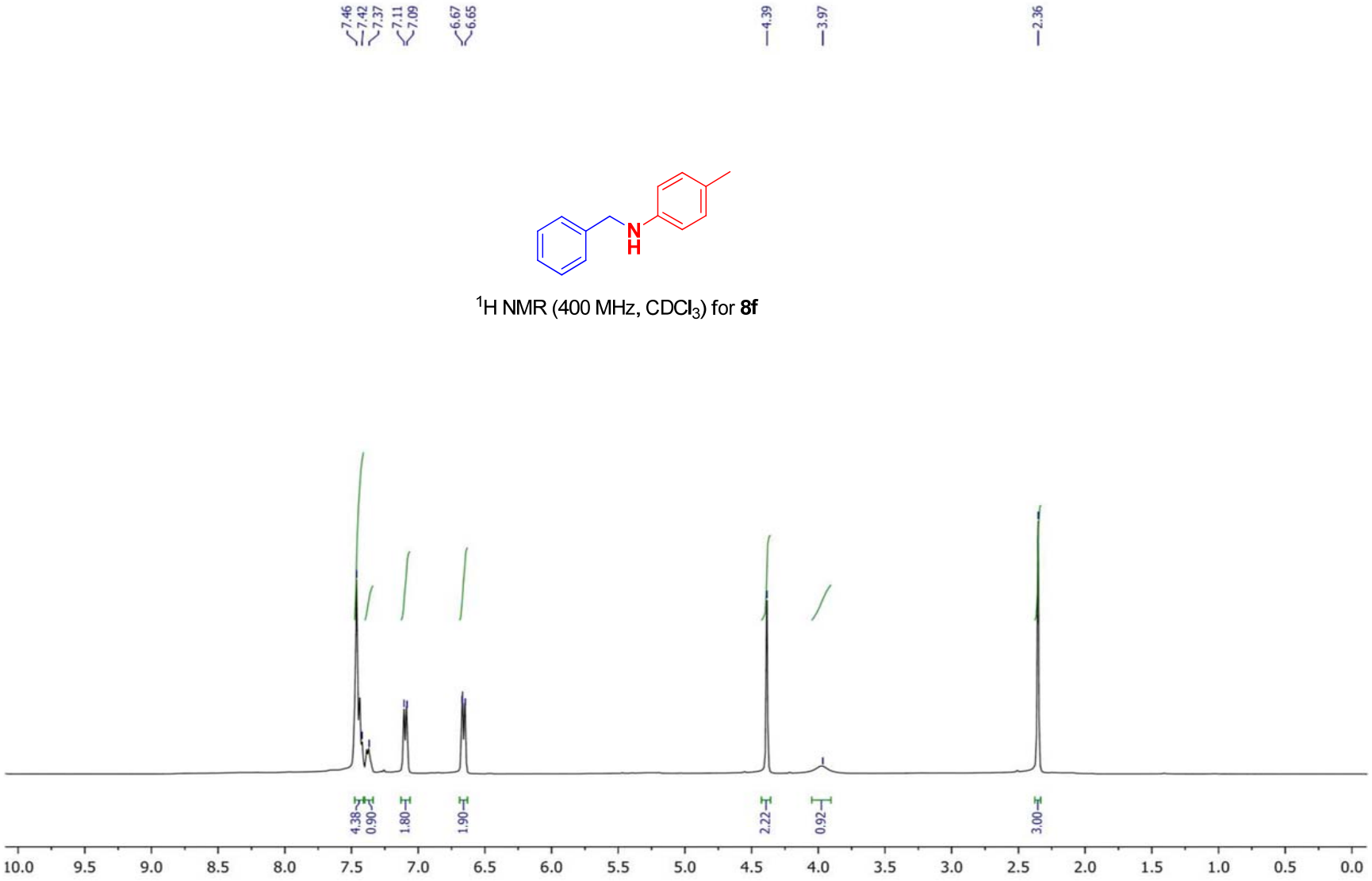
^{13}C NMR (100 MHz, $CDCl_3$) for **8d**



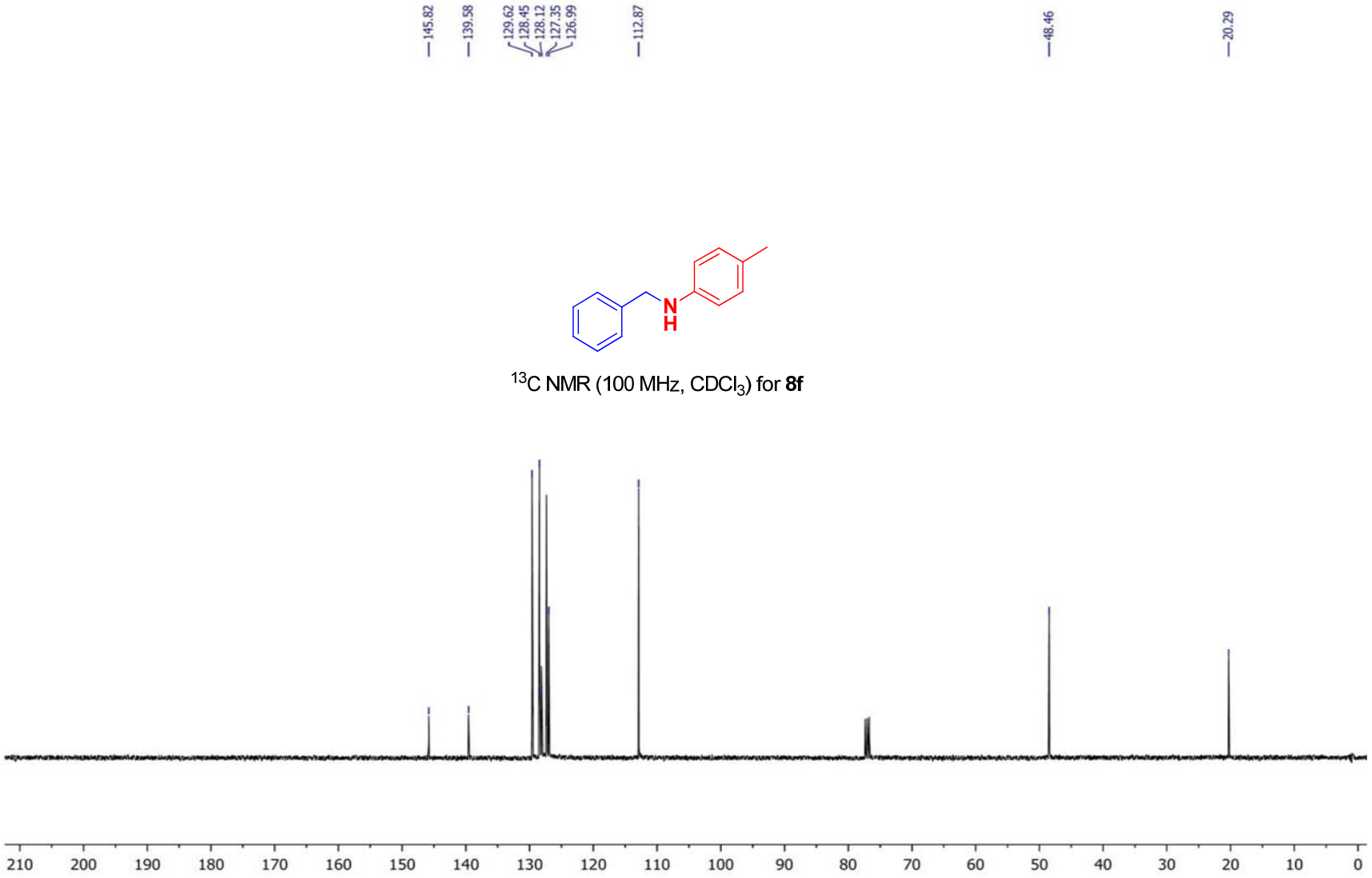
^{1}H NMR (400 MHz, $CDCl_3$) for **8e**



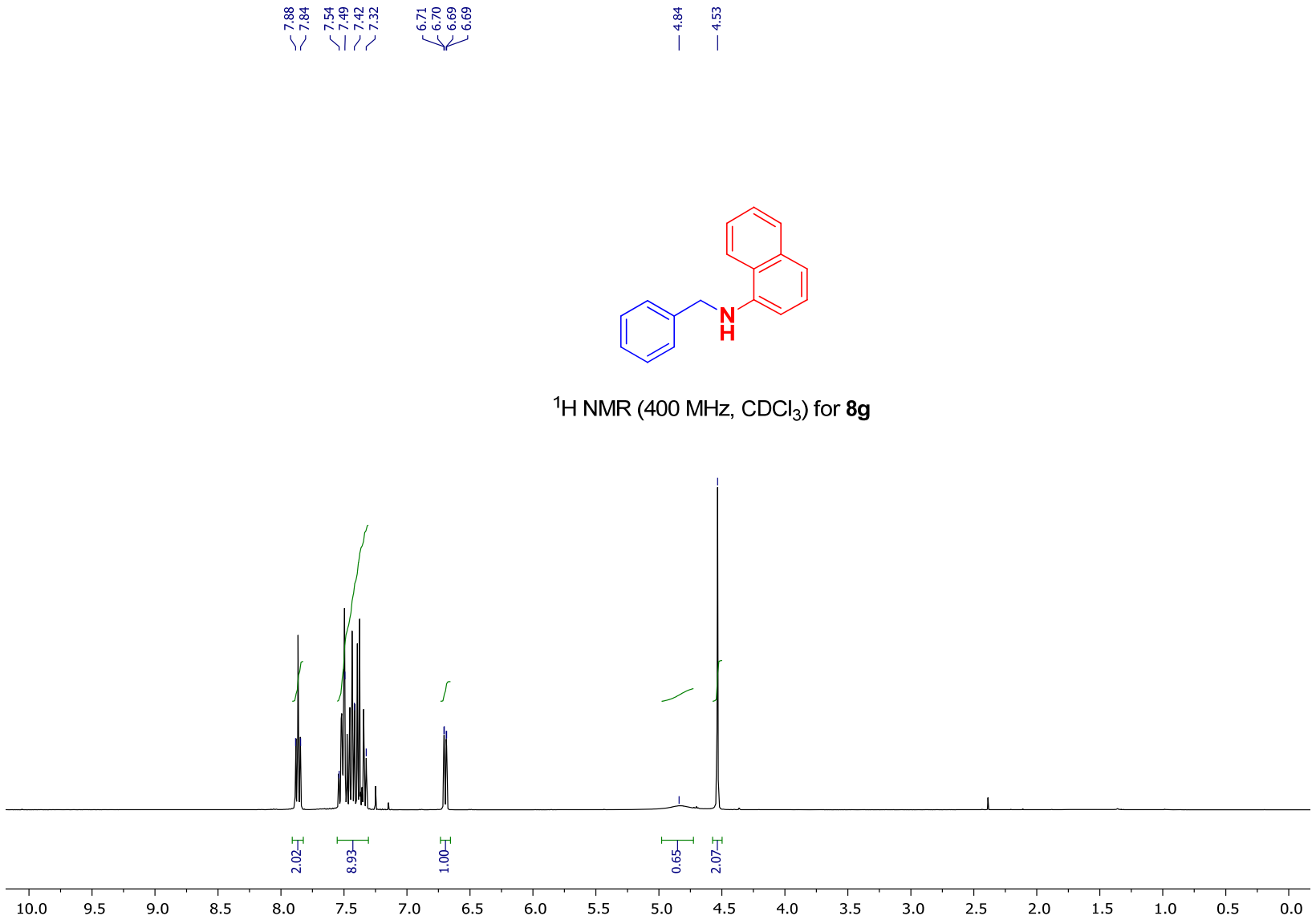
^{13}C NMR (100 MHz, $CDCl_3$) for **8e**



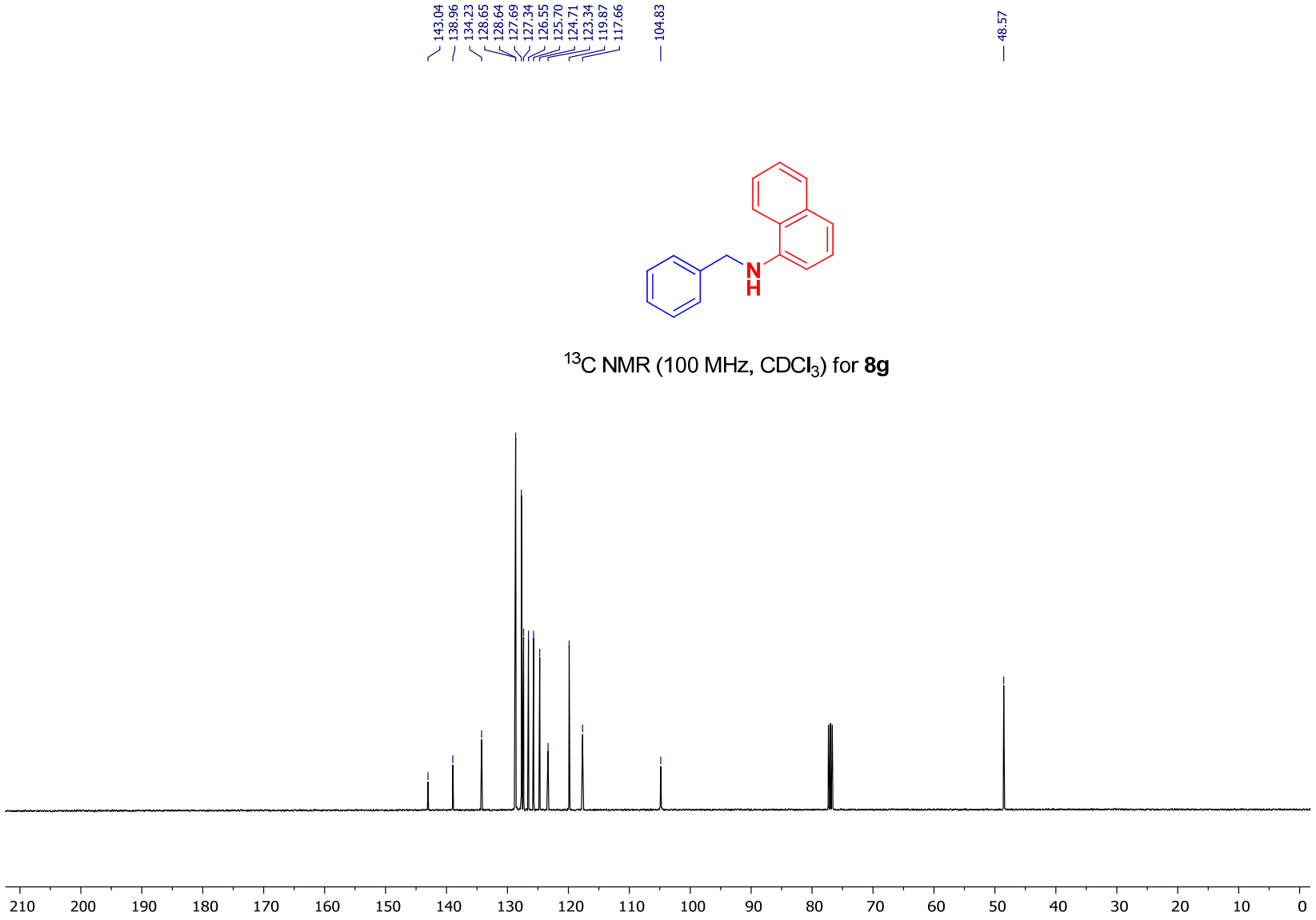
^{1}H NMR (400 MHz, $CDCl_3$) for **8f**



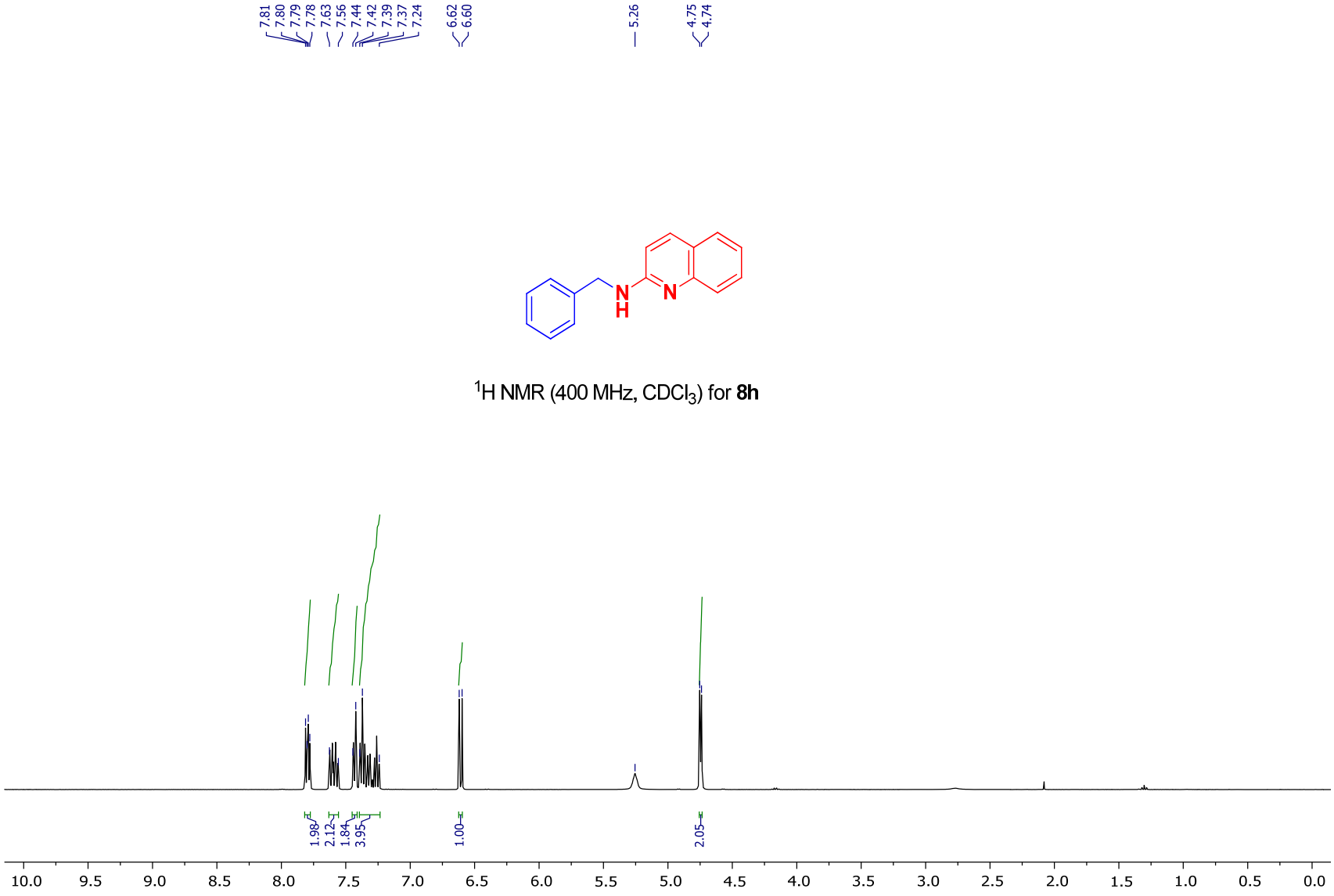
^{13}C NMR (100 MHz, $CDCl_3$) for **8f**



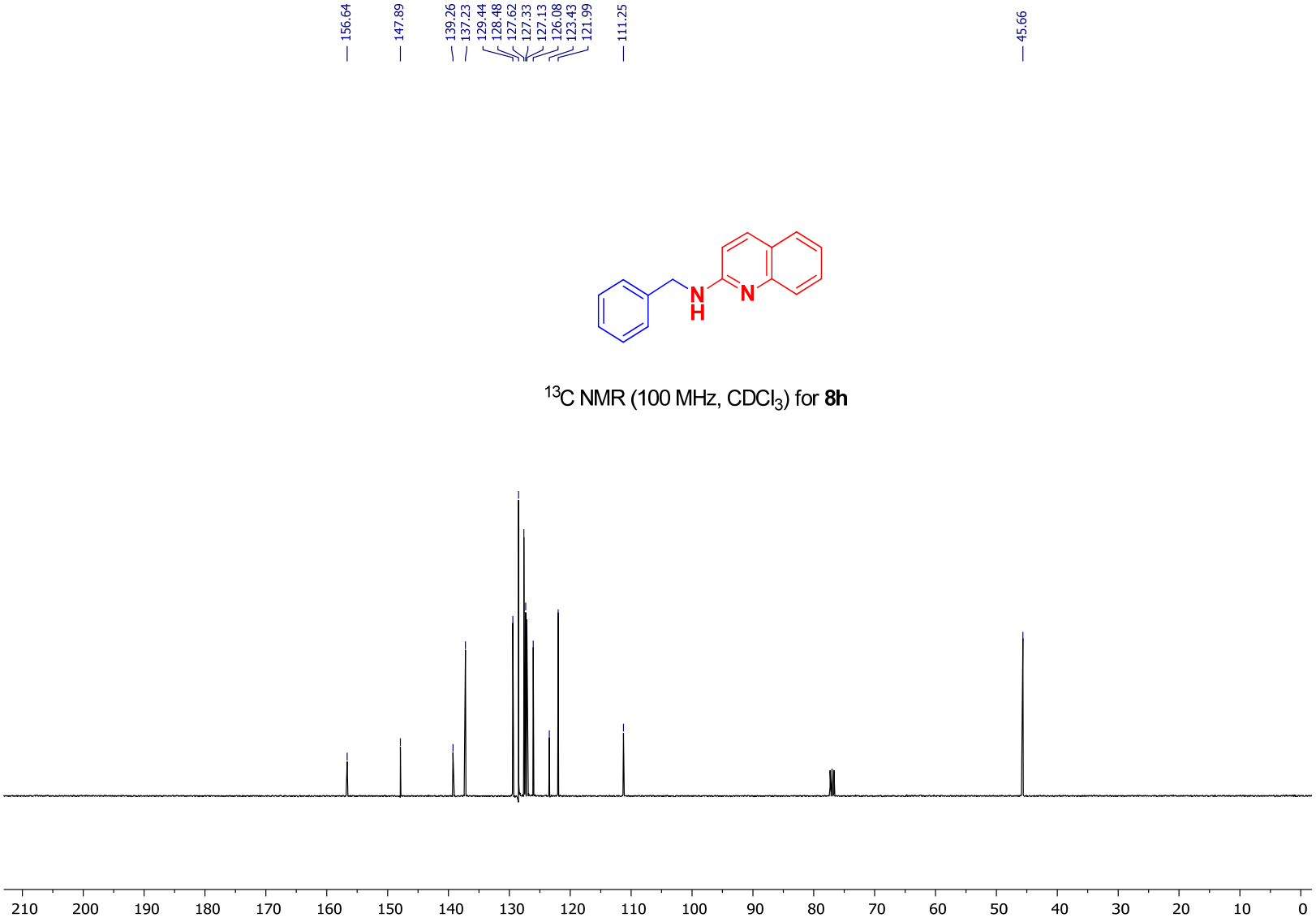
^{1}H NMR (400 MHz, $CDCl_3$) for **8g**



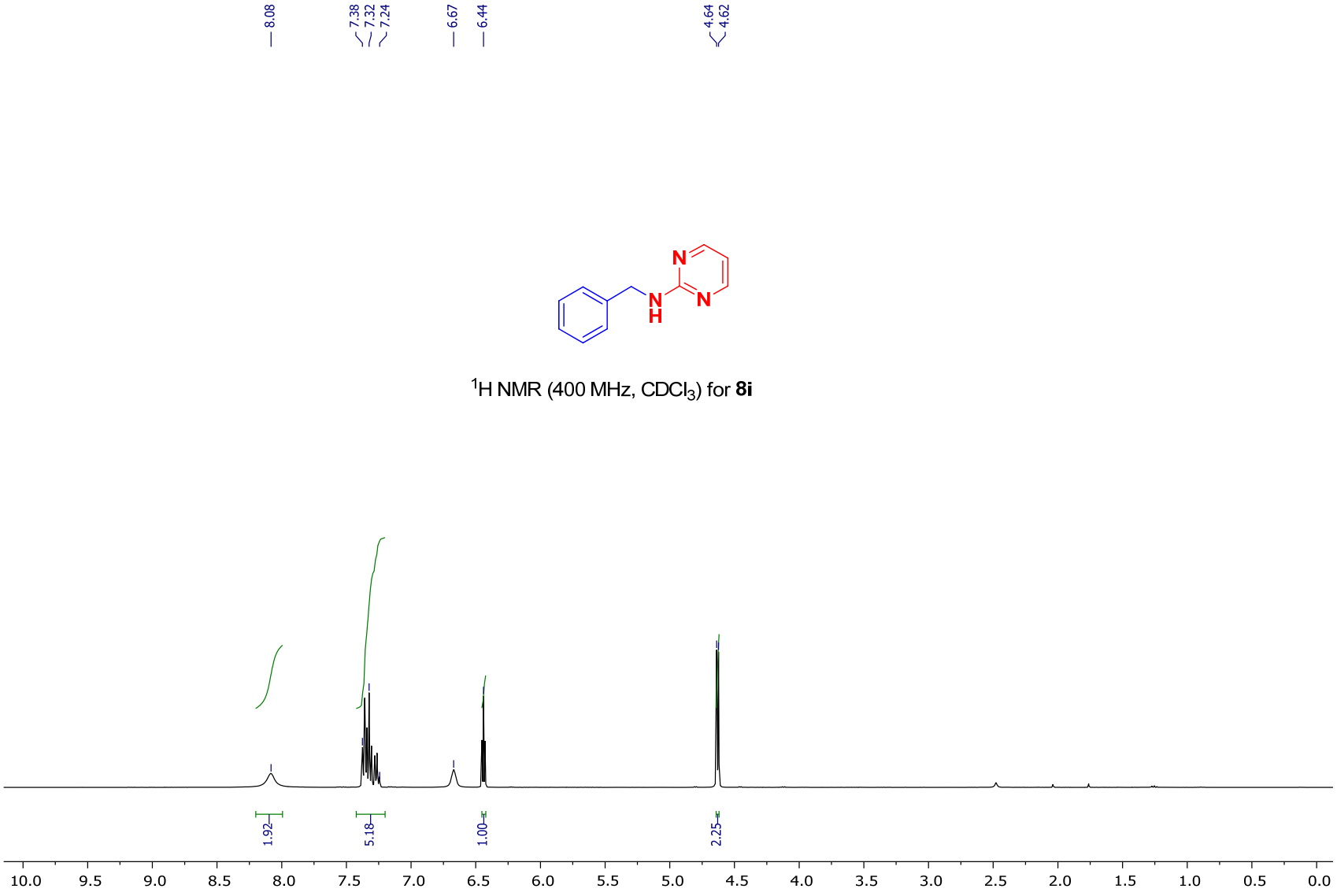
^{13}C NMR (100 MHz, $CDCl_3$) for **8g**



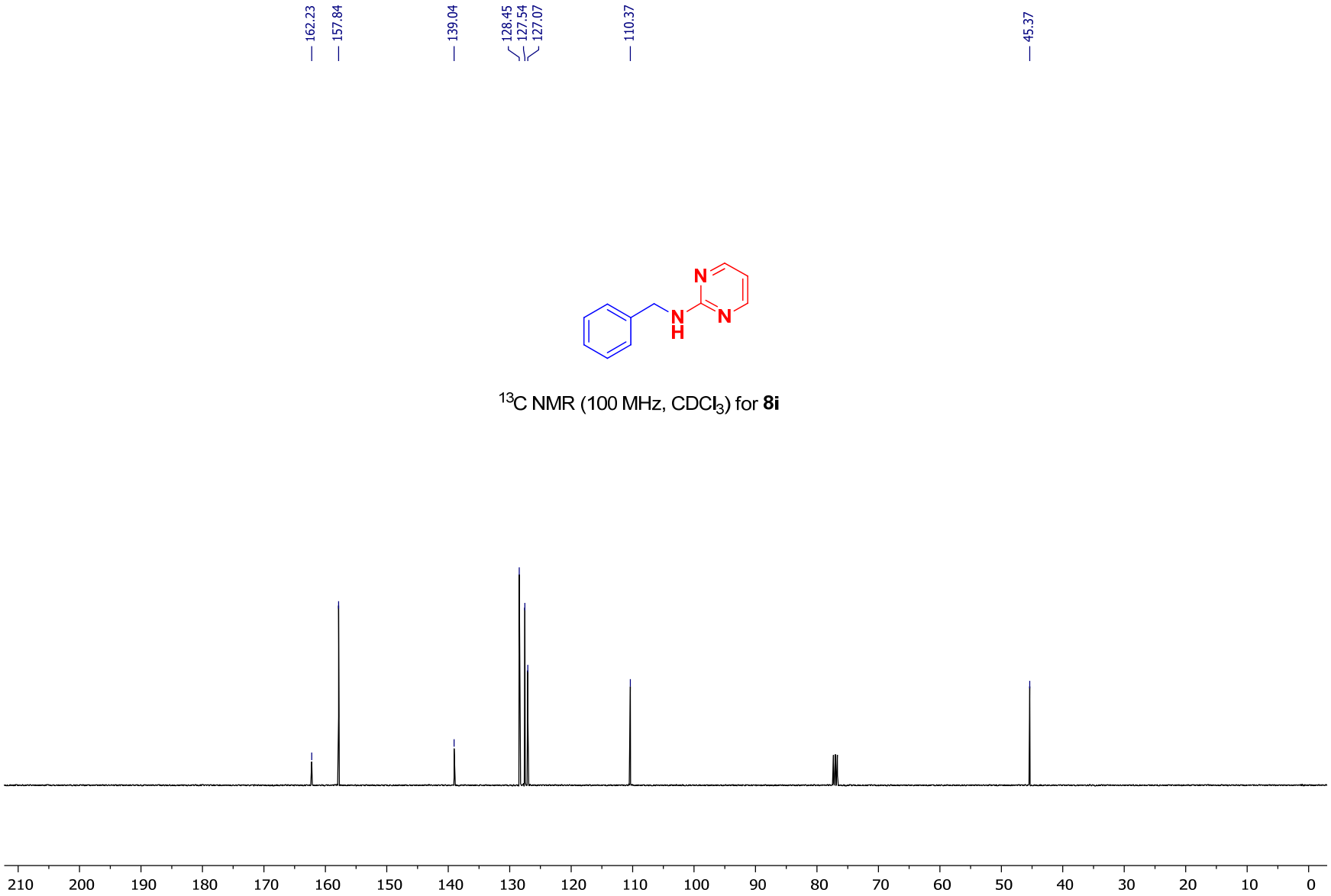
^{1}H NMR (400 MHz, $CDCl_3$) for **8h**



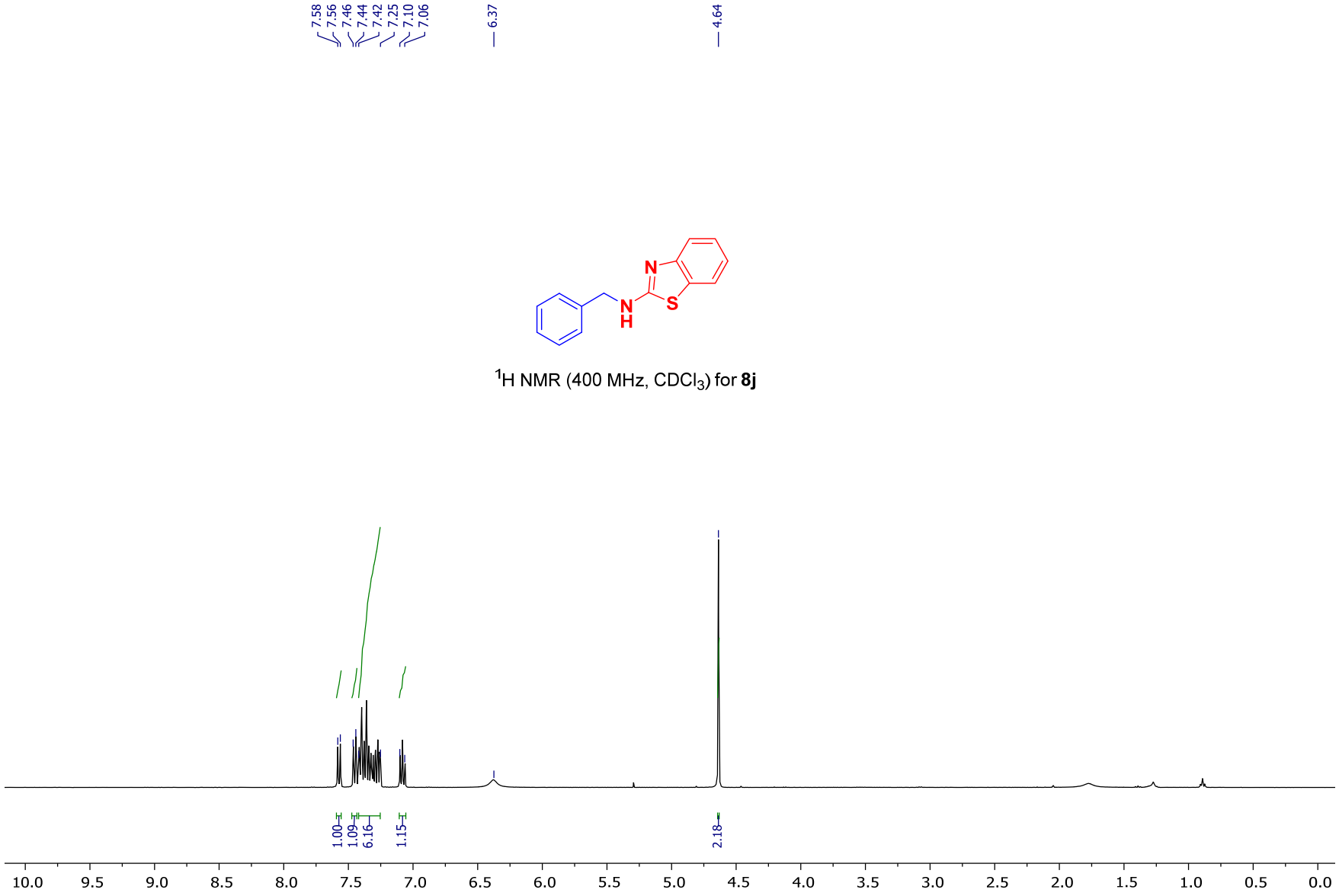
^{13}C NMR (100 MHz, $CDCl_3$) for **8h**



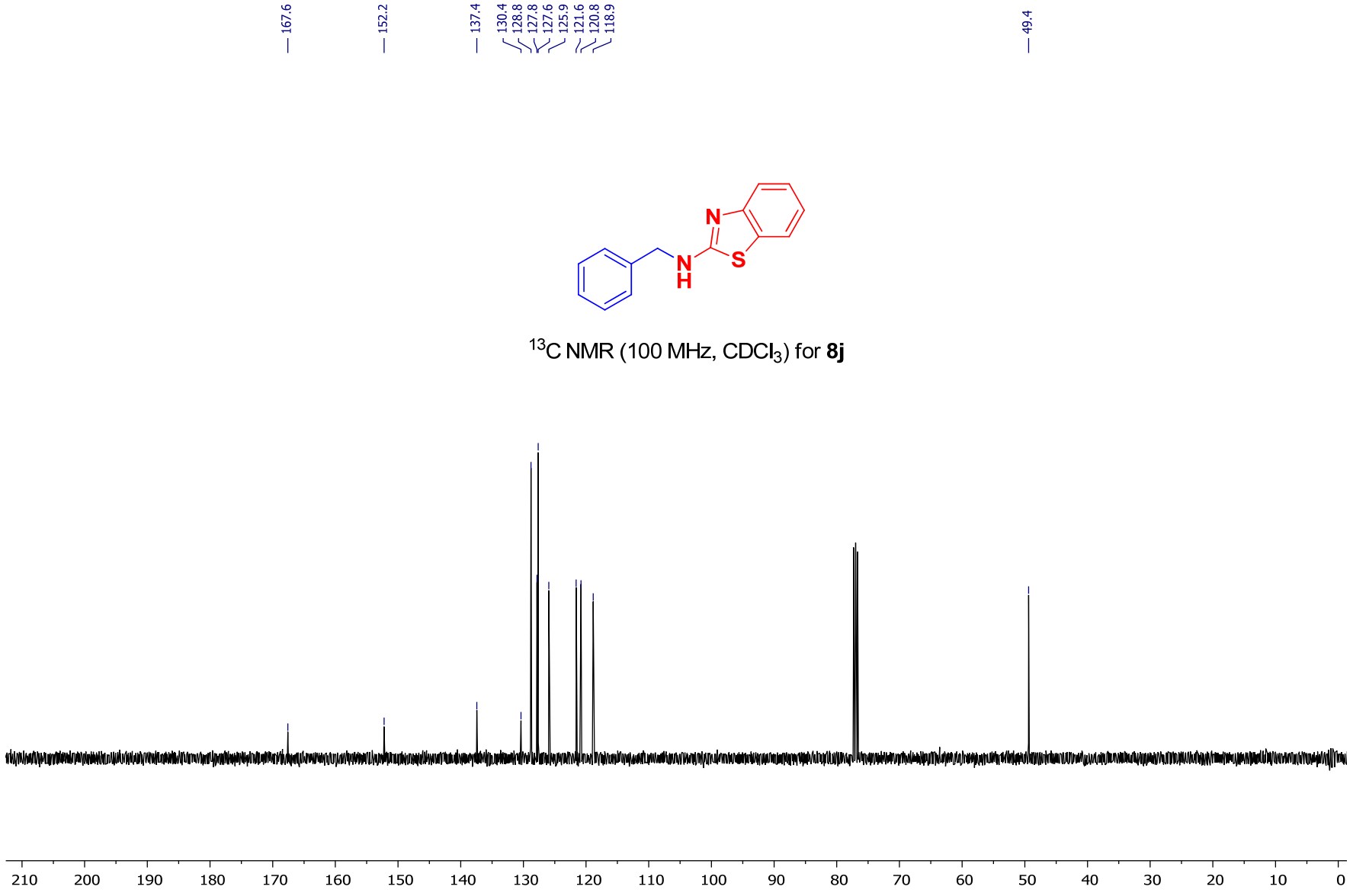
^{1}H NMR (400 MHz, $CDCl_3$) for **8i**



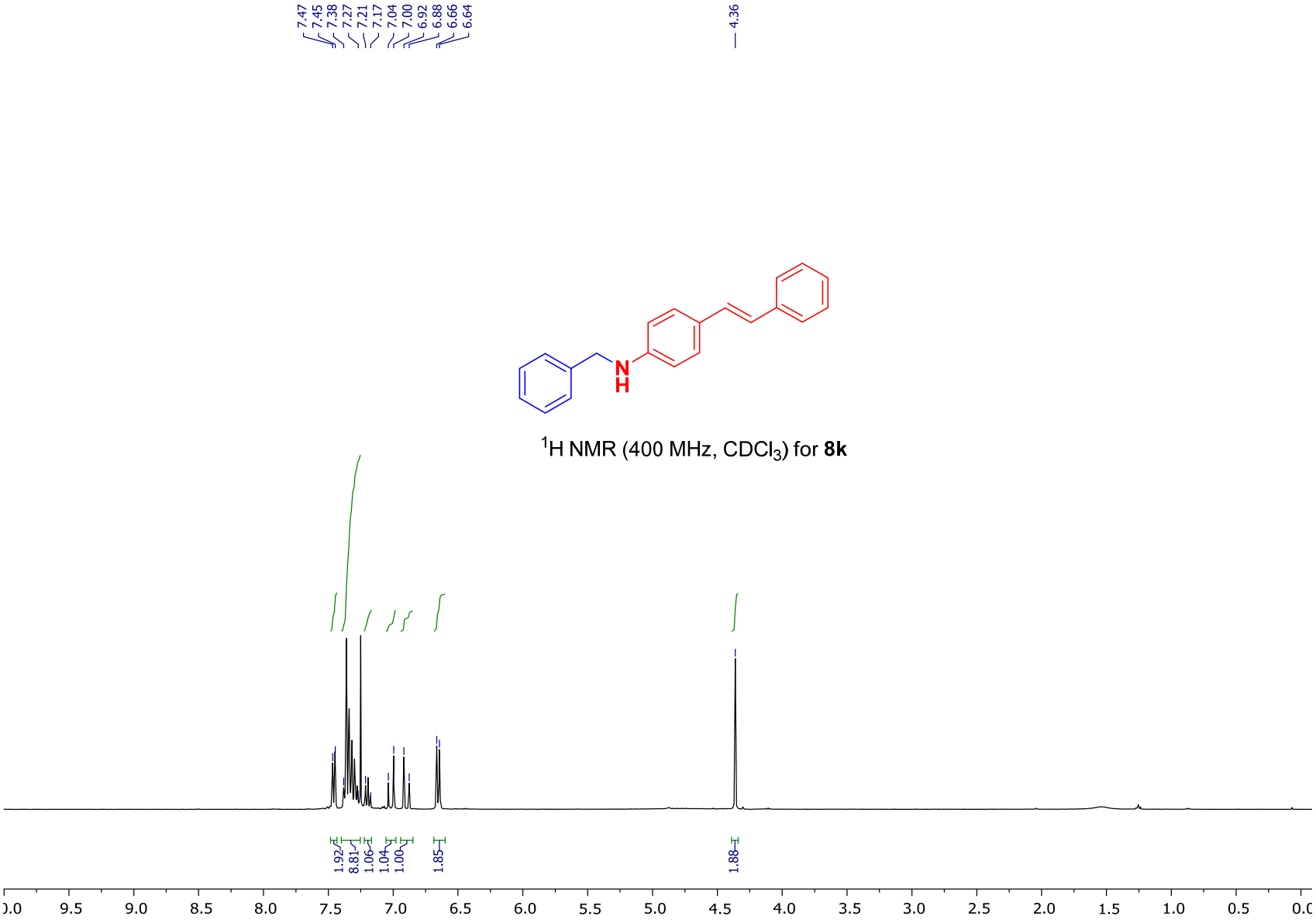
^{13}C NMR (100 MHz, $CDCl_3$) for **8i**



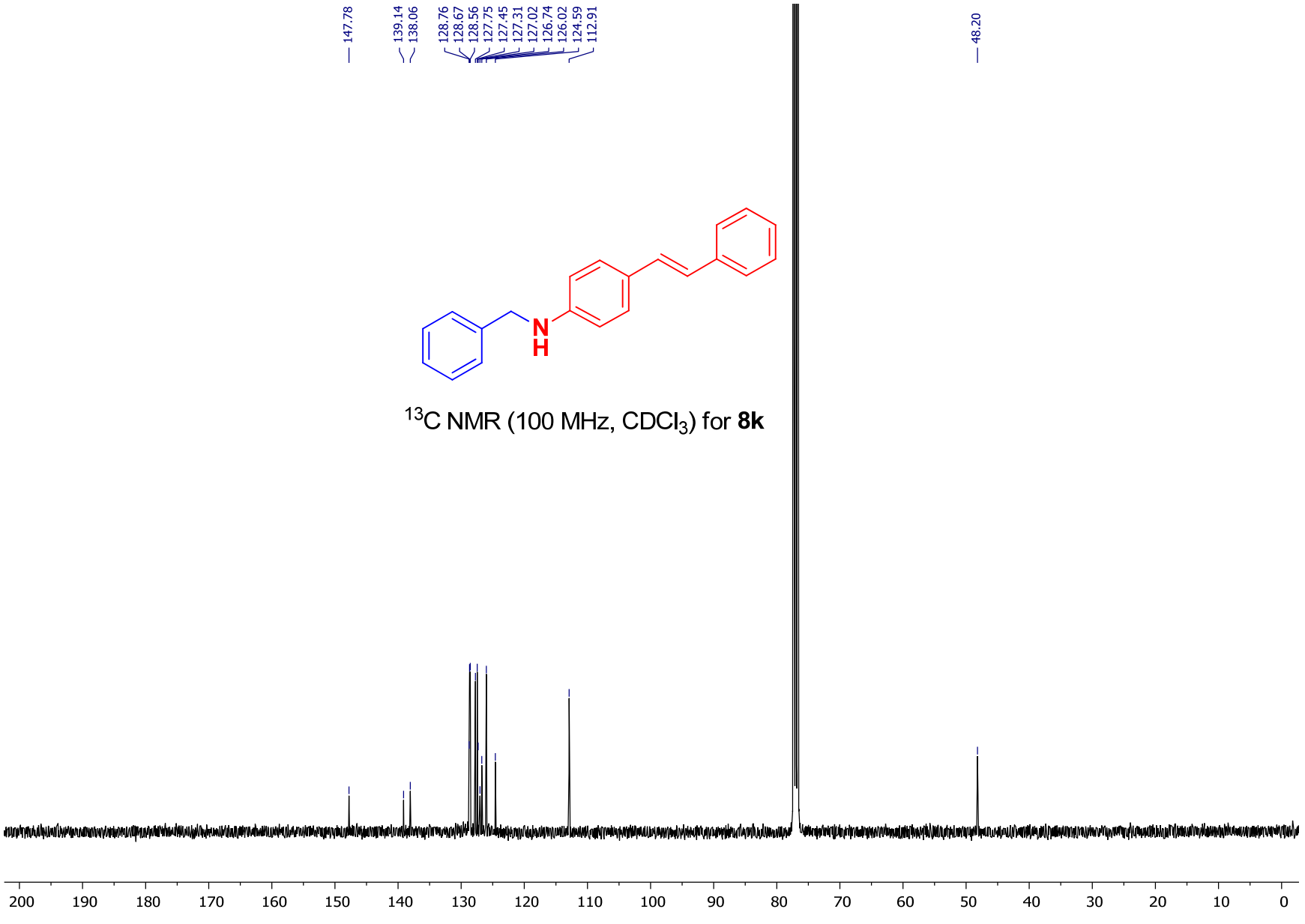
^{1}H NMR (400 MHz, $CDCl_3$) for **8j**



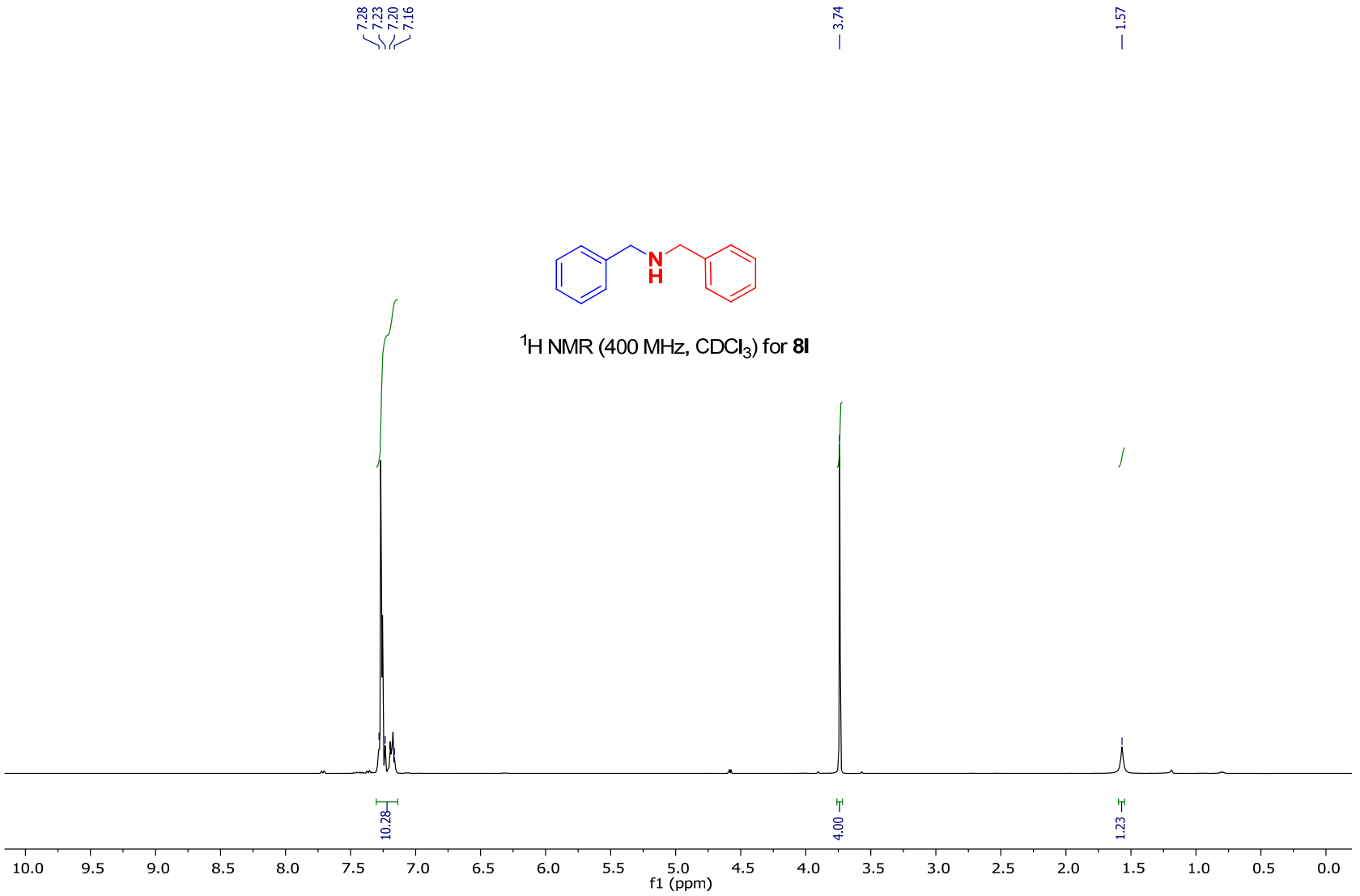
^{13}C NMR (100 MHz, $CDCl_3$) for **8j**



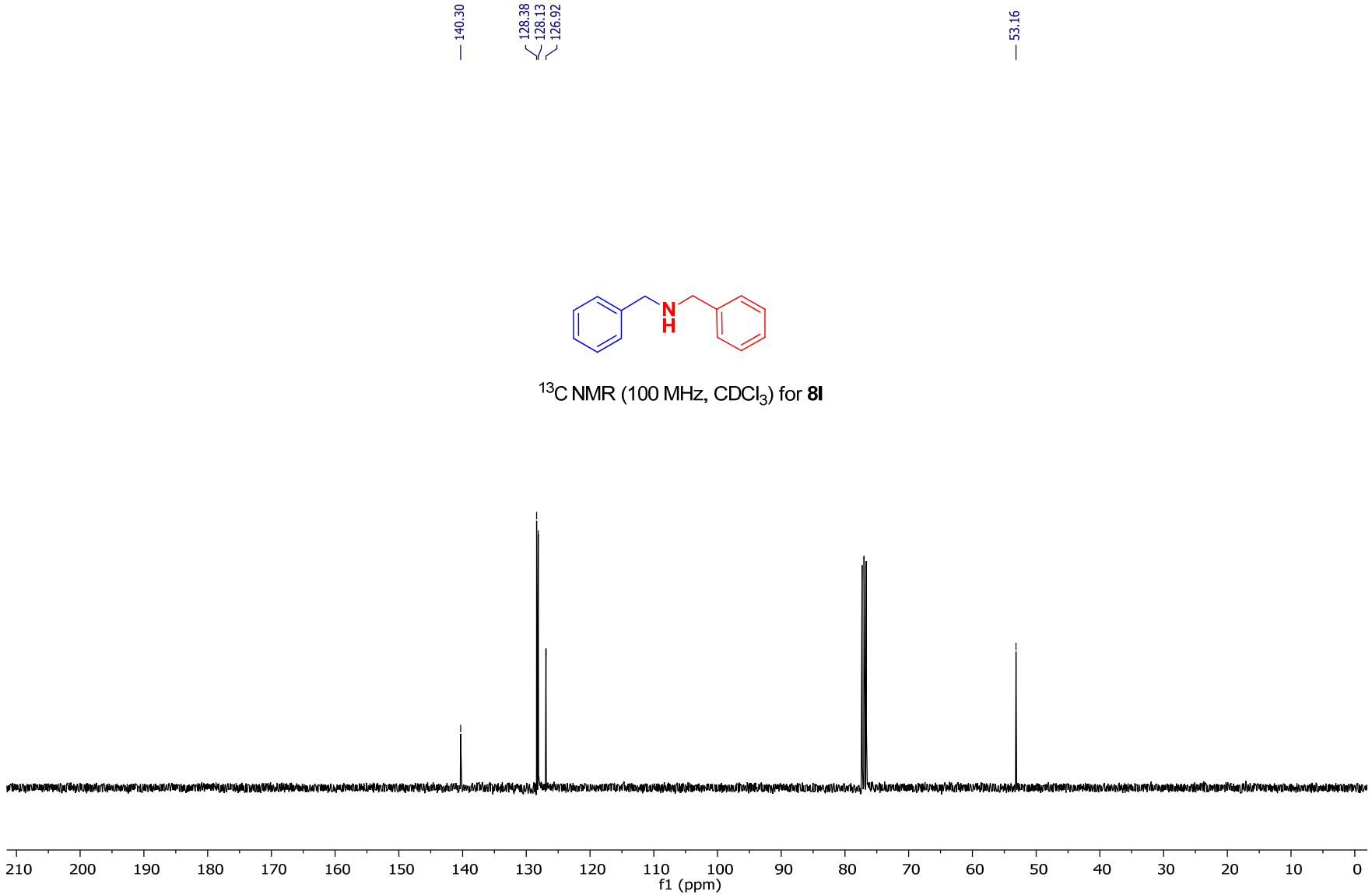
^{1}H NMR (400 MHz, $CDCl_3$) for **8k**



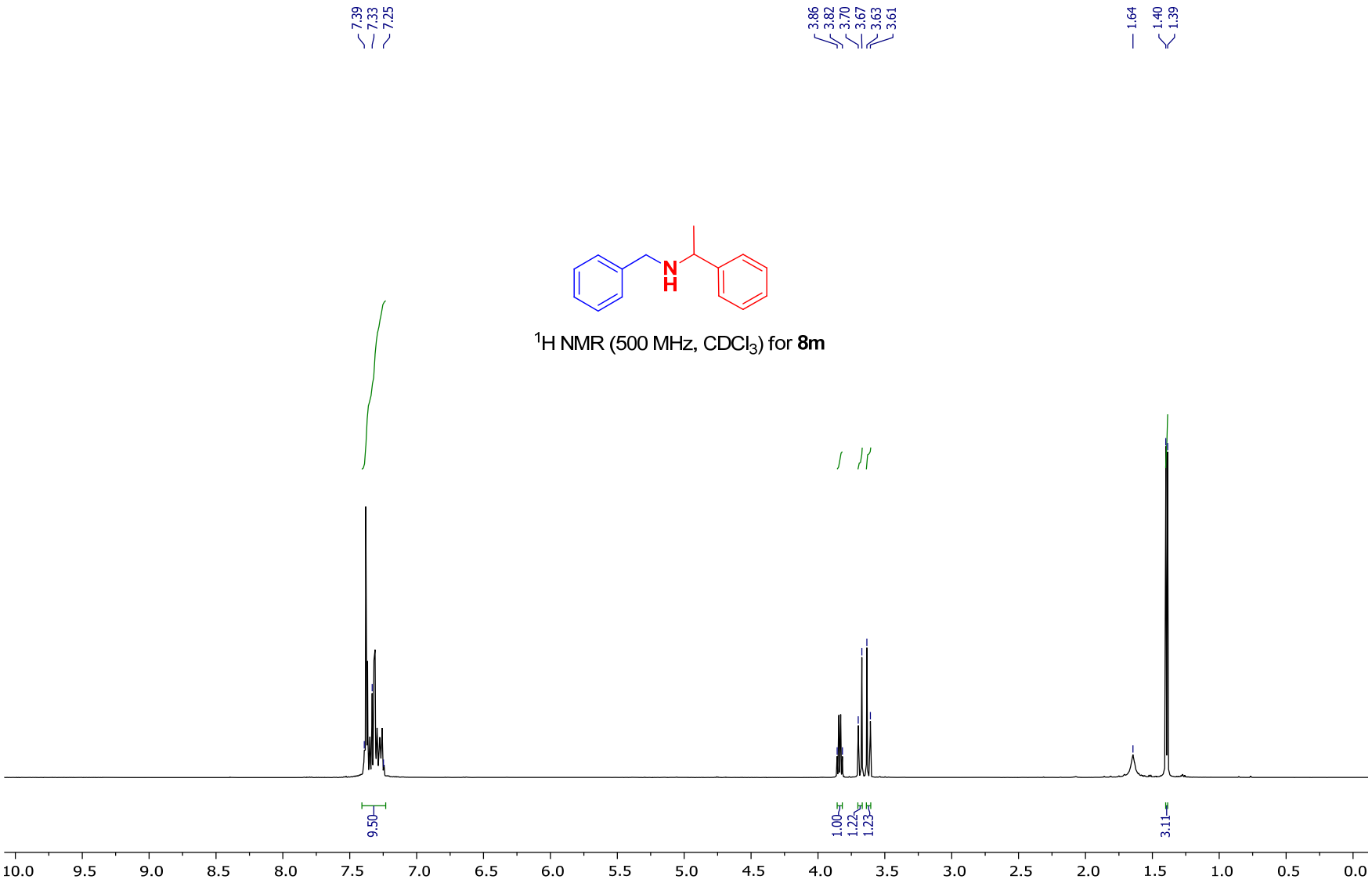
^{13}C NMR (100 MHz, $CDCl_3$) for **8k**



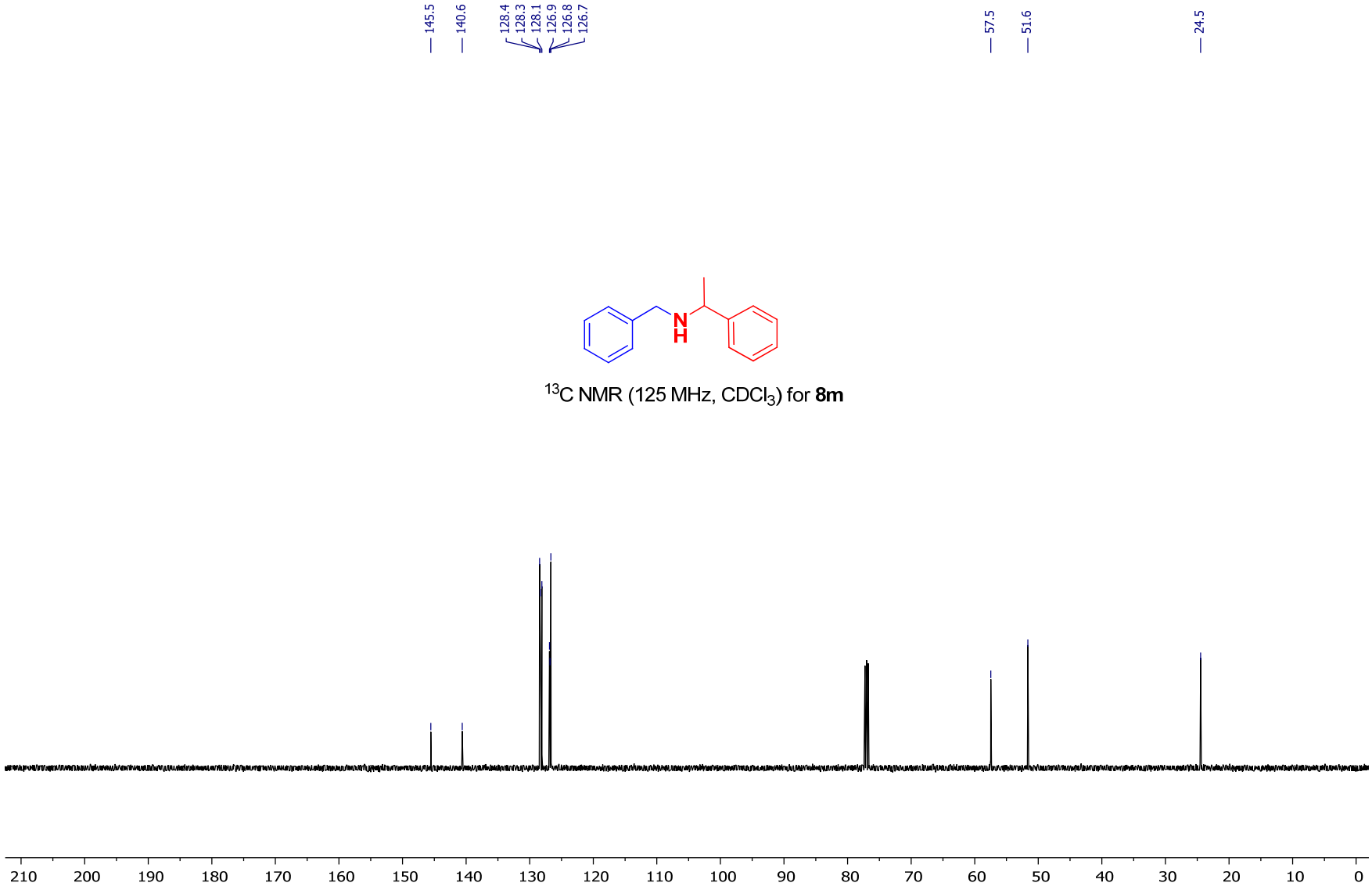
^{1}H NMR (400 MHz, $CDCl_3$) for **8l**



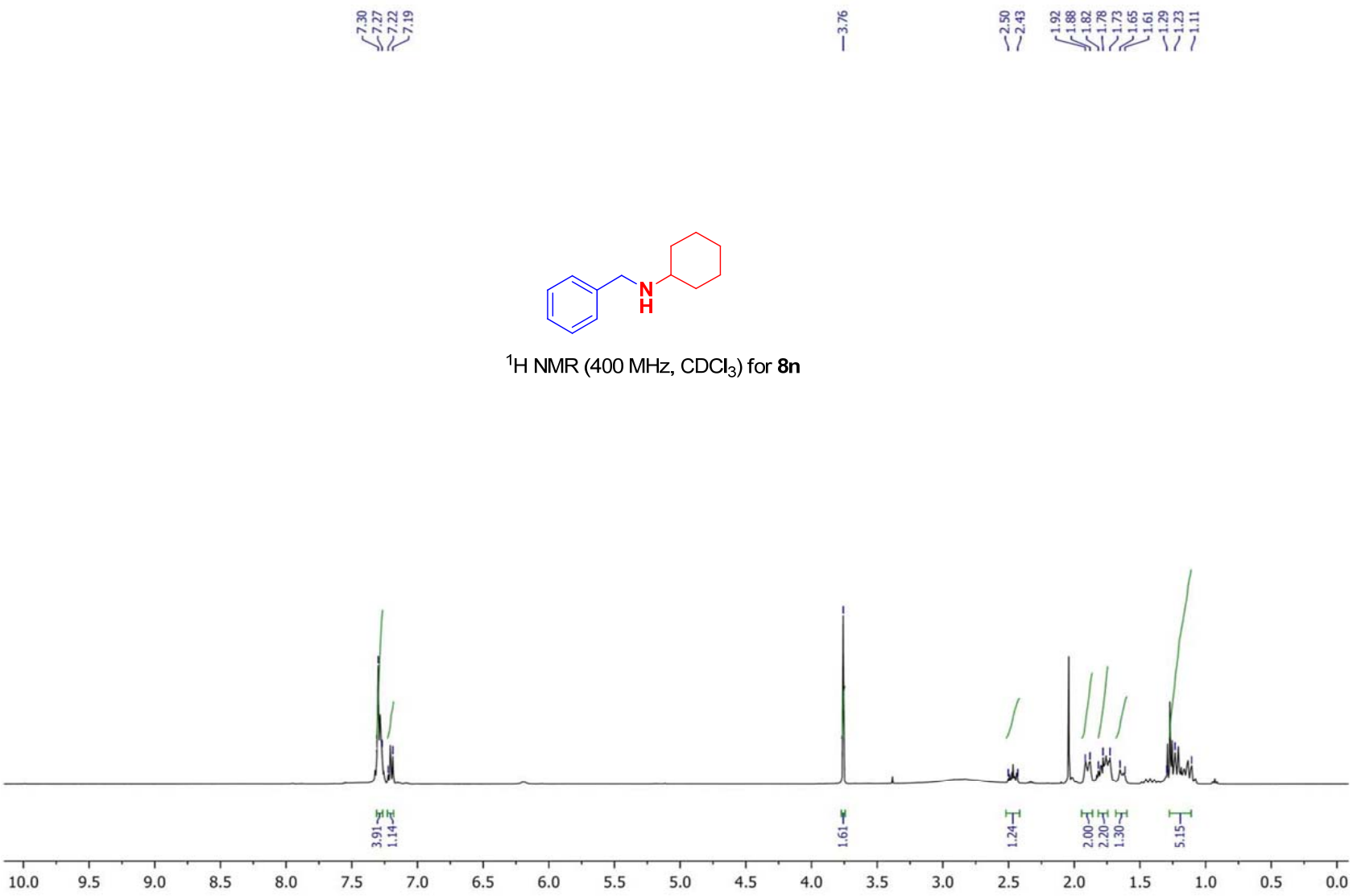
^{13}C NMR (100 MHz, $CDCl_3$) for **8l**



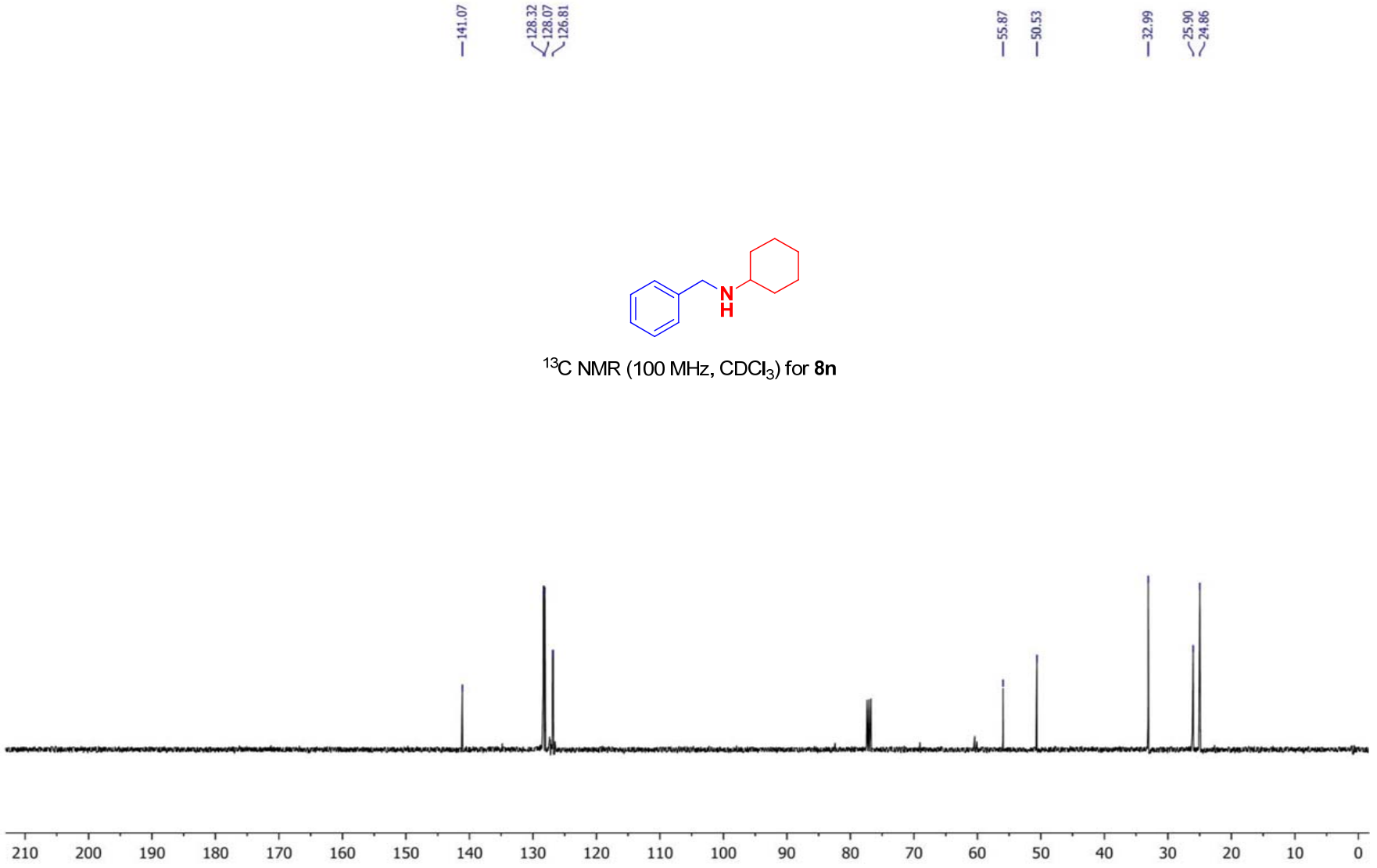
^{1}H NMR (500 MHz, $CDCl_3$) for **8m**



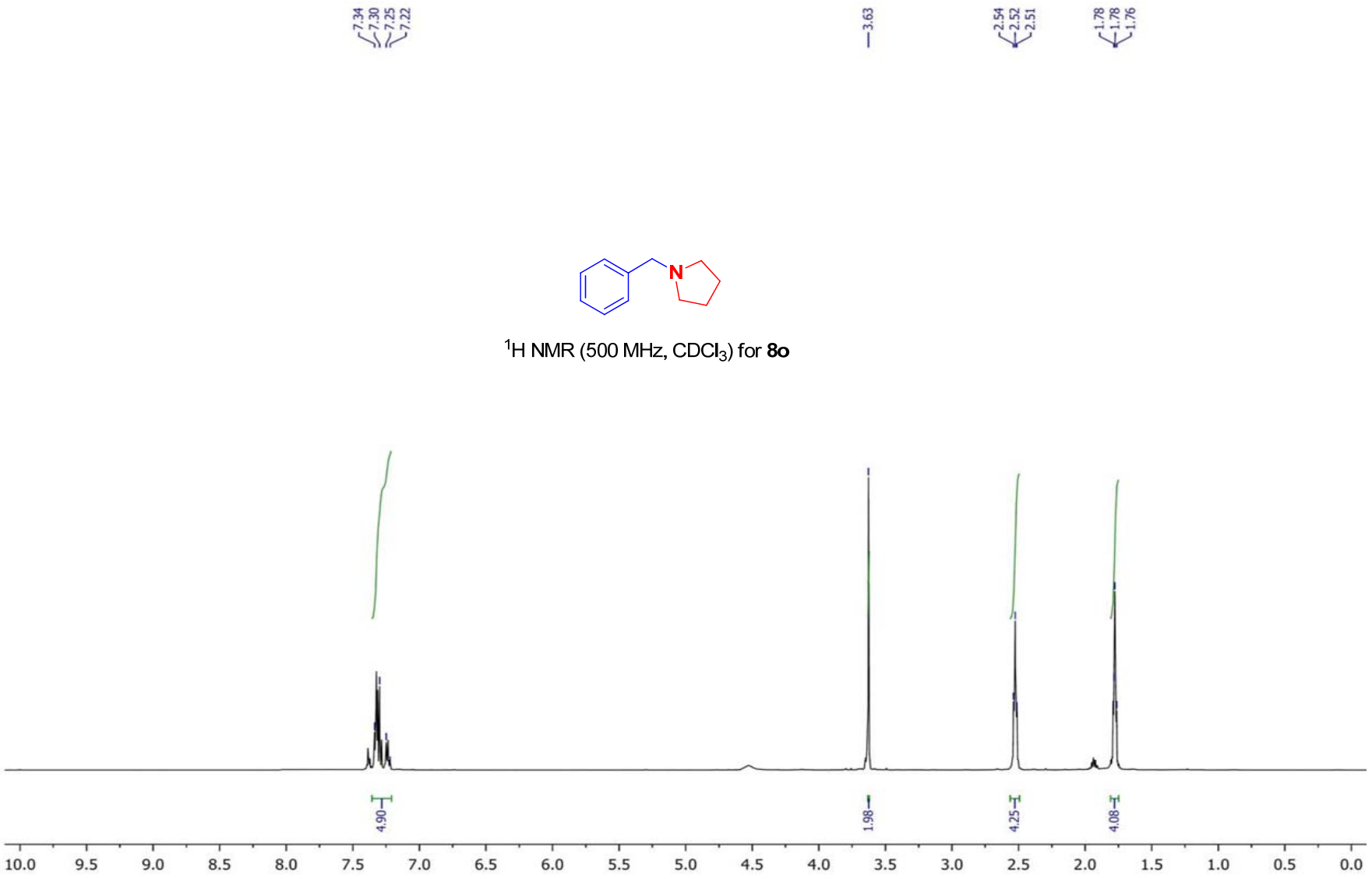
^{13}C NMR (125 MHz, $CDCl_3$) for **8m**



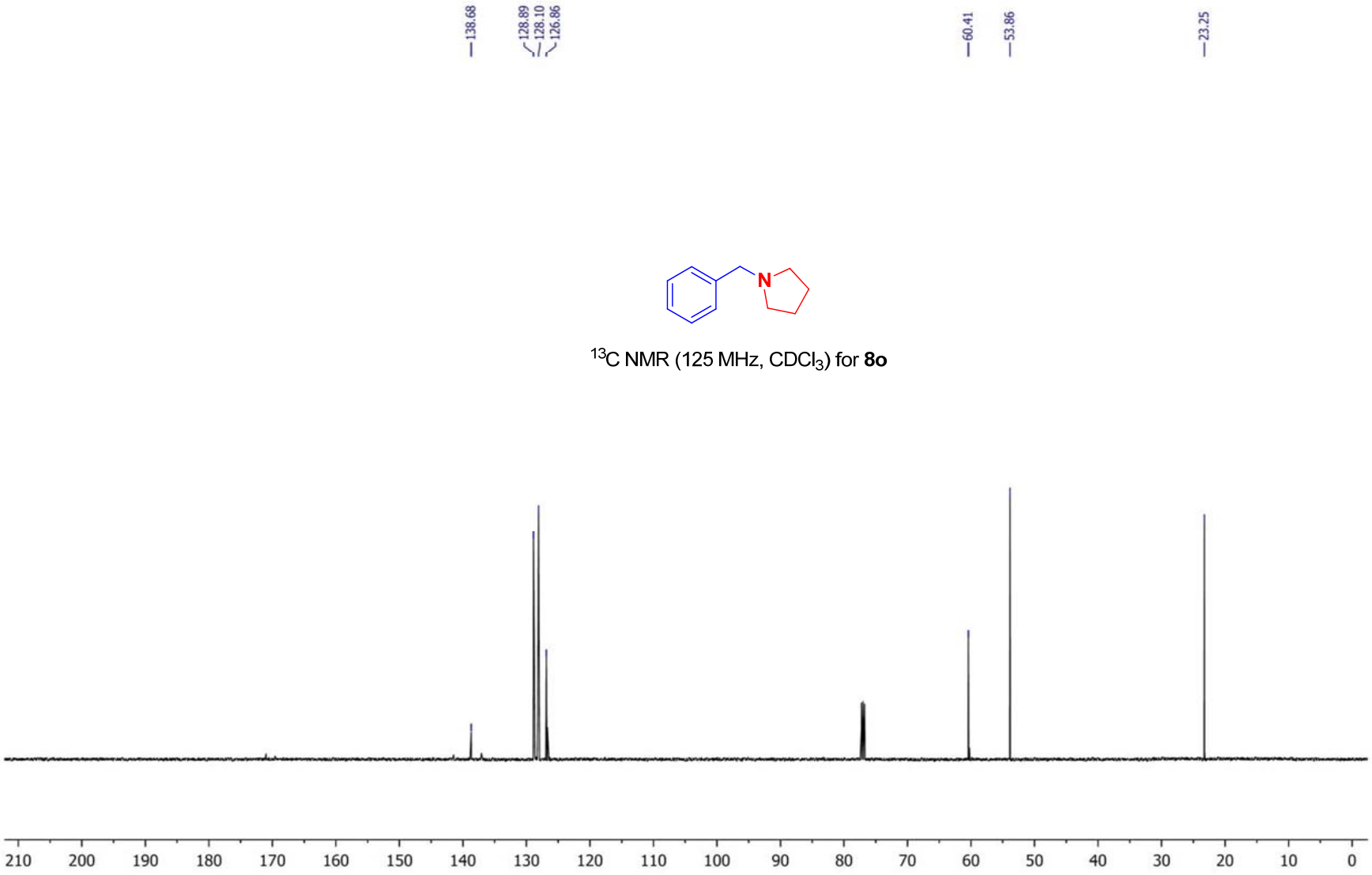
^{1}H NMR (400 MHz, $CDCl_3$) for **8n**



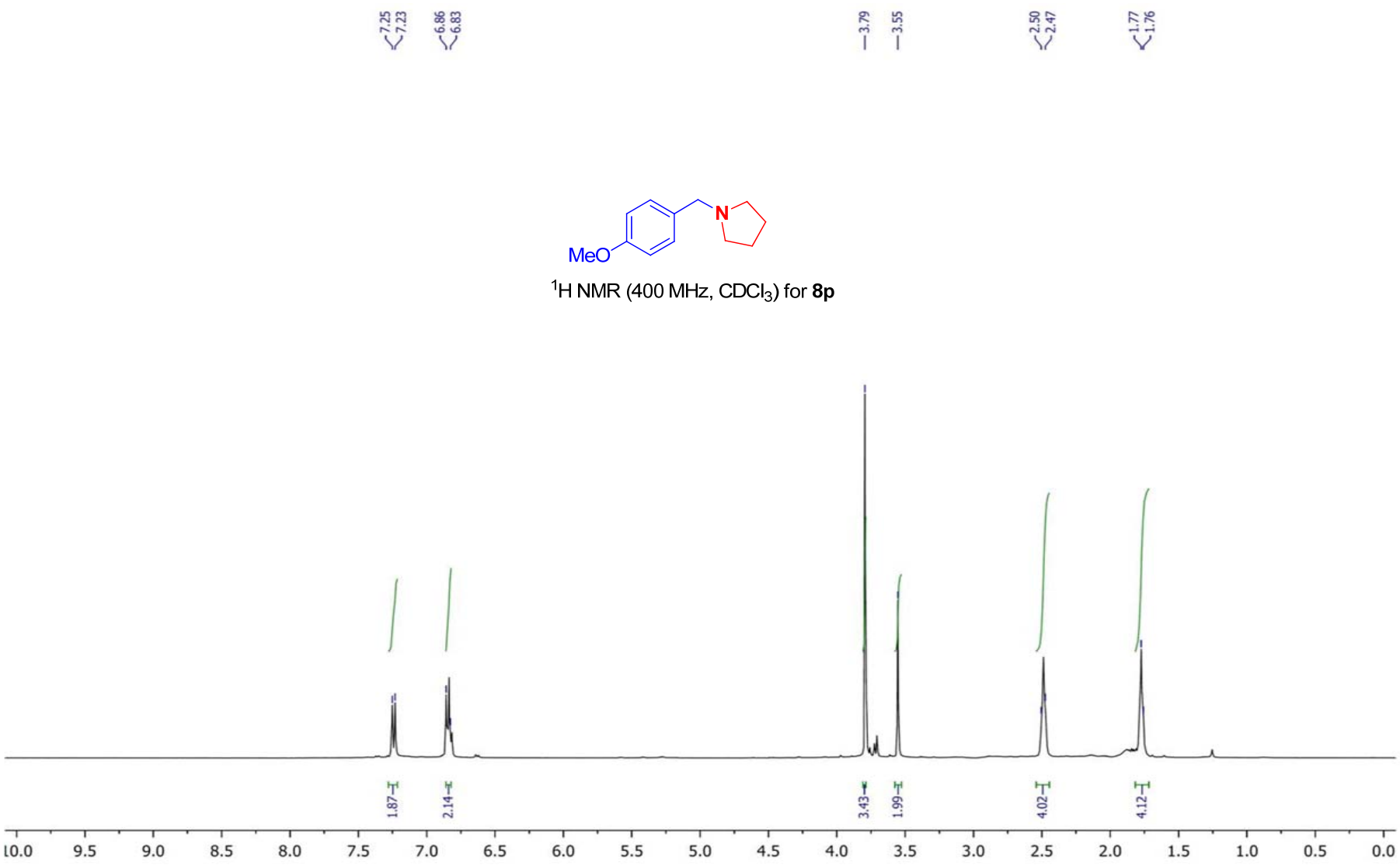
^{13}C NMR (100 MHz, $CDCl_3$) for **8n**



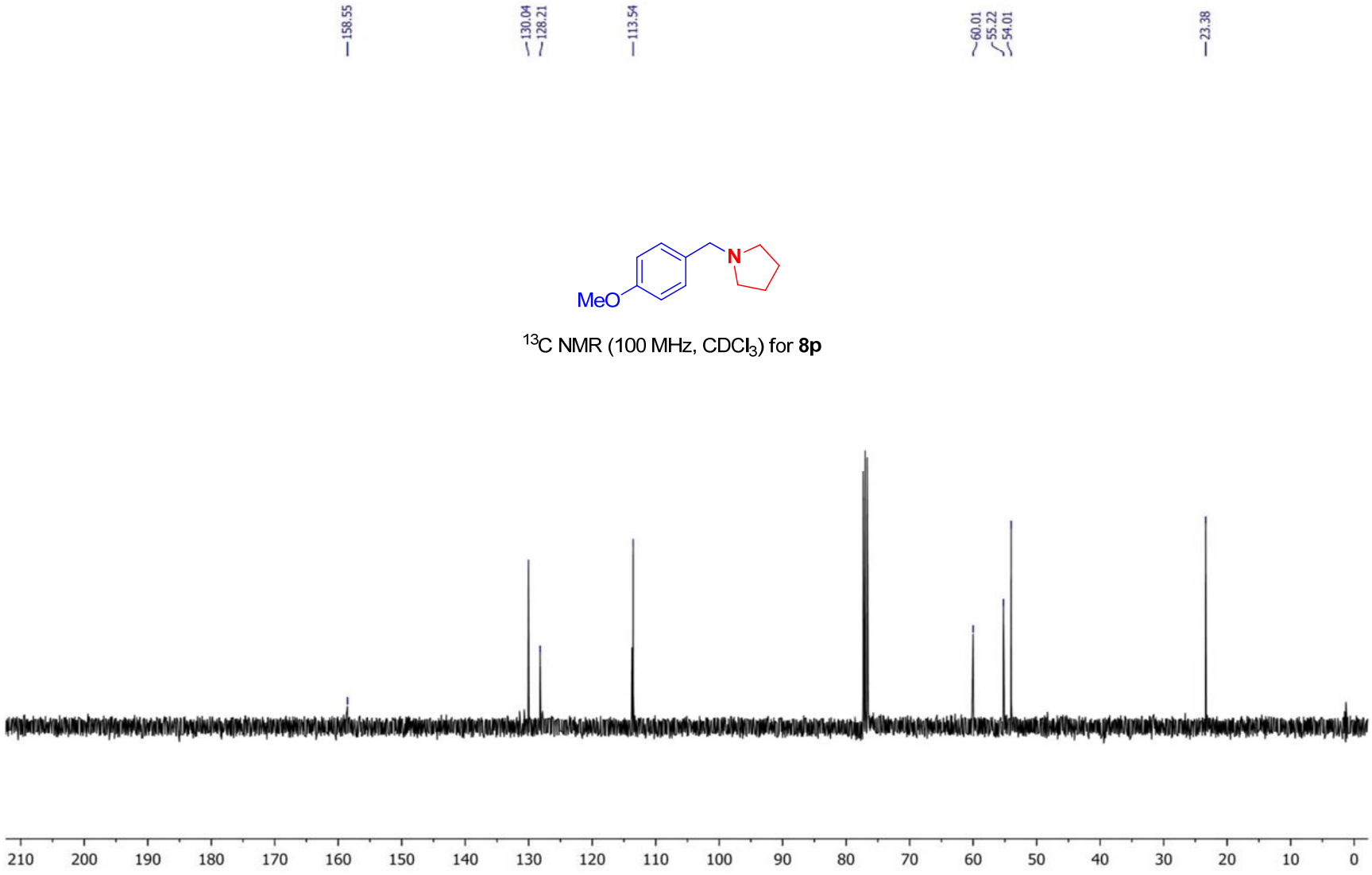
^{1}H NMR (500 MHz, $CDCl_3$) for **8o**



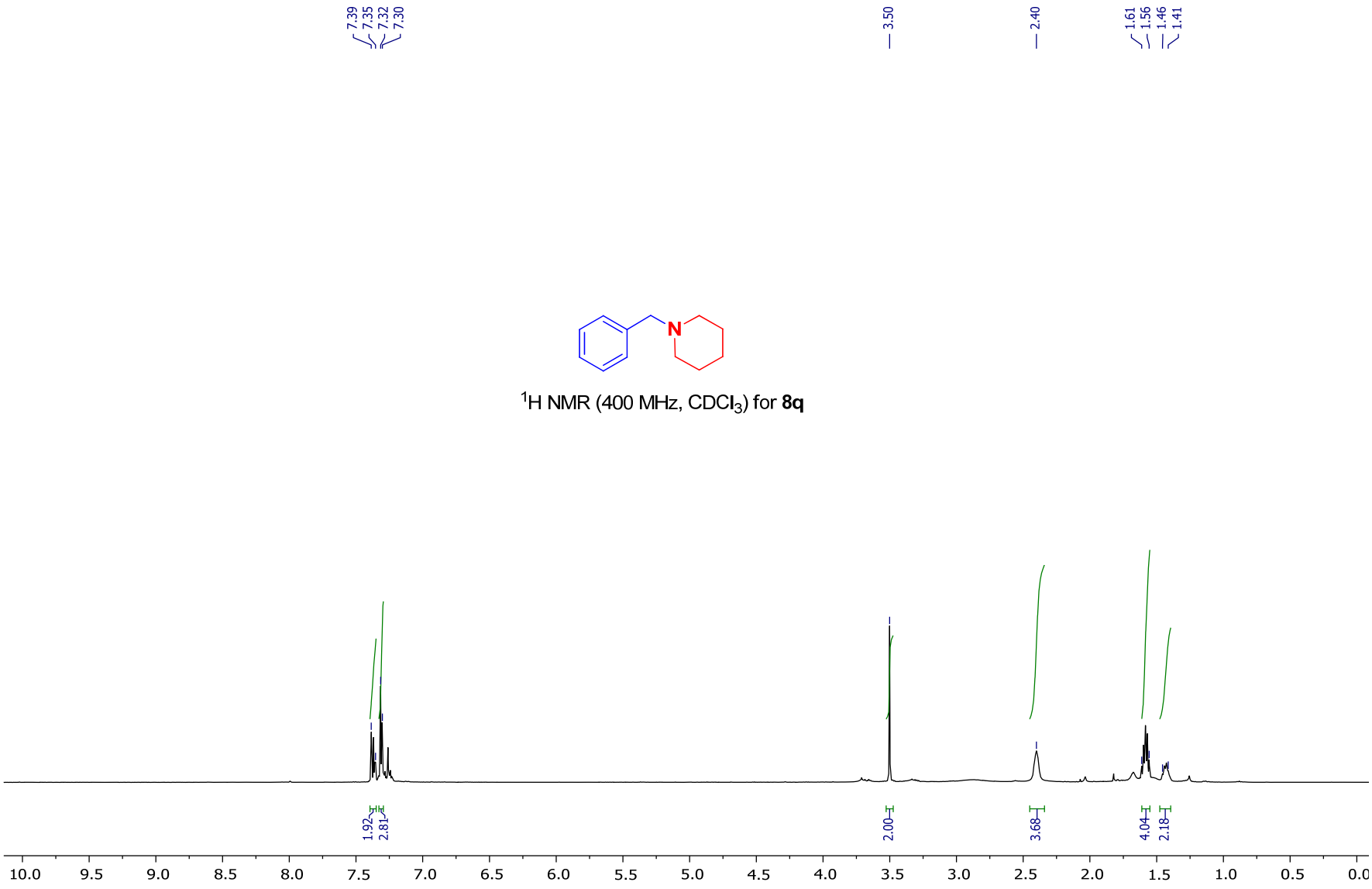
^{13}C NMR (125 MHz, $CDCl_3$) for **8o**



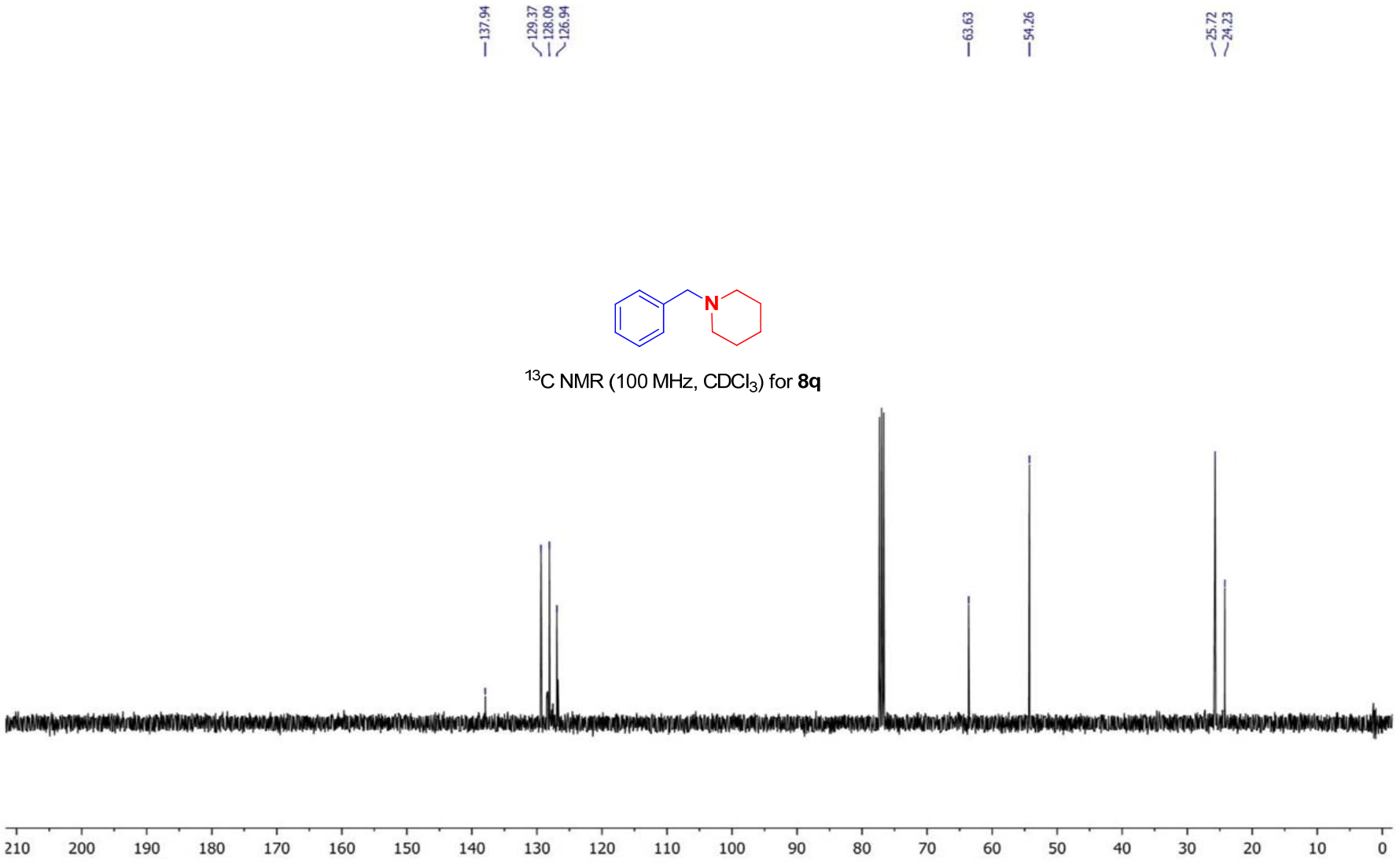
^{1}H NMR (400 MHz, $CDCl_3$) for **8p**



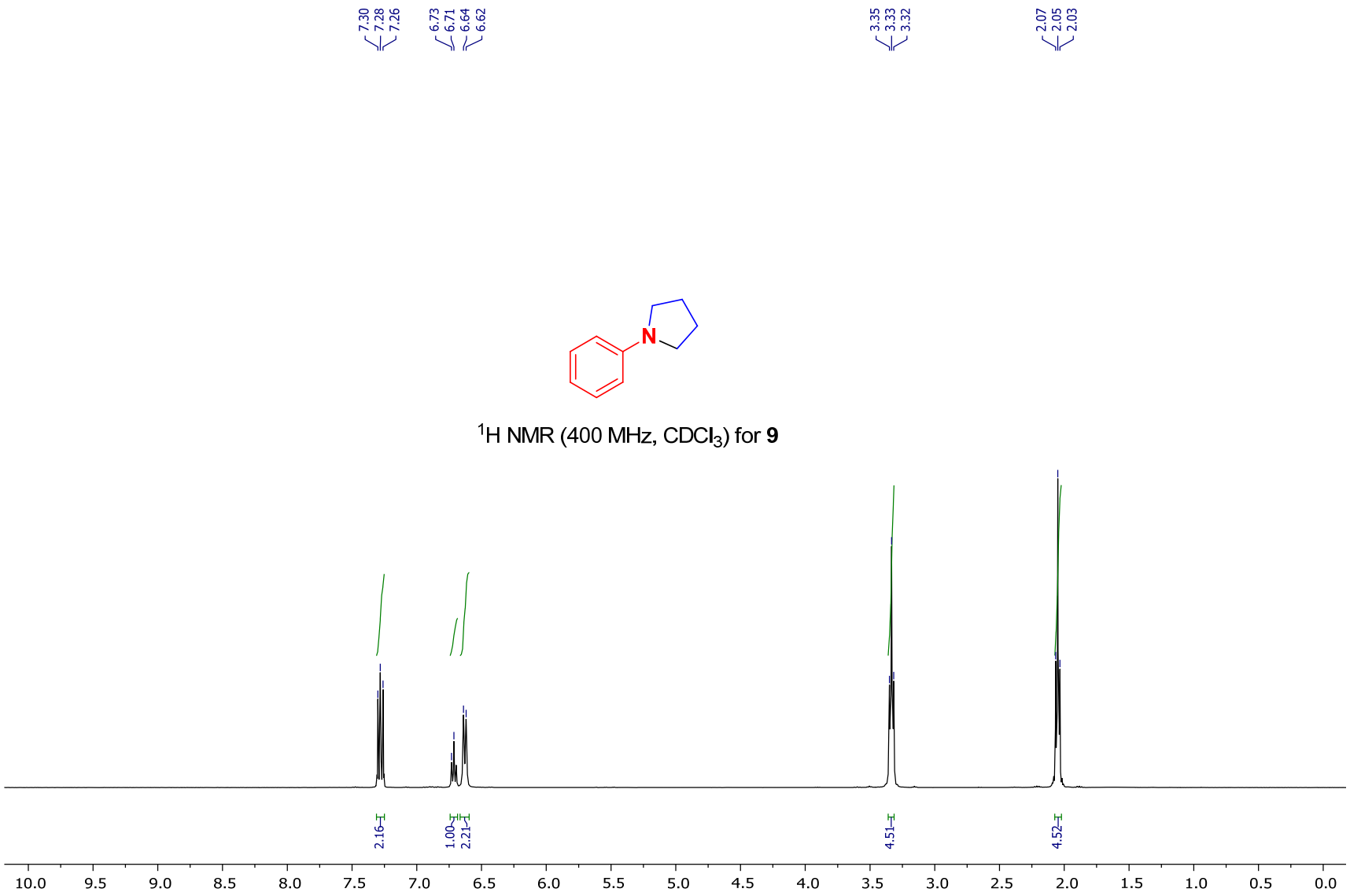
^{13}C NMR (100 MHz, $CDCl_3$) for **8p**



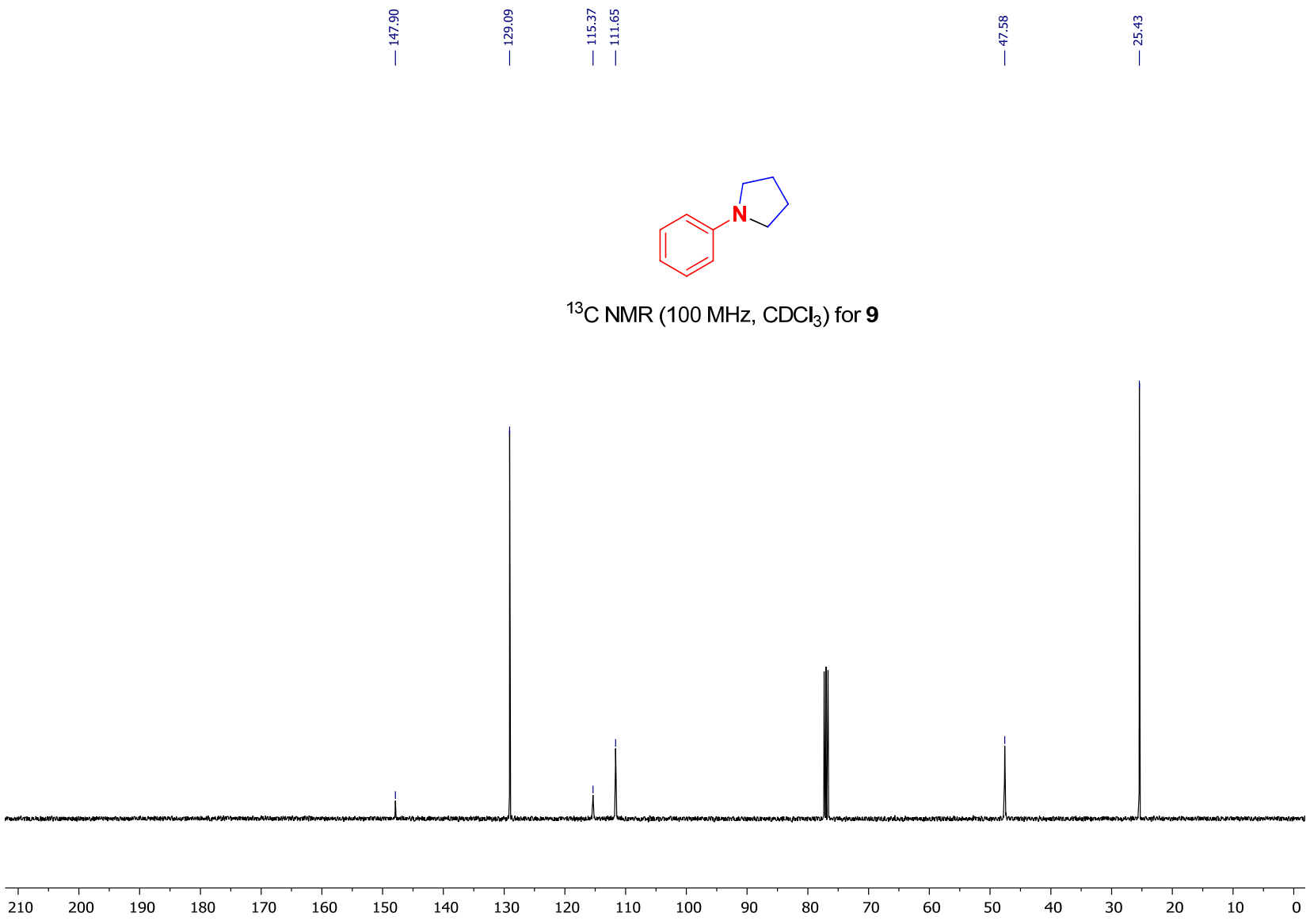
^{1}H NMR (400 MHz, $CDCl_3$) for **8q**



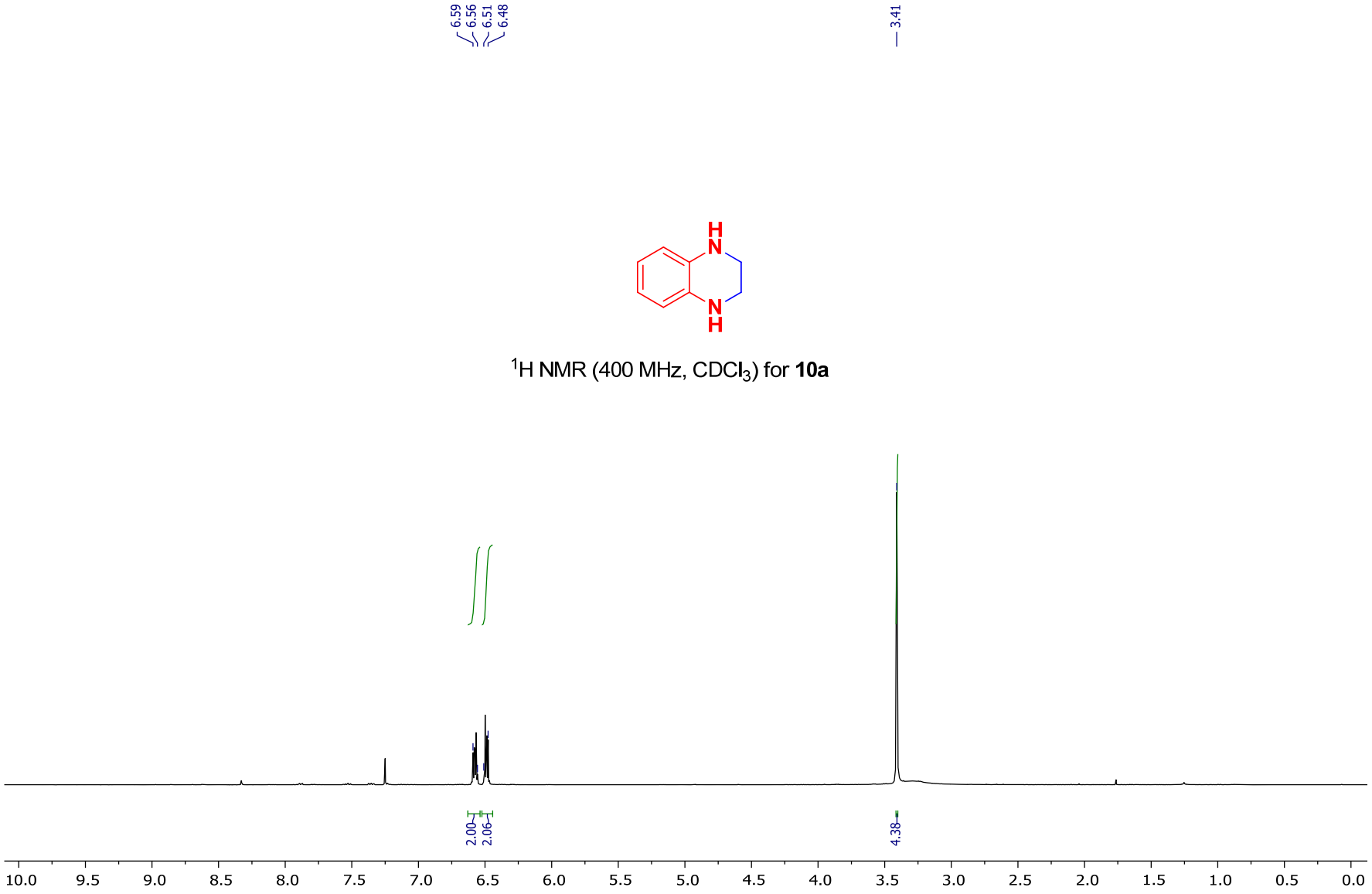
^{13}C NMR (100 MHz, $CDCl_3$) for **8q**



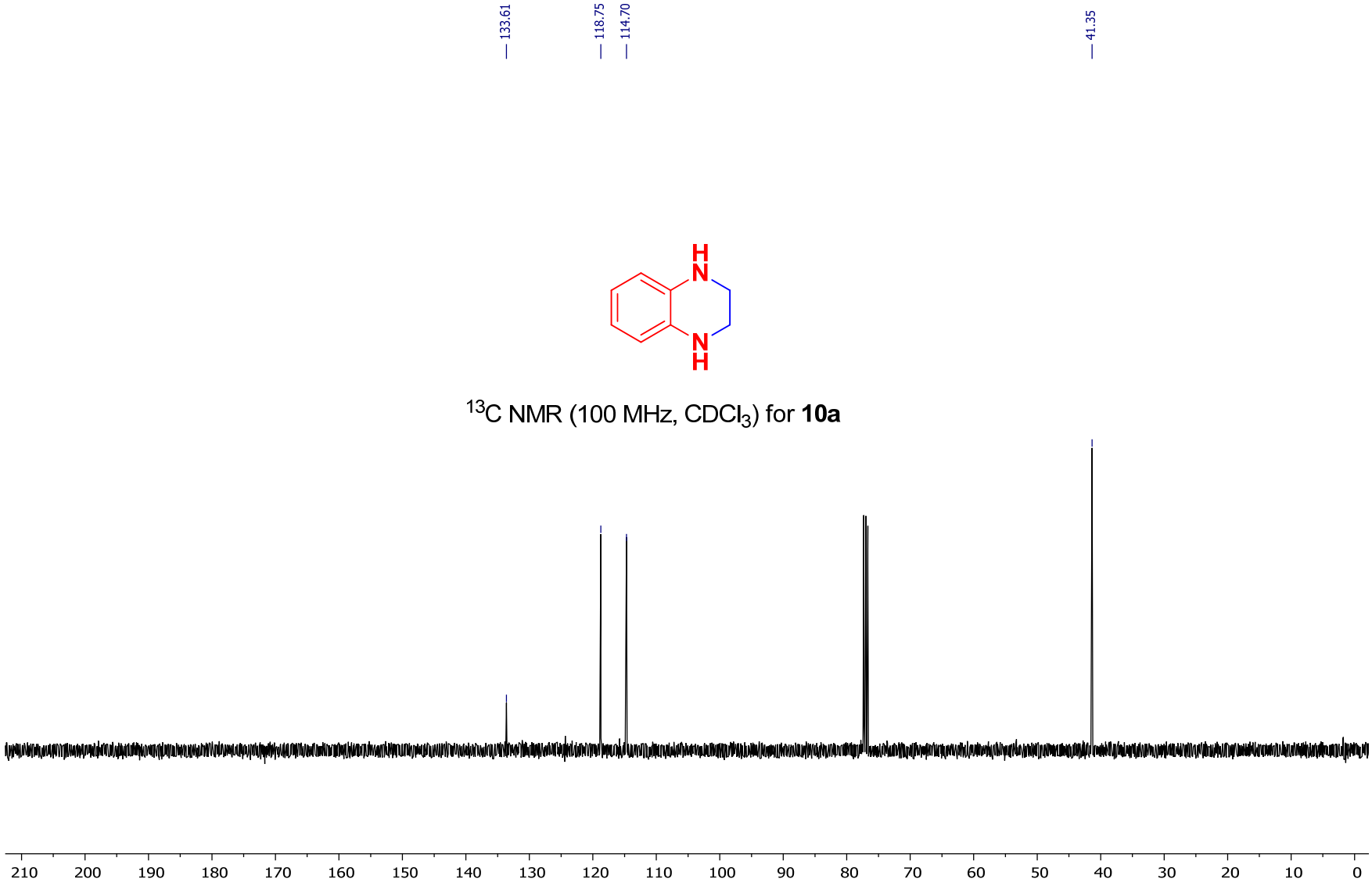
^{1}H NMR (400 MHz, $CDCl_3$) for **9**



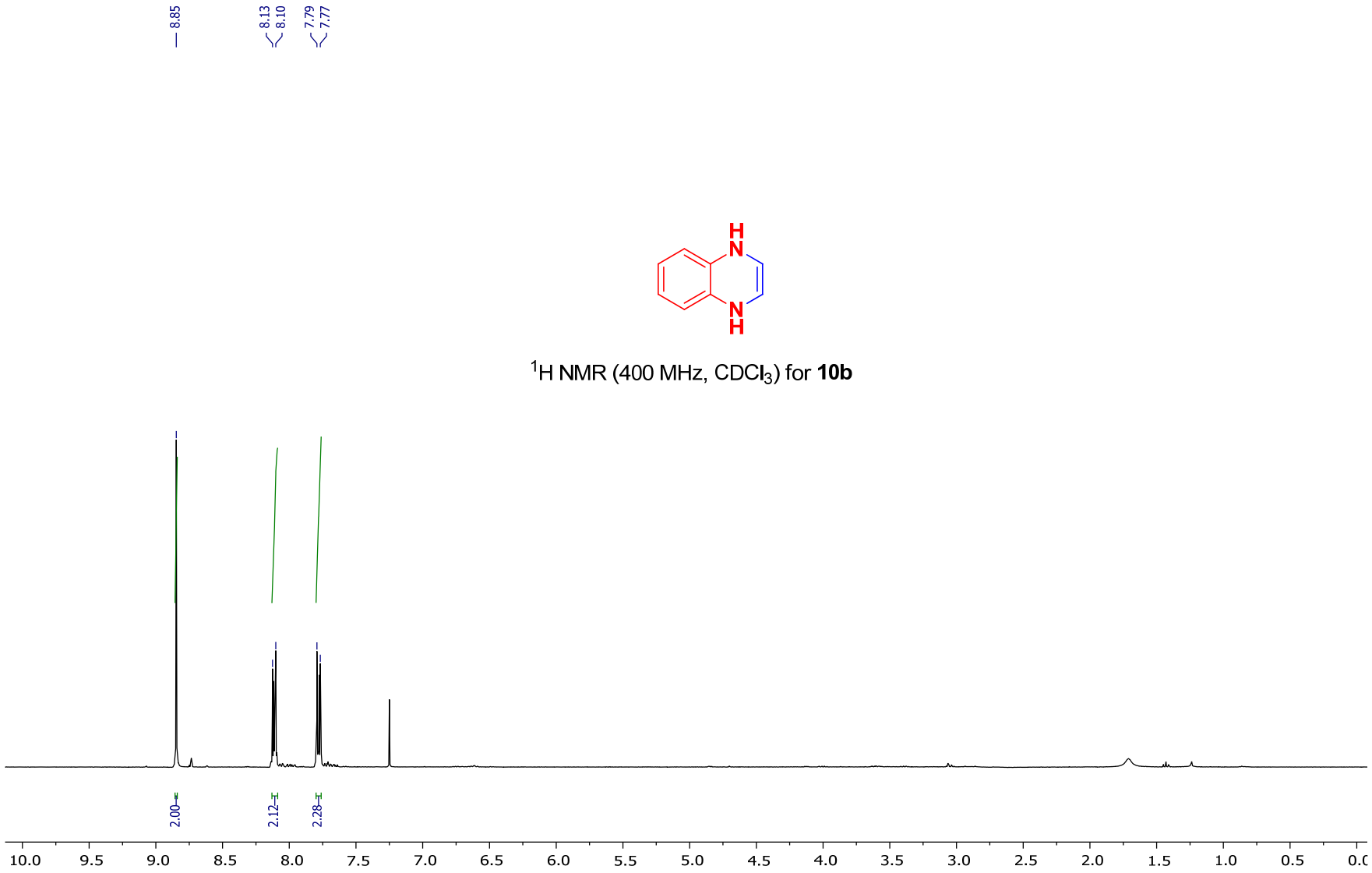
^{13}C NMR (100 MHz, $CDCl_3$) for **9**



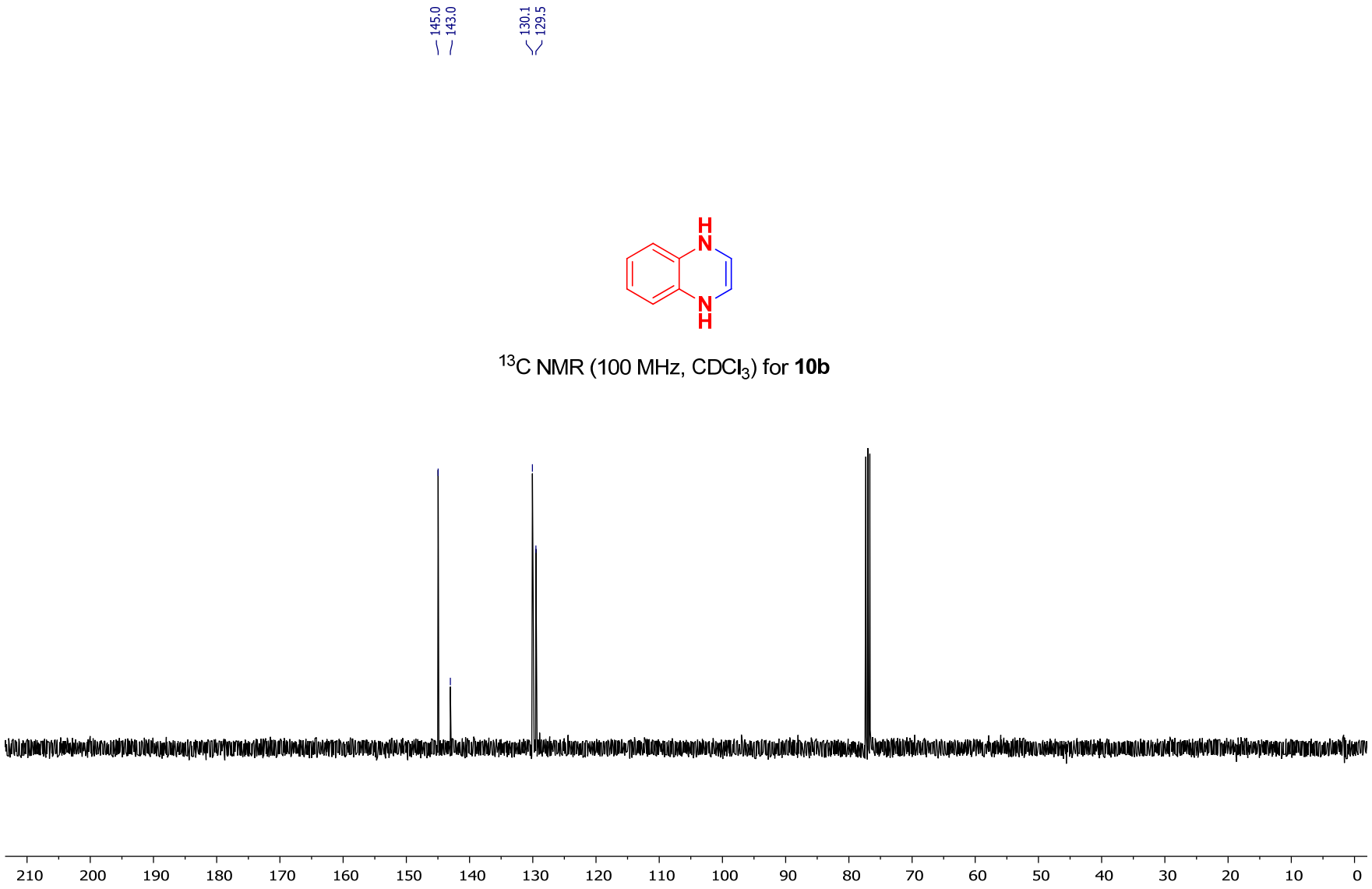
^{1}H NMR (400 MHz, $CDCl_3$) for **10a**



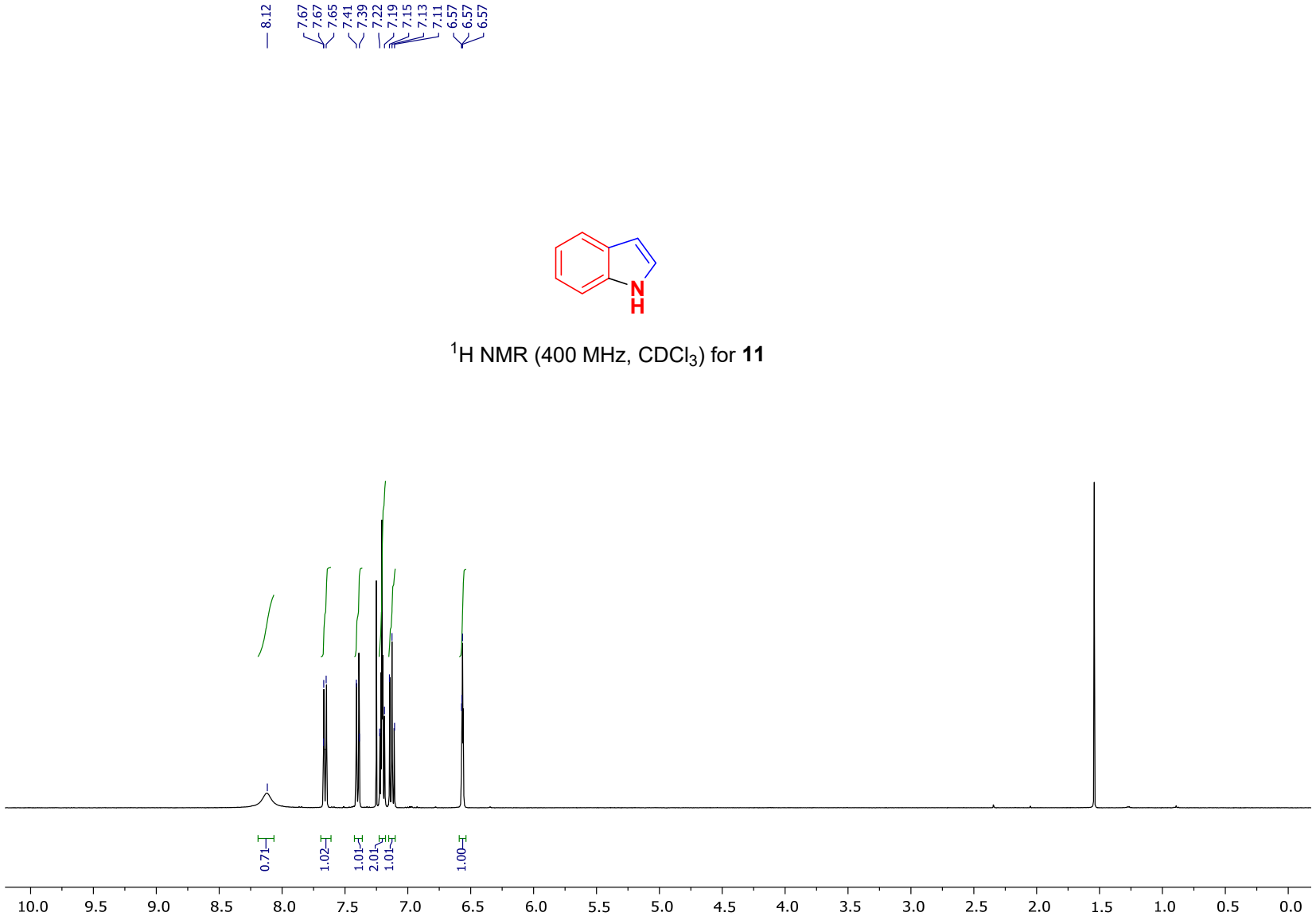
^{13}C NMR (100 MHz, $CDCl_3$) for **10a**



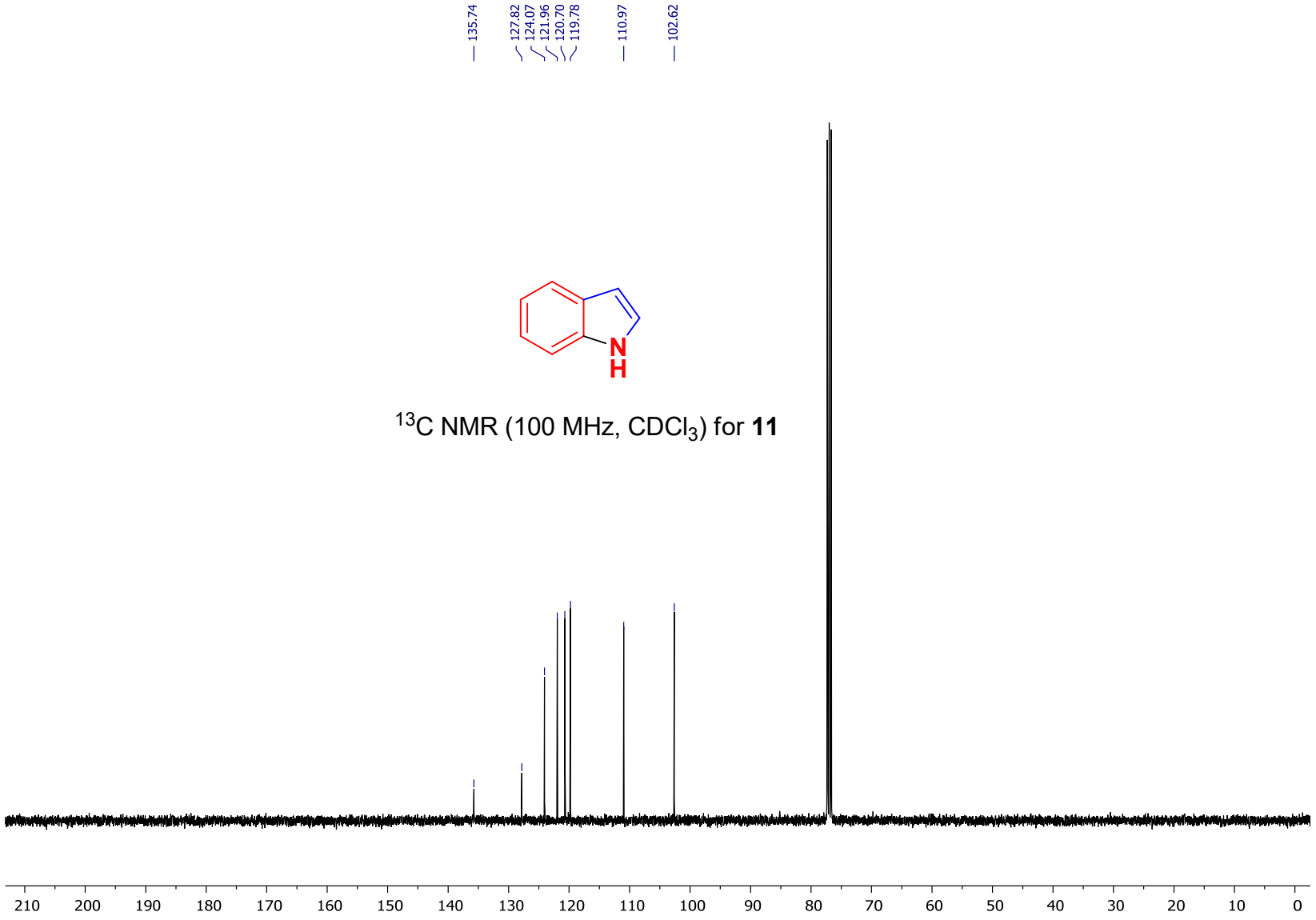
^{1}H NMR (400 MHz, $CDCl_3$) for **10b**



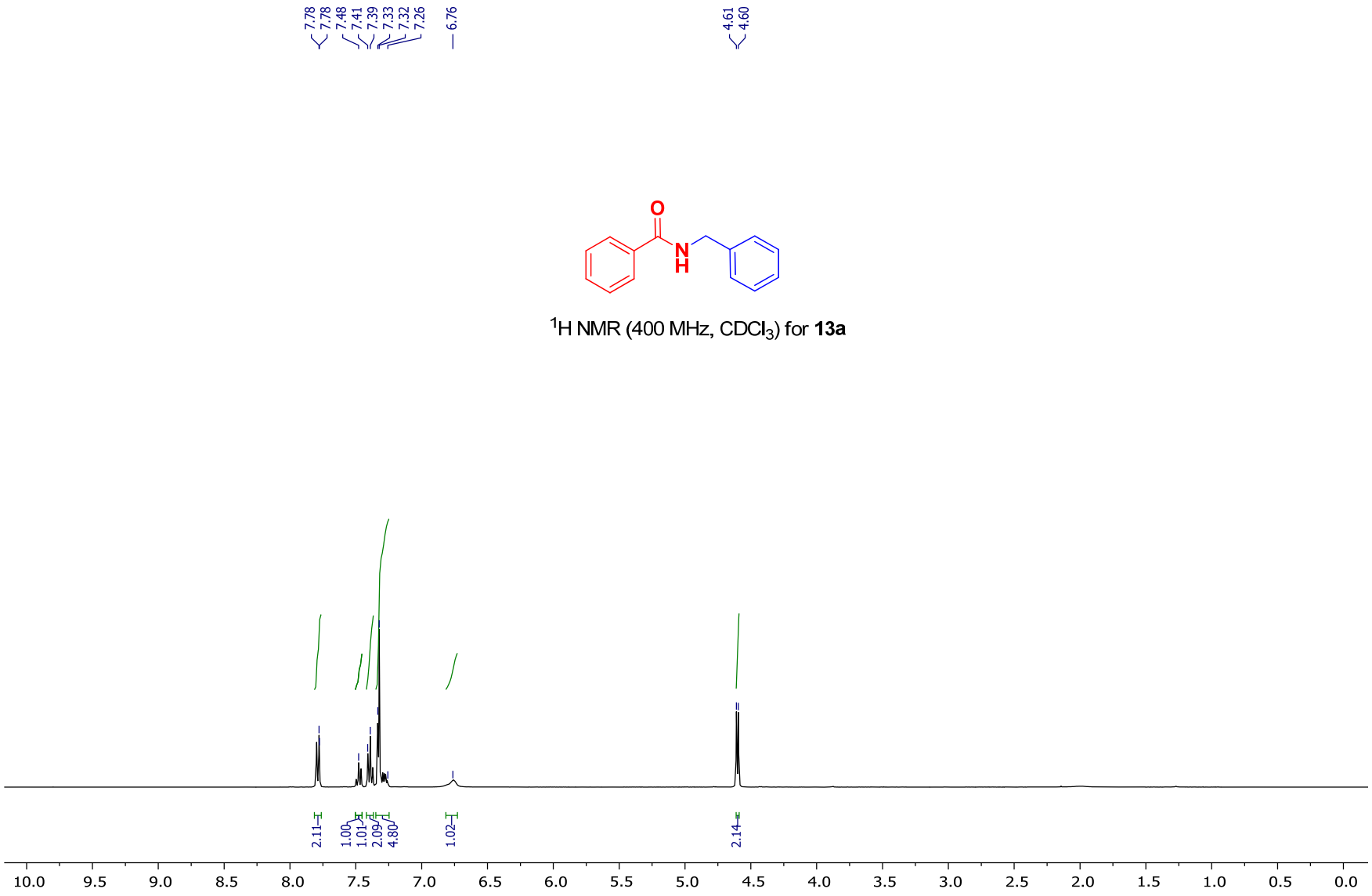
^{13}C NMR (100 MHz, $CDCl_3$) for **10b**



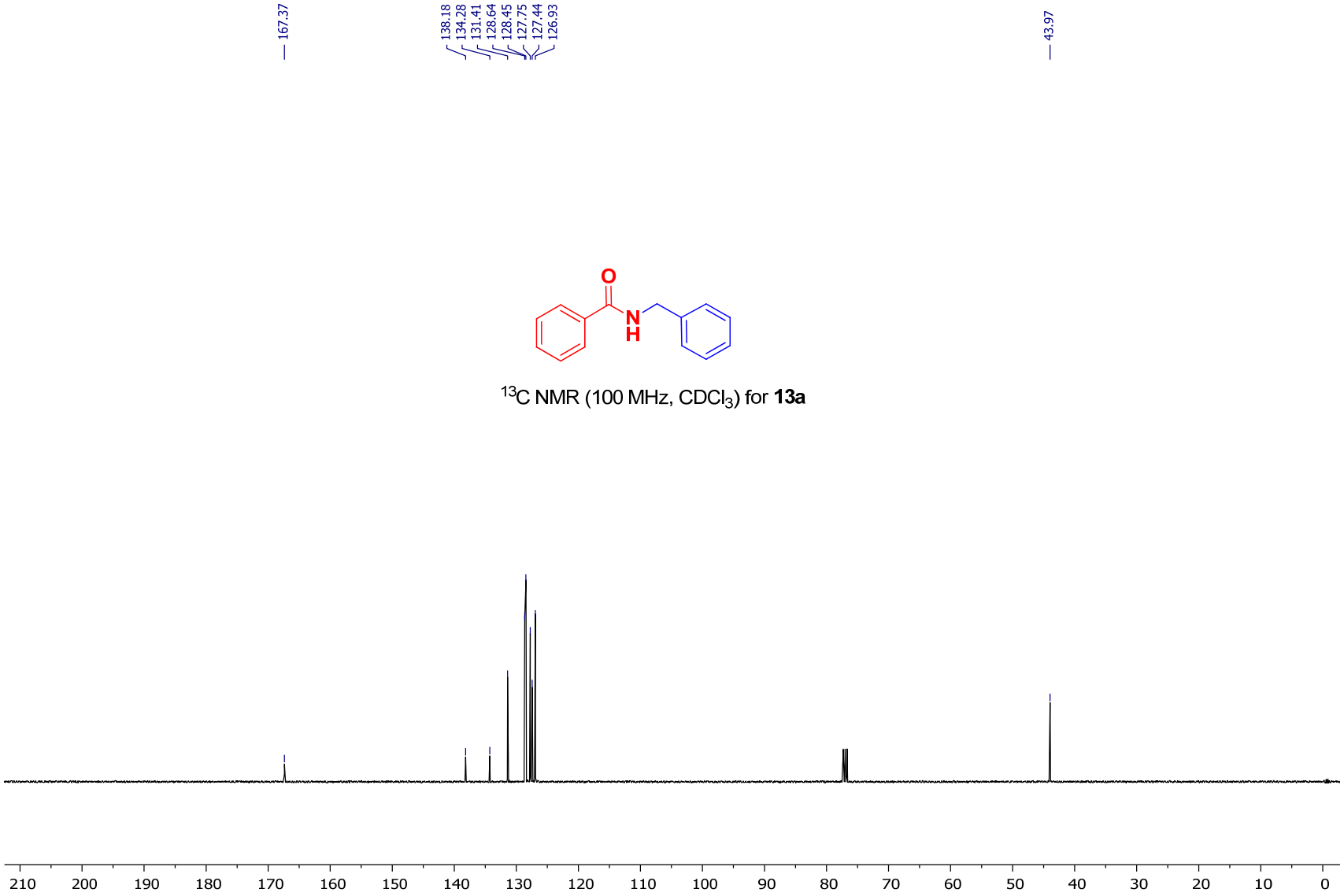
^{1}H NMR (400 MHz, $CDCl_3$) for **11**



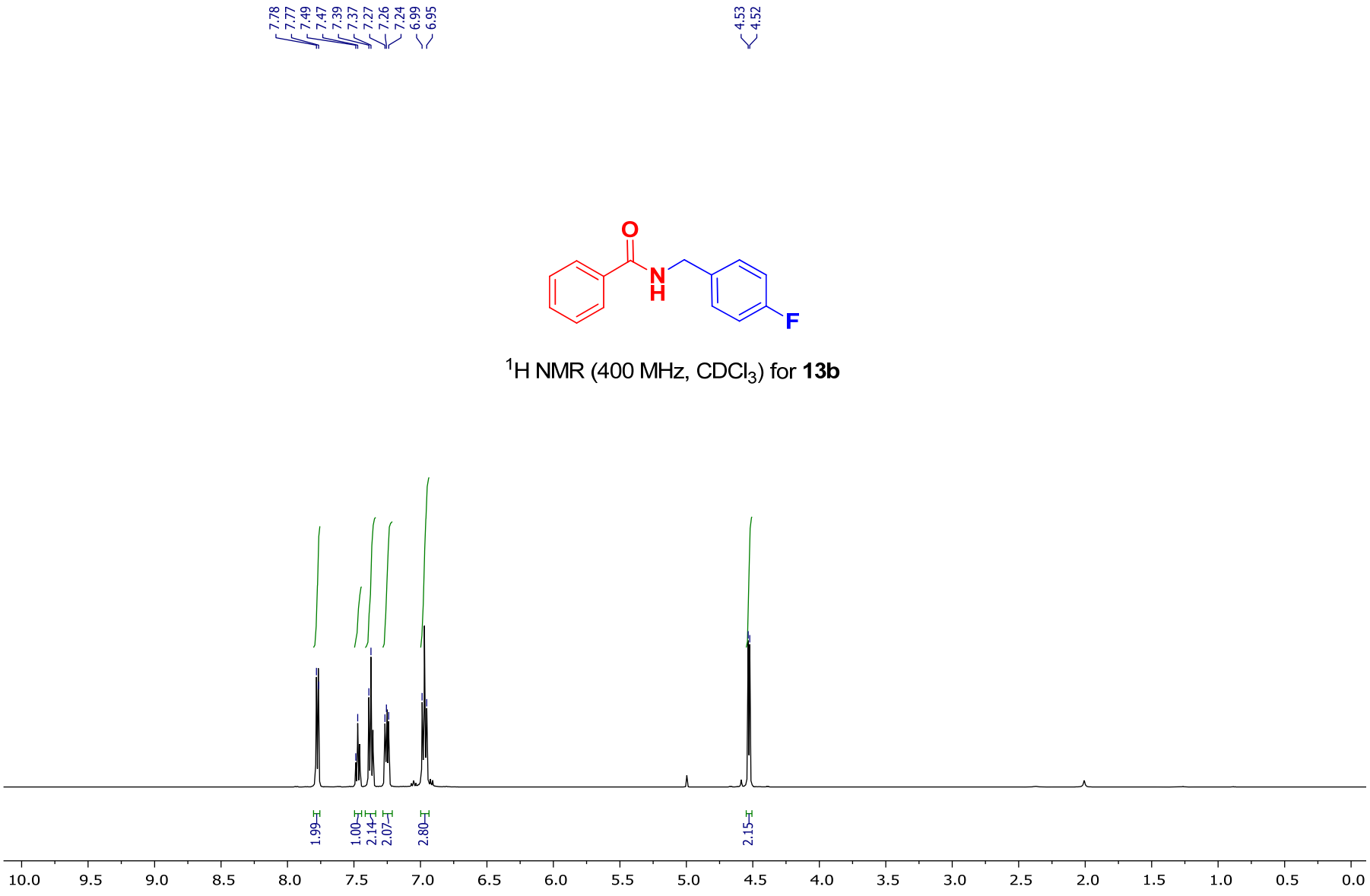
^{13}C NMR (100 MHz, $CDCl_3$) for **11**



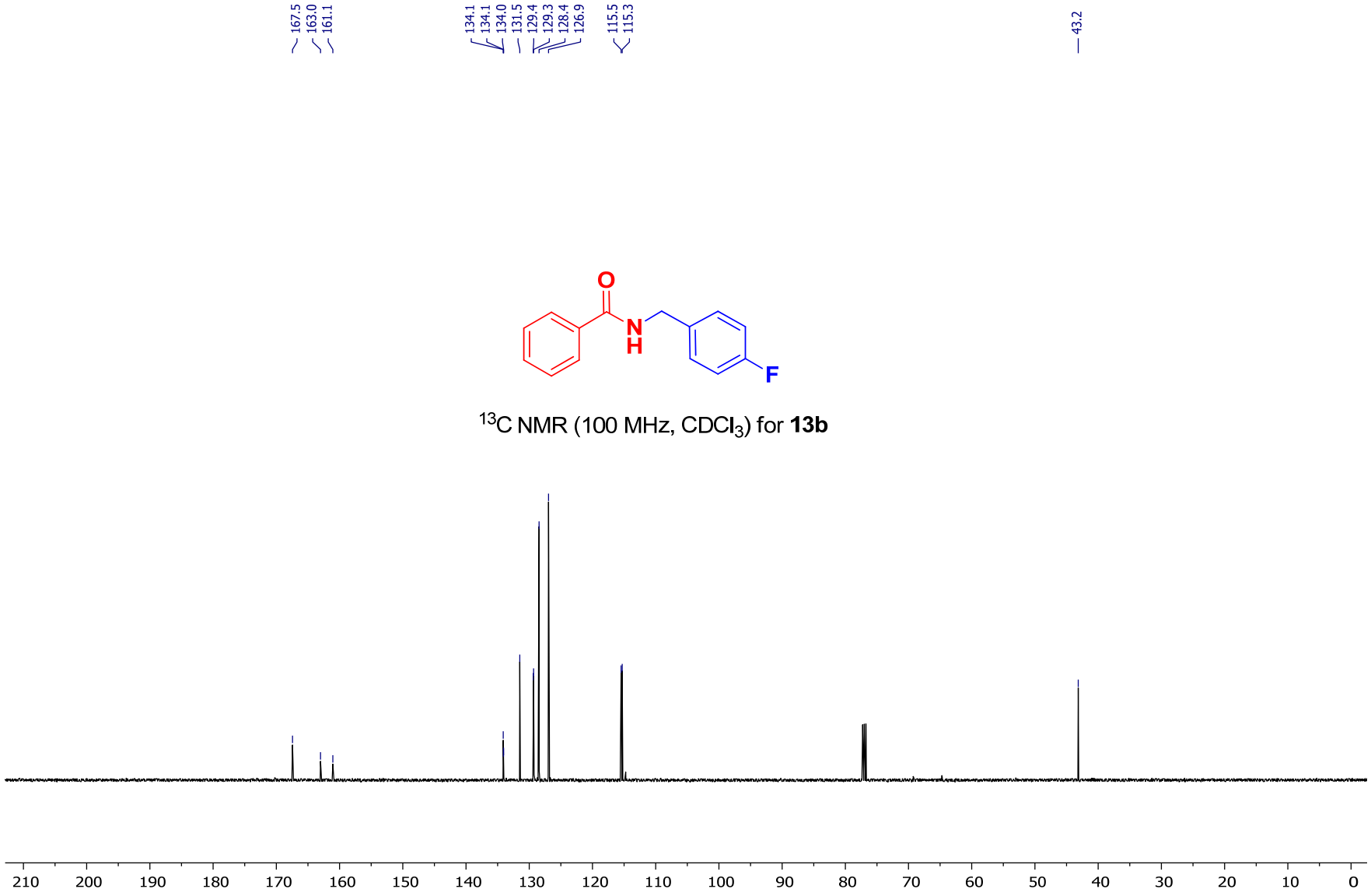
^{1}H NMR (400 MHz, $CDCl_3$) for **13a**



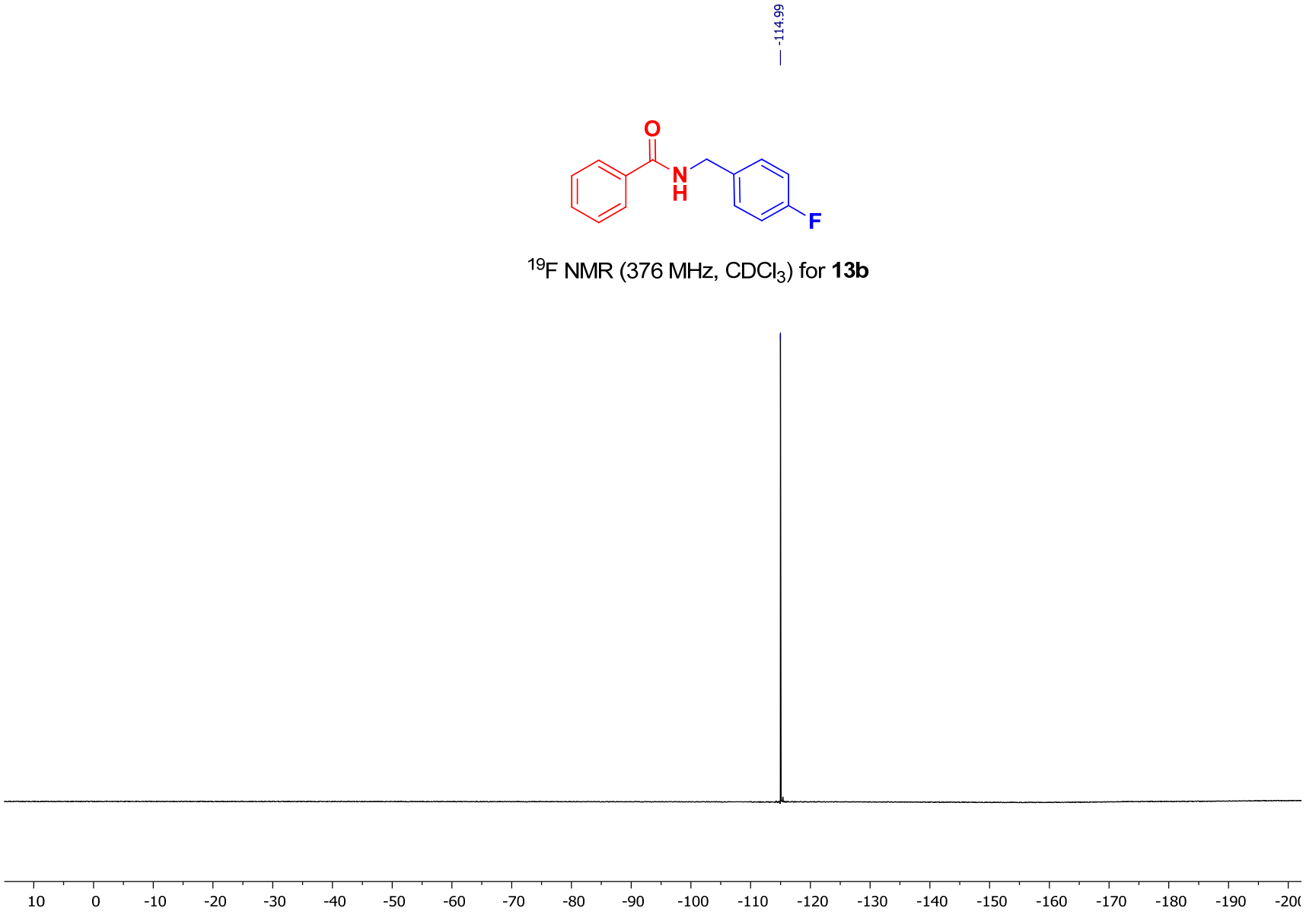
^{13}C NMR (100 MHz, $CDCl_3$) for **13a**



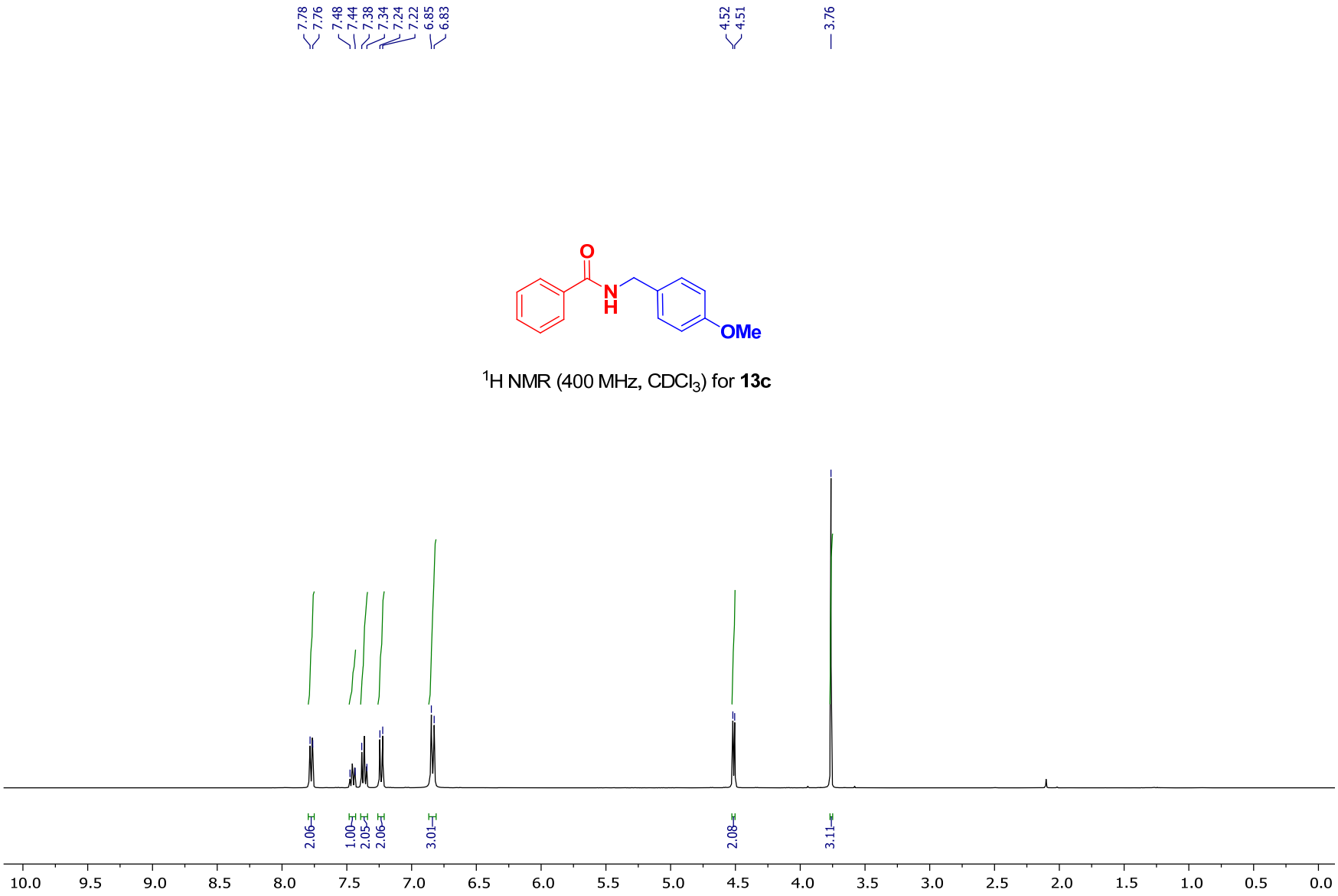
^{1}H NMR (400 MHz, $CDCl_3$) for **13b**



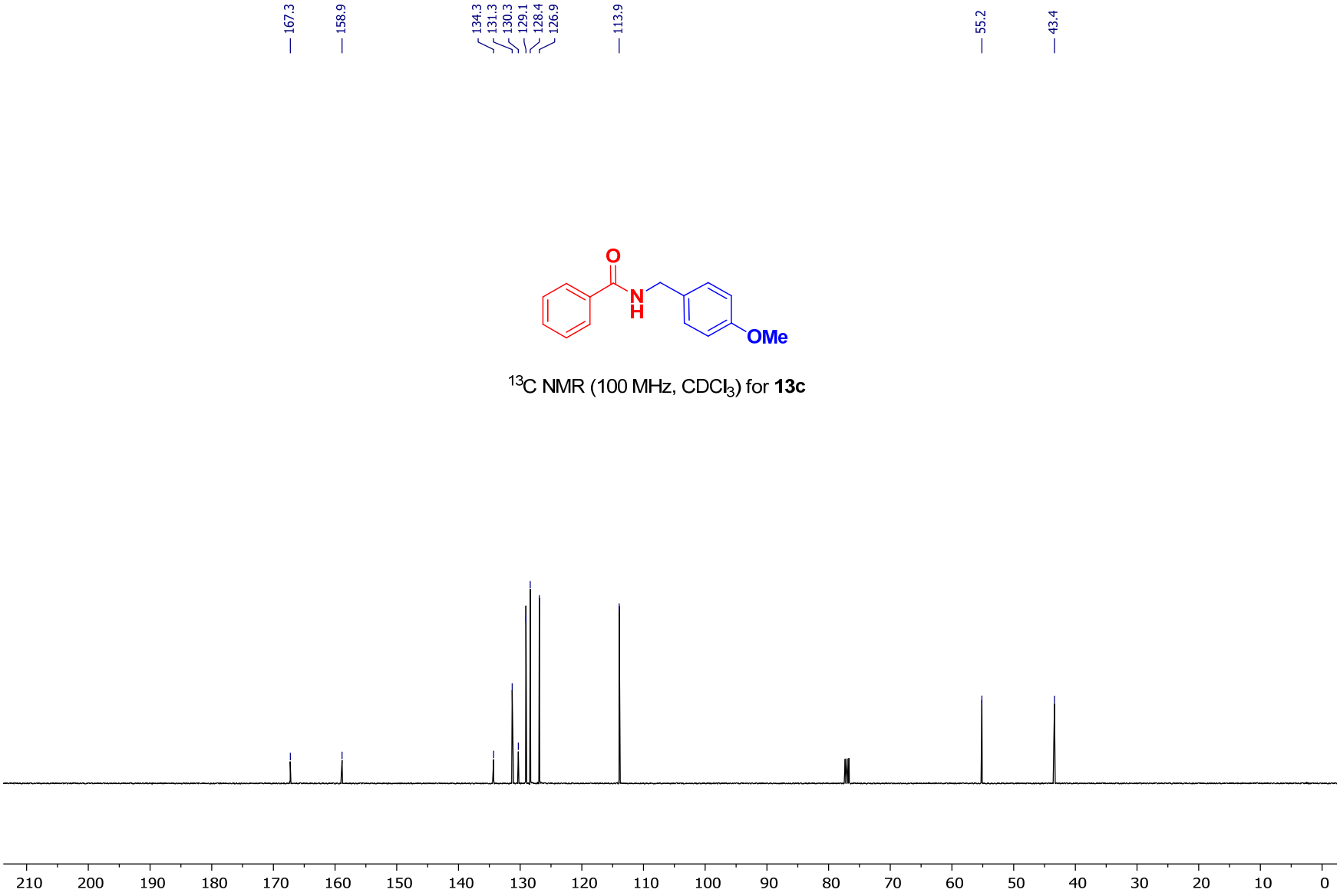
^{13}C NMR (100 MHz, $CDCl_3$) for **13b**



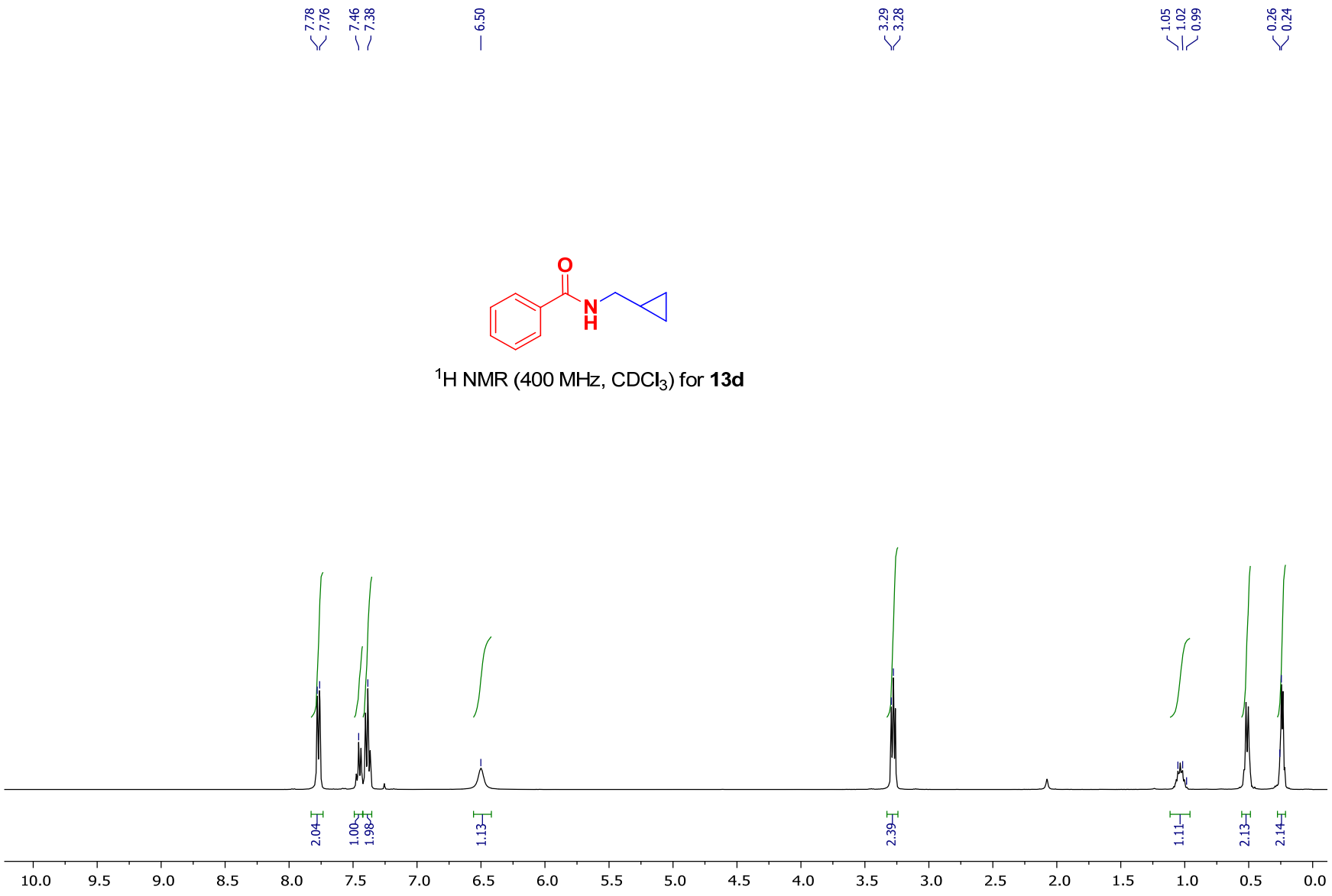
^{19}F NMR (376 MHz, $CDCl_3$) for **13b**



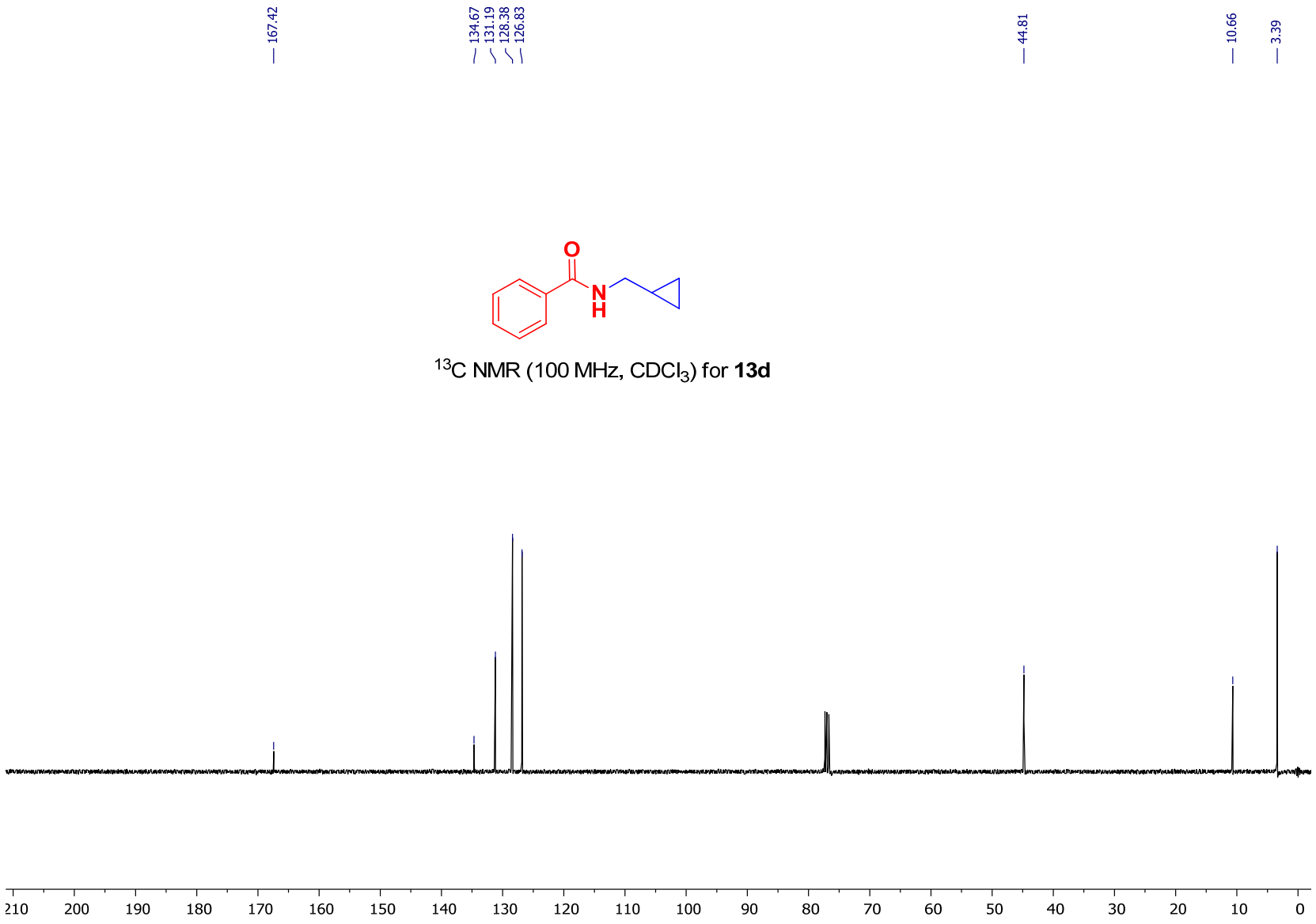
^{1}H NMR (400 MHz, $CDCl_3$) for **13c**



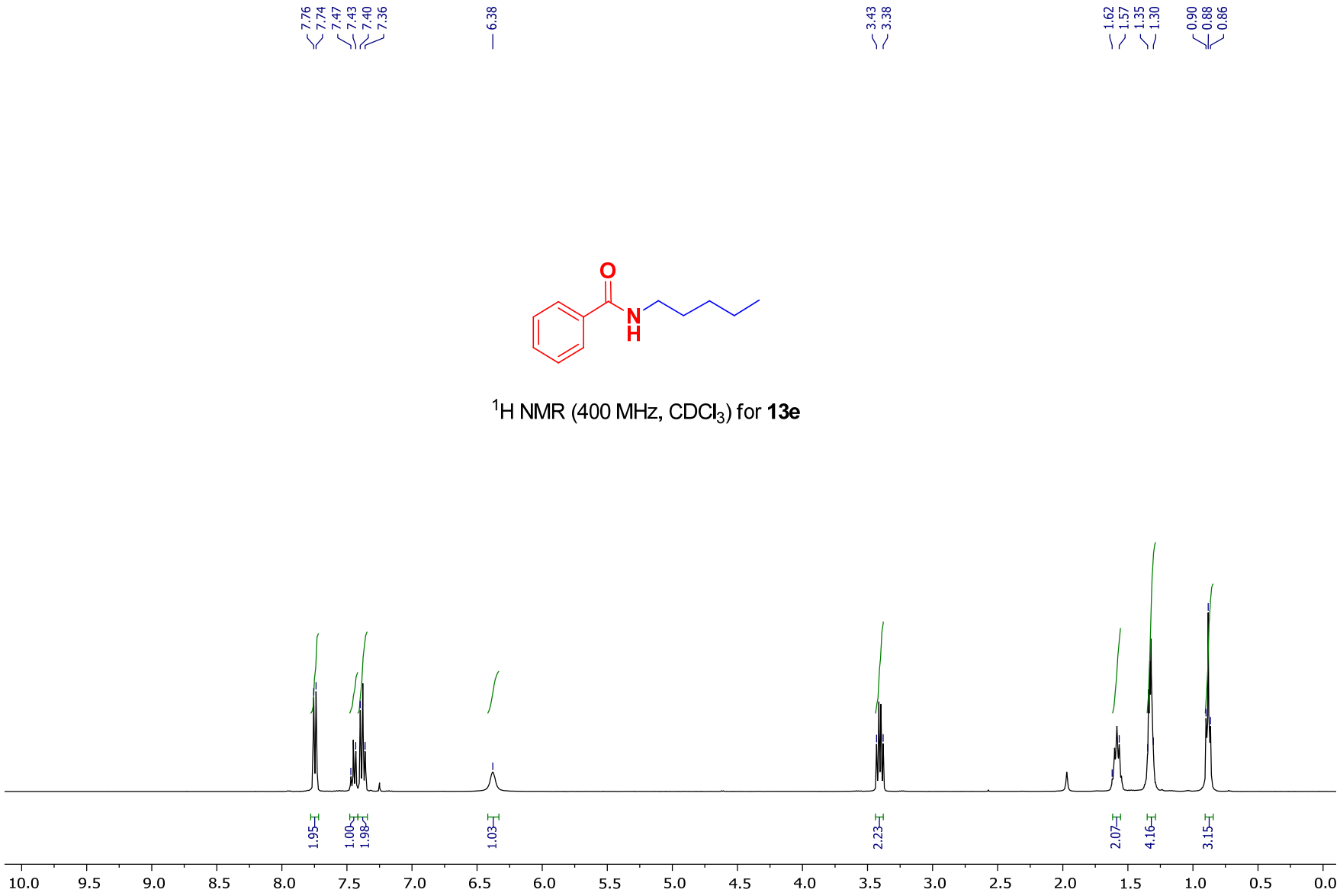
^{13}C NMR (100 MHz, $CDCl_3$) for **13c**



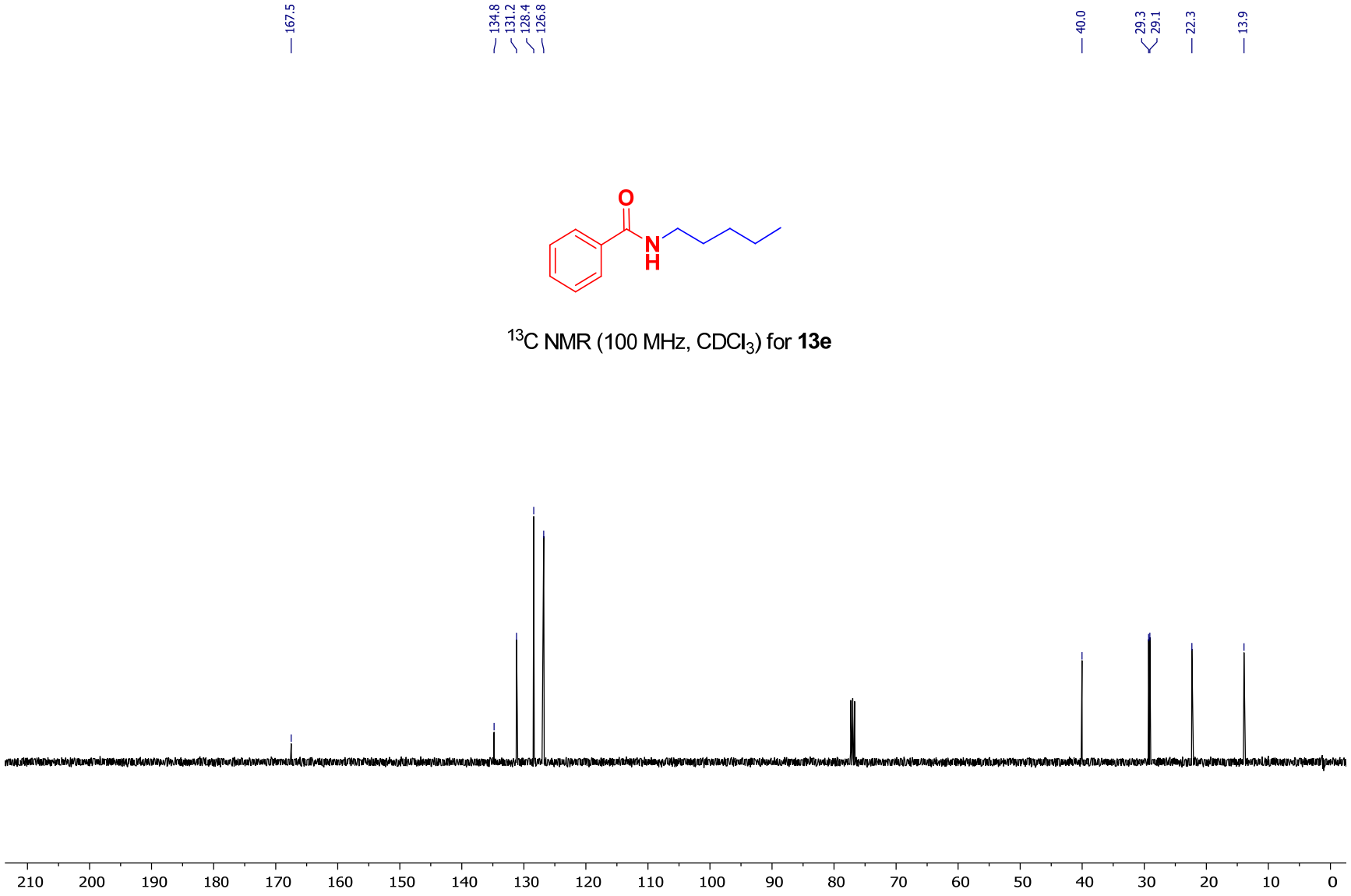
^{1}H NMR (400 MHz, $CDCl_3$) for **13d**



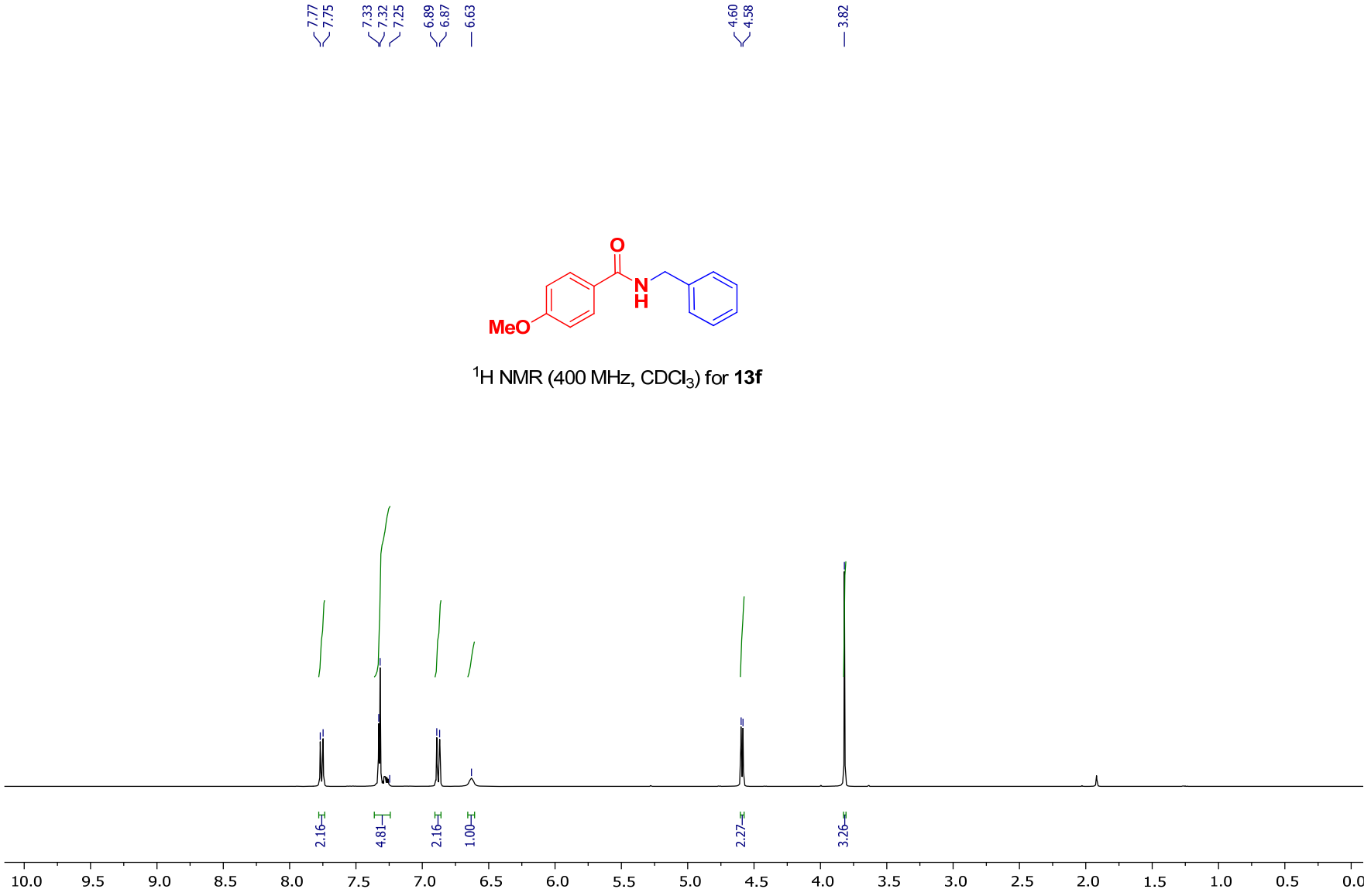
^{13}C NMR (100 MHz, $CDCl_3$) for **13d**



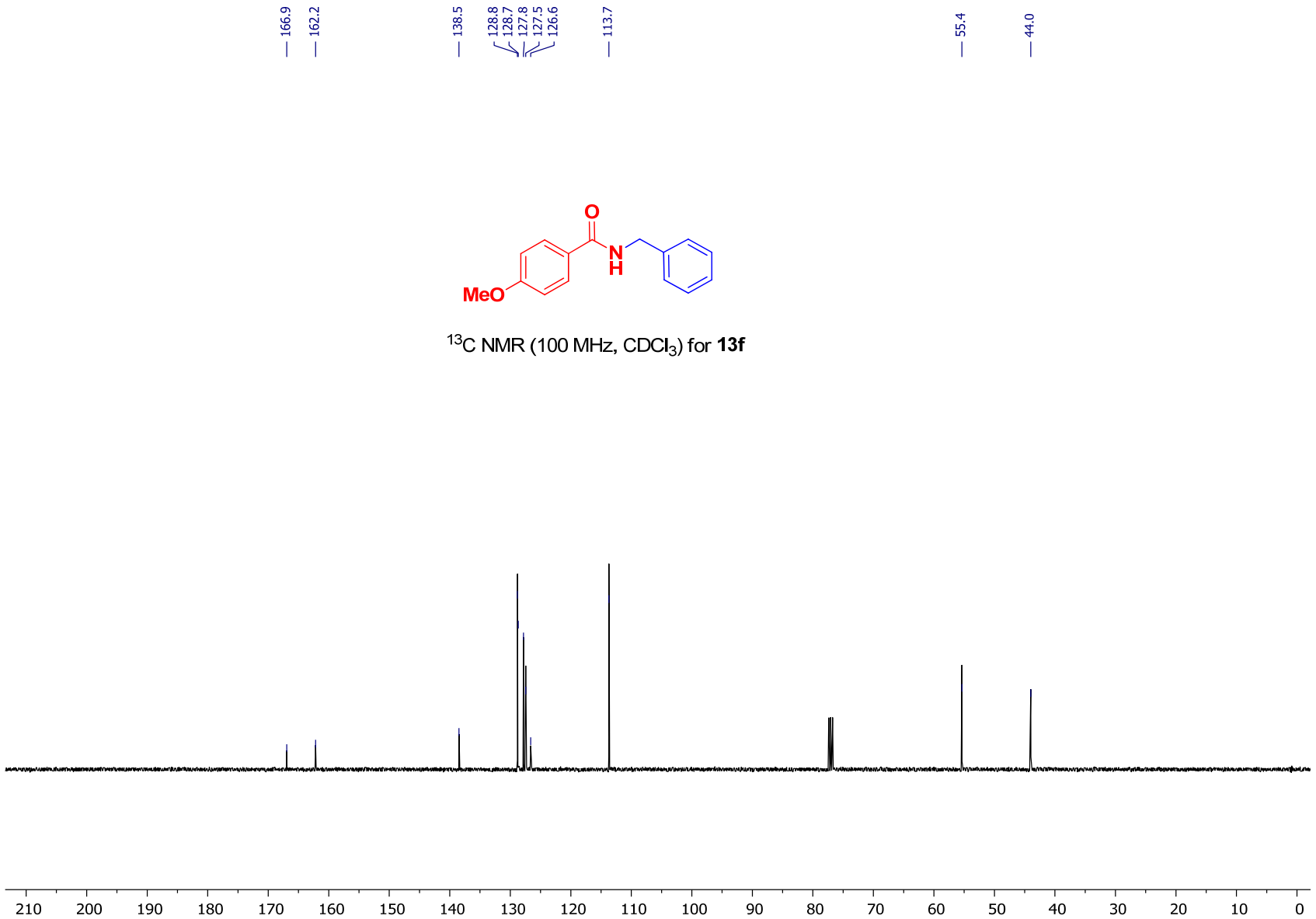
^{1}H NMR (400 MHz, $CDCl_3$) for **13e**



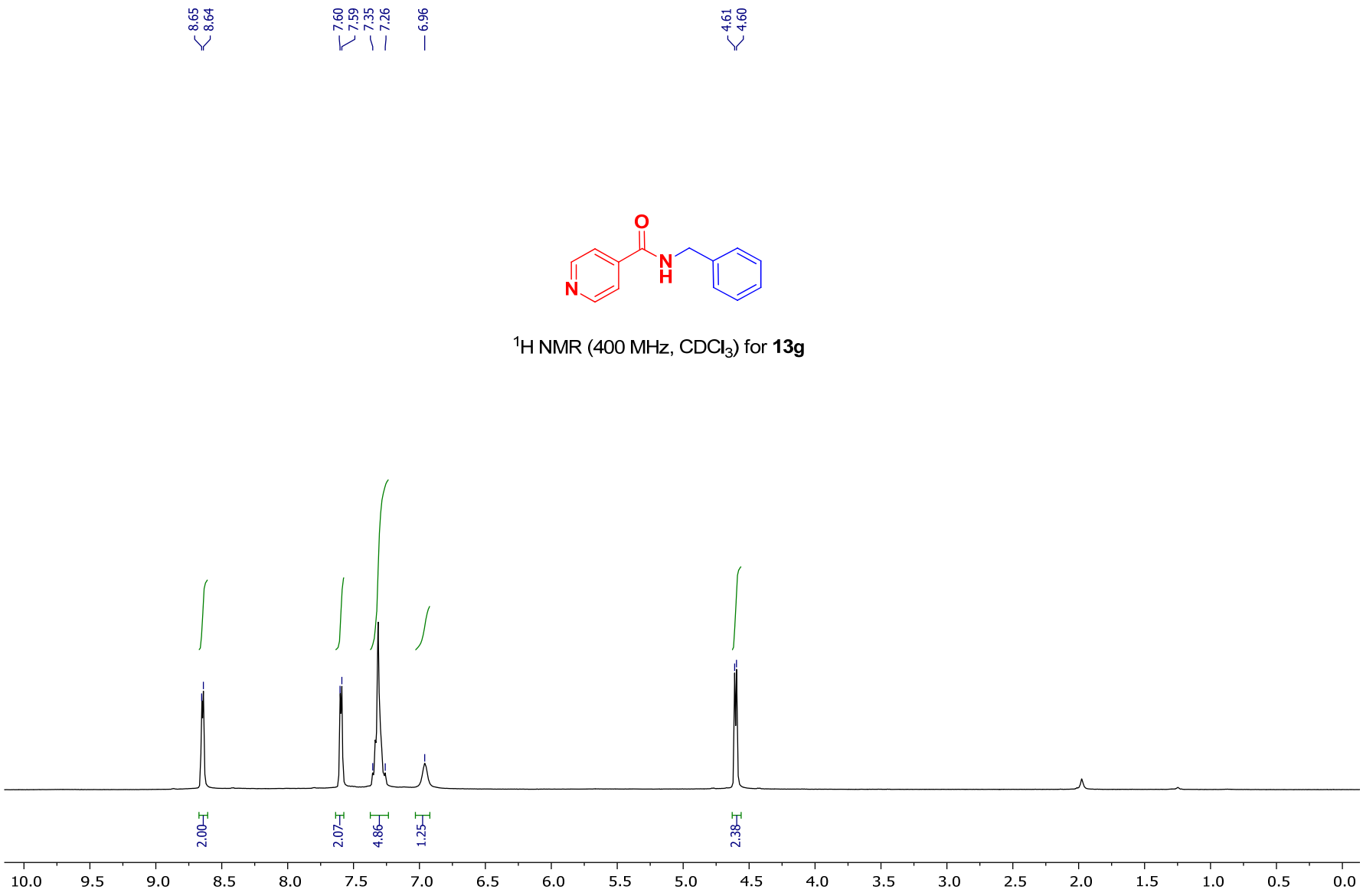
^{13}C NMR (100 MHz, $CDCl_3$) for **13e**



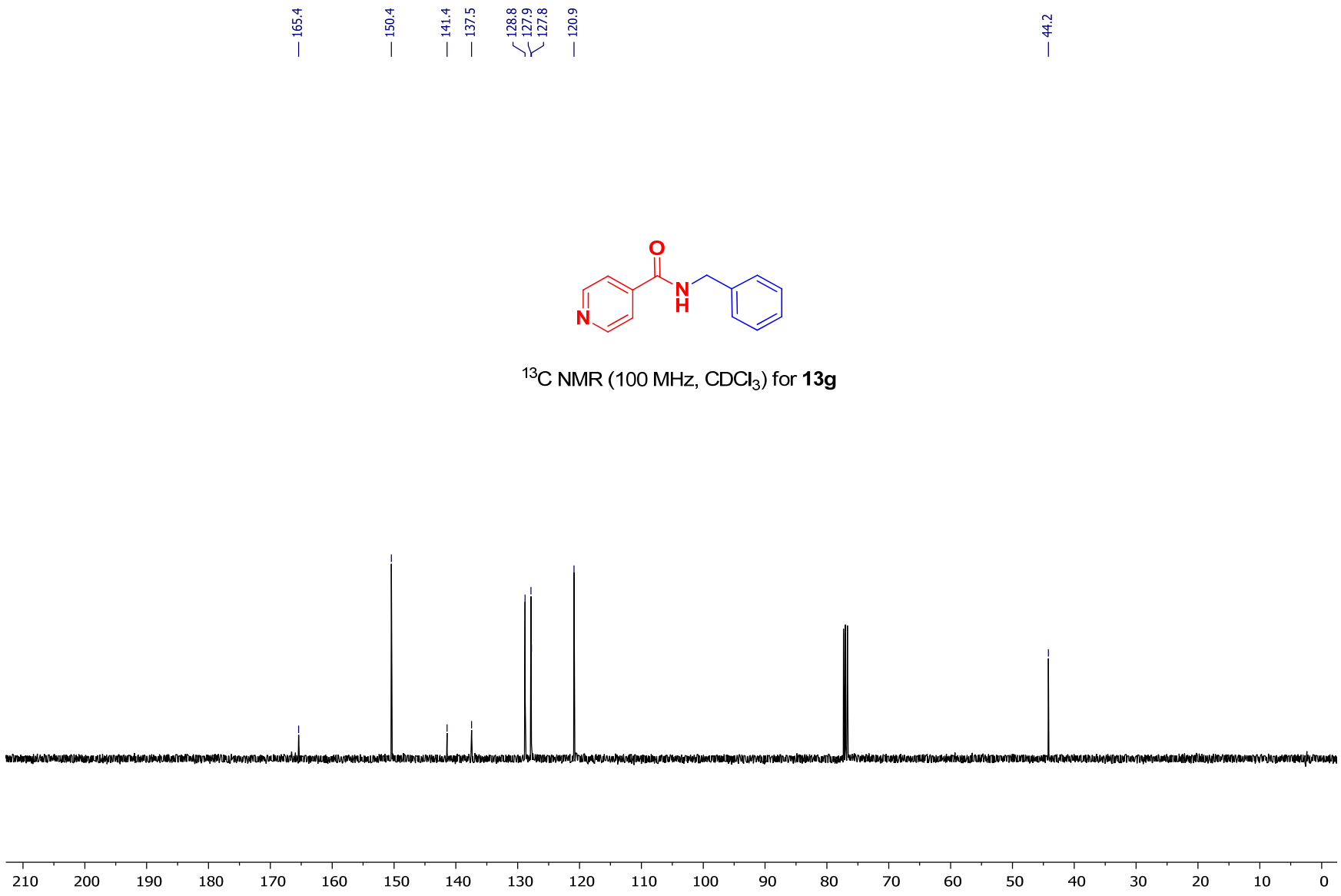
^{1}H NMR (400 MHz, $CDCl_3$) for **13f**



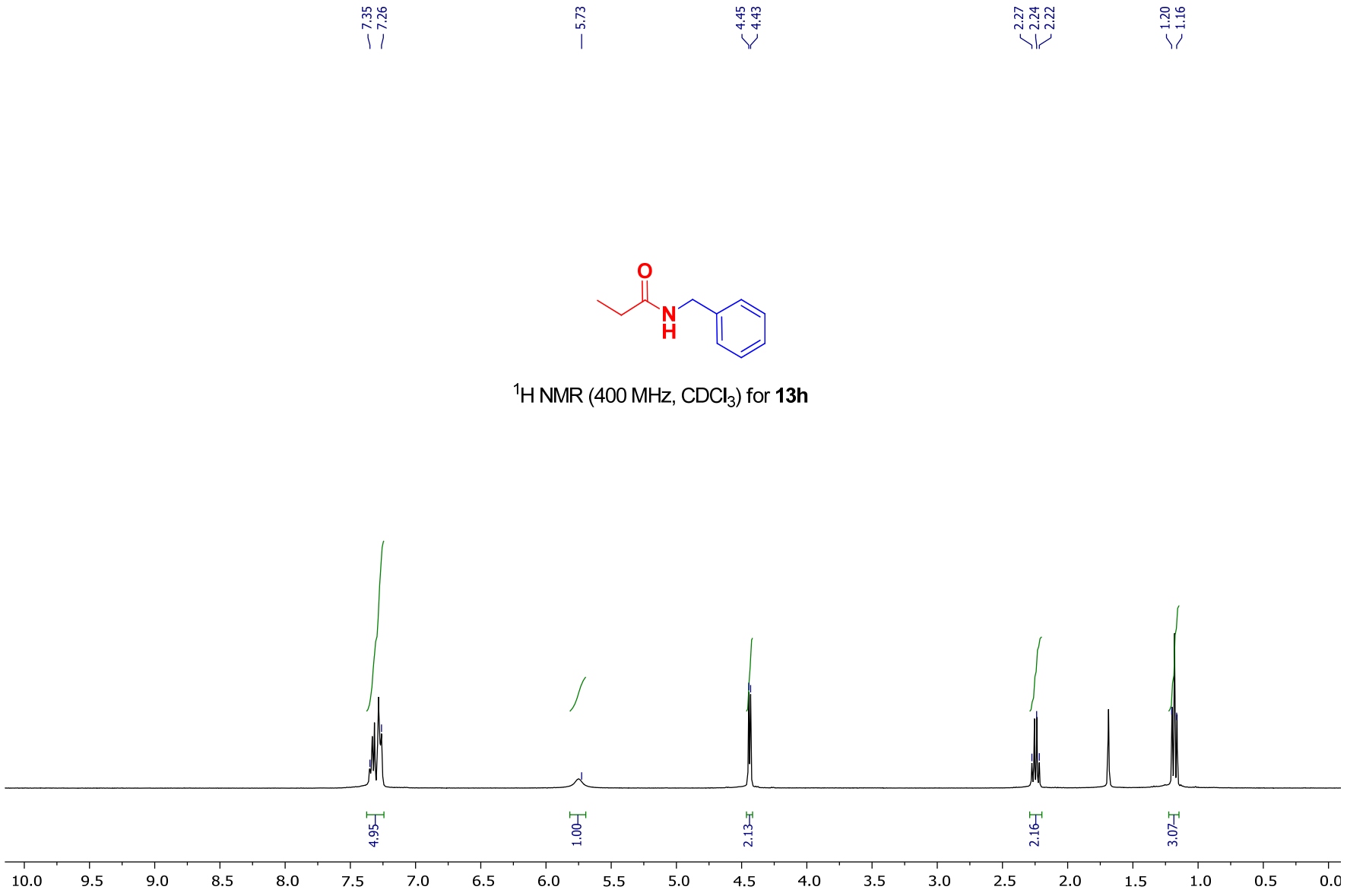
^{13}C NMR (100 MHz, $CDCl_3$) for **13f**



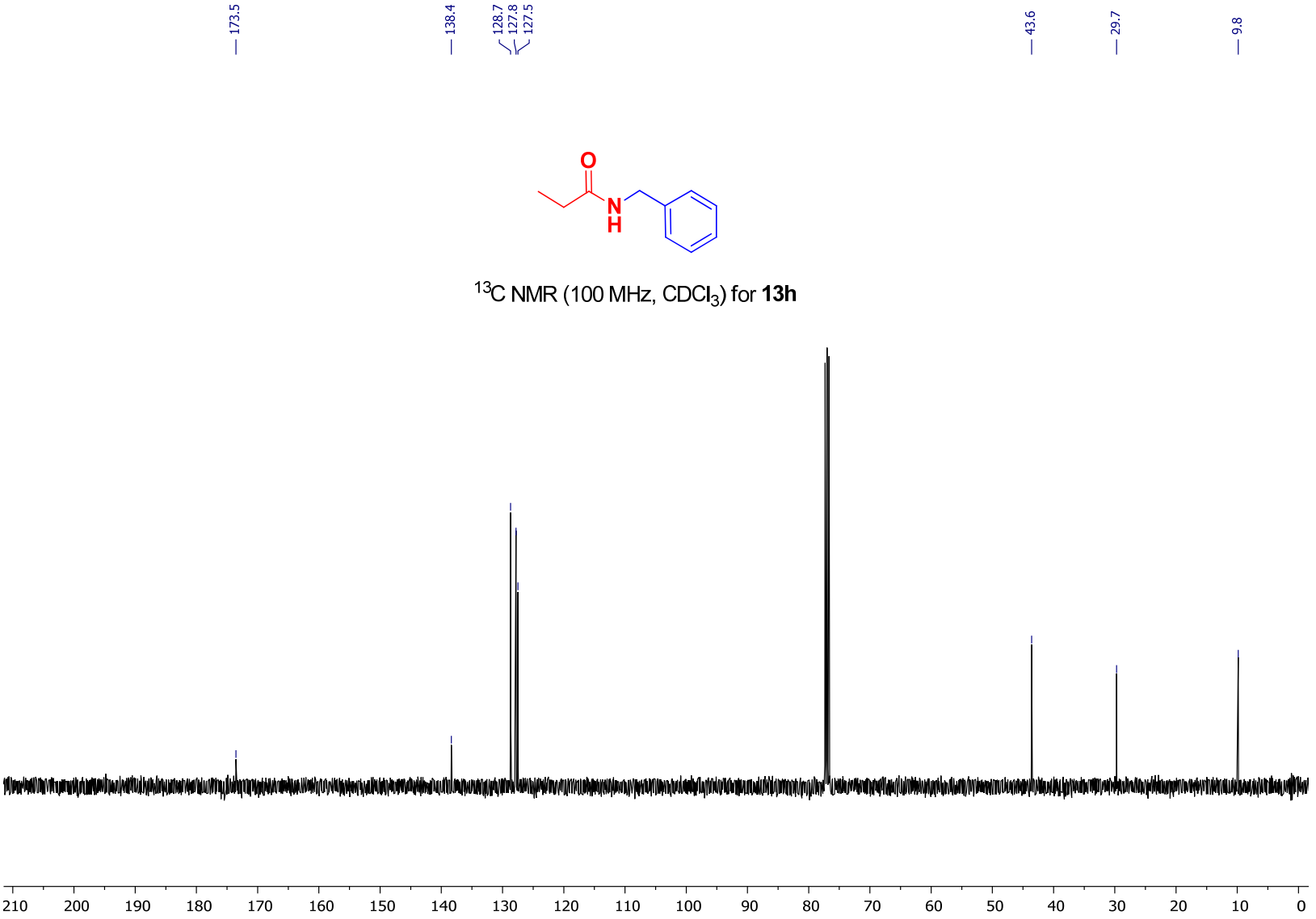
^{1}H NMR (400 MHz, $CDCl_3$) for **13g**



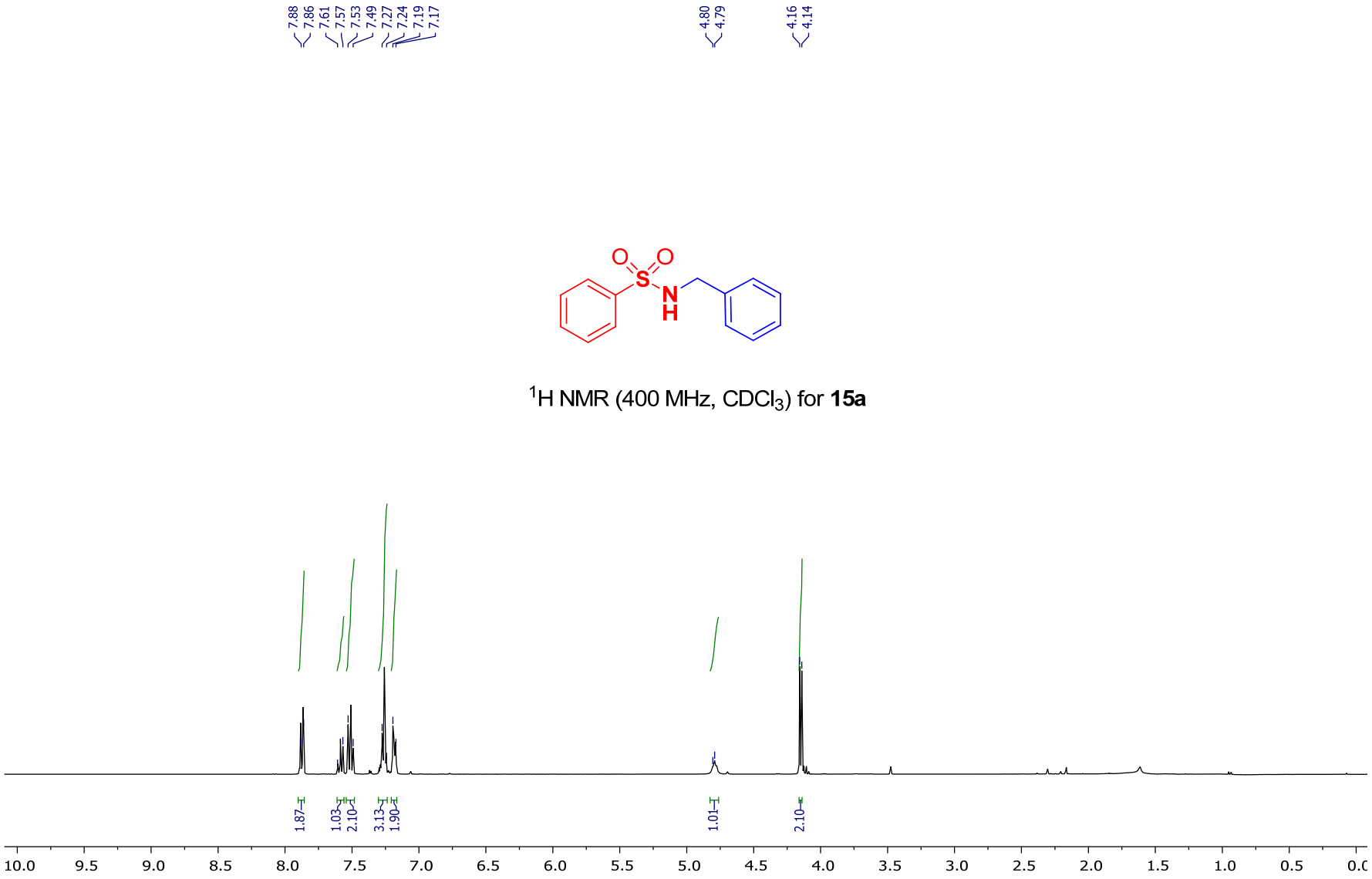
^{13}C NMR (100 MHz, $CDCl_3$) for **13g**



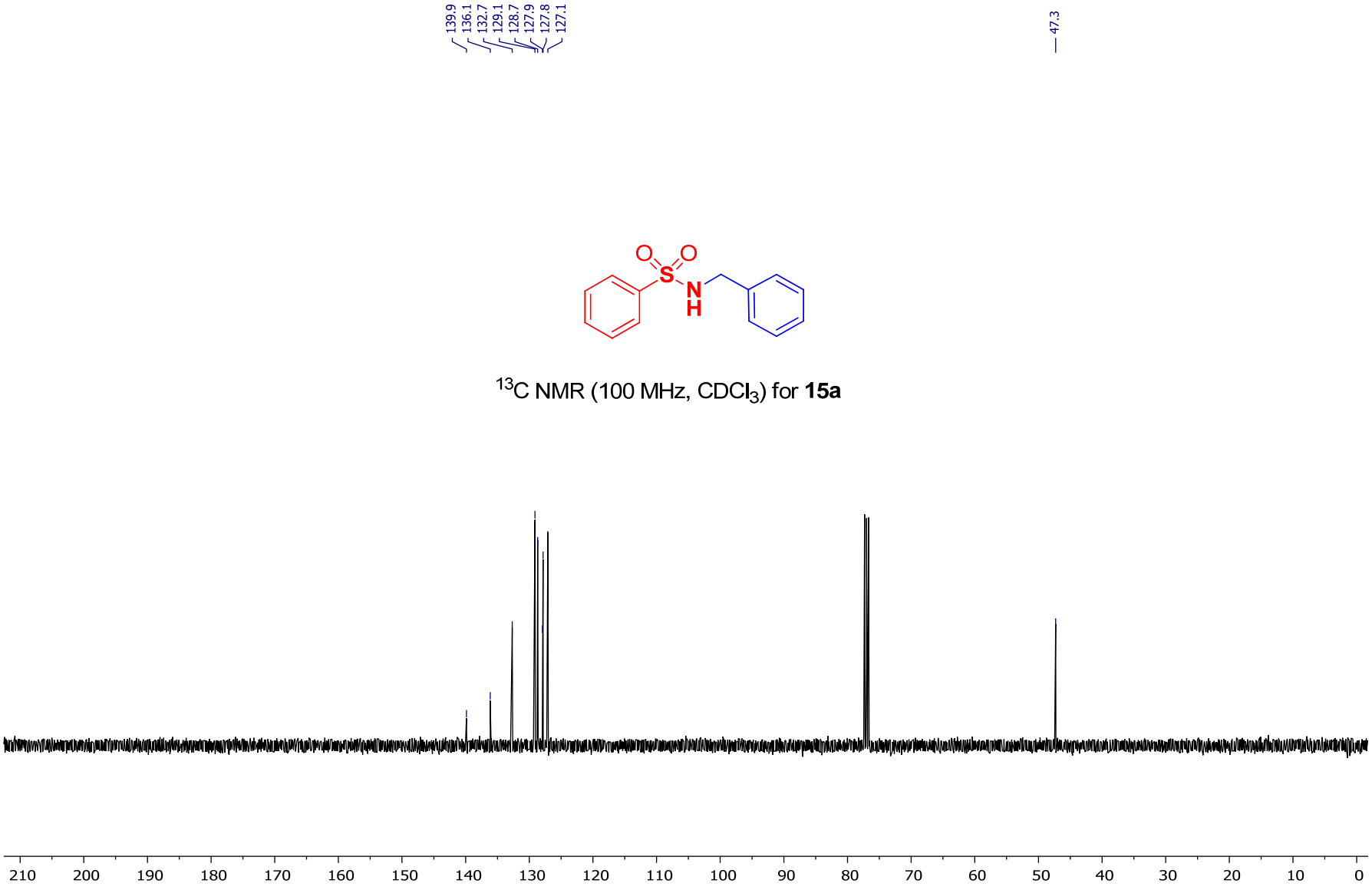
^{1}H NMR (400 MHz, $CDCl_3$) for **13h**



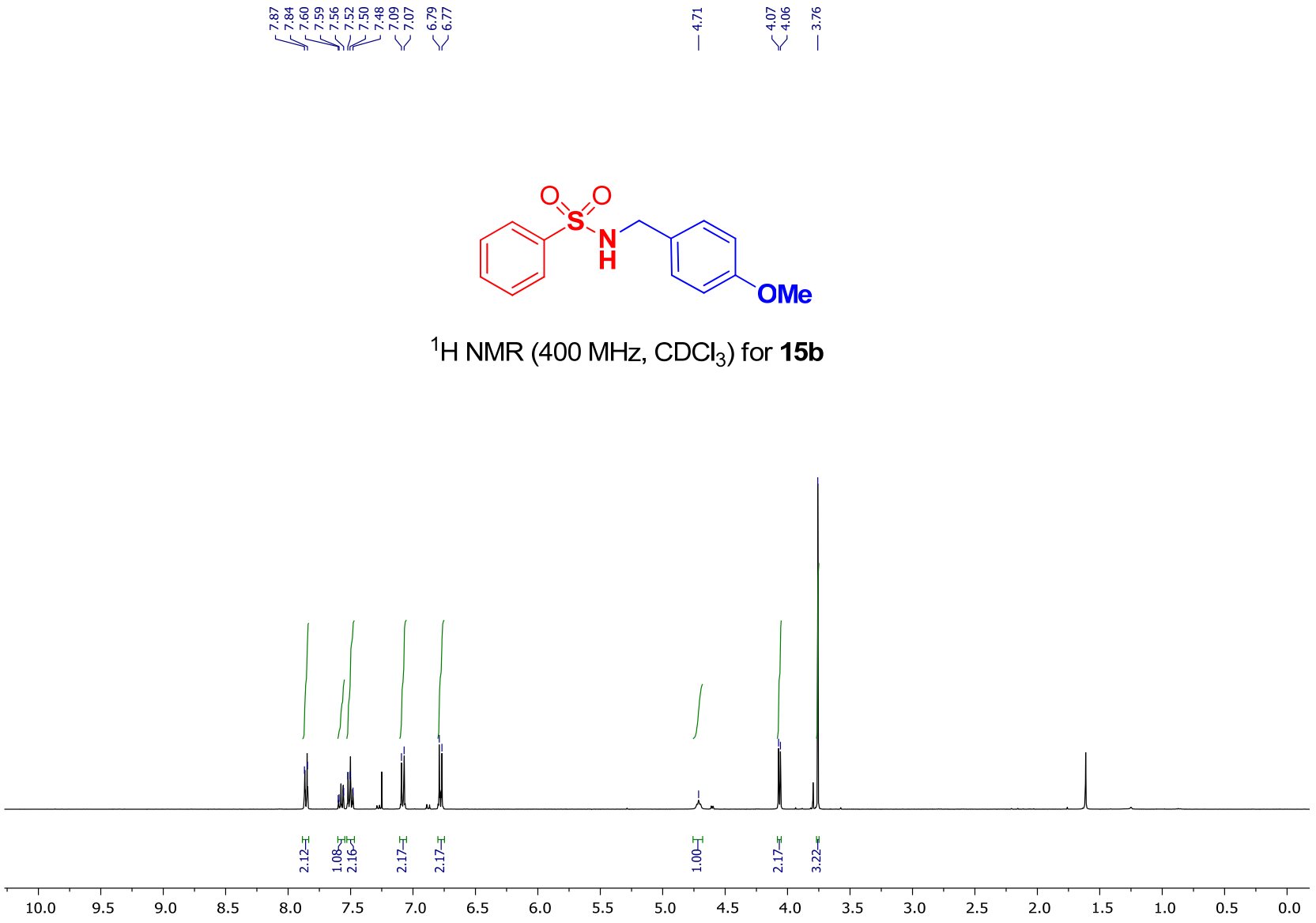
^{13}C NMR (100 MHz, $CDCl_3$) for **13h**



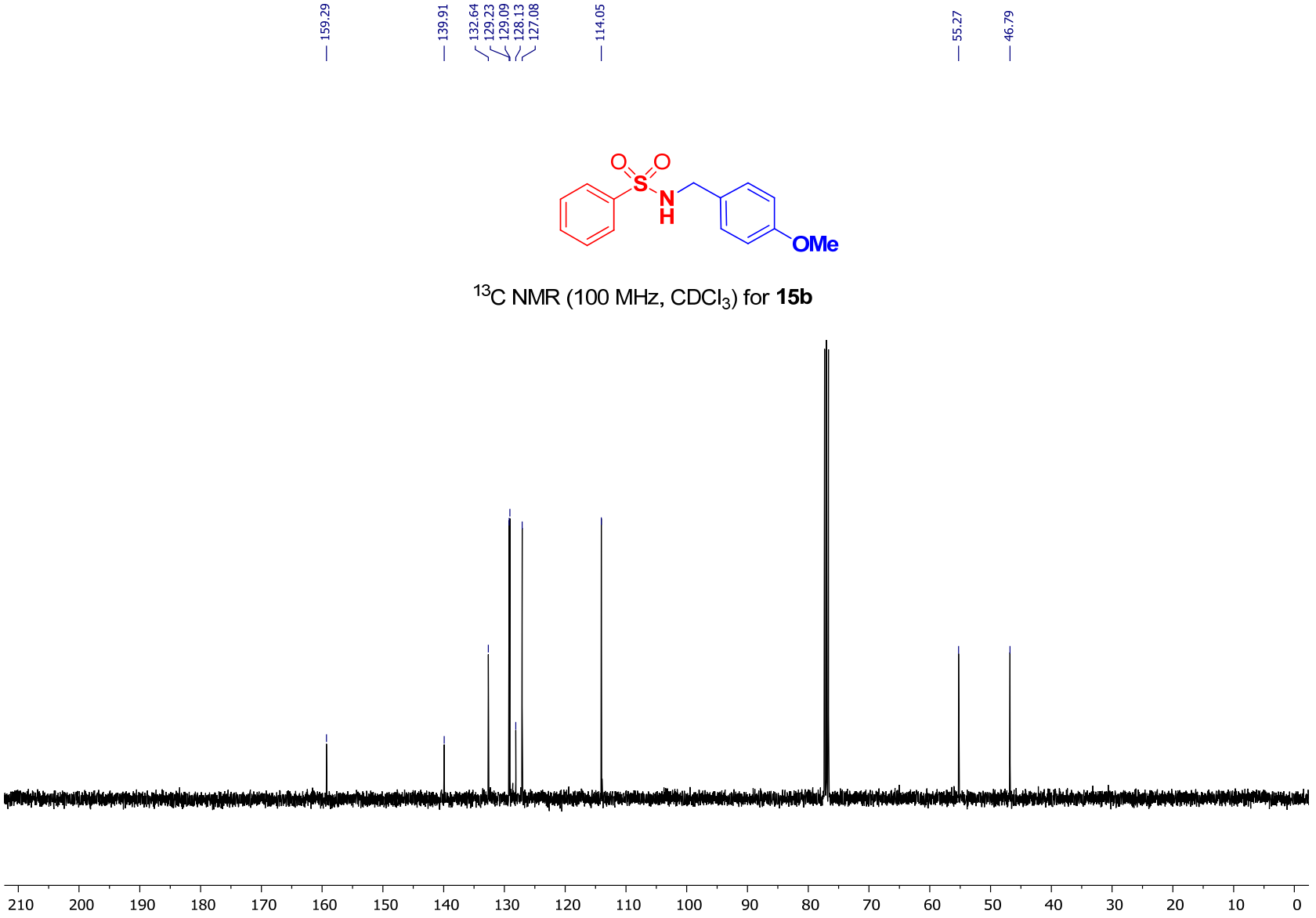
^{1}H NMR (400 MHz, $CDCl_3$) for **15a**



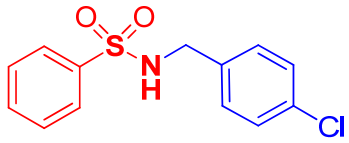
^{13}C NMR (100 MHz, $CDCl_3$) for **15a**



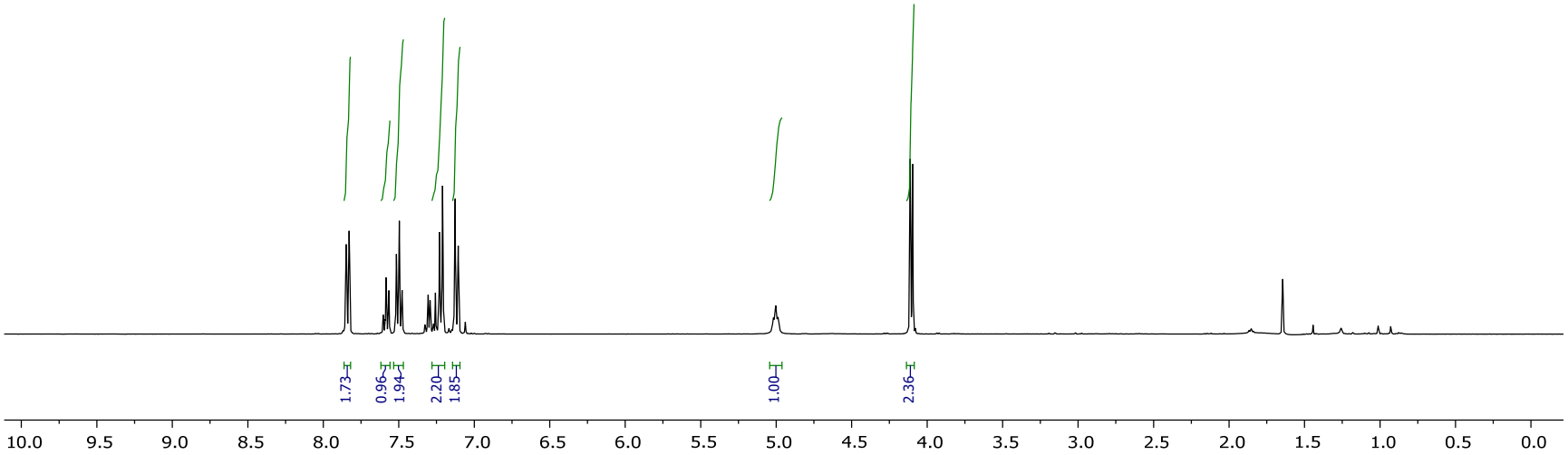
^{1}H NMR (400 MHz, $CDCl_3$) for **15b**

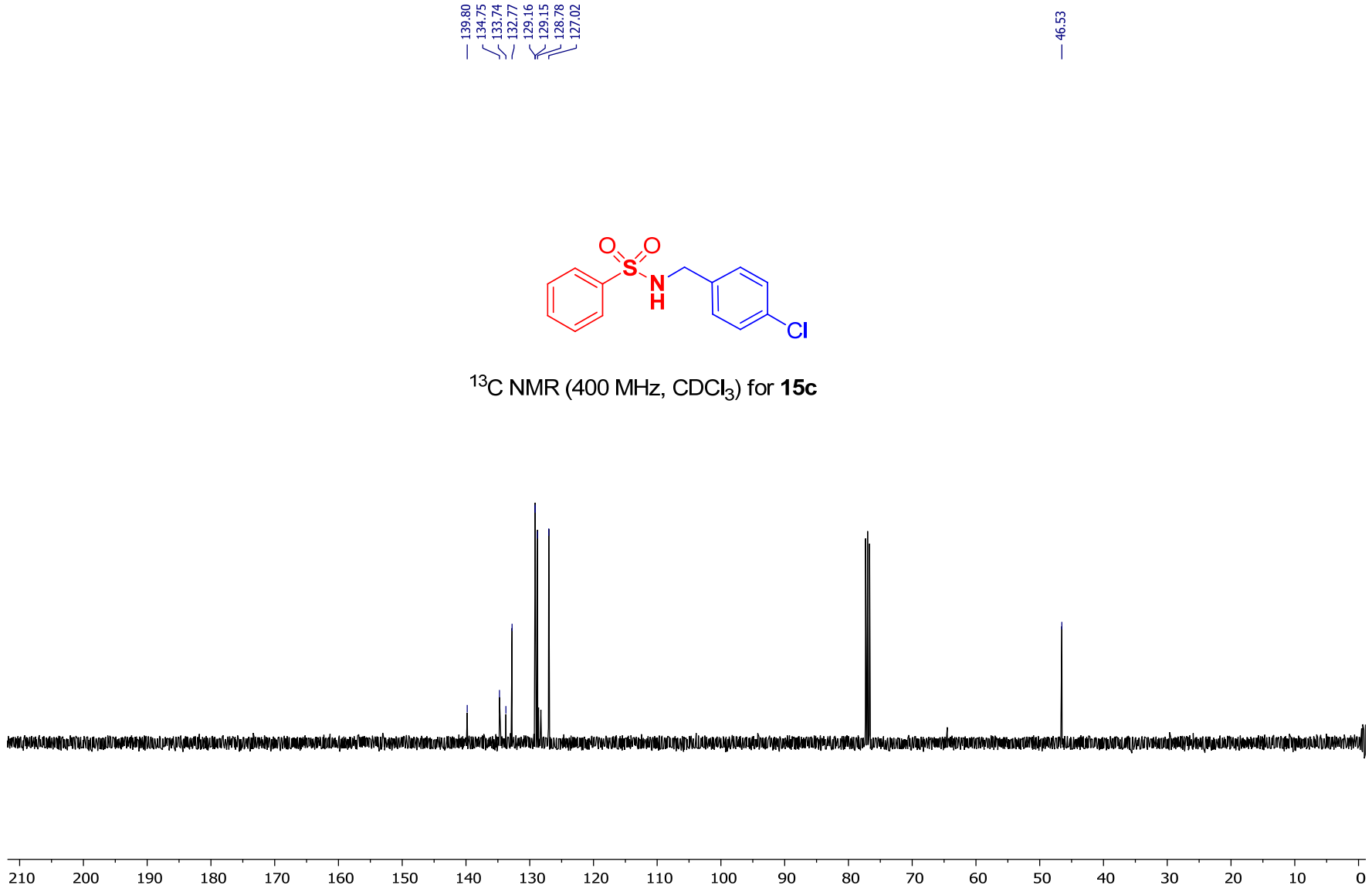


^{13}C NMR (100 MHz, $CDCl_3$) for **15b**

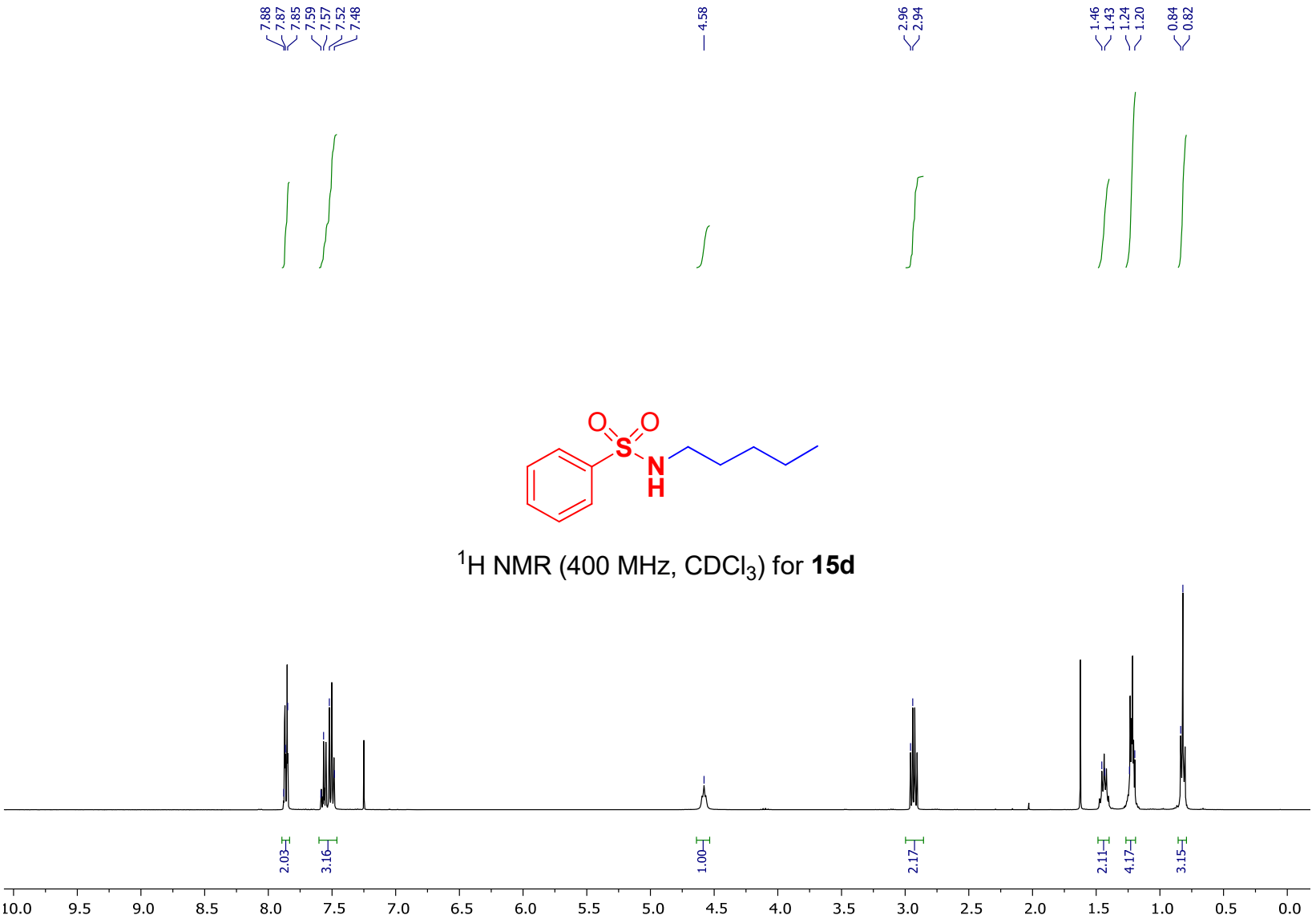


^{1}H NMR (400 MHz, $CDCl_3$) for **15c**

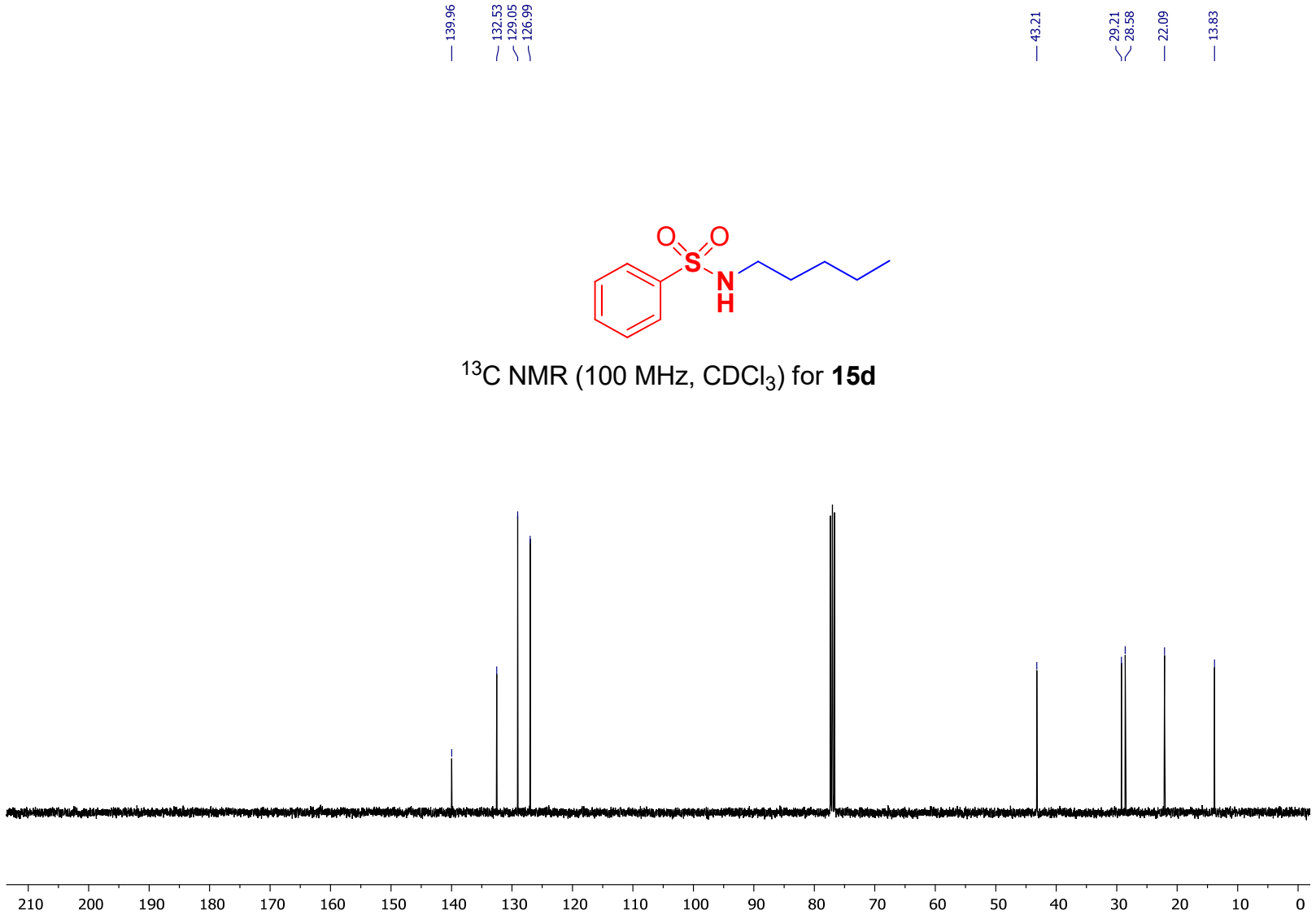




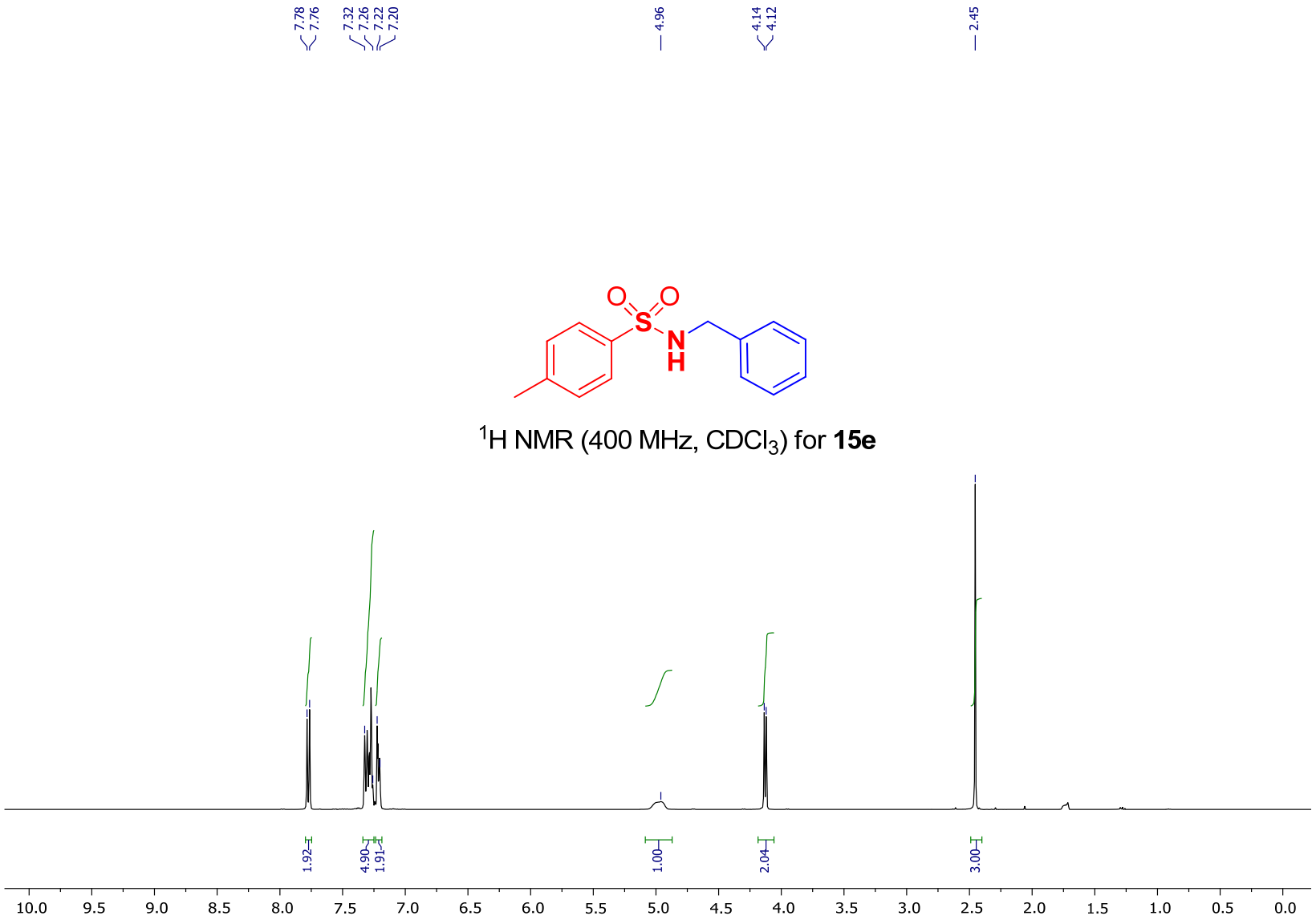
^{13}C NMR (400 MHz, $CDCl_3$) for **15c**



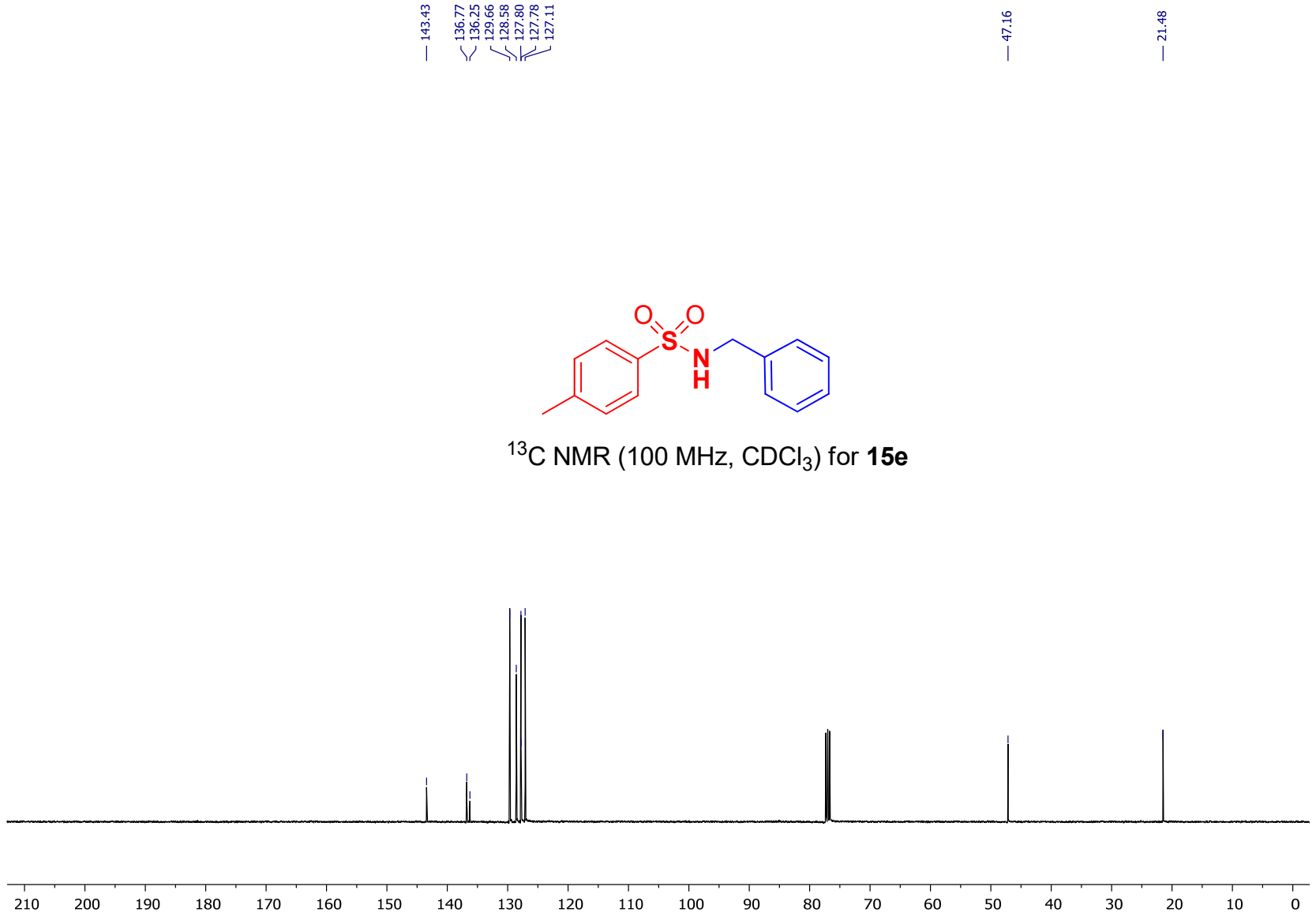
^{1}H NMR (400 MHz, $CDCl_3$) for **15d**



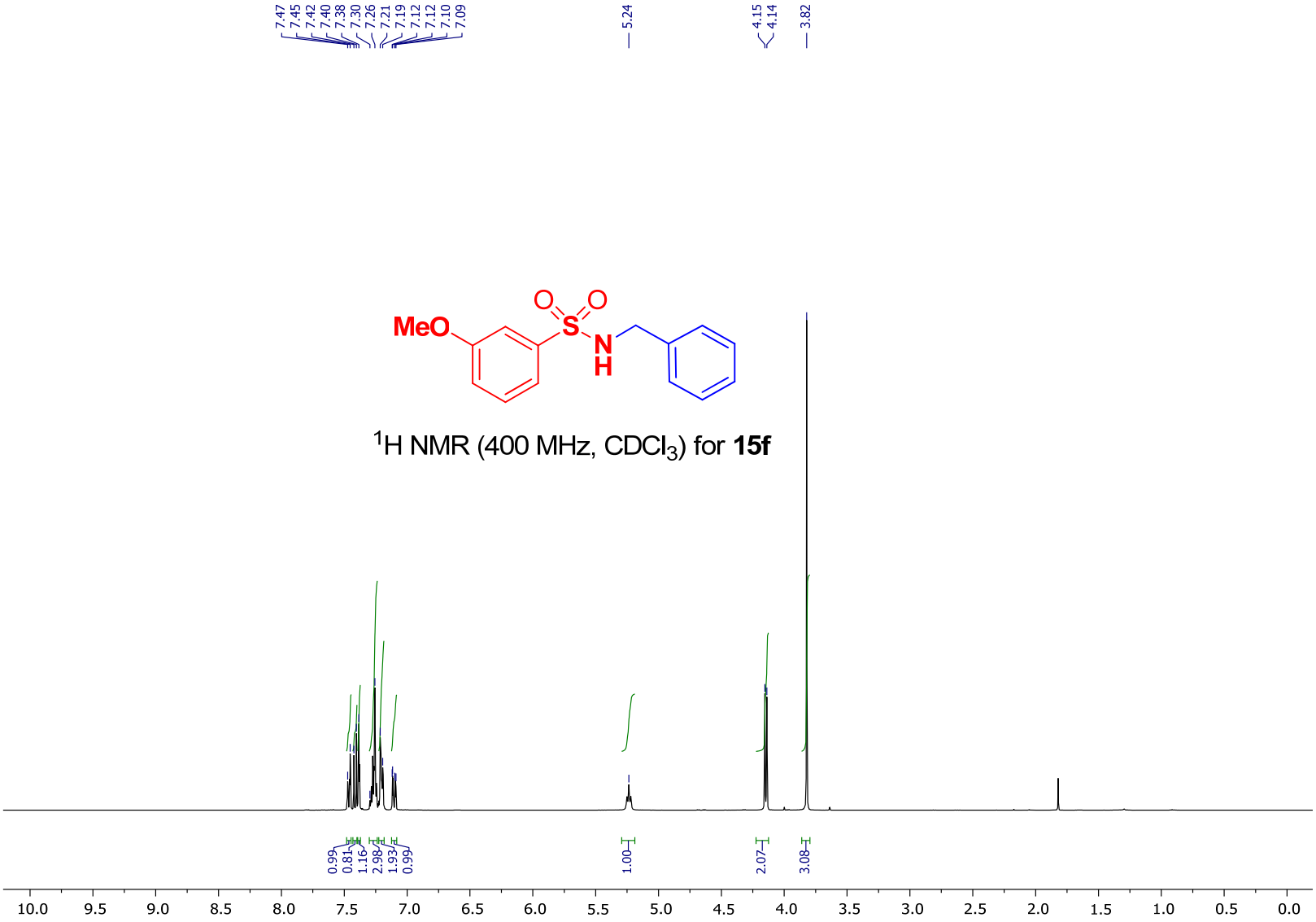
^{13}C NMR (100 MHz, $CDCl_3$) for **15d**



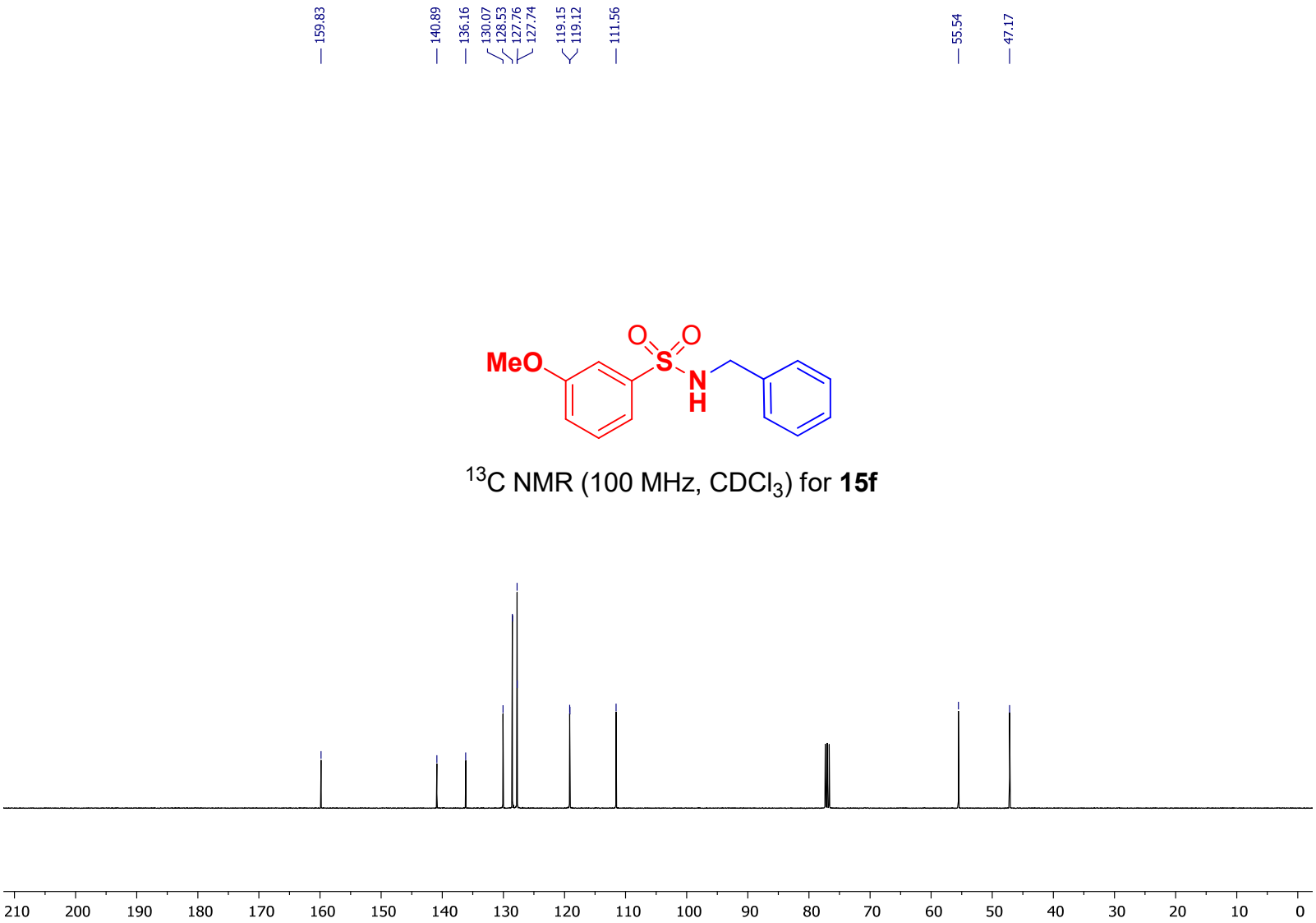
^{1}H NMR (400 MHz, $CDCl_3$) for **15e**



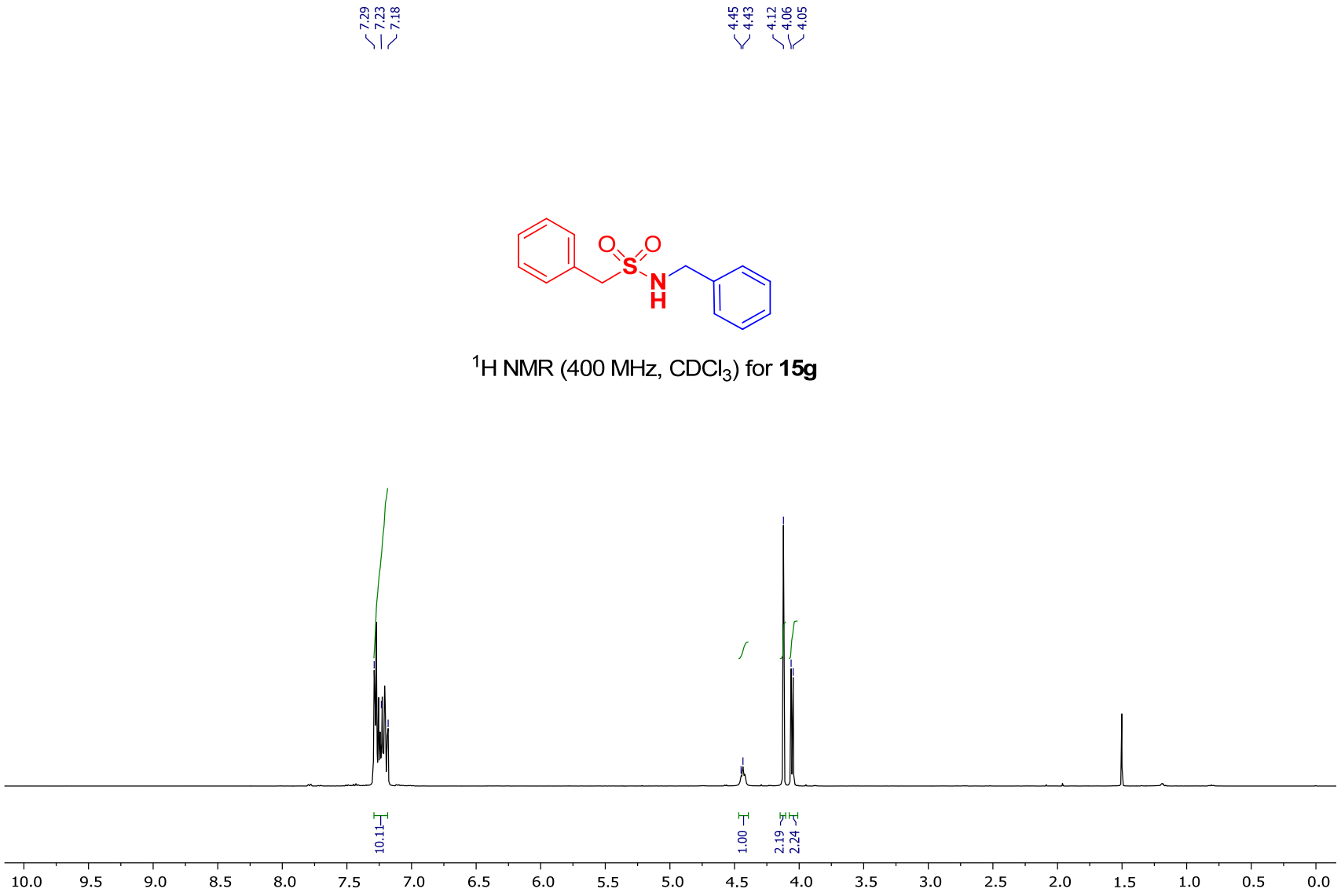
^{13}C NMR (100 MHz, $CDCl_3$) for **15e**



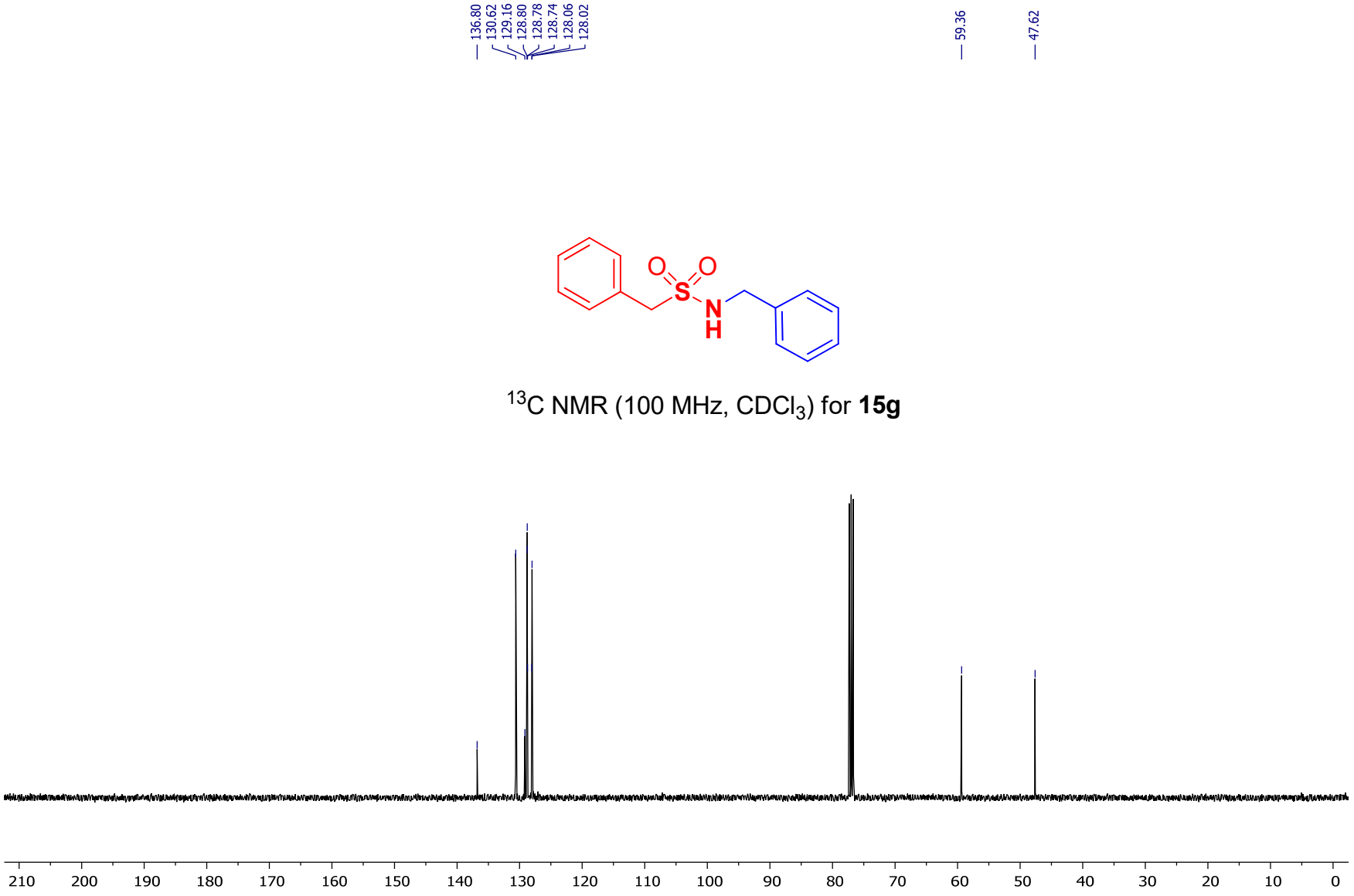
^{1}H NMR (400 MHz, $CDCl_3$) for **15f**



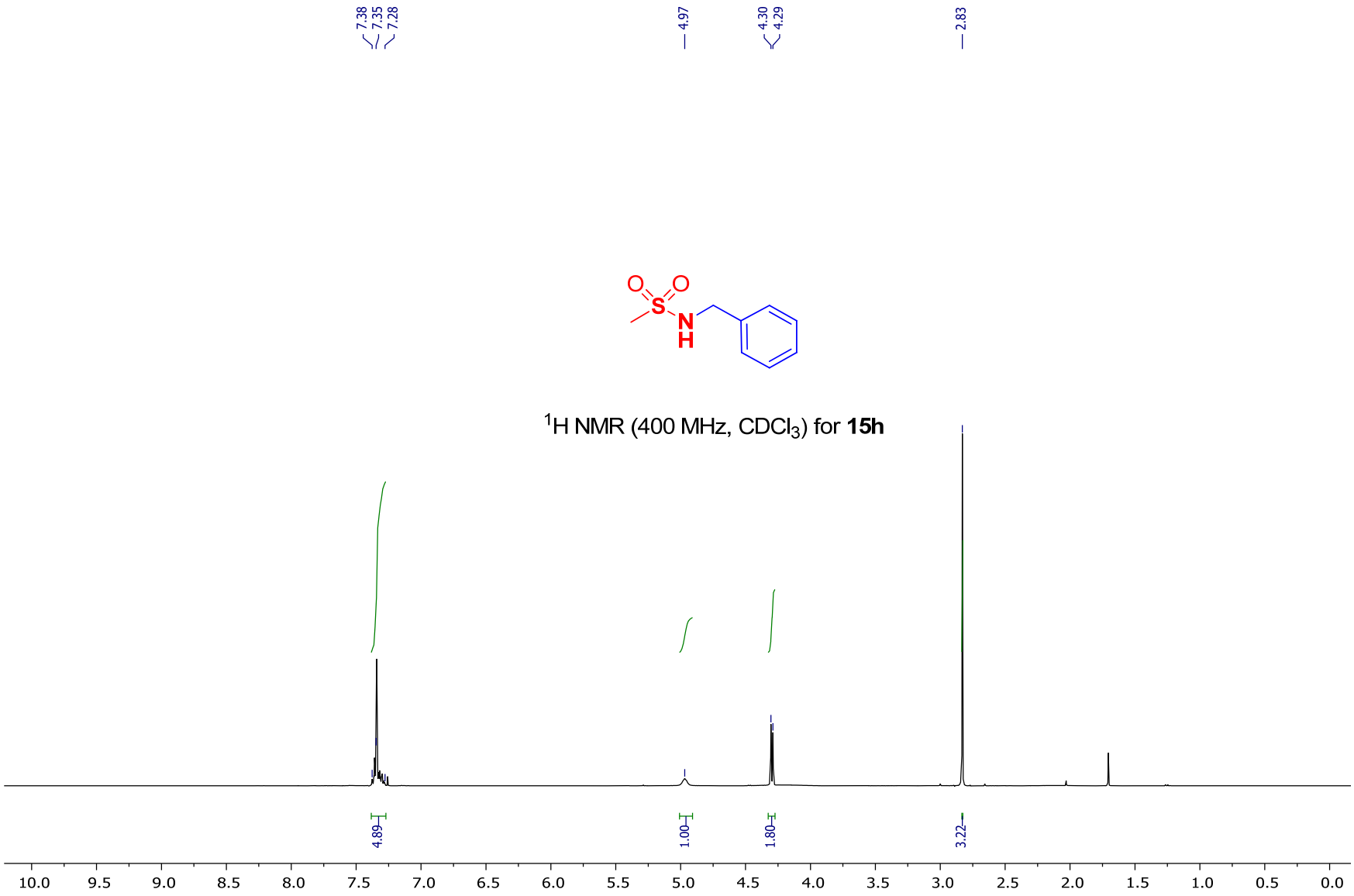
^{13}C NMR (100 MHz, $CDCl_3$) for **15f**



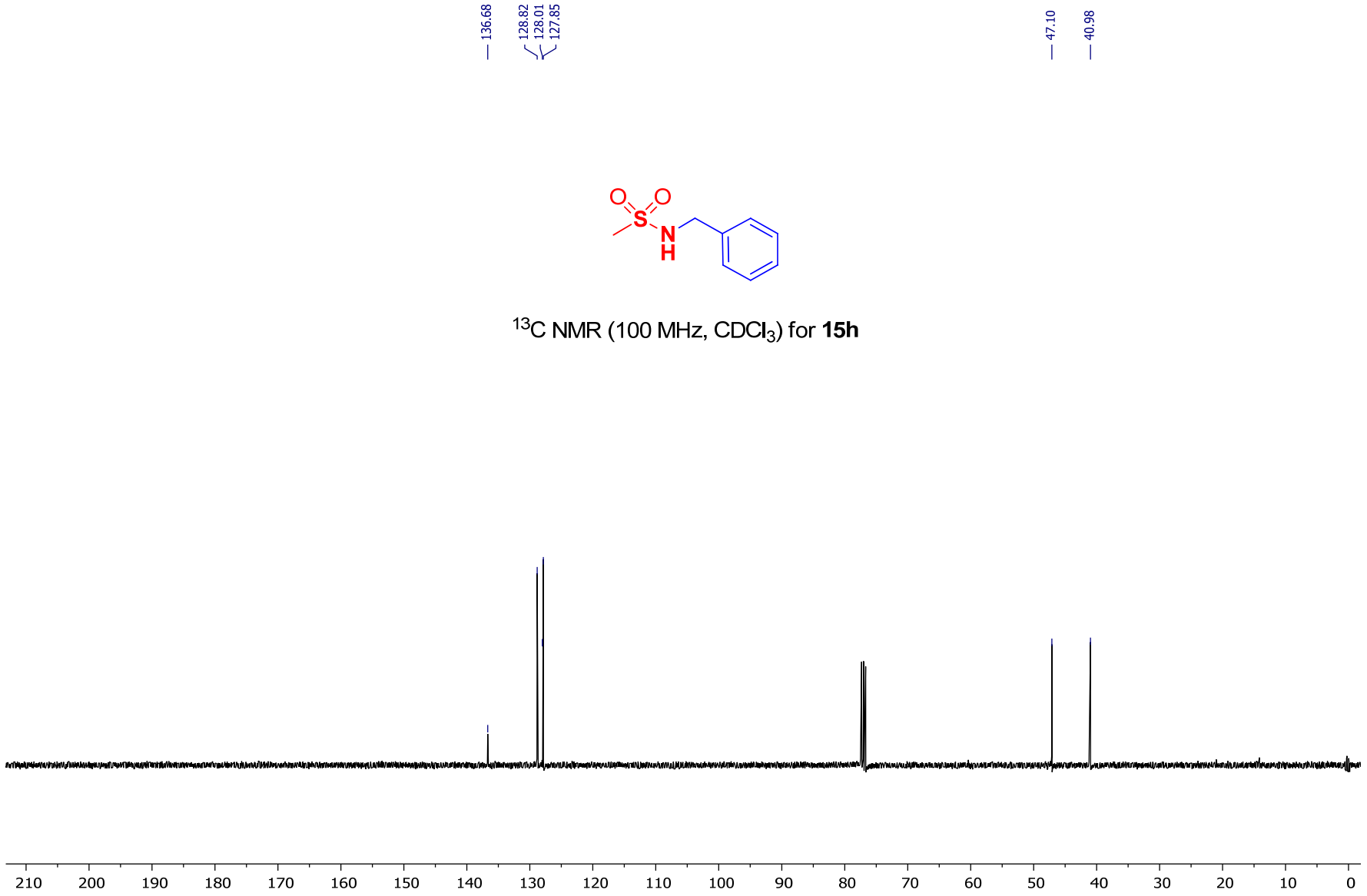
^{1}H NMR (400 MHz, $CDCl_3$) for **15g**



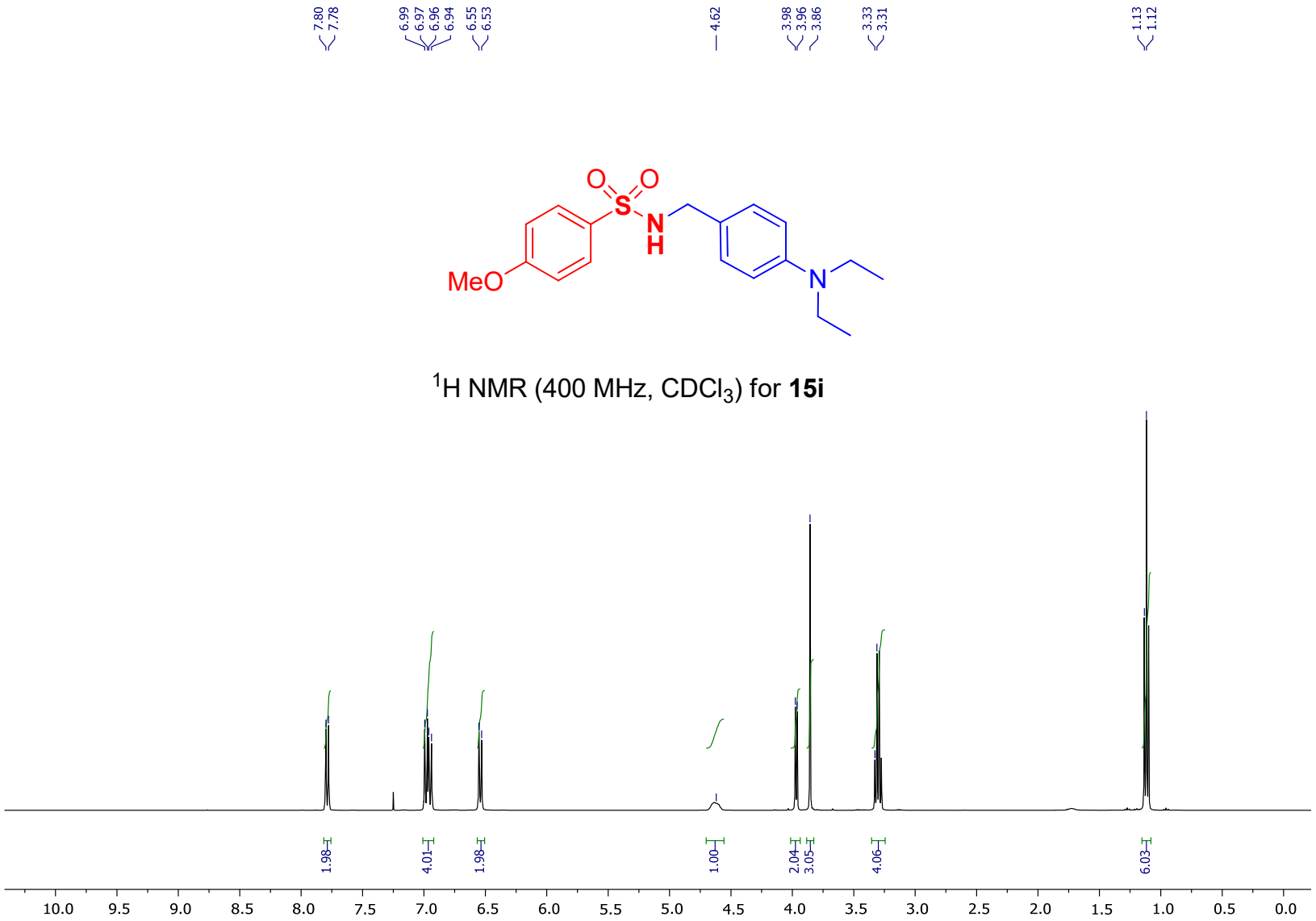
^{13}C NMR (100 MHz, $CDCl_3$) for **15g**



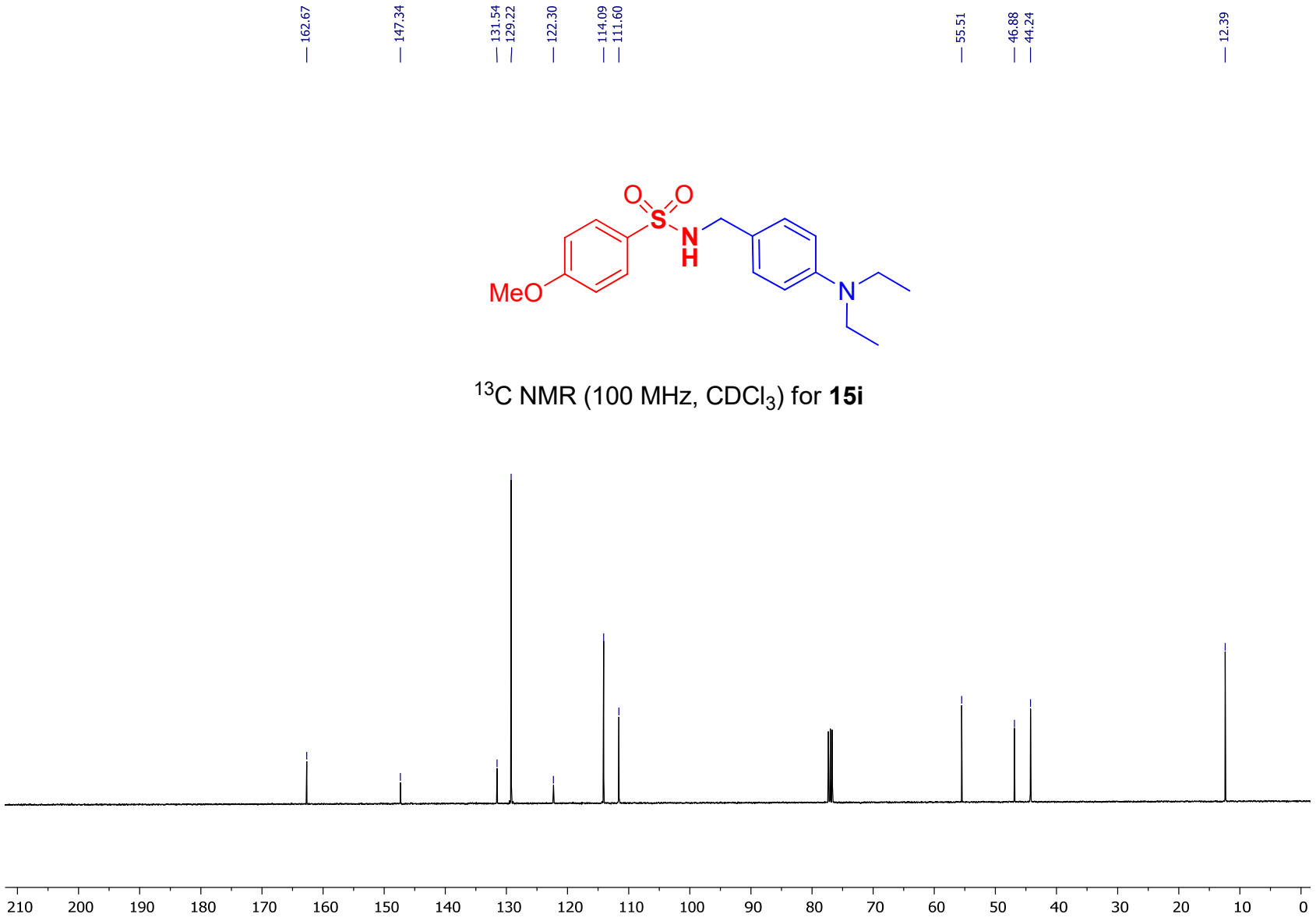
^{1}H NMR (400 MHz, $CDCl_3$) for **15h**



^{13}C NMR (100 MHz, $CDCl_3$) for **15h**



^{1}H NMR (400 MHz, $CDCl_3$) for **15i**



^{13}C NMR (100 MHz, $CDCl_3$) for **15i**

6. References

(1) R. Cano, M. Yus and D. J. Ramon, Impregnated palladium on magnetite as catalyst for multicomponent reductive amination reactions and other related reducing processes, *Tetrahedron*, 2011, **67**, 8079−8085.

(2) H. Ohta, Y. Yuyama, Y. Uozumi and Y. M. A. Yamada, In-water dehydrative alkylation of ammonia and amines with alcohols by a polymeric bimetallic catalyst, *Org. Lett.*, 2011, **13**, 3892–3895.

(3) R. Pothikumar, V. T. Bhat and K. Namitharan, Pyridine mediated transition-metal-free direct alkylation of anilines using alcohols via borrowing hydrogen conditions, *Chem. Commun*., 2020, **56**, 13607−13610.

(4) S. P. Shan, X. Xiaoke, B. Gnanaprakasam, T. T. Dang, B. Ramalingam, H. V. Huynh and A. M. Seayad, Benzimidazolin-2-ylidene N-heterocyclic carbene complexes of ruthenium as a simple catalyst for the N-alkylation of amines using alcohols and diols, *RSC Adv.*, 2015, **5**, 4434−4442.

(5) R. Cano, D. J. Ramon and M. Yus, Impregnated ruthenium on magnetite as a recyclable catalyst for the N-alkylation of amines, sulfonamides, sulfinamides, and nitroarenes using alcohols as electrophiles by a hydrogen autotransfer process, *J. Org. Chem.*, 2011, **76**, 5547−5557.

(6) M. S. Thakur, O. S. Nayal, A. Sharma, R. Rana, N. Kumar and S. K. Maurya, An efficient metal-free mono N-alkylation of anilines via reductive amination using hydrosilanes, *Eur. J. Org. Chem.*, 2018, **47**, 6729−6732.

(7) A. Nagarsenkar, S. K. Prajapti and B. N. Babu, An efficient catalytic reductive amination: A facile one-pot access to 1,2-dihydropyrrolo[3,4-b]indol-3(4H)-ones by using $B(C_6F_5)_3$/$NaBH_4$, *J. Chem. Sci.*, 2015, **127**, 711-716.

(8) G. Barzano, R. Mao, M. Garreau, J. Waser and X. Hu, Tandem photoredox and copper-catalyzed decarboxylative C(sp^3)-N coupling of anilines and imines using an organic photocatalyst, *Org. Lett.*, 2020, **22**, 5412−5416.

(9) S. Elangovan, J. Neumann, J.-B. Sortais, K. Junge, C. Darcel and M. Beller, Efficient and selective N-alkylation of amines with alcohols catalyzed by manganese pincer complexes, *Nat. Commun.*, 2016, **7**, 12641.

(10) P. Liu, N. T. Tung, X. Xu, J. Yang and F. Li, N-methylation of amines with methanol in the presence of carbonate salt catalyzed by a metal-ligand bifunctional ruthenium catalyst [(p-cymene)Ru(2,2'-bpyO)(H_2O)], *J. Org. Chem*., 2021, **86**, 2621−2631.

(11) M. Huang, Y. Li, Y. Li, J. Liu, S. Shu, Y. Liu and Z. Ke, Room temperature N-heterocyclic carbene manganese catalyzed selective N-alkylation of anilines with alcohols, *Chem. Commun*., 2019, **55**, 6213−6216.

(12) C. Zhang, Z. Liang, F. Lu, X. Jia, G. Zhang and M-L., Base-mediated cascade amidination/N-alkylation of amines by alcohols, *Chem. Commun.*, 2020, **56**, 10489−10492.

(13) W-Z. Bi, K. Sun, C. Qu, X.-L. Chen, L.-B. Qu, S.-H. Zhu, X. Li, H.-T. Wu, L.-K. Duan and Y-F. Zhao, A direct metal-free C2-H functionalization of quinoline N-oxides: a highly selective amination and alkylation strategy towards 2-substituted quinolines. *Org. Chem. Front.*, 2017, **4**, 1595−1600.

(14) P. Saha, T. Ramana, N. Purkait, M. A. Ali, R. Paul and T. Punniyamurthy, Ligand-free copper-catalyzed synthesis of Substituted benzimidazoles, 2-aminobenzimidazoles, 2-aminobenzothiazoles, and benzoxazoles, *J. Org. Chem.*, 2009, **74**, 8719−8725.

(15) C. Zhang, Z. Li, J. Chen, S. Qi, Y. Fang, S. Zhang, C. Ren, F. Lu, Z. Liang, S. Jiang, X. Jia, S. Yu and G. Zhang, Base-mediated amination of alcohols using amidines, *J. Org. Chem.*, 2020, **85**, 7728−7738.

(16) Q. Lei, C. Wang, Y. Wei, J. Xiao, D. Xue, D. Talwar and J. Xiao, Fast reductive amination by transfer hydrogenation "on water", *Chem. Eur. J*., 2013, **19**, 4021−4029.

(17) G. A. Molander, P. E. Gormisky and D. L. Sandrock, Scope of aminomethylations via Suzuki-Miyaura cross-coupling of organotrifluoroborates, *J. Org. Chem.*, 2008, **73**, 2052−2057.

(18) T. Kubo, C. Katoh, K. Yamada, K. Okano, H. Tokuyama and T. Fukuyama, A mild inter- and intramolecular amination of aryl halides with a combination of CuI and CsOAc, *Tetrahedron*, 2008, **64**, 11230−11236.

(19) R. Veligeti, R. B. Madhu, J. Anireddy, V. R. Pasupuleti, V. K. R. Avula, K. S. Ethiraj, S. Uppalanchi, S. Kasturi, Y. Perumal, H. S. Anantaraju, N. Polkam, M. R. Guda, S. Vallela and G. V. Zyryanov, Synthesis of novel cytotoxic tetracyclic acridone derivatives and study of their molecular docking, ADMET, QSAR, bioactivity and protein binding properties, *Sci. Rep.*, 2020, **10**, 20720.

(20) D. Zhang, T. Iwai and M. Sawamura, Ir-Catalyzed reversible acceptorless dehydrogenation/hydrogenation of N-substituted and unsubstituted heterocycles enabled by a polymer-cross-linking bisphosphine, *Org. Lett.*, 2020, **22**, 5240−5245.

(21) D. Wei, P. Yang, C. Yu, F. Zhao, Y. Wang and Z. Peng, N-Alkylation of amines with alcohols catalyzed by manganese(II) chloride or bromopentacarbonylmanganese(I), *J. Org. Chem.*, 2021, **86**, 2254−2263.

(22) J. Das and D. Banerjee, Nickel-catalyzed phosphine free direct N-alkylation of amides with alcohols, *J. Org. Chem.*, 2018, **83**, 3378−3384.

(23) G-W. Wang, N. G. McCreanor, M. H. Shaw, W. G. Whittingham and J. F. Bower, New initiation modes for directed carbonylative C-C bond activation: Rhodium-catalyzed (3 + 1 + 2) cycloadditions of aminomethylcyclopropanes, *J. Am. Chem. Soc.*, 2016, **138**, 13501−13504.

(24) S. Gaspa, A. Porcheddu and L. De Luca, Iron-catalysed oxidative amidation of alcohols with amines, *Org. Biomol. Chem.*, 2013, **11**, 3803−3807.

(25) P. V. Ramachandran, H. J. Hamann and S. Choudhary, Amine-boranes as dual-purpose reagents for direct amidation of carboxylic acids, *Org. Lett.*, 2020, **22**, 8593−8597.

(26) S. Y. Lee, C-W. Lee and D. Y. Oh, Dephosphonylation of β-carbonyl phosphonates, *J. Org. Chem.*, 1999, **64**, 7017–7022.

(27) B. G. Reed-Berendt and L. C. Morrill, Manganese-catalyzed N-alkylation of sulfonamides using alcohols, *J. Org. Chem.*, 2019, **84**, 3715–3724.

(28) H. Wen, N. Luo, Q. Zhu and R. Luo, Amide iridium complexes as catalysts for transfer hydrogenation reduction of N-sulfonylimine, *J. Org. Chem*., 2021, **86**, 3850−3859.

(29) S. Chung and J. Kim, Cu-catalyzed aerobic oxidative synthesis of sulfonamides from sulfonyl hydrazides and amines, *Tetrahedron Lett*., 2019, **60**, 792−795.

(30) A. S. Deeming, C. J. Russell and M. C. Willis, Combining organometallic reagents, the sulfur dioxide surrogate DABSO, and amines: A one-pot preparation of sulfonamides, amenable to array synthesis, *Angew. Chem., Int. Ed.*, 2015, **54**, 1168−1171.

(31) Y. Ai, P. Liu, R. Liang, Y. Liu and F. Li, The N-alkylation of sulfonamides with alcohols in water catalyzed by a water-soluble metal-ligand bifunctional iridium complex [Cp*Ir(biimH_2)(H_2O)][OTf]$_2$, *New J. Chem*., 2019, **43**, 10755−10762.