Formation and [3,3]-Sigmatropic Rearrangement of *O*-Allyl Nitronic Esters: a New Route to γ,δ-Unsaturated Nitro Compounds

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Experimental Procedures

General

1-(1-Methylethenyl)cyclohexene[6] was prepared by Wittig reaction of 1-acetyl-1-cyclohexene and methylenetriphenylphosphine: the ylide was prepared from methyltriphenylphosphoniumbromide using butyllithium in THF, a slight modification of the reported procedure. Reactions were routinely conducted under N_2 and concentration was performed at reduced pressure. DMF was distilled at atmospheric pressure: a substantial wet fore cut was discarded. NMR spectra were taken in $CDCl_3$ solution at 500 MHz (^1H spectra) or 126 MHz (^{13}C spectra).

$SnCl_4$-catalyzed reaction of 1-(1-methylethenyl)cyclohexene and trans-β-nitrostyrene

A 0.52 g (2 mmol) portion of tin(IV) chloride was added dropwise over 5 min to a cold (-78 °C) stirred solution containing 0.49 g (4 mmol) of 1-(1-methylethenyl)cyclohexene and 0.3 g (2 mmol) of *trans*-β-nitrostyrene in toluene (8 mL). The resulting solution was stirred for 30 min and ethyl acetate (20 mL) was added dropwise maintaining a temperature below -70°C. Saturated aqueous $NaHCO_3$ (20 mL) was added dropwise, again maintaining the temperature below -70°C. The resulting mixture was allowed to warm to 10 °C. The organic layer was separated and the aqueous layer was extracted with ethyl acetate (three 20-mL portions). The combined organic layers were washed with saturated $NaHCO_3$ (three 20-mL portions) followed by brine (three 20-mL portions), dried (anhydrous Na_2SO_4), and concentrated. Immediate examination of the ^1H NMR spectrum of the crude product showed a 40:60 ratio of nitronic esters **4** and **5**. Traces of unreacted β-nitrostyrene and nitro compound **7** were also present in this crude product.

The crude product was dissolved in ethanol (10 mL, 200 proof). After 1 day, the solution was concentrated: examination of the ^1H NMR spectrum now showed a mixture of nitronic ester **4** and the nitro compound **7**. This material was purified by flash chromatography on silica gel (hexanes-ethyl acetate, gradient from 9:1 to 1:1). An 0.24 g portion of nitro compound **7** (45% yield) was isolated from early fractions: mp 122-123 °C; IR 1544, 1374 cm^{-1} (NO_2); ^1H NMR δ 7.2 -7.32 (m, 5H), 5.17 (dd, 1H, *J* = 6.8, 12.2 Hz, H_5), 3.43 (m, 1H, H_6), 2.7-2.8 (m, 2H, H_{4a} and H_1), 2.30 (dd, 1H, *J* = 5.8, 17.6 Hz, H_7), 2.23 (dd, 1H, *J* = 11.2, 17.6 Hz, $H_{7'}$), 1.91 (m, 1H), 1.85 (m, 1H), 1.72 (m, 1H), 1.64 (s, 3H), 1.42-1.52 (m, 3H), 1.26 (m, 1H); ^{13}C NMR δ 141.6, 131.2, 128.8, 127.0, 126.9, 122.5, 90.1 (CNO_2), 42.8, 40.8, 39.7, 30.8, 29.7, 27.9, 26.3, 18.1.

Anal. Calcd for: C, 75.24; H, 7.79; N, 5.16. Found: C, 75.06; H, 8.09; N, 5.09.

An 0.17 g portion of nitronic ester **4** (32% yield) was isolated from latter chromatography fractions: mp 104-105 °C; IR 1614 cm^{-1} (C=N)[9]; ^1H NMR δ 7.35 (m, 2H), 7.29 (m, 1H), 7.21 (m, 2H), 6.33 (dd, 1H, *J* = 1.0, 2.9 Hz, H_3), 5.40 (bs, 1H, HC=C), 3.63 (m, 1H, *J* = 2.9, 6.8, 11.7 Hz, H_4), 2.47 (ddd, 1H, *J* = 1.0, 6.8, 14.2 Hz, H_5), 2.15-2.0 (m, 4H), 1.83 (dd, 1H, *J* = 12.2, 14.2 Hz, $H_{5'}$), 1.71 (m, 2H), 1.62 (m, 2H), 1.44 (s, 3H); ^{13}C NMR δ 139.8, 135.7, 129.1, 127.7, 127.5, 122.9, 114.2 (C=N), 87.2 (C-O), 38.8, 36.6, 26.5, 25.0, 23.9, 22.8, 22.0.

Anal. Calcd for: C, 75.24; H, 7.79; N, 5.16. Found: C, 75.22; H, 7.58; N, 5.14.

Isomerization of nitronic ester 4 to nitro compound 6

A solution containing 0.54 g (2 mmol) of **4** in DMF (12 mL) was warmed at 90-95 °C for 2 h. The resulting solution was cooled and diluted with benzene (15 mL) and ethyl acetate (15 mL). The diluted solution was washed with water (twenty 20-mL portions), dried (anhydrous Na_2SO_4), and concentrated. Flash chromatography on silica gel (hexanes-ethyl acetate, 9:1) gave 0.47 g (87% yield) of nitro compound **6**: mp 101-102 °C; IR 1547, 1367 cm^{-1} (NO_2); ^1H NMR δ 7.32 (m, 2H), 7.26 (m, 1H), 7.18 (m, 2H), 4.98 (dd, 1H, *J* = 3.4, 5.9 Hz, H_5), 3.20 (ddd, 1H, *J* = 3.4, 5.4, 12.2 Hz, H_6), 3.03 (dd, 1H, *J* = 12.2, 17.1 Hz, H_7), 2.87 (d, 1H, *J* = 14.1 Hz, H_1), 2.62 (m, 1H, H_{4a}), 2.13 (dd, 1H, *J* = 5.4, 17.1 Hz, $H_{7'}$), 1.78 (s) on 1.7-1.85 (m) [7H total], 1.40 (m, 1H), 1.25 (m, 1H), 1.04 (m, 1H); ^{13}C NMR δ 140.1, 129.1, 127.9, 127.4, 126.5, 125.1, 92.5 (CNO_2), 42.7, 41.3, 32.6, 29.1, 28.9, 26.3, 26.1, 19.4; MS (FAB) M+1 Calcd for $C_{17}H_{22}NO_2$ 272.1651. Found: 272.1658.

Isomerization of nitro compound 6 to nitro compound 8

A solution containing 0.16 g (0.6 mmol) of **6** in DMF (6 mL) was refluxed for 6 h. The resulting solution was cooled and diluted with benzene (15 mL) and ethyl acetate (15 mL). The diluted solution was washed with water (twenty 20-mL portions), dried (anhydrous Na_2SO_4), and concentrated. Preparative TLC on silica gel (hexanes-ethyl acetate, 9:1) gave 0.13 g (81% yield) of nitro compound **8**: mp 103-104 °C; IR 1545, 1372 cm^{-1} (NO_2); ^1H NMR δ 7.29 (m, 2H), 7.24 (m, 1H), 7.19 (m, 2H), 4.61 (dd, 1H, *J* = 9.8, 11.8 Hz, H_5), 3.32 (apparent td, 1H, *J* = 5.4, 11.7 Hz, H_6), 2.77 (m, 2H, H_1 and H_{4a}), 2.39 (m, 1H, H_7), 2.25 (m, 1H,

$H_{7'}$), 1.91 (m, 1H), 1.80 (m, 2H), 1.68 (s) on 1.65-1.7 (m) [4H total], 1.35 (m, 1H), 1.19 (m, 2H); ^{13}C NMR δ 139.9, 129.2, 128.7, 127.5, 127.3, 123.9, 95.7 (CNO_2), 44.6, 43.8, 39.6, 32.2, 28.9, 26.3, 25.3, 18.4.

Anal. Calcd for: C, 75.24; H, 7.79; N, 5.16. Found: C, 75.16; H, 7.75; N, 5.17.

Interconversion of nitronic esters 4 and 5

An 0.6 g portion of a crude mixture of nitronic esters (**4/5**, 47:53, respectively; 3% of **7** was also present) was prepared from 0.31 g (2.1 mmol) of β-nitrostyrene using the previously described method. The crude mixture was dissolved in toluene (8 mL) and the solution was cooled (Dry Ice/acetone bath). An 0.52 g (2 mmol) portion of tin(IV) chloride was added dropwise over 10 min to the cold solution maintaining the temperature below -70°C. The resulting solution was allowed to warm to -55°C (Dry Ice/cyclohexanone bath) and was stirred for 40 min. Ethyl acetate (20 mL) was added dropwise to the recooled (-78°C) solution at a rate maintaining a temperature lower than -70°C. Saturated aqueous $HaHCO_3$ was added, again at a rate maintaining a temperature lower than -70°C. The resulting mixture was allowed to warm to 0-5 °C. The organic layer was separated and the aqueous layer was extracted with ethyl acetate (three 20-mL portions). The combined organic layers were washed with saturated $NaHCO_3$ (three 20-mL portions) followed by brine (three 20-mL portions), dried (anhydrous Na_2SO_4), and concentrated giving 0.61 g of an oil. Immediate examination of the ^1H NMR spectrum of the crude product showed a 65:35 ratio of nitronic esters **4** and **5**. A trace (4%) of nitro compound **7** was also present in this crude product.

The crude product was dissolved in ethanol (10 mL). After 24 h at room temperature, the solution was concentrated to an oil consisting of nitro compound 7 and nitronic ester **4**. This material was purified by flash chromatography on silica gel (hexanes-ethyl acetate, gradient from 9:1 to 1:1). An 0.15 g portion (27% yield) of nitro compound 7 and an 0.24 g portion (41% yield) of nitronic ester **4** were obtained pure.

Conversion of nitronic ester 4 to nitro compounds 7-8

An 0.04 g (0.15 mmol) portion of tin(IV) chloride was added dropwise to a cold (-78°C) solution containing 0.04 g (0.15 mmol) of nitronic ester **4** in toluene (1 mL) at a rate maintaining the temperature below -70°C. After 15 min, the resulting solution was allowed to warm to room temperature and was stirred for 22 h. The brown reaction mixture was diluted with toluene (10 mL) and ethyl acetate (20 mL). The resulting solution was washed with saturated $NaHCO_3$ (two 25-mL portions) followed by brine (25 mL), dried (anhydrous Na_2SO_4), and concentrated to 0.04 g of an oil. This consisted of a 77:23 mixture (^1H NMR) of the two nitro compounds **7** and **8**, respectively. None of the nitro compound **6** was formed under these conditions.

Notes and references

6 Prepared from 1-acetylcyclohexene: L. D. Quin and B. G. Marsi, *Heteroat. Chem.* **1990**, *1*, 93.

9 The C=N frequencies for a series of nitronic esters (H-C=N(O)O where the nitronic C- and O-atoms are in a 6-membered ring) were reported to be 1615-1616 cm^{-1}: S. E. Denmark, Y.-C. Moon, C. J. Cramer, M. S. Dappen, and C.B.W. Senanayake, *Tetrahedron* **1990**, *46*, 7373.

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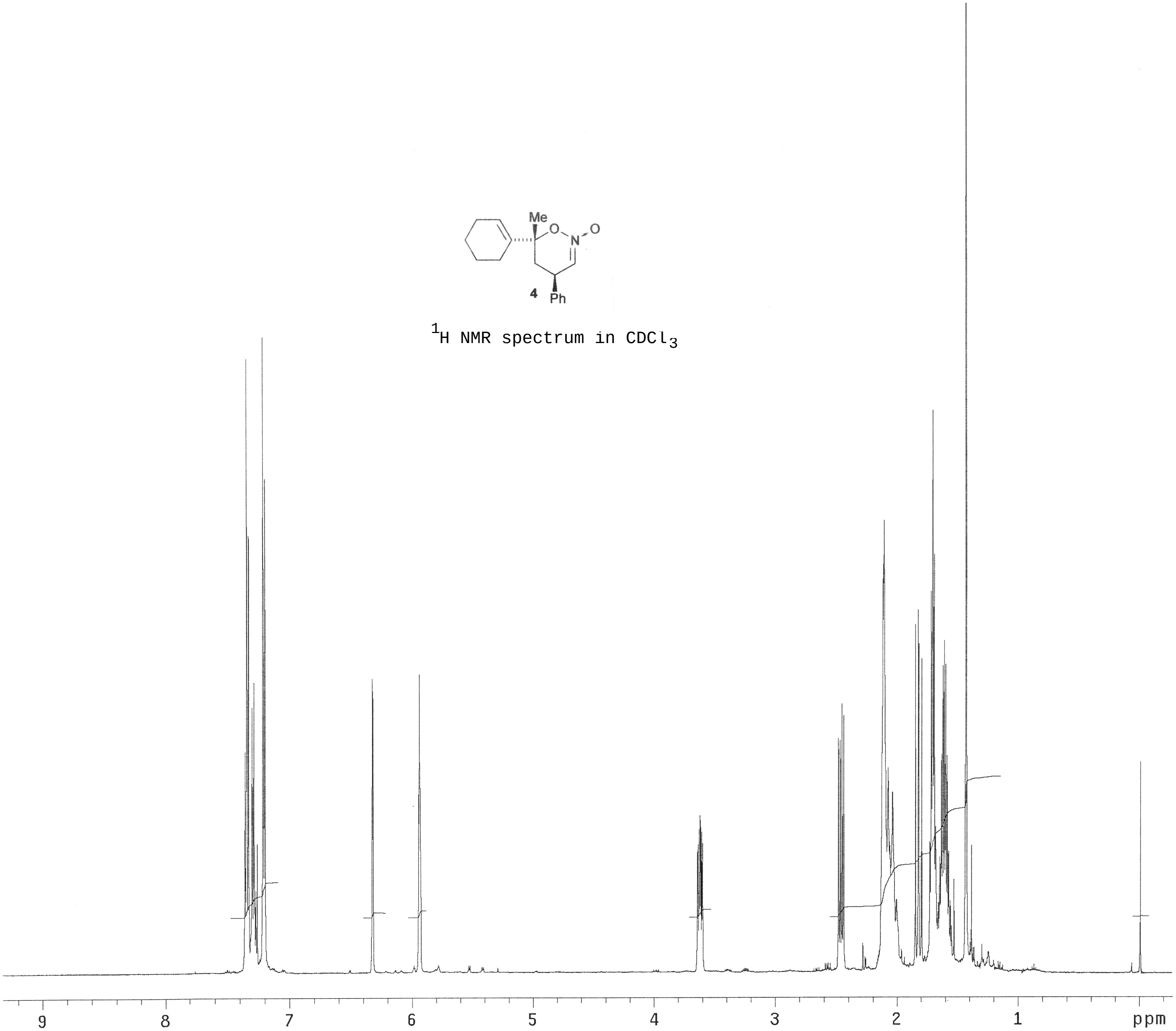
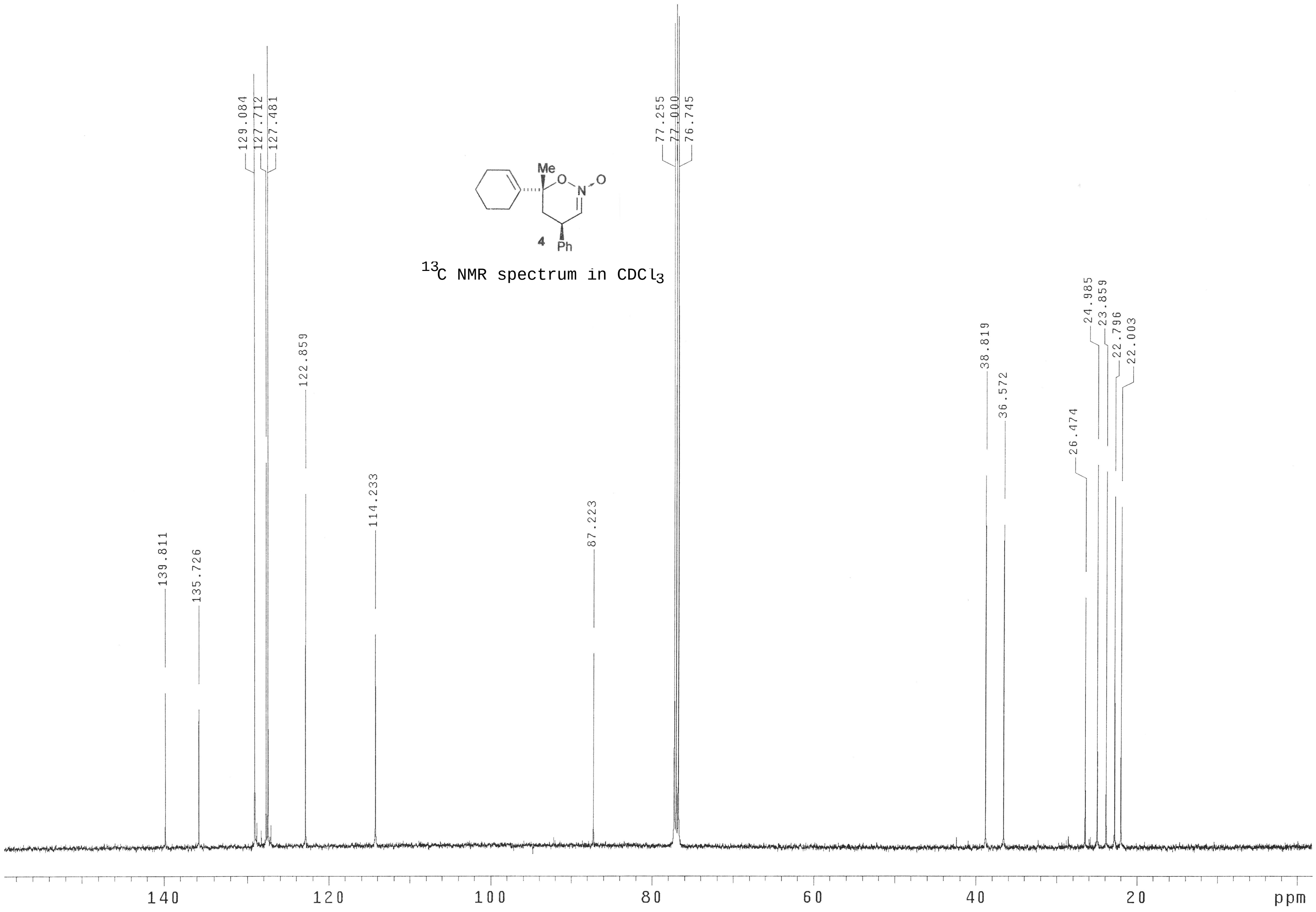
^{1}H NMR spectrum in $CDCl_3$





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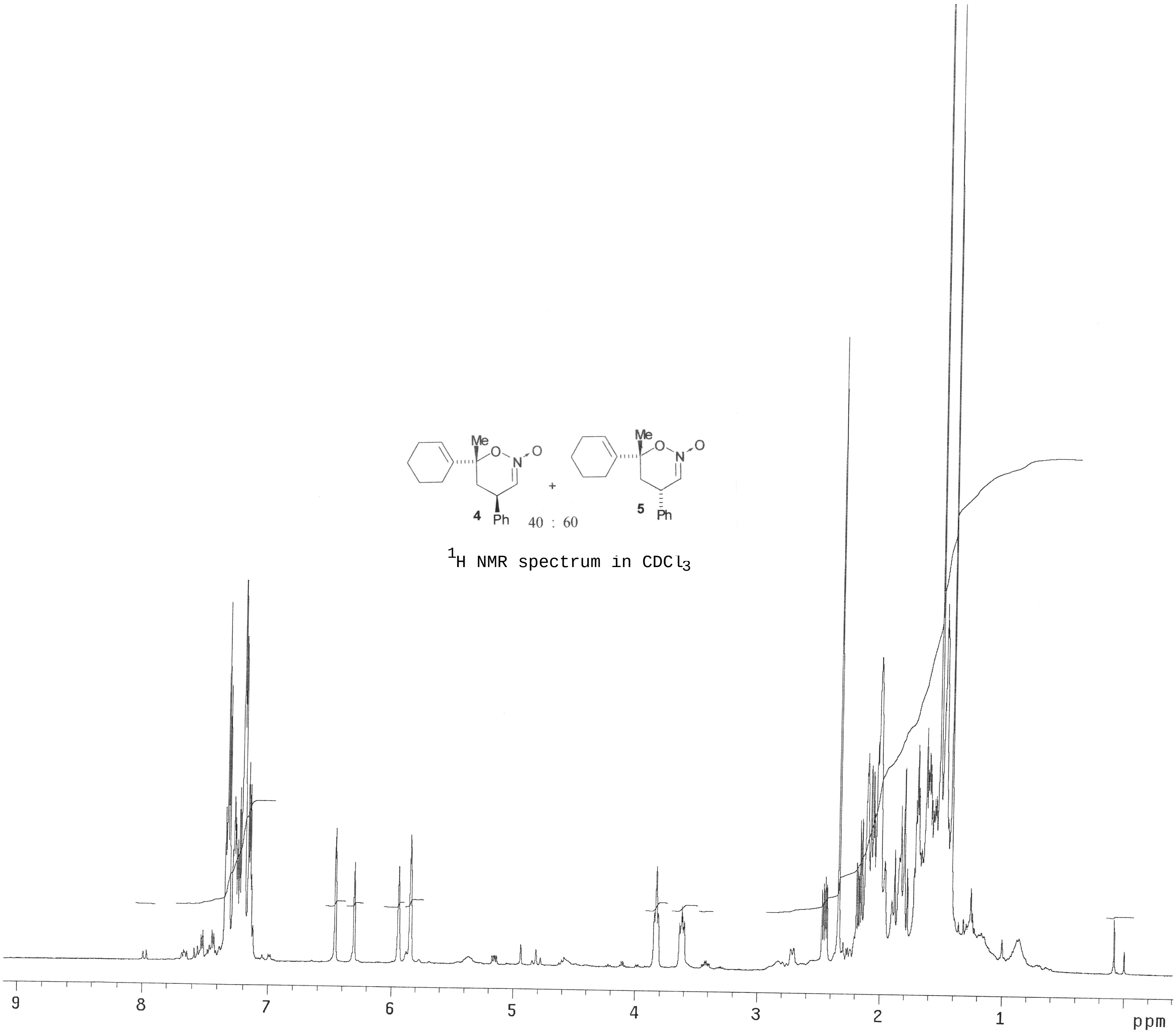

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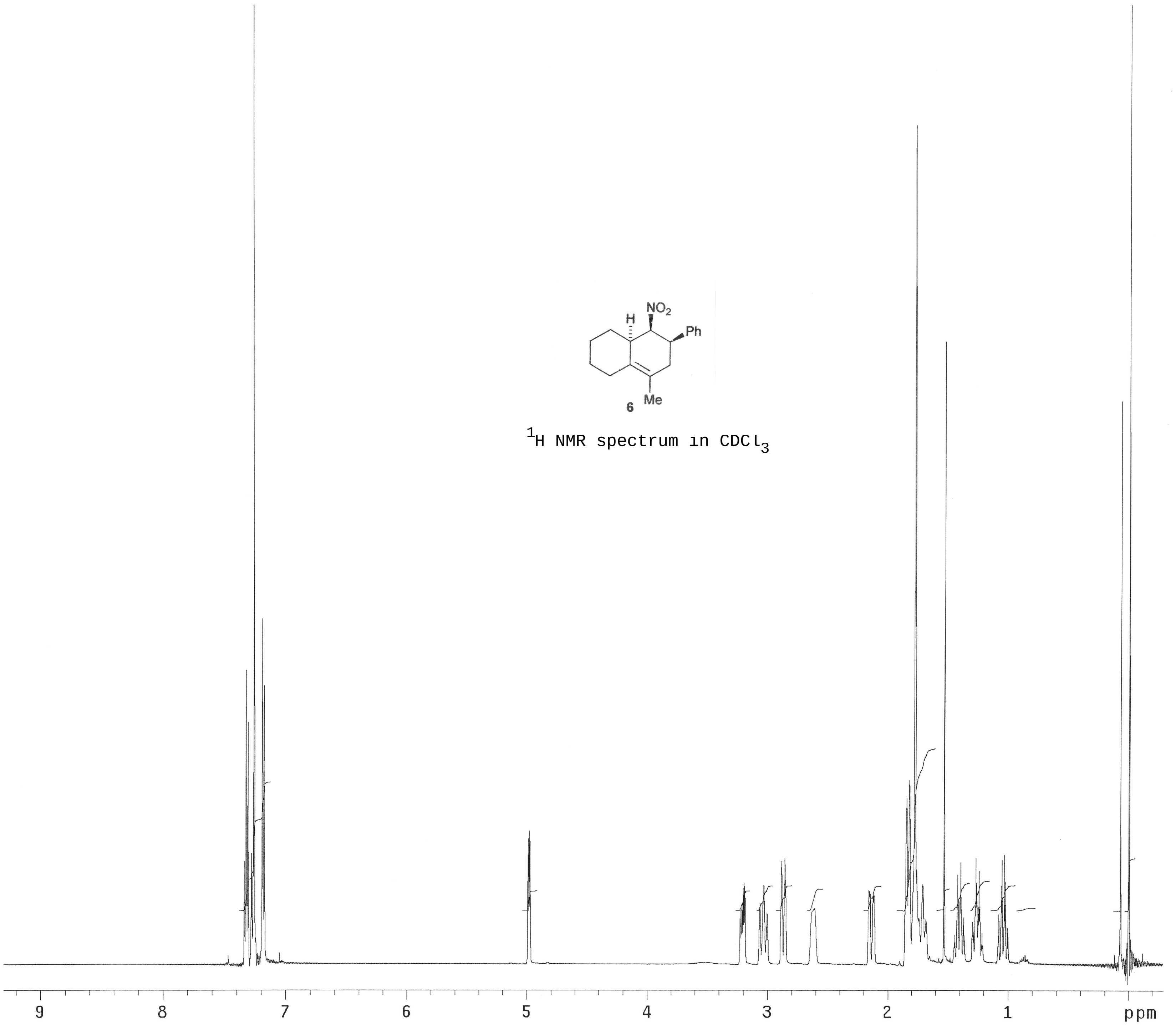
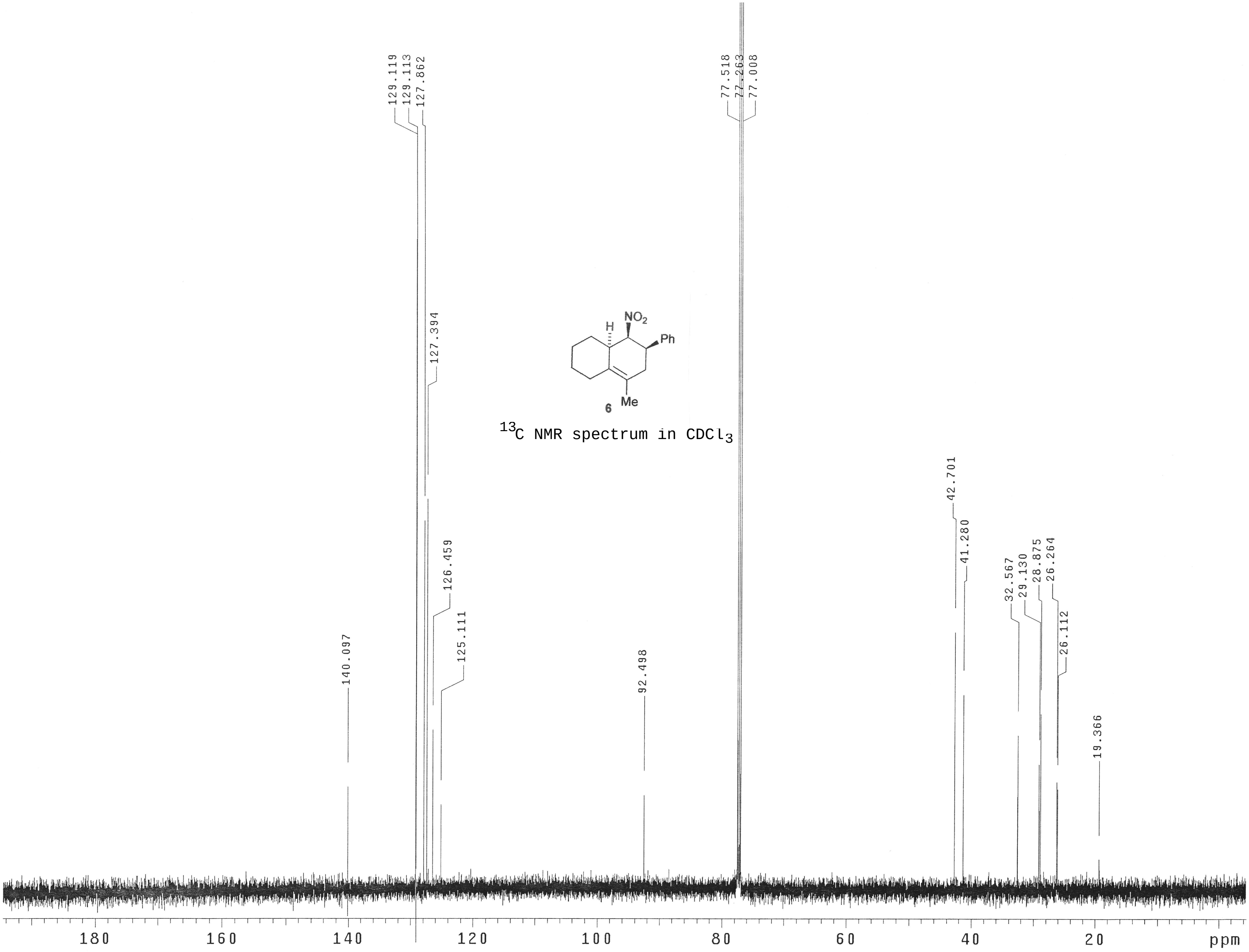


^{1}H NMR spectrum in CDCl$_3$

Supplementary Material (ESI) for Chemical Communications



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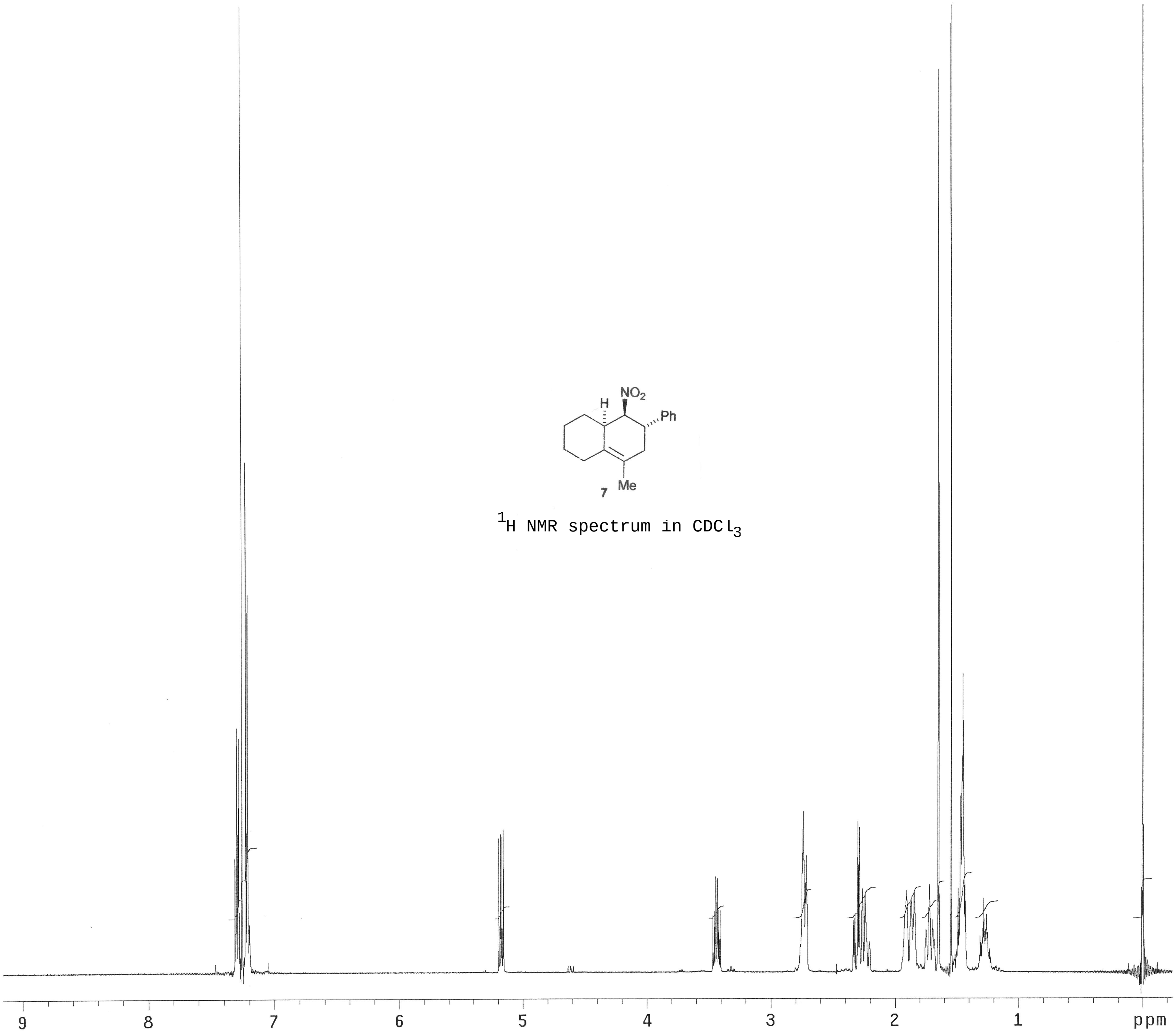

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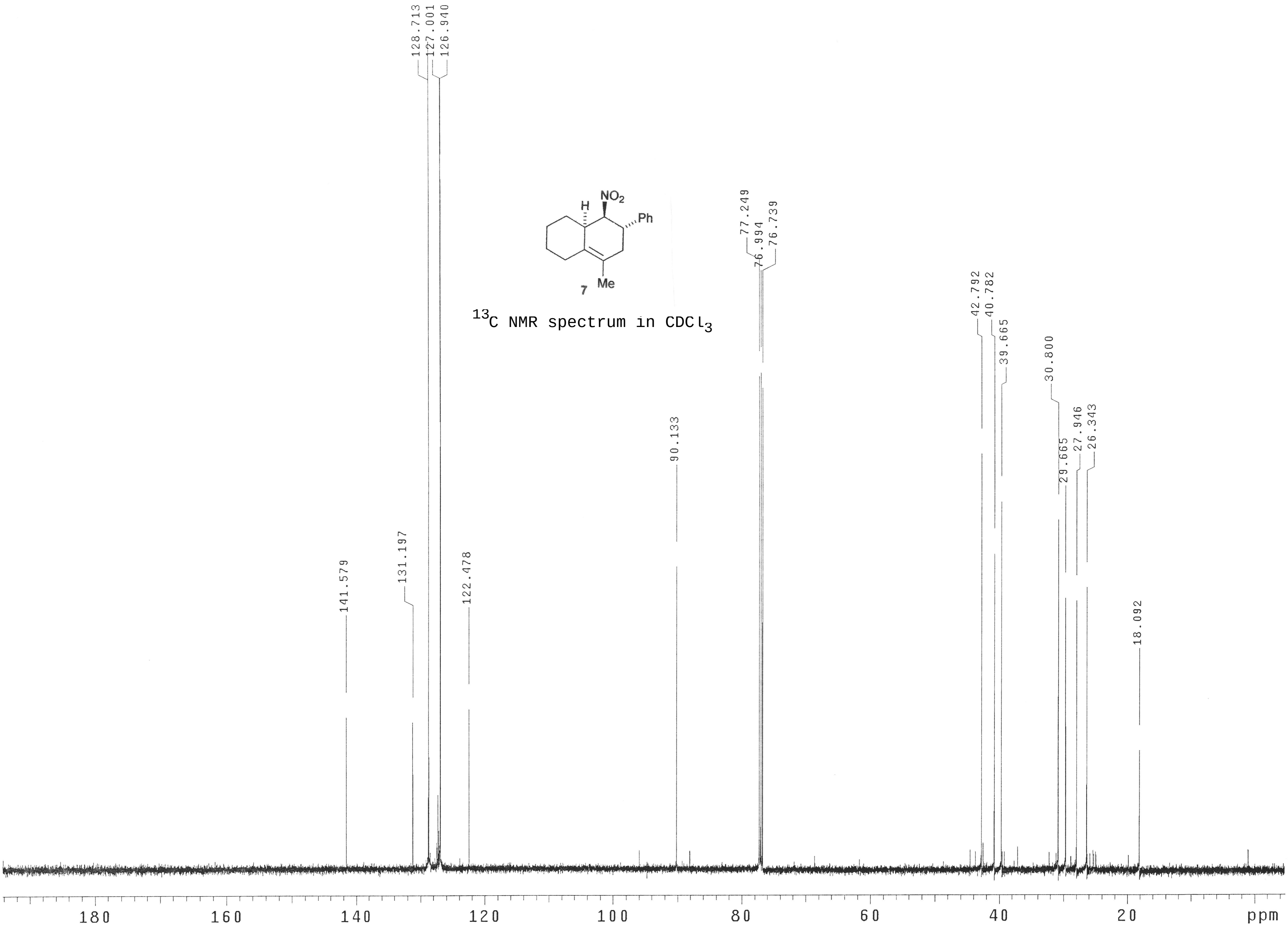

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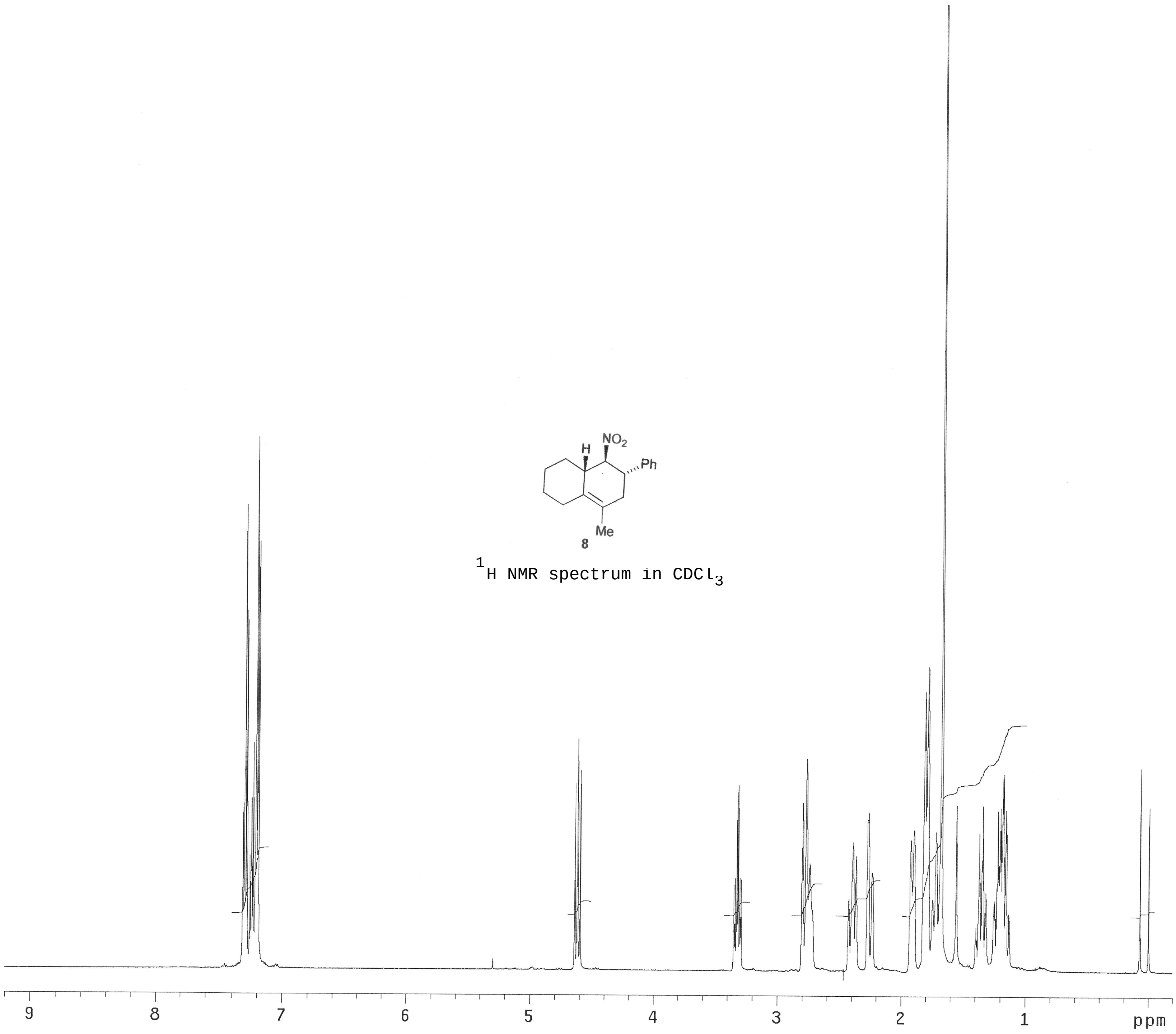

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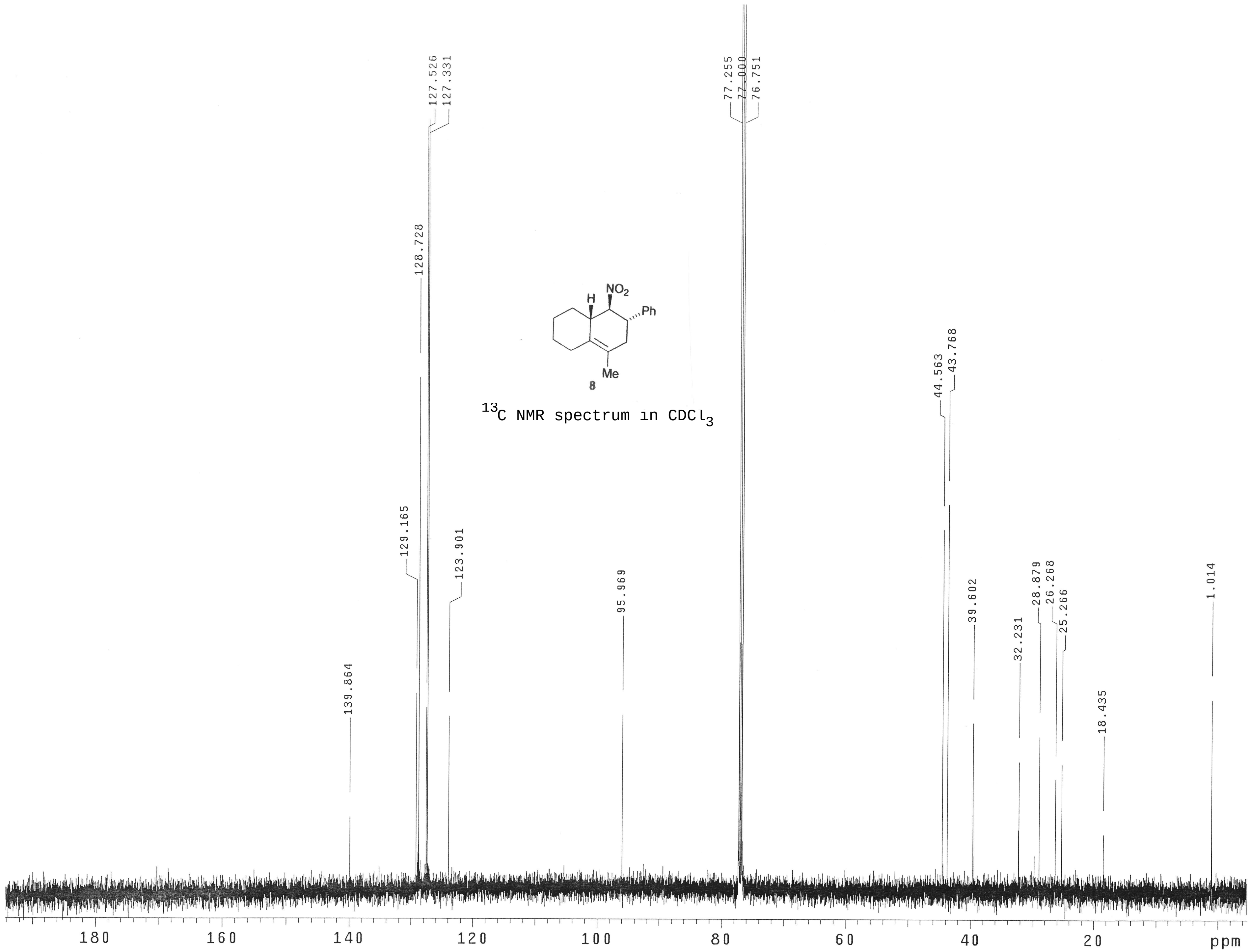

^{13}C NMR spectrum in $CDCl_3$