

Supporting Information

Metal-Free Synthesis of Methylene-Bridged bis-1,3-Dicarbonyl
Compounds *via* Oxidative C-C Bond Cleavage of Tertiary Aliphatic
Amines

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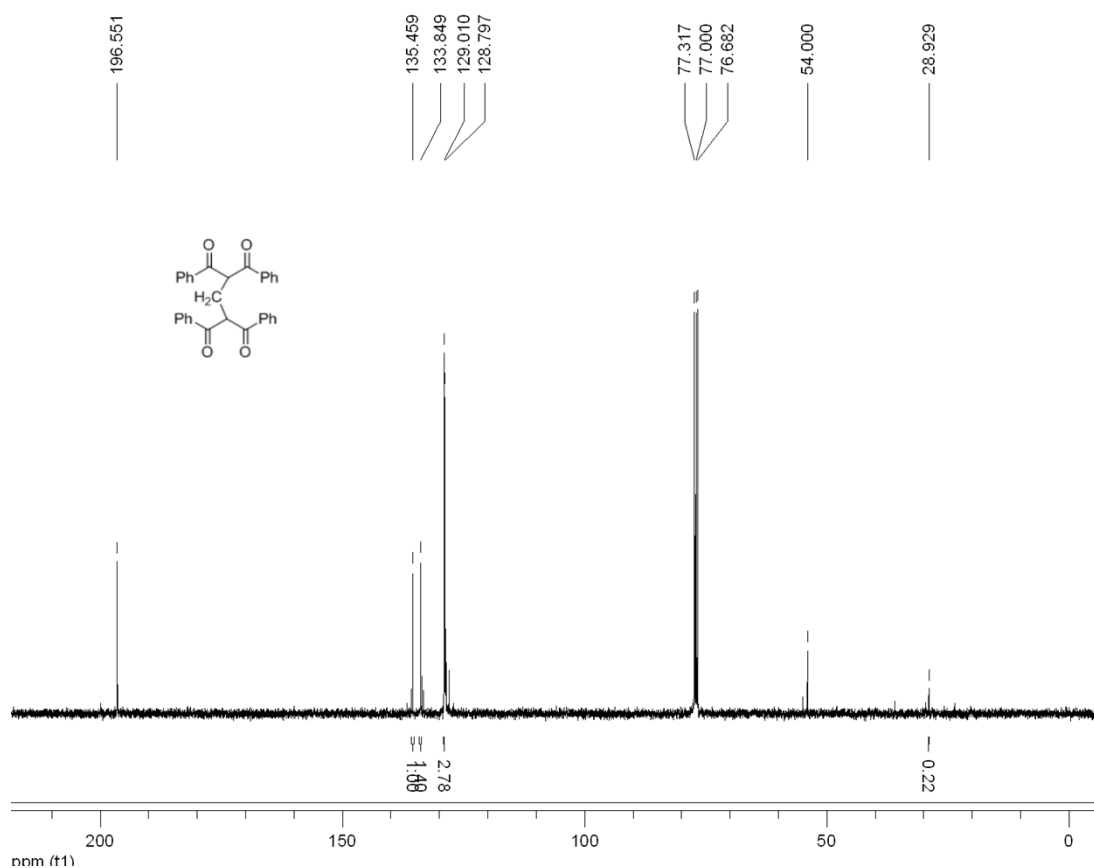
1. Mechanistic Experiments

1.1 The ^{13}C -labeled DIPEA experiments

^{13}C Enrichments of afforded products were calculated from the integrated resonances detected by inverse gated decoupling ^{13}C NMR.^[4] Carbon resonances were integrated and standardized to three different positions: C (135.5 ppm), C (133.9 ppm), and C (129.0 ppm). The ratio of the integrated signal from the labeled sample to unlabeled product was determined, then three sets were averaged. This quotient was multiplied by the natural abundance of ^{13}C (1.1%) to give the percent ^{13}C incorporations at each carbon position of ^{13}C -3a.

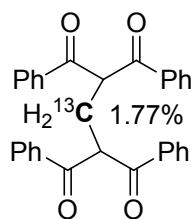
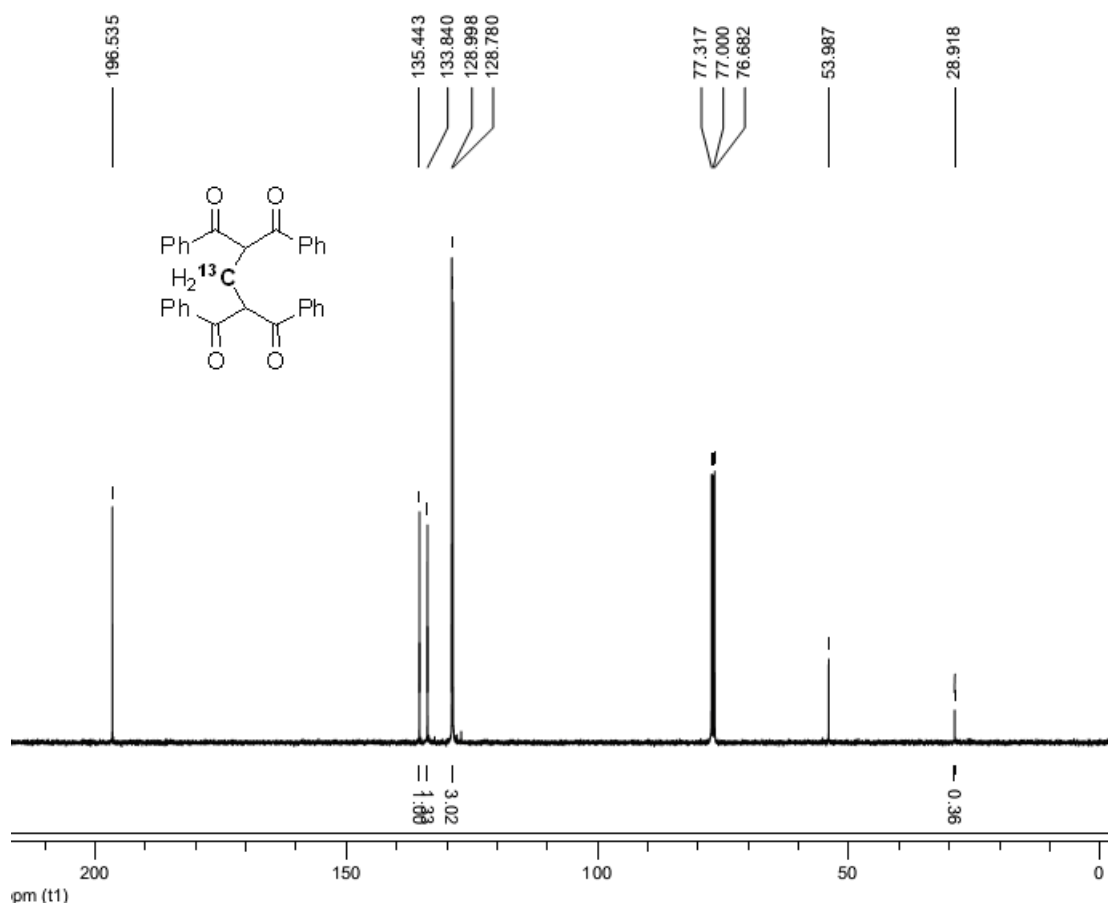
2, 4-Dibenzoyl-1, 5-diphenylpentane-1, 5-dione (3a)

Inverse gated decoupling ^{13}C NMR: (100 MHz, CDCl_3) δ 135.5 (int. = 1.00), 133.9 (int. = 1.40), 129.0 (int. = 2.78), 28.9 (- CH_2 -, int. = 0.22).



2, 4-Dibenzoyl-1, 5-diphenylpentane-1, 5-dione (^{13}C -3a)

Inverse gated decoupling ^{13}C NMR: (100 MHz, CDCl_3) δ 135.5 (int. = 1.00), 133.9 (int. = 1.33), 129.0 (int. = 3.02), 28.9 (- CH_2 -, int. = 0.36).



^{13}C -3a

Carbon		$^{-13}\text{CH}_2-$
Authentic δ (ppm)		28.93
Labeled δ (ppm)		28.92
C (135.5 ppm)	Ratio Labeled	0.36
	Ratio Unlabeled	0.22
	Labeled/Unlabeled	1.64
C (133.9 ppm)	Ratio Labeled	0.27
	Ratio Unlabeled	0.16
	Labeled/Unlabeled	1.69
C (129.0 ppm)	Ratio Labeled	0.12
	Ratio Unlabeled	0.08
	Labeled/Unlabeled	1.50
Average Labeled/Unlabeled		1.61
Absolute Abundance (%)		1.77

1.2 NMR tracking experiment

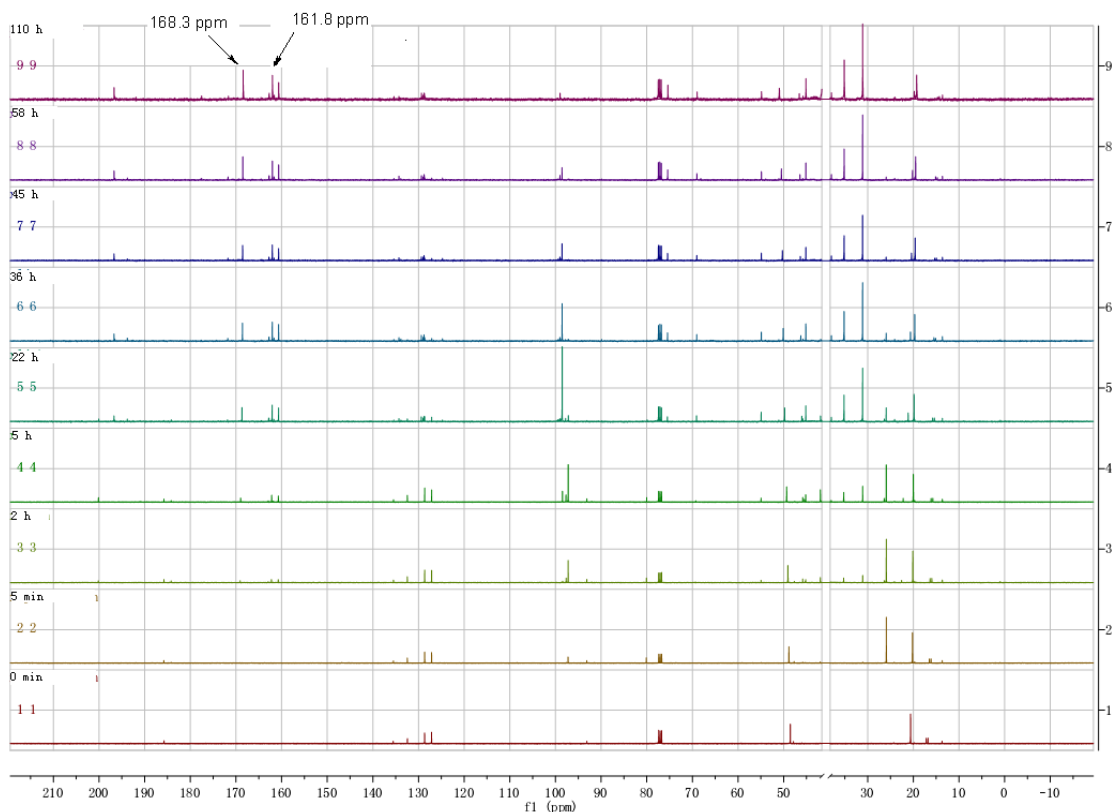


Figure 1S. ^{13}C NMR tracking experiment

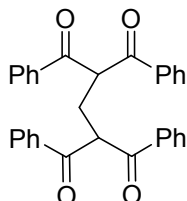
2. Experimental details and characterization data for products 3

General information: ^1H NMR spectra were recorded on AVANCE 400 spectrometer and the chemical shifts were reported in parts per million (ppm) relative to internal standard TMS (0 ppm) for CDCl_3 . The peak patterns are indicated as follows: s, singlet; d, doublet; bs, broad singlet; dd, doublet of doublet; t, triplet; m, multiplet; q, quartet. The coupling constants, J , are reported in Hertz (Hz). ^{13}C NMR spectra were obtained on the same spectrometer and referenced to the internal solvent signals (central peak is 77.0 ppm in CDCl_3). CDCl_3 was used as the NMR solvents.

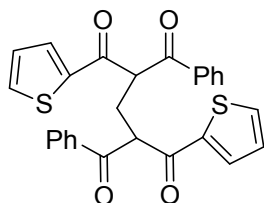
Mass spectra were determined with APEX II (Bruker Inc.) for ESI-MS. Flash column chromatography was performed over silica gel 200-300. All reagents were weighed and handled in air at room temperature and all reactions were performed under an air atmosphere. Unless otherwise noted, all reagents were purchased from commercial suppliers without further purification. Bu_4NI was purchased from Alfa Aesar. [(1- ^{13}C)ethyl]bis(propan-2-yl)amine was purchased from Wuxi Beita Pharmatech Co., Ltd. See the NMR data in this supporting information.

General procedure for products 3: An oven-dried Schlenk tube was charged with 1, 3-dicarbonyl compounds **1** (0.5 mmol) and tetrabutylammonium iodide (TBAI, 36.9

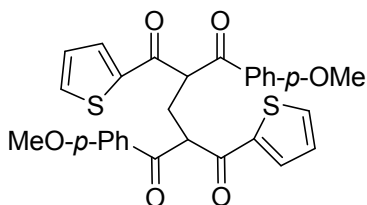
mg, 0.1 mmol) under air at room temperature, then N-ethyl-diisopropylamine **2f** (1.5 mmol) and tert-butyl hydroperoxide (TBHP, 2.0 mmol, 70% aqueous solution) were added. The resulting mixture was stirred at 60 °C for 5 h. The resulting reaction mixture was mixed with few silica gel and concentrated, then purified by flash column chromatography on silica gel with ethyl acetate/petroleum ether (1:20) as eluent to give the desired product **3**.



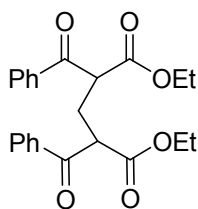
2, 4-dibenzoyl-1, 5-diphenylpentane-1, 5-dione 3a.^[1] ¹H NMR (400 MHz) δ 8.14 (d, $J = 7.6$ Hz, 8H), 7.57-7.60 (m, 4H), 7.47-7.50 (m, 8H), 5.74 (t, $J = 7.2$ Hz, 2H), 2.76 (t, $J = 7.2$ Hz, 2H); ¹³C NMR (100 MHz) δ 196.5, 135.5, 133.8, 129.0, 128.8, 54.0, 28.9.



2, 4-dibenzoyl-1, 5-di(thiophen-2-yl)pentane-1, 5-dione 3b. ¹H NMR (400 MHz) δ 8.15-8.09 (m, 4H), 8.06 (d, $J = 3.2$ Hz, 1H), 8.00 (d, $J = 3.2$ Hz, 1H), 7.69-7.67 (m, 2H), 7.61-7.56 (m, 2H), 7.51-7.46 (m, 4H), 7.17-7.12 (m, 2H), 5.54 (t, $J = 7.2$ Hz, 2H), 2.81 (t, $J = 7.2$ Hz, 2H); ¹³C NMR (100 MHz) δ 195.9, 189.0, 142.9, 135.5, 135.2, 133.9, 133.6, 129.0, 128.8, 128.7, 55.2, 29.4; HRMS m/z (ESI) calcd for C₂₇H₂₀O₄S₂ (M⁺+H): 473.0876; found: 473.0876.

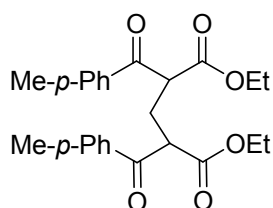


2, 4-bis(4-methoxybenzoyl)-1, 5-di(thiophen-2-yl)pentane-1, 5-dione 3c. The ratio of two diastereomers is 1:1. **Two diastereomers:** ¹H NMR (400 MHz) δ 8.15-8.11 (m, 4H), 7.99 (d, $J = 3.6$ Hz, 1H), 7.92 (d, $J = 3.6$ Hz, 1H), 7.66-7.64 (m, 2H), 7.13-7.09 (m, 2H), 6.98-6.95 (m, 4H), 5.50-5.45 (m, 2H), 3.86 (s, 6H), 2.78-2.74 (m, 2H); ¹³C NMR (100 MHz) δ 194.5, 194.4, 189.3, 189.2, 164.2, 164.1, 143.2, 143.0, 134.9, 134.8, 133.5, 133.3, 131.3, 131.2, 128.6, 128.5, 128.4, 114.3, 114.2, 55.5, 55.0, 29.6, 29.5; HRMS m/z (ESI) calcd for C₂₉H₂₄O₆S₂ (M⁺+H): 533.1087; found: 533.1096.



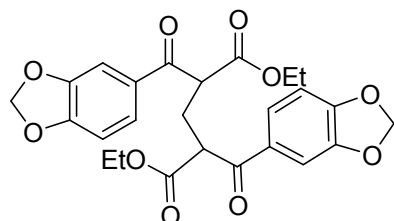
Diethyl 2, 4-dibenzoylpentanedioate 3d. ^[2] The ratio of two diastereomers is 1:1.

Two diastereomers: ¹H NMR (400 MHz) δ 8.04 (d, $J = 7.2$ Hz, 4H), 7.60-7.56 (m, 2H), 7.51-7.45 (m, 4H), 4.62 (t, $J = 7.2$ Hz, 1H), 4.54 (t, $J = 7.2$ Hz, 1H), 4.23-4.20 (m, 2H), 4.12-4.08 (m, 2H), 2.78-2.54 (m, 2H), 1.21 (t, $J = 7.2$ Hz, 3H), 1.10 (t, $J = 7.2$ Hz, 3H); ¹³C NMR (100 MHz) δ 195.1, 194.8, 169.6, 169.3, 135.9, 135.4, 133.7, 128.9, 128.8, 61.6, 51.6, 51.3, 28.2, 27.6, 14.0, 13.8.



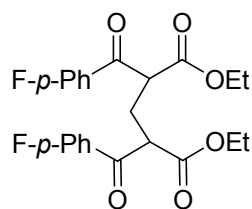
Diethyl 2, 4-bis(4-methylbenzoyl)pentanedioate 3e. ^[3] The ratio of two diastereomers is 1.3:1.

Two diastereomers: ¹H NMR (400 MHz) δ 7.95-7.92 (m, 4H), 7.30-7.24 (m, 4H), 4.58 (t, $J = 7.2$ Hz, 1H), 4.50 (t, $J = 7.2$ Hz, 1H), 4.24-4.06 (m, 4H), 2.74-2.52 (m, 2H), 2.42 (s, 3H), 2.40 (s, 3H), 1.22 (t, $J = 7.2$ Hz, 3H), 1.11 (t, $J = 7.2$ Hz, 3H); ¹³C NMR (100 MHz) δ 194.7, 194.4, 169.7, 169.4, 144.7, 133.4, 133.0, 129.4, 129.0, 61.5, 51.5, 51.2, 28.3, 27.7, 21.6, 14.0, 13.9.

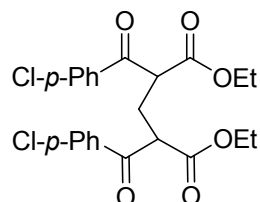


Diethyl 2, 4-bis(benzo[d][1, 3]dioxole-5-carbonyl)pentanedioate 3f. The ratio of two diastereomers is 1.5:1.

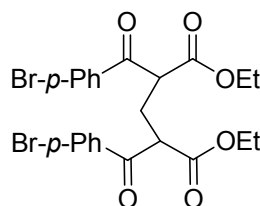
Two diastereomers: ¹H NMR (400 MHz) δ 7.70-7.66 (m, 2H), 7.51-7.48 (m, 2H), 6.89-6.84 (m, 2H), 6.05-6.04 (m, 4H), 4.51-4.40 (m, 2H), 4.24-4.09 (m, 4H), 2.70-2.49 (m, 2H), 1.23 (t, $J = 7.2$ Hz, 3H), 1.14 (t, $J = 7.2$ Hz, 3H); ¹³C NMR (100 MHz) δ 193.2, 192.8, 169.7, 169.4, 152.4, 148.4, 148.3, 130.7, 130.2, 125.7, 125.5, 108.5, 108.0, 102.0, 61.6, 51.4, 51.1, 28.6, 28.0, 14.0, 13.9; HRMS m/z (ESI) calcd for C₂₅H₂₄O₁₀ (M⁺⁺Na): 507.1262; found: 507.1260.



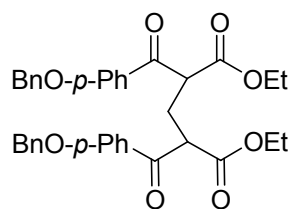
Diethyl 2, 4-bis(4-fluorobenzoyl)pentanedioate 3g. The ratio of two diastereomers is 1.3:1. **Two diastereomers:** ^1H NMR (400 MHz) δ 8.12-8.07 (m, 4H), 7.20-7.13 (m, 4H), 4.58 (t, $J = 7.2\text{Hz}$, 1H), 4.49 (t, $J = 7.2\text{Hz}$, 1H), 4.24-4.09 (m, 4H), 2.73-2.50 (m, 2H), 1.22 (t, $J = 7.2\text{Hz}$, 3H), 1.12 (t, $J = 7.2\text{Hz}$, 3H); ^{13}C NMR (100 MHz) δ 193.6, 193.2, 169.5, 169.1, 167.5, 164.9, 131.8, 131.7, 131.6, 131.5, 116.1, 115.9, 61.8, 51.5, 51.2, 28.1, 27.5, 14.0, 13.9; HRMS m/z (ESI) calcd for $\text{C}_{23}\text{H}_{22}\text{F}_2\text{O}_6$ (M^{++}Na): 455.1277; found: 455.1280.



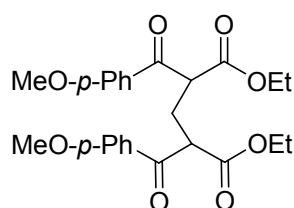
Diethyl 2, 4-bis(4-chlorobenzoyl)pentanedioate 3h. The ratio of two diastereomers is 1.5:1. **Two diastereomers:** ^1H NMR (400 MHz) δ 8.00-7.98 (m, 4H), 7.48-7.44 (m, 4H), 4.56 (t, $J = 7.2\text{Hz}$, 1H), 4.47 (t, $J = 7.2\text{Hz}$, 1H), 4.23-4.09 (m, 4H), 2.72-2.50 (m, 2H), 1.21 (t, $J = 7.2\text{Hz}$, 3H), 1.12 (t, $J = 7.2\text{Hz}$, 3H); ^{13}C NMR (100 MHz) δ 193.9, 193.5, 169.4, 169.0, 140.5, 134.2, 133.7, 130.3, 130.2, 129.2, 61.8, 51.4, 51.2, 28.0, 27.4, 14.0, 13.9; HRMS m/z (ESI) calcd for $\text{C}_{23}\text{H}_{22}\text{Cl}_2\text{O}_6$ (M^{++}Na): 487.0686; found: 487.0683.



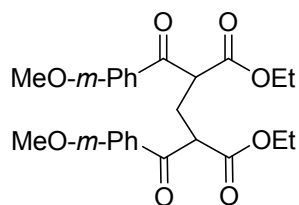
Diethyl 2, 4-bis(4-bromobenzoyl)pentanedioate 3i. ^[3] The ratio of two diastereomers is 1.2:1. **Two diastereomers:** ^1H NMR (400 MHz) δ 7.92-7.89 (m, 4H), 7.66-7.61 (m, 4H), 4.54 (t, $J = 7.2\text{Hz}$, 1H), 4.45 (t, $J = 7.2\text{Hz}$, 1H), 4.23-4.09 (m, 4H), 2.73-2.50 (m, 2H), 1.22 (t, $J = 7.2\text{Hz}$, 3H), 1.12 (t, $J = 7.2\text{Hz}$, 3H); ^{13}C NMR (100 MHz) δ 194.1, 193.8, 169.4, 169.0, 134.6, 134.2, 132.2, 130.4, 130.3, 129.3, 129.2, 61.8, 51.4, 51.2, 27.9, 27.6, 14.0, 13.9.



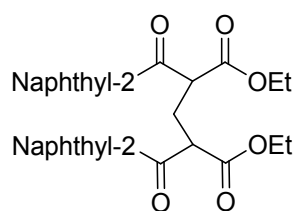
Diethyl 2, 4-bis(4-(benzyloxy)benzoyl)pentanedioate 3j. ^1H NMR (400 MHz) δ 8.03 (d, $J = 8.8\text{Hz}$, 4H), 7.41-7.34 (m, 10H), 7.01 (d, $J = 9.2\text{ Hz}$, 4H), 5.13 (s, 4H), 4.58-4.46 (m, 2H), 4.26-4.17 (m, 4H), 2.52 (t, $J = 7.2\text{Hz}$, 2H), 1.23 (t, $J = 7.2\text{Hz}$, 6H); ^{13}C NMR (100 MHz) δ 193.7, 169.9, 163.2, 136.0, 131.4, 128.7, 128.6, 128.3, 127.4, 114.8, 70.2, 61.5, 51.4, 28.6, 14.0; HRMS m/z (ESI) calcd for $\text{C}_{37}\text{H}_{36}\text{O}_8$ (M^++Na): 631.2303; found: 631.2308.



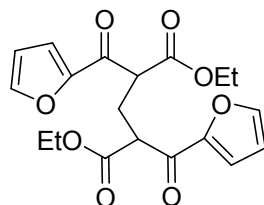
Diethyl 2, 4-bis(4-methoxybenzoyl)pentanedioate 3k. ^[3] The ratio of two diastereomers is 1.2:1. **Two diastereomers:** ^1H NMR (400 MHz) δ 8.05-8.01 (m, 4H), 6.97-6.91 (m, 4H), 4.55 (t, $J = 7.2\text{Hz}$, 1H), 4.48 (t, $J = 7.2\text{Hz}$, 1H), 4.22-4.19 (m, 2H), 4.12- 4.06 (m, 2H), 3.87 (s, 3H), 3.85 (s, 3H), 2.74-2.50 (m, 2H), 1.22 (t, $J = 7.2\text{Hz}$, 3H), 1.12 (t, $J = 7.2\text{Hz}$, 3H); ^{13}C NMR (100 MHz) δ 193.7, 193.3, 169.9, 169.5, 164.0, 131.3, 131.2, 128.9, 128.4, 113.9, 61.4, 55.5, 51.3, 51.1, 28.5, 27.9, 14.0, 13.9.



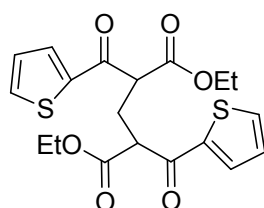
Diethyl 2, 4-bis(3-methoxybenzoyl)pentanedioate 3l. The ratio of two diastereomers is 1.5:1. **Two diastereomers:** ^1H NMR (400 MHz) δ 7.65-7.62 (m, 2H), 7.57-7.55 (m, 2H), 7.41-7.35 (m, 2H), 7.16-7.11 (m, 2H), 4.58 (t, $J = 7.2\text{Hz}$, 1H), 4.50 (t, $J = 7.2\text{Hz}$, 1H), 4.25-4.10 (m, 4H), 3.88 (s, 2H), 3.86 (s, 4H), 2.78-2.53 (m, 2H), 1.22 (t, $J = 7.2\text{Hz}$, 3H), 1.13 (t, $J = 7.2\text{Hz}$, 3H); ^{13}C NMR (100 MHz) δ 195.0, 194.6, 169.7, 169.3, 159.9, 137.2, 136.7, 129.8, 121.5, 121.4, 120.7, 120.6, 112.8, 61.6, 55.5, 51.7, 51.5, 28.4, 27.8, 14.0, 13.9; HRMS m/z (ESI) calcd for $\text{C}_{25}\text{H}_{28}\text{O}_8$ (M^++Na): 479.1677; found: 479.1677.



Diethyl 2, 4-di(2-naphthoyl)pentanedioate 3m. The ratio of two diastereomers is 1:1. **Two diastereomers:** ^1H NMR (400 MHz) δ 8.62 (d, $J = 19.6\text{Hz}$, 2H), 8.13-8.12 (m, 1H), 8.05-8.01 (m, 2H), 7.95-7.90 (m, 2H), 7.89-7.81 (m, 3H), 7.64-7.52 (m, 4H), 4.80 (t, $J = 7.6\text{Hz}$, 1H), 4.75 (t, $J = 7.6\text{Hz}$, 1H), 4.30-4.22 (m, 2H), 4.16-4.07 (m, 2H), 2.91-2.69 (m, 2H), 1.23 (t, $J = 7.2\text{Hz}$, 3H), 1.10 (t, $J = 7.2\text{Hz}$, 3H); ^{13}C NMR (100 MHz) δ 195.1, 194.7, 169.7, 169.5, 135.9, 135.8, 133.2, 132.8, 132.5, 132.4, 131.2, 131.0, 129.9, 129.8, 128.9, 128.8, 128.7, 128.6, 127.8, 127.7, 126.9, 126.87, 124.1, 124.0, 61.7, 51.6, 51.5, 28.5, 28.0, 14.0, 13.9; HRMS m/z (ESI) calcd for $\text{C}_{31}\text{H}_{28}\text{O}_6$ ($\text{M}^+\text{+Na}$): 519.1779; found: 519.1778.

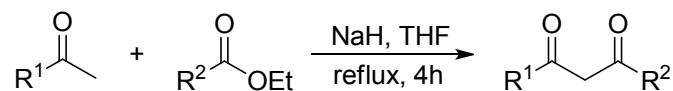


Diethyl 2, 4-di(furan-2-carbonyl)pentanedioate 3n. The ratio of two diastereomers is 1.2:1. **Two diastereomers:** ^1H NMR (400 MHz) δ 7.61-7.57 (m, 2H), 7.36-7.34 (m, 2H), 6.67-6.53 (m, 2H), 4.31-4.24 (m, 2H), 4.21-4.10 (m, 4H), 2.64-2.57 (m, 2H), 1.22 (t, $J = 7.2\text{Hz}$, 3H), 1.16 (t, $J = 7.2\text{Hz}$, 3H); ^{13}C NMR (100 MHz) δ 183.1, 182.9, 168.9, 168.8, 151.6, 151.4, 147.3, 119.3, 119.2, 112.6, 61.6, 51.5, 51.4, 27.2, 26.7, 14.0, 13.9; HRMS m/z (ESI) calcd for $\text{C}_{19}\text{H}_{20}\text{O}_8$ ($\text{M}^+\text{+Na}$): 399.1051; found: 399.1047.



Diethyl 2, 4-di(thiophene-2-carbonyl)pentanedioate 3o. The ratio of two diastereomers is 1.5:1. **Two diastereomers:** ^1H NMR (400 MHz) δ 7.93-7.90 (m, 2H), 7.72-7.67 (m, 2H), 7.17-7.11 (m, 2H), 4.45-4.36 (m, 2H), 4.24-4.12 (m, 4H), 2.76-2.59 (m, 2H), 1.23 (t, $J = 7.2\text{Hz}$, 3H), 1.16 (t, $J = 7.2\text{Hz}$, 3H); ^{13}C NMR (100 MHz) δ 187.6, 187.3, 169.1, 168.8, 143.1, 142.7, 135.3, 135.2, 133.9, 133.7, 128.5, 61.8, 52.5, 52.4, 28.6, 27.9, 14.0, 13.9; HRMS m/z (ESI) calcd for $\text{C}_{19}\text{H}_{20}\text{O}_6\text{S}_2$ ($\text{M}^+\text{+Na}$): 431.0594; found: 431.0599.

3. General procedure for 1, 3-dicarbonyl compounds:

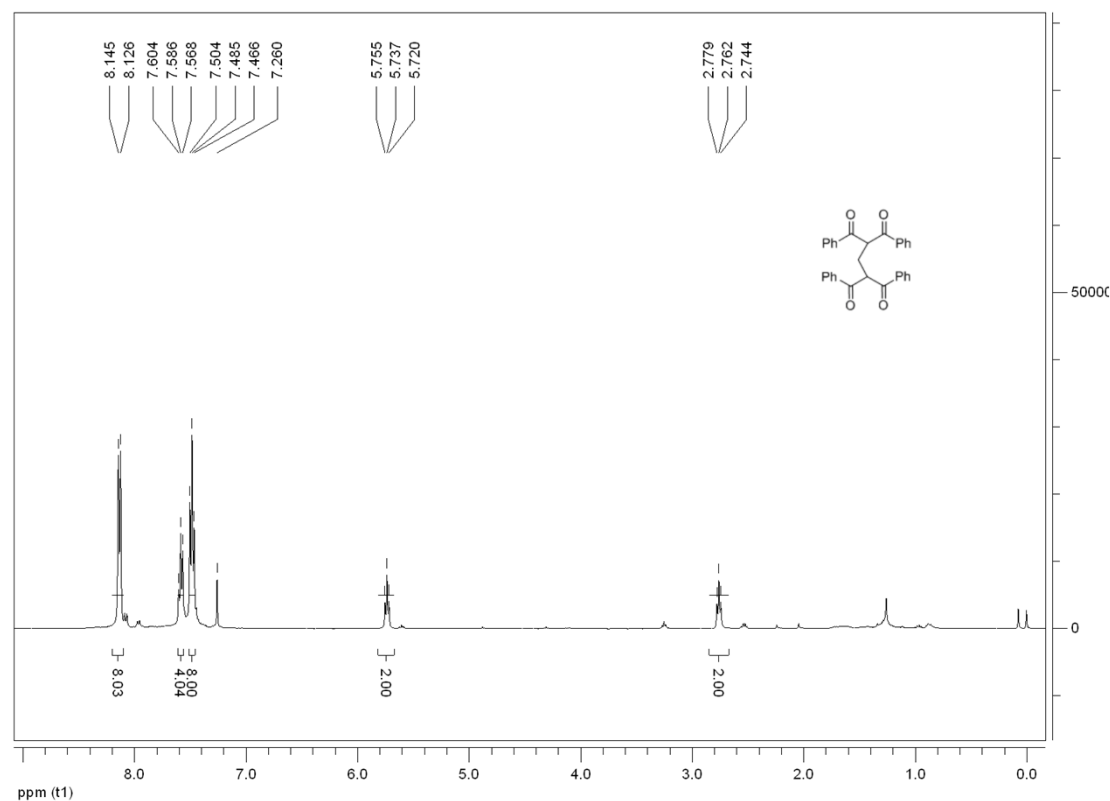


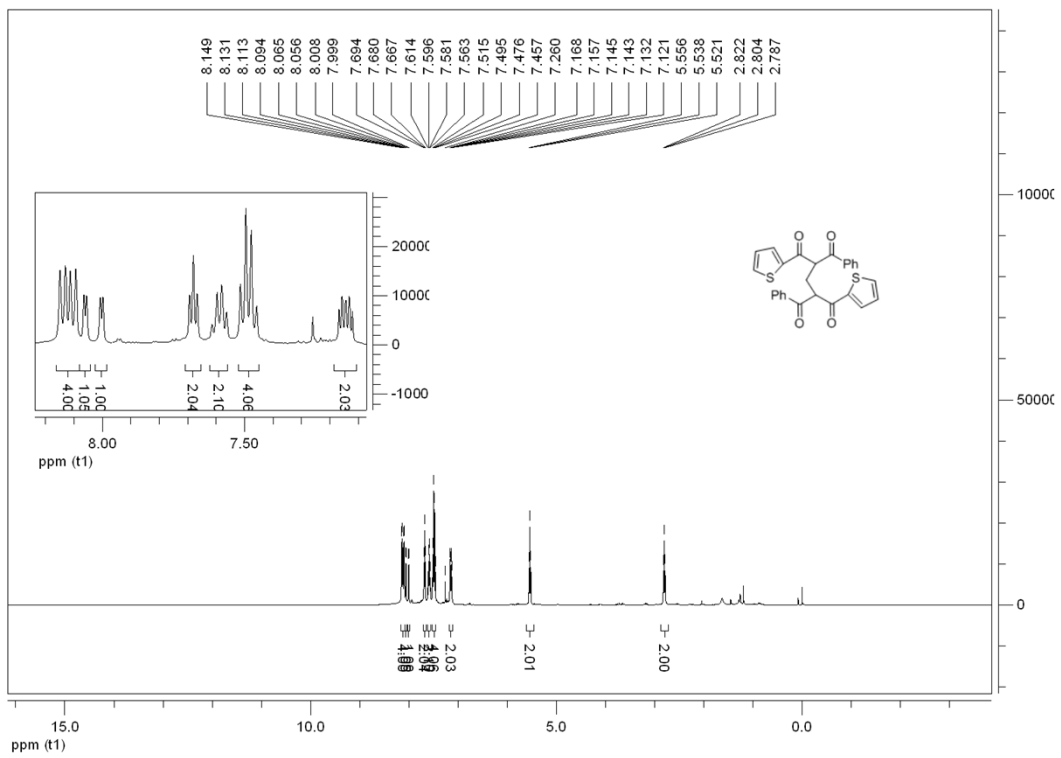
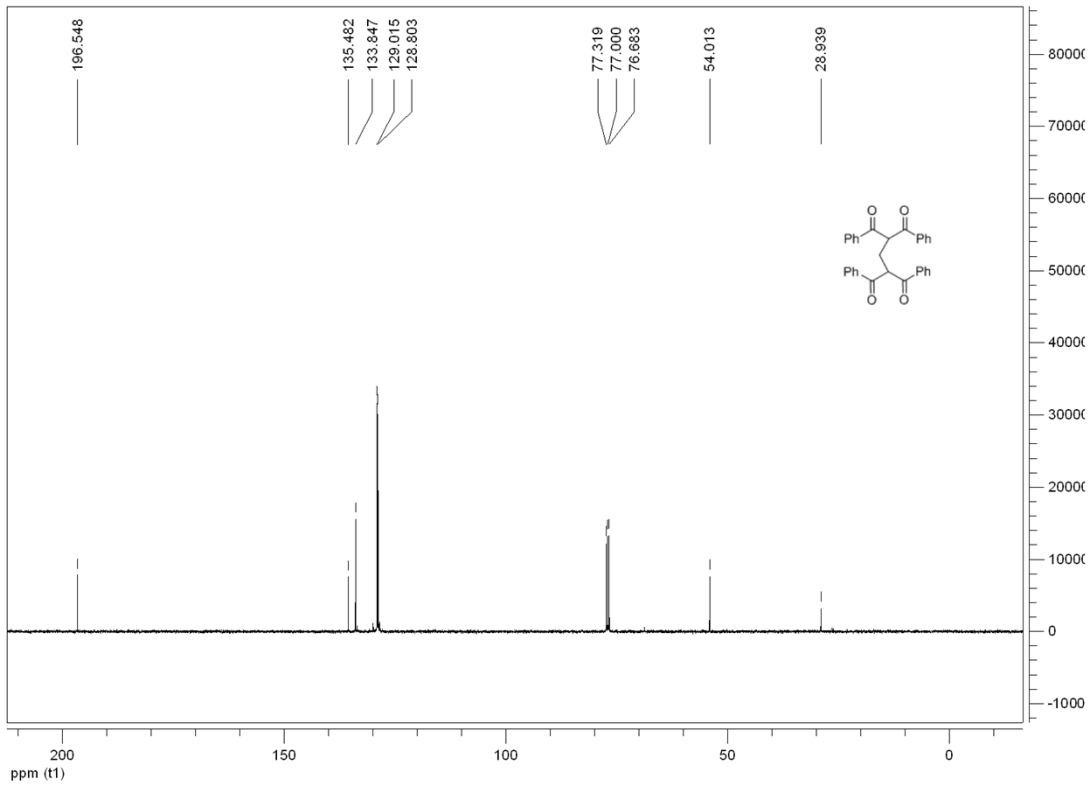
To a mixture of NaH (28 mmol), the corresponding ester (20 mmol) in dry THF (20 mL) was added the solution of acetophenone or substituted acetophenone (10 mmol) in THF (10 mL) dropwise over 0.5 h, the mixture was refluxed for 2-8 h. The reaction was detected by TLC. The reaction was quenched with dilute acetic acid aqueous solution, and extracted with ethyl acetate for three times. The combined organic phase was dried with anhydrous Na₂SO₄ over night, filtrated, and concentrated under reduced pressure. The residue was further purified with silica gel chromatography, eluted with ethyl acetate/petroleum ether (v/v1:30) to give 1, 3-dicarbonyl compounds.

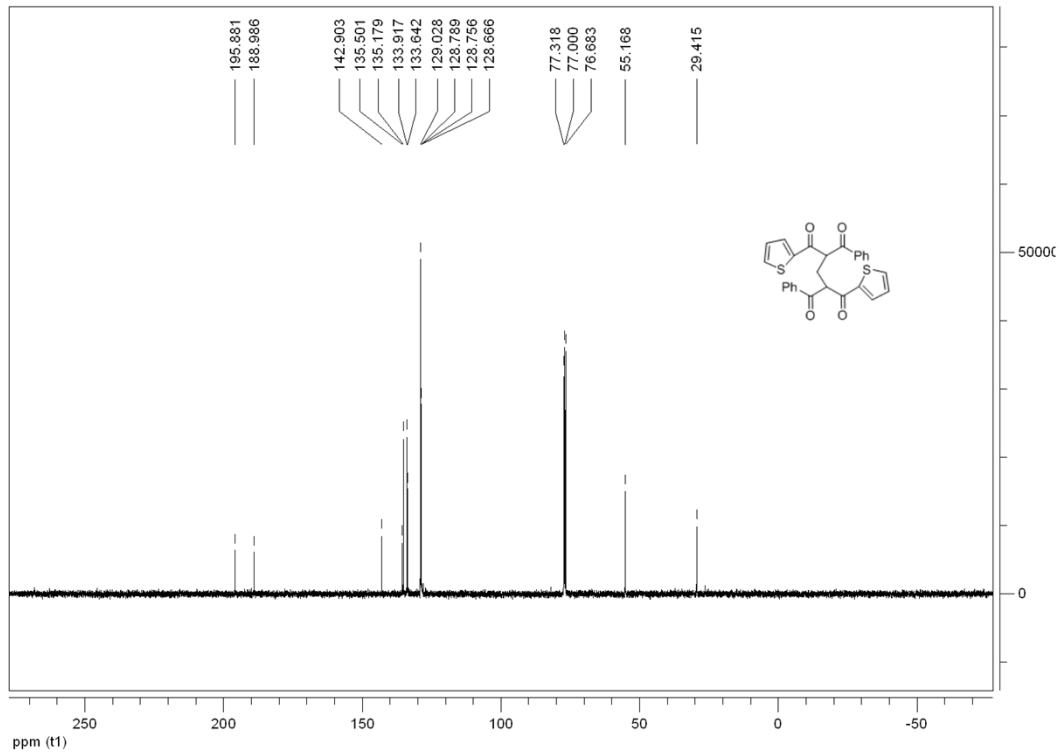
4. References:

- [1] Hwang, D.-R.; Uang, B.-J. *Org. Lett.* **2002**, *4*, 463.
 [2] Sartori, G.; Maggi, R.; Bigi, F.; Porta, C.; Tao, X.; Bernardi, G. L.; Ianelli S.; Nardelli, M. *Tetrahedron.* **1995**, *51*, 12179.
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5. Copies of ¹H NMR, ¹³C NMR and HRMS spectra for all compounds

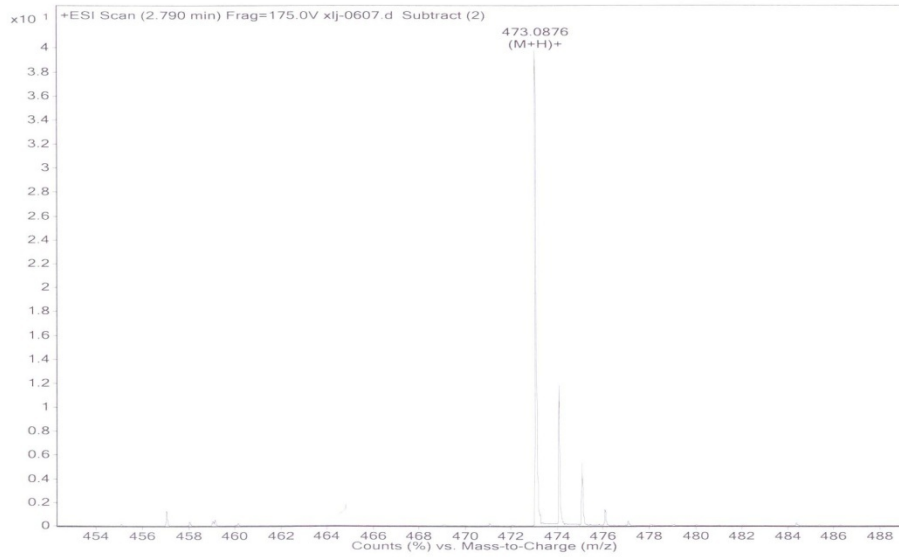


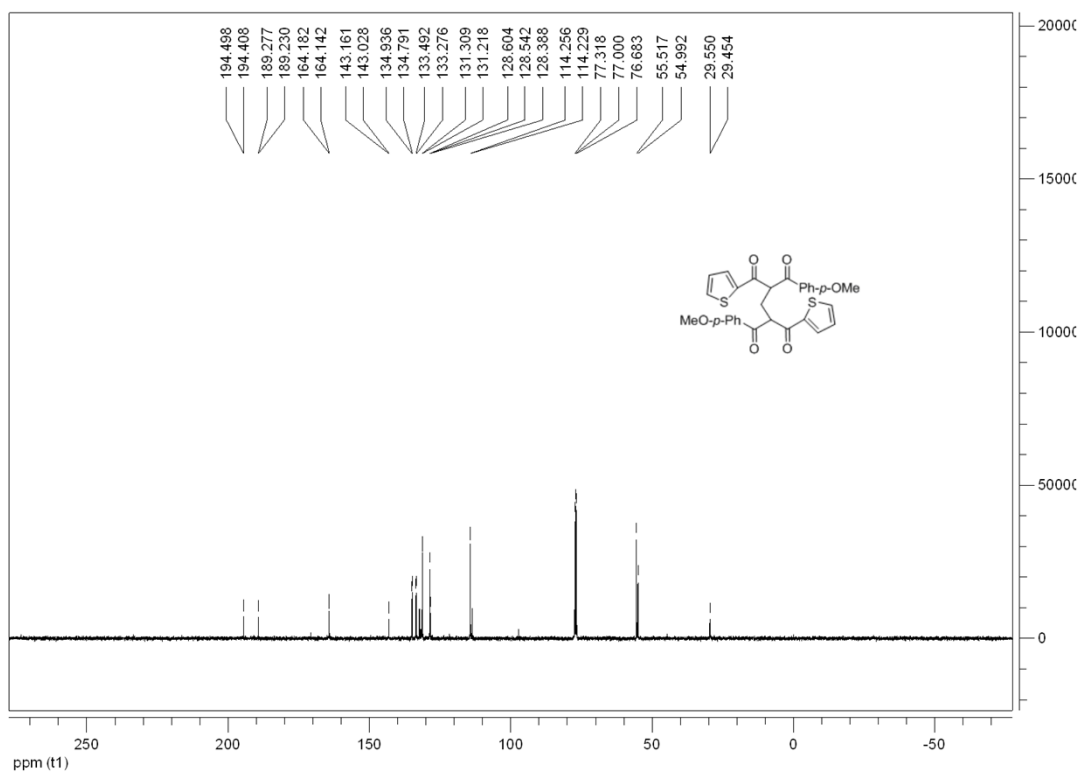
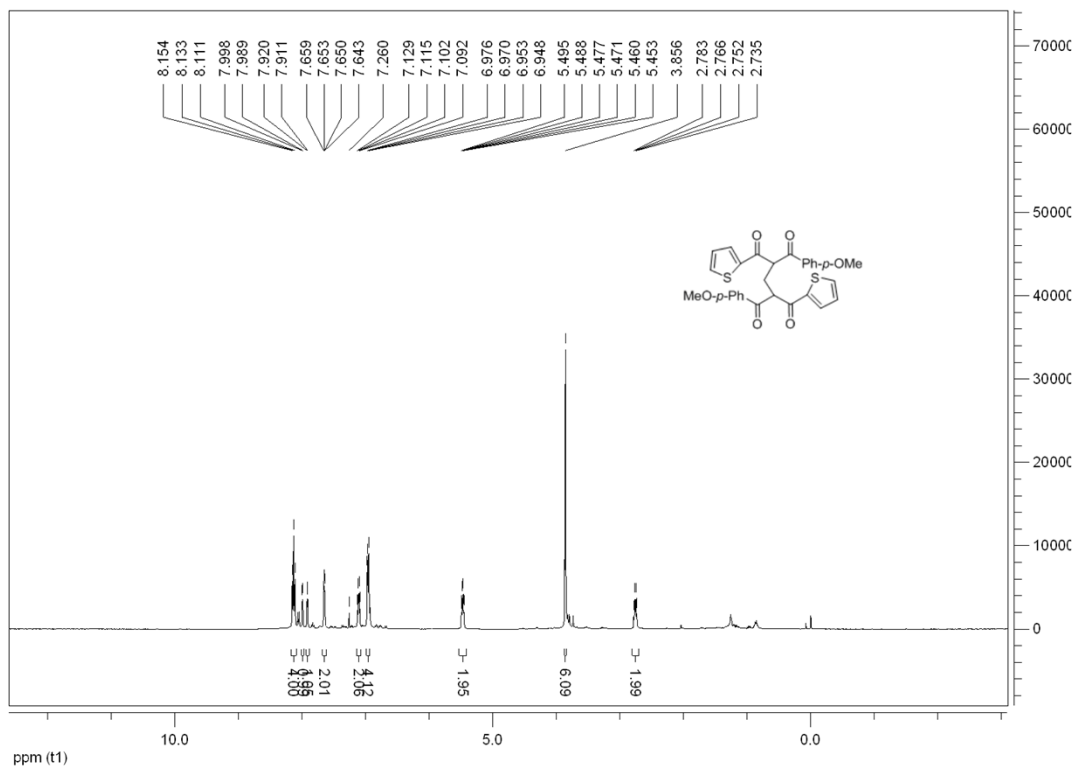




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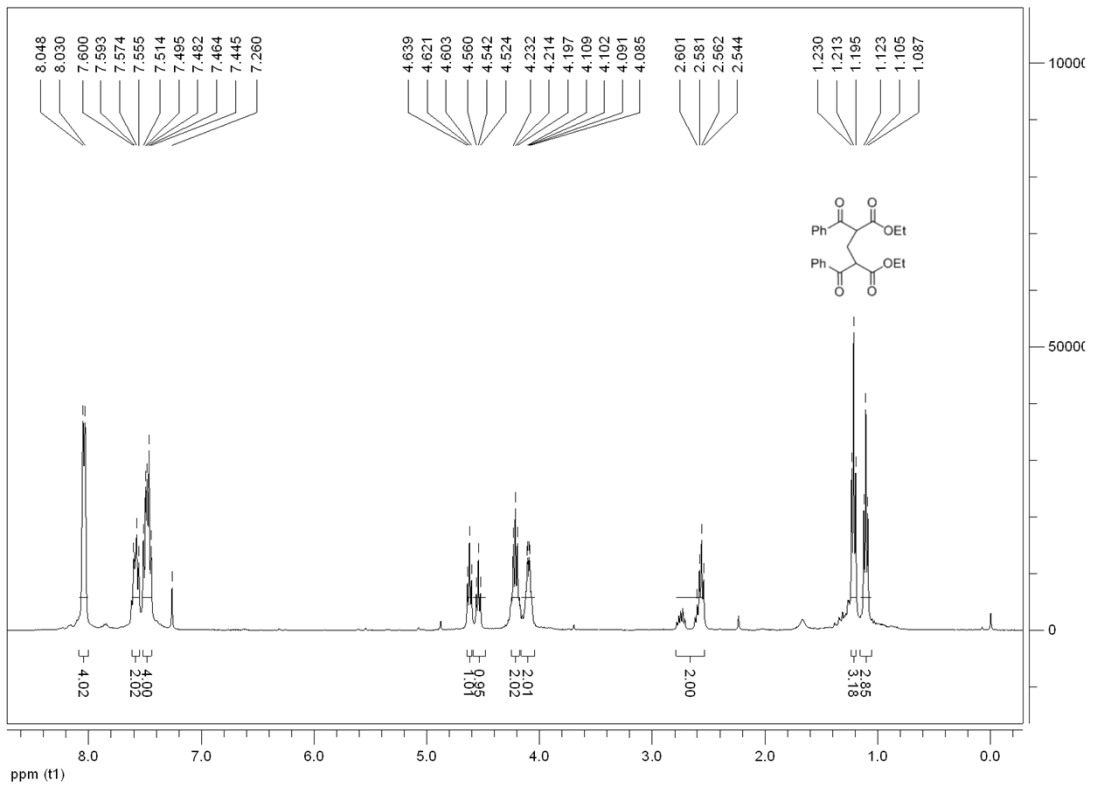
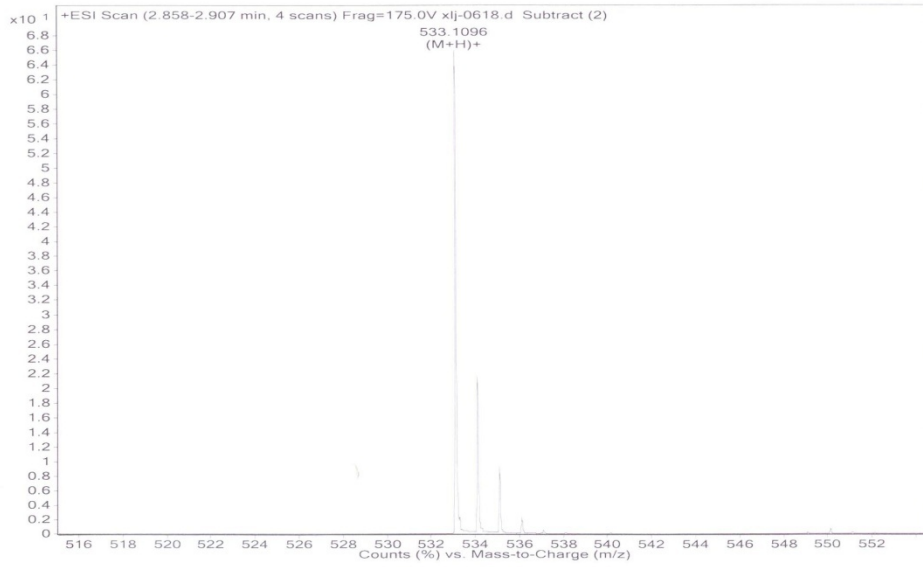
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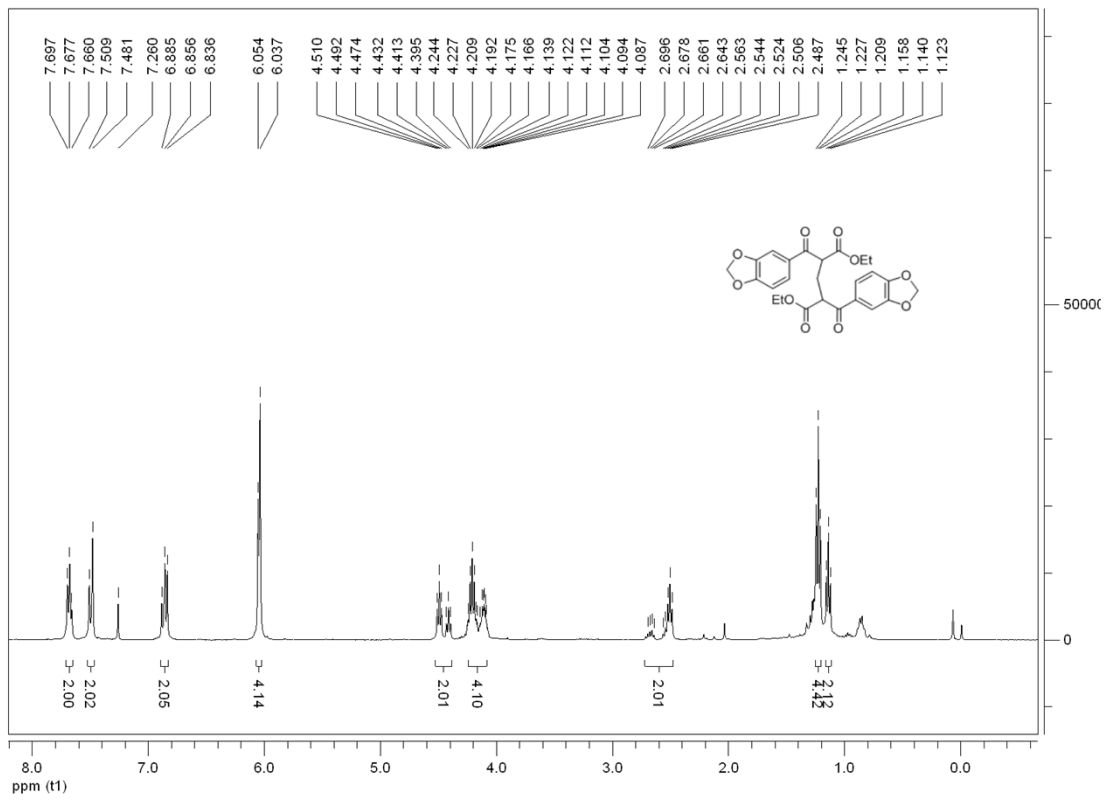
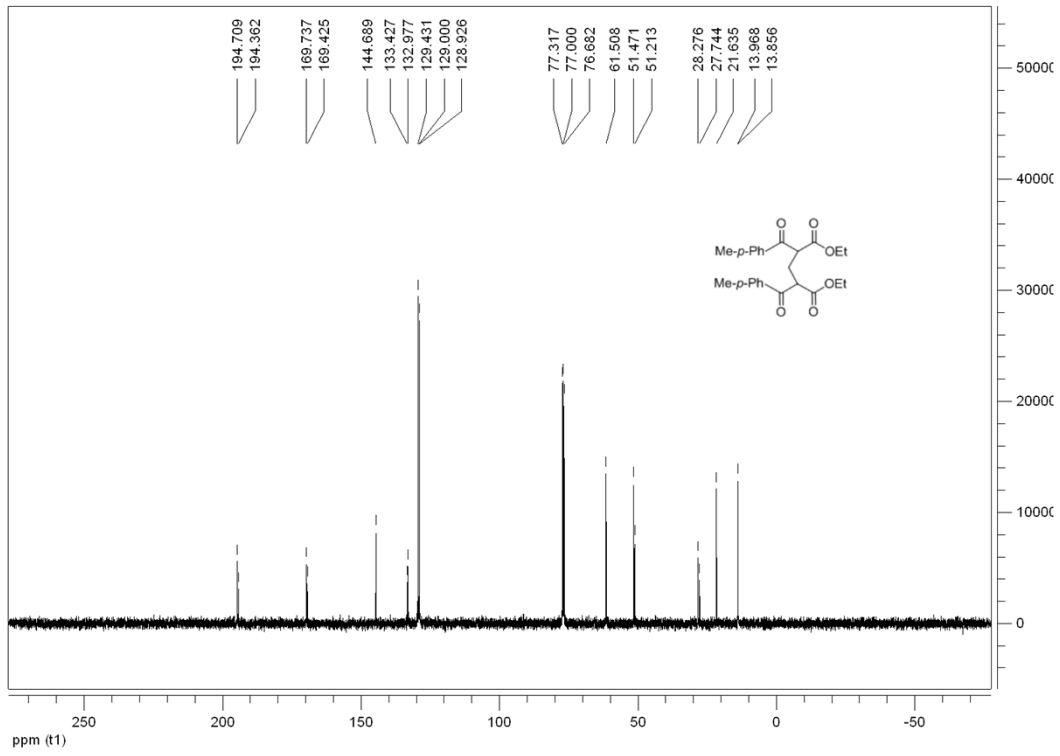


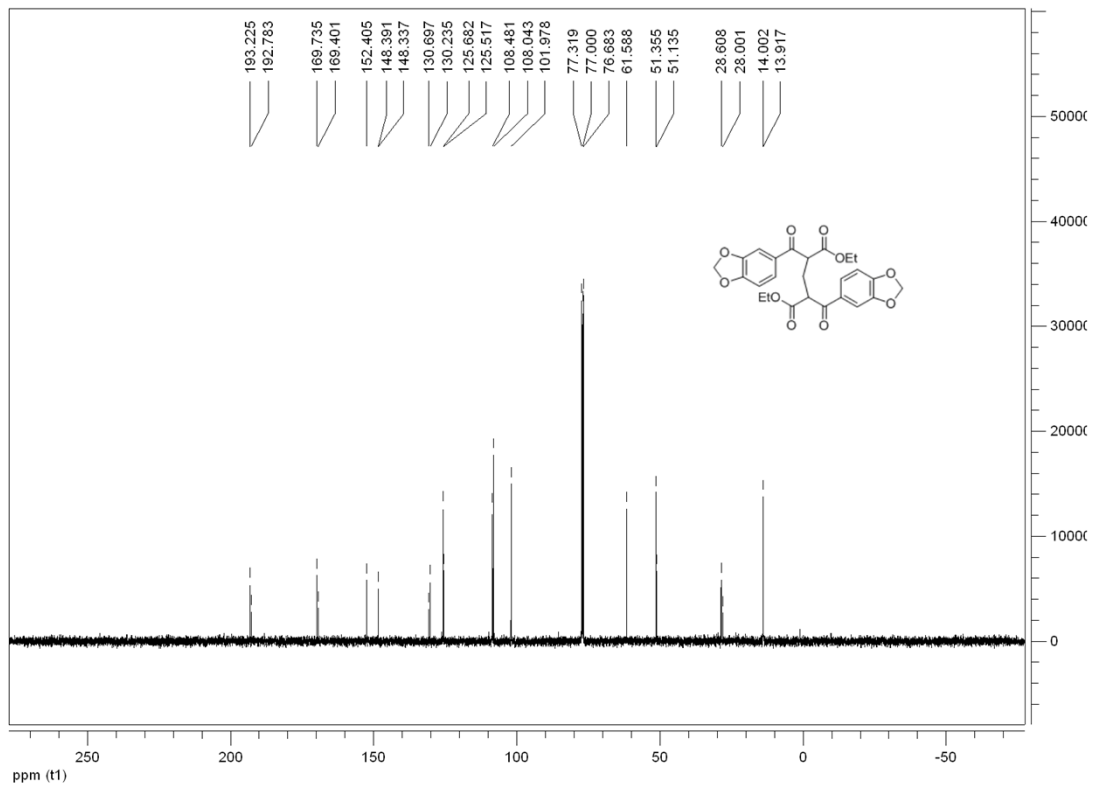


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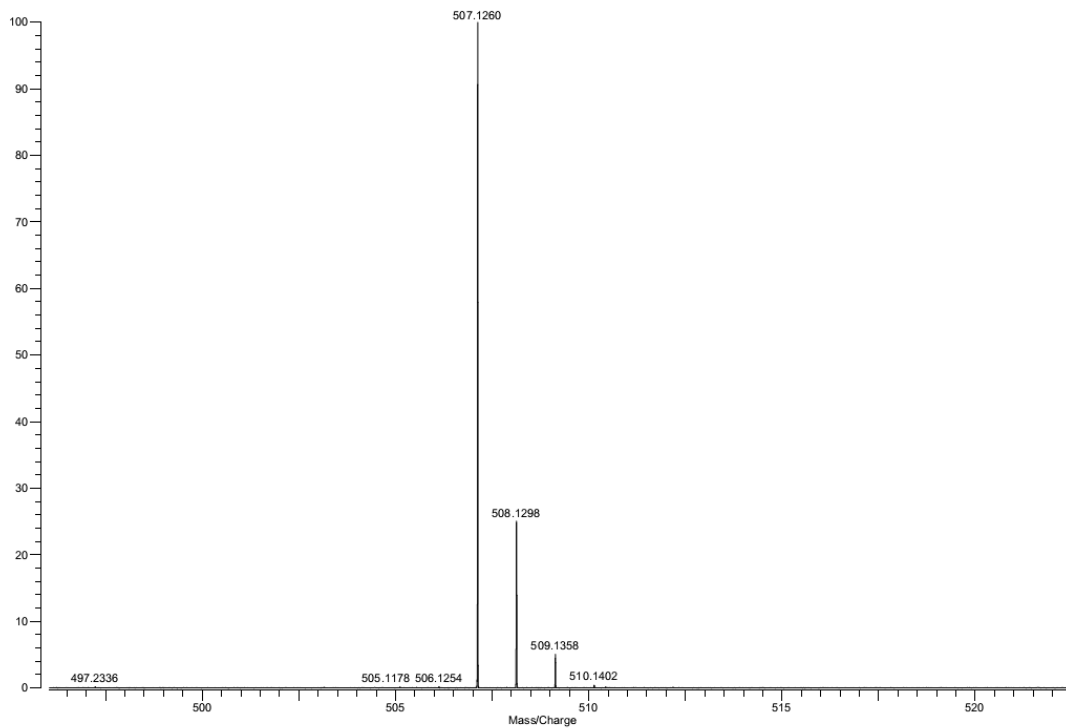


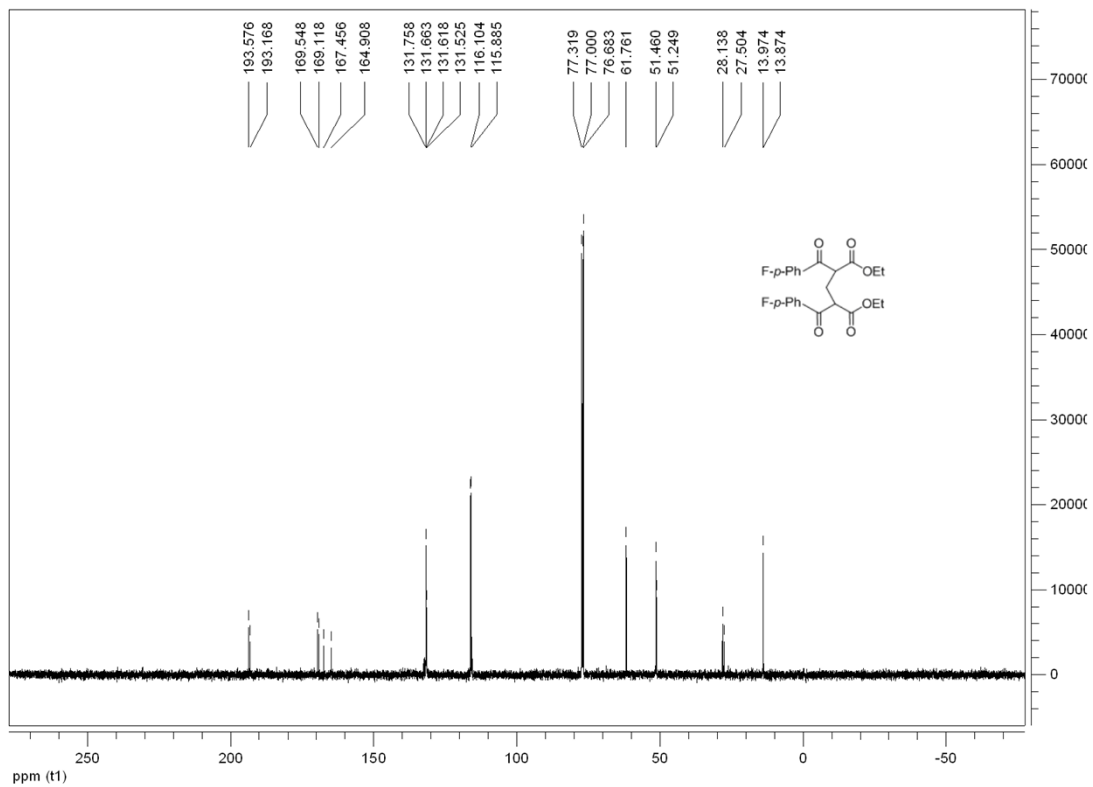
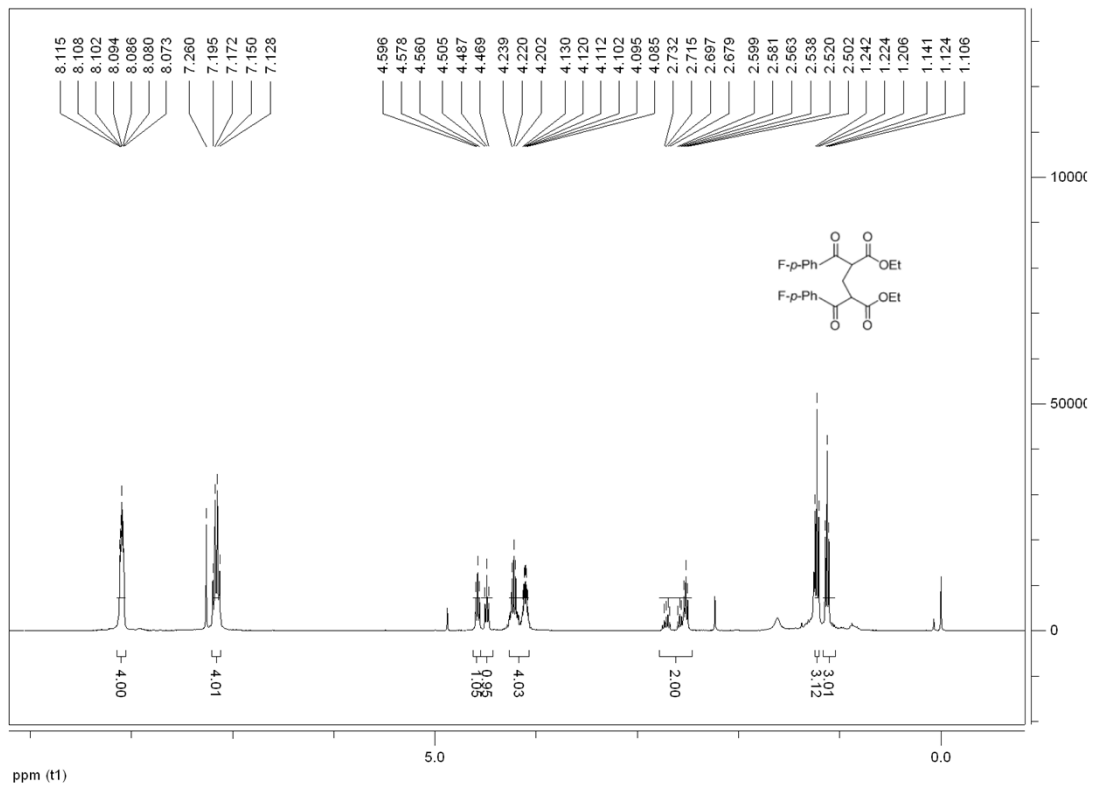


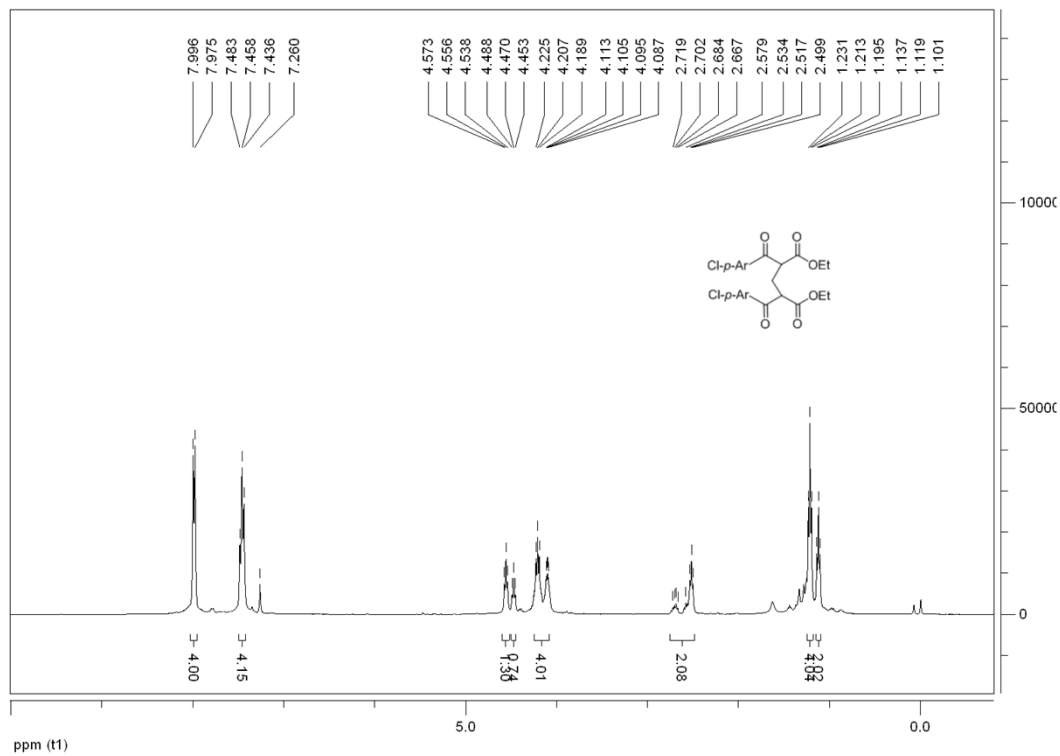
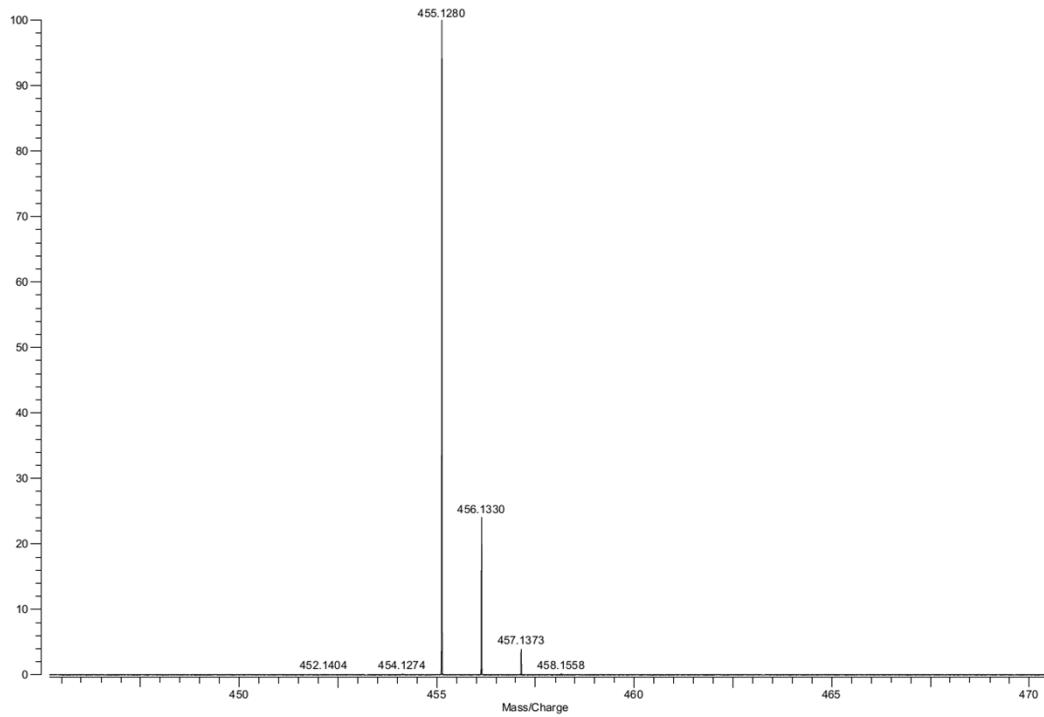
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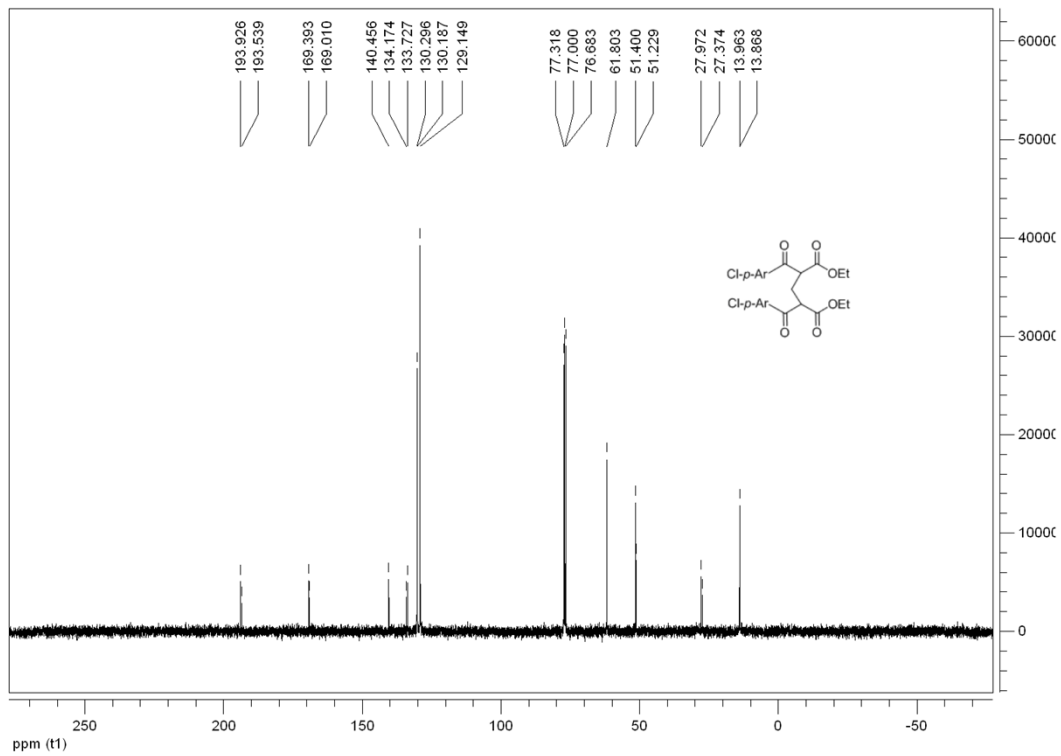
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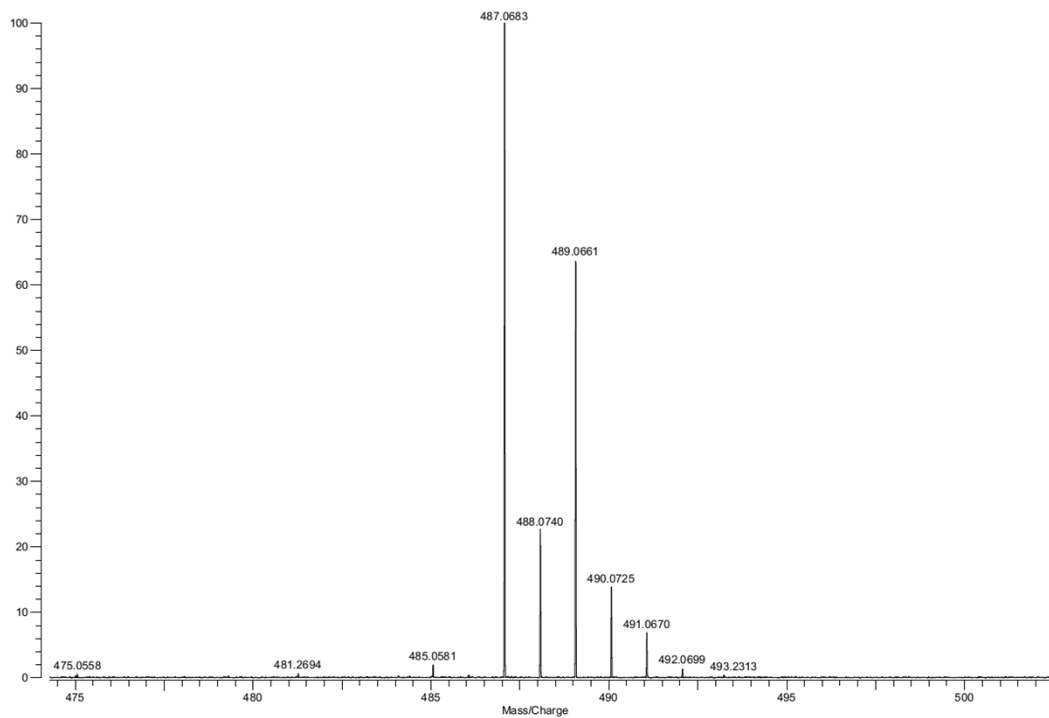


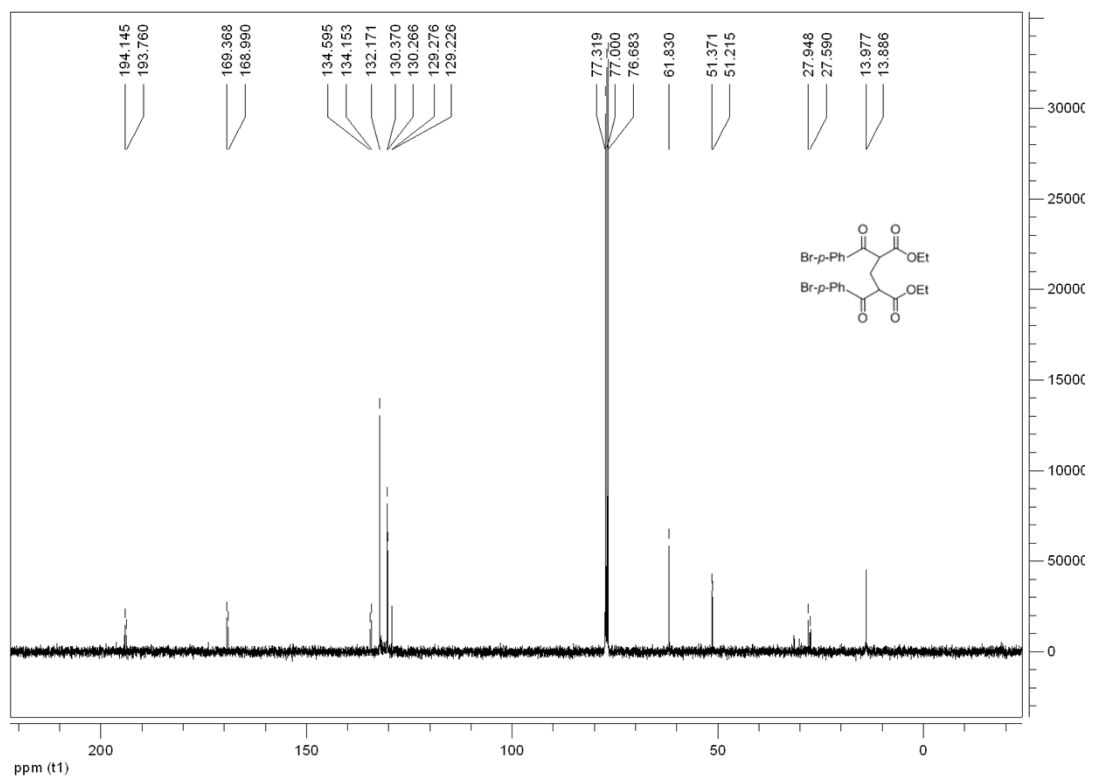
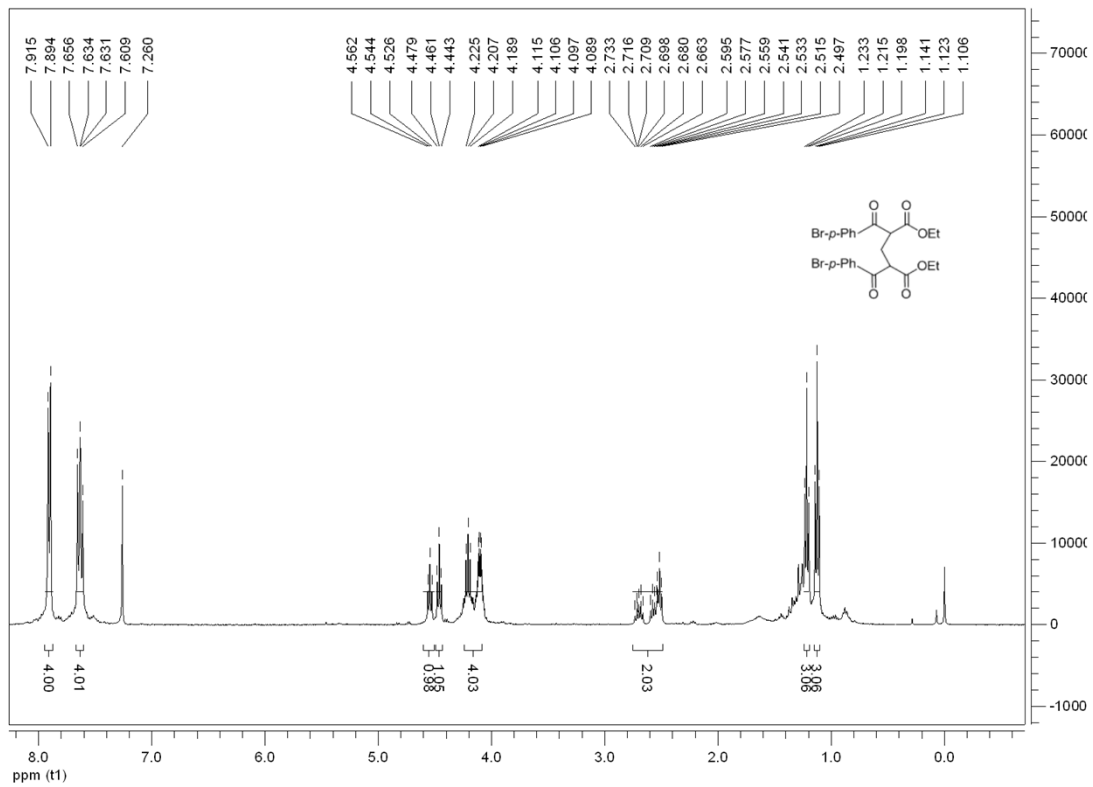


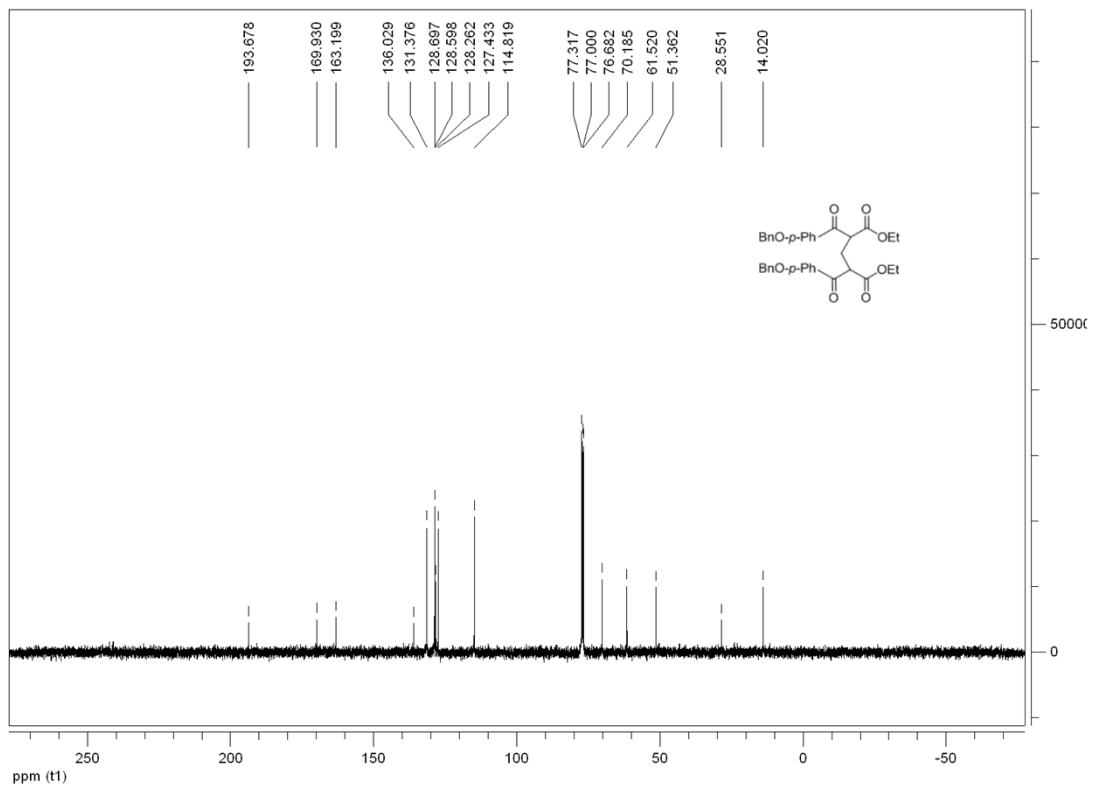
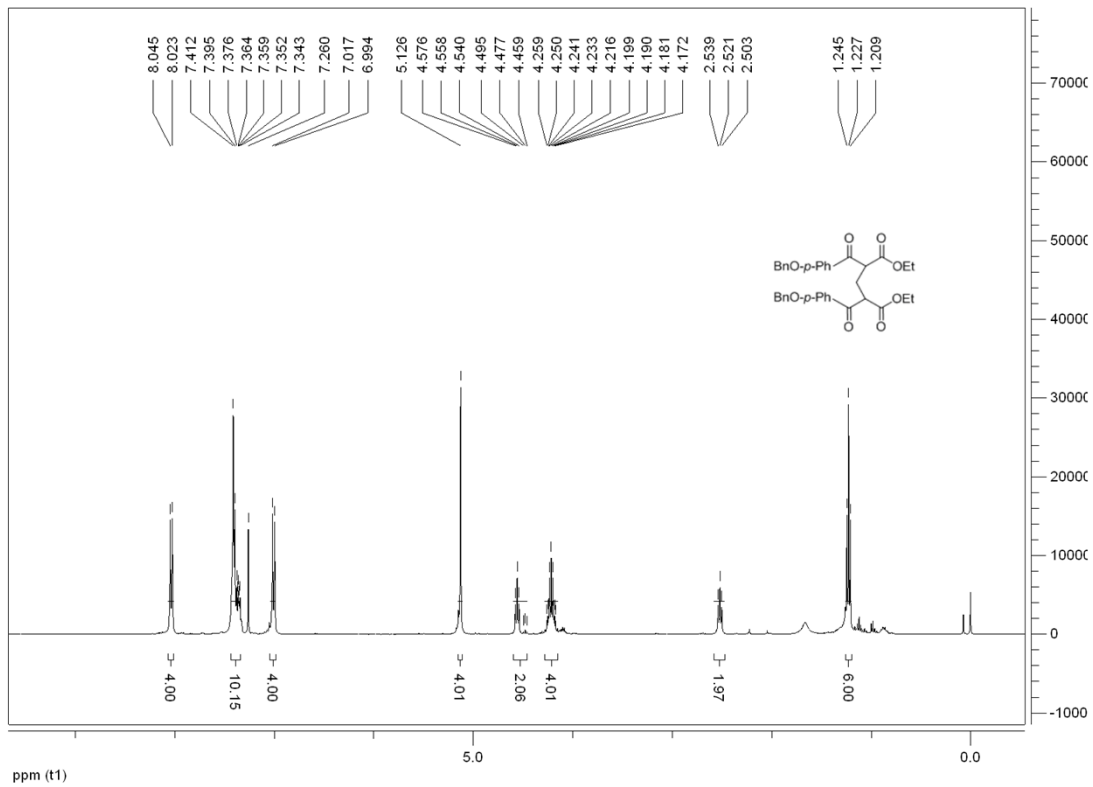


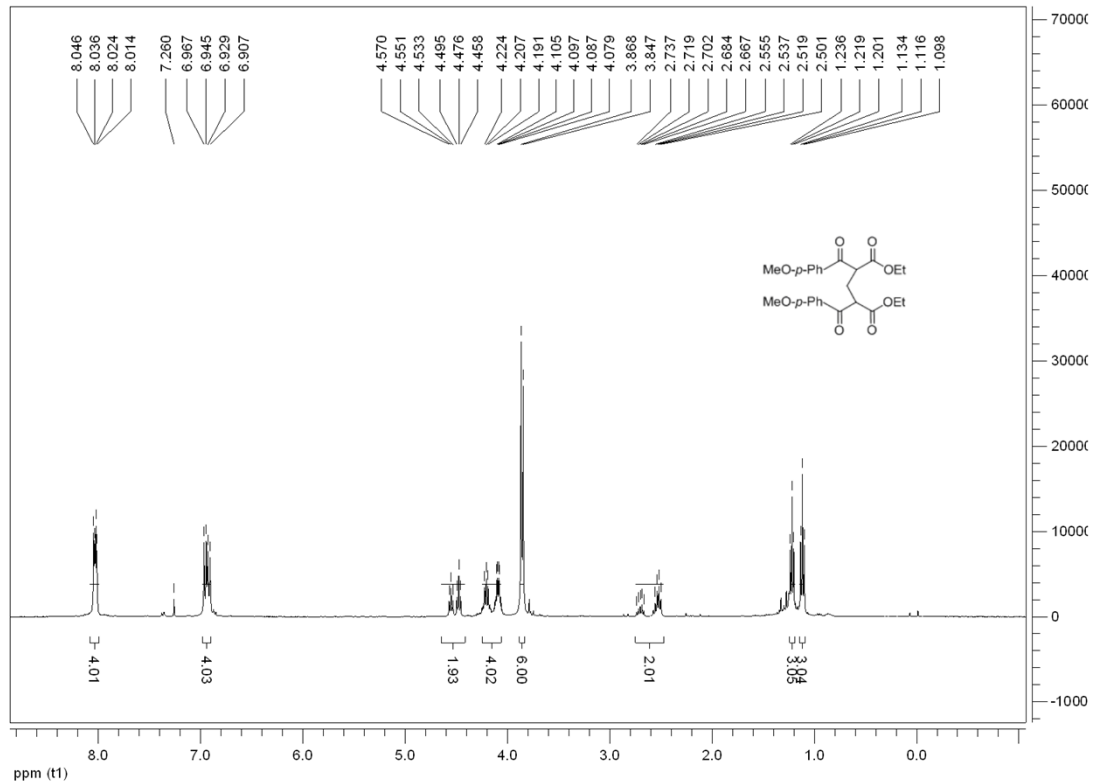
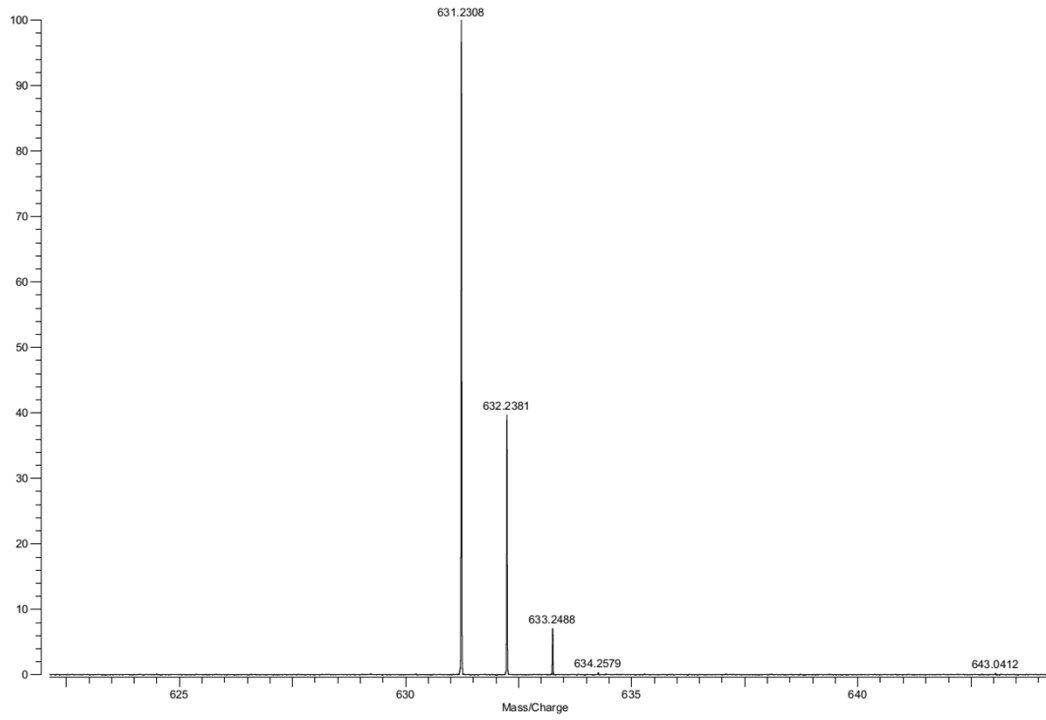
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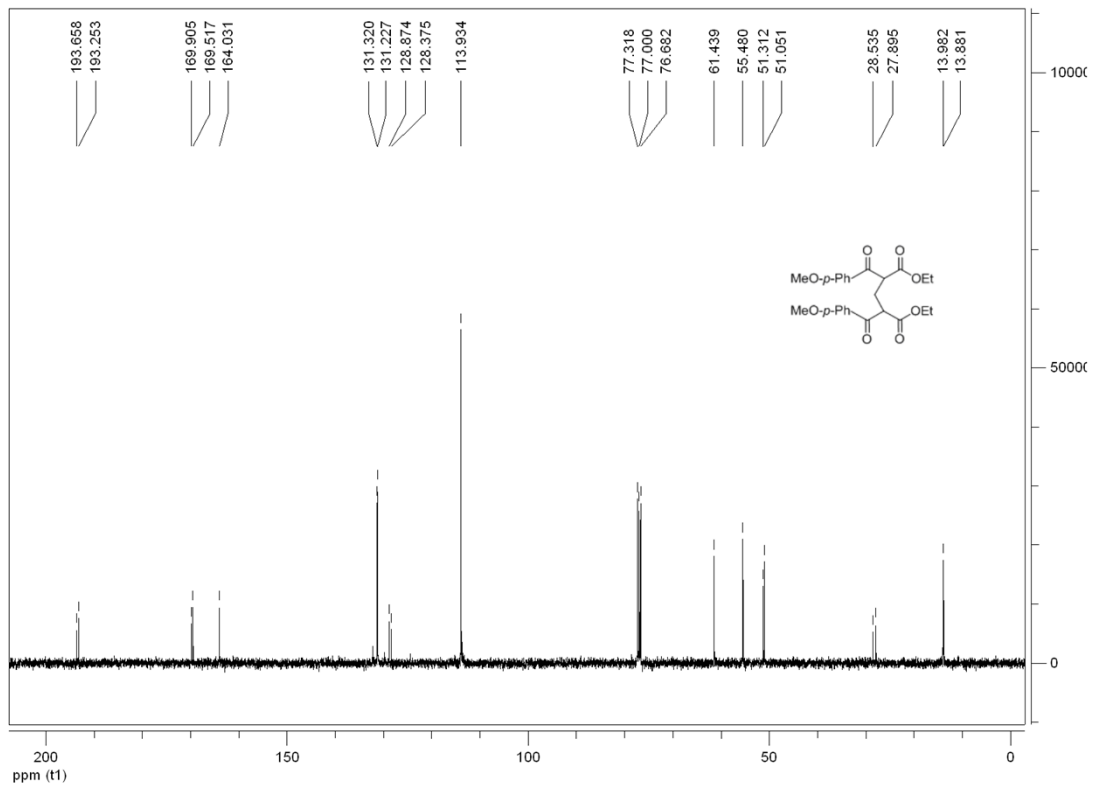
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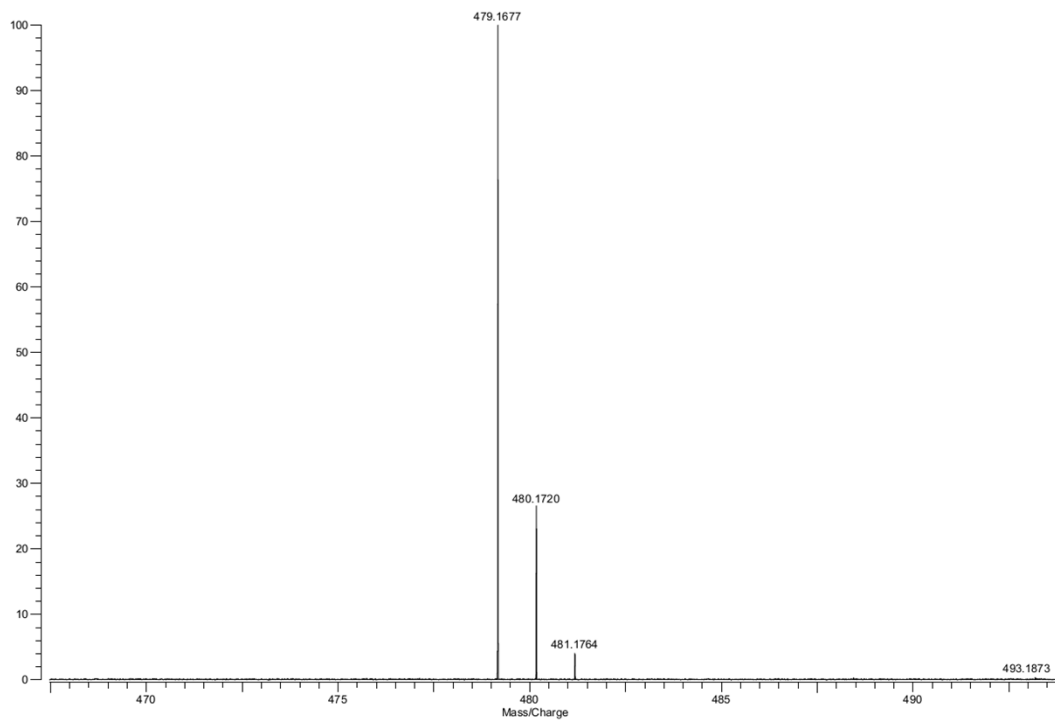


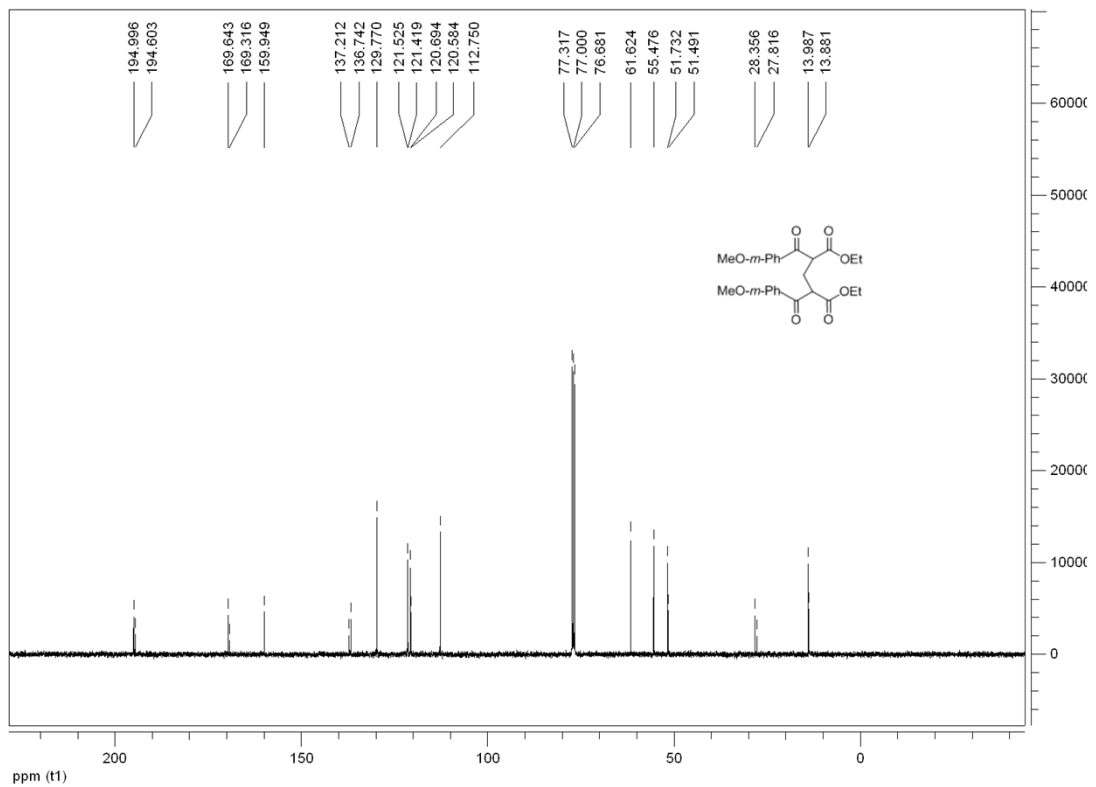
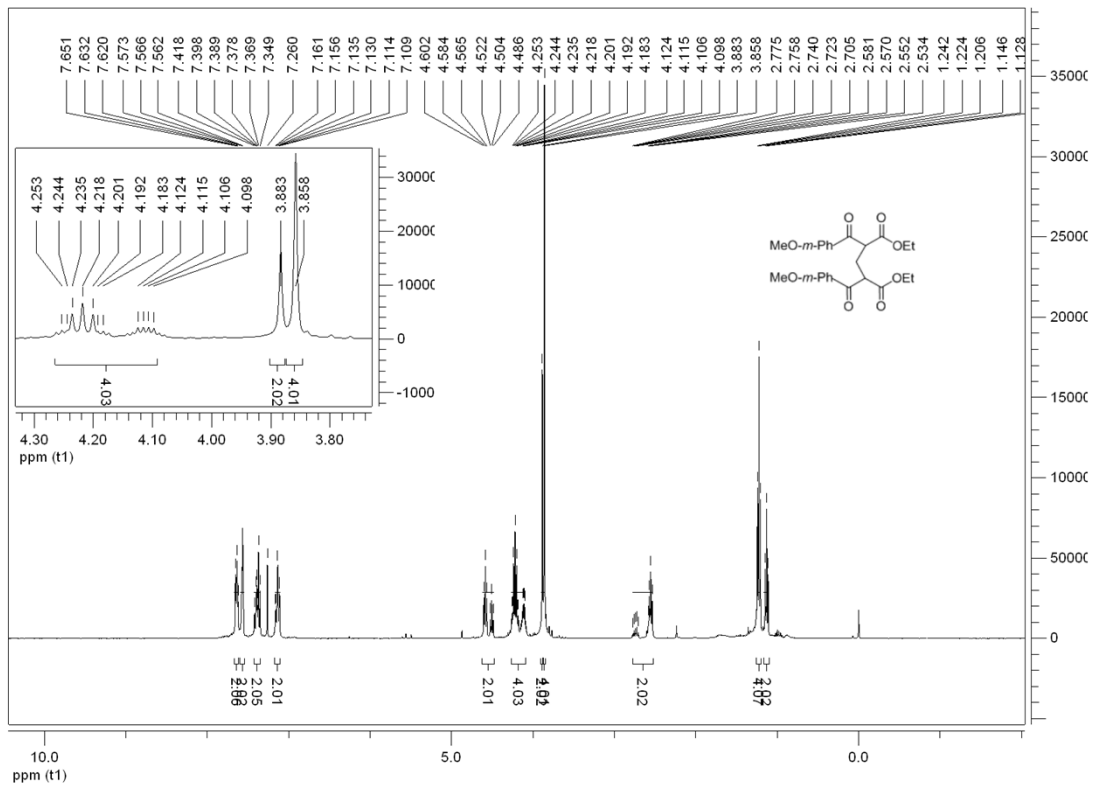


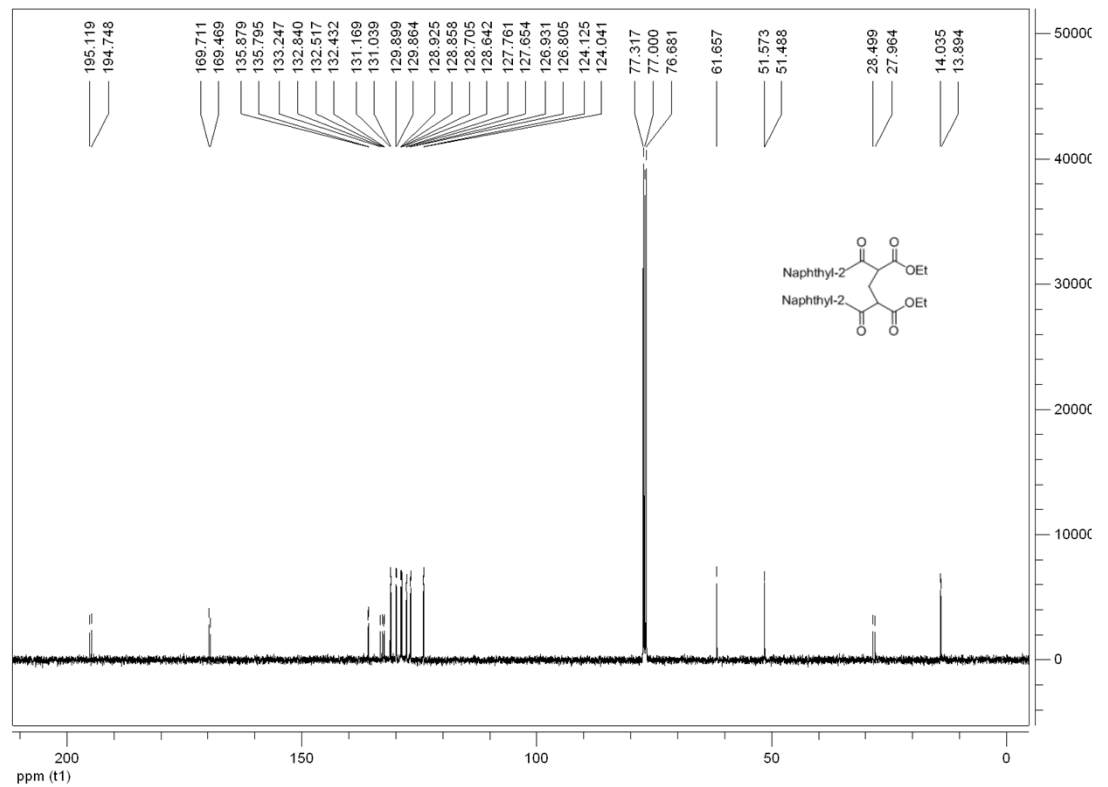
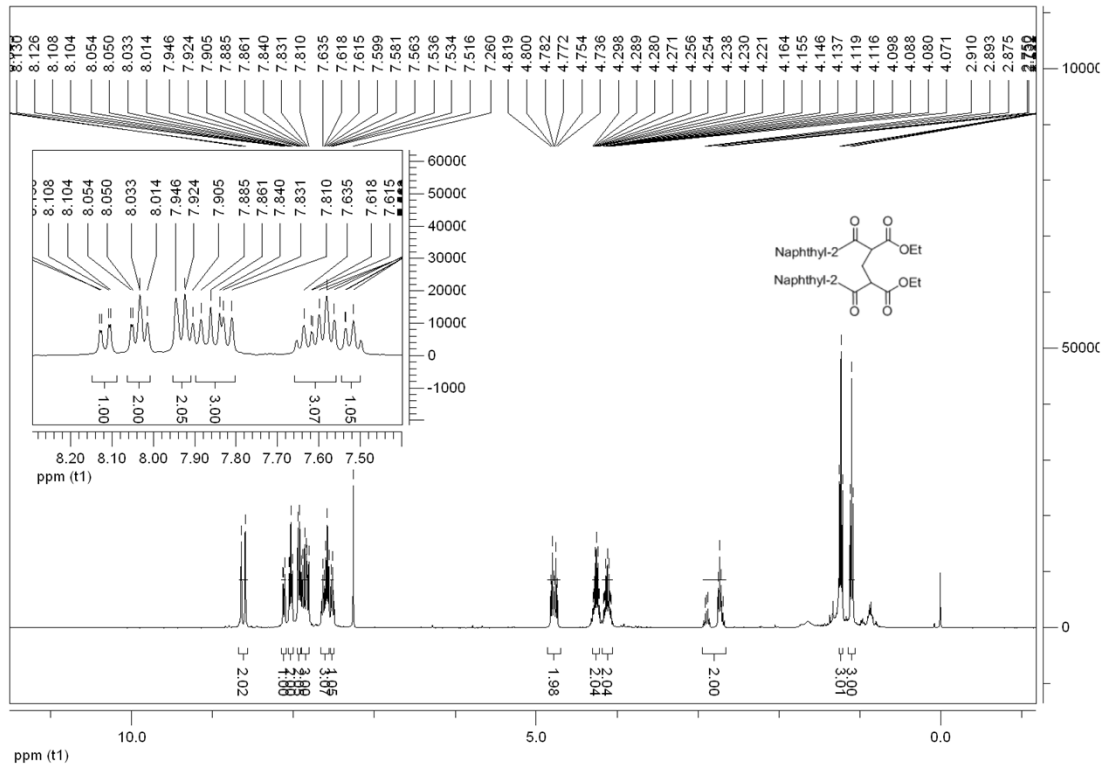


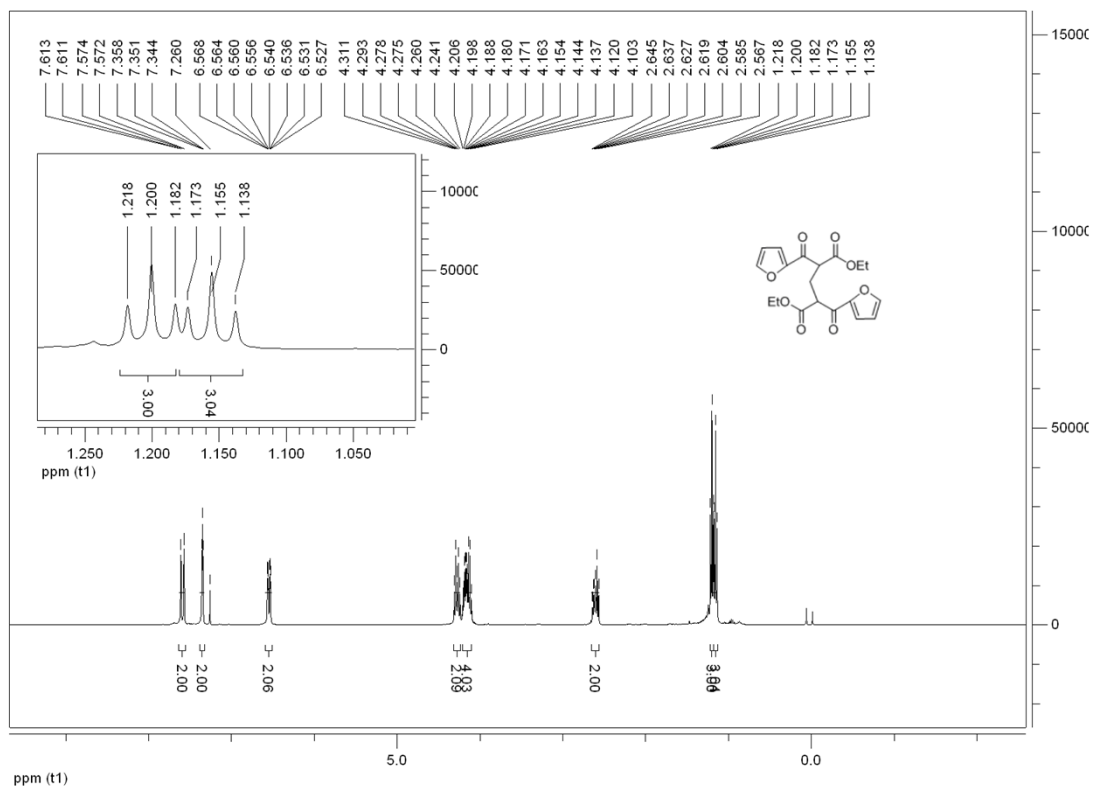
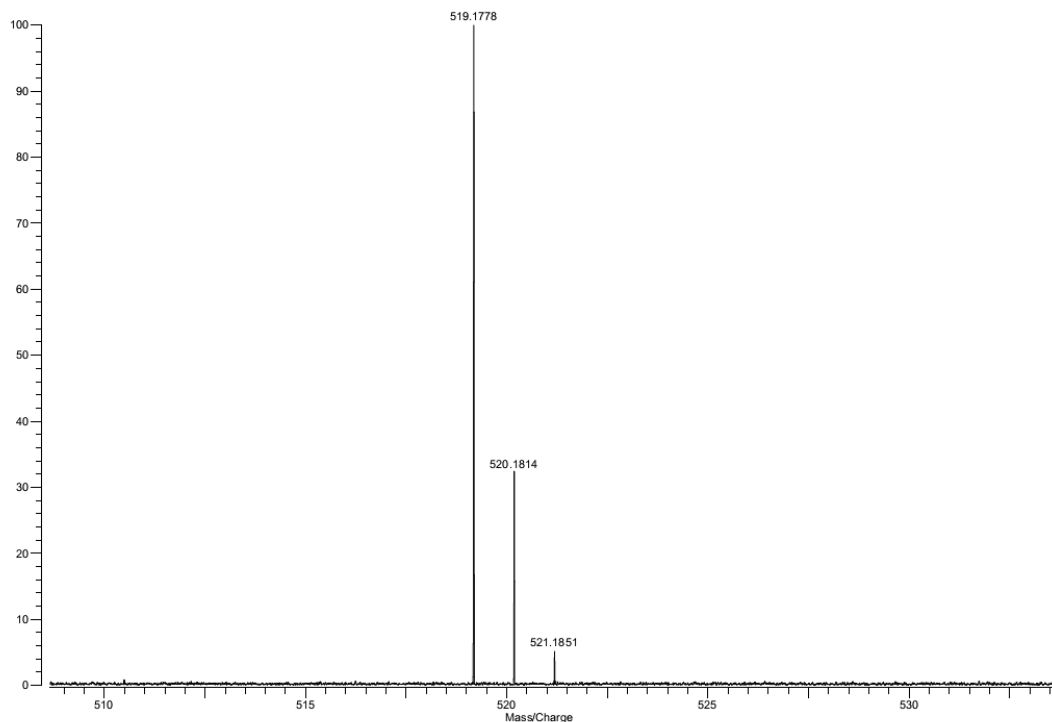
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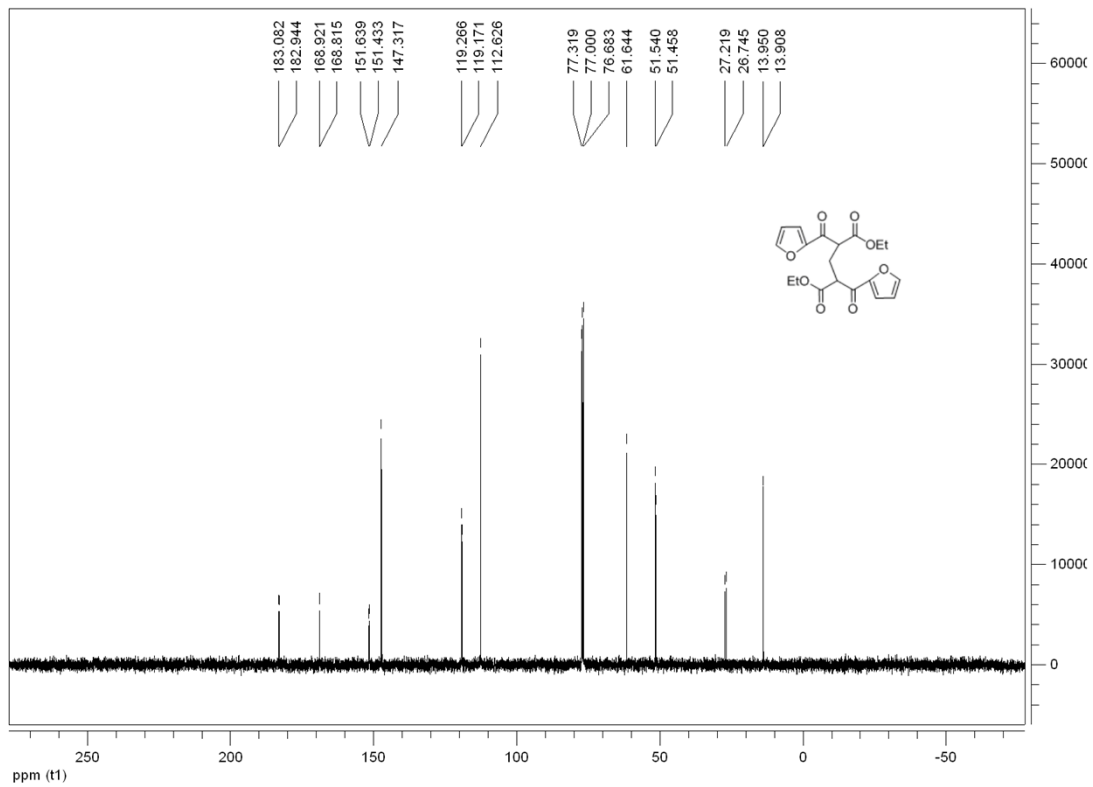
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