

Cu/Ag-catalyzed double decarboxylative cross-coupling reaction between cinnamic acids and aliphatic acids in aqueous solution

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Supporting Information

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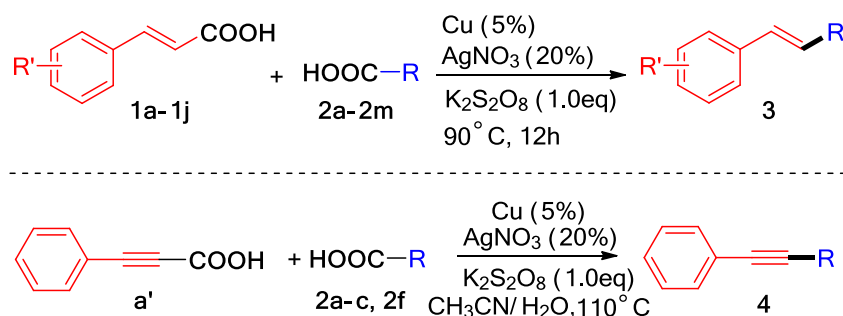
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I. General Information

All experiments were carried out using common flask in air. All substrates were purchased from commercial suppliers and used as received directly unless otherwise noted. All solvents and other commercially available reagents were purchased from Acros or TCI companies and used directly. Reactions were monitored by thin layer chromatography (TLC) (*Qingdao Haiyang Chemical Co. Ltd. Silica gel 60 F254*). Products were detected using a UV/Vis lamp (254 nm). Column chromatography was performed on *Qingdao Haiyang Chemical Co. Ltd. Gel 60* (200–300 mesh). The ^1H and ^{13}C NMR spectras were obtained on a Bruker 400 MHz NMR Fourier transform spectrometer. ^1H NMR data was reported as: chemical shift (δ ppm), multiplicity, coupling constant (Hz), and integration. ^{13}C NMR data was reported in terms of chemical shift (δ ppm) multiplicity, and coupling constant (Hz). Hertz (Hz).The spectra are referenced against the internal solvent (CDCl_3 , δ ^1H = 7.26 ppm, ^{13}C = 77.0 ppm; DMSO-d_6 , δ ^1H = 2.50 ppm, ^{13}C = 40.0 ppm). Data is reported as follows: s= singlet, d= doublet, t= triplet, q=quartet and m= multiplet. ESI-MS spectra were recorded on a Bruker Esquire 3000. High resolution mass spectra (HR MS) were obtained on a Waters Micromass Q-Tof MicroTM instrument using the ESI technique.

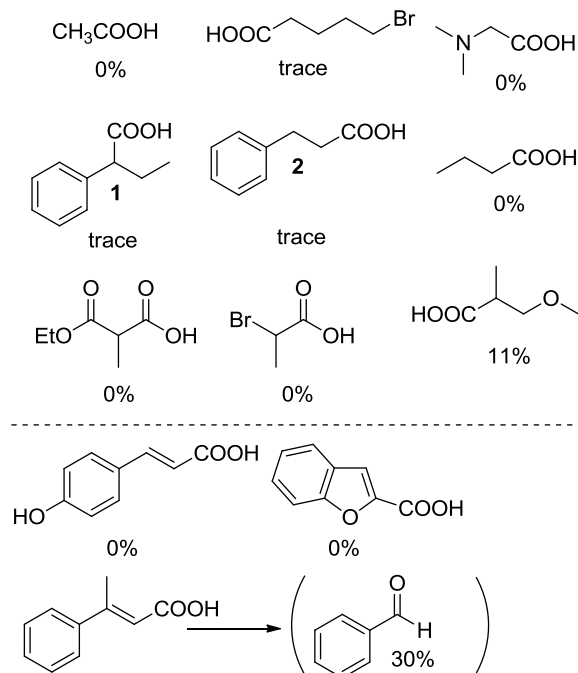
II. Experimental Section

(a) General Procedure:



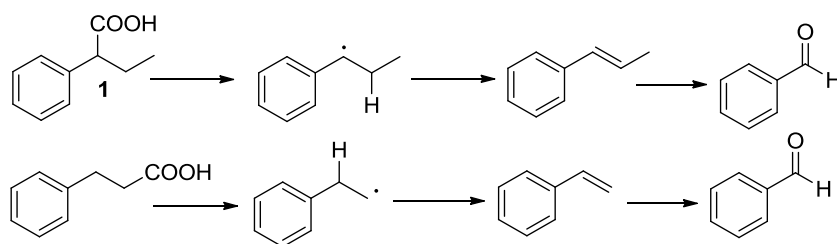
An 50 mL vial was charged with magnetic stir bar, cinnamic acid (**1**) or phenylpropionic acid (**a'**) (1.0 mmol), aliphatic acid (**2**, 1.5 mmol), copper powder (0.05 mmol), AgNO₃ (0.2 mmol) and K₂S₂O₈ (1.0 mmol) were added in turn, followed by CH₃CN/H₂O (3 mL/3 mL). After stirring at 90 °C for 12 h (or at 110 °C for 12 h), The reaction mixture was concentrated in vacuo and extracted with EtOAc (3 × 10 mL). The combined organic phase was washed by saturated NaHCO₃ solution and dried by anhydrous Na₂SO₄ and then evaporated under reduced pressure. The isolated yield was obtained by flash chromatography column on silica gel (gradient eluent of Ethyl acetate in Petroleum: 0 ~ 2%, v/v).

(b) Under the optimized conditions, the following substrates were not effective in this transformation.

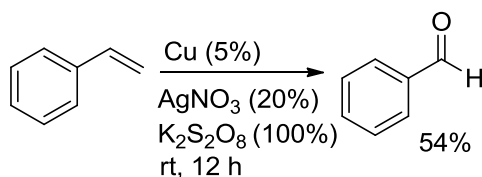


Scheme S1

In a word, primary acids failed to proceed under current conditions. The reactions of secondary acids containing ether, halide or ketone groups on adjacent position also do not proceed or produce low yields. Future studies will be aimed at overcoming these limitations. According to our test results, for **1** and **2**, in their reactions, about 40% benzaldehyde was isolated. They maybe proceed via the following routes:



We did the controlled experiment:

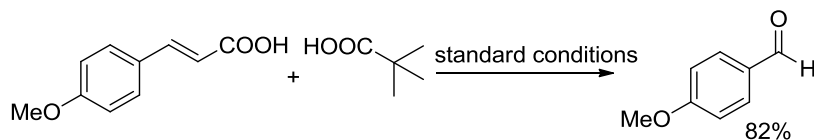


Scheme S2

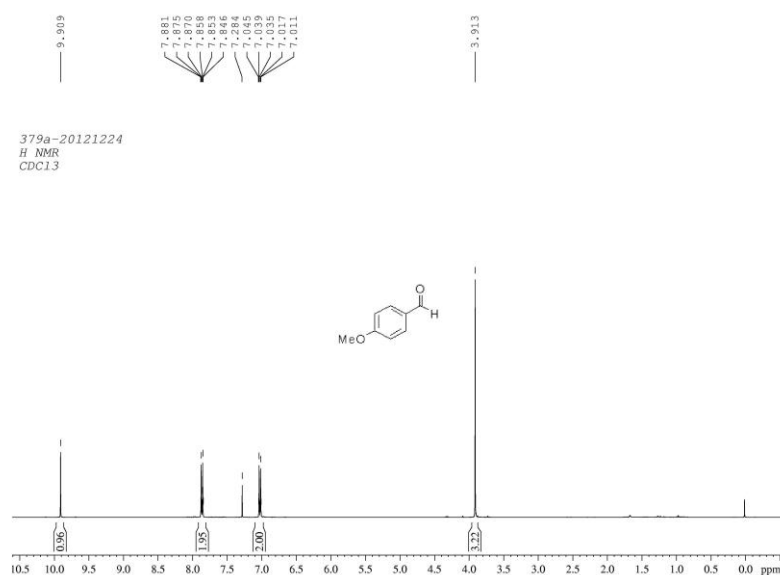
S4

(c) Other experiments

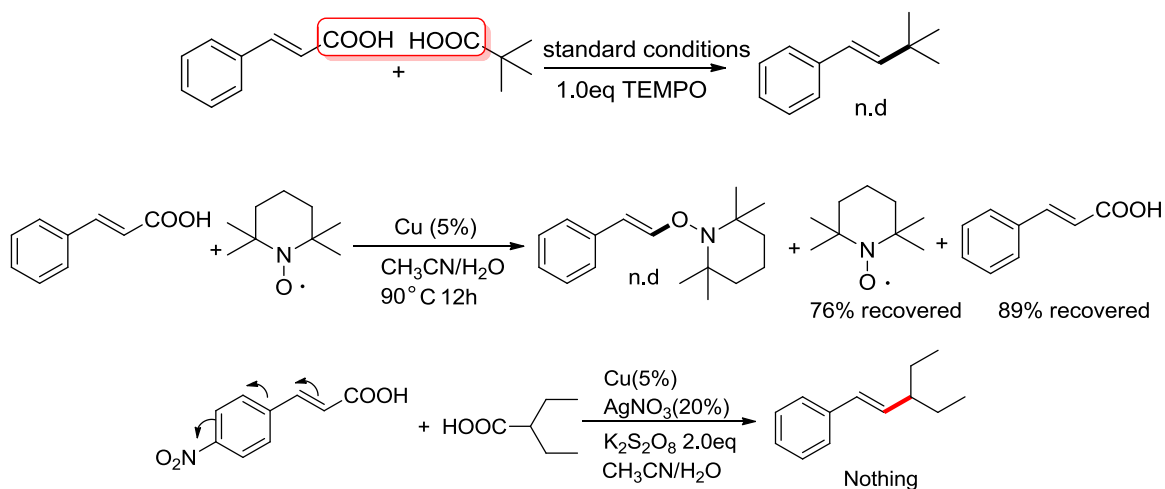
For (*E*)-4-Methoxycinnamic acid, we obtained an interesting result and we do not know the mechanism of this reaction until now.



Scheme S3



TEMPO could shut off the reaction:



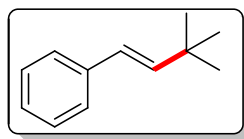
Scheme S4

S5

III References and Notes

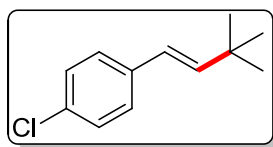
- (1) J. H. Delcamp and M. C. White, *J. Am. Chem. Soc.*, **2006**, *128*, 15076.
- (2) Z. Cui, X. Shang, X. F. Shao and Z. Q. Liu, *Chem. Sci.*, **2012**, *3*, 2853.
- (3) Y. J. Jang, Y. K. Shih, J. Y. Liu, W. Y. Kuo and C. F. Yao, *Chem. Eur. J.*, **2003**, *9*, 2123.
- (4) R. Trivedi and J. A. Tunge, *Org. Lett.*, **2009**, *11*, 5650.

Characterizations of Products



1-((*E*)-3,3-dimethylbut-1-enyl)benzene(**3aa**)¹

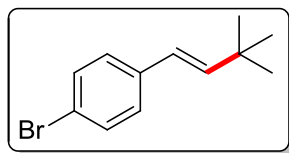
The mixture of *trans*-Cinnamic acid (1.0 mmol), Cu (0.05 mmol), AgNO₃ (0.2 mmol), K₂S₂O₈ (1.0 mmol) and Pivalic acid (1.5 mmol) in acetonitrile (3 mL) and water (3 mL) was stirred at 90°C for 12 h. After the usual work-up, compound **3aa** was isolated as a colorless oil. Yield: 78%. R_f = 0.9 (petroleum ether). ¹H NMR (400MHz, CDCl₃) 7.38-7.40 (m, 2H), 7.30-7.34 (m, 2H), 7.19-7.23 (m, 1H), 6.35 (d, *J* = 16.0 Hz, 1H), 6.30 (d, *J* = 16.0 Hz, 1H), 1.15 (s, 9H). ¹³C NMR (100MHz, CDCl₃) 141.8, 138.0, 128.5, 126.7, 126.0, 124.5, 33.4, 29.6



1-chloro-4-((*E*)-3,3-dimethylbut-1-enyl)benzene (**3ba**)

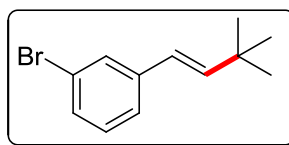
The mixture of 4-Chlorocinnamic acid (1.5 mmol), Cu (0.075 mmol), AgNO₃ (0.3 mmol), K₂S₂O₈ (1.5 mmol) and Pivalic acid (1.5 mmol) in acetonitrile (5 mL) and water (5 mL) was stirred at 90°C for 12 h. After the usual work-up, compound **3ba** was isolated as a white solid, mp: 57-59°C. Yield: 85%. R_f = 0.9 (petroleum ether). ¹H NMR (400MHz, CDCl₃) 7.26-7.31 (m, 4H), 6.21-6.30 (t, *J* = 16.8 Hz, 2H), 1.13 (s, 9H)

^{13}C NMR (100MHz, CDCl_3) 142.5, 136.5, 132.2, 128.5, 127.2, 123.4, 33.4, 29.5. **HRMS ESI (m/z): $[\text{M}+\text{H}]^+$** calcd for $\text{C}_{12}\text{H}_{16}\text{Cl}$, 195.0941; found, 195.0930



1- bromo-4-((E)-3,3-dimethylbut-1-enyl)benzene (3ca)

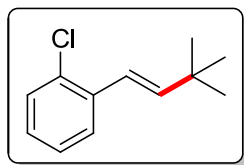
The mixture of 4-Bromocinnamic acid (1.5 mmol), Cu (0.075 mmol), AgNO_3 (0.3 mmol), $\text{K}_2\text{S}_2\text{O}_8$ (1.5 mmol) and Pivalic acid (1.5 mmol) in acetonitrile (5 mL) and water (5 mL) was stirred at 90°C for 12 h. After the usual work-up, compound **3ca** was isolated as a colorless oil. Yield: 62%. $R_f = 0.9$ (petroleum ether). **^1H NMR (400MHz, CDCl_3)** 7.41-7.43 (d, $J = 8.4$ Hz, 2H), 7.23-7.25 (d, $J = 8.4$ Hz, 2H), 6.21-6.30 (t, $J = 16.8$ Hz, 2H), 1.13 (s, 9H) **^{13}C NMR (100MHz, CDCl_3)** 142.6, 137.0, 131.5, 127.5, 123.5, 120.3, 33.4, 29.7. **HRMS ESI (m/z): $[\text{M}+\text{H}]^+$** calcd for $\text{C}_{12}\text{H}_{16}\text{Br}$, 239.0435; found, 239.0422



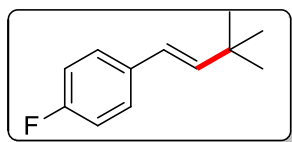
1- bromo-3-((E)-3,3-dimethylbut-1-enyl)benzene (3da)

The mixture of trans-3-Bromocinnamic acid (1.5 mmol), Cu (0.075 mmol), AgNO_3 (0.3 mmol), $\text{K}_2\text{S}_2\text{O}_8$ (1.5 mmol) and Pivalic acid (1.5 mmol) in acetonitrile (5 mL) and water (5 mL) was stirred at 90°C for 12

h. After the usual work-up, compound **3da** was isolated as a colorless oil. Yield: 47%. $R_f = 0.9$ (petroleum ether). $^1\text{H NMR}$ (400MHz, CDCl_3) 7.54 (s, 1H), 7.31-7.34 (m, 1H), 7.27-7.29 (m, 1H), 7.15-7.19 (t, $J = 7.8$ Hz, 1H), 6.31 (d, $J = 16.4$ Hz, 1H), 6.25 (d, $J = 16.4$ Hz, 1H), 1.13 (s, 9H) $^{13}\text{C NMR}$ (100MHz, CDCl_3) 143.4, 140.2, 129.9, 129.5, 128.8, 124.8, 123.3, 122.7, 33.5, 29.4. **HRMS ESI** (m/z): $[\text{M}+\text{H}]^+$ calcd for $\text{C}_{12}\text{H}_{16}\text{Br}$, 239.0435; found, 239.0425

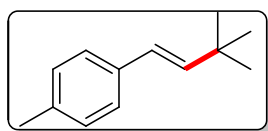


1-chloro-2-((E)-3,3-dimethylbut-1-enyl)benzene (3ea) The mixture of 2-Chlorocinnamic acid (1.5 mmol), Cu (0.075 mmol), AgNO_3 (0.3 mmol), $\text{K}_2\text{S}_2\text{O}_8$ (1.5 mmol) and Pivalic acid (1.5 mmol) in acetonitrile (5 mL) and water (5 mL) was stirred at room temperature for 2 h and then 90°C for 10 h. After the usual work-up, compound **3ea** was isolated as a colorless oil. Yield: 82%. $R_f = 0.95$ (petroleum ether). $^1\text{H NMR}$ (400MHz, CDCl_3) 7.52-7.55 (dd, $J = 1.6$ Hz, 6.0Hz, 1H), 7.34-7.36 (dd, $J = 1.2$ Hz, 6.8Hz, 1H), 7.20-7.24 (m, 1H), 7.13-7.17 (m, 1H), 6.73 (d, $J = 16.0$ Hz, 3H), 6.27 (d, $J = 16.0$ Hz, 1H), 1.16 (s, 9H) $^{13}\text{C NMR}$ (100MHz, CDCl_3) 144.6, 136.1, 132.8, 129.5, 127.7, 126.7, 126.5, 121.0, 33.8, 29.5. **HRMS ESI** (m/z): $[\text{M}+\text{H}]^+$ calcd for $\text{C}_{12}\text{H}_{16}\text{Cl}$, 195.0941; found, 195.0938



1- fluoro-4-((*E*)-3,3-dimethylbut-1-enyl)benzene (3fa)

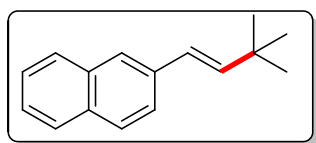
The mixture of 4-Fluorocinnamic acid (1.5 mmol), Cu (0.05 mmol), AgNO₃ (0.2 mmol), K₂S₂O₈ (1.0 mmol) and Pivalic acid (1.0 mmol) in acetonitrile (3 mL) and water (3 mL) was stirred at 90°C for 12 h. After the usual work-up, compound **3fa** was isolated as a colorless oil. Yield: 29%. R_f = 0.95 (petroleum ether). ¹H NMR (400MHz, CDCl₃) 7.35 (d, *J* = 5.2 Hz, 1H), 7.33 (d, *J* = 5.2 Hz, 1H), 6.98-7.02 (t, *J* = 8.0 Hz, 2H), 6.30 (d, *J* = 16.0 Hz, 1H), 6.20 (d, *J* = 16.0 Hz, 1H), 1.13 (s, 9H) ¹³C NMR (100MHz, CDCl₃) 163.0, 160.6, 141.6, 134.1, 127.4, 123.4, 115.4, 33.3, 29.5. HRMS ESI (*m/z*): [M+H]⁺ calcd for C₁₂H₁₆F, 179.1236; found, 179.1233



1- methyl-4-((*E*)-3,3-dimethylbut-1-enyl)benzene(3ga)

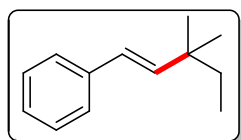
The mixture of 4-Methylcinnamic acid (trans) (1.5 mmol), Cu (0.075 mmol), AgNO₃ (0.3 mmol), K₂S₂O₈ (1.5 mmol) and Pivalic acid (1.5 mmol) in acetonitrile (5 mL) and water (5 mL) was stirred at room temperature for 2 h and then 90°C for 10 h. After the usual work-up, compound **3ga** was isolated as a colorless oil. Yield: 36%. R_f = 0.85

(petroleum ether). **¹H NMR (400MHz, CDCl₃)** 7.27-7.29 (m, 2H), 7.11-7.13 (d, *J* = 8.0 Hz, 2H), 6.31 (d, *J* = 16.4 Hz, 1H), 6.24 (d, *J* = 16.4 Hz, 1H), 2.34 (s, 3H), 1.13 (s, 9H). **¹³C NMR (100MHz, CDCl₃)** 140.8, 136.3, 135.2, 129.1, 125.8, 124.3, 33.2, 29.6, 21.1. **HRMS ESI (m/z):** **[M+H]⁺** calcd for C₁₃H₁₉, 175.1487; found, 175.1459



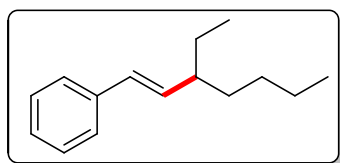
2-((*E*)-3,3-dimethylbut-1-enyl)naphthalene (**3ha**)

The mixture of 3-(Naphtha-2-yl)acrylic acid (1.5 mmol), Cu (0.075 mmol), AgNO₃ (0.3 mmol), K₂S₂O₈ (1.5 mmol) and Pivalic acid (1.5 mmol) in acetonitrile (5 mL) and water (5 mL) was stirred at 90°C for 12 h. After the usual work-up, compound **3ha** was isolated as a white solid, mp: 47-51 °C. Yield: 40%. *R_f* = 0.90 (petroleum ether). **¹H NMR (400MHz, CDCl₃)** 7.80 (t, *J* = 7.6 Hz, 3H), 7.73 (s, 1H), 7.61-7.64 (dd, *J* = 1.6 Hz, 6.8 Hz, 1H), 7.41-7.48 (m, 2H), 6.52 (d, *J* = 17.2 Hz, 1H), 6.43 (d, *J* = 17.2 Hz, 1H), 1.19 (s, 9H) **¹³C NMR (100MHz, CDCl₃)** 142.3, 135.5, 133.7, 132.6, 128.0, 127.7, 127.6, 126.0, 125.4, 125.3, 124.7, 123.6, 33.5, 22.7. **HRMS ESI (m/z):** **[M+H]⁺** calcd for C₁₆H₁₉, 211.1487; found, 211.1482



1-((*E*)-3,3-dimethylpent-1-enyl)benzene (**3ab**)

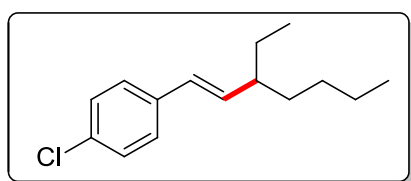
The mixture of trans-Cinnamic acid (1.5 mmol), Cu (0.075 mmol), AgNO₃ (0.3 mmol), K₂S₂O₈ (1.5 mmol) and 2,2-Dimethylbutyric acid (2.0 mmol) in acetonitrile (5 mL) and water (5 mL) was stirred at 90 °C for 12 h. After the usual work-up, compound **3ab** was isolated as a colorless oil. Yield: 89%. R_f = 0.95 (petroleum ether). ¹H NMR (400MHz, CDCl₃) 7.40 (dd, *J* = 1.6 Hz, 8.8Hz, 2H), 7.30-7.34 (m, 2H), 7.23 (ddd, *J* = 6.4 Hz, 2.4 Hz, 1.2 Hz, 1H), 6.33 (d, *J* = 16.0 Hz, 1H), 6.21 (d, *J* = 16.0 Hz, 1H), 1.47 (q, *J* = 7.6 Hz, 2H), 1.10 (s, 6H), 0.88 (t, *J* = 7.2 Hz, 3H) ¹³C NMR (100MHz, CDCl₃) 140.6, 138.1, 128.4, 126.7, 126.0, 125.8, 36.4, 35.5, 26.7, 9.06. HRMS ESI (*m/z*): [M+H]⁺ calcd for C₁₃H₁₉, 175.1487; found, 175.1488



1-((*S,E*)-3-ethylhept-1-enyl)benzene (**3ac**)

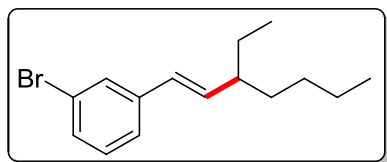
The mixture of trans-Cinnamic acid (1.5 mmol), Cu (0.05 mmol), AgNO₃ (0.2 mmol), K₂S₂O₈ (1.0 mmol) and 2-Ethylhexanoic acid (1.0 mmol) in acetonitrile (3 mL) and water (3 mL) was stirred at 90 °C for 12 h. After the usual work-up, compound **3ac** was isolated as a colorless oil. Yield: 90%. R_f = 0.95 (petroleum ether). ¹H NMR (400MHz, CDCl₃) 7.38-7.40 (d, *J* = 7.8 Hz, 2H), 7.30-7.34 (m, 2H), 7.21 (t, *J* = 7.4 Hz, 1H), 6.36 (d, *J*

= 15.6 Hz, 1H), 5.94-6.01 (dd, $J = 8.8$ Hz, 15.6 Hz, 1H), 1.99-2.08 (m, 1H), 1.45-1.57 (m, 2H), 1.22-1.40 (m, 6H), 0.88-0.92 (m, 6H) ^{13}C NMR (100MHz, CDCl_3) 137.9, 135.6, 129.6, 128.4, 126.7, 125.9, 45.2, 34.9, 29.6, 28.2, 22.9, 14.1, 11.9. **HRMS ESI (m/z):** $[\text{M}+\text{H}]^+$ calcd for $\text{C}_{15}\text{H}_{23}$, 203.1800; found, 203.1794



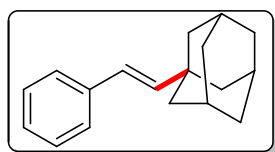
1- chloro-4-((*S,E*)-3-ethylhept-1-enyl)benzene (**3bc**)

The mixture of 4-Chlorocinnamic acid (1.5 mmol), Cu (0.05 mmol), AgNO_3 (0.2 mmol), $\text{K}_2\text{S}_2\text{O}_8$ (1.0 mmol) and 2-Ethylhexanoic acid (1.0 mmol) in acetonitrile (3 mL) and water (3 mL) was stirred at 90°C for 12 h. After the usual work-up, compound **3bc** was isolated as a colorless oil. Yield: 92%. $R_f = 0.94$ (petroleum ether). ^1H NMR (400MHz, CDCl_3) 7.26-7.31 (m, 4H), 6.31 (d, $J = 15.6$ Hz, 1H), 5.92-5.98 (dd, $J = 8.8$ Hz, 15.6 Hz, 1H), 1.98-2.07 (m, 1H), 1.44-1.57 (m, 2H), 1.21-1.39 (m, 6H), 0.87-0.91 (m, 6H) ^{13}C NMR (100MHz, CDCl_3) 136.4, 136.3, 132.2, 128.5, 128.4, 127.1, 45.2, 34.8, 29.6, 28.1, 22.9, 14.1, 11.9. **HRMS ESI (m/z):** $[\text{M}+\text{H}]^+$ calcd for $\text{C}_{15}\text{H}_{22}\text{Cl}$, 237.1410; found, 237.1402



1- bromo-3-((*S,E*)-3-ethylhept-1-enyl)benzene (**3dc**)

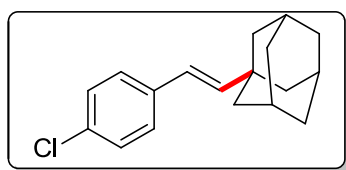
The mixture of trans-3-Bromocinnamic acid (1.5 mmol), Cu (0.05 mmol), AgNO₃ (0.2 mmol), K₂S₂O₈ (1.0 mmol) and 2-Ethylhexanoic acid (1.0 mmol) in acetonitrile (3 mL) and water (3 mL) was stirred at 90°C for 12 h. After the usual work-up, compound **3dc** was isolated as a colorless oil. Yield: 71%. R_f = 0.92 (petroleum ether). **¹H NMR (400MHz, CDCl₃)** 7.53 (d, *J* = 1.6 Hz, 1H), 7.32-7.34 (m, 1H), 7.26 (m, 1H), 7.17 (t, *J* = 7.8 Hz, 1H), 6.29 (d, *J* = 16.0 Hz, 1H), 5.95-6.01 (dd, *J* = 8.8 Hz, 16.0 Hz, 1H), 1.98-2.07 (m, 1H), 1.43-1.57 (m, 2H), 1.21-1.39 (m, 6H), 0.87-0.91 (m, 6H) **¹³C NMR (100MHz, CDCl₃)** 140.1, 137.3, 129.9, 129.5, 128.7, 128.3, 124.7, 122.7, 45.2, 34.7, 29.6, 28.1, 22.8, 14.1, 11.8. **HRMS ESI (m/z): [M+H]⁺** calcd for C₁₅H₂₂Br, 281.0905; found, 281.0877



(1-phenylethenyl)adanantine (**3ad**)²

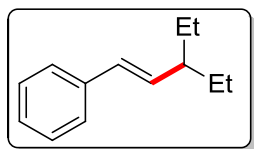
The mixture of trans-Cinnamic acid (1.5 mmol), Cu (0.05 mmol), AgNO₃ (0.2 mmol), K₂S₂O₈ (1.0 mmol) and 1-Adamantanecarboxylic acid (1.0 mmol) in acetonitrile (3 mL) and water (3 mL) was stirred at 90°C for 12 h. After the usual work-up, compound **3ad** was isolated as a white solid.

Yield: 65%. $R_f = 0.90$ (petroleum ether). **^1H NMR (400MHz, CDCl_3)** 7.39 (d, $J = 7.2$ Hz, 2H), 7.29-7.33 (m, 2H), 7.22 (t, $J = 7.2$ Hz, 1H), 6.28 (d, $J = 16.4$ Hz, 1H), 6.15 (d, $J = 16.4$ Hz, 1H), 2.05 (s, 3H), 1.70-1.79 (m, 12H) **^{13}C NMR (100MHz, CDCl_3)** 142.1, 138.2, 128.4, 126.7, 126.0, 124.4, 42.2, 36.9, 35.1, 28.4.



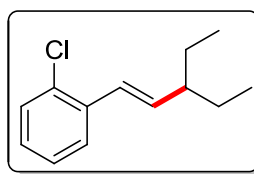
1-((4-chlorophenyl)ethenyl)adamantine (3bd)

The mixture of 4-Chlorocinnamic acid (1.5 mmol), Cu (0.05 mmol), AgNO_3 (0.2 mmol), $\text{K}_2\text{S}_2\text{O}_8$ (1.0 mmol) and 1-Adamantanecarboxylic acid (1.0 mmol) in acetonitrile (3 mL) and water (3 mL) was stirred at 90°C for 12 h. After the usual work-up, compound **3bd** was isolated as a white solid. Yield: 70%. $R_f = 0.9$ (petroleum ether). **^1H NMR (400MHz, CDCl_3)** 7.29-7.31 (dd, $J = 2.0$ Hz, 4.4 Hz, 2H), 7.25-7.27 (dd, $J = 2.0$ Hz, 4.4 Hz, 2H), 6.22 (d, $J = 16.4$ Hz, 1H), 6.11 (d, $J = 16.4$ Hz, 1H), 2.05 (s, 3H), 1.72-1.79 (m, 3H), 1.69 (s, 9H) **^{13}C NMR (100MHz, CDCl_3)** 142.7, 136.7, 132.1, 128.5, 127.2, 123.4, 42.1, 36.8, 35.2, 28.4. **HRMS ESI (m/z): $[\text{M}+\text{H}]^+$** calcd for $\text{C}_{18}\text{H}_{22}\text{Cl}$, 273.1410; found, 273.1412



1-((*E*)-3-ethylpent-1-en-1-yl)benzene (**3ae**)

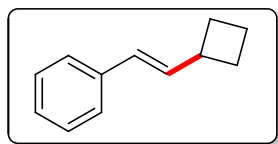
The mixture of trans-Cinnamic acid (1.5 mmol), Cu (0.05 mmol), AgNO₃ (0.2 mmol), K₂S₂O₈ (1.0 mmol) and 2-Ethylbutyric acid (1.0 mmol) in acetonitrile (3 mL) and water (3 mL) was stirred at 90°C for 12 h. After the usual work-up, compound **3ae** was isolated as a colorless oil. Yield: 82%. R_f = 0.95 (petroleum ether). ¹H NMR (400MHz, CDCl₃) 7.39 (d, *J* = 7.6 Hz, 2H), 7.34 (t, *J* = 7.6 Hz, 2H), 7.23 (t, *J* = 7.2 Hz, 1H), 6.38 (d, *J* = 16.0 Hz, 1H), 5.94-6.00 (dd, *J* = 8.8 Hz, 16.0 Hz, 1H), 1.59-2.00 (m, 1H), 1.48-1.59 (m, 2H), 1.27-1.41 (m, 2H), 0.92 (t, *J* = 7.4 Hz, 6H) ¹³C NMR (100MHz, CDCl₃) 137.9, 135.3, 129.8, 128.4, 126.7, 125.9, 46.9, 27.8, 11.9. HRMS ESI (*m/z*): [*M*+*H*]⁺ calcd for C₁₃H₁₉, 175.1487; found, 175.1475



1-chloro-2-((*E*)-3-ethylpent-1-en-1-yl)benzene (**3be**)

The mixture of 2-Chlorocinnamic acid (1.5 mmol), Cu (0.075 mmol), AgNO₃ (0.3 mmol), K₂S₂O₈ (1.5 mmol) and 2-Ethylbutyric acid (1.5 mmol) in acetonitrile (5 mL) and water (5 mL) was stirred at room temperature for 2 h and then 90°C for 10 h. After the usual work-up,

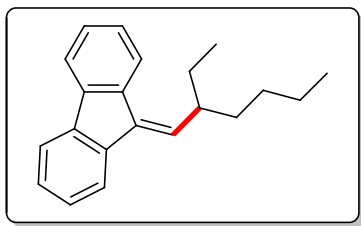
compound **3be** was isolated as a colorless oil. Yield: 89%. $R_f = 0.90$ (petroleum ether). **^1H NMR (400MHz, CDCl_3)** 7.55 (dd, $J = 2.0$ Hz, 8.0 Hz, 1H), 7.36 (dd, $J = 1.2$ Hz, 7.6 Hz, 1H), 7.24 (td, $J = 7.2$ Hz, 0.8 Hz, 1H), 7.17 (td, $J = 7.6$ Hz, 1.6 Hz, 1H), 6.75 (d, $J = 16.0$ Hz, 1H), 5.98 (dd, $J = 9.2$ Hz, 16.0 Hz, 1H), 1.60-2.08 (m, 1H), 1.51-1.60 (m, 2H), 1.32-1.49 (m, 2H), 0.94 (t, $J = 7.4$ Hz, 6H) **^{13}C NMR (100MHz, CDCl_3)** 138.2, 136.1, 132.5, 129.5, 127.7, 126.7, 126.4, 46.9, 27.7, 11.8. **HRMS ESI (m/z): $[\text{M}+\text{H}]^+$** calcd for $\text{C}_{13}\text{H}_{18}\text{Cl}$, 209.1097; found, 209.1096



1-((*E*)-2-cyclobutylvinyl)benzene (**3af**)

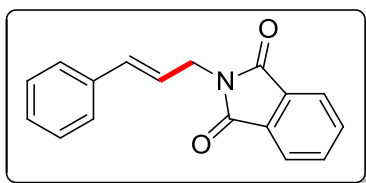
The mixture of trans-Cinnamic acid (1.5 mmol), Cu (0.05 mmol), AgNO_3 (0.2 mmol), $\text{K}_2\text{S}_2\text{O}_8$ (1.0 mmol) and Cyclobutanecarboxylic acid (1.0 mmol) in acetonitrile (3 mL) and water (3 mL) was stirred at 90°C for 12 h. After the usual work-up, compound **3af** was isolated as a colorless oil. Yield: 63%. $R_f = 0.90$ (petroleum ether). **^1H NMR (400MHz, CDCl_3)** 7.36-7.38 (dd, $J = 2.0$ Hz, 8.4 Hz, 2H), 7.29-7.33 (m, 2H), 7.23 (ddd, $J = 6.8$ Hz, 2.8Hz, 1.2Hz, 1H), 6.39 (d, $J = 16.0$ Hz, 1H), 6.33 (d, $J = 16.0$ Hz, 1H), 3.13 (dd, $J = 5.6$ Hz, 8.0 Hz, 1H), 2.17-2.23 (m, 2H), 1.91-2.01 (m, 3H), 1.82-1.90 (m, 1H). **^{13}C NMR (100MHz, CDCl_3)** 137.7, 135.3, 128.4, 127.5, 126.8, 125.9, 38.7, 28.7, 18.6. **HRMS ESI (m/z): $[\text{M}+\text{H}]^+$** calcd

for C₁₂H₁₅, 159.1174; found, 159.1158



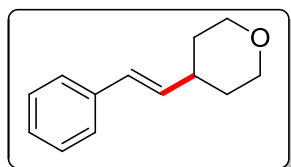
9-(heptan-3-ylidene)-9H-fluorene (**3ic**)

The mixture of 2-(9H-fluoren-9-ylidene)acetic acid (1.0 mmol), Cu (0.05 mmol), AgNO₃ (0.2 mmol), K₂S₂O₈ (1.0 mmol) and 2-Ethylhexanoic acid (1.0 mmol) in acetonitrile (3 mL) and water (3 mL) was stirred at room temperature for 2 h and then 90 °C for 12 h. After the usual work-up, compound **3ic** was isolated as a colorless oil. Yield: 96%. R_f = 0.95 (petroleum ether). **¹H NMR (400MHz, CDCl₃)** 7.98 (d, *J* = 7.6 Hz, 1H), 7.80 (d, *J* = 7.6 Hz, 1H), 7.71-7.75 (m, 2H), 7.30-7.41 (m, 4H), 6.55 (d, *J* = 10.4 Hz, 1H), 3.20-3.34 (m, 1H), 1.69-1.75 (m, 2H), 1.50-1.57 (m, 2H), 1.32-1.38 (m, 4H), 1.00 (t, *J* = 7.4 Hz, 3H), 0.89 (t, *J* = 7.0 Hz, 3H) **¹³C NMR (100MHz, CDCl₃)** 140.9, 139.6, 138.3, 137.6, 136.8, 135.1, 127.5, 127.3, 126.9, 126.8, 124.8, 119.8, 119.7, 119.4, 40.4, 35.3, 29.8, 28.7, 22.9, 14.1, 12.0. **HRMS ESI (m/z): [M+H]⁺** calcd for C₂₁H₂₅, 277.1956; found, 277.1948



2- cinnamylisoindoline-1,3-dione (**3ag**)

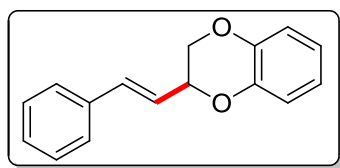
The mixture of trans-Cinnamic acid (1.5 mmol), Cu (0.05 mmol), AgNO₃ (0.2 mmol), K₂S₂O₈ (2.0 mmol) and N-phthaloylglycine (1.0 mmol) in acetonitrile (3 mL) and water (3 mL) was stirred at 90°C for 12 h. After the usual work-up, compound **3ag** was isolated as a yellow solid, mp: 126-130°C. Yield: 35%. R_f = 0.6 (petroleum ether/ethyl acetate = 10 : 1). ¹H NMR (400MHz, CDCl₃) 7.90 (q, *J* = 2.8 Hz, 2H), 7.73-7.76 (m, 2H), 7.39 (d, *J* = 8.4 Hz, 2H), 7.32 (d, *J* = 7.2 Hz, 2H), 7.22-7.26 (m, 1H), 6.70 (d, *J* = 15.6 Hz, 1H), 6.31 (dt, *J* = 15.6 Hz, 6.4 Hz, 1H), 4.48 (dd, *J* = 0.8 Hz, 6.4 Hz, 2H) ¹³C NMR (100MHz, CDCl₃) 167.9, 136.2, 134.0, 133.7, 132.1, 128.5, 127.9, 126.5, 123.3, 122.7, 39.6. HRMS ESI (*m/z*): [M+H]⁺ calcd for C₁₇H₁₄NO₂, 264.1025; found, 264.1015



tetrahydro-4-styryl-2H-pyran (**3ah**)³

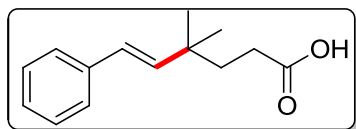
The mixture of trans-Cinnamic acid (1.5 mmol), Cu (0.05 mmol), AgNO₃ (0.2 mmol), K₂S₂O₈ (1.0 mmol) and Tetrahydro-2H-pyran-4-carboxylic acid (1.0 mmol) in acetonitrile (3 mL) and water (3 mL) was stirred at room temperature for 2 h and then 70°C for 10 h. After the usual work-up, compound **3ah** was isolated as a colorless oil. Yield: 28%. R_f = 0.70 (petroleum ether/ethyl acetate = 20 : 1). ¹H NMR (400MHz,

CDCl₃) 7.39 (d, $J = 8.0$ Hz, 2H), 7.30-7.34 (m, 2H), 7.21-7.25 (m, 1H), 6.43 (d, $J = 16.0$ Hz, 1H), 6.21 (dd, $J = 6.8$ Hz, 16.0 Hz, 1H), 4.01-4.05 (m, 2H), 3.52 (td, $J = 11.6$ Hz, 2.0 Hz, 2H), 2.19-2.42 (m, 1H), 1.43-1.76 (m, 4H) **¹³C NMR (100MHz, CDCl₃)** 137.5, 134.6, 128.5, 128.2, 127.1, 126.0, 38.3, 32.6.



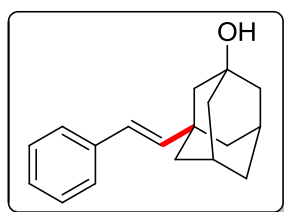
(S)-2,3-dihydro-2-styrylbenzo[*b*][1,4]dioxine (3ai)

The mixture of trans-Cinnamic acid (1.5 mmol), Cu (0.075 mmol), AgNO₃(0.3mmol), K₂S₂O₈ (1.5 mmol) and 1,4-Benzodioxan-2-carboxylic acid (1.5 mmol) in acetonitrile (5 mL) and water (5 mL) was stirred at room temperature for 2 h and then 90°C for 12 h. After the usual work-up, compound **3ai** was isolated as a yellow solid, mp: 65-68°C. Yield: 70%. $R_f = 0.5$ (petroleum ether/ethyl acetate = 10 : 1). **¹H NMR (400MHz, CDCl₃)** 7.44-7.46 (m, 2H), 7.35-7.39 (m, 2H), 7.29-7.33 (m, 1H), 6.88-6.99 (m, 4H), 6.884 (d, $J = 16.0$ Hz, 1H), 6.29 (dd, $J = 6.4$ Hz, 16.0 Hz, 1H), 4.80-4.85 (m, 1H), 4.37 (dd, $J = 2.4$ Hz, 11.2 Hz, 1H), 4.05 (dd, $J = 8.0$ Hz, 11.2 Hz, 1H) **¹³C NMR (100MHz, CDCl₃)** 143.2, 143.0, 135.9, 134.3, 128.7, 128.3, 126.7, 123.1, 121.7, 121.5, 117.4, 117.1, 73.7, 67.8. **HRMS ESI (m/z): [M+H]⁺** calcd for C₁₆H₁₅O₂, 239.1072; found, 239.1070



(E)-4,4-dimethyl-6-phenylhex-5-enoic acid (3aj)

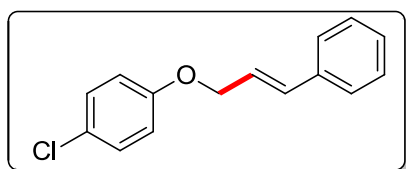
The mixture of trans-Cinnamic acid (1.0 mmol), Cu (0.05 mmol), AgNO₃ (0.2 mmol), K₂S₂O₈ (1.0 mmol) and Dimethylglutonic acid (1.2 mmol) in acetonitrile (3 mL) and water (3 mL) was stirred at room temperature for 2 h and then 70 °C for 10 h. After the usual work-up, compound **3aj** was isolated as a sticky yellow liquid. Yield: 49%. *R*_f = 0.40 (petroleum ether/ethyl acetate = 2 : 1). ¹H NMR (400MHz, CDCl₃) 7.38 (d, *J* = 8.0 Hz, 2H), 7.33 (q, *J* = 7.6 Hz, 2H), 7.23 (t, *J* = 7.2 Hz, 1H), 6.33 (d, *J* = 16.0 Hz, 1H), 6.16 (d, *J* = 16.0 Hz, 1H), 2.34 (td, *J* = 8.0 Hz, 4.0 Hz, 2H), 1.78 (m, 2H), 1.14 (s, 6H) ¹³C NMR (100MHz, CDCl₃) 180.0, 138.8, 137.5, 128.5, 127.0, 126.9, 126.0, 37.2, 35.9, 29.8, 26.9. HRMS ESI (*m/z*): [*M*-H] calcd for C₁₄H₁₇O₂, 217.1229; found, 217.1171



3-((E)-styryl)adamantan-1-ol (3ak)

The mixture of trans-Cinnamic acid (1.0 mmol), Cu (0.05 mmol), AgNO₃ (0.2 mmol), K₂S₂O₈ (1.0 mmol) and 3-hydroxy-1-adamantanecarboxylic acid (1.2 mmol) in acetonitrile (3 mL) and water (3 mL) was stirred at

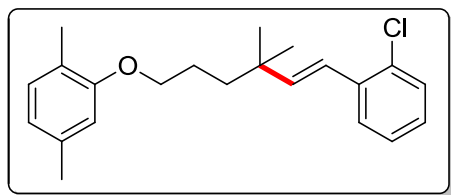
90°C for 12 h. After the usual work-up, compound **3bk** was isolated as a yellow solid, mp: 58-62°C. Yield: 76%. $R_f = 0.3$ (petroleum ether/ethyl acetate = 4 : 1). **^1H NMR (400MHz, CDCl_3)** 7.38-7.39 (m, 2H), 7.29-7.37 (m, 2H), 7.19-7.24 (m, 1H), 6.32 (d, $J = 16.0$ Hz, 1H), 6.17 (d, $J = 16.0$ Hz, 1H), 2.29 (s, 2H), 1.58-1.78 (m, 13H). **^{13}C NMR (100MHz, CDCl_3)** 139.9, 137.8, 128.5, 126.9, 126.1, 125.2, 68.9, 49.6, 44.6, 40.9, 38.8, 35.3, 30.6. **HRMS ESI (m/z): $[\text{M}+\text{H}]^+$** calcd for $\text{C}_{18}\text{H}_{23}\text{O}$, 255.1749; found, 255.1745



1-((*E*)-3-(4-chlorophenoxy)prop-1-enyl)benzene (3al**)⁴**

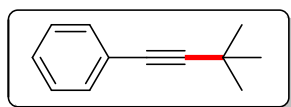
The mixture of trans-Cinnamic acid (1.0 mmol), Cu (0.05 mmol), AgNO_3 (0.2 mmol), $\text{K}_2\text{S}_2\text{O}_8$ (1.0 mmol) and 4-Chlorophenoxyacetic acid (1.0 mmol) in acetonitrile (3 mL) and water (3 mL) was stirred at room temperature for 2 h and then 90°C for 10 h. After the usual work-up, compound **3al** was isolated as a yellow solid, mp: 79-81°C. Yield: 65%. $R_f = 0.6$ (petroleum ether/ethyl acetate = 10 : 1). **^1H NMR (400MHz, CDCl_3)** 7.44 (d, $J = 8.0$ Hz, 2H), 7.33-7.37 (m, 2H), 7.25-7.30 (m, 6H: ArH overlapping CHCl_3), 6.89-6.93 (dt, $J = 8.8$ Hz, 3.6 Hz, 2H), 6.76 (d, $J = 16.0$ Hz, 1H), 6.45 (dt, $J = 16.0$ Hz, 5.6 Hz, 1H), 4.70 (dd, $J = 1.6$ Hz, 6.0 Hz, 2H) **^{13}C NMR (100MHz, CDCl_3)** 157.2, 136.2, 133.3, 129.3,

128.6, 128.0, 126.6, 125.7, 123.9, 116.0, 68.9.



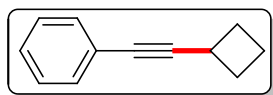
(*E*)-2-(((6-(2-chlorophenyl)-4,4-dimethylhex-5-en-1-yl)oxy)-1,4-dimethylbenzene (3em**)**

The mixture of Gemfibrozil (1.0 mmol), Cu (0.05 mmol), AgNO₃ (0.2 mmol), K₂S₂O₈ (1.0 mmol) and (*E*)-3-(2-chlorophenyl)acrylic acid (1.0 mmol) in acetonitrile (3 mL) and water (3 mL) was stirred at room temperature for 2 h and then 70 °C for 10 h. After the usual work-up, compound **3em** was isolated as a colorless oil. Yield: 20%. R_f = 0.8 (petroleum ether/ethyl acetate = 10:1). ¹H NMR (400MHz, CDCl₃) 7.52 (d, *J* = 7.6Hz, 1H), 7.35 (d, *J* = 7.6Hz, 1H), 7.22 (t, *J* = 7.6 Hz, 1H), 7.17 (t, *J* = 7.6 Hz, 1H), 7.14 (d, *J* = 7.6 Hz, 1H), 6.66-6.74 (m, 3H), 6.21 (d, *J* = 16 Hz, 1H), 3.95 (t, *J* = 6.4 Hz, 2H), 2.3 (s, 3H), 2.2 (s, 3H), 1.77-1.84 (m, 2H), 1.56-1.63 (m, 2H), 1.19 (s, 6H). ¹³C NMR (100MHz, CDCl₃) 157.04, 143.21, 136.46, 136.10, 132.82, 130.28, 129.57, 127.87, 126.74, 126.64, 123.60, 122.71, 120.61, 111.99, 68.33, 39.29, 36.53, 27.21, 24.97, 21.42, 15.84. HRMS ESI (*m/z*): [*M*+*H*]⁺ calcd for C₂₂H₂₈ClO, 343.1829; found, 343.1807



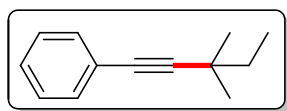
1-(3,3-dimethylbut-1-ynyl)benzene (**4a'a**)

The mixture of Phenylpropionic acid (1.5 mmol), Cu (0.075 mmol), AgNO₃ (0.3 mmol), K₂S₂O₈ (1.5 mmol) and Pivalic acid (1.5 mmol) in acetonitrile (5 mL) and water (5 mL) was stirred at 110°C for 15 h. After the usual work-up, compound **4a'a** was isolated as a colorless oil. Yield: 88%. R_f = 0.9 (petroleum ether). ¹H NMR (400MHz, CDCl₃) 7.39-7.42 (m, 2H), 7.27-7.32 (m, 3H), 1.35 (s, 9H) ¹³C NMR (100MHz, CDCl₃) 131.5, 128.1, 127.3, 124.0, 98.5, 79.0, 31.0, 27.9. ESI-HRMS: (m/z): [M+H]⁺ calcd for C₁₂H₁₅, 159.1174; found, 159.1180



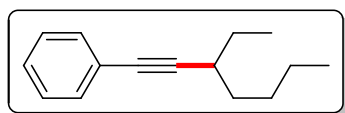
1-(2-cyclobutylethynyl)benzene (**4a'f**)

The mixture of Phenylpropionic acid (1.5 mmol), Cu (0.05 mmol), AgNO₃ (0.2 mmol), K₂S₂O₈ (1.0 mmol) and Cyclobutanecarboxylic acid (1.0 mmol) in acetonitrile (3 mL) and water (3 mL) was stirred at 110°C for 15 h. After the usual work-up, compound **4a'f** was isolated as a colorless oil. Yield: 84%. R_f = 0.9 (petroleum ether). ¹H NMR (400MHz, CDCl₃) 7.40-7.43 (m, 2H), 7.28-7.32 (m, 3H), 3.21-3.29 (m, 1H), 2.32-2.39 (m, 2H), 2.19-2.29 (m, 2H), 1.91-2.04 (m, 2H). ¹³C NMR (100MHz, CDCl₃) 131.5, 128.1, 127.5, 123.9, 93.9, 81.1, 30.0, 25.5, 19.2. HRMS ESI (m/z): [M+H]⁺ calcd for C₁₂H₁₃, 157.1017; found, 157.1013



1-(3,3-dimethylpent-1-ynyl)benzene (**4a'b**)

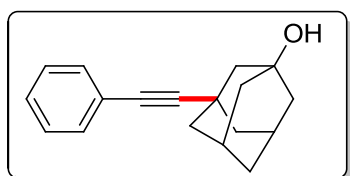
The mixture of Phenylpropionic acid (1.5 mmol), Cu (0.075 mmol), AgNO₃ (0.3 mmol), K₂S₂O₈ (1.5 mmol) and 2,2-Dimethylbutyric acid (1.5 mmol) in acetonitrile (5 mL) and water (5 mL) was stirred at 110°C for 15 h. After the usual work-up, compound **4a'b** was isolated as a colorless oil. Yield: 91%. R_f = 0.9 (petroleum ether). ¹H NMR (400MHz, CDCl₃) 7.43 (dt, *J* = 7.2 Hz, 2.4 Hz, 2H), 7.27-7.32 (m, 3H), 1.57 (q, *J* = 7.6 Hz, 2H), 1.29 (s, 6H), 1.10 (t, *J* = 7.6 Hz, 3H), ¹³C NMR (100MHz, CDCl₃) 131.6, 128.1, 127.4, 124.2, 97.2, 80.4, 36.1, 32.1, 28.8, 9.8. HRMS ESI (*m/z*): [*M*+*H*]⁺ calcd for C₁₃H₁₇, 173.1330; found, 173.1335



1-(3-ethylhept-1-ynyl)benzene (**4a'c**)

The mixture of Phenylpropionic acid (1.5 mmol), Cu (0.075 mmol), AgNO₃ (0.3 mmol), K₂S₂O₈ (1.5mmol) and 2-Ethylhexanoic acid (2.0 mmol) in acetonitrile (5 mL) and water (5 mL) was stirred at 110°C for 15 h. After the usual work-up, compound **4a'c** was isolated as a colorless oil. Yield: 95%. R_f = 0.9 (petroleum ether). ¹H NMR (400MHz, CDCl₃) 7.41-7.44 (m, 2H), 7.27-7.32 (m, 3H), 2.47-2.51 (m, 1H), 1.44-1.63 (m,

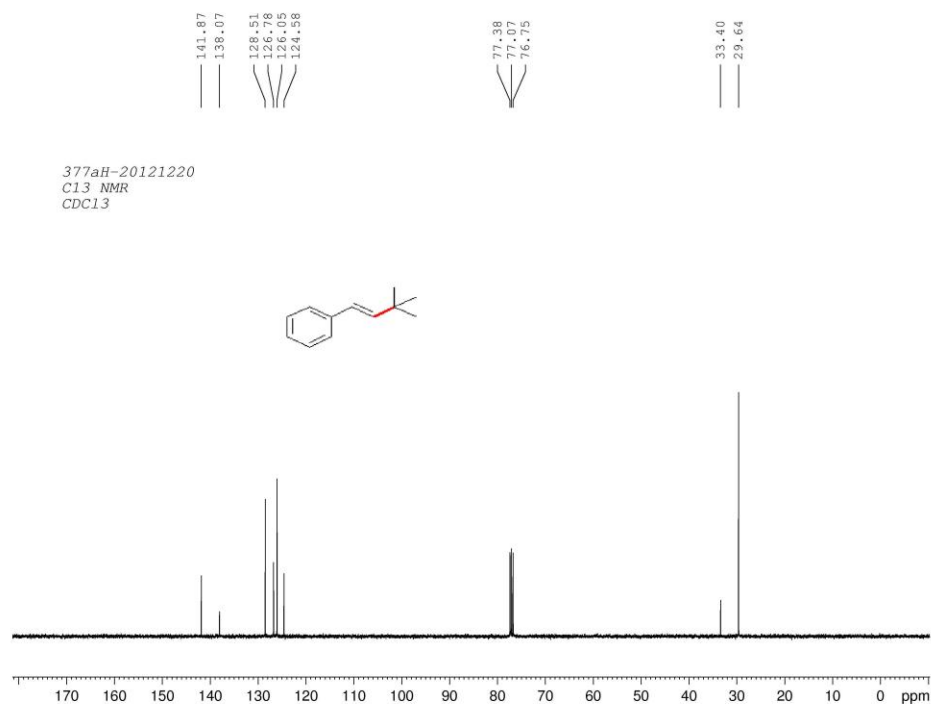
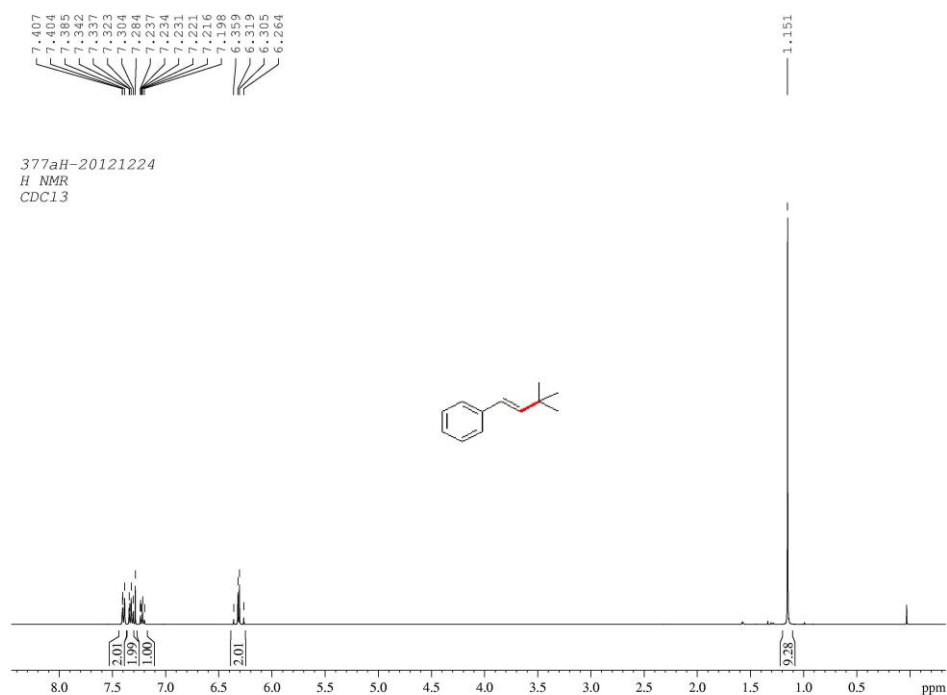
6H), 1.36-1.43 (m, 3H), 1.10 (t, $J = 7.2$ Hz, 3H), 0.97 (t, $J = 7.2$ Hz, 3H)
 ^{13}C NMR (100MHz, CDCl_3) 131.6, 128.1, 127.3, 124.2, 93.7, 81.7, 34.5,
34.0, 29.7, 28.2, 22.6, 14.1, 11.9. **HRMS ESI (m/z): $[\text{M}+\text{H}]^+$** calcd for
 $\text{C}_{15}\text{H}_{21}$, 201.1643; found, 201.1636

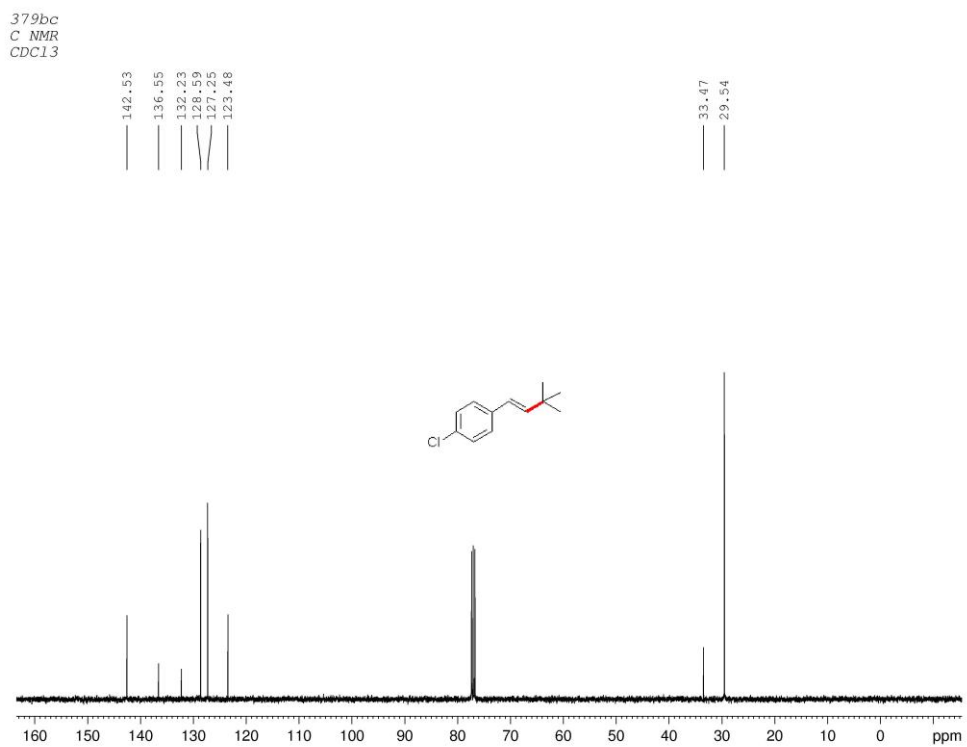
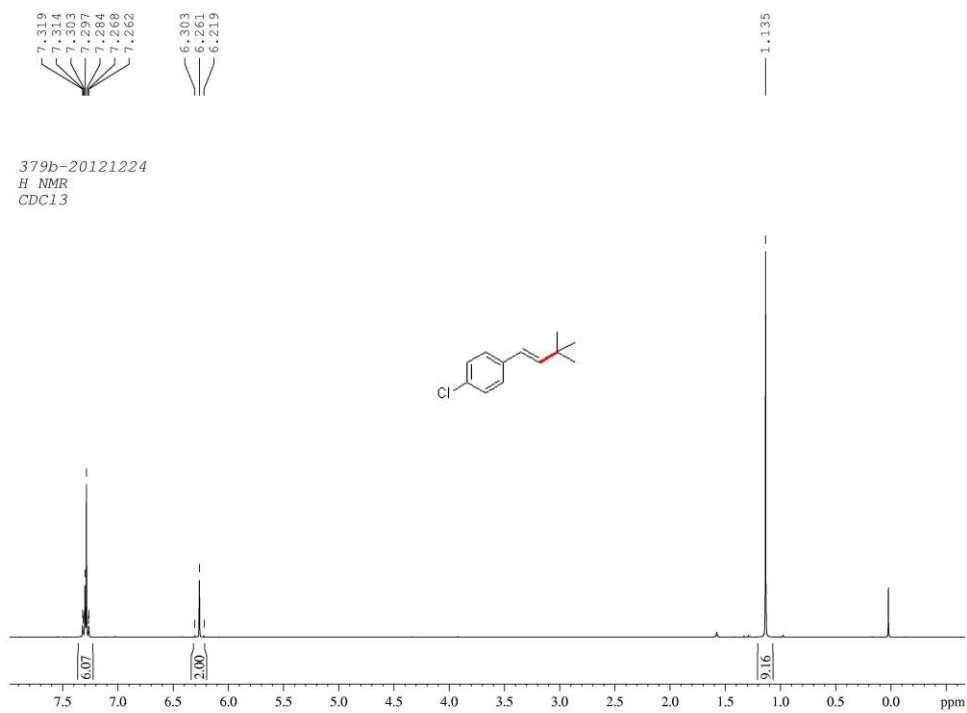


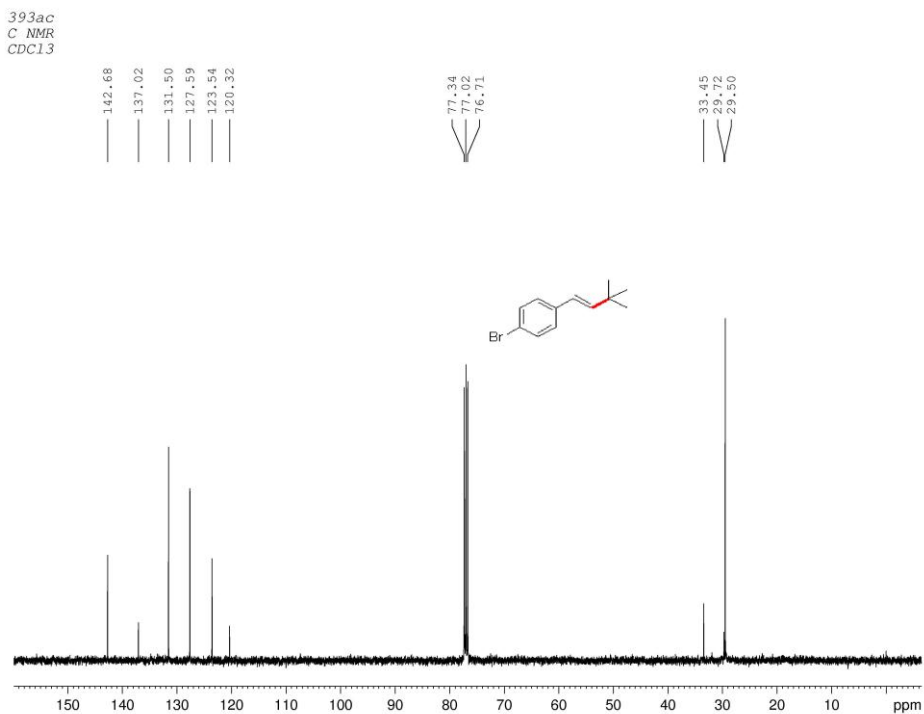
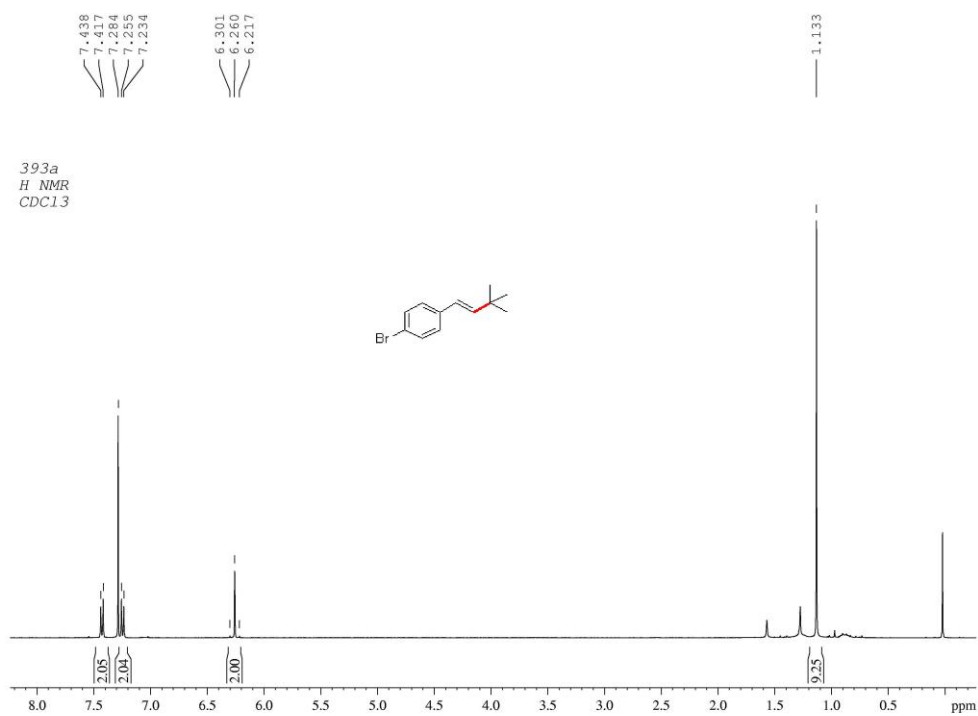
3-(phenylethynyl)adamantan-1-ol (**4a'k**)

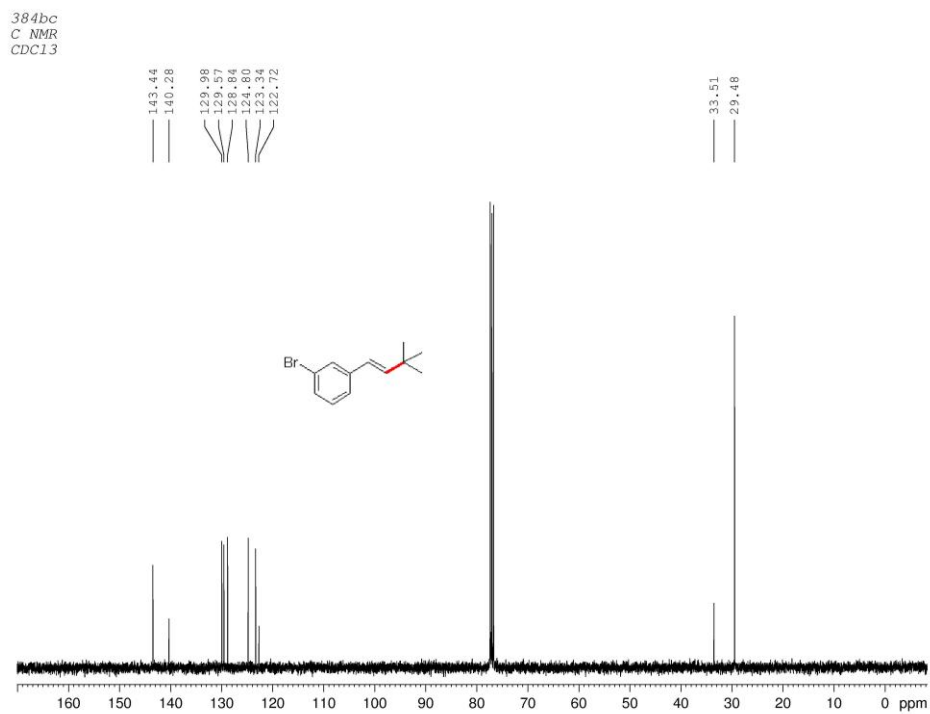
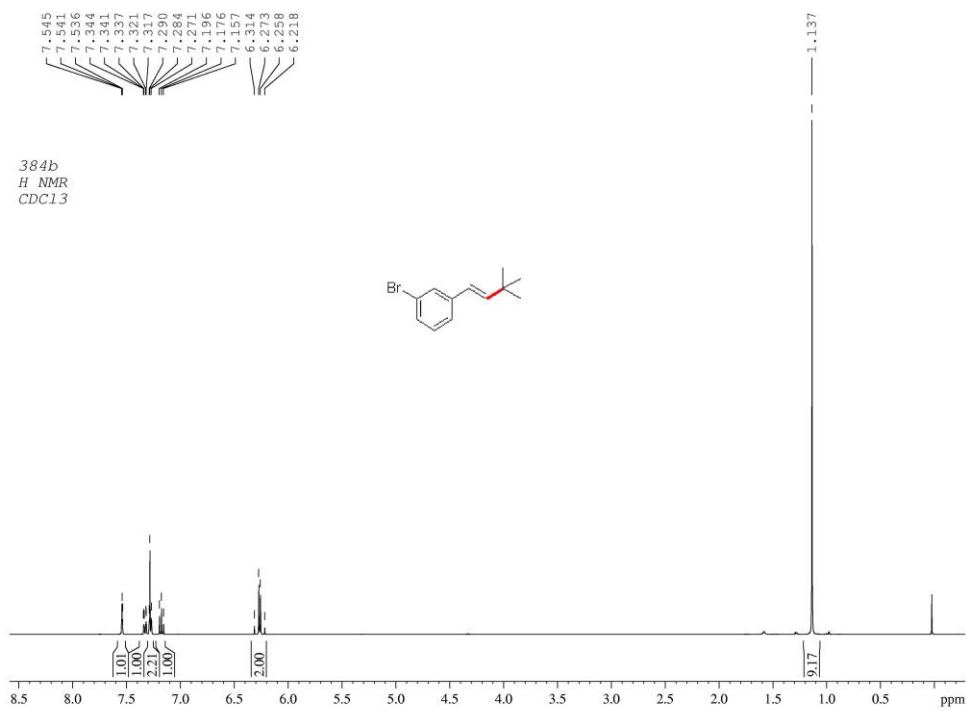
The mixture of Phenylpropionic acid (1.5 mmol), Cu (0.075 mmol),
 AgNO_3 (0.3 mmol), $\text{K}_2\text{S}_2\text{O}_8$ (1.5mmol) and 3-hydroxy-1-adamantanecar-
boxylic acid (2.0 mmol) in acetonitrile (5 mL) and water (5 mL) was
stirred at 110°C for 12 h. After the usual work-up, compound **4a'd** was
isolated as a colorless oil. Yield: 85%. $R_f = 0.4$ (petroleum ether/ethyl
acetate = 4:1). **^1H NMR (400MHz, CDCl_3)** 7.39-7.42 (m, 2H), 7.28-7.31
(m, 3H), 2.26 (s, 2H), 1.93 (s, 2H), 1.88 (s, 4H), 1.73 (s, 4H), 1.56-1.66
(m, 3H). **^{13}C NMR (100MHz, CDCl_3)** 131.6, 128.2, 127.6, 123.7, 96.5,
79.9, 68.0, 50.2, 44.2, 41.6, 34.9, 33.2, 30.4. **HRMS ESI (m/z): $[\text{M}+\text{H}]^+$**
calcd for $\text{C}_{18}\text{H}_{21}\text{O}$, 253.1592; found, 253.1581

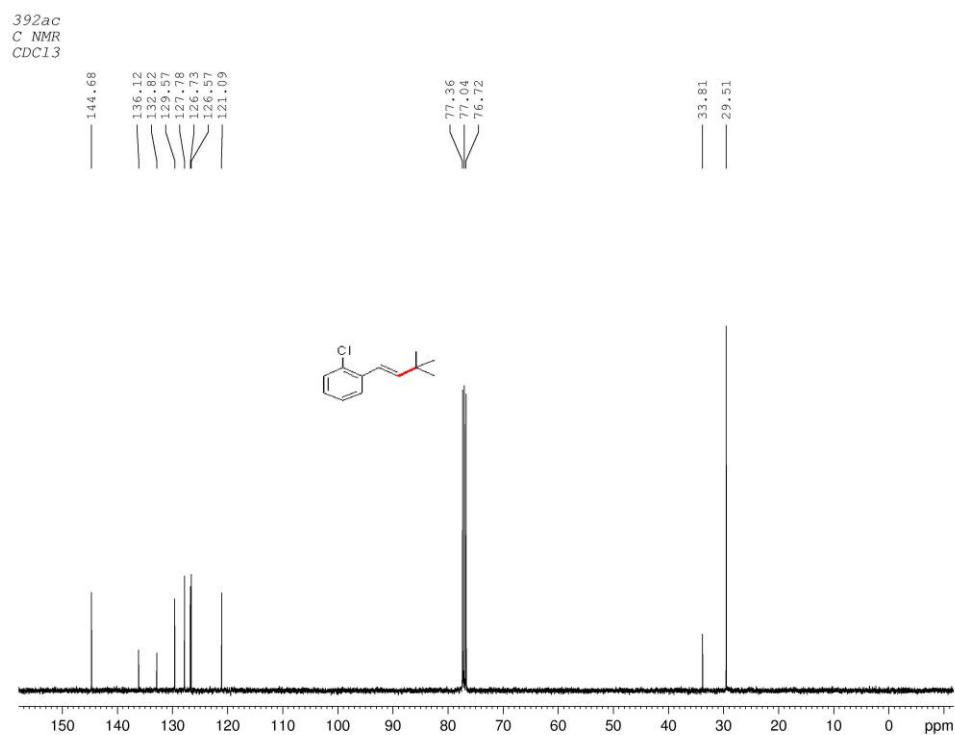
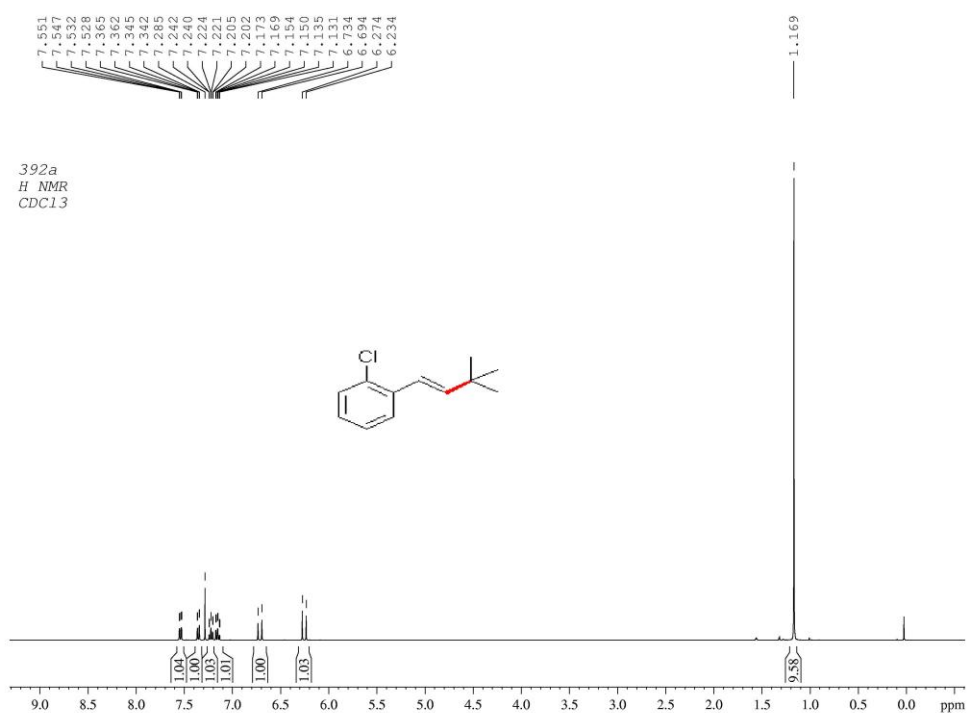
IV. NMR Spectrum Copies

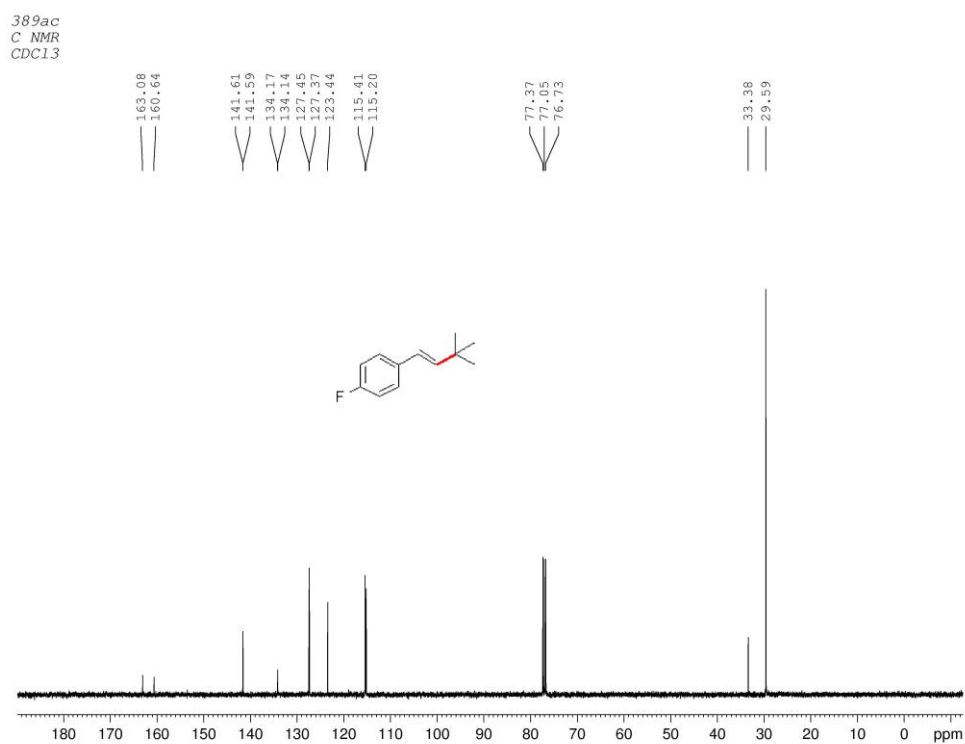
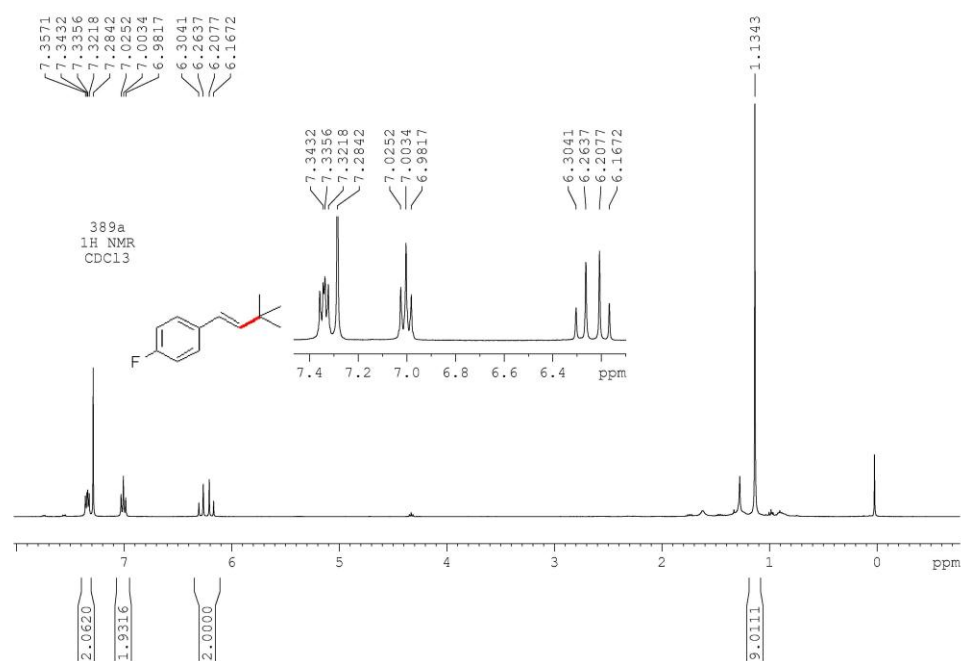


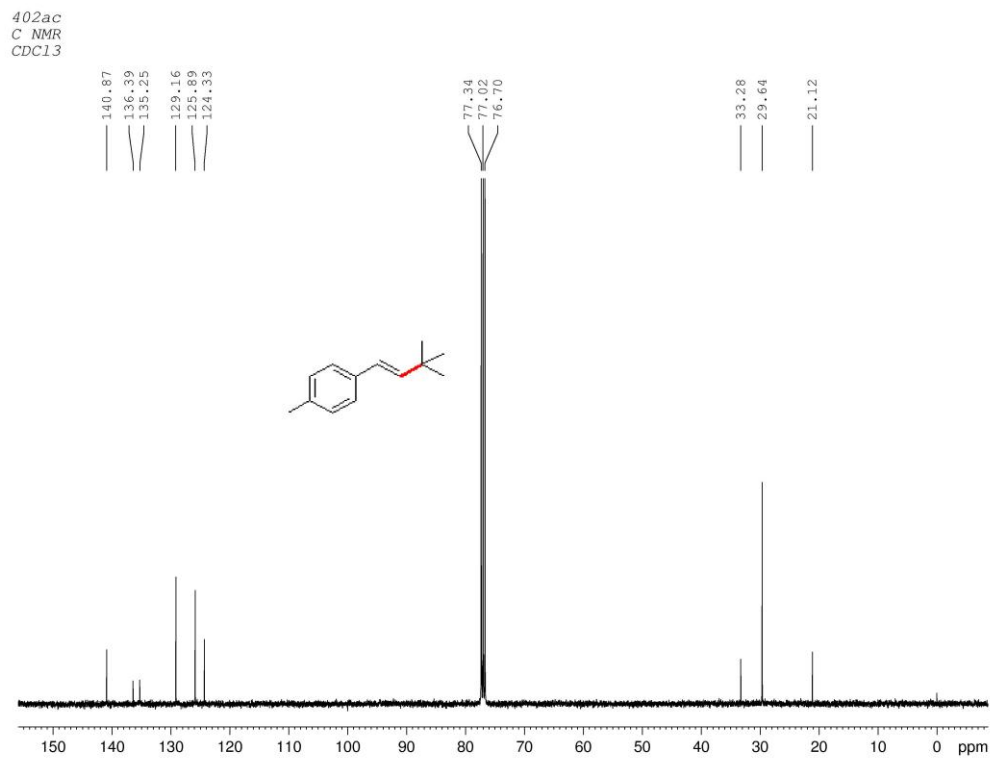
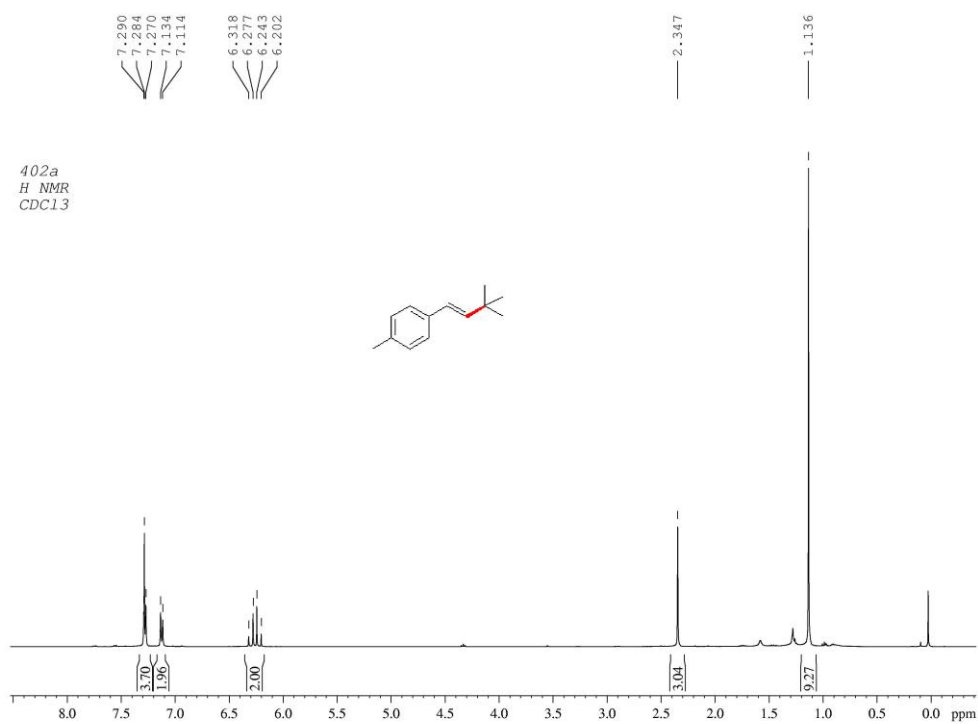


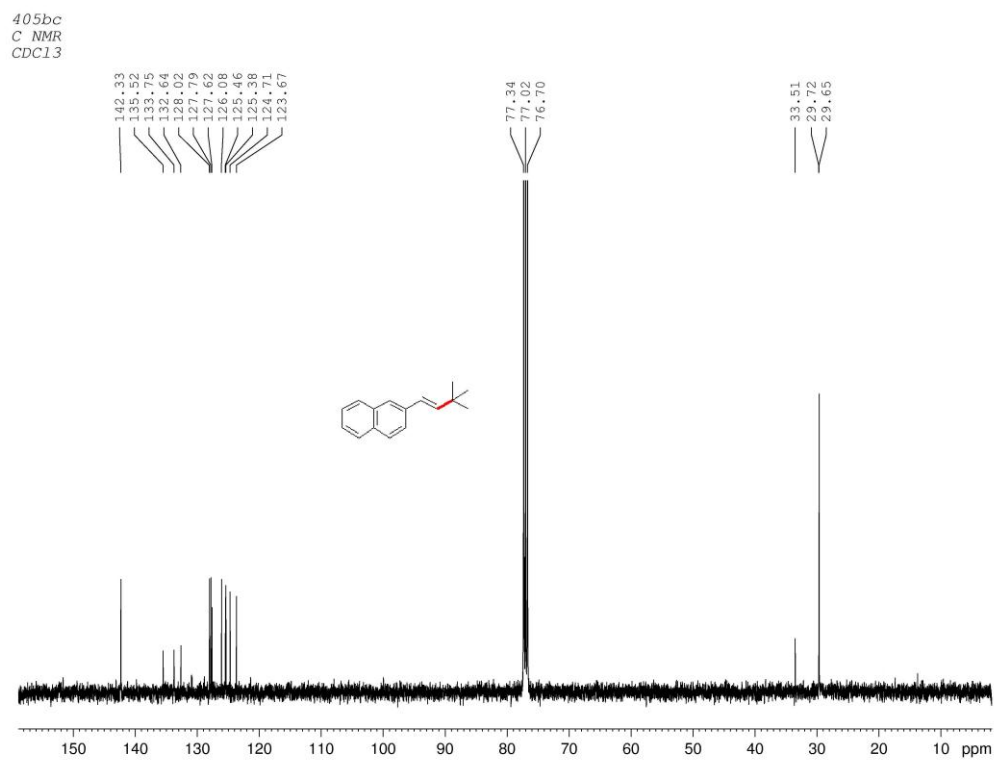
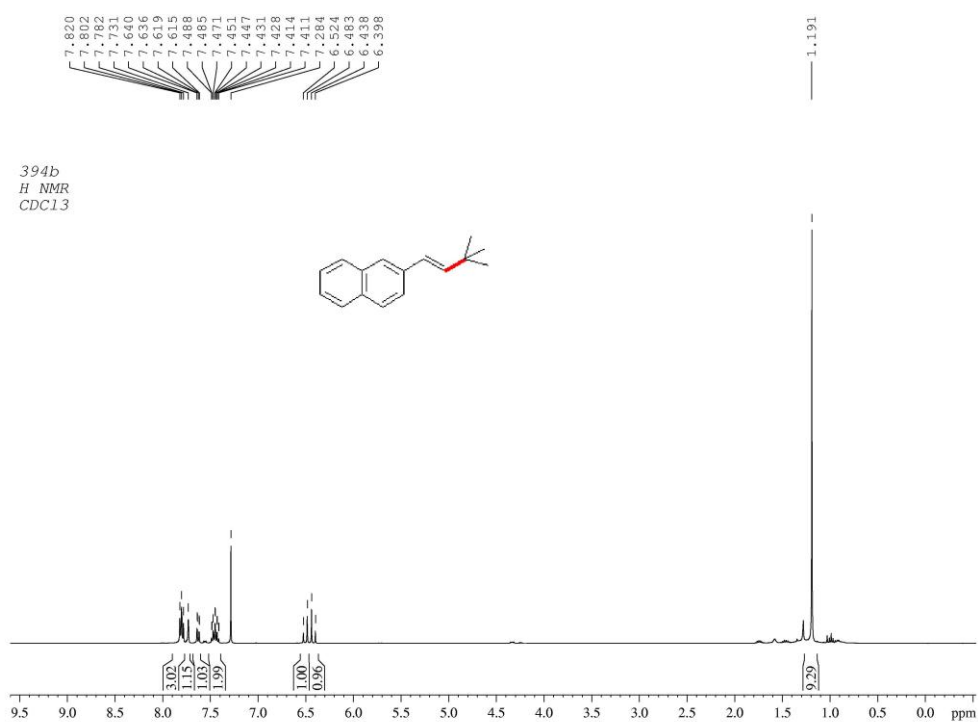


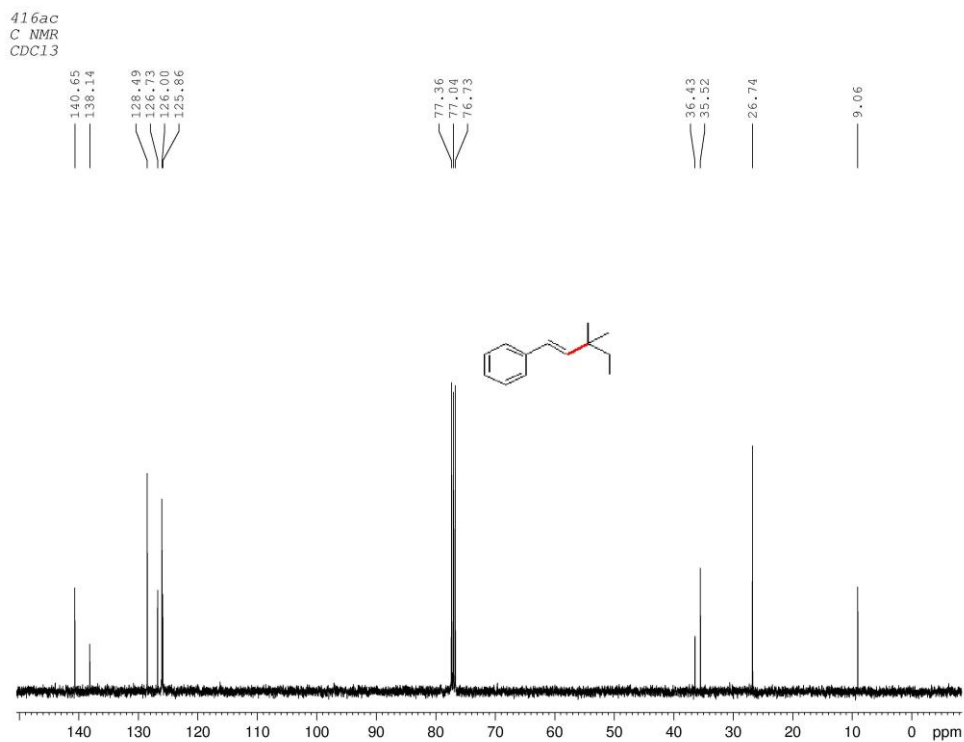
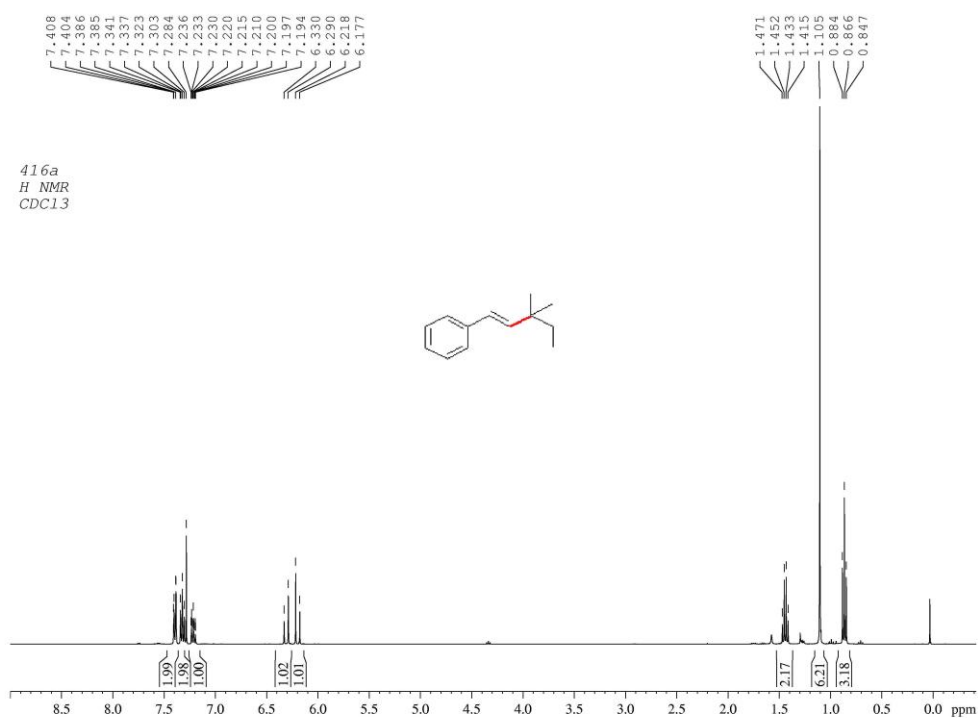


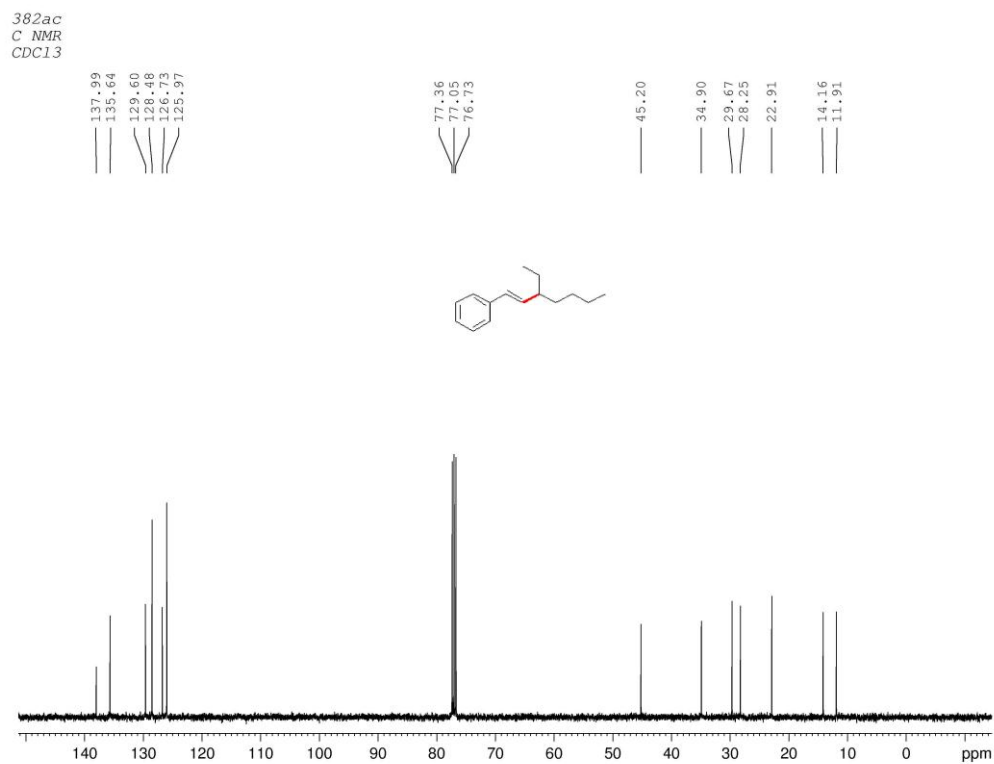
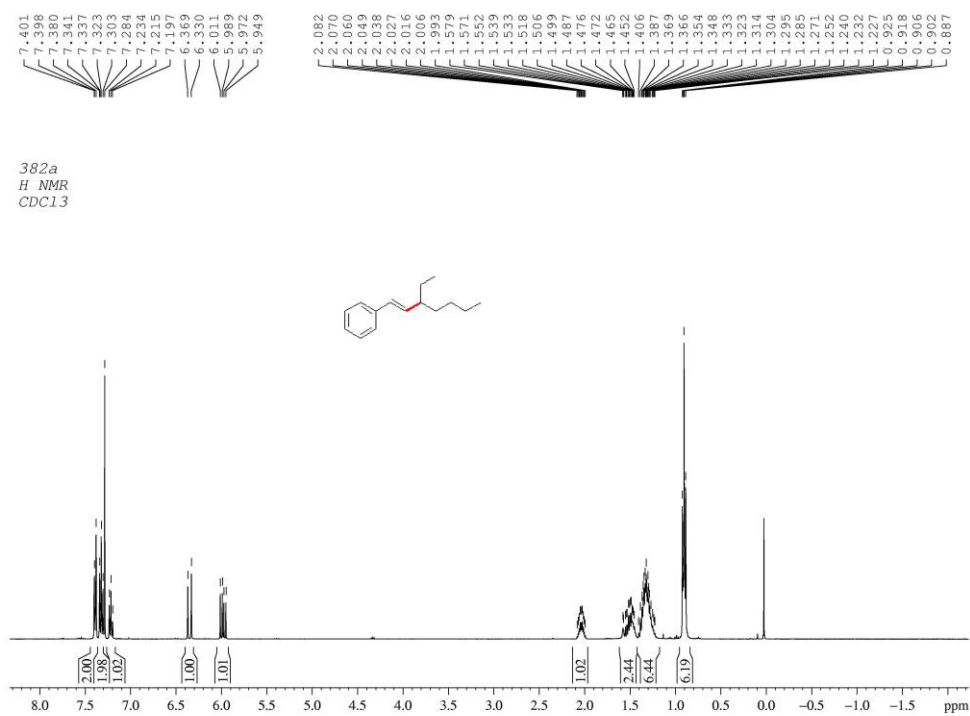


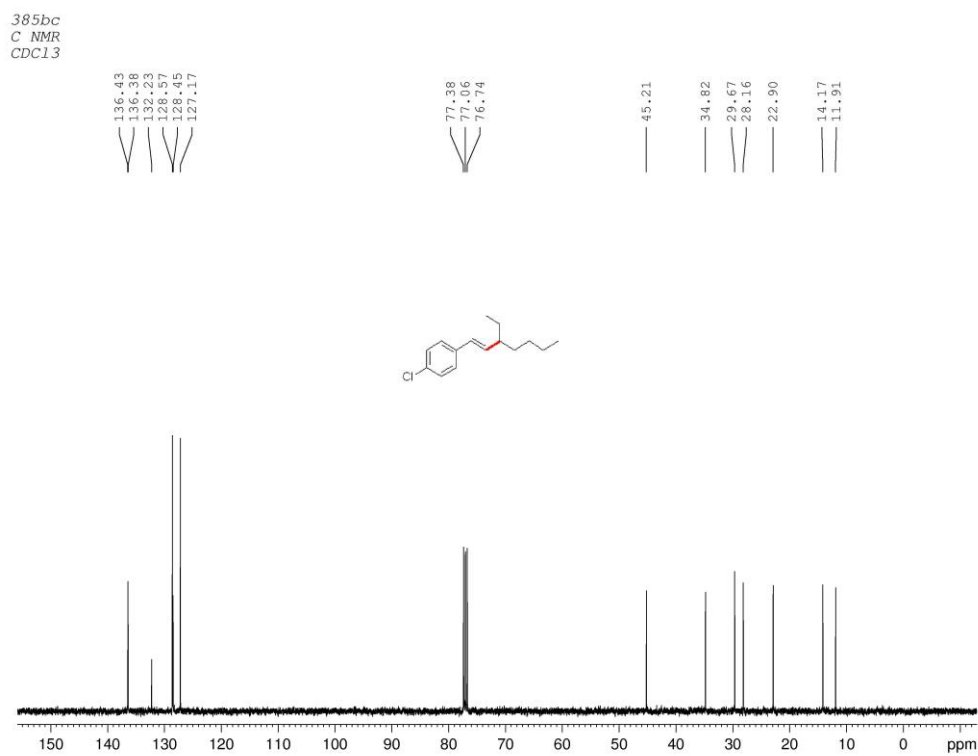
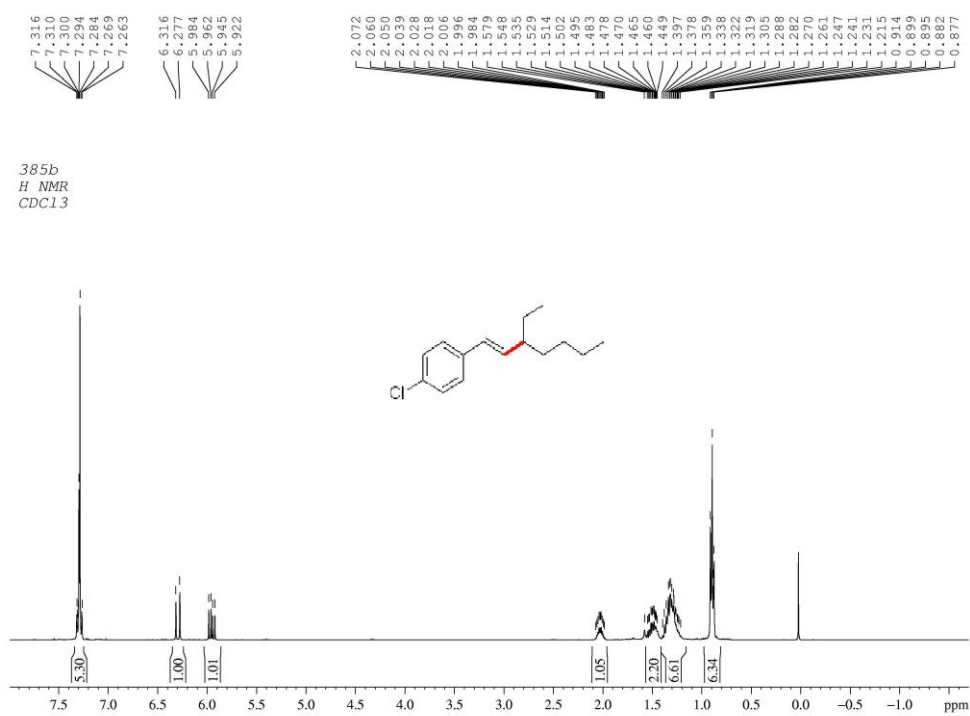


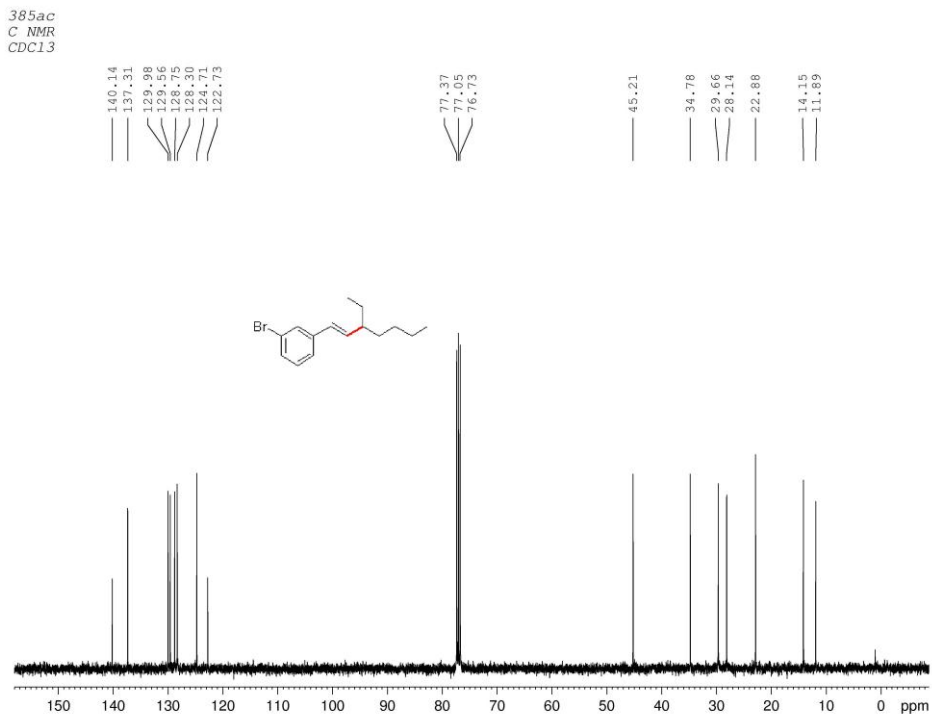
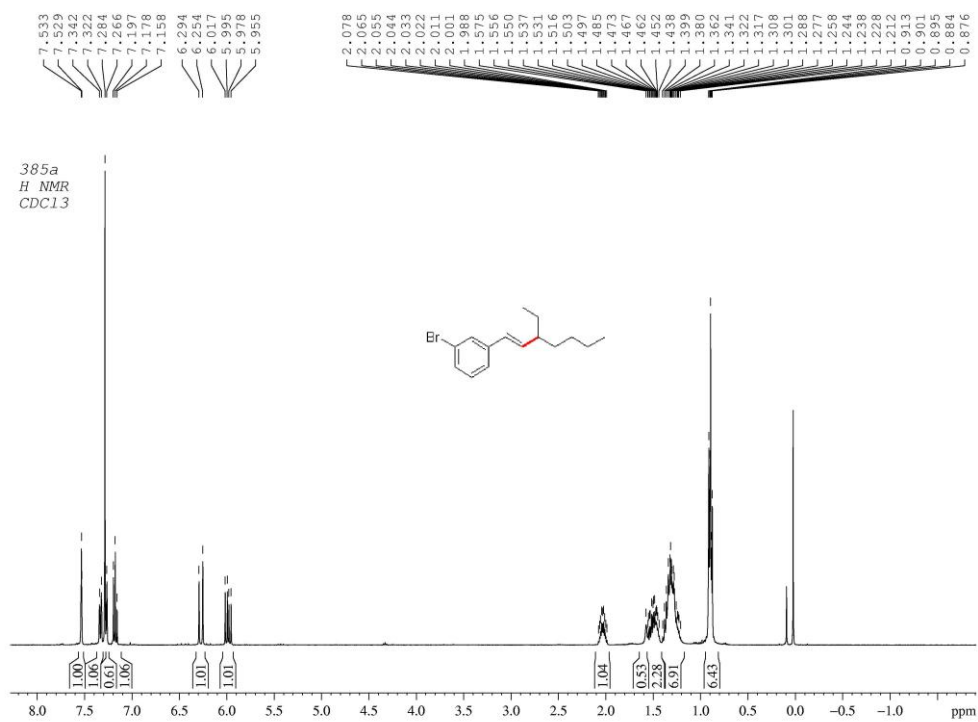


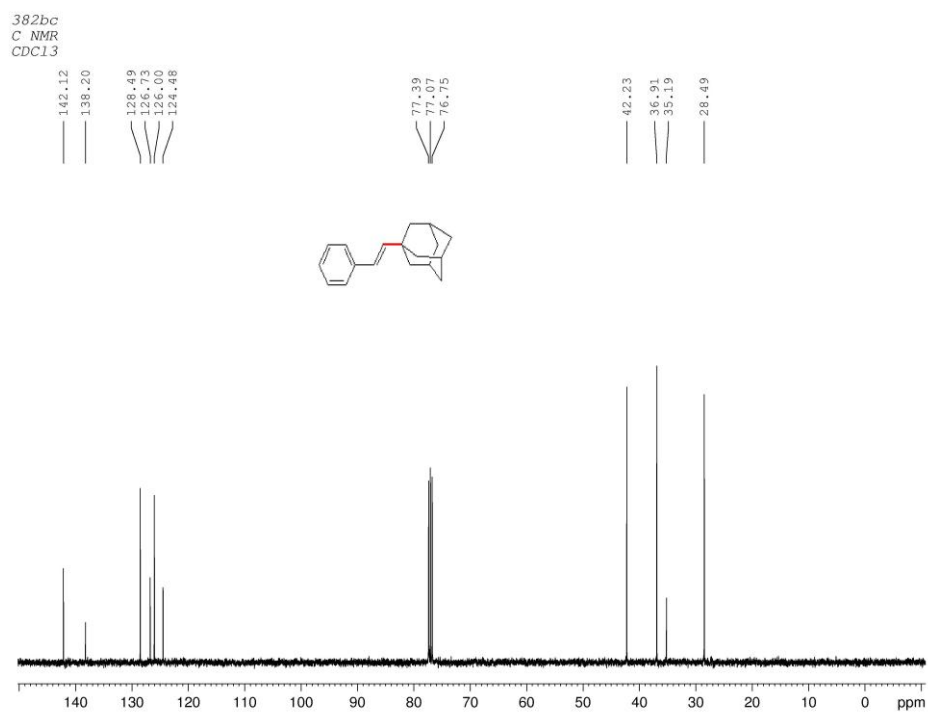
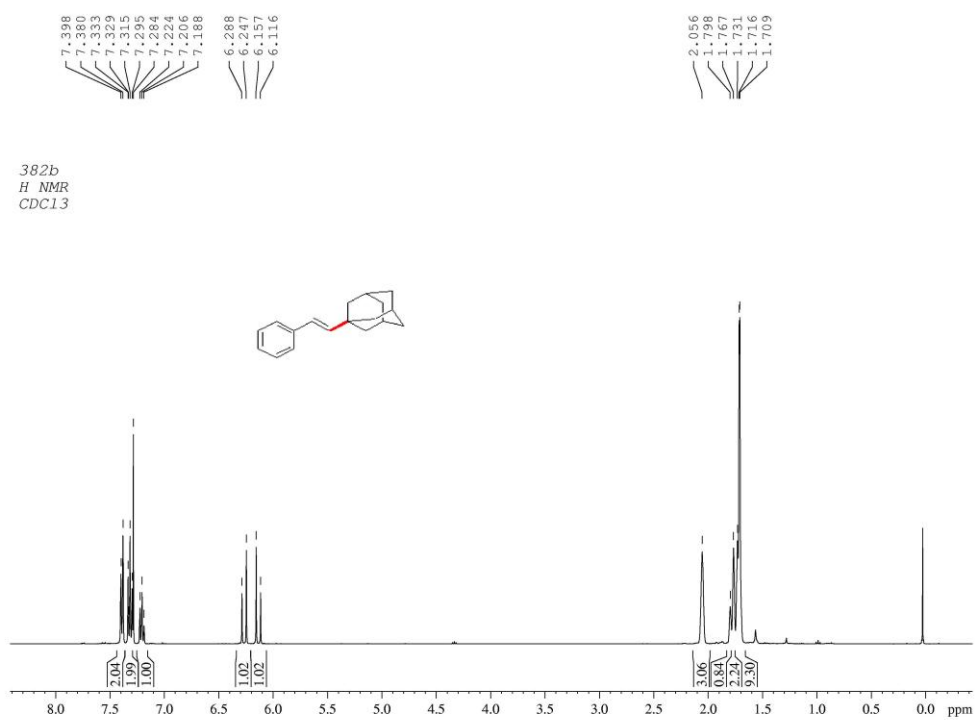


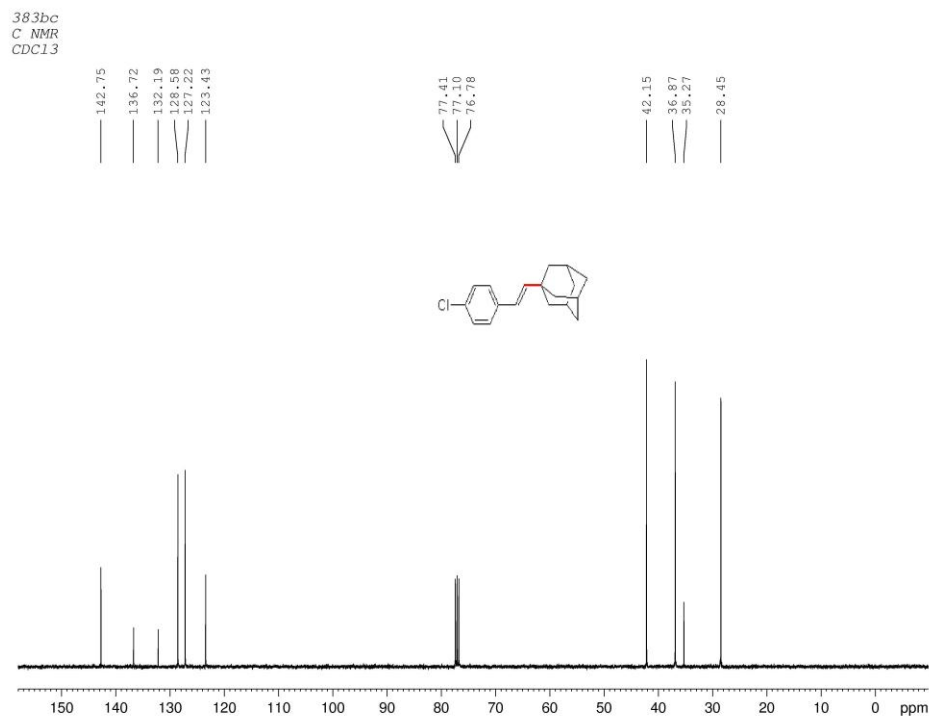
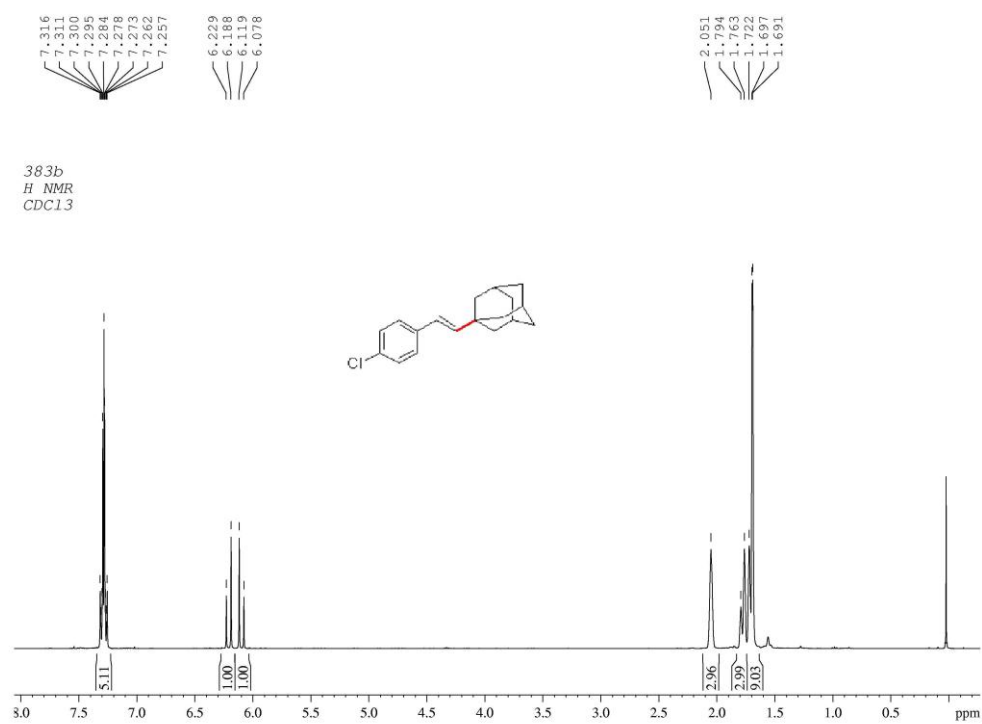


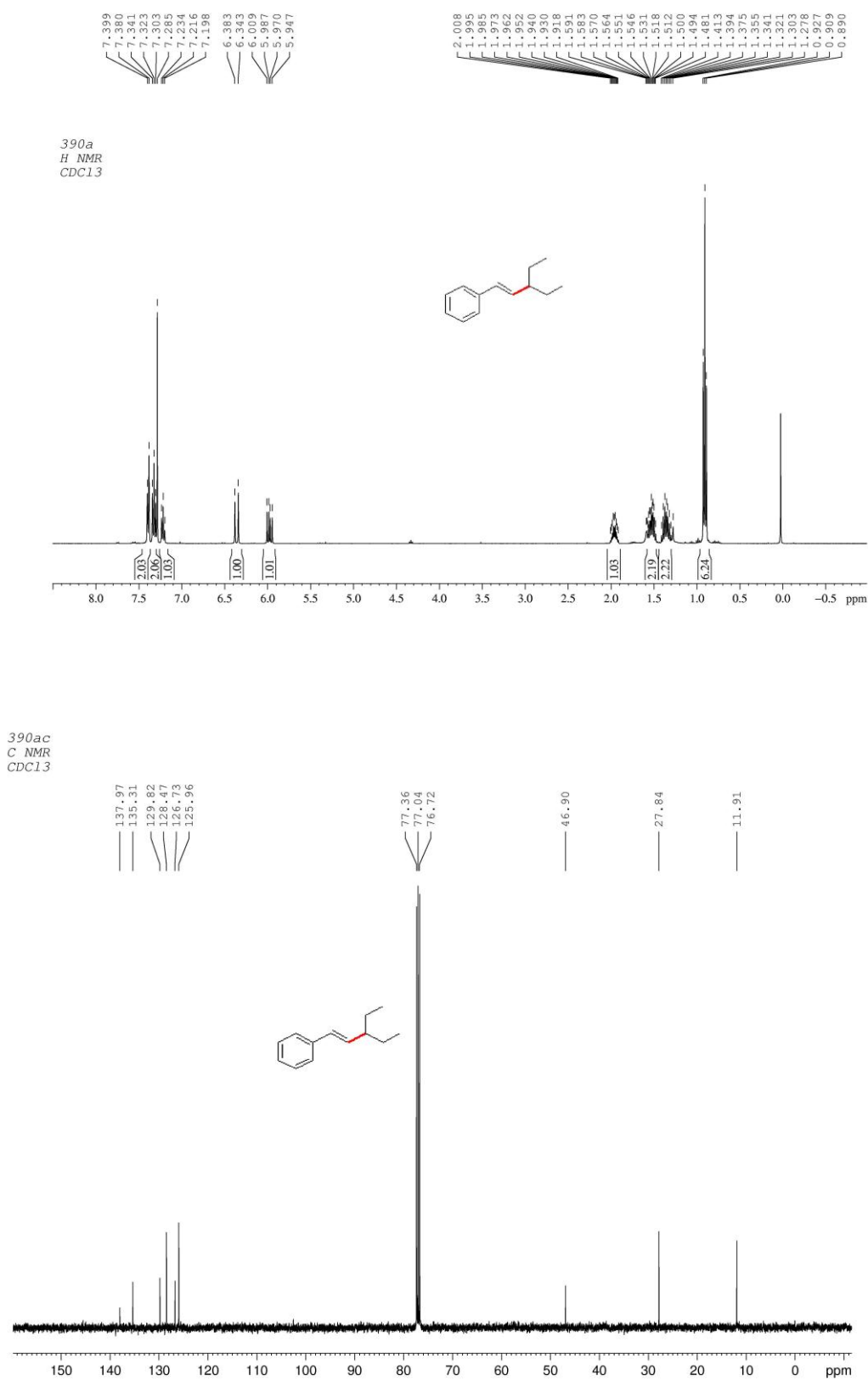


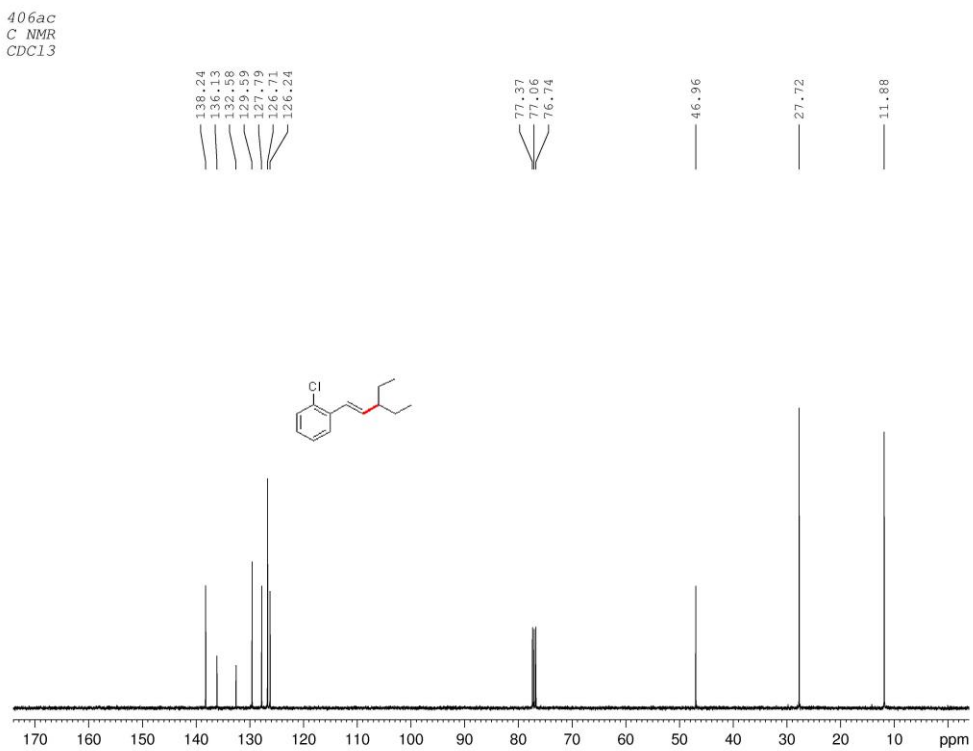
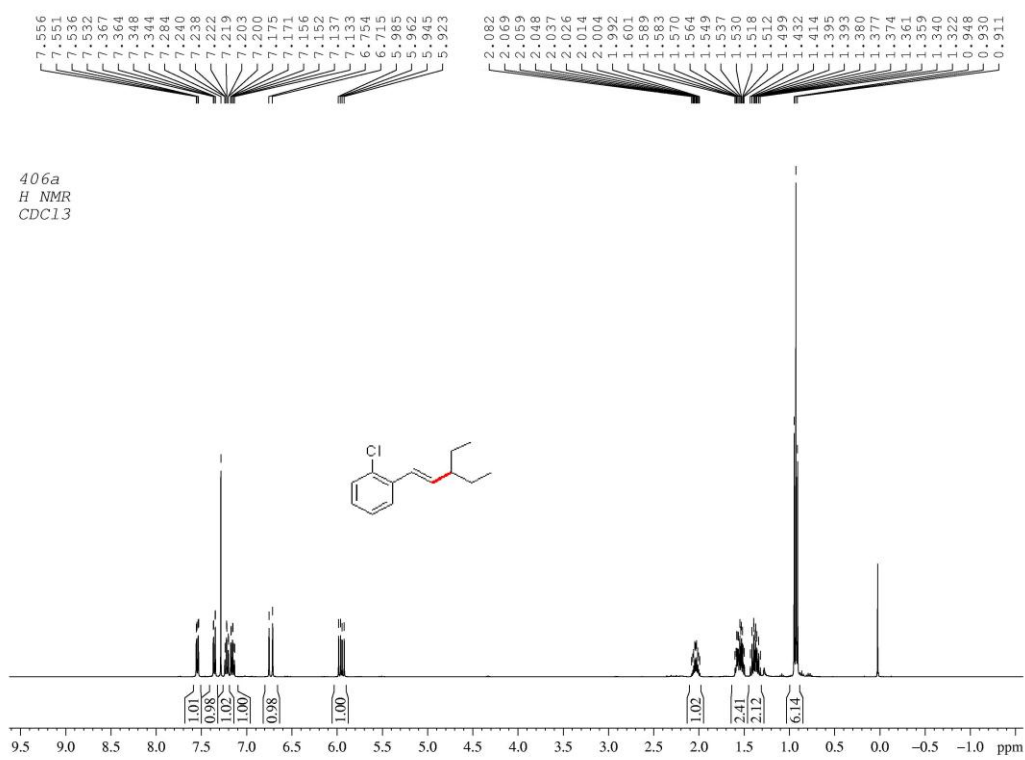


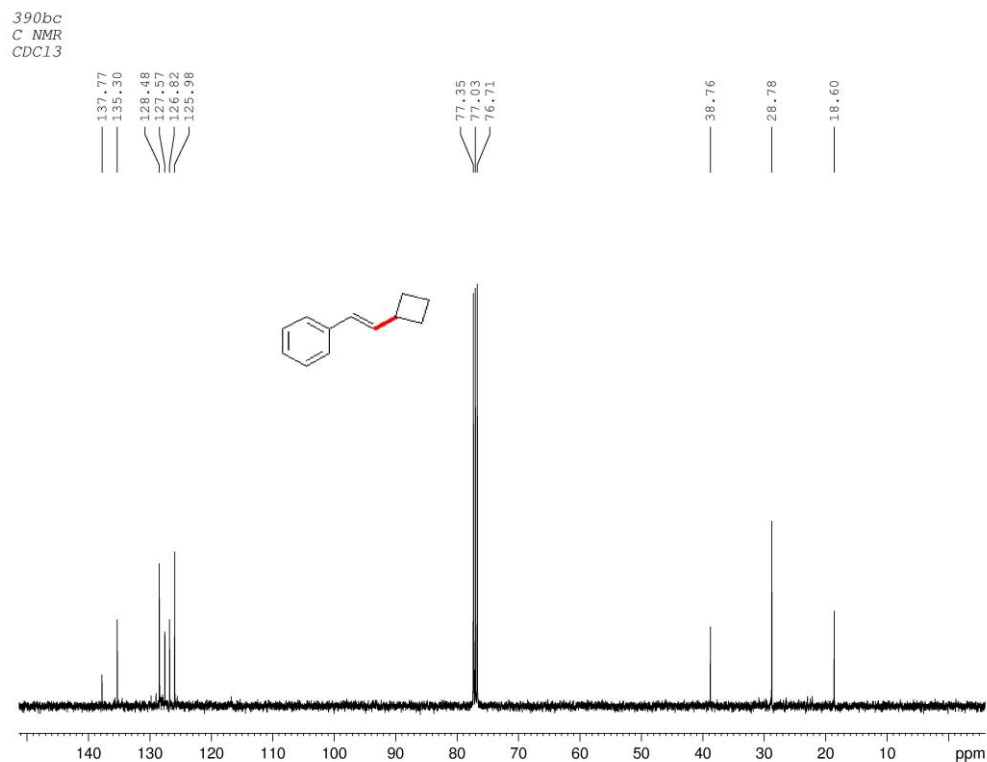
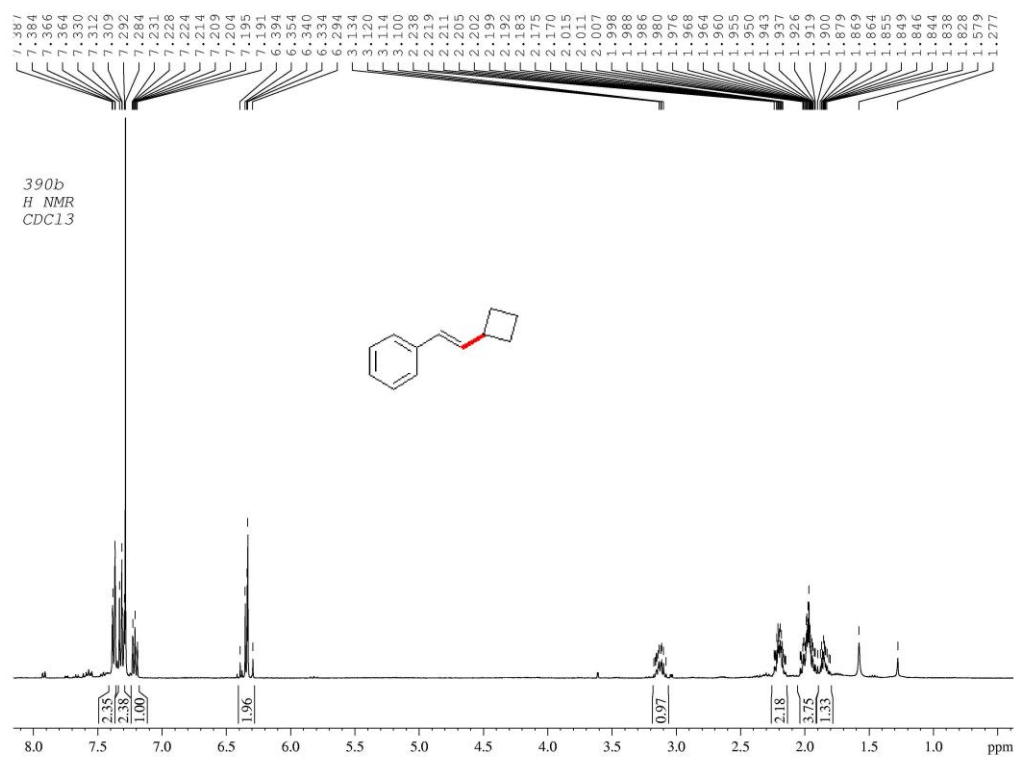


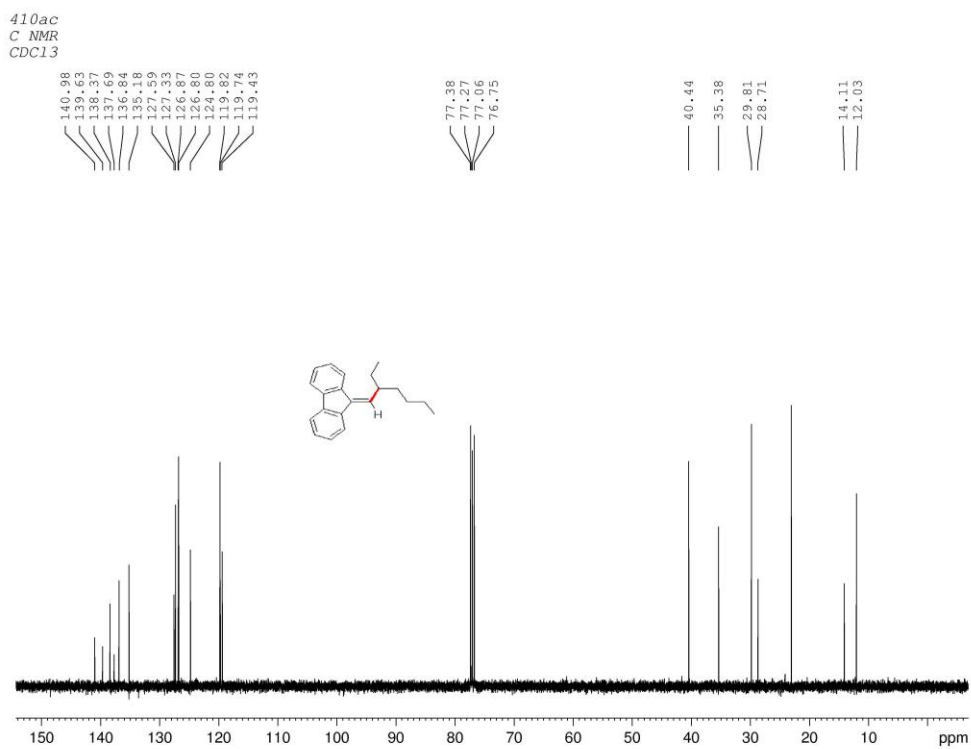
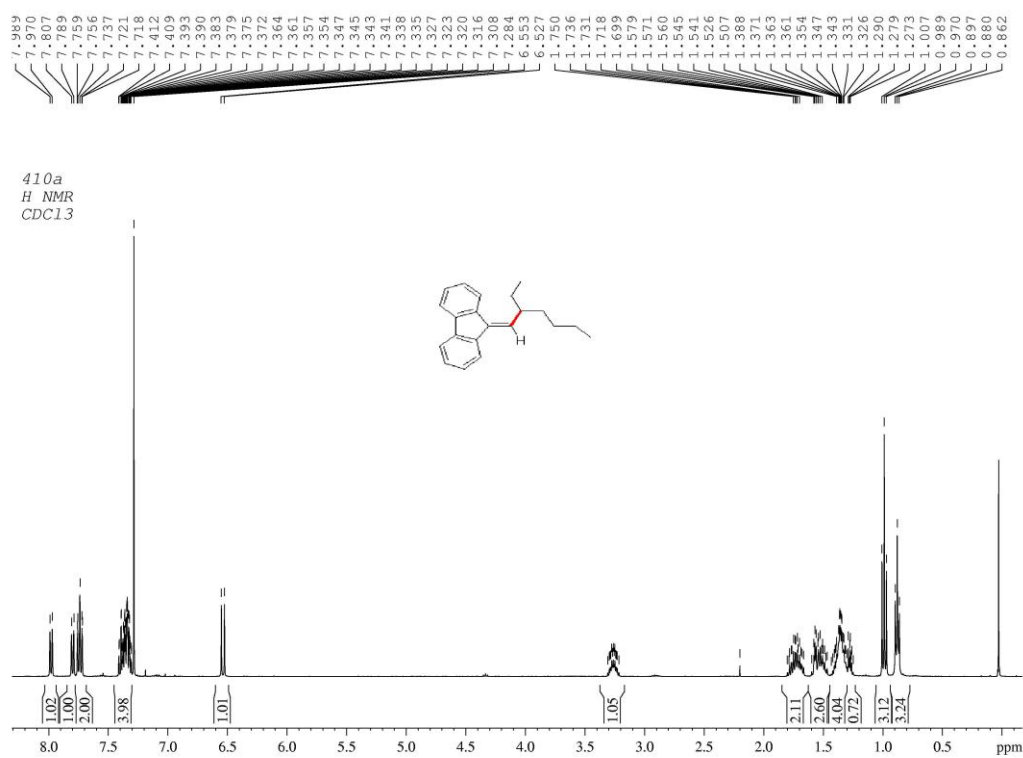


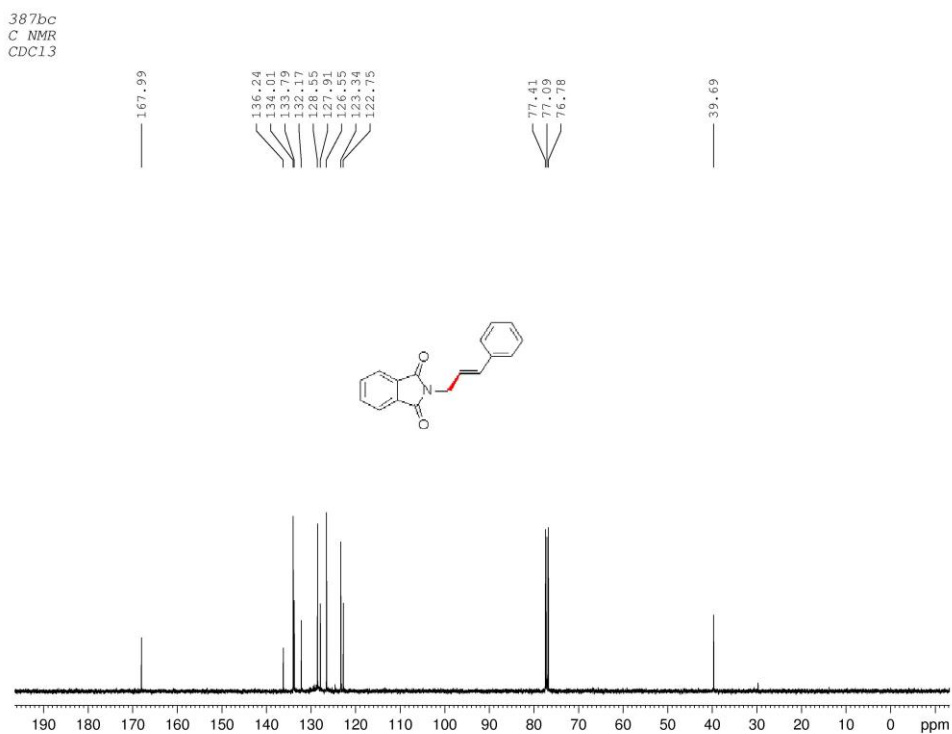
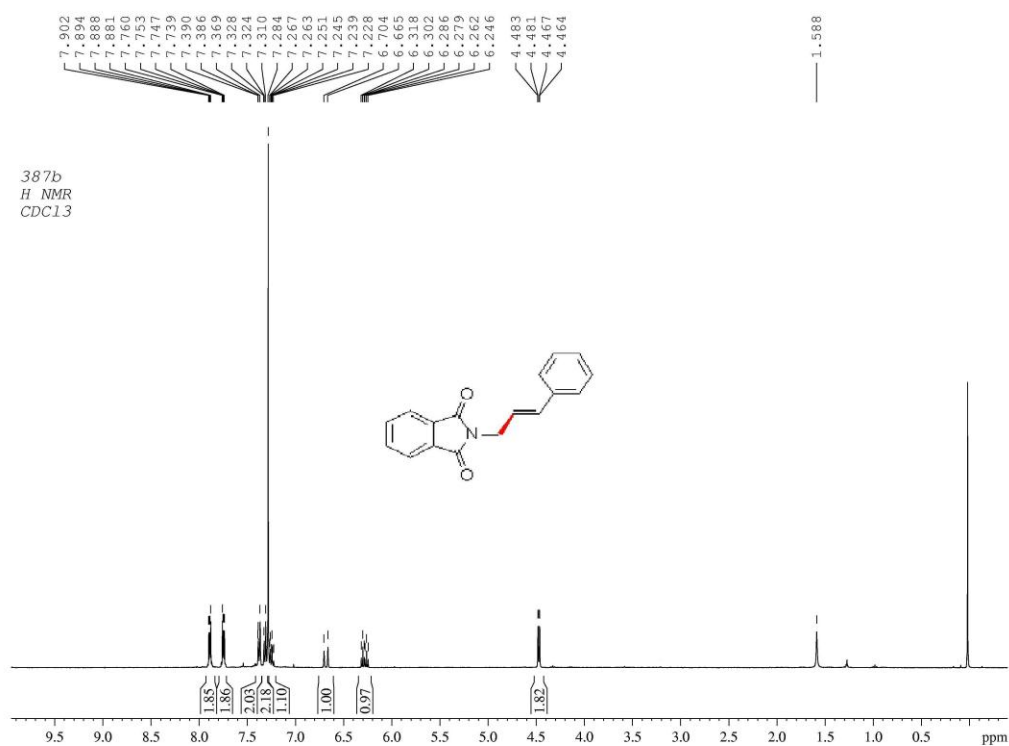


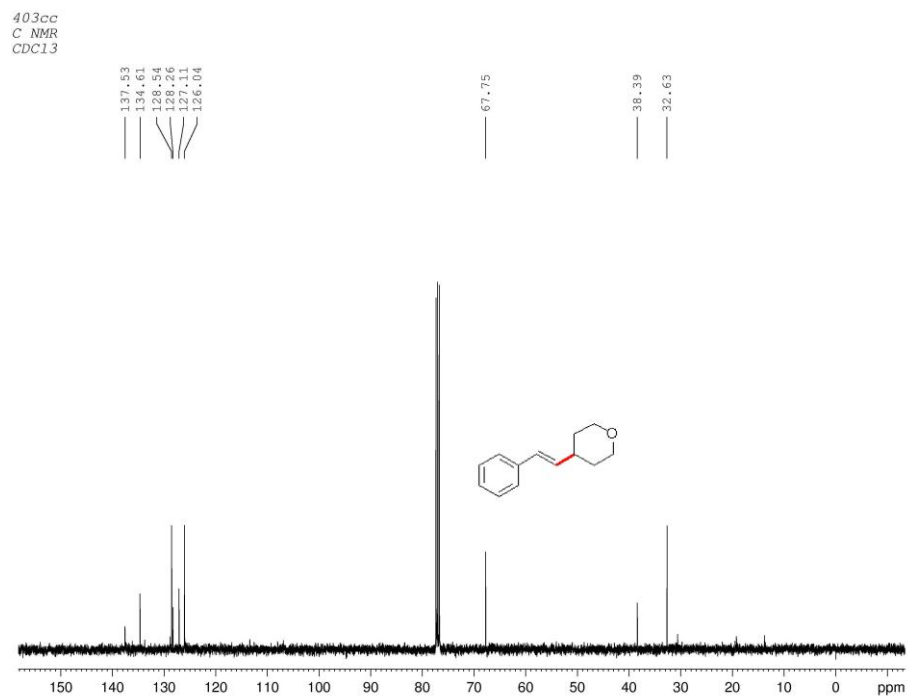
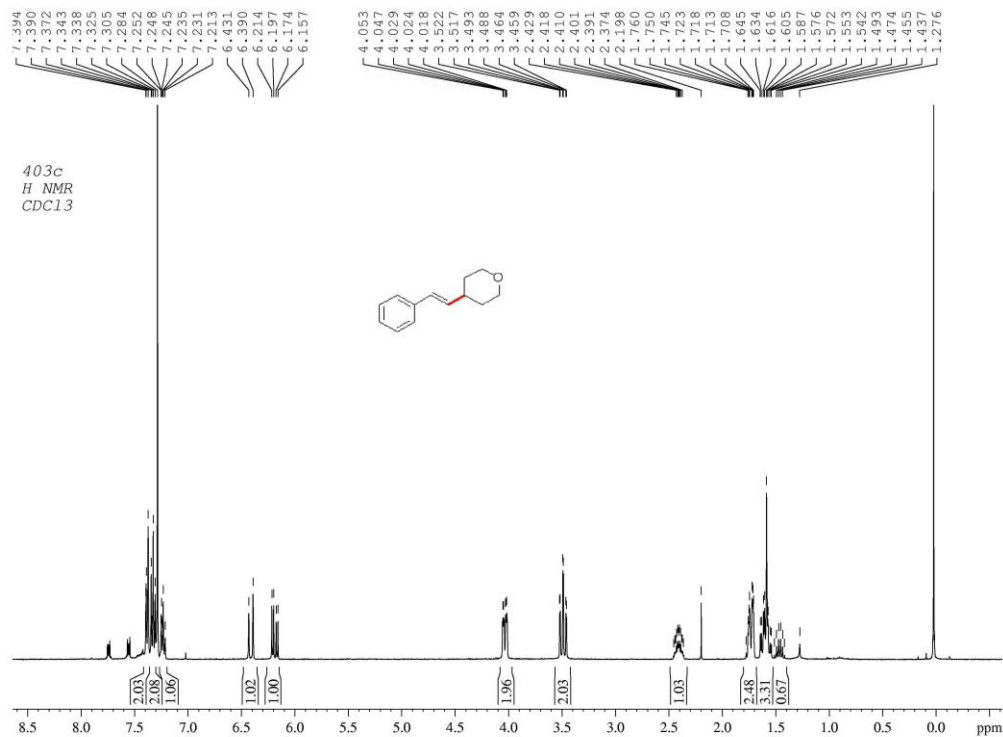


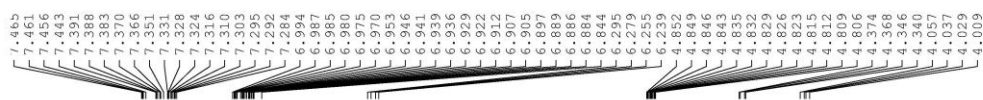




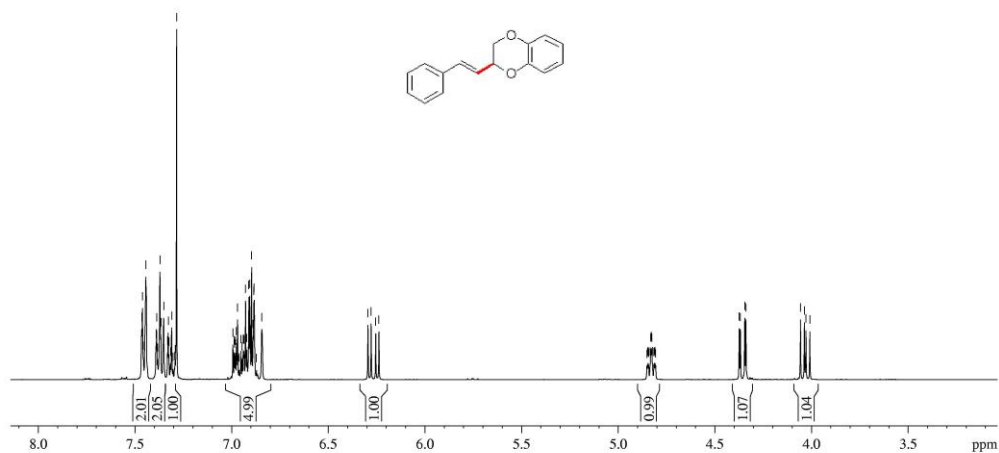








409a
H NMR
CDCl₃



409ac
C NMR
CDCl₃

