

Stereoselective Synthesis of Trisubstituted (*Z*)-Alkenes from Ketones via the Julia-Kocienski Olefination Using 1-Methyl- and 1-*tert*-Butyl-1*H*-tetrazol-5-yl Alkyl Sulfones

Kaori Ando,* and Daiki Takama

Department of Chemistry and Biomolecular Science, Faculty of Engineering, Gifu University,

Yanagido 1-1, Gifu 501-1193, Japan

ando@gifu-u.ac.jp

Supporting information

1. Experimental procedures (S1–S10)
2. References for the Supplementary Information (S10)
3. ¹H NMR and ¹³C NMR spectra of **3a-3f**, **1b**, **1d**, **7b**, *Z*- and *E*-**5a**, **5b-5n**, **8**, **9**, **10** and NOE of **5b-5l**, **5n**, **8d**, **9j** (S11–S47)

General Information

Commercially available reagents were used without purification. *N,N*-Dimethylformamide (DMF), tetrahydrofuran (THF) and dimethoxyethane (DME) were dried using Molecular Sieves 4A. All reactions in dry solvents were carried out under argon atmosphere. Analytical thin-layer chromatography (TLC) was performed on Merck TLC plates (No. 5715) precoated with silica gel 60 F₂₅₄. Column chromatography was carried out using Kanto silica gel 60N (spherical, neutral, 63–210 μm). The ¹H NMR (400 MHz) and ¹³C NMR (100 MHz) spectra were recorded on a JNM-ECS-400 spectrometer (JEOL) in CDCl₃. Tetramethylsilane (0.0 ppm) and CDCl₃ (77.0 ppm) were used as an internal standard for ¹H NMR and ¹³C NMR, respectively. ¹H NMR data are reported as follows: chemical shift, integration, multiplicity (s = singlet, d = doublet, t = triplet, q = quartet, dd = doublet of doublets, brs = broad singlet, m = multiplet), coupling constants (Hz). High-resolution mass spectra were recorded on a JMS-MStation 700 mass spectrometer (magnetic sector).

Preparation of mercaptotetrazole 2: (Method A)¹ To a solution of NaN₃ (0.663 g, 10 mmol) and H₂O (4 mL) was added a solution of isothiocyanate (10 mmol) in *i*-PrOH (3.0 mL) at 120 °C using oil bath and the resulting mixture was refluxed for 24 h. The mixture was treated with conc. HCl (1 mL) at 0 °C and then extracted twice with AcOEt (10 and 5 mL). The combined extracts were washed with brine, dried (MgSO₄), and concentrated to give **2**, which was used in the next step without further purification.

1-Cyclohexyl-5-mercaptotetrazole (2c): (Method A) 1.824 g, 99% yield (10 mmol scale) as a yellow solid, ¹H NMR (CDCl₃, 400 MHz): δ 4.62 (tt, 1H, *J* = 4.0, 11.6 Hz), 1.76-2.11 (m, 7H), 1.21-1.54 (m, 4H).

1-*tert*-Butyl-5-mercaptotetrazole (2d): (Method A) 1.971 g, 83% yield (15 mmol scale) as a brown solid. ¹H NMR

(CDCl₃, 400 MHz): δ 1.86 (s, 9H).

1-Adamantyl-5-mercaptotetrazole (2e): (Method A') To a solution of NaN₃ (0.650 g, 10 mmol) and H₂O (4 mL) was added a solution of 1-adamantylisothiocyanate (1.933 g, 10 mmol) in DMF (30.0 mL) at 120 °C using oil bath and the resulting mixture was refluxed for 24 h. The mixture was treated with conc. HCl (1 mL) at 0 °C and then extracted twice with AcOEt (10 and 5 mL). The combined extracts were washed with brine, dried (MgSO₄), and concentrated to give **2e** as a colorless solid (2.096 g, y. 89%). m.p. 170.2-171.3 °C (recrystallized from hexane/CH₂Cl₂ (2:1)). ¹H NMR (CDCl₃, 400 MHz): δ 2.59 (d, 6H, *J* = 2.8 Hz), 2.27 (m, 4H), 1.78 (d, 6H, *J* = 2.8 Hz).³

1-(2,6-Dimethylphenyl)-5-mercaptotetrazole (2f): (Method A) 1.027 g, quant. (5 mmol scale) as a pale yellow solid. ¹H NMR (CDCl₃, 400 MHz): δ 7.40 (t, 1H, *J* = 7.8 Hz), 7.25 (d, 2H, *J* = 7.8 Hz), 2.13 (s, 6H).²

[Preparation of sulfone reagents 3, 1, 7]

1-Phenyl-1H-tetrazol-5-yl pentyl sulfone (3a): (Method B) To a solution of 5-mercapto-1-phenyltetrazole **2a** (1.782 g, 10.0 mmol) in THF (25 mL) was added 60% NaH (0.44 g, 11.0 mmol) at 0 °C. After the mixture was stirred at 0 °C for 10 min, 1-iodopentane (1.57 mL, 12.0 mmol) was added and the resulting mixture was stirred at RT for 4 h. The reaction was quenched with NH₄Cl aq., and the mixture was extracted twice with AcOEt (15 and 5 mL). The combined extracts were washed with brine, dried (MgSO₄), and concentrated. Column chromatography (silica gel; hexane/AcOEt (3:1)) provided the sulfide (2.459 g, 99%) as pale yellow oil; ¹H NMR (CDCl₃, 400 MHz): δ 7.52-7.61 (m, 5H), 3.40 (t, 2H, *J* = 7.3 Hz), 1.83 (quin, 2H, *J* = 7.3 Hz), 1.31-1.46 (m, 4H), 0.91 (t, 3H, *J* = 7.3 Hz). The oil was treated with (NH₄)₆Mo₇O₂₄•H₂O (1.248 g, 1.0 mmol) and 34.5% H₂O₂ (7.8 mL, 88 mmol) in EtOH (20 mL). After the resulting mixture was stirred at RT for 11 h, aq. Na₂SO₃ was added slowly at 0 °C and extracted twice with AcOEt (20 mL and 10 mL). The combined extracts were washed with brine, dried with MgSO₄, and concentrated. Column chromatography (silica gel, hexane/AcOEt 2:1) provided **3a** (2.747 g, 99% yield) as colorless needles. m.p. 37-38 °C⁴ (recrystallized from hexane/CH₂Cl₂ (3:1)); ¹H NMR (CDCl₃, 400 MHz): δ 7.58-7.73 (m, 5H), 3.70-3.78 (m, 2H), 1.92-1.99 (m, 2H), 1.33-1.56 (m, 4H), 0.93 (t, 3H, *J* = 7.1 Hz).⁴

1-Methyl-1H-tetrazol-5-yl pentyl sulfone (3b): (Method C) To a solution of 86% KOH (0.718 g, 11 mmol) in H₂O (2 mL) was added 5-mercapto-1-methyltetrazole **2b** (1.162 g, 10.0 mmol) and THF (4 mL) at 0 °C. 10 min later, *n*-C₅H₁₁I (1.43 mL, 11 mmol) was added dropwise and the resulting mixture was stirred at 50 °C using oil bath for 4 h. The reaction was quenched with aq. NH₄Cl, and the mixture was extracted twice with AcOEt (15 and 5 mL). The combined extracts were washed with brine, dried (MgSO₄), and concentrated to give the sulfide (1.957 g, 94.2% purity, y. 99%) as pale yellow oil. ¹H NMR (CDCl₃, 400 MHz): δ 3.92 (s, 3H), 3.35 (t, 2H, *J* = 7.6 Hz), 1.81 (quin, 2H, *J* = 7.6 Hz), 1.33-1.47 (m, 4H), 0.91 (t, 3H, *J* = 7.1 Hz). To a solution of the above sulfide in EtOH (20 mL) was added (NH₄)₆Mo₇O₂₄•4H₂O (1.24 g, 1 mmol) and then 34.5% H₂O₂ aq. (8.0 mL, 90 mmol) at 0 °C and the resulting mixture was stirred at RT for 18 h. After Na₂SO₃ aq. was added slowly at 0 °C, the mixture was extracted with AcOEt twice (15 mL and 10 mL). The combined extracts were washed with brine, dried with MgSO₄, and concentrated. Column chromatography (hex/AcOEt 3:1) provided **3b** (2.161 g, 99% from **2b**) as colorless oil. ¹H

NMR (CDCl₃, 400 MHz): δ 4.36 (s, 3H), 3.66 (t, 2H, $J = 8.0$ Hz), 1.93 (quin, 2H, $J = 8.0$ Hz), 1.34-1.53 (m, 4H), 0.93 (t, 3H, $J = 7.3$ Hz)⁵; ¹³C{¹H} NMR (CDCl₃, 100 MHz): δ 153.2, 55.7, 36.0, 30.0, 21.9, 21.5, 13.5.

1-(Cyclohexyl)-1H-tetrazol-5-yl pentyl sulfone (3c): (Method B) 2.675 g, 93% yield from **2c** (10.0 mmol) as pale yellow oil by the same procedure as **3a**. ¹H NMR (CDCl₃, 400 MHz): δ 4.91 (tt, 1H, $J = 3.9, 11.5$ Hz), 3.66-3.71 (m, 2H), 2.15-2.23 (m, 2H), 1.90-2.08 (m, 6H), 1.74-1.82 (m, 1H), 1.28-1.53 (m, 7H), 0.93 (t, 3H, $J = 7.3$ Hz); ¹³C{¹H} NMR (CDCl₃, 100 MHz): δ 152.6, 60.8, 55.8, 32.8, 30.1, 25.0, 24.7, 22.0, 21.6, 13.6; HRMS (Fab): m/z [M + Na]⁺ Calcd for C₁₂H₂₂N₄O₂SNa⁺ 309.1356, Found: 309.1362.

1-tert-Butyl-1H-tetrazole-5-yl pentyl sulfone (3d): (Method B) 1.894 g, 97% yield from **2d** (7.5 mmol) by two steps (98%, 99%) as pale yellow oil by the same procedure as **3a**. ¹H NMR (CDCl₃, 400 MHz): δ 3.78-3.84 (m, 2H), 1.94-2.03 (m, 2H), 1.86 (s, 9H), 1.34-1.55 (m, 4H), 0.94 (t, 3H, $J = 7.3$ Hz)⁶; ¹³C{¹H} NMR (CDCl₃, 100 MHz): δ 153.8, 65.1, 56.3, 30.1, 29.4, 21.8, 21.6, 13.4.

1-Adamantyl-1H-tetrazole-5-yl pentyl sulfone (3e): (Method B) 2.672 g, 79% yield from **2e** by two steps (88%, 90%) as colorless solid by the same procedure as **3a**. m.p. 66.0-67.1 °C (recrystallized from hexane/CH₂Cl₂ (5:1)); ¹H NMR (CDCl₃, 400 MHz): δ 3.78-3.83 (m, 2H), 2.46-2.49 (m, 6H), 2.28-2.34 (m, 3H), 1.93-2.02 (m, 2H), 1.75-1.85 (m, 6H), 1.35-1.54 (m, 4H), 0.94 (t, 3H, $J = 7.1$ Hz); ¹³C{¹H} NMR (CDCl₃, 100 MHz): δ 154.1, 66.2, 56.7, 41.8, 35.4, 30.3, 29.8, 22.1, 21.8, 13.7; HRMS (Fab): m/z [M + Na]⁺ Calcd for C₁₆H₂₆N₄O₂SNa⁺ 361.1669, Found: 361.1669.

1-(2,6-dimethylphenyl)-1H-tetrazol-5-yl pentyl sulfone (3f): (Method B) 0.604 g, 98% yield from **2f** as colorless solid by the same procedure as **3a**. m.p. 50-52 °C (recrystallized from hexane/CH₂Cl₂ (3:1)); ¹H NMR (CDCl₃, 400 MHz): δ 7.41 (t, 1H, $J = 7.8$ Hz), 7.23 (d, 2H, $J = 7.8$ Hz), 3.67-3.72 (m, 2H), 2.00 (s, 6H), 1.90-2.00 (m, 2H), 1.34-1.53 (m, 4H), 0.93 (t, 3H, $J = 7.1$ Hz); ¹³C{¹H} NMR (CDCl₃, 100 MHz): δ 154.2, 135.8, 131.6, 131.4, 128.7, 55.6, 30.2, 22.0, 21.7, 17.3, 13.6; HRMS (Fab): m/z [M + Na]⁺ Calcd for C₁₄H₂₀N₄O₂SNa⁺ 331.1199, Found: 331.1224.

1-Methyl-1H-tetrazol-5-yl ethyl sulfone (1b): (Method C') After adding C₂H₅I (0.90 mL, 11 mmol) instead of *n*-C₅H₁₁I, the resulting mixture was stirred at RT for 2 h and the reaction was quenched to give the sulfide (1.957 g, 96.1% purity, y. 94%) as pale yellow oil. ¹H NMR (CDCl₃, 400 MHz): δ 3.91 (s, 3H), 3.37 (q, 2H, $J = 7.3$ Hz), 1.49 (t, 3H, $J = 7.3$ Hz). The above sulfide was oxidized according to Method C to provide **1b** (1.558 g, 88% from **2b**) as colorless solid. m.p. 92-93 °C (recrystallized from hexane/CH₂Cl₂ (3:1)); ¹H NMR (CDCl₃, 400 MHz): δ 4.37 (s, 3H), 3.71 (q, 2H, $J = 7.4$ Hz), 1.53 (t, 3H, $J = 7.3$ Hz)⁵; ¹³C{¹H} NMR (CDCl₃, 100 MHz): δ 152.8, 50.5, 36.1, 6.8; HRMS (EI): m/z [M + H]⁺ Calcd for C₄H₉N₄O₂S⁺ 177.0441, Found: 177.0427.

1-tert-Butyl-1H-tetrazol-5-yl ethyl sulfone (1d): (Method B) The sulfide: 1.024 g in 92% yield from **2d** (6.00 mmol) as colorless oil. **1d**: 1.164 g in 89% from **2d** (6.00 mmol) as colorless solid. m.p. 46-47 °C (recrystallized

from hexane/CH₂Cl₂ (3:1)); ¹H NMR (CDCl₃, 400 MHz): δ 3.85 (q, 2H, *J* = 7.4 Hz), 1.86 (s, 9H), 1.56 (t, 3H, *J* = 7.3 Hz)⁷; ¹³C{¹H} NMR (CDCl₃, 100 MHz): δ 153.6, 65.4, 51.4, 29.6, 7.1;⁷ HRMS (EI): *m/z* [M + H]⁺ Calcd for C₇H₁₅N₄O₂S⁺ 219.0910, Found: 219.0904.

1-Methyl-1*H*-tetrazol-5-yl (3,7-dimethyl-6-octen-1-yl) sulfone (7b): (Method D) To a solution of citronellol (1.82 mL, 10.0 mmol) in THF (30 mL) were added methanesulfonyl chloride (0.95 mL, 12.0 mmol) and triethylamine (1.82 mL, 13.0 mmol). After the mixture was stirred at RT for 2.5 h, a solution of **2b** (1.511 g, 13.0 mmol) and 60% NaH (1.040 g, 26.0 mmol) in THF (10 mL) was added at 0 °C. The resulting mixture was heated to reflux for 21 h using oil bath. The reaction was quenched with NH₄Cl aq., and the mixture was extracted twice with AcOEt (20 and 10 mL). The combined extracts were washed with brine, dried (MgSO₄), and concentrated. Column chromatography (silica gel; hexane/AcOEt (4:1)) provided the sulfide (2.363 g, 93%) as pale yellow oil; ¹H NMR (CDCl₃, 400 MHz): δ 5.08 (tt, 1H, *J* = 1.4, 7.1 Hz), 3.91 (s, 3H), 3.28-3.45 (m, 2H), 1.90-2.06 (m, 2H), 1.75-1.86 (m, 1H), 1.60-1.68 (m, 2H), 1.68 (s, 3H), 1.60 (s, 3H), 1.33-1.43 (m, 1H), 1.16-1.27 (m, 1H), 0.95 (d, 3H, *J* = 6.4 Hz). The above sulfide (2.078 g, 8.17 mmol) was oxidized according to Method B to provide **7b** (2.129 g, 91%) as colorless oil. ¹H NMR (CDCl₃, 400 MHz): δ 5.06 (t, 1H, *J* = 7.2 Hz), 4.36 (s, 3H), 3.59-3.74 (m, 2H), 1.90-2.07 (m, 3H), 1.60-1.81 (m, 2H), 1.69 (s, 3H), 1.60 (s, 3H), 1.33-1.42 (m, 1H), 1.19-1.29 (m, 1H), 0.97 (d, 3H, *J* = 6.8 Hz); ¹³C{¹H} NMR (CDCl₃, 100 MHz): δ 153.2, 132.0, 123.8, 54.0, 36.2, 36.0, 31.4, 28.2, 25.7, 25.2, 18.9, 17.7; HRMS (EI): *m/z* [M + H]⁺ Calcd for C₁₂H₂₃N₄O₂S⁺ 287.1536, Found: 287.1524.

[The olefination reaction of *n*-pentyl sulfone reagents **3** with ketones **4**]

Procedure A (entry 7 in Table 1) LiHMDS was prepared from HMDS (0.121 mL, 0.57 mmol) and *n*-BuLi hexane solution (0.365 mL, 0.57 mmol) in THF (0.9 mL) at 0 °C. To a solution of **3b** (0.065 g, 0.30 mmol) and acetophenone **4a** (0.035 mL, 0.30 mmol) in THF (1.0 mL) under argon was added LiHMDS (0.33 mmol) at -78 °C. After 30 min and 1 h, LiHMDS (0.12 mmol) was added respectively and the reaction was quenched with NH₄Cl aq. after 1.5 h. The mixture was extracted twice with AcOEt (12 and 5 mL) and the combined extracts were washed with brine, dried (MgSO₄), and concentrated. Column chromatography (hexane) provided **5a** (0.048 g, 92%) (*Z:E* = 95:5) as colorless oil.

Z-2-Phenyl-2-heptene (5a): (entry 11 in Table 1) (Procedure A) Using **3f** instead of **3b**, 80% yield (0.042 g, *Z:E* = 99:1) as colorless oil. ¹H NMR (CDCl₃, 400 MHz): *Z*: δ 7.16-7.35 (m, 5H), *5.78 (t, 1H, *J* = 7.3 Hz), 5.45 (dt, 1H, *J* = 1.4, 7.3 Hz), *2.20 (q, 2H, *J* = 7.3 Hz), 2.02 (d, 3H, *J* = 1.4 Hz), 1.97 (q, 2H, *J* = 7.3 Hz), 1.20-1.35 (m, 4H), *0.93 (t, 3H, *J* = 7.1 Hz), 0.83 (t, 3H, *J* = 7.1 Hz) (**E* isomer⁸); ¹³C{¹H} NMR (CDCl₃, 100 MHz): δ 142.3, 135.9, 128.1, 128.0, 127.7, 126.3, 32.4, 28.8, 25.6, 22.3, 13.9; HRMS (EI): *m/z* [M]⁺ Calcd for C₁₃H₁₈⁺ 174.1403, Found: 174.1391.

Procedure B: E-2-Phenyl-2-heptene (E-5a) (entry 15 in Table 1) To a solution of **3b** (0.066 g, 0.30 mmol) and acetophenone **4a** (0.035 mL, 0.30 mmol) in THF (1.0 mL) under argon was added KHMDS (0.5 M in toluene) (0.66 mL, 0.33 mmol) at -78 °C. After 30 min and 1 h, KHMDS (0.24 mL, 0.12 mmol) was added respectively and the

reaction was quenched with NH₄Cl aq. after 1.5 h. The mixture was extracted twice with AcOEt (12 and 5 mL) and the combined extracts were washed with brine, dried (MgSO₄), and concentrated. Column chromatography (hexane) provided **E-5a** (0.032 g, 61%) (*Z:E* = 8:92) as colorless oil. ¹H NMR (CDCl₃, 400 MHz): *E*:⁸ δ 7.17-7.40 (m, 5H), 5.78 (dt, 1H, *J* = 1.4, 7.1 Hz), *5.45 (t, 1H, *J* = 7.3 Hz), 2.03 (d, 3H, *J* = 1.4 Hz), 2.20 (q, 2H, *J* = 7.2 Hz), 1.33-1.48 (m, 4H), 0.93 (t, 3H, *J* = 7.1 Hz) (**Z* isomer).

Z-2-(4-Methoxyphenyl)-2-heptene (5b): (Scheme 3) (Procedure A) 86% yield (0.053 g, *Z:E* = 92:8) as colorless oil. ¹H NMR (CDCl₃, 400 MHz): *Z*: δ *7.30-7.33 (m, 1H), 7.10-7.14 (m, 2H), 6.85-6.89 (m, 2H), *5.70 (t, 1H, *J* = 7.3 Hz), 5.42 (t, 1H, *J* = 6.8 Hz), 3.81 (s, 3H), *3.80 (s, 3H), *2.18 (q, 2H, *J* = 7.3 Hz), 2.00 (s, 3H), 1.94-2.02 (m, 2H), 1.20-1.36 (4H, m), *0.92 (t, 3H, *J* = 7.3 Hz), 0.83 (t, 3H, *J* = 7.3 Hz) (**E* isomer); ¹³C{¹H} NMR (CDCl₃, 100 MHz): δ 158.0, 135.2, 134.5, 129.0, 127.5, 113.3, 55.1, 32.4, 29.7, 25.6, 22.3, 14.0; HRMS (EI): *m/z* [M]⁺ Calcd for C₁₄H₂₀O⁺ 204.1509, Found: 204.1493. *Z*-Stereochemistry was determined by ¹H NMR NOE measurement.

Z-2-(4-Chlorophenyl)-2-heptene (5c): (Scheme 3) (Procedure A) 86% yield (0.054 g, *Z:E* = 94:6) as colorless oil. ¹H NMR (CDCl₃, 400 MHz): *Z*: δ 7.29 (d, 2H, *J* = 8.2 Hz), 7.10 (d, 2H, *J* = 8.2 Hz), *5.77 (t, 1H, *J* = 7.1 Hz), 5.46 (t, 1H, *J* = 7.3 Hz), *2.19 (q, 2H, *J* = 7.0 Hz), 1.99 (s, 3H), 1.94 (q, 2H, *J* = 7.2 Hz), 1.20-1.36 (m, 4H), *0.93 (t, 3H, *J* = 7.1 Hz), 0.83 (t, 3H, *J* = 6.9 Hz) (**E* isomer); ¹³C{¹H} NMR (CDCl₃, 100 MHz): δ 140.6, 134.7, 132.0, 129.4, 128.6, 128.4, 32.2, 28.8, 25.4, 22.3, 13.9; HRMS (EI): *m/z* [M]⁺ Calcd for C₁₃H₁₇Cl⁺ 208.1013, Found: 208.1021. *Z*-Stereochemistry was determined by ¹H NMR NOE measurement.

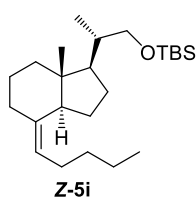
Z-2-(4-Bromophenyl)-2-heptene (5d): (Scheme 3) (Procedure A) 89% yield (0.068 g, *Z:E* = 93:7) as colorless oil. ¹H NMR (CDCl₃, 400 MHz): *Z*: δ 7.42-7.46 (m, 2H), 7.03-7.07 (m, 2H), *5.77 (tq, 1H, *J* = 7.1, 1.4 Hz), 5.47 (tq, 1H, *J* = 7.3, 1.4 Hz), *2.18 (q, 2H, *J* = 7.0 Hz), 1.99 (q, 3H, *J* = 1.4 Hz), 1.94 (q, 2H, *J* = 7.3 Hz), 1.20-1.34 (m, 4H), *0.93 (t, 3H, *J* = 7.1 Hz), 0.83 (t, 3H, *J* = 7.1 Hz) (**E* isomer); ¹³C{¹H} NMR (CDCl₃, 100 MHz): δ 141.1, 134.7, 131.1, 129.7, 128.6, 120.2, 32.2, 28.8, 25.3, 22.3, 13.9; HRMS (EI): *m/z* [M]⁺ Calcd for C₁₃H₁₇Br⁺ 252.0508, Found: 252.0492. *Z*-Stereochemistry was determined by ¹H NMR NOE measurement.

Z-3-Phenyl-3-octene (5e): (Scheme 3) (Procedure A) 92% yield (0.052 g, *Z:E* = 98:2) as colorless oil. ¹H NMR (CDCl₃, 400 MHz): *Z*:⁶ δ 7.29-7.35 (m, 2H), 7.20-7.25 (m, 1H), 7.13 (d, 2H, *J* = 7.8 Hz), *5.63 (t, 1H, *J* = 7.2 Hz), 5.41 (t, 1H, *J* = 7.6 Hz), *2.51 (q, 2H, *J* = 7.8 Hz), 2.33 (q, 2H, *J* = 7.6 Hz), 1.91 (q, 2H, *J* = 7.2 Hz), 1.19-1.34 (m, 4H), 0.95 (t, 3H, *J* = 7.4 Hz), 0.82 (t, 3H, *J* = 7.1 Hz) (**E* isomer⁶); *Z*-Stereochemistry was determined by ¹H NMR NOE measurement.

Z-1,2-Diphenyl-2-heptene (5f): (Scheme 3) (Procedure A) 52% yield (0.039 g, *Z:E* = 94:6) as colorless oil prepared by the same as **5h**. ¹H NMR (CDCl₃, 400 MHz): *Z*:¹⁰ δ 7.02-7.27 (m, 10H), *5.98 (t, 1H, *J* = 7.3 Hz), 5.47 (t, 1H, *J* = 7.3 Hz), *3.88 (s, 2H), 3.62 (s, 2H), *2.25 (q, 2H, *J* = 7.2 Hz), 1.96 (q, 2H, *J* = 7.2 Hz), 1.19-1.35 (m, 4H), *0.91 (t, 3H, *J* = 7.1 Hz), 0.82 (t, 3H, *J* = 7.1 Hz) (**E* isomer¹⁰).

Z-2-Cyclohexyl-2-heptene (5g): (Scheme 3) (Procedure A) Using **3f** instead of **3b**, **5g** was obtained in 91% yield (0.049 g, *Z:E* = 95:5) as colorless oil. ¹H NMR (CDCl₃, 400 MHz): *Z*: δ *5.11 (t, 1H, *J* = 6.9 Hz), 5.05 (dt, 1H, *J* = 0.9, 7.1 Hz), 2.35-2.44 (m, 1H), 1.99 (q, 2H, *J* = 6.7 Hz), 1.60 (d, 3H, *J* = 0.9 Hz), 1.40-1.50 (m, 2H), 1.09-1.36 (m, 9H), 0.86-0.92 (m, 3H), (**E* isomer¹¹); ¹³C{¹H} NMR (CDCl₃, 100 MHz): δ 140.0, 124.4, 39.7, 32.5, 31.1, 27.0, 26.7, 26.3, 22.4, 19.6, 14.0; HRMS (EI): *m/z* [M]⁺ Calcd for C₁₃H₁₈⁺ 174.1403, Found: 174.1391. HRMS (EI): *m/z* calcd for C₁₃H₂₄⁺ (M⁺) 180.1873, found: 180.1864. *Z*-Stereochemistry was determined by ¹H NMR NOE measurement.

Z-2-Methyl-1-pentylidenecyclohexane (5h): (Scheme 3) (Procedure A) 97% yield (0.048 g, *Z:E* = 95:5) as colorless oil. ¹H NMR (CDCl₃, 400 MHz): *Z*: δ 5.01 (dt, 1H, *J* = 1.4, 7.3 Hz), 2.85 (quin, 1H, *J* = 6.9 Hz), 2.17-2.28 (m, 1H), 1.88-2.06 (m, 3H), 1.74 (brd, 1H, *J* = 11.9 Hz), 1.41-1.64 (m, 4H), 1.17-1.36 (m, 5H), 1.04 (d, 3H, *J* = 6.9 Hz), *1.01 (d, 3H, *J* = 6.9 Hz), 0.89 (t, 3H, *J* = 6.6 Hz) (**E* isomer¹²); ¹³C{¹H} NMR (CDCl₃, 100 MHz): δ 142.9, 121.5, 33.3, 32.5, 32.5, 30.1, 28.7, 26.5, 22.4, 21.0, 18.2, 14.0; HRMS (EI): *m/z* [M]⁺ Calcd for C₁₃H₁₈⁺ 174.1403, Found: 174.1391. HRMS (EI): *m/z* calcd for C₁₂H₂₂⁺ (M⁺) 166.1716, found: 166.1703. *Z*-Stereochemistry was determined by ¹H NMR NOE measurement.



Z-5i: (Scheme 3) (Procedure A) 82% yield (0.093 g, *Z:E* = 98:2) as colorless oil. ¹H NMR (CDCl₃, 400 MHz): *Z*: δ 5.20 (dt, 1H, *J* = 1.8, 7.1 Hz), *5.10 (t, 1H, *J* = 7.4 Hz), 3.66 (dd, 1H, *J* = 3.7, 9.6 Hz), *3.61 (dd, 1H, *J* = 4.1, 9.6 Hz), 3.35 (dd, 1H, *J* = 8.2, 9.6 Hz), *3.31 (dd, 1H, *J* = 7.7, 9.6 Hz), 2.42 (dd, 1H, *J* = 7.8, 11.4 Hz), 2.12-2.21 (m, 1H), 1.83-2.03 (m, 4H), 1.68-1.75 (m, 1H), 1.25-1.62 (m, 12H), 0.97 (d, 3H, *J* = 6.4 Hz), 0.95 (s, 3H), 0.90 (s, 9H), 0.87-0.91 (m, 3H),

0.04 (s, 6H) (**E* isomer); ¹³C{¹H} NMR (CDCl₃, 100 MHz): δ 138.9, 124.7, 66.8, 53.5, 48.7, 43.9, 38.7, 36.9, 32.7, 32.2, 29.4, 28.1, 26.7, 26.0, 23.4, 22.4, 21.7, 18.4, 18.0, 14.1, -5.4; HRMS (EI): *m/z* [M]⁺ Calcd for C₁₃H₁₈⁺ 174.1403, Found: 174.1391. HRMS (EI): *m/z* calcd for C₂₄H₄₆OSi⁺ (M⁺) 378.3312, found: 378.3296. *Z*-Stereochemistry was determined by ¹H NMR NOE measurement.

Procedure C: Z-3,4-Dimethyl-4-nonene (5j): (Scheme 3) LiHMDS was prepared from HMDS (0.096 mL, 0.45 mmol) and *n*-BuLi hexane solution (0.29 mL, 0.45 mmol) in THF (0.9 mL) at 0 °C. A solution of **3f** (0.093 g, 0.30 mmol) in THF (1.0 mL) was treated with LiHMDS (0.33 mmol) for 1 min at -78 °C, and 3-methyl-2-pentanone **4j** (0.037 mL, 0.30 mmol) was added. After 30 min and 1 h, LiHMDS (0.12 mmol) was added respectively and the reaction was quenched with NH₄Cl aq. at -78 °C after 2 h. The mixture was extracted twice with AcOEt (12 and 5 mL) and the combined extracts were washed with brine, dried (MgSO₄), and concentrated. Column chromatography (hexane) provided **5j** (0.038 g, 82%) (*Z:E* = 94:6) as colorless oil. ¹H NMR (CDCl₃, 400 MHz): *Z*: δ 5.12 (t, 1H, *J* = 7.1 Hz), 2.52 (sextet, 1H, *J* = 7.1 Hz), 1.94-2.04 (m, 2H), 1.54 (s, 3H), *1.49 (s, 3H), 1.22-1.38 (m, 6H), 0.94 (d, 3H, *J* = 6.9 Hz), 0.89 (t, 3H, *J* = 6.9 Hz), 0.80 (t, 3H, *J* = 7.3 Hz) (**E* isomer); ¹³C{¹H} NMR (CDCl₃, 100 MHz): δ 138.7, 125.6, 35.6, 32.4, 27.6, 27.0, 22.4, 19.1, 17.9, 14.0, 12.3; HRMS (EI): *m/z* [M]⁺ Calcd for C₁₃H₁₈⁺ 174.1403, Found: 174.1391. HRMS (EI): *m/z* calcd for C₁₁H₂₂⁺ (M⁺) 154.1716, found: 154.1714. *Z*-Stereochemistry was determined by ¹H NMR NOE measurement.

Z-2,4-Dimethyl-4-nonene (5k): (Scheme 3) (Procedure A) Using **3d** instead of **3b**, **5k** was obtained in 68% yield (0.032 g, Z:E = 93:7) as colorless oil. ¹H NMR (CDCl₃, 400 MHz): Z: δ 5.17 (t, 1H, J = 7.1 Hz), *5.09 (t, 1H, J = 6.6 Hz), 1.97 (q, 2H, J = 6.7 Hz), 1.89 (d, 2H, J = 7.3 Hz), 1.70-1.84 (m, 1H), 1.65 (q, 3H, J = 0.9 Hz), *1.56 (s, 3H), 1.25-1.35 (m, 4H), 0.89 (t, 3H, J = 6.9 Hz), 0.86 (d, 6H, J = 6.4 Hz), *0.83 (d, 3H, J = 6.9 Hz) (*E isomer¹³); ¹³C{¹H} NMR (CDCl₃, 100 MHz): δ 134.2, 126.4, 41.1, 32.3, 27.7, 26.6, 23.7, 22.5, 22.5, 14.0; Z-Stereochemistry was determined by ¹H NMR NOE measurement.

Z-6-Methyl-5-dodecene (5l): (Scheme 3) (Procedure A) Using **3d** instead of **3b** and LiHMDS (1.1 + 0.4 eq), **5l** was obtained in 91% yield (0.050 g, Z:E = 90:10) as colorless oil. ¹H NMR (CDCl₃, 400 MHz): Z: δ 5.11 (t, 1H, J = 7.1 Hz), 1.93-2.02 (m, 4H), 1.67 (q, 3H, J = 1.4 Hz), *1.58 (s, 3H), 1.23-1.39 (m, 12H), 0.85-0.92 (m, 6H) (*E isomer¹⁴); ¹³C{¹H} NMR (CDCl₃, 100 MHz): δ 135.4, 125.2, 32.3, 31.9, 31.8, 29.3, 28.0, 27.5, 23.4, 22.7, 22.4, 14.1, 14.0; HRMS (EI): m/z [M]⁺ Calcd for C₁₃H₁₈⁺ 174.1403, Found: 174.1391. HRMS (EI): m/z calcd for C₁₃H₂₆⁺ (M⁺) 182.2029, found: 182.2034. Z-Stereochemistry was determined by ¹H NMR NOE measurement.

1,3,3-Trimethyl-2-[(1Z,3E)-3-methyl-1,3-octadien-1-yl]cyclohexene (5m): (Scheme 3) (Procedure A) Using **3d** instead of **3b**, **5m** was obtained in 76% yield (0.056 g, Z:E = 95:5) as colorless oil. ¹H NMR (CDCl₃, 400 MHz): Z: δ 6.41 (d, 1H, J = 16.0 Hz), 6.07 (d, 1H, J = 16.0 Hz), *5.41 (t, 1H, J = 7.3 Hz), 5.33 (t, 1H, J = 7.4 Hz), 2.15 (q, 2H, J = 6.9 Hz), 2.01 (t, 2H, J = 6.2 Hz), 1.85 (s, 3H), *1.78 (s, 3H), 1.71 (s, 3H), *1.69 (s, 3H), 1.58-1.66 (m, 2H), 1.44-1.48 (m, 2H), 1.29-1.40 (m, 4H), 1.02 (s, 6H), 0.86-0.92 (m, 3H) (*E isomer¹⁵).

Procedure A': Z-2-*t*-Butyldimethylsilyloxy-3-methyl-3-octene (5n): (Scheme 3) To a solution of **3d** (0.078 g, 0.30 mmol), 3-*t*-butyldimethylsilyloxy-2-butanone **4n** (0.061 g, 0.30 mmol), and LiCl (0.013 g, 0.30 mmol) in THF (1.0 mL) under argon was added LiHMDS (0.33 mmol) (see Procedure A) at -78 °C. After 30 min and 1 h, LiHMDS (0.12 mmol) was added respectively and the reaction was allowed to warm to -40 °C over 1 h and quenched with aq. NH₄Cl. The mixture was extracted twice with AcOEt (12 and 5 mL) and the combined extracts were washed with brine, dried (MgSO₄), and concentrated. Column chromatography (hexane:AcOEt = 10:1) provided **5n** in 67% yield (0.051 g, 92%) (Z:E = 95:5) as colorless oil. ¹H NMR (CDCl₃, 400 MHz): Z: δ *5.31 (t, 1H, J = 7.3 Hz), 5.03 (t, 1H, J = 7.3 Hz), 4.71 (q, 1H, J = 6.4 Hz), 1.90-2.12 (m, 2H), 1.66 (q, 3H, J = 1.2 Hz), 1.28-1.34 (m, 4H), 1.16 (d, 3H, J = 6.4 Hz), 0.87-0.91 (m, 3H), 0.88 (s, 9H), 0.04 (s, 3H), 0.01 (s, 3H) (*E isomer); ¹³C{¹H} NMR (CDCl₃, 100 MHz): δ 139.0, 124.3, 66.4, 32.2, 26.9, 25.8, 22.8, 22.4, 18.2, 17.3, 14.0, -4.9; HRMS (EI): m/z [M]⁺ Calcd for C₁₃H₁₈⁺ 174.1403, Found: 174.1391. HRMS (EI): m/z calcd for C₁₅H₃₂O₂Si⁺ (M⁺) 256.2217, found: 256.2193. Z-Stereochemistry was determined by ¹H NMR NOE measurement.

[The olefination reaction of sulfone reagents **1** and **7** with ketones **4**]

Procedure A'': Z-2-Phenyl-2-butene (8a) (entry 5 in Table 2) LiHMDS was prepared from HMDS (0.125 mL, 0.57 mmol) and *n*-BuLi hexane solution (1.56 M) (0.365 mL, 0.57 mmol) in THF (0.9 mL) at 0 °C. To a solution of **1d** (0.066 g, 0.30 mmol) and acetophenone **4a** (0.035 mL, 0.30 mmol) in THF (1.0 mL) under argon was added

LiHMDS (0.33 mmol) at -40 °C. After 30 min and 1 h, LiHMDS (0.12 mmol) was added respectively and the reaction was quenched with NH₄Cl aq. after 1.5 h. The mixture was extracted twice with AcOEt (12 and 5 mL) and the combined extracts were washed with brine, dried (MgSO₄), and concentrated. Column chromatography (hexane) provided **8a** (0.029 g, 71%) (*Z:E* = 97:3) as colorless oil. ¹H NMR (CDCl₃, 400 MHz): *Z*:¹⁶ δ 7.18-7.38 (m, 5H), *5.86 (q, 1H, *J* = 6.9 Hz), 5.56 (q, 1H, *J* = 6.9 Hz), 2.03 (s, 3H), *1.80 (d, 3H, *J* = 6.9 Hz), 1.57 (d, 3H, *J* = 6.9 Hz) (**E* isomer¹⁶).

Z-2-(4-Methoxyphenyl)-2-butene (8b): (entry 6 in Table 2) (Procedure A'') 74% yield (0.036 g, *Z:E* = 95:5) as colorless oil. ¹H NMR (CDCl₃, 400 MHz): *Z*:¹⁷ δ *7.28-7.32 (m, 2H), 7.12-7.16 (m, 2H), 6.86-6.90 (m, 2H), *5.86 (qq, 1H, *J* = 6.9, 1.4 Hz), 5.52 (qq, 1H, *J* = 7.0, 1.5 Hz), 3.82 (s, 3H), *3.80 (s, 3H), 2.00 (quin, 3H, *J* = 1.5 Hz), *1.78 (dq, 3H, *J* = 6.9, 0.9 Hz), 1.61 (dq, 3H, *J* = 7.3, 1.5 Hz) (**E* isomer).

Z-2-(4-Bromophenyl)-2-butene (8d): (entry 7 in Table 2) (Procedure A'') 77% yield (0.049 g, *Z:E* = 99:1) as pale yellow oil. ¹H NMR (CDCl₃, 400 MHz): *Z*:¹⁸ δ 7.45 (d, 2H, *J* = 8.2 Hz), 7.07 (d, 2H, *J* = 8.2 Hz), *5.86 (q, 1H, *J* = 6.9 Hz), 5.58 (q, 1H, *J* = 7.0 Hz), 1.99 (s, 3H), *1.78 (d, 3H, *J* = 6.9 Hz), 1.58 (d, 3H, *J* = 6.4 Hz) (**E* isomer¹⁸). ¹³C{¹H} NMR (CDCl₃, 100 MHz): δ 140.7, 135.6, 131.1, 129.8, 122.3, 120.2, 25.2, 14.8; HRMS (EI): *m/z* [M]⁺ Calcd for C₁₃H₁₈⁺ 174.1403, Found: 174.1391. HRMS (EI): *m/z* calcd for C₁₀H₁₁Br⁺ (M⁺) 210.0039, found: 210.0023. *Z*-Stereochemistry was determined by ¹H NMR NOE measurement.

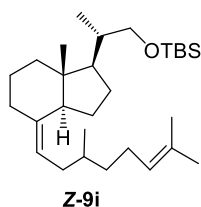
1,3,3-Trimethyl-2-[(1*E*,3*Z*)-3-methyl-1,3-pentadien-1-yl]cyclohexene (8m): (entry 9 in Table 2) (Procedure A'') using 1.1+0.6x2 eq of base instead of 1.1+0.4x2 eq 77% yield (0.047 g, *Z:E* = 98:2) as colorless oil. ¹H NMR (CDCl₃, 400 MHz): *Z*: δ 6.44 (d, 1H, *J* = 16.3 Hz), 6.08 (d, 1H, *J* = 16.3 Hz), *5.50 (q, 1H, *J* = 7.0 Hz), 5.39 (q, 1H, *J* = 7.0 Hz), 2.01 (t, 2H, *J* = 6.4 Hz), 1.84-1.87 (m, 3H), 1.71-1.74 (m, 6H), 1.59-1.66 (m, 2H), 1.45-1.49 (m, 2H), 1.02 (s, 6H), 0.86 (d, 3H, *J* = 7.2 Hz) (**E* isomer); ¹³C{¹H} NMR (CDCl₃, 100 MHz): *Z*:²⁰ δ 138.2, 133.2, 130.0, 128.6, *128.1, 126.7, *125.2, *123.9, 123.2, 39.5, 34.1, 32.9, 28.9, 21.7, 20.4, 19.3, *13.8, 13.0, *11.9 (**E* isomer²⁰); HRMS (EI): *m/z* [M]⁺ Calcd for C₁₃H₁₈⁺ 174.1403, Found: 174.1391. HRMS (EI): *m/z* calcd for C₁₃H₂₄⁺ (M⁺) 204.1873, found: 204.1866.

Z-1-Isopropyl-4-methyl-2-ethylidenecyclohexane (8o): (entry 10 in Table 2) (Procedure A'') using **1b** instead of **1d** 85% yield (0.042 g, *Z:E* = 99:1) as colorless oil. ¹H NMR (CDCl₃, 400 MHz): *Z*: δ 5.16 (dq, 1H, *J* = 1.8, 6.7 Hz), 2.36-2.43 (m, 1H), 2.16 (d, 1H, *J* = 10.5 Hz), 1.84-2.01 (m, 2H), 1.75 (tt, 1H, *J* = 13.7, 4.4 Hz), 1.45-1.66 (m, 6H), 1.15-1.22 (m, 1H), 0.94 (d, 3H, *J* = 6.4 Hz), 0.88 (d, 3H, *J* = 6.9 Hz), *0.84 (d, 3H, *J* = 6.9 Hz), 0.77 (d, 3H, *J* = 6.4 Hz) (**E* isomer¹⁹); ¹³C{¹H} NMR (CDCl₃, 100 MHz): δ 138.9, 118.5, 43.2, 29.3, 29.2, 26.9, 26.4, 22.8, 21.1, 20.9, 17.9, 12.9; HRMS (EI): *m/z* [M]⁺ Calcd for C₁₃H₁₈⁺ 174.1403, Found: 174.1391. HRMS (EI): *m/z* calcd for C₁₂H₂₂⁺ (M⁺) 166.1716, found: 166.1701.

Z-5,9-Dimethyl-2-phenyl-2,8-decadiene (9a): (Scheme 5) (Procedure A) 91% yield (0.067 g, *Z:E* = 97:3) as colorless oil. ¹H NMR (CDCl₃, 400 MHz): *Z*: δ *5.79 (t, 1H, *J* = 7.3 Hz), 5.47 (dt, 1H, *J* = 1.4, 7.3 Hz), 5.05 (t, 1H, *J*

= 7.1 Hz), 2.03 (q, 3H, $J = 1.4$ Hz), 1.76-2.02 (m, 4H), 1.67 (d, 3H, $J = 0.9$ Hz), 1.56 s, (s, 3H), 1.39-1.50 (m, 1H), 1.24-1.33 (m, 1H), 1.02-1.12 (m, 1H), *0.94 (d, 3H, $J = 6.9$ Hz), 0.83 (d, 3H, $J = 6.9$ Hz) (**E* isomer); $^{13}\text{C}\{^1\text{H}\}$ NMR (CDCl_3 , 100 MHz): δ 142.4, 136.7, 131.0, 128.0, 128.0, 126.5, 126.3, 124.9, 36.7, 36.1, 33.4, 25.8, 25.7, 25.6, 19.6, 17.6; HRMS (EI): m/z [M^+] Calcd for $\text{C}_{13}\text{H}_{18}^+$ 174.1403, Found: 174.1391. HRMS (EI): m/z calcd for $\text{C}_{18}\text{H}_{26}^+$ (M^+) 242.2029, found: 242.2017.

Z-3,7-Dimethyl-6-octen-1-ylidene-2-methylcyclohexane (9h): (Scheme 5) (Procedure A) 93% yield (0.065 g, *Z*:*E* = 99:1) as colorless oil. ^1H NMR (CDCl_3 , 400 MHz): *Z*: δ 5.10 (t, 1H, $J = 6.9$ Hz), 5.02 (t, 1H, $J = 7.3$ Hz), 2.80-2.89 (m, 1H), 2.23 (dt, 1H, $J = 2.3, 13.3$ Hz), 1.68 (s, 3H), 1.61 (s, 3H), 1.08-2.06 (m, 14H), 1.04 (d, 3H, $J = 7.3$ Hz), 0.86 (d, 3H, $J = 6.4$ Hz) (**E* isomer); $^{13}\text{C}\{^1\text{H}\}$ NMR (CDCl_3 , 100 MHz): δ 143.5, 130.9, 125.0, 120.1, 36.9, 36.7, 34.0, 33.3, 33.3, 32.7, 30.1, 28.8, 25.7, 21.1, 19.7, 18.1, 17.6; HRMS (EI): m/z [M^+] Calcd for $\text{C}_{13}\text{H}_{18}^+$ 174.1403, Found: 174.1391. HRMS (EI): m/z calcd for $\text{C}_{17}\text{H}_{30}^+$ (M^+) 234.2342, found: 234.2334.



Z-9i: (Scheme 5) (Procedure A) 61% yield (0.071 g, *Z*:*E* = 99:1) from **4i** (0.084 g, 0.26 mmol) as colorless oil. ^1H NMR (CDCl_3 , 400 MHz): *Z*: δ 5.19 (t, 1H, $J = 7.3$ Hz), 5.10 (t, 1H, $J = 7.1$ Hz), 3.66 (dd, 1H, $J = 3.7, 9.6$ Hz), 3.35 (t, 1H, $J = 8.7$ Hz), 2.42 (t, 1H, $J = 8.7$ Hz), 2.13-2.23 (m, 1H), 1.68-1.98 (m, 6H), 1.68 (s, 3H), 1.60 (s, 3H), 1.25-1.60 (m, 10H), 1.06-1.18 (m, 1H), *1.01 (d, 3H, $J = 6.4$ Hz), 0.97 (d, 1H, $J = 6.9$ Hz), 0.90 (s, 9H), 0.94 (s, 3H), 0.86 (dd, 3H, $J = 4.1, 6.4$ Hz), 0.04 (s, 6H) (**E* isomer); $^{13}\text{C}\{^1\text{H}\}$ NMR (CDCl_3 , 100 MHz): δ 139.6, 131.0, 125.0, 123.3, 66.8, 53.5, 48.7, 44.0, 38.7, 36.9, 34.4, 33.4, 33.4, 32.3, 29.4, 29.3, 28.1, 28.0, 26.0, 25.7, 23.4, 21.7, 19.7, 19.7, 18.4, 18.0, 17.7, -5.3; HRMS (EI): m/z [M^+] Calcd for $\text{C}_{13}\text{H}_{18}^+$ 174.1403, Found: 174.1391. HRMS (EI): m/z calcd for $\text{C}_{29}\text{H}_{54}\text{OSi}^+$ (M^+) 446.3938, found: 446.3937.

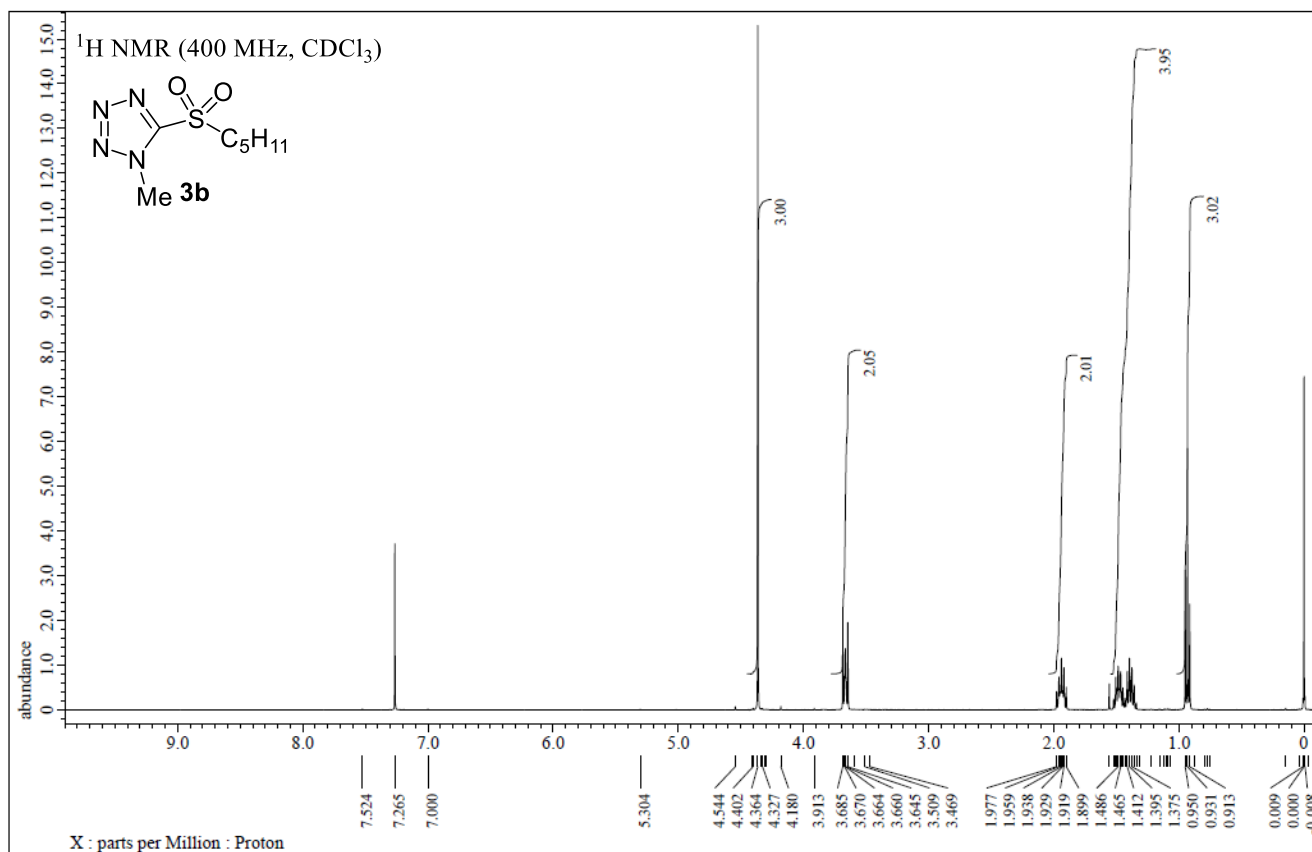
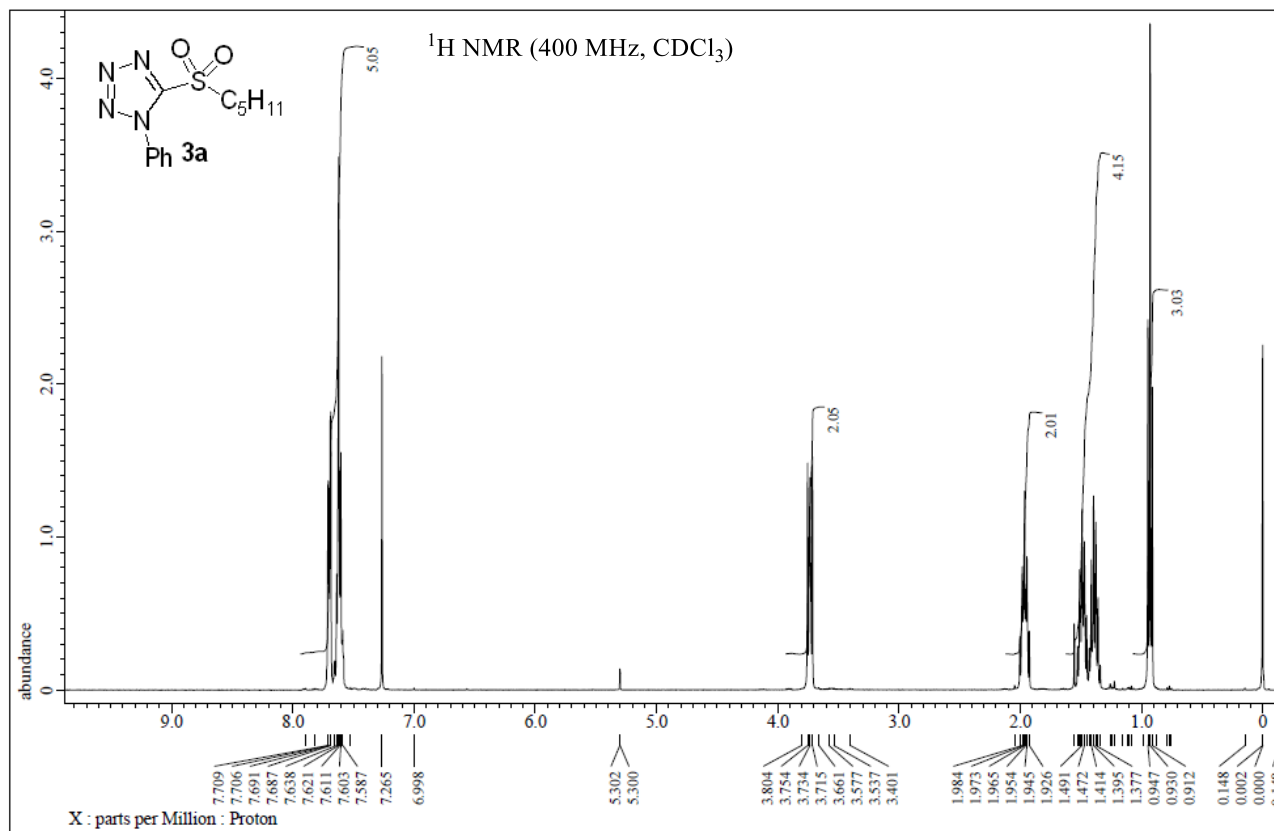
Z-2,6,9,10-Tetramethyl-2,8-dodecadiene (9j): (Scheme 5) (Procedure A) 87% yield (0.058 g, *Z*:*E* = 94:6) as colorless oil. ^1H NMR (CDCl_3 , 400 MHz): *Z*: δ 5.06-5.15 (m, 2H), 2.51 (sextet, 1H, $J = 7.1$ Hz), 1.77-2.05 (m, 4H), 1.68 (d, 3H, $J = 0.9$ Hz), 1.60 (s, 3H), 1.56 (d, 3H, $J = 0.9$ Hz), 1.24-1.48 (m, 4H), 1.07-1.18 (m, 1H), *0.97 (d, 3H, $J = 6.8$ Hz), 0.94 (d, 3H, $J = 6.9$ Hz), 0.86 (dd, 3H, $J = 3.0, 6.6$ Hz), 0.80 (dt, 3H, $J = 1.4, 7.3$ Hz) (**E* isomer); $^{13}\text{C}\{^1\text{H}\}$ NMR (CDCl_3 , 100 MHz): δ 139.3, 130.9, 125.0, 124.2, 37.0, 36.8, 35.6, 34.5, 33.4, 27.6, 25.6, 19.7, 19.6, 19.0, 18.0, 17.6, 12.3; HRMS (EI): m/z [M^+] Calcd for $\text{C}_{13}\text{H}_{18}^+$ 174.1403, Found: 174.1391. HRMS (EI): m/z calcd for $\text{C}_{16}\text{H}_{30}^+$ (M^+) 222.2342, found: 222.2330. *Z*-Stereochemistry was determined by ^1H NMR NOE measurement.

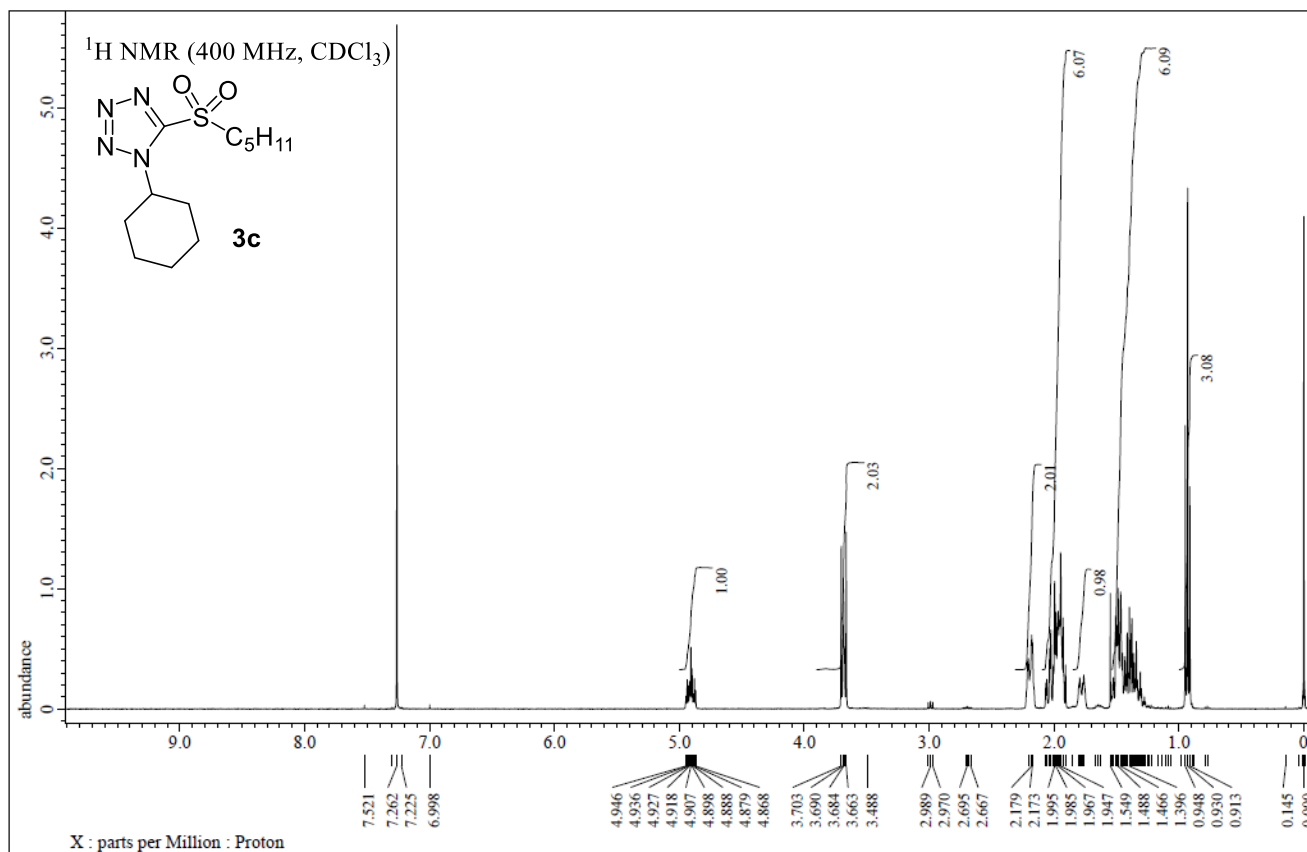
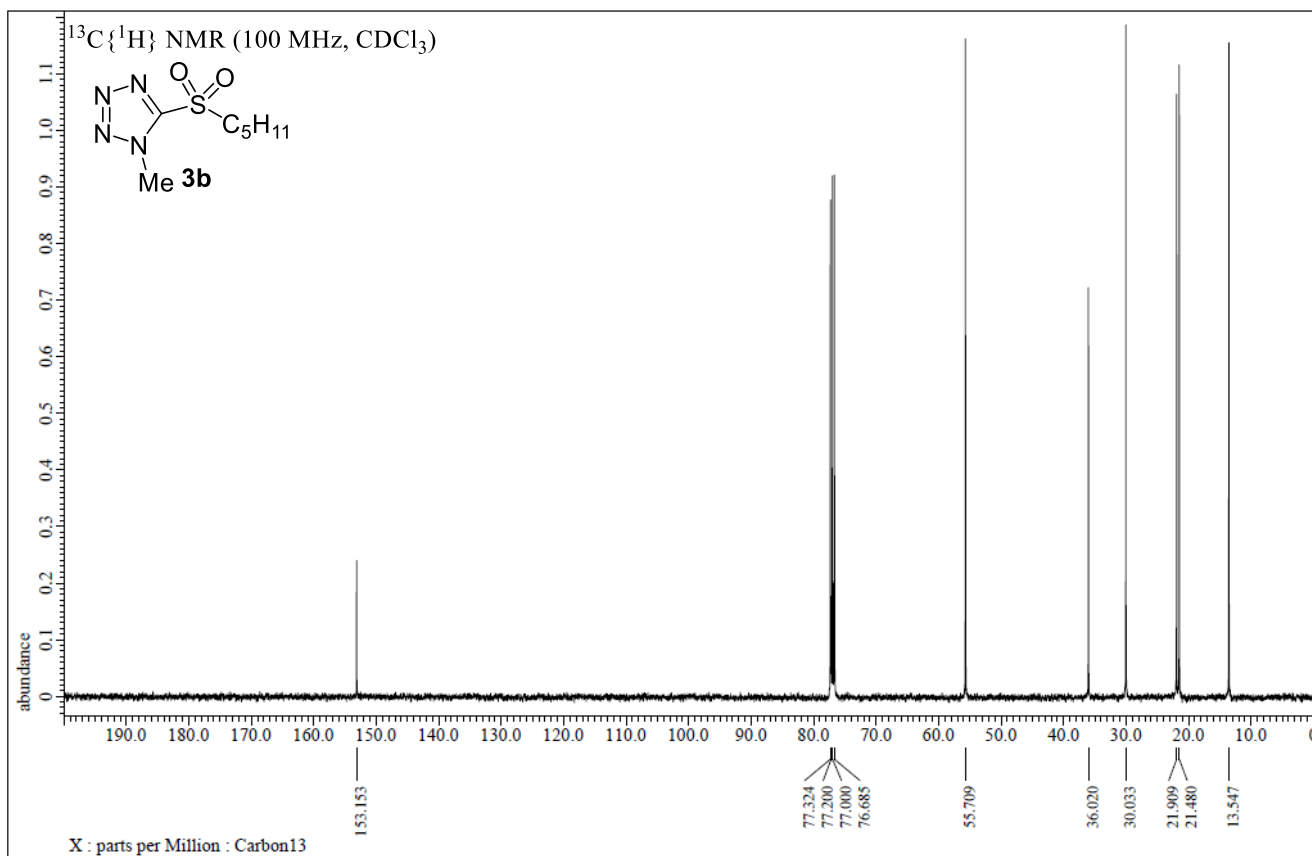
Intermediates 10 (Scheme 6) To a solution of **3b** (0.065 g, 0.30 mmol), acetophenone **4a** (0.035 mL, 0.30 mmol), and $\text{MgBr}_2 \cdot \text{Et}_2\text{O}$ (0.155 g, 0.60 mmol) in THF (1.0 mL) under argon was added LiHMDS (0.33 mmol) (see Procedure A) at -78 °C. After 30 min and 1 h, LiHMDS (0.12 mmol) was added respectively and the reaction was quenched with NH_4Cl aq. after 1.5 h. The mixture was extracted twice with AcOEt (10 and 5 mL) and the combined extracts were washed with brine, dried (MgSO_4), and concentrated. Column chromatography (hexane only to hexane:AcOEt = 4:1) provided **10** (0.059 g, 58%, dr = 63:37) and **5a** (0.006 g, 11%) (*Z*:*E* = 87:13). In addition, **3b** (20%) and **4a** (14%) were detected by the ^1H NMR spectra of the crude mixture. **10** as pale yellow oil. ^1H NMR

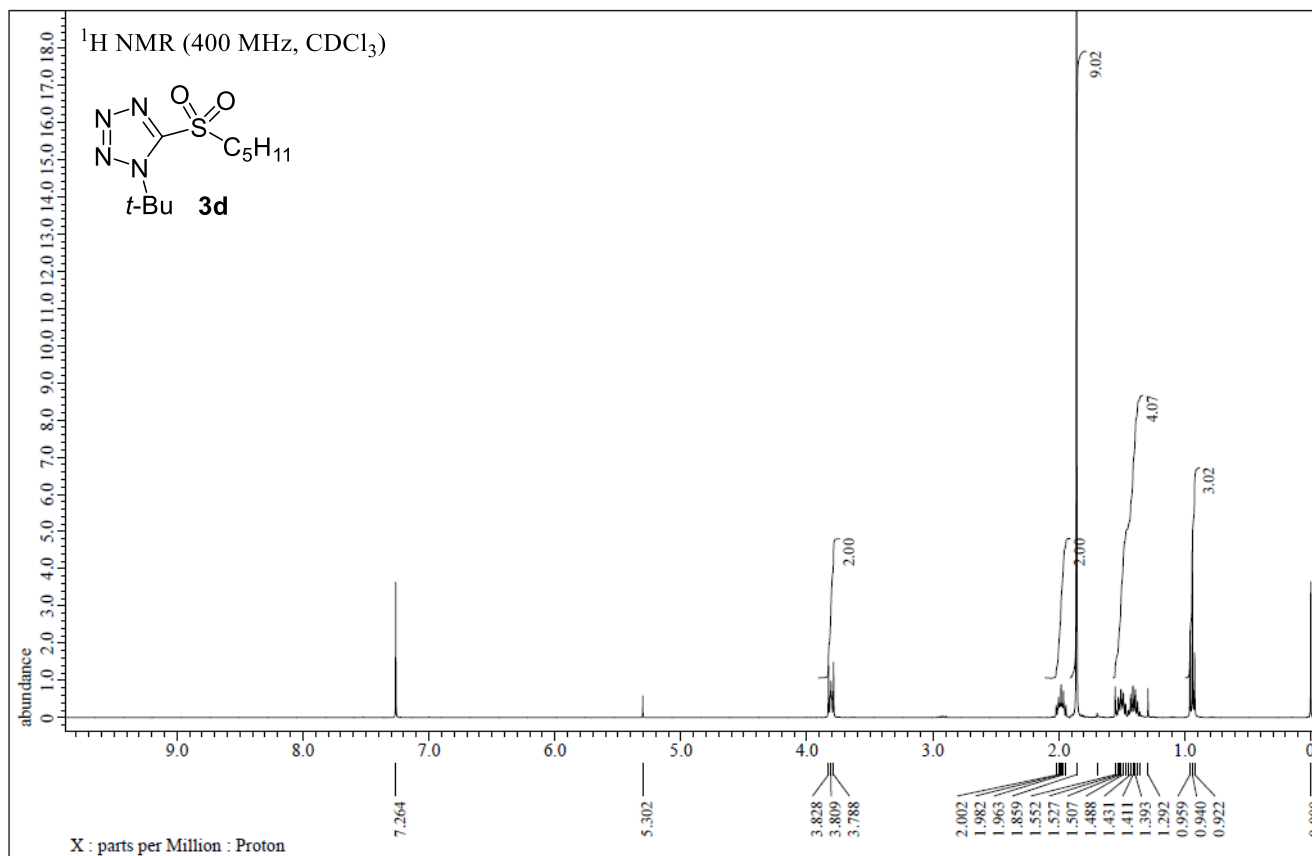
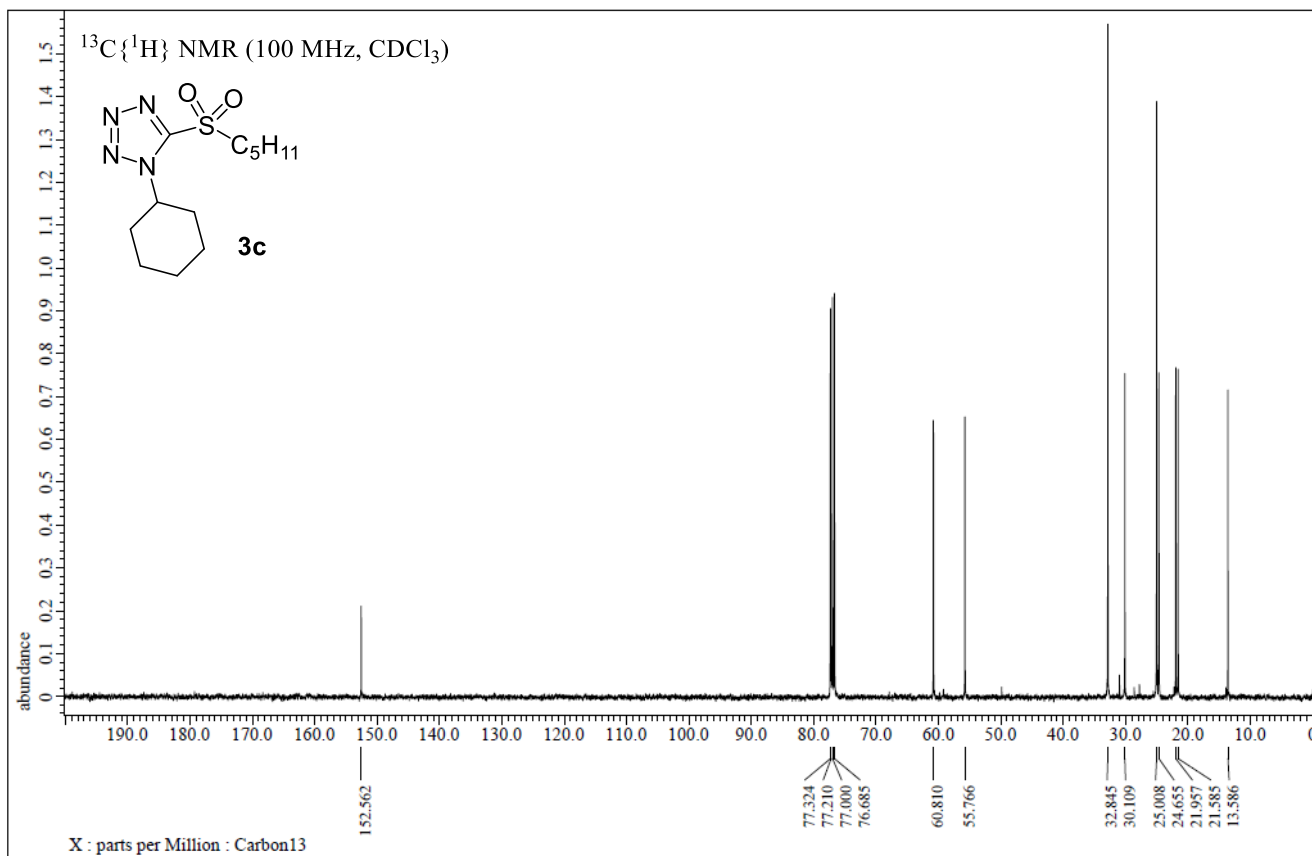
(CDCl₃, 400 MHz): δ *7.46 (d, 2H, $J = 7.8$ Hz), *7.36 (t, 2H, $J = 7.8$ Hz), 7.20-7.30 (m 5H), *4.34 (s, 3H), 4.16-4.21 (m, 1H), 4.03 (s, 3H), *3.33 (s, 1H), 3.11 (s, 1H), 1.08-2.18 (m, 6H), 1.75 (s, 3H), *1.71 (s, 3H), 0.80 (t, 3H, $J = 7.3$ Hz), *0.64 (t, 3H, $J = 7.3$ Hz) (*minor diastereomer); HRMS (EI): m/z [M]⁺ Calcd for C₁₃H₁₈⁺ 174.1403, Found: 174.1391. HRMS (ESI): m/z calcd for C₁₅H₂₂N₄NaO₃S⁺ [(M + Na)⁺] 361.1305, found: 361.1298.

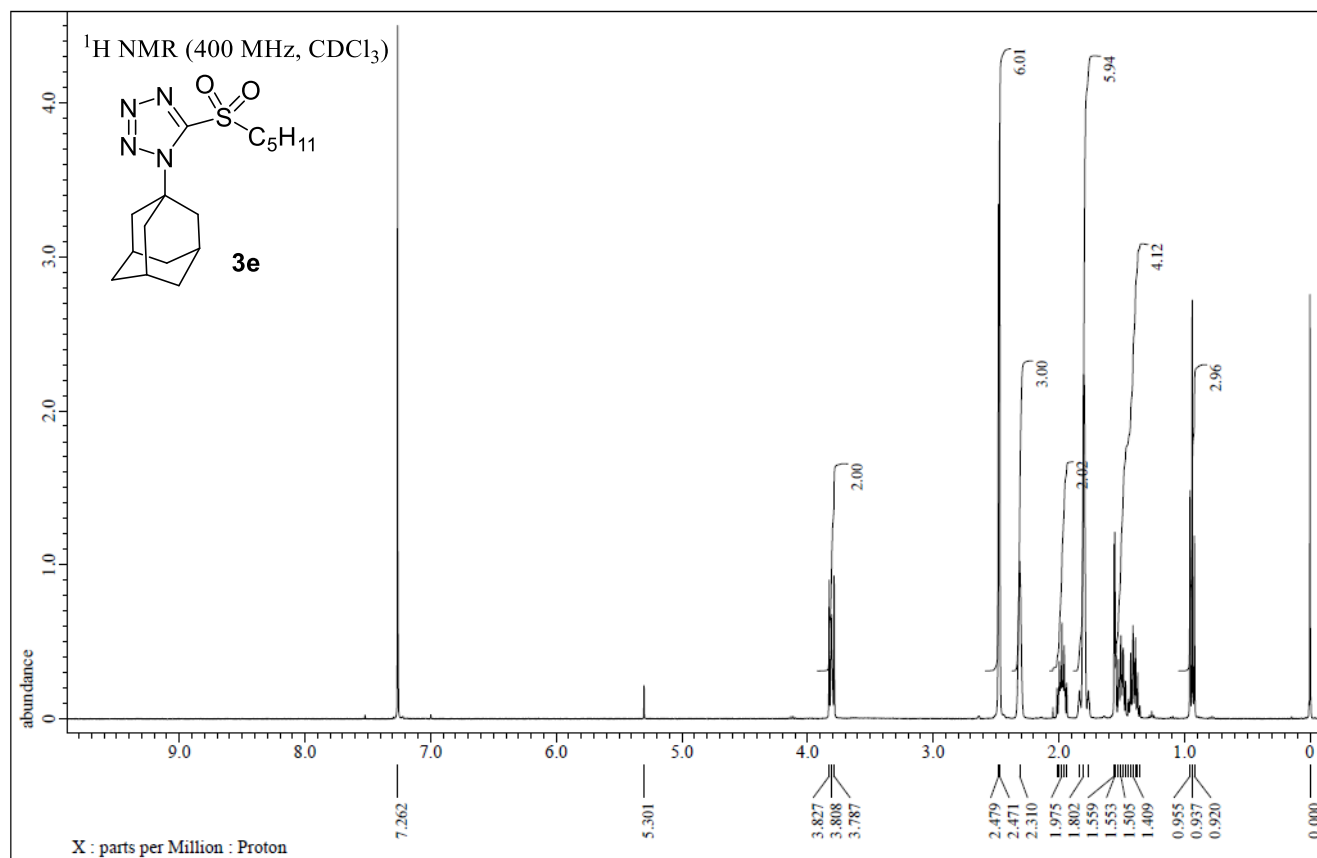
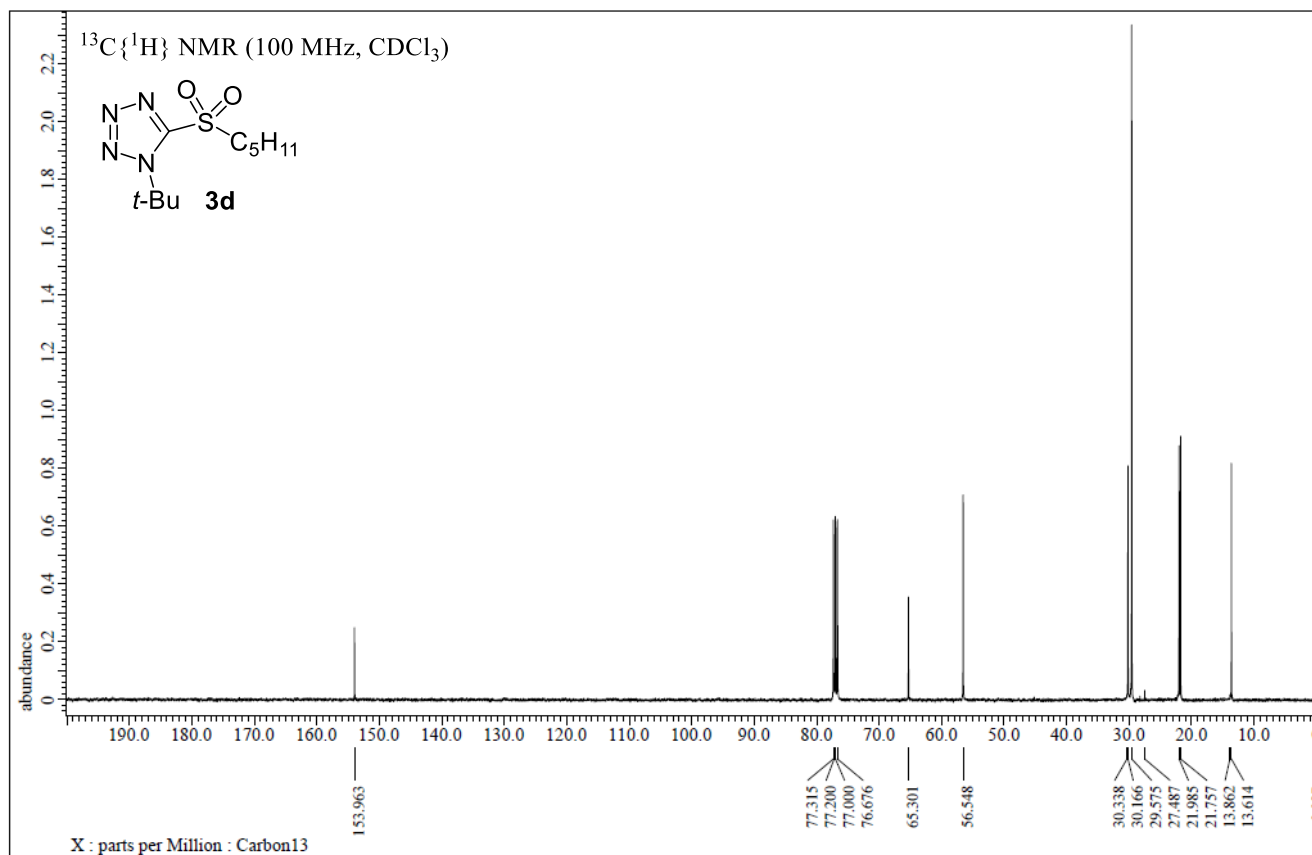
References:

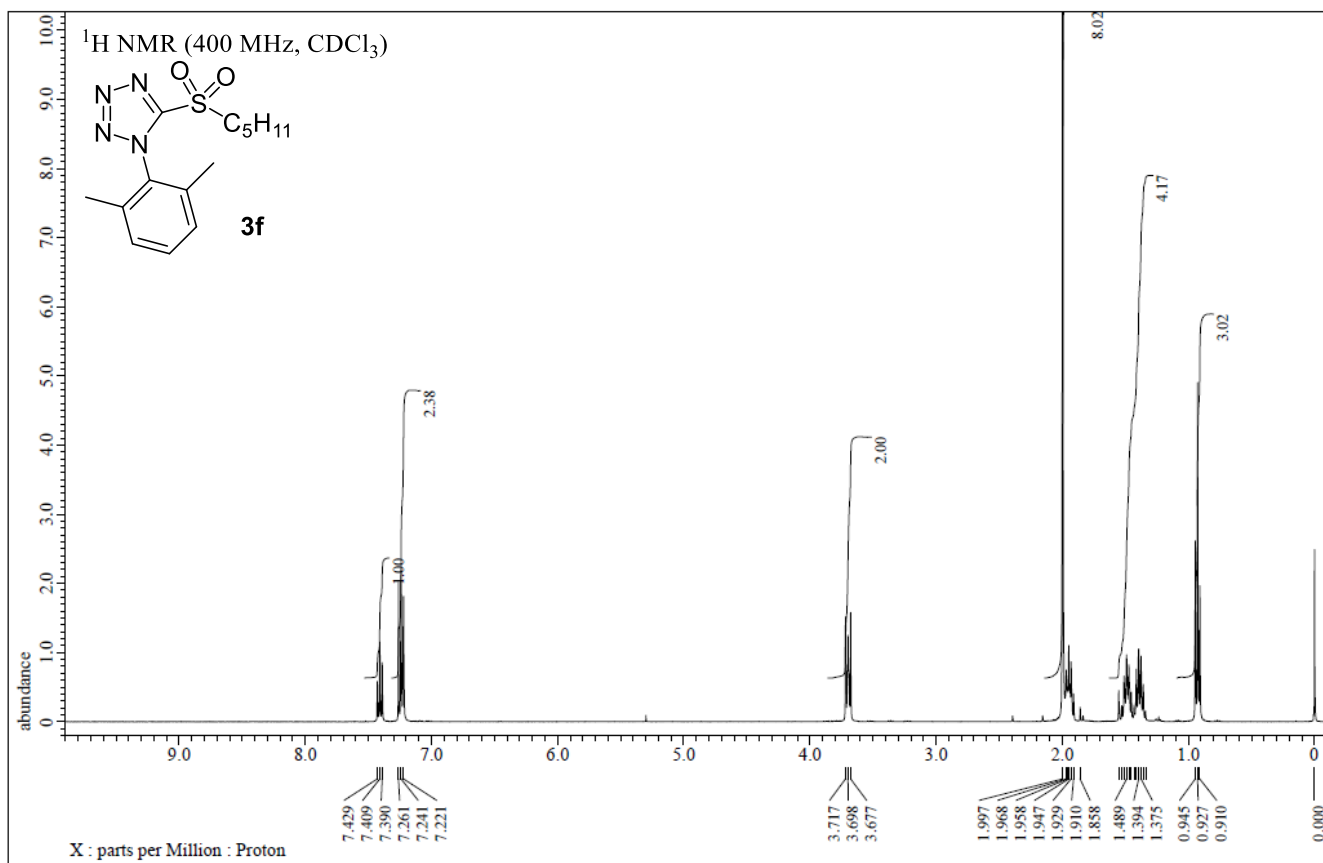
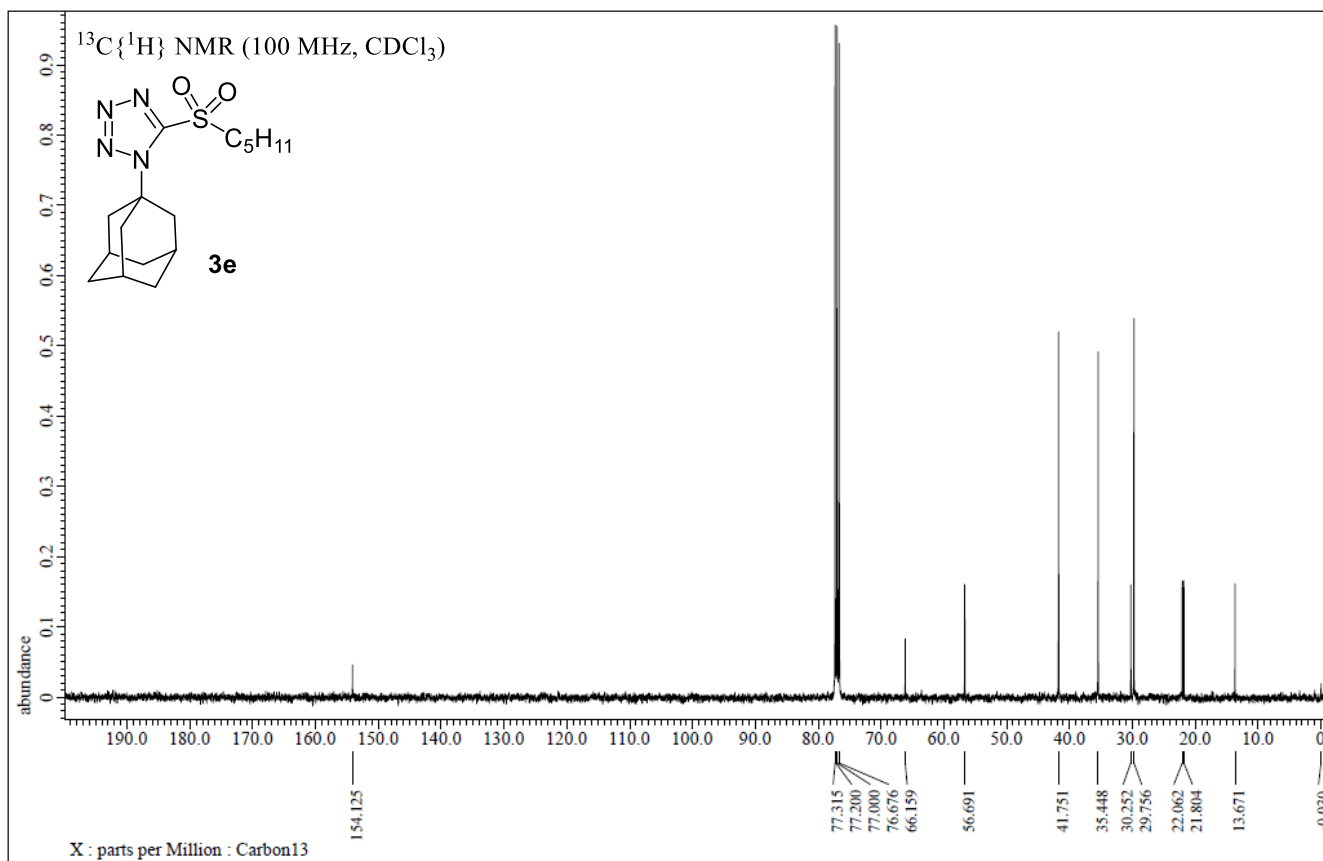
- 1) Quast, H.; Bieber, L. *Chem. Ber.* **1981**, *114*, 3253.
- 2) Lee, H. H.; Han, S.; Gyoung, Y. S.; Kim, Y.; Lee, K.; Jang, Y.; Lee, S. W. *Inorg. Chim. Acta* **2011**, *378*, 174.
- 3) ZarubaeV, V. V.; Golod, E. L.; Anfimov, P. M.; Shtro, A. A.; Saraev, V. V.; GavrilloV, A. S.; Logvinov, A. V.; Kiselev, O. I. *Bioorg. Med. Chem.* **2010**, *18*, 839.
- 4) Hohn, E.; Paleček, J.; Pietruszka, J.; Frey, W. *Eur. J. Org. Chem.* **2009**, 3765.
- 5) Ando, K.; Kawano, D.; Takama, D.; Semii, Y. *Tetrahedron Lett.* **2019**, *60*, 1566.
- 6) Aïssa, C. *J. Org. Chem.* **2006**, *71*, 360.
- 7) Sakaine, G.; Smits, G. *J. Org. Chem.* **2018**, *83*, 5323.
- 8) Guan, W.; Michael, A. K.; McIntosh, M. L.; Koren-Selfridge, L.; Scott, J. P.; Clark, T. B. *J. Org. Chem.* **2014**, *79*, 7199.
- 9) Chou, S. P.; Kuo, H.; Wang, C.; Tsai, C.; Sun, C. *J. Org. Chem.* **1989**, *54*, 868.
- 10) Huang, T.; Chang, H.; Wu, M.; Cheng, C. *J. Org. Chem.* **2002**, *67*, 99.
- 11) Bhalerao, U. T.; Rapoport, H. *J. Am. Chem. Soc.*, **1971**, *93*, 4835.
- 12) Montchamp, J.; Negishi, E. *J. Am. Chem. Soc.*, **1998**, *120*, 5345.
- 13) Schmidt, Y.; Breit, B. *Chem. Eur. J.* **2011**, *17*, 11780.
- 14) Xu, S.; Lee, C.; Rao, H.; Negishi, E. *Adv Synth Catal.* **2011**, *353*, 2981.
- 15) Lopez-Sanchez, C.; Hernandez-Cervantes, C.; Rosales, A.; Alvarez-Corral, M.; Munoz-Dorado, M.; Rodriguez-Garcia, I. *Tetrahedron* **2009**, *65*, 9542.
- 16) Fristrup, P.; Tanner, D.; Norrby, P. *Chirality* 2003, *15*, 360.
- 17) Yuan, D.; Tu, Y.; Fan, C. *J. Org. Chem.* **2008**, *73*, 7797.
- 18) Asano, M.; Tomita, R.; Koike, T.; Akita, M. *J. Fluorine Chem.* **2015**, *179*, 83.
- 19) Fernandes, R. A.; Chaudhari, D. A. *Eur. J. Org. Chem.* **2012**, 1945.
- 20) Rauchshwalbe, G.; Zellner, A.; Schlosser, M. *Eur. J. Org. Chem.* **2001**, 3903.
- 21) Englert, G. *Helv. Chim. Acta* **1975**, *58*, 2367.

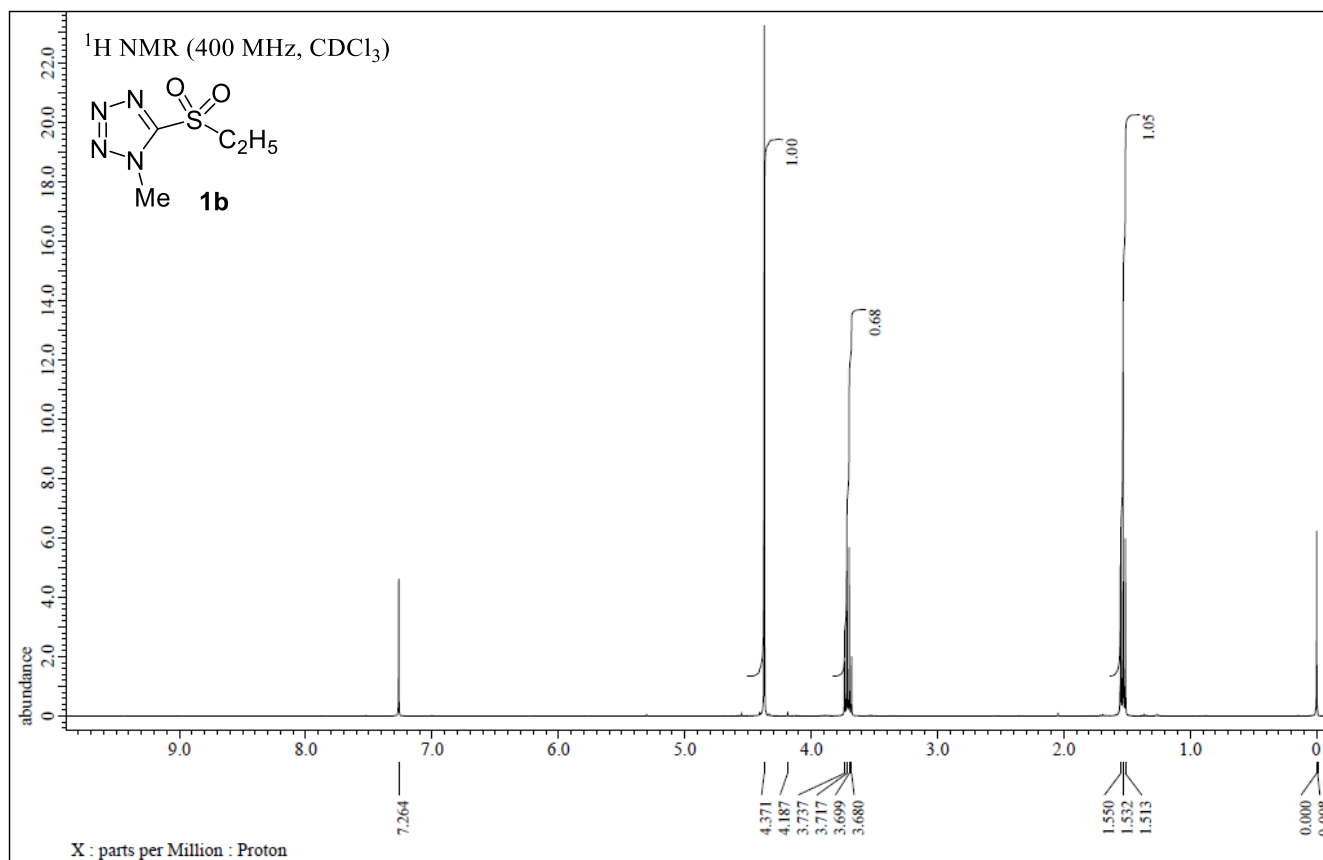
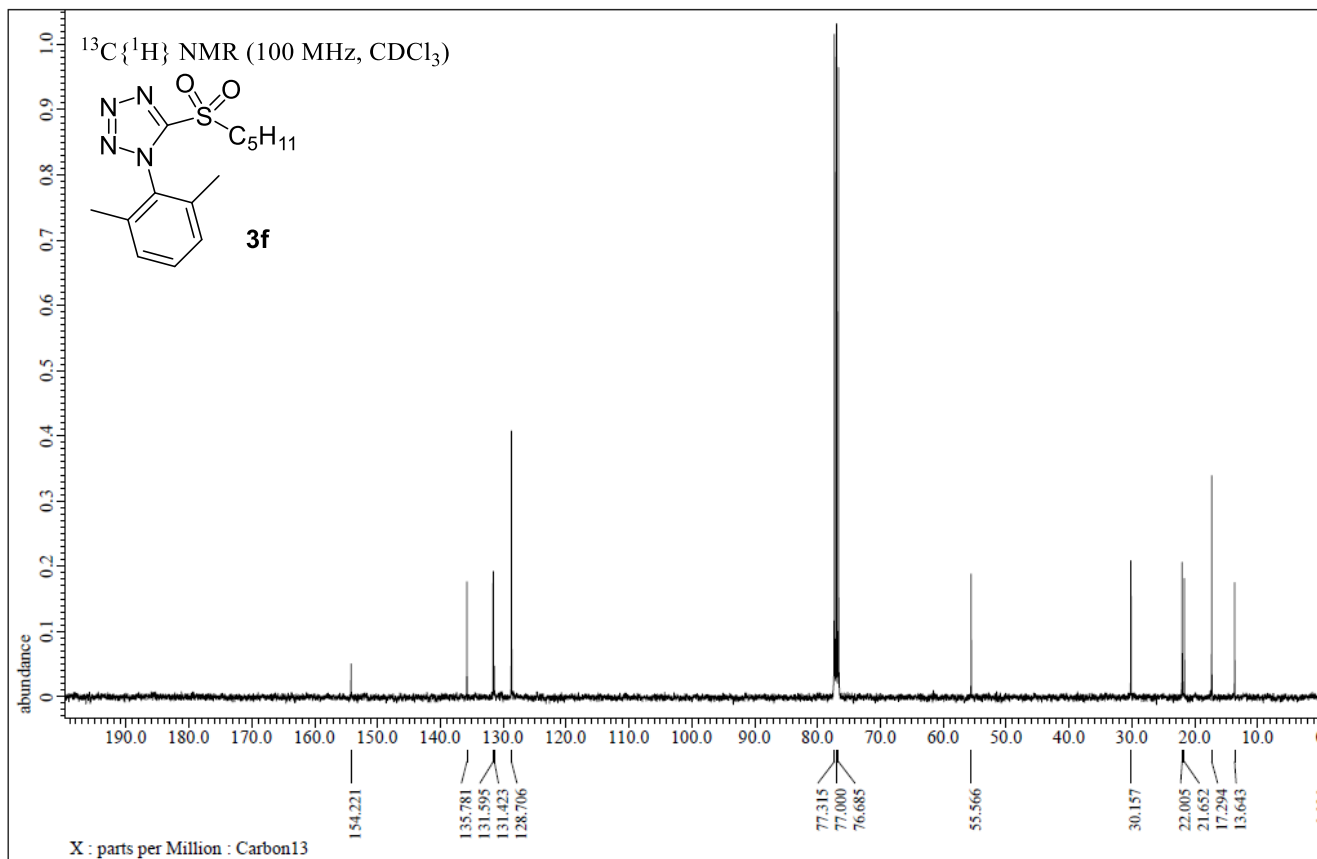


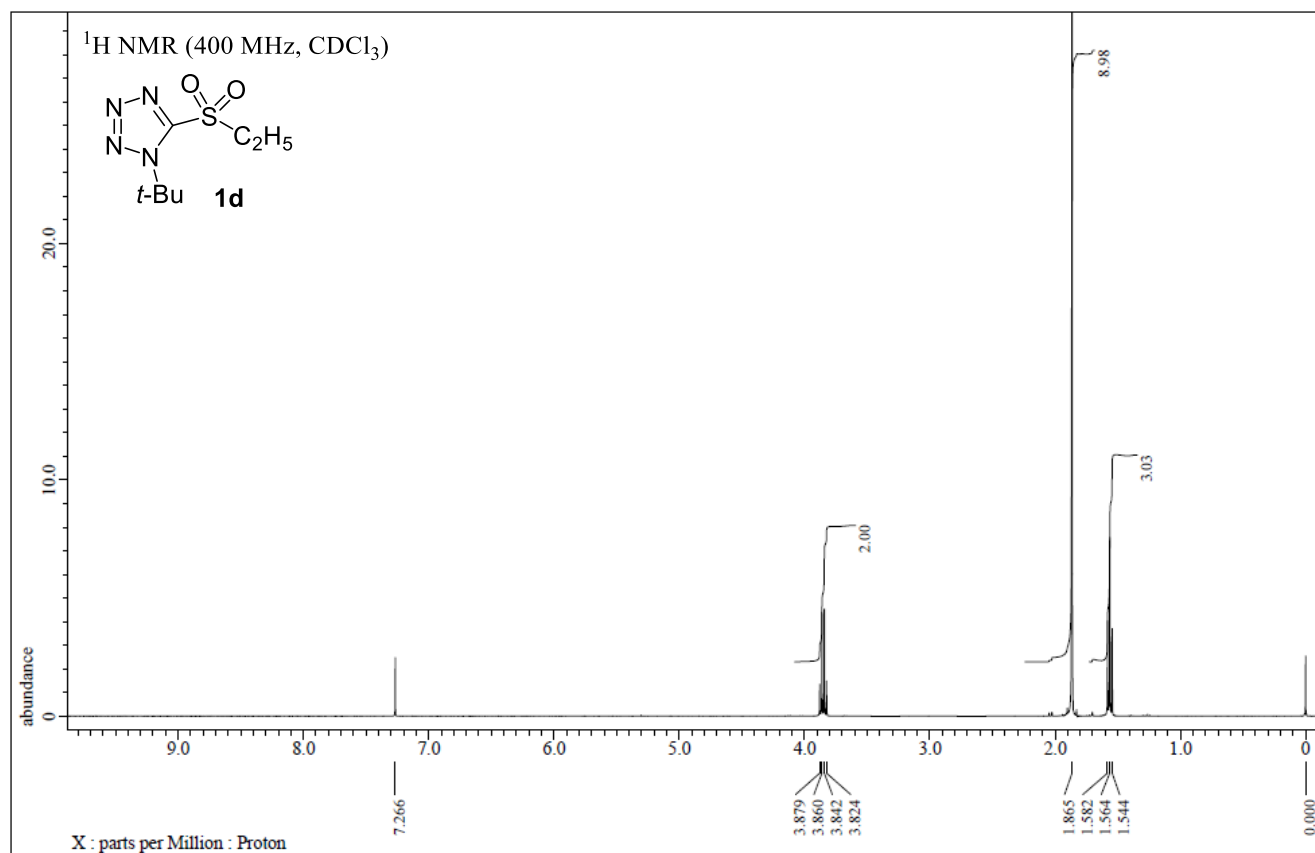
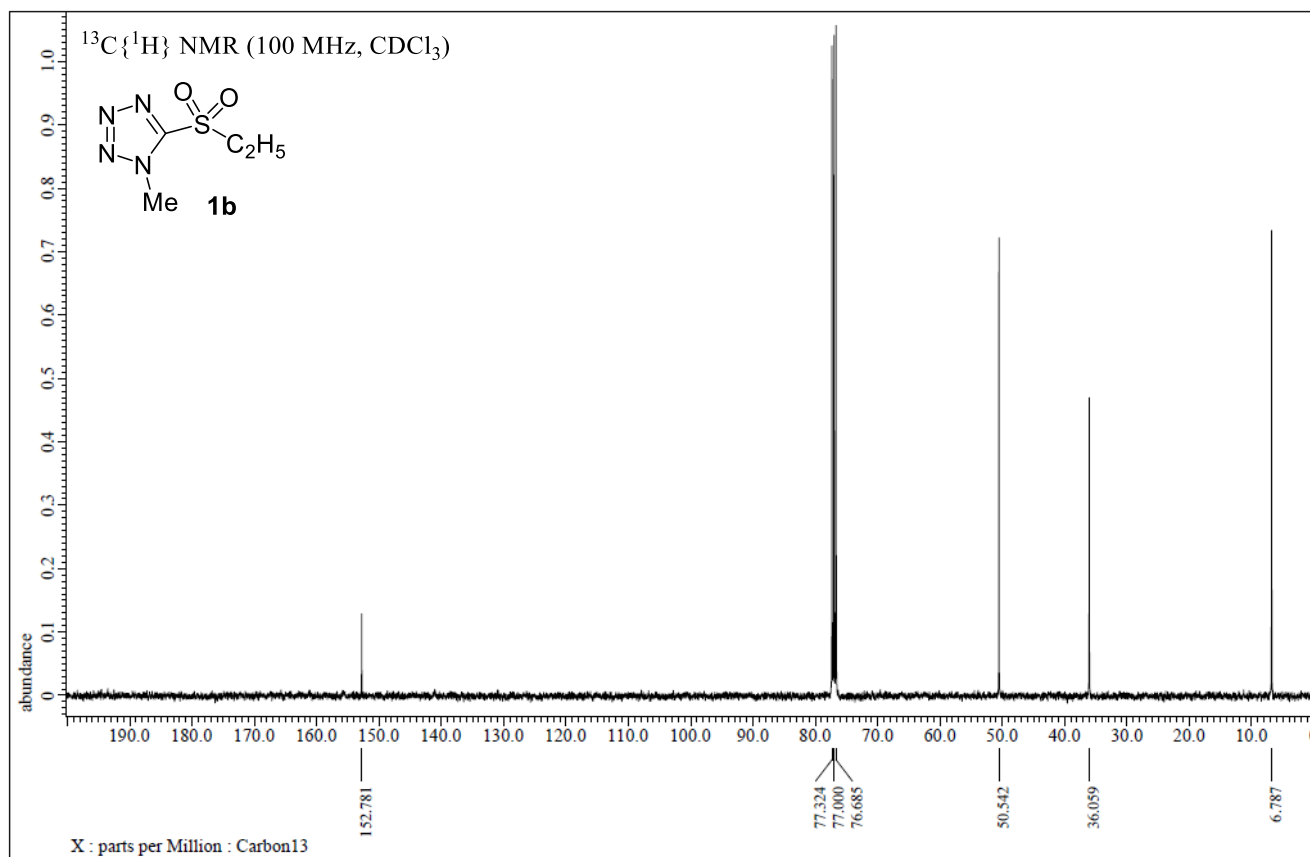


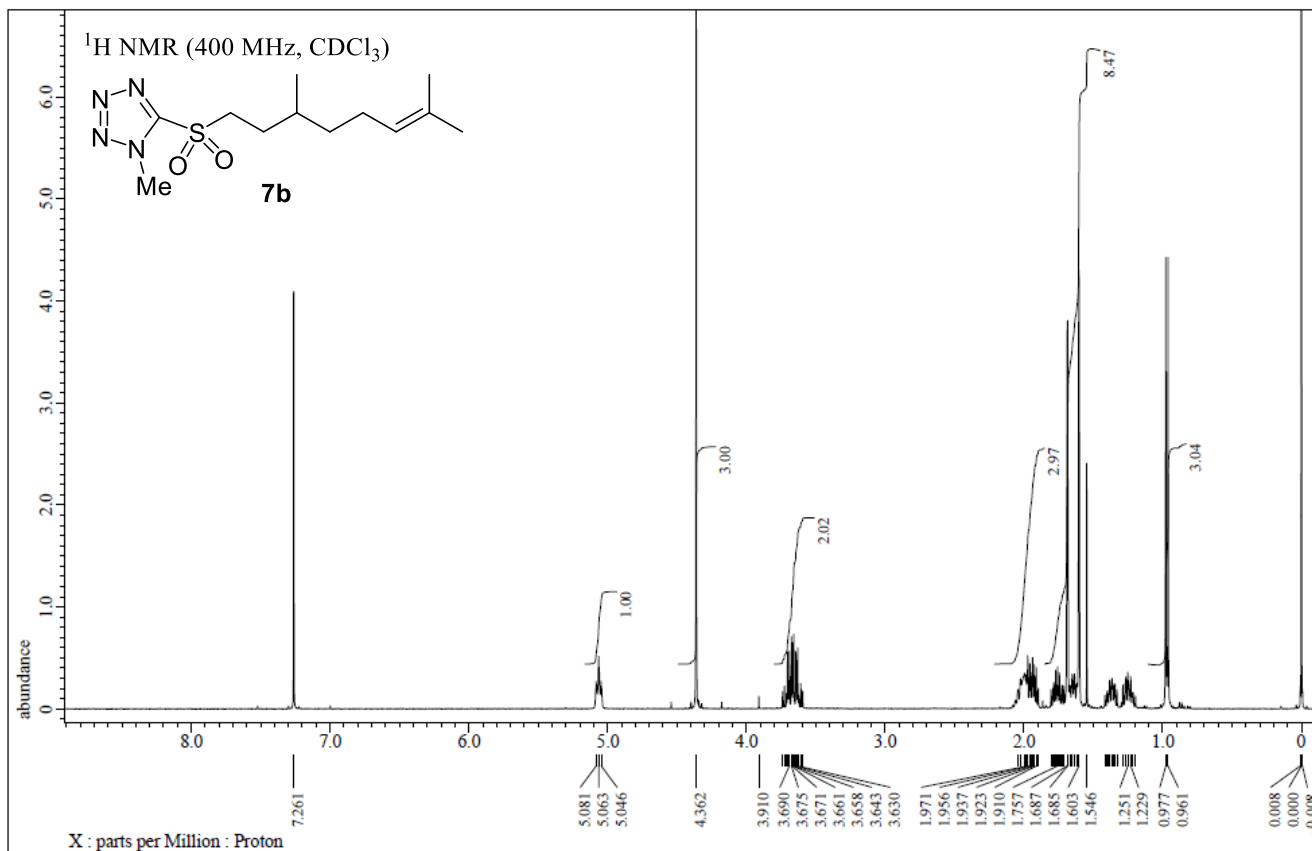
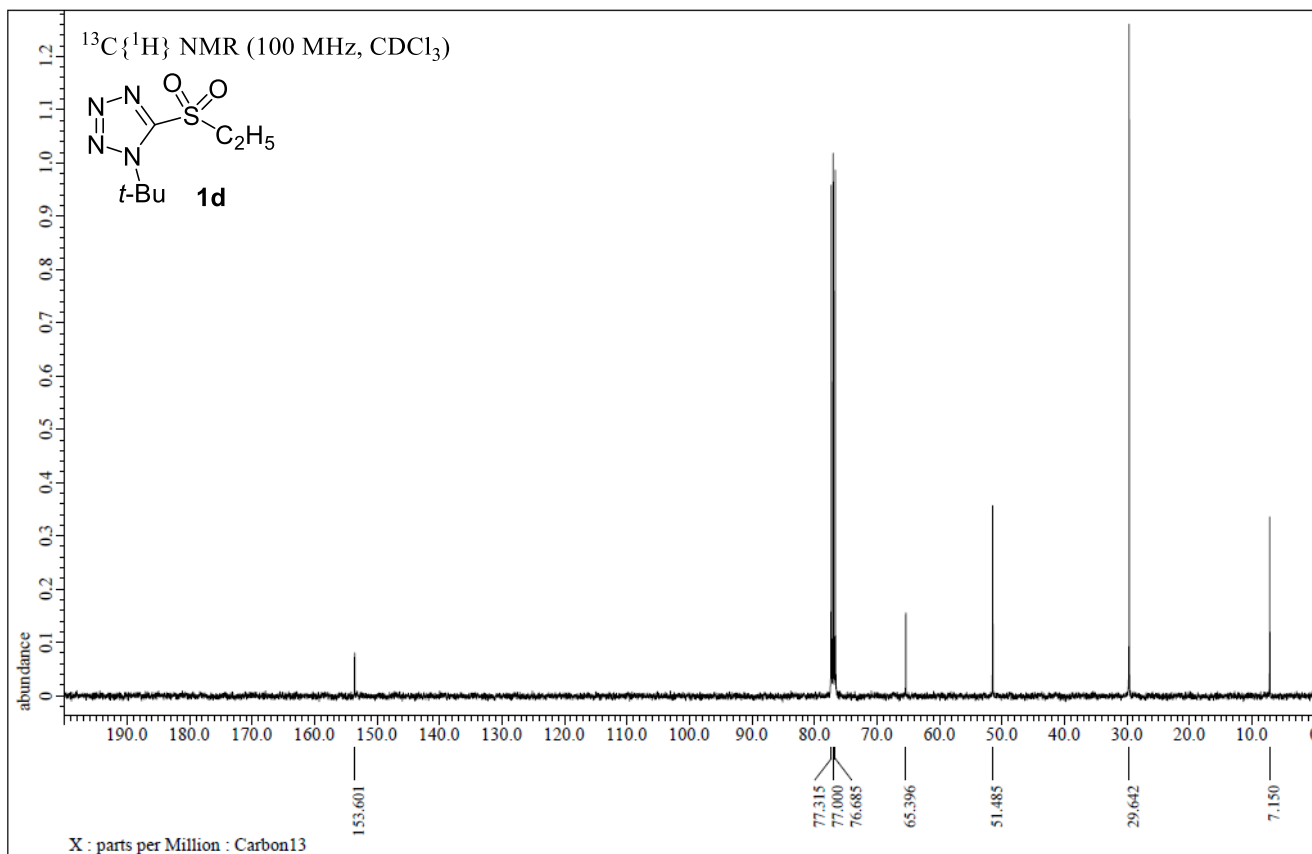


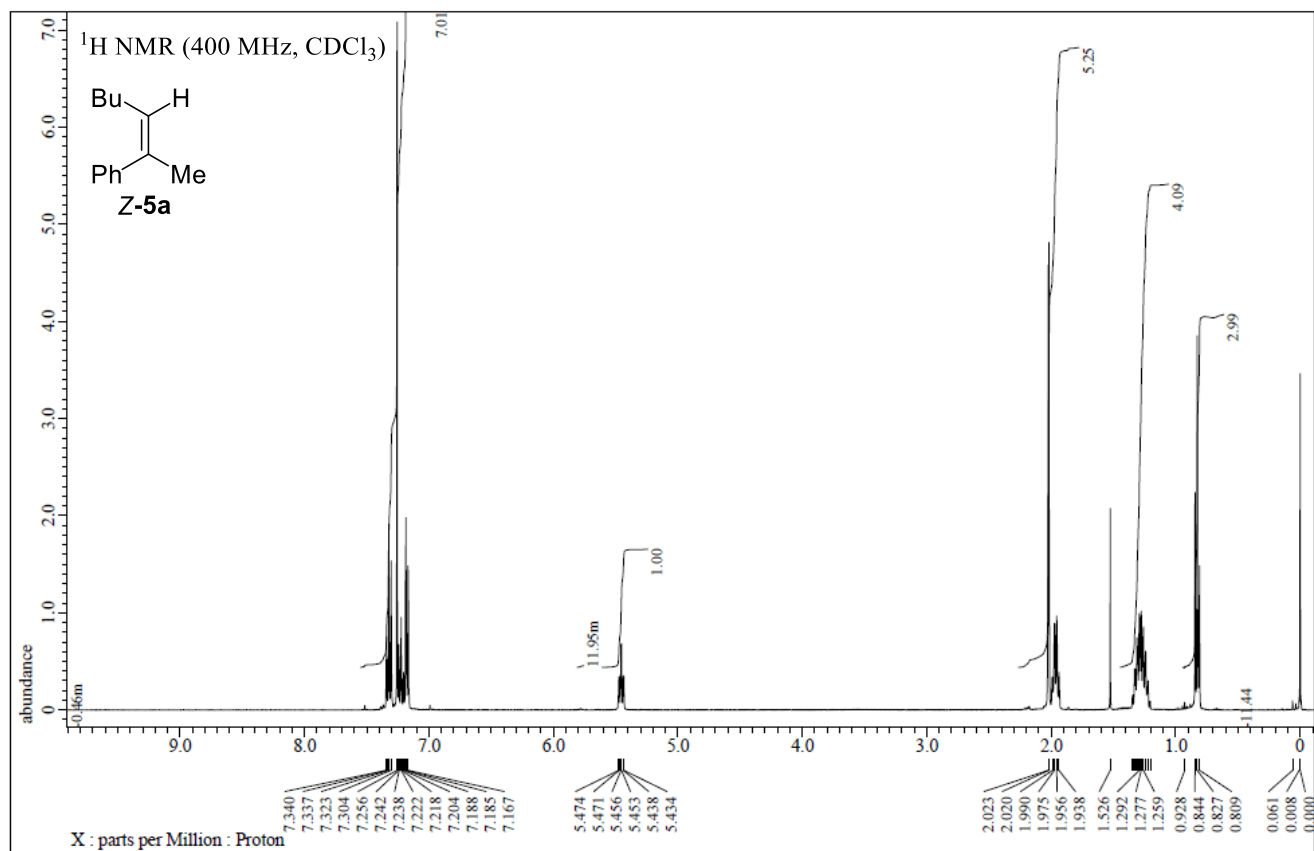
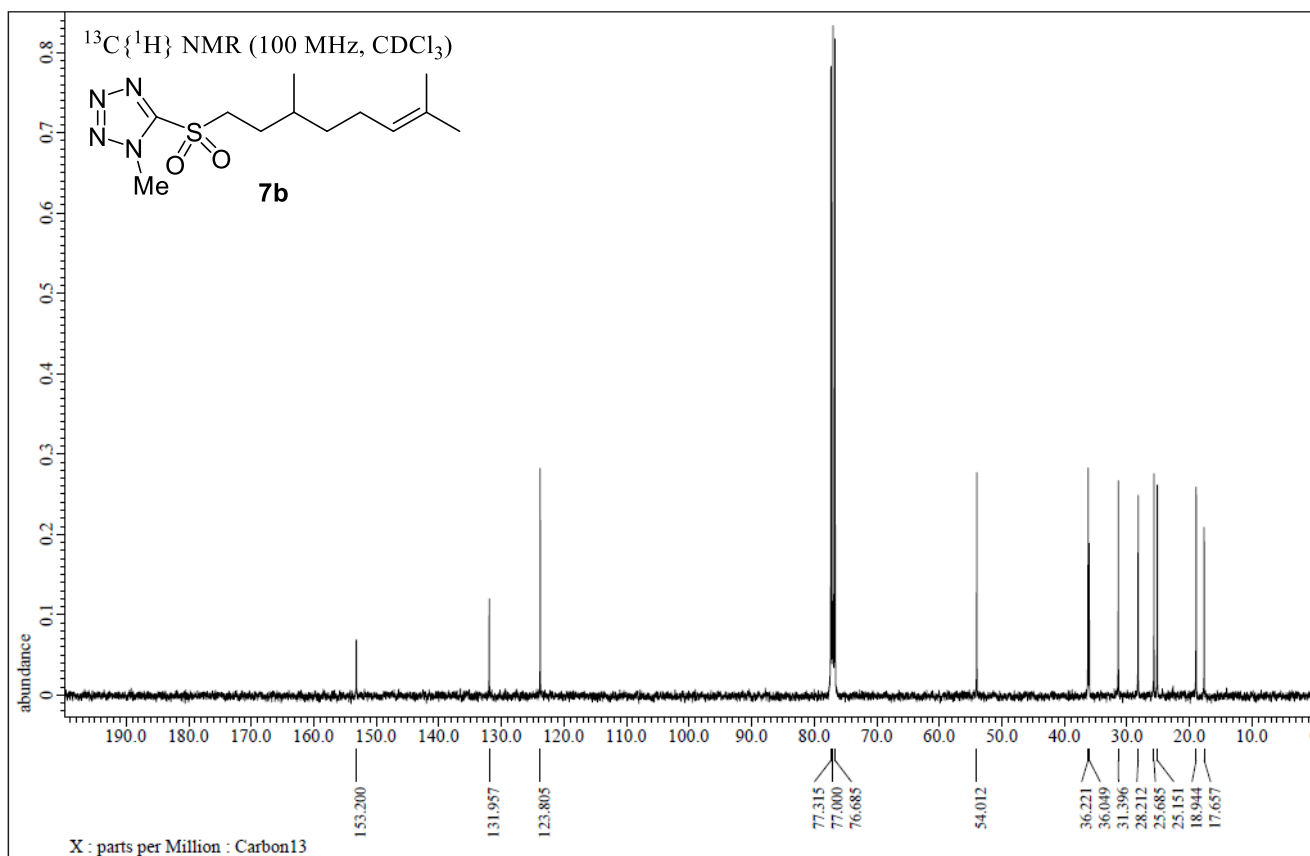


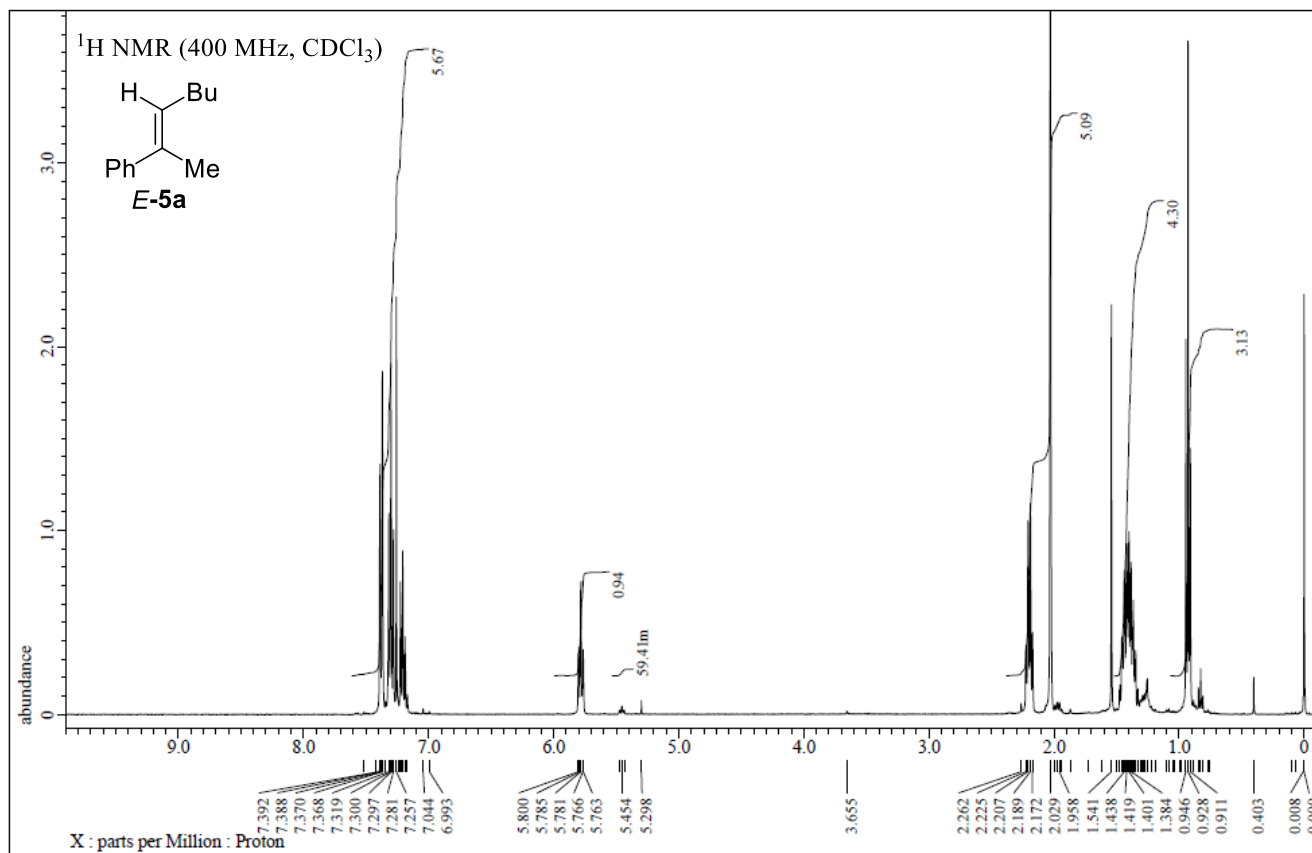
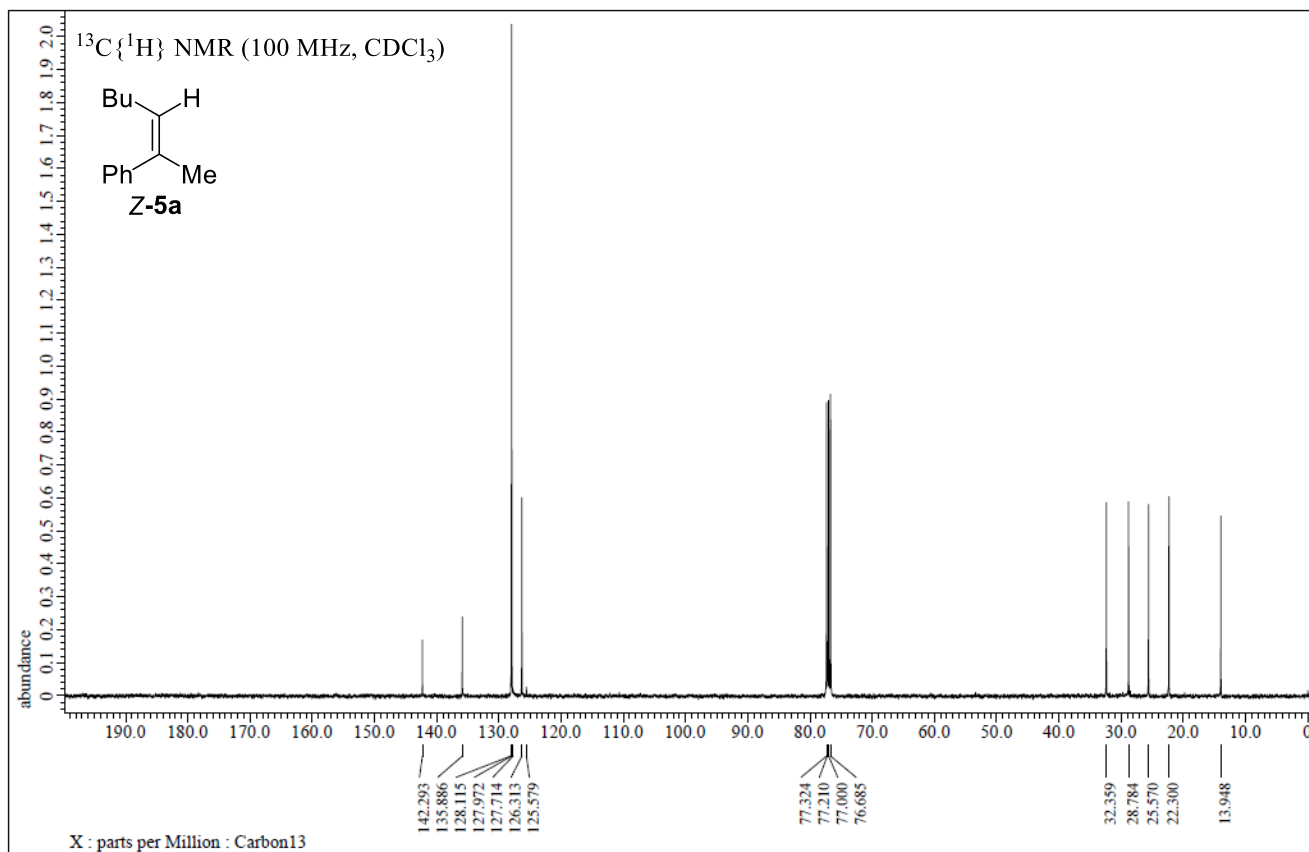


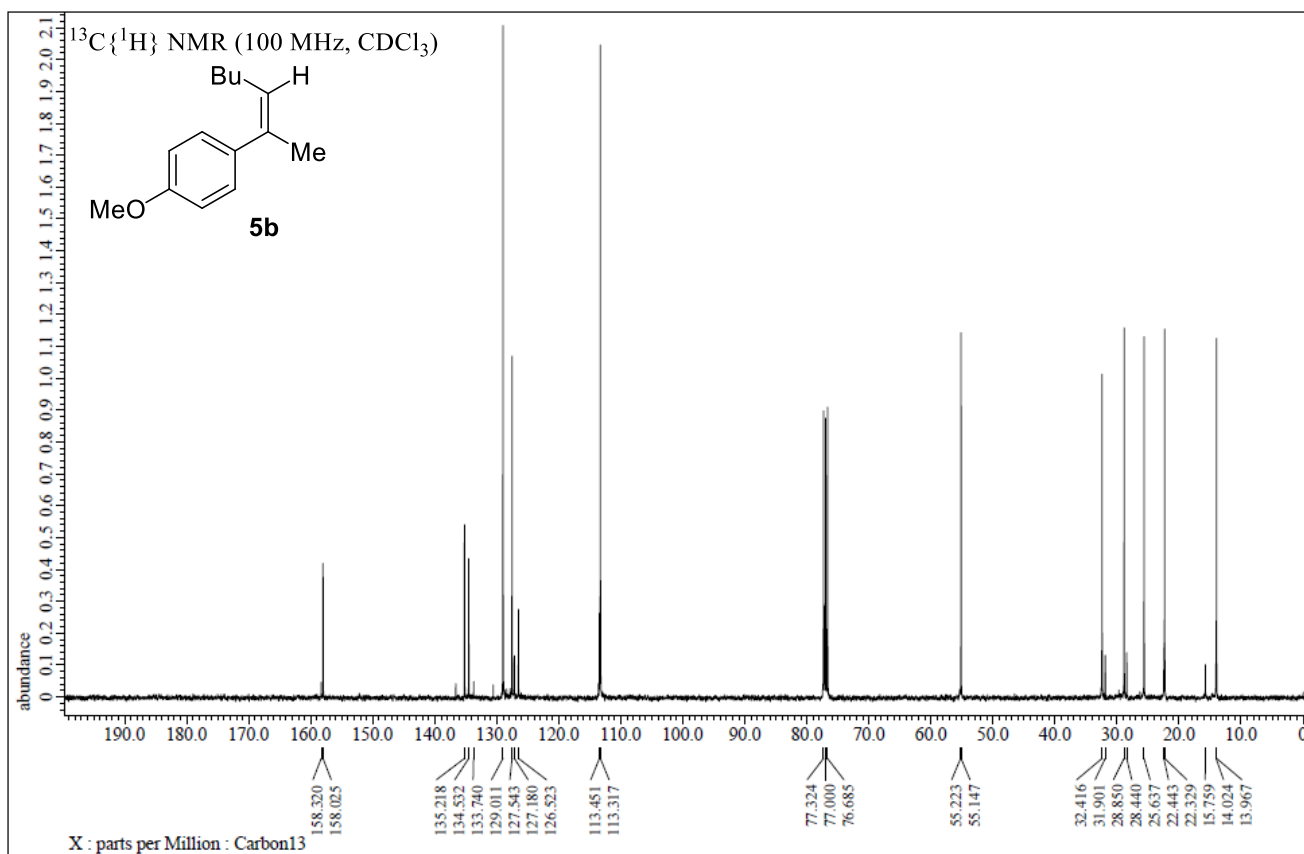
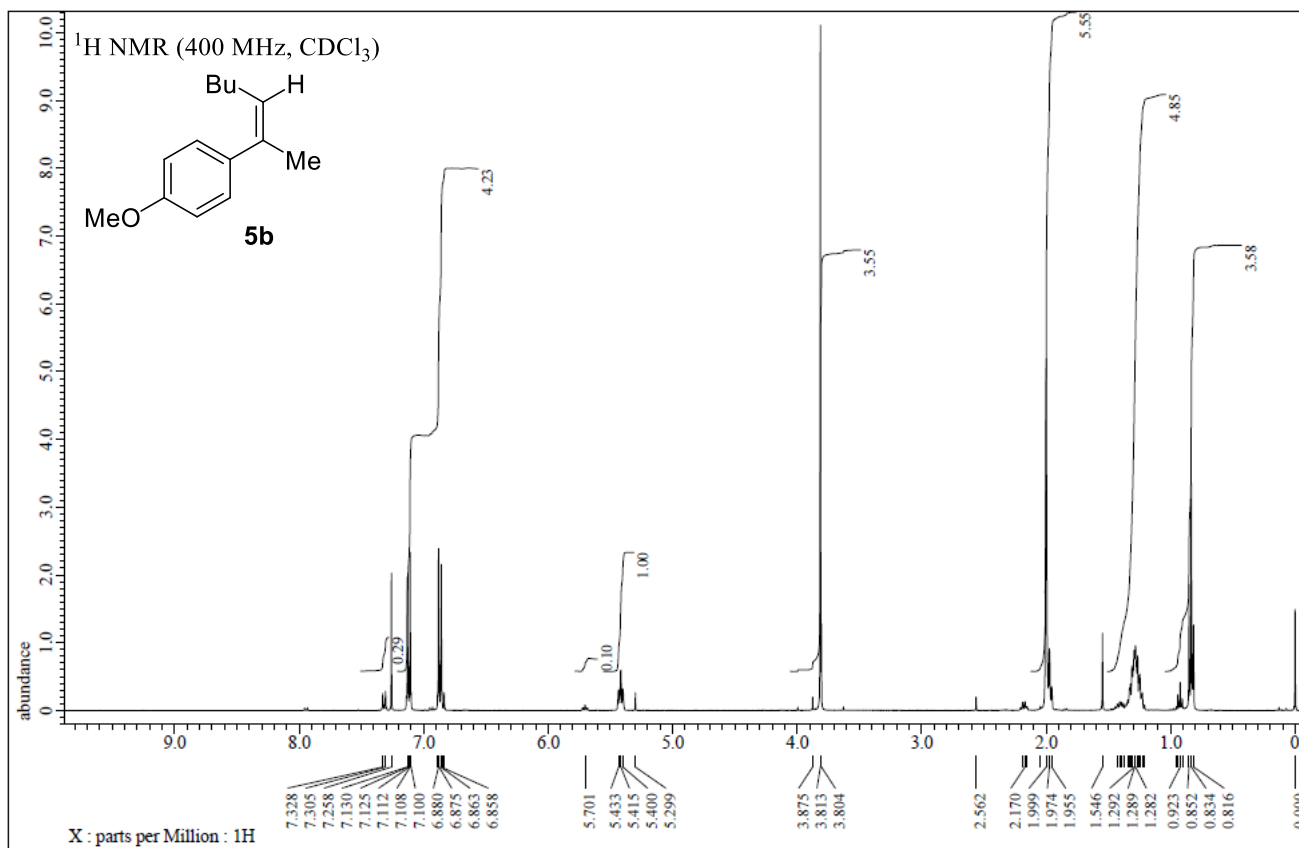


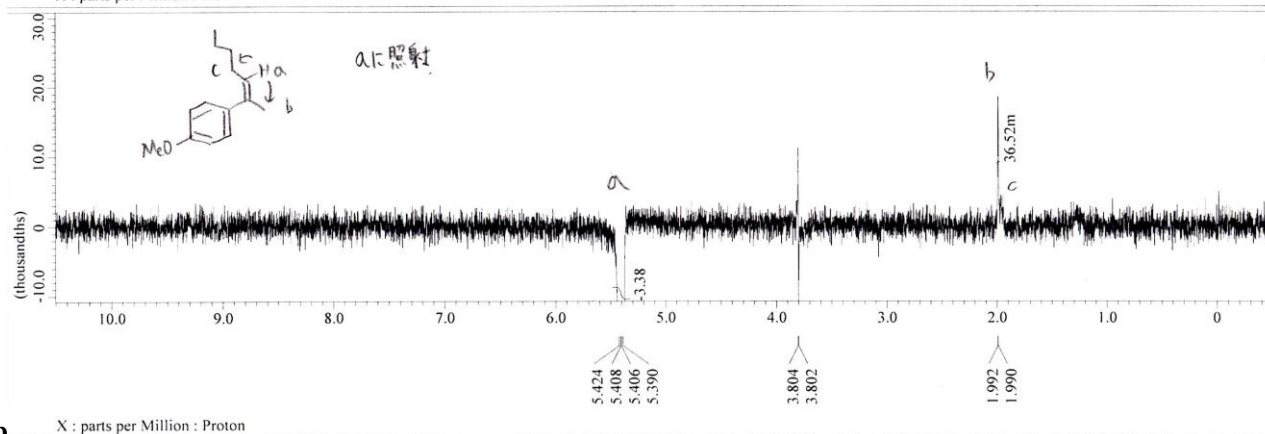
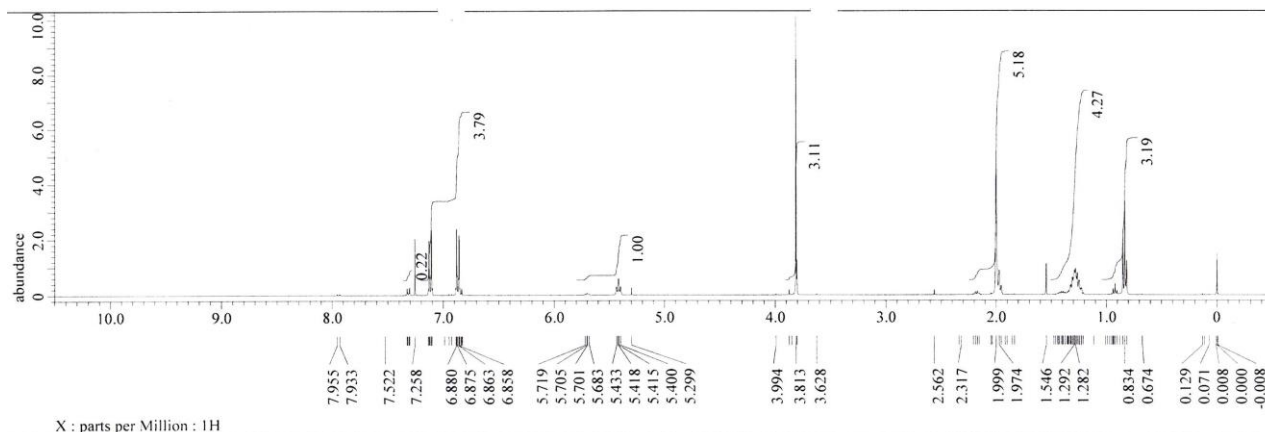




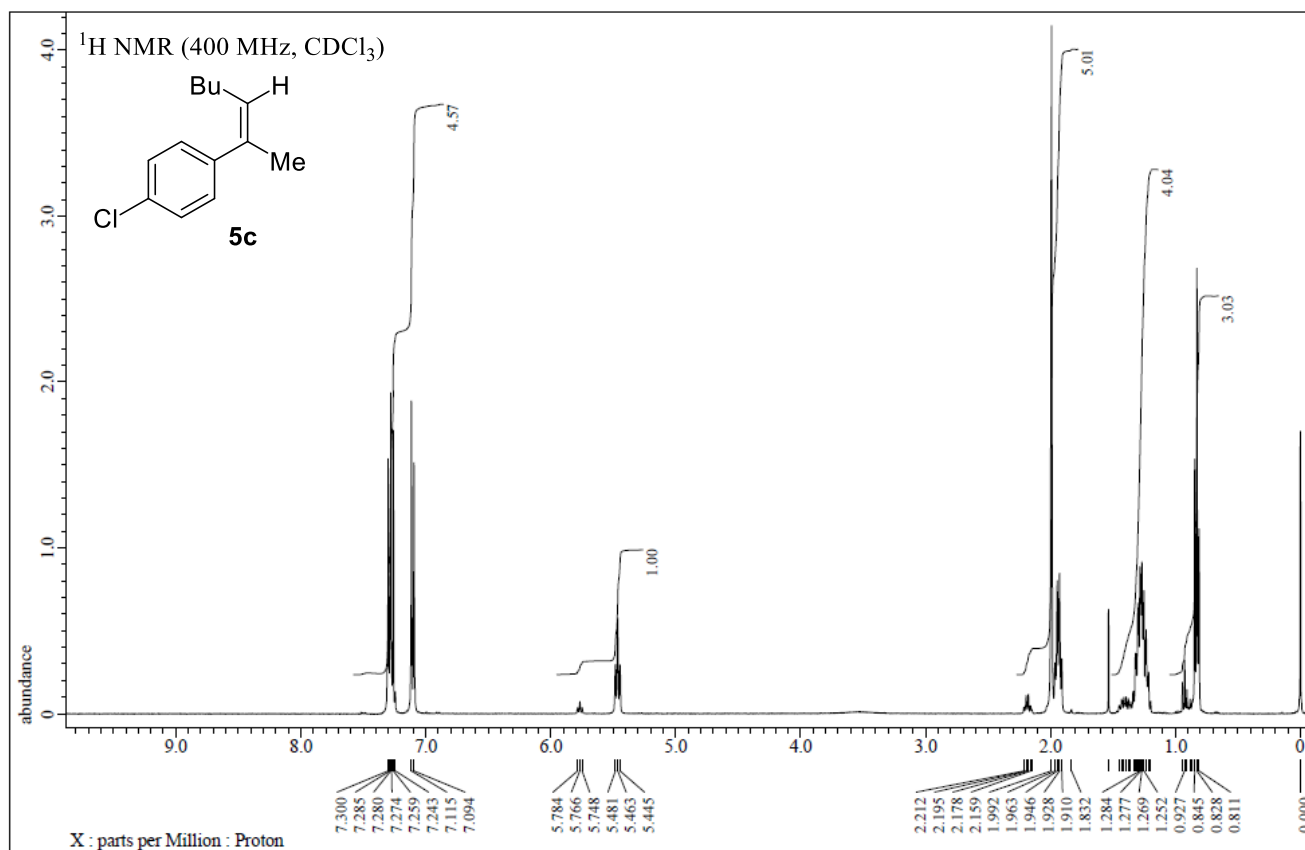


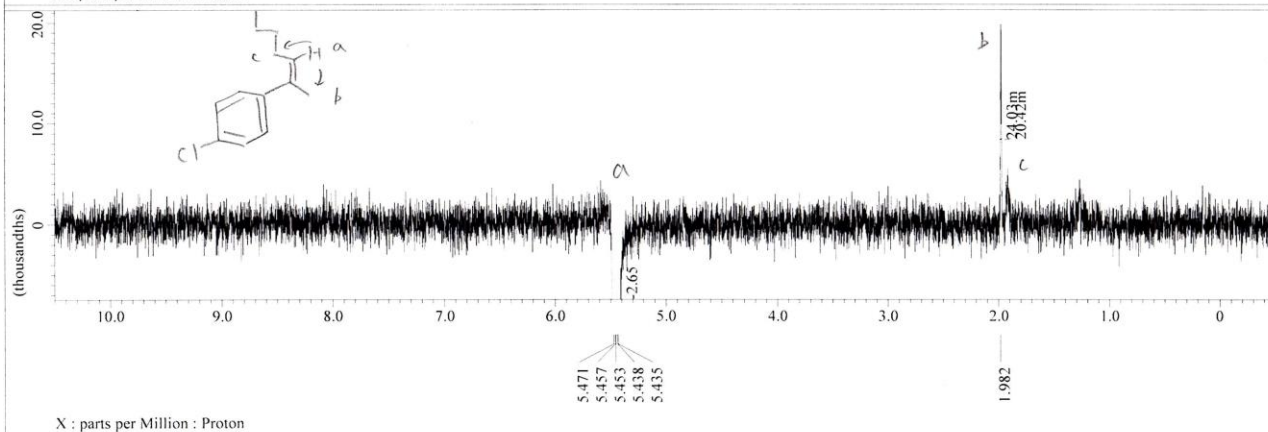
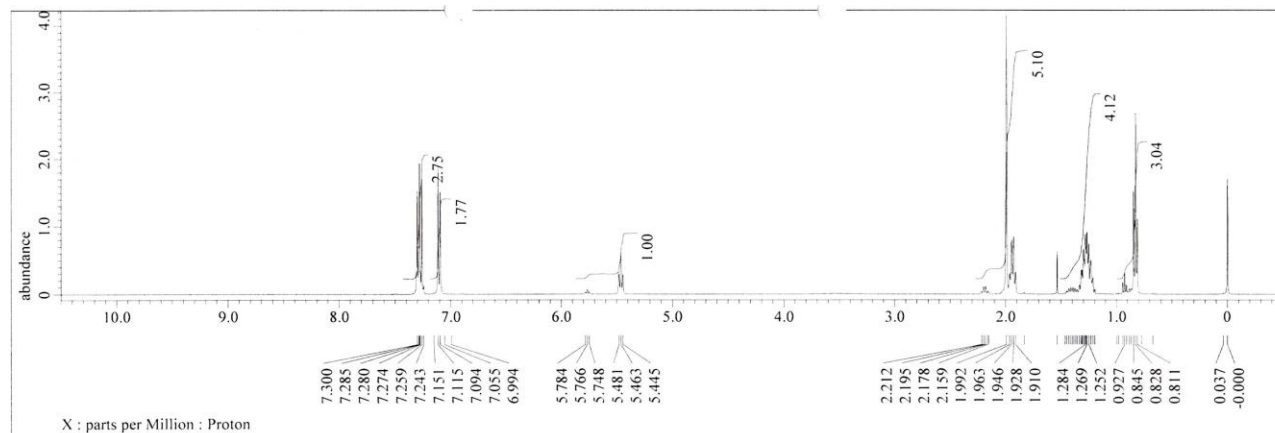
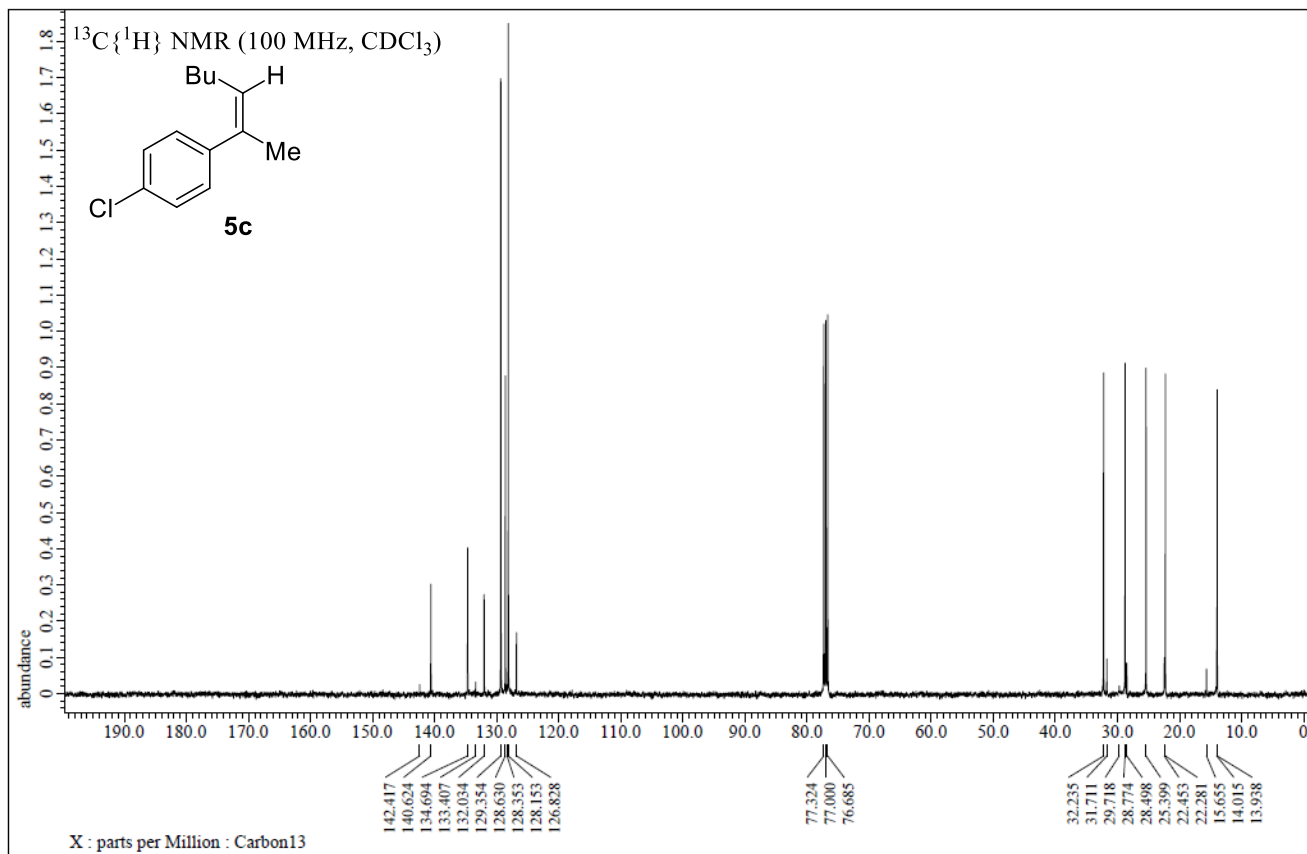




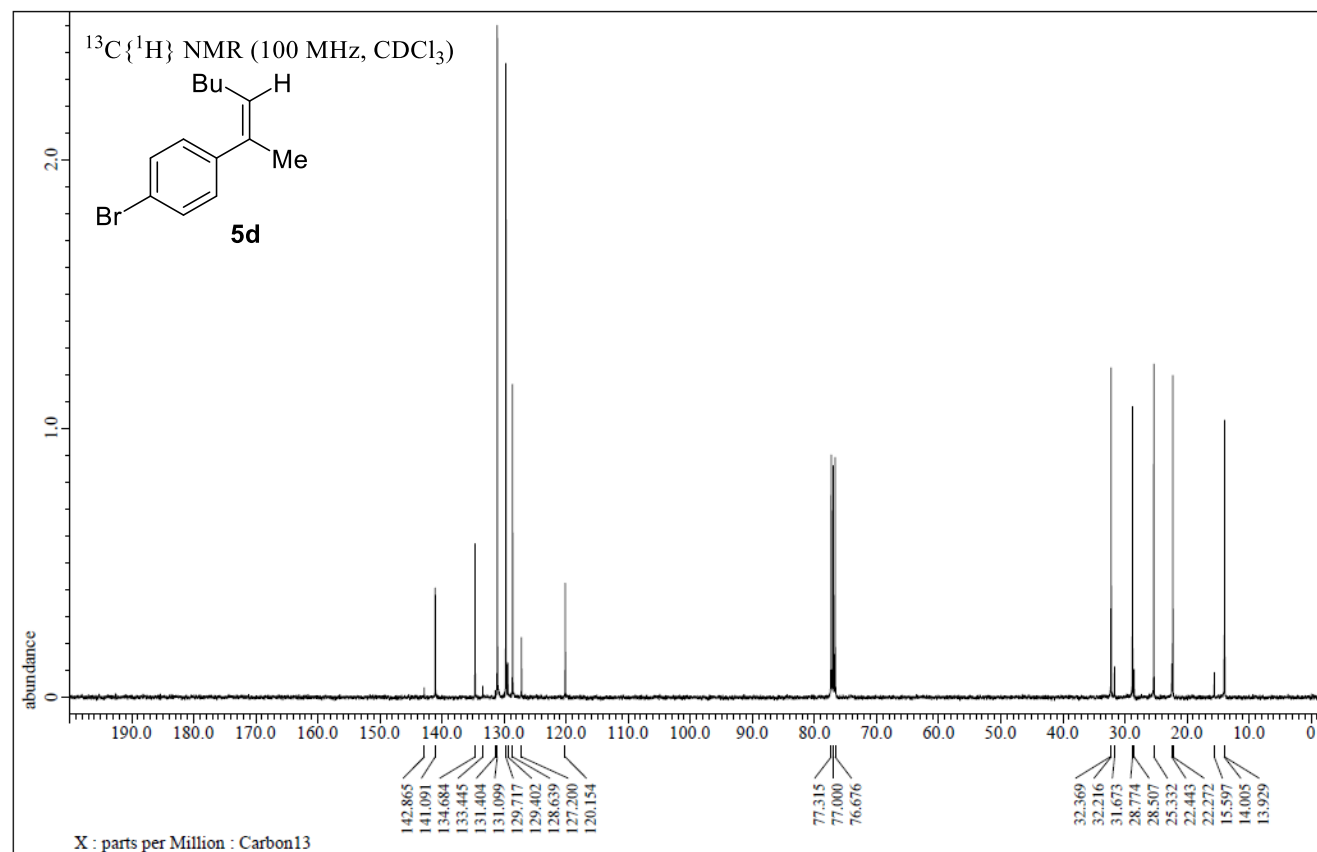
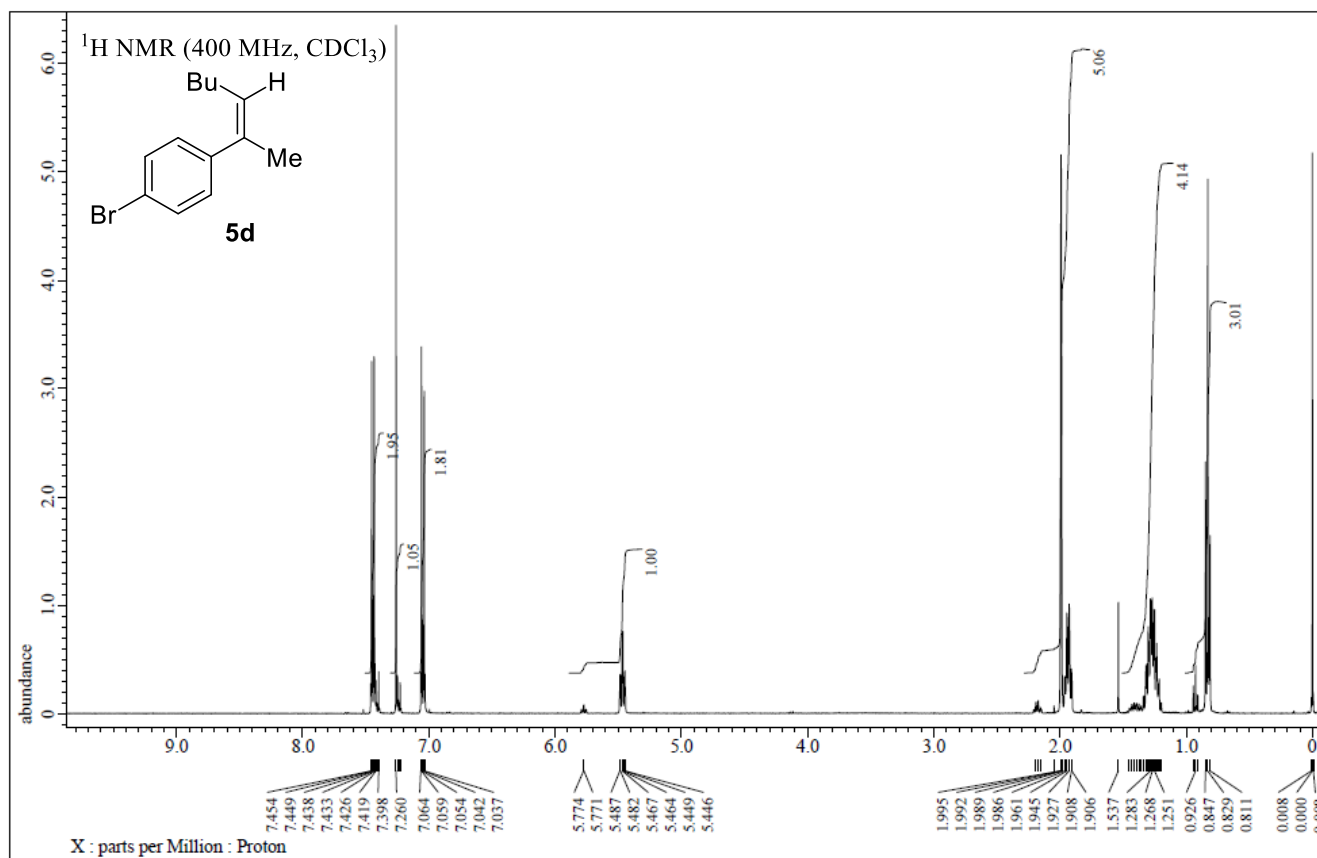


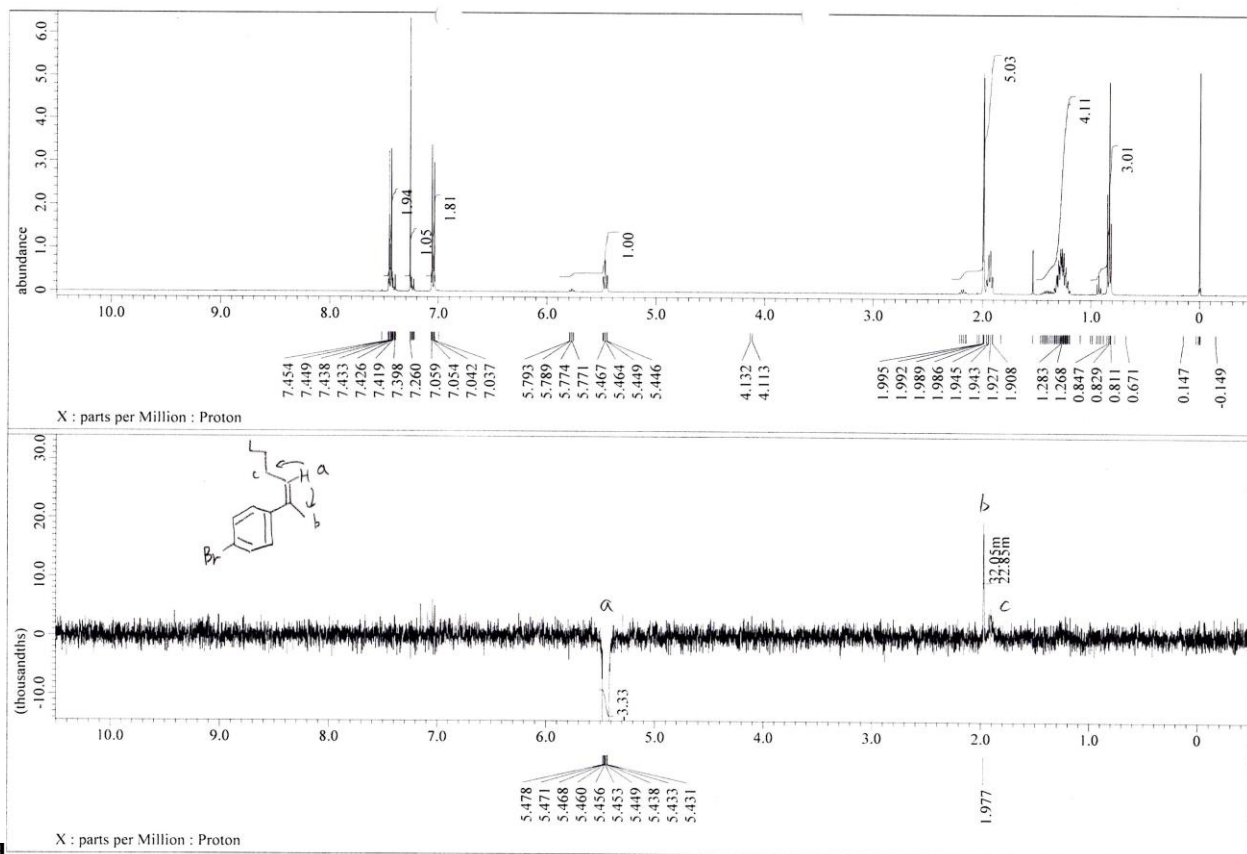
5b



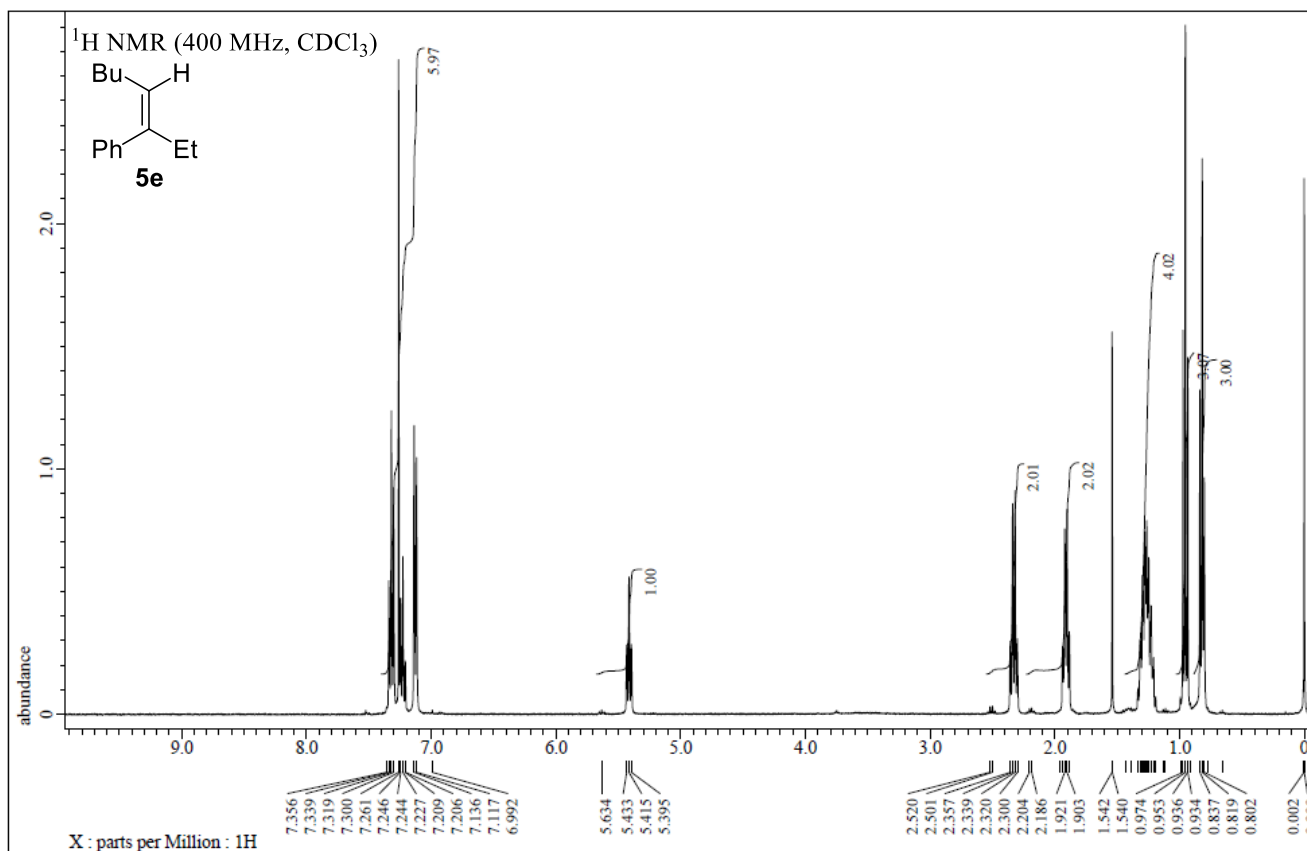


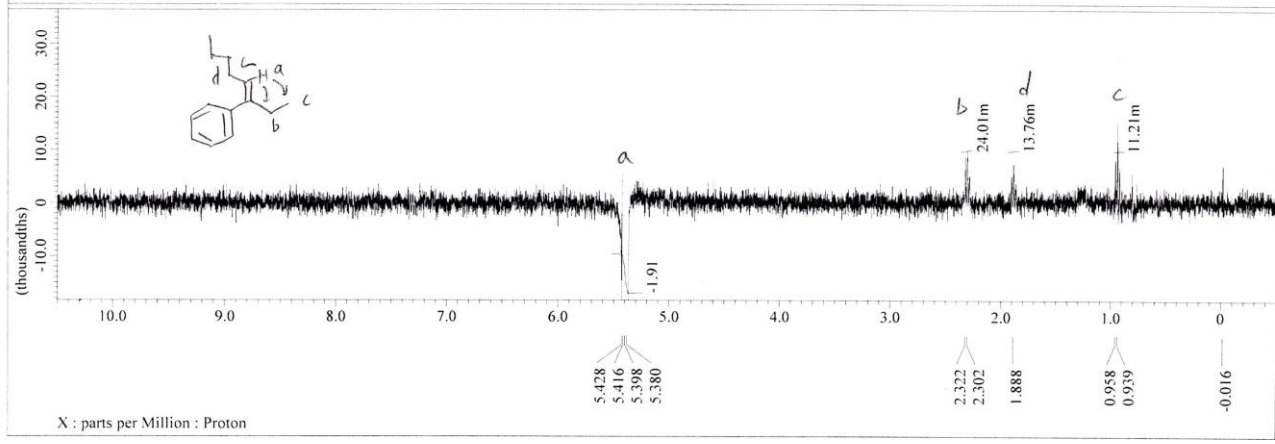
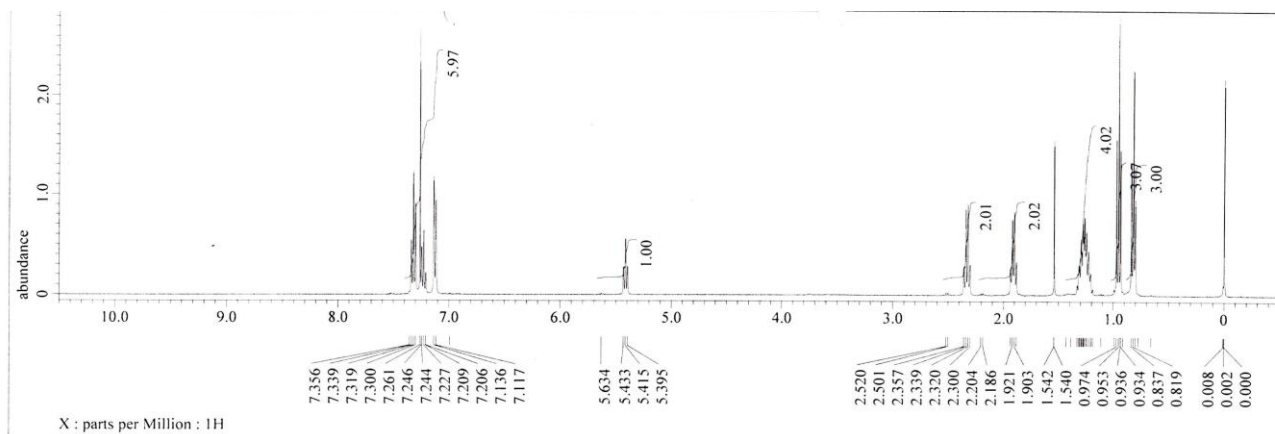
5c



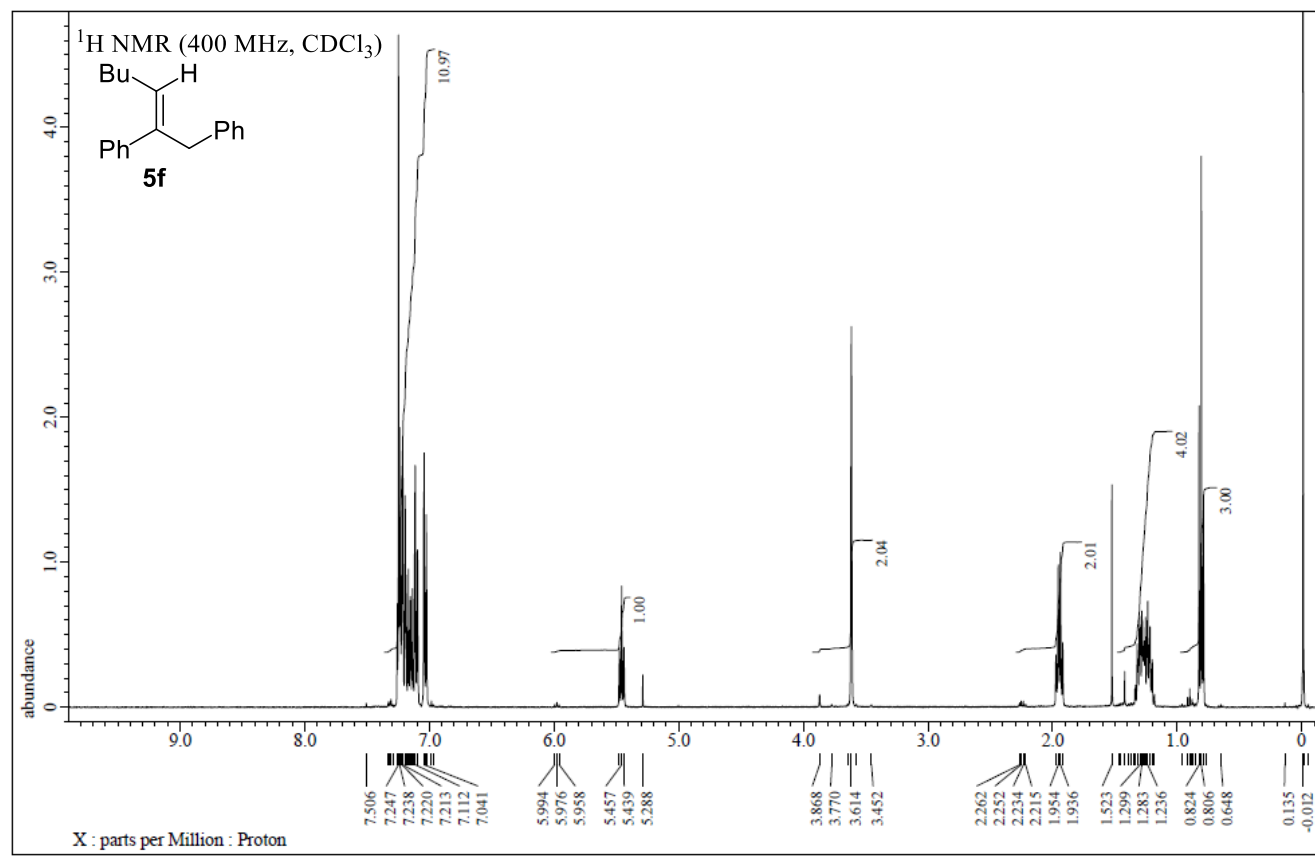


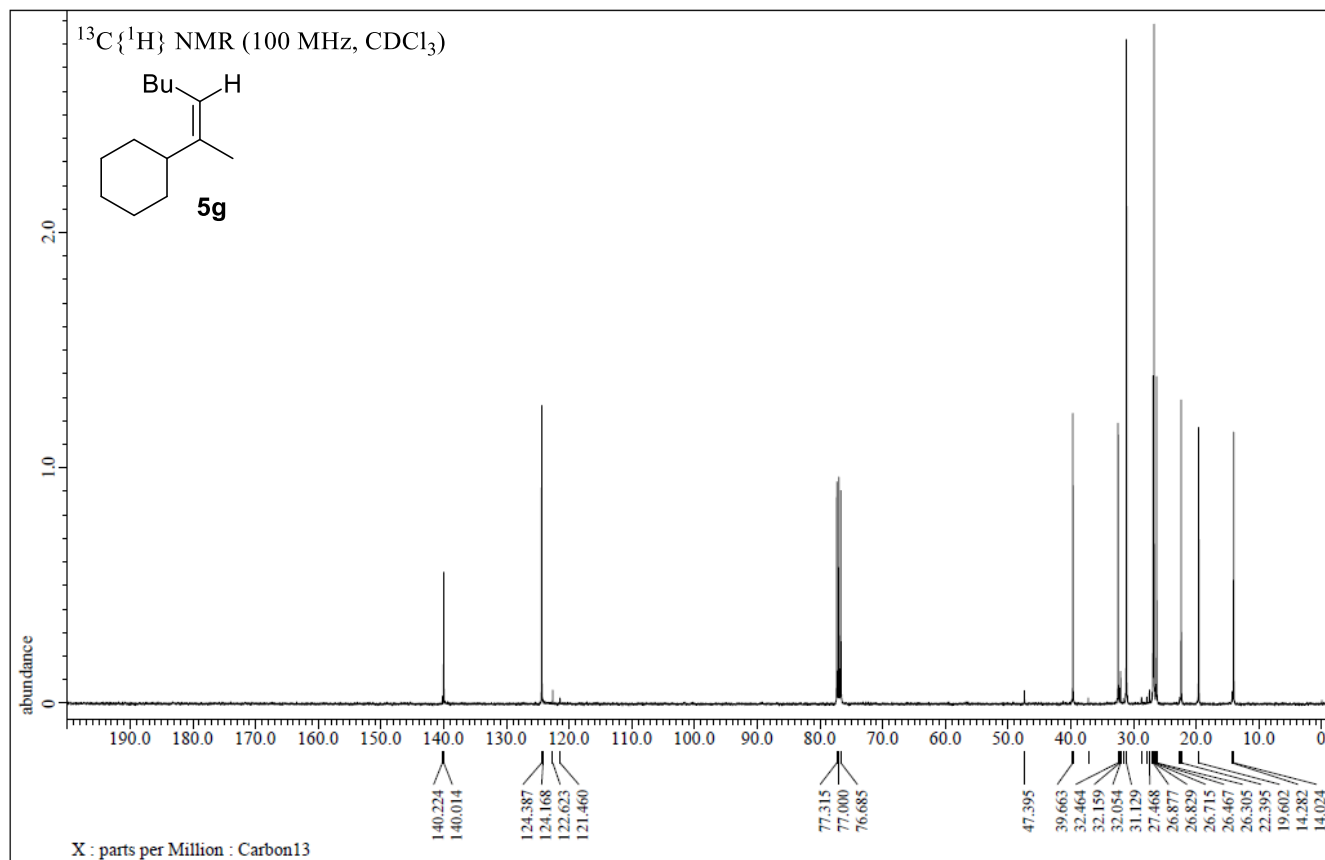
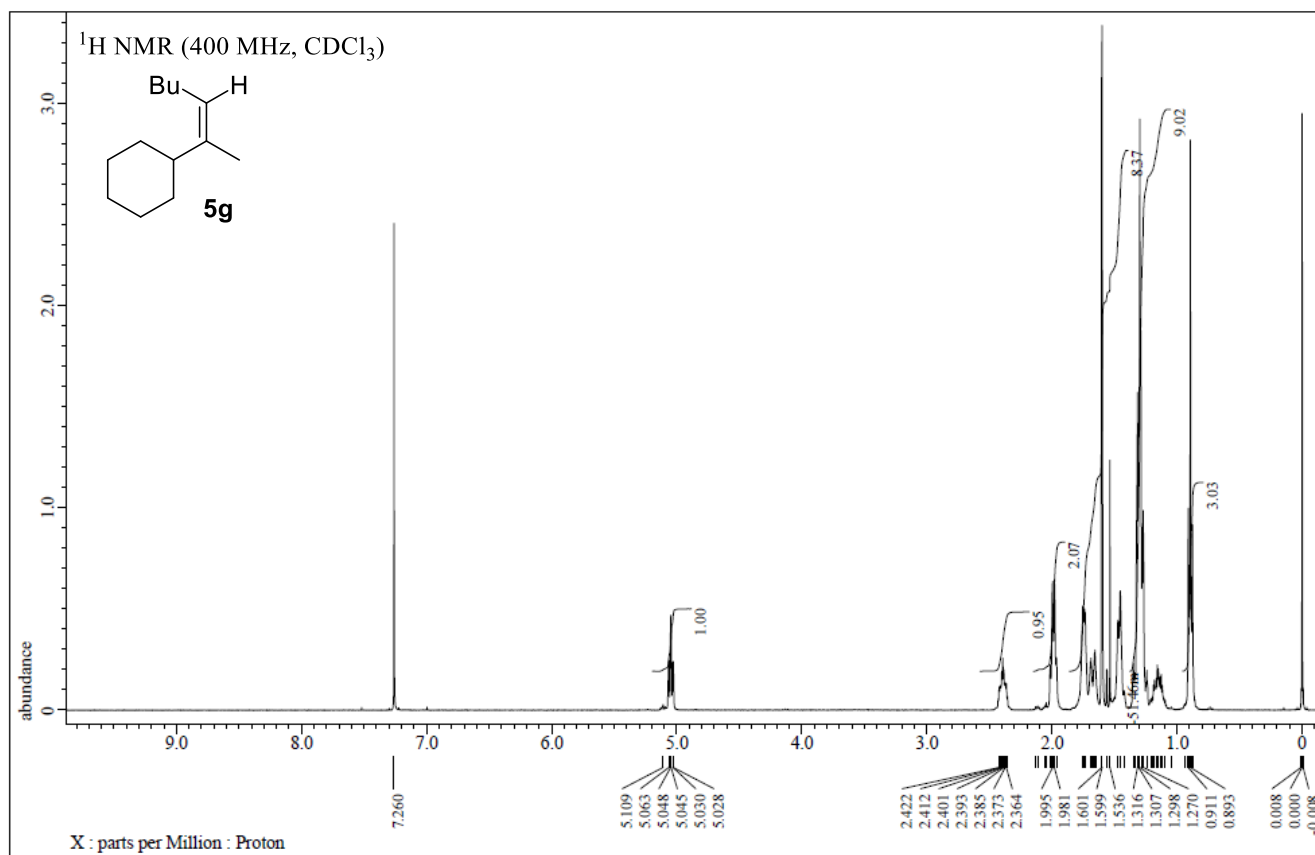
5d

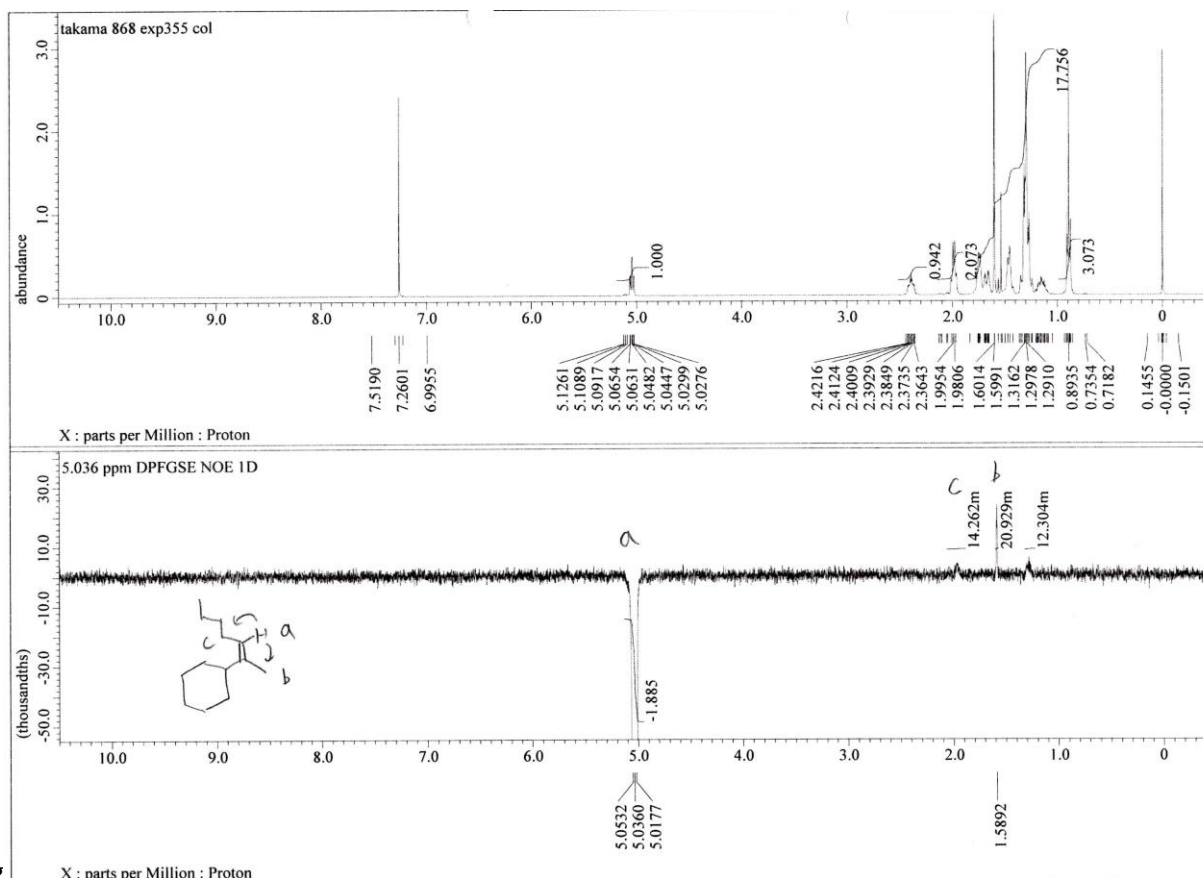




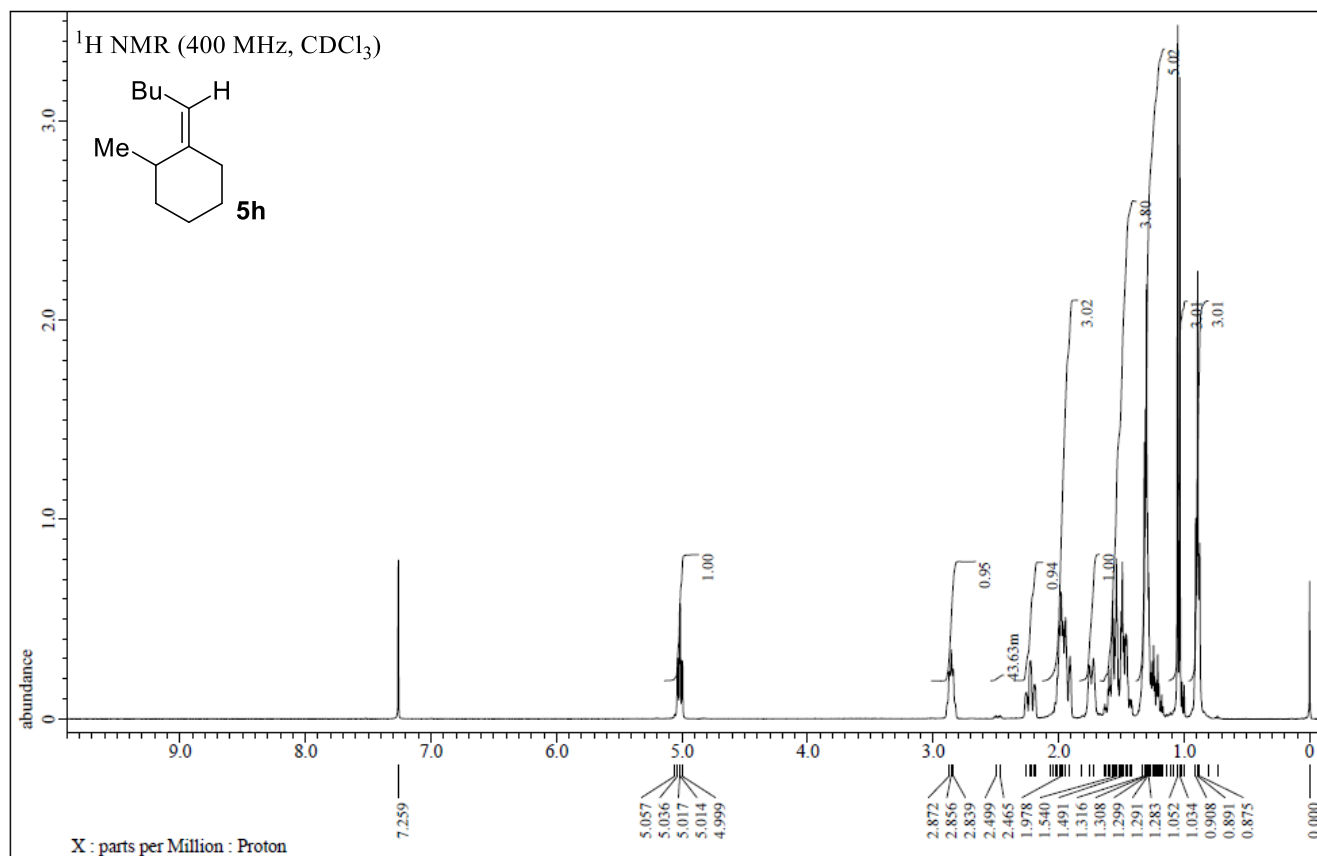
5e

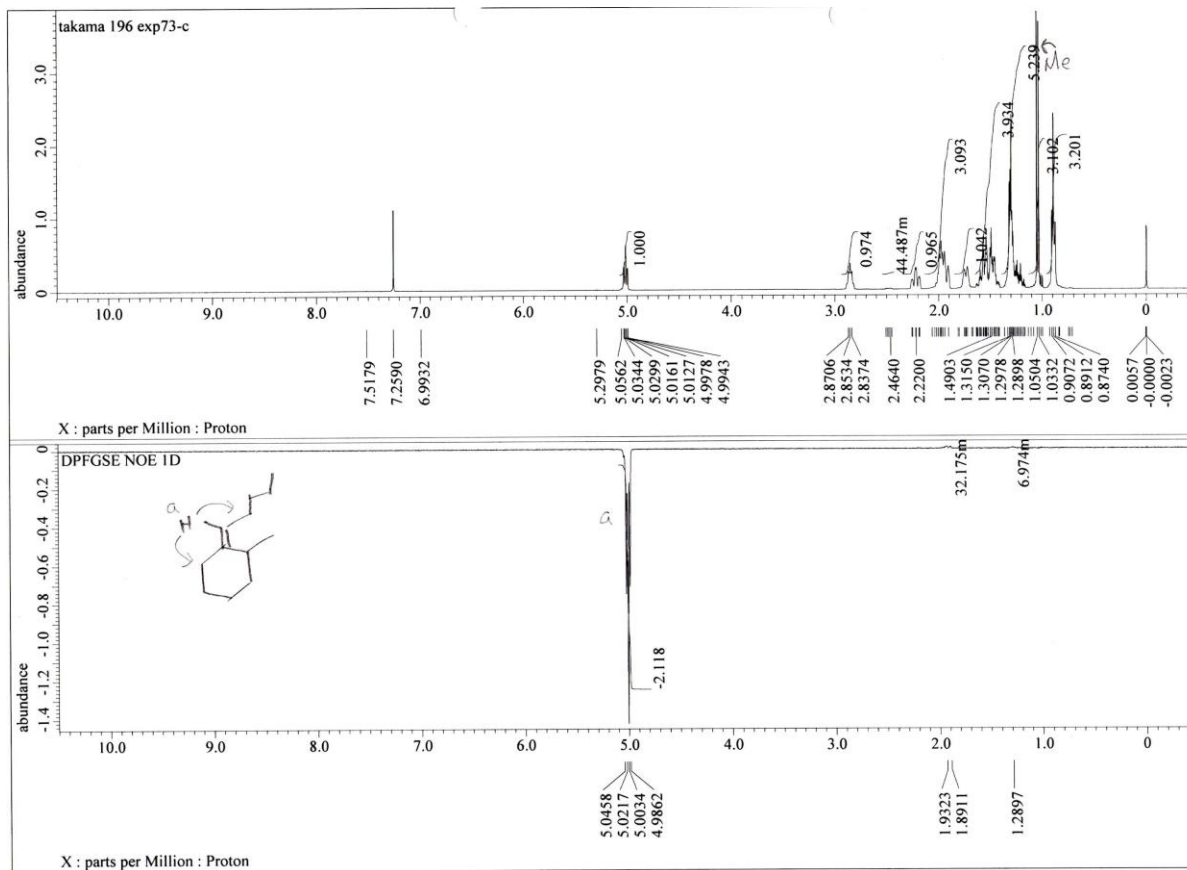
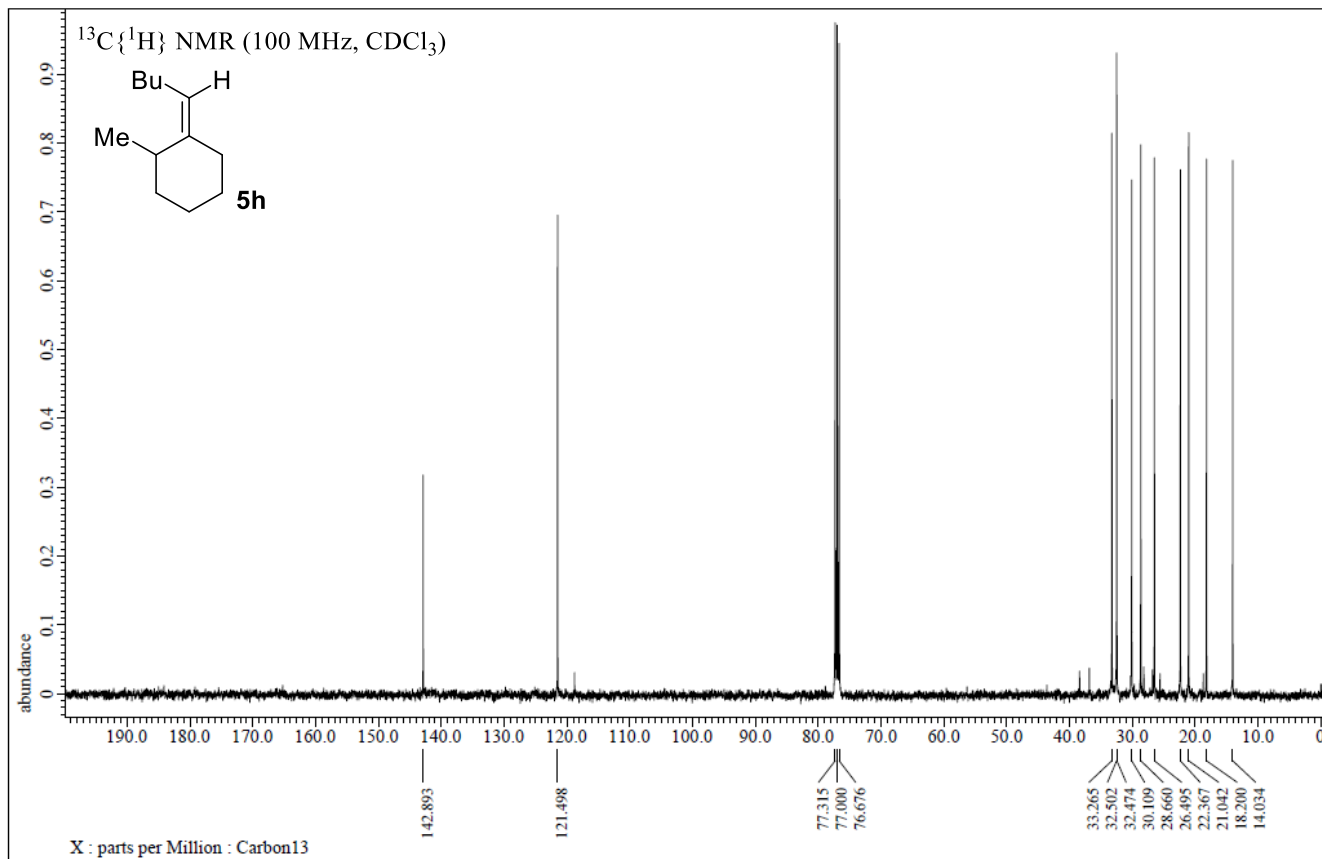




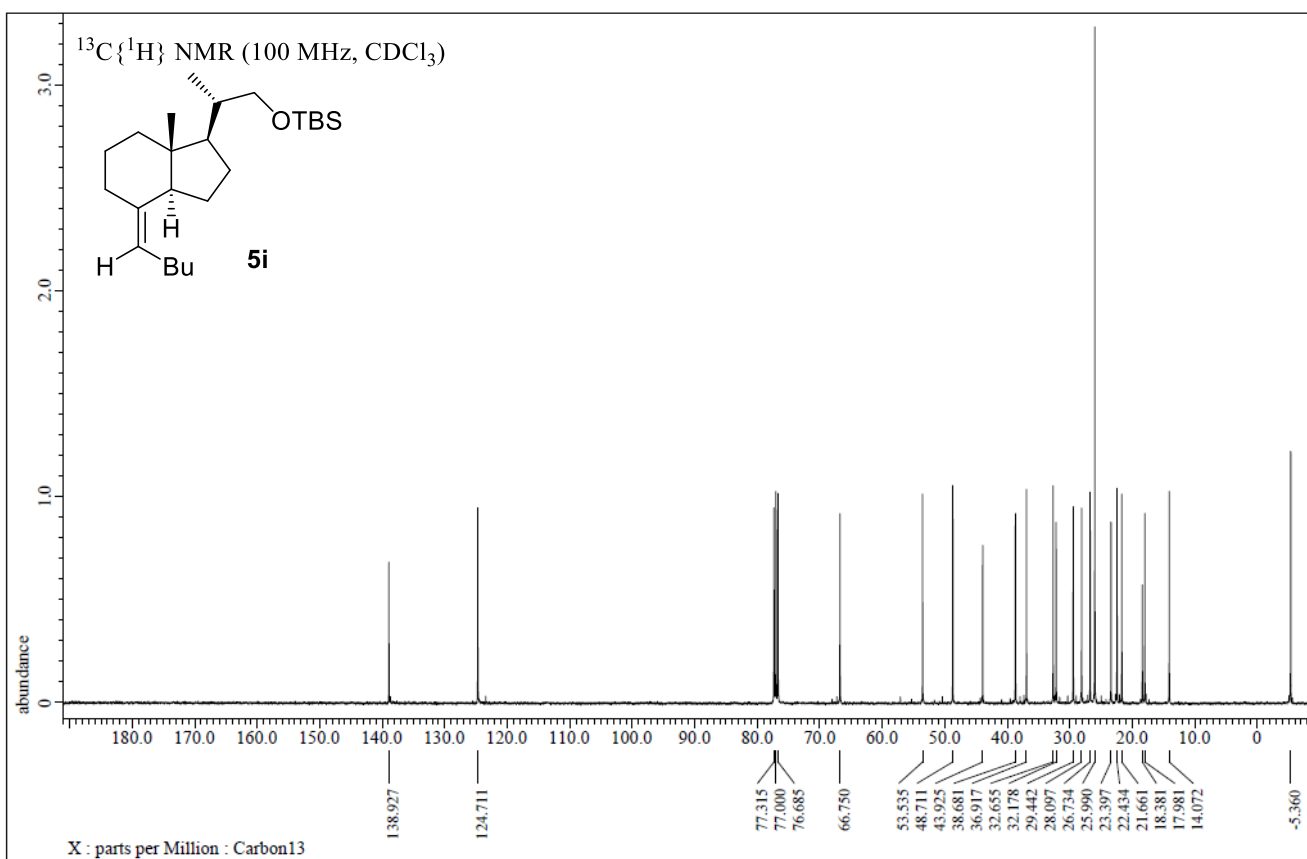
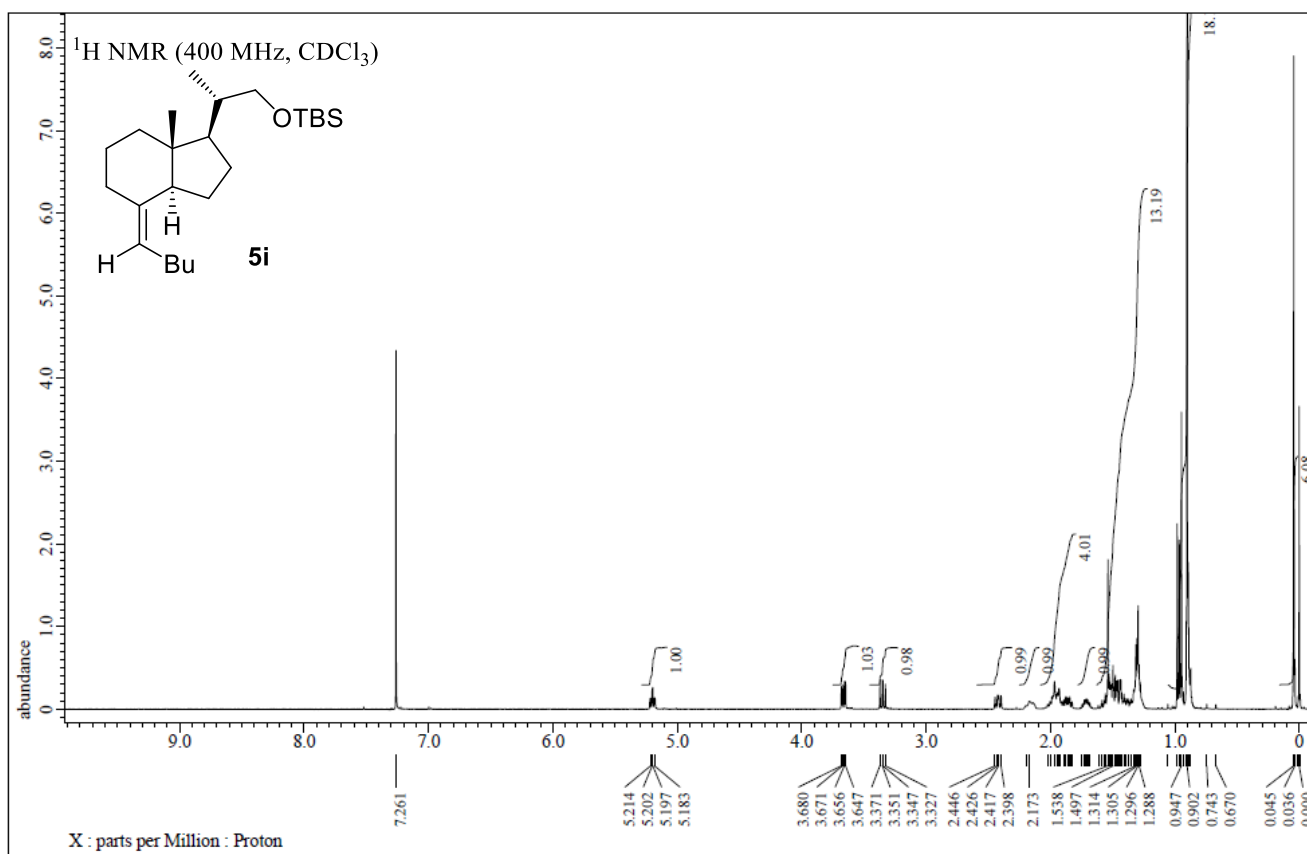


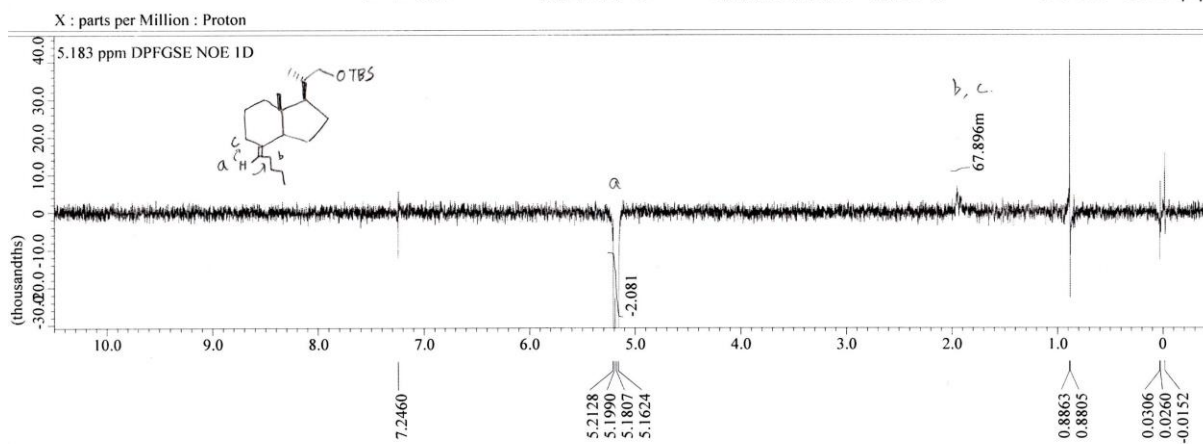
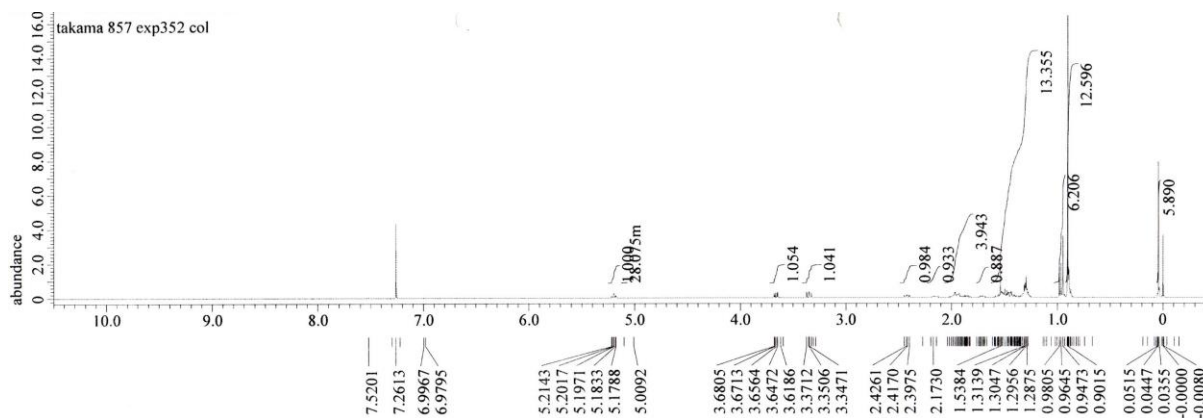
5g



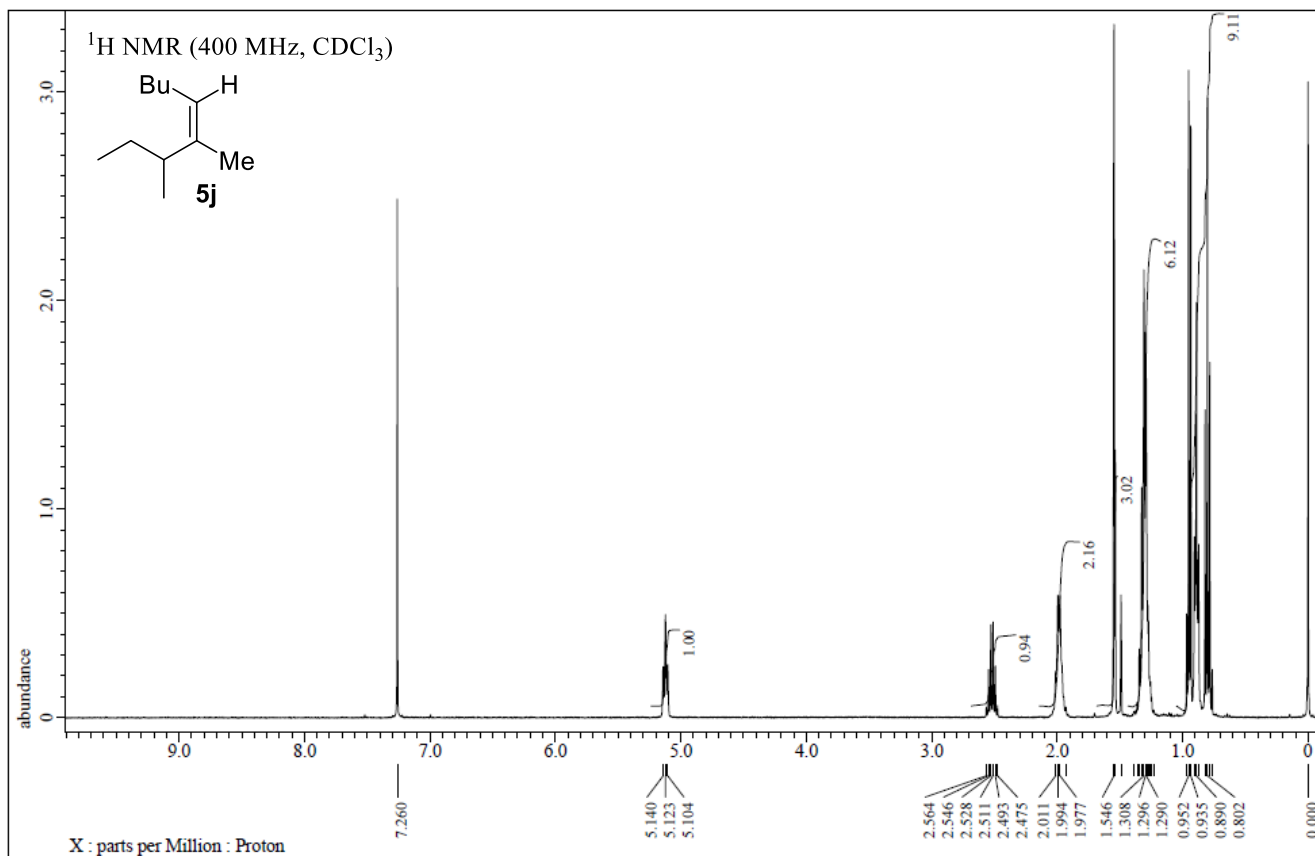


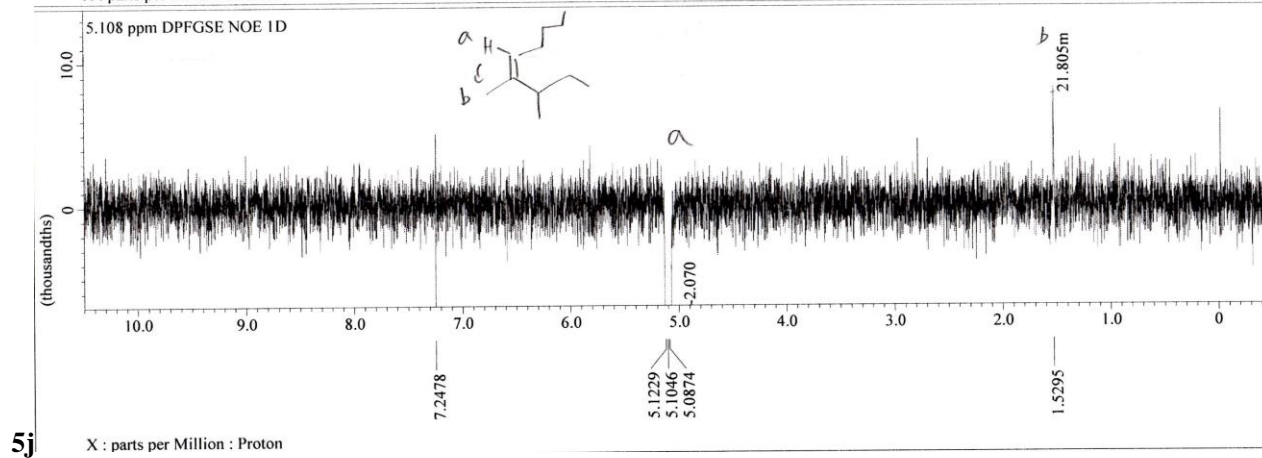
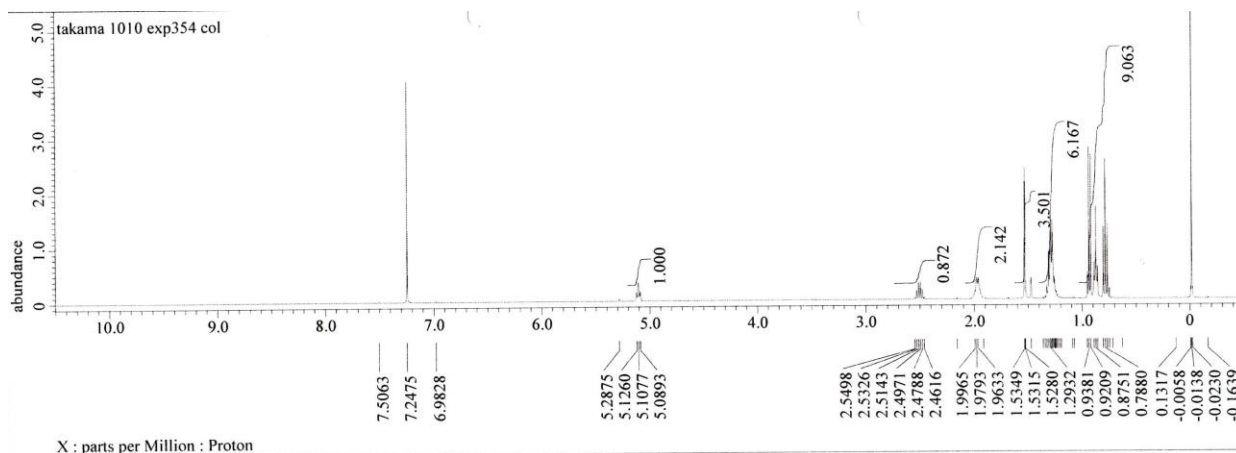
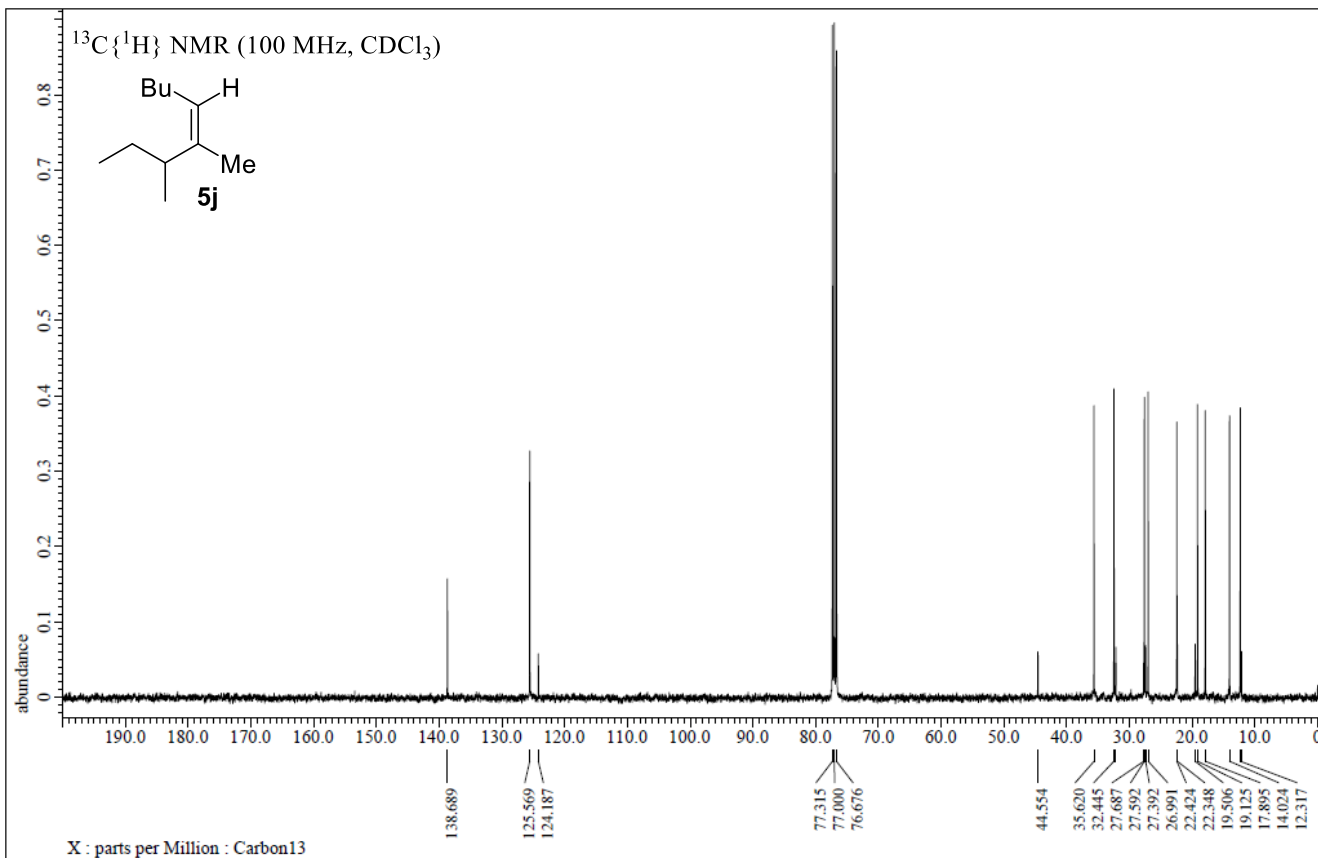
5h



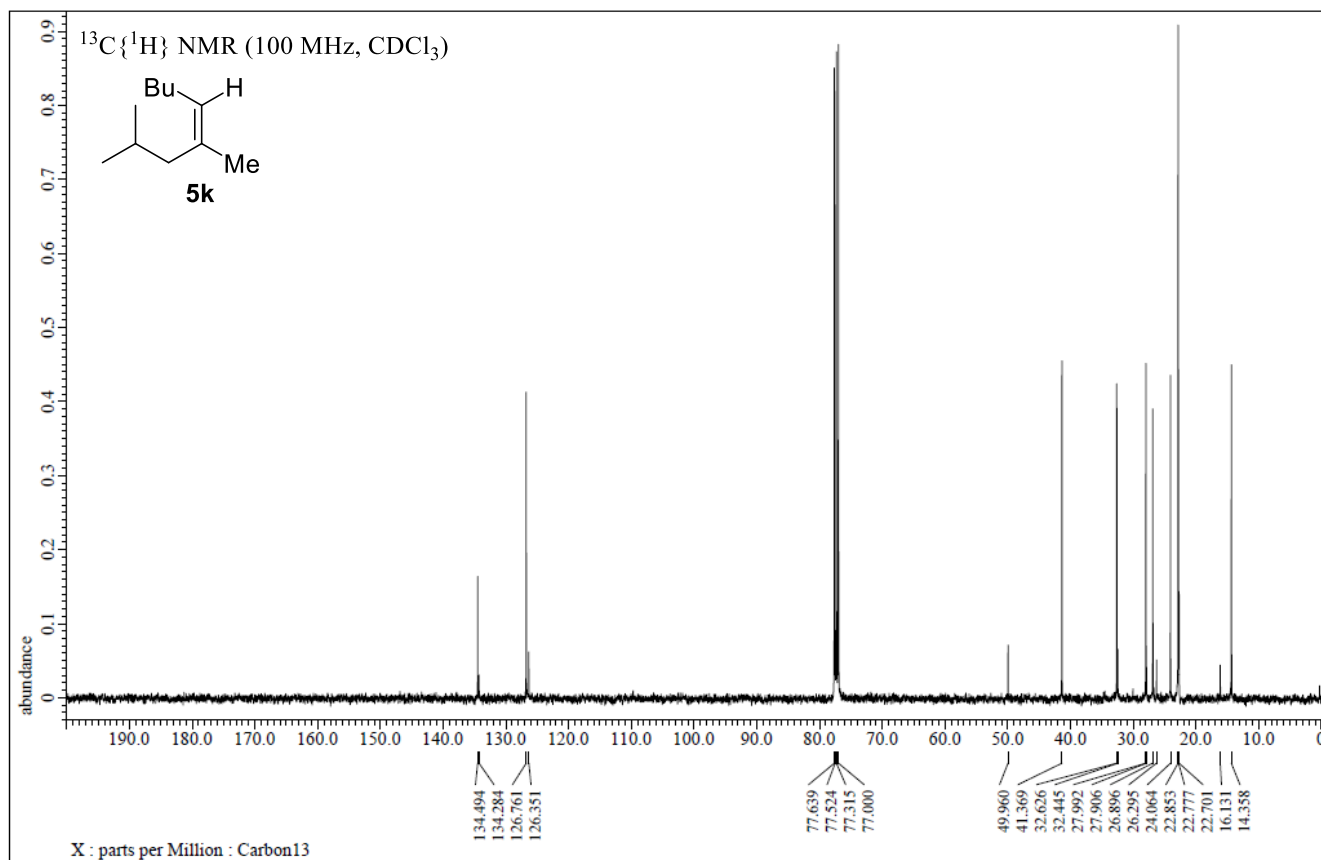
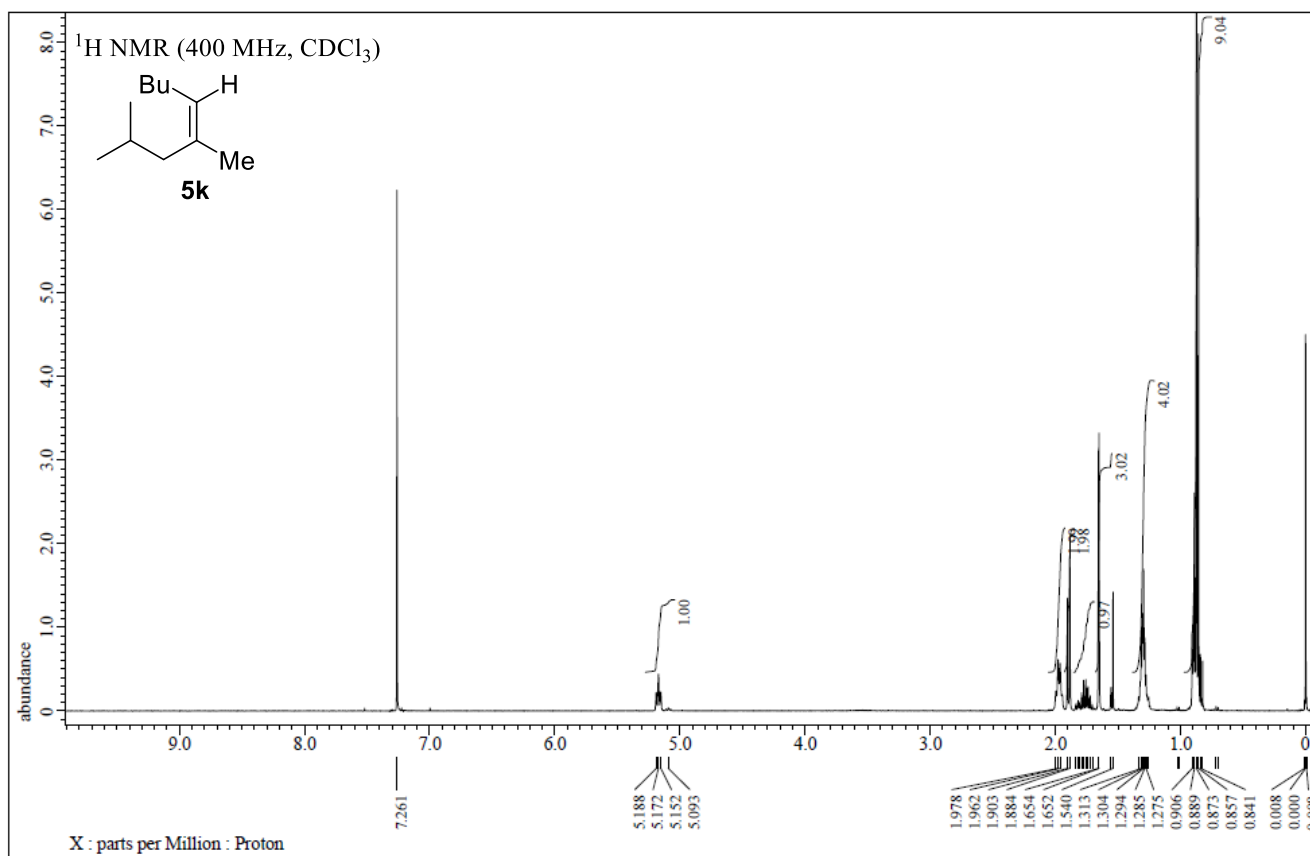


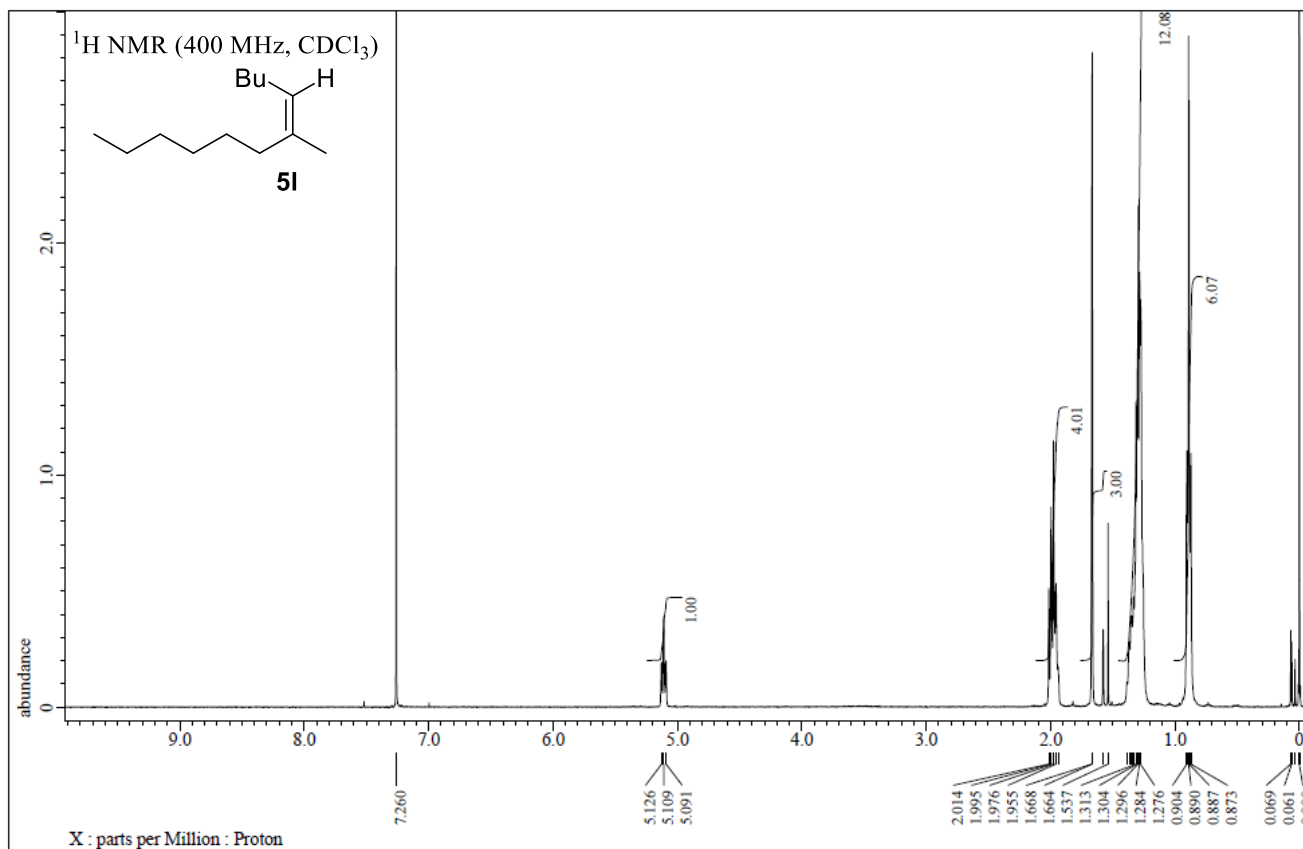
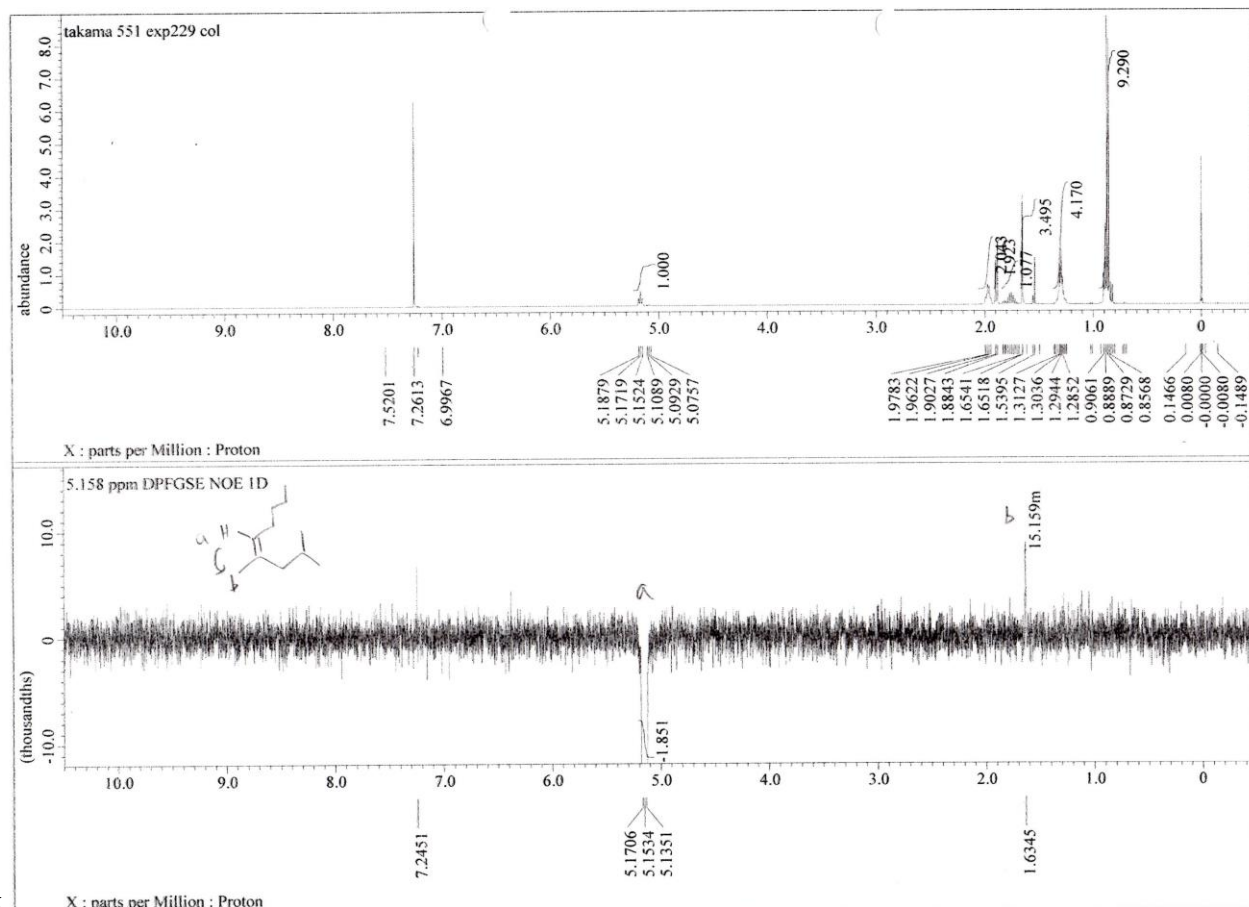
5i X : parts per Million : Proton

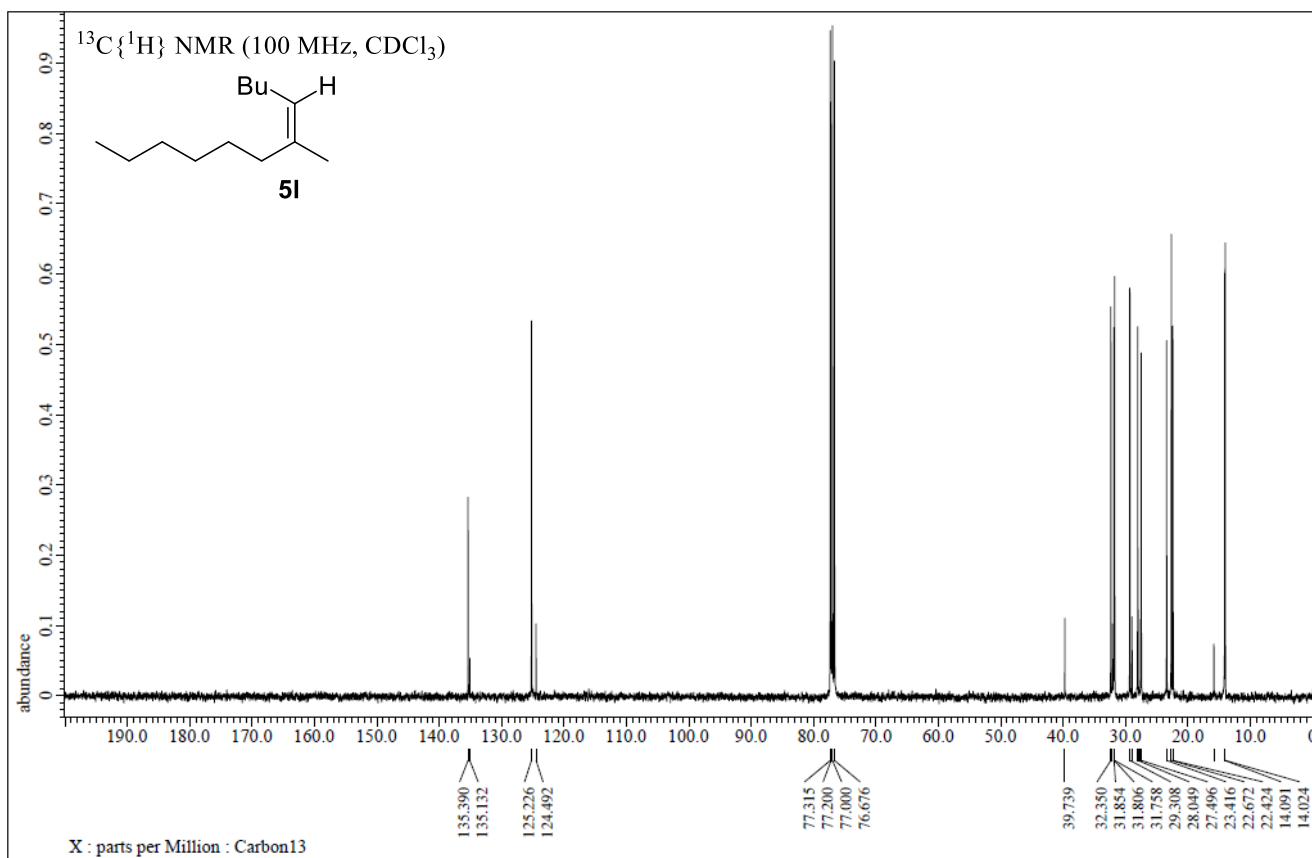




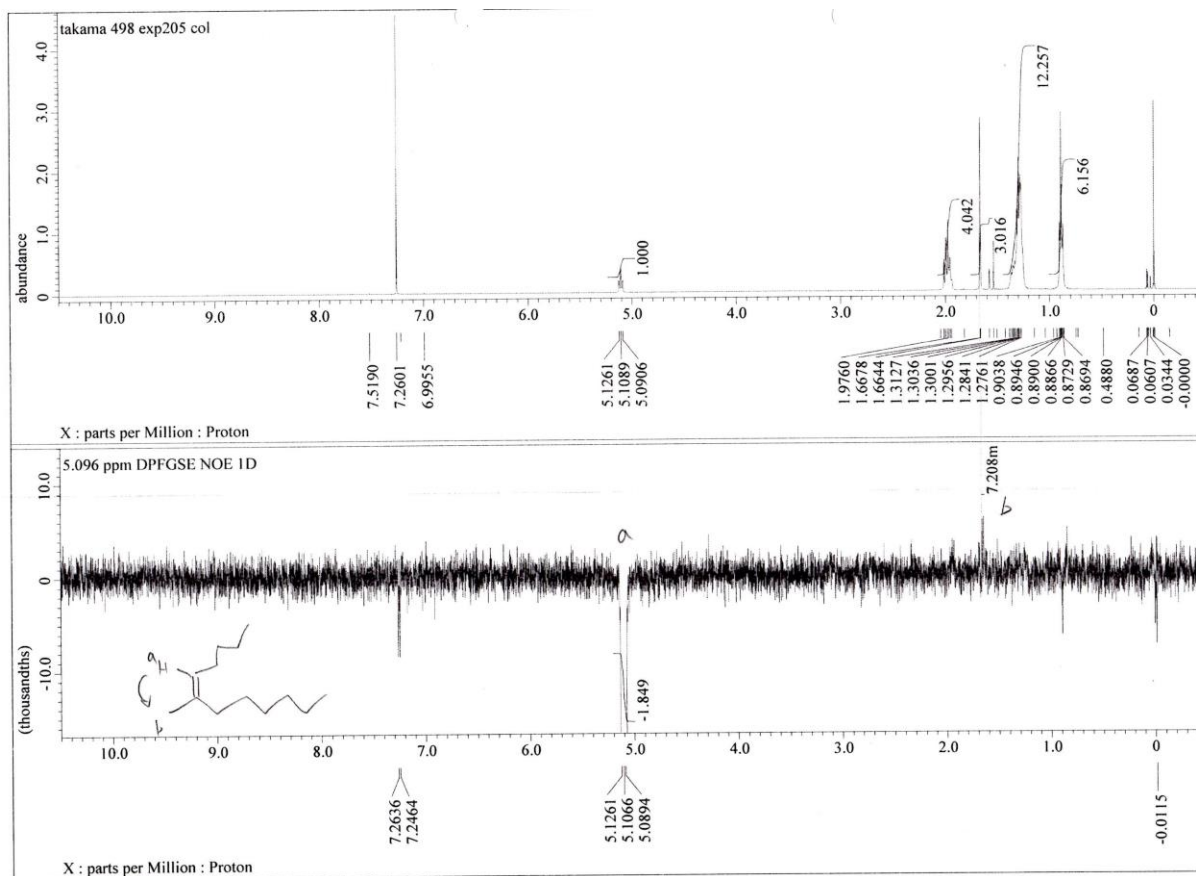
5j



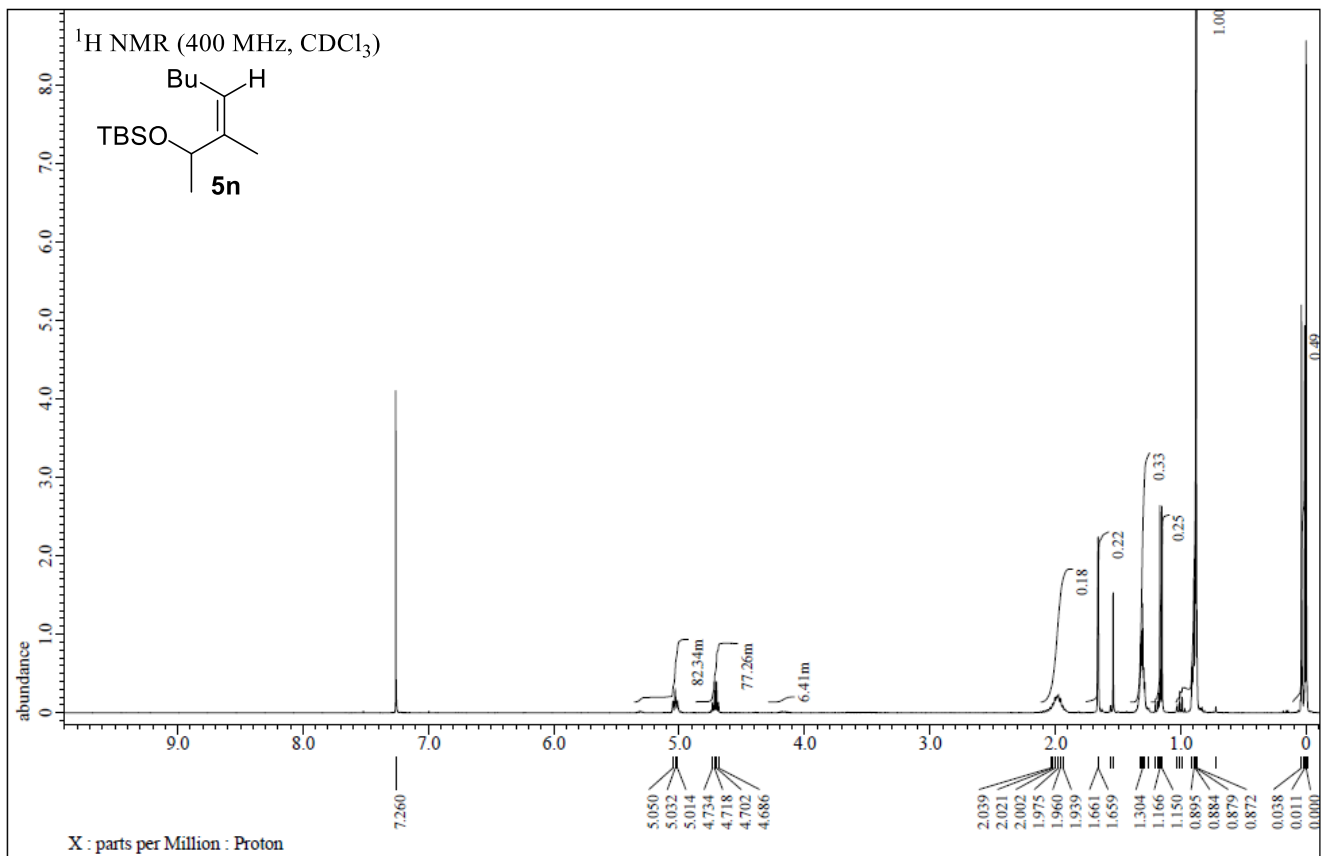
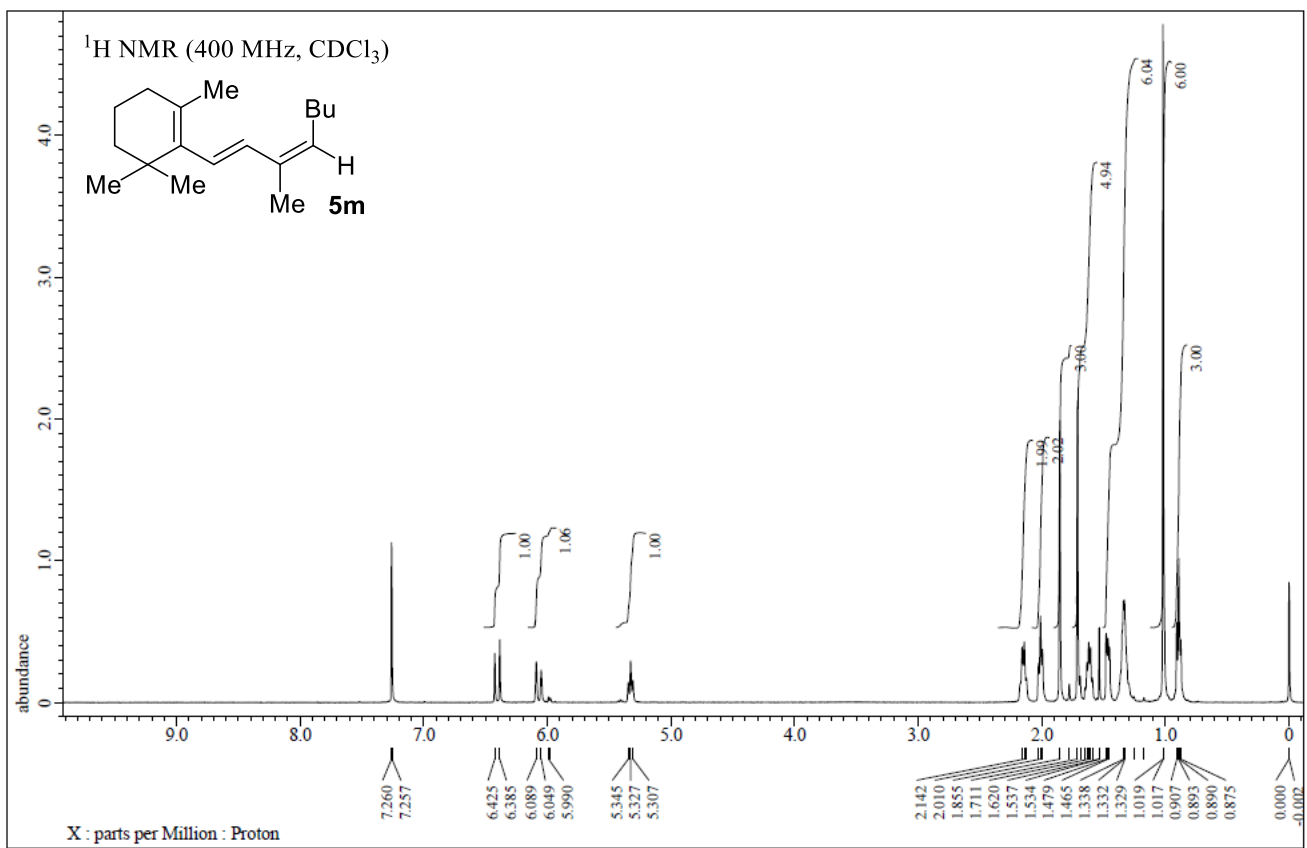


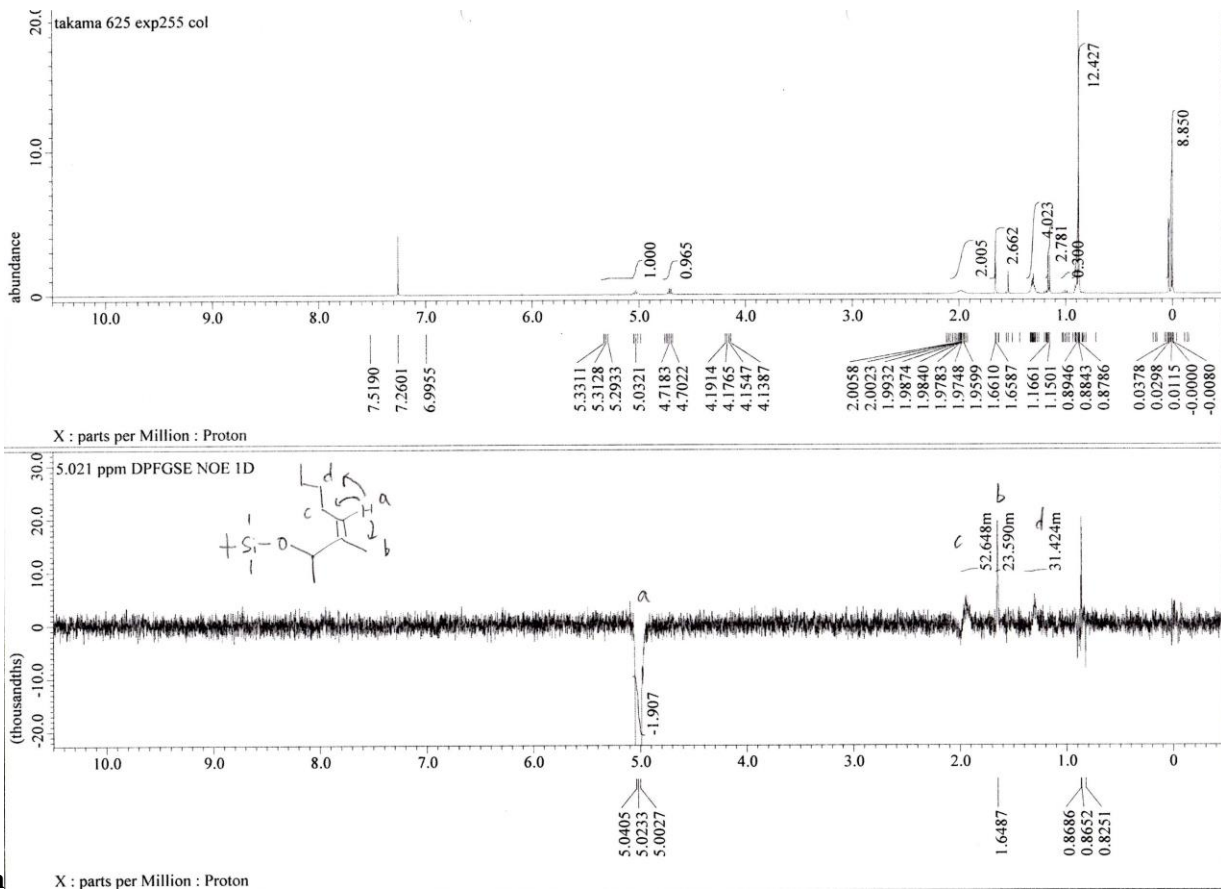
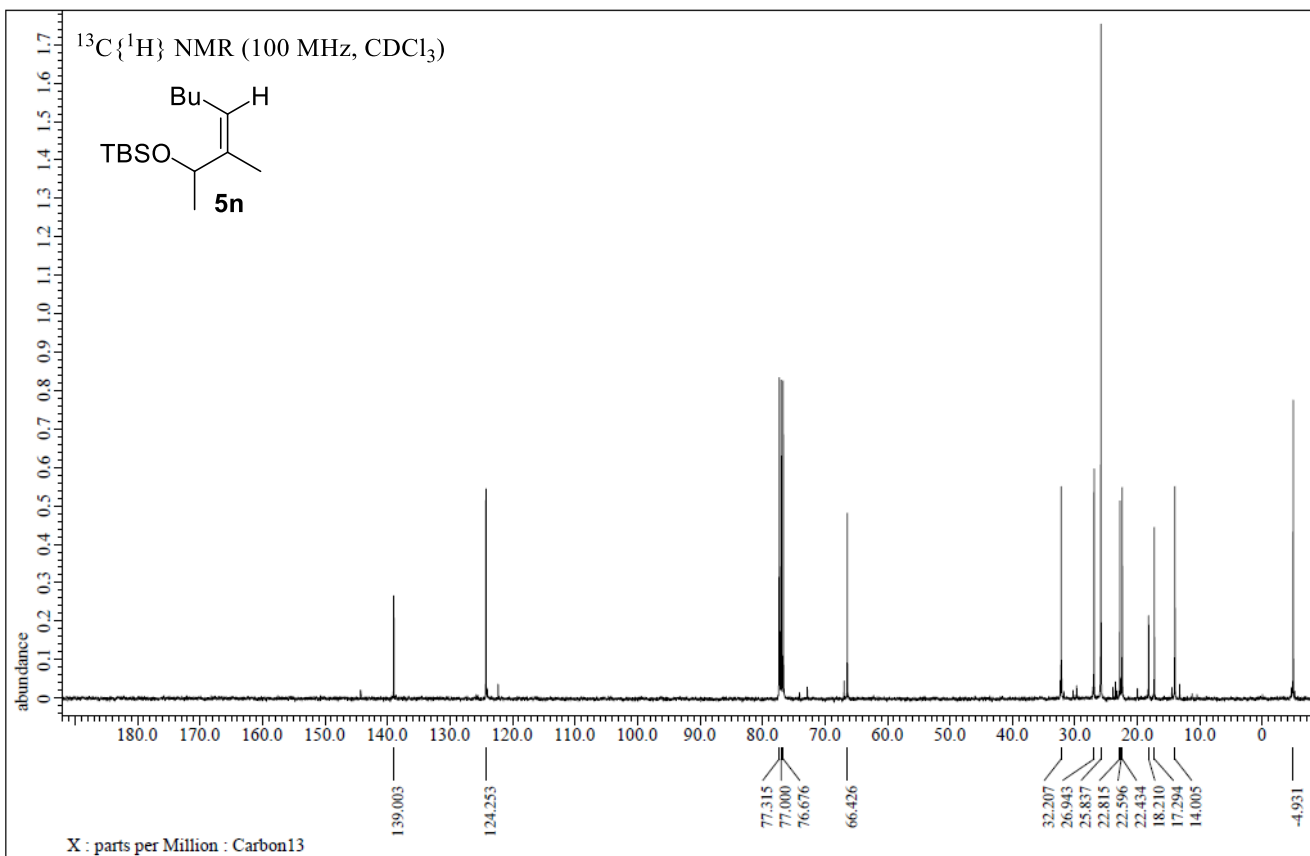


5I

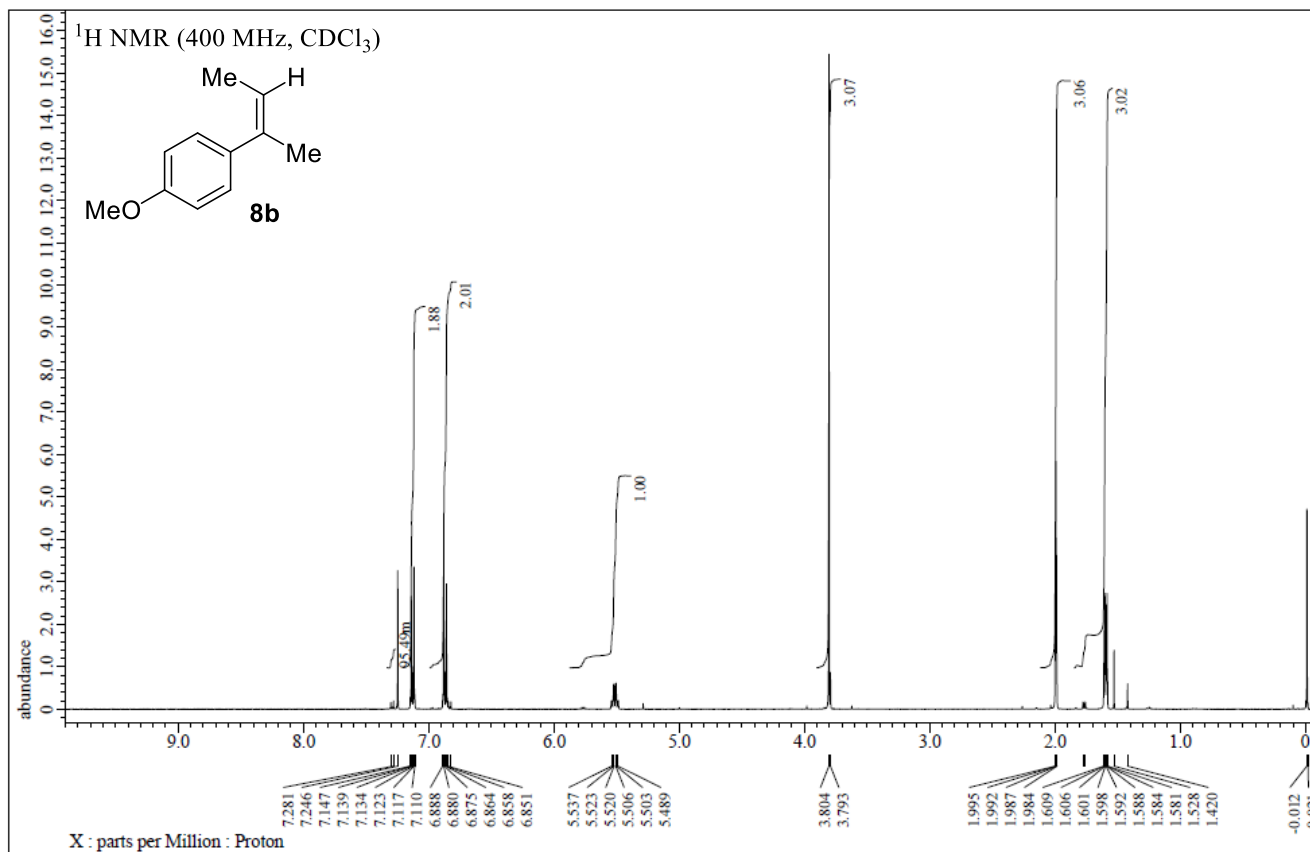
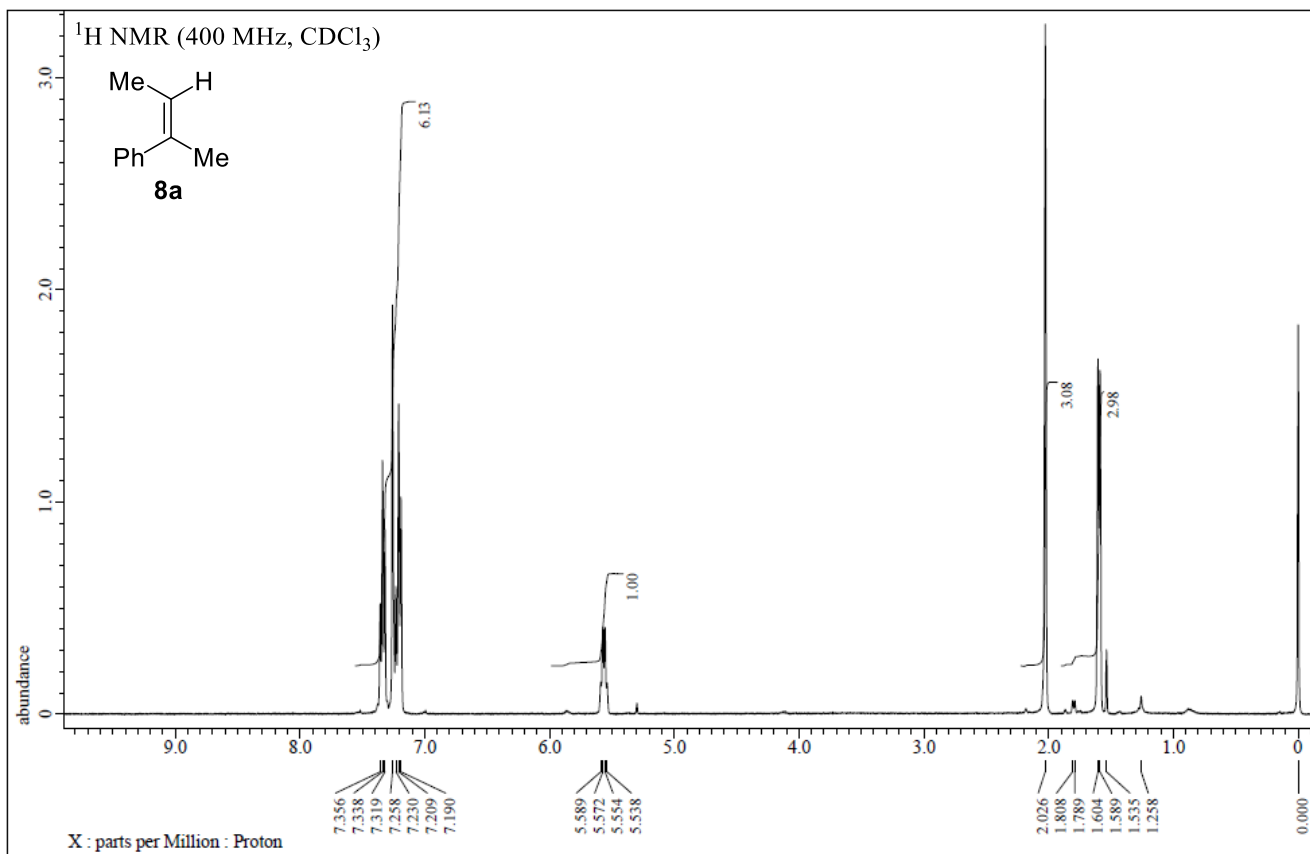


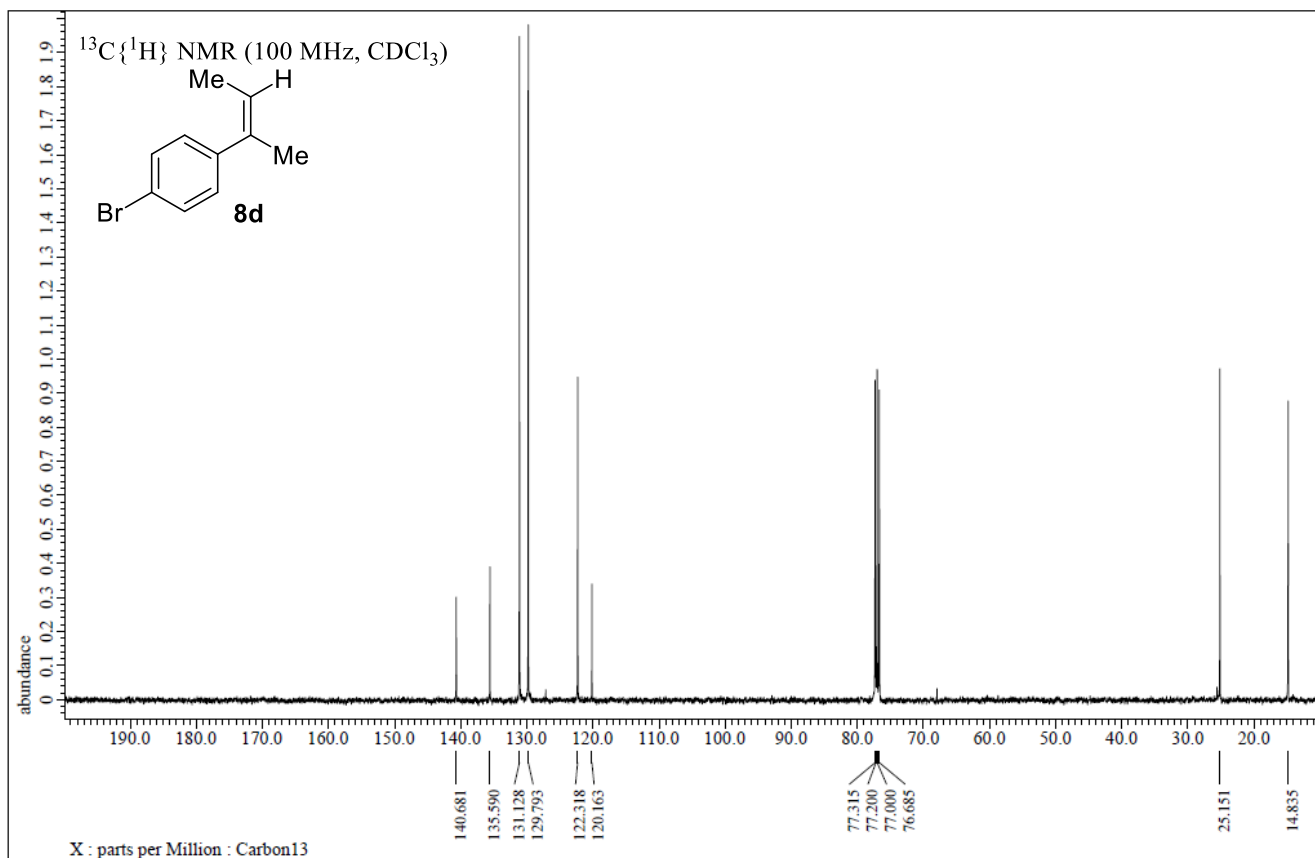
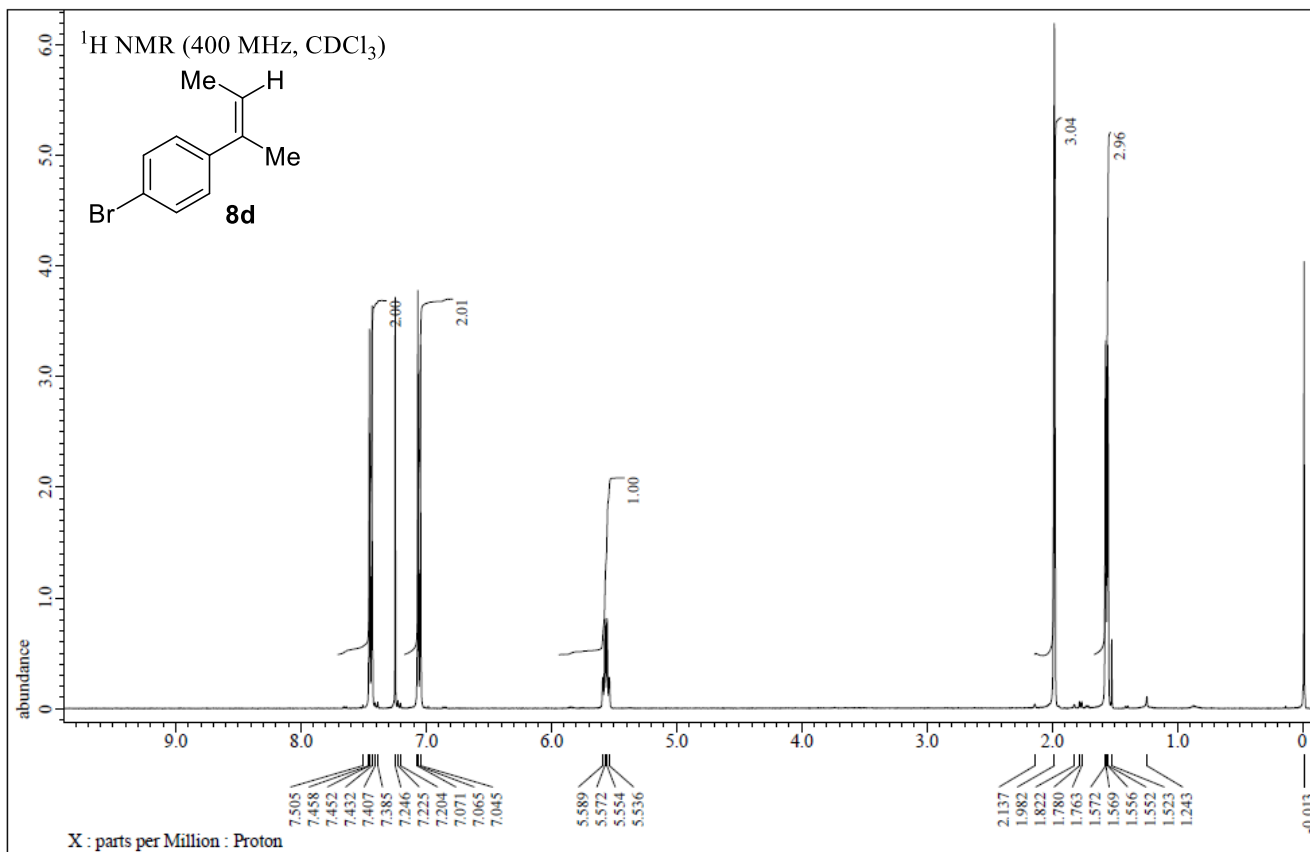
5I

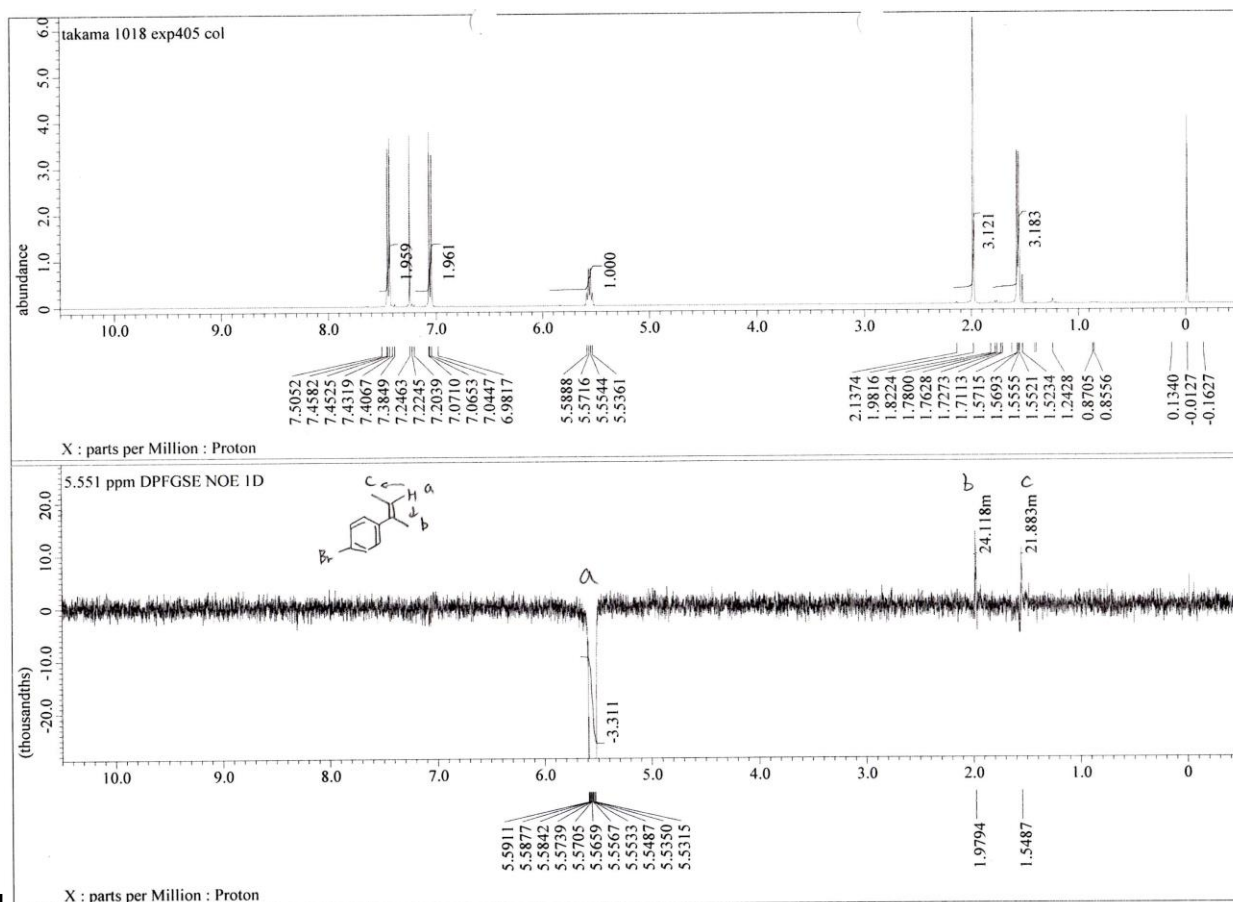




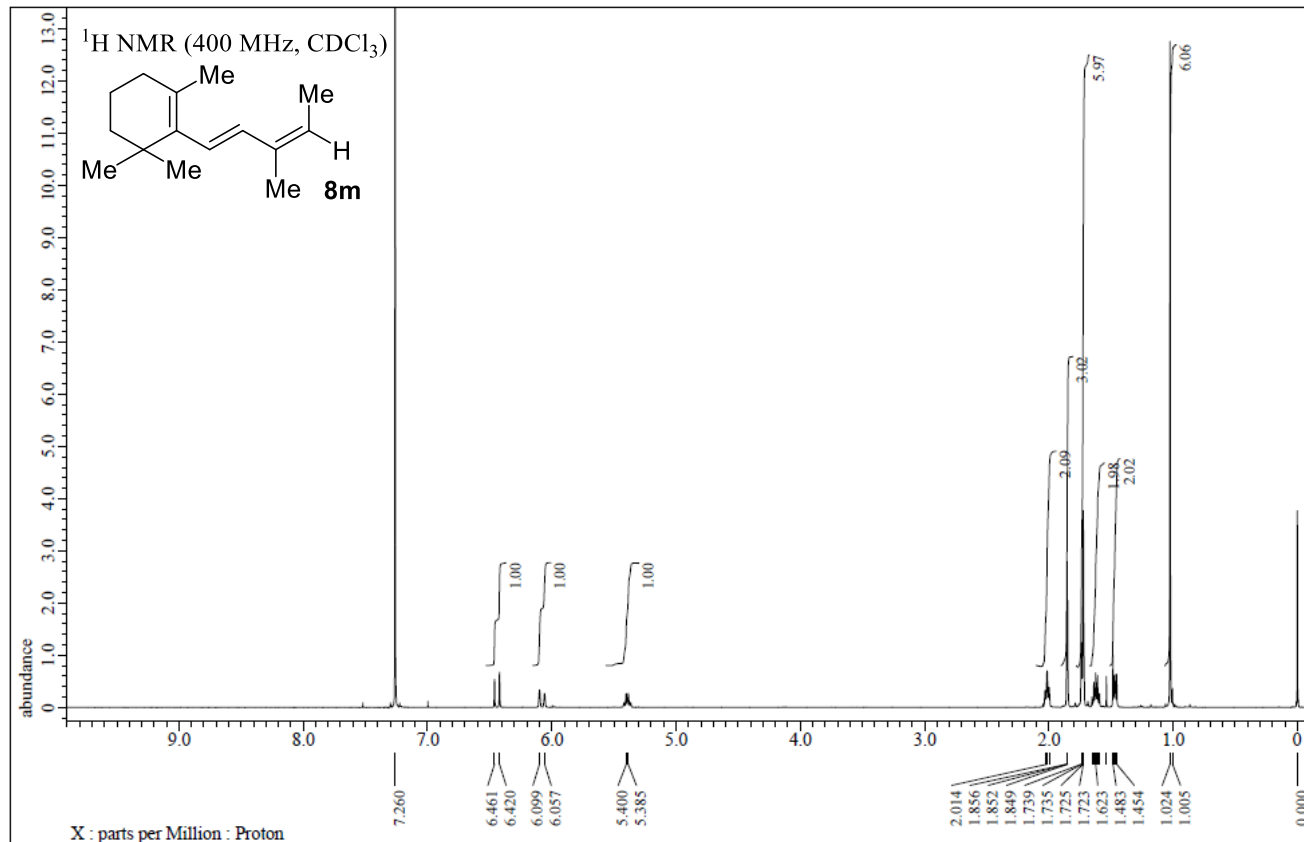
5n

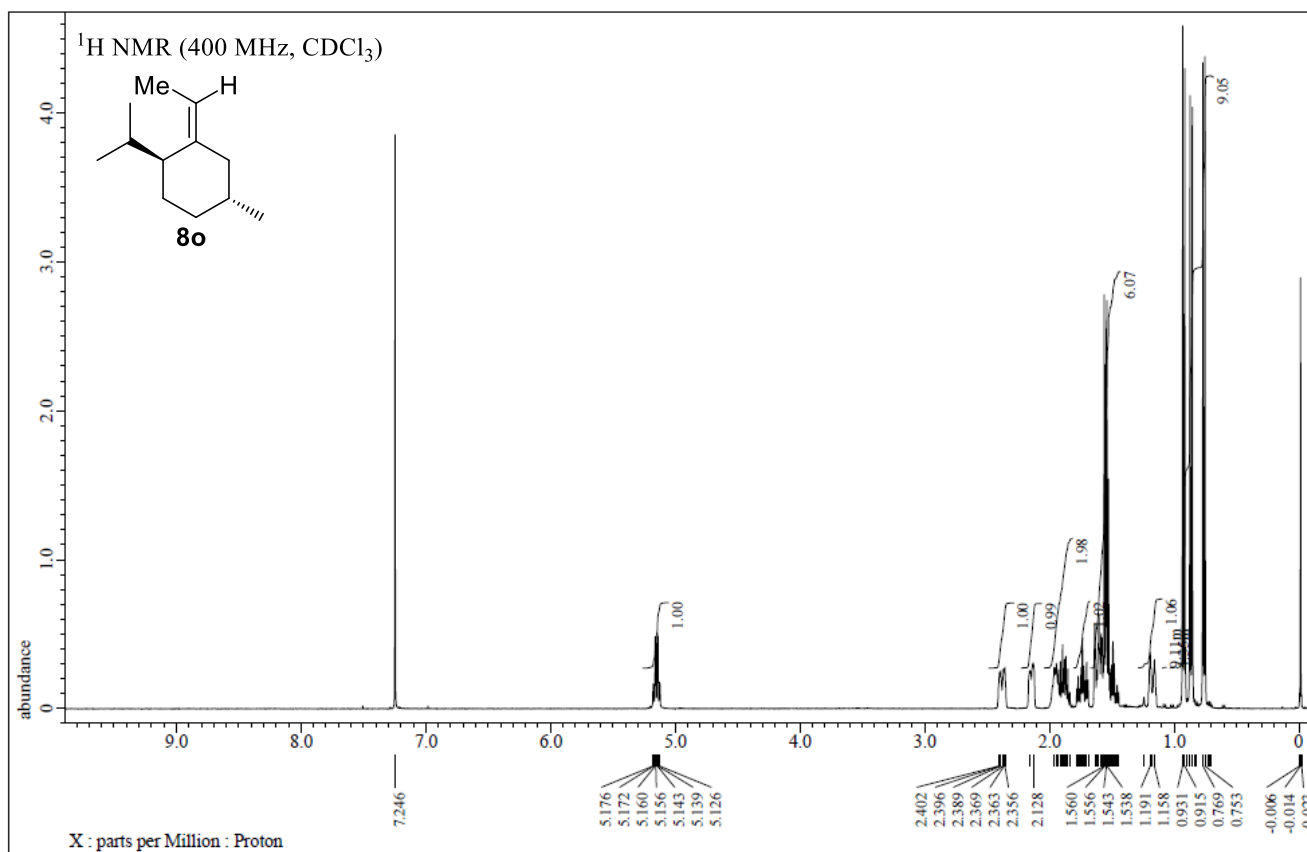
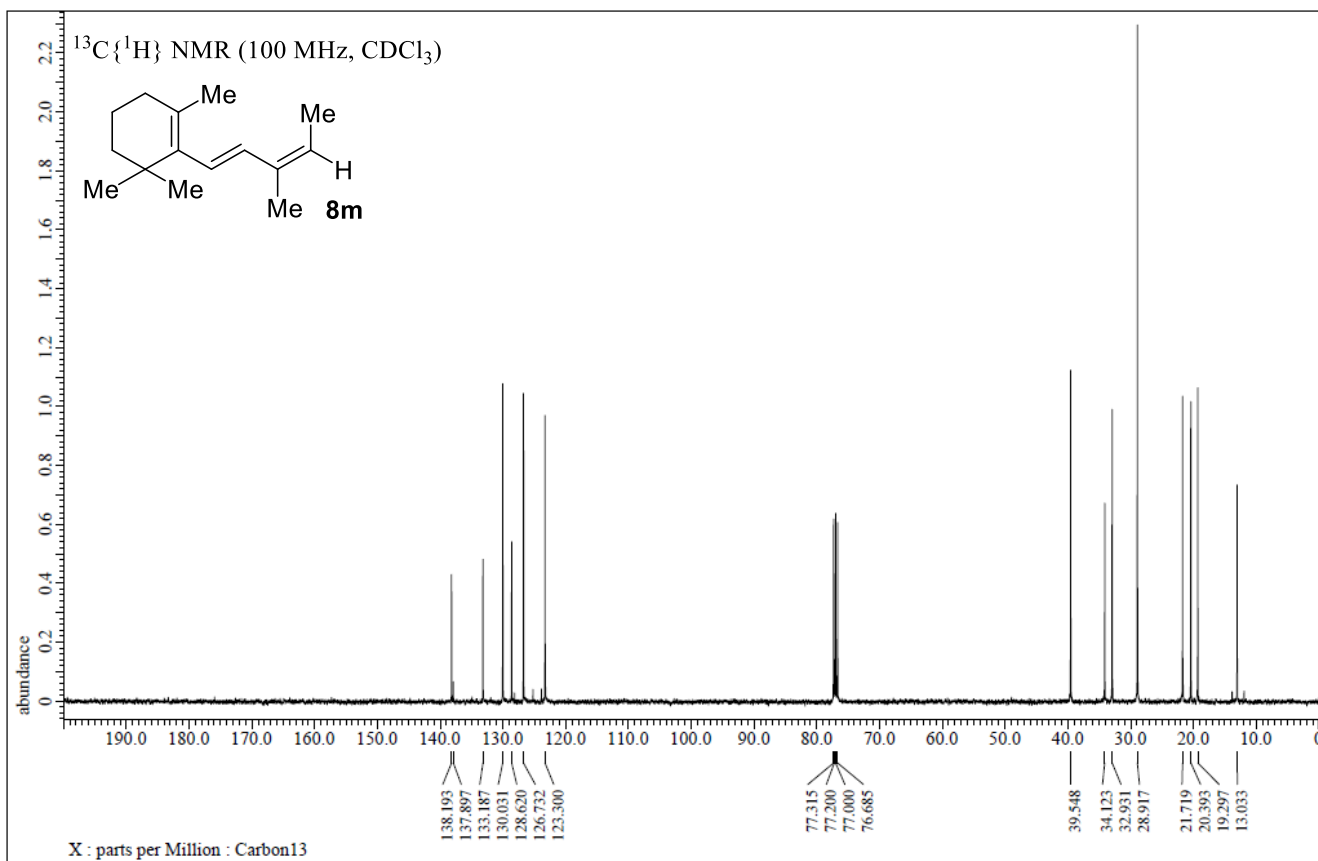


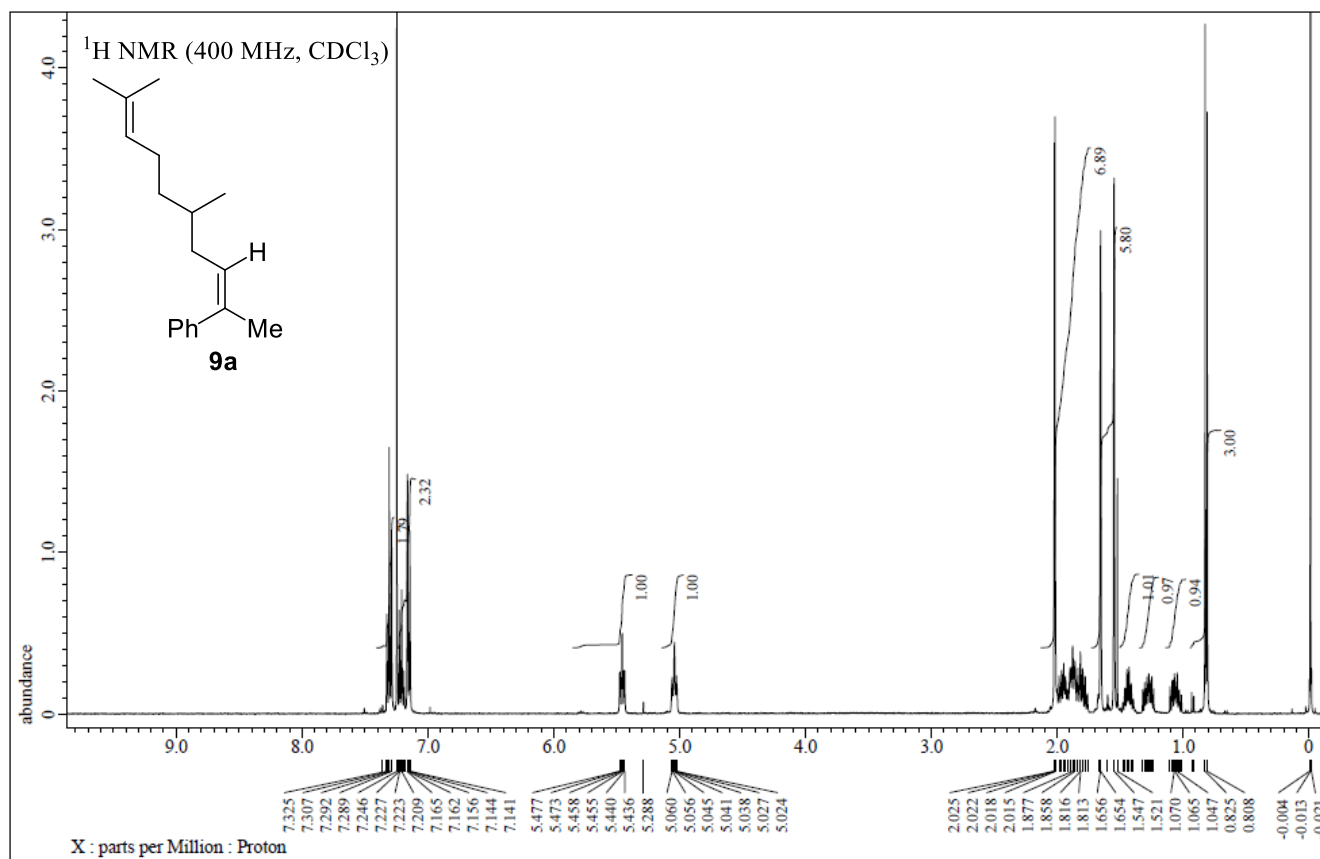
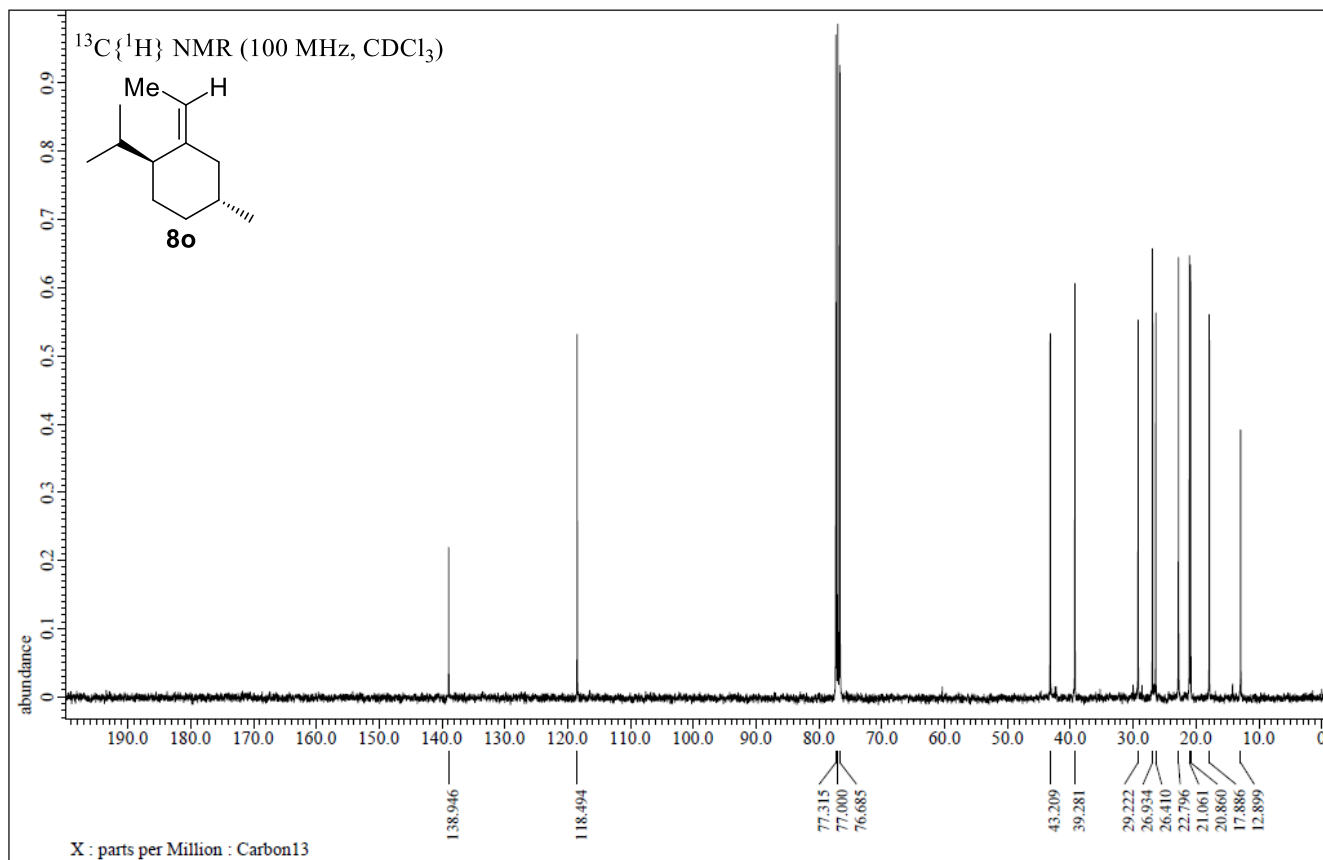


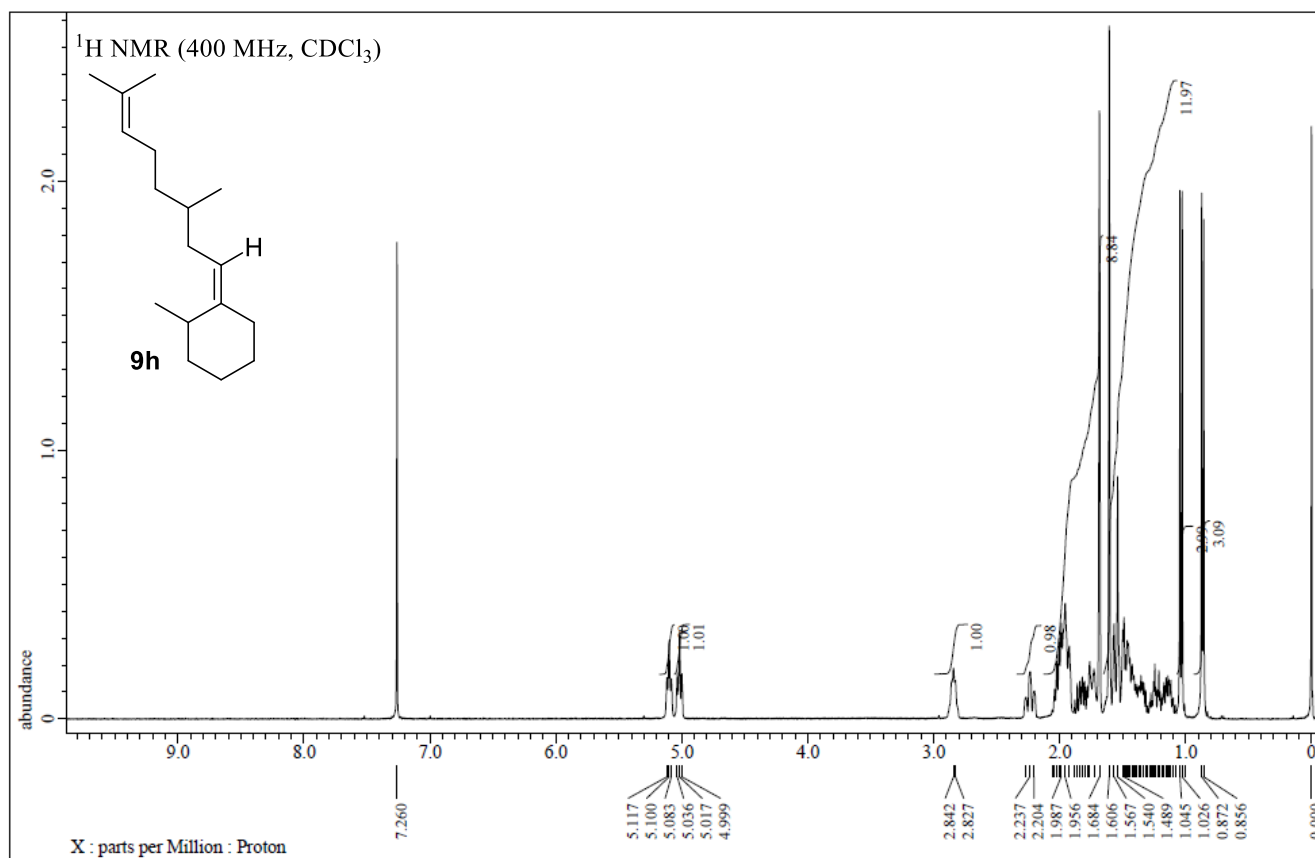
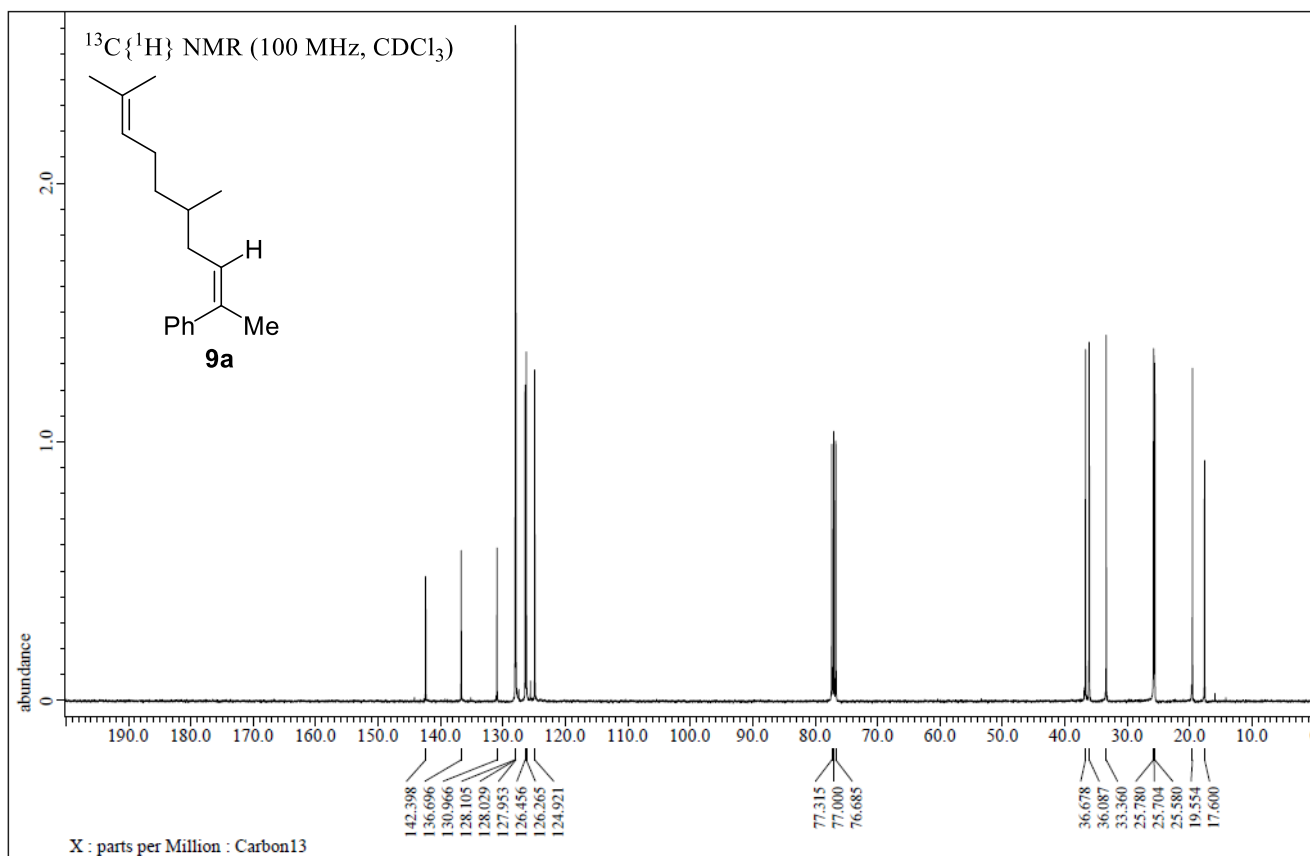


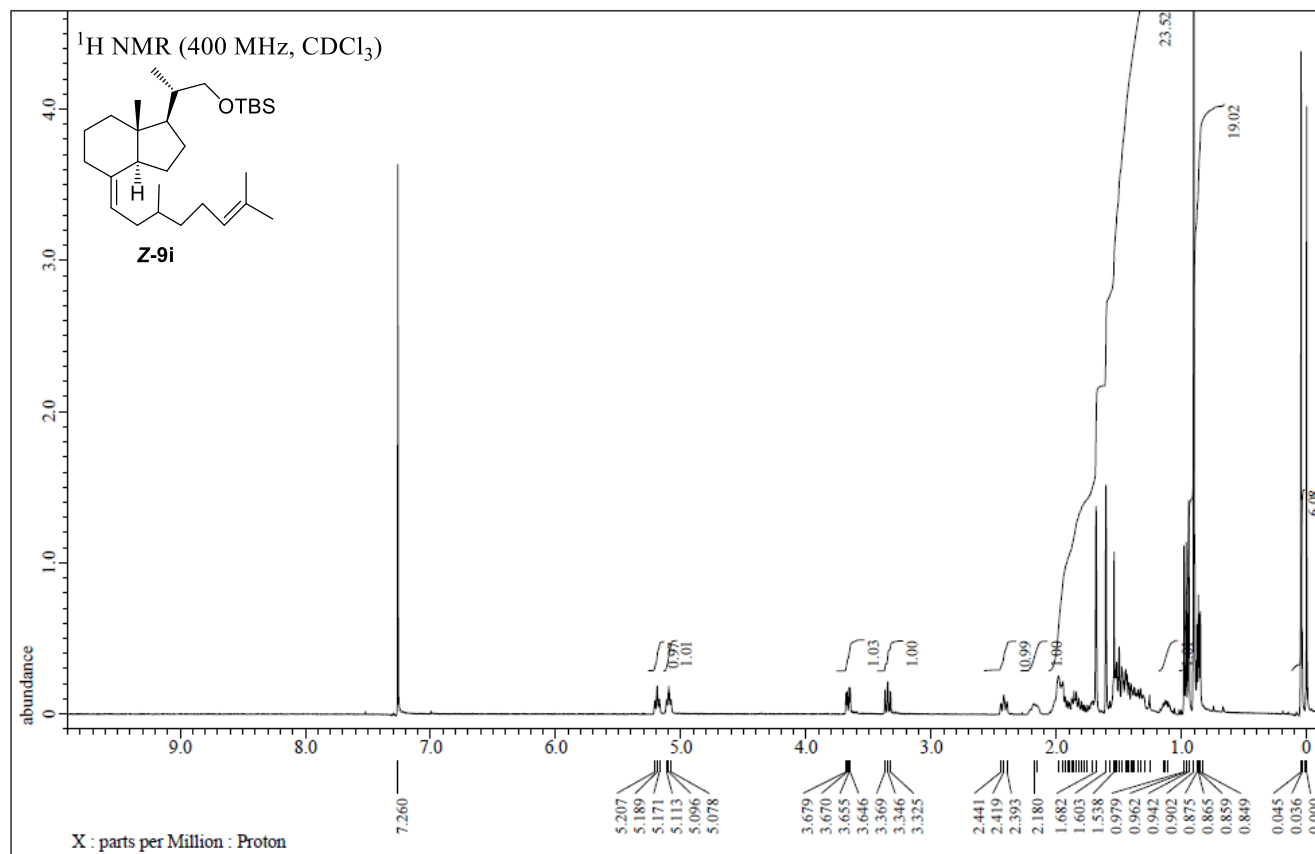
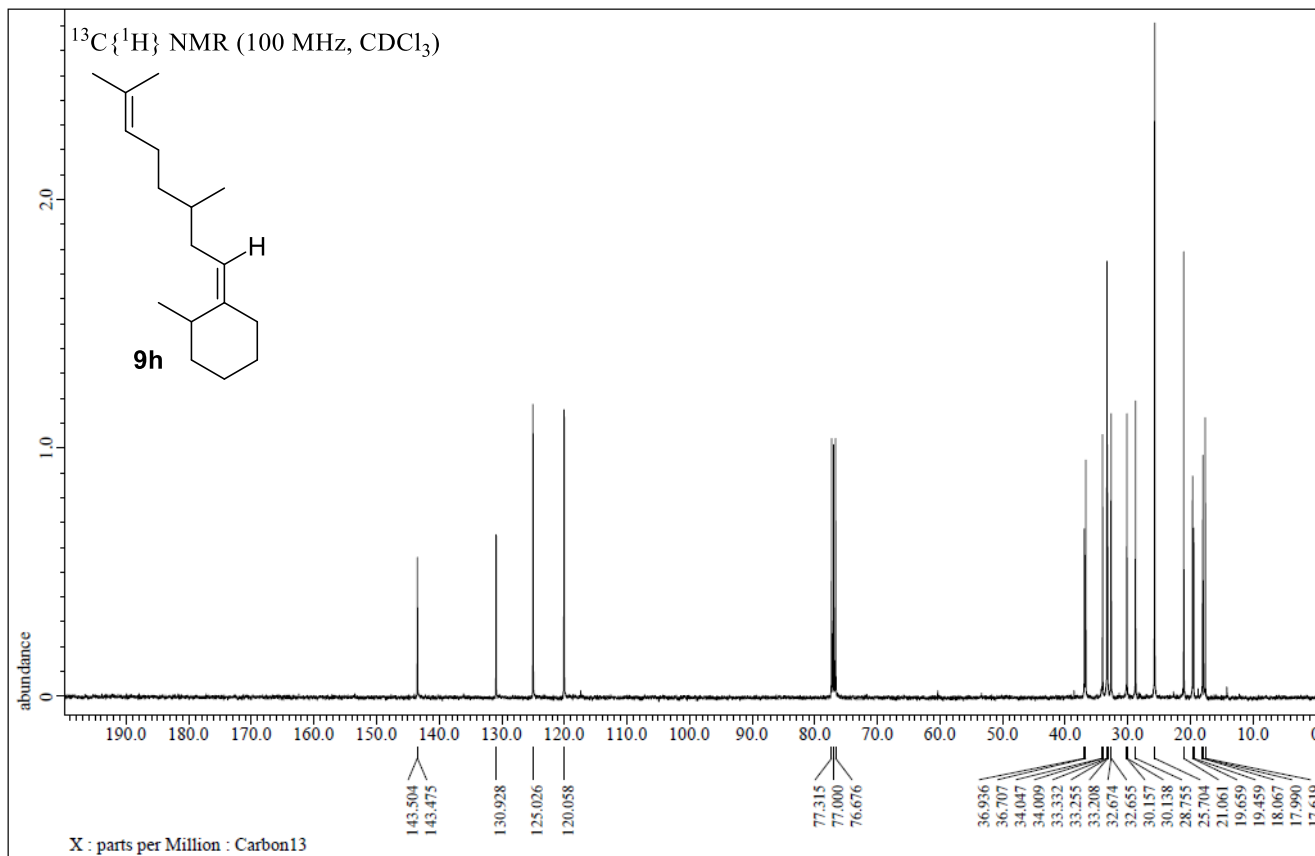
8d

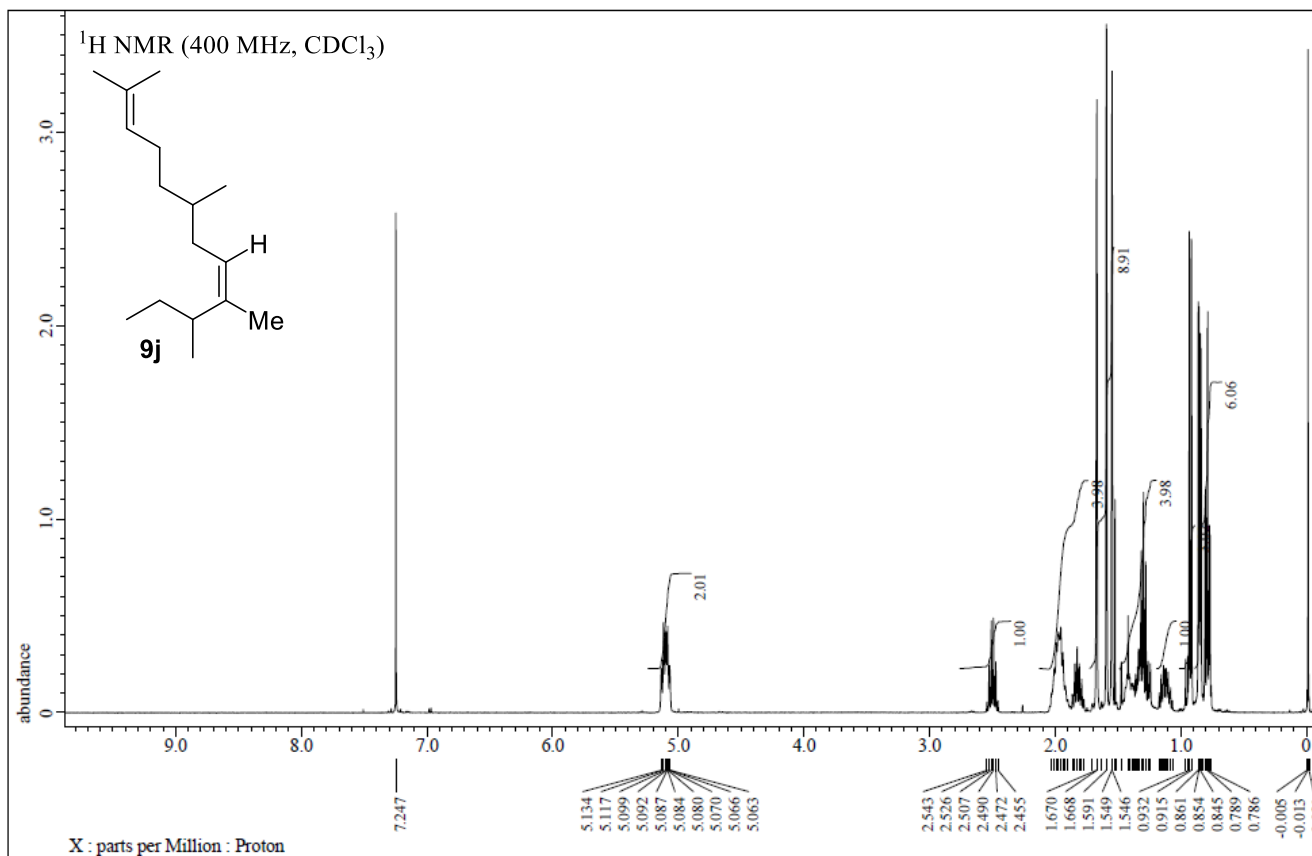
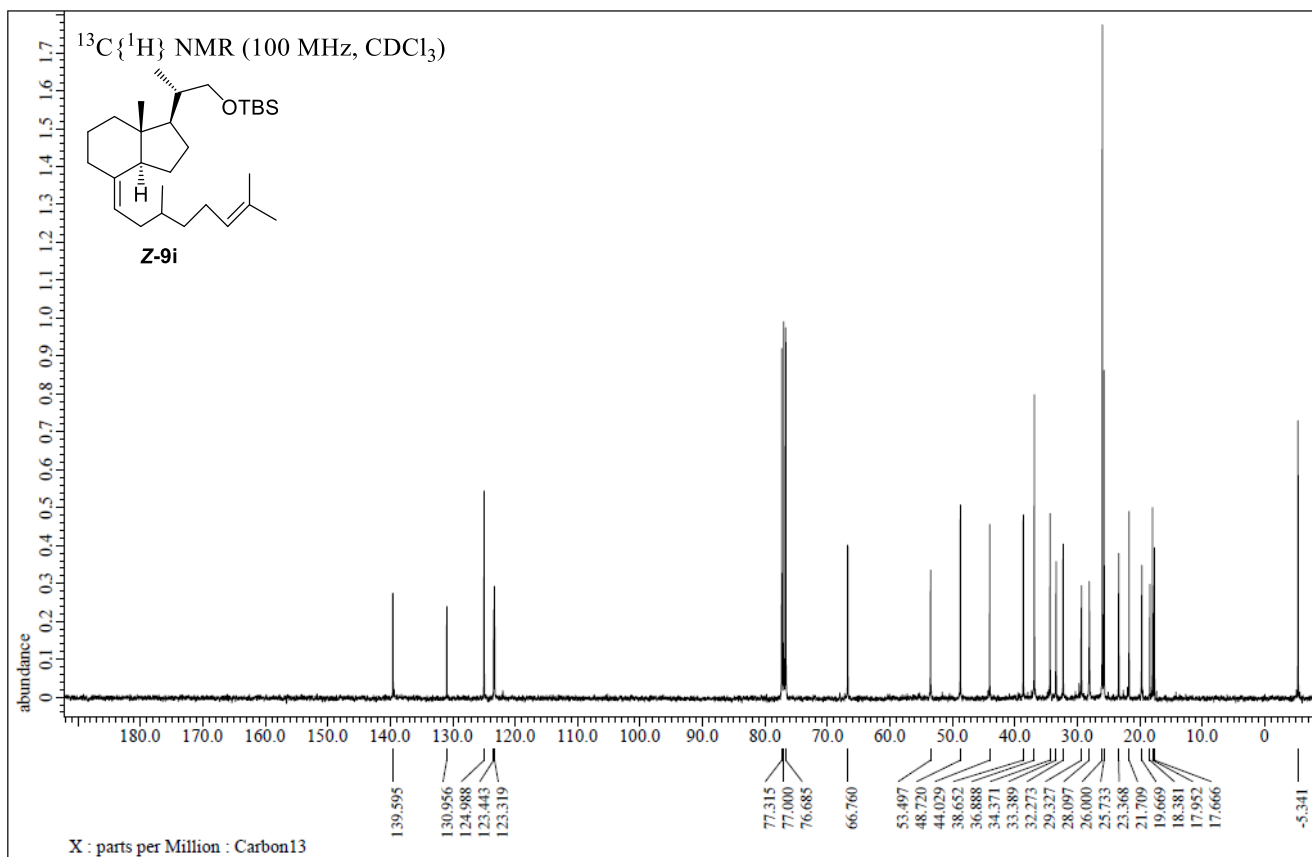


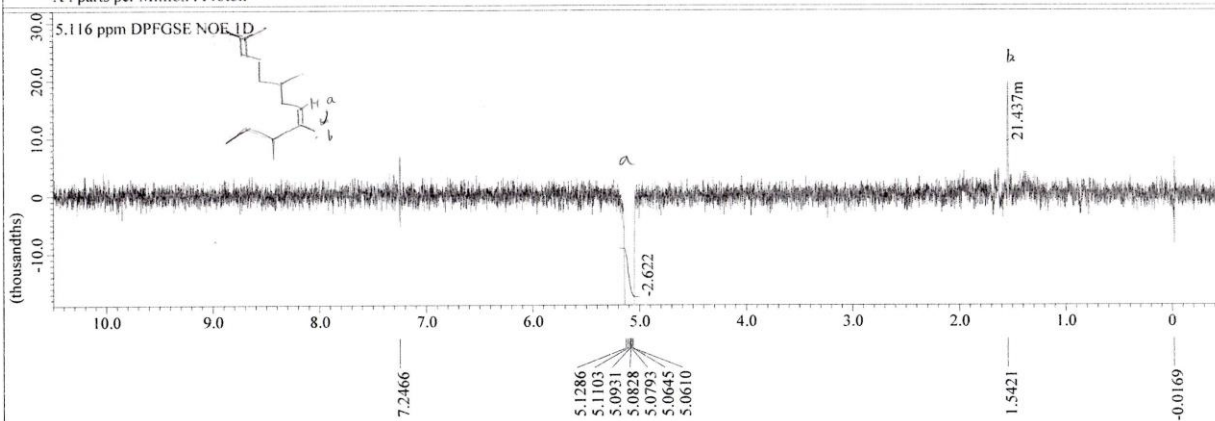
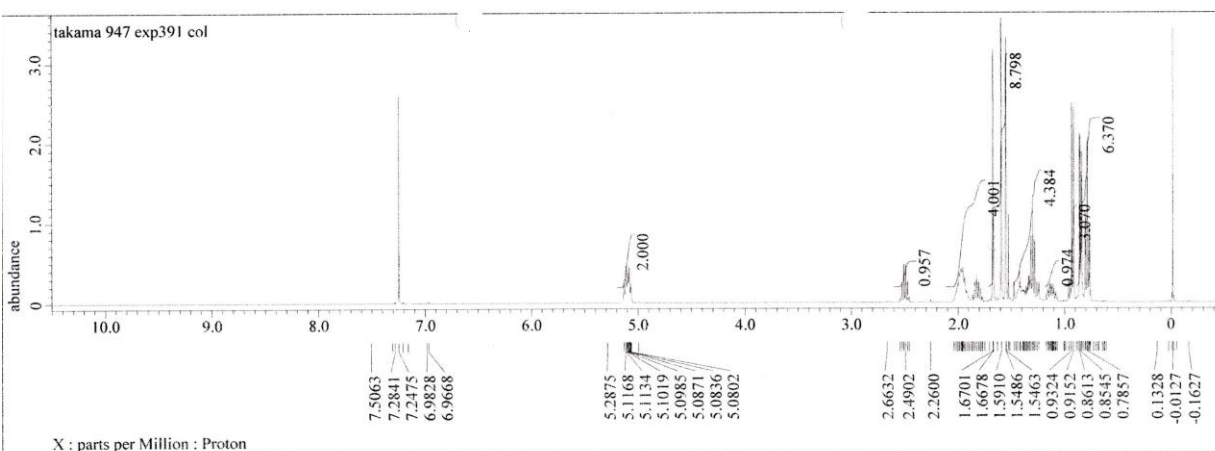
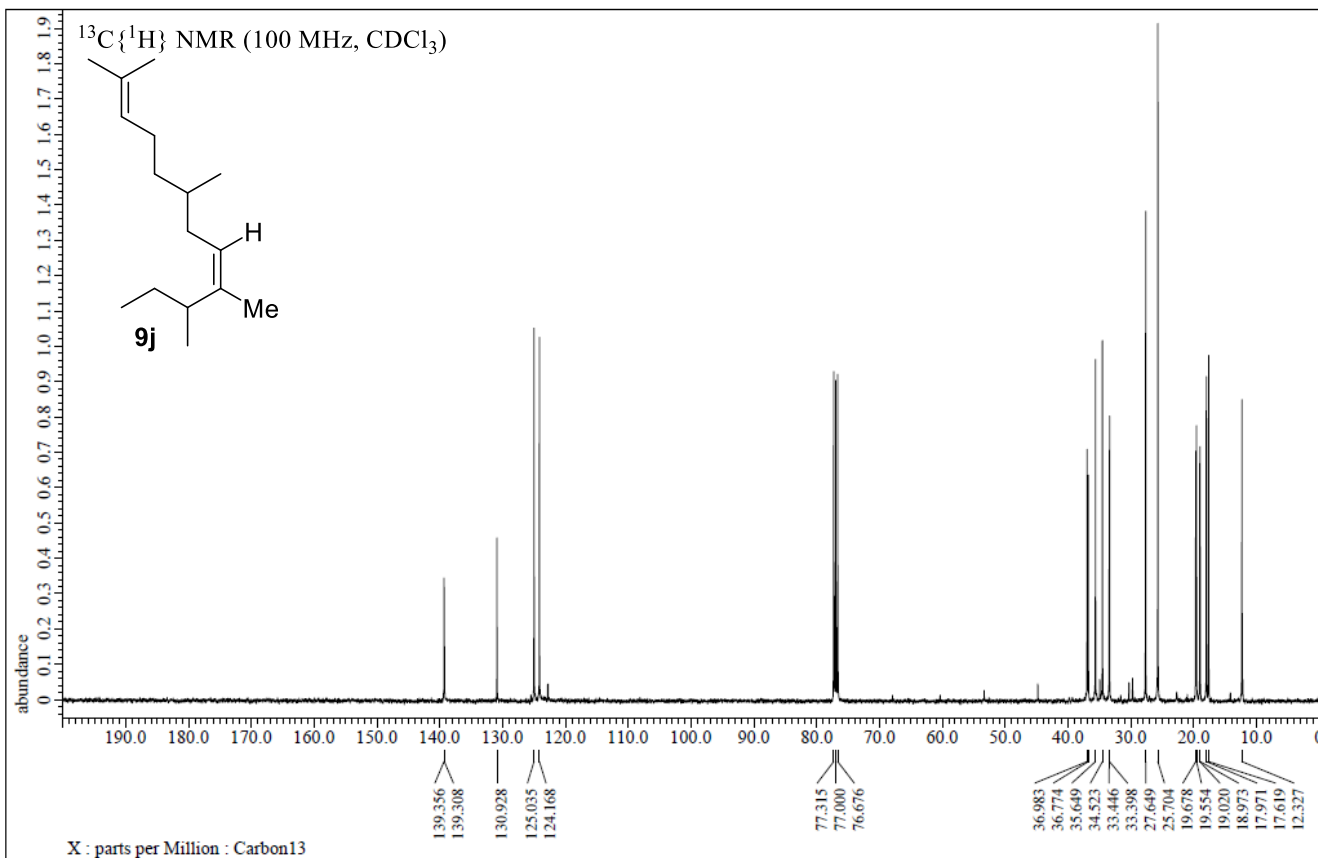












9j

