

Ruthenium-Catalyzed Hydro-Alkynylation Cyclization of 1, 6-Enynes Induced by Substituent Effects

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Supporting Information

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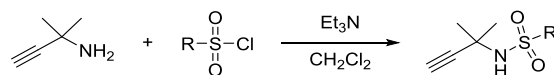
Part 1: General experimental procedures

All reactions, unless otherwise stated, were carried out under argon atmosphere using oven-dried (120 °C) glasswares. Reaction solvents were degassed and purified according to the standard procedures.¹ Toluene was distilled from lithium aluminum hydride. Diethyl ether and tetrahydrofuran were distilled from sodium (benzophenone ketyl). 1,2-dimethoxyethane, dichloromethane, acetonitrile and N, N-dimethylformamide were distilled from calcium hydride. Acetone was refluxed over potassium permanganate before being distilled. A fraction of petroleum distilled between 40-55 °C was used for column chromatography. All ruthenium complexes were purchased and used as received. Analytical TLC was performed on ready-made plates coated with silica gel on aluminum (Merck 60 F₂₅₄) using UV light and *p*-anisaldehyde with heating as developing agent.

Flash chromatography was performed using E. Merck silica gel 60 (230-400 mesh) according to the protocol of Still, Khan and Mitra.² ¹H NMR spectra were recorded on either a Bruker Avance DPX-300 or DPX-400 spectrometer as solutions in deuteriochloroform (CDCl₃), unless otherwise indicated. Chemical shifts are given in parts per million (δ units) downfield from tetramethylsilane using the residual solvent signal (CHCl₃ 7.26, benzene 7.15) as internal standard. ¹H NMR information is given in the following format: multiplicity (s, singlet; d, doublet; t, triplet; q, quartet; qui, quintet; sept, septet; m, multiplet), coupling constant(s) (J) in Hertz (Hz), number of protons. The prefix app is occasionally applied when the true signal multiplicity was unresolved and br indicates the signal in question broadened. Carbon (¹³C) NMR spectra are reported in ppm (δ) relative to residual CHCl₃ (δ 77.36) unless otherwise noted. High-resolution mass spectra (HRMS) were performed at the “Spectropôle” of Aix Marseille Université

Part 2: Preparations of 1, 6-enynes

Procedure A³

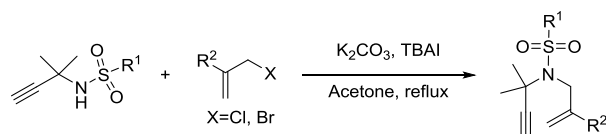


To a solution of 2-Methyl-3-butyn-2-amine (10 mmol) and Et₃N (20 mmol) in dry dichloromethane (30 mL) was added gradually the sulfonyl chloride (12 mmol) at 0 °C. Upon the completion of addition, the reaction solution was stirred overnight. Then the reaction mixture was washed with 10% HCl solution (50 mL), brine (30 mL), dried over Na₂SO₄, and evaporated under vacuum. Purification by flash chromatography over silica gel afforded the desired sulfonamide.

¹ Armarego, W. L. F.; Chai, C. L. L. *Purification of Laboratory Chemicals*, 5th Ed; Butterworth Heinemann: New York, **2003**.

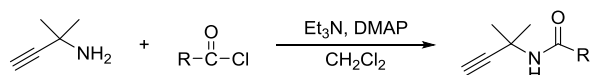
² Still, W. C.; Khan, M.; Mitra, A. *J. Org. Chem.* **1978**, *43*, 2923-2925.

³ Z. Ni, L. Giordano, A. Tenaglia, *Chem. Eur. J.* **2014**, *20*, 11703-11706.

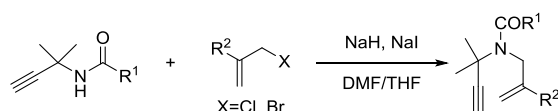


To a solution of sulfonamide (2 mmol) in acetone was added the allylic halide (4 mmol), potassium carbonate (4 mmol) and tetrabutylammonium iodide (0.2 mmol). The reaction solution was stirred overnight at 60 °C. The solvent was evaporated under vacuo. The residue was taken up in ethyl acetate, washed with distilled water (50 mL), brine (30 mL) and then dried over Na₂SO₄, concentrated under vacuo. The crude product was purified by flash chromatography.

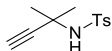
Procedure B³



To a solution of 2-Methyl-3-butyn-2-amine (10 mmol), Et₃N (20 mmol) and DMAP (1 mmol) in dry dichloromethane (30 mL) was gradually added the alkanoyl chloride (12 mmol) at 0 °C. The reaction solution was stirred overnight at room temperature, and then was washed with 10% HCl (50 mL), brine (30 mL), and dried over Na₂SO₄. After evaporation of the solvent under vacuum, the residue was purified by flash chromatography.

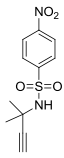


To a cooled (0 °C) suspension of sodium hydride (2 mmol) in THF/DMF (1/2, 20 mL) was slowly added the amide (2 mmol). The mixture was stirred for 1 h at 0 °C. Then, NaI (0.2 mmol) and allylic halide (2.2 mmol) were added. The mixture was warmed to rt and stirred until completion of the reaction (TLC monitoring). Saturated aqueous NH₄Cl (30 mL) was added at 0 °C and the resulting mixture was extracted with Et₂O (3 × 15 mL), washed with brine, dried over Na₂SO₄, and concentrated under vacuo. The crude residue was purified by column chromatography.

 **4-Methyl-N-(2-methylbut-3-yn-2-yl)benzenesulfonamide** was prepared according to procedure A; obtained: 1.73 g (73%), white solid; R_f (PE/Et₂O = 5: 5) 0.3;

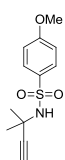
¹H NMR (400 MHz, Chloroform-*d*) δ 7.83 (d, *J* = 8.3 Hz, 2H), 7.30 (d, *J* = 8.1 Hz, 2H), 5.08 (br s, 1H), 2.44 (s, 3H), 2.11 (s, 1H), 1.56 (s, 6H).

¹³C NMR (75 MHz, Chloroform-*d*) δ 143.3 (C), 139.1 (C), 129.4 (CH x 2), 127.8 (CH x 2), 85.6 (C), 71.5 (CH), 50.0 (C), 31.0 (CH₃), 21.8 (CH₃ x 2).

 **N-(2-methylbut-3-yn-2-yl)-4-nitrobenzenesulfonamide** was prepared according to procedure A; obtained: 1.45 g (54%), faint yellow solid; R_f (PE/Et₂O = 6: 4) 0.4;

¹H NMR (300 MHz, Chloroform-*d*) δ 8.34 (d, *J* = 8.8 Hz, 2H), 8.11 (d, *J* = 8.8 Hz, 2H), 5.15 (s, 1H), 2.10 (s, 1H), 1.59 (s, 6H).

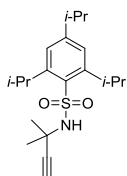
¹³C NMR (75 MHz, Chloroform-*d*) δ 150.3 (C), 147.6 (C), 129.2 (CH x 2), 124.2 (CH x 2), 84.8 (C), 72.5 (CH), 50.7 (C), 31.2 (CH₃ x 2).



4-Methoxy-N-(2-methylbut-3-yn-2-yl)benzenesulfonamide was prepared according to procedure **A**; obtained: 2.13 g (84%), white solid; R_f (PE/Et₂O =6: 4) 0.2;

¹H NMR (400 MHz, Chloroform-d) δ 7.84 (d, J = 8.9 Hz, 2H), 6.95 (d, J = 8.9 Hz, 2H), 4.82 (s, 1H), 3.86 (s, 3H), 2.10 (s, 1H), 1.54 (s, 6H).

¹³C NMR (75 MHz, Chloroform-d) δ 163.0 (C), 133.8 (C), 130.0 (CH x 2), 114.0 (CH x 2), 85.8 (C), 71.5 (CH), 55.9 (CH₃), 50.0 (C), 31.0 (CH₃ x 2).



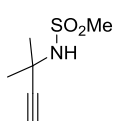
2,4,6-Triisopropyl-N-(2-methylbut-3-yn-2-yl)benzenesulfonamide was prepared according to procedure **A**; obtained: 1.47 g (42%), white solid; R_f (PE/Et₂O =8: 2) 0.3;

¹H NMR (400 MHz, Chloroform-d) δ 7.13 (s, 2H), 4.59 (s, 1H), 4.20 (hept, J = 6.7 Hz, 2H), 2.89 (hept, J = 6.9 Hz, 1H), 2.07 (s, 1H), 1.56 (s, 6H), 1.28 (d, J = 6.8 Hz, 12H), 1.24 (d, J = 6.9 Hz, 6H).

¹³C NMR (75 MHz, Chloroform-d) δ 152.9 (C), 150.2 (C x 2), 135.0 (C), 123.9 (CH x 2), 86.0 (C), 71.3 (CH), 50.6 (C), 34.5 (CH x 2), 31.1 (CH₃ x 2), 29.8 (CH), 25.1 (CH₃ x 4), 24.0 (CH₃ x 2).

IR (neat) ν : 3302, 3054, 2964, 2118, 1980, 1600, 1264, 1217, 732, 703, 549 cm⁻¹.

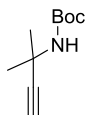
MS m/z (ESI-MS) calcd. for ([M+Na⁺]): C₂₀H₃₁NO₂SN⁺ 372.20, Found 372.23.



N-(2-methylbut-3-yn-2-yl)methanesulfonamide was prepared according to procedure **A**; obtained: 1.45 g (90%), colorless oil; R_f (PE/Et₂O =6: 4) 0.3;

¹H NMR (300 MHz, Chloroform-d) δ 4.72 (br s, 1H), 3.16 (s, 3H), 2.50 (s, 1H), 1.63 (s, 6H).

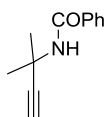
¹³C NMR (75 MHz, Chloroform-d) δ 86.2 (C), 72.1 (CH), 50.1 (C), 42.9 (CH₃), 31.4 (CH₃ x 2).



tert-Butyl (2-methylbut-3-yn-2-yl)carbamate was prepared according to procedure **B**; obtained: 1.78 g (97%), white solid; R_f (PE/Et₂O =6: 4) 0.2;

¹H NMR (300 MHz, Chloroform-d) δ 4.75 (br s, 1H), 2.23 (s, 1H), 1.51 (s, 6H), 1.38 (s, 9H).

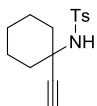
¹³C NMR (75 MHz, Chloroform-d) δ 154.3 (C), 87.7 (C), 79.8 (CH), 68.9 (C), 47.2 (C), 29.7 (CH₃ x 2), 28.6 (CH₃ x 3).



N-(2-methylbut-3-yn-2-yl)benzamine was prepared according to procedure **B**; obtained: 1.69 g (90%), white solid; R_f (PE/Et₂O =6: 4) 0.3;

¹H NMR (400 MHz, Chloroform-d) δ 7.75 – 7.73 (m, 2H), 7.48 – 7.43 (m, 1H), 7.39 – 7.35 (m, 2H), 6.35 (brs, 1H), 2.37 (s, 1H), 1.74 (s, 6H).

¹³C NMR (75 MHz, Chloroform-d) δ 166.8 (C), 135.0 (C), 131.7 (CH), 128.7 (CH x 2), 127.2 (CH x 2), 87.4 (C), 69.6 (CH), 48.2 (C), 29.3 (CH₃ x 2).

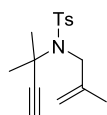


N-(1-ethynylcyclohexyl)-4-methylbenzenesulfonamide was prepared according to

procedure **A**; obtained: 1.61 g (58%), white solid; R_f (PE/Et₂O =6: 4) 0.3;

¹H NMR (400 MHz, Chloroform-d) δ 7.80 (d, J = 8.3 Hz, 2H), 7.26 (d, J = 8.0 Hz, 2H), 5.14 (s, 1H), 2.41 (s, 3H), 2.11 (s, 1H), 2.02 – 1.98 (m, 2H), 1.67 – 1.51 (m, 7H), 1.19 – 1.16 (m, 1H).

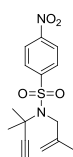
¹³C NMR (75 MHz, Chloroform-d) δ 143.1 (C), 139.5 (C), 129.3 (CH x 2), 127.8 (CH x 2), 83.9 (C), 74.0 (CH), 54.4 (C), 38.9 (CH₂ x 2), 25.1 (CH₂), 22.5 (CH₂ x 2), 21.7 (CH₃).



4-Methyl-N-(2-methylallyl)-N-(2-methylbut-3-yn-2-yl) benzenesulfonamide (1a) was prepared according to procedure **A**; obtained: 542 mg (93%), white solid; R_f (PE/Et₂O =8: 2) 0.5;

¹H NMR (400 MHz, Chloroform-d) δ 7.73 (d, J = 8.4 Hz, 2H), 7.26 (d, J = 8.4 Hz, 2H), 5.09 (s, 1H), 4.94 – 4.93 (m, 1H), 4.10 (s, 2H), 2.41 (s, 3H), 2.19 (s, 1H), 1.79 (s, 3H), 1.65 (s, 6H).

¹³C NMR (75 MHz, Chloroform-d) δ 143.3 (C), 143.2 (C), 139.4 (C), 129.5 (CH x 2), 127.8 (CH x 2), 112.5 (CH₂), 86.1 (C), 72.0 (CH), 56.6 (C), 54.1 (CH₂), 31.1 (CH₃ x 2), 21.8 (CH₃), 20.5 (CH₃).



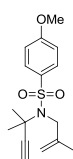
N-(2-methylallyl)-N-(2-methylbut-3-yn-2-yl)-4-nitrobenzenesulfonamide (1c) was prepared according to procedure **A**; obtained: 554 mg (86%), white solid; R_f (PE/Et₂O =8: 2) 0.5;

¹H NMR (400 MHz, Chloroform-d) δ 8.32 (d, J = 8.9 Hz, 2H), 8.04 (d, J = 8.9 Hz, 2H), 5.06 (s, 1H), 4.98 (s, 1H), 4.16 (s, 2H), 2.24 (s, 1H), 1.80 (s, 3H), 1.68 (s, 6H).

¹³C NMR (75 MHz, Chloroform-d) δ 149.9 (C), 147.8 (C), 142.4 (C), 128.9 (CH x 2), 124.1 (CH x 2), 113.1 (CH₂), 85.3 (C), 72.9 (CH), 56.8 (C), 54.0 (CH₂), 30.9 (CH₃ x 2), 20.3 (CH₃).

IR (neat) ν : 3282, 2988, 2945, 2112, 1528, 1347, 1088, 854, 737, 564 cm⁻¹.

MS m/z (ESI-MS) calcd. for ([M+H⁺]): C₁₅H₁₉N₂O₄S⁺ 323.11, Found 323.12.



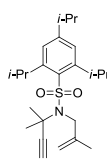
4-Methoxy-N-(2-methylallyl)-N-(2-methylbut-3-yn-2-yl)benzenesulfonamide (1d) was prepared according to procedure **A**; obtained: 553 mg (90%), white solid; R_f (PE/Et₂O =7: 3) 0.3;

¹H NMR (300 MHz, Chloroform-d) δ 7.78 (d, J = 8.9 Hz, 2H), 6.93 (d, J = 8.9 Hz, 2H), 5.08 (s, 1H), 4.93 (s, 1H), 4.07 (s, 2H), 3.86 (s, 3H), 2.19 (s, 1H), 1.78 (s, 3H), 1.65 (s, 6H).

¹³C NMR (75 MHz, Chloroform-d) δ 162.9 (C), 143.3 (C), 134.1 (C), 130.0 (CH x 2), 114.1 (CH x 2), 112.4 (CH₂), 86.3 (C), 71.8 (CH), 56.6 (C), 55.9 (CH₃), 54.1 (CH₂), 31.2 (CH₃ x 2), 20.6 (CH₃).

IR (neat) ν : 3273, 3077, 2985, 2841, 2113, 1659, 1579, 1442, 1258, 1091, 992, 833, 776, 627, 573 cm⁻¹.

MS m/z (ESI-MS) calcd. for ([M+H⁺]): C₁₆H₂₂NO₃S⁺ 308.13, Found 308.18.



2,4,6-Triisopropyl-N-(2-methylallyl)-N-(2-methylbut-3-yn-2-yl)benzenesulfonamide (1e) was prepared according to procedure **A**; obtained: 743 mg (92%), white solid; R_f (PE/Et₂O =9: 1) 0.6;

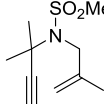
¹H NMR (400 MHz, Chloroform-d) δ 7.11 (s, 2H), 5.06 (s, 1H), 4.87 (s, 1H), 4.18 (s,

2H), 4.12 (hept, $J = 6.9$ Hz, 2H), 2.88 (hept, $J = 6.9$ Hz, 1H), 2.38 (s, 1H), 1.78 (s, 3H), 1.66 (s, 6H), 1.26 (d, $J = 6.7$ Hz, 12H), 1.24 (d, $J = 6.9$ Hz, 6H).

^{13}C NMR (75 MHz, Chloroform- d) δ 152.9 (C), 150.4 (C x 2), 143.6 (C), 136.7 (C), 124.1 (CH x 2), 114.1 (CH₂), 87.0 (C), 72.4 (CH), 57.1 (C), 53.5 (CH₂), 34.4 (CH x 2), 30.4 (CH₃ x 2), 29.3 (CH), 25.1 (CH₃ x 4), 24.0 (CH₃ x 2), 20.8 (CH₃).

IR (neat) ν : 3301, 3055, 2963, 2118, 1600, 1422, 1315, 1264, 991, 731, 703, 571 cm^{-1} .

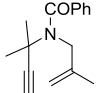
MS m/z (ESI-MS) calcd. for $([\text{M}+\text{H}^+])$: C₂₄H₃₈NO₂S⁺ 404.26, Found 404.32.

 ***N*-(2-methylallyl)-*N*-(2-methylbut-3-yn-2-yl)methanesulfonamide (1f)** was prepared according to procedure A; obtained: 396 mg (92%), white solid; R_f (PE/Et₂O = 6: 4) 0.4;

^1H NMR (300 MHz, Chloroform- d) δ 5.07 (s, 1H), 4.94 (s, 1H), 3.91 (s, 2H), 3.04 (s, 3H), 2.48 (s, 1H), 1.77 (s, 3H), 1.71 (s, 6H).

^{13}C NMR (75 MHz, Chloroform- d) δ 143.0 (C), 111.9 (CH₂), 86.5 (C), 72.3 (CH), 56.1 (C), 52.8 (CH₂), 41.1 (CH₃), 31.1 (CH₃ x 2), 20.4 (CH₃).

MS m/z (ESI-MS) calcd. for $([\text{M}+\text{Na}^+])$: C₁₀H₁₇NO₂SN⁺ 238.09, Found 238.10.

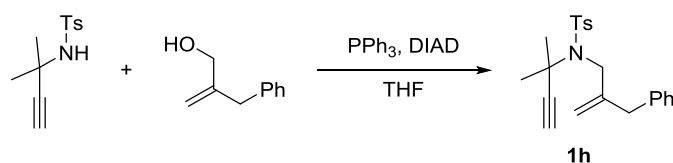
 ***N*-(2-methylallyl)-*N*-(2-methylbut-3-yn-2-yl)benzamide (1g)** was prepared according to procedure B; obtained: 348 mg (72%), white solid; R_f (PE/Et₂O = 7: 3) 0.5;

^1H NMR (400 MHz, Chloroform- d) δ 7.44 – 7.43 (m, 2H), 7.36 – 7.32 (m, 3H), 5.11 (s, 1H), 5.00 (s, 1H), 3.95 (s, 2H), 2.44 (s, 1H), 1.89 (s, 6H), 1.55 (s, 3H).

^{13}C NMR (75 MHz, Chloroform- d) δ 173.0 (C), 143.5 (C), 138.6 (C), 129.6 (CH), 128.4 (CH x 2), 126.5 (CH x 2), 112.5 (CH₂), 87.8 (C), 71.6 (CH), 55.5 (C), 54.7 (CH₂), 28.6 (CH₃ x 2), 20.4 (CH₃).

MS m/z (ESI-MS) calcd. for $([\text{M}+\text{H}^+])$: C₁₆H₂₀NO⁺ 242.15, Found 242.13.

***N*-(2-benzylallyl)-4-methyl-*N*-(2-methylbut-3-yn-2-yl)benzenesulfonamide (1h)**



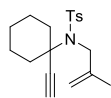
To a stirred and cooled (0 °C) solution of 4-methyl-*N*-(2-methylbut-3-yn-2-yl) benzenesulfonamide (474.6 mg, 2.0 mmol), 2-benzylprop-2-en-1-ol (296.4 mg, 2.0 mmol) and PPh₃ (524.6 mg, 2.0 mmol) in THF (10 mL) was slowly added diisopropylazodicarboxylate (404.4 mg, 2.0 mmol). The resulting mixture was warmed to room temperature and stirred for 12 h. Then the solvent was removed under vacuo and the residue was purified by flash chromatography to give 338 mg (46%) of **1h** as a white solid, R_f (PE/Et₂O = 7: 3) 0.5.

^1H NMR (400 MHz, Chloroform- d) δ 7.68 (d, $J = 8.3$ Hz, 2H), 7.32 – 7.27 (m, 2H), 7.25 – 7.19 (m, 5H), 5.27 (s, 1H), 4.92 (h, $J = 1.5$ Hz, 1H), 4.06 (s, 2H), 3.40 (s, 2H), 2.41 (s, 3H), 2.11 (s, 1H), 1.62 (s, 6H).

¹³C NMR (101 MHz, Chloroform-*d*) δ 146.0 (C), 139.1 (C), 139.1 (C), 139.0 (C), 129.6 (CH x 2), 129.5 (CH x 2), 128.7 (CH x 2), 128.0 (CH x 2), 126.6 (CH₂), 113.6 (CH₂), 86.2 (C), 71.86 (C), 56.79 (C), 52.87 (CH₂), 41.18 (CH₂), 31.12 (CH₃ x 2), 21.84 (CH₃).

IR (neat) ν : 3280, 3061, 2988, 2925, 2114, 1655, 1494, 1387, 1264, 1149, 1089, 813, 775, 543 cm⁻¹.

MS *m/z* (ESI-MS) calcd. for ([M+Na⁺]): C₂₂H₂₆NO₂S⁺ 368.17, Found 368.20.

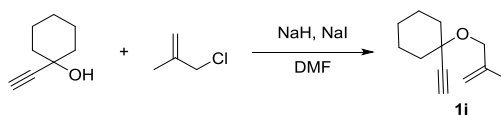


***N*-(1-ethynylcyclohexyl)-4-methyl-*N*-(2-methylallyl)benzenesulfonamide (1i)** was prepared according to procedure A; obtained: 650 mg (98%), white solid; *R_f* (PE/Et₂O =8/2) 0.5;

¹H NMR (400 MHz, Chloroform-*d*) δ 7.72 (d, *J* = 8.4 Hz, 2H), 7.25 (d, *J* = 8.4 Hz, 2H), 5.12 (s, 1H), 4.94 (p, *J* = 1.5 Hz, 1H), 4.11 (s, 2H), 2.41 (s, 3H), 2.24 (s, 1H), 2.07 (d, *J* = 11.2 Hz, 2H), 1.88 (td, *J* = 12.6, 3.6 Hz, 2H), 1.80 (s, 3H), 1.67 – 1.57 (m, 3H), 1.55 – 1.51 (m, 2H), 1.16 – 1.04 (m, 1H).

¹³C NMR (75 MHz, Chloroform-*d*) δ 143.6 (C), 143.2 (C), 139.7 (C), 129.5 (CH x 2), 127.8 (CH x 2), 112.2 (CH₂), 83.5 (C), 75.3 (CH), 62.6 (C), 53.8 (CH₂), 38.0 (CH₂ x 2), 25.0 (CH₂), 23.8 (CH₂ x 2), 21.8 (CH₃), 20.7 (CH₃).

1-Ethynyl-1-((2-methylallyl)oxy)cyclohexane (1j)⁴

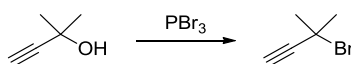


To a stirred and cooled (0 °C) suspension of NaH (400 mg, 10 mmol, 60% oil dispersion) in *N,N*-dimethylformamide (30 mL) was added 1-ethynylcyclohexanol (1.24, 10 mmol) portionwise. After 30 min, NaI (149.9 mg, 1 mmol) and methallyl chloride (1.1 g, 12 mmol) were added. The resulting mixture was stirred overnight at rt, and then carefully treated with aqueous NH₄Cl solution (30 mL). The solution was extracted with Et₂O (3 × 10 mL), and the combined extracts were washed with brine, dried over Na₂SO₄, and concentrated in vacuo. The crude residue was purified by column chromatography to afford 1.13 g (63%) of **1j** as a colorless oil, *R_f* (PE) 0.3.

¹H NMR (300 MHz, Chloroform-*d*) δ 5.01 (s, 1H), 4.86 (s, 1H), 4.01 (s, 2H), 2.45 (s, 1H), 1.95 – 1.87 (m, 2H), 1.77 (s, 3H), 1.71 – 1.48 (m, 7H), 1.34 – 1.28 (m, 1H).

¹³C NMR (75 MHz, Chloroform-*d*) δ 143.3 (C), 111.7 (CH₂), 85.7 (C), 73.9 (C), 73.5 (CH), 67.5 (CH₂), 37.4 (CH₂ x 2), 25.7 (CH₂), 23.0 (CH₂ x 2), 20.14 (CH₃)

3-bromo-3-methylbut-1-yne⁵



To a flame-dried round flask containing 2-methyl-3-butyn-2-ol (84 g, 1.03 mol) cooled at 0 °C was added PBr₃ (92.0 g, 0.34 mol) dropwise over a 3 h period time. The reaction was warmed to rt and stirred for an additional 30 min. Distillation of the light green solution using a 10 cm Vigreux

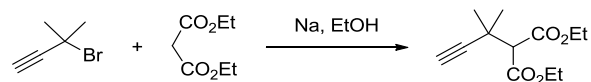
⁴ A Gans äter, M Pierobon, *Synlett*. **2000**, 9, 1357-1359.

⁵ B. M. Trost, Y. Hu, D. B. Horne, *J. Am. Chem. Soc.* **2007**, 129, 11781-11790.

column gave 41.2 g (28%) of desired product as a colorless oil (bp. 25-30 °C/55 mm Hg). ¹H NMR matched the reported data.

¹H NMR (300 MHz, Chloroform-*d*) δ 2.73 (s, 1H), 2.04 (s, 6H).

Diethyl 2-(2-methylbut-3-yn-2-yl)malonate⁶

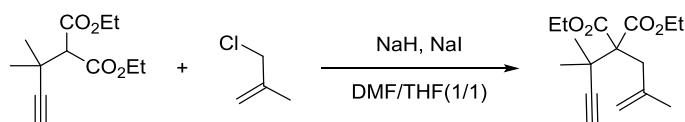


To a freshly prepared solution of sodium ethylate [sodium (460 mg, 0.02 mol)] in EtOH (50 mL) warmed at 60 °C was added dimethyl malonate (3.2 g, 0.02 mol). After 1 h, 3-bromo-3-methylbut-1-yne (2.9 g, 0.02 mol) was added and the mixture was stirred for 1 h at 65 °C, 30 min at 80 °C and finally 15 h at 50 °C. The resulting mixture was filtered and concentrated under vacuo. The residue was treated with ice-cooled conc. hydrochloric acid (20 mL) and extracted with Et₂O (6 x 15 mL). The combined organic layers were washed with water (2 x 30 mL) and a saturated NaHCO₃ solution (2 x 30 mL), dried over Na₂SO₄, and concentrated in vacuo. Distillation under reduced pressure using a 10 cm Vigreux column provided 1.89 g (42%) of desired product as a colorless oil (b.p. 98-101 °C/2-4 Torr). ¹H NMR matched the reported data.

¹H NMR (400 MHz, Chloroform-*d*) δ 4.21 (q, *J* = 7.1 Hz, 4H), 3.45 (s, 1H), 2.19 (s, 1H), 1.46 (s, 6H), 1.27 (t, *J* = 7.1 Hz, 6H).

¹³C NMR (75 MHz, Chloroform-*d*) δ 166.5 (C x 2), 88.1 (C), 68.6 (CH), 60.6 (CH₂ x 2), 59.7 (C), 31.8 (C), 26.8 (CH₃ x 2), 13.4 (CH₃ x 2).

Diethyl 2-(2-methylallyl)-2-(2-methylbut-3-yn-2-yl)malonate (1k)



To a cooled (0 °C) solution of sodium hydride (80 mg, 2 mmol, 60% oil dispersion) in THF/DMF (1/1, 20 mL) was slowly added diethyl 2-(2-methylbut-3-yn-2-yl)malonate (452.5 mg, 2 mmol). The mixture was stirred for 1 h at 0 °C. Then, NaI (30.0 mg, 0.2 mmol) and methallyl chloride (199.2 mg, 2.2 mmol) were added. The mixture was warmed to room temperature and stirred overnight. Saturated aqueous NH₄Cl (20 mL) was added at 0 °C, and the resulting mixture was extracted with Et₂O (3 x 10 mL). The combined extracts were washed with brine (20 mL), dried over Na₂SO₄, and concentrated in vacuo. The residue was purified by column chromatography to give 291.6 mg (52%) of **1k** as a colorless oil, *R*_f (PE/Et₂O = 19: 1) 0.5.

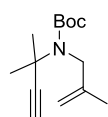
¹H NMR (400 MHz, Chloroform-*d*) δ 4.78 (p, *J* = 1.6 Hz, 1H), 4.74 (dt, *J* = 2.0, 1.0 Hz, 1H), 4.18 (q, *J* = 7.1 Hz, 4H), 2.98 (s, 2H), 2.25 (s, 1H), 1.74 (s, 3H), 1.43 (s, 6H), 1.27 (t, *J* = 7.1 Hz, 6H).

¹³C NMR (75 MHz, Chloroform-*d*) δ 169.8 (C x 2), 143.1 (C), 114.9 (CH₂), 89.7 (C), 70.6 (CH), 63.9 (C), 61.2 (CH₂ x 2), 40.6 (CH₂), 38.1 (C), 27.3 (CH₃ x 2), 24.1 (CH₃), 14.2 (CH₃ x 2).

IR (neat) ν: 3307, 3273, 2981, 2935, 2358, 2164, 1882, 1303, 1242, 1067, 644 cm⁻¹.

⁶ B. Stulgies, P. Prinz, J. Magull, K. Rauch, K. Meindl, S. Rühl, A. de Meijere, *Chem. Eur. J.* **2005**, *11*, 308-320.

MS *m/z* (ESI-MS) calcd. for ([M+H]⁺): C₁₆H₂₅O₄⁺ 281,17 Found 281,22.

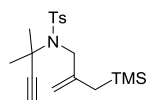


tert-Butyl (2-methylallyl)(2-methylbut-3-yn-2-yl)carbamate (1l) was prepared according to procedure **B**; obtained: 403 mg (85%), colorless; *R_f* (PE/Et₂O = 8: 2) 0.5;

¹H NMR (400 MHz, Chloroform-*d*) δ 4.86 (dd, *J* = 1.7, 0.9 Hz, 1H), 4.85 – 4.82 (m, 1H), 3.98 (td, *J* = 1.7, 0.8 Hz, 2H), 2.36 (s, 1H), 1.71 (dt, *J* = 1.6, 0.8 Hz, 3H), 1.70 (s, 6H), 1.46 (s, 9H).

¹³C NMR (75 MHz, Chloroform-*d*) δ 155.10 (C), 143.44 (C), 109.95 (CH₂), 88.50 (C), 80.24 (C), 70.60 (CH), 53.76 (C), 51.53 (CH₂), 29.55 (CH₃ x 2), 28.67 (CH₃ x 3), 20.32 (CH₃).

MS *m/z* (ESI-MS) calcd. for ([M+H]⁺): C₁₄H₂₄NO₂⁺ 238.18, Found 238.17.



4-Methyl-N-(2-methylbut-3-yn-2-yl)-N-(2-((trimethylsilyl)methyl)allyl)benzenesulfonamide (1m) was prepared according to procedure **A**; obtained: 516 mg (71%), colorless oil; *R_f* (PE/Et₂O = 9: 1) 0.5;

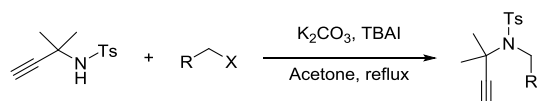
¹H NMR (400 MHz, Chloroform-*d*) δ 7.73 (d, *J* = 8.3 Hz, 2H), 7.25 (d, *J* = 8.1 Hz, 2H), 5.04 (m, 1H), 4.76 (s, 1H), 4.01 (s, 2H), 2.41 (s, 3H), 2.18 (s, 1H), 1.66 (s, 6H), 1.55 (s, 2H), 0.07 (s, 9H).

¹³C NMR (75 MHz, Chloroform-*d*) δ 145.4 (C), 144.3 (C), 140.5 (C), 130.5 (CH x 2), 128.9 (CH x 2), 110.6 (CH₂), 87.4 (C), 72.7 (CH), 57.5 (C), 55.7 (CH₂), 32.2 (CH₃ x 2), 25.5 (CH₂), 22.8 (CH₃), 0.09 (CH₃ x 3).

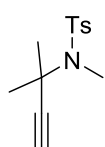
IR (neat) *v*: 3268, 2988, 2951, 2112, 1645, 1418, 1149, 1089, 889, 838, 659, 541 cm⁻¹.

MS *m/z* (ESI-MS) calcd. for ([M+Na]⁺): C₁₉H₂₉NO₂SN₂Si⁺ 386.16, Found 386.28.

Procedure C: *N*-alkylation of 4-methyl-N-(2-methylbut-3-yn-2-yl)benzenesulfonamide



To a solution of 4-methyl-N-(2-methylbut-3-yn-2-yl)benzenesulfonamide (474.6 mg, 2 mmol) in acetone (20 mL) was added the alkyl halide (4 mmol), potassium carbonate (552.8 mg, 4 mmol) and tetrabutylammonium iodide (73.9 mg, 0.2 mmol). The resulting mixture was stirred overnight at 60 °C and then evaporated under vacuo. The residue was taken up in ethyl acetate (30 mL), washed with brine (30 mL), dried over Na₂SO₄, and concentrated under vacuo. The crude product was purified by flash chromatography.



N,4-dimethyl-N-(2-methylbut-3-yn-2-yl)benzenesulfonamide (6a) was prepared according to procedure **C** using iodomethane, obtained: 462 mg (92%), white solid; *R_f* (PE/Et₂O = 9: 1) 0.5.

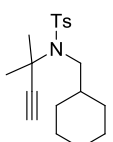
¹H NMR (300 MHz, Chloroform-*d*) δ 7.72 (d, *J* = 8.3 Hz, 2H), 7.27 (d, *J* = 8.5 Hz, 2H), 3.08 (s, 3H), 2.41 (s, 3H), 2.23 (s, 1H), 1.67 (s, 6H).

¹³C NMR (75 MHz, Chloroform-*d*) δ 143.4 (C), 138.8 (C), 129.7 (CH x 2), 127.7 (CH x 2), 85.8

(C), 72.1 (CH), 55.9 (C), 34.5 (CH₃), 30.2 (CH₃ x 2), 21.8 (CH₃).

IR (neat) ν : 3271, 2989, 2942, 2112, 1968, 1495, 1461, 1365, 1245, 905, 706, 546 cm⁻¹.

MS m/z (ESI-MS) calcd. for ([M+H⁺]): C₁₃H₁₈NO₂S⁺ 252,11 Found 252.10.

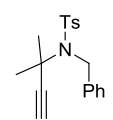
 ***N*-(cyclohexylmethyl)-4-methyl-*N*-(2-methylbut-3-yn-2-yl)benzenesulfonamide (6b)** was prepared according to procedure **C** using (bromomethyl)cyclohexane, obtained: 480 mg (72%), white solid; R_f (PE/Et₂O =9: 1) 0.4.

¹H NMR (300 MHz, Chloroform-*d*) δ 7.69 (d, J = 8.3 Hz, 2H), 7.25 (d, J = 7.2 Hz, 2H), 3.43 (d, J = 6.7 Hz, 2H), 2.40 (s, 3H), 2.28 (s, 1H), 1.89 – 1.67 (m, 6H), 1.65 (s, 6H), 1.26 – 1.18 (m, 3H), 1.06 – 0.86 (m, 2H).

¹³C NMR (75 MHz, Chloroform-*d*) δ 142.0 (C), 140.1 (C), 128.6 (CH x 2), 126.4 (CH x 2), 85.8 (C), 71.4 (CH), 55.5 (C), 54.6 (CH₂), 38.1 (CH), 30.28 (CH₃ x 2), 30.25 (CH₂ x 2), 25.9 (CH₂), 25.6 (CH₂ x 2), 20.8 (CH₃).

IR (neat) ν : 3267, 2984, 2924, 2850, 2111, 1495, 1329, 1154, 1144, 991, 902, 812, 647, 542 cm⁻¹.

MS m/z (ESI-MS) calcd. for ([M+H⁺]): C₁₉H₂₈NO₂S⁺ 334,18 Found 334,25.

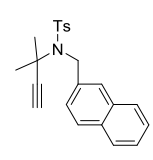
 ***N*-benzyl-4-methyl-*N*-(2-methylbut-3-yn-2-yl)benzenesulfonamide (6c)** was prepared according to procedure **C** using (bromomethyl)benzene, obtained: 616 mg (94%), white solid; R_f (PE/Et₂O =9: 1) 0.6.

¹H NMR (400 MHz, Chloroform-*d*) δ 7.66 (d, J = 8.1 Hz, 2H), 7.48 (d, J = 7.5 Hz, 2H), 7.32 (d, J = 7.8 Hz, 2H), 7.27 – 7.23 (m, 3H), 4.82 (s, 2H), 2.40 (s, 3H), 2.26 (s, 1H), 1.61 (s, 6H).

¹³C NMR (75 MHz, Chloroform-*d*) δ 143.3 (C), 139.7 (C), 139.6 (C), 129.6 (CH x 2), 128.6 (CH x 2), 127.9 (CH x 2), 127.7 (CH x 2), 127.3 (CH), 86.4 (C), 72.5 (CH), 57.2 (C), 52.4 (CH₂), 31.2 (CH₃ x 2), 21.8 (CH₃).

IR (neat) ν : 3297, 3086, 3028, 2845, 2102, 1603, 1496, 1437, 1203, 1072, 912, 739, 639, 548 cm⁻¹.

MS m/z (ESI-MS) calcd. for ([M+H⁺]): C₁₉H₂₂NO₂S⁺ 328,14 Found 328,29.

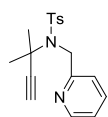
 **4-Methyl-*N*-(2-methylbut-3-yn-2-yl)-*N*-(naphthalen-2-ylmethyl)benzenesulfonamide (6d)** was prepared according to procedure **C** using 2-(bromomethyl)naphthalene, obtained: 732 mg (97%), white solid; R_f (PE/EA =8: 2) 0.3.

¹H NMR (300 MHz, Chloroform-*d*) δ 7.86 – 7.80 (m, 4H), 7.72 – 7.69 (m, 2H), 7.63 (dd, J = 8.6, 1.8 Hz, 1H), 7.48 – 7.44 (m, 2H), 7.23 (d, J = 8.1 Hz, 2H), 4.99 (s, 2H), 2.39 (s, 3H), 2.28 (s, 1H), 1.64 (s, 6H).

¹³C NMR (75 MHz, Chloroform-*d*) δ 143.4 (C), 139.7 (C), 137.3 (C), 133.6 (C), 133.0 (C), 129.6 (CH x 2), 128.3 (CH), 128.2 (CH), 127.9 (CH), 127.8 (CH x 2), 126.7 (CH), 126.3 (CH), 126.02 (CH), 125.99 (CH), 86.52 (C), 72.65 (CH), 57.4 (C), 52.6 (CH₂), 31.33 (CH₃ x 2), 21.73 (CH₃).

IR (neat) ν : 3284, 2987, 2942, 2111, 1633, 1599, 1330, 1148, 1089, 936, 812, 655, 572 cm⁻¹.

MS m/z (ESI-MS) calcd. for ([M+H⁺]): C₂₃H₂₄NO₂S⁺ 378,15 Found 378,26.



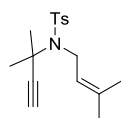
4-Methyl-N-(2-methylbut-3-yn-2-yl)-N-(pyridin-2-ylmethyl)benzenesulfonamide (6e) was prepared according to procedure **C** using 2-(bromomethyl)pyridine, obtained: 611 mg (93%), white solid; R_f (PE/EA = 7: 3) 0.3.

^1H NMR (300 MHz, Chloroform-*d*) δ 8.50 (dt, J = 4.9, 1.2 Hz, 1H), 7.80 – 7.77 (m, 2H), 7.74 – 7.66 (m, 2H), 7.30 – 7.26 (m, 2H), 7.16 (ddd, J = 6.9, 4.9, 1.9 Hz, 1H), 4.88 (s, 2H), 2.42 (s, 3H), 2.12 (s, 1H), 1.60 (s, 6H).

^{13}C NMR (75 MHz, Chloroform-*d*) δ 160.0 (C), 148.9 (CH), 143.6 (C), 138.6 (C), 136.9 (CH), 129.7 (CH x 2), 127.9 (CH x 2), 122.21 (CH), 122.16 (CH), 85.5 (C), 72.3 (CH), 56.8 (C), 54.3 (CH₂), 31.2 (CH₃ x 2), 21.8 (CH₃).

IR (neat) ν : 3286, 3054, 2939, 2115, 1632, 1509, 1494, 1305, 1233, 1089, 951, 813, 705, 572 cm⁻¹.

MS m/z (ESI-MS) calcd. for ([M+H⁺]): C₁₈H₂₁N₂O₂S⁺ 329,13 Found 329,17.



4-Methyl-N-(3-methylbut-2-en-1-yl)-N-(2-methylbut-3-yn-2-yl)benzenesulfonamide (6f) was prepared according to procedure **C** using 1-bromo-3-methylbut-2-ene, obtained: 544 mg (89%), white solid; R_f (PE/Et₂O = 8: 2) 0.4.

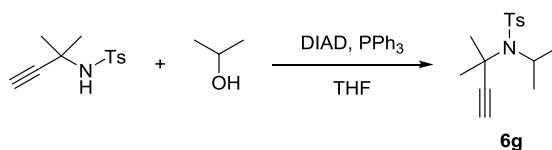
^1H NMR (300 MHz, Chloroform-*d*) δ 7.74 (d, J = 8.3 Hz, 2H), 7.25 (d, J = 6.7 Hz, 2H), 5.38 (t, J = 6.3 Hz, 1H), 4.16 (d, J = 6.3 Hz, 2H), 2.41 (s, 3H), 2.32 (s, 1H), 1.72 (s, 3H), 1.68 (s, 6H), 1.66 (s, 3H).

^{13}C NMR (75 MHz, Chloroform-*d*) δ 143.0 (C), 140.5 (C), 133.6 (C), 129.6 (CH x 2), 127.5 (CH x 2), 123.9 (CH), 87.1 (C), 72.0 (CH), 56.5 (C), 46.8 (CH₂), 31.0 (CH₃ x 2), 26.0 (CH₃), 21.8 (CH₃), 18.2 (CH₃).

IR (neat) ν : 3289, 2990, 2945, 2112, 1598, 1444, 1263, 1149, 1089, 925, 813, 707, 652, 572 cm⁻¹.

MS m/z (ESI-MS) calcd. for ([M+H⁺]): C₁₇H₂₄NO₂S⁺ 306,15 Found 306,16.

N-isopropyl-4-methyl-N-(2-methylbut-3-yn-2-yl)benzenesulfonamide (6g)



To a solution of 4-methyl-N-(2-methylbut-3-yn-2-yl) benzenesulfonamide (474.6 mg, 2.0 mmol), isopropanol (120.2 mg, 2.0 mmol) and PPh₃ (524.4 mg, 2.0 mmol) in dry THF (20 mL) was slowly added diisopropyl azodicarboxylate (404.4 mg, 2.0 mmol) at 0 °C. The resulting mixture was warmed to room temperature and stirred for 12 h. Then the solvent was removed under vacuo and the crude product was purified by flash chromatography to give 262.6 mg (47 %) of **6g** as a white solid; R_f (PE/Et₂O = 8: 2) 0.50.

^1H NMR (400 MHz, Chloroform-*d*) δ 7.76 (d, J = 8.3 Hz, 2H), 7.26 (d, J = 8.1 Hz, 2H), 4.18 (hept, J = 6.9 Hz, 1H), 2.41 (s, 3H), 2.36 (s, 1H), 1.64 (s, 3H), 1.62 (s, 3H), 1.60 (s, 6H).

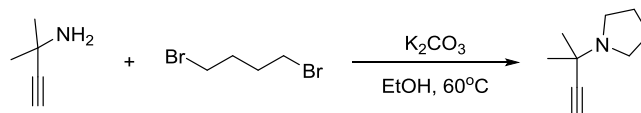
^{13}C NMR (75 MHz, Chloroform-*d*) δ 142.8 (C), 129.7 (CH x 2), 127.1 (CH x 2), 87.6 (C), 71.3 (CH), 57.2 (C), 54.4 (CH), 30.2 (CH₃ x 2), 23.6 (CH₃ x 2), 21.7 (CH₃). (The quaternary atom

attached to the methyl group of tosylate was not detected).

IR (neat) ν : 3267, 2976, 2937, 2113, 1599, 1456, 1233, 1117, 778, 636, 530 cm^{-1} .

MS m/z (ESI-MS) calcd. for $[\text{M}+\text{H}^+]$: $\text{C}_{15}\text{H}_{22}\text{NO}_2\text{S}^+$ 280,14 Found 280,20.

1-(2-Methylbut-3-yn-2-yl)pyrrolidine (**6h**)⁷



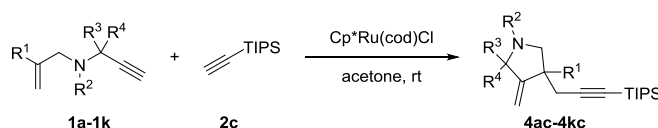
To a solution of 2-methylbut-3-yn-2-amine (1.7 g, 20 mmol) and K_2CO_3 (1.4 g, 10 mmol) in EtOH was added 1,4-dibromobutane (2.2 g, 10 mmol). The resulting mixture was stirred for 72 h at 60 °C. After cooling to rt, the mixture was treated with 10% K_2CO_3 (20 mL) and extracted with Et_2O (3 x 20 mL). The combined extracts were washed with brine, dried over Na_2SO_4 , and concentrated under vacuo. The crude solid was purified by recrystallization (PE/EA 1/1) to give 2.3 g (85%) of **6h** as a white solid.

^1H NMR (300 MHz, Chloroform- d) δ 2.74 – 2.69 (m, 4H), 2.23 (s, 1H), 1.82 – 1.77 (m, 4H), 1.41 (s, 6H).

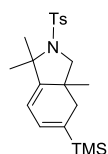
^{13}C NMR (75 MHz, Chloroform- d) δ 85.0 (C), 70.4 (CH), 53.0 (C), 47.33 ($\text{CH}_2 \times 2$), 28.97 ($\text{CH}_2 \times 2$), 23.05 ($\text{CH}_3 \times 2$).

Part 3: $\text{Cp}^*\text{Ru}(\text{cod})\text{Cl}$ -catalyzed reactions

1. Cross-coupling reactions of **1a-1k** with alkynes **2c**



Procedure D: To a solution of **1**, 6-enyne (0.2 mmol) and (triisopropylsilyl)acetylene (1 mmol) in acetone was added $\text{Cp}^*\text{Ru}(\text{cod})\text{Cl}$ (0.01 mmol). The reaction mixture was stirred at room temperature until complete consumption of **1**, 6-enynes (monitoring by TLC), filtered over celite, and concentrated in vacuo. The residue was purified by flash column chromatography to afford corresponding adduct **4ac-4kc**.



1,1,3a-Trimethyl-2-tosyl-5-(trimethylsilyl)-2,3,3a,4-tetrahydro-1H-isoindeole (3aa) was obtained according to procedure D using **1a** and **2b** as coupling partners, obtained: 58.4 mg (75%); colorless oil; R_f (PE/ Et_2O 8/2) 0.55.

^1H NMR (400 MHz, Chloroform- d) δ 7.75 (d, J = 8.3 Hz, 2H), 7.27 (d, J = 8.5 Hz, 2H),

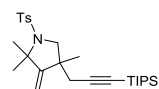
⁷ S. Bertrand, N. Hoffmann, S. Humbel, J. P. Pete, *J. Org. Chem.* **2000**, 65, 8690-8703.

6.18 (dd, $J = 5.0, 3.0$ Hz, 1H), 5.65 (d, $J = 5.0$ Hz, 1H), 3.39 (d, $J = 9.1$ Hz, 1H), 3.00 (d, $J = 9.1$ Hz, 1H), 2.41 (s, 3H), 2.19 (d, $J = 16.2$ Hz, 1H), 2.03 (dd, $J = 16.2, 3.0$ Hz, 1H), 1.67 (s, 3H), 1.45 (s, 3H), 0.95 (s, 3H), 0.05 (s, 9H).

^{13}C NMR (101 MHz, Chloroform- d) δ 156.2 (C), 143.1 (C), 138.3 (C), 135.9 (C), 131.3 (CH), 129.7 (CH x 2), 127.8 (CH x 2), 114.2 (CH), 67.6 (C), 61.4 (CH₂), 38.8 (C), 37.28 (CH₂), 31.19 (CH₃), 28.46 (CH₃), 21.80 (CH₃), 21.22 (CH₃), -2.33 (CH₃ x 3).

IR (neat) ν : 2960, 2923, 2861, 1597, 1449, 1341, 1156, 1093, 1016, 912, 813, 663, 548 cm^{-1} .

HRMS (ESI-MS) calcd. for $\text{C}_{21}\text{H}_{32}\text{NO}_2\text{SSi}^+$ ($[\text{M}+\text{H}]^+$): 390.1918, found 390.1917.



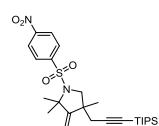
2,2,4-Trimethyl-3-methylene-1-tosyl-4-(3-(triisopropylsilyl)prop-2-yn-1-yl)pyrrolidine (4ac); obtained: 90.0 mg (95%); colorless oil; R_f (PE/Et₂O 8/2) 0.45.

^1H NMR (400 MHz, Chloroform- d) δ 7.74 (d, $J = 8.3$ Hz, 2H), 7.26 (d, $J = 8.0$ Hz, 2H), 4.87 (s, 2H), 3.37 (d, $J = 9.7$ Hz, 1H), 3.12 (d, $J = 9.7$ Hz, 1H), 2.40 (s, 3H), 2.32 (d, $J = 16.9$ Hz, 1H), 2.24 (d, $J = 16.9$ Hz, 1H), 1.56 (s, 3H), 1.52 (s, 3H), 1.20 (s, 3H), 1.07 (s, 2H), 1.04 – 0.99 (m, 19H).

^{13}C NMR (75 MHz, Chloroform- d) δ 163.7 (C), 143.2 (C), 138.4 (C), 129.7 (CH x 2), 127.7 (CH x 2), 105.3 (C), 105.2 (CH₂), 82.9 (C), 68.7 (C), 57.3 (CH₂), 44.1 (C), 31.3 (CH₂), 29.7 (CH₃), 29.4 (CH₃), 24.6 (CH₃), 21.8 (CH₃), 18.9 (CH₃ x 6), 11.6 (CH x 3).

IR (neat) ν : 2940, 2891, 2864, 2170, 1462, 1338, 1159, 1149, 1091, 1027, 753, 658, 581, 548 cm^{-1} .

HRMS (ESI-MS) calcd. for $\text{C}_{27}\text{H}_{44}\text{NO}_2\text{SSi}^+$ ($[\text{M}+\text{H}]^+$): 474.2857, found 474.2855.



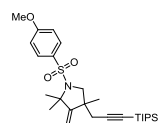
2,2,4-Trimethyl-3-methylene-1-((4-nitrophenyl)sulfonyl)-4-(3-(triisopropylsilyl)prop-2-yn-1-yl)pyrrolidine (4cc); obtained: 87.8 mg (87%); colorless oil; R_f (PE/Et₂O 8/2) 0.45.

^1H NMR (400 MHz, Chloroform- d) δ 8.33 (d, $J = 8.9$ Hz, 2H), 8.05 (d, $J = 8.9$ Hz, 2H), 4.92 (s, 1H), 4.91 (s, 1H), 3.50 (d, $J = 10.0$ Hz, 1H), 3.20 (d, $J = 10.0$ Hz, 1H), 2.30 (d, $J = 16.9$ Hz, 1H), 2.23 (d, $J = 16.9$ Hz, 1H), 1.57 (s, 3H), 1.52 (s, 3H), 1.22 (s, 3H), 1.07 (s, 2H), 1.02 (d, $J = 4.2$ Hz, 19H).

^{13}C NMR (101 MHz, Chloroform- d) δ 162.6 (C), 150.1 (C), 147.1 (C), 128.8 (CH x 2), 124.5 (CH x 2), 105.9 (CH₂), 104.8 (C), 83.4 (C), 69.4 (C), 57.4 (CH₂), 44.3 (C), 31.2 (CH₂), 30.0 (CH₃), 29.4 (CH₃), 24.4 (CH₃), 18.9 (CH₃ x 6), 11.5 (CH x 3).

IR (neat) ν : 2941, 2890, 2865, 2170, 1606, 1531, 1463, 1349, 1165, 1090, 1029, 919, 883, 677, 614, 571 cm^{-1} .

HRMS (ESI-MS) calcd. for $\text{C}_{26}\text{H}_{41}\text{N}_2\text{O}_4\text{SSi}^+$ ($[\text{M}+\text{H}]^+$): 505.2551, found 505.2553.



1-((4-Methoxyphenyl)sulfonyl)-2,2,4-trimethyl-3-methylene-4-(3-(triisopropylsilyl)prop-2-yn-1-yl)pyrrolidine (4dc); obtained: 81.3 mg (83%); colorless oil; R_f (PE/Et₂O 8/2) 0.43.

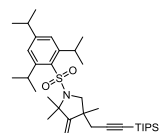
^1H NMR (400 MHz, Chloroform- d) δ 7.79 (d, $J = 9.0$ Hz, 2H), 6.93 (d, $J = 8.9$ Hz, 2H), 4.88 (s, 2H), 3.85 (s, 3H), 3.35 (d, $J = 9.7$ Hz, 1H), 3.09 (d, $J = 9.7$ Hz, 1H), 2.33 (d, $J = 16.8$ Hz, 1H),

2.24 (d, $J = 16.8$ Hz, 1H), 1.56 (s, 3H), 1.53 (s, 3H), 1.20 (s, 3H), 1.01 (d, $J = 4.7$ Hz, 21H).

^{13}C NMR (101 MHz, Chloroform- d) δ 163.6 (C), 163.9 (C), 133.0 (C), 129.8 (CH x 2), 114.2 (CH x 2), 105.3 (C), 105.3 (CH₂), 82.8 (C), 68.6 (C), 57.2 (CH₂), 55.8 (CH₃), 44.0 (C), 31.3 (CH₂), 29.6 (CH₃), 29.4 (CH₃), 24.5 (CH₃), 18.9 (CH₃ x 6), 11.6 (CH x 3).

IR (neat) ν : 2941, 2864, 2170, 1597, 1579, 1497, 1462, 1338, 1258, 1157, 1092, 1026, 968, 883, 817, 677, 584, 560 cm^{-1} .

HRMS (ESI-MS) calcd. for $\text{C}_{27}\text{H}_{44}\text{NO}_3\text{SSi}^+$ ($[\text{M}+\text{H}]^+$): 490.2806, found 490.2807.



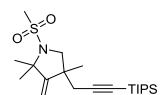
2,2,4-Trimethyl-3-methylene-1-((2,4,6-triisopropylphenyl)sulfonyl)-4-(3-(triisopropylsilyl)prop-2-yn-1-yl)pyrrolidine (4ec); obtained: 111 mg (95%); colorless oil; R_f (PE/Et₂O 9/1) 0.40.

^1H NMR (400 MHz, Chloroform- d) δ 7.14 (s, 2H), 4.92 (s, 2H), 4.36 (hept, $J = 6.8$ Hz, 2H), 3.24 (d, $J = 8.9$ Hz, 1H), 3.02 (d, $J = 8.9$ Hz, 1H), 2.89 (hept, $J = 6.9$ Hz, 1H), 2.46 (d, $J = 16.8$ Hz, 1H), 2.22 (d, $J = 16.8$ Hz, 1H), 1.71 (s, 3H), 1.69 (s, 3H), 1.29 – 1.21 (m, 23H), 0.95 – 0.91 (m, 19H).

^{13}C NMR (75 MHz, Chloroform- d) δ 164.6 (C), 153.4 (C), 151.9 (C x 2), 132.7 (C), 124.1 (CH x 2), 105.2 (C), 104.9 (CH₂), 82.8 (C), 69.9 (C), 56.6 (CH₂), 44.1 (C), 34.4 (CH x 2), 32.0 (CH₂), 30.0 (CH), 29.3 (CH₃), 29.0 (CH₃), 25.3 (CH₃ x 2), 25.0 (CH₃ x 2), 24.3 (CH₃), 23.9 (CH₃), 23.8 (CH₃), 18.9 (CH₃ x 3), 18.9 (CH₃ x 3), 11.5 (CH x 3).

IR (neat) ν : 2958, 2855, 2170, 1600, 1462, 1364, 1317, 1163, 1146, 1076, 950, 882, 676, 582 cm^{-1} .

HRMS (ESI-MS) calcd. for $\text{C}_{35}\text{H}_{60}\text{NO}_2\text{SSi}^+$ ($[\text{M}+\text{H}]^+$): 586.4109, found 586.4115.



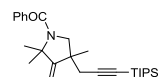
2,2,4-Trimethyl-3-methylene-1-(methanesulfonyl)-4-(3-(triisopropylsilyl)prop-2-yn-1-yl)pyrrolidine (4fc); obtained: 56.5 mg (71%); colorless oil; R_f (PE/Et₂O 7/3) 0.30.

^1H NMR (400 MHz, Chloroform- d) δ 4.96 (s, 1H), 4.93 (s, 1H), 3.54 (d, $J = 9.7$ Hz, 1H), 3.20 (d, $J = 9.7$ Hz, 1H), 2.91 (s, 3H), 2.51 (d, $J = 16.9$ Hz, 1H), 2.38 (d, $J = 16.9$ Hz, 1H), 1.55 (s, 6H), 1.30 (s, 3H), 1.06 (d, $J = 3.9$ Hz, 21H).

^{13}C NMR (75 MHz, Chloroform- d) δ 163.2 (C), 105.7 (CH₂), 105.2 (C), 83.4 (C), 68.0 (C), 57.5 (CH₂), 44.0 (C), 40.6 (CH₃), 31.4 (CH₂), 29.6 (CH₃), 29.3 (CH₃), 24.8 (CH₃), 19.0 (CH₃ x 6), 11.6 (CH x 3).

IR (neat) ν : 2940, 2892, 2864, 2171, 1463, 1332, 1159, 1141, 1027, 960, 882, 763, 661, 522 cm^{-1} .

HRMS (ESI-MS) calcd. for $\text{C}_{21}\text{H}_{40}\text{NO}_2\text{SSi}^+$ ($[\text{M}+\text{H}]^+$): 398.2544, found 398.2543.



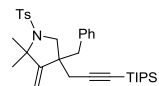
Phenyl(2,2,4-trimethyl-3-methylene-4-(3-(triisopropylsilyl)prop-2-yn-1-yl)pyrrolidin-1-yl)methanone (4gc); obtained: 61.9 mg (73%); colorless oil; R_f (PE/Et₂O 8/2) 0.35.

^1H NMR (400 MHz, Chloroform- d) δ 7.39 (s, 5H), 5.01 (s, 1H), 4.95 (s, 1H), 3.59 (d, $J = 11.2$ Hz, 1H), 3.24 (d, $J = 11.2$ Hz, 1H), 2.50 (d, $J = 16.9$ Hz, 1H), 2.36 (d, $J = 16.9$ Hz, 1H), 1.72 (s, 3H), 1.71 (s, 3H), 1.28 (s, 3H), 1.12 (s, 2H), 1.02 – 0.98 (m, 19H).

^{13}C NMR (75 MHz, Chloroform-*d*) δ 170.6 (C), 164.2 (C), 139.0 (C), 129.4 (CH), 128.7 (CH x 2), 126.5 (CH x 2), 105.3 (C), 105.1 (CH₂), 83.0 (C), 66.1 (C), 59.4 (CH₂), 44.4 (C), 31.2 (CH₂), 28.0 (CH₃), 27.8 (CH₃), 24.6 (CH₃), 18.9 (CH₃ x 6), 11.6 (CH x 3).

IR (neat) ν : 2959, 2940, 2863, 2170, 1640, 1460, 1395, 1118, 1027, 993, 882, 698, 674, 595 cm⁻¹.

HRMS (ESI-MS) calcd. for C₂₇H₄₂NOSi⁺ ([M+H]⁺): 424.3030, found 424.3027.



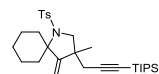
4-Benzyl-2,2-dimethyl-3-methylene-1-tosyl-4-(3-(triisopropylsilyl)prop-2-yn-1-yl)pyrrolidine (4hc); obtained: 78.1 mg (71%); colorless oil; *R_f* (PE/Et₂O 8/2) 0.65.

^1H NMR (400 MHz, Chloroform-*d*) δ 7.74 (d, *J* = 8.3 Hz, 2H), 7.28 (d, *J* = 8.1 Hz, 2H), 7.23 – 7.20 (m, 3H), 7.08 – 7.06 (m, 2H), 4.94 (s, 1H), 4.67 (s, 1H), 3.37 (d, *J* = 9.8 Hz, 1H), 3.13 (d, *J* = 9.8 Hz, 1H), 2.84 (d, *J* = 13.5 Hz, 1H), 2.80 (d, *J* = 13.5 Hz, 1H), 2.42 (s, 3H), 2.31 (d, *J* = 17.0 Hz, 1H), 2.23 (d, *J* = 17.0 Hz, 1H), 1.67 (s, 3H), 1.48 (s, 3H), 1.06 – 1.02 (d, *J* = 3.8 Hz, 21H).

^{13}C NMR (75 MHz, Chloroform-*d*) δ 160.4 (C), 143.4 (C), 138.0 (C), 137.2 (C), 131.0 (CH x 2), 129.8 (CH x 2), 128.3 (CH x 2), 127.9 (CH x 2), 126.9 (CH), 107.3 (CH₂), 105.4 (C), 84.0 (C), 69.0 (C), 55.6 (CH₂), 48.0 (C), 42.6 (CH₂), 30.3 (CH₃), 28.7 (CH₃), 27.9 (CH₂), 21.8 (CH₃), 19.0 (CH₃ x 6), 11.7 (CH x 3).

IR (neat) ν : 2940, 2863, 2170, 1600, 1462, 1303, 1151, 1091, 991, 908, 730, 671, 577, 549 cm⁻¹.

HRMS (ESI-MS) calcd. for C₃₃H₄₈NO₂SSi⁺ ([M+H]⁺): 554.3170, found 554.3170.



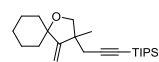
3-Methyl-4-methylene-1-tosyl-3-(3-(triisopropylsilyl)prop-2-yn-1-yl)-1-azaspiro[4.5]decane (4ic); obtained: 88.4 mg (86%); colorless oil; *R_f* (PE/Et₂O 8/2) 0.42.

^1H NMR (400 MHz, Chloroform-*d*) δ 7.75 (d, *J* = 8.3 Hz, 2H), 7.25 (d, *J* = 7.2 Hz, 2H), 5.35 (s, 1H), 4.88 (s, 1H), 3.37 (d, *J* = 9.9 Hz, 1H), 3.13 (d, *J* = 9.9 Hz, 1H), 2.65 – 2.55 (m, 2H), 2.40 (s, 3H), 2.28 (d, *J* = 16.8 Hz, 1H), 2.19 (d, *J* = 16.8 Hz, 1H), 1.82 (d, *J* = 12.8 Hz, 1H), 1.71 – 1.64 (m, 7H), 1.16 (s, 3H), 1.08 (s, 2H), 1.03 – 0.99 (m, 19H).

^{13}C NMR (75 MHz, Chloroform-*d*) δ 161.7 (C), 143.1 (C), 139.2 (C), 129.7 (CH x 2), 127.6 (CH x 2), 107.6 (CH₂), 105.5 (C), 82.8 (C), 71.4 (C), 56.9 (CH₂), 44.9 (C), 35.7 (CH₂), 35.2 (CH₂), 31.7 (CH₂), 24.8 (CH₃), 24.6 (CH₂), 22.5 (CH₂), 22.4 (CH₂), 21.8 (CH₃), 18.9 (CH₃ x 6), 11.6 (CH x 3).

IR (neat) ν : 2938, 2890, 2864, 2171, 1598, 1460, 1304, 1155, 1092, 1033, 967, 881, 671, 587 cm⁻¹.

HRMS (ESI-MS) calcd. for C₃₀H₄₈NO₂SSi⁺ ([M+H]⁺): 514.3170, found 514.3167.



Triisopropyl(3-(3-methyl-4-methylene-1-oxaspiro[4.5]decan-3-yl)prop-1-yn-1-yl)silane (4jc); obtained: 59.1 mg (82%); colorless oil; *R_f* (PE/Et₂O 19/1) 0.65.

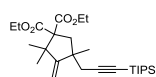
^1H NMR (400 MHz, Chloroform-*d*) δ 4.85 (s, 1H), 4.78 (s, 1H), 3.89 (d, *J* = 9.0 Hz, 1H), 3.55 (d, *J* = 9.0 Hz, 1H), 2.44 (d, *J* = 16.8 Hz, 1H), 2.27 (d, *J* = 16.8 Hz, 1H), 1.77 – 1.55 (m, 8H), 1.35 – 1.25 (m, 2H), 1.24 (s, 3H), 1.09 – 1.03 (m, 21H).

^{13}C NMR (75 MHz, Chloroform-*d*) δ 164.2 (C), 106.4 (C), 103.4 (CH₂), 84.7 (C), 82.1 (C), 75.1 (CH₂), 46.4 (C), 37.4 (CH₂), 36.7 (CH₂), 31.4 (CH₂), 25.8 (CH₂), 24.1 (CH₃), 22.8 (CH₂ x 2), 19.0

(CH₃ x 6), 11.7 (CH x 3).

IR (neat) ν : 2930, 2863, 2170, 1461, 1447, 1145, 1057, 1043, 935, 883, 674, 637 cm⁻¹.

HRMS (ESI-MS) calcd. for C₂₃H₄₁OSi⁺ ([M+H]⁺): 361.2921, found 361.2924.



Diethyl 2,2,4-trimethyl-3-methylene-4-(3-(triisopropylsilyl)prop-2-yn-1-yl)cyclopentane-1,1-dicarboxylate (4kc); obtained: 76.8 mg (83%); colorless oil; R_f (PE/Et₂O 8/2) 0.40.

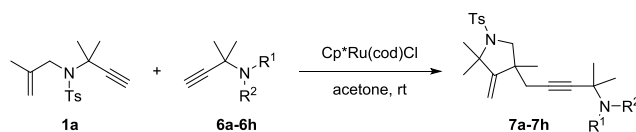
¹H NMR (400 MHz, Chloroform-*d*) δ 4.92 (s, 1H), 4.87 (s, 1H), 4.23 – 4.12 (m, 4H), 2.64 (d, *J* = 15.0 Hz, 1H), 2.45 (d, *J* = 17.0 Hz, 1H), 2.31 (d, *J* = 15.0 Hz, 1H), 2.30 (d, *J* = 17.0 Hz, 1H), 1.33 (s, 3H), 1.28 – 1.23 (m, 9H), 1.21 (s, 3H), 1.09 – 1.03 (m, 21H).

¹³C NMR (101 MHz, Chloroform-*d*) δ 171.4 (C), 171.1 (C), 167.4 (C), 107.3 (C), 104.4 (CH₂), 81.8 (C), 65.7 (C), 61.3 (CH₂ x 2), 49.5 (C), 43.2 (CH₂), 43.1 (C), 35.4 (CH₂), 30.1 (CH₃), 26.8 (CH₃), 25.5 (CH₃), 19.0 (CH₃ x 6), 14.4 (CH₃), 14.47 (CH₃), 11.7 (CH x 3).

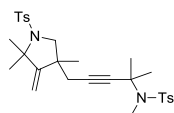
IR (neat) ν : 2959, 2941, 2865, 2168, 1731, 1463, 1365, 1268, 1234, 1119, 1031, 883, 675, 637 cm⁻¹.

HRMS (ESI-MS) calcd. for C₂₇H₄₇O₄Si⁺ ([M+H]⁺): 463.3238, found 463.3240.

2. Cross-coupling reactions of **1a** with alkynes **6a-6h**



Cross-adducts **7a-7h** were obtained according to procedure **D** using **1a** and **6a-6h** as coupling partners.



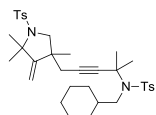
N,4-dimethyl-N-(2-methyl-5-(3,5,5-trimethyl-4-methylene-1-tosylpyrrolidin-3-yl)pent-3-yn-2-yl)benzenesulfonamide (7a); obtained: 87.9 mg (81%); colorless oil; R_f (PE/Et₂O 6/4) 0.35;

¹H NMR (400 MHz, Chloroform-*d*) δ 7.69 (dd, *J* = 20.3, 8.3 Hz, 4H), 7.27 (s, 2H), 7.25 (s, 2H), 4.84 (s, 1H), 4.78 (s, 1H), 3.23 (d, *J* = 9.7 Hz, 1H), 2.99 (d, *J* = 9.7 Hz, 1H), 2.97 (s, 3H), 2.40 (s, 6H), 2.12 (d, *J* = 16.7 Hz, 1H), 2.00 (d, *J* = 16.7 Hz, 1H), 1.55 (s, 3H), 1.54 (s, 3H), 1.49 (s, 3H), 1.48 (s, 3H), 1.05 (s, 3H).

¹³C NMR (101 MHz, Chloroform-*d*) δ 163.4 (C), 143.4 (C), 143.2 (C), 139.0 (C), 138.2 (C), 129.8 (CH x 2), 129.7 (CH x 2), 127.6 (CH x 2), 127.5 (CH x 2), 105.3 (CH₂), 84.5 (C), 81.0 (C), 68.5 (C), 57.2 (CH₂), 56.3 (C), 43.9 (C), 34.5 (CH₃), 30.4 (CH₃ x 2), 29.9 (CH₂), 29.7 (CH₃), 29.3 (CH₃), 24.5 (CH₃), 21.8 (CH₃ x 2).

IR (neat) ν : 2976, 2869, 2239, 1598, 1364, 1160, 1090, 947, 741, 580 cm⁻¹.

HRMS (ESI-MS) calcd. for C₂₉H₃₉N₂O₄S₂⁺ ([M+H]⁺): 543.2346, found 543.2344.



N-(cyclohexylmethyl)-4-methyl-N-(2-methyl-5-(3,5,5-trimethyl-4-methylene-1-tosylpyrrolidin-3-yl)pent-3-yn-2-yl)benzenesulfonamide (7b); obtained: 101 mg

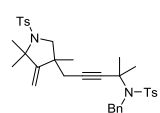
(81%); colorless oil; R_f (PE/Et₂O 6/4) 0.35;

¹H NMR (300 MHz, Chloroform-*d*) δ 7.74 (d, J = 8.3 Hz, 2H), 7.66 (d, J = 8.3 Hz, 2H), 7.28 (s, 2H), 7.24 (s, 2H), 4.87 (s, 1H), 4.82 (s, 1H), 3.36 (d, J = 6.8 Hz, 2H), 3.27 (d, J = 9.7 Hz, 1H), 3.03 (d, J = 9.7 Hz, 1H), 2.41 (s, 6H), 2.16 (d, J = 16.7 Hz, 1H), 2.06 (d, J = 16.7 Hz, 1H), 1.86 – 1.71 (m, 6H), 1.54 (s, 6H), 1.51 (s, 3H), 1.51 (s, 3H), 1.30 – 1.18 (m, 3H), 1.09 (s, 3H), 1.00 – 0.89 (m, 3H).

¹³C NMR (75 MHz, Chloroform-*d*) δ 162.4 (C), 142.4 (C), 141.8 (C), 140.2 (C), 137.3 (C), 128.8 (CH x 2), 128.6 (CH x 2), 126.8 (CH x 2), 126.3 (CH x 2), 104.4 (CH₂), 84.6 (C), 80.3 (C), 67.6 (C), 56.4 (CH₂), 55.8 (C), 54.4 (CH₂), 42.9 (C), 38.2 (CH), 30.6 (CH₃), 30.5 (CH₃), 30.4 (CH₂ x 2), 29.1 (CH₂), 28.7 (CH₃), 28.4 (CH₃), 25.9 (CH₂), 25.6 (CH₂ x 2), 23.7 (CH₃), 20.8 (CH₃), 20.7 (CH₃).

IR (neat) ν : 2955, 2931, 2892, 2250, 1493, 1364, 1239, 1132, 1099, 903, 729, 524 cm⁻¹.

HRMS (ESI-MS) calcd. for C₃₅H₅₂N₃O₄S₂ ([M+NH₄]⁺): 642.3394, found 642.3401.



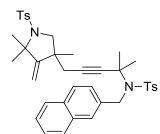
N-benzyl-4-methyl-N-(2-methyl-5-(3,5,5-trimethyl-4-methylene-1-tosylpyrrolidin-3-yl)pent-3-yn-2-yl)benzenesulfonamide (7c); obtained: 103 mg (83%); colorless oil; R_f (PE/Et₂O 7/3) 0.40;

¹H NMR (400 MHz, Chloroform-*d*) δ 7.71 (d, J = 8.3 Hz, 2H), 7.62 (d, J = 8.3 Hz, 2H), 7.41 (d, J = 7.4 Hz, 2H), 7.31 (t, J = 7.4 Hz, 3H), 7.23 (d, J = 7.4 Hz, 4H), 4.83 (s, 1H), 4.76 (s, 1H), 4.72 (s, 2H), 3.21 (d, J = 9.7 Hz, 1H), 2.96 (d, J = 9.7 Hz, 1H), 2.40 (s, 3H), 2.38 (s, 3H), 2.10 (d, J = 16.7 Hz, 1H), 1.98 (d, J = 16.7 Hz, 1H), 1.51 (s, 6H), 1.49 (s, 3H), 1.48 (s, 3H), 1.01 (s, 3H).

¹³C NMR (75 MHz, Chloroform-*d*) δ 163.3 (C), 143.4 (C), 143.2 (C), 139.8 (C), 139.8 (C), 138.1 (C), 129.7 (CH x 2), 129.6 (CH x 2), 128.5 (CH x 2), 127.70 (CH x 2), 127.68 (CH x 2), 127.65 (CH x 2), 127.2 (CH), 105.3 (CH₂), 85.2 (C), 81.4 (C), 68.5 (C), 57.6 (C), 57.2 (CH₂), 52.3 (CH₂), 43.7 (C), 31.5 (CH₃ x 2), 29.9 (CH₂), 29.7 (CH₃), 29.3 (CH₃), 24.5 (CH₃), 21.8 (CH₃ x 2).

IR (neat) ν : 2956, 2869, 2551, 1731, 1454, 1149, 1090, 914, 735, 572 cm⁻¹.

HRMS (ESI-MS) calcd. for C₃₅H₄₆N₃O₄S₂⁺ ([M+NH₄]⁺): 636.2924, found 636.2926.



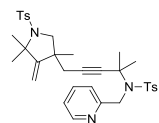
4-Methyl-N-(2-methyl-5-(3,5,5-trimethyl-4-methylene-1-tosylpyrrolidin-3-yl)pent-3-yn-2-yl)-N-(naphthalen-2-ylmethyl)benzenesulfonamide (7d); obtained: 110 mg (82%); colorless oil; R_f (PE/Et₂O 6/4) 0.35;

¹H NMR (300 MHz, Chloroform-*d*) δ 7.84 – 7.75 (m, 4H), 7.73 – 7.64 (m, 4H), 7.56 (dd, J = 8.7, 1.7 Hz, 1H), 7.46 (hept, J = 4.5 Hz, 2H), 7.21 (d, J = 8.1 Hz, 4H), 4.89 (s, 2H), 4.82 (s, 1H), 4.74 (s, 1H), 3.22 (d, J = 9.7 Hz, 1H), 2.96 (d, J = 9.7 Hz, 1H), 2.38 (s, 3H), 2.35 (s, 3H), 2.11 (d, J = 16.7 Hz, 1H), 1.98 (d, J = 16.6 Hz, 1H), 1.55 (s, 6H), 1.49 (s, 3H), 1.47 (s, 3H), 1.00 (s, 3H).

¹³C NMR (75 MHz, Chloroform-*d*) δ 163.4 (C), 143.4 (C), 143.2 (C), 139.9 (C), 138.2 (C), 137.4 (C), 133.6 (C), 133.0 (C), 129.7 (CH x 2), 129.6 (CH x 2), 128.3 (CH), 128.2 (CH), 128.0 (CH), 127.7 (CH x 4), 126.5 (CH), 126.4 (CH), 126.0 (CH), 125.9 (CH), 105.3 (CH₂), 85.4 (C), 81.6 (C), 68.5 (C), 57.9 (C), 57.2 (CH₂), 52.5 (CH₂), 43.8 (C), 31.6 (CH₃), 31.5 (CH₃), 30.0 (CH₂), 29.7 (CH₃), 29.3 (CH₃), 24.6 (CH₃), 21.8 (CH₃ x 2).

IR (neat) ν : 2975, 2928, 2868, 2254, 1599, 1364, 1146, 1089, 907, 728, 544 cm^{-1} .

HRMS (ESI-MS) calcd. for $\text{C}_{39}\text{H}_{48}\text{N}_3\text{O}_4\text{S}_2$ ($[\text{M}+\text{NH}_4]^+$): 686.3081, found 686.3082



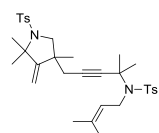
4-Methyl-N-(2-methyl-5-(3,5,5-trimethyl-4-methylene-1-tosylpyrrolidin-3-yl)pent-3-yn-2-yl)-N-(pyridin-2-ylmethyl)benzenesulfonamide (7e); obtained: 99.2 mg (80%); colorless oil; R_f (PE/Et₂O 5/5) 0.35;

¹H NMR (300 MHz, Chloroform-*d*) δ 8.50 (s, 1H), 7.72 (dd, J = 14.1, 5.8 Hz, 6H), 7.27 (d, J = 8.2 Hz, 4H), 7.14 (s, 1H), 4.80 (s, 3H), 4.72 (s, 1H), 3.15 (d, J = 9.2 Hz, 1H), 2.93 (d, J = 9.2 Hz, 1H), 2.42 (s, 3H), 2.39 (s, 3H), 1.99 (d, J = 16.8 Hz, 1H), 1.86 (d, J = 16.8 Hz, 1H), 1.51 (s, 6H), 1.47 (s, 6H), 0.95 (s, 3H).

¹³C NMR (75 MHz, Chloroform-*d*) δ 163.3 (C), 160.2 (C), 148.9 (CH), 143.5 (C), 143.4 (C), 138.9 (C), 138.2 (C), 136.9 (CH), 129.8 (CH x 4), 128.0 (CH x 2), 127.7 (CH x 2), 122.2 (CH), 122.1 (CH), 105.3 (CH₂), 84.5 (C), 81.3 (C), 68.5 (C), 57.4 (C), 57.2 (CH₂), 54.3 (CH₂), 43.6 (C), 31.5 (CH₃), 31.5 (CH₃), 29.9 (CH₂), 29.7 (CH₃), 29.2 (CH₃), 24.3 (CH₃), 21.8 (CH₃), 21.7 (CH₃).

IR (neat) ν : 2973, 2882, 2247, 1655, 1379, 1327, 1087, 1044, 897, 803, 644 cm^{-1} .

HRMS (ESI-MS) calcd. for $\text{C}_{34}\text{H}_{42}\text{N}_3\text{O}_4\text{S}_2^+$ ($[\text{M}+\text{H}]^+$): 620.2611, found 620.2612.



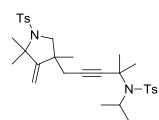
4-Methyl-N-(2-methyl-5-(3,5,5-trimethyl-4-methylene-1-tosylpyrrolidin-3-yl)pent-3-yn-2-yl)-N-(3-methylbut-2-en-1-yl)benzenesulfonamide (7f); obtained: 96.7 mg (81%); colorless oil; R_f (PE/Et₂O 6/4) 0.35;

¹H NMR (400 MHz, Chloroform-*d*) δ 7.71 (dd, J = 12.6, 8.3 Hz, 4H), 7.26 (d, J = 8.1 Hz, 2H), 7.25 (d, J = 8.1 Hz, 2H), 5.33 (tq, J = 4.8, 1.5 Hz, 1H), 4.85 (s, 1H), 4.81 (s, 1H), 4.08 (d, J = 6.1 Hz, 2H), 3.27 (d, J = 9.7 Hz, 1H), 3.02 (d, J = 9.7 Hz, 1H), 2.40 (s, 3H), 2.40 (s, 3H), 2.17 (d, J = 16.7 Hz, 1H), 2.07 (d, J = 16.7 Hz, 1H), 1.71 (s, 3H), 1.64 (s, 3H), 1.56 (s, 6H), 1.50 (s, 3H), 1.49 (s, 3H), 1.08 (s, 3H).

¹³C NMR (75 MHz, Chloroform-*d*) δ 162.9 (C), 142.8 (C), 142.3 (C), 140.2 (C), 137.8 (C), 132.8 (C), 129.2 (CH x 2), 129.0 (CH x 2), 127.1 (CH x 2), 126.9 (CH x 2), 123.6 (CH), 104.7 (CH₂), 85.1 (C), 80.1 (C), 68.0 (C), 56.7 (CH₂), 56.2 (C), 46.1 (CH₂), 43.3 (C), 30.6 (CH₃ x 2), 29.5 (CH₂), 29.1 (CH₃), 28.8 (CH₃), 25.4 (CH₃), 23.9 (CH₃), 21.2 (CH₃), 21.1 (CH₃), 17.6 (CH₃).

IR (neat) ν : 2961, 2918, 2850, 2253, 1734, 1598, 1494, 1363, 1149, 1090, 970, 814, 673, 547 cm^{-1} .

HRMS (ESI-MS) calcd. for $\text{C}_{33}\text{H}_{45}\text{N}_2\text{O}_4\text{S}_2^+$ ($[\text{M}+\text{H}]^+$): 597.2815, found 597.2814.



N-isopropyl-4-methyl-N-(2-methyl-5-(3,5,5-trimethyl-4-methylene-1-tosylpyrrolidin-3-yl)pent-3-yn-2-yl)benzenesulfonamide (7g); obtained: 104 mg (91%); colorless oil; R_f (PE/Et₂O 6/4) 0.35;

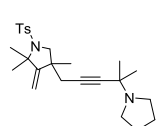
¹H NMR (400 MHz, Chloroform-*d*) δ 7.72 (d, J = 7.6 Hz, 4H), 7.27 (s, 2H), 7.25 (s, 2H), 4.87 (s, 1H), 4.83 (s, 1H), 4.08 (p, J = 6.9 Hz, 1H), 3.30 (d, J = 9.7 Hz, 1H), 3.05 (d, J = 9.7 Hz, 1H), 2.25 (d, J = 16.7 Hz, 1H), 2.16 (d, J = 16.7 Hz, 1H), 1.57 (d, J = 6.7 Hz, 6H), 1.52 (s, 3H), 1.51 (s, 4H), 1.50 – 1.49 (m, 6H), 1.13 (s, 3H).

¹³C NMR (75 MHz, Chloroform-*d*) δ 162.5 (C), 142.4 (C), 141.7 (C), 137.3 (C), 128.8 (CH x 2),

128.7 (CH x 2), 126.8 (CH x 2), 126.0 (CH x 2), 104.4 (CH₂), 85.3 (C), 79.2 (C), 67.6 (C), 56.5 (C), 56.3 (CH₂), 53.1 (CH), 43.0 (C), 30.4 (CH₃), 29.5 (CH₃), 29.1 (CH₂), 28.7 (CH₃), 28.4 (CH₃), 23.6 (CH₃), 22.7 (CH₃), 22.6 (CH₃), 20.8 (CH₃), 20.7 (CH₃) (Attention: one carbon connecting the methyl of tosylate around 140 ppm is not visible in ¹³C NMR).

IR (neat) v: 2987, 2911, 2257, 1424, 1333, 1218, 1195, 1112, 907, 735, 523 cm⁻¹.

HRMS (ESI-MS) calcd. for C₃₁H₄₆N₃O₄S₂ ([M+NH₄]⁺): 588.2924, found 588.2926.



2,2,4-Trimethyl-4-(4-methyl-4-(pyrrolidin-1-yl)pent-2-yn-1-yl)-3-methylene-1-tosylpyrrolidine (7h); obtained: 66.9 mg (78%); faint yellow oil; R_f (EA with 3% of Et₃N) 0.30;

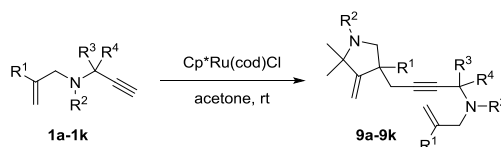
¹H NMR (400 MHz, Chloroform-*d*) δ 7.75 (d, *J* = 8.3 Hz, 2H), 7.27 (d, *J* = 8.3 Hz, 2H), 4.87 (s, 1H), 4.86 (s, 1H), 3.38 (d, *J* = 9.7 Hz, 1H), 3.08 (d, *J* = 9.7 Hz, 1H), 2.63 (br s, 4H), 2.41 (s, 3H), 2.30 (d, *J* = 16.6 Hz, 1H), 2.18 (d, *J* = 16.6 Hz, 1H), 1.77 – 1.74 (m, 4H), 1.54 (s, 3H), 1.53 (s, 3H), 1.31 (s, 6H), 1.17 (s, 3H).

¹³C NMR (75 MHz, Chloroform-*d*) δ 163.7 (C), 143.3 (C), 138.5 (C), 129.7 (CH x 2), 127.7 (CH x 2), 105.1 (CH₂), 84.0 (C), 80.6 (C), 68.6 (C), 57.2 (CH₂), 54.2 (C), 48.4 (CH₂ x 2), 44.1 (C), 30.1 (CH₃ x 2), 30.0 (CH₂), 29.6 (CH₃), 29.5 (CH₃), 24.7 (CH₃), 24.1 (CH₂ x 2), 21.8 (CH₃).

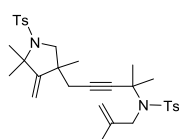
IR (neat) v: 3358, 3200, 2923, 2906, 2856, 2166, 1512, 1445, 1301, 1129, 997, 898, 679, 590 cm⁻¹.

HRMS (ESI-MS) calcd. for C₂₅H₃₇N₂O₂S⁺ ([M+H]⁺): 429.2570, found 429.2569.

3. Self-coupling reactions of 1a-1k



Cross-adducts **9a-9k** were obtained according to procedure **D** using **1a-1k** as reactant.



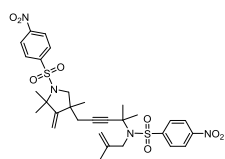
4-Methyl-N-(2-methyl-5-(3,5,5-trimethyl-4-methylene-1-tosylpyrrolidin-3-yl)pent-3-yn-2-yl)-N-(2-methylallyl)benzenesulfonamide (8a), obtained: 53.0 mg (91%); colorless oil; R_f (PE/Et₂O 6/4) 0.35;

¹H NMR (400 MHz, Chloroform-*d*) δ 7.70 (dd, *J* = 15.8, 8.4 Hz, 4H), 7.28 – 7.24 (m, 4H), 5.03 (s, 1H), 4.91 (s, 1H), 4.84 (s, 1H), 4.78 (s, 1H), 4.02 (s, 2H), 3.23 (d, *J* = 9.7 Hz, 1H), 2.98 (d, *J* = 9.7 Hz, 1H), 2.40 (s, 6H), 2.09 (d, *J* = 16.7 Hz, 1H), 1.99 (d, *J* = 16.7 Hz, 1H), 1.76 (s, 3H), 1.54 (s, 6H), 1.50 (s, 3H), 1.48 (s, 3H), 1.04 (s, 3H).

¹³C NMR (101 MHz, Chloroform-*d*) δ 163.1 (C), 143.3 (C), 143.2 (C), 143.0 (C), 139.5 (C), 138.0 (C), 129.6 (CH x 2), 129.4 (CH x 2), 127.6 (CH x 2), 127.5 (CH x 2), 112.1 (CH₂), 105.2 (CH₂), 84.7 (C), 80.6 (C), 68.3 (C), 57.0 (CH₂), 56.9 (C), 54.0 (CH₂), 43.6 (C), 31.3 (CH₃), 31.2 (CH₃), 29.7 (CH₂), 29.5 (CH₃), 29.1 (CH₃), 24.4 (CH₃), 21.6 (CH₃ x 2), 20.4 (CH₃).

IR (neat) v: 2978, 2931, 2250, 1657, 1494, 1330, 1148, 1090, 905, 724, 570 cm⁻¹.

HRMS (ESI-MS) calcd. for $C_{32}H_{46}N_3O_4S_2^+$ ($[M+NH_4]^+$): 600.2924, found 600.2925.



***N*-(2-methyl-5-(3,5,5-trimethyl-4-methylene-1-((4-nitrophenyl)sulfonyl)pyrrolidin-3-yl)pent-3-yn-2-yl)-*N*-(2-methylallyl)-4-nitrobenzenesulfonamide (8c)**, obtained: 58.7 mg (91%); pale yellow oil; R_f (PE/Et₂O 6/4) 0.30;

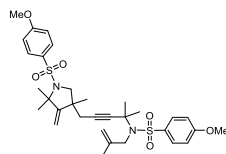
¹H NMR (400 MHz, Chloroform-d) δ 8.33 (dd, J = 8.8, 6.0 Hz, 4H), 8.04 – 8.00 (m, 4H), 4.97 (s, 1H), 4.94 (p, J = 1.5 Hz, 1H), 4.88 (d, J = 1.2 Hz, 1H), 4.82 (d, J = 1.2 Hz, 1H), 4.10 (s, 2H), 3.41 (d, J = 9.8 Hz, 1H), 3.04 (d, J = 9.8 Hz, 1H), 2.13 (d, J = 16.7 Hz, 1H), 2.02 (d, J = 16.7 Hz, 1H), 1.77 (s, 3H), 1.61 (s, 6H), 1.51 (s, 3H), 1.45 (s, 3H), 1.06 (s, 3H).

¹³C NMR (101 MHz, Chloroform-d) δ 162.4 (C), 150.1 (C), 150.0 (C), 148.5 (C), 146.8 (C), 142.5 (C), 128.9 (CH x 2), 128.8 (CH x 2), 124.5 (CH x 2), 124.2 (CH x 2), 113.2 (CH₂), 106.0 (CH₂), 85.3 (C), 81.2 (C), 69.13 (C), 57.5 (CH₂), 57.4 (C), 53.8 (CH₂), 43.9 (C), 31.4 (CH₃), 31.3 (CH₃), 29.9 (CH₂), 29.9 (CH₃), 29.3 (CH₃), 24.6 (CH₃), 20.5 (CH₃).

IR (neat) ν : 2986, 2895, 2254, 1531, 1349, 1165, 1149, 903, 724, 613 cm⁻¹.

HRMS (ESI-MS) calcd. for $C_{30}H_{40}N_5O_8S_2^+$ ($[M+NH_4]^+$): 662.2313, found 662.2316.

4-Methoxy-*N*-(5-(1-((4-methoxyphenyl)sulfonyl)-3,5,5-trimethyl-4-methylenepyrrolidin-3-yl)-2-methylpent-3-yn-2-yl)-*N*-(2-methylallyl)benzenesulfonamide (8d), obtained: 53.5 mg (87%); colorless oil; R_f (PE/Et₂O 6/4) 0.25;

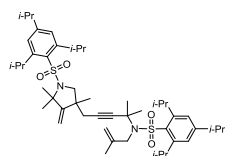


¹H NMR (400 MHz, Chloroform-d) δ 7.76 (dd, J = 16.0, 8.9 Hz, 4H), 6.96 – 6.90 (m, 4H), 5.02 (s, 1H), 4.90 (p, J = 1.6 Hz, 1H), 4.85 (s, 1H), 4.78 (s, 1H), 3.99 (s, 2H), 3.86 (s, 3H), 3.85 (s, 3H), 3.21 (d, J = 9.6 Hz, 1H), 2.96 (d, J = 9.6 Hz, 1H), 2.11 (d, J = 16.7 Hz, 1H), 2.01 (d, J = 16.7 Hz, 1H), 1.75 (s, 3H), 1.55 (s, 6H), 1.50 (s, 3H), 1.48 (s, 3H), 1.05 (s, 3H).

¹³C NMR (101 MHz, Chloroform-d) δ 163.4 (C), 162.9 (C), 162.8 (C), 143.3 (C), 134.3 (C), 132.8 (C), 129.8 (CH x 2), 129.8 (CH x 2), 114.2 (CH x 2), 114.1 (CH x 2), 112.1 (CH₂), 105.3 (CH₂), 85.0 (C), 80.7 (C), 68.43 (C), 57.2 (CH₂), 57.0 (C), 55.9 (CH₃), 55.9 (CH₃), 54.0 (CH₂), 43.8 (C), 31.4 (CH₃ x 2), 30.0 (CH₂), 29.7 (CH₃), 29.2 (CH₃), 24.5 (CH₃), 20.6 (CH₃).

IR (neat) ν : 2974, 2932, 2256, 1595, 1497, 1145, 1090, 907, 677, 552 cm⁻¹.

HRMS (ESI-MS) calcd. for $C_{32}H_{43}N_2O_6S_2^+$ ($[M+H]^+$): 615.2557, found 615.2557.



***N*-(5-(1-((2,6-diisopropyl-4-nitrophenyl)sulfonyl)-3,5,5-trimethyl-4-methylenepyrrolidin-3-yl)-2-methylpent-3-yn-2-yl)-2,6-diisopropyl-*N*-(2-methylallyl)-4-nitrobenzenesulfonamide (8e)**, obtained: 76.7 mg (95%); colorless oil; R_f (PE/Et₂O 9/1) 0.45;

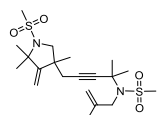
¹H NMR (400 MHz, Chloroform-d) δ 7.11 (s, 2H), 7.08 (s, 2H), 4.90 (s, 1H), 4.88 (s, 1H), 4.85 (s, 1H), 4.74 (s, 1H), 4.31 (hept. J = 6.7 Hz, 2H), 4.06 (hept. J = 6.7 Hz, 2H), 4.04 (s, 2H), 3.13 (d, J = 8.9 Hz, 1H), 2.96 (d, J = 8.9 Hz, 1H), 2.91 – 2.80 (m, 2H), 2.30 (d, J = 16.6 Hz, 1H), 1.97 (d, J = 16.6 Hz, 1H), 1.69 (s, 6H), 1.65 (s, 3H), 1.36 (s, 6H), 1.23 (m, 36H), 1.12 (s, 3H).

¹³C NMR (101 MHz, Chloroform-d) δ 164.3 (C), 153.5 (C), 152.7 (C), 151.8 (C x 2), 150.2 (C x 2), 143.5 (C), 136.8 (C), 132.7 (C), 124.1 (CH x 2), 124.0 (CH x 2), 113.6 (CH₂), 104.9 (CH₂),

85.9 (C), 81.3 (C), 69.9 (C), 57.5 (C), 56.2 (CH₂), 53.5 (CH₂), 44.0 (C), 34.4 (CH x 2), 34.4 (CH x 2), 30.8 (CH₂), 30.6 (CH), 30.5 (CH), 30.0 (CH₃), 29.30 (CH₃ x 2), 29.27 (CH₃ x 2), 28.7 (CH₃), 25.2 (CH₃), 25.1 (CH₃ x 2), 25.0 (CH₃ x 2), 24.98 (CH₃), 24.0 (CH₃), 23.9 (CH₃), 23.88 (CH₃), 23.86 (CH₃), 23.7 (CH₃), 20.8 (CH₃).

IR (neat) ν : 2962, 2911, 2254, 1600, 1462, 1384, 1143, 1038, 902, 723, 583 cm⁻¹.

HRMS (ESI-MS) calcd. for C₄₈H₇₈N₃O₄S₂⁺ ([M+NH₄]⁺): 824.5428, found 824.5427.



N-(2-methyl-5-(3,5,5-trimethyl-4-methylene-1-(methylsulfonyl)pyrrolidin-3-yl)pent-3-yn-2-yl)-N-(2-methylallyl)methanesulfonamide (8f), obtained: 39.6 mg (92%); colorless oil; *R_f* (PE/EA 6/4) 0.40;

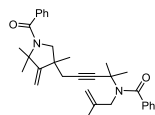
¹H NMR (300 MHz, Chloroform-*d*) δ 5.02 (s, 1H), 4.94 (s, 1H), 4.93 (s, 2H), 3.88 (s, 2H), 3.49 (d, *J* = 9.6 Hz, 1H), 3.14 (d, *J* = 9.6 Hz, 1H), 3.00 (s, 3H), 2.91 (s, 3H), 2.46 (d, *J* = 16.8 Hz, 1H), 2.33 (d, *J* = 16.8 Hz, 1H), 1.74 (s, 3H), 1.67 (s, 6H), 1.54 (s, 3H), 1.52 (s, 3H), 1.26 (s, 3H).

¹³C NMR (75 MHz, Chloroform-*d*) δ 162.0 (C), 142.1 (C), 110.8 (CH₂), 104.8 (CH₂), 84.5 (C), 79.9 (C), 66.8 (C), 56.4 (CH₂), 55.5 (C), 51.5 (CH₂), 42.8 (C), 40.7 (CH₃), 39.3 (CH₃), 30.3 (CH₃ x 2), 29.1 (CH₂), 28.7 (CH₃), 28.0 (CH₃), 23.8 (CH₃), 19.5 (CH₃).

IR (neat) ν : 2975, 2933, 2871, 2255, 1659, 1322, 1138, 961, 765, 518 cm⁻¹.

HRMS (ESI-MS) calcd. for C₂₀H₃₈N₃O₄S₂⁺ ([M+NH₄]⁺): 448.2298, found 448.2298.

N-(5-(1-benzoyl-3,5,5-trimethyl-4-methylenepyrrolidin-3-yl)-2-methylpent-3-yn-2-yl)-N-(2-methylallyl)benzamide (8g); obtained: 35.2 mg (73%); colorless oil; *R_f* (PE/Et₂O 4/6) 0.35;

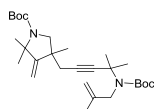


¹H NMR (400 MHz, Chloroform-*d*) δ 7.45 – 7.30 (m, 10H), 5.01 (s, 2H), 4.96 (s, 1H), 4.89 (s, 1H), 3.87 (s, 2H), 3.57 (d, *J* = 11.1 Hz, 1H), 3.20 (d, *J* = 11.1 Hz, 1H), 2.45 (d, *J* = 16.7 Hz, 1H), 2.29 (d, *J* = 16.7 Hz, 1H), 1.81 (s, 3H), 1.79 (s, 3H), 1.74 (s, 3H), 1.69 (s, 3H), 1.48 (s, 3H), 1.23 (s, 3H).

¹³C NMR (101 MHz, Chloroform-*d*) δ 172.8 (C), 163.9 (C), 143.5 (C x 2), 138.9 (C), 138.8 (C), 129.5 (CH x 2), 128.7 (CH x 2), 128.4 (CH x 2), 126.6 (CH x 2), 126.3 (CH x 2), 112.1 (CH₂), 105.2 (CH₂), 86.6 (C), 80.4 (C), 66.0 (C), 59.2 (CH₂), 56.0 (C), 54.8 (CH₂), 44.4 (C), 30.1 (CH₂), 28.77 (CH₃ x 2), 28.75 (CH₃ x 2), 24.2 (CH₃), 20.4 (CH₃).

IR (neat) ν : 2974, 2933, 2244, 1630, 1396, 1156, 904, 724, 646 cm⁻¹.

HRMS (ESI-MS) calcd. for C₃₂H₃₉N₂O₂⁺ ([M+H]⁺): 483.3006, found 483.3006.



tert-Butyl-4-(4-((tert-butoxycarbonyl)(2-methylallyl)amino)-4-methylpent-2-yn-1-yl)-2,2,4-trimethyl-3-methylenepyrrolidine-1-carboxylate (8l); obtained: 39.4 mg (83%); colorless oil; *R_f* (PE/Et₂O 9/1) 0.50;

¹H NMR (400 MHz, Chloroform-*d*) δ 4.89 (s, 2H), 4.81 (s, 2H), 4.00 (s, 2H), 3.48 (d, *J* = 11.1 Hz, 1H), 3.18 (dd, *J* = 39.6, 11.1 Hz, 1H), 2.37 – 2.23 (m, 2H), 1.68 (d, *J* = 5.0 Hz, 9H), 1.49 – 1.42 (m, 24H), 1.20 (s, 3H).

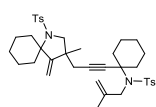
¹³C NMR (75 MHz, Chloroform-*d*) δ 163.9, 142.54, 108.62, 85.76, 78.90, 56.02, 53.73,

51.22 , 29.80 , 28.87 , 28.85 , 27.90 , 27.75 , 24.42 , 19.52 .

¹³C NMR (75 MHz, Chloroform-*d*) δ 164.6 (C), 154.2 (C x 2), 142.5 (C), 108.6 (CH₂), 104.2 (CH₂), 85.8 (C), 79.4 (C), 78.9 (C x 2), 63.4 (C), 56.0 (CH₂), 53.7 (C), 51.2 (CH₂), 41.7 (C), 29.8 (CH₂), 28.9 (CH₃), 28.8 (CH₃), 28.3 (CH₃), 27.9 (CH₃ x 3), 27.8 (CH₃ x 3), 25.8 (CH₃), 24.4 (CH₃), 19.5 (CH₃).

IR (neat) ν : 2979, 2899, 2252, 1680, 1388, 1238, 1164, 903, 732, 649 cm⁻¹.

HRMS (ESI-MS) calcd. for C₂₈H₄₇N₂O₄⁺ ([M+H]⁺): 475.3530, found 475.3533.



4-Methyl-N-(1-(3-(3-methyl-4-methylene-1-tosyl-1-azaspiro[4.5]decan-3-yl)prop-1-yn-1-yl)cyclohexyl)-N-(2-methylallyl)benzenesulfonamide (8i), obtained: 58.3 mg (88%); colorless oil; *R_f* (PE/Et₂O 6/4) 0.35;

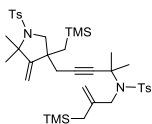
¹H NMR (300 MHz, Chloroform-*d*) δ 7.73 (d, *J* = 8.3 Hz, 2H), 7.67 (d, *J* = 8.3 Hz, 2H), 7.27 – 7.23 (m, 4H), 5.32 (s, 1H), 5.06 (s, 1H), 4.91 (s, 1H), 4.78 (s, 1H), 4.01 (s, 2H), 3.19 (d, *J* = 9.7 Hz, 1H), 2.99 (d, *J* = 9.7 Hz, 1H), 2.66 – 2.51 (m, 2H), 2.40 (s, 6H), 2.03 (d, *J* = 16.7, 1H), 1.99 (d, *J* = 16.7, 1H), 1.95 – 1.93 (m, 2H), 1.87 – 1.82 (dd, *J* = 12.6, 2.7 Hz, 2H), 1.77 (s, 3H), 1.71 – 1.65 (m, 6H), 1.59 – 1.46 (m, 4H), 1.41 – 1.19 (m, 4H), 1.00 (s, 3H).

¹³C NMR (75 MHz, Chloroform-*d*) δ 161.4 (C), 143.7 (C), 143.3 (C), 143.0 (C), 139.9 (C), 138.9 (C), 129.7 (CH x 2), 129.5 (CH x 2), 127.8 (CH x 2), 127.6 (CH x 2), 112.0 (CH₂), 107.6 (CH₂), 84.0 (C), 82.0 (C), 71.4 (C), 63.0 (C), 57.0 (CH₂), 53.7 (CH₂), 44.7 (C), 38.2 (CH₂ x 2), 35.5 (CH₂), 35.4 (CH₂), 30.4 (CH₂), 25.1 (CH₂), 25.0 (CH₃), 24.5 (CH₂), 24.02 (CH₂), 23.97 (CH₂), 22.5 (CH₂), 22.4 (CH₂), 21.8 (CH₃ x 2), 20.7 (CH₃).

IR (neat) ν : 2988, 2930, 2253, 1626, 1398, 1299, 1152, 1096, 903, 739, 597 cm⁻¹.

HRMS (ESI-MS) calcd. for C₃₈H₅₄N₃O₄S₂⁺ ([M+NH₄]⁺): 680.3550, found 680.3550.

N-(5-(5,5-dimethyl-4-methylene-1-tosyl-3-((trimethylsilyl)methyl)pyrrolidin-3-yl)-2-methylpent-3-yn-2-yl)-4-methyl-N-(2-((trimethylsilyl)methyl)allyl)benzenesulfonamide (8m); obtained: 35.9 mg (50%); colorless oil; *R_f* (PE/Et₂O 6/4) 0.40;

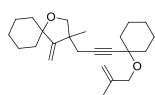


¹H NMR (400 MHz, Chloroform-*d*) δ 7.74 (dd, *J* = 10.6, 8.3 Hz, 4H), 7.32 – 7.26 (m, 4H), 5.03 (d, *J* = 1.6 Hz, 1H), 4.88 (s, 1H), 4.84 (s, 1H), 4.77 (s, 1H), 3.98 (s, 2H), 3.24 (d, *J* = 9.5 Hz, 1H), 3.08 (d, *J* = 9.5 Hz, 1H), 2.44 (s, 3H), 2.44 (s, 3H), 2.15 (d, *J* = 1.9 Hz, 2H), 1.59 (s, 6H), 1.56 (s, 2H), 1.54 (s, 3H), 1.50 (s, 3H), 1.09 (d, *J* = 15.0 Hz, 1H), 0.78 (d, *J* = 15.0 Hz, 1H), 0.10 (s, 9H), 0.00 (s, 9H).

¹³C NMR (101 MHz, Chloroform-*d*) δ 164.2 (C), 145.5 (C), 144.4 (C), 144.0 (C), 140.8 (C), 139.0 (C), 130.7 (CH x 2), 130.5 (CH x 2), 128.8 (CH x 2), 128.8 (CH x 2), 110.4 (CH₂), 107.0 (CH₂), 86.5 (C), 81.9 (C), 69.1 (C), 58.7 (CH₂), 57.9 (C), 55.6 (CH₂), 47.4 (C), 32.6 (CH₃), 32.5 (CH₃), 31.5 (CH₂), 31.3 (CH₃), 30.3 (CH₃), 27.2 (CH₂), 25.5 (CH₂), 22.8 (CH₃ x 2), 1.8 (CH₃ x 3), 0.1 (CH₃ x 3).

IR (neat) ν : 2952, 2897, 2255, 1599, 1333, 1149, 1090, 837, 708, 571 cm⁻¹.

HRMS (ESI-MS) calcd. for C₃₈H₆₂N₃O₄S₂Si₂⁺ ([M+NH₄]⁺): 744.3715, found 744.3724.



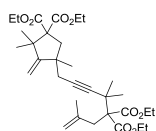
3-Methyl-3-(3-(1-((2-methylallyl)oxy)cyclohexyl)prop-2-yn-1-yl)-4-methylene-1-oxaspiro[4.5]decane (8j); obtained: 30.0 mg (84%); colorless oil; R_f (PE/Et₂O 8/2) 0.35;

¹H NMR (300 MHz, Chloroform-*d*) δ 4.99 (s, 1H), 4.84 (s, 2H), 4.78 (s, 1H), 3.97 (s, 2H), 3.85 (d, J = 8.9 Hz, 1H), 3.53 (d, J = 8.9 Hz, 1H), 2.42 (d, J = 16.6 Hz, 1H), 2.25 (d, J = 16.6 Hz, 1H), 1.88 – 1.82 (m, 2H), 1.75 (s, 3H), 1.71 – 1.46 (m, 14H), 1.39 – 1.24 (m, 4H), 1.20 (s, 3H).

¹³C NMR (75 MHz, Chloroform-*d*) δ 164.0 (C), 143.5 (C), 111.5 (CH₂), 103.4 (CH₂), 84.7 (C), 83.8 (C), 83.2 (C), 75.0 (CH₂), 74.2 (C), 67.5 (CH₂), 46.4 (C), 37.9 (CH₂), 37.8 (CH₂), 37.4 (CH₂), 36.6 (CH₂), 30.1 (CH₂ x 2), 25.9 (CH₂), 25.7 (CH₂), 24.1 (CH₃), 23.3 (CH₂), 22.8 (CH₂), 22.7 (CH₂), 20.2 (CH₃).

IR (neat) ν : 2933, 2856, 2245, 1721, 1447, 1143, 968, 774, 647 cm⁻¹.

HRMS (ESI-MS) calcd. for C₂₄H₄₀NO₂⁺ ([M+NH₄]⁺): 374.3054, found 374.3054.



Diethyl 4-(5,5-bis(ethoxycarbonyl)-4,4,7-trimethyloct-7-en-2-yn-1-yl)-2,2,4-trimethyl-3-methylenecyclopentane-1,1-dicarboxylate (8k); obtained: 39.8 mg (71%), colorless oil; R_f (PE/Et₂O = 8: 2) 0.50;

¹H NMR (400 MHz, Chloroform-*d*) δ 4.91 (s, 1H), 4.86 (s, 1H), 4.76 (s, 1H), 4.70 (s, 1H), 4.20 – 4.14 (m, 8H), 2.96 (s, 2H), 2.60 (d, J = 15.0 Hz, 1H), 2.36 (t, J = 16.7 Hz, 1H), 2.27 (d, J = 15.0, 1H), 2.24 (t, J = 16.7 Hz, 1H), 1.73 (s, 3H), 1.38 (s, 6H), 1.30 (s, 3H), 1.26 – 1.23 (m, 18H).

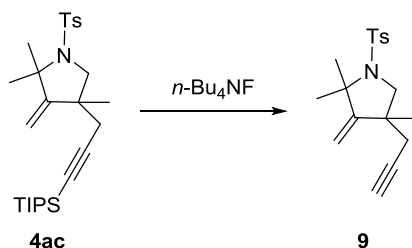
¹³C NMR (75 MHz, Chloroform-*d*) δ 170.3 (C), 170.22 (C), 169.0 (C x 2), 166.6 (C), 142.3 (C), 113.4 (CH₂), 103.2 (CH₂), 85.7 (C), 79.8 (C), 64.7 (C), 63.3 (C), 60.22 (CH₂), 60.20 (CH₂), 60.1 (CH₂ x 2), 48.5 (C), 42.4 (CH₂), 42.2 (C), 39.7 (CH₂), 37.3 (C), 33.5 (CH₂), 29.1 (CH₃), 26.7 (CH₃), 26.6 (CH₃), 25.5 (CH₃), 24.8 (CH₃), 23.3 (CH₃), 13.4 (CH₃ x 2), 13.3 (CH₃ x 2).

IR (neat) ν : 2978, 2937, 2255, 1725, 1446, 1365, 1232, 1095, 949, 769, 592 cm⁻¹.

HRMS (ESI-MS) calcd. for C₃₂H₅₂NO₈⁺ ([M+NH₄]⁺): 578.3687, found 578.3687.

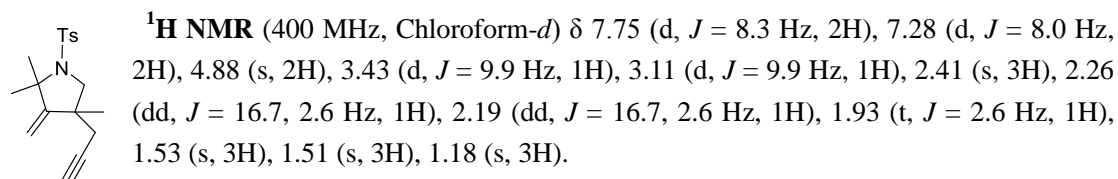
Part 4: Transformation of cross-coupling products

2,2,4-Trimethyl-3-methylene-4-(prop-2-yn-1-yl)-1-tosylpyrrolidine (9)



To a solution of **4ac** (1.9 g, 4 mmol) in THF (30 mL) was added *n*-Bu₄NF (8 mL, 8 mmol, 1.0 M

in THF). The resulting mixture was stirred overnight at room temperature, and concentrated under vacuo. The crude residue was purified by flash chromatography to give 1.3 g (99%) of **9** as a colorless oil; R_f (PE/Et₂O 8/2) 0.45.

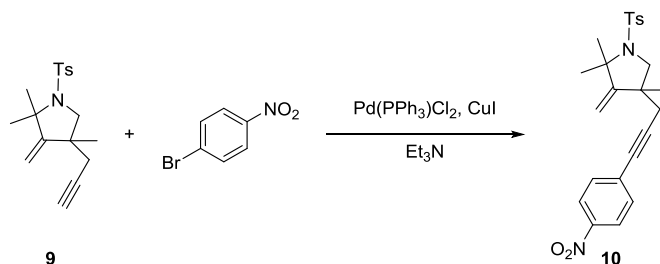


¹³C NMR (75 MHz, Chloroform-*d*) δ 163.5 (C), 143.3 (C), 138.5 (C), 129.7 (CH x 2), 127.7 (CH x 2), 105.4 (CH₂), 81.2 (C), 70.7 (CH), 68.6 (C), 57.4 (CH₂), 43.6 (C), 30.0 (CH₂), 29.5 (CH₃), 29.4 (CH₃), 24.5 (CH₃), 21.8 (CH₃).

IR (neat) ν : 2941, 2892, 2865, 1463, 1333, 1149, 1092, 995, 918, 881, 801, 673, 581, 549 cm⁻¹.

HRMS (ESI-MS) calcd. for C₁₈H₂₄NO₂S⁺ ([M+H]⁺): 318.1522, found 318.1523.

2,2,4-Trimethyl-3-methylene-4-(3-(4-nitrophenyl)prop-2-yn-1-yl)-1-tosylpyrrolidine (**10**)



To a solution of **9** (158.7 mg, 0.5 mmol) and 4-bromonitrobenzene (121.2 mg, 0.6 mmol) in Et₃N (5 mL) was added Pd(PPh₃)Cl₂ (17.5 mg, 0.025 mmol) and CuI (4.8 mg, 0.025 mmol). The resulting mixture was stirred at 50 °C for 15 h and then cooled to rt and diluted with MTBE (30 mL). The mixture was filtered over celite. The filtrate was washed with brine (10 mL), dried over Na₂SO₄, and concentrated under vacuo. The crude residue was purified by flash chromatography to give 149 mg (68%) of **10** as a pale yellow oil, R_f (PE/Et₂O 1/1) 0.50.

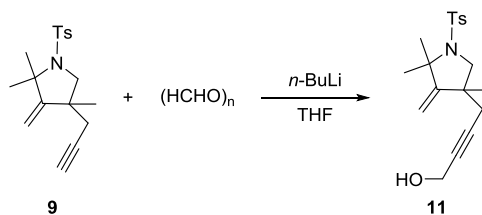
¹H NMR (400 MHz, Chloroform-*d*) δ 8.15 (d, J = 8.9 Hz, 2H), 7.77 (d, J = 8.3 Hz, 2H), 7.45 (d, J = 8.3 Hz, 2H), 7.27 (d, J = 9.2 Hz, 2H), 4.95 (s, 2H), 3.49 (d, J = 9.8 Hz, 1H), 3.14 (d, J = 9.8 Hz, 1H), 2.56 (d, J = 17.0 Hz, 1H), 2.46 (d, J = 17.0 Hz, 1H), 2.39 (s, 3H), 1.59 (s, 3H), 1.52 (s, 3H), 1.24 (s, 3H).

¹³C NMR (75 MHz, Chloroform-*d*) δ 163.3 (C), 147.1 (C), 143.4 (C), 138.3 (C), 132.6 (CH x 2), 130.7 (CH x 2), 129.7 (C), 127.7 (CH x 2), 123.8 (CH x 2), 105.7 (CH₂), 93.1 (C), 81.4 (C), 68.6 (C), 57.4 (CH₂), 44.1 (C), 31.0 (CH₂), 29.7 (CH₃), 29.2 (CH₃), 24.7 (CH₃), 21.8 (CH₃).

IR (neat) ν : 3078, 2974, 2930, 2869, 2221, 1592, 1516, 1340, 1158, 1148, 1090, 1033, 853, 583 cm⁻¹.

HRMS (ESI-MS) calcd. for C₂₄H₂₇N₂O₄S⁺ ([M+H]⁺): 439.1686, found 439.1690.

4-(3,5,5-Trimethyl-4-methylene-1-tosylpyrrolidin-3-yl)but-2-yn-1-ol (**11**)



To a solution of enyne **9** (158.7 mg, 0.5 mmol) in dry THF (10 mL) was dropwise added *n*-BuLi (0.38 mL, 0.6 mmol, 1.6 M in hexanes) at -78 °C. The mixture was gradually warmed to 0 °C and stirred for an additional 1 h. The oven-dried paraformaldehyde (18.0 mg, 0.6 mmol) was added in one portion and the resulting mixture was warmed to room temperature, and then heated to 40 °C for 1 h. Saturated aqueous NH₄Cl (20 mL) was added and the mixture was extracted with ethyl acetate (3×10 mL). The combined organic layers were washed with brine and dried over Na₂SO₄. After evaporation of the solvents, the residue was purified by column chromatography to afford 142.5 mg (82%) of **11** as a colorless oil, *R*_f (PE/Et₂O 2/3) 0.35.

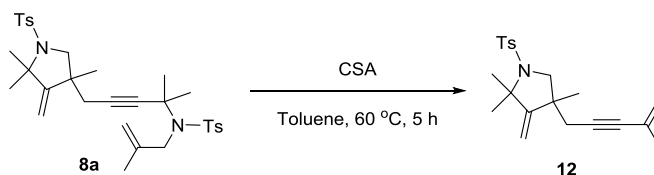
¹H NMR (300 MHz, Chloroform-*d*) δ 7.75 (d, *J* = 8.3 Hz, 2H), 7.28 (d, *J* = 8.2 Hz, 2H), 4.88 (s, 1H), 4.87 (s, 1H), 4.19 (t, *J* = 2.0 Hz, 2H), 3.44 (d, *J* = 9.8 Hz, 1H), 3.08 (d, *J* = 9.8 Hz, 1H), 2.42 (s, 3H), 2.32 (dt, *J* = 16.7, 2.0 Hz, 1H), 2.22 (dt, *J* = 16.7, 2.0 Hz, 1H), 1.58 (br s, 1H), 1.55 (s, 3H), 1.49 (s, 3H), 1.17 (s, 3H).

¹³C NMR (101 MHz, Chloroform-*d*) δ 163.6 (C), 143.4 (C), 138.4 (C), 129.8 (CH x 2), 127.8 (CH x 2), 105.4 (CH₂), 83.2 (C), 80.9 (C), 68.6 (C), 57.4 (CH₂), 51.6 (CH₂), 43.8 (C), 30.5 (CH₂), 29.7 (CH₃), 29.2 (CH₃), 24.6 (CH₃), 21.8 (CH₃).

IR (neat) *v*: 3506, 2969, 2926, 2868, 1732, 1599, 1425, 1364, 1289, 1260, 1148, 1091, 815, 657, 582, 549 cm⁻¹.

HRMS (ESI-MS) calcd. for C₁₉H₂₆NO₃S⁺ ([M+H]⁺): 348.1628, found 348.1630.

2,2,4-Trimethyl-3-methylene-4-(4-methylpent-4-en-2-yn-1-yl)-1-tosylpyrrolidie (**12**)



To a solution of the **8a** (291 mg, 0.5 mmol) in toluene (5 mL) was added camphorsulfonic acid (139.4 mg, 0.6 mmol). The mixture was stirred for 5 h at 60 °C, and cooled to room temperature. After addition of saturated aqueous NaHCO₃ (1 mL), the solution was washed with brine (10 mL), dried over Na₂SO₄, and concentrated under vacuo. The residue was purified by column chromatography to give 156 mg (87%) of **12** as a colorless oil, *R*_f (PE/Et₂O 3/1) 0.65.

¹H NMR (400 MHz, Chloroform-*d*) δ 7.76 (d, *J* = 8.3 Hz, 2H), 7.28 (d, *J* = 8.1 Hz, 2H), 5.13 (s, 2H), 4.89 (s, 2H), 3.42 (d, *J* = 9.8 Hz, 1H), 3.12 (d, *J* = 9.8 Hz, 1H), 2.41 (s, 3H), 2.37 (d, *J* = 16.8 Hz, 1H), 2.27 (d, *J* = 16.8 Hz, 1H), 1.81 (s, 3H), 1.53 (s, 6H), 1.18 (s, 3H).

¹³C NMR (101 MHz, Chloroform-*d*) δ 163.5 (C), 143.3 (C), 138.4 (C), 129.7 (CH x 2), 127.7 (CH x 2), 127.2 (C), 121.1 (CH₂), 105.3 (CH₂), 86.0 (C), 84.1 (C), 68.6 (C), 57.3 (CH₂), 44.1 (C), 30.7

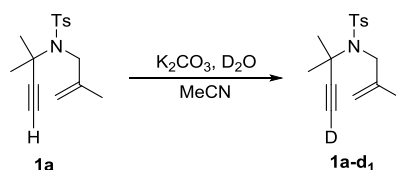
(CH₂), 29.5 (CH₃), 29.4 (CH₃), 24.6 (CH₃), 23.9 (CH₃), 21.8 (CH₃).

IR (neat) ν : 2980, 2946, 2877, 1552, 1490, 1339, 1266, 1185, 979, 865, 773, 619, 578 cm⁻¹.

HRMS (ESI-MS) calcd. for C₂₁H₂₈NO₂S⁺ ([M+H]⁺): 358.1835, found 358.1836.

Part 5: Deuterium labeling experiments

4-Methyl-*N*-(2-methylallyl)-*N*-(4-deutero-2-methylbut-3-yn-2-yl)benzenesulfonamide (**1a-d₁**)



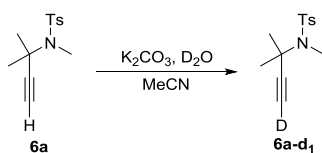
To a suspension of K₂CO₃ (207 mg, 1.5 mmol) in dry MeCN (5 mL) was added **1a** (291.4 mg, 1 mmol). The mixture was stirred for 2 h at room temperature. Then D₂O (1 mL, 50 mmol) was added and the reaction solution was stirred overnight, then diluted with CH₂Cl₂ (5 mL) and water was separated. The organic layers were dried over anhydrous Na₂SO₄, filtered and concentrated under vacuo to afford 290.6 mg (99%) **1a-d₁** (95% of deuteration determined by ¹H NMR).

¹H NMR (300 MHz, Chloroform-*d*) δ 7.73 (d, *J* = 8.1 Hz, 2H), 7.26 (t, *J* = 4.1 Hz, 3H), 5.08 (s, 1H), 4.94 (s, 1H), 4.11 (s, 2H), 2.41 (s, 3H), 2.19 (s, 0.05H), 1.79 (s, 3H), 1.66 (s, 6H).

¹³C NMR (75 MHz, Chloroform-*d*) δ 143.3 (C), 143.2 (C), 139.5 (C), 129.6 (CH x 2), 127.8 (CH x 2), 112.5 (CH₂), [85.8, 85.7, 85.6](C), [71.9, 71.7, 71.5](CH), 56.7 (C), 54.2 (CH₂), 31.1 (CH₃ x 2), 21.8 (CH₃), 20.6 (CH₃).

HRMS (ESI-MS) calcd. for C₁₆H₂₁DNO₂S ([M+H]⁺): 293.1429, found 293.1429.

N-Ethyl-4-methyl-*N*-(4-deutero-2-methylbut-3-yn-2-yl)benzenesulfonamide (**6a-d₁**)



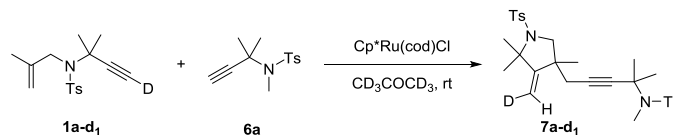
By using the above method, 245 mg (97%) of **6a-d₁** (97% of deuteration determined by ¹H NMR) were obtained.

¹H NMR (300 MHz, Chloroform-*d*) δ 7.72 (d, *J* = 8.2 Hz, 2H), 7.27 (d, *J* = 8.3 Hz, 3H), 3.08 (s, 3H), 2.42 (s, 3H), 2.24 (s, 0.03H), 1.67 (s, 6H).

¹³C NMR (75 MHz, Chloroform-*d*) δ 143.3 (C), 138.7 (C), 129.6 (CH x 2), 127.6 (CH x 2), [85.3, 85.2, 85.1] (C), [72.4, 72.2, 71.9] (CH), 55.8 (C), 34.4 (CH₃), 30.1 (CH₃ x 2), 21.7 (CH₃).

HRMS (ESI-MS) calcd. for C₁₃H₁₇DNO₂S⁺ ([M+H]⁺): 253.1116, found 253.1115.

***N*,4-dimethyl-*N*-(2-methyl-5-(3,5,5-trimethyl-4-methylene-1-tosylpyrrolidin-3-yl)pent-3-yn-2-yl)benzenesulfonamide (7a-d₁)**



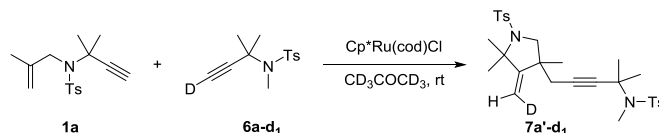
7a-d₁ was prepared according procedure **D** using **1a-d₁** and **6a** as coupling partners in CD₃COCD₃. Obtained: 83.7 mg (77%), colorless oil, R_f (PE/Et₂O 6/4) 0.35.

¹H NMR (400 MHz, Chloroform-*d*) δ 7.70 (dd, *J* = 20.2, 8.3 Hz, 4H), 7.28 (s, 2H), 7.26 (s, 2H), 4.84 (s, 0.06H), 4.77 (s, 1H), 3.23 (d, *J* = 9.7 Hz, 1H), 2.99 (d, *J* = 9.7 Hz, 1H), 2.97 (s, 3H), 2.40 (s, 3H), 2.40 (s, 3H), 2.13 (d, *J* = 16.7 Hz, 1H), 2.00 (d, *J* = 16.7 Hz, 1H), 1.56 (s, 3H), 1.55 (s, 3H), 1.50 (s, 3H), 1.49 (s, 3H), 1.05 (s, 3H).

¹³C NMR (75 MHz, Chloroform-*d*) δ 163.4 (C), 143.4 (C), 143.2 (C), 139.1 (C), 138.3 (C), 129.7 (CH x 2), 129.6 (CH x 2), 127.7 (CH x 2), 127.6 (CH x 2), [105.3, 105.0, 104.7](CH₂), 84.5 (C), 81.0 (C), 68.5 (C), 57.2 (CH₂), 56.3 (C), 43.8 (C), 34.4 (CH₃), 30.4 (CH₃ x 2), 29.9 (CH₂), 29.6 (CH₃), 29.3 (CH₃), 24.5 (CH₃), 21.8 (CH₃ x 2).

HRMS (ESI-MS) calcd. for C₂₉H₃₈DN₂O₄S₂⁺ ([M+H]⁺): 544.2409, found 544.2410.

***N*,4-dimethyl-*N*-(2-methyl-5-(3,5,5-trimethyl-4-methylene-1-tosylpyrrolidin-3-yl)pent-3-yn-2-yl)benzenesulfonamide (7a'-d₁)**



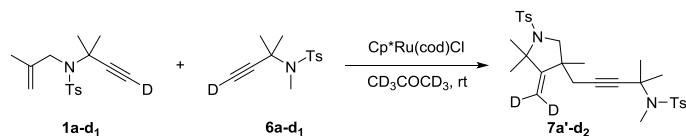
7a'-d₁ was prepared according procedure **D** using **1a** and **6a-d₁** as coupling partners in CD₃COCD₃. Obtained: 85.9 mg (79%), colorless oil, R_f (PE/Et₂O 6/4) 0.35.

¹H NMR (400 MHz, Chloroform-*d*) δ 7.70 (dd, *J* = 20.2, 8.3 Hz, 4H), 7.28 (s, 2H), 7.26 (s, 2H), 4.83 (s, 1H), 4.79 (s, 0.07H), 3.23 (d, *J* = 9.7 Hz, 1H), 2.99 (d, *J* = 9.7 Hz, 1H), 2.97 (s, 3H), 2.41 (s, 3H), 2.40 (s, 3H), 2.13 (d, *J* = 16.7 Hz, 1H), 2.01 (d, *J* = 16.7 Hz, 1H), 1.56 (s, 3H), 1.55 (s, 3H), 1.50 (s, 3H), 1.49 (s, 3H), 1.06 (s, 3H).

¹³C NMR (75 MHz, Chloroform-*d*) δ 163.4 (C), 143.4 (C), 143.2 (C), 139.1 (C), 138.3 (C), 129.7 (CH x 2), 129.6 (CH x 2), 127.8 (CH x 2), 127.6 (CH x 2), [105.3, 105.0, 104.7](CH₂), 84.6 (C), 81.0 (C), 68.5 (C), 57.2 (CH₂), 56.3 (C), 43.9 (C), 34.4 (CH₃), 30.4 (CH₃ x 2), 30.0 (CH₂), 29.65 (CH₃), 29.34 (CH₃), 24.5 (CH₃), 21.8 (CH₃ x 2).

C₂₉H₃₈DN₂O₄S₂⁺ ([M+H]⁺): 544.2409, found 544.2408.

***N*,4-dimethyl-*N*-(2-methyl-5-(3,5,5-trimethyl-4-methylene-1-tosylpyrrolidin-3-yl)pent-3-yn-2-yl)benzenesulfonamide (7a-d₂)**



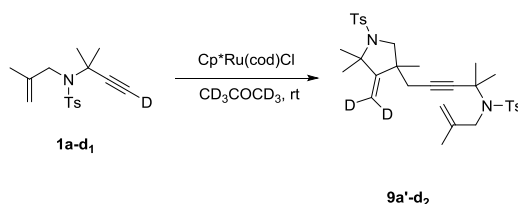
7a'-d₁ was prepared according procedure **D** using **1a-d₁** and **6a-d₁** as coupling partners in CD₃COCD₃. Obtained: 79.5 mg (73%), colorless oil, *R_f* (PE/Et₂O 6/4) 0.35.

¹H NMR (400 MHz, Chloroform-*d*) δ 7.70 (dd, *J* = 20.1, 8.3 Hz, 4H), 7.27 (d, *J* = 7.5 Hz, 4H), 4.83 (s, 0.05H), 4.77 (s, 0.08H), 3.24 (d, *J* = 9.7 Hz, 1H), 2.99 (d, *J* = 9.7 Hz, 1H), 2.97 (s, 3H), 2.41 (d, *J* = 1.5 Hz, 6H), 2.13 (d, *J* = 16.7 Hz, 1H), 2.01 (d, *J* = 16.7 Hz, 1H), 1.56 (s, 3H), 1.55 (s, 3H), 1.50 (s, 3H), 1.49 (s, 3H), 1.06 (s, 3H).

¹³C NMR (75 MHz, Chloroform-*d*) δ 163.2 (C), 143.4 (C), 143.2 (C), 139.1 (C), 138.3 (C), 129.7 (CH x 2), 129.7 (CH x 2), 127.8 (CH x 2), 127.6 (CH x 2), 84.6 (C), 81.0 (C), 68.5 (C), 57.2 (CH₂), 56.3 (C), 43.8 (C), 34.4 (CH₃), 30.4 (CH₃ x 2), 30.0 (CH₂), 29.7 (CH₃), 29.4 (CH₃), 24.5 (CH₃), 21.8 (CH₃ x 2).

HRMS (ESI-MS) calcd. for ([M]⁺): C₂₉H₃₇D₂N₂O₄S₂⁺ ([M+H]⁺): 545.2471, found 545.2470.

4-Methyl-N-(2-methyl-5-(3,5,5-trimethyl-4-dideuteromethylene-1-tosylpyrrolidin-3-yl)pent-3-yn-2-yl)-N-(2-methylallyl)benzenesulfonamide (9a-d₂)



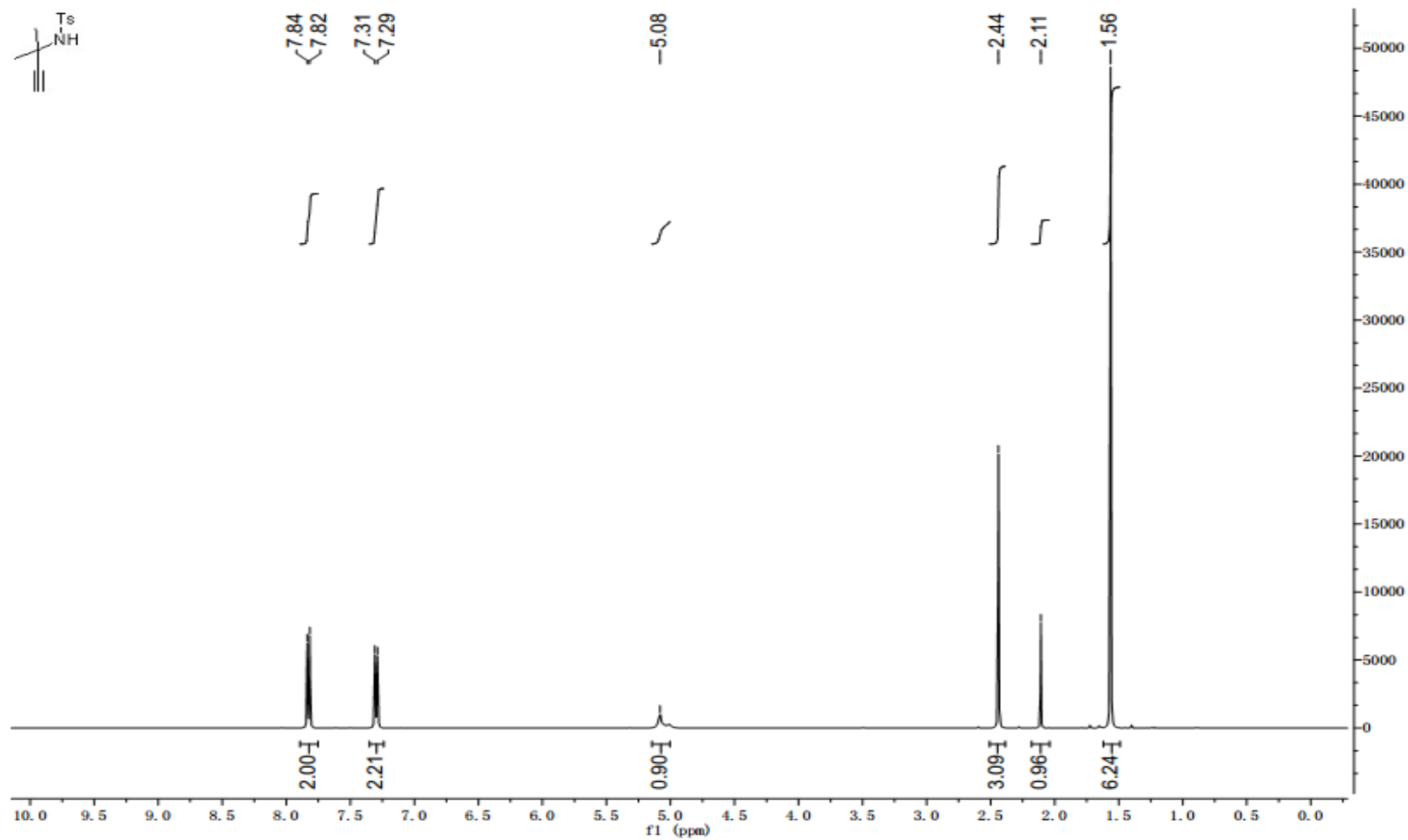
7a'-d₁ was prepared according procedure **D** using **1a-d₁** as reactant in CD₃COCD₃. Obtained: 49.7 mg (85%), colorless oil, *R_f* (PE/Et₂O 6/4) 0.35.

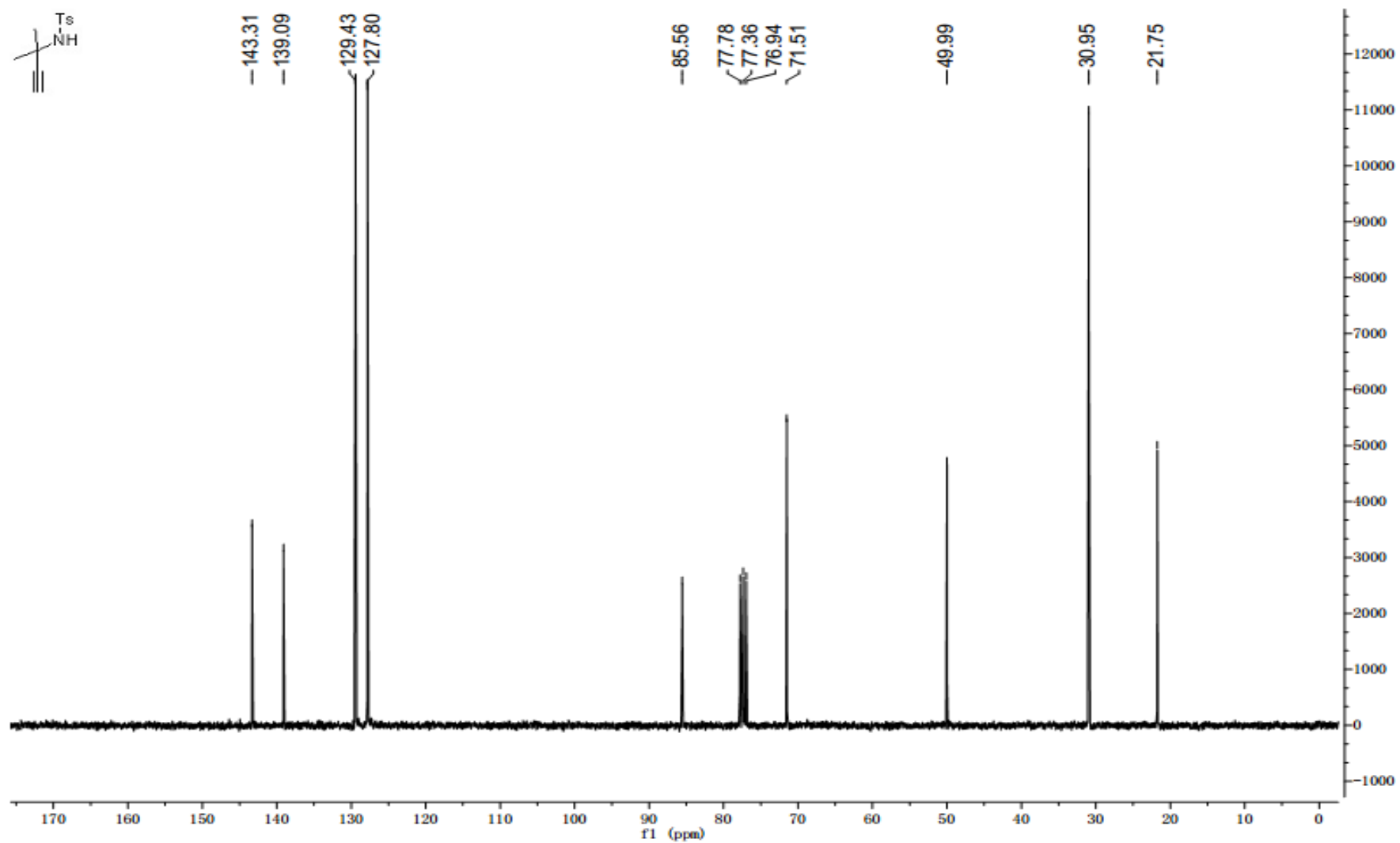
¹H NMR (400 MHz, Chloroform-*d*) δ 7.72 (d, *J* = 8.3 Hz, 2H), 7.68 (d, *J* = 8.3 Hz, 2H), 7.28 (s, 2H), 7.25 (d, *J* = 6.2 Hz, 2H), 5.02 (s, 1H), 4.90 (s, 1H), 4.83 (s, 0.05H), 4.76 (s, 0.07H), 4.02 (s, 2H), 3.23 (d, *J* = 9.7 Hz, 1H), 2.98 (d, *J* = 9.7 Hz, 1H), 2.40 (s, 6H), 2.10 (d, *J* = 16.7 Hz, 1H), 1.99 (d, *J* = 16.7 Hz, 1H), 1.76 (s, 3H), 1.54 (s, 6H), 1.50 (s, 3H), 1.48 (s, 3H), 1.04 (s, 3H).

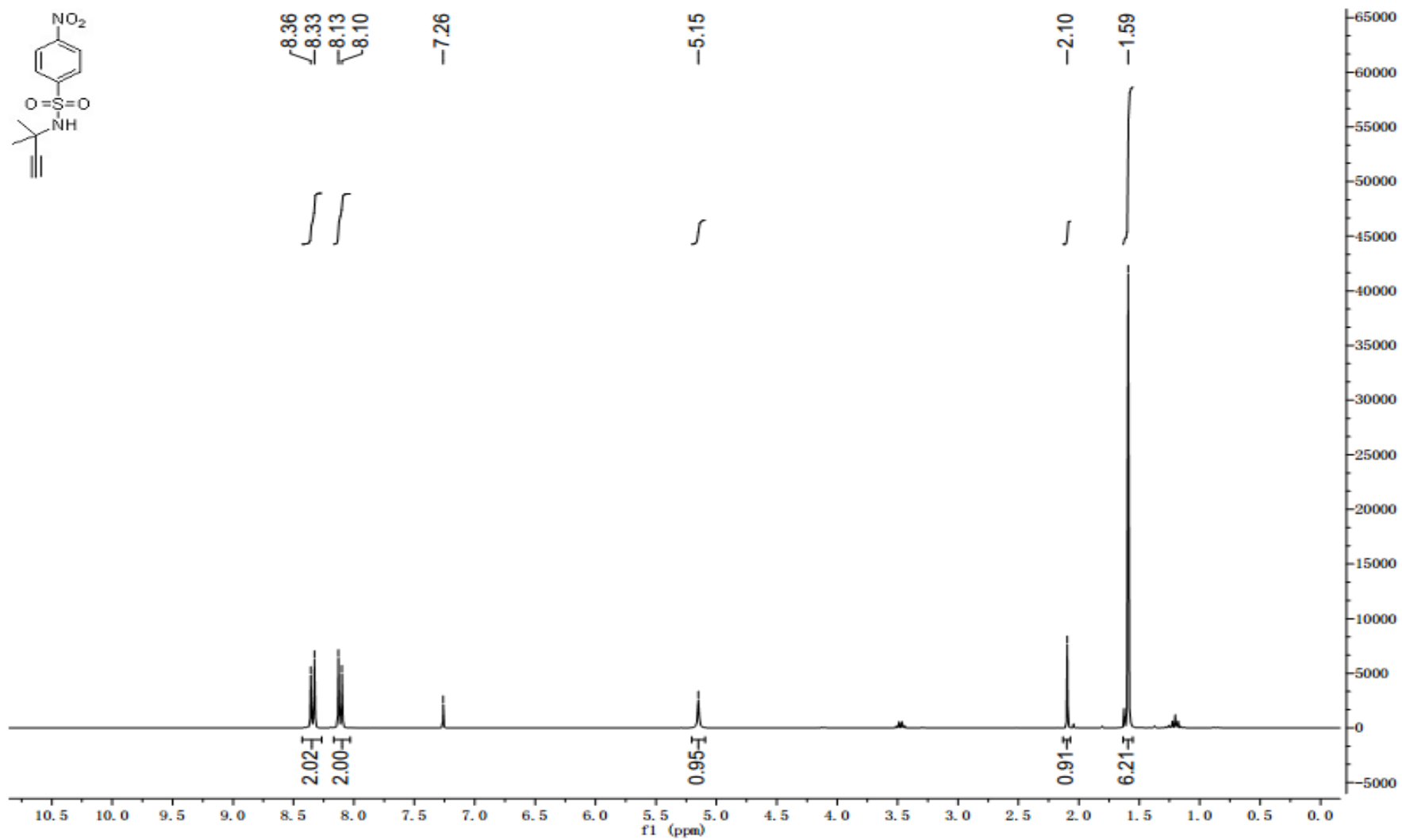
¹³C NMR (75 MHz, Chloroform-*d*) δ 163.3 (C), 143.4 (C), 143.3 (C), 143.1 (C), 139.8 (C), 138.3 (C), 129.7 (CH x 2), 129.5 (CH x 2), 127.8 (CH x 2), 127.7 (CH x 2), 112.3 (CH₂), 85.1 (C), 80.8 (C), 68.5 (C), 57.3 (CH₂), 57.1 (C), 54.1 (CH₂), 43.8 (C), 31.4 (CH₃), 31.3 (CH₃), 30.0 (CH₂), 29.7 (CH₃), 29.3 (CH₃), 24.5 (CH₃), 21.8 (CH₃ x 2), 20.6 (CH₃).

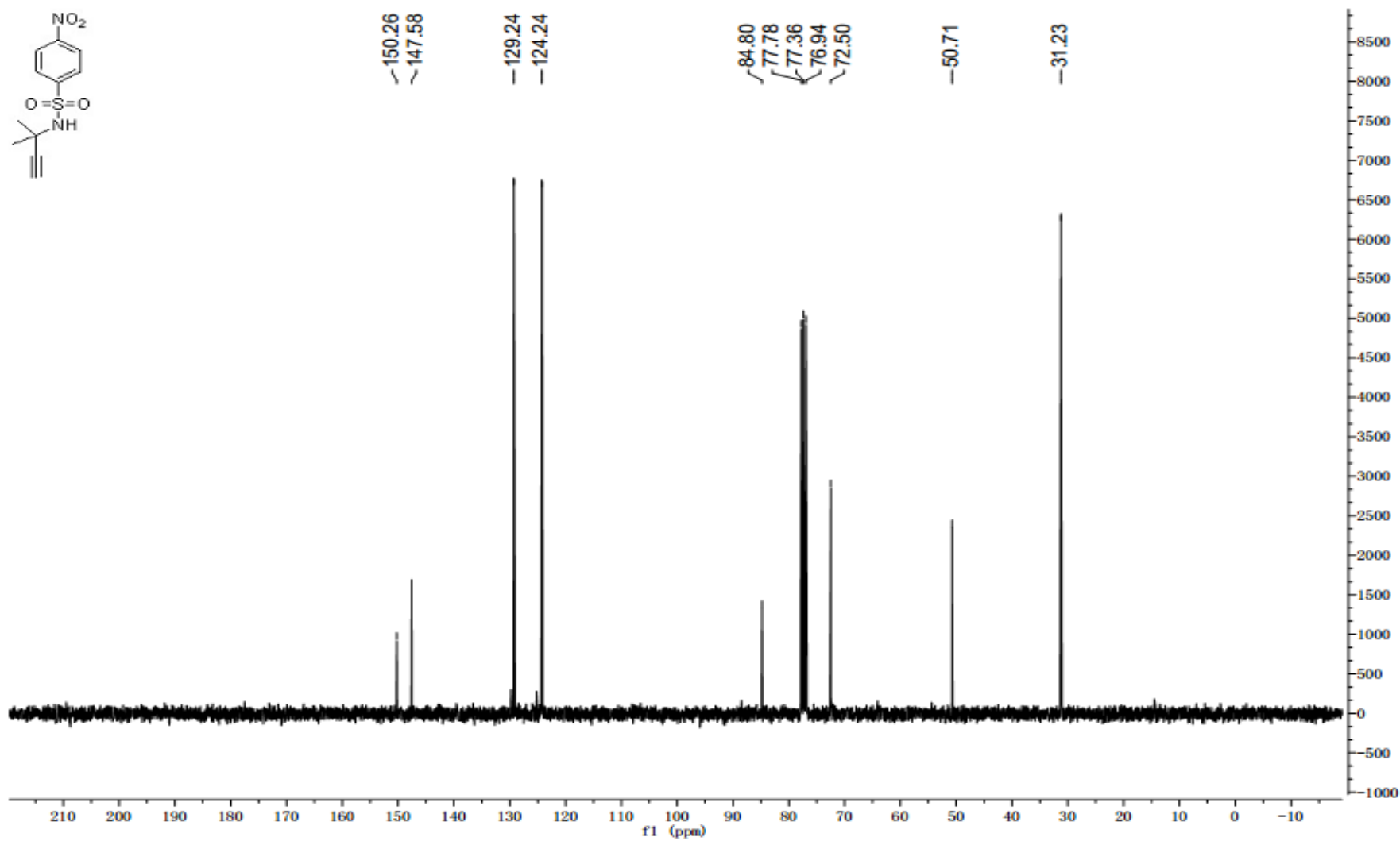
HRMS (ESI-MS) calcd. for ([M]⁺): C₃₂H₄₁D₂N₂O₄S₂⁺ ([M+H]⁺): 585.2784, found 585.2793.

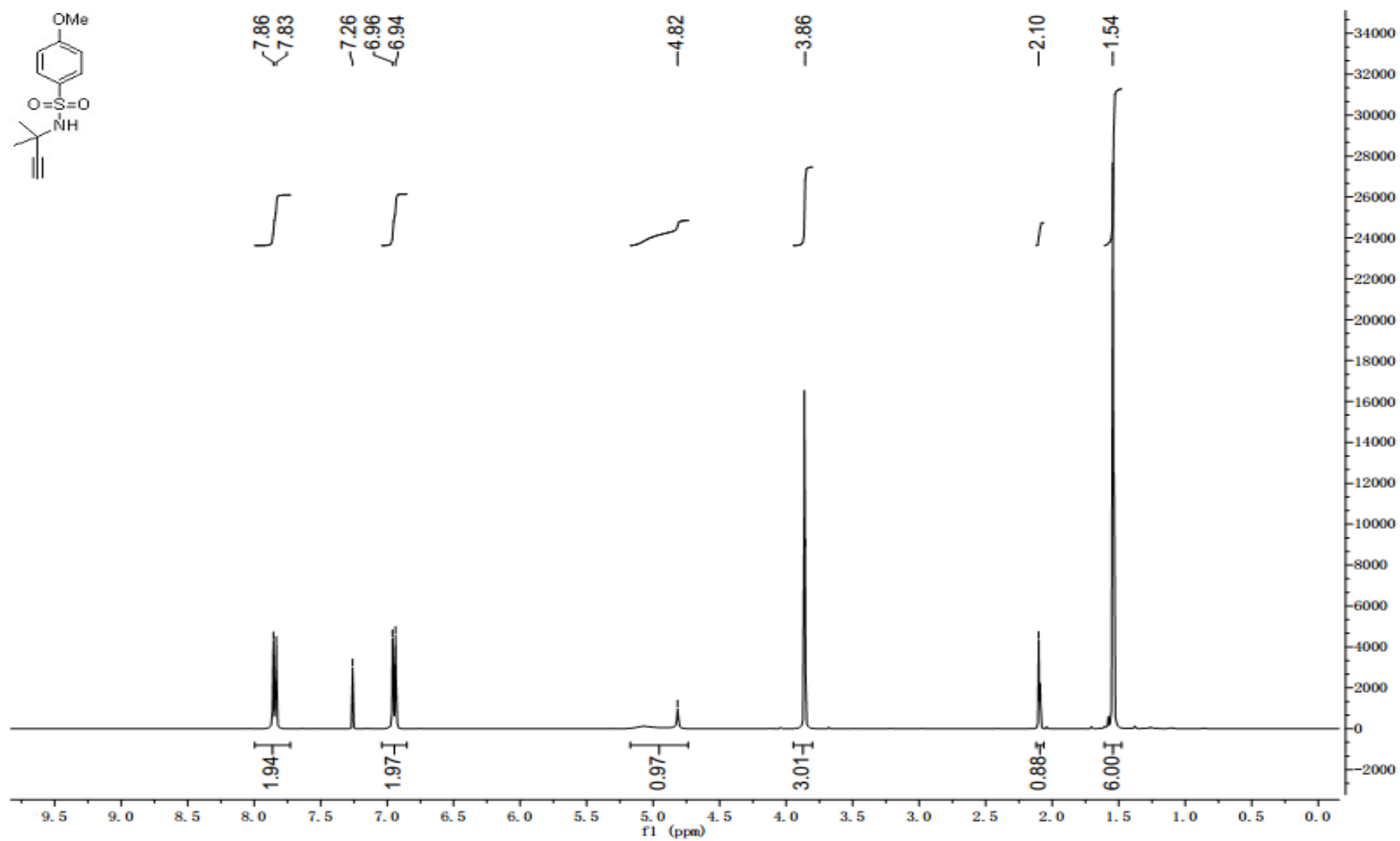
Part 6: NMR spectra

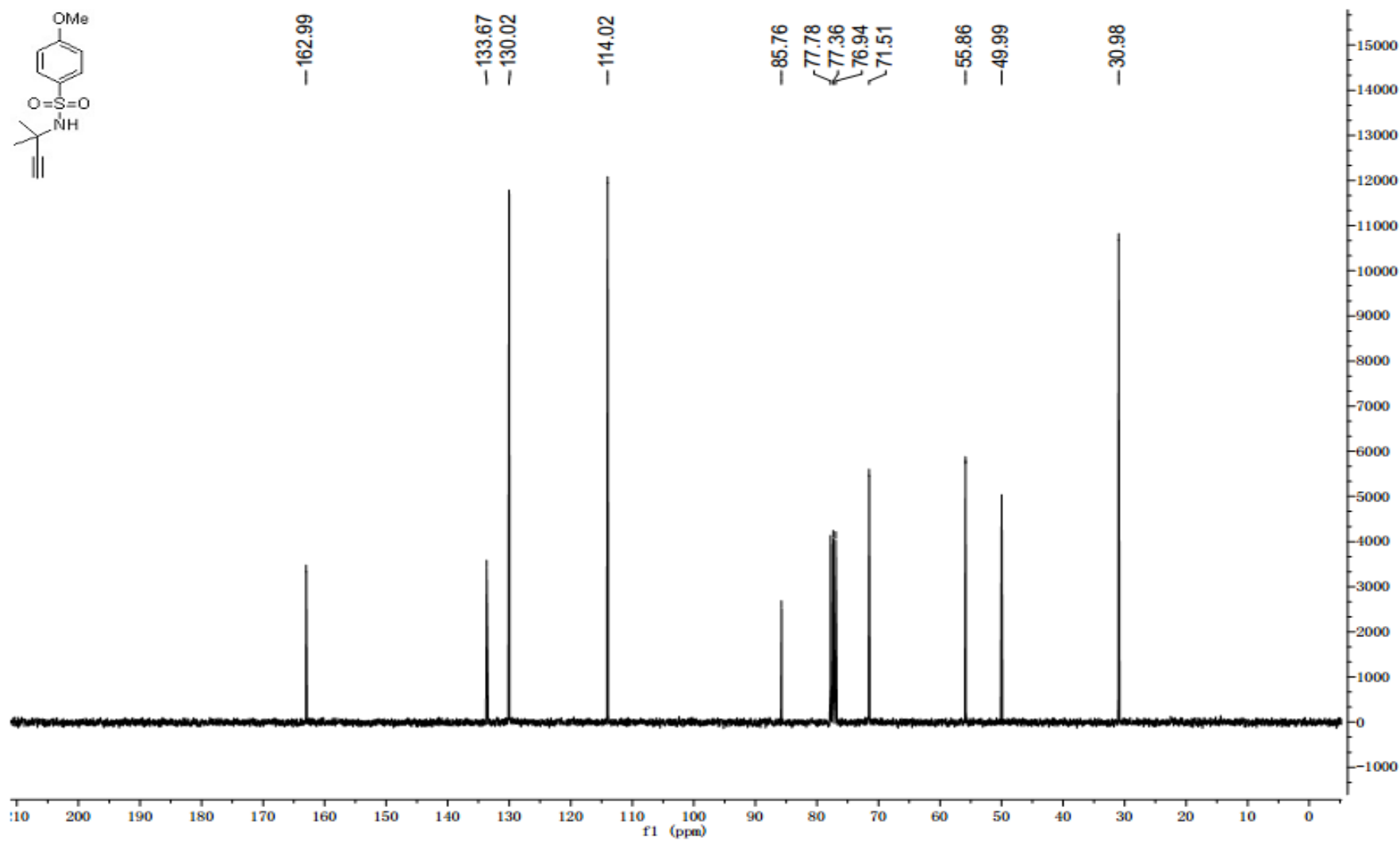


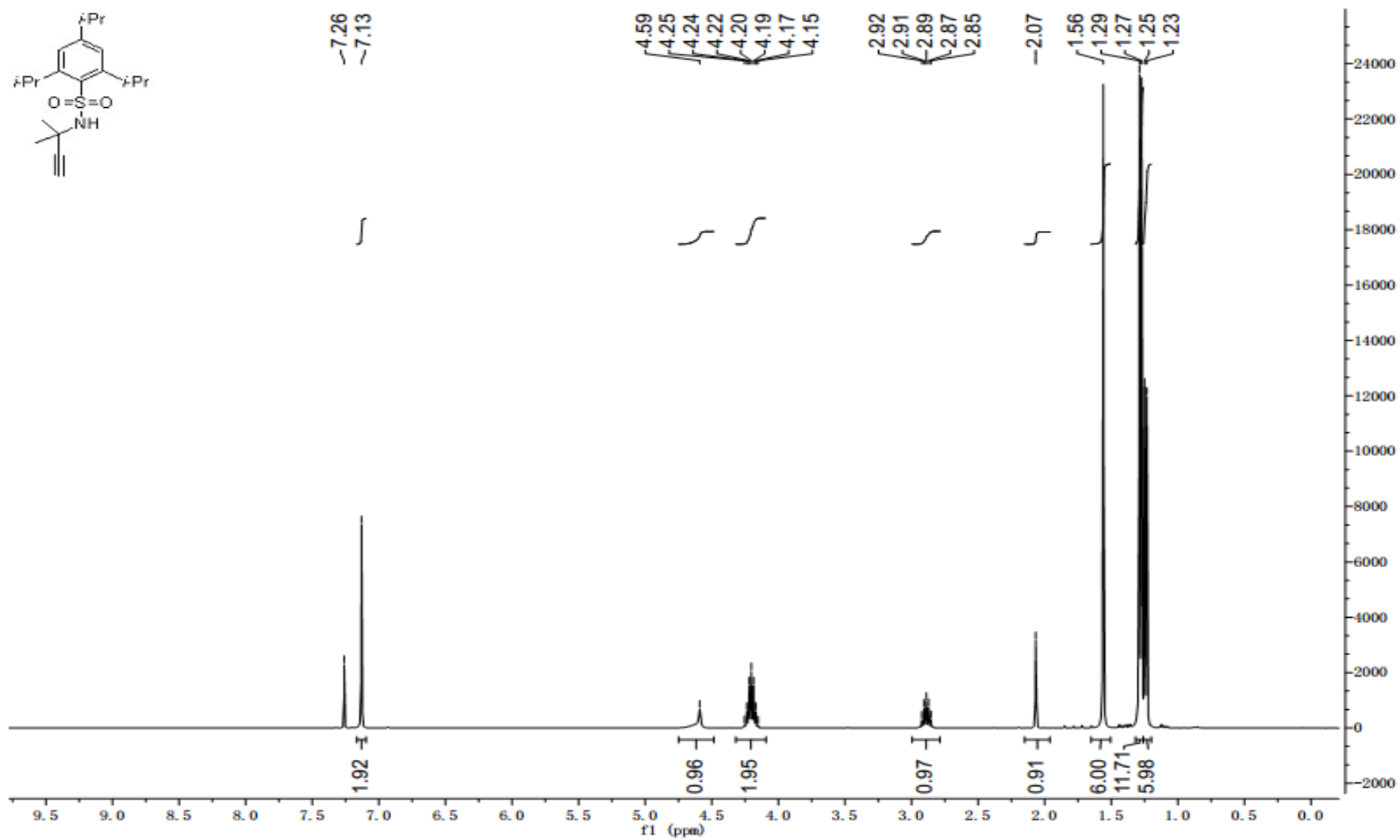


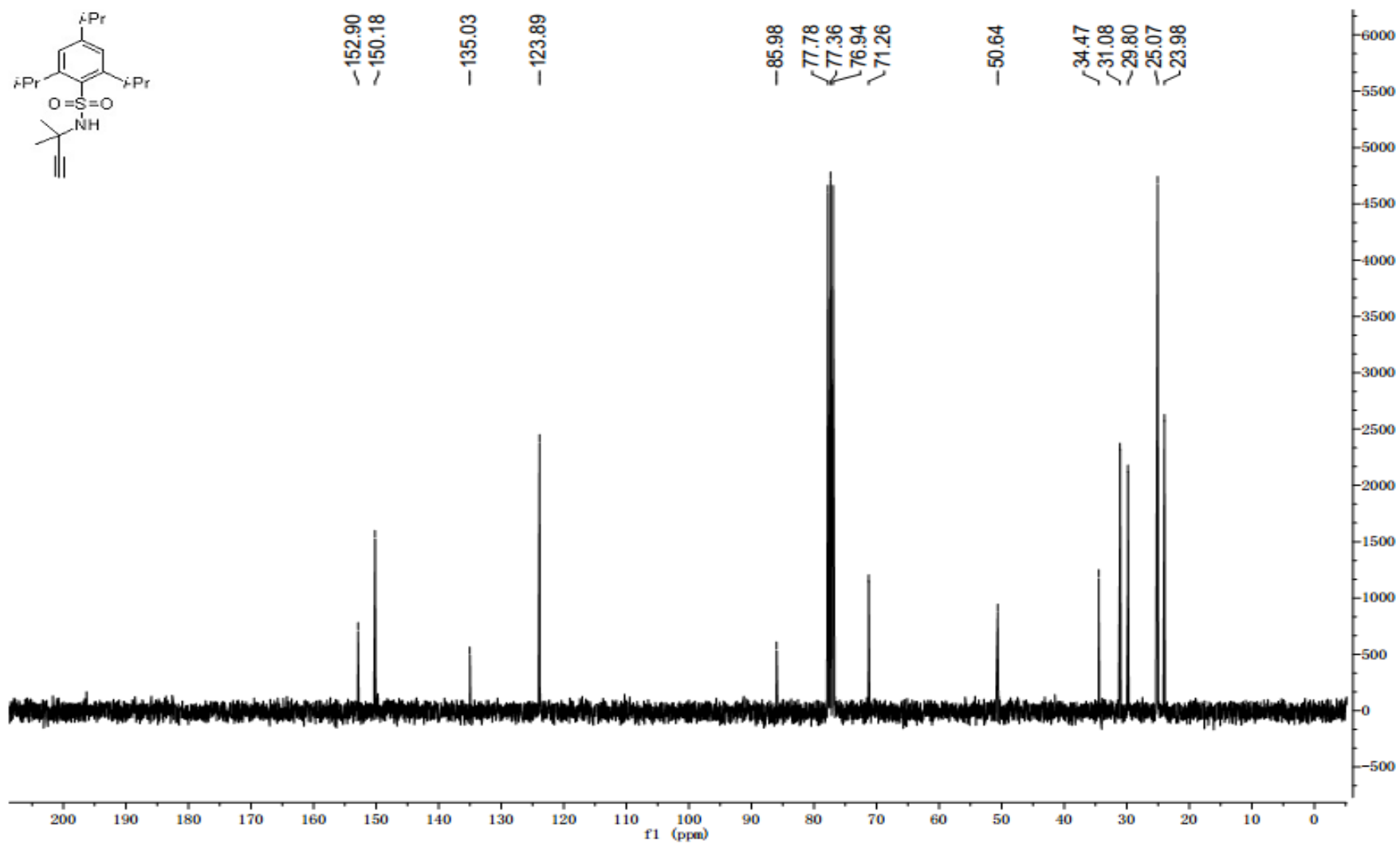


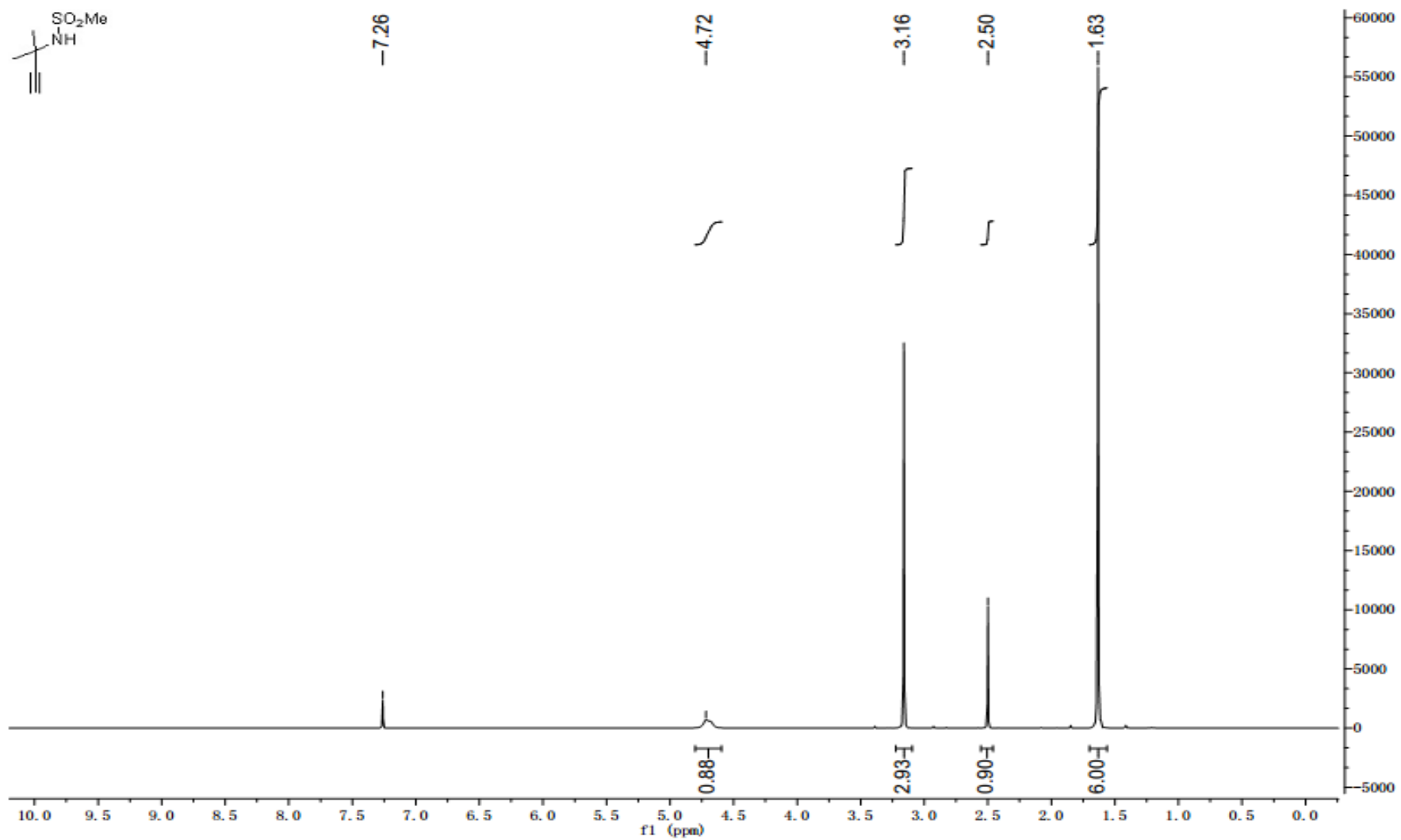


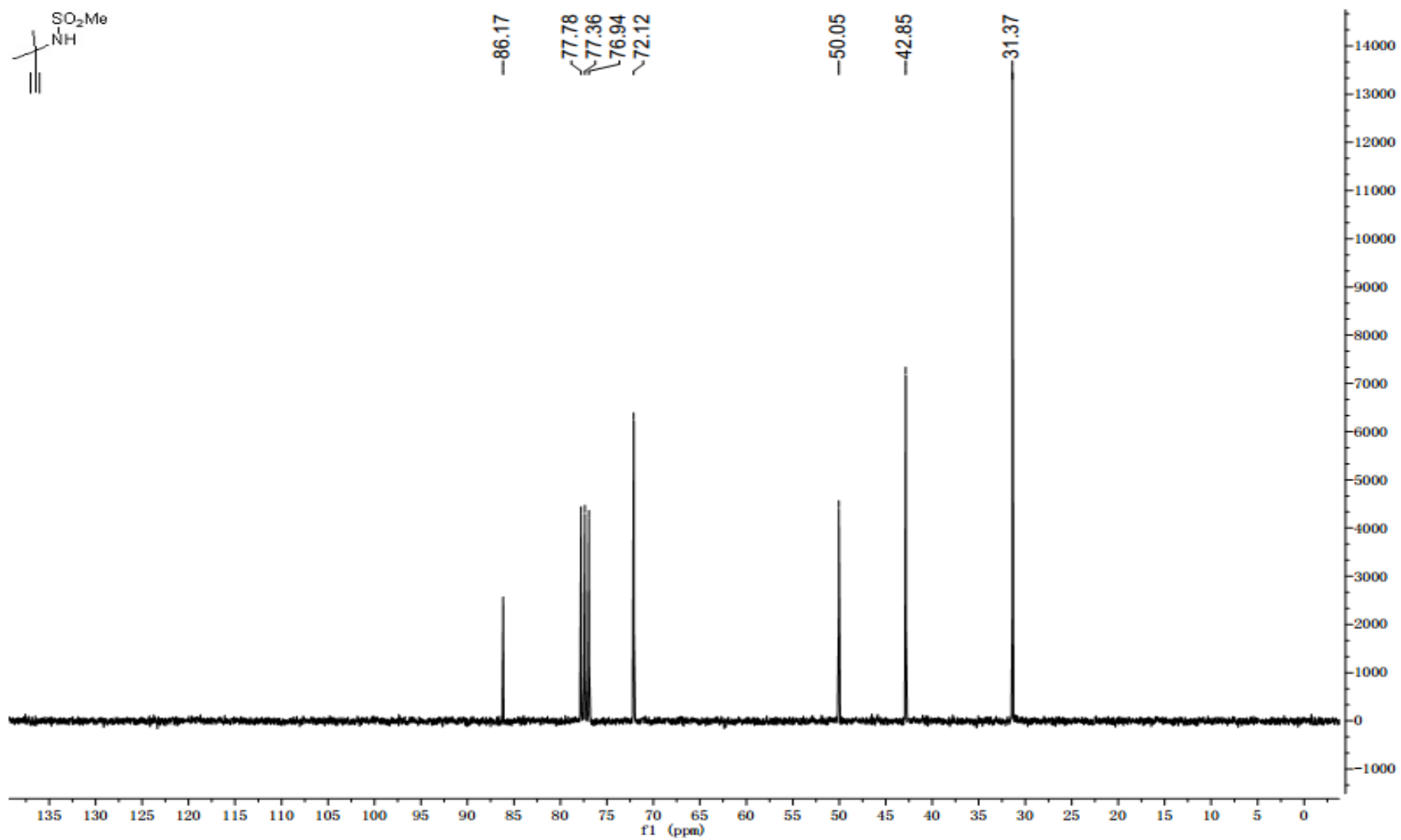


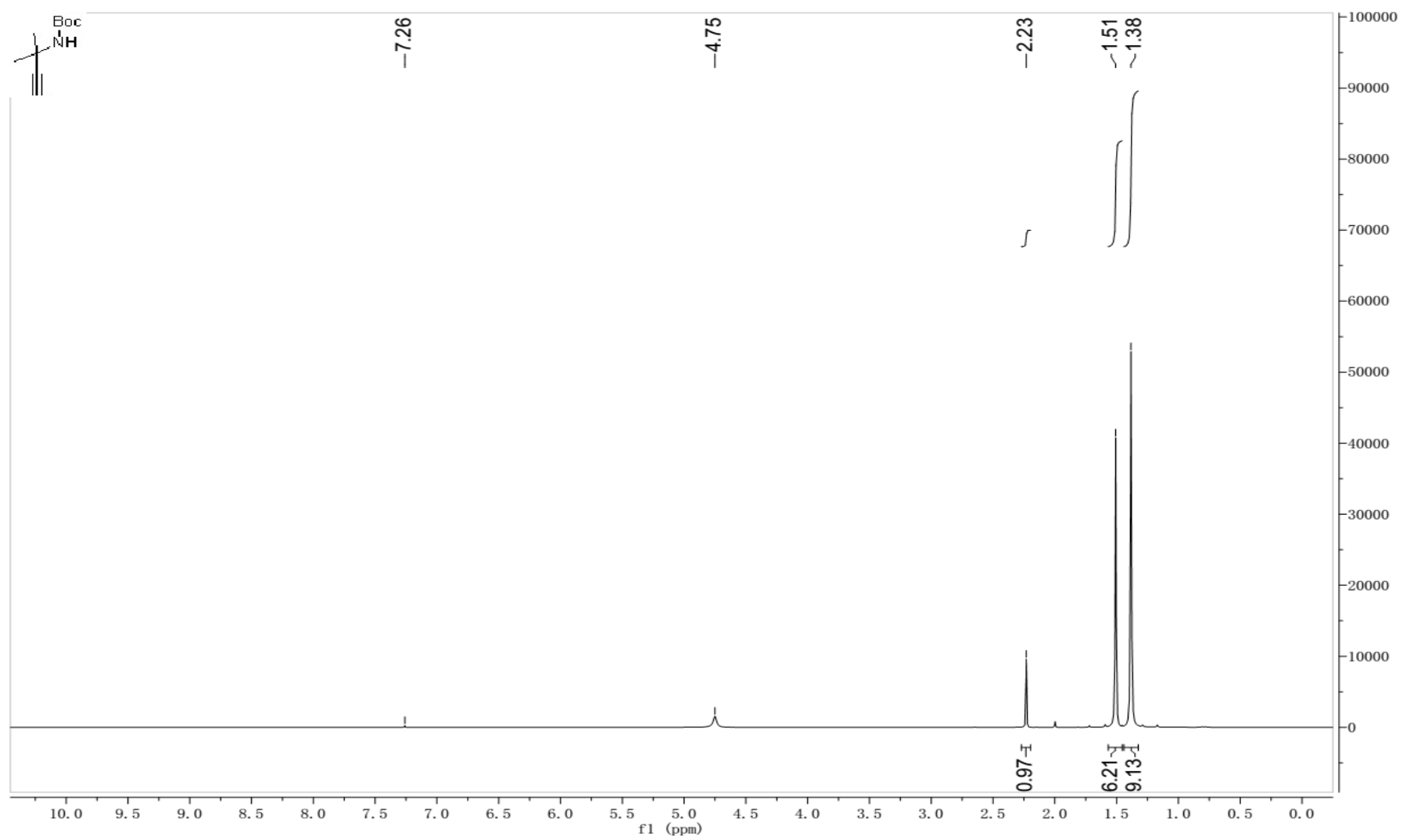


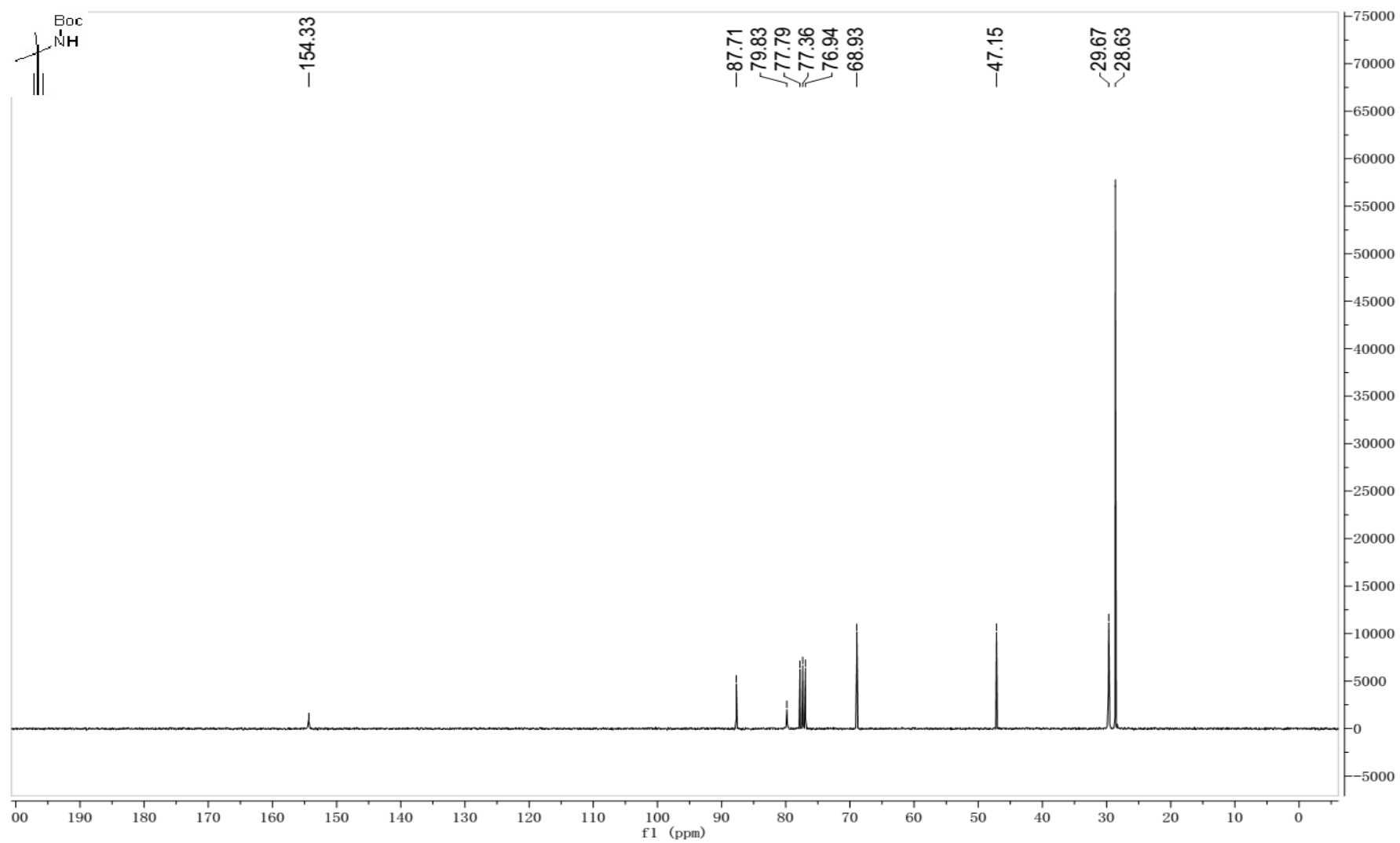


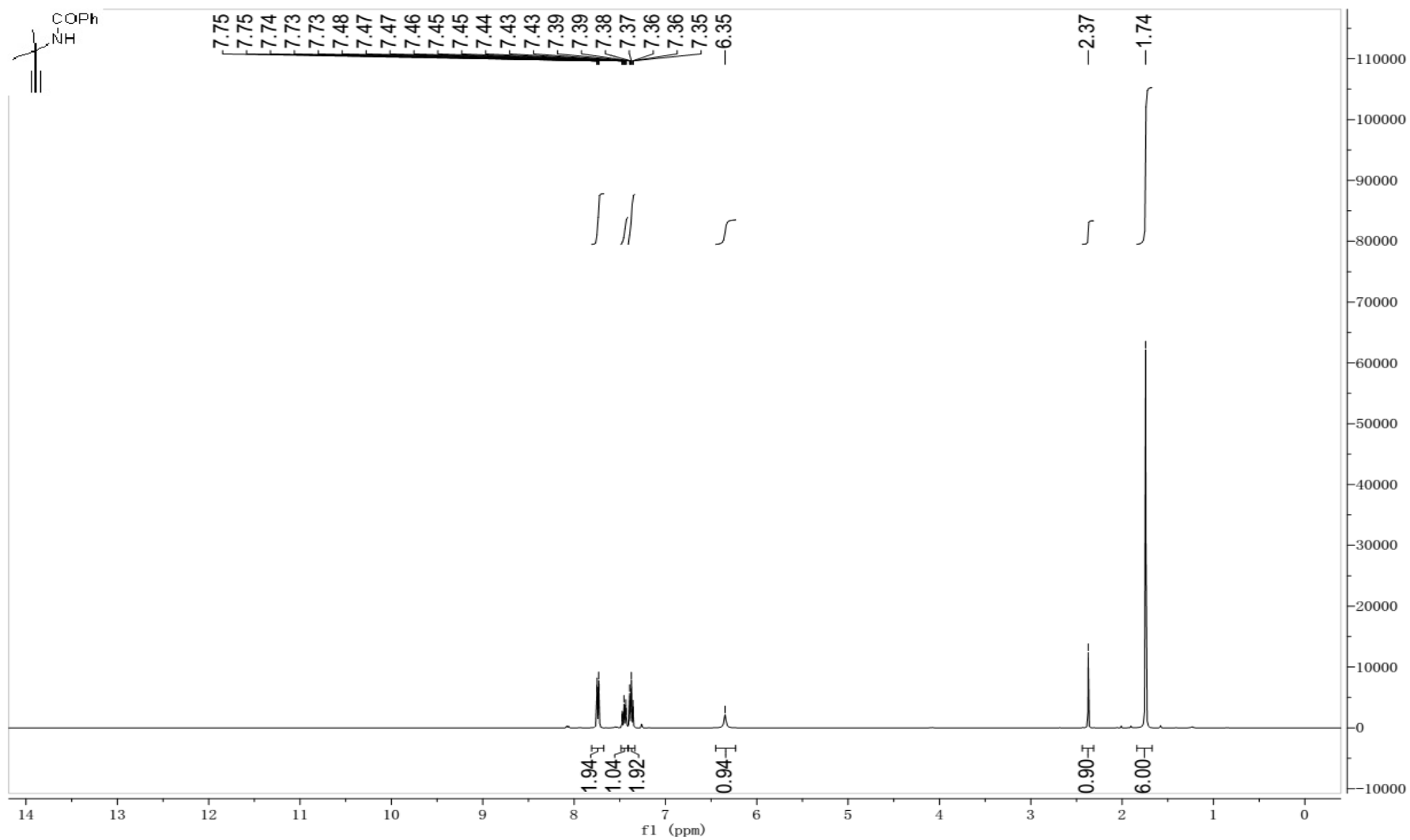


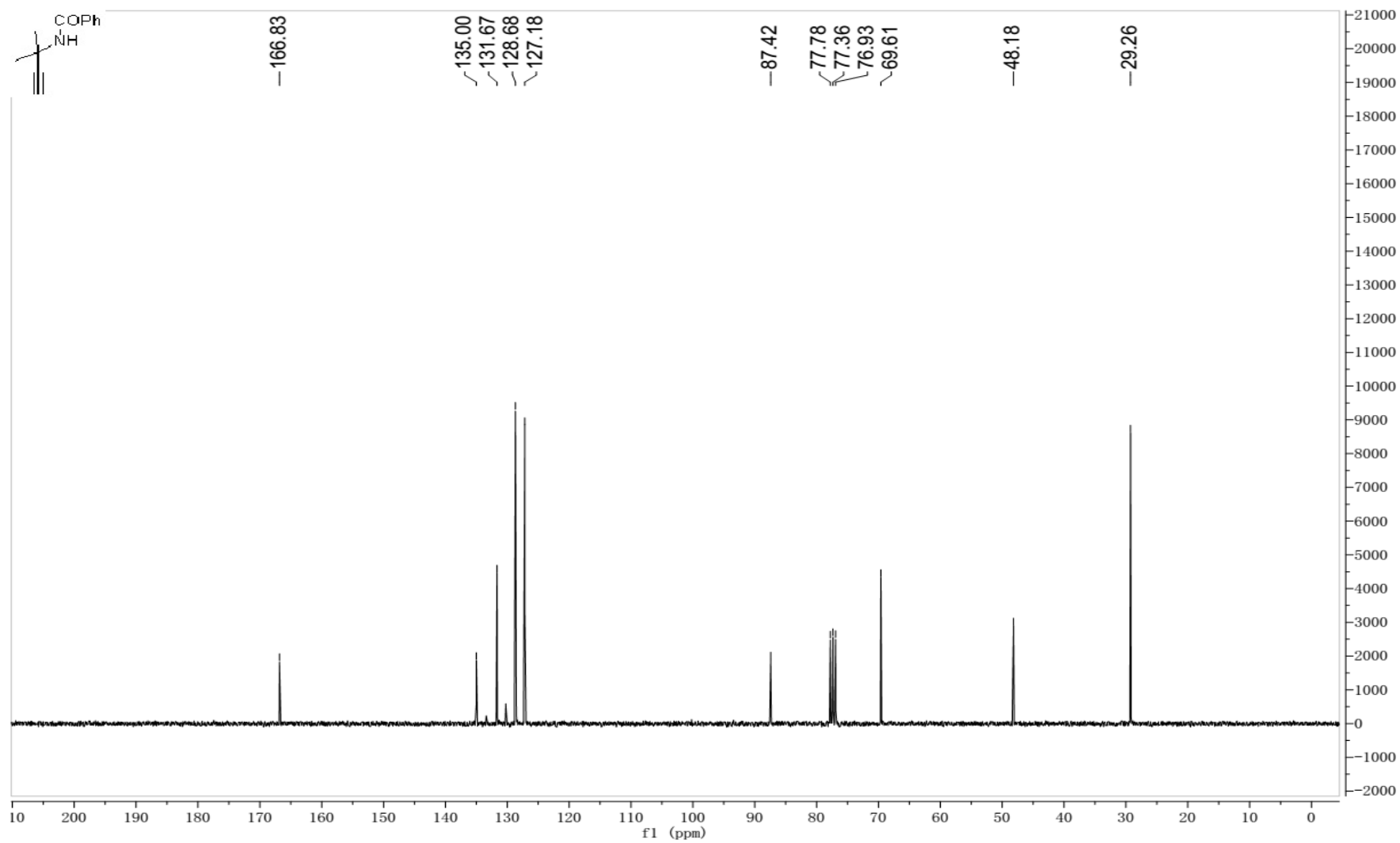


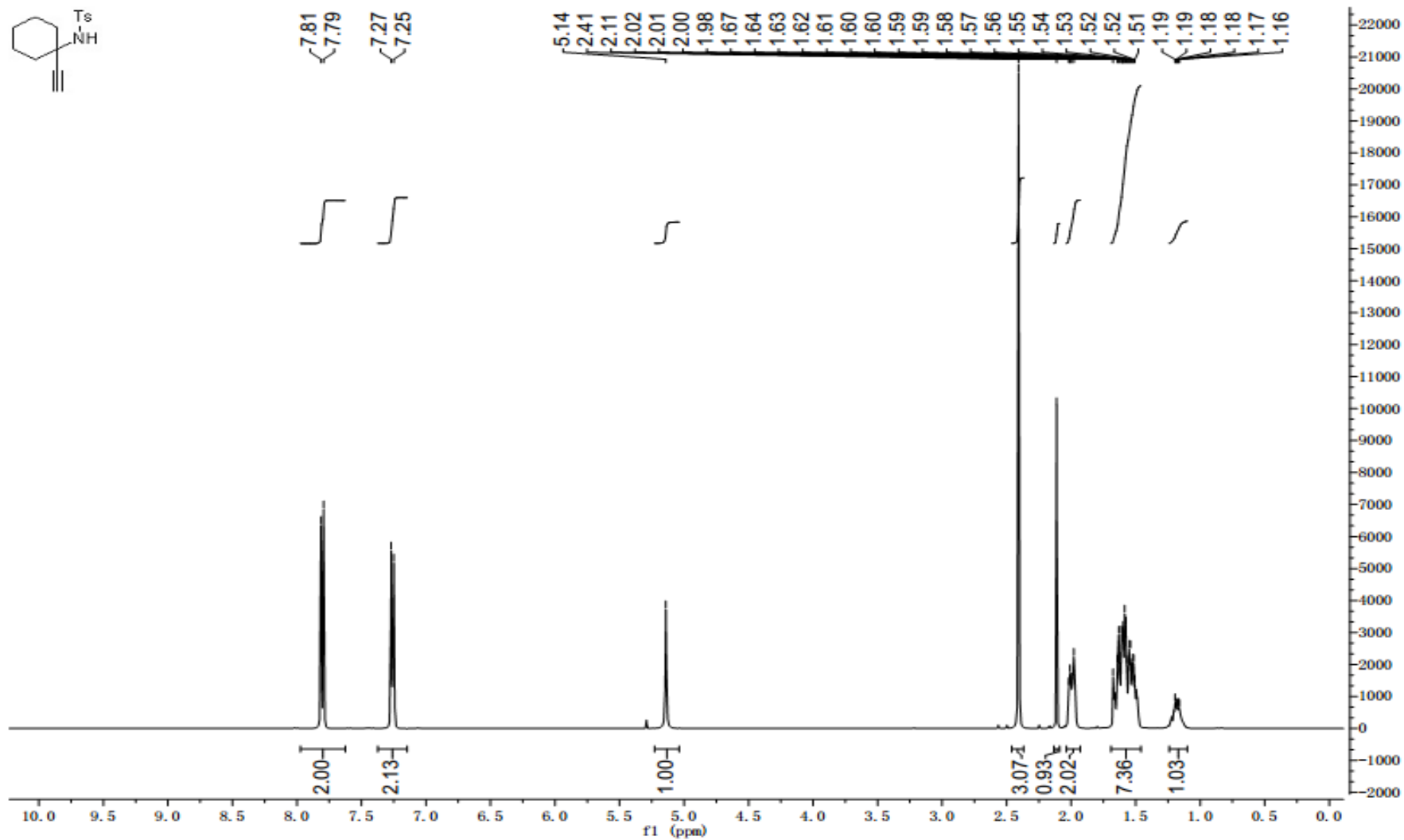
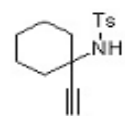


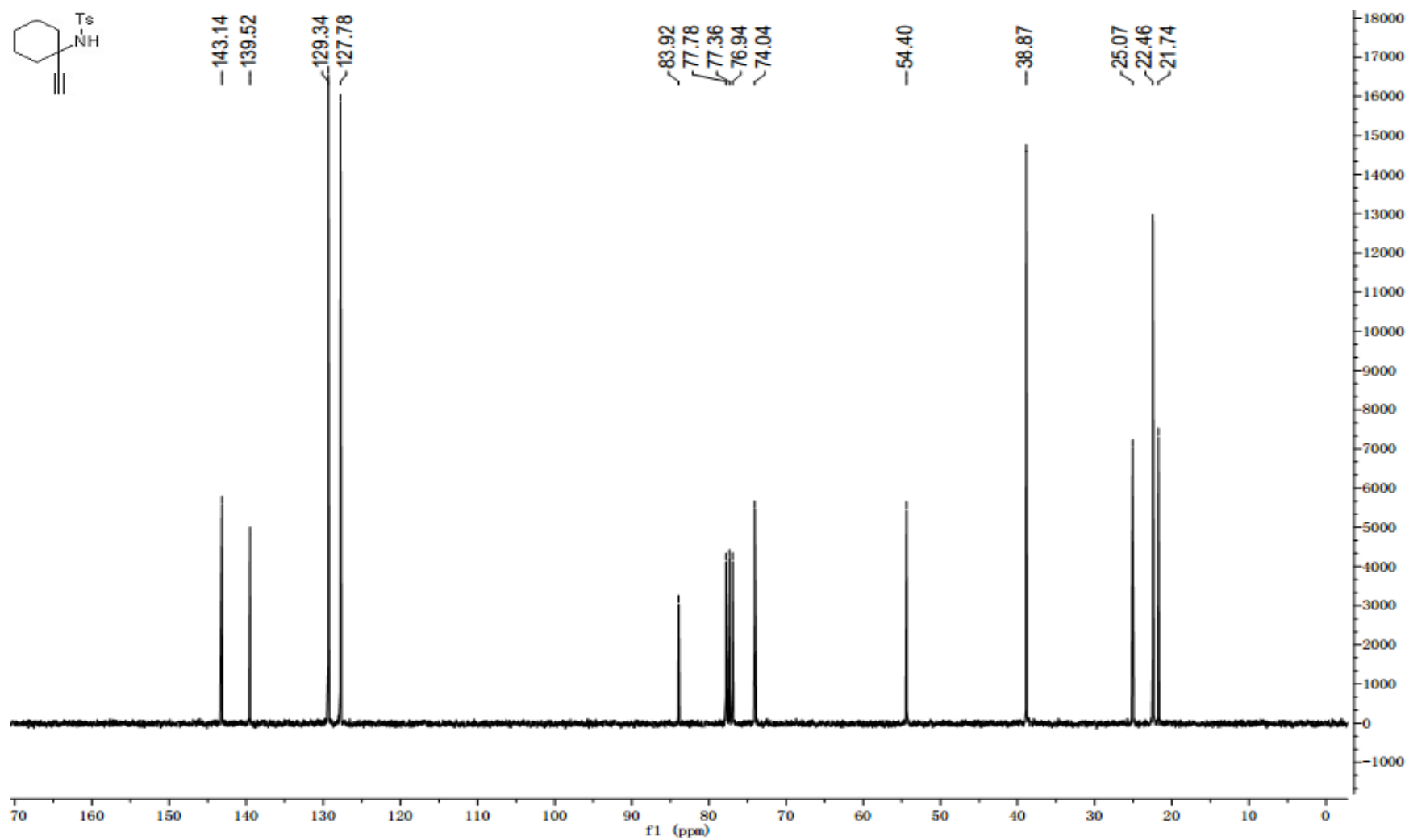


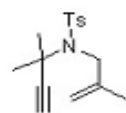




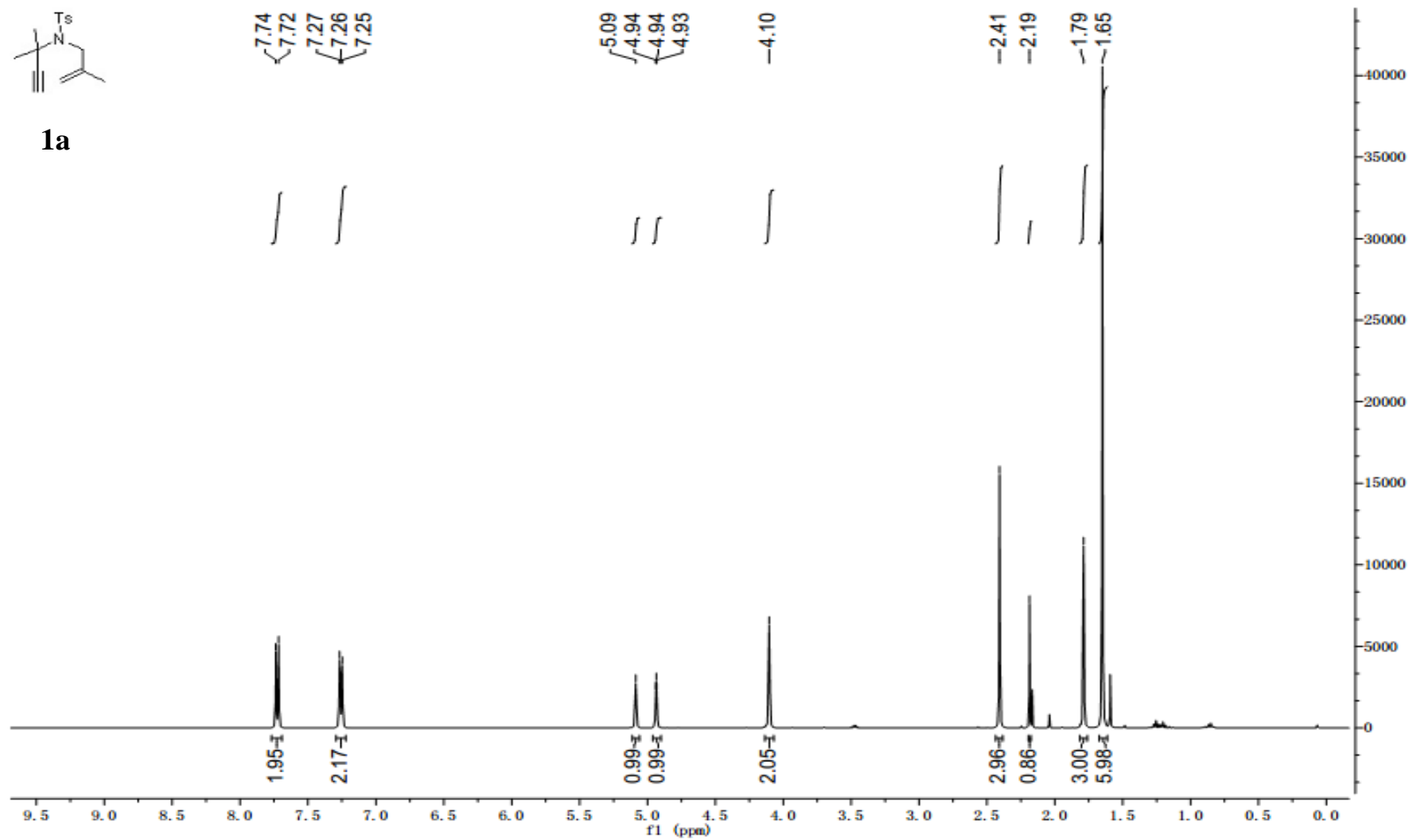


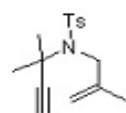




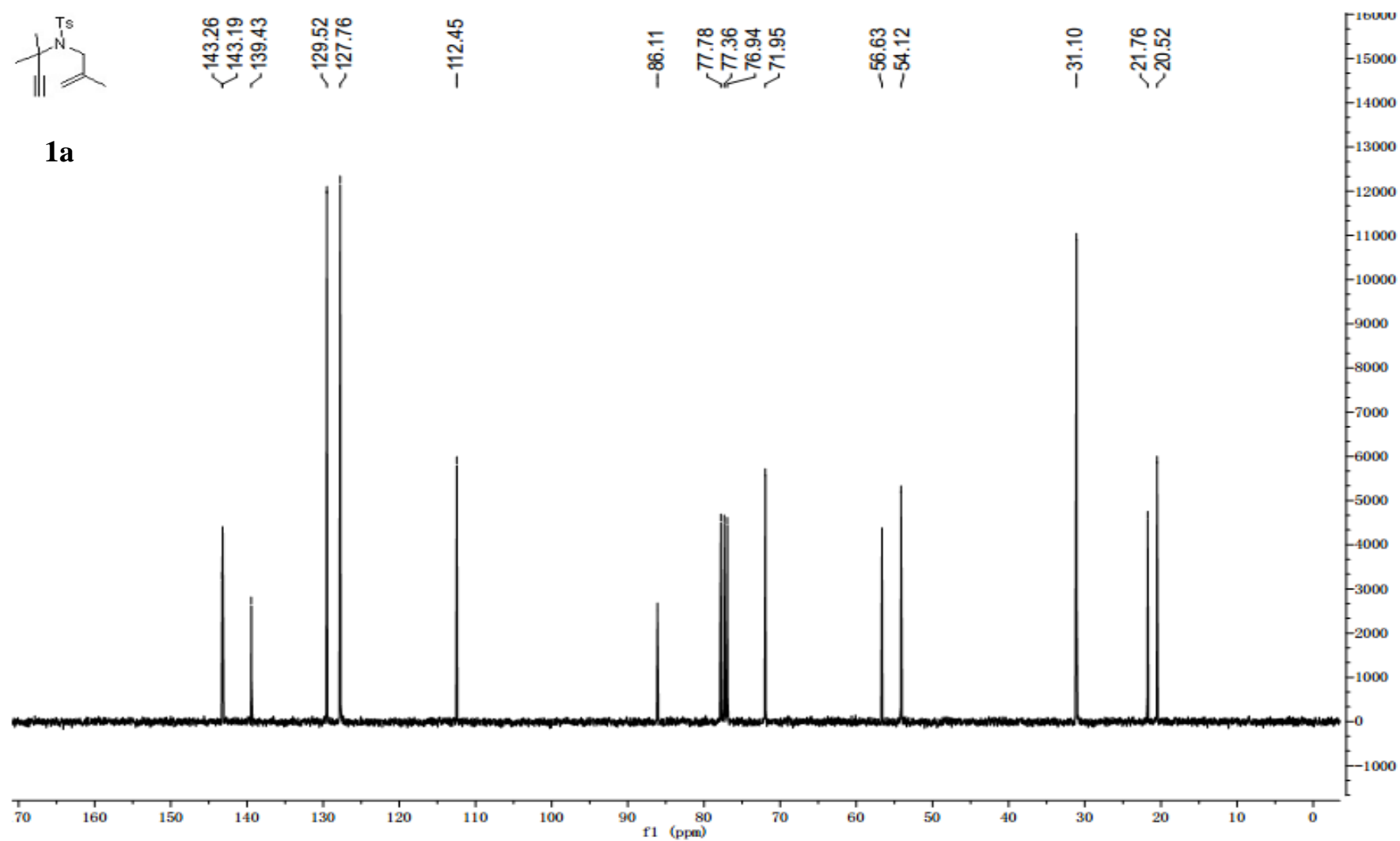


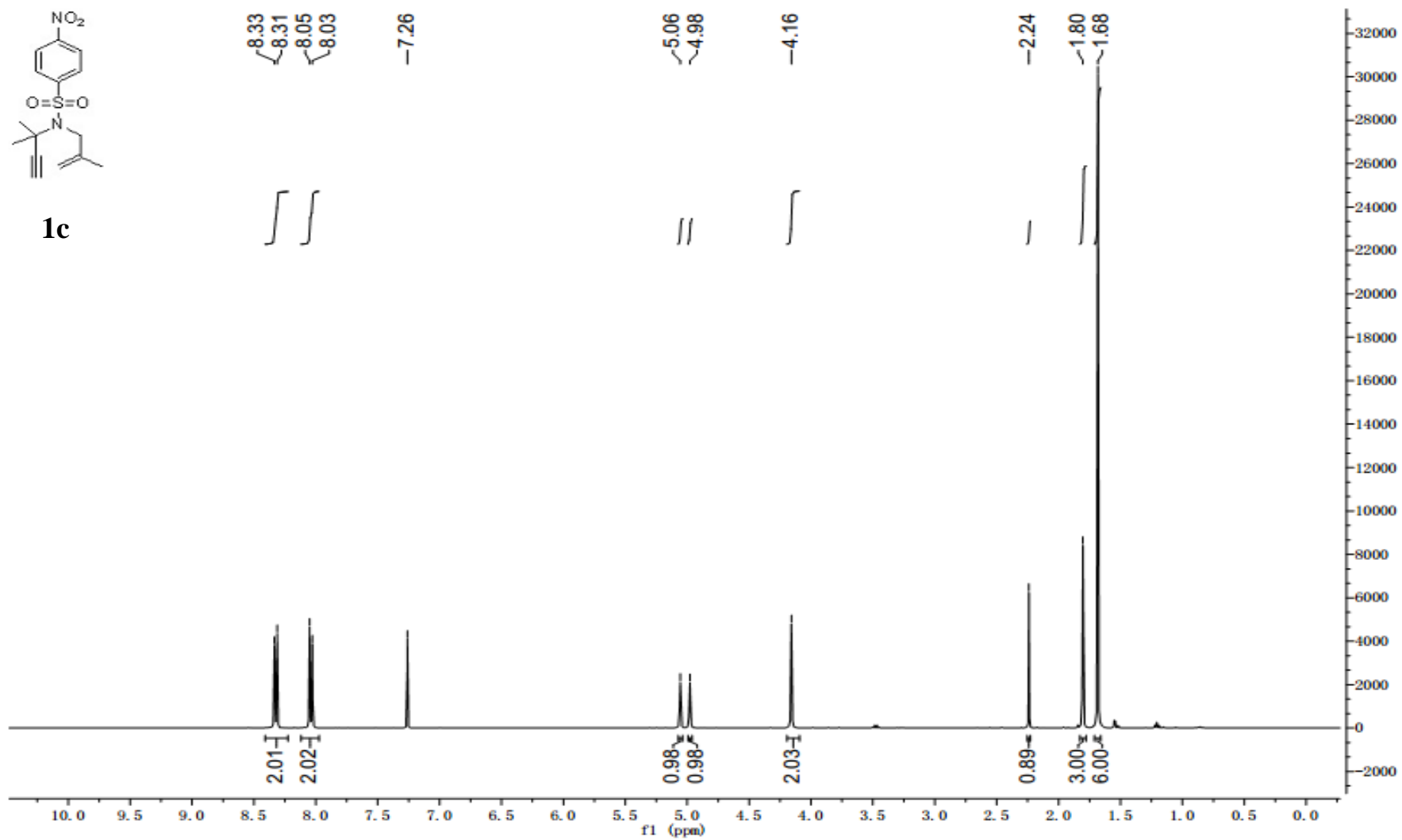
1a

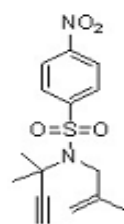




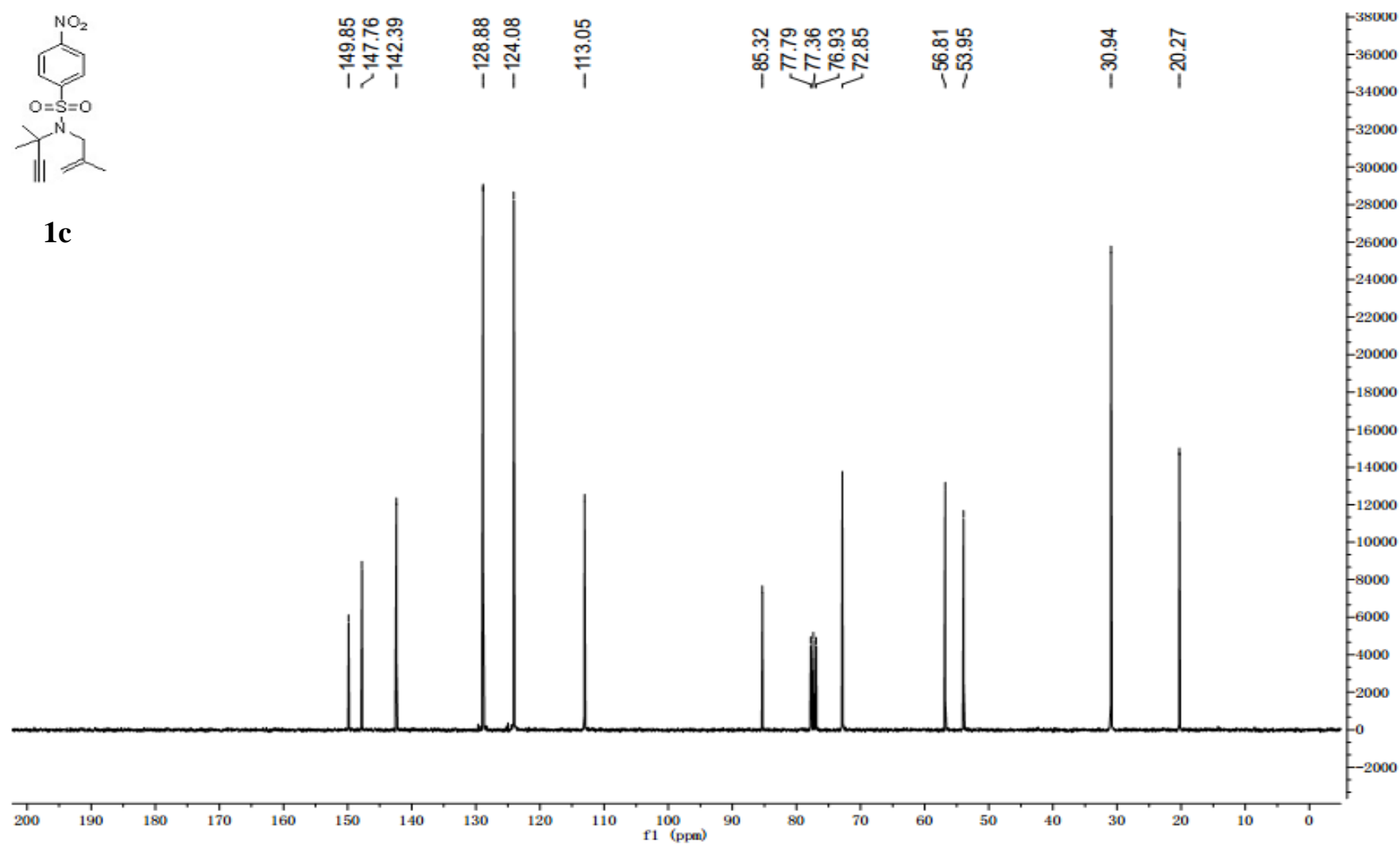
1a

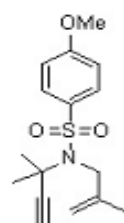




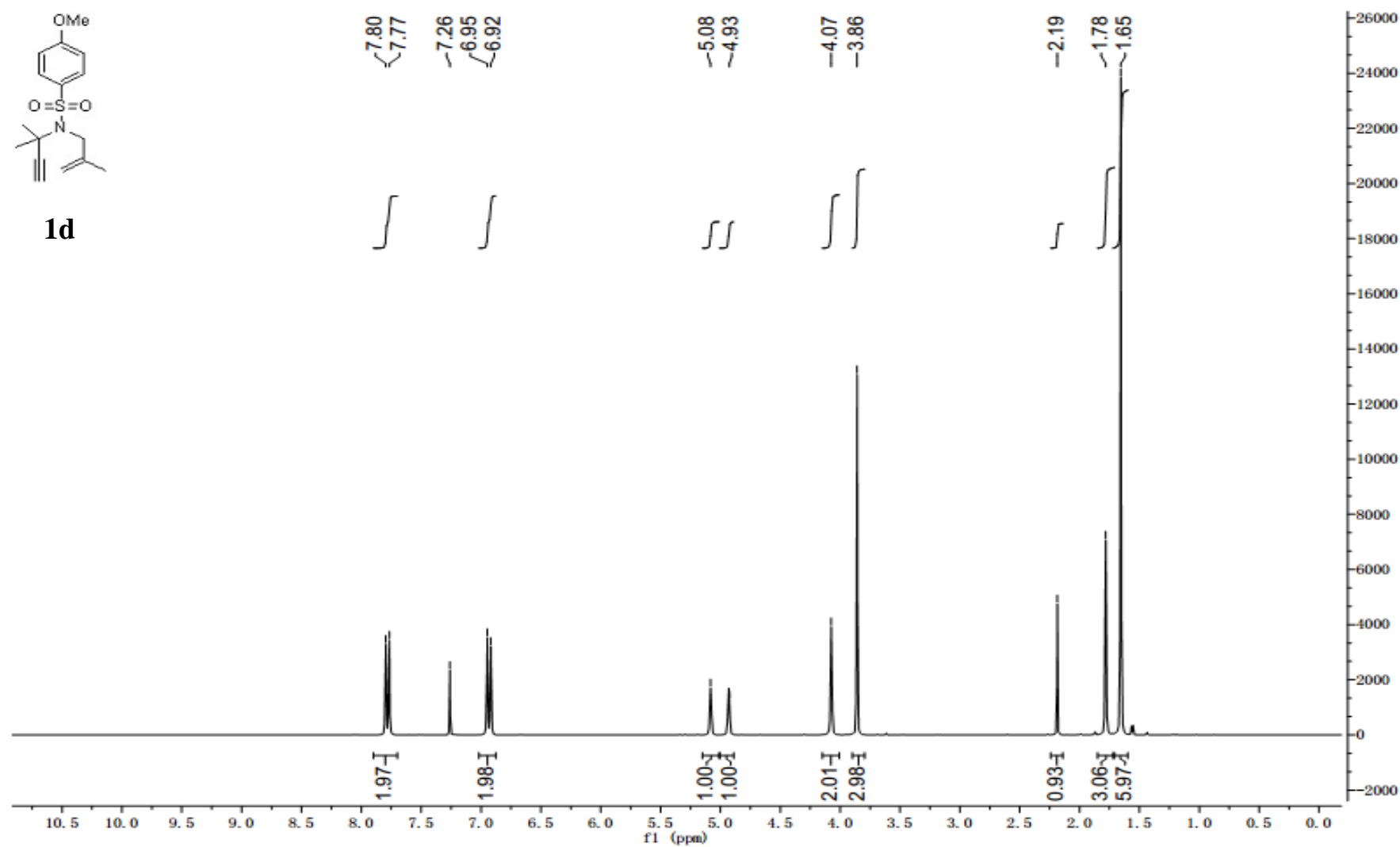


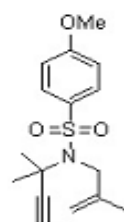
1c



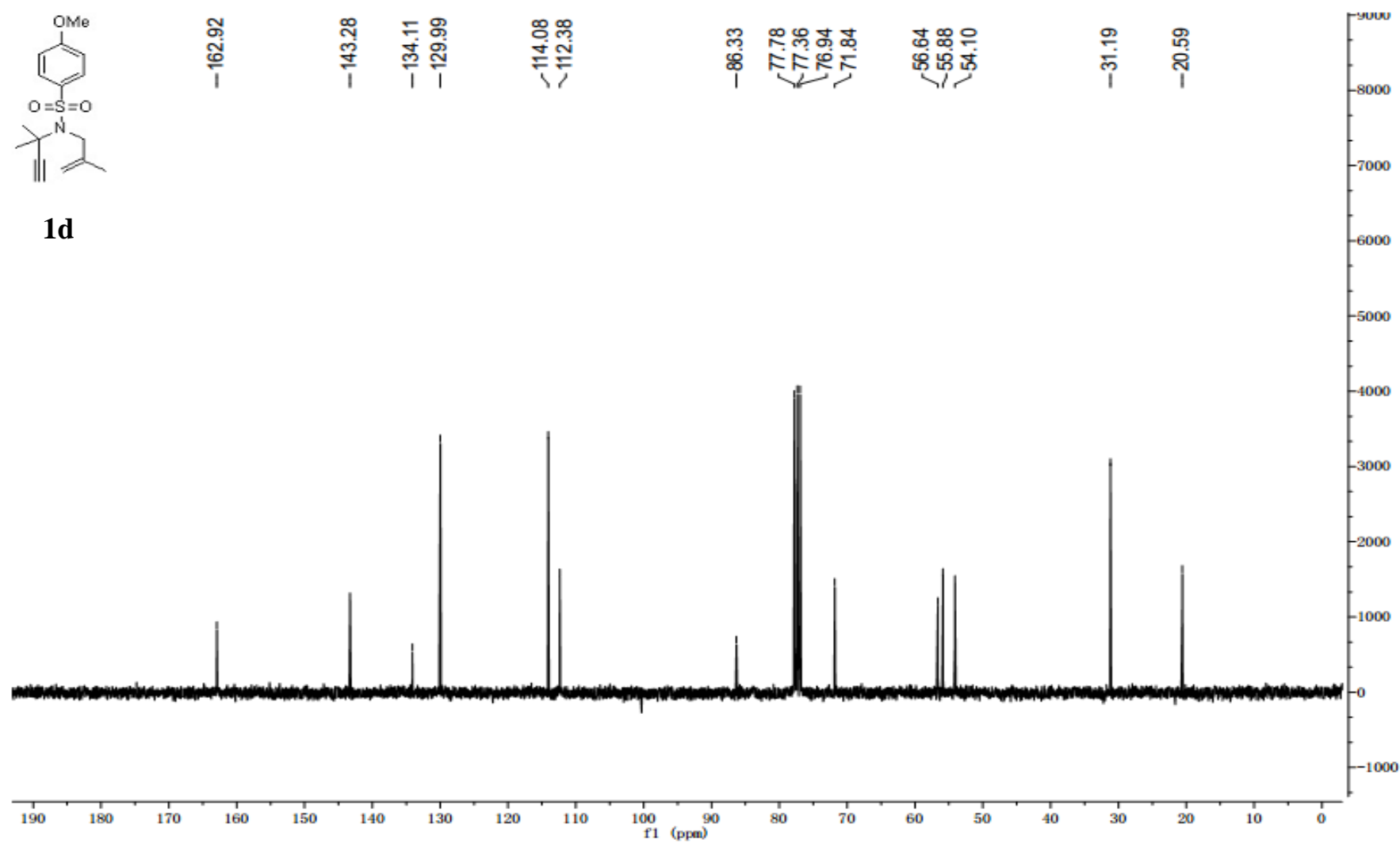


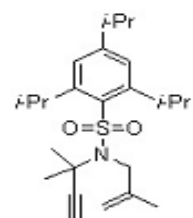
1d



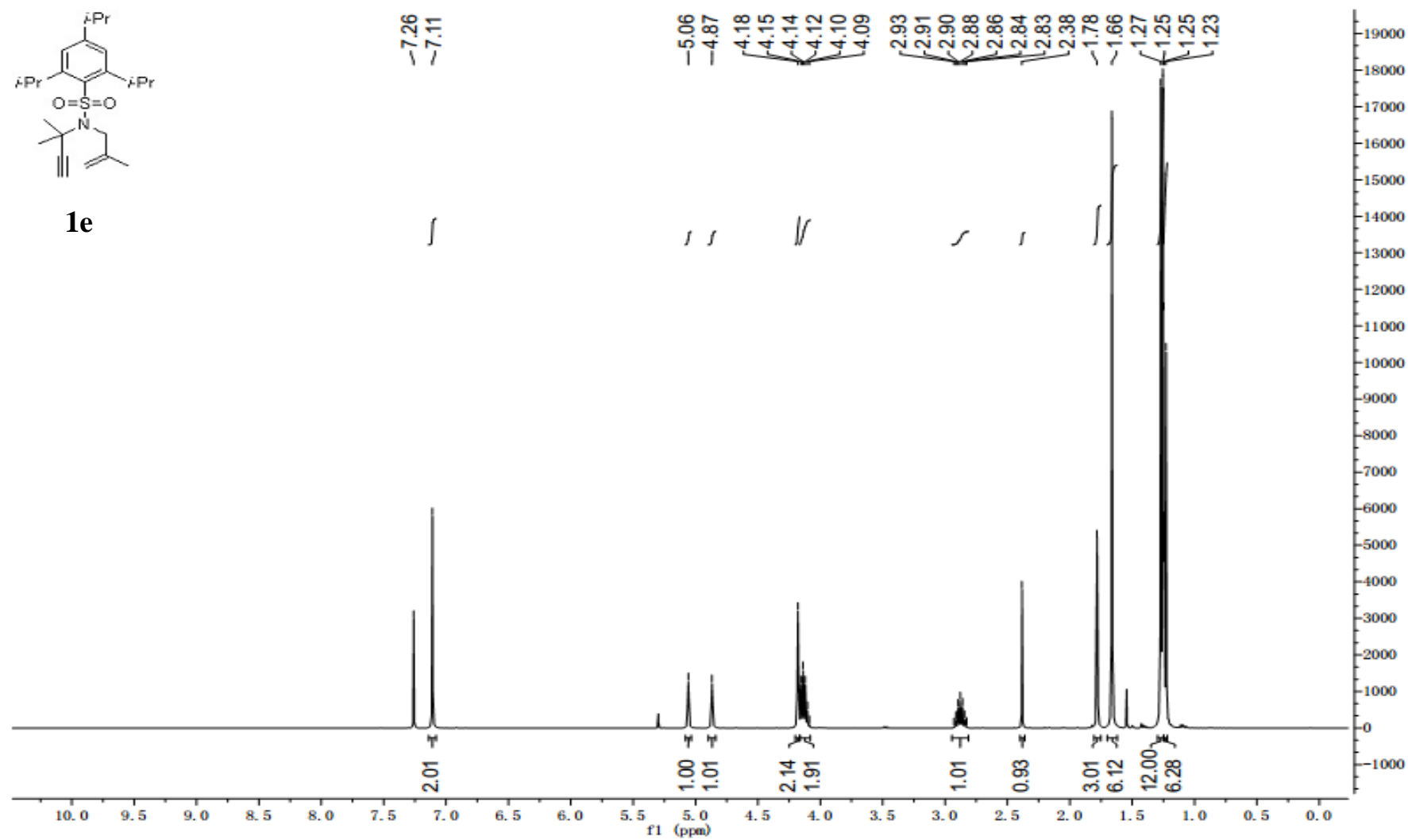


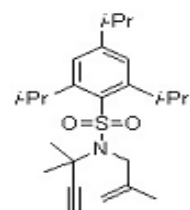
1d



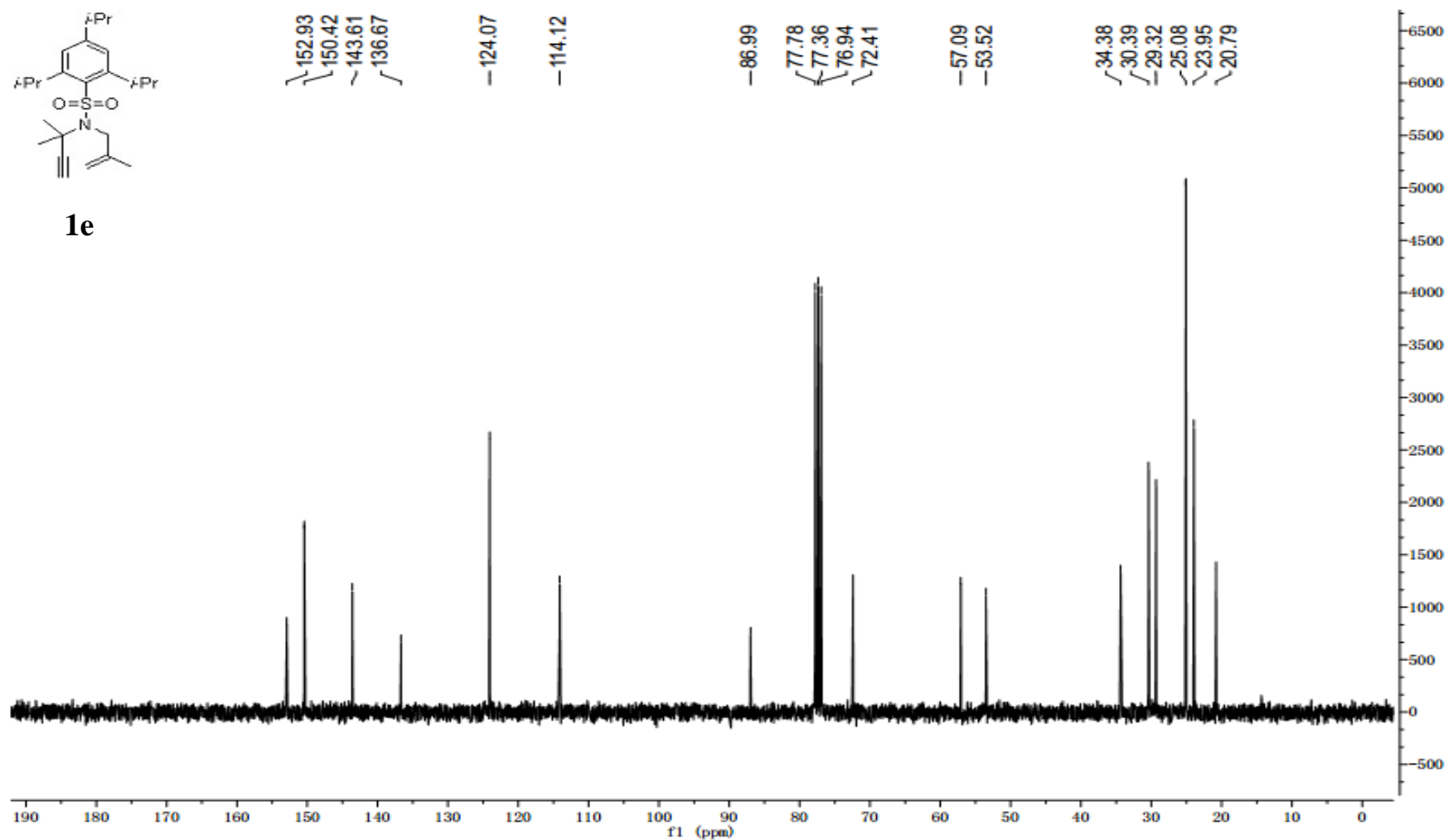


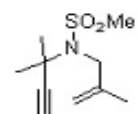
1e



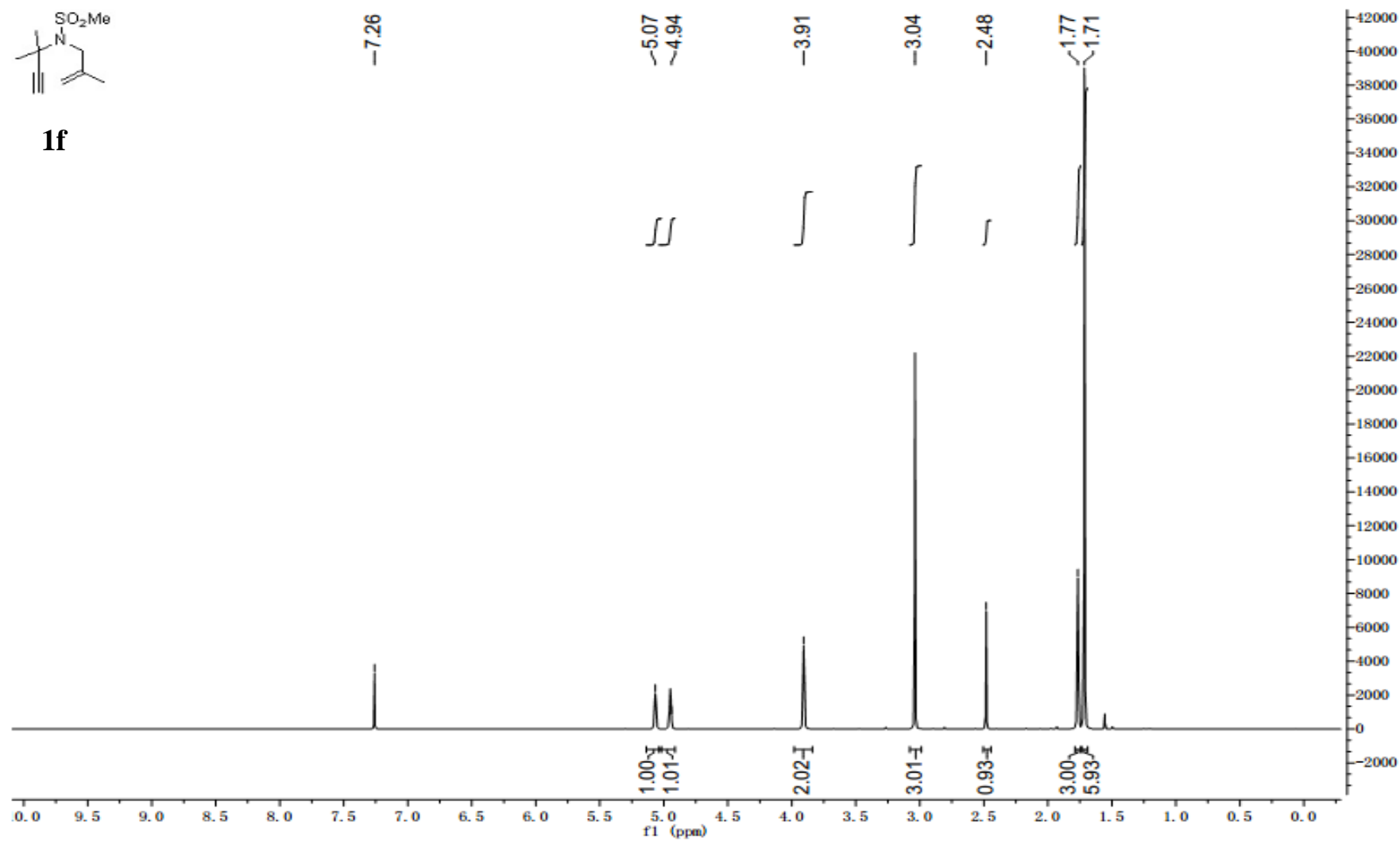


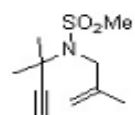
1e



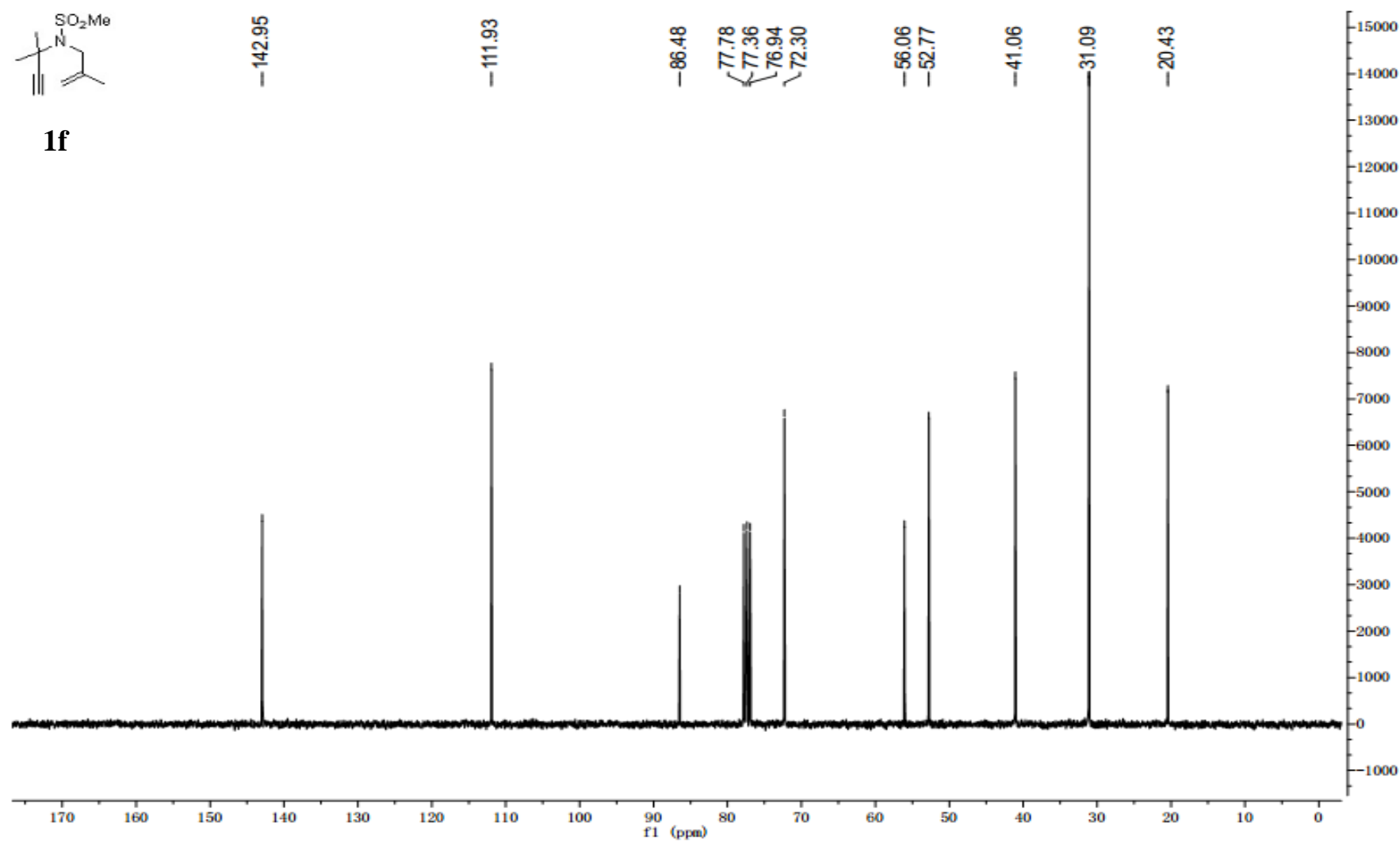


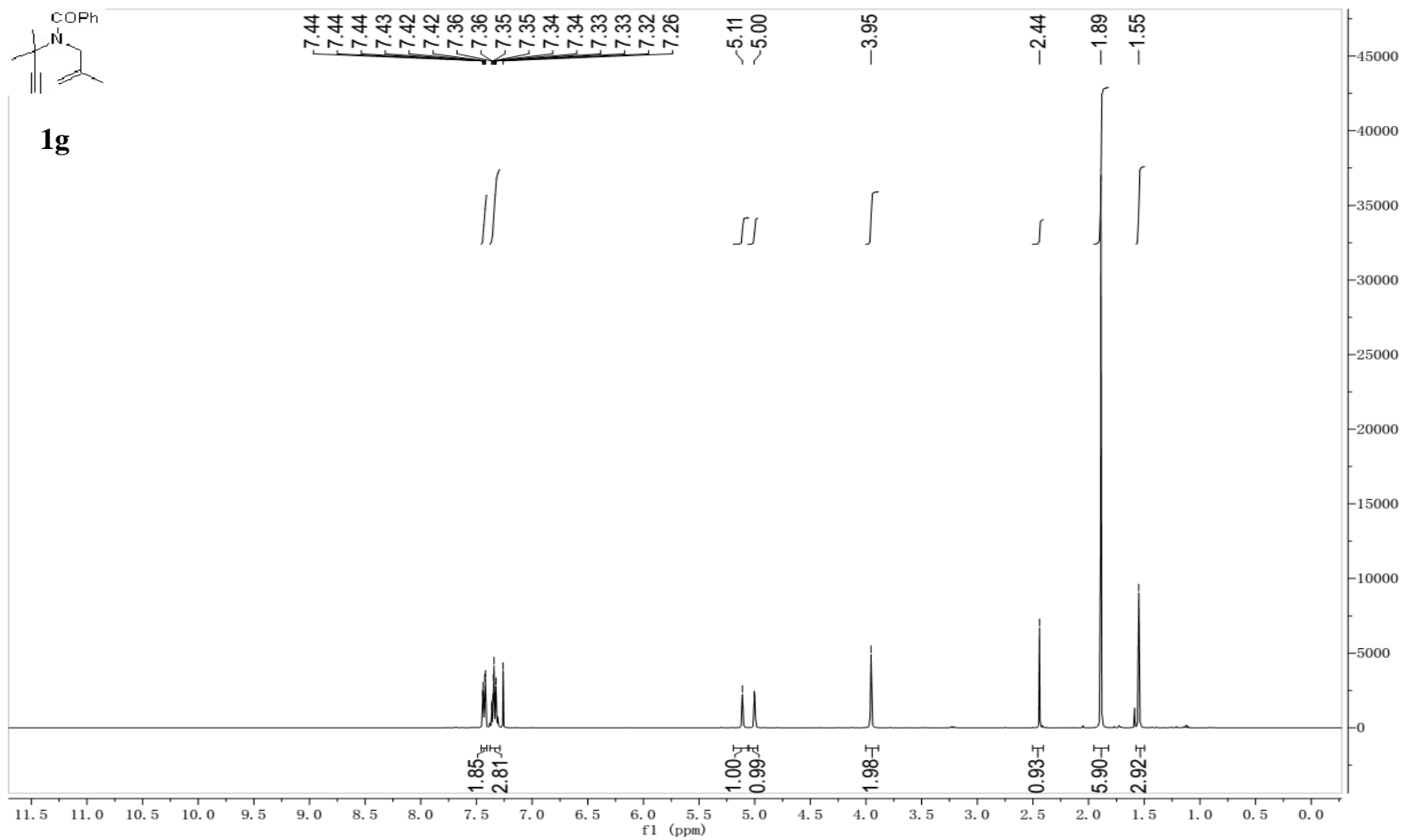
1f

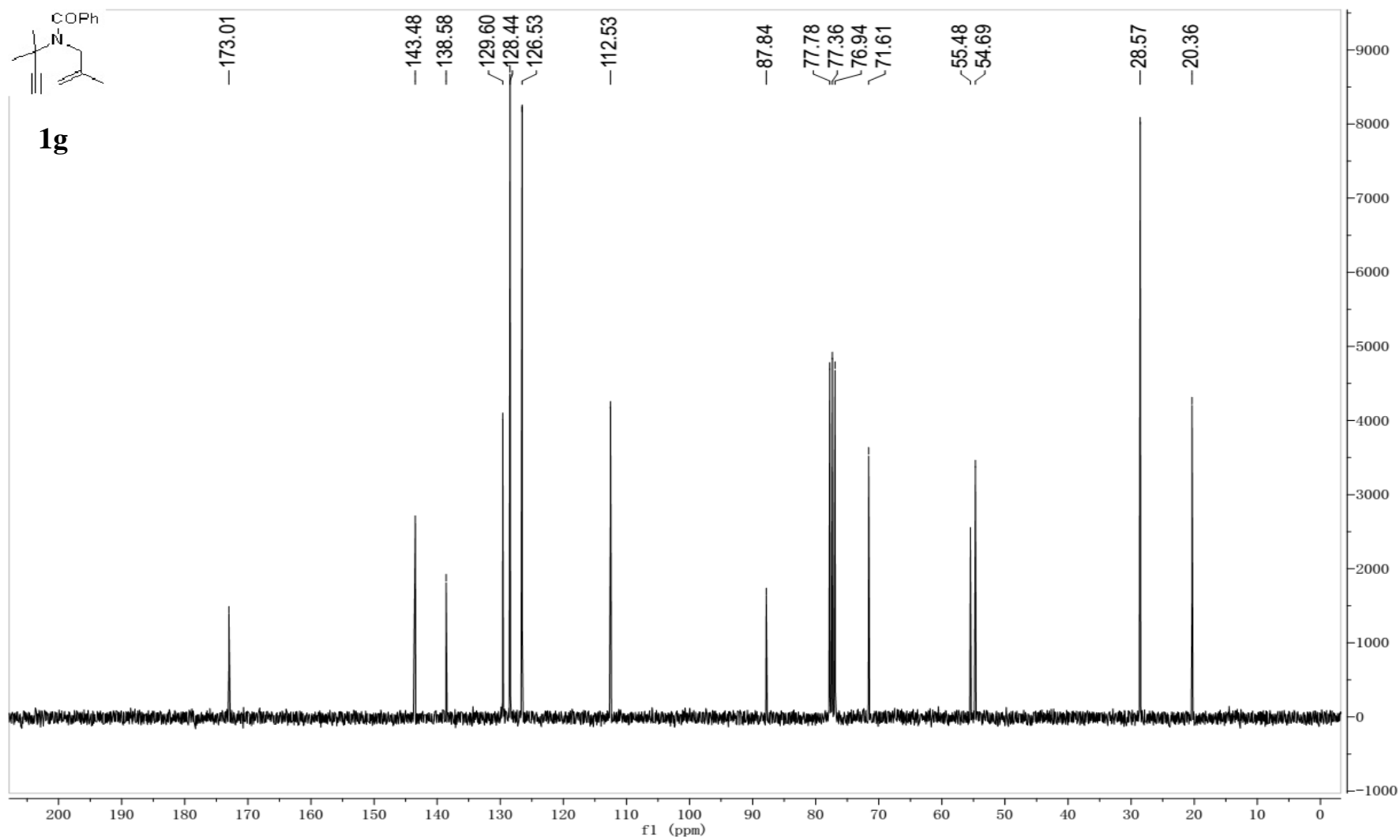


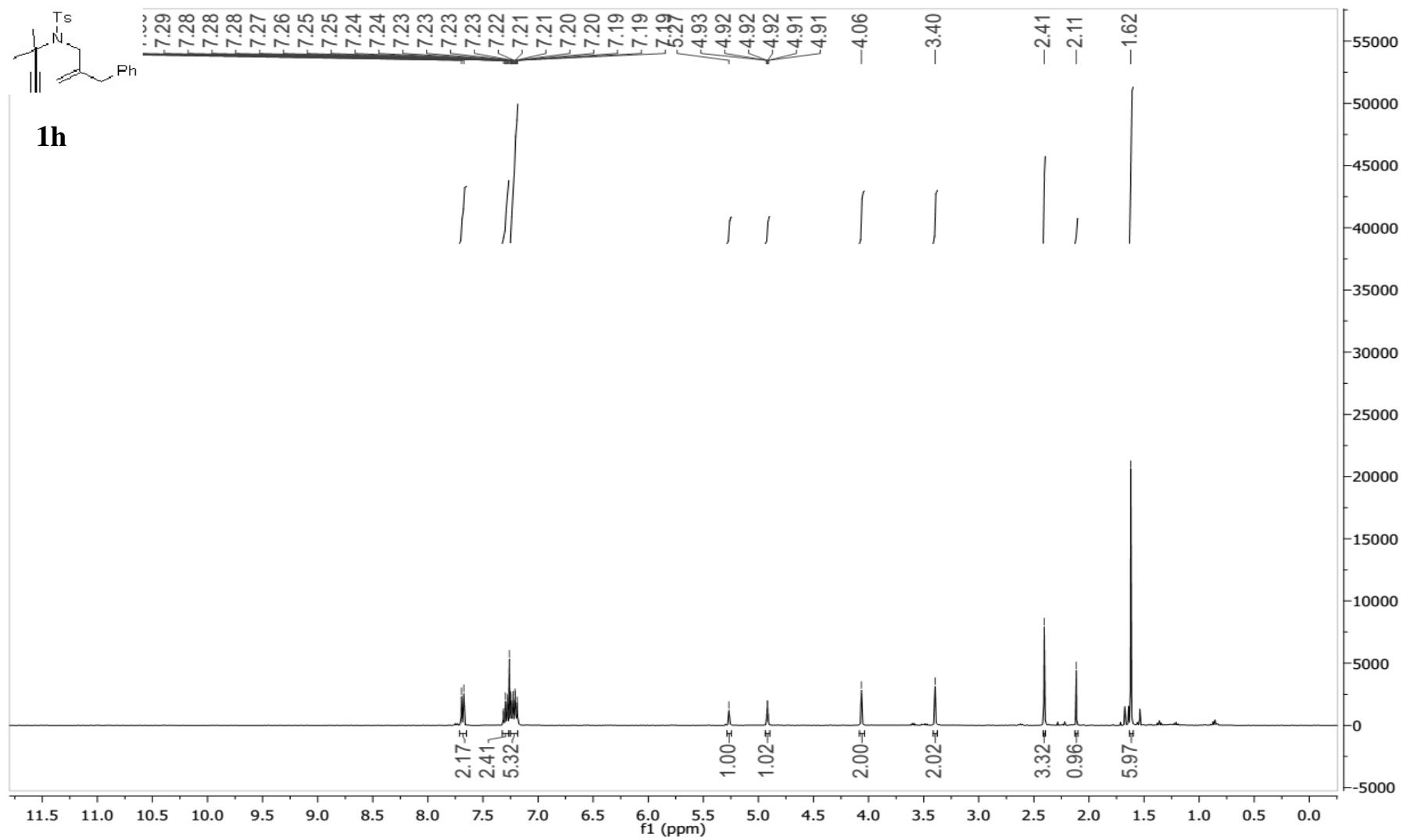


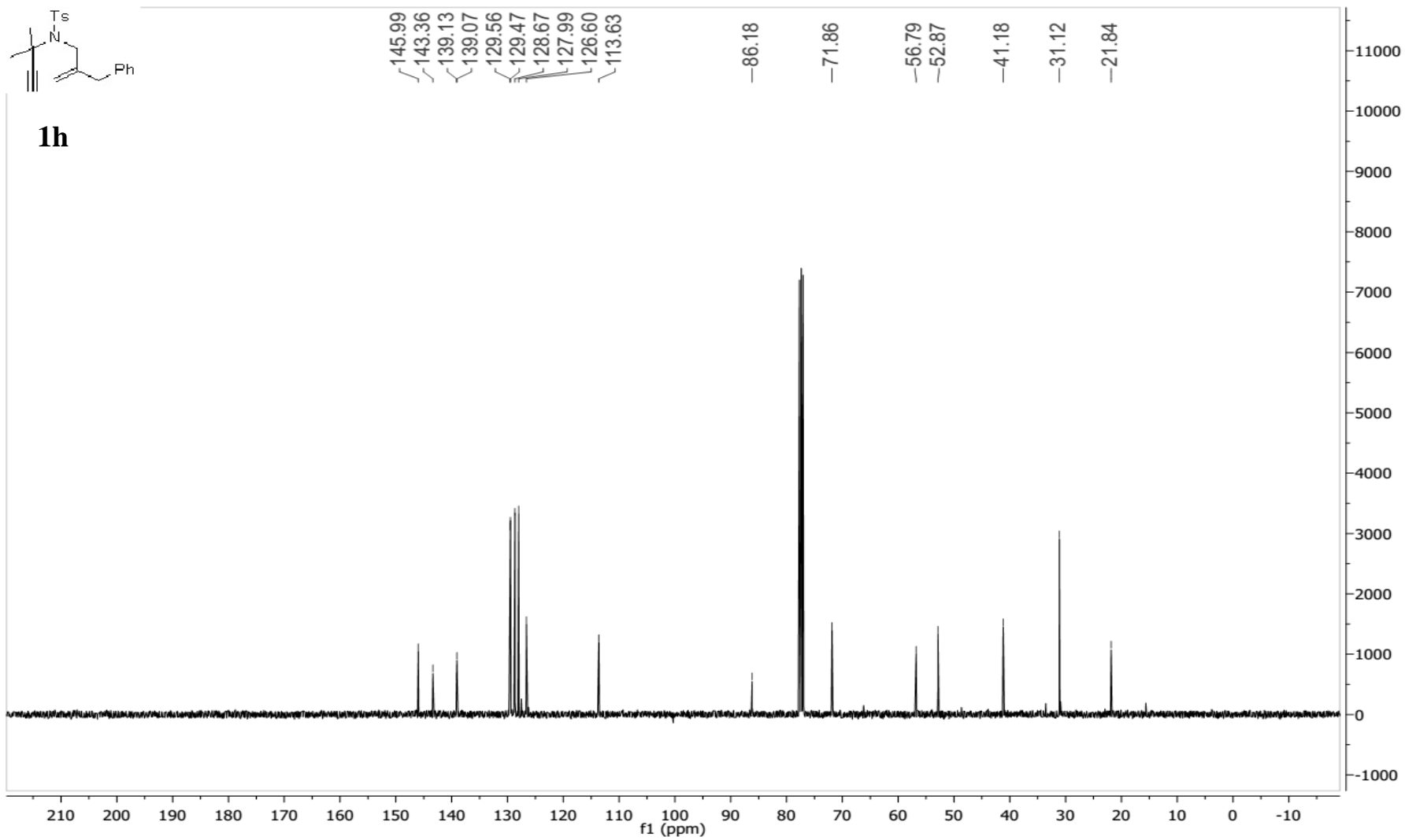
1f

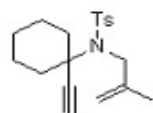




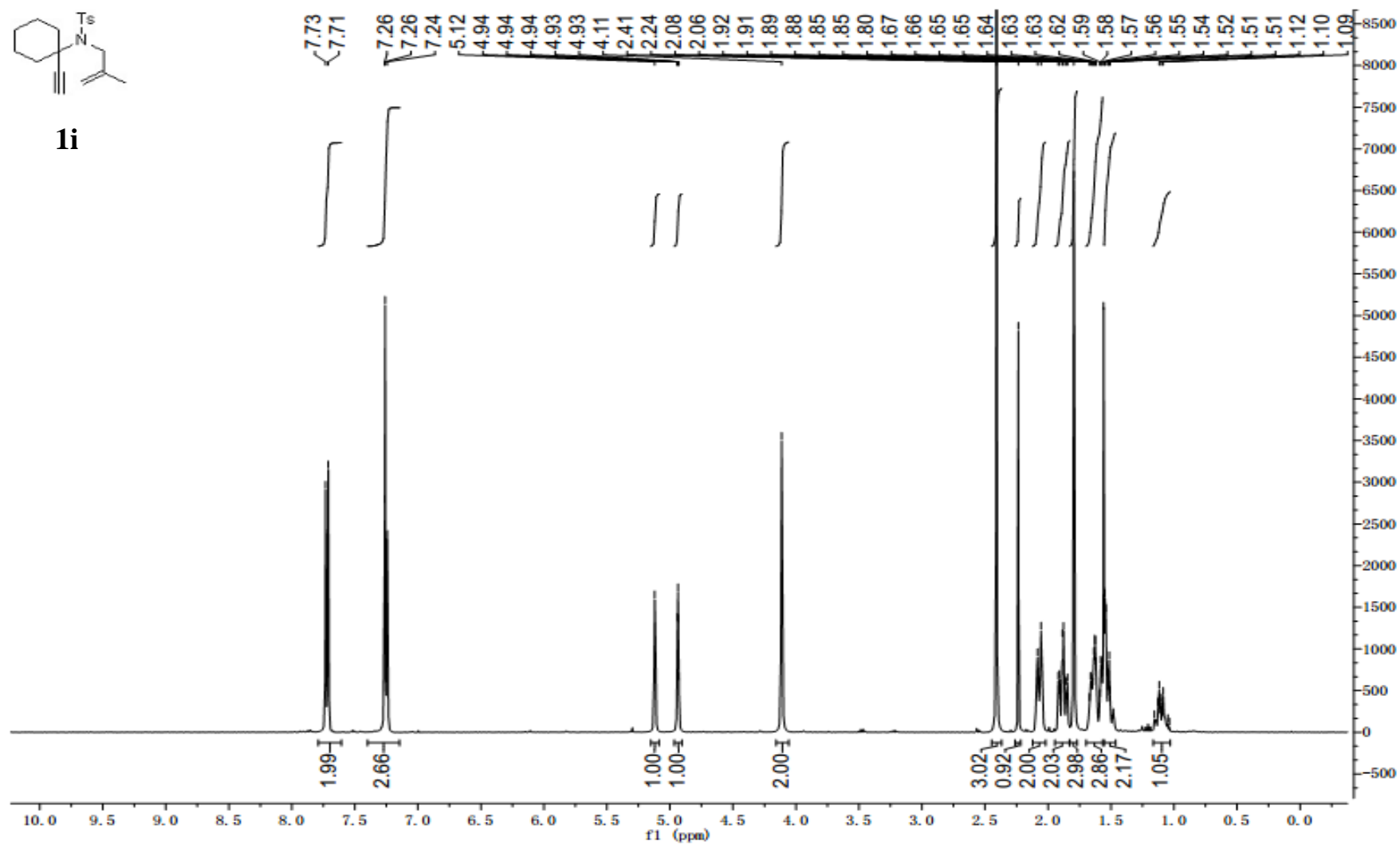


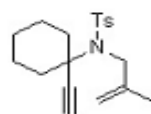




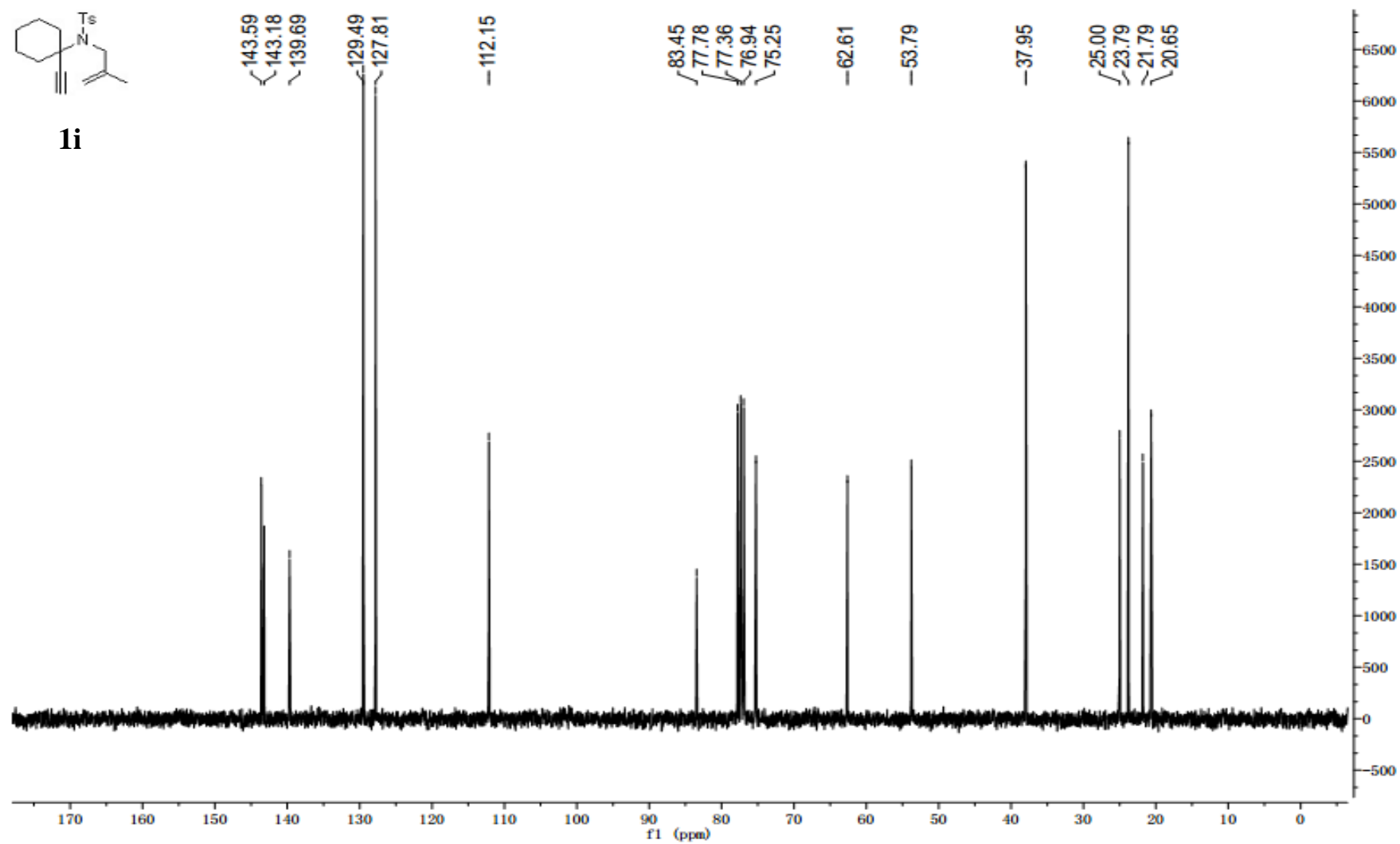


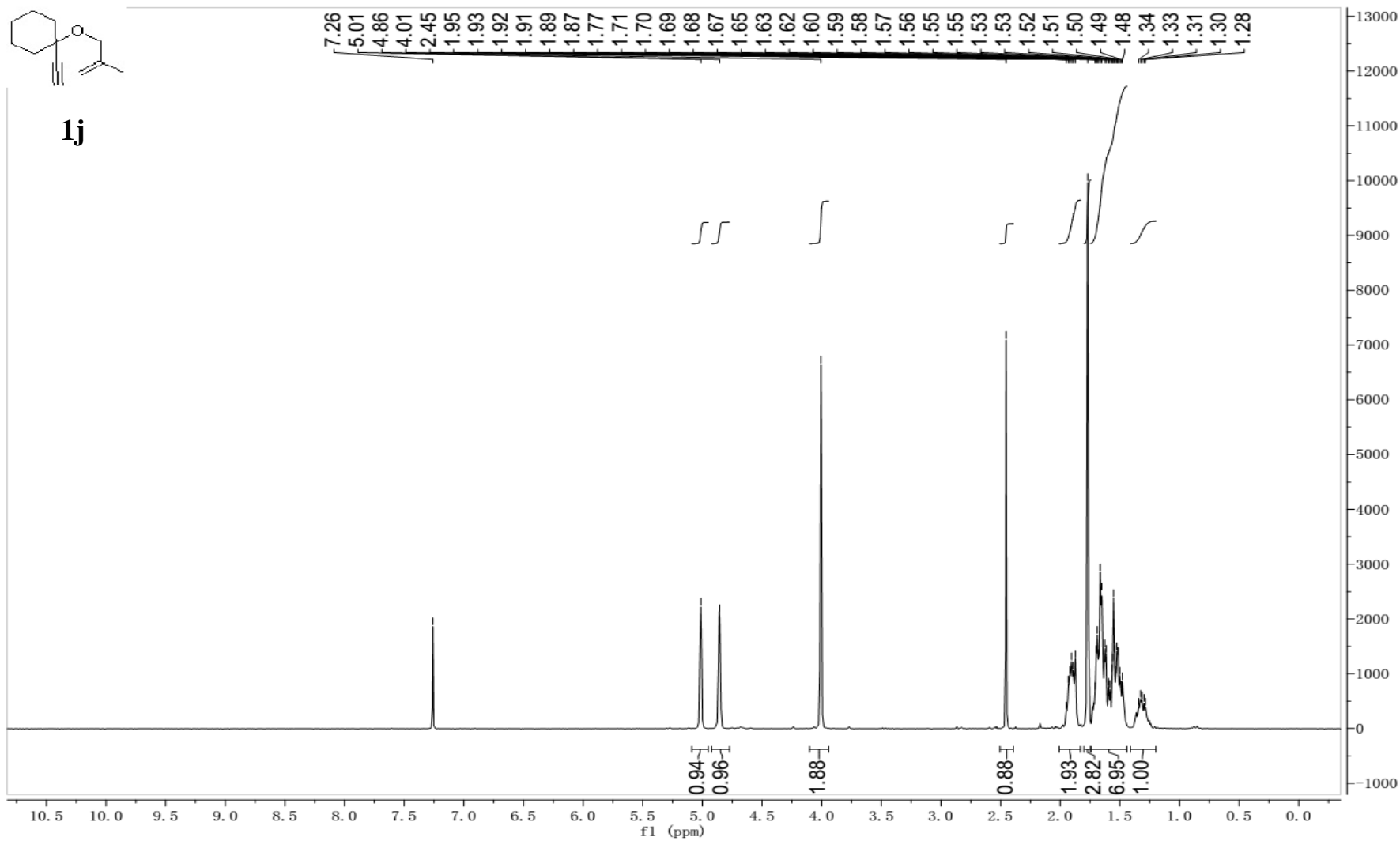
1i

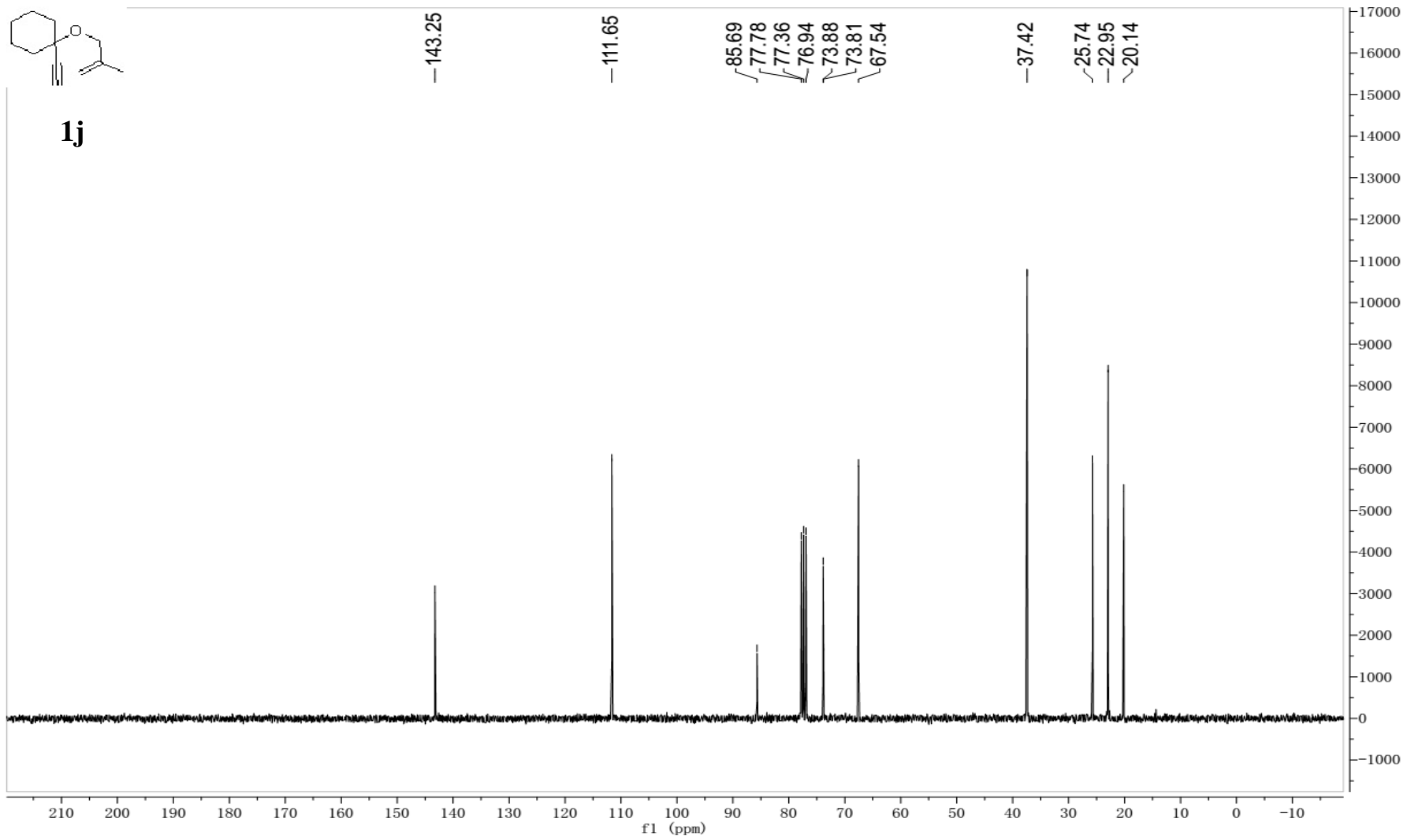


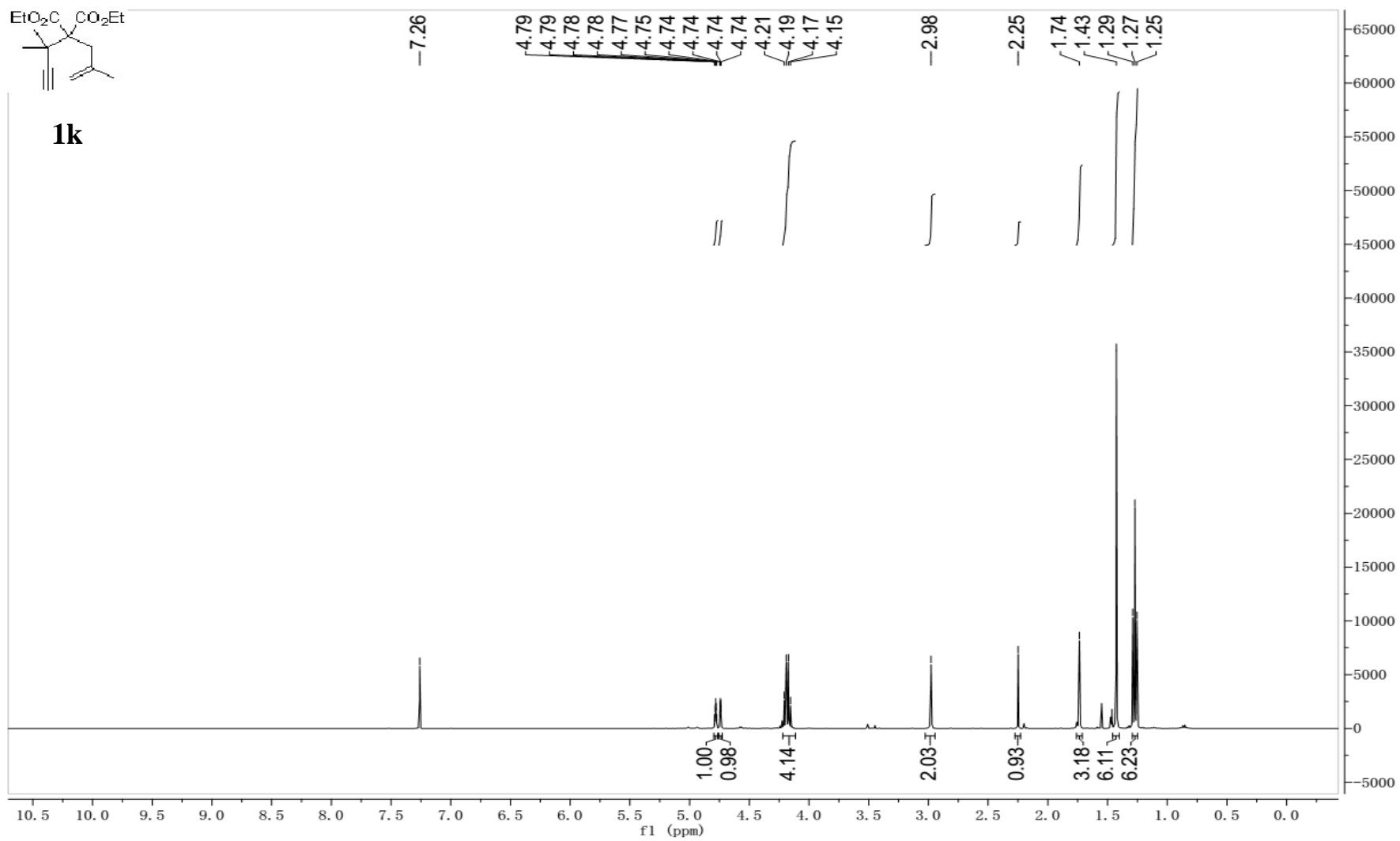


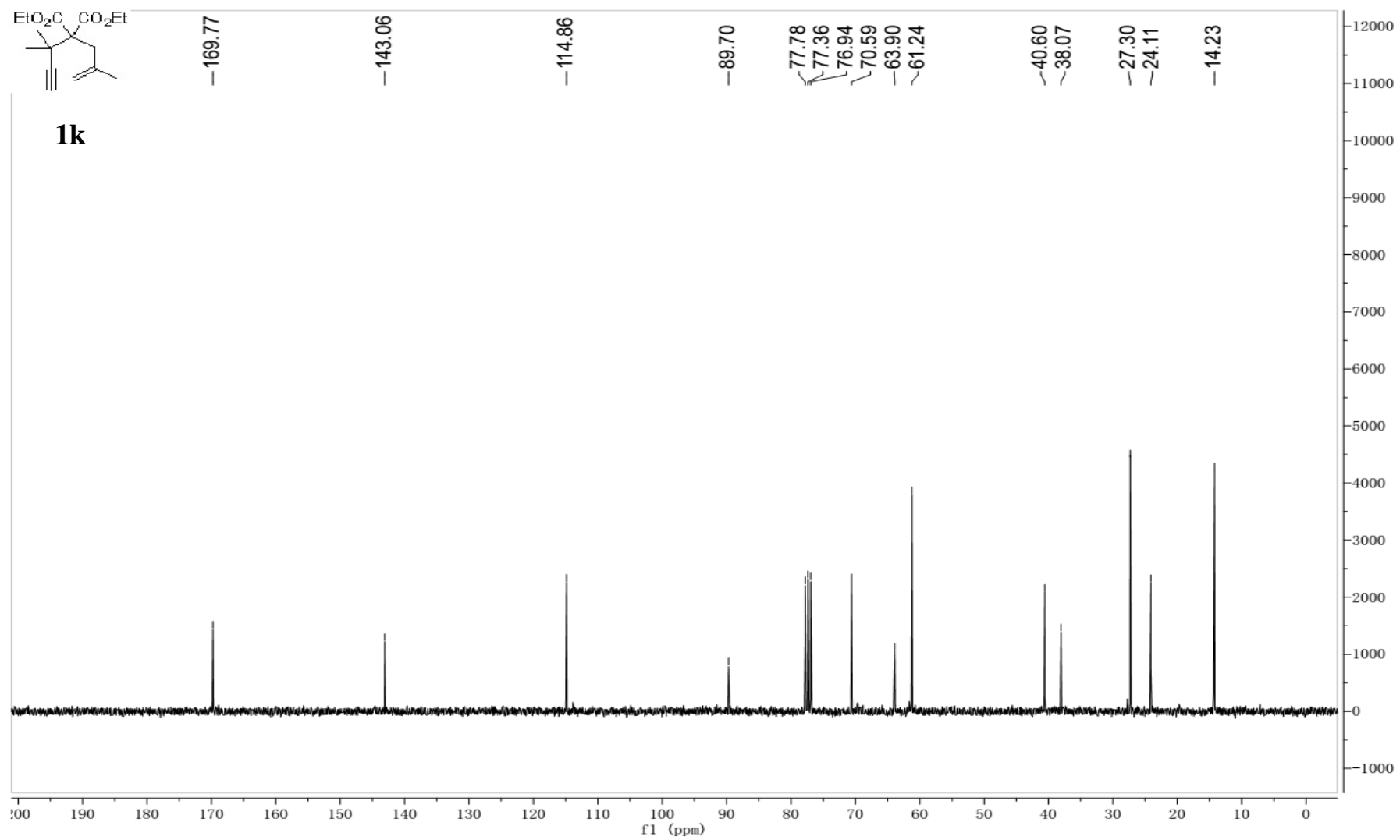
1i

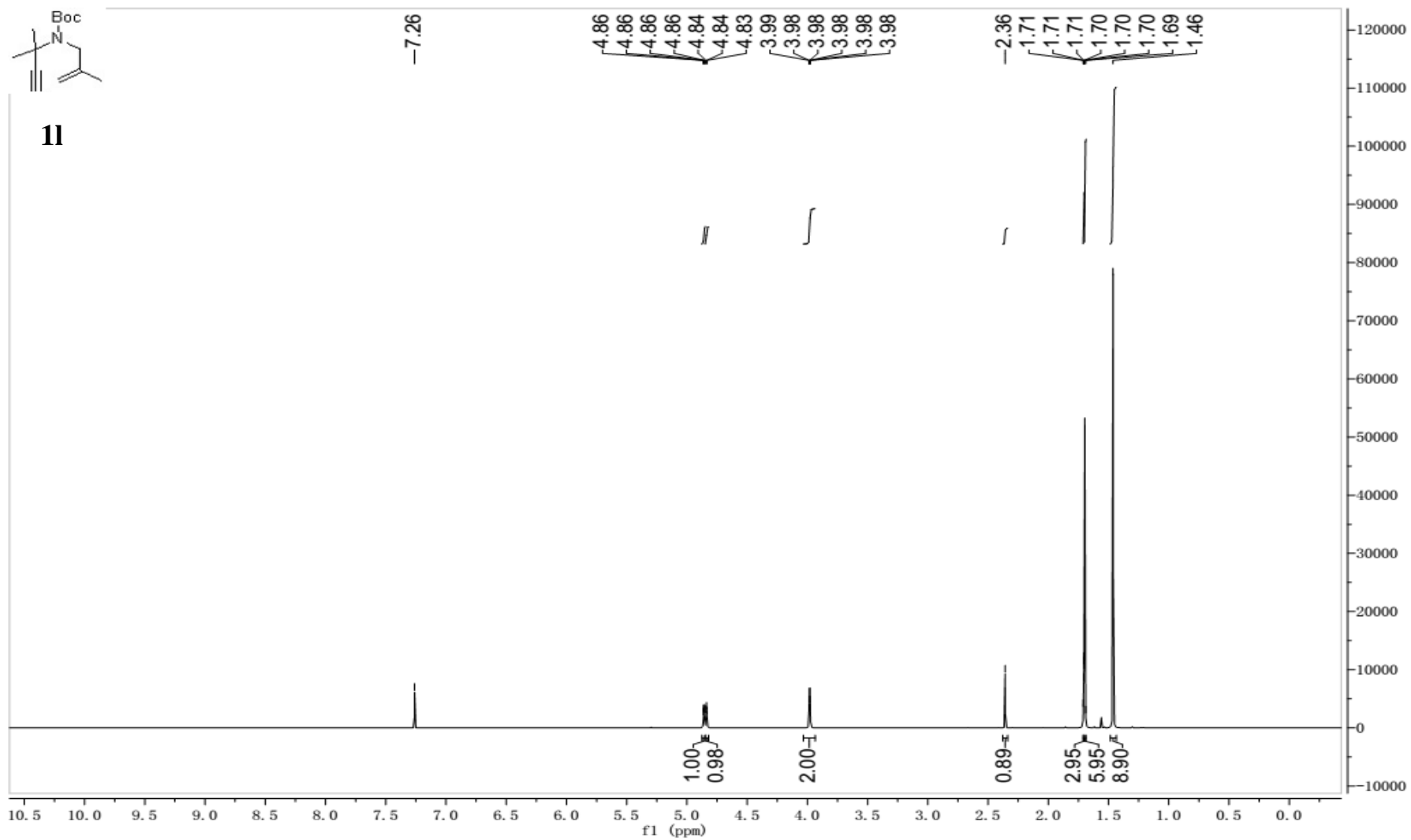


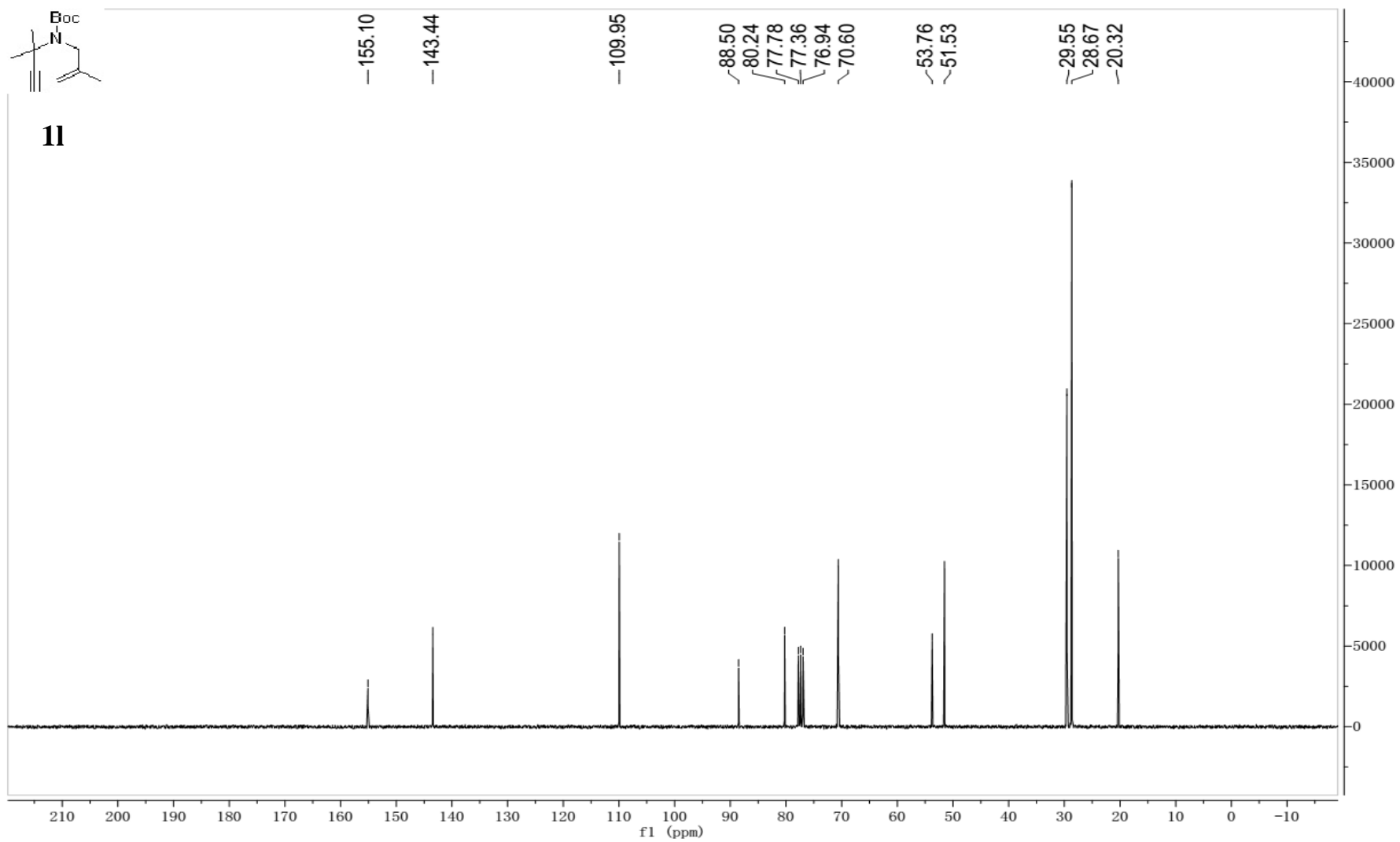


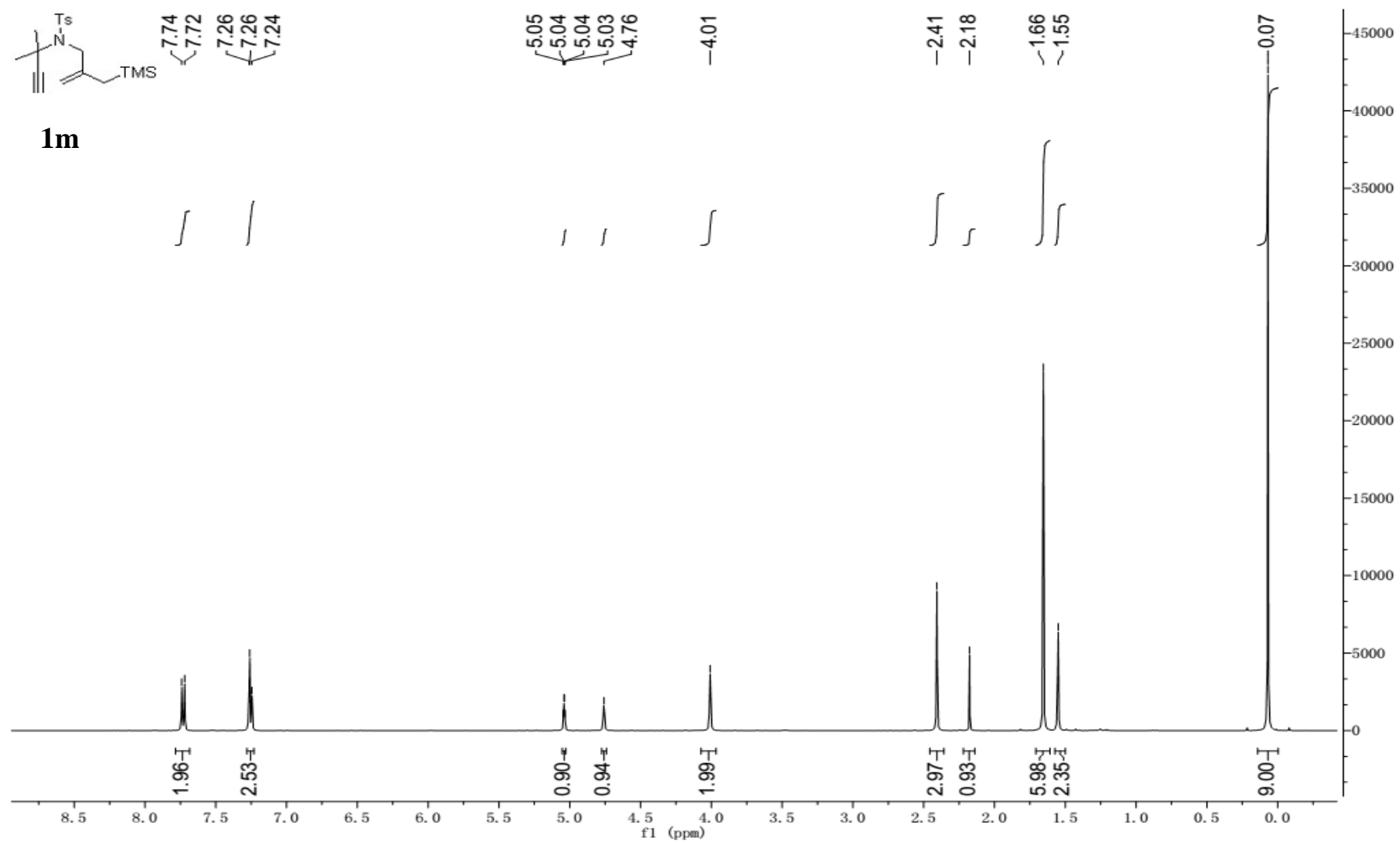


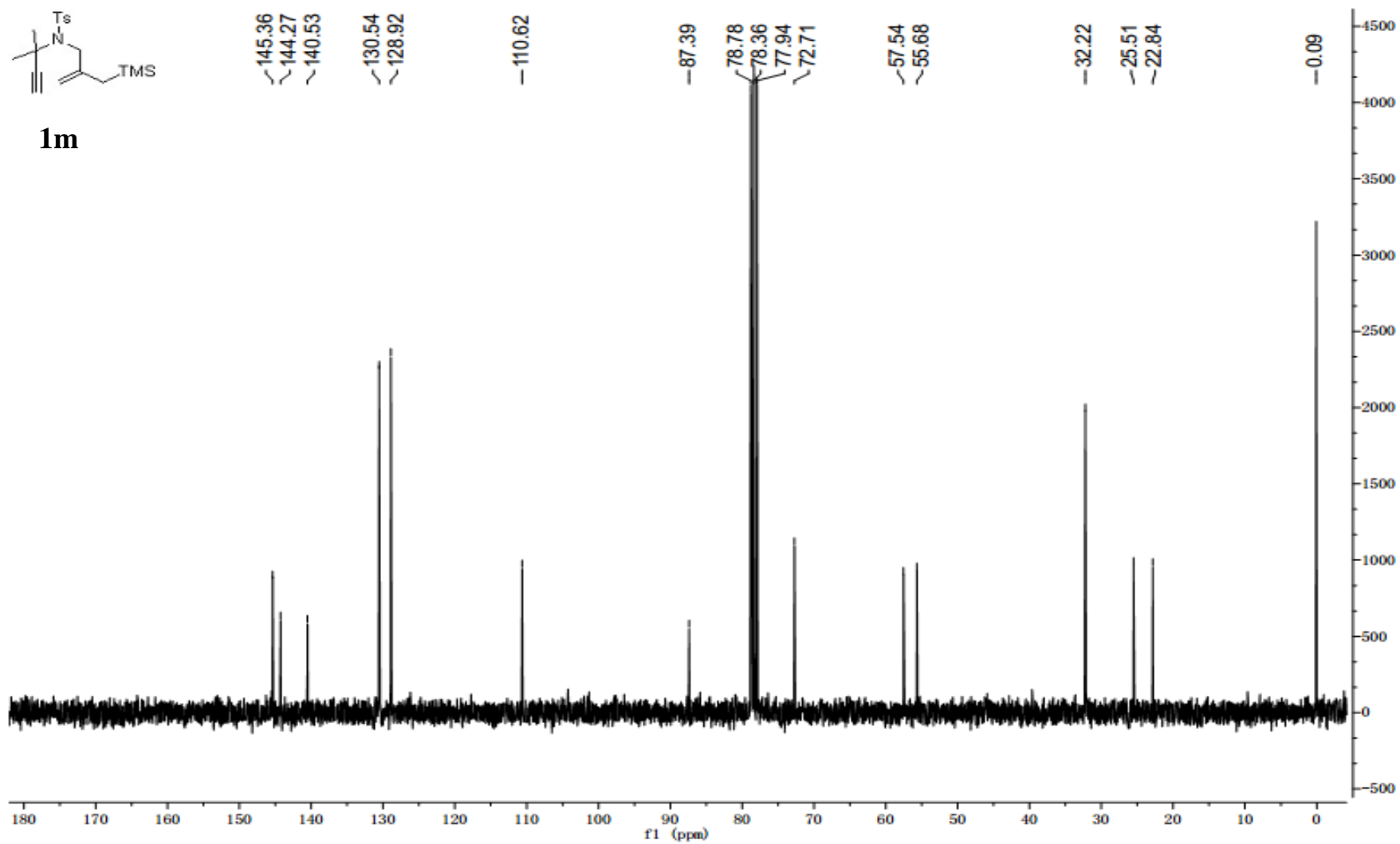


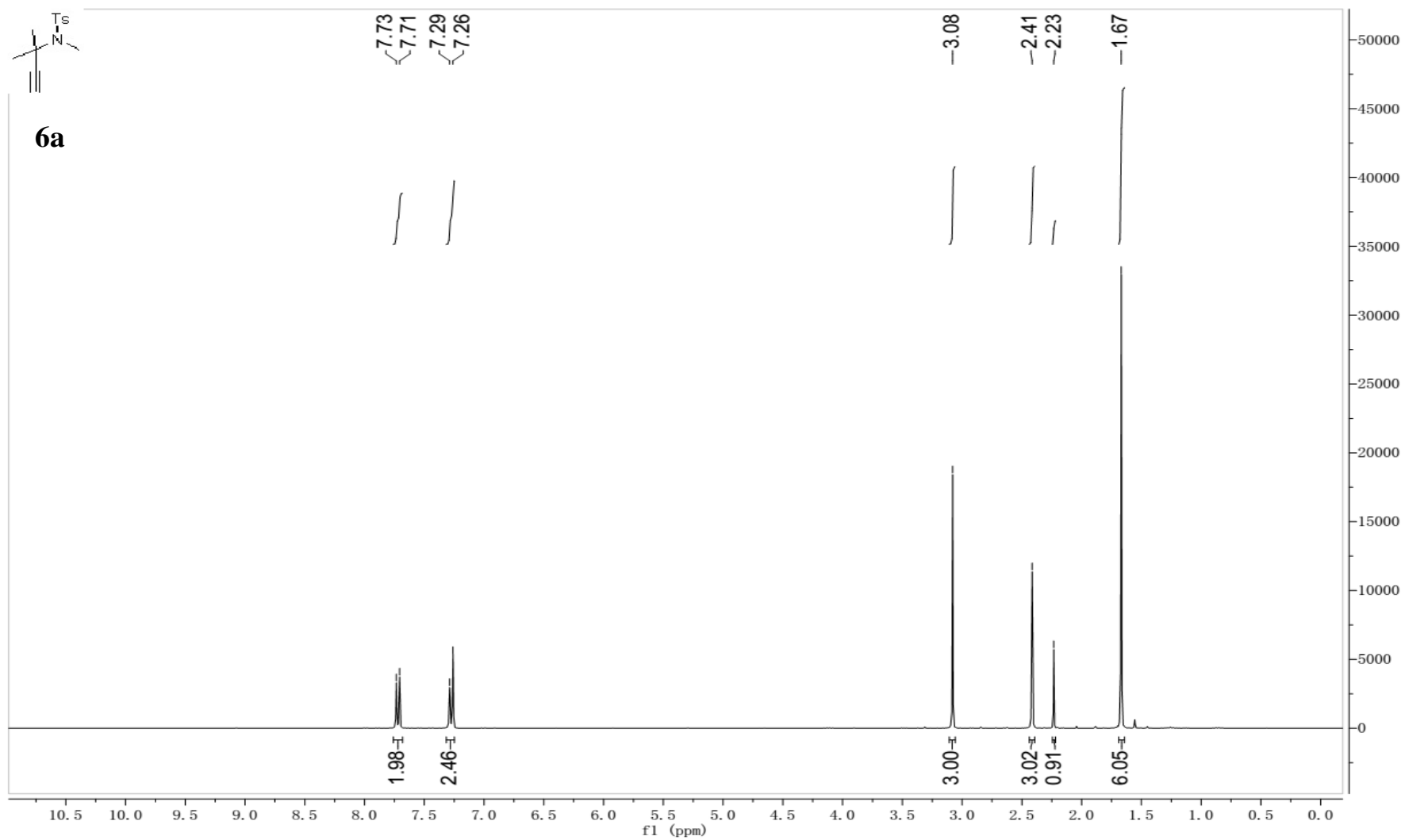


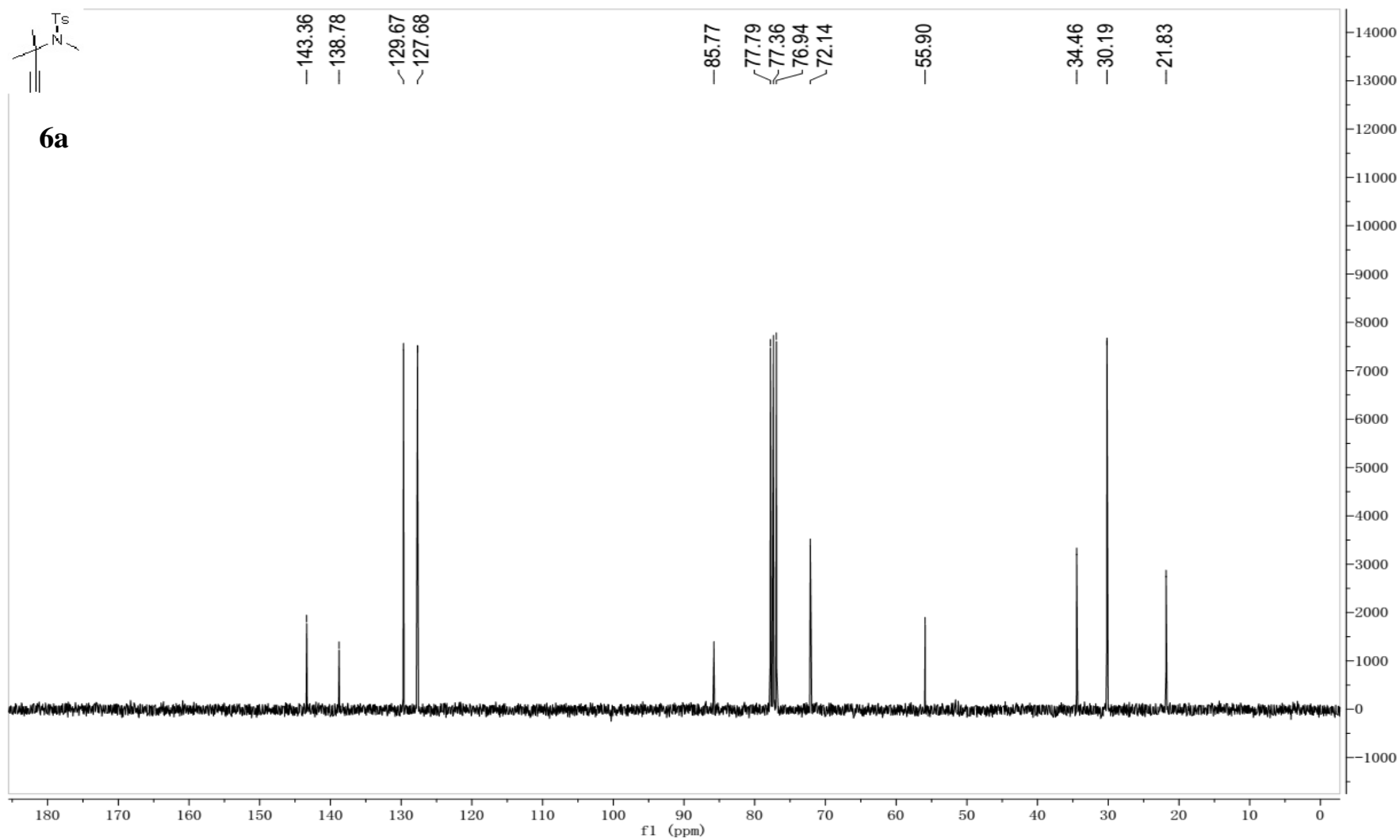


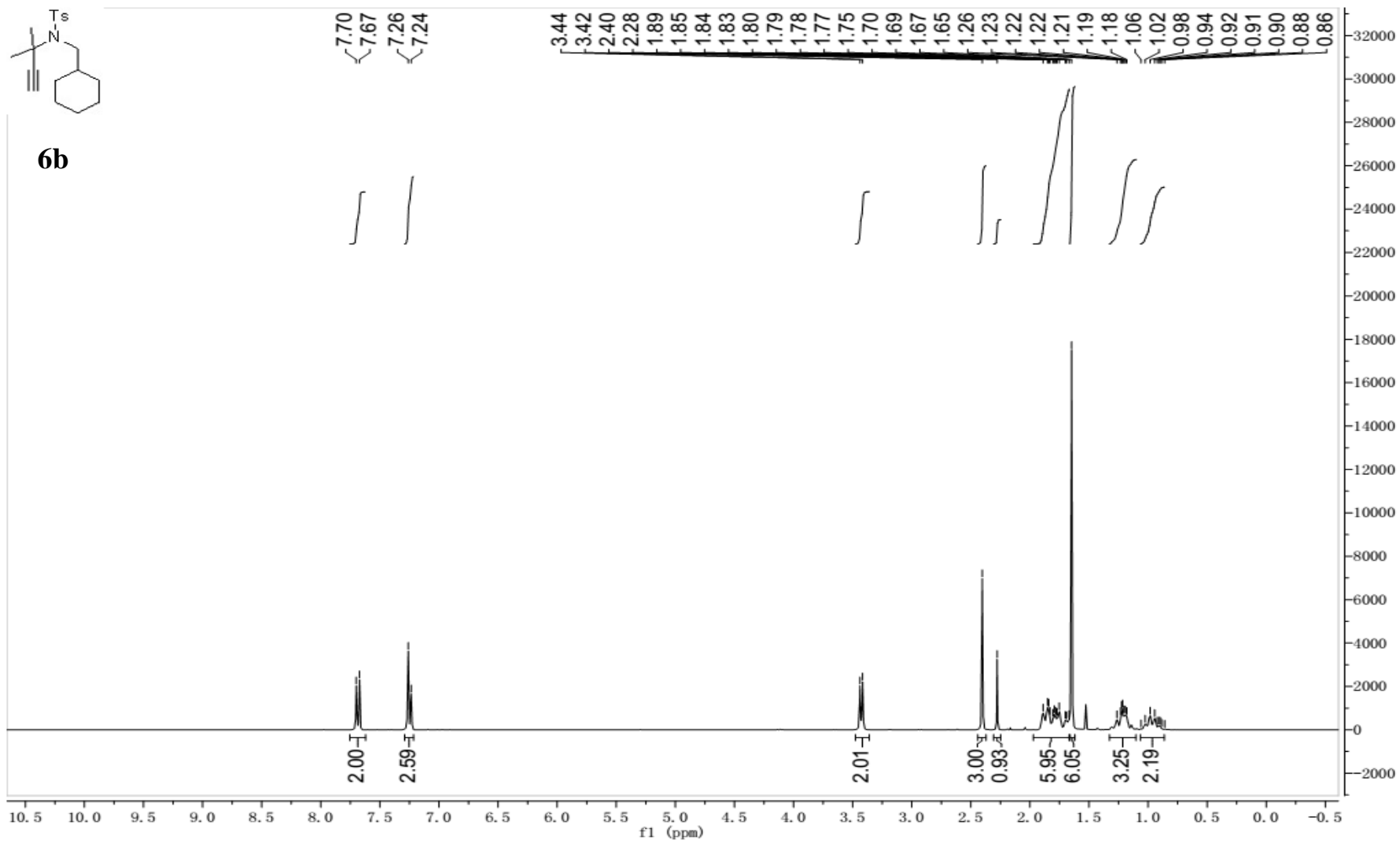


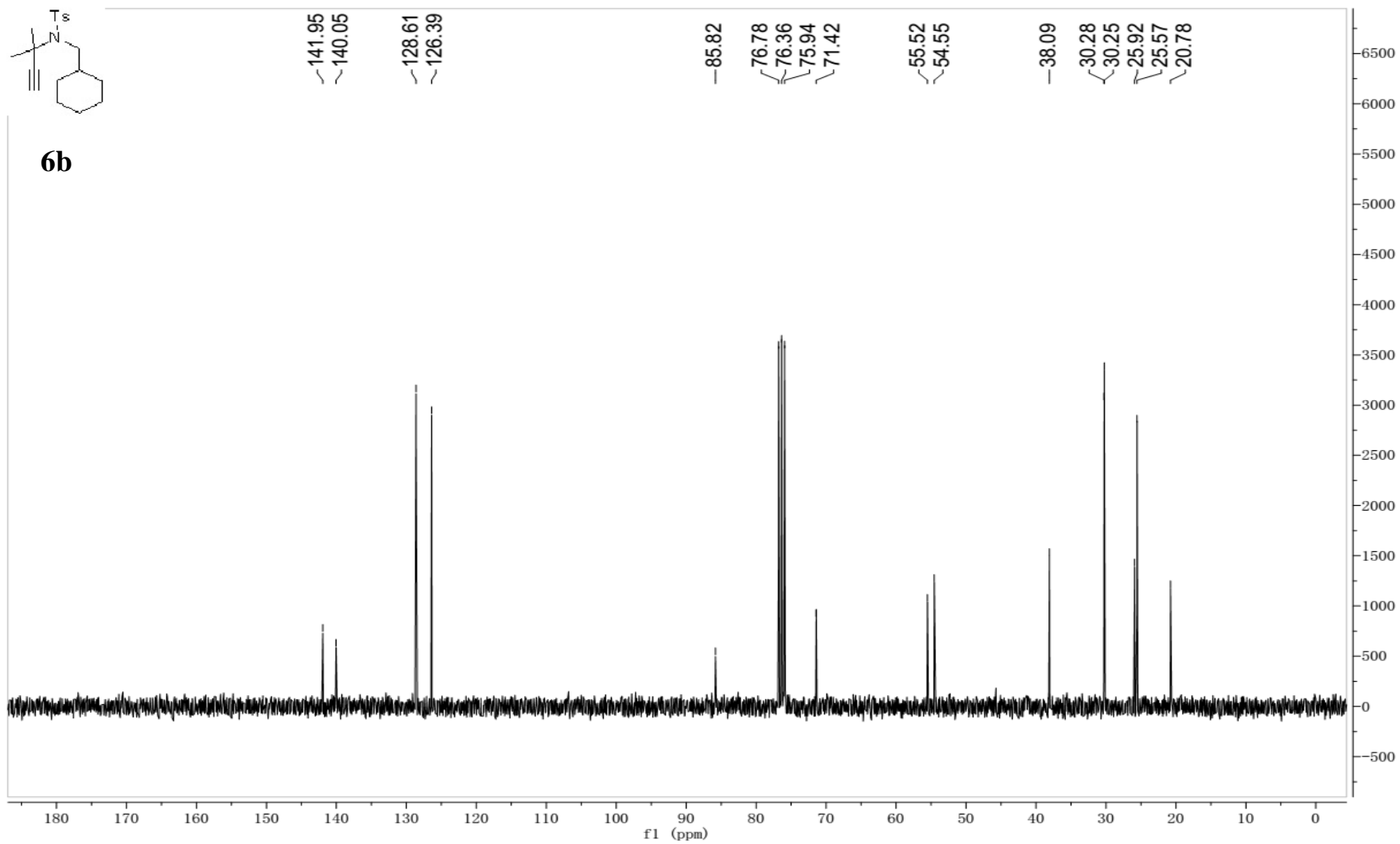


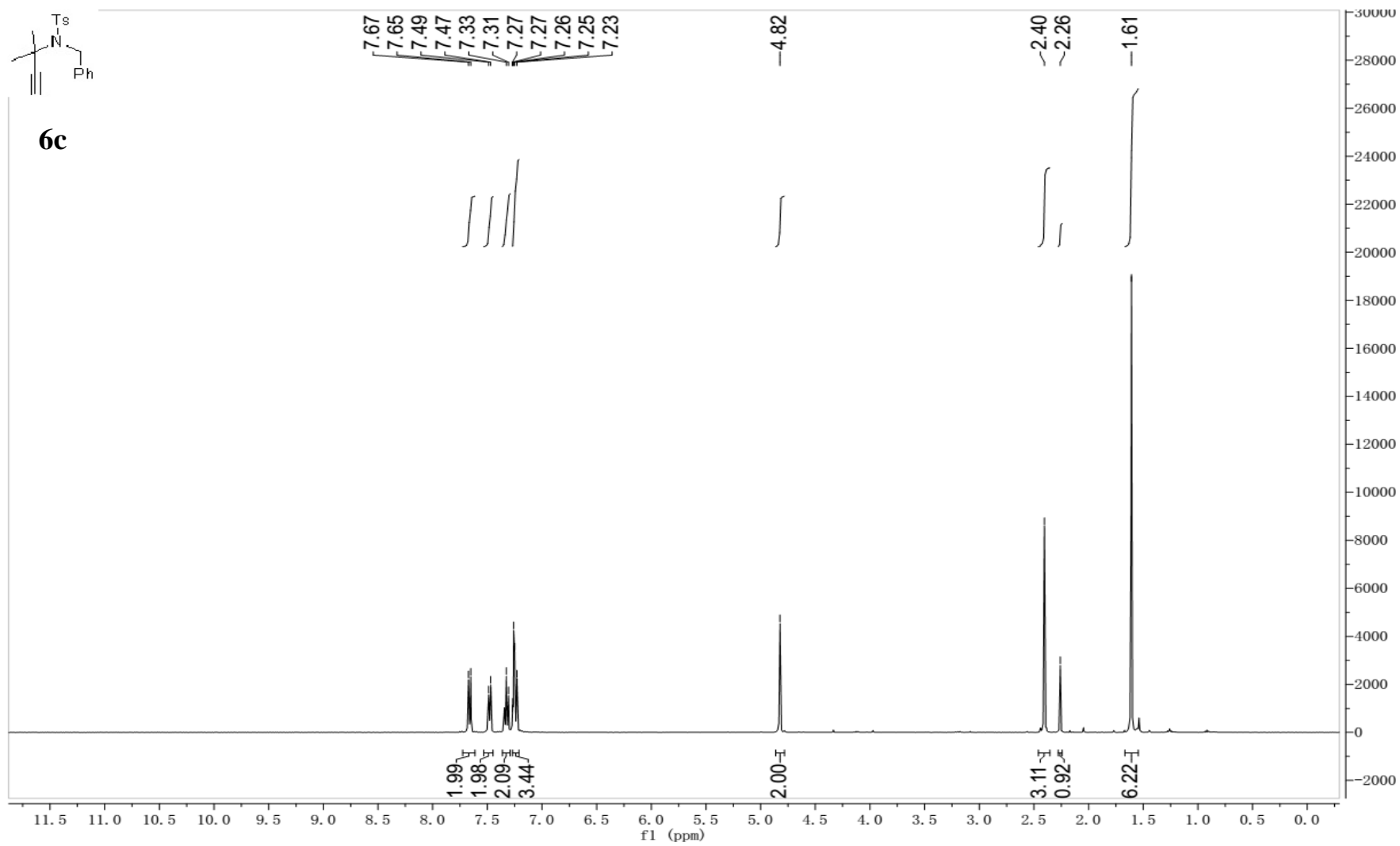


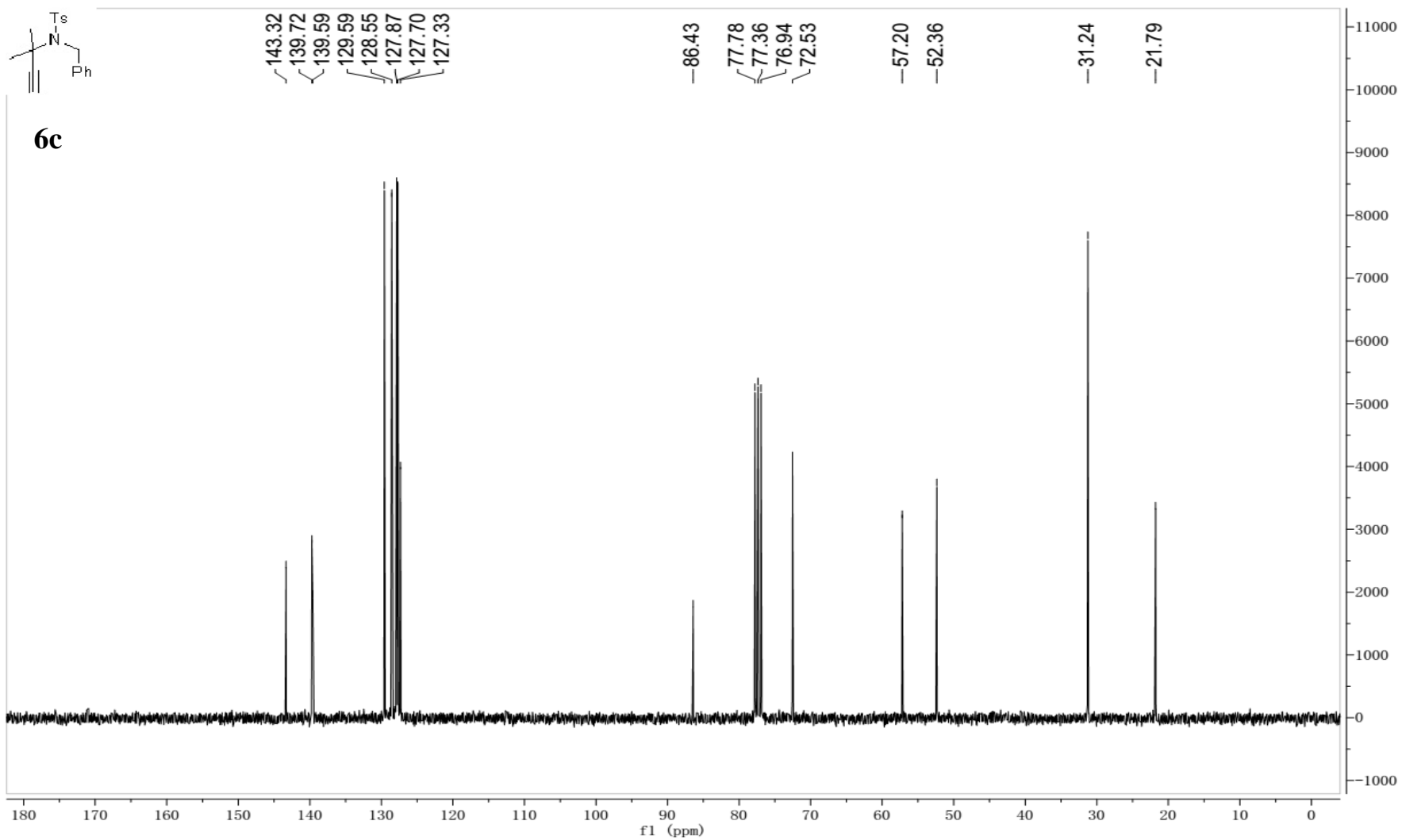


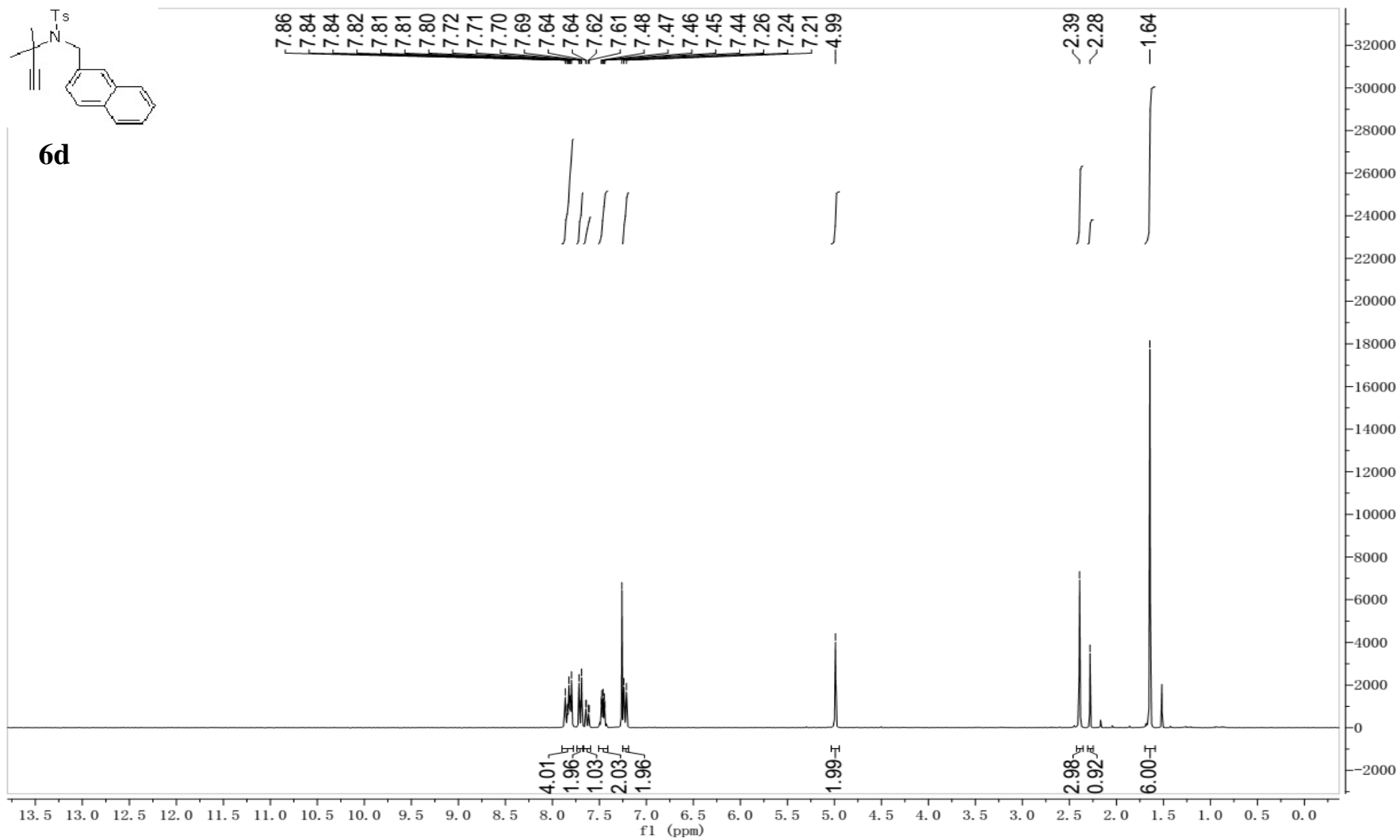


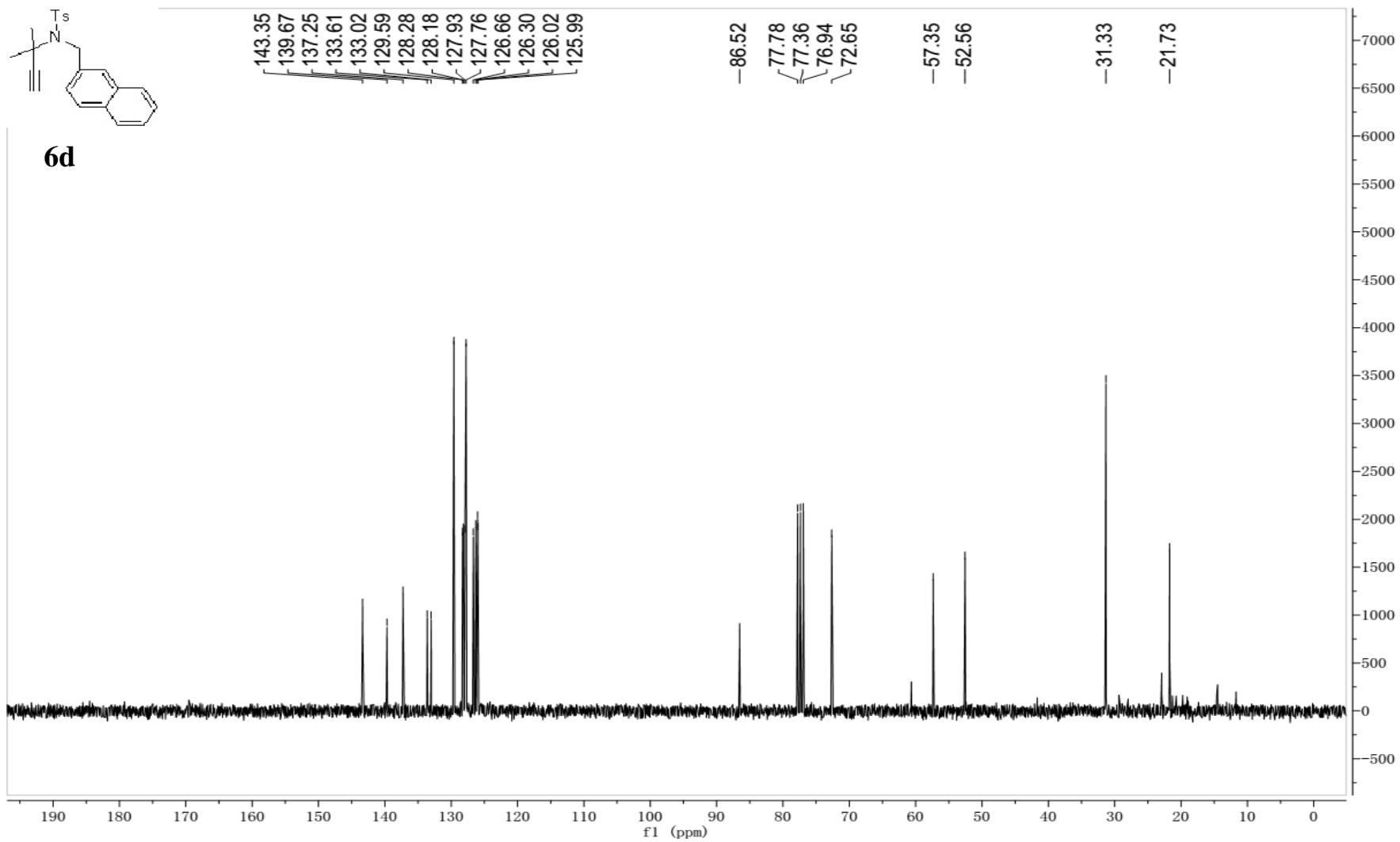


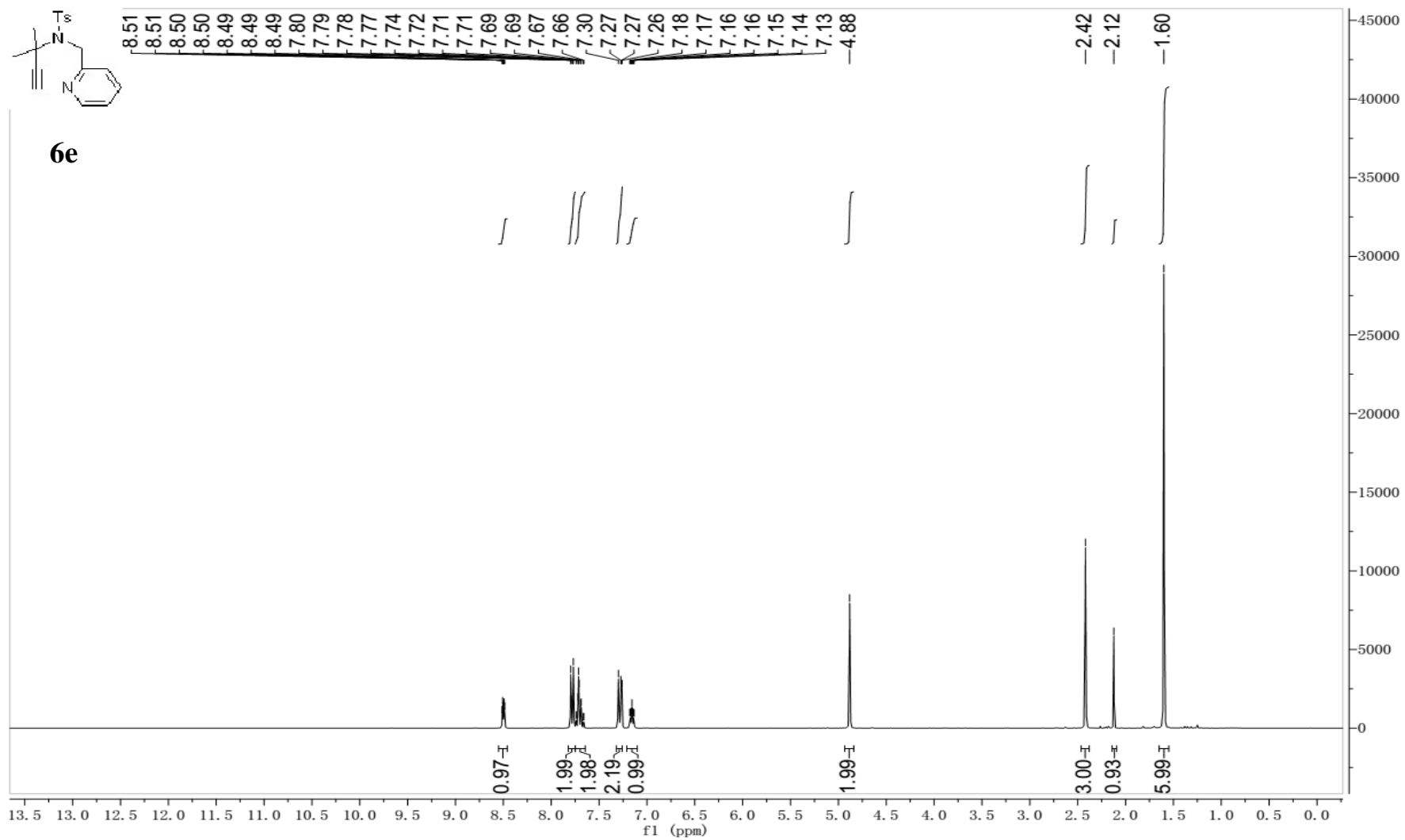


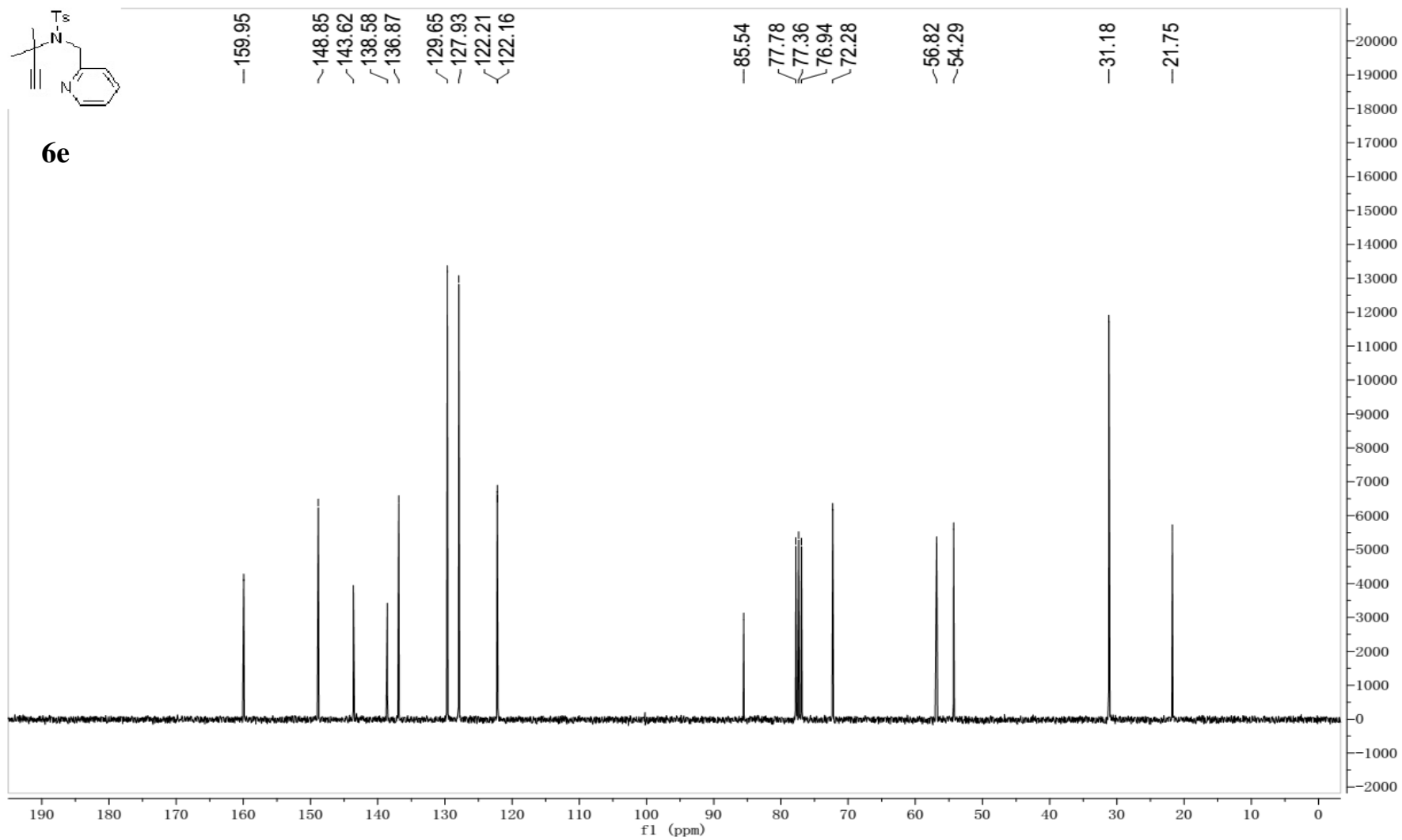


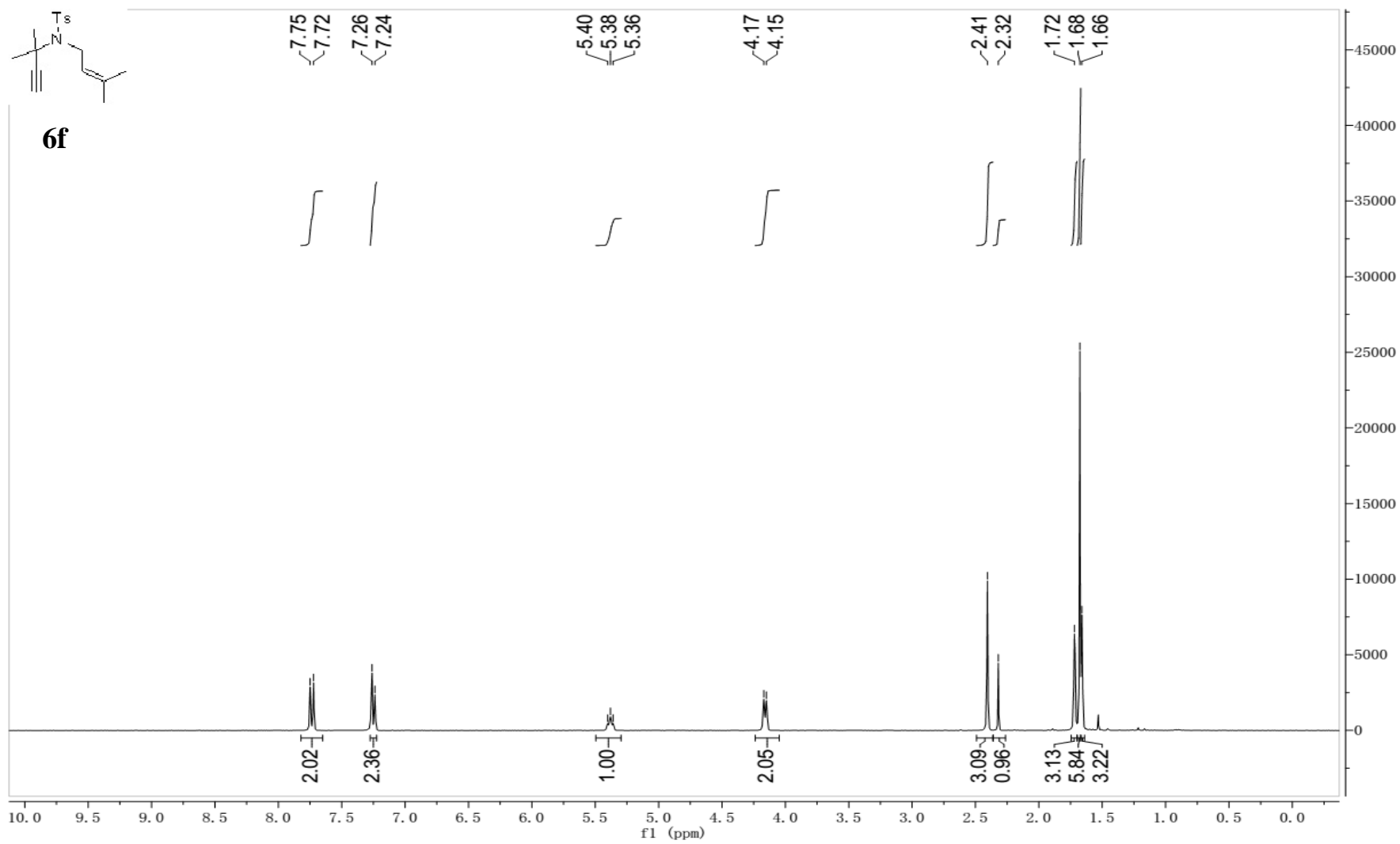


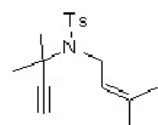




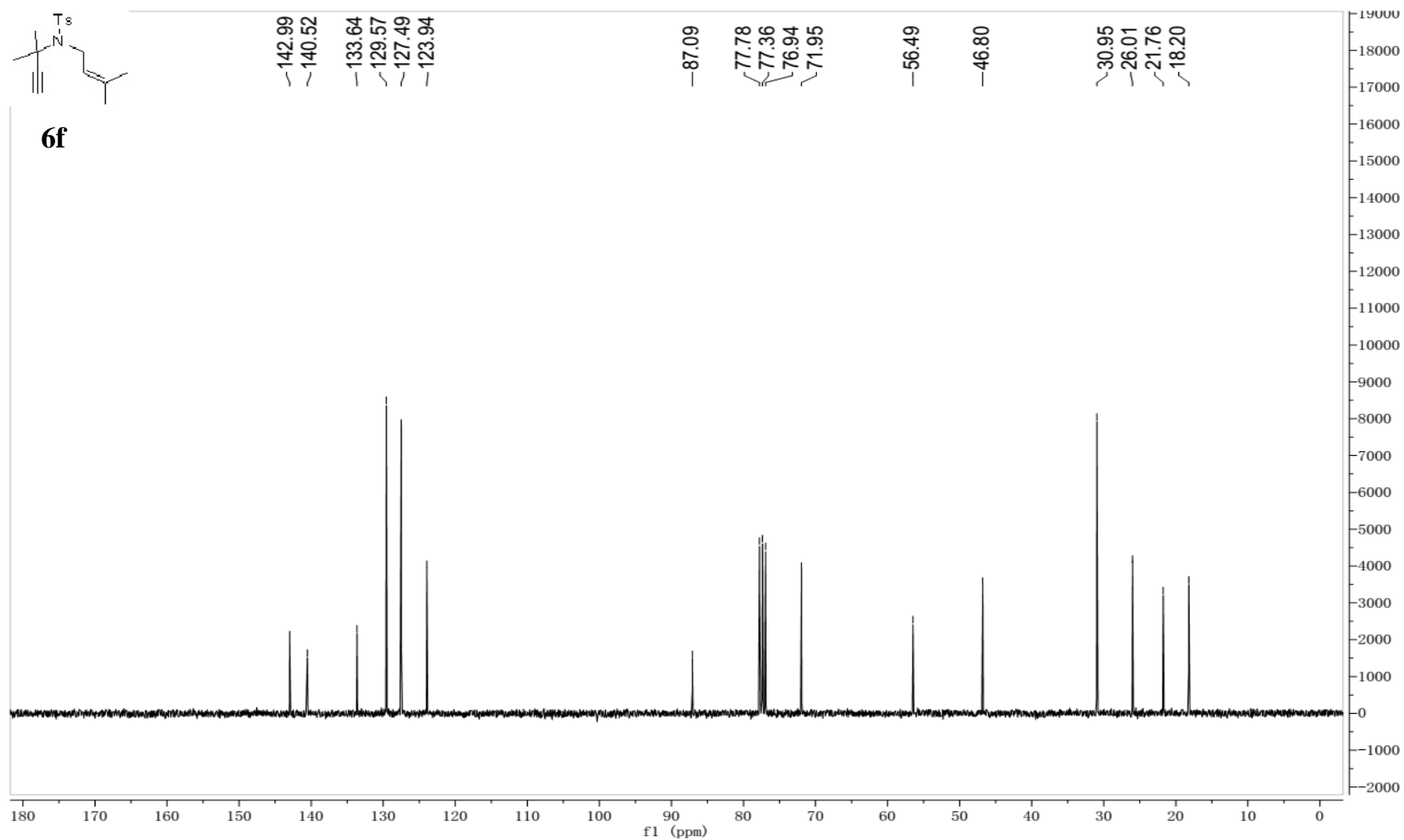


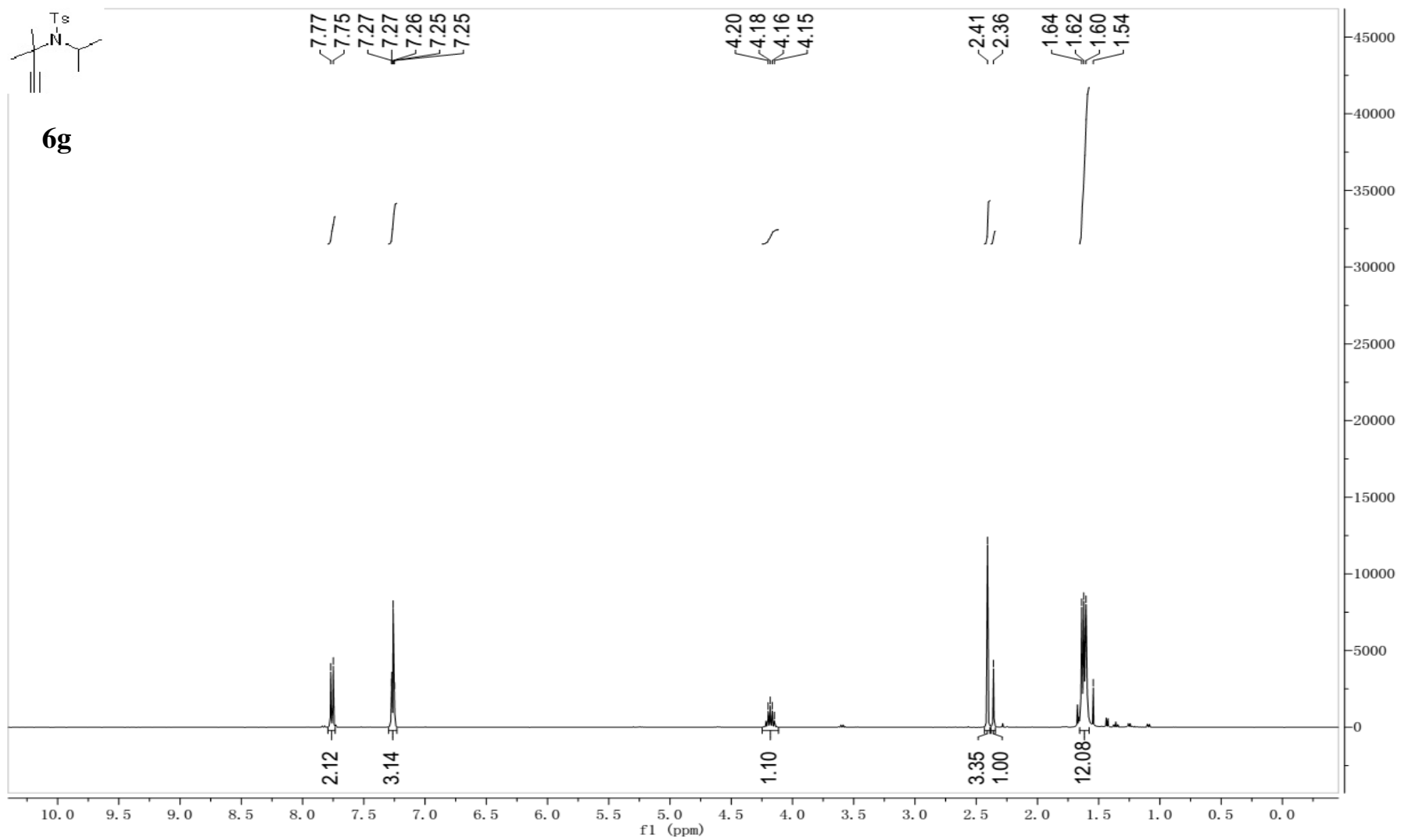


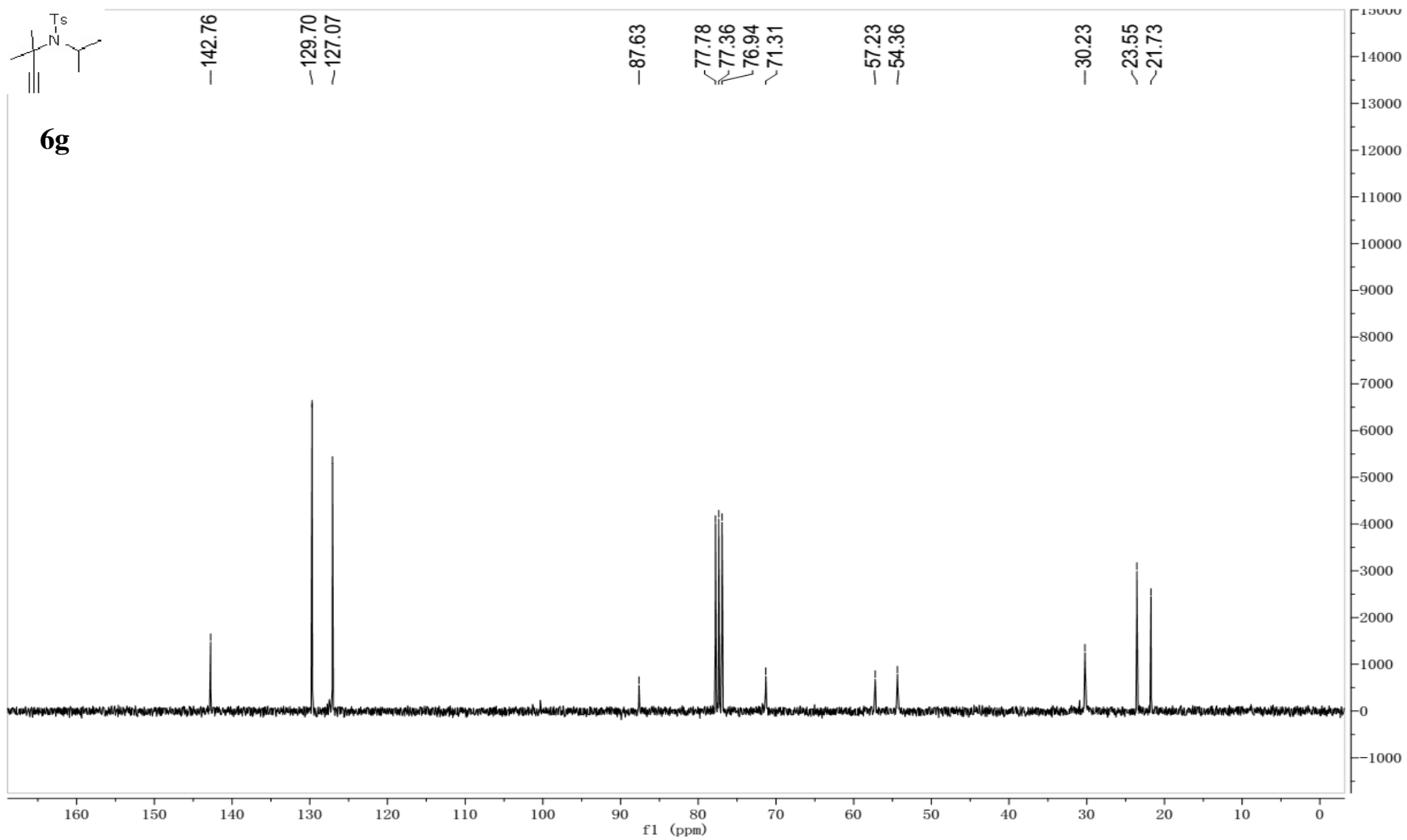


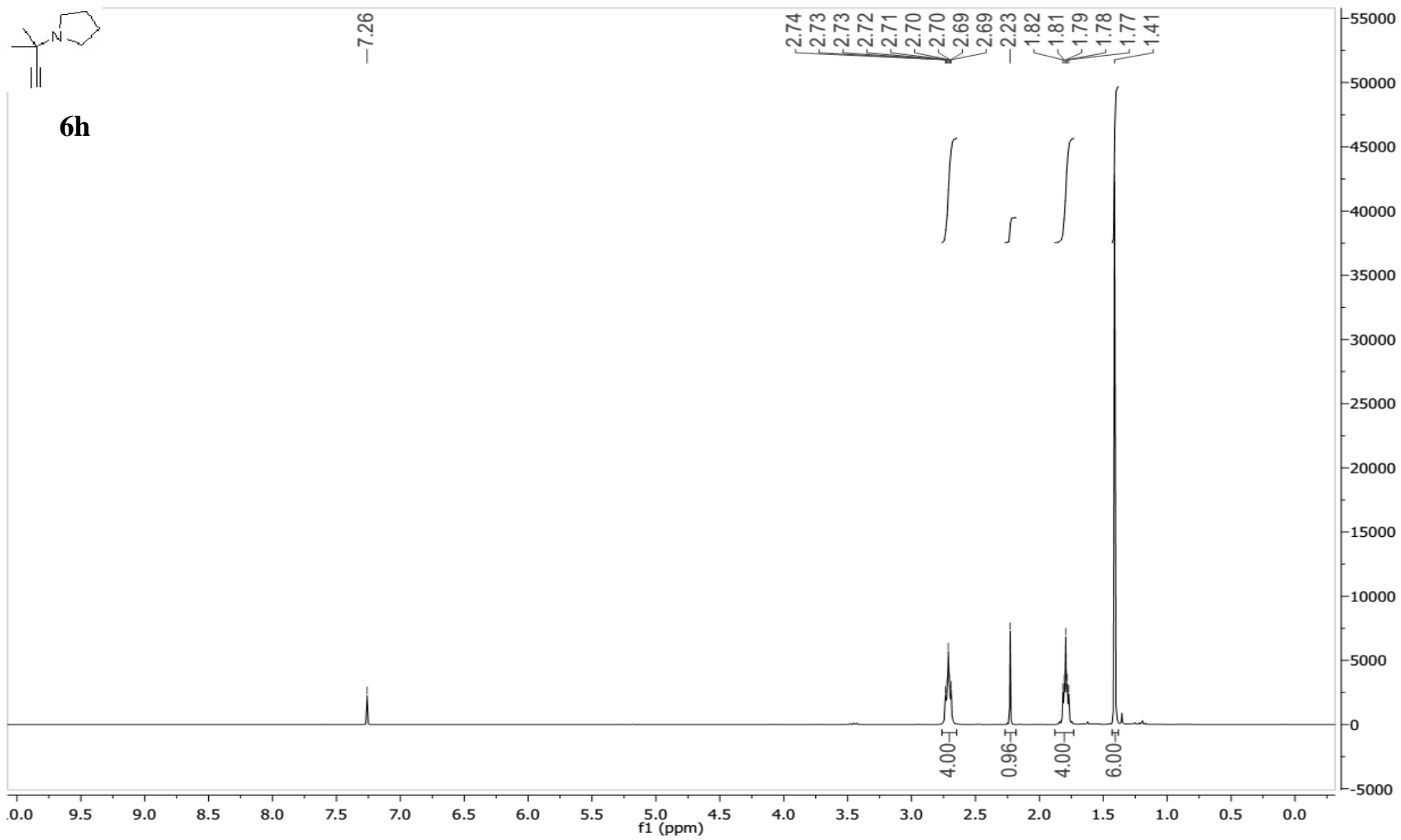


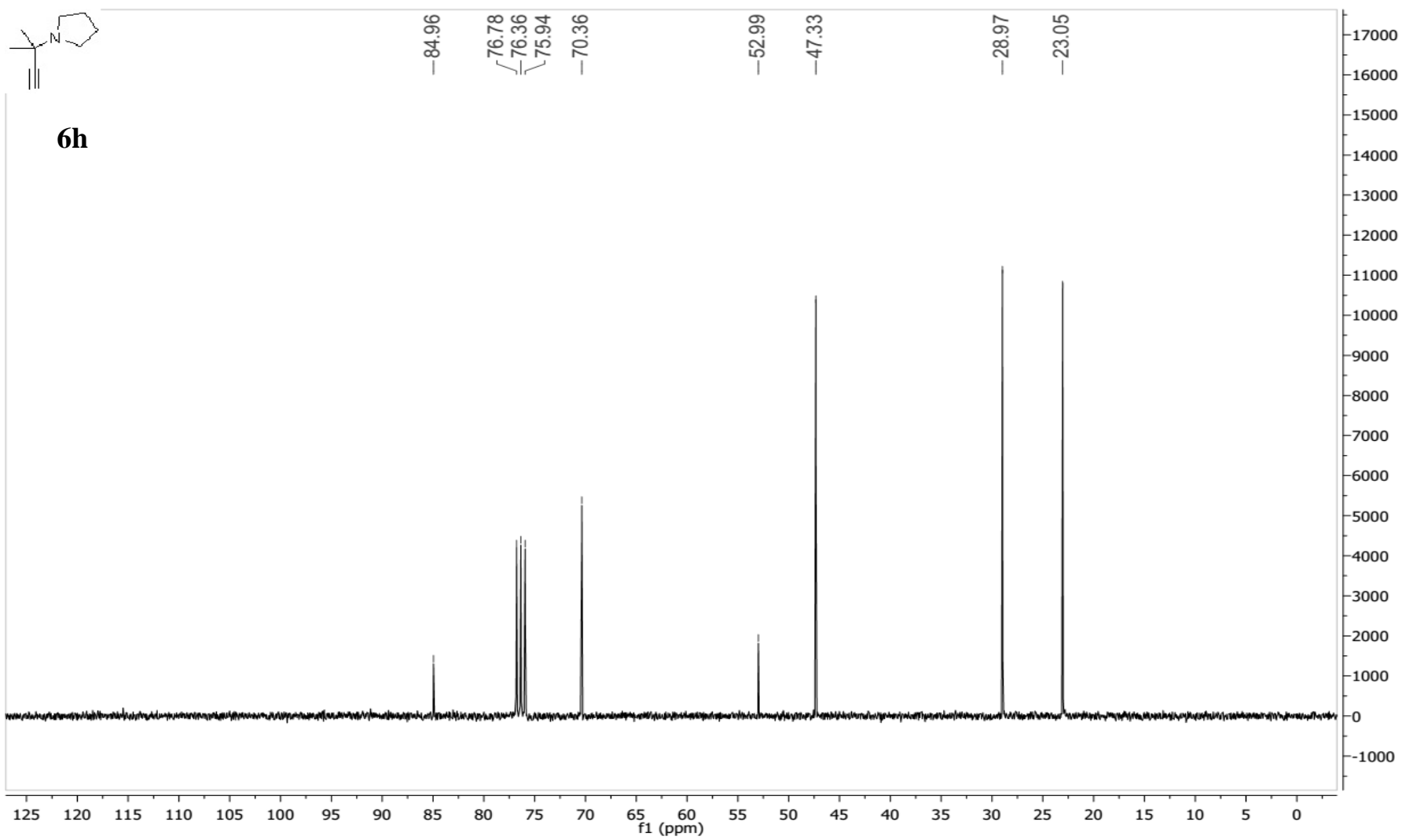
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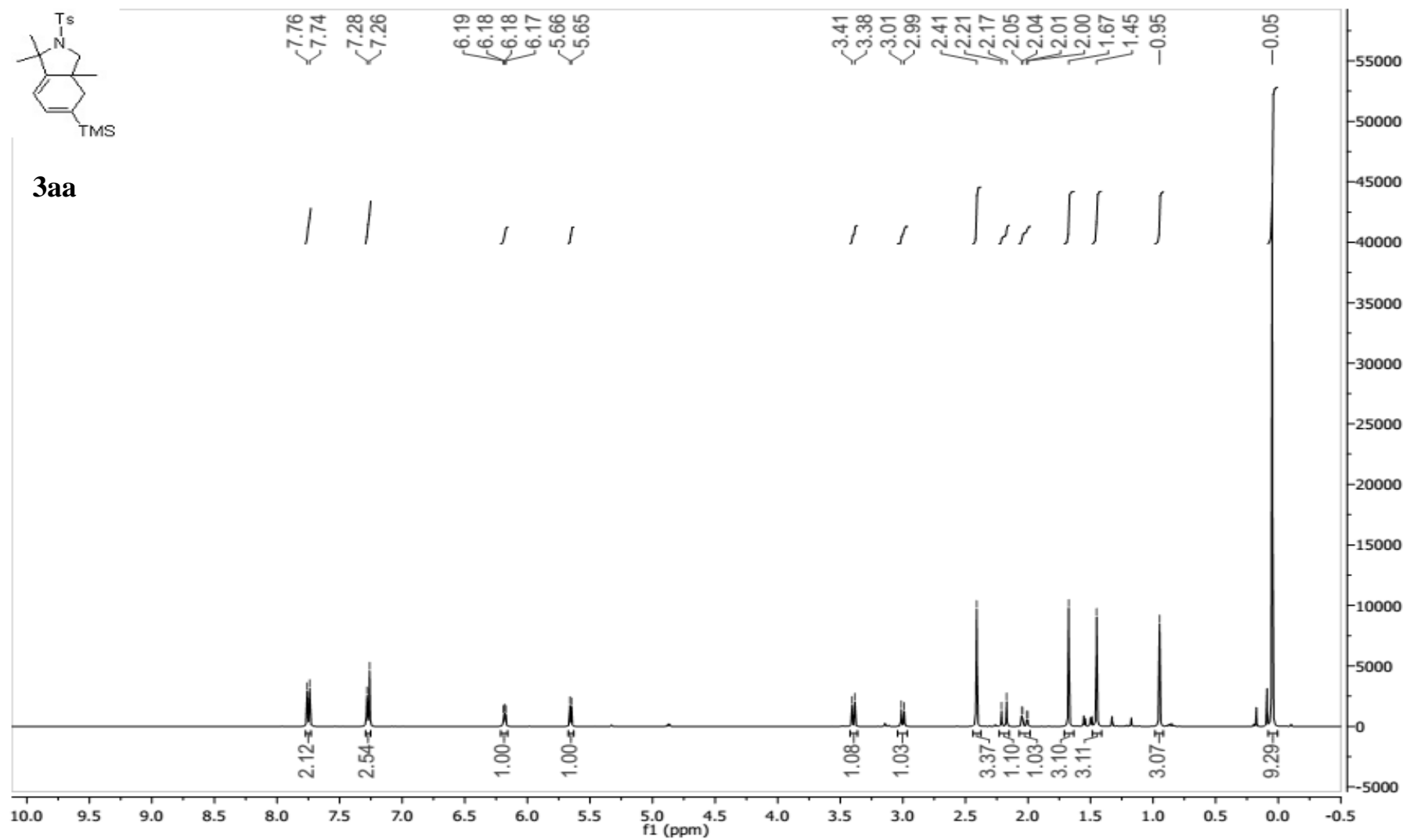


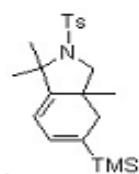




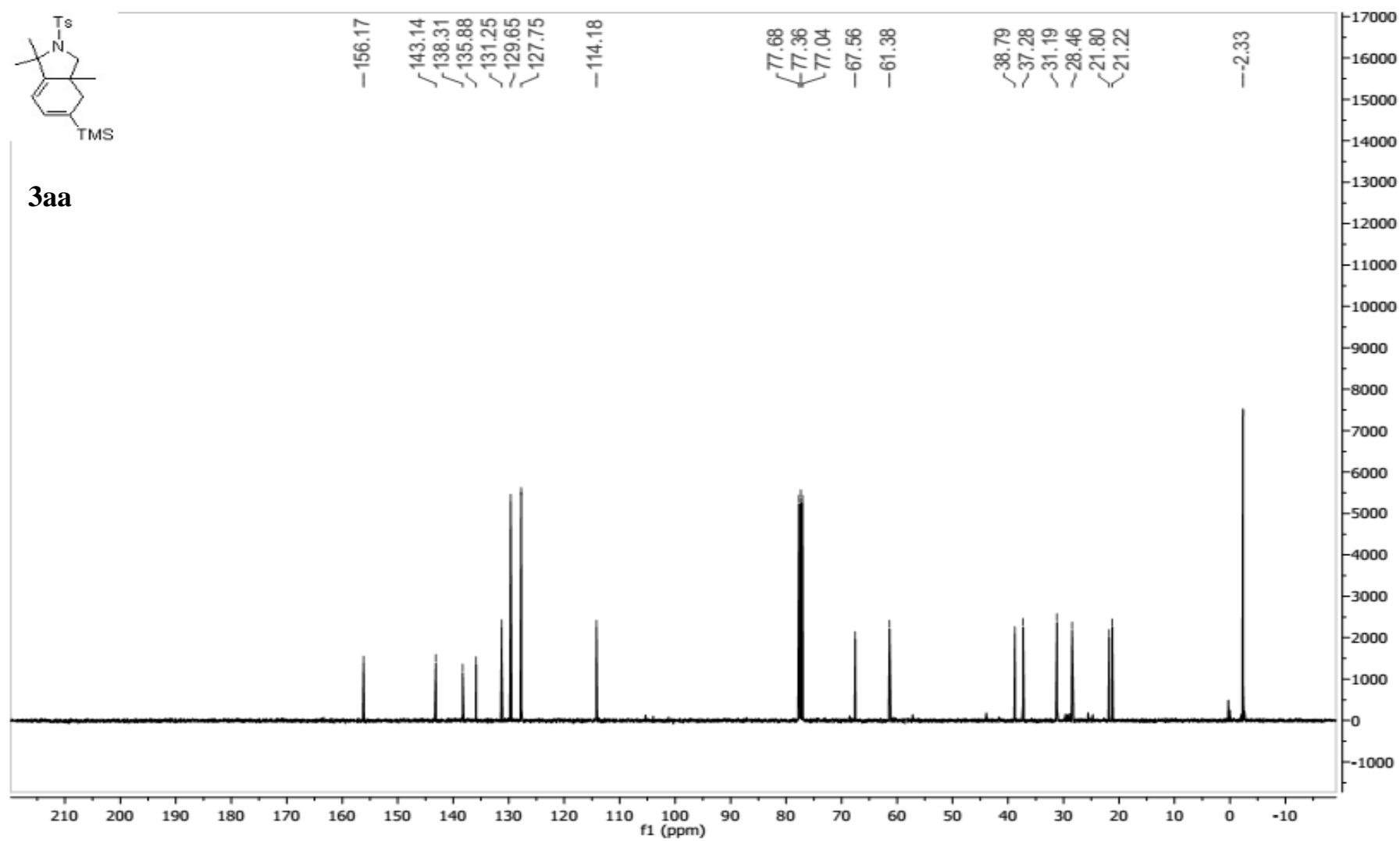


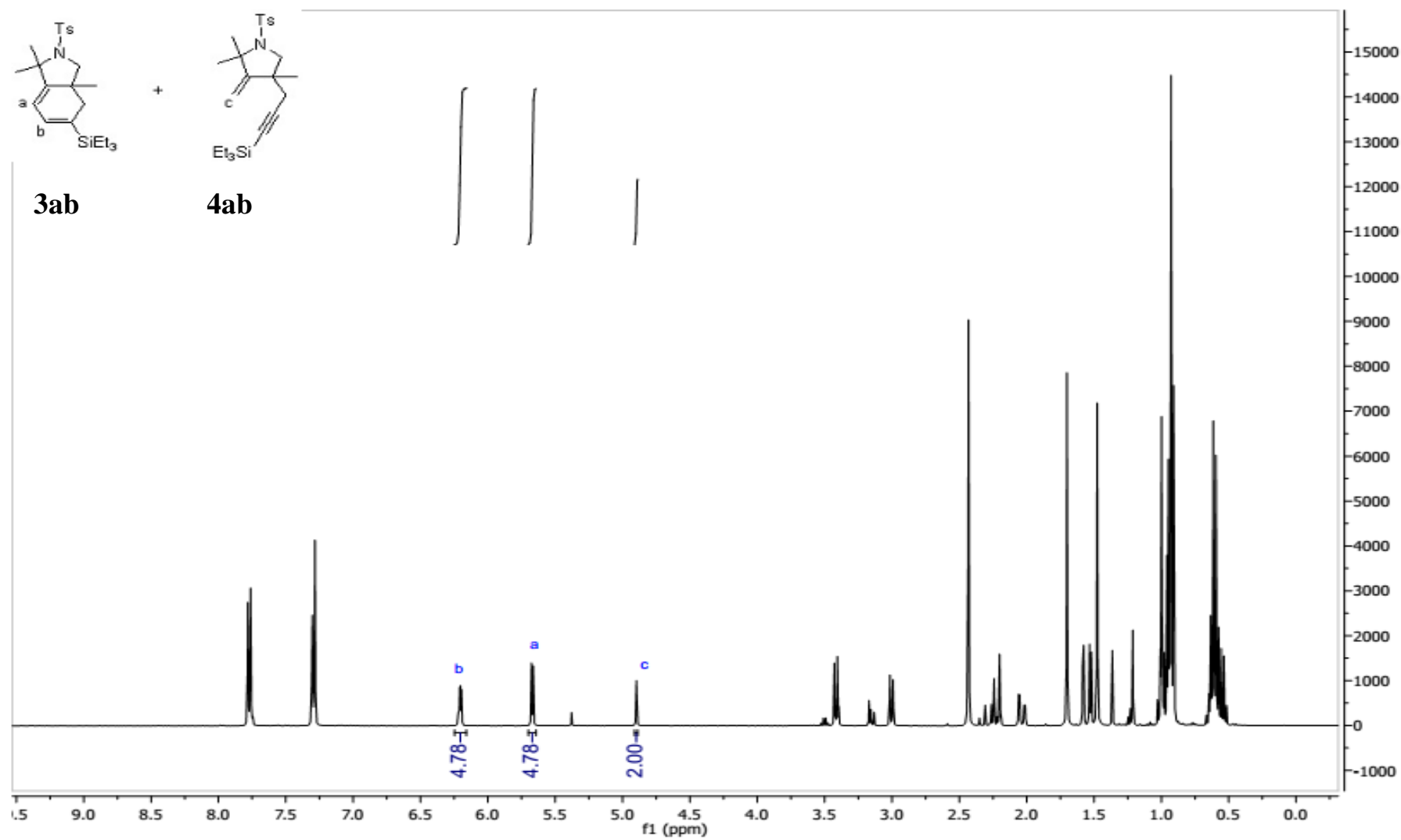


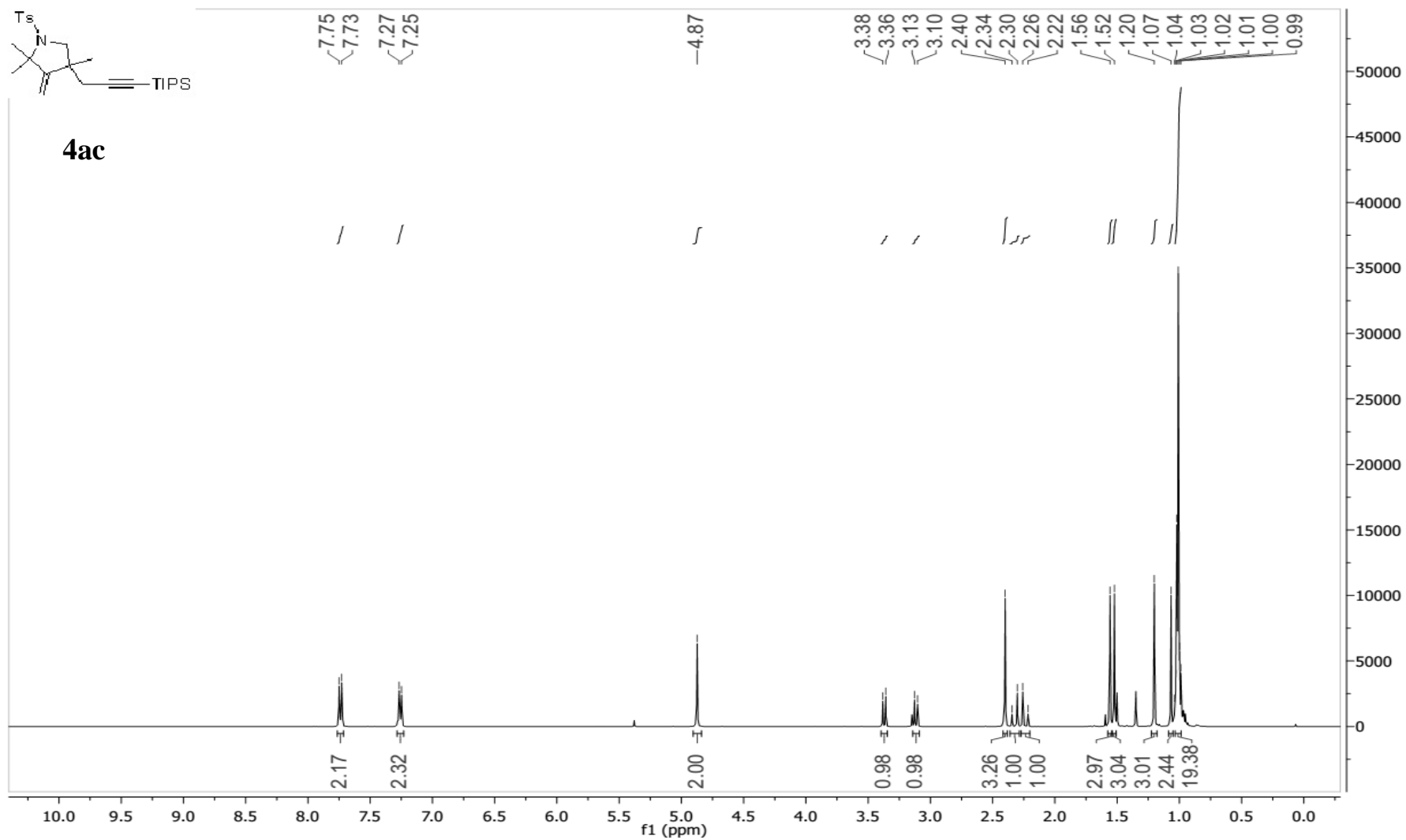


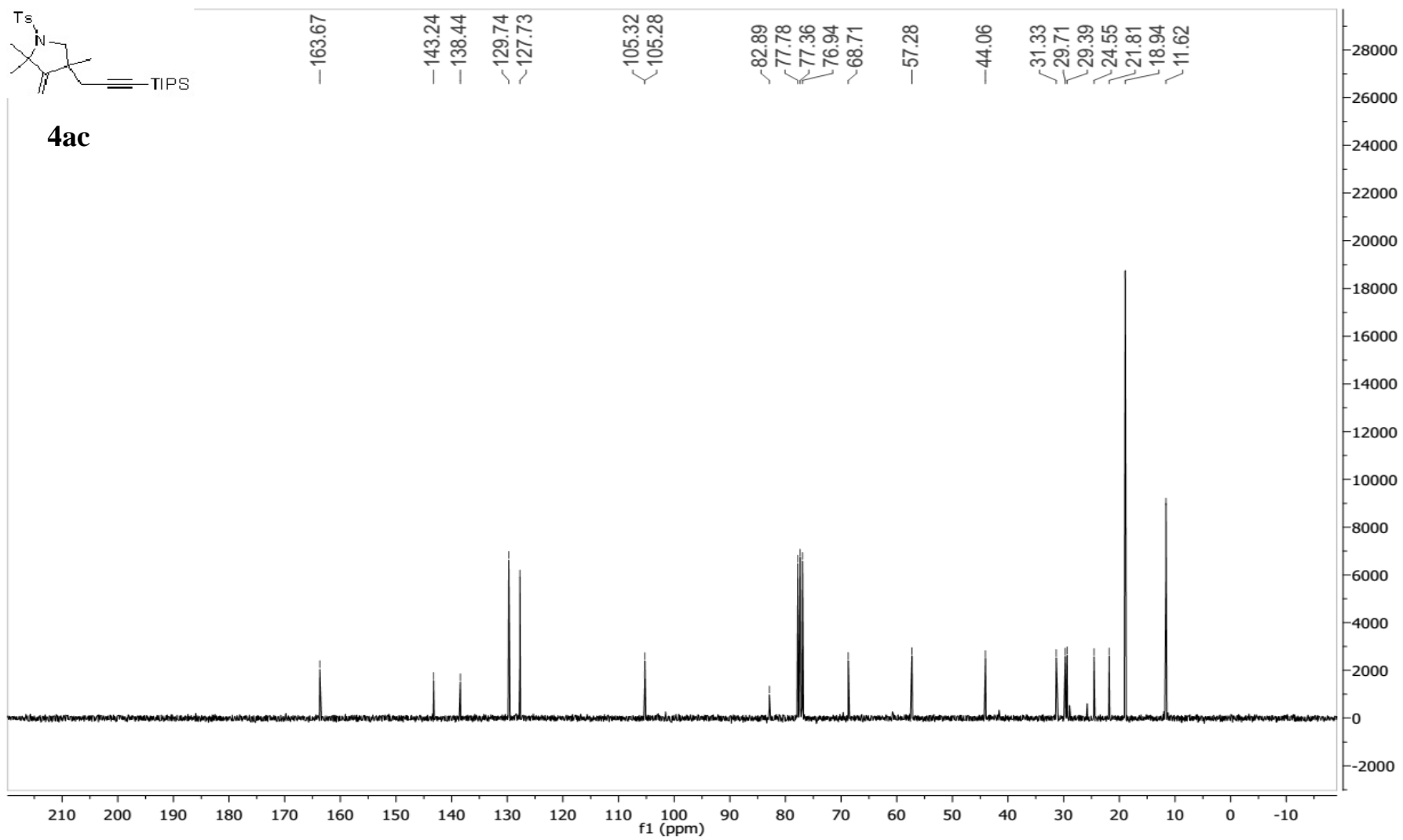


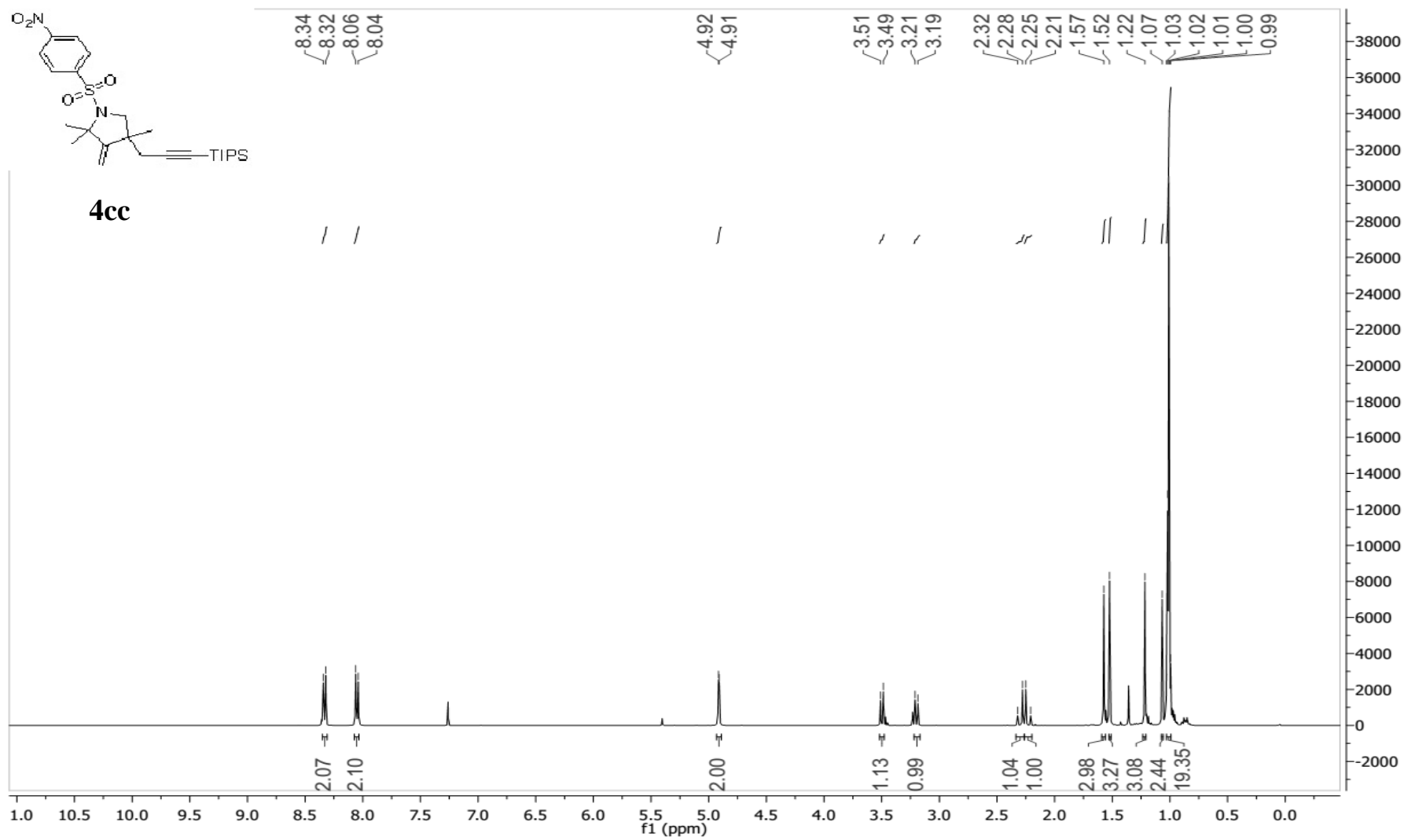
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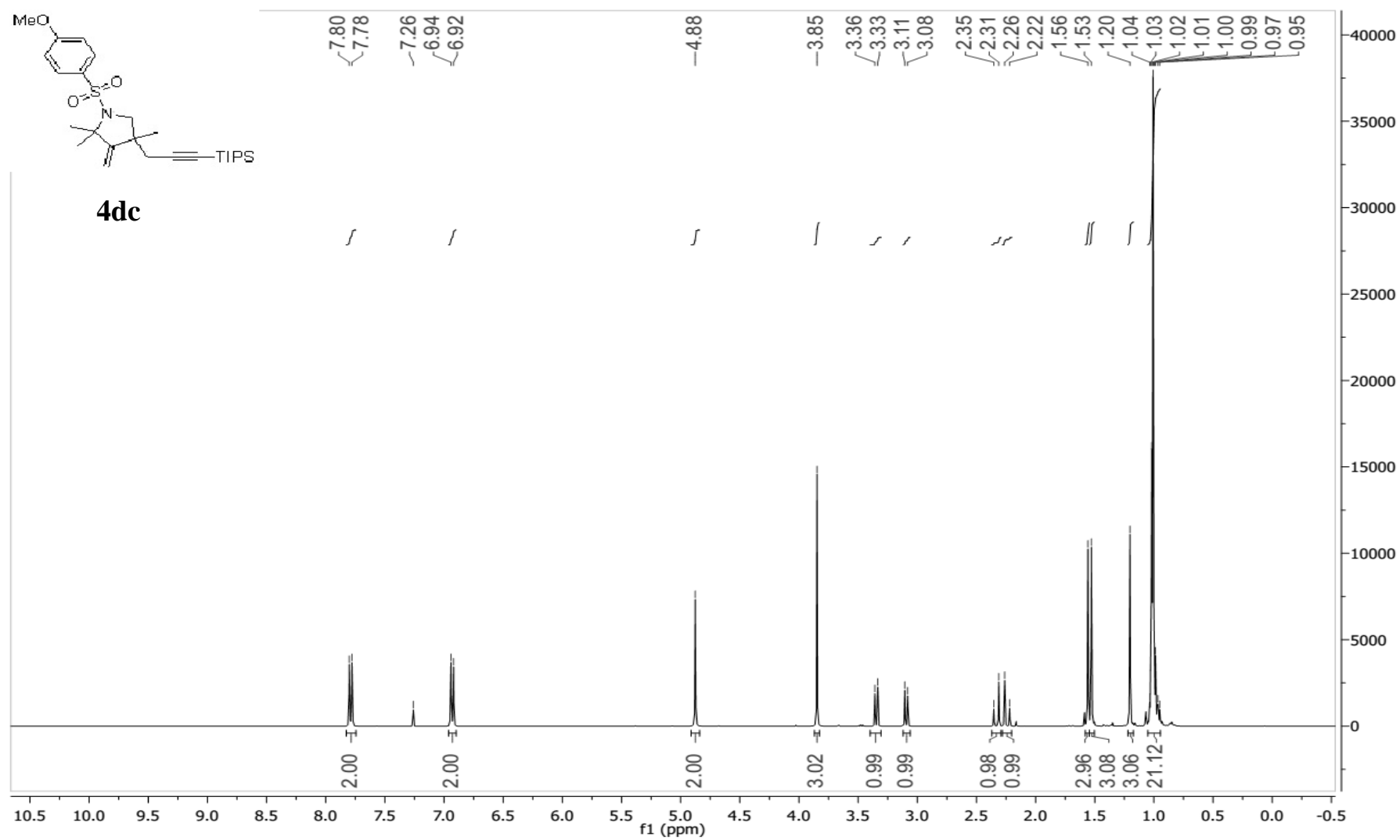


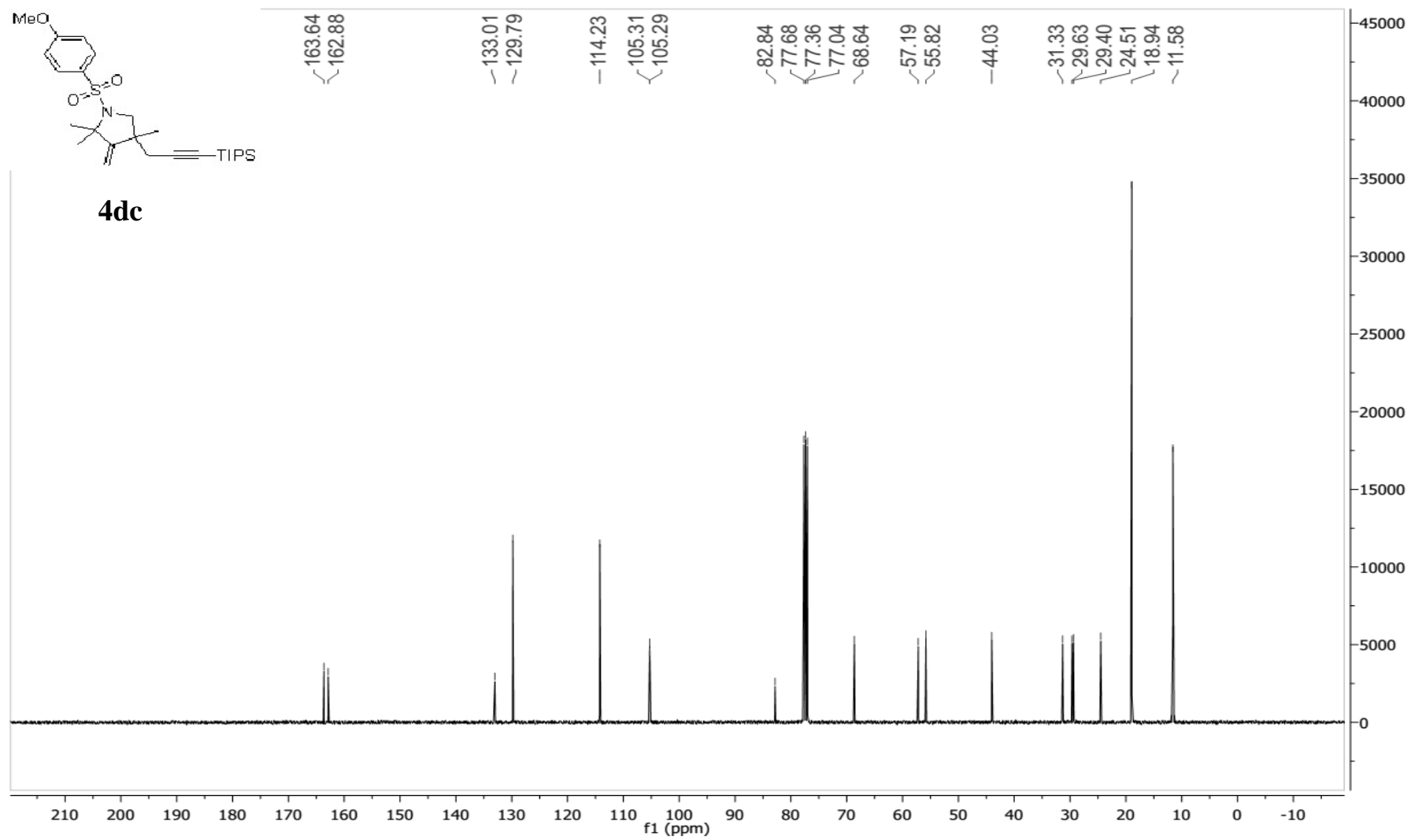


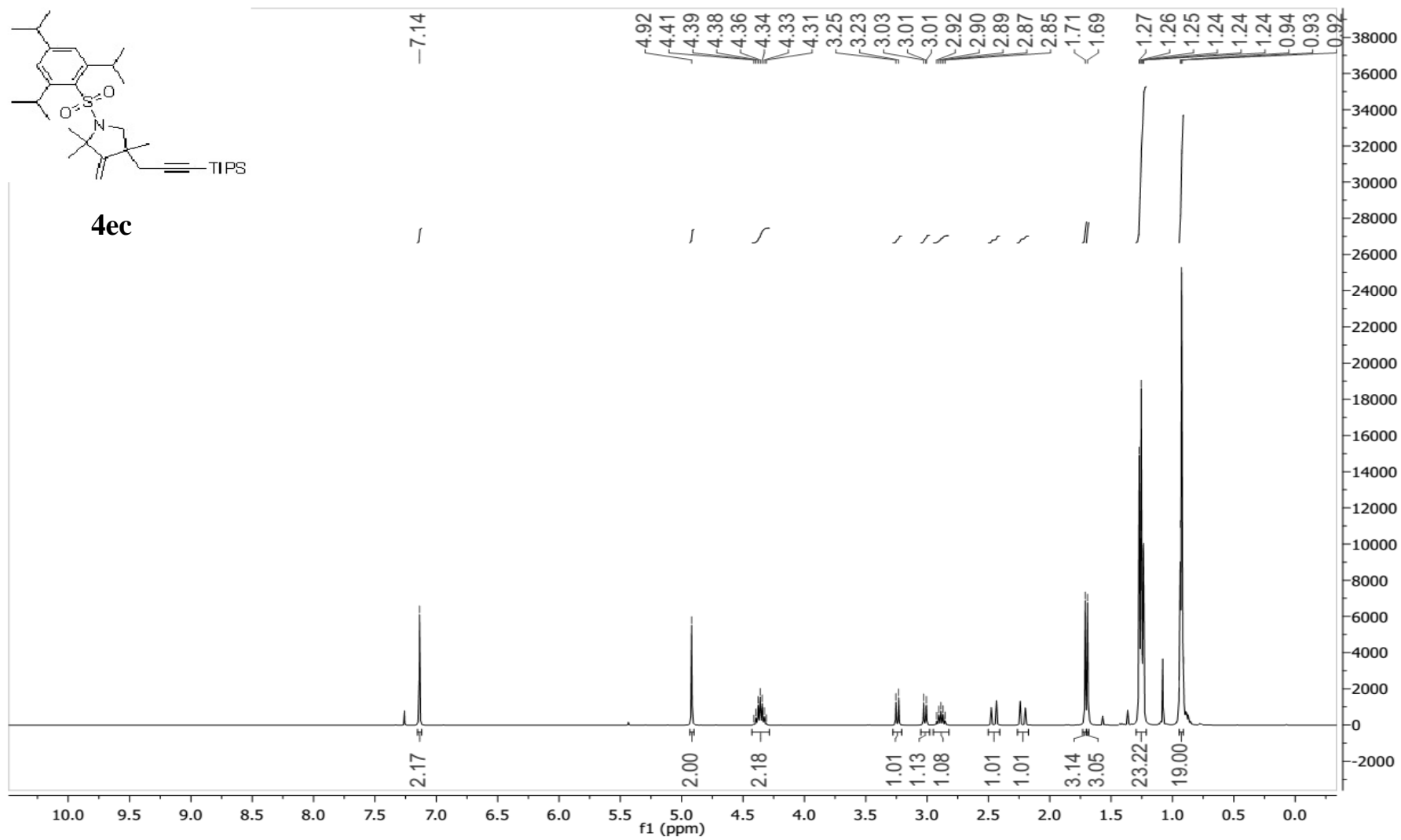


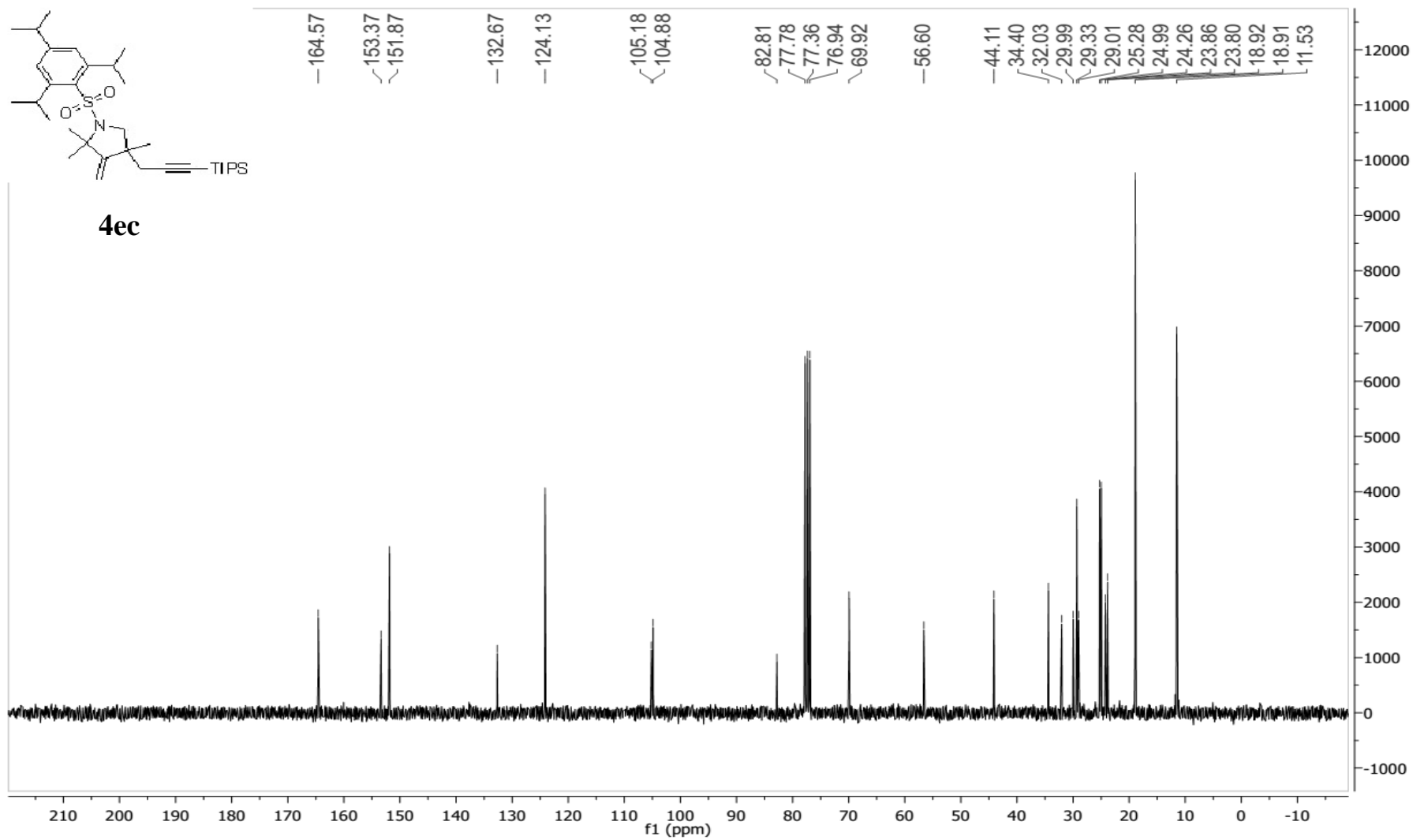


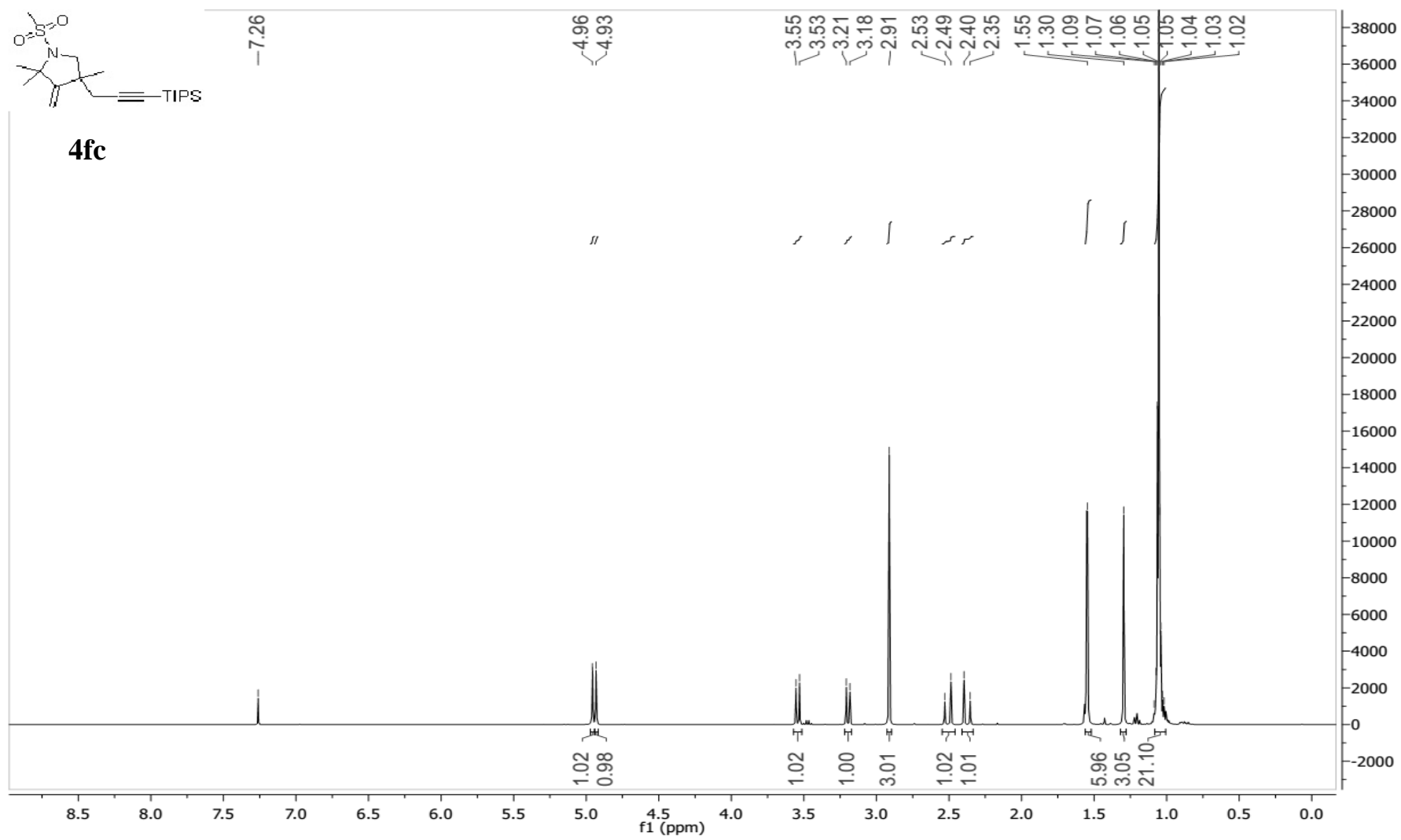


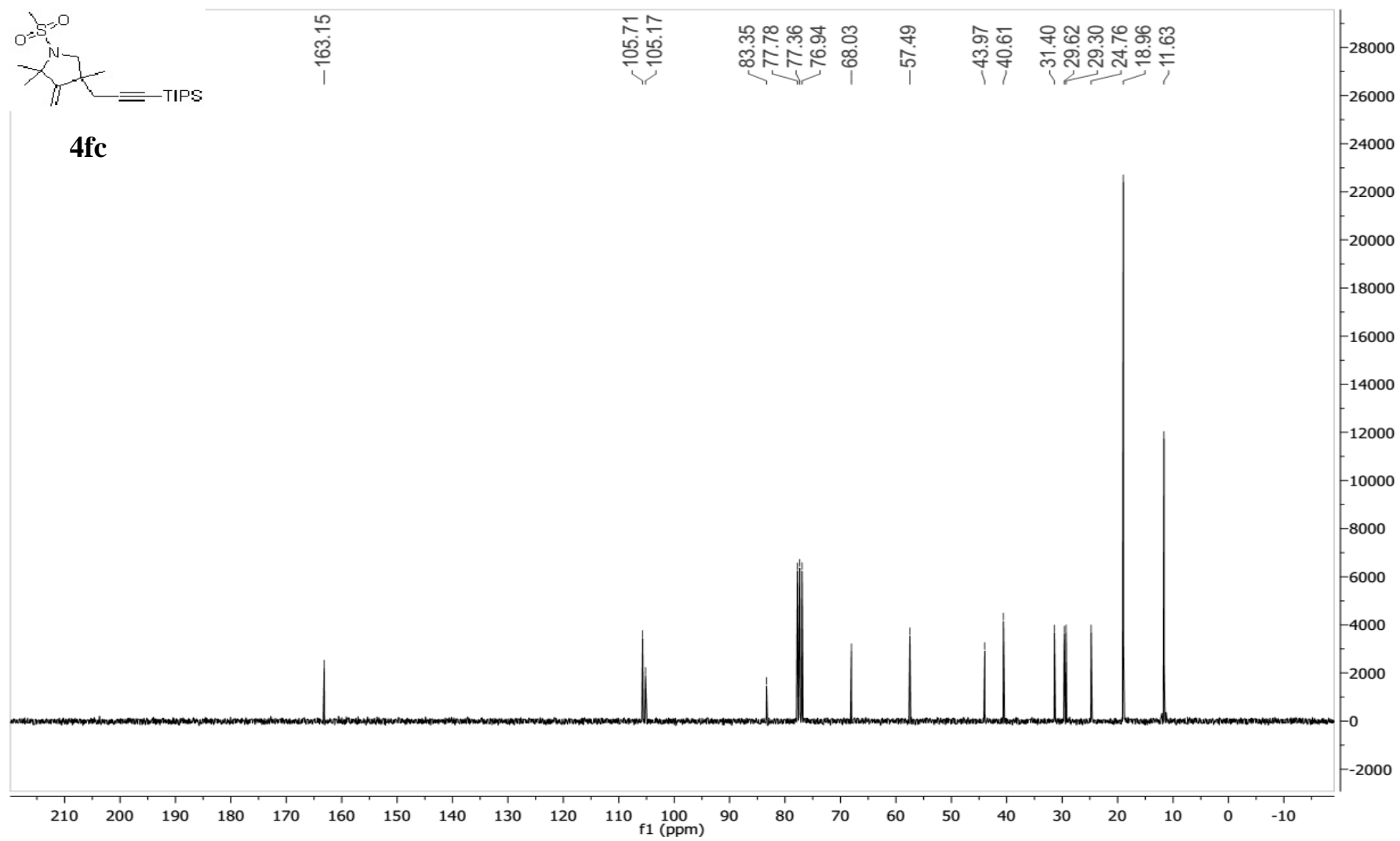


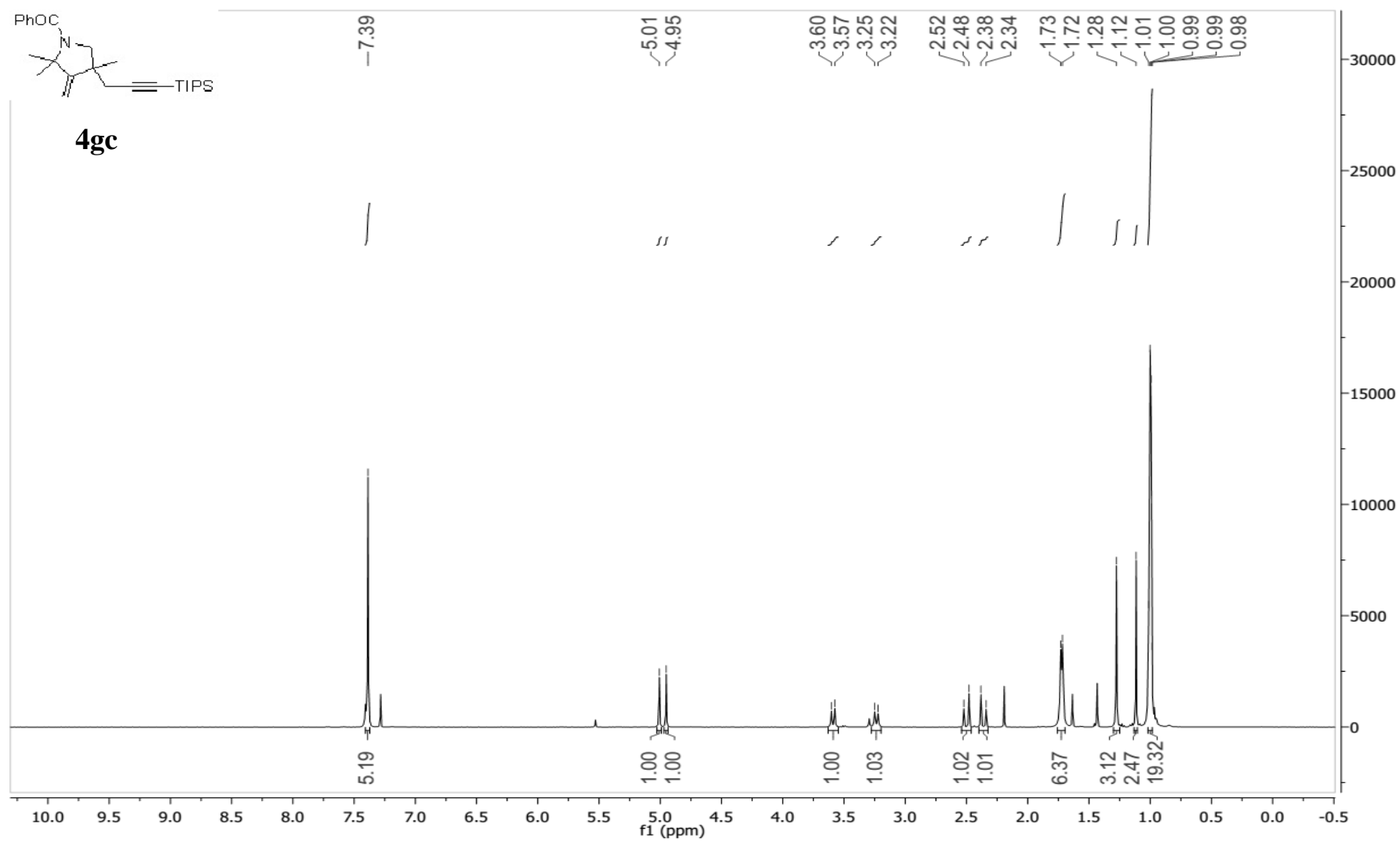


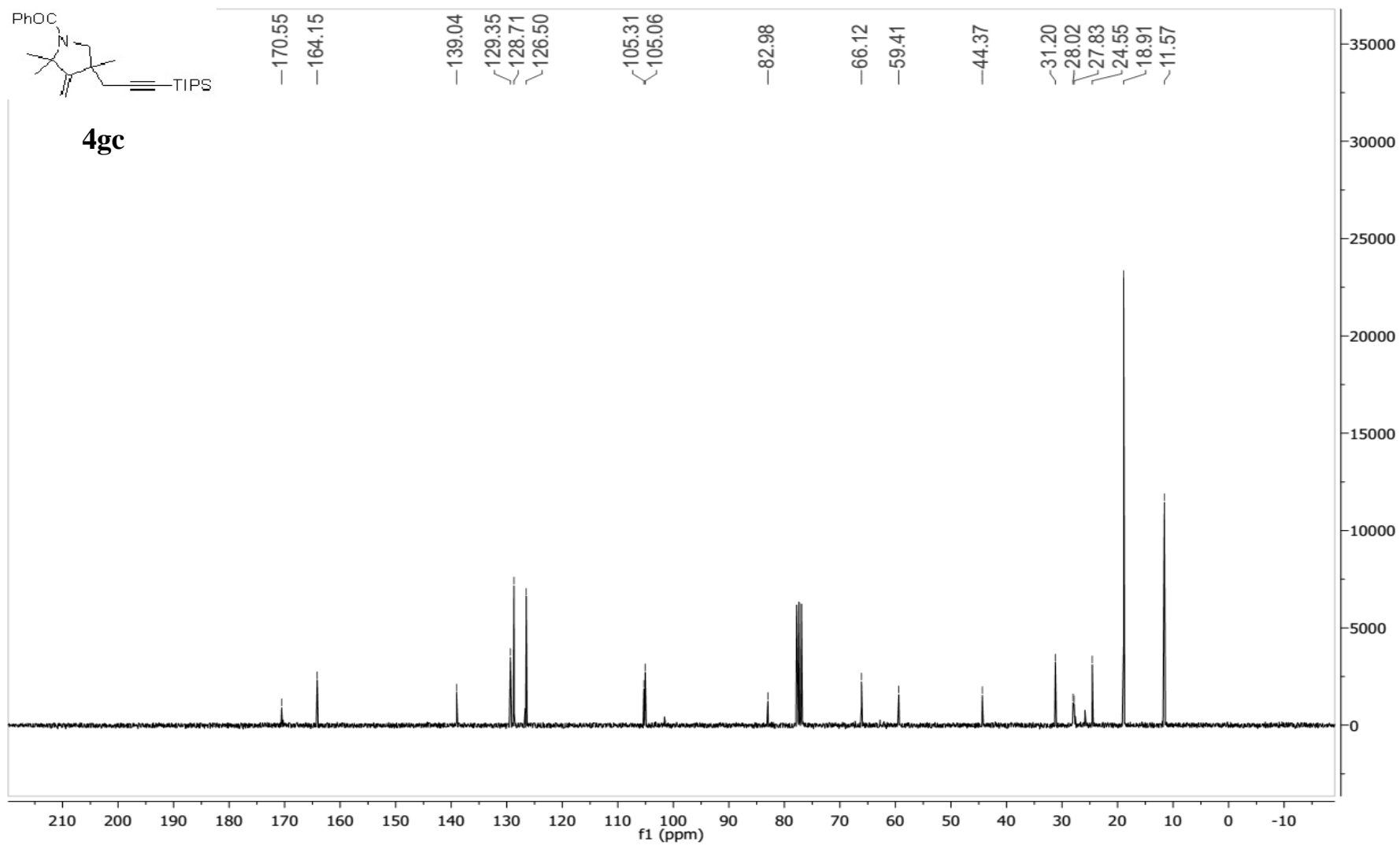


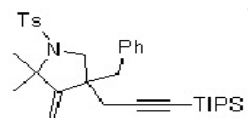




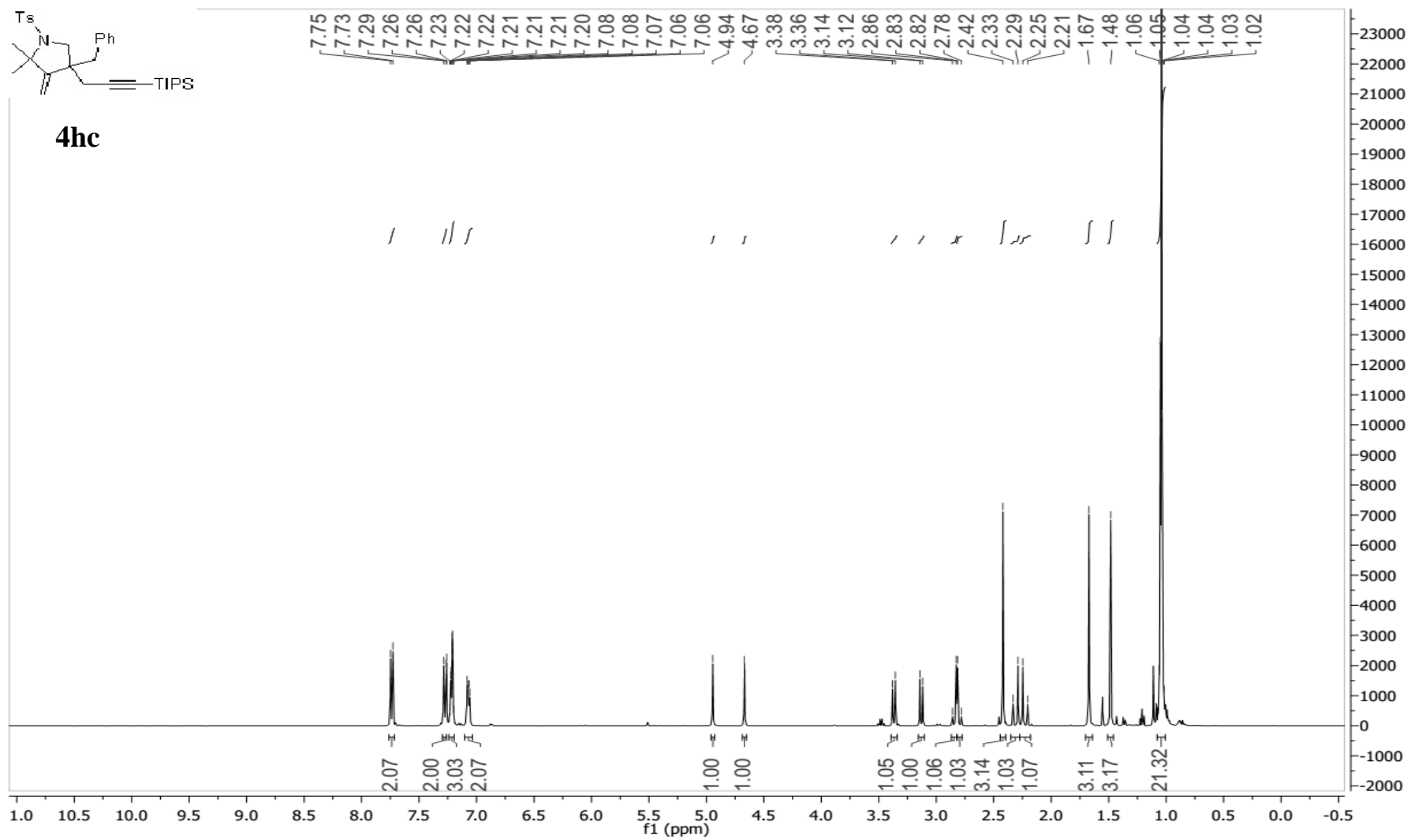


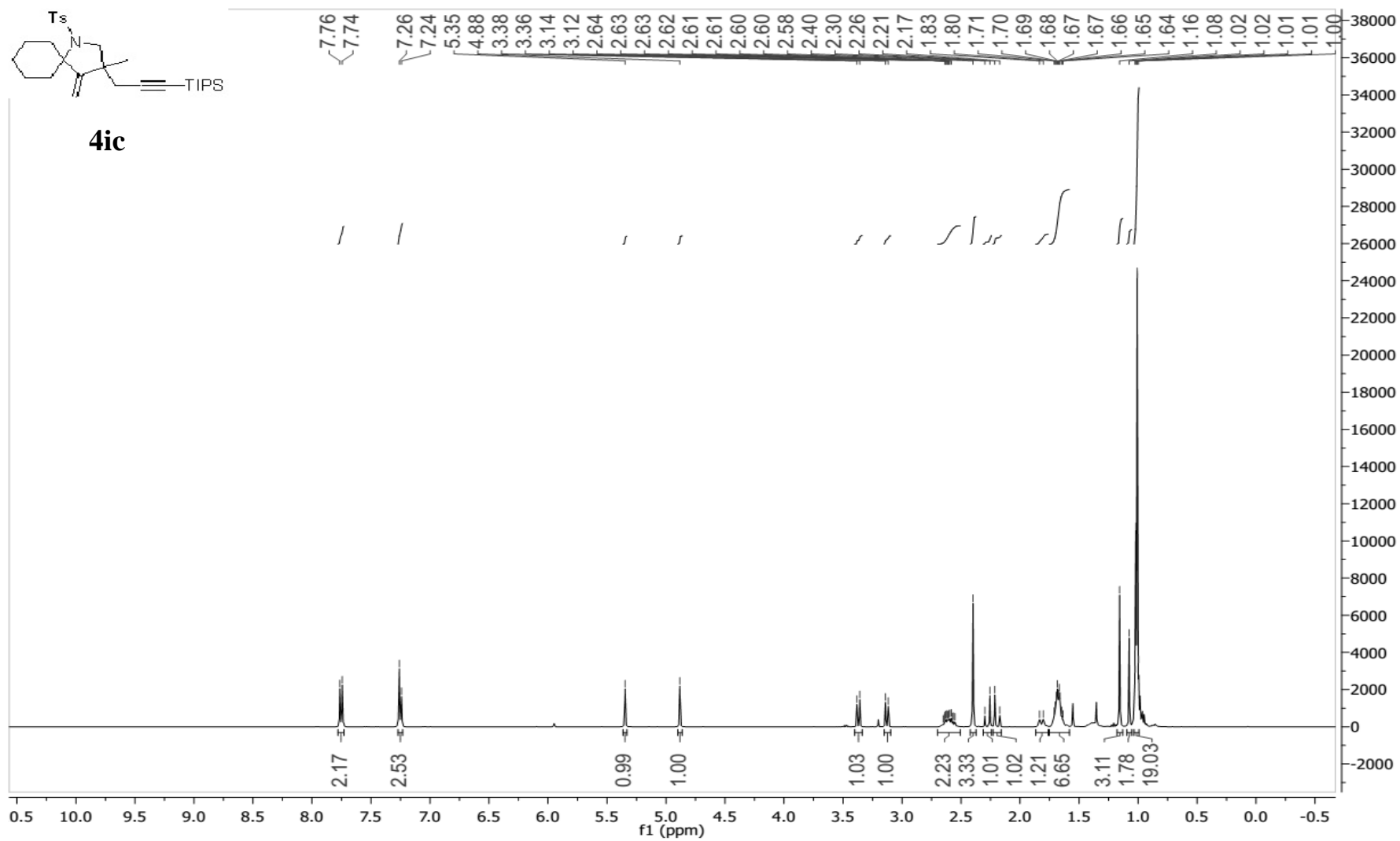


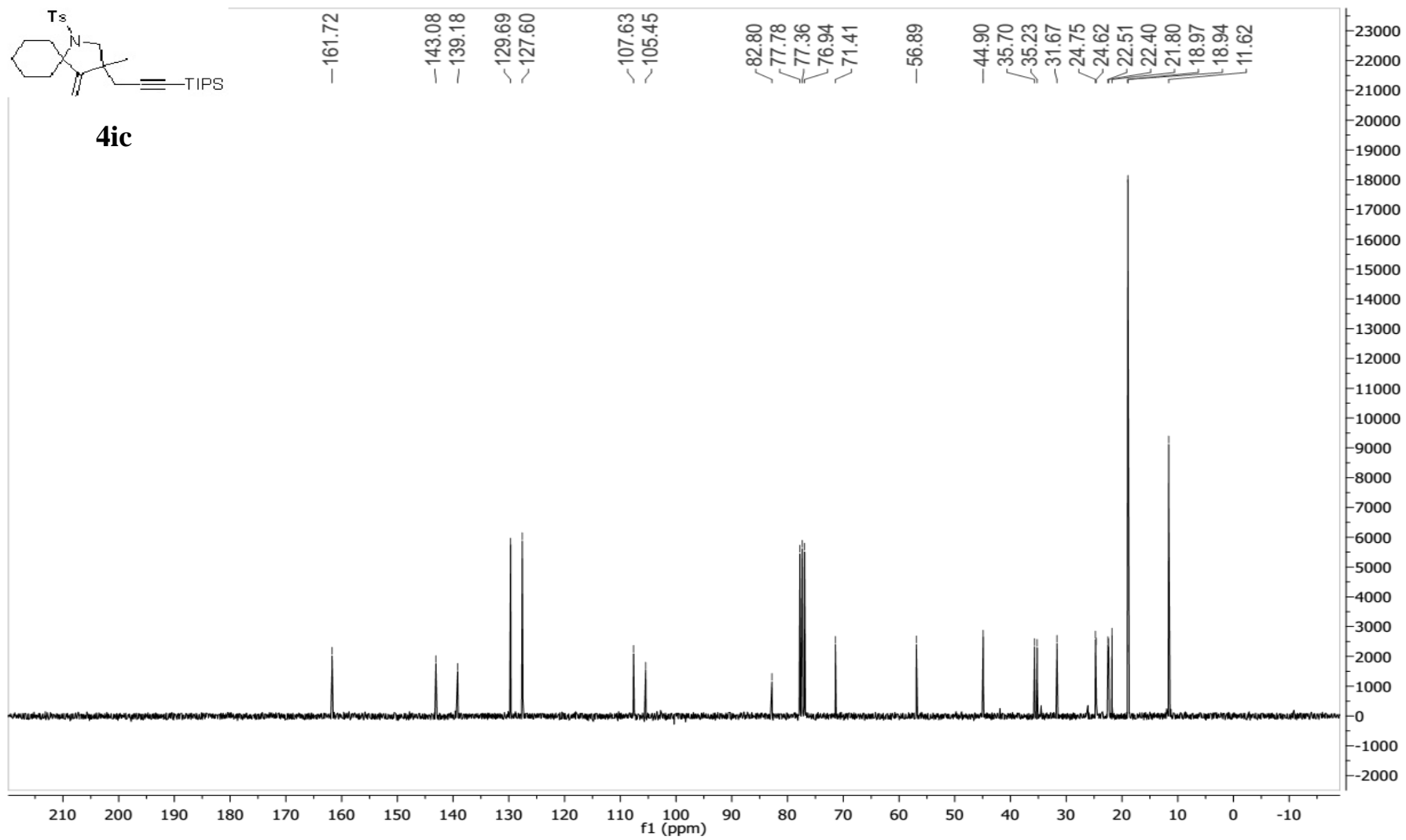


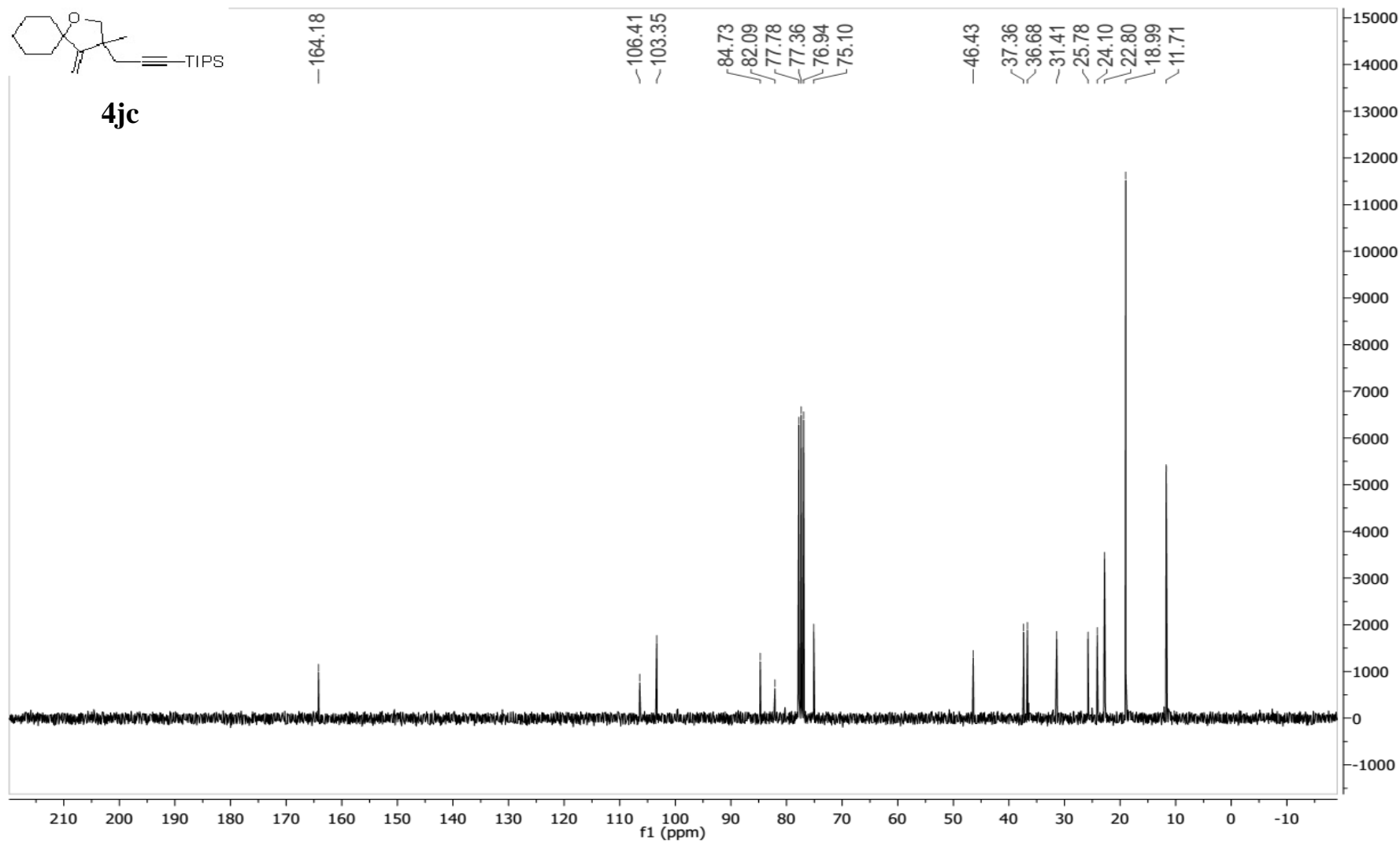


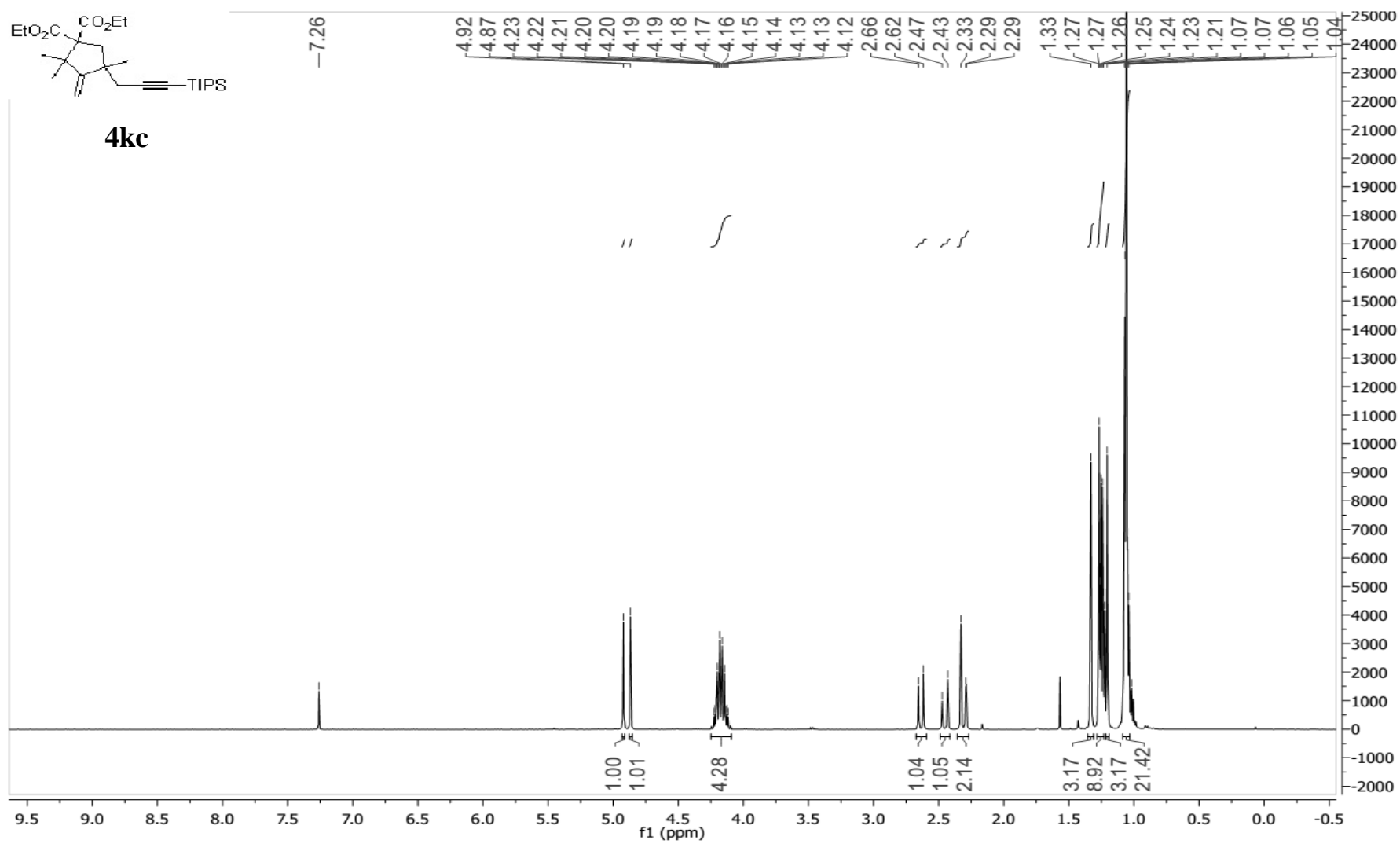
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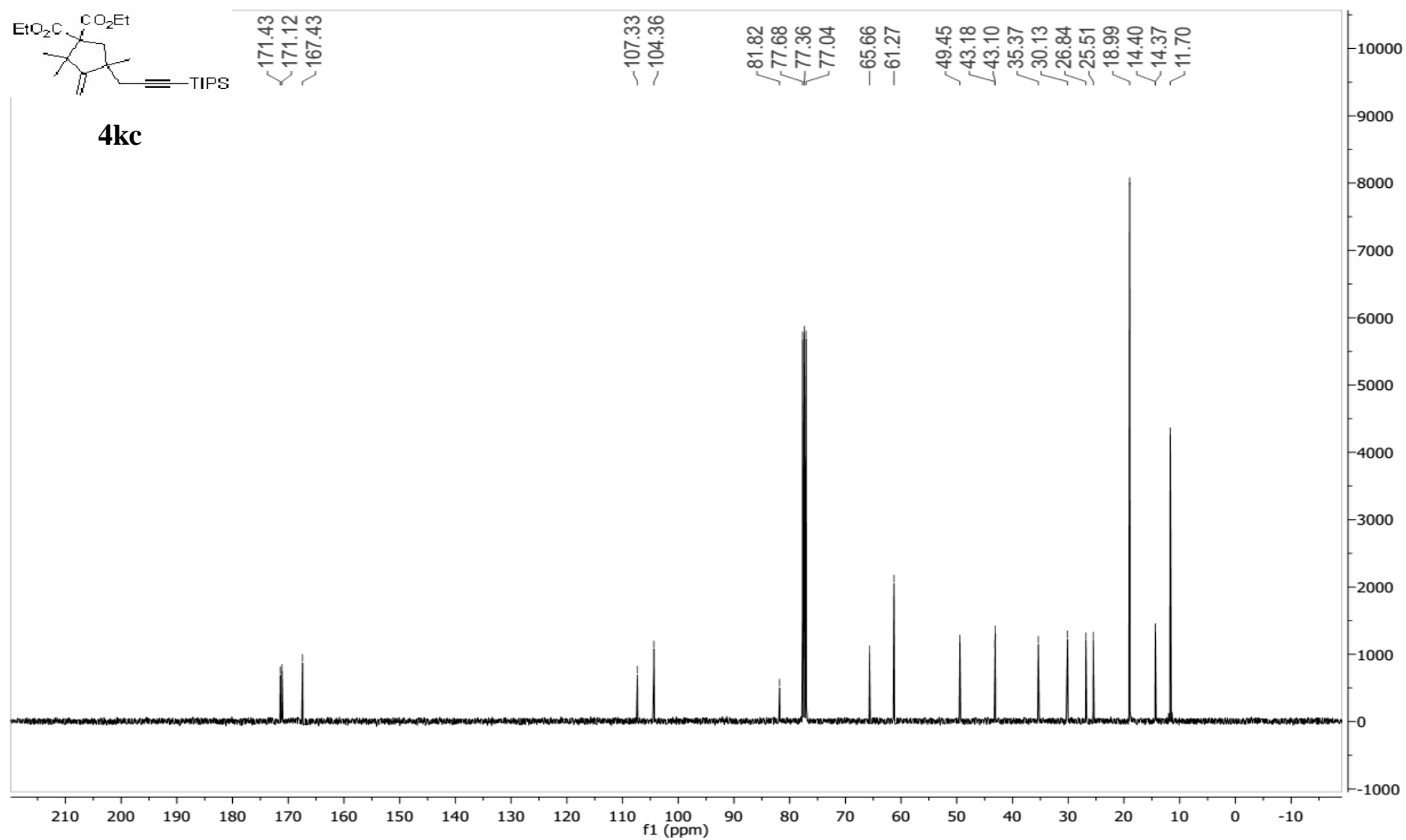


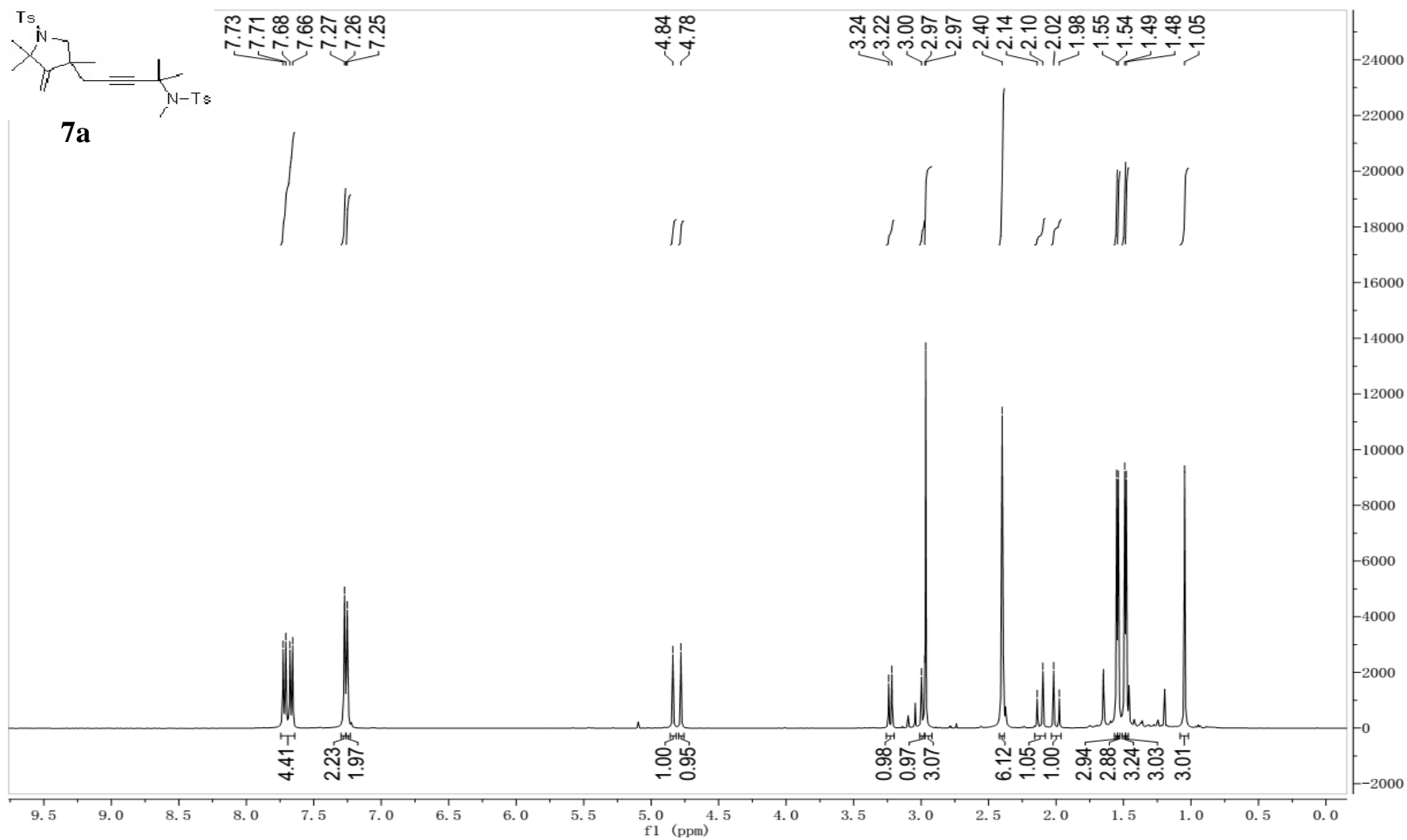


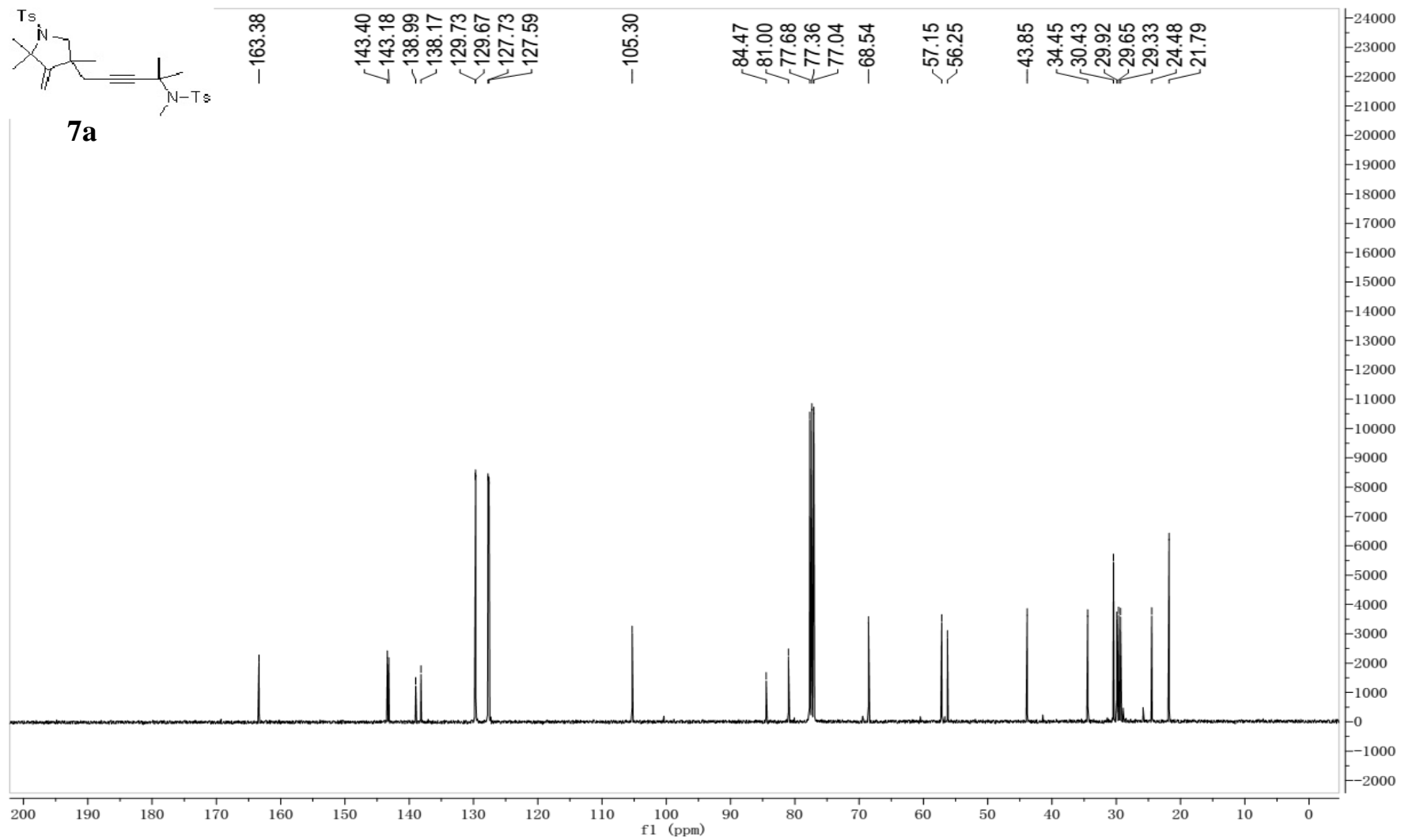




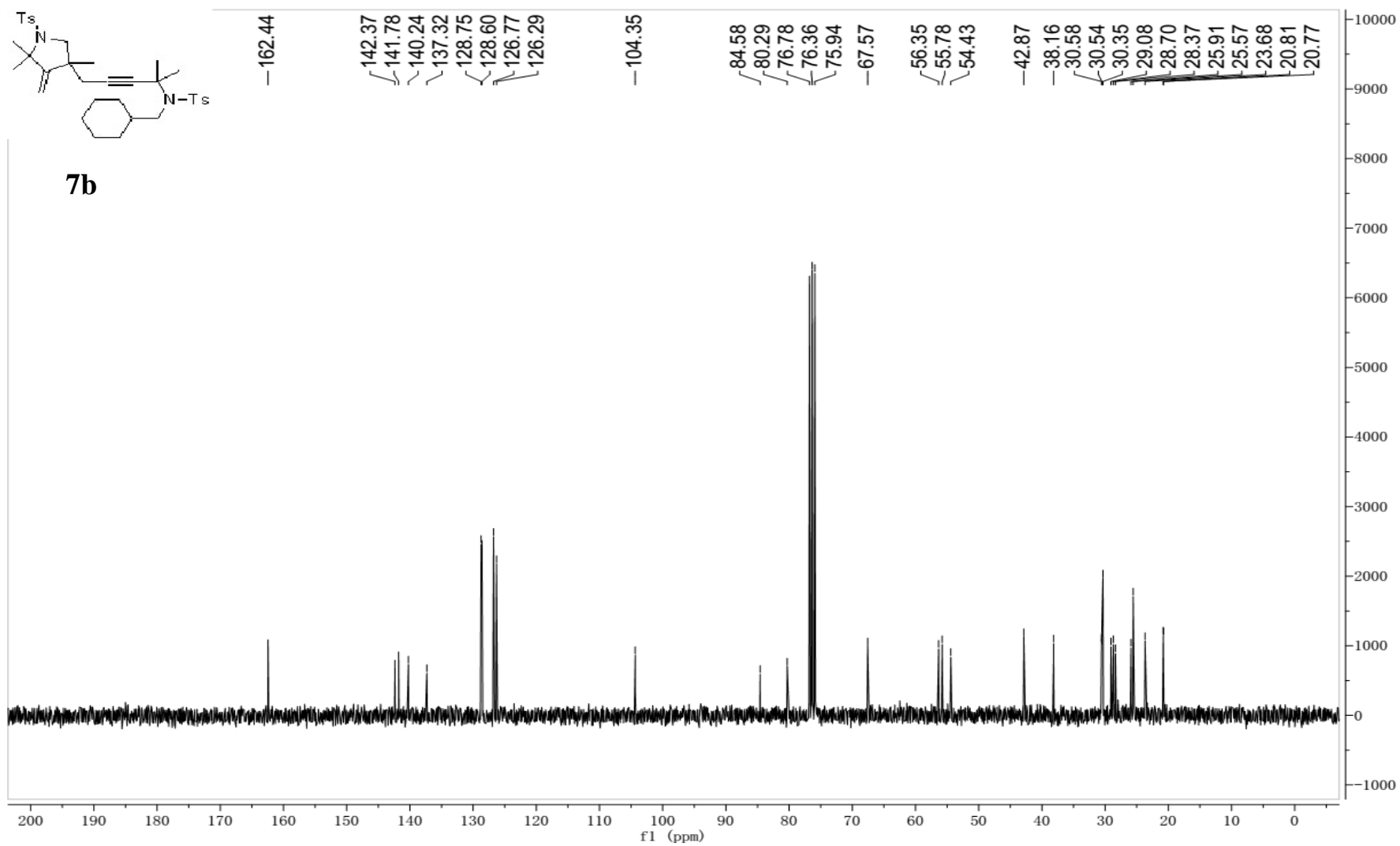


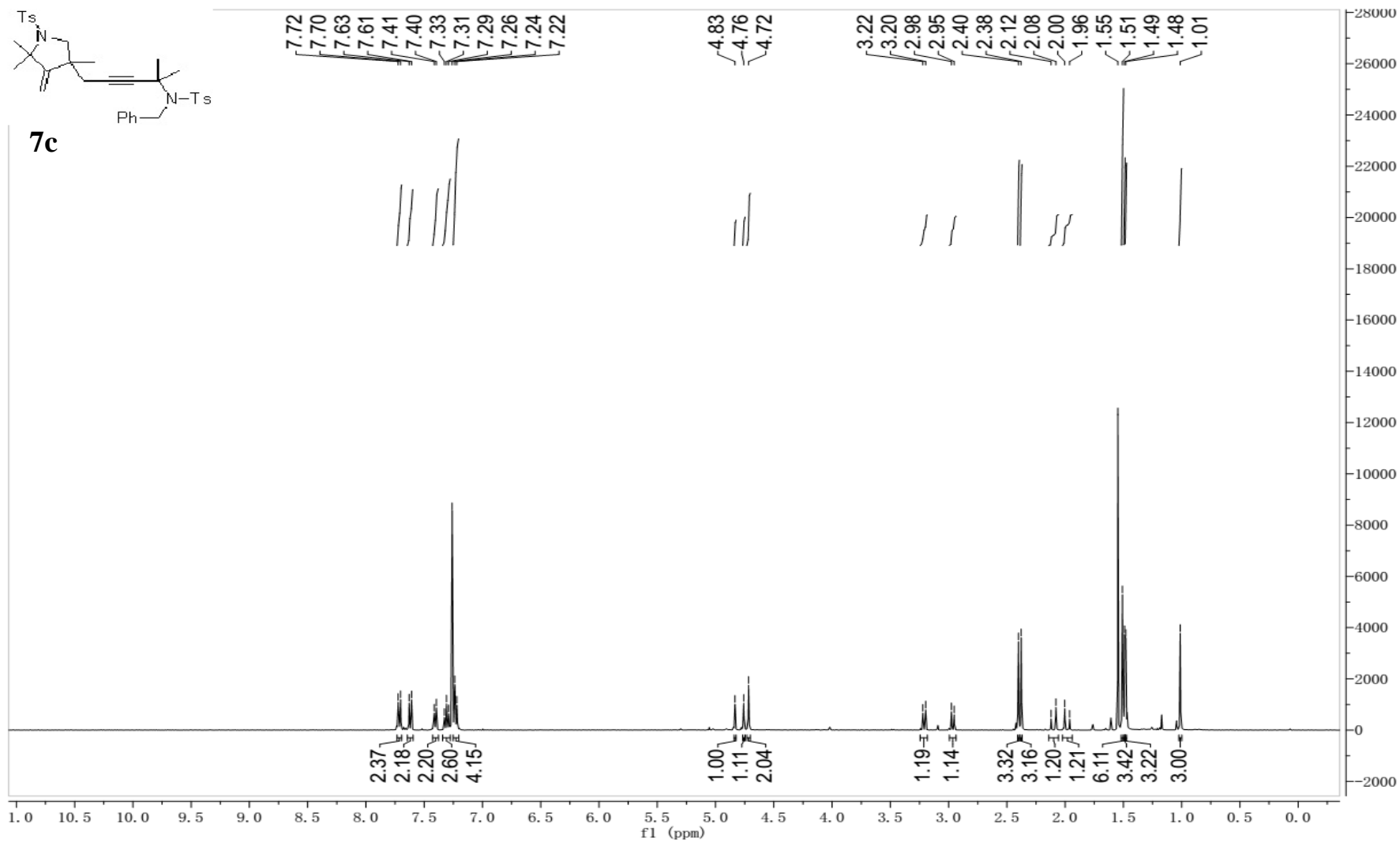


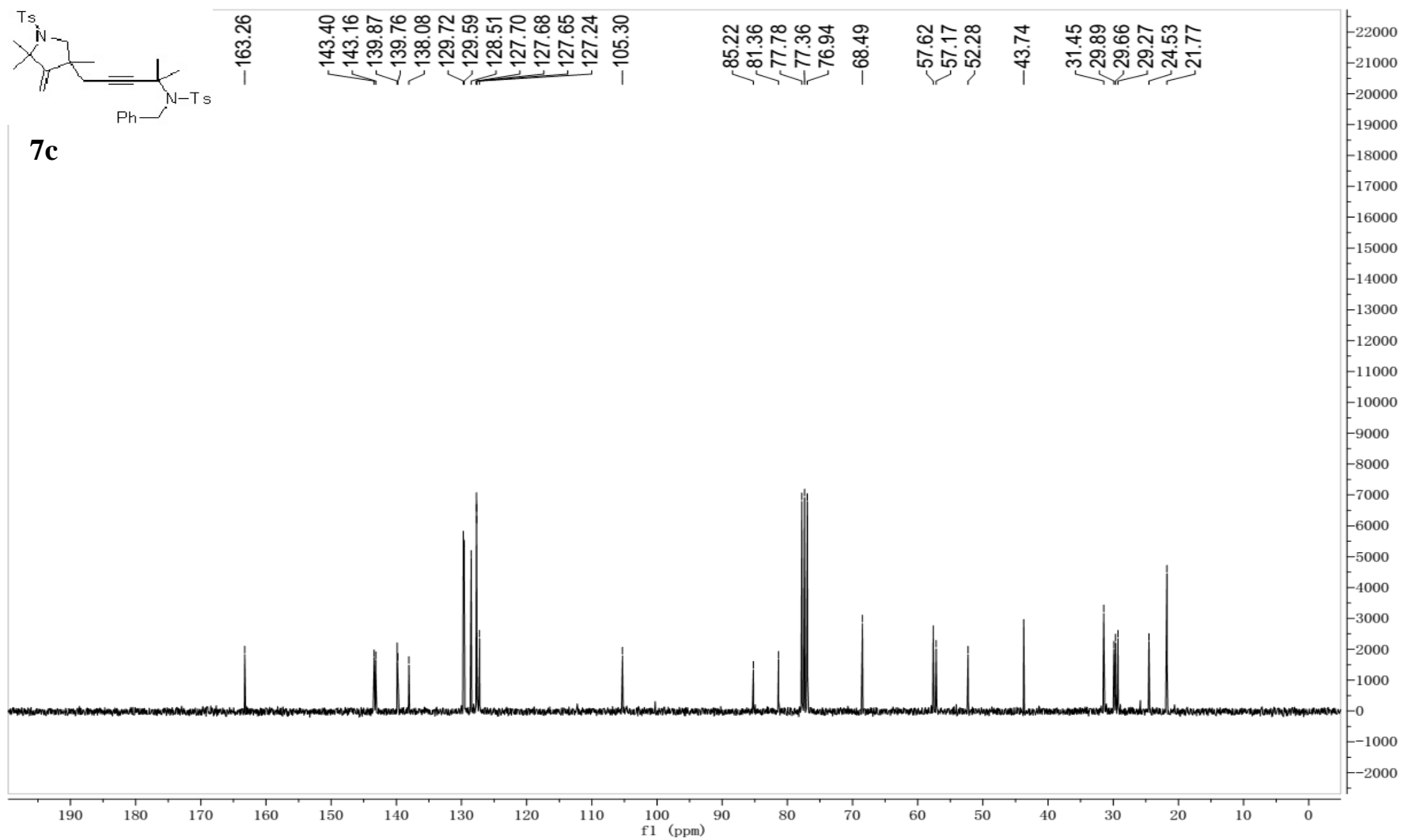


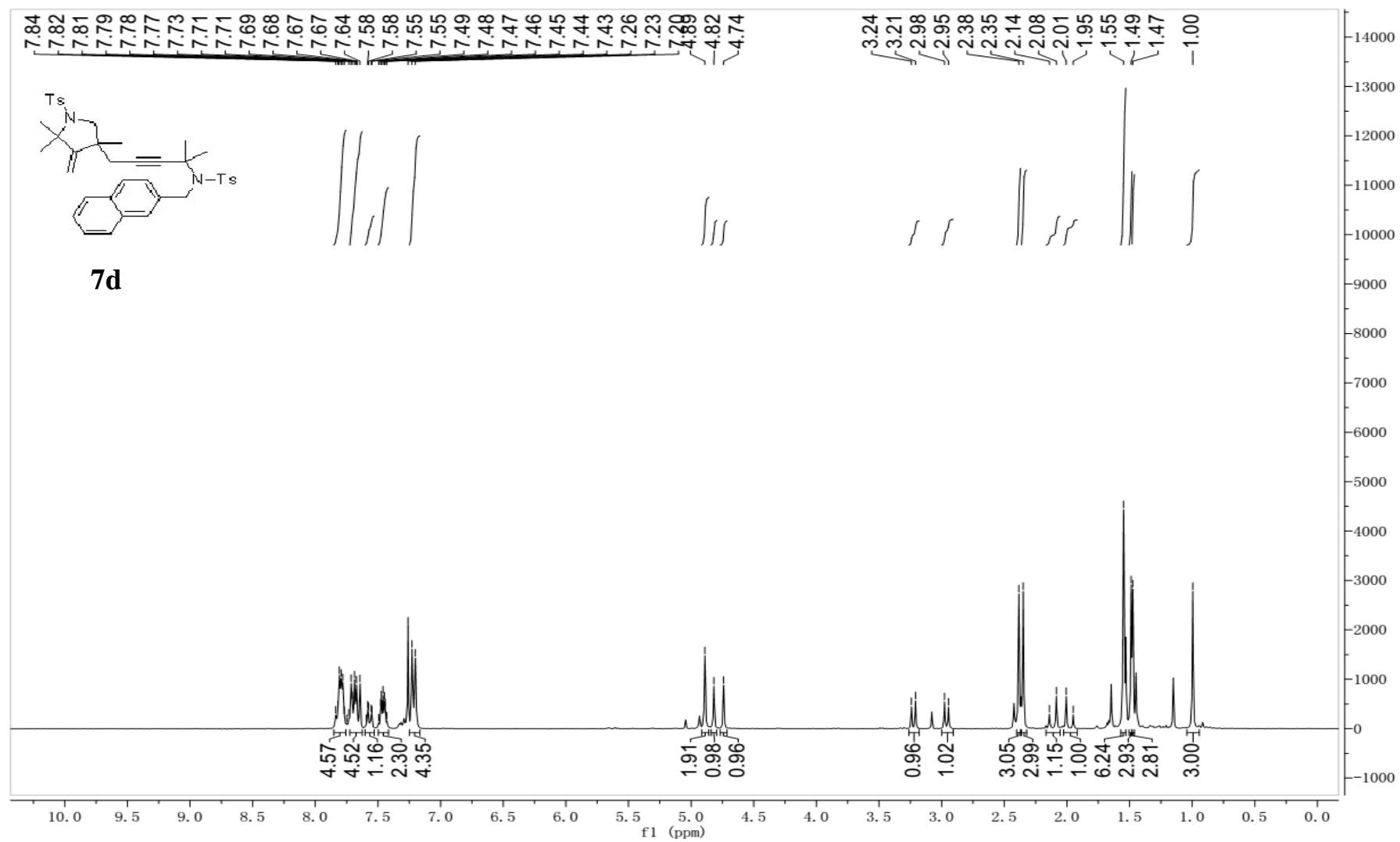


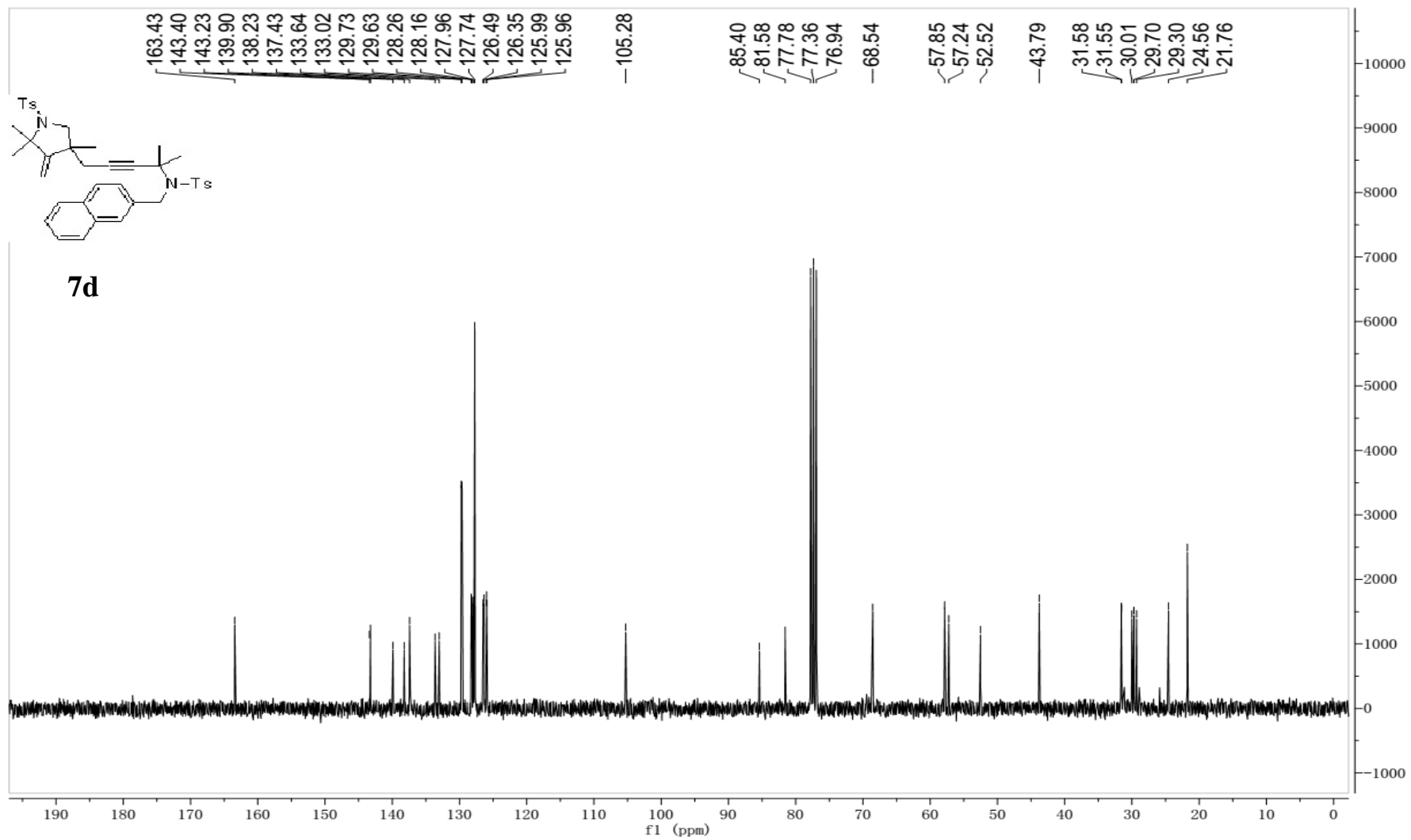


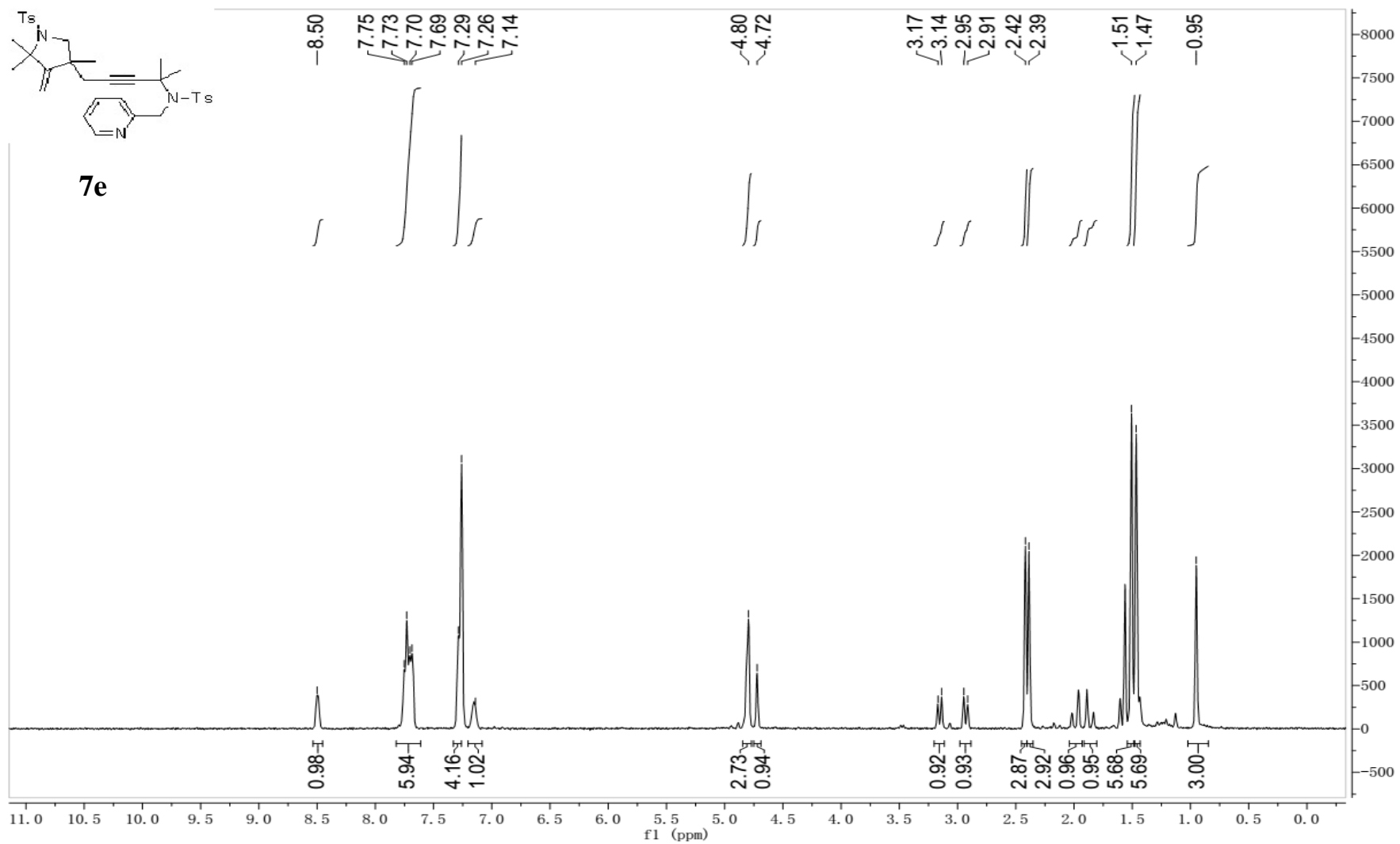


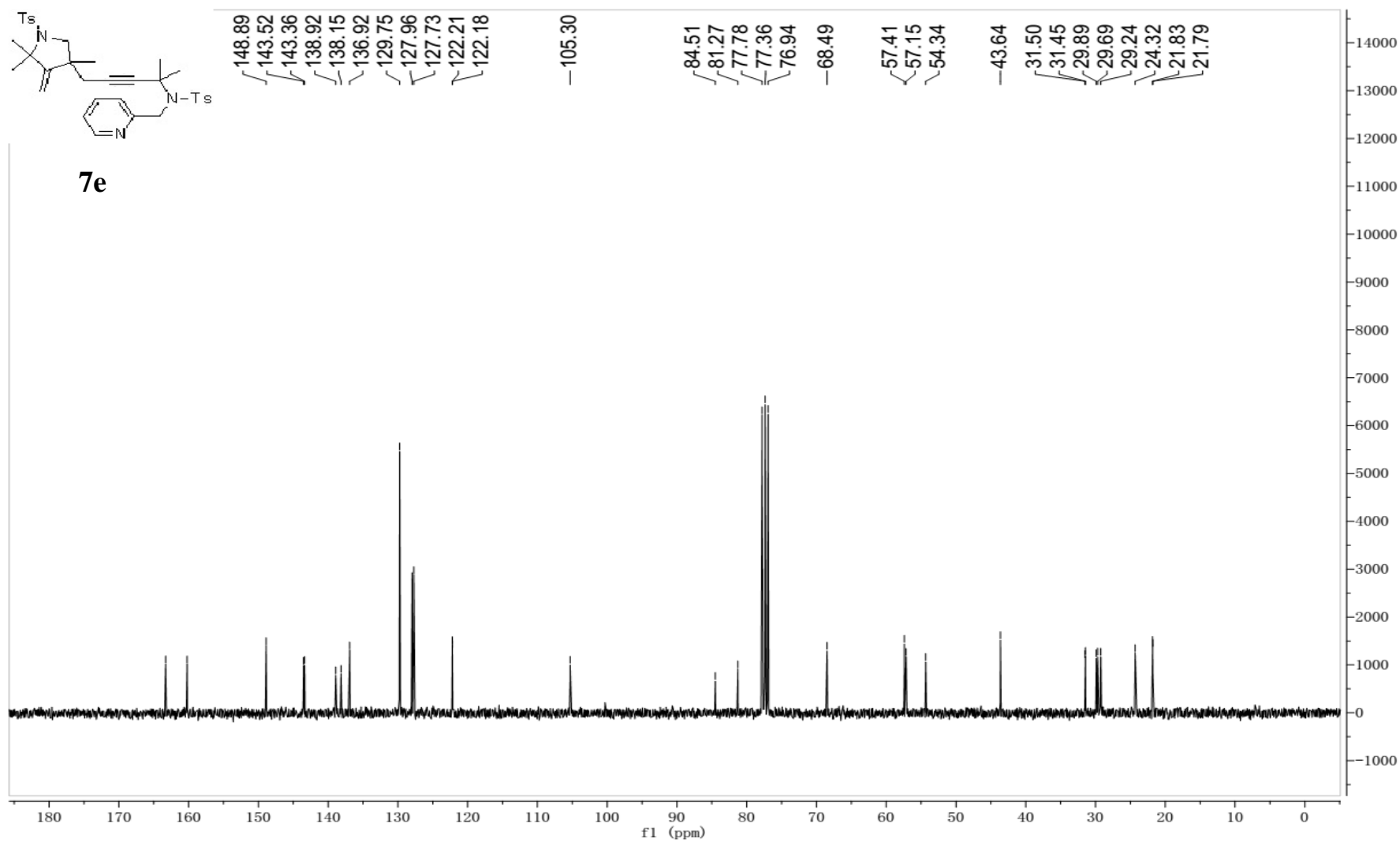


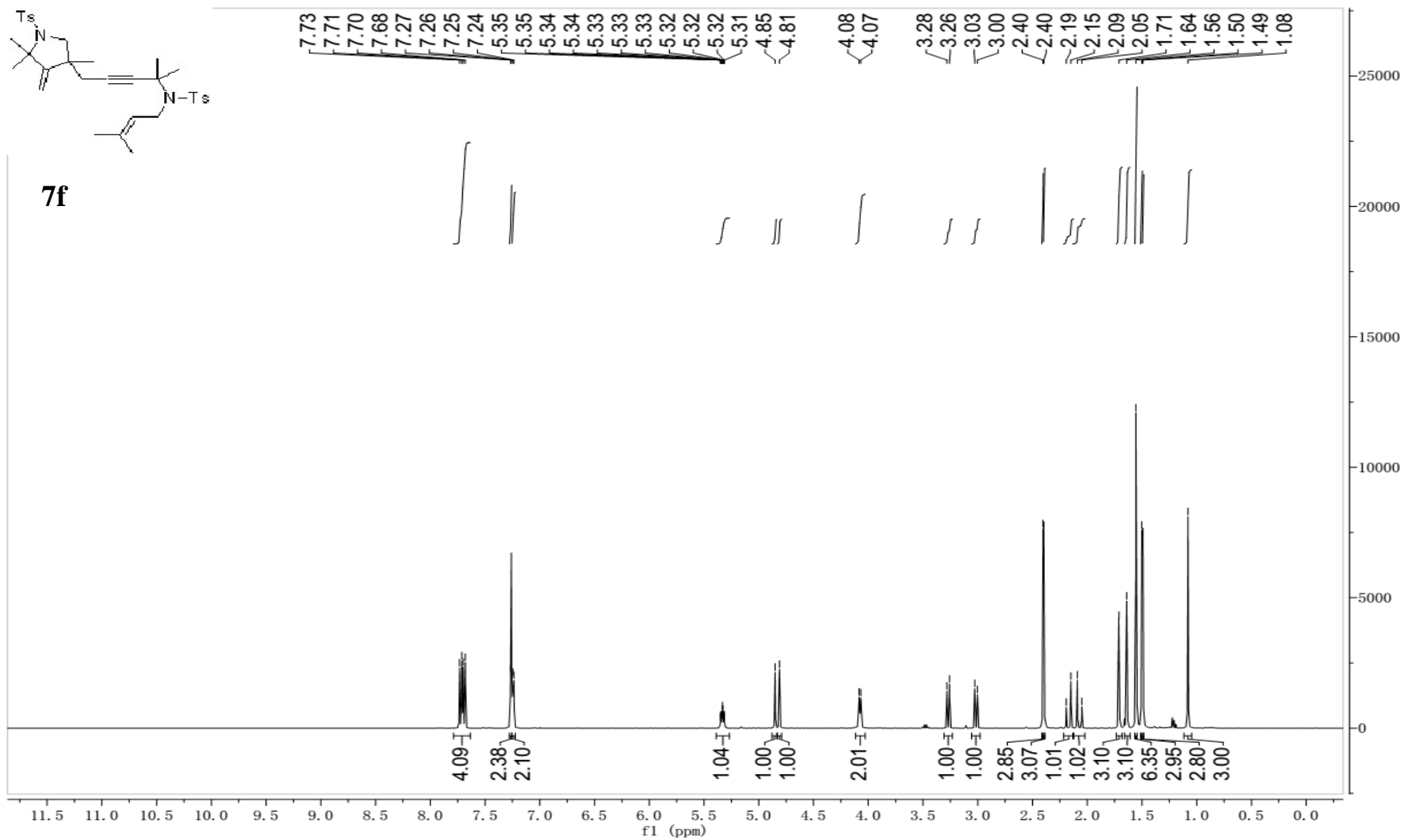


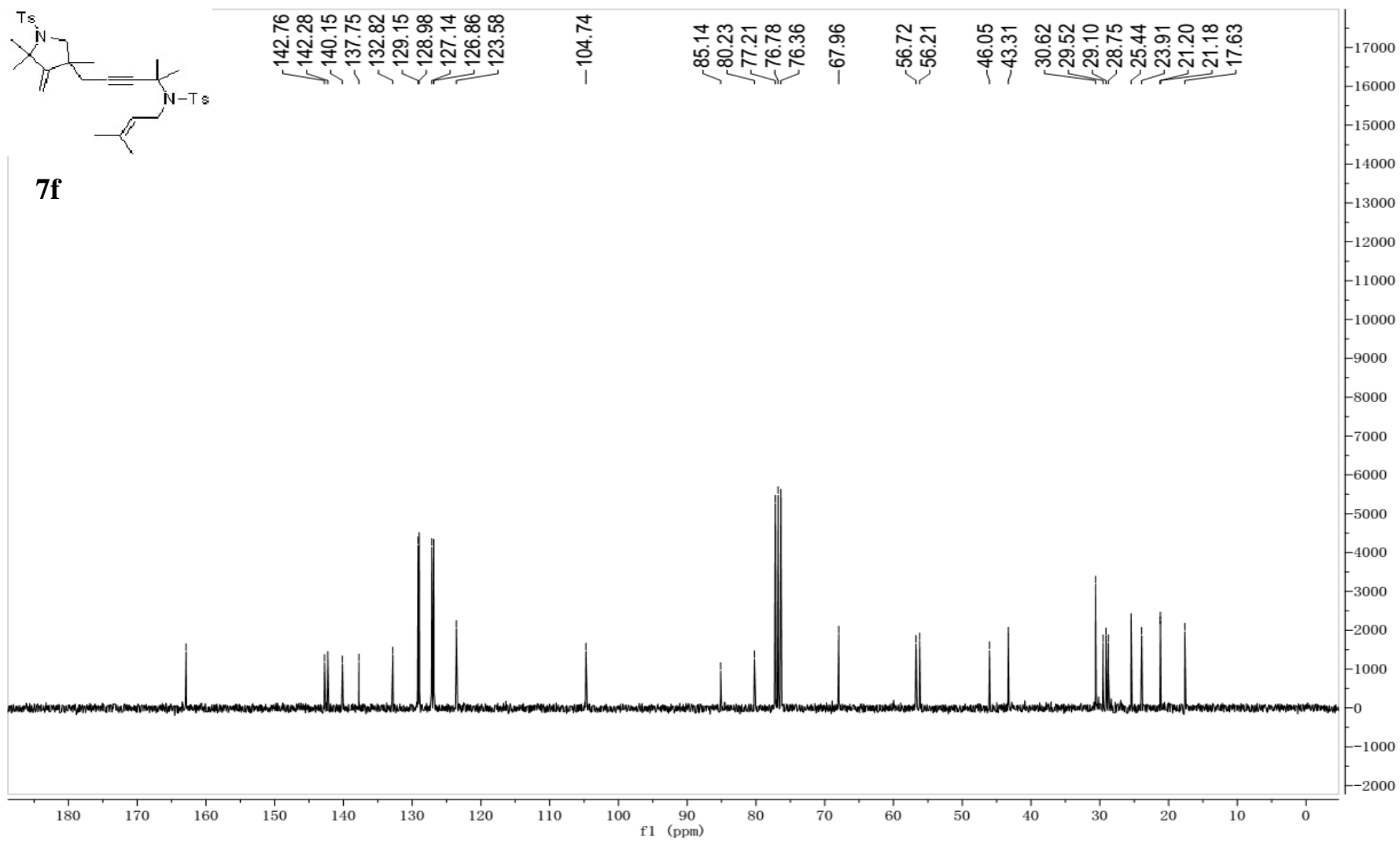


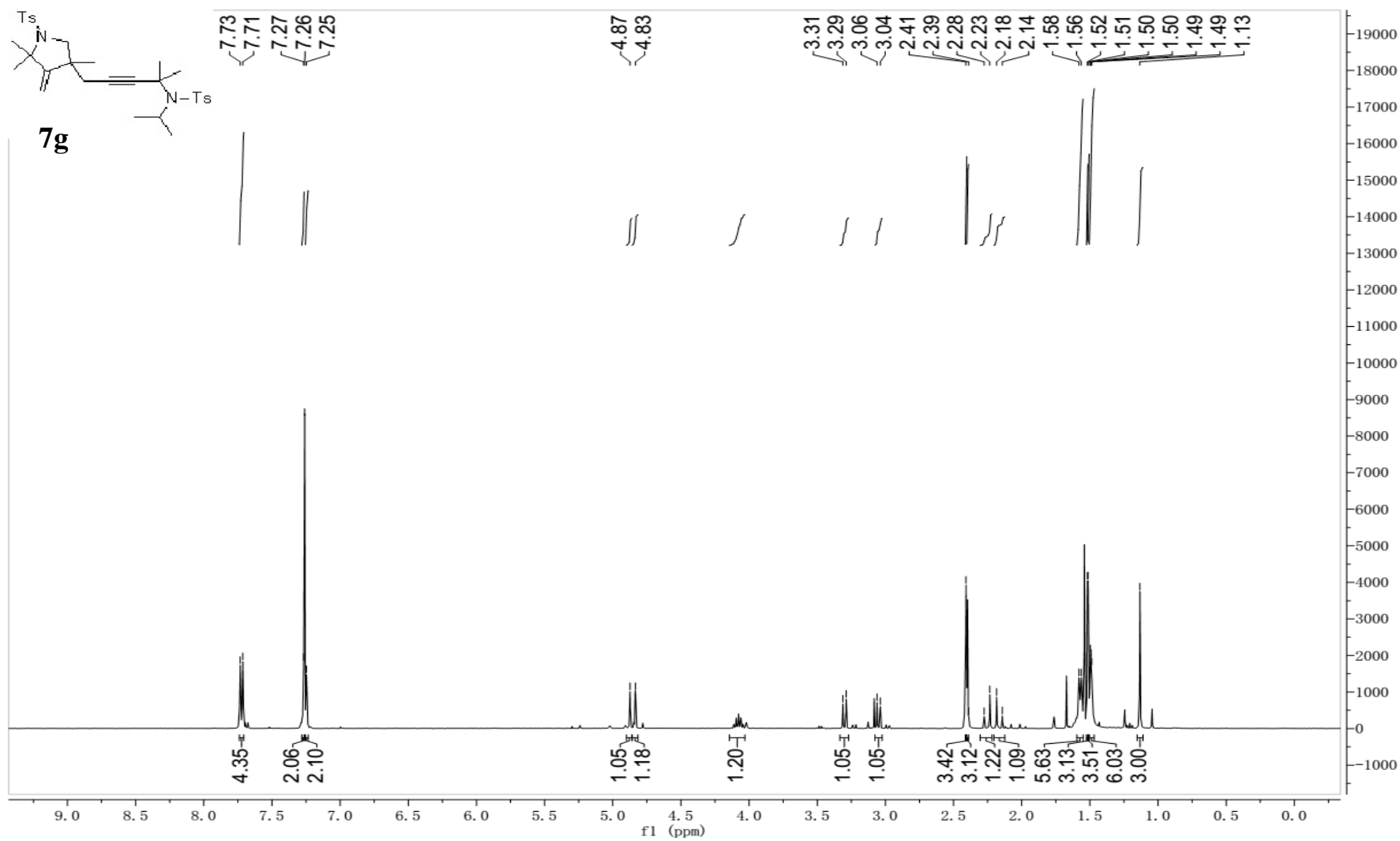


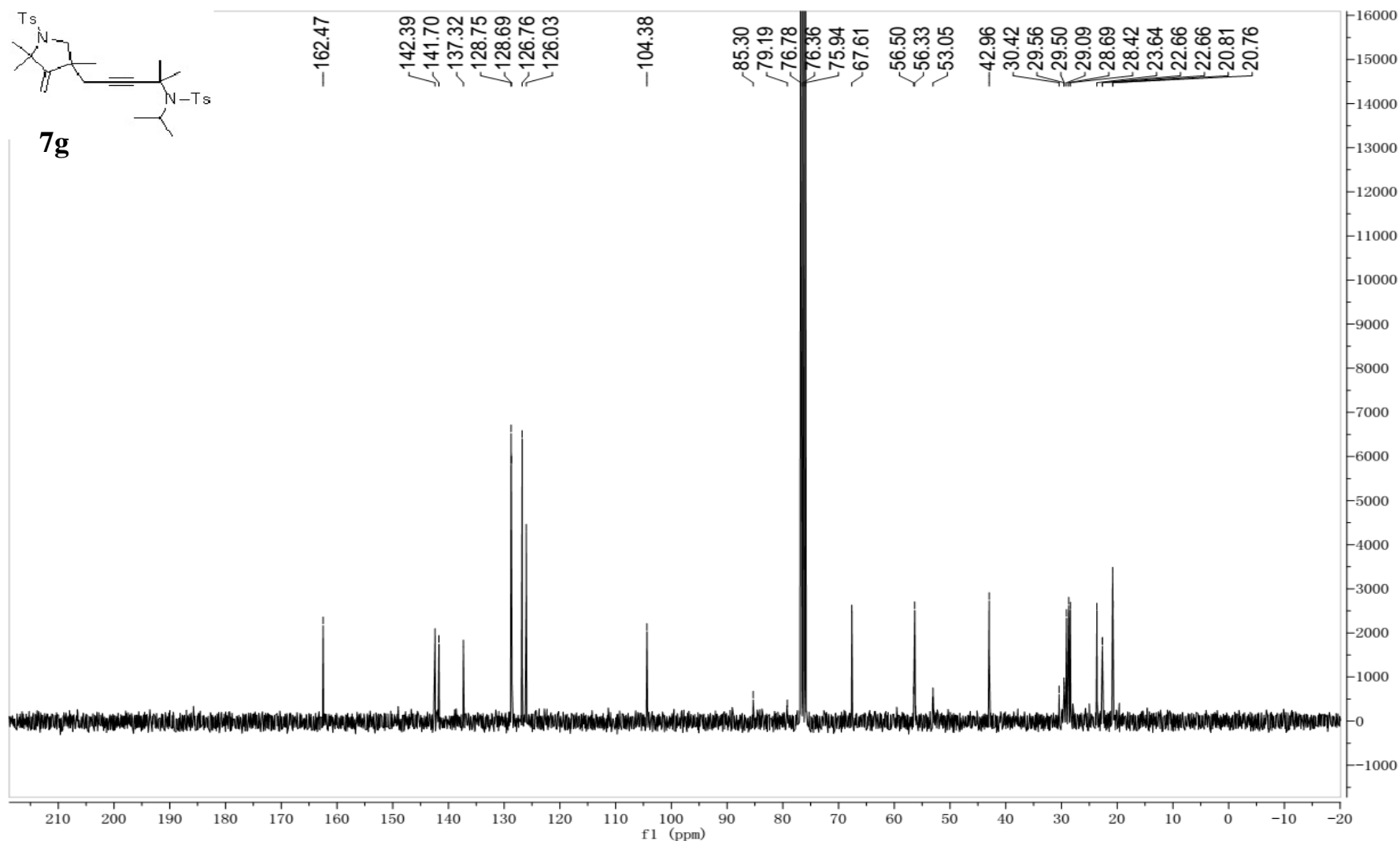


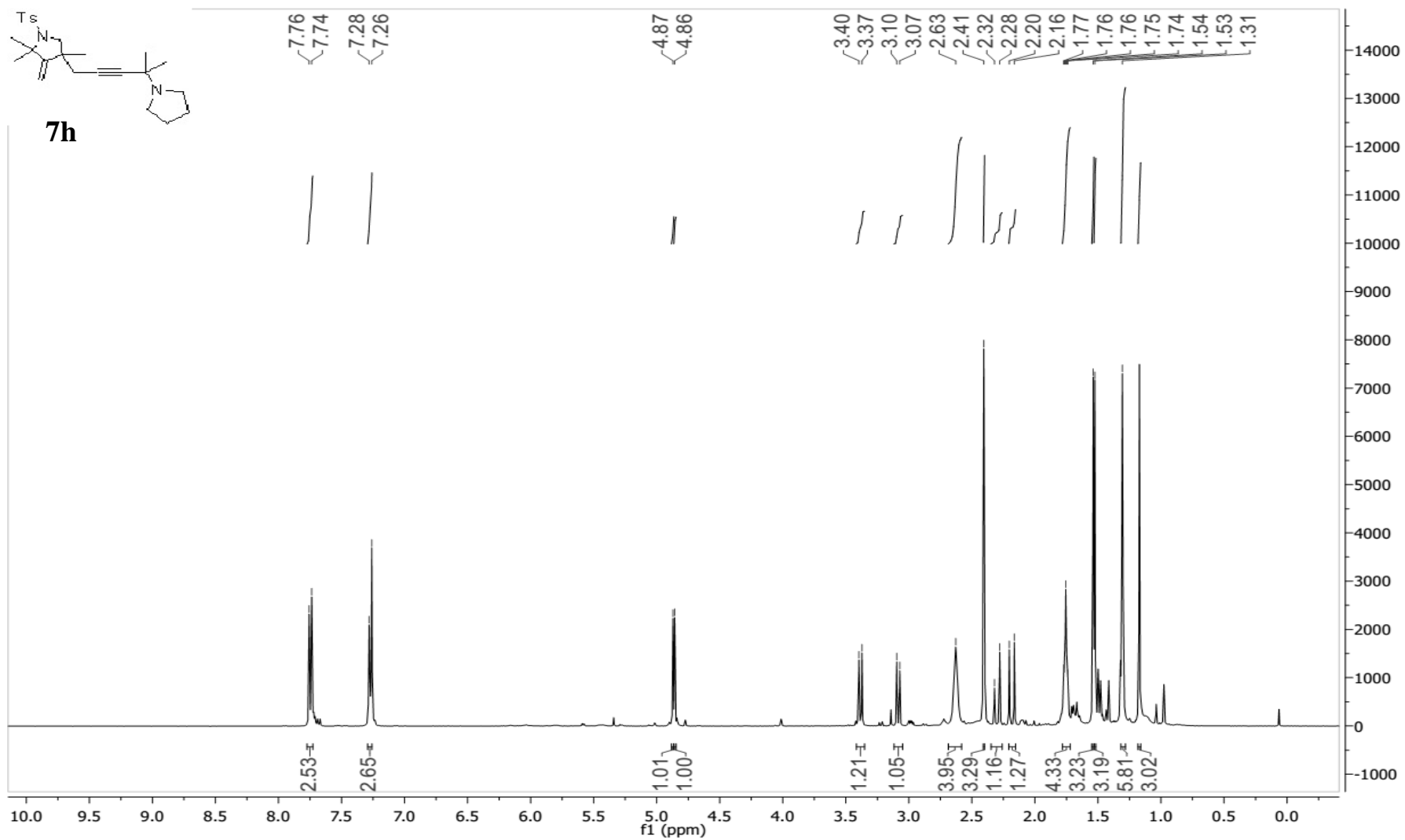


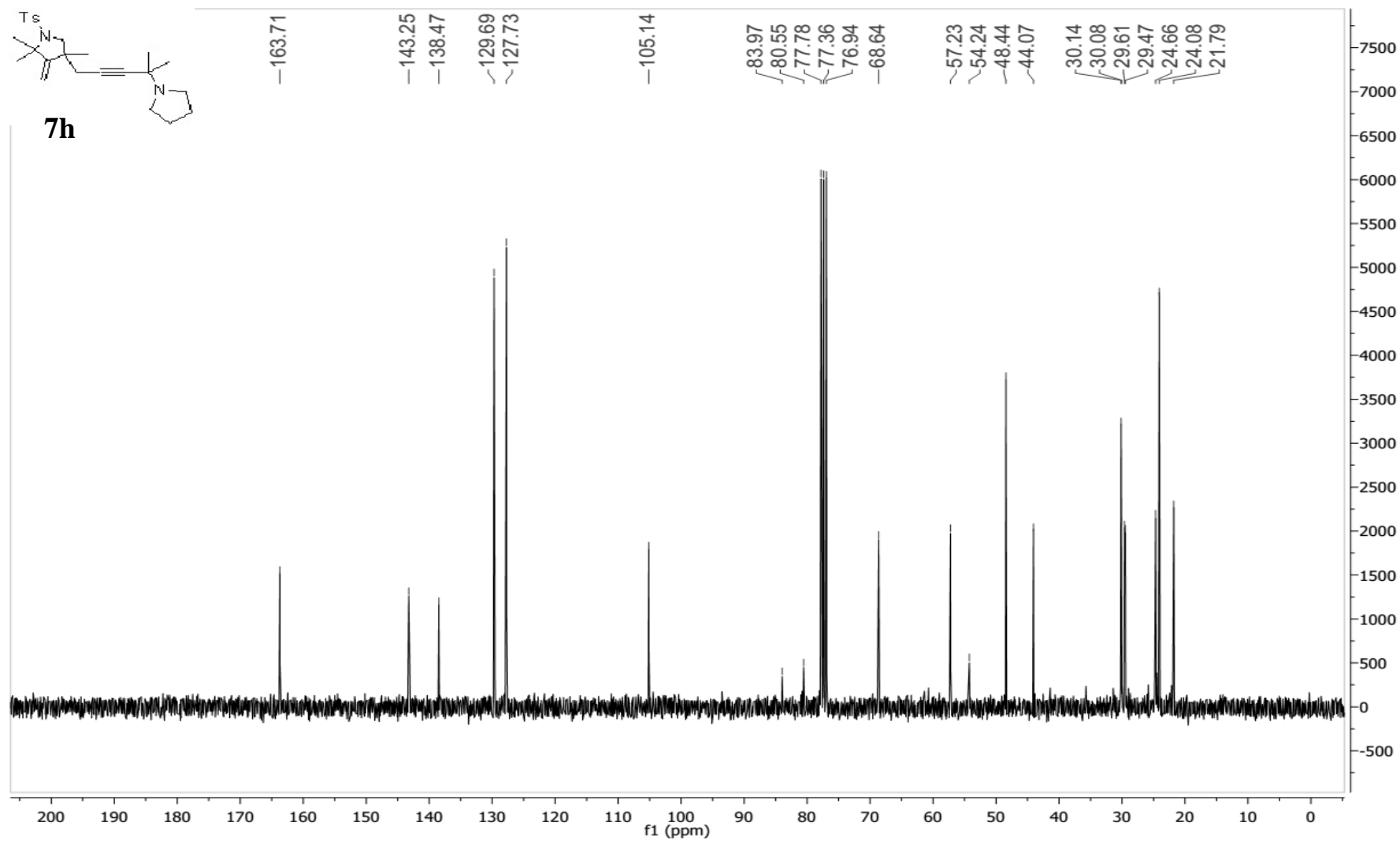


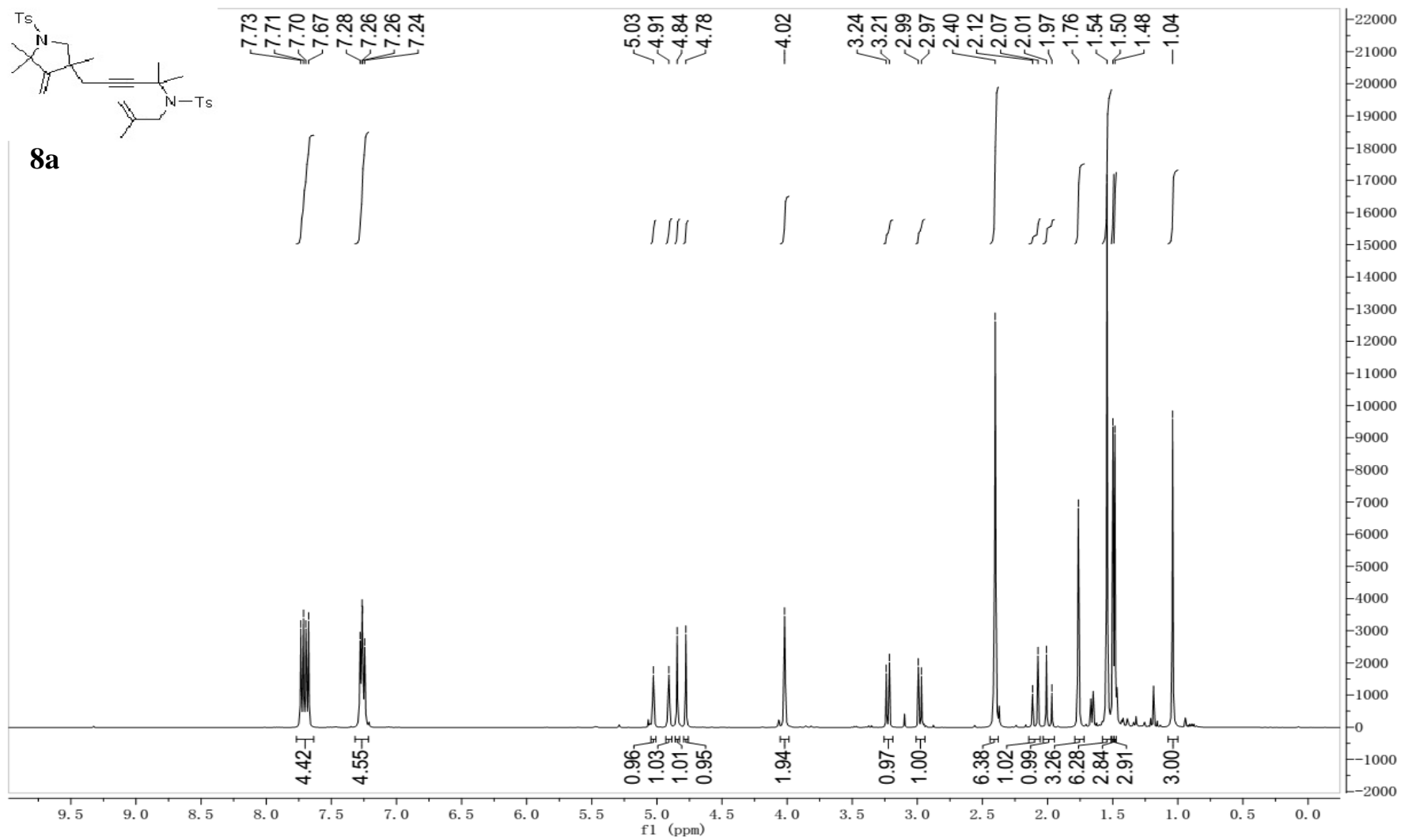


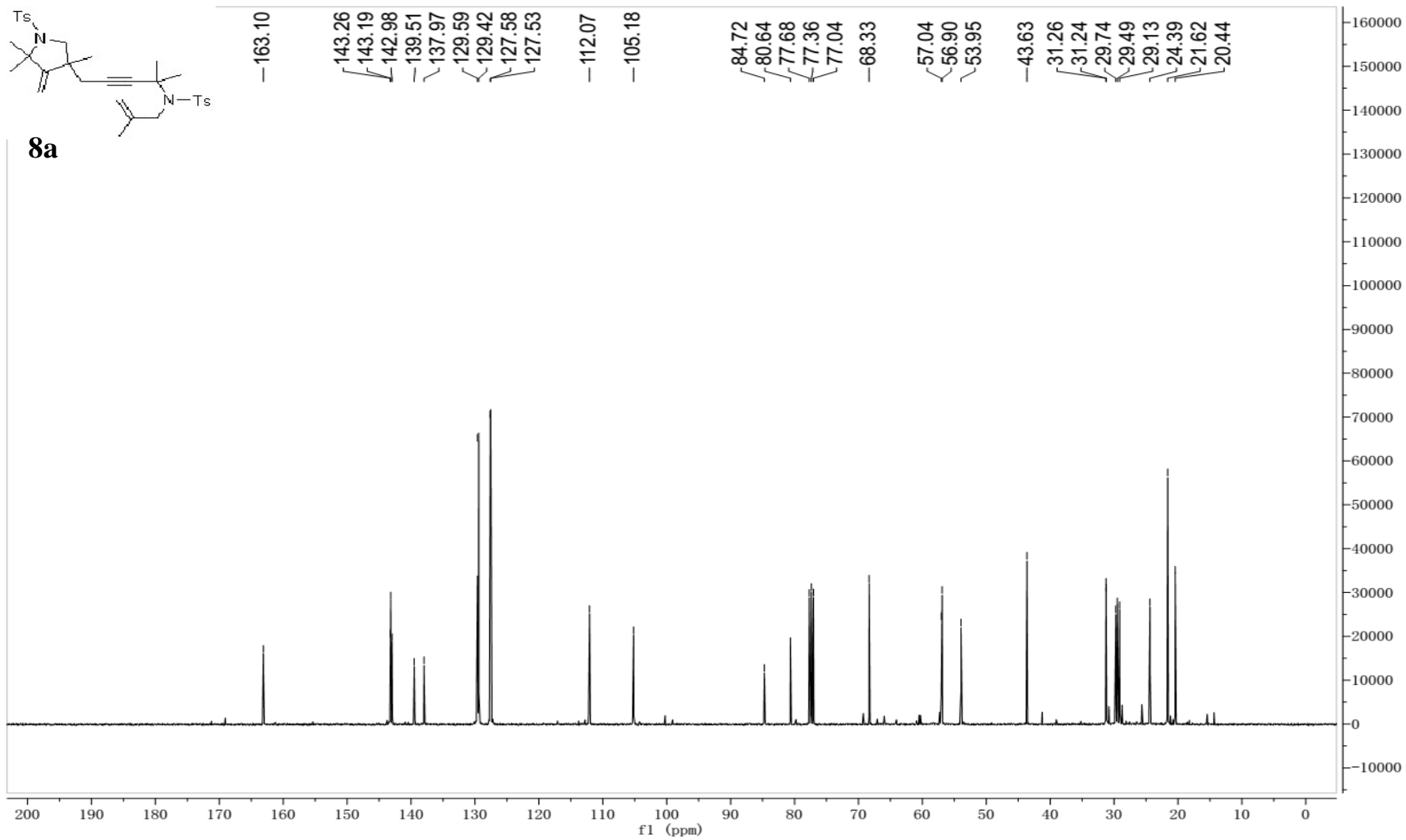


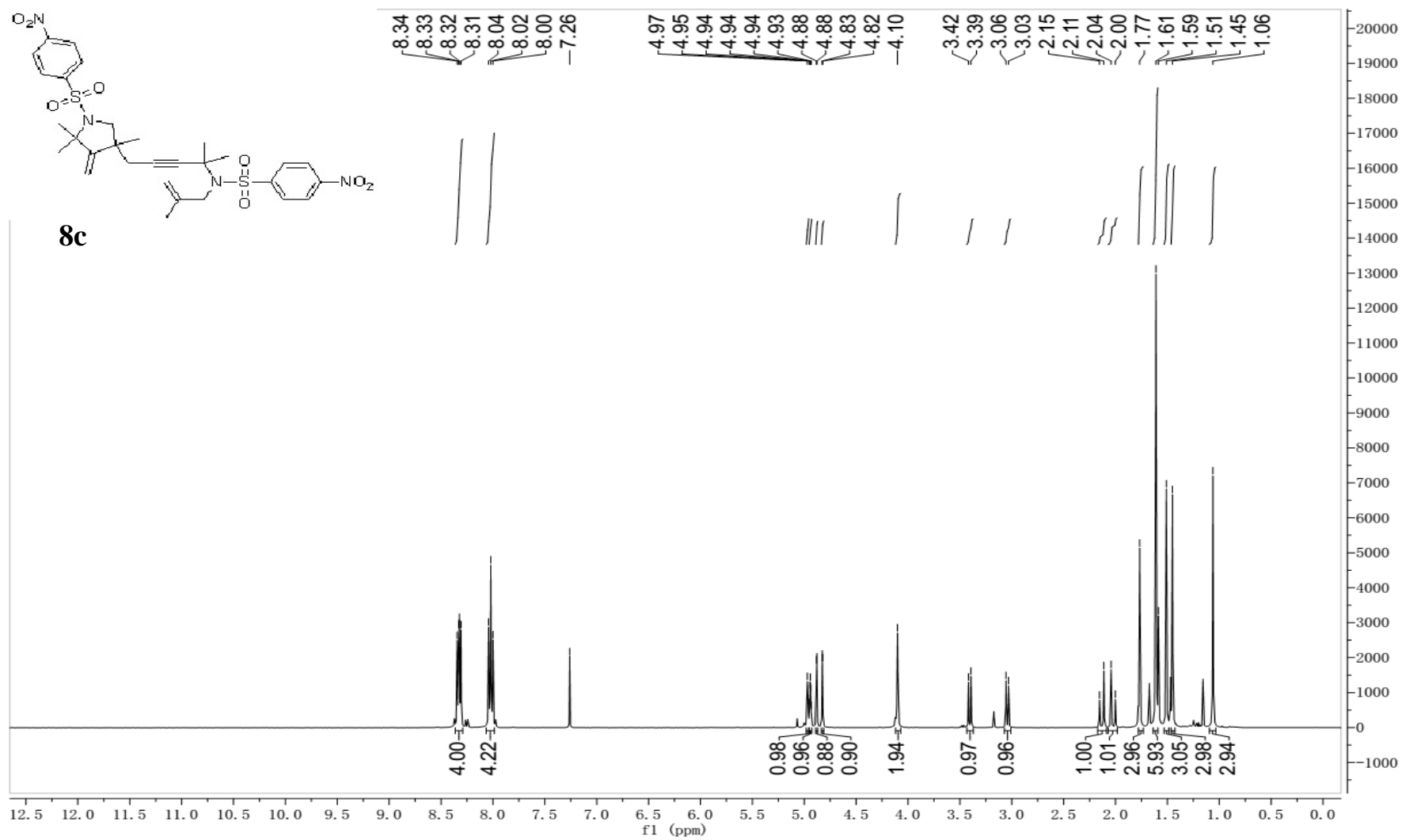


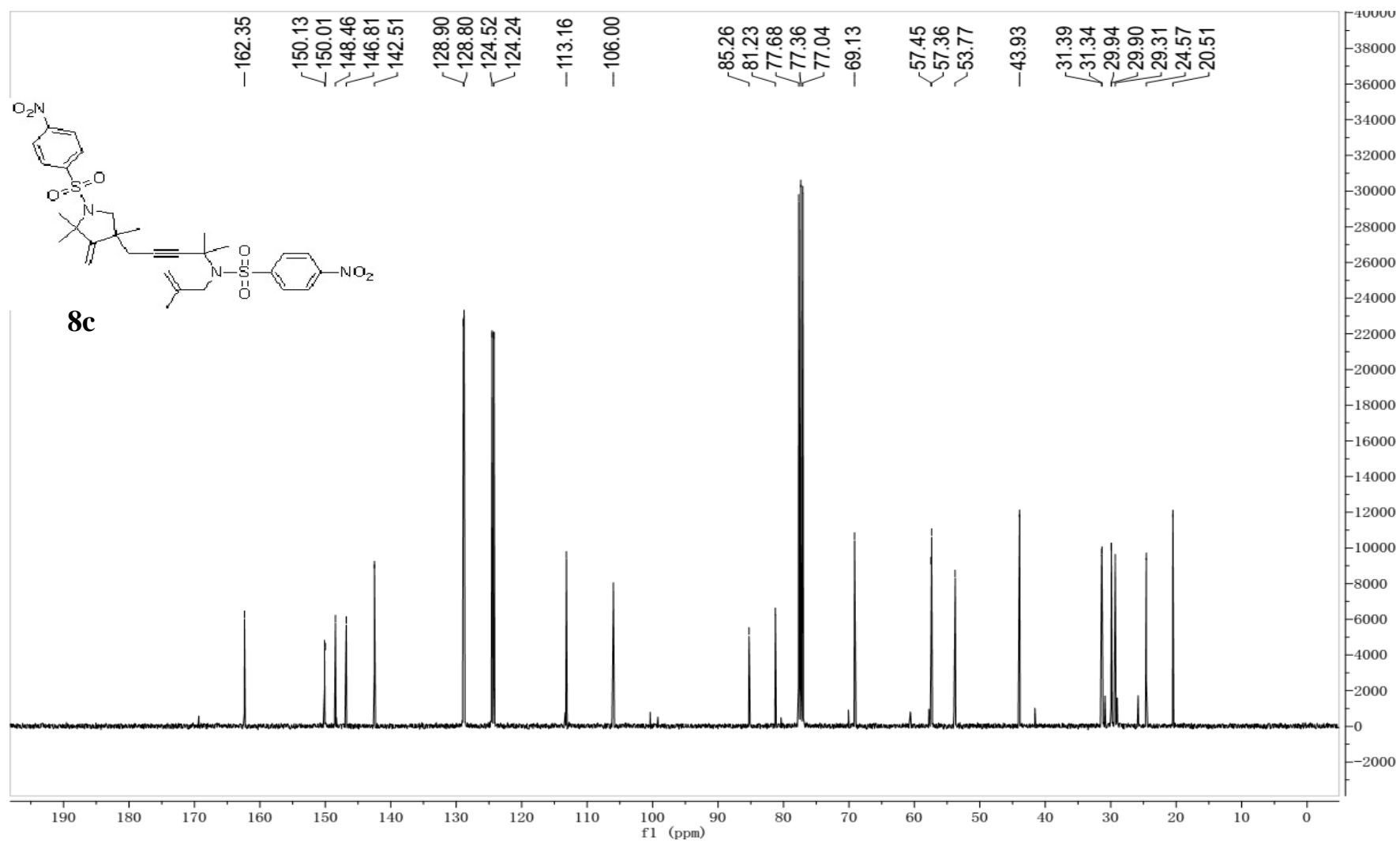


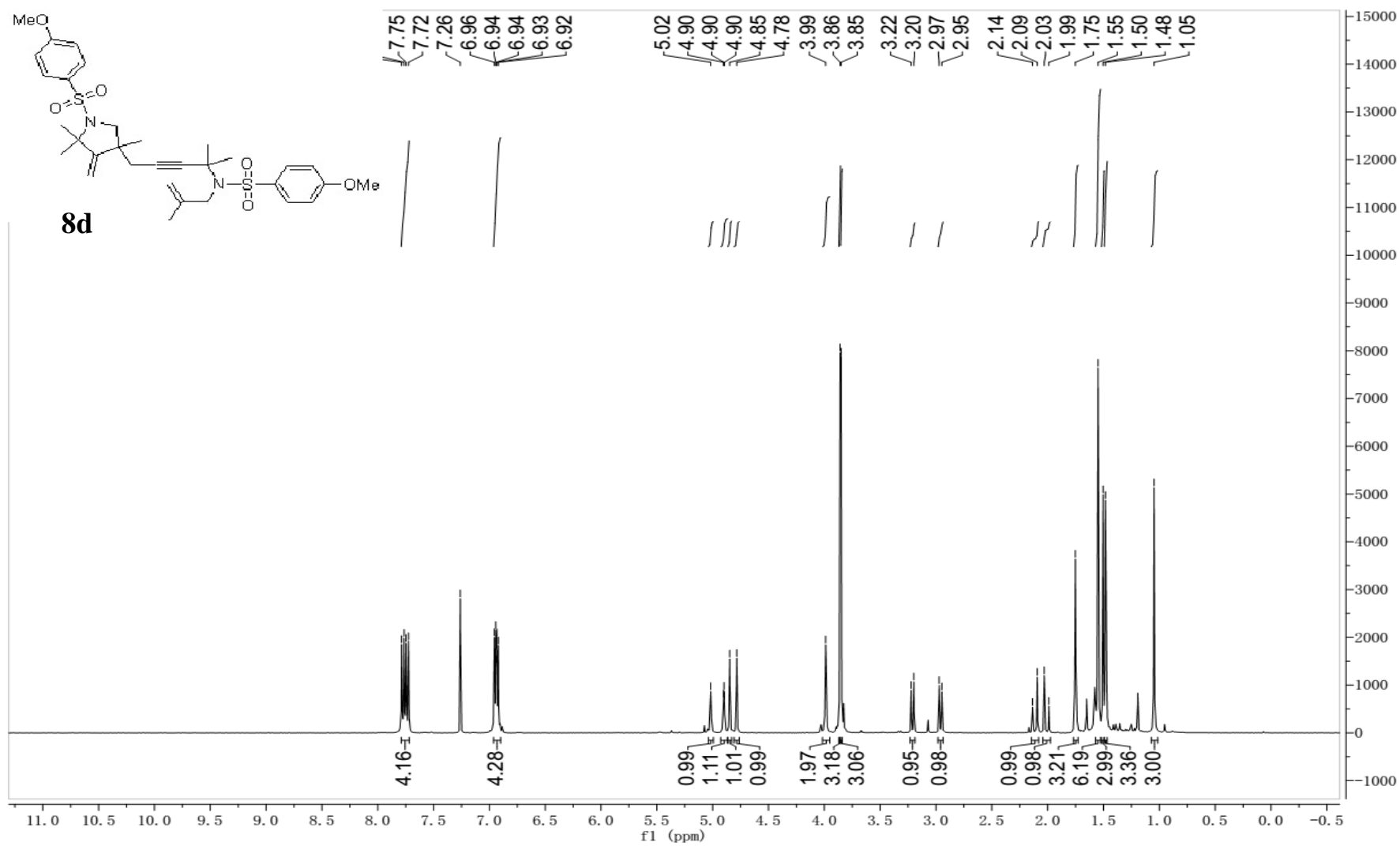


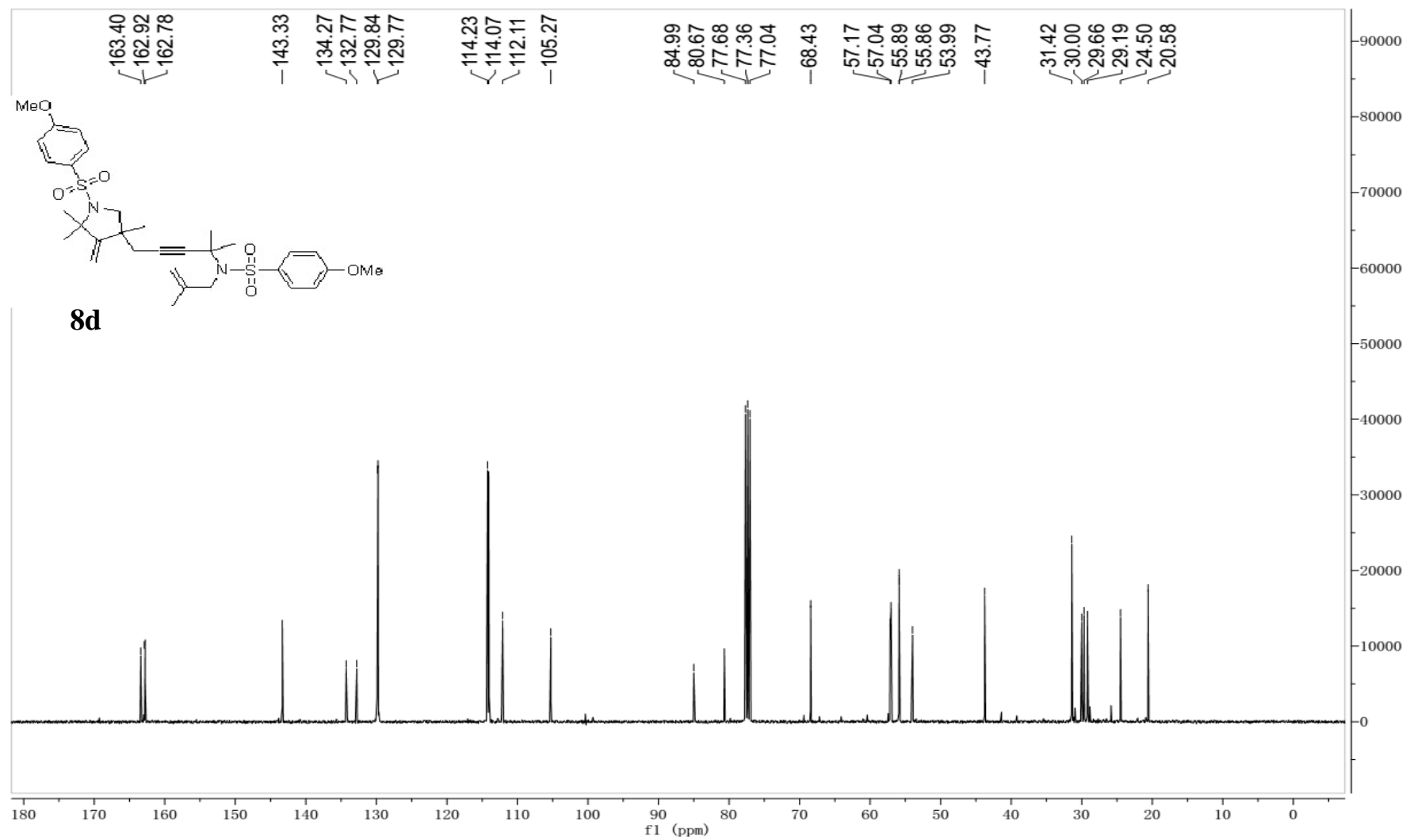


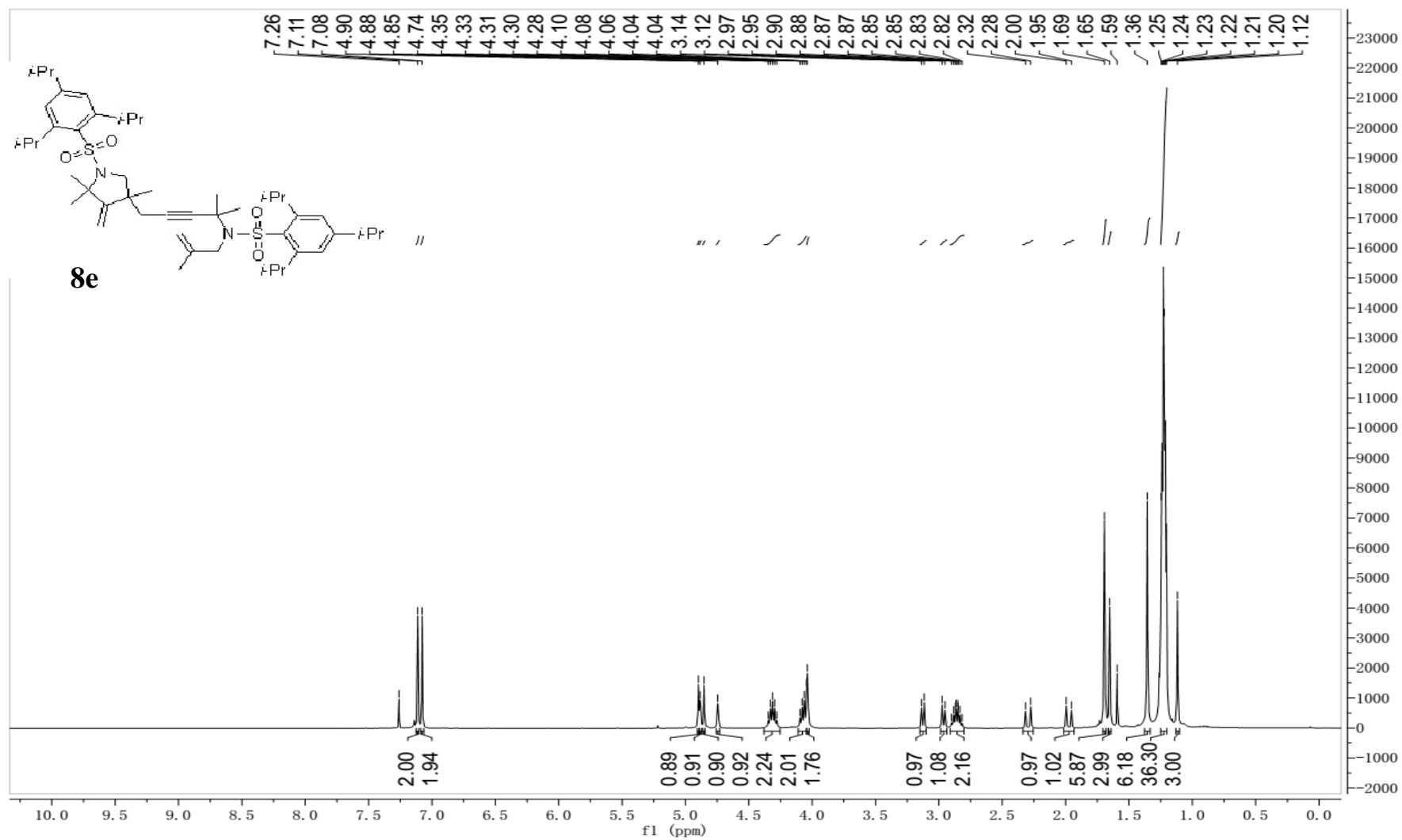


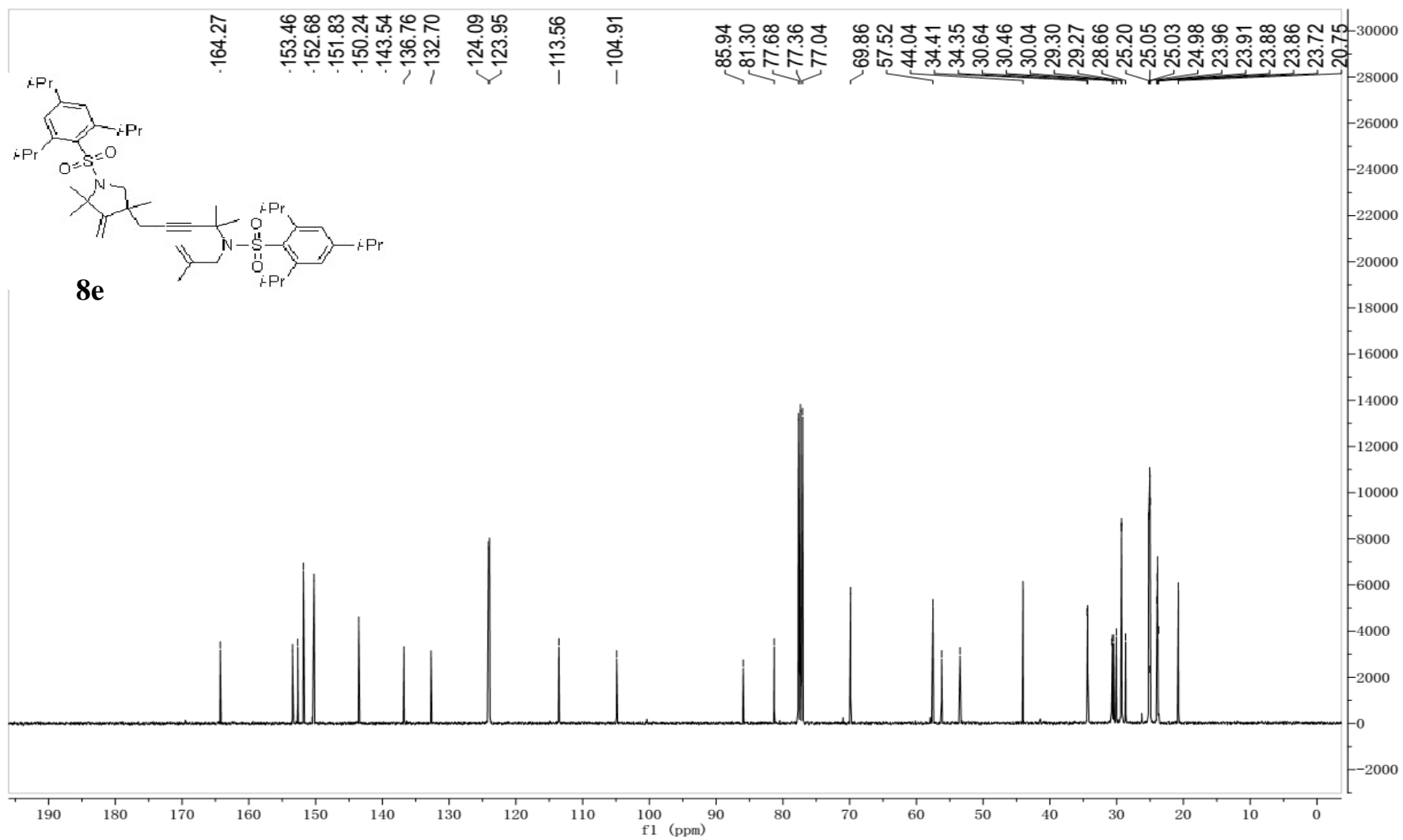


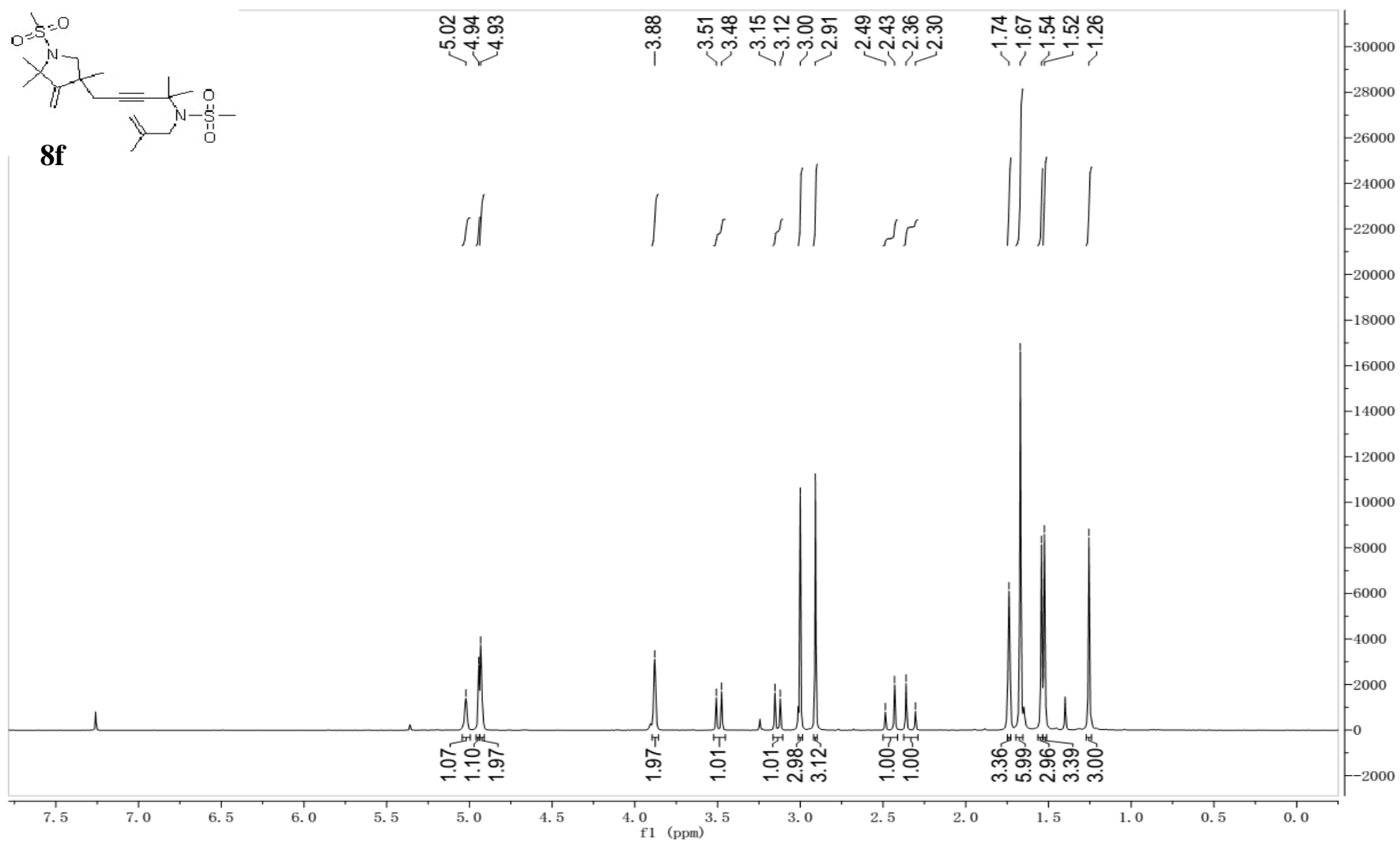


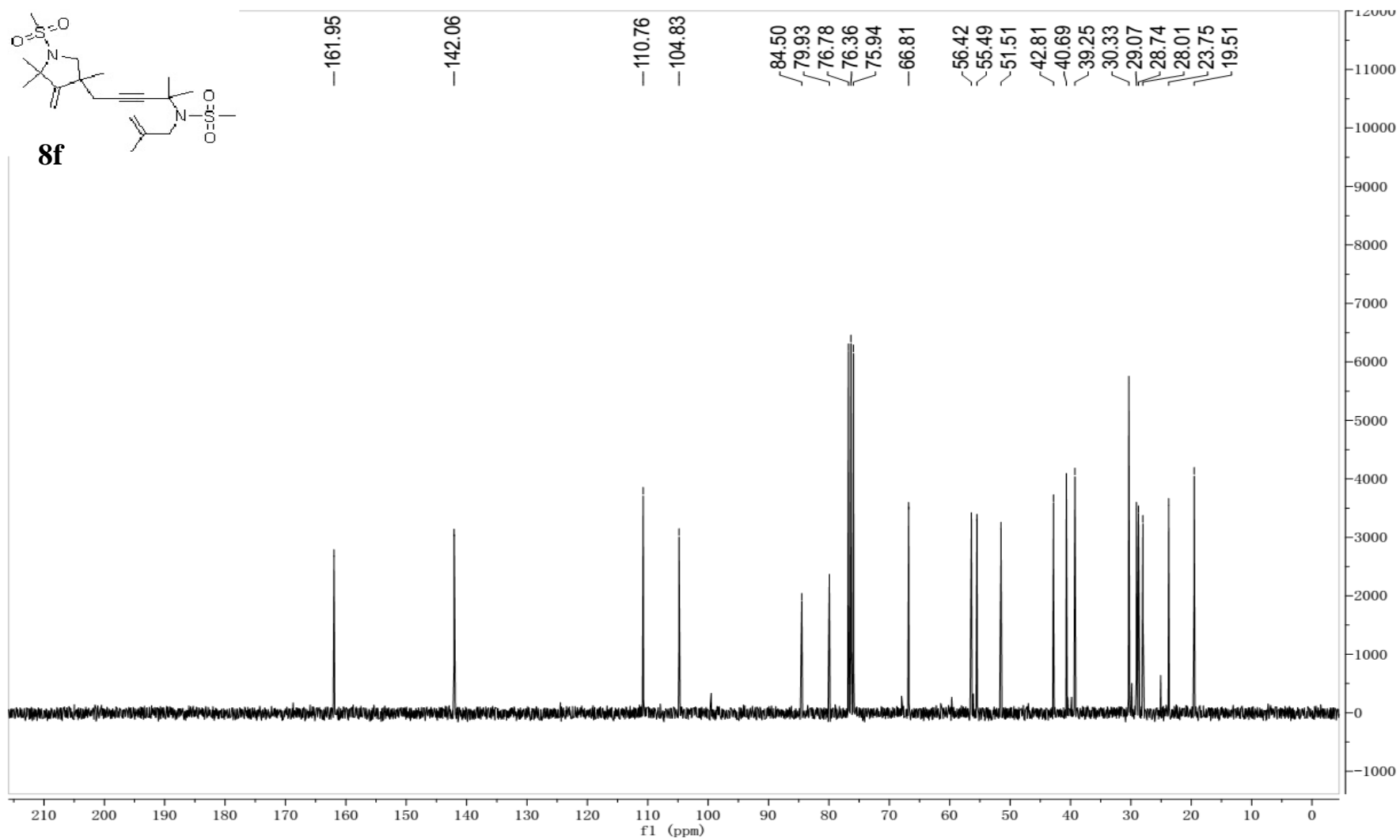


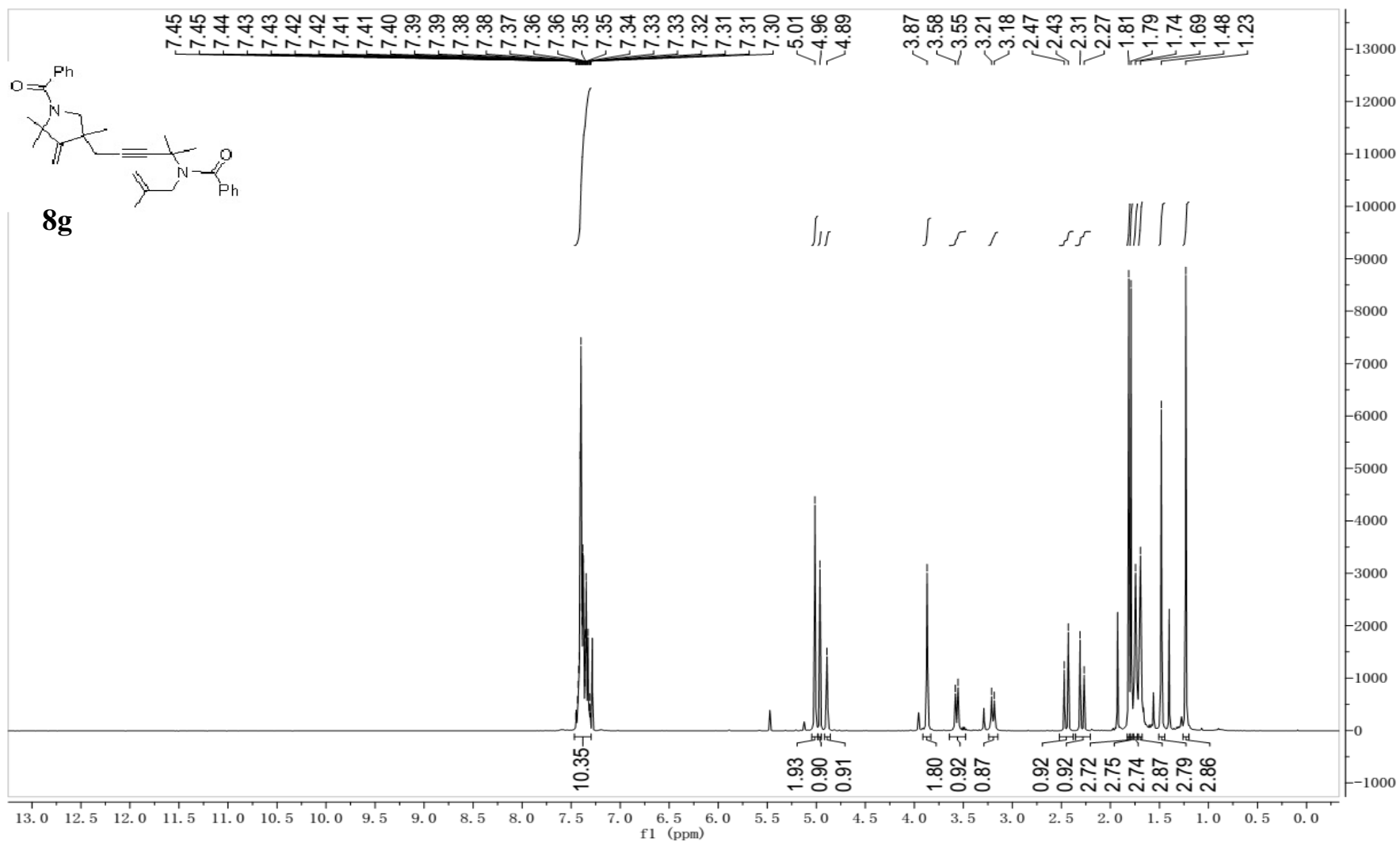


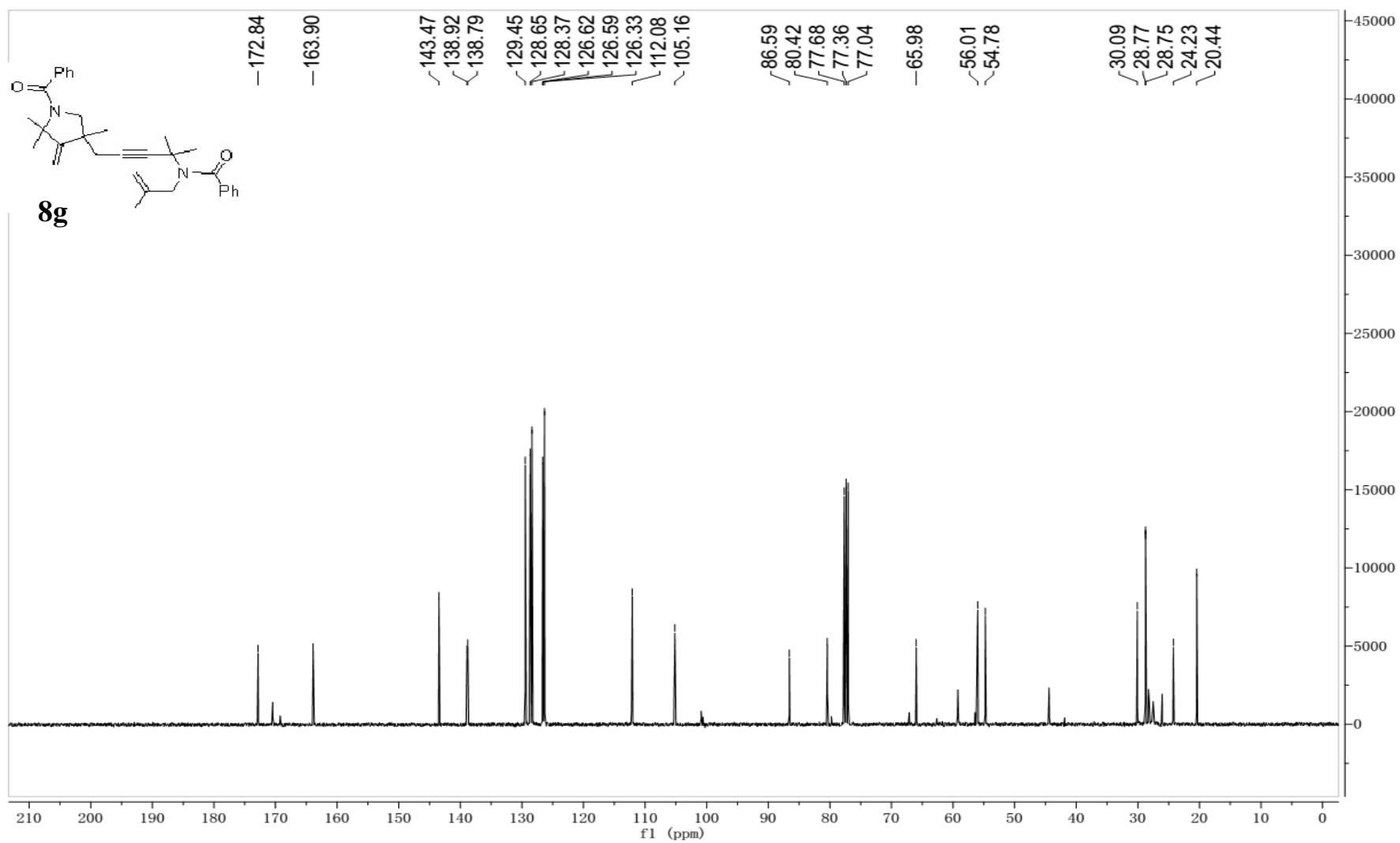


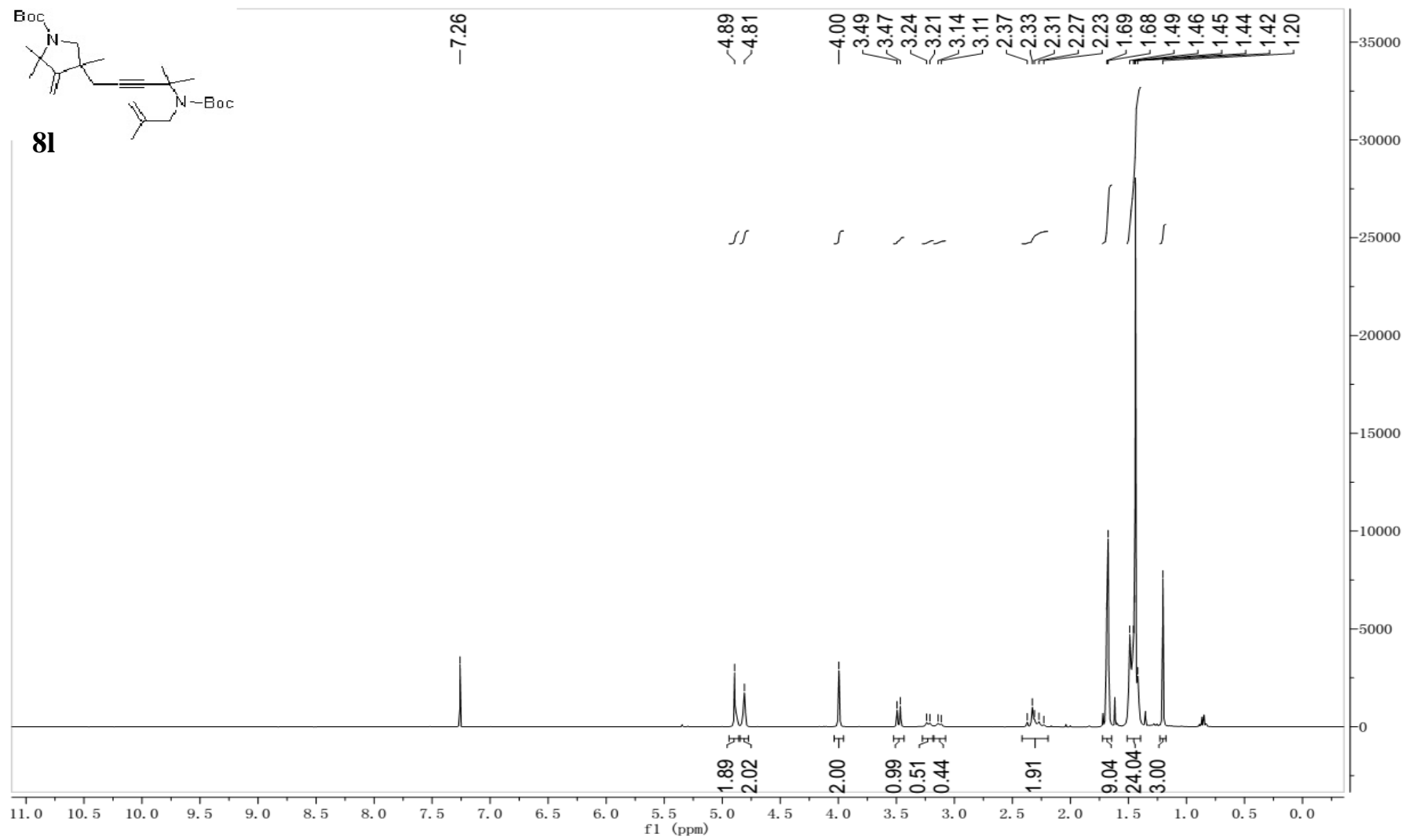


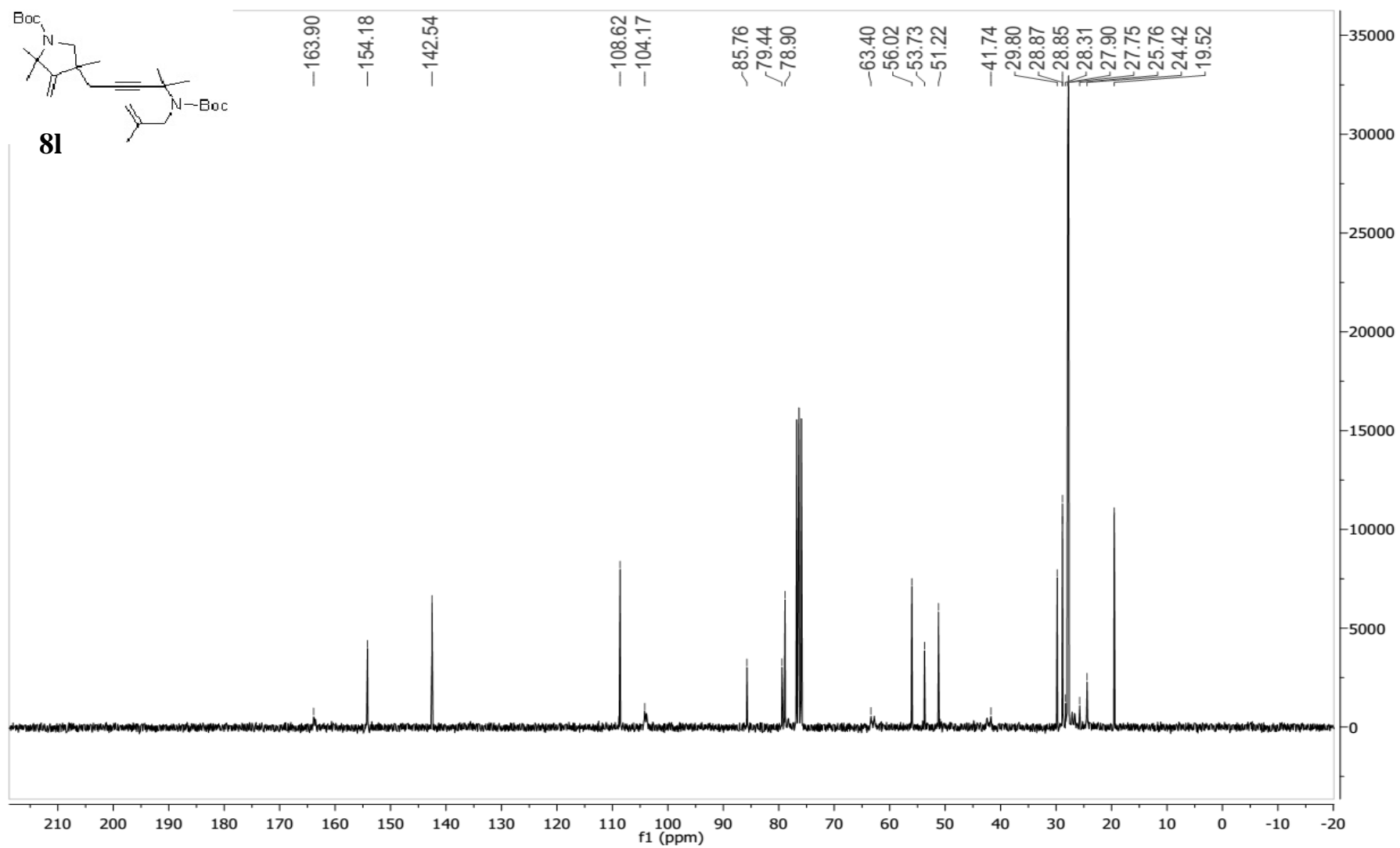


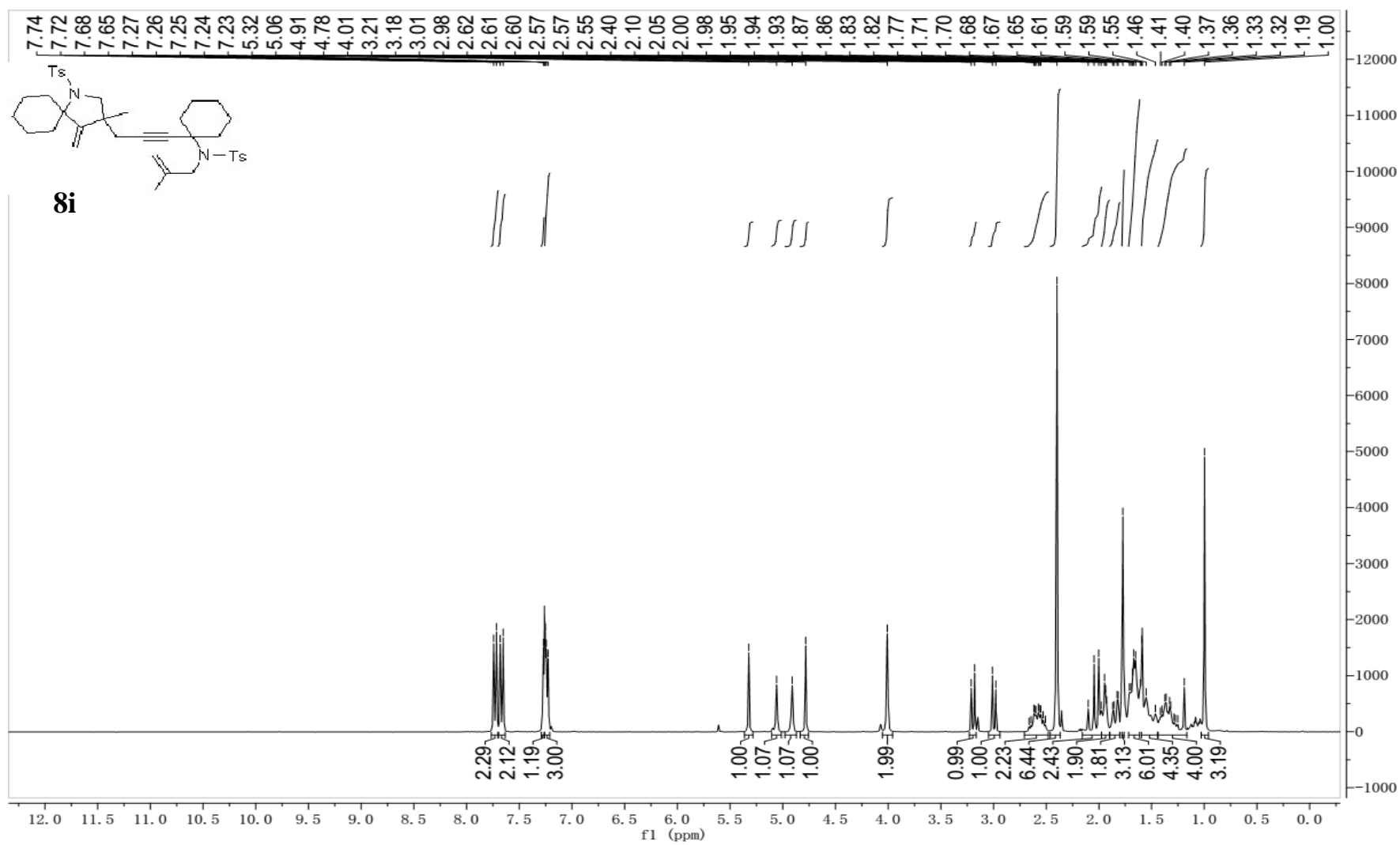


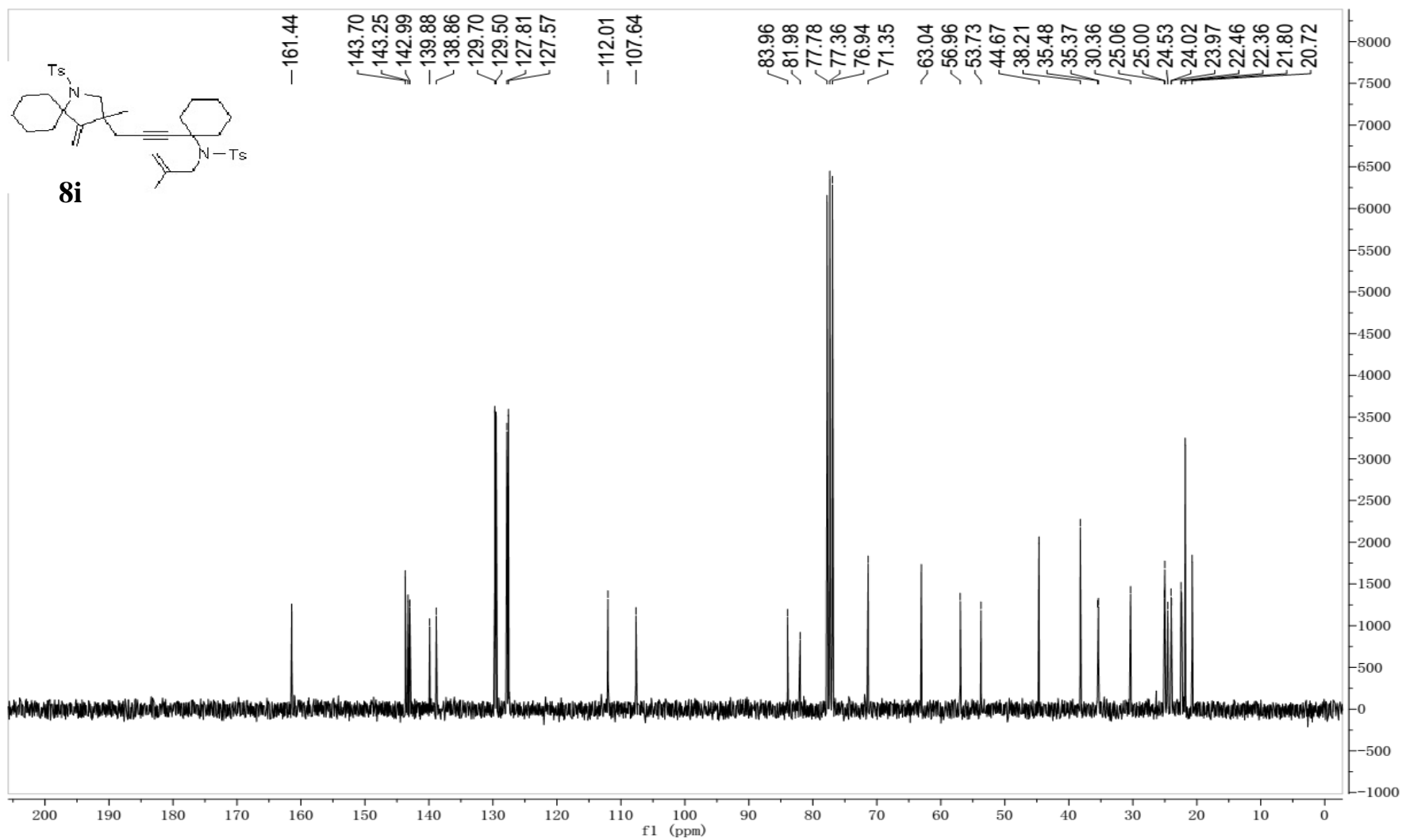


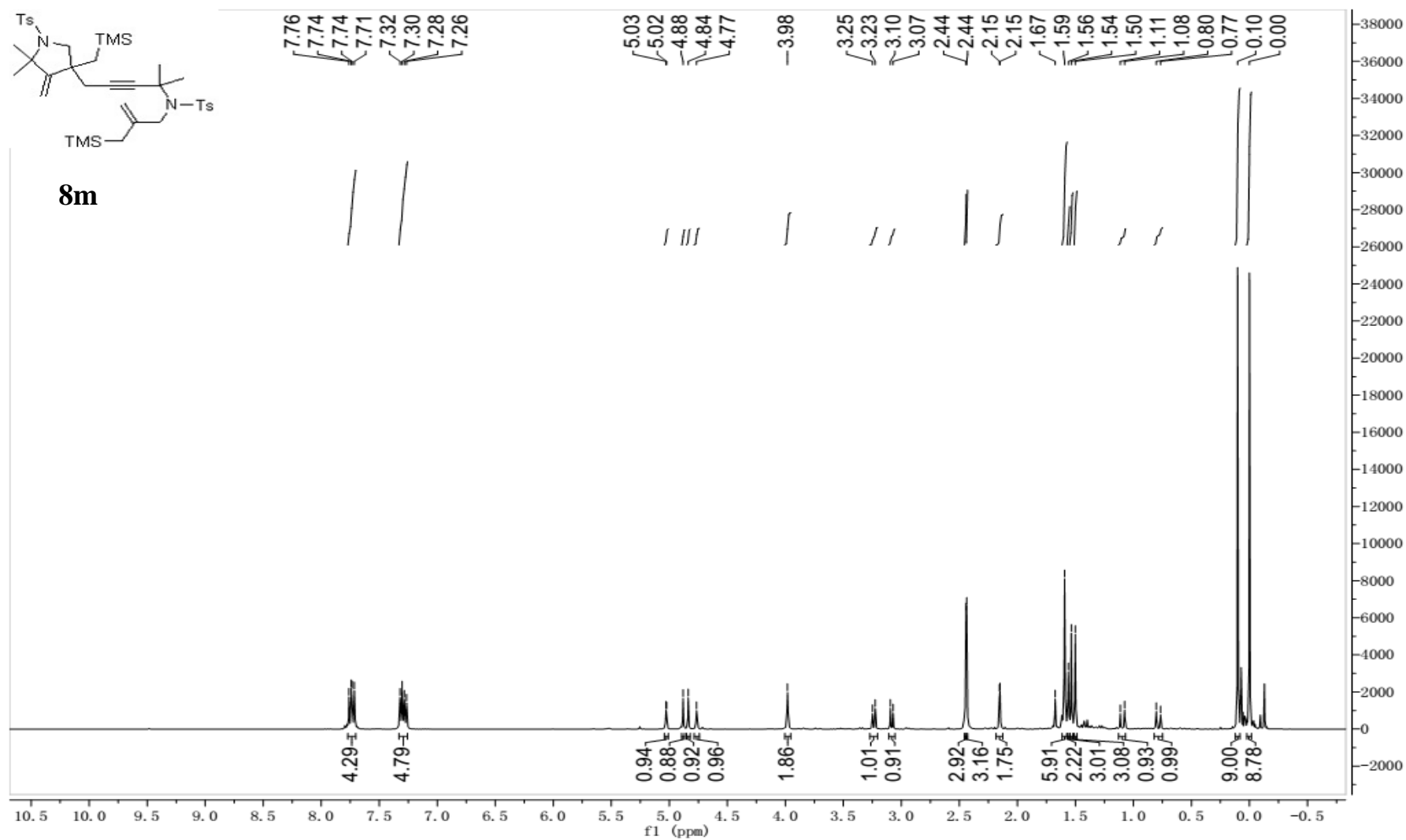


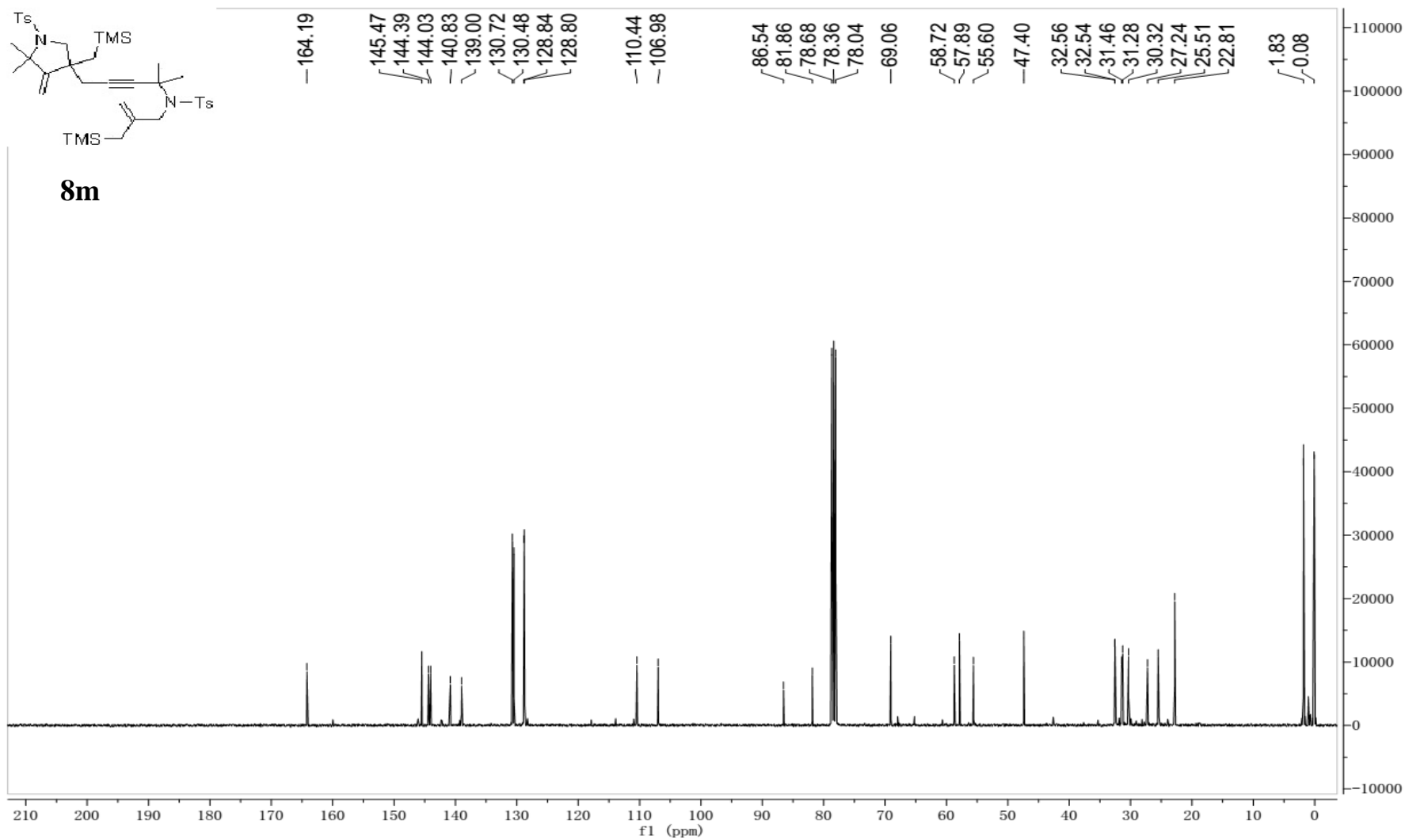


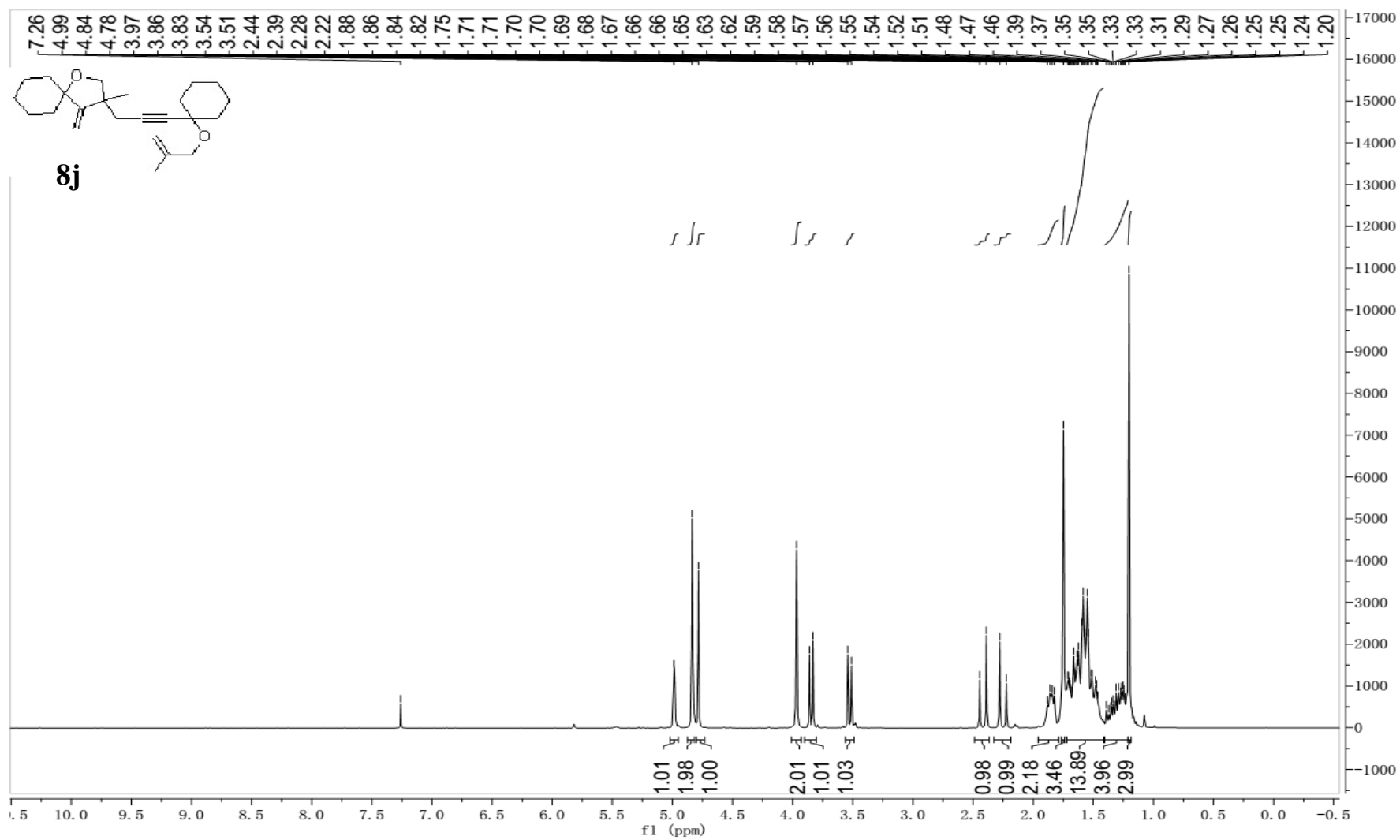


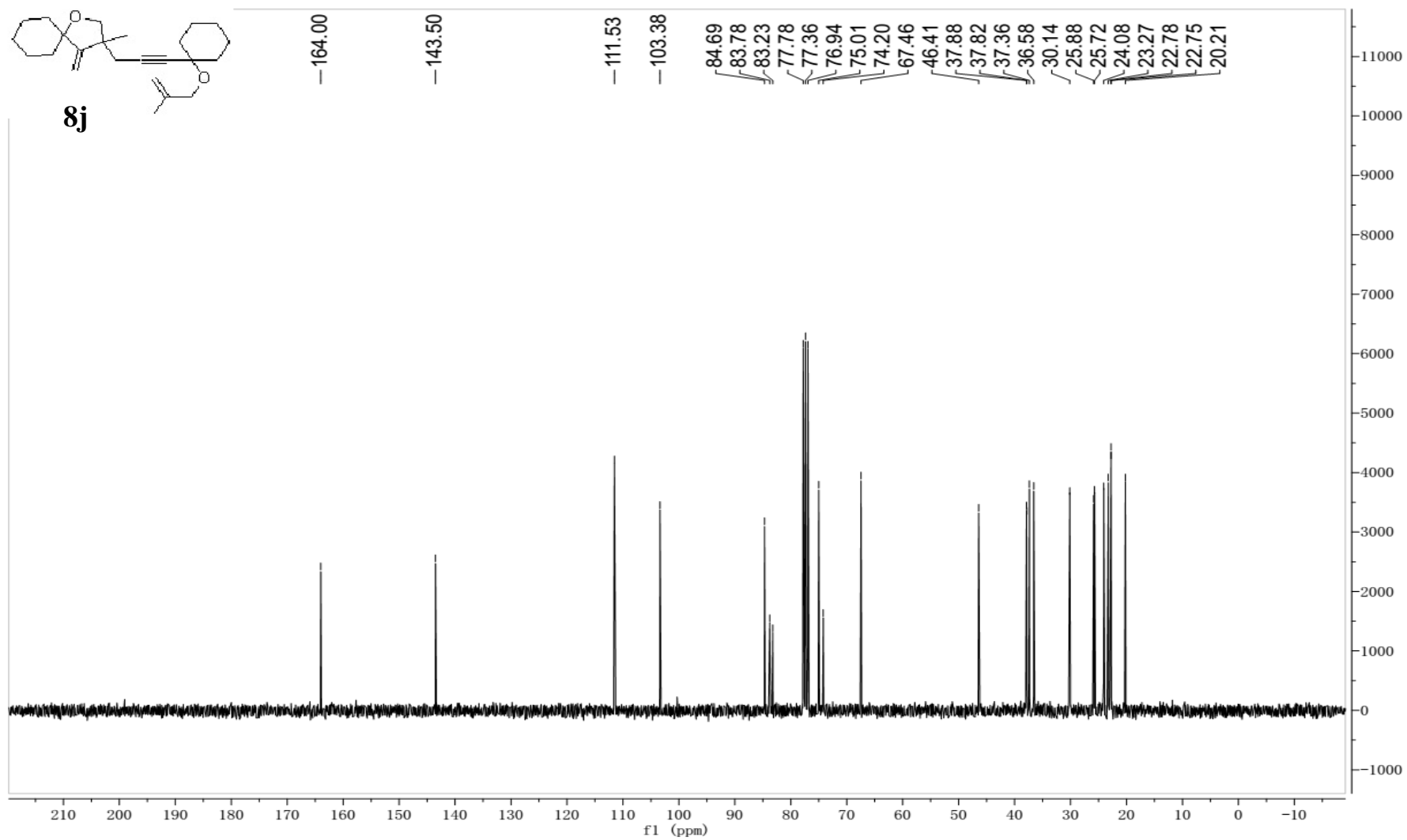


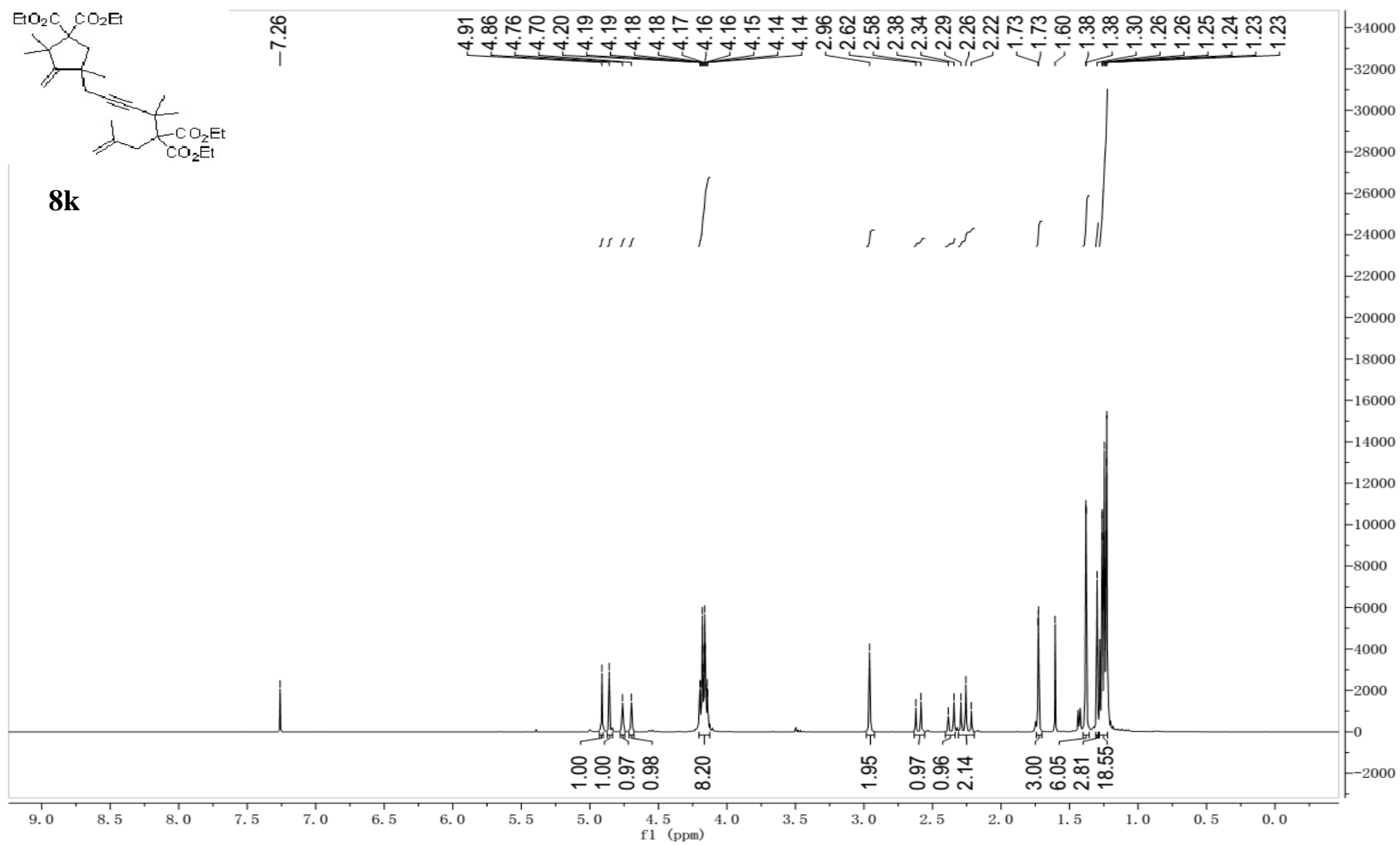


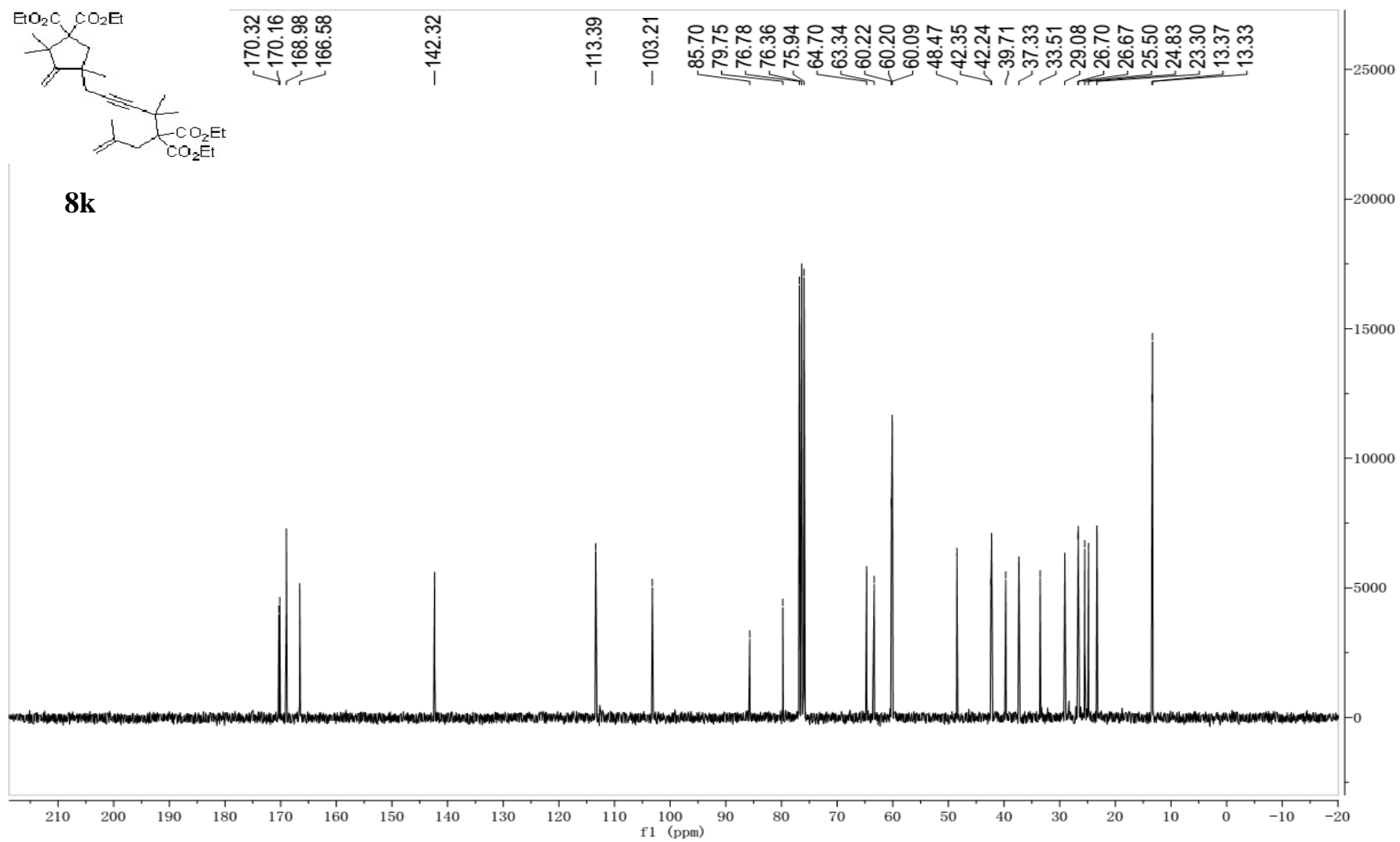


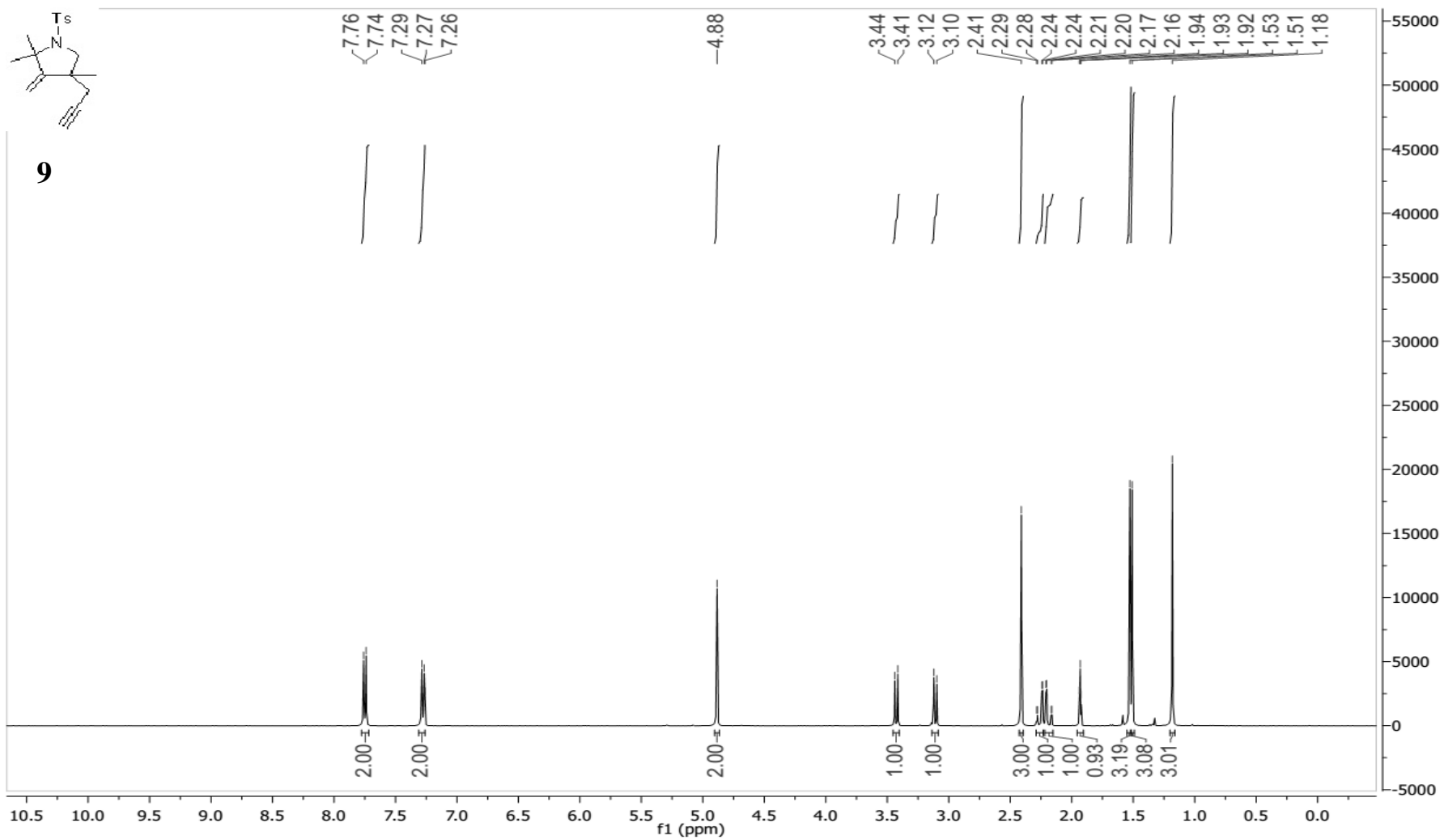


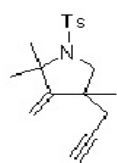












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