Ru^{II}-Catalyzed Vinylative Dearomatization of Naphthols via a C(sp^2)-H Bond Activation Approach

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Supporting Information

Table of Contents:

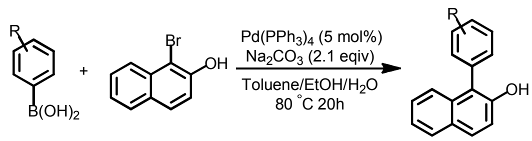
A. General information:

All reactions were carried out under an argon atmosphere using Standard Schlenk-Lines or a glovebox (Innovative Technology). All reagents were used as received unless otherwise noted. DCE, DME, THF and DMF were dried over CaH_2. Toluene, 1,4-dioxane and ^{t}AmOH were dried over sodium. Analytical thin-layer chromatography was performed with 0.25 mm coated commercial silica gel plates (TLC Silica Gel 60 F_{254}); visualization of the developed chromatogram was performed by fluorescence. Flash Chromatography was performed with silica gel (300-400 mesh). Proton nuclear magnetic resonance (^{1}H NMR) data were acquired on a Varian Unity Inova-400 (400 MHz) spectrometer. Chemical shifts are reported in delta (δ) units, in parts per million (ppm) downfield from tetramethylsilane. Splitting patterns are designated as s, singlet; d, doublet; t, triplet; m, multiplet, br, broad. Coupling constants *J* are quoted in Hz. Carbon-13 nuclear magnetic resonance (^{13}C NMR) data were acquired at 100 MHz on a Varian Unity Inova-400 spectrometer. Chemical shifts are reported in ppm relative to the center line of a triplet at 77.0 ppm for chloroform-*d*. Infrared (IR) data were recorded as films on potassium bromide plates on a Bruker Tensor 27 FT-IR spectrometer. Absorbance frequencies are reported in reciprocal centimeters (cm^{-1}). Mass spectra were acquired on a

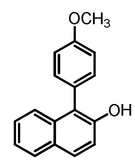
Bruker Daltonics MicroTof-Q II mass spectrometer. **1a**[1], **1b**[2], **1d**[3], **1k**[1], **2a-m**[4], **2g**[5] and **2h-i**[6] were prepared according to literature methods.

B. Preparation of substrates:

The following 1-aryl-2-naphthol substrates were prepared by Suzuki-Miyaura coupling reactions between 1-bromonaphthalen-2-ol and corresponding phenylboronic acid (see below equation).[7]

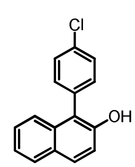


A 50 mL round bottom flask with a stir bar was fitted with a rubber septum and flame dried under high vacuum. The flask was purged with argon and charged with $Pd(PPh_3)_4$ (115.6 mg, 0.1 mmol), Na_2CO_3 (445.2 mg, 4.2 mmol), 1-bromonaphthalen-2-ol (446.1 mg, 2.0 mmol), aryboronic acid (4.0 mmol), 10.0 mL toluene, 2.0 mL ethanol, and 2.2 mL deoxygenated water. The reaction mixture was then heated at 80 ℃ for 20 h. After the reaction was cooled down to room temperature, the organic layer was separated and the aqueous layer was extracted with ethyl acetate (10 mL×3), and the combined organic layer was dried over $MgSO_4$ and concentrated. The crude products were purified by flash chromatography on silica gel to afford desired 1-aryl-2-naphthols.



1-(4-Methoxyphenyl)naphthalen-2-ol (1c)

White solid (0.33 g, 67% yield). PE/EA = 10:1, R_f = 0.33. Mp: 114-115 ºC. ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.81 (t, *J* = 7.3 Hz, 2H), 7.41-7.39 (m, 1H), 7.36-7.34 (m, 3H), 7.27 (d, *J* = 9.0 Hz, 2H), 7.12 (d, *J* = 8.5 Hz, 2H), 5.21 (s, 1H), 3.81 (s, 3H). ^{13}C NMR (100 MHz, $CDCl_3$): δ 159.9, 150.6, 133.9, 132.6, 129.6, 129.1, 128.3, 126.6, 126.0, 124.9, 123.5, 120.9, 117.5, 115.3, 55.6. IR: 3473, 3057, 2934, 1618, 1510, 1464, 1245, 825. HRMS (ESI) m/z calculated for $C_{17}H_{14}O_2Na$ $[M+Na]^+$ 273.0892, found 273.0895.



1-(4-Chlorophenyl)naphthalen-2-ol (1e)

White solid (0.42 g, 83% yield). PE/EA = 10:1, R_f = 0.57. Mp: 75-76 ºC. ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.84 (d, *J* = 8.3 Hz, 2H), 7.55-7.47 (m, 3H), 7.43-7.30 (m, 4H), 7.27 (d, *J* = 9.0 Hz, 1H),

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[3] Rasmussen, L. K.; Begtrup, M.; Ruhland, T. *J. Org. Chem*. **2004**, 69, 6890.
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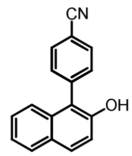
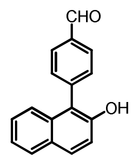
[7] Makino, T.; Yamasaki, R.; Saito, S. *Synthesis* **2008**, *6*, 859.

5,14 (s, 1H). ^{13}C NMR (100 MHz, $CDCl_3$): δ 150.4, 134.8, 133.5, 133.0, 132.92, 130.2, 130.1, 129.2, 128.4, 127.0, 124.7, 123.8, 120.1, 117.7. IR: 3636, 3060, 1596, 1512, 1268, 817, 747. HRMS (ESI) m/z calculated for $C_{16}H_{11}ClONa$ $[M+Na]^+$ 277.0396, found 277.0394.



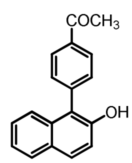
4-(2-Hydroxynaphthalen-1-yl)benzonitrile (1f)

White solid (0.34 g, 69% yield). PE/EA = 10:1, R_f = 0.28. Mp: 177-178 ºC. ^1H NMR (400 MHz, $CDCl_3$): δ 7.90-7.82 (m, 4H), 7.59 (d, *J* =8.0 Hz, 2H), 7.39 (t, *J* =8.0 Hz, 2H), 7.34 (s, 1H), 7.25 (d, *J* = 8.2 Hz, 1H), 5.26 (s, 1H). ^{13}C NMR (100 MHz, $CDCl_3$): δ 150.3, 140.6, 133.2, 132.9, 132.5, 130.7, 129.2, 128.5, 127.3, 124.2, 124.0, 119.7, 118.9, 117.9, 112.2. IR: 3384, 3055, 2241, 1604, 1510, 847. HRMS (ESI) m/z calculated for $C_{17}H_{11}NONa$ $[M+Na]^+$ 268.0739, found 268.0745.



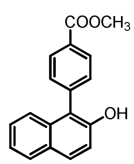
4-(2-Hydroxynaphthalen-1-yl)benzaldehyde (1g)

Yellow solid (0.36 g, 73% yield). PE/EA = 10:1, R_f = 0.27. Mp: 205-206 ºC. ^1H NMR (400 MHz, $CDCl_3$): δ 10.12 (s, 1H), 8.09 (d, *J* = 7.6 Hz, 2H), 7.84 (d, *J* = 8.2 Hz, 2H), 7.64 (d, *J* = 7.6 Hz, 2H), 7.36 (s, 3H), 7.26 (d, *J* = 6.4 Hz, 1H), 5.11 (s, 1H). ^{13}C NMR (100 MHz, DMSO): δ 198.3, 157.2, 148.7, 140.2, 138.3, 137.3, 134.9, 134.8, 133.5, 133.3, 132.0, 129.0, 128.1, 125.3, 123.7. IR: 3264, 3048, 1682, 1603, 1504, 816. HRMS (ESI) m/z calculated for $C_{17}H_{12}O_2Na$ $[M+Na]^+$ 271.0735, found 271.0728.



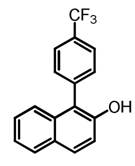
1-(4-(2-Hydroxynaphthalen-1-yl)phenyl)ethanone (1h)

White solid (0.31 g, 59% yield). PE/EA = 10:1, R_f = 0.22. Mp: 204-205 ºC. ^1H NMR (400 MHz, $CDCl_3$): δ 8.16 (d, *J* = 8.0 Hz, 2H), 7.83 (d, *J* = 8.5 Hz, 2H), 7.56 (d, *J* = 8.0 Hz, 2H), 7.36 (s, 3H), 7.26 (d, *J* = 6.2 Hz, 1H), 5.14 (s, 1H), 2.70 (s, 3H). ^{13}C NMR (100 MHz, DMSO): δ 203.1, 157.2, 147.2, 140.8, 138.4, 136.8, 134.7, 133.5, 133.3, 131.9, 129.0, 128.1, 125.4, 123.7, 32.2. IR: 3358, 3059, 2952, 1667, 1600, 1510, 1462, 821. HRMS (ESI) m/z calculated for $C_{18}H_{14}O_2Na$ $[M+Na]^+$ 285.0892, found 285.0892.



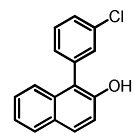
Methyl 4-(2-hydroxynaphthalen-1-yl)benzoate (1i)

White solid (0.36 g, 64% yield). PE/EA = 10:1, R_f = 0.25. Mp: 150-151 ºC. ^1H NMR (400 MHz, $CDCl_3$): δ 8.23 (d, *J* = 7.8 Hz, 2H), 7.83 (d, *J* = 8.3 Hz, 2H), 7.53 (d, *J* = 7.7 Hz, 2H), 7.36 (s, 3H), 7.27 (d, J = 8.9 Hz, 1H), 5.28 (s, 1H), 3.93 (s, 3H). ^{13}C NMR (100 MHz, $CDCl_3$): δ 167.0, 150.3, 139.9, 133.1, 131.7, 131.6, 130.9, 130.2, 129.1, 128.4, 127.0, 124.5, 123.6, 120.3, 117.8, 77.6, 77.3, 77.0, 52.6. IR: 3438, 3061, 2948, 1706, 1611, 1506, 1434, 821. HRMS (ESI) m/z calculated for $C_{18}H_{14}O_3Na$ $[M+Na]^+$ 301.3841, found 301.3845.



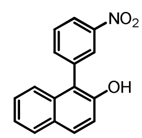
1-(4-(Trifluoromethyl)phenyl)naphthalen-2-ol (1j)

White solid (0.41 g, 71% yield). PE/EA = 10:1, R_f = 0.30. Mp: 100-101 ºC. ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.85-7.78 (m, 4H), 7.58 (d, J = 7.4 Hz, 2H), 7.35-7.30 (m, 3H), 7.26 (s, 1H), 4.97(s, 1H). ^{13}C NMR (100 MHz, $CDCl_3$): δ 150.3, 138.8, 133.2, 132.0, 131.3, 131.1, 131.0, 129.2, 128.5, 127.2, 126.7, 124.5, 123.9, 120.0, 117.8. IR: 3251, 3066, 1617, 1505, 1325, 816. HRMS (ESI) m/z calculated for $C_{17}H_{11}F_3ONa$ $[M+Na]^+$ 311.0660, found 311.0665.



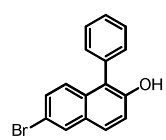
1-(3-Chlorophenyl)naphthalen-2-ol (1l)

Brown oil (0.36 g, 70% yield). PE/EA = 10:1, R_f = 0.49. ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.85 (d, J = 8.0 Hz, 2H), 7.59 (d, J = 7.9 Hz, 2H), 7.39-7.32 (m, 5H), 7.29 (d, J = 8.8 Hz, 1H), 5.14 (s, 1H). ^{13}C NMR (100 MHz, $CDCl_3$): δ 150.4, 136.6, 135.7, 133.3, 131.6, 131.1, 130.3, 129.7, 129.2, 128.9, 128.4, 127.1, 124.6, 123.8, 119.96, 117.8. IR: 3498, 3056, 1621, 1513, 815, 721. HRMS (ESI) m/z calculated for $C_{16}H_{11}ClONa$ $[M+Na]^+$ 277.0396, found 277.0399.



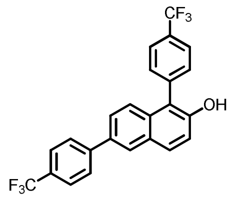
1-(3-Nitrophenyl)naphthalen-2-ol (1m)

Yellow solid (0.43 g, 81% yield). PE/EA = 10:1, R_f = 0.32. Mp: 112-113 ºC. ^{1}H NMR (400 MHz, $CDCl_3$): δ 8.33-8.27 (m, 2H), 7.85 (d, J = 8.4 Hz, 2H), 7.80-7.69 (m, 2H), 7.41-7.26 (m, 3H), 7.23 (s, 1H), 5.25 (s, 1H). ^{13}C NMR (100 MHz, $CDCl_3$): δ 150.4, 149.0, 137.9, 137.1, 133.2, 130.7, 130.4, 129.2, 128.6, 127.4, 126.6, 124.2, 124.0, 123.3, 119.18, 117.9, 110.0. IR: 3428, 3059, 1622, 1527, 813. HRMS (ESI) m/z calculated for $C_{16}H_{11}NO_3Na$ $[M+Na]^+$ 288.0637, found 288.0636.



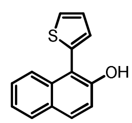
6-Bromo-1-phenylnaphthalen-2-ol (1n)

White solid (0.38 g, 63% yield). PE/EA = 10:1, R_f = 0.26. Mp: 118-119 ºC. ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.96 (s, 1H), 7.71 (d, J = 8.9 Hz, 1H), 7.59 (t, J = 7.2 Hz, 2H), 7.55-7.47 (m, 1H), 7.39-7.33 (m, 3H), 7.27 (d, J = 8.8 Hz, 2H), 5.18 (s, 1H). ^{13}C NMR (100 MHz, $CDCl_3$): δ 150.7, 133.7, 132.0, 131.3, 130.2, 130.1, 130.0, 129.9, 129.0, 128.8, 126.7, 121.4, 118.7, 117.3. IR: 3505, 3057, 1613, 1502, 818. HRMS (ESI) m/z calculated for $C_{16}H_{11}BrONa$ $[M+Na]^+$ 320.9841, found 320.9848.



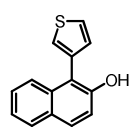
1,6-Bis(4-(trifluoromethyl)phenyl)naphthalen-2-ol (1o)

White solid (0.61 g, 71% yield). PE/EA = 10:1, R_f = 0.19. Mp: 171-172 ºC. ^1H NMR (400 MHz, $CDCl_3$): δ 8.06 (s, 1H), 7.91 (d, J = 8.0 Hz, 2H), 7.75-7.70 (m, 4H), 7.61-7.56 (m, 3H), 7.50-7.40 (m, 1H), 7.35-7.27 (m, 2H), 5.06 (s, 1H). ^{13}C NMR (100 MHz, $CDCl_3$): δ 150.8, 144.5, 138.4, 135.1, 132.8, 131.9, 130.8, 129.3, 127.6, 126.8, 126.4, 126.0, 125.4, 119.9, 118.6. IR: 3441, 3055, 1616, 1474, 1327, 844, 823. HRMS (ESI) m/z calculated for $C_{24}H_{14}F_6ONa$ $[M+Na]^+$ 455.0847, found 455.0853.



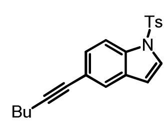
1-(Thiophen-2-yl)naphthalen-2-ol (1p)

Yellow solid (0.27 g, 59% yield). PE/EA = 10:1, R_f = 0.35. Mp: 55-56 ºC. ^1H NMR (400 MHz, $CDCl_3$): δ 7.90-7.75 (m, 2H), 7.63 (t, J = 7.0 Hz, 2H), 7.50-7.34 (m, 2H), 7.29 (d, J = 8.3 Hz, 2H), 7.20 (d, J = 2.5 Hz, 1H), 5.61 (s, 1H). ^{13}C NMR (100 MHz, $CDCl_3$): δ 152.2, 134.6, 134.5, 131.0, 130.1, 129.0, 128.7, 128.4, 128.3, 127.2, 124.8, 123.8, 117.4, 113.2. IR: 3506, 3129, 1620, 1595, 1401, 817, 705. HRMS (ESI) m/z calculated for $C_{14}H_{10}OSNa$ $[M+Na]^+$ 249.0350, found 249.0354.



1-(Thiophen-3-yl)naphthalen-2-ol (1q)

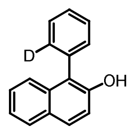
Yellow oil (0.36 g, 80% yield). PE/EA = 10:1, R_f = 0.37. ^1H NMR (400 MHz, $CDCl_3$): δ 7.86-7.76 (m, 2H), 7.69-7.59 (m, 1H), 7.52 (d, J = 8.1 Hz, 1H), 7.44 (s, 1H), 7.42-7.32 (m, 2H), 7.27 (d, J = 9.1 Hz, 1H), 7.20 (d, J = 4.6 Hz, 1H), 5.42 (s, 1H). ^{13}C NMR (100 MHz, $CDCl_3$): δ 151.1, 134.4, 133.7, 130.2, 130.0, 129.1, 128.3, 127.9, 126.9, 125.9, 124.8, 123.6, 117.5, 115.9. IR: 3427, 3128, 1621, 1595, 1401, 860, 750. HRMS (ESI) m/z calculated for $C_{14}H_{10}OSNa$ $[M+Na]^+$ 249.0350, found 249.0355.



5-(3-Phenylprop-1-yn-1-yl)-1-tosyl-1H-indole (2i)

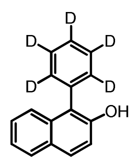
In a dried test tube, a mixture of 1-hexyne (80.0 μL, 0.80 mmol), 5-bromo-1-tosyl-*1H*-indole (0.25 g, 0.70 mmol) and $Pd(PPh_3)_4$ (40.0 mg, 0.04 mmol) in pyrrolidine (1.8 mL, 0.40 M) under argon was stirred at 50 °C overnight. Afterwards, volatiles were evaporated and the residue was purified by flash column chromatography to give 0.15 g (61% yield) of **2i**. PE/EA = 5:1, R_f = 0.42. ^1H NMR (400

MHz, $CDCl_3$): δ 8.04-7.82 (m, 1H), 7.72-7.68 (m, 2H), 7.64-7.49 (m, 2H), 7.47-7.26 (m, 1H), 7.26-7.08 (m, 2H), 6.54 (d, J = 4.0 Hz, 1H), 2.40 (t, J = 6.9 Hz, 2H), 2.25(s, 3H), 1.63-1.53 (m, 4H), 0.92 (d, J = 7.2 Hz, 3H). ^{13}C NMR (100 MHz, $CDCl_3$): δ 145.3, 135.2, 134.1, 131.0, 130.1, 128.3, 127.3, 127.0, 124.8, 119.4, 113.6, 109.1, 89.8, 80.8, 31.1, 22.3, 21.7, 19.3, 13.9. IR: 3130, 2989, 1596, 1455, 1401, 813, 589. HRMS (ESI) m/z calculated for C21H21NO2SNa $[M+Na]^+$ 374.1191, found 374.1188.



2'-Deuteriol-phenylnaphthalen-2-ol (**1a**-d_1)

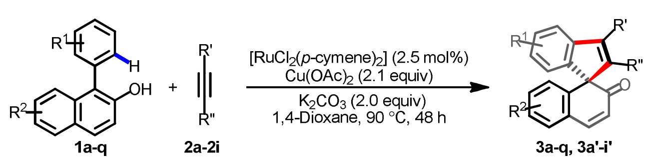
A 10 mL round flask equipped with a stirrer bar was charged with 1-(2-bromophenyl)naphthalen-2-ol (149 mg, 0.5 mmol) and Et_2O (2.0 mL). The solution was cooled to -78 °C, followed by dropwise addition of ^{n}BuLi (2.7 M in hexane, 0.89 mL). The resulting mixture was stirred at -78 °C for 15 min, then warmed to 0 °C and stirred for additional 2 h. The reaction was quenched by careful addition of D_2O (0.5 mL), followed by vigorous stirring at room temperature for 1 h. The reaction mixture was diluted with EtOAc (10 mL), the organic phase was dried over $MgSO_4$, filtered, and concentrated. The crude product was purified by flash chromatography on silica gel to give 2'-Deuteriol-phenylnaphthalen-2-ol as a white solid (96.3 mg, 87% yield). ^1H NMR (400 MHz, $CDCl_3$): δ 7.83 (d, J = 8.4 Hz, 2H), 7.60 (d, J = 5.9 Hz, 2H), 7.51 (d, J = 6.8 Hz, 1H), 7.43 (dd, J = 18.7, 10.4 Hz, 2H), 7.39-7.35 (m, 2H), 7.32-7.20 (d, J = 8.8 Hz, 1H), 5.17 (s, 1H). ^{13}C NMR (100 MHz, $CDCl_3$): δ 150.4, 134.3, 133.5, 131.4, 129.9, 129.8, 129.1, 128.8, 128.3, 126.7, 124.9, 123.6, 121.2, 117.6. HRMS (ESI) m/z calculated for $C_{16}H_{11}DONa$ $[M+Na]^+$ 244.0849, found 244.0841.



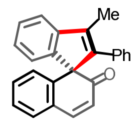
2',3',4',5',6'-Pentadeuterio-phenylnaphthalen-2-ol (**1a**-d_5)

White solid (88% yield, 75% deuterated). For the intermolecular KIE experiment, the 1:1 mixture of **1a** and **1a**-d_5 was obtained by mixing this title product with **1a** directly in a right ratio.

C. Catalytic results:

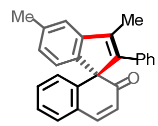


In a glovebox , a 5.0 mL vial equipped with a stir bar was charged with $[RuCl_2(p\text{-cymene})_2]$ (3.1 mg, 0.005 mmol), $Cu(OAc)_2$ (76.0 mg, 0.42 mmol), K_2CO_3 (55.2 mg, 0.40 mmol), 1-aryl-2-naphthol (0.20 mmol), and alkyne (0.30 mmol), followed by sequential addition of 1,4-dioxane (1.0 mL). The vial was sealed with a Teflon screw cap and then the reaction mixture was heated at 90 °C for 48 h. The crude product was then subjected to a silica gel column to afford the desired product.



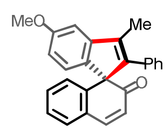
3-Methyl-2-phenyl-2'H-spiro[indene-1,1'-naphthalen]-2'-one (3a)

White solid (56.8 mg, 85% yield). PE/EA = 20:1, R_f = 0.31. Mp: 130-131 ºC. ^1H NMR (400 MHz, $CDCl_3$): δ 7.58 (d, J = 9.8 Hz, 1H), 7.41 (d, J = 7.2 Hz, 1H), 7.36 (d, J = 7.2 Hz, 1H), 7.34-7.27 (m, 1H), 7.19-7.15 (m, 5H), 7.05-6.99 (m, 3H), 6.94 (d, J = 7.0 Hz, 1H), 6.82 (d, J = 7.3 Hz, 1H), 6.33 (d, J = 9.8 Hz, 1H), 2.40 (s, 3H). ^{13}C NMR (100 MHz, $CDCl_3$): δ 197.6, 147.9, 146.5, 146.3, 144.6, 141.1, 139.9, 130.5, 129.9, 129.8, 128.8, 128.3, 127.8, 127.5, 127.2, 127.1, 126.7, 126.3, 121.6, 120.6, 71.9, 12.4. IR: 3061, 2924, 1664, 1602, 1561, 1394, 756, 697. HRMS (ESI) m/z calculated for $C_{25}H_{18}ONa$ $[M+Na]^+$ 357.1258, found 357.1256.



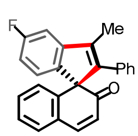
3,5-Dimethyl-2-phenyl-2'H-spiro[indene-1,1'-naphthalen]-2'-one (3b)

White solid (53.0 mg, 76% yield). PE/EA = 20:1, R_f = 0.22. Mp: 149-150 ºC. ^1H NMR (400 MHz, $CDCl_3$): δ 7.57 (d, J = 9.9 Hz, 1H), 7.35 (d, J = 7.3 Hz, 1H), 7.27-7.10 (m, 6H), 7.03 (d, J = 7.1 Hz, 2H), 6.89 (d, J = 7.4 Hz, 1H), 6.85-6.80 (m, 2H), 6.32 (d, J = 9.9 Hz, 1H), 2.39 (s, 6H). ^{13}C NMR (100 MHz, $CDCl_3$): δ 197.9, 146.8, 146.3, 145.3, 144.9, 141.4, 140.0, 137.8, 135.4, 130.6, 130.0, 129.9, 128.9, 128.3, 127.5, 127.3, 127.2, 127.1, 126.8, 121.5, 121.4, 71.8, 21.8, 12.6. IR: 3055, 2918, 1663, 1599, 1562, 1395, 770, 697. HRMS (ESI) m/z calculated for $C_{26}H_{20}ONa$ $[M+Na]^+$ 371.1412, found 371.1408.



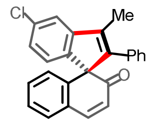
5-Methoxy-3-methyl-2-phenyl-2'H-spiro[indene-1,1'-naphthalen]-2'-one (3c)

White solid (48.8 mg, 67% yield). PE/EA = 20:1, R_f = 0.13. Mp: 184-185 ºC. ^1H NMR (400 MHz, $CDCl_3$): δ 7.56 (d, J = 9.9 Hz, 1H), 7.34 (d, J = 7.4 Hz, 1H), 7.27-7.09 (m, 5H), 7.02 (d, J = 7.2 Hz, 2H), 6.96 (s, 1H), 6.84 (t, J = 7.1 Hz, 2H), 6.60 (d, J = 8.1 Hz, 1H), 6.31 (d, J = 9.9 Hz, 1H), 3.82 (s, 3H), 2.38 (s, 3H). ^{13}C NMR (100 MHz, $CDCl_3$): δ 198.0, 160.0, 148.2, 146.3, 145.9, 140.3, 139.9, 135.3, 130.6, 130.0, 129.8, 128.8, 128.3, 127.5, 127.4, 127.3, 127.1, 126.7, 122.4, 111.7, 106.7, 71.5, 55.7, 12.6. IR: 3056, 2938, 1662, 1601, 1563, 1395, 1217, 769, 698. HRMS (ESI) m/z calculated for $C_{26}H_{20}O_2Na$ $[M+Na]^+$ 387.1361, found 387.1357.



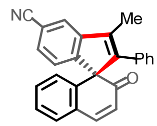
5-Fluoro-3-methyl-2-phenyl-2'H-spiro[indene-1,1'-naphthalen]-2'-one (3d)

White solid (61.3 mg, 87% yield). PE/EA = 20:1, R_f = 0.35. Mp: 161-162 ºC. ^1H NMR (400 MHz, $CDCl_3$): δ 7.57 (d, J = 9.9 Hz, 1H), 7.36 (d, J = 7.4 Hz, 1H), 7.20-7.17 (m, 4H), 7.10 (d, J = 8.6 Hz, 1H), 7.01 (d, J = 7.3 Hz, 2H), 6.87 (dd, J = 7.9, 5.0 Hz, 2H), 6.81 (d, J = 7.7 Hz, 1H), 6.75 (t, J= 8.5 Hz, 1H), 6.31 (d, J = 9.9 Hz, 1H), 2.35 (s, 3H). ^{13}C NMR (100 MHz, $CDCl_3$): δ 197.4, 146.5, 143.5, 140.7, 139.2, 134.9, 130.7,130.0, 128.9, 128.5, 127.9, 127.6, 127.3, 126.7, 122.9, 122.8, 113.0, 112.8, 110.0, 108.2, 108.0, 71.4, 12.6. IR: 3057, 2920, 1664, 1598, 1562, 1395, 1237, 769, 697. HRMS (ESI) m/z calculated for $C_{25}H_{17}FONa$ $[M+Na]^+$ 375.1161, found 375.1163.



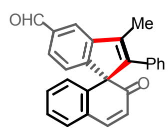
5-Chloro-3-methyl-2-phenyl-2'H-spiro[indene-1,1'-naphthalen]-2'-one (**3e**)

White solid (65.7 mg, 89% yield). PE/EA = 20:1, R_f = 0.21. Mp: 181-182 ºC. ^1H NMR (400 MHz, $CDCl_3$): δ 7.57 (d, J = 9.9 Hz, 1H), 7.37 (d, J = 10.1 Hz, 2H), 7.26 (t, J = 7.3 Hz, 1H), 7.23-7.13 (m, 4H), 7.02-6.94 (m, 3H), 6.86 (d, J = 7.9 Hz, 1H), 6.81 (d, J = 7.7 Hz, 1H), 6.32 (d, J = 9.9 Hz, 1H), 2.35 (s, 3H). ^{13}C NMR (100 MHz, $CDCl_3$): δ 197.1, 148.6, 146.7, 146.6, 146.3, 140.4, 139.1, 134.8, 134.0, 130.7, 130.1, 130.0, 128.8, 128.4, 127.9, 127.6, 127.3, 126.6, 126.2, 122.8, 121.0, 71.7, 12.5. IR: 3058, 2921, 1664, 1595, 1563, 1395, 769, 743, 699. HRMS (ESI) m/z calculated for $C_{25}H_{17}ClONa$ $[M+Na]^+$ 391.0866, found 391.0874.



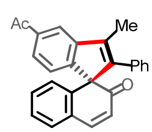
3-Methyl-2'-oxo-2-phenyl-2'H-spiro[indene-1,1'-naphthalene]-5-carbonitrile (**3f**)

White solid (56.8 mg, 79% yield). PE/EA = 20:1, R_f = 0.36. Mp: 171-172 ºC. ^1H NMR (400 MHz, $CDCl_3$): δ 7.73 (s, 1H), 7.68 (d, J = 9.9 Hz, 1H), 7.51-7.41 (m, 2H), 7.36 (dd, J = 13.7, 6.1 Hz, 2H), 7.31-7.22 (m, 3H), 7.12-7.00 (m, 3H), 6.84 (d, J = 7.7 Hz, 1H), 6.40 (d, J = 9.9 Hz, 1H), 2.45 (s, 3H). ^{13}C NMR (100 MHz, $CDCl_3$): δ 196.2, 152.6, 147.9, 147.4, 146.8, 139.2, 138.5, 134.2, 130.9, 130.5, 130.3, 130.1, 128.8, 128.5, 128.3, 127.9, 127.3, 126.5, 123.8, 122.6, 119.3, 111.9, 72.1,12.4. IR: 3057, 2923, 2227, 1664, 1599, 1562, 1395, 772, 697. HRMS (ESI) m/z calculated for $C_{26}H_{17}NONa$ $[M+Na]^+$ 382.1208, found 382.1210.



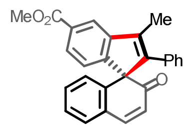
3-Methyl-2'-oxo-2-phenyl-2'H-spiro[indene-1,1'-naphthalene]-5-carbaldehyde (**3g**)

White solid (67.4 mg, 93% yield). PE/EA = 20:1, R_f = 0.28. Mp: 80-81 ºC. ^1H NMR (400 MHz, $CDCl_3$): δ 10.02 (s, 1H), 7.92 (s, 1H), 7.69-7.55 (m, 2H), 7.39 (d, J = 7.4 Hz, 1H), 7.31-7.24 (m, 1H), 7.17-7.11 (m, 4H), 7.08 (d, J = 7.6 Hz, 1H), 7.00 (d, J = 6.7 Hz, 2H), 6.78 (d, J = 7.7 Hz, 1H), 6.33 (d, J = 9.9 Hz, 1H), 2.42 (s, 3H). ^{13}C NMR (100 MHz, $CDCl_3$): δ 196.6, 192.3, 154.4, 147.9, 146.8, 146.6, 139.8, 139.2, 136.6, 134.6, 130.8, 130.3, 130.0, 129.7, 128.9, 128.5, 128.2, 127.8, 127.4, 126.7, 122.4, 120.7, 72.3, 12.6. IR: 3055, 2923, 2725, 1697, 1663, 1596, 1563, 1396, 775, 699. HRMS (ESI) m/z calculated for $C_{26}H_{18}O_2Na$ $[M+Na]^+$ 385.1205, found 385.1211.



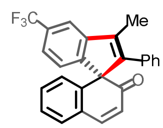
3-Methyl-2'-oxo-2-phenyl-2'H-spiro[indene-1,1'-naphthalene]-5-carbaldehyde (**3h**)

White solid (64.7 mg, 86% yield). PE/EA = 20:1, R_f = 0.25. Mp: 79-80 ºC. ^1H NMR (400 MHz, $CDCl_3$): δ 7.99 (s, 1H), 7.69 (d, J = 7.4 Hz, 1H), 7.60 (d, J = 9.8 Hz, 1H), 7.38 (d, J = 7.3 Hz, 1H), 7.26 (t, *J* = 7.1 Hz, 1H), 7.16-7.10 (m, 4H), 7.01-6.98 (m, 3H), 6.79 (d, *J* = 7.5 Hz, 1H), 6.33 (d, *J* = 9.8 Hz, 1H), 2.60 (s, 3H), 2.42 (s, 3H). ^{13}C NMR (100 MHz, $CDCl_3$): δ 198.2, 196.8, 153.2, 147.4, 146.7, 146.2, 140.0, 139.4, 137.2, 134.8, 130.8, 130.2, 130.0, 128.9, 128.5, 128.1, 127.7, 127.4, 127.3, 126.7, 121.8, 120.2, 72.1, 27.1, 12.6. IR: 3056, 2924, 1724, 1663, 1595, 1562, 1396, 775, 698. HRMS (ESI) m/z calculated for $C_{27}H_{20}O_2Na$ $[M+Na]^+$ 399.1361, found 399.1355.



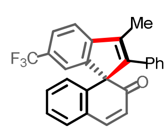
3-Methyl-2'-oxo-2-phenyl-2'H-spiro[indene-1,1'-naphthalene]-5-carboxylate (3i)

White solid (72.2 mg, 92% yield). PE/EA = 20:1, R_f = 0.33. Mp: 72-73 ºC. ^{1}H NMR (400 MHz, $CDCl_3$): δ 8.07 (s, 1H), 7.79 (d, *J* = 7.4 Hz, 1H), 7.59 (d, *J* = 9.8 Hz, 1H), 7.37 (d, *J* = 7.1 Hz, 1H), 7.30-7.11 (m, 5H), 7.06- 6.93 (m, 3H), 6.78 (d, *J* = 7.4 Hz, 1H), 6.32 (d, *J* = 9.8 Hz, 1H), 3.91 (s, 3H), 2.42 (s, 3H). ^{13}CNMR (100 MHz, $CDCl_3$): δ 196.9, 167.3, 152.8, 149.2, 147.1, 146.7, 146.0, 140.1, 139.5, 134.8, 130.8, 130.1, 130.1, 128.9, 128.5, 128.3, 128.1, 127.6, 127.3, 126.7, 121.8, 121.7, 72.1, 52.4, 12.6. IR: 3056, 2924, 1720, 1664, 1595, 1562, 1395, 1249, 776, 699. HRMS (ESI) m/z calculated for $C_{27}H_{20}O_3Na$ $[M+Na]^+$ 415.1310, found 415.1312.



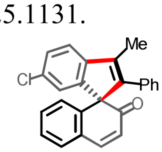
3-Methyl-2-phenyl-5-(trifluoromethyl)-2'H-spiro[indene-1,1'-naphthalen]-2'-one (3j)

White solid (76.5 mg, 95% yield). PE/EA = 20:1, R_f = 0.32. Mp: 140-141 ºC. ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.64 (s, 1H), 7.60 (d, *J* = 9.9 Hz, 1H), 7.39 (d, *J* = 7.3 Hz, 1H), 7.34 (d, *J* = 7.6 Hz, 1H), 7.31-7.24 (m, 1H), 7.18-7.12 (m, 4H), 7.02 (t, *J* = 7.0 Hz, 3H), 6.79 (d, *J* = 7.6 Hz, 1H), 6.33 (d, *J* = 9.8 Hz, 1H), 2.40 (s, 3H). ^{13}C NMR (100 MHz, $CDCl_3$): δ 196.7, 151.5, 147.5, 146.9, 146.7, 139.8, 139.0, 134.6, 130.8, 130.2, 130.1, 128.9, 128.5, 128.1, 127.8, 127.3, 126.6, 123.5, 123.4, 122.1, 117.5, 117.4, 72.1, 12.5. IR: 3058, 2921, 1664, 1595, 1564, 1395, 1311, 771, 698. HRMS (ESI) m/z calculated for $C_{26}H_{17}F_3ONa$ $[M+Na]^+$ 425.1129, found 425.1134.



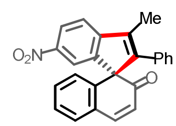
3-Methyl-2-phenyl-6-(trifluoromethyl)-2'H-spiro[indene-1,1'-naphthalen]-2'-one (3k)

White solid (64.4 mg, 80% yield). PE/EA = 20:1, R_f = 0.32. Mp: 130-131 ºC. ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.64-7.56 (m, 2H), 7.48 (d, *J* = 7.7 Hz, 1H), 7.39 (d, *J* = 7.2 Hz, 1H), 7.32-7.24 (m, 1H), 7.18-7.15 (m, 4H), 7.13 (s, 1H), 7.00 (d, *J* = 5.7 Hz, 2H), 6.77 (d, *J* = 7.5 Hz, 1H), 6.33 (d, *J* = 9.8 Hz, 1H), 2.39 (s, 3H). ^{13}C NMR (100 MHz, $CDCl_3$): δ 196.8, 150.3, 148.4, 147.9, 146.8, 139.7, 139.1, 134.6, 130.8, 130.3, 130.1, 128.9, 128.5, 128.2, 127.8, 127.3, 126.6, 125.6, 125.5, 120.7, 118.7, 118.6, 71.9, 12.5. IR: 3058, 2922, 1664, 1601, 1564, 1395, 1325, 752, 699. HRMS (ESI) m/z calculated for $C_{26}H_{17}F_3ONa$ $[M+Na]^+$ 425.1129, found 425.1131.



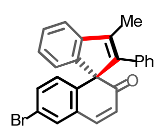
6-Chloro-3-methyl-2-phenyl-2'H-spiro[indene-1,1'-naphthalen]-2'-one (3l)

White solid (61.2 mg, 83% yield). PE/EA = 20:1, R_f = 0.24. Mp: 180-181 ºC. ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.59 (d, J = 9.8 Hz, 1H), 7.37 (d, J = 7.0 Hz, 1H), 7.30-7.22 (m, 3H), 7.18-7.14 (m, 4H), 7.01 (d, J = 6.6 Hz, 2H), 6.91 (s, 1H), 6.81 (d, J = 7.5 Hz, 1H), 6.33 (d, J = 9.8 Hz, 1H), 2.37 (s, 3H). ^{13}C NMR (100 MHz, $CDCl_3$): δ 197.0, 149.4, 146.7, 145.3, 145.2, 140.2, 139.2, 134.9, 131.9, 130.8, 130.2, 130.0, 128.8, 128.4, 128.2, 128.0, 127.5, 127.3, 126.6, 122.3, 121.5, 71.8, 12.6. IR: 3056, 2921, 1663, 1594, 1564, 1395, 766, 741, 699. HRMS (ESI) m/z calculated for $C_{25}H_{17}ClONa$ $[M+Na]^+$ 391.0866, found 391.0870.



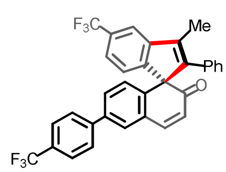
3-Methyl-6-nitro-2-phenyl-2'H-spiro[indene-1,1'-naphthalen]-2'-one (3m)

White solid (63.7 mg, 84% yield). PE/EA = 5:1, R_f = 0.42. Mp: 210-211 ºC. ^{1}H NMR (400 MHz, $CDCl_3$): δ 8.25 (d, J = 8.2 Hz, 1H), 7.75 (s, 1H), 7.65 (d, J = 9.9 Hz, 1H), 7.50 (d, J = 8.3 Hz, 1H), 7.42 (d, J = 7.5 Hz, 1H), 7.30 (t, J = 7.5 Hz, 1H), 7.21-7.18 (m, 4H), 7.01 (d, J = 5.1 Hz, 2H), 6.76 (d, J = 7.7 Hz, 1H), 6.35 (d, J = 9.9 Hz, 1H), 2.42 (s, 3H). ^{13}C NMR (100 MHz, $CDCl_3$): δ 195.9, 153.5, 150.8, 148.8, 147.1, 146.2, 138.9, 138.8, 134.2, 130.9, 130.5, 130.1, 128.8, 128.6, 128.5, 128.2, 127.2, 126.5, 124.5, 120.6, 117.3, 71.8, 12.6. IR: 3057, 2920, 1663, 1596, 1562, 1384, 1338, 750, 699. HRMS (ESI) m/z calculated for $C_{25}H_{17}NO_3Na$ $[M+Na]^+$ 402.1106, found 402.1103.



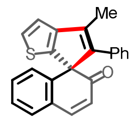
6'-Bromo-3-methyl-2-phenyl-2'H-spiro[indene-1,1'-naphthalen]-2'-one (**3n**)

White solid (58.7 mg, 71% yield). PE/EA = 5:1, R_f = 0.58. Mp: 162-163 ºC. ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.53-7.48 (m, 2H), 7.41 (d, J = 7.5 Hz, 1H), 7.34-7.29 (m, 1H), 7.26-7.16 (m, 4H), 7.04-6.97 (m, 3H), 6.92 (d, J = 7.5 Hz, 1H), 6.68 (d, J = 8.3 Hz, 1H), 6.37 (d, J = 10.0 Hz, 1H), 2.40 (s, 3H). ^{13}C NMR (100 MHz, $CDCl_3$): δ 196.8, 147.3, 146.3, 144.5, 144.1, 140.3, 139.9, 134.9, 133.2, 132.2, 131.8, 128.9, 128.7, 128.3, 128.1, 127.8, 127.3, 126.4, 121.5, 121.1, 120.7, 71.6, 12.5. IR: 3056, 2963, 1665, 1598, 1551, 1364, 751, 697. HRMS (ESI) m/z calculated for $C_{25}H_{17}BrONa$ $[M+Na]^+$ 435.0361, found 435.0367.



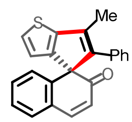
3-Methyl-2-phenyl-5-(trifluoromethyl)-6'-(4-(trifluoromethyl)phenyl)-2'H-spiro[indene-1,1'-naphthalen]-2'-one (**3o**)

Light yellow solid (104.9 mg, 96% yield). PE/EA = 20:1, R_f = 0.26. Mp: 160-161 ºC. ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.67 (d, J = 9.3 Hz, 5H), 7.60 (s, 1H), 7.42-7.31 (m, 2H), 7.22-7.17 (m, 4H), 7.11-7.03 (m, 3H), 6.88 (d, J = 8.1 Hz, 1H), 6.41 (d, J = 9.9 Hz, 1H), 2.43 (s, 3H). ^{13}C NMR (100 MHz, $CDCl_3$): δ 196.4, 151.2, 147.5, 146.6, 146.3, 143.3, 139.8, 139.6, 139.4, 134.6, 130.7, 129.5, 128.9, 128.8, 128.6, 128.1, 127.9, 127.5, 127.4, 126.1, 126.0, 123.6, 123.5, 122, 117.6, 117.5, 71.8, 12.6. IR: 3058, 2918, 1666, 1599, 1552, 1326, 1124, 752, 699. HRMS (ESI) m/z calculated for $C_{33}H_{20}F_6ONa$ $[M+Na]^+$ 569.1316, found 569.1321.



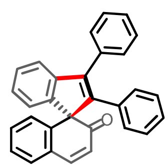
6-Methyl-5-phenyl-2'H-spiro[cyclopenta[b]thiophene-4,1'-naphthalen]-2'-one (3p)

Yellow solid (49.0 mg, 72% yield). PE/EA = 20:1, R_f = 0.39. Mp: 108-109 ºC. ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.42 (d, J = 9.9 Hz, 1H), 7.35-7.10 (m, 7H), 7.04 (d, J = 4.7 Hz, 1H), 6.98-6.76 (m, 3H), 6.21 (d, J = 9.8 Hz, 1H), 2.27 (s, 3H). ^{13}C NMR (100 MHz, $CDCl_3$): δ 196.7, 153.2, 148.2, 146.6, 146.0, 140.3, 136.2, 135.2, 130.7, 130.0, 129.8, 129.2, 128.8, 128.3, 128.0, 127.4, 127.2, 126.5, 119.1, 69.8, 13.8. IR: 3055, 2919, 1664, 1597, 1562, 1395, 763, 701. HRMS (ESI) m/z calculated for $C_{23}H_{16}OSNa$ $[M+Na]^+$ 363.0820, found 363.0811.



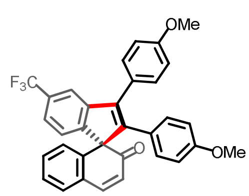
4-Methyl-5-phenyl-2'H-spiro[cyclopenta[b]thiophene-6,1'-naphthalen]-2'-one (3q)

Yellow solid (55.2 mg, 81% yield). PE/EA = 20:1, R_f = 0.37. Mp: 150-151 ºC. ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.55 (d, J = 9.9 Hz, 1H), 7.35 (d, J = 7.3 Hz, 1H), 7.29-7.10 (m, 6H), 6.99 (d, J = 7.1 Hz, 2H), 6.87 (d, J = 7.6 Hz, 1H), 6.66 (d, J = 4.7 Hz, 1H), 6.32 (d, J = 9.9 Hz, 1H), 2.41 (s, 3H). ^{13}C NMR (100 MHz, $CDCl_3$): δ 196.5, 149.9, 149.6, 146.1, 145.9, 139.8, 136.3, 135.2, 130.7, 130.0, 129.9, 128.5, 128.4, 127.8, 127.1, 127.0, 126.8, 126.6, 120.3, 69.9, 14.5. IR: 3057, 2924, 1662, 1598, 1561, 1394, 764, 694. HRMS (ESI) m/z calculated for $C_{23}H_{16}OSNa$ $[M+Na]^+$ 363.0820, found 363.0821.



2,3-Diphenyl-2'H-spiro[indene-1,1'-naphthalen]-2'-one (3a')

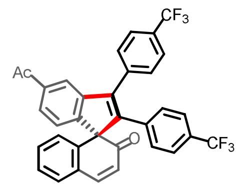
White solid (53.1 mg, 67% yield). PE/EA = 20:1, R_f = 0.28. Mp: 176-177 ºC. ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.68 (d, J = 9.9 Hz, 1H), 7.54 (d, J = 7.2 Hz, 2H), 7.43-7.38 (m, 5H), 7.26-7.23 (m, 3H), 7.20-7.14 (m, 1H), 7.02-6.96 (m, 5H), 6.86 (d, J = 6.5 Hz, 2H), 6.41 (d, J = 9.9 Hz, 1H). ^{13}C NMR (100 MHz, $CDCl_3$): δ 197.0, 147.9, 146.5, 145.6, 145.2, 144.9, 141.3, 135.4, 134.5, 130.9, 130.2, 129.9, 129.8, 129.3, 129.1, 128.2, 128.1, 128.0, 127.8, 127.3, 127.1, 126.8, 126.6, 122.1, 121.9, 71.9. IR: 3059, 1663, 1598, 1562, 758, 699. HRMS (ESI) m/z calculated for $C_{30}H_{20}ONa$ $[M+Na]^+$ 419.1412, found 419.1412.



2,3-Bis(4-methoxyphenyl)-5-(trifluoromethyl)-2'H-spiro[indene-1,1'-naphthalen]-2'-one (3b')

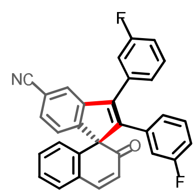
Light yellow solid (93.4 mg, 89% yield). PE/EA = 20:1, R_f = 0.12. Mp: 90-91 ºC. ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.71 (d, J = 9.9 Hz, 1H), 7.50-7.42 (m, 4H), 7.29 (dd, J = 16.4, 8.9 Hz, 2H), 7.19 (t, J

= 7.4 Hz, 1H), 7.06 (d, *J* = 7.9 Hz, 1H), 7.02 (d, *J* = 8.4 Hz, 2H), 6.92 (d, *J* = 7.7 Hz, 1H), 6.79 (d, *J* = 8.6 Hz, 2H), 6.55 (d, *J* = 8.6 Hz, 2H), 6.41 (d, *J* = 9.9 Hz, 1H), 3.89 (s, 3H), 3.65 (s, 3H). ^{13}C NMR (100 MHz, $CDCl_3$): δ 196.3, 159.6, 158.9, 150.9, 146.9, 146.7, 146.3, 142.1, 140.5, 131.1, 130.9, 130.6, 130.4, 129.8, 128.2, 127.0, 126.9, 126.6, 126.5, 123.2, 123.1, 122.0, 118.4, 118.3, 114.8, 113.8, 71.6, 55.5, 55.2. IR: 3058, 2932, 1667, 1613, 1505, 1316, 832. HRMS (ESI) m/z calculated for $C_{33}H_{23}F_3O_3Na$ $[M+Na]^+$ 547.1497, found 547.1503.



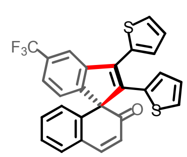
5-Acetyl-2,3-bis(4-(trifluoromethyl)phenyl)-2'H-spiro[indene-1,1'-naphthalen]-2'-one (3c')

White solid (104.6 mg, 91% yield). PE/EA = 20:1, R_f = 0.14. Mp: 240-241 ºC. ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.89 (s, 1H), 7.85 (d, *J* = 7.9 Hz, 1H), 7.79-7.72 (m, 2H), 7.71 (s, 1H), 7.64 (d, *J* = 7.8 Hz, 2H), 7.49 (d, *J* = 7.4 Hz, 1H), 7.35 (t, *J* = 7.4 Hz, 1H), 7.31-7.25 (m, 2H), 7.25-7.19 (m, 1H), 7.10 (d, *J* = 7.8 Hz, 1H), 6.96-6.75 (m, 3H), 6.41 (d, *J* = 9.9 Hz, 1H), 3.88 (s, 3H). ^{13}C NMR (100 MHz, $CDCl_3$): δ 197.7, 195.3, 152.2, 147.0, 146.2, 145.1, 144.7, 139.1, 137.9, 137.5, 137.3, 131.3, 130.8, 130.0, 129.8, 129.4, 128.7, 128.1, 127.0, 126.5, 125.4, 125.3, 122.3, 121.5, 72.1, 27.0. IR: 3058, 2926, 1725, 1667, 1326, 1168, 1125, 763, 692. HRMS (ESI) m/z calculated for $C_{34}H_{20}F_6O_2Na$ $[M+Na]^+$ 597.1265, found 597.1265.



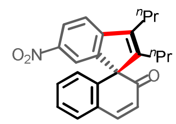
2,3-Bis(3-fluorophenyl)-2'-oxo-2'H-spiro[indene-1,1'-naphthalene]-5-carbonitrile (3d')

White solid (75.0 mg, 82% yield). PE/EA = 20:1, R_f = 0.52. Mp: 218-219 ºC. ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.72 (d, *J* = 9.9 Hz, 1H), 7.54 (s, 1H), 7.48 (dd, *J* = 10.5, 6.0 Hz, 2H), 7.43-7.32 (m, 2H), 7.31-7.12 (m, 4H), 7.09 (d, *J* = 7.7 Hz, 1H), 7.00 (dd, *J* = 14.3, 7.7 Hz, 1H), 6.86 (d, *J* = 7.7 Hz, 1H), 6.78 (t, *J* = 7.5 Hz, 1H), 6.60 (d, *J* = 7.7 Hz, 1H), 6.51 (d, *J* = 10.3 Hz, 1H), 6.40 (d, *J* = 9.9 Hz, 1H). ^{13}C NMR (100 MHz, $CDCl_3$): δ 194.9, 164.7, 163.7, 152.1, 147.1, 146.9, 146.0, 143.1, 138.7, 135.6, 131.4, 131.3, 131.0, 130.8, 130.1, 130.0, 129.8, 128.8, 127.0, 126.4, 125.3, 125.1, 122.9, 119.0, 116.5, 116.3, 116.1, 116.0, 115.8, 115.4, 115.2, 112.2, 72.1. IR: 3068, 2227, 1665, 1581, 1395, 760, 695. HRMS (ESI) m/z calculated for $C_{31}H_{17}F_2NONa$ $[M+Na]^+$ 480.1176, found 480.1178.



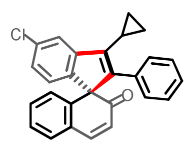
2,3-Di(thiophen-2-yl)-5-(trifluoromethyl)-2'H-spiro[indene-1,1'-naphthalen]-2'-one (3e')

White solid (45.7 mg, 48% yield). PE/EA = 20:1, R_f = 0.41. Mp: 75-76 ºC. ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.78 (d, *J* = 9.9 Hz, 1H), 7.62 (d, *J* = 4.8 Hz, 1H), 7.51 (d, *J* = 7.4 Hz, 1H), 7.46 (s, 1H), 7.29-719 (m, 6H), 7.09 (dd, *J* = 14.9, 6.3 Hz, 2H), 6.92 (d, *J* = 7.6 Hz, 1H), 6.79-6.69 (m, 1H), 6.45 (d, *J* = 5.3 Hz, 1H). ^{13}C NMR (100 MHz, $CDCl_3$): δ 195.1, 149.7, 146.7, 146.2, 143.7, 140.2, 136.1, 135.2, 133.5, 131.4, 130.5, 129.5, 129.2, 128.7, 128.6, 128.4, 128.1, 127.9, 127.0, 126.3, 123.7, 123.6, 121.9, 118.8, 118.7, 71.5. IR: 3059, 2927, 1668, 1562, 1319, 1124, 704. HRMS (ESI) m/z calculated for $C_{27}H_{15}F_3OS_2Na$ $[M+Na]^+$ 499.0414, found 499.0420.



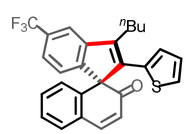
6-Nitro-2,3-dipropyl-2'H-spiro[indene-1,1'-naphthalen]-2'-one (3f')

White solid (47.8 mg, 64% yield). PE/EA = 20:1, R_f = 0.49. Mp: 153-154 ºC. ^{1}H NMR (400 MHz, $CDCl_3$): δ 8.30-8.13 (m, 1H), 7.80-7.61 (m, 2H), 7.46 (d, J = 7.4 Hz, 1H), 7.44-7.29 (m, 2H), 7.19 (t, J = 7.3 Hz, 1H), 6.58 (d, J = 7.6 Hz, 1H), 6.37 (d, J = 9.9 Hz, 1H), 2.65 (t, J = 7.4 Hz, 2H), 2.35-2.17 (m, 1H), 2.14-1.98 (m, 1H), 1.72-1.68 (m, 2H), 1.15 (dd, J = 15.2, 7.6 Hz, 2H), 1.07 (dd, J = 17.0, 9.8 Hz, 3H), 0.77 (t, J = 7.2 Hz, 3H). ^{13}C NMR (100 MHz, $CDCl_3$): δ 196.1, 154.2, 153.7, 149.7, 146.8, 145.7, 142.0, 138.8, 130.8, 130.5, 130.2, 128.4, 127.2, 126.7, 124.4, 119.7, 117.4, 71.0, 30.3, 27.8, 22.2, 22.1, 14.9, 14.4. IR: 3058, 2926, 1665, 1516, 1381, 1337. HRMS (ESI) m/z calculated for $C_{24}H_{23}NO_3Na$ $[M+Na]^+$ 396.1576, found 396.1567.



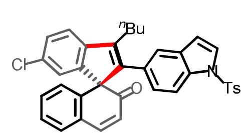
5-Chloro-3-cyclopropyl-2-phenyl-2'H-spiro[indene-1,1'-naphthalen]-2'-one (3g')

White solid (62.4 mg, 79% yield). PE/EA = 20:1, R_f = 0.40. Mp: 70-71 ºC. ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.56 (d, J = 8.4 Hz, 2H), 7.37 (d, J = 6.6 Hz, 2H), 7.25 (t, J = 7.1 Hz, 2H), 7.15-7.11 (m, 4H), 7.00 (d, J = 7.8 Hz, 1H), 6.82 (d, J = 7.9 Hz, 1H), 6.74 (d, J = 7.6 Hz, 1H), 6.30 (d, J = 9.9 Hz, 1H), 1.95-1.90 (m, 1H), 1.14-0.76 (m, 2H), 0.60-0.55 (m, 2H). ^{13}C NMR (100 MHz, $CDCl_3$): δ 196.8, 148.4, 147.8, 146.4, 146.2, 143.9, 140.7, 134.5, 133.9, 130.8, 130.1, 129.9, 129.2, 128.1, 127.9, 127.6, 127.1, 126.6, 126.1, 122.7, 121.8, 110.0, 71.2, 8.9, 7.7. IR: 3057, 2927, 1664, 1593, 1562, 1458, 824, 774, 700. HRMS (ESI) m/z calculated for $C_{27}H_{19}ClONa$ $[M+Na]^+$ 417.1022, found 417.1022.



3-Butyl-2-(thiophen-2-yl)-5-(trifluoromethyl)-2'H-spiro[indene-1,1'-naphthalen]-2'-one (3h')

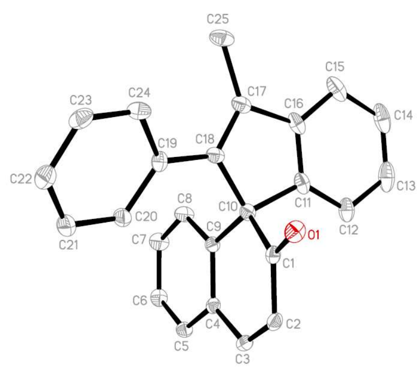
White solid (73.0 mg, 81% yield). PE/EA = 20:1, R_f = 0.21. Mp: 156-157 ºC. ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.84 (t, J = 8.1 Hz, 1H), 7.73 (d, J = 9.9 Hz, 1H), 7.58 (s, 1H), 7.47 (d, J = 7.5 Hz, 1H), 7.40-7.09 (m, 3H), 7.00 (d, J = 7.8 Hz, 1H), 6.89-6.80 (m, 1H), 6.75 (d, J = 7.7 Hz, 1H), 6.49 (d, J = 3.2 Hz, 1H), 6.40 (d, J = 9.9 Hz, 1H), 3.21-2.94 (m, 2H), 1.80-1.76 (m, 2H), 1.68-1.55 (m, 2H), 1.05-0.98 (m, 3H). ^{13}C NMR (100 MHz, $CDCl_3$): δ 195.9, 150.5, 146.6, 146.2, 143.4, 140.6, 139.2, 136.8, 131.9, 131.2, 130.4, 129.7, 128.3, 127.3, 126.7, 126.5, 126.2, 124.4, 123.3, 121.8, 117.6, 117.5, 71.6, 30.7, 26.9, 23.5, 14.3. IR: 3054, 2926, 1667, 1562, 1384, 1320, 775, 701. HRMS (ESI) m/z calculated for $C_{27}H_{21}F_3OSNa$ $[M+Na]^+$ 473.1163, found 473.1158.



3-Butyl-6-chloro-2-(1-tosyl-1H-indol-5-yl)-2'H-spiro[indene-1,1'-naphthalen]-2'-one (3i')

White solid (87.0 mg, 72% yield). PE/EA = 20:1, R_f = 0.37. Mp: 115-116 ºC. ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.74-7.69 (m, 3H), 7.48 (t, J = 6.7 Hz, 2H), 7.42-7.14 (m, 7H), 7.10 (s, 1H), 6.85-6.80 (m, 3H), 6.49 (d, J = 3.3 Hz, 1H), 6.24 (d, J = 9.9 Hz, 1H), 2.66 (t, J = 6.7 Hz, 2H), 2.33 (s, 3H), 1.79-1.60 (m, 2H), 1.39 (dd, J = 14.5, 7.2 Hz, 2H), 0.87-0.83 (m, 3H). ^{13}C NMR (100 MHz, $CDCl_3$): δ 197.1, 150.0, 146.6, 145.6, 145.2, 144.6, 143.9, 140.0, 135.5, 134.1, 131.8, 130.7, 130.3, 130.1, 128.0, 127.4, 127.0, 126.7, 125.7, 122.7, 121.8, 121.7, 113.3, 109.3, 72.2, 31.2, 26.2, 23.0, 21.8, 14.1. IR: 3058, 2957, 2939, 1664, 1595, 1561, 1456, 1373, 670, 584. HRMS (ESI) m/z calculated for $C_{37}H_{30}ClNO_3SNa$ [M+Na]$^+$ 626.1533, found 626.1529.

D. Regiochemical determination:



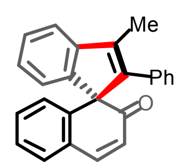
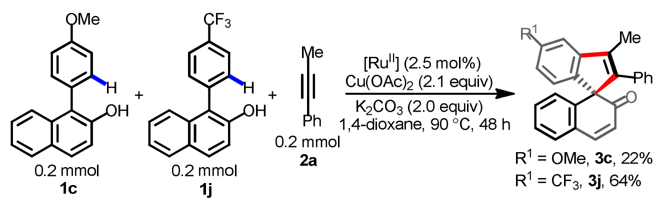


Figure S1. Crystal structure of compound **3a**.

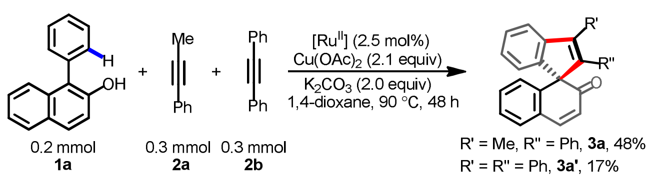
E. Competing experiments:

(a) Intermolecular competition between naphthols **1c** and **1j**.



In a glovebox , a 5.0 mL vial equipped with a stir bar was charged with [$RuCl_2$(p-cymene)$_2$] (3.1 mg, 0.005 mmol), $Cu(OAc)_2$ (76.0 mg, 0.42 mmol), K_2CO_3 (55.2 mg, 0.40 mmol), **1c** (57.6 mg, 0.20 mmol), **1j** (50.2 mg, 0.20 mmol) and **2a** (23.2 mg, 0.20 mmol), followed by sequential addition of 1,4-dioxane (1.0 mL). The vial was sealed with a Teflon screw cap and then the reaction mixture was heated at 90 °C for 48 h. The crude product was then subjected to a silica gel column to afford 16.0 mg of **3c** (22% yield) and 51.5 mg of **3j** (64% yield).

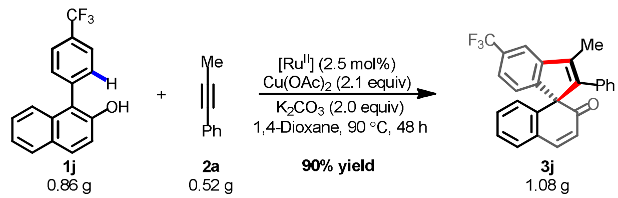
(b) Intermolecular competition between alkynes **2a** and **2b**.



In a glovebox , a 5.0 mL vial equipped with a stir bar was charged with [$RuCl_2$(p-cymene)$_2$] (3.1 mg, 0.005 mmol), $Cu(OAc)_2$ (76.0 mg, 0.42 mmol), K_2CO_3 (55.2 mg, 0.40 mmol), **1a** (44.0 mg, 0.20

mmol), **2a** (34.8 mg, 0.30 mmol) and **2b** (53.4 mg, 0.30 mmol), followed by sequential addition of 1,4-dioxane (1.0 mL). The vial was sealed with a Teflon screw cap and then the reaction mixture was heated at 90 °C for 48 h. The crude product was then subjected to a silica gel column to afford 32.1 mg of **3a** (48% yield) and 13.5 mg of **3a'** (17% yield).

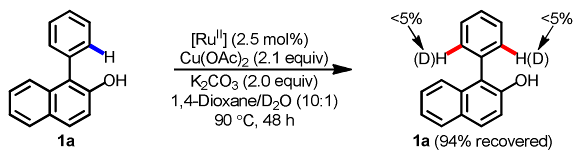
F. Gram-scale preparation of **3j**:



In a glovebox , a 50 mL vial equipped with a stir bar was charged with [$RuCl_2$(*p*-cymene)$_2$] (46.5 mg, 0.075 mmol), $Cu(OAc)_2$ (1.14 g, 6.3 mmol), K_2CO_3 (0.83 g, 6.0 mmol), **1j** (0.86 g, 3.0 mmol) and **2a** (0.52 g, 4.5 mmol), followed by sequential addition of 1,4-dioxane (15.0 mL). The vial was sealed with a Teflon screw cap and then the reaction mixture was heated at 90 °C for 48 h. The crude product was then subjected to a silica gel column to afford 1.08 g **3j** (90% yield).

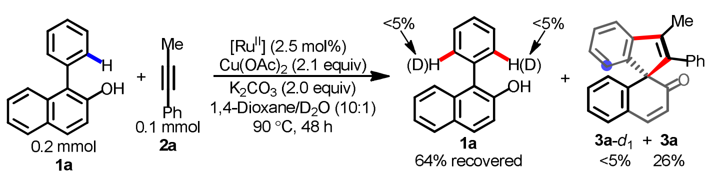
G. Deuterium-labeling experiments:

(a) Treatment of substrate **1a** in the presence of D_2O.



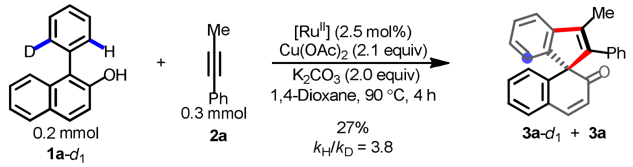
In a glovebox , a 5.0 mL vial equipped with a stir bar was charged with [$RuCl_2$(*p*-cymene)$_2$] (3.1 mg, 0.005 mmol), $Cu(OAc)_2$ (76.0 mg, 0.42 mmol), K_2CO_3 (55.2 mg, 0.40 mmol), **1a** (44.0 mg, 0.20 mmol), and 1,4-dioxane (1.0 mL), followed by sequential addition of D_2O (0.1 mL) outside the glovebox. The vial was sealed with a Teflon screw cap and then the reaction mixture was heated at 90 °C for 48 h. The recovered starting material (41.4 mg, 94%) was checked by both ^1H NMR and HRMS, which showed that no detectable deuterium was observed.

(b) Treatment of substrate **1a** with 0.5 equiv of **2a** in the presence of D_2O.



In a glovebox , a 5.0 mL vial equipped with a stir bar was charged with [$RuCl_2$(*p*-cymene)$_2$] (3.1 mg, 0.005 mmol), $Cu(OAc)_2$ (76.0 mg, 0.42 mmol), K_2CO_3 (55.2 mg, 0.40 mmol), **1a** (44.0 mg, 0.20 mmol), **2a** (11.6 mg, 0.10 mmol), and 1,4-dioxane (1.0 mL), followed by sequential addition of D_2O (0.1 mL) outside the glovebox. The vial was sealed with a Teflon screw cap and then the reaction mixture was heated at 90 °C for 48 h. The crude product was then subjected to a silica gel column to afford 17.4 mg **3a** (26% yield) and 28.3 mg of **1a** (64%). Both the recovered starting material **1a** and product **2a** were checked by the combination of ^1H NMR with HRMS, which showed that no detectable deuterium was observed.

(c) Intramolecular kinetic isotope effect experiment.



In a glovebox , a 5.0 mL vial equipped with a stir bar was charged with [$RuCl_2$(*p*-cymene)$_2$] (3.1 mg, 0.005 mmol), $Cu(OAc)_2$ (76.0 mg, 0.42 mmol), K_2CO_3 (55.2 mg, 0.40 mmol), **1a**-d_1 (44.3 mg, 0.2 mmol), and **2a** (34.8 mg, 0.30 mmol), followed by sequential addition of 1,4-dioxane (1.0 mL). The vial was sealed with a Teflon screw cap and then the reaction mixture was heated at 90 °C for 4 h. The crude product was then subjected to a silica gel column to afford a mixture of **3a**-d_1 and **3a** in 27% yield (18.1 mg). The ratio between **3a**-d_1 and **3a** was determined to be 3.8 by HRMS.

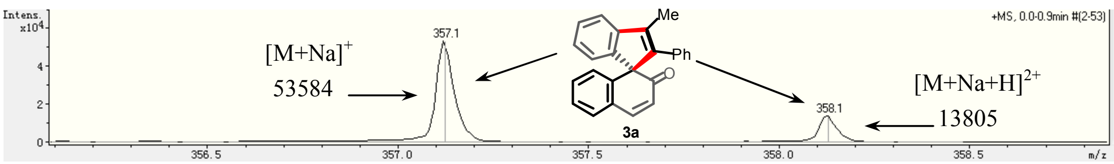


Figure S2. Mass spectra of compound **3a**.

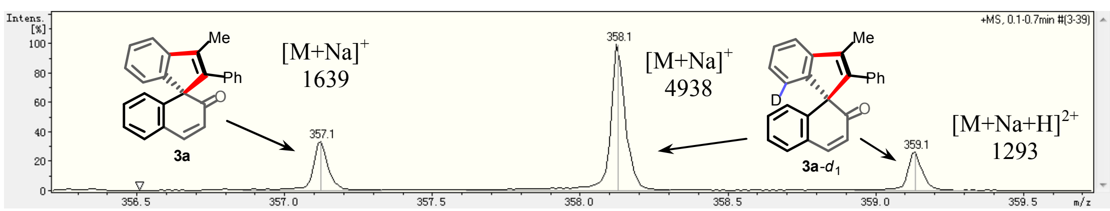
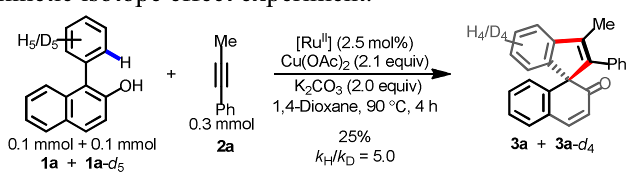


Figure S3. Mass spectra of the mixture of **3a**-d_1 and **3a**.

KIE for the intramolecular experiment: k_H/k_D = (1293+4938)/1639 = 3.8

(d) Intermolecular kinetic isotope effect experiment.



In a glovebox , a 5.0 mL vial equipped with a stir bar was charged with [$RuCl_2$(*p*-cymene)$_2$] (3.1 mg, 0.005 mmol), $Cu(OAc)_2$ (76.0 mg, 0.42 mmol), K_2CO_3 (55.2 mg, 0.40 mmol), [**1a**-d_5 (29.9 mg, 75% deuterated) + **1a** (14.7 mg)] and **2a** (34.8 mg, 0.30 mmol), followed by sequential addition of 1,4-dioxane (1.0 mL). The vial was sealed with a Teflon cap and the reaction mixture was heated at 90 °C for 4 h. The crude product was then subjected to a silica gel column to afford a mixture of **3a** and **3a**-d_4 in 25% yield (16.7 mg). The ratio between **3a** and **3a**-d_4 was determined to be 5.0 by HRMS.

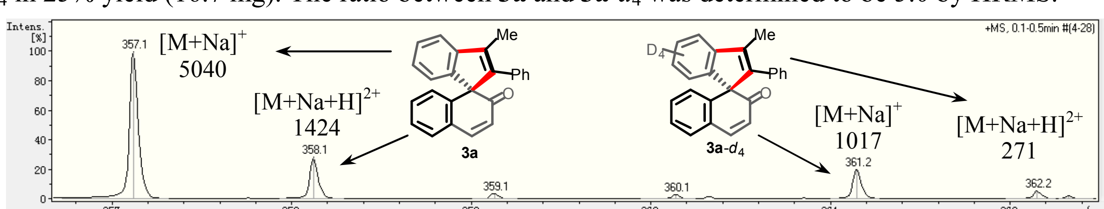
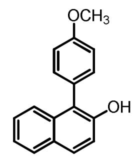


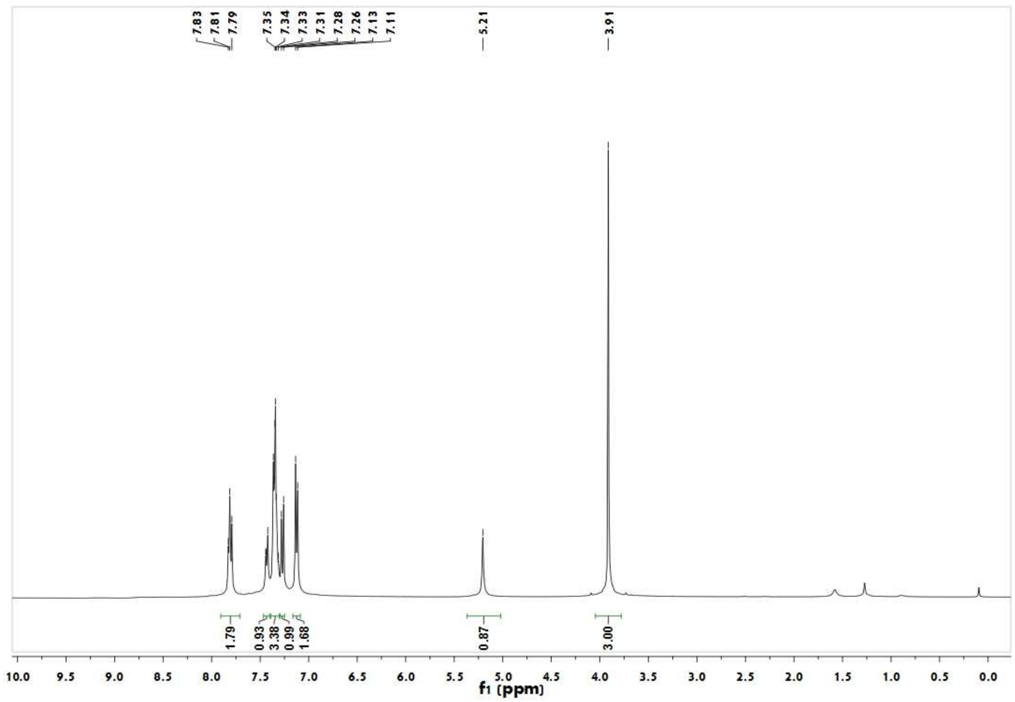
Figure S4. Mass spectra of the mixture of **3a** and **3a**-d_4.

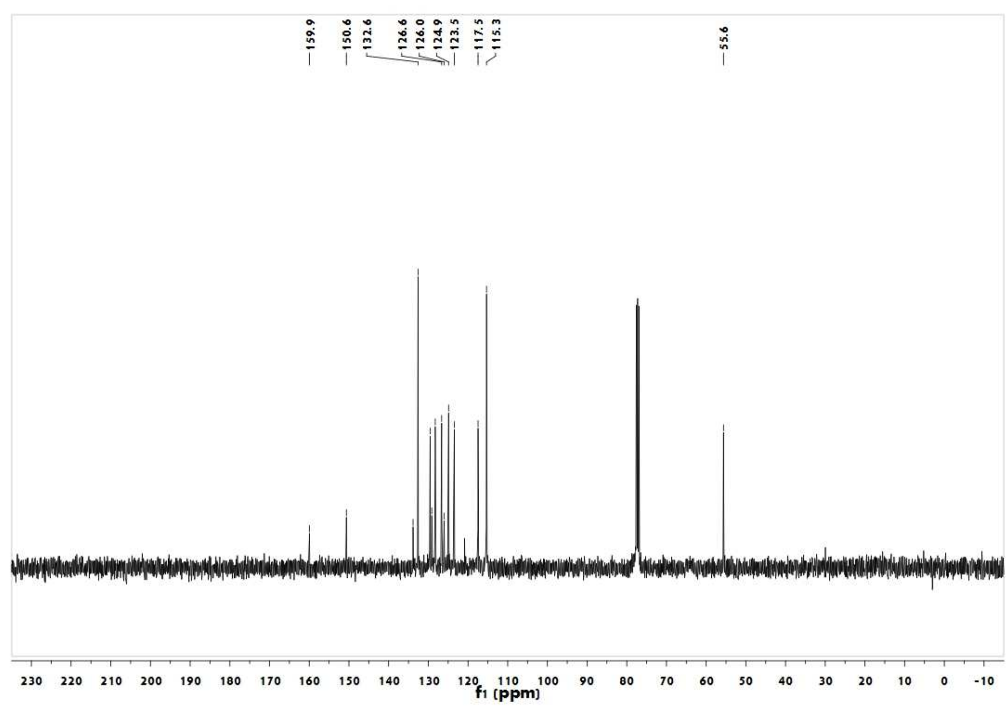
KIE for the intermolecular experiment: k_H/k_D = (5040+1424)/(1017+271) = 5.0

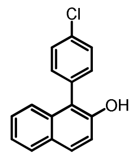
H. NMR spectra:



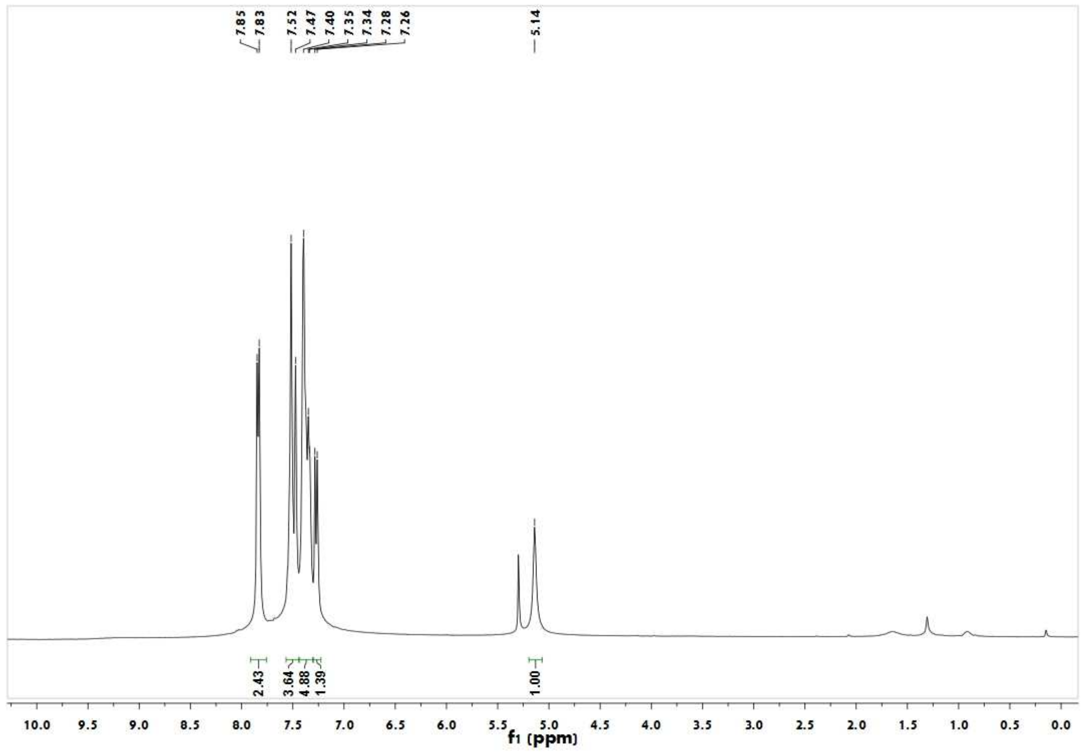
(**1c**)






Cl
OH

(**1e**)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7.83
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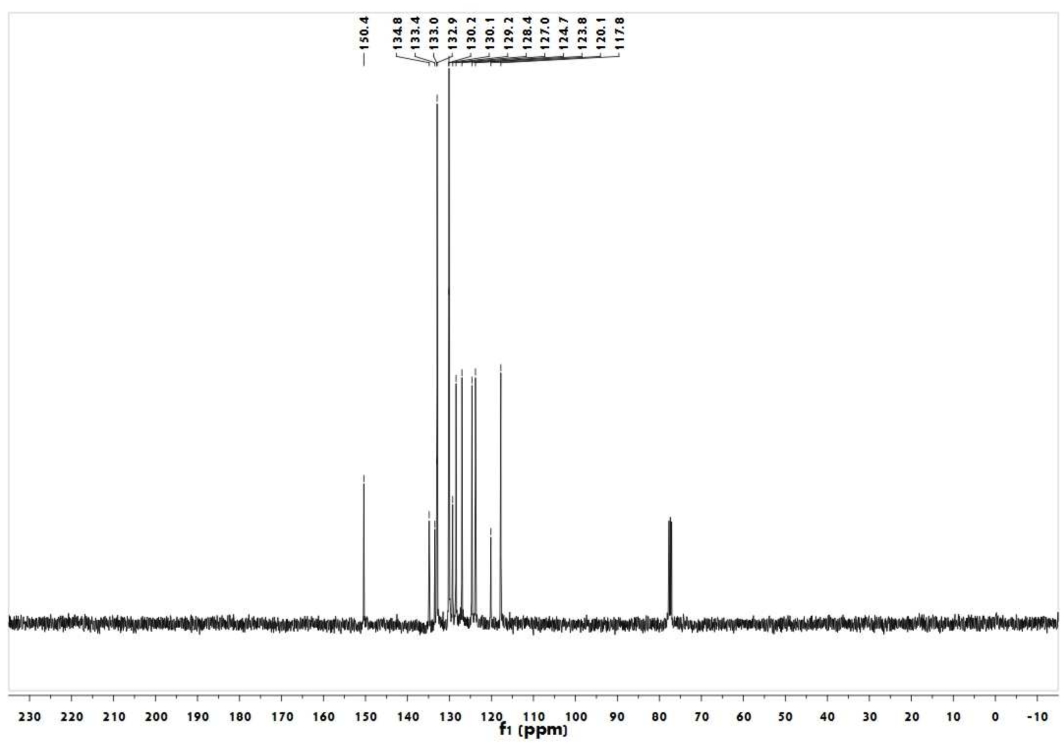
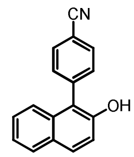
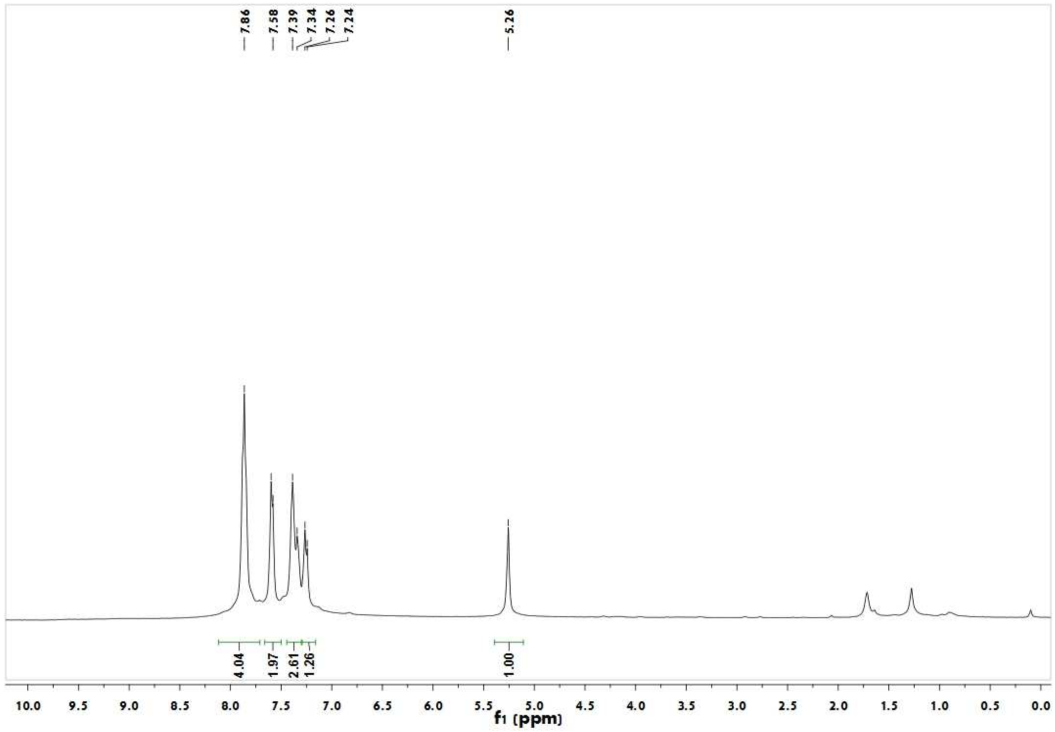
7.47
7.40
7.35
7.34
7.28
7.26
5.14
2.43
3.64
4.88
1.39
1.00
10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0
f1 (ppm)


150.4
134.8
133.4
133.0
132.9
130.2
130.1
129.2
128.4
127.0
124.7
123.8
120.1
117.8
230 220 210 200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 -10
f1 (ppm)


CN
OH

(1f)


7.86
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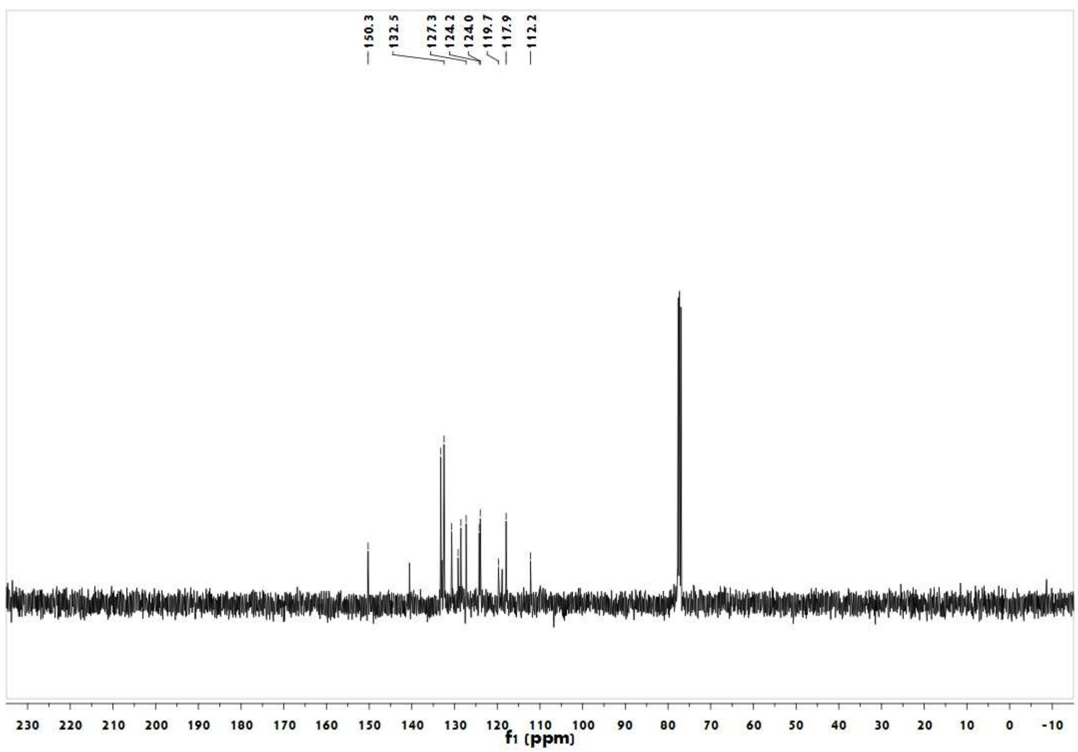
7.34
7.26
7.24
5.26
4.04
1.97
2.61
1.26
1.00
f1 (ppm)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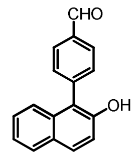
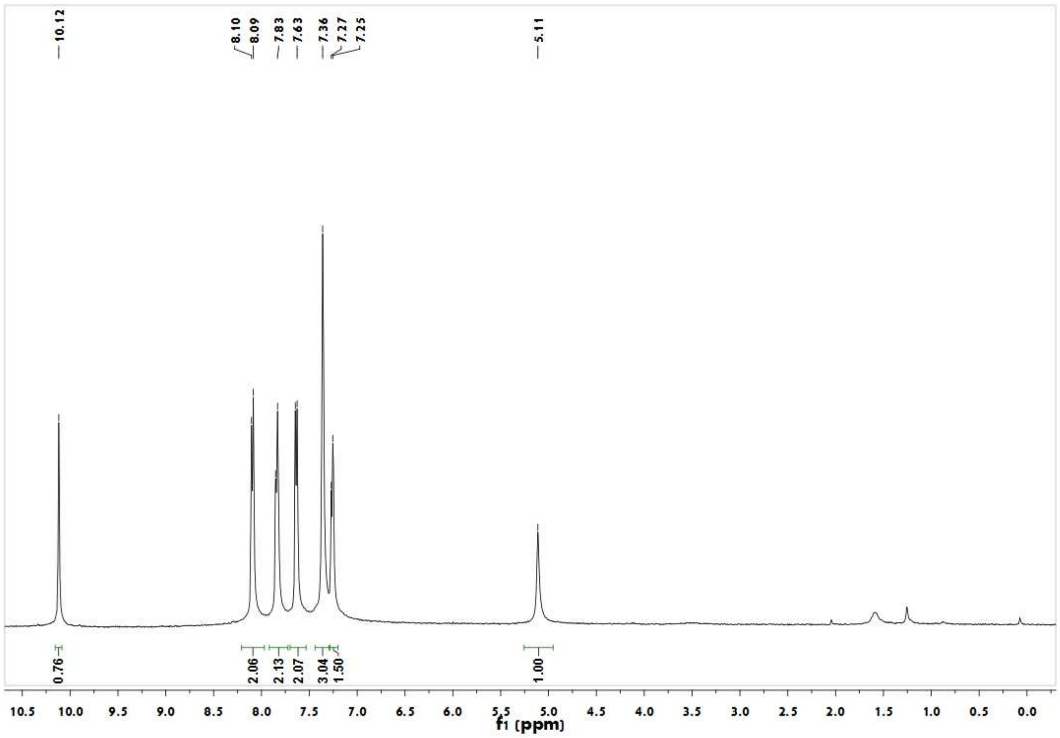
124.2
124.0
119.7
117.9
112.2
f1 (ppm)


CHO
OH

(**1g**)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8.10
8.09
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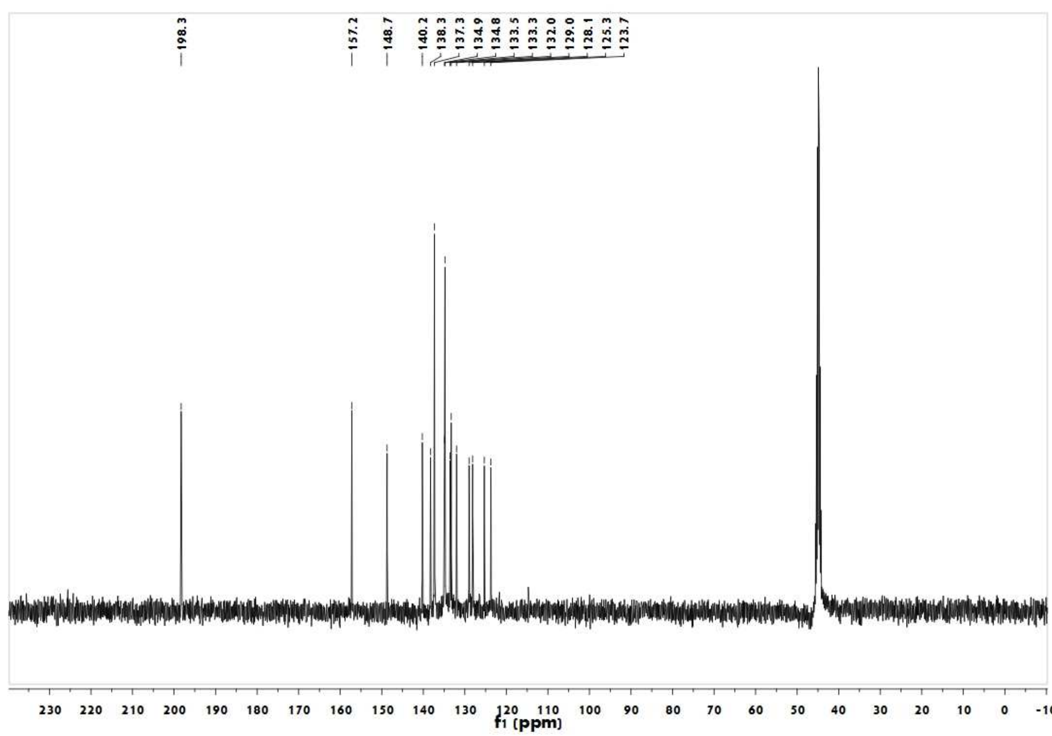
7.63
7.36
7.27
7.25
5.11
0.76
2.06
2.13
2.07
3.04
1.50
1.00
10.5 10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0
f1 (ppm)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157.2
148.7
140.2
138.3
137.3
134.9
134.8
133.5
133.3
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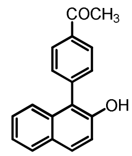
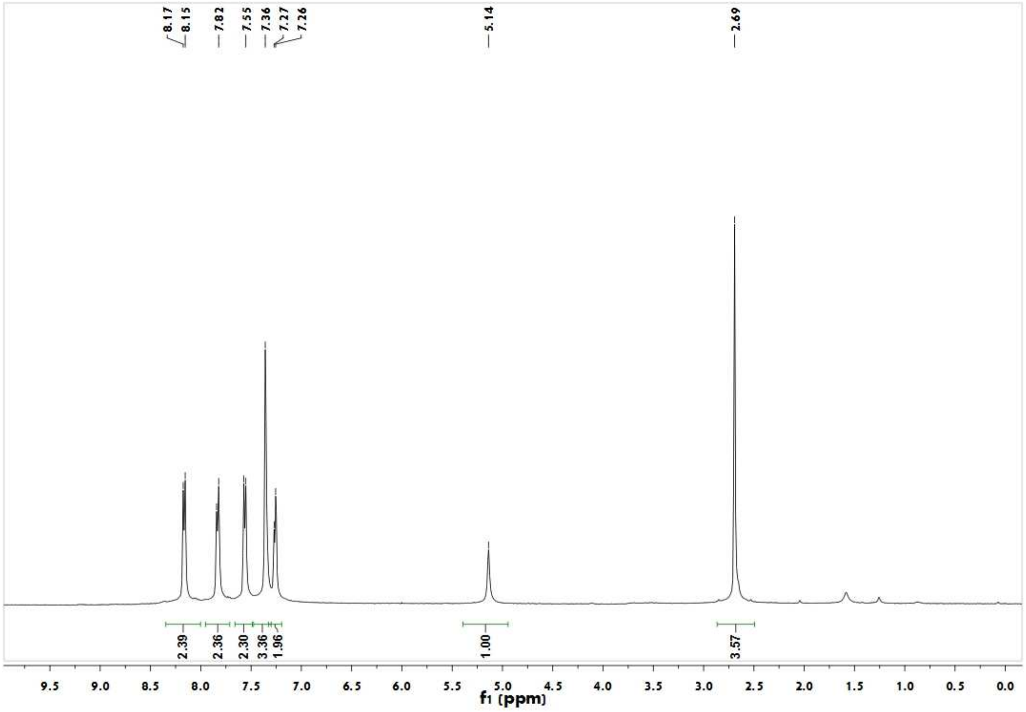
129.0
128.1
125.3
123.7
230 220 210 200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 -10
f1 (ppm)


COCH3
OH

(**1h**)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8.15
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7.26
5.14
2.69
2.39
2.36
2.30
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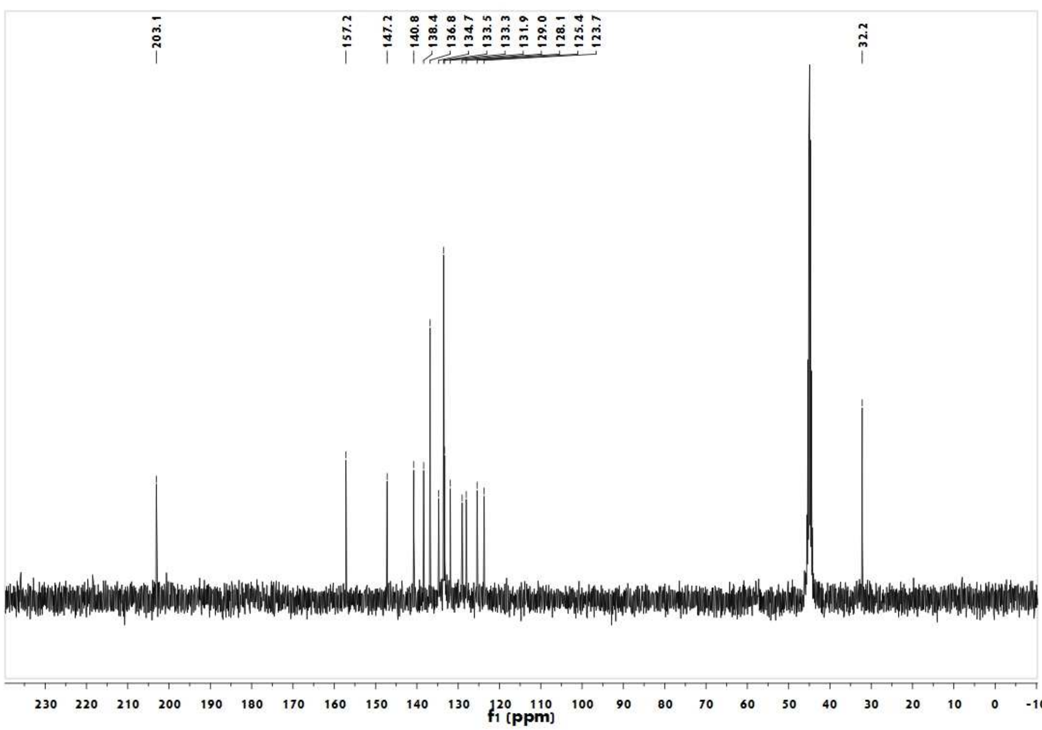
1.96
1.00
3.57
9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0
f1 (ppm)


203.1
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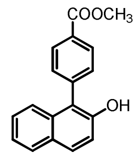
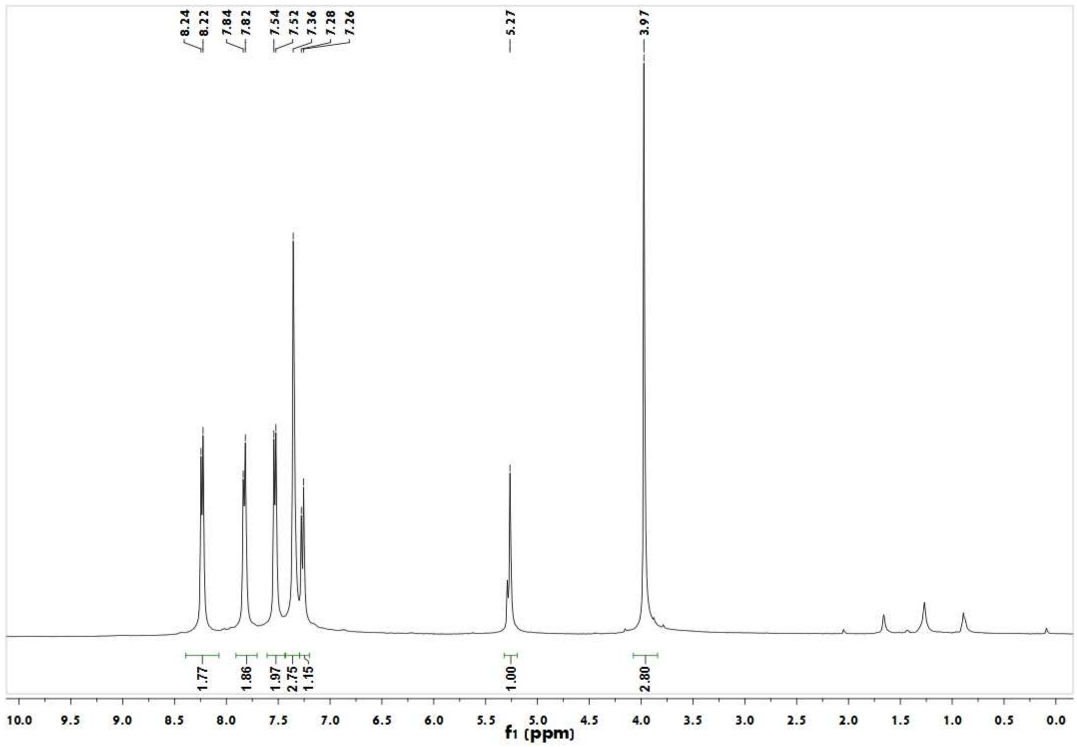
147.2
140.8
138.4
136.8
134.7
133.5
133.3
131.9
129.0
128.1
125.4
123.7
32.2
230 220 210 200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 -10
f1 (ppm)



COOCH3
OH

(**1i**)



8.24
8.22
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7.28
7.26
5.27
3.97
1.77
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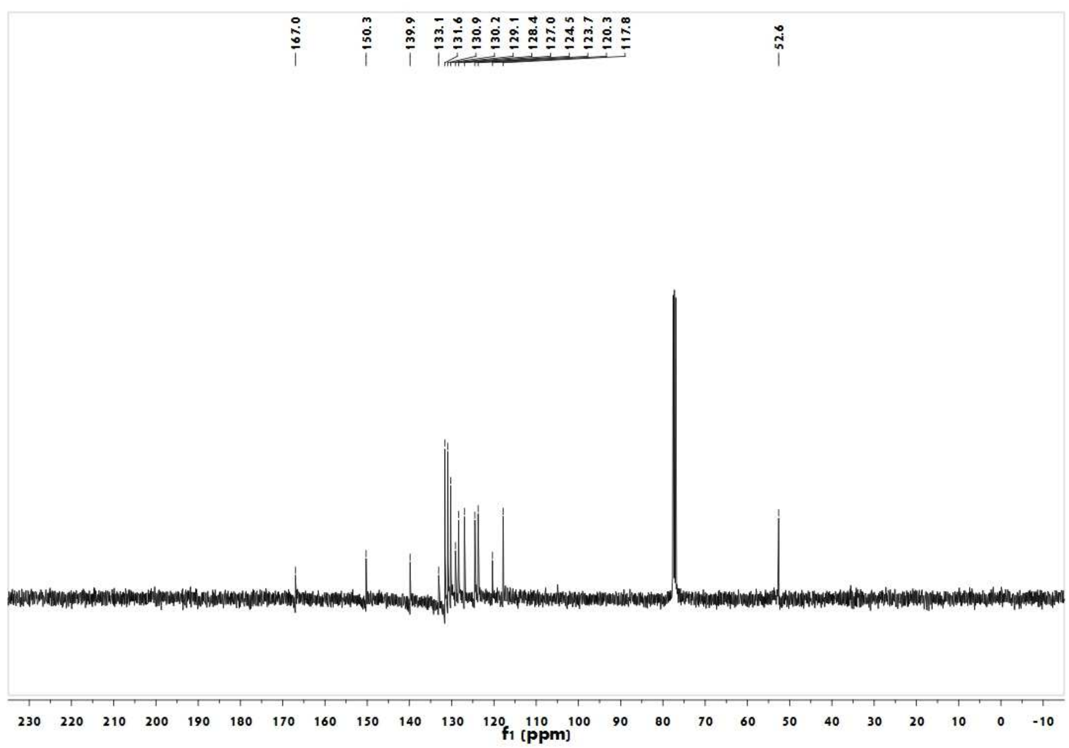
1.97
2.75
1.15
1.00
2.80
10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0
f1 (ppm)



167.0
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139.9
133.1
131.6
130.9
130.2
129.1
128.4
127.0
124.5
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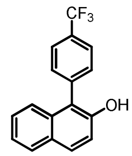
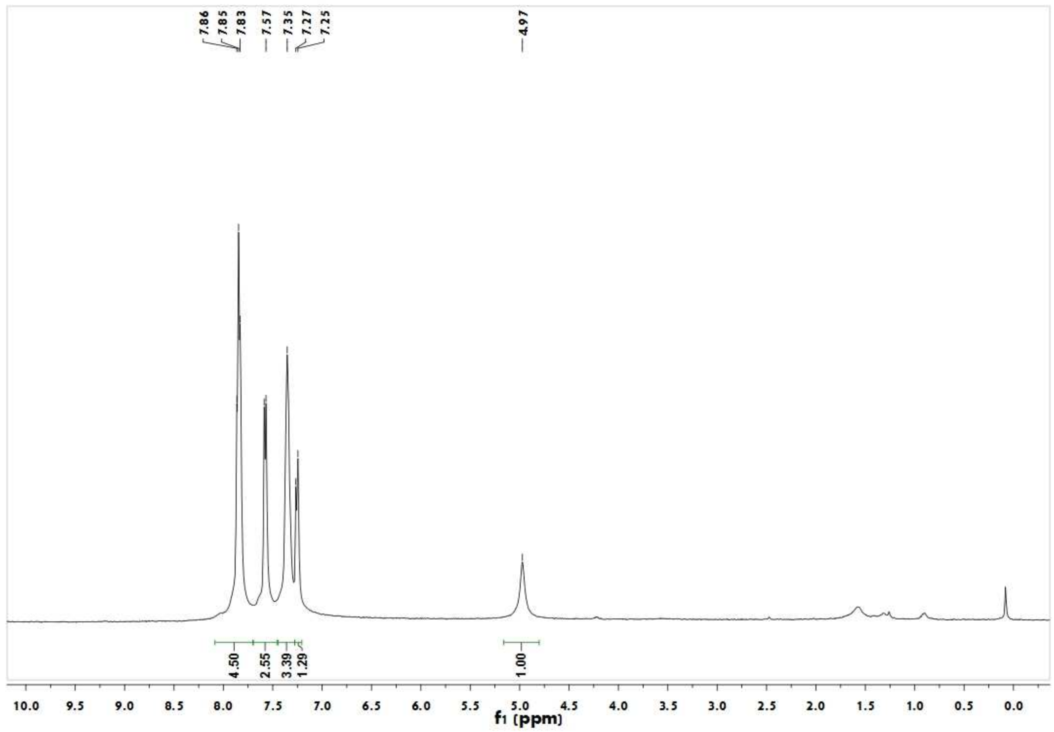
120.3
117.8
52.6
230 220 210 200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 -10
f1 (ppm)



CF3
OH

(**1j**)



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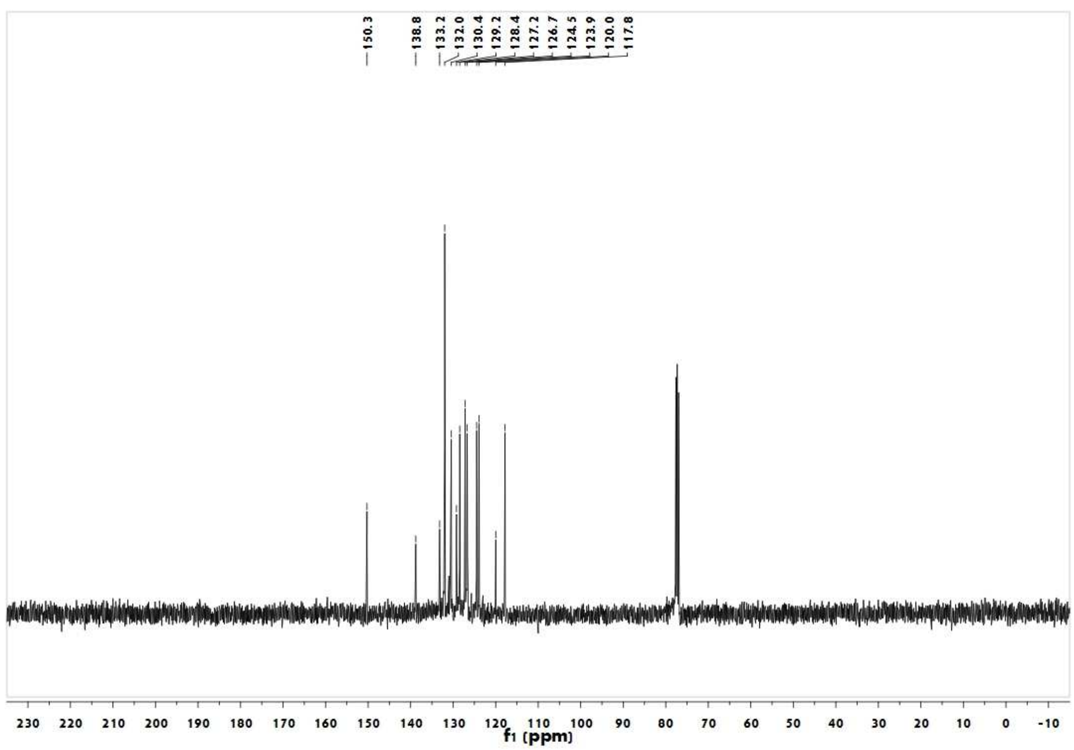
1.29
1.00
10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0
f1 (ppm)



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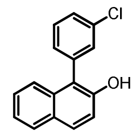
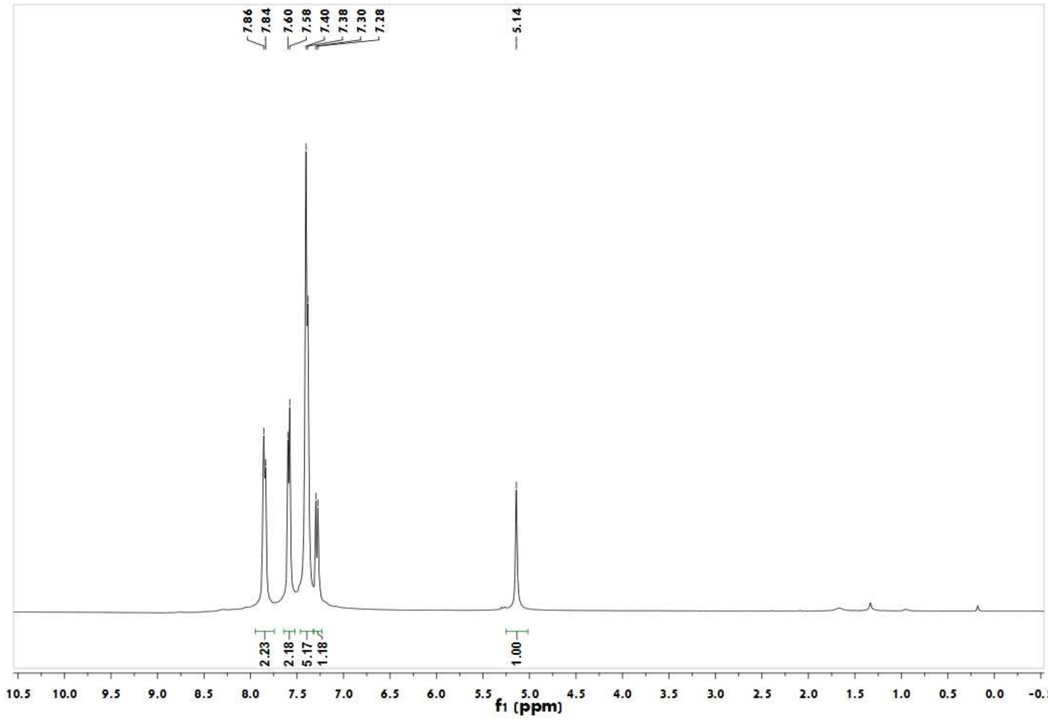
138.8
133.2
132.0
130.4
129.2
128.4
127.2
126.7
124.5
123.9
120.0
117.8
230 220 210 200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 -10
f1 (ppm)


Cl
OH

(**1l**)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7.28
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5.17
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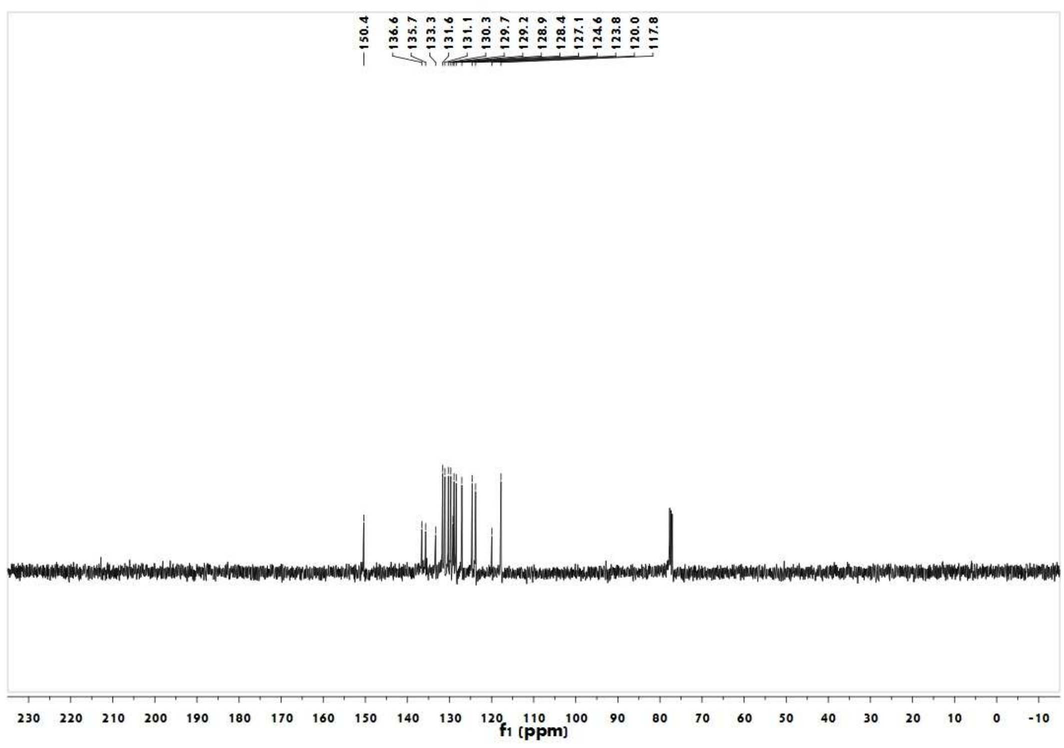
1.00
10.5 10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0 -0.5
f1 (ppm)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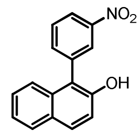
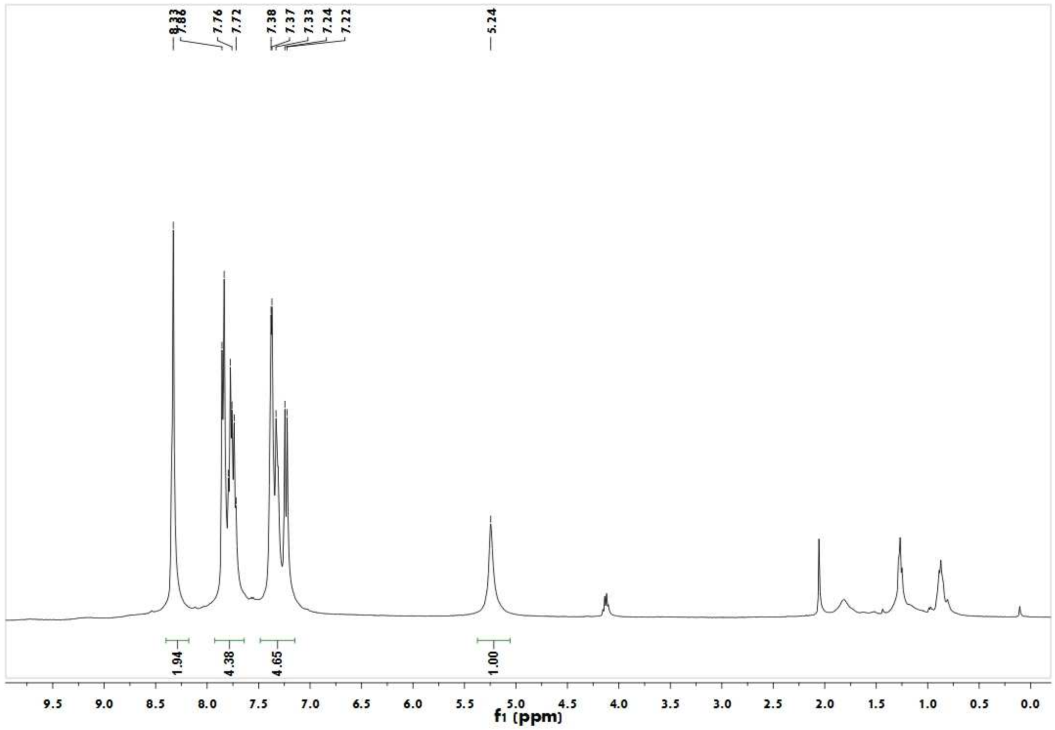
133.3
131.6
131.1
130.3
129.7
129.2
128.9
128.4
127.1
124.6
123.8
120.0
117.8
230 220 210 200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 -10
f1 (ppm)



(**1m**)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7.33
7.24
7.22
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4.38
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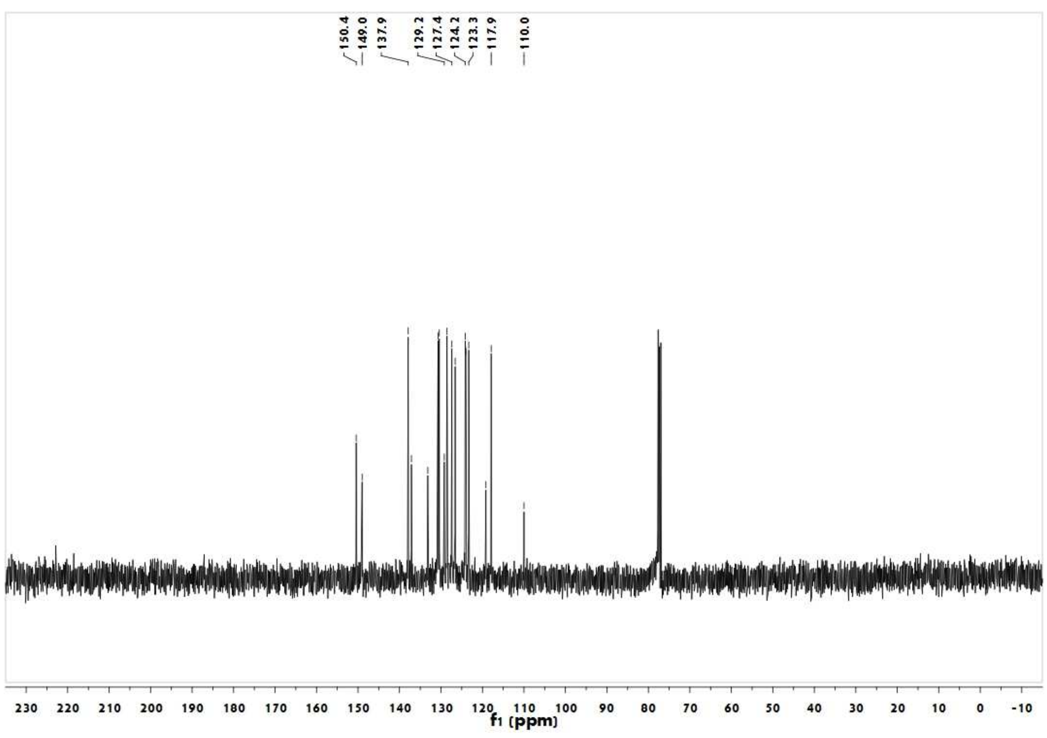
1.00
9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0
f1 (ppm)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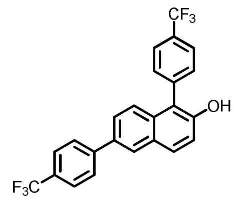
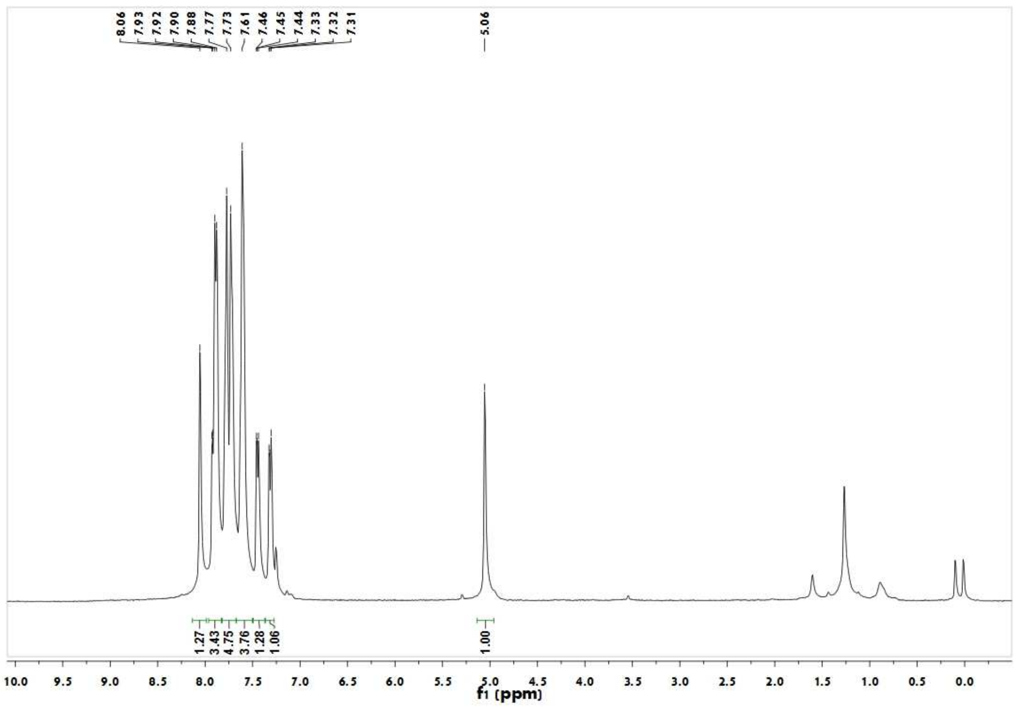
127.4
124.2
123.3
117.9
110.0
230 220 210 200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 -10
f1 (ppm)



(**1o**)



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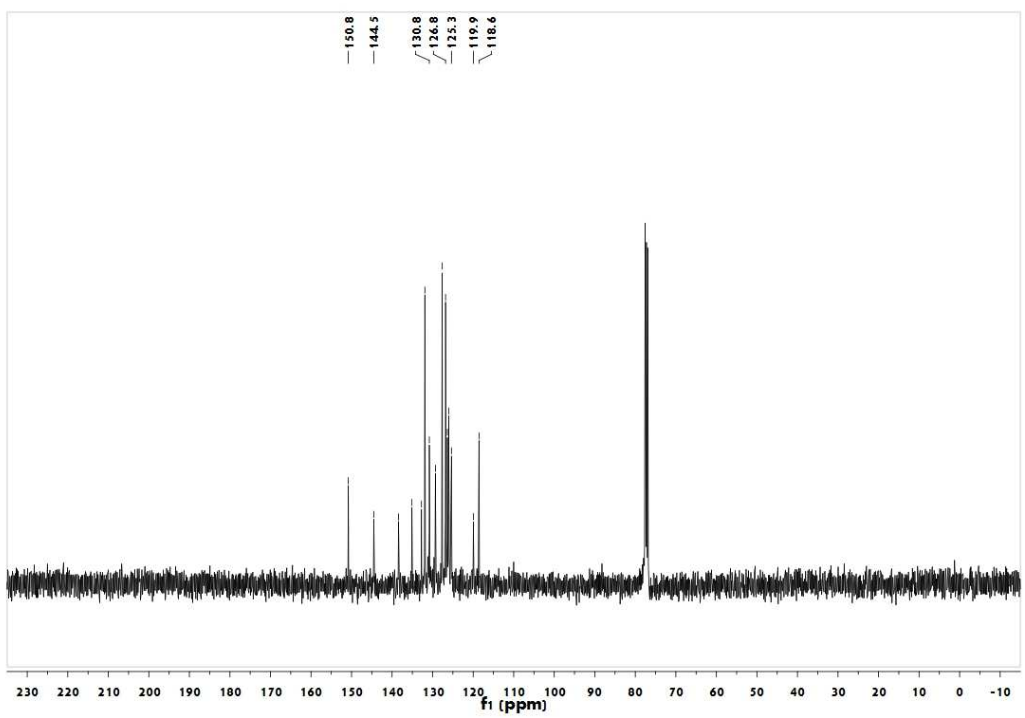
7.44
7.33
7.32
7.31
5.06
1.27
3.43
4.75
3.76
1.28
1.06
1.00
10.0
9.5
9.0
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
f1 (ppm)



150.8
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125.3
119.9
118.6
230
220
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200
190
180
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100
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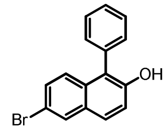
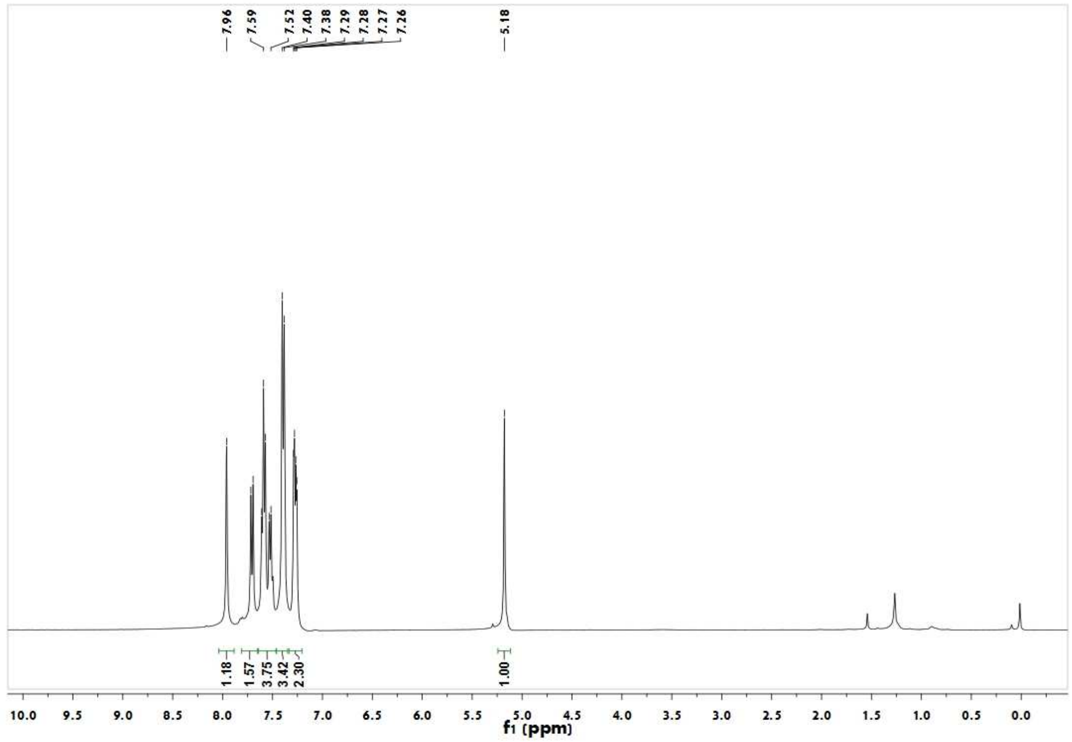
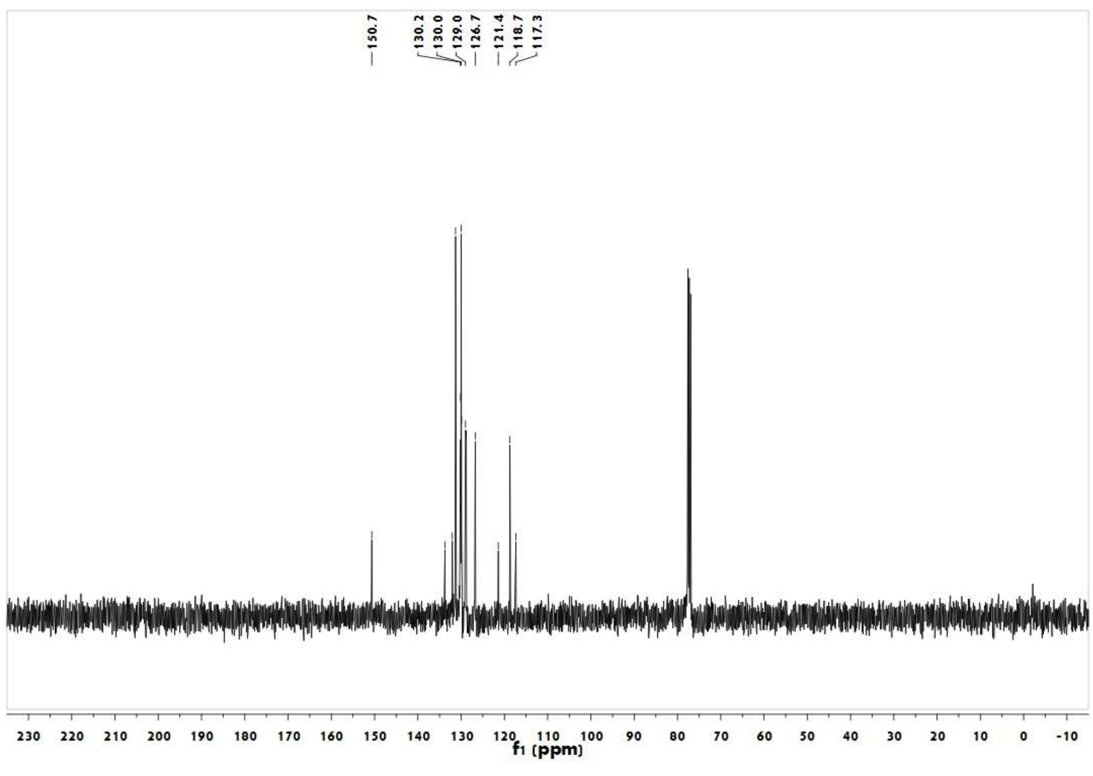
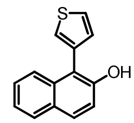
40
30
20
10
0
-10
f1 (ppm)



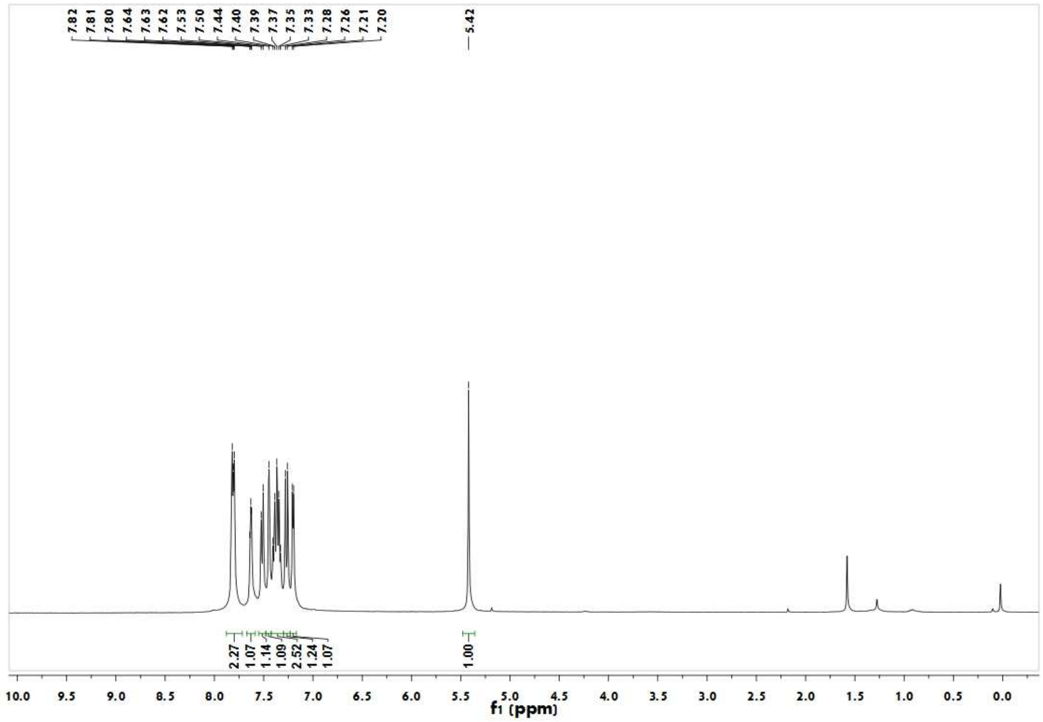
(**1n**)






S
OH

(**1q**)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7.62
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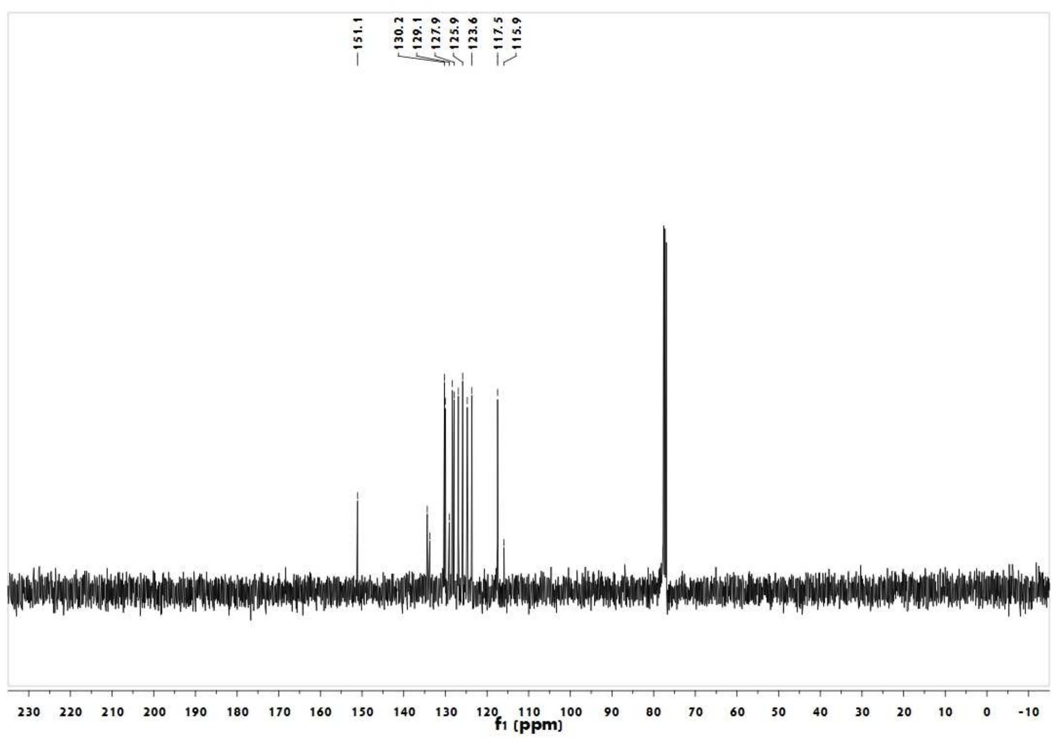
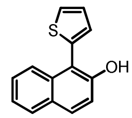
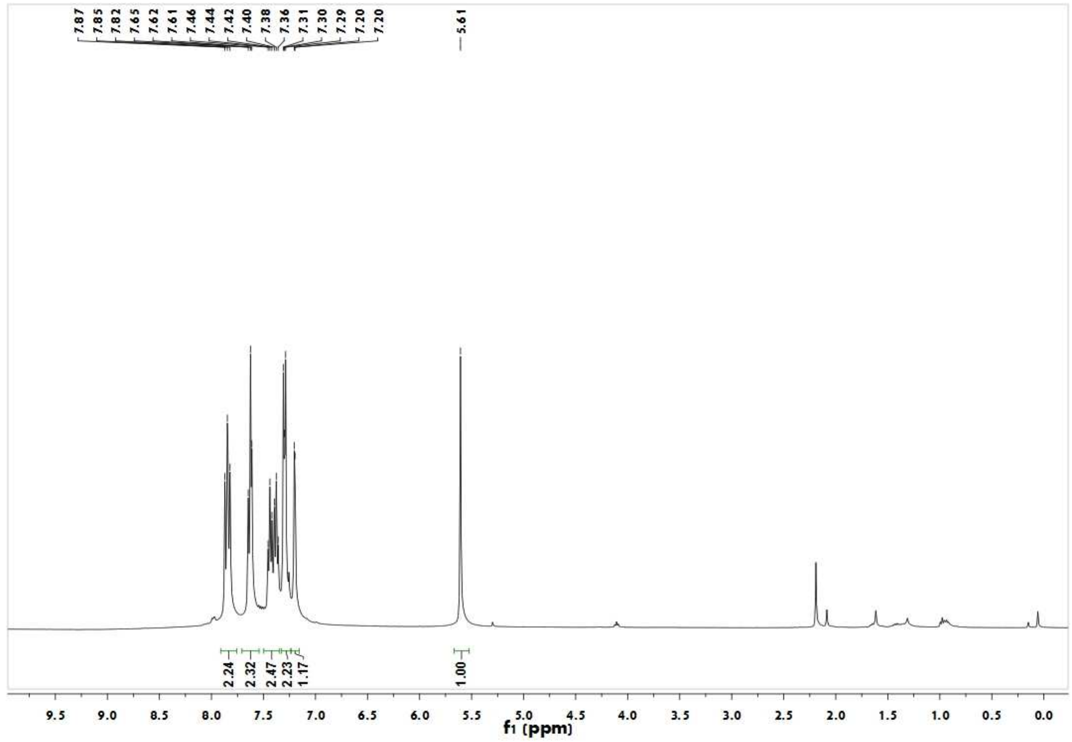
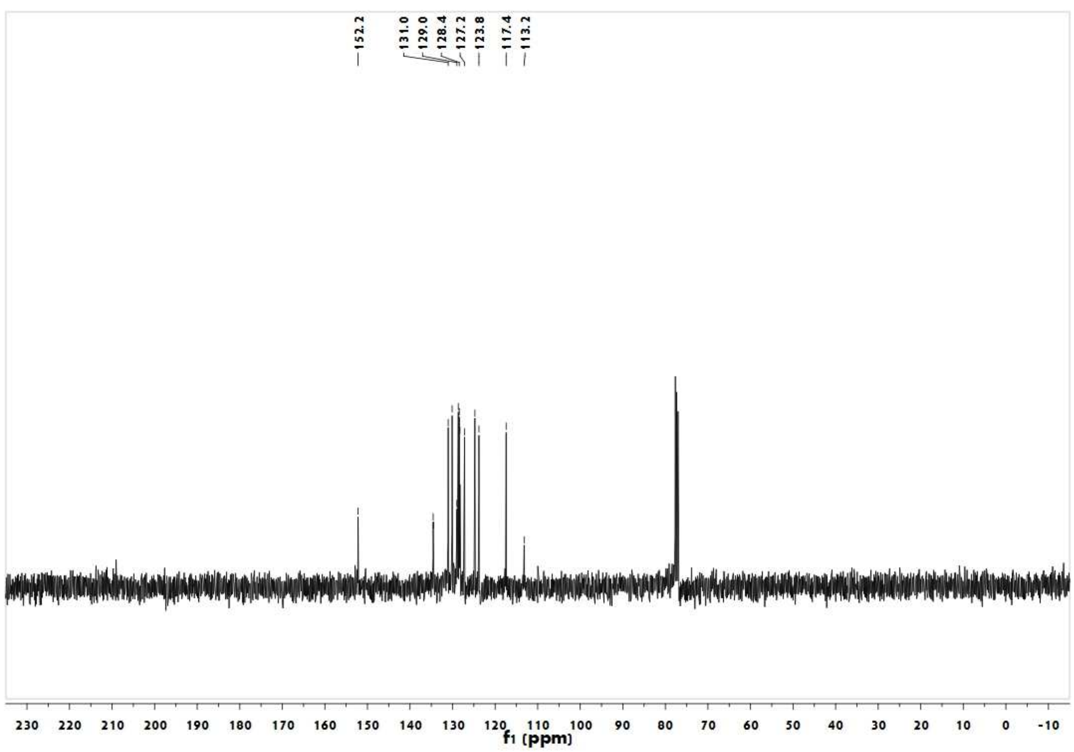
7.50
7.44
7.40
7.39
7.37
7.35
7.33
7.28
7.26
7.21
7.20
5.42
2.27
1.07
1.14
1.09
2.52
1.24
1.07
1.00
10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0
f1 (ppm)

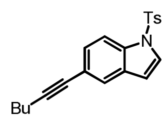

151.1
130.2
129.1
127.9
125.9
123.6
117.5
115.9
230 220 210 200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 -10
f1 (ppm)



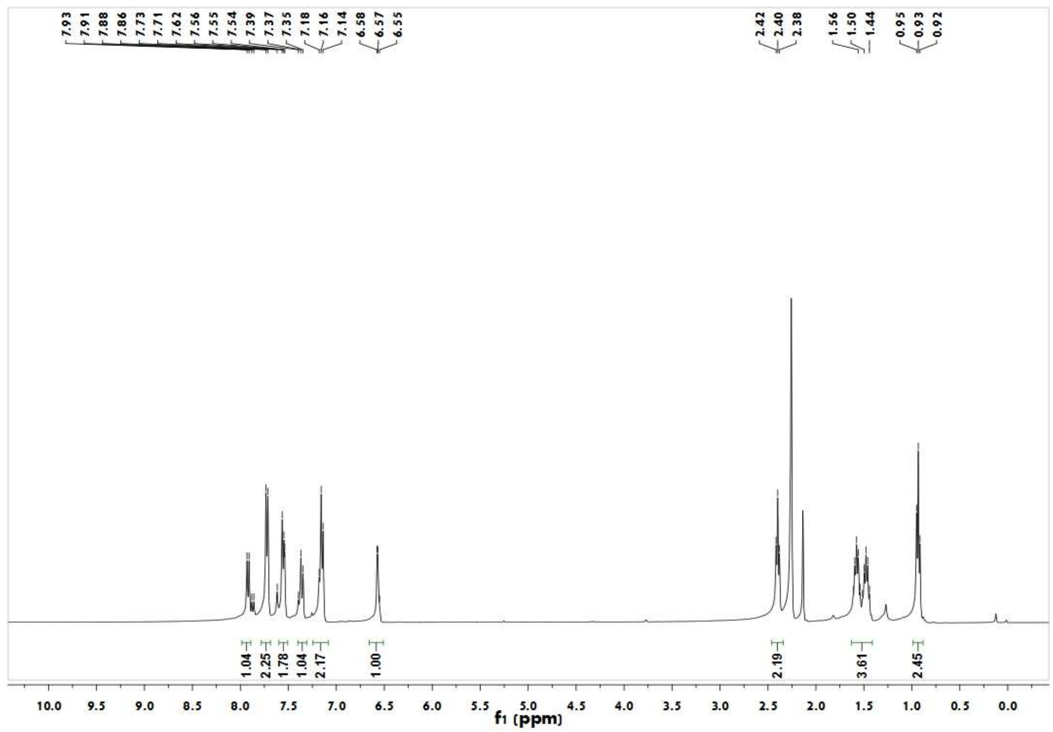
(**1p**)

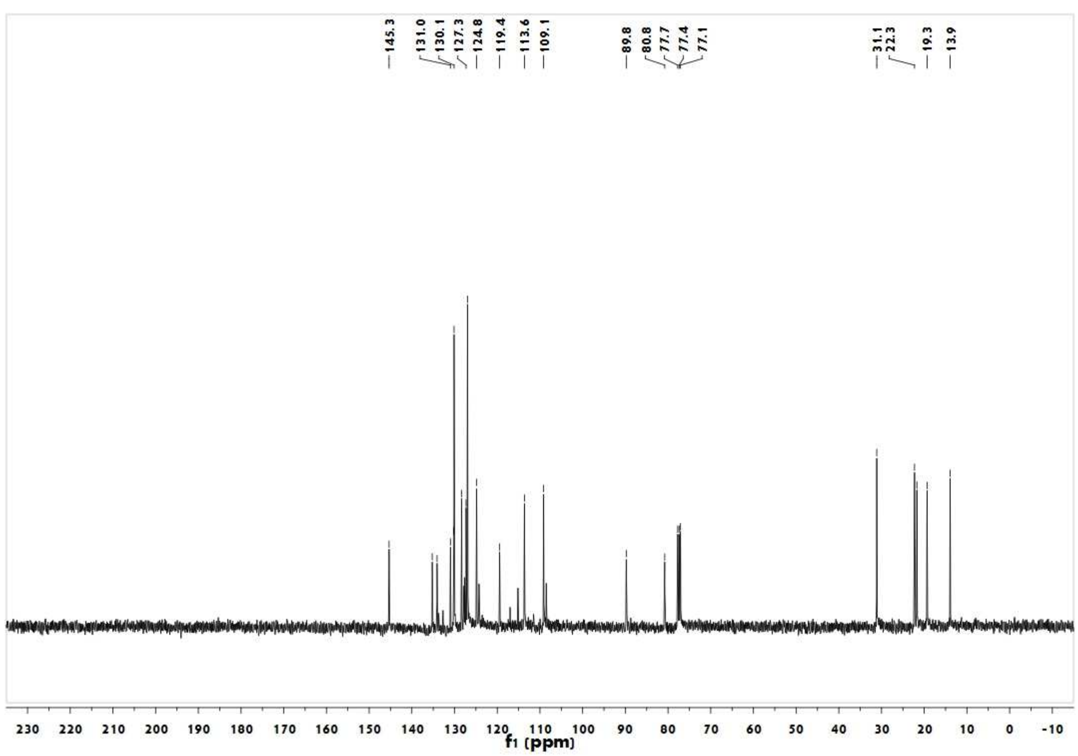


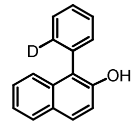



Ts
N
Bu

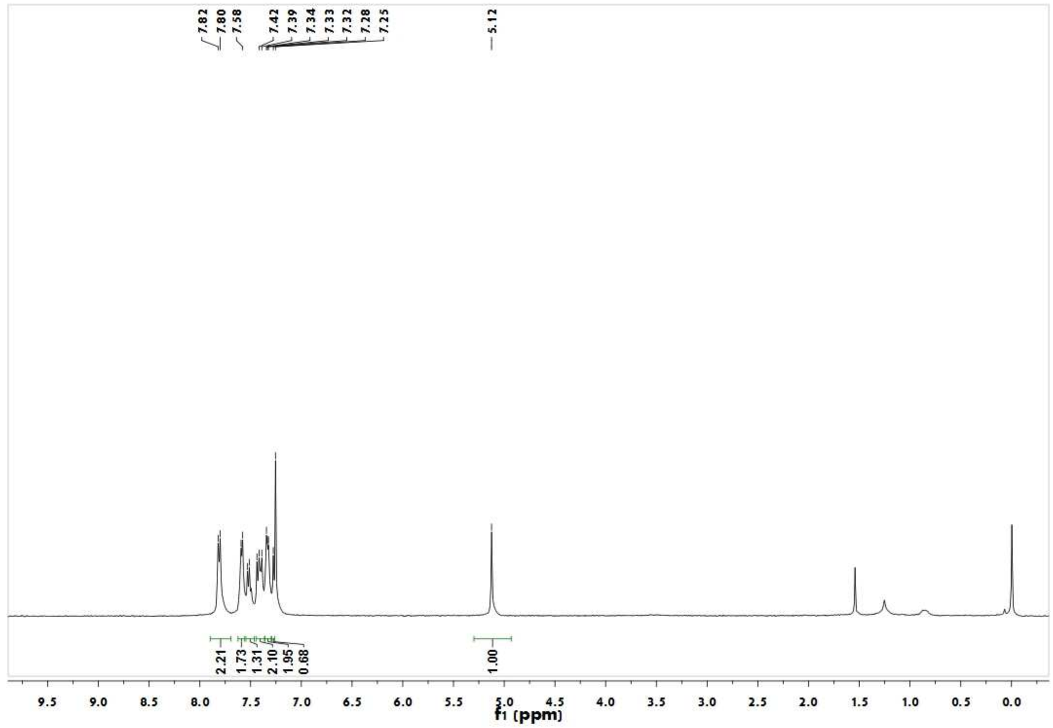
(**2i**)

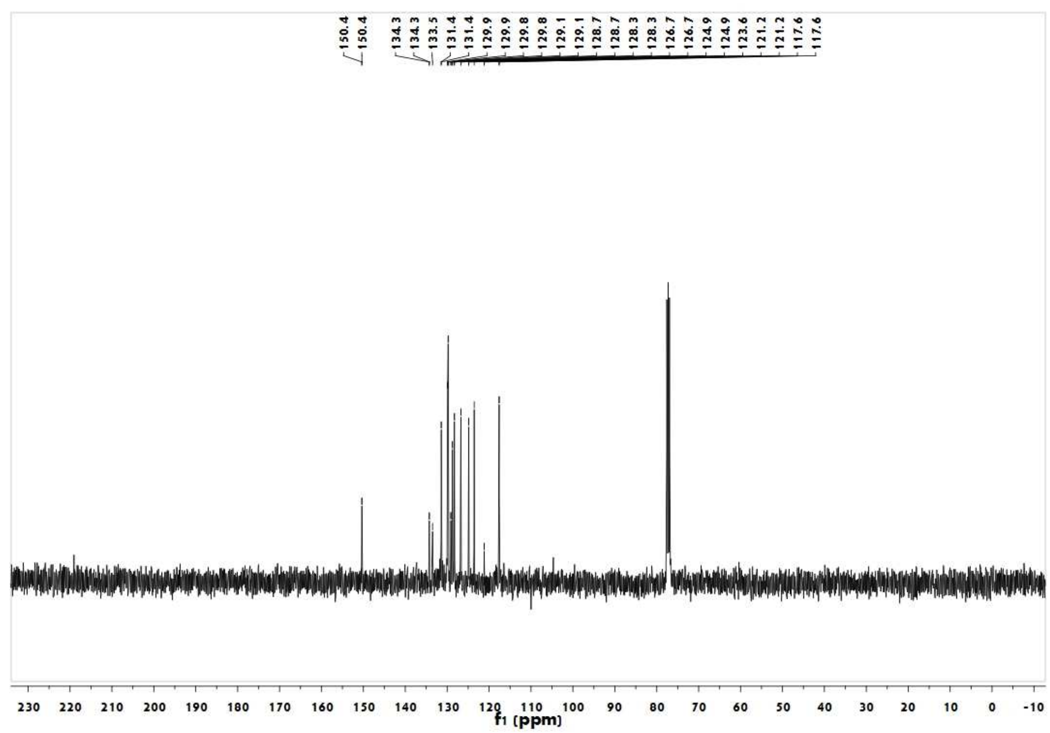

7.93
7.91
7.88
7.86
7.73
7.71
7.62
7.56
7.55
7.54
7.39
7.37
7.35
7.18
7.16
7.14
6.58
6.57
6.55
2.42
2.40
2.38
1.56
1.50
1.44
0.95
0.93
0.92
1.04
2.25
1.78
1.04
2.17
1.00
2.19
3.61
2.45
10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0
f1 (ppm)

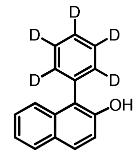

145.3
131.0
130.1
127.3
124.8
119.4
113.6
109.1
89.8
80.8
77.7
77.4
77.1
31.1
22.3
19.3
13.9
230 220 210 200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 -10
f1 (ppm)



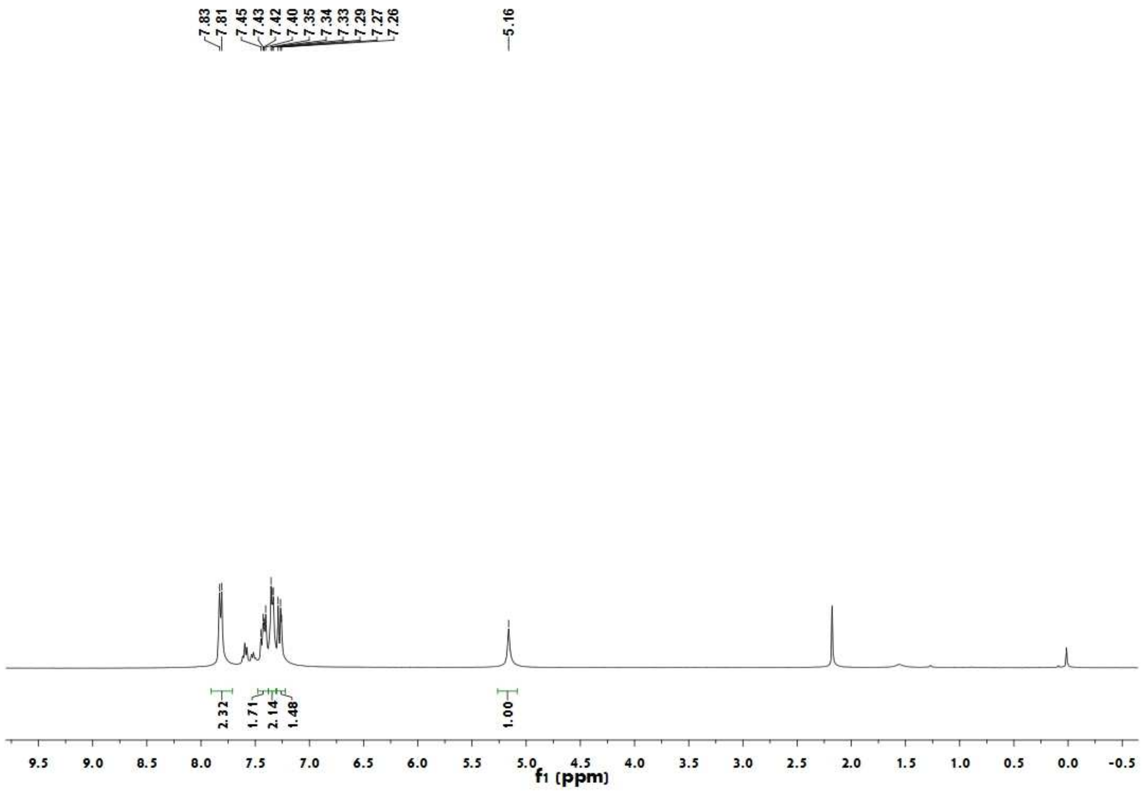
(**1a-*d*$_1$**)

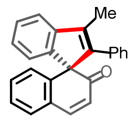




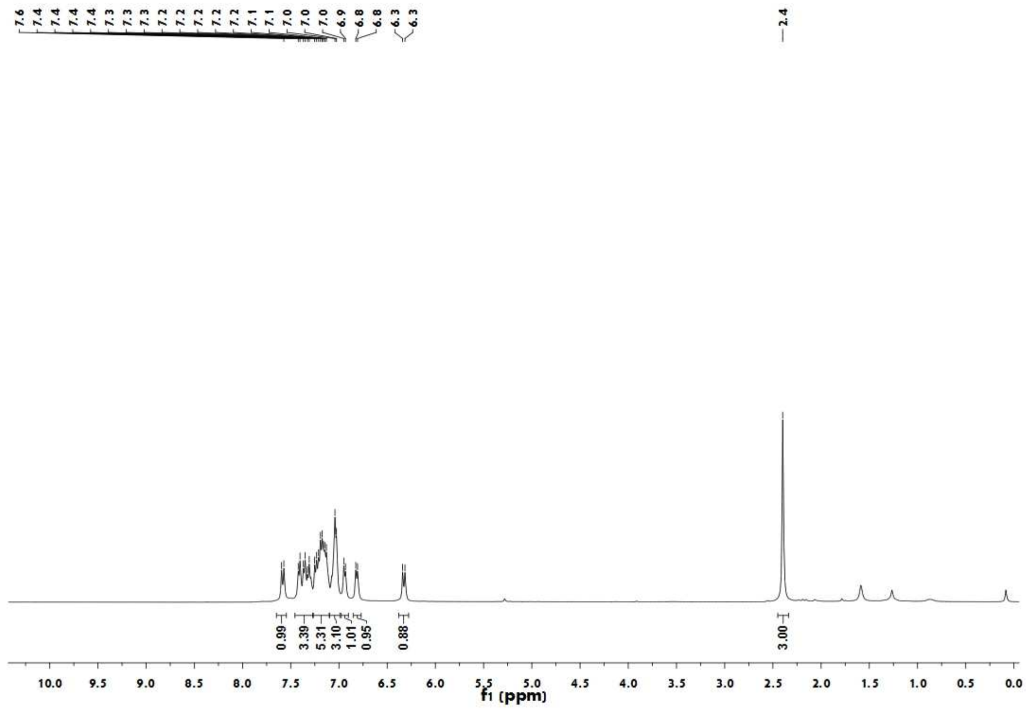


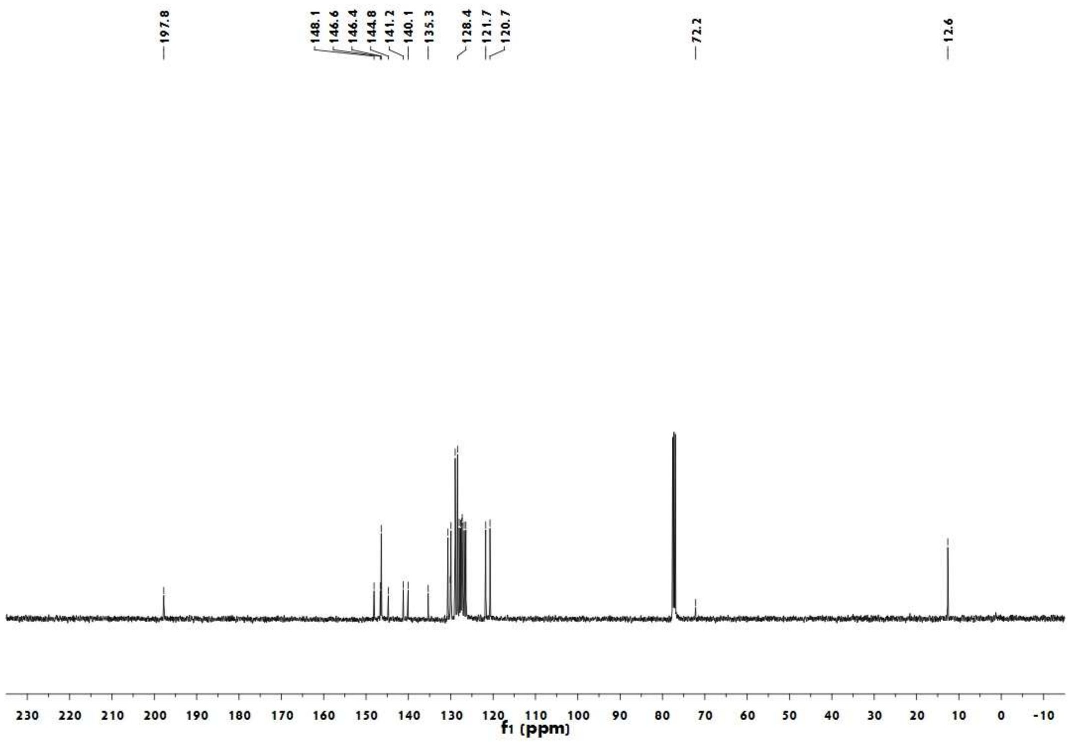
($\mathbf{1a}$-d_5, 75% deuterated)

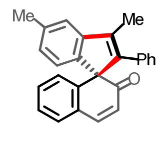



Me
Ph
O

(**3a**)

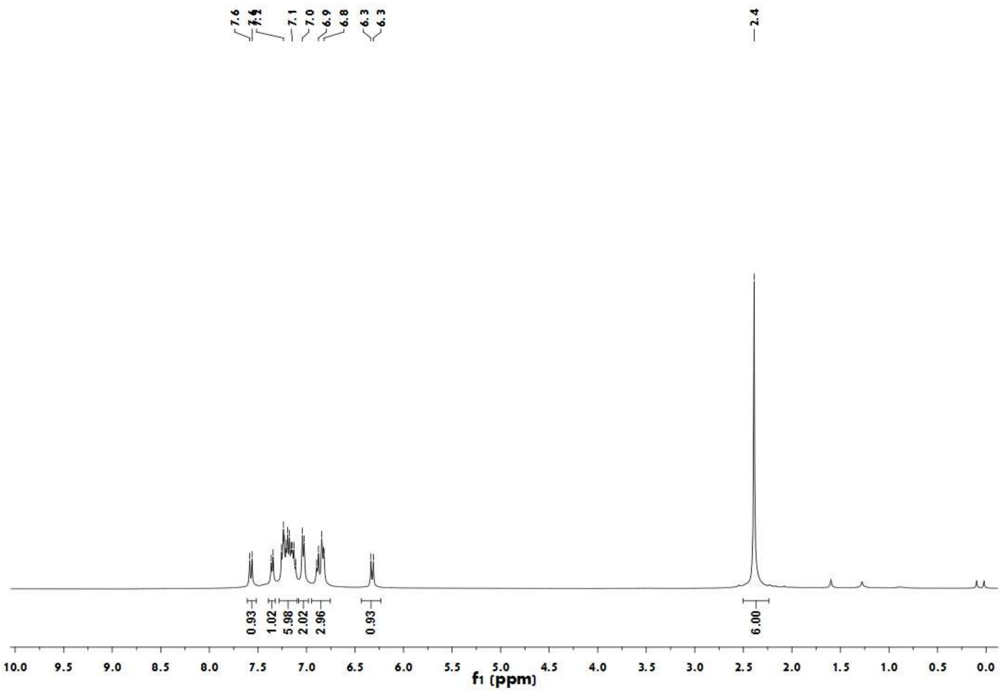

7.6
7.4
7.4
7.4
7.4
7.3
7.3
7.3
7.2
7.2
7.2
7.2
7.2
7.1
7.1
7.0
7.0
7.0
6.9
6.9
6.8
6.8
6.3
6.3
2.4
0.99
3.39
5.31
3.10
1.01
0.95
0.88
3.00
10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0
f1 (ppm)


197.8
148.1
146.6
146.4
144.8
141.2
140.1
135.3
128.4
121.7
120.7
72.2
12.6
230 220 210 200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 -10
f1 (ppm)

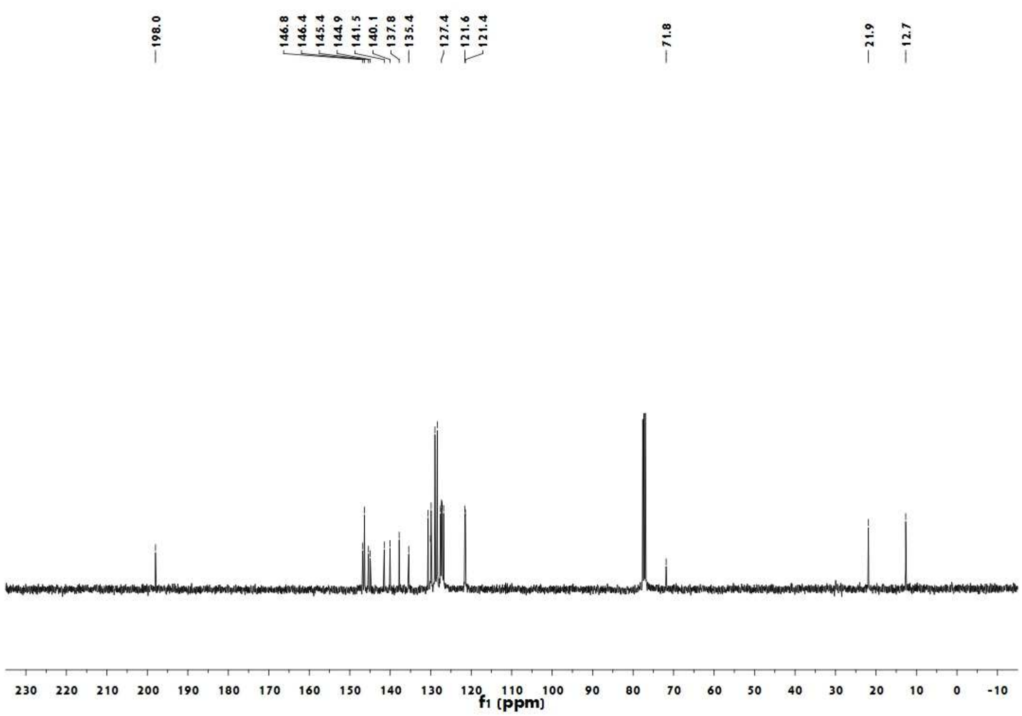


Me
Me
Ph
O

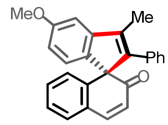
(**3b**)



7.6
7.4
7.2
7.1
7.0
6.9
6.8
6.3
6.3
2.4
0.93
1.02
5.98
2.02
2.96
0.93
6.00
10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0
f1 (ppm)

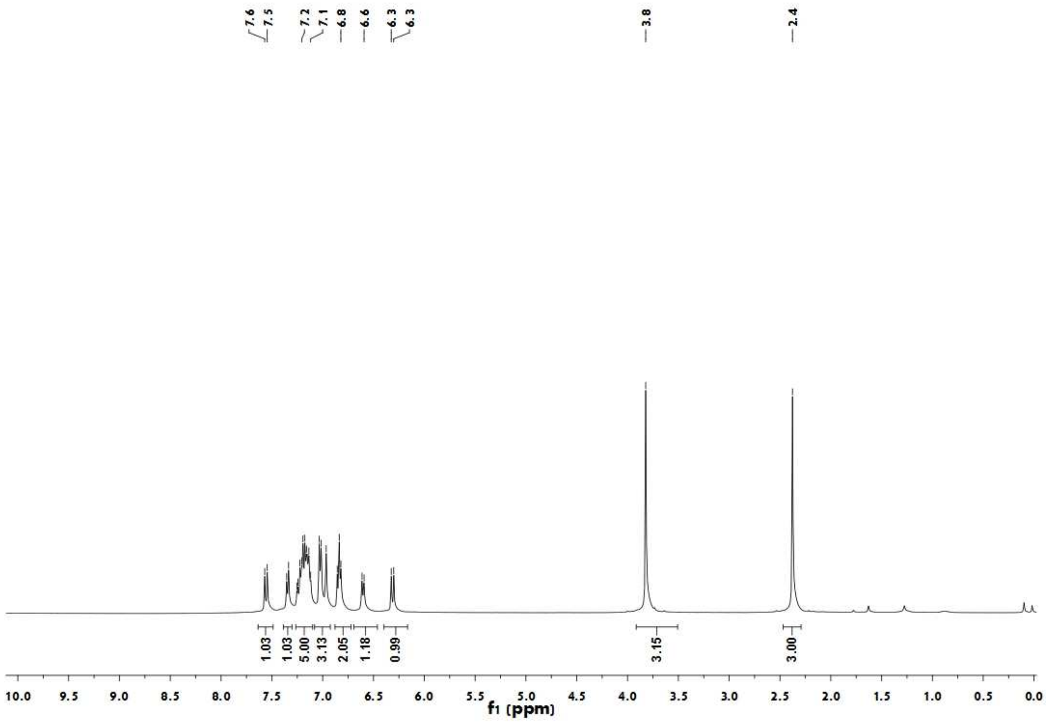


198.0
146.8
146.4
145.4
144.9
141.5
140.1
137.8
135.4
127.4
121.6
121.4
71.8
21.9
12.7
230 220 210 200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 -10
f1 (ppm)

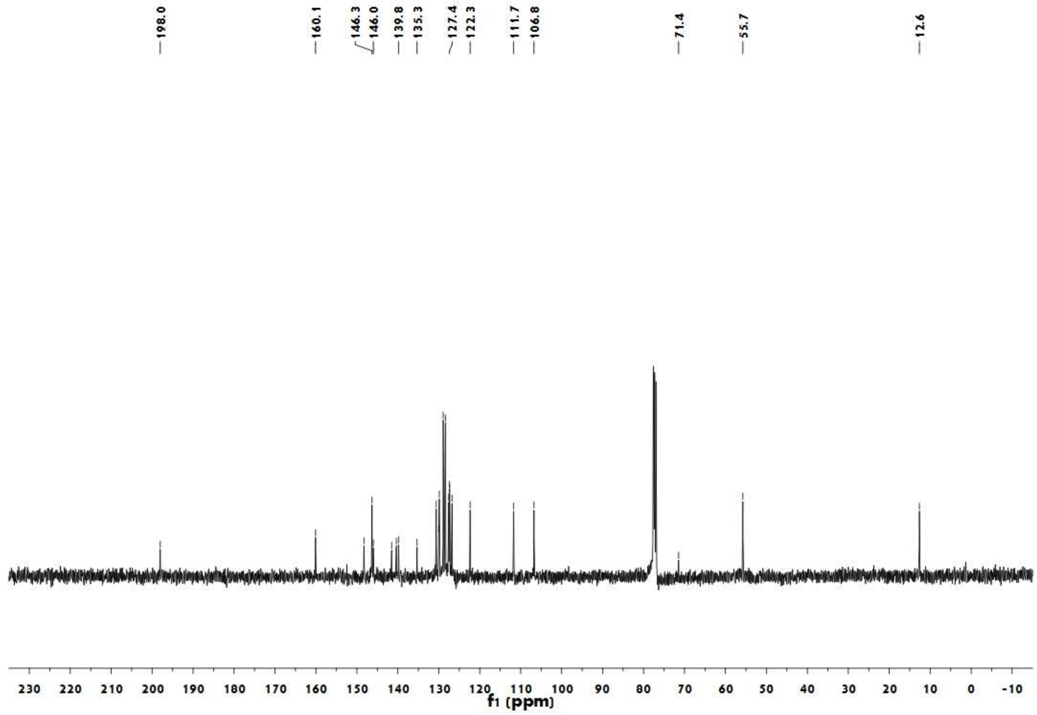


MeO
Me
Ph
O

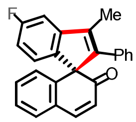
(**3c**)



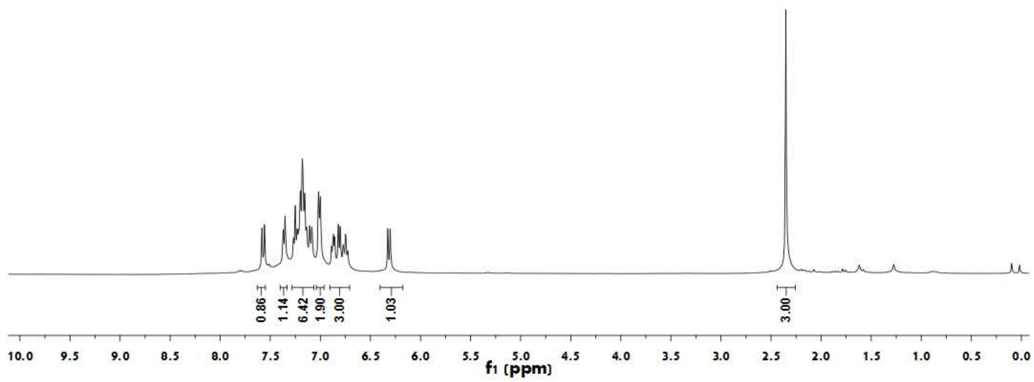
7.6
7.5
7.2
7.1
6.8
6.6
6.3
6.3
3.8
2.4
1.03
1.03
5.00
3.13
2.05
1.18
0.99
3.15
3.00
10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0
f1 (ppm)

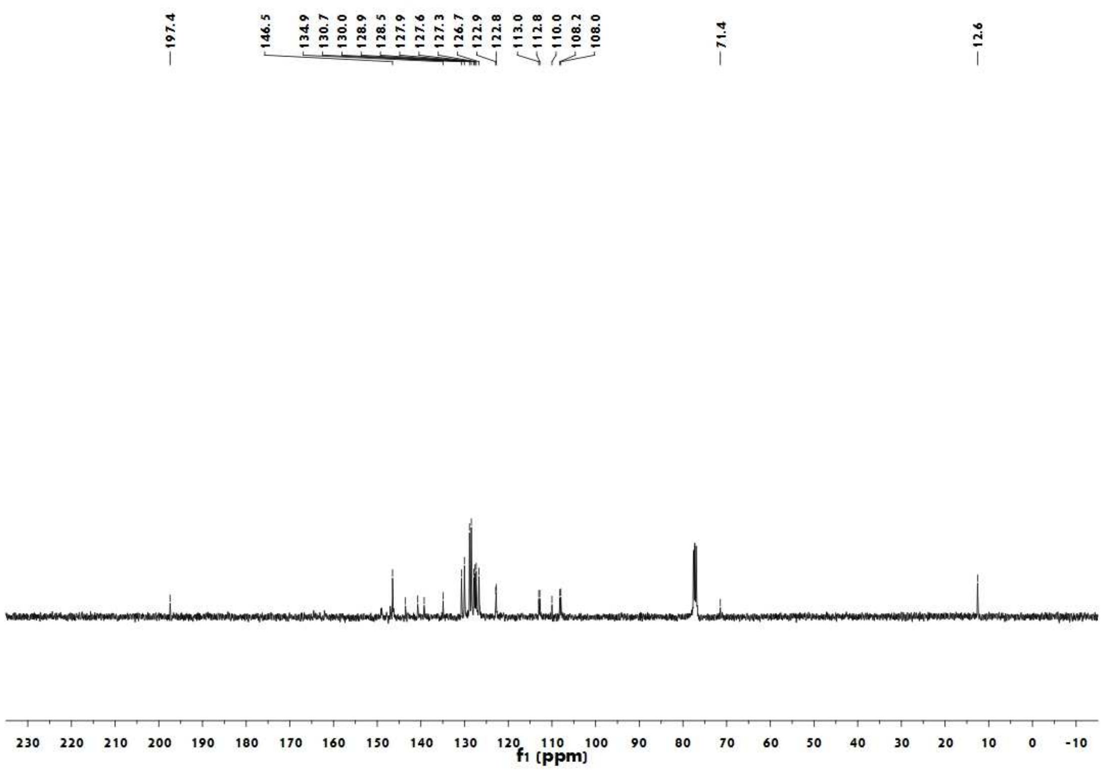


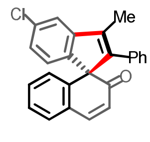
198.0
160.1
146.3
146.0
139.8
135.3
127.4
122.3
111.7
106.8
71.4
55.7
12.6
230 220 210 200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 -10
f1 (ppm)


F
Me
Ph
O

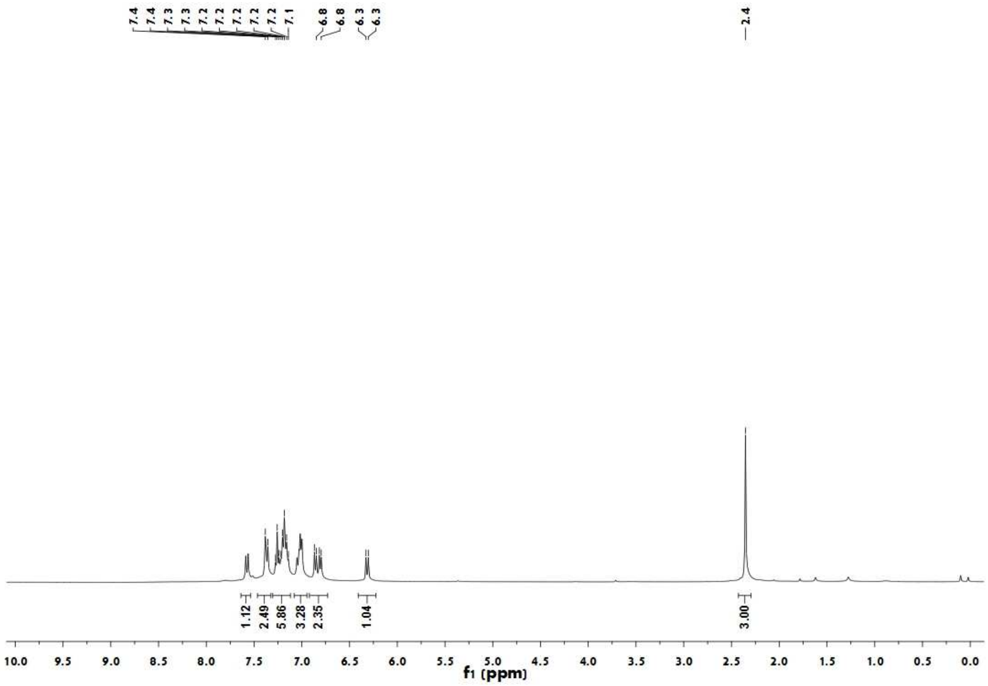
(**3d**)

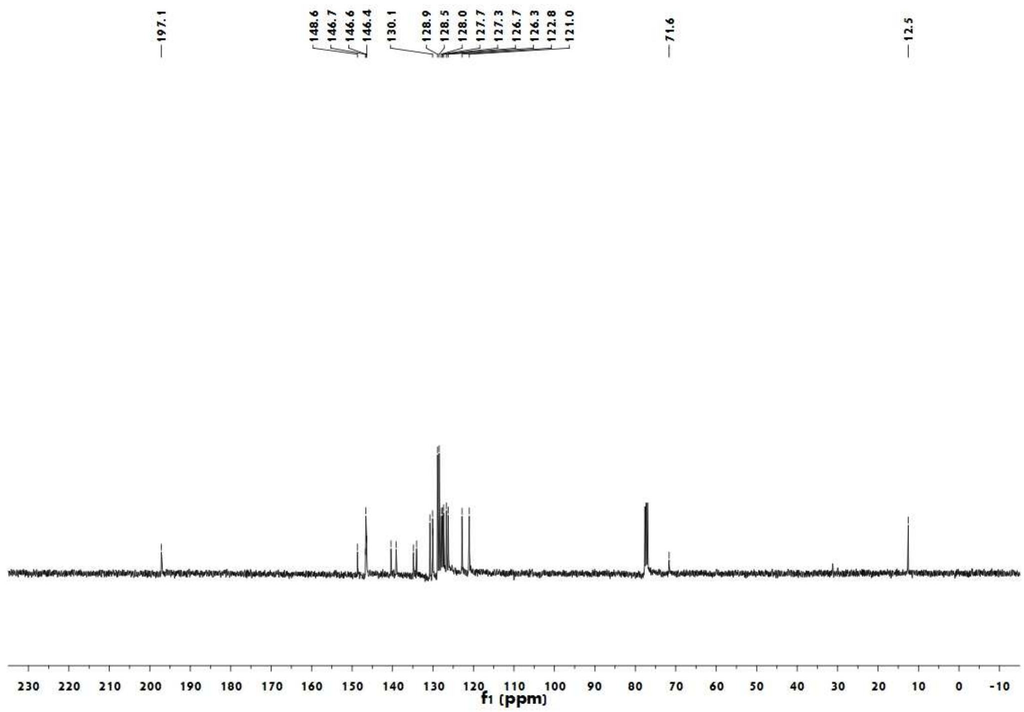

0.86
1.14
6.42
1.90
3.00
1.03
3.00
10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0
f1 (ppm)

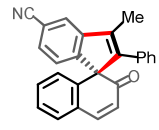

197.4
146.5
134.9
130.7
130.0
128.9
128.5
127.9
127.6
127.3
126.7
122.9
122.8
113.0
112.8
110.0
108.2
108.0
71.4
12.6
230 220 210 200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 -10
f1 (ppm)


Cl
Me
Ph
O

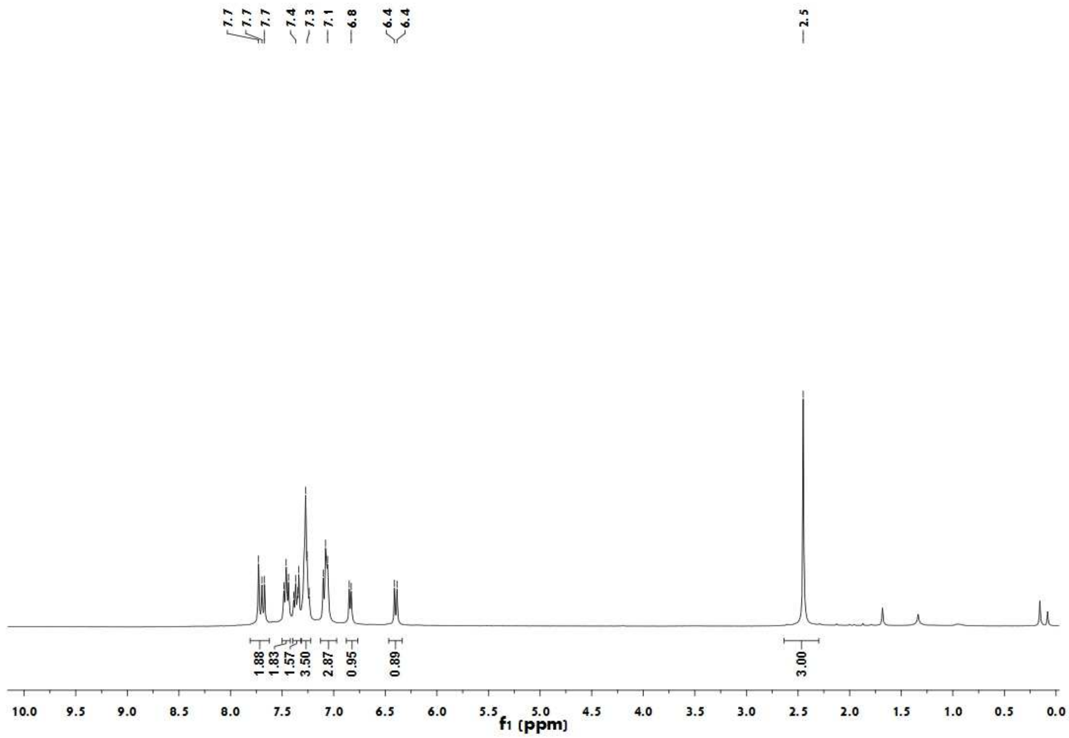
(**3e**)

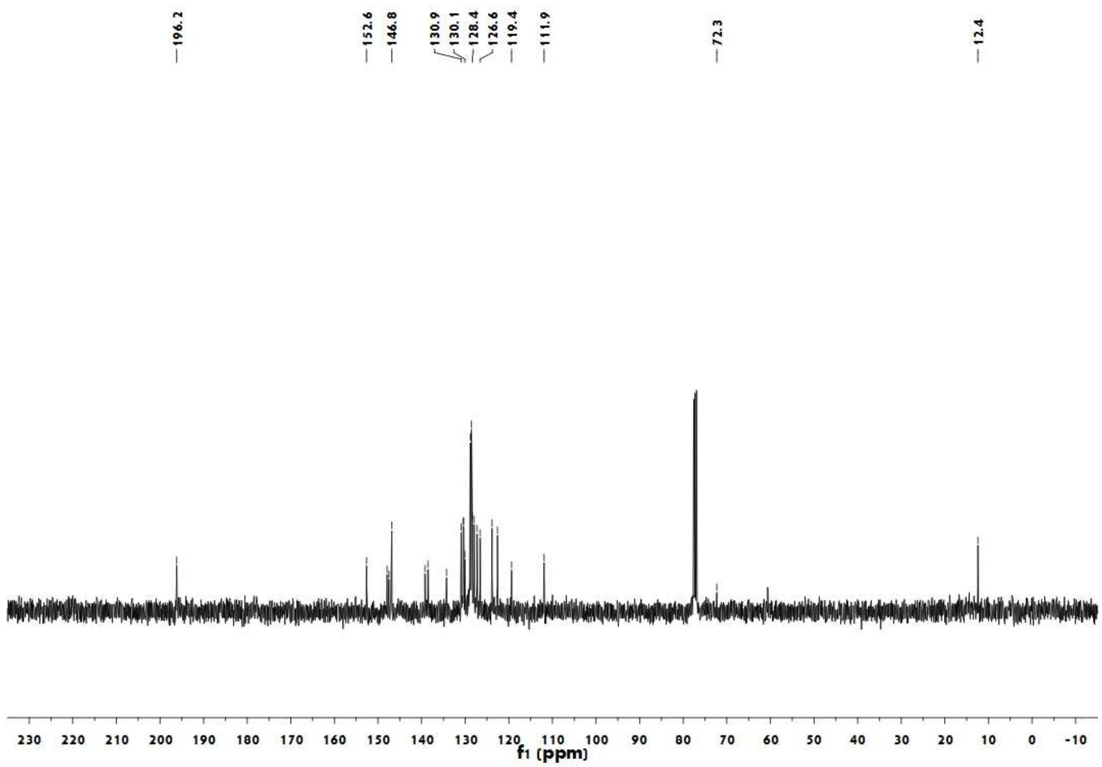

7.4
7.4
7.3
7.3
7.2
7.2
7.2
7.2
7.2
7.1
6.8
6.8
6.3
6.3
2.4
1.12
2.49
5.86
3.28
2.35
1.04
3.00
10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0
f1 (ppm)

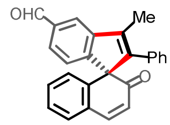

197.1
148.6
146.7
146.6
146.4
130.1
128.9
128.5
128.0
127.7
127.3
126.7
126.3
122.8
121.0
71.6
12.5
230 220 210 200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 -10
f1 (ppm)



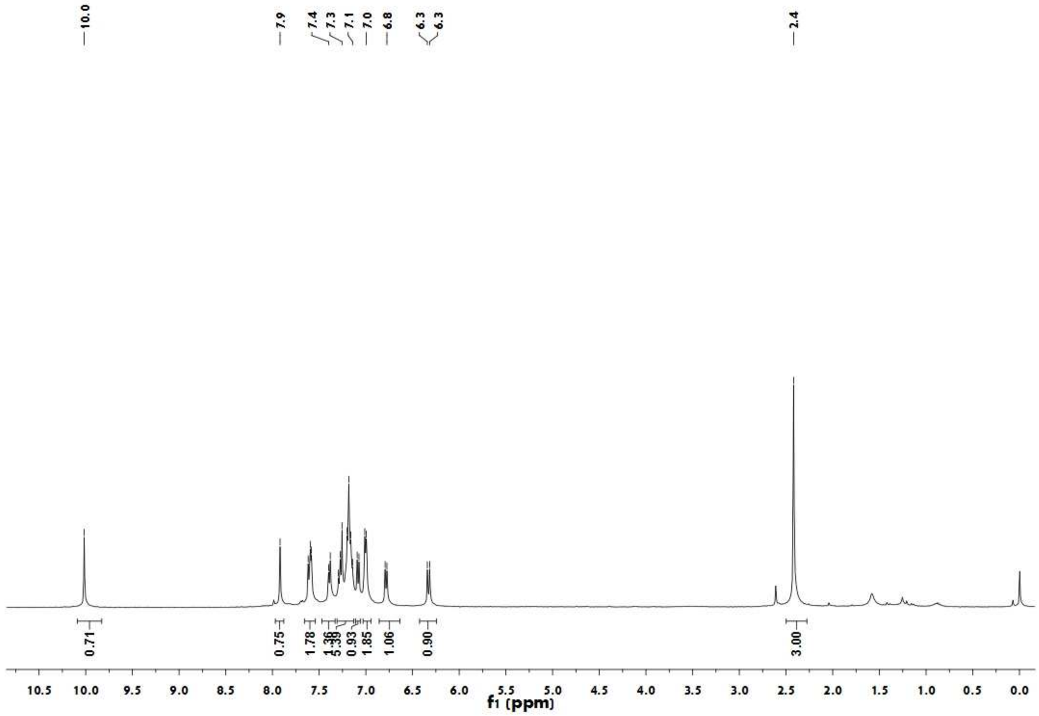
(**3f**)

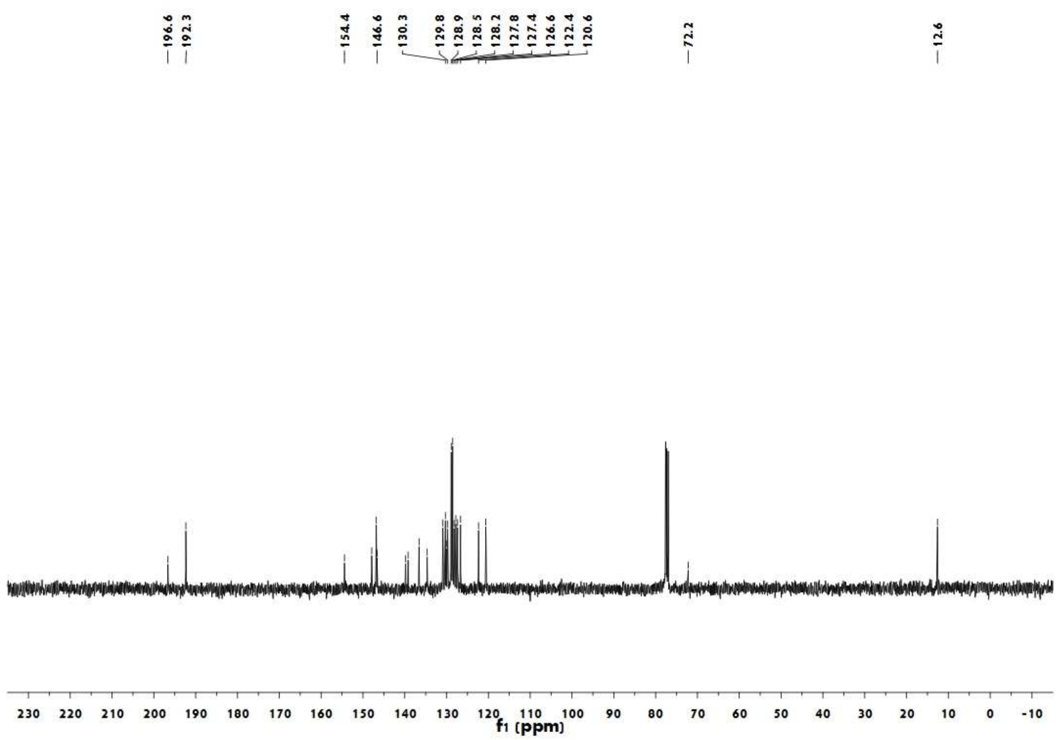


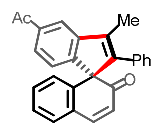



OHC
Me
Ph
O

(**3g**)

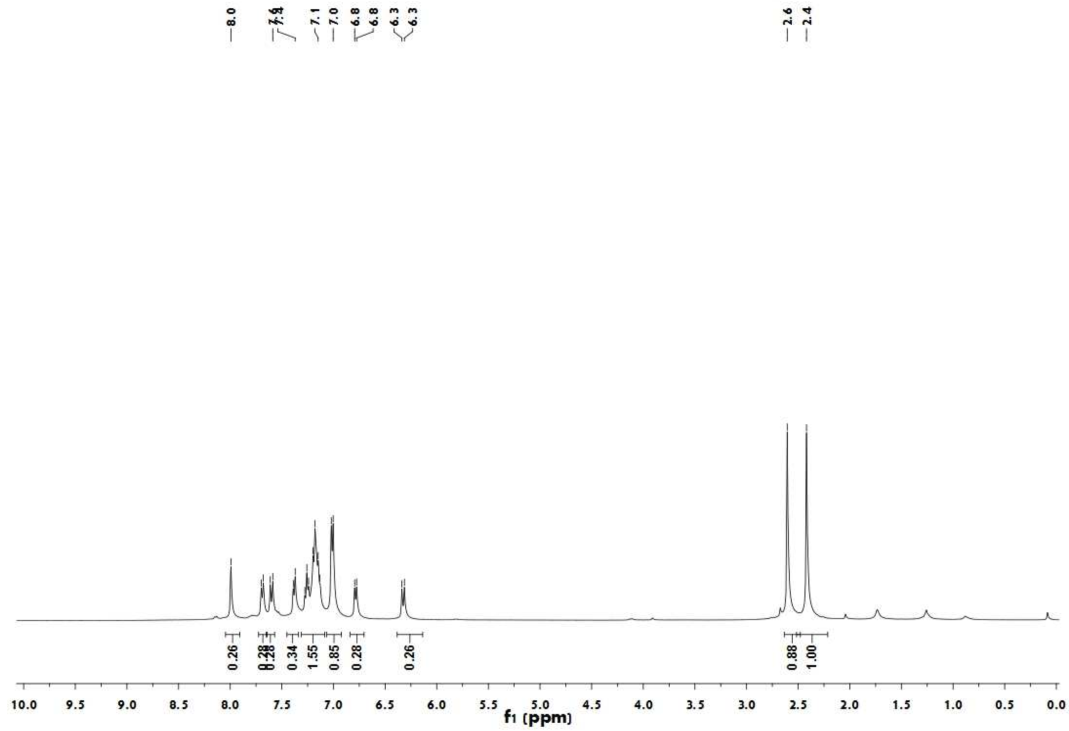

10.0
7.9
7.4
7.3
7.1
7.0
6.8
6.3
6.3
2.4
0.71
0.75
1.78
1.36
5.38
0.93
1.85
1.06
0.90
3.00
f1 (ppm)


196.6
192.3
154.4
146.6
130.3
129.8
128.9
128.5
128.2
127.8
127.4
126.6
122.4
120.6
72.2
12.6
f1 (ppm)

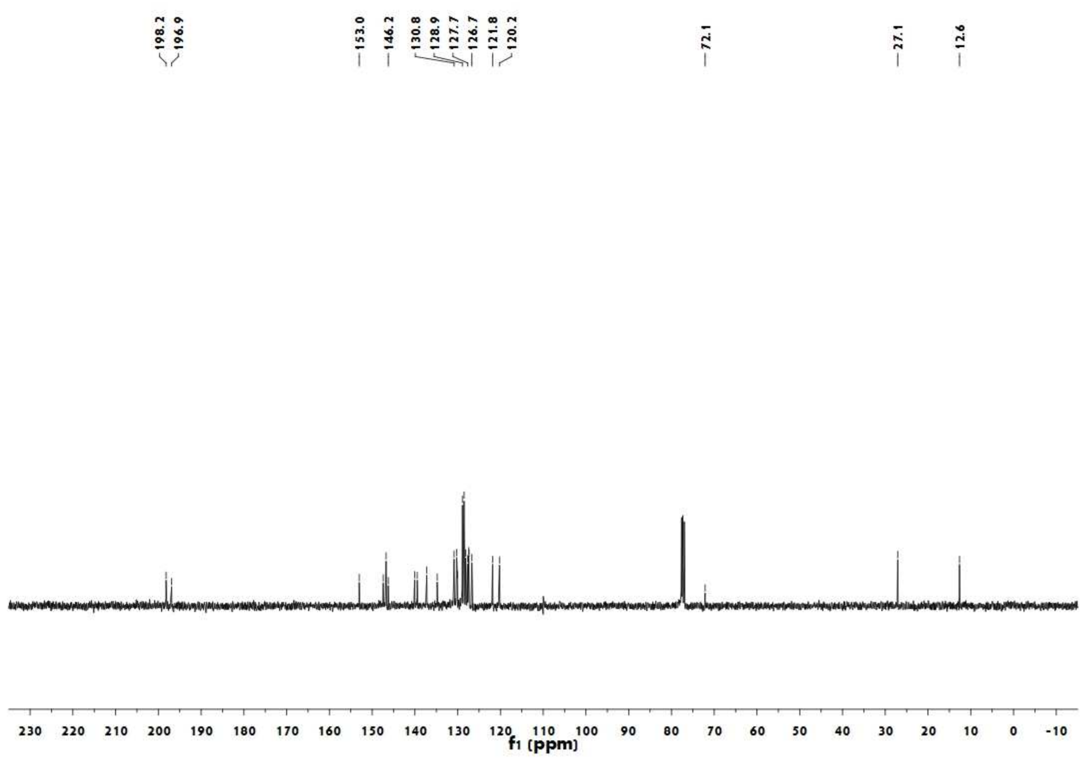


Ac
Me
Ph
O

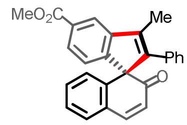
(**3h**)



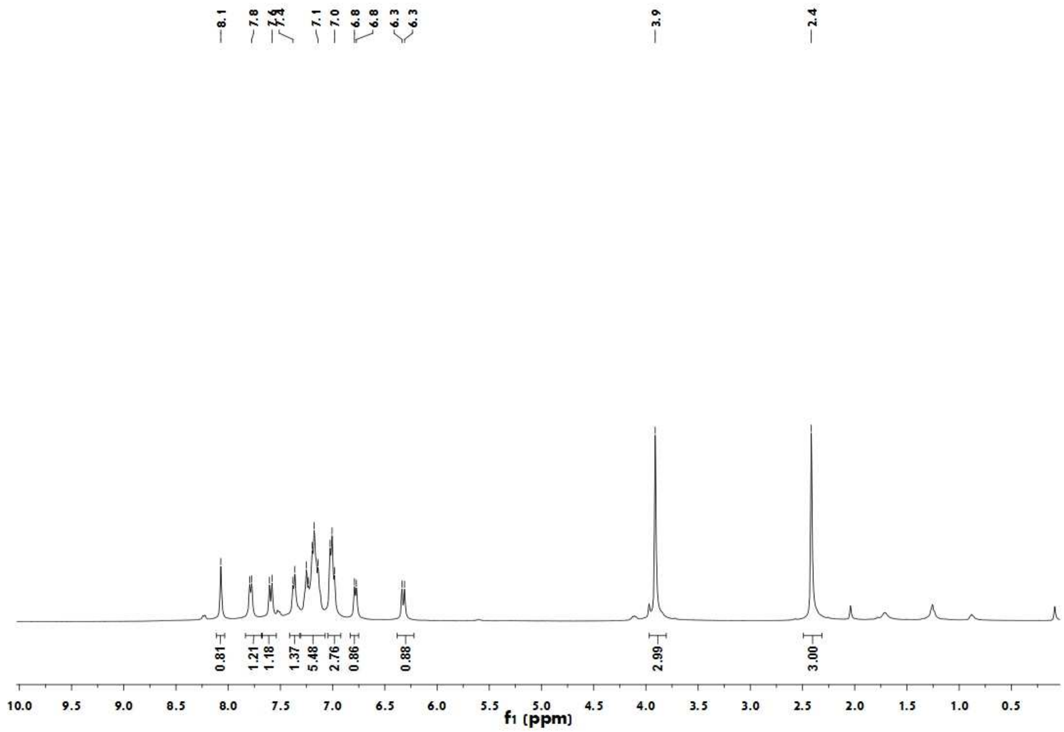
8.0
7.6
7.4
7.1
7.0
6.8
6.8
6.3
6.3
2.6
2.4
0.26
0.34
1.55
0.85
0.28
0.26
0.88
1.00
f1 (ppm)

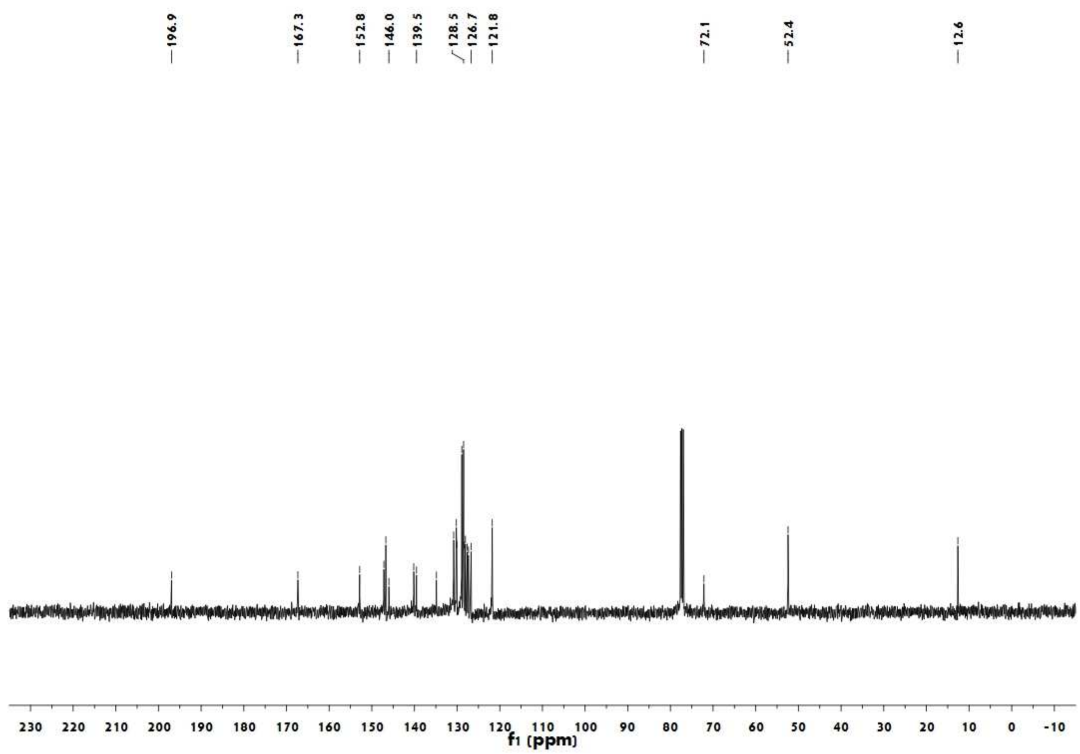


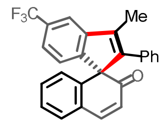
198.2
196.9
153.0
146.2
130.8
128.9
127.7
126.7
121.8
120.2
72.1
27.1
12.6
f1 (ppm)


MeO2C
Me
Ph
O

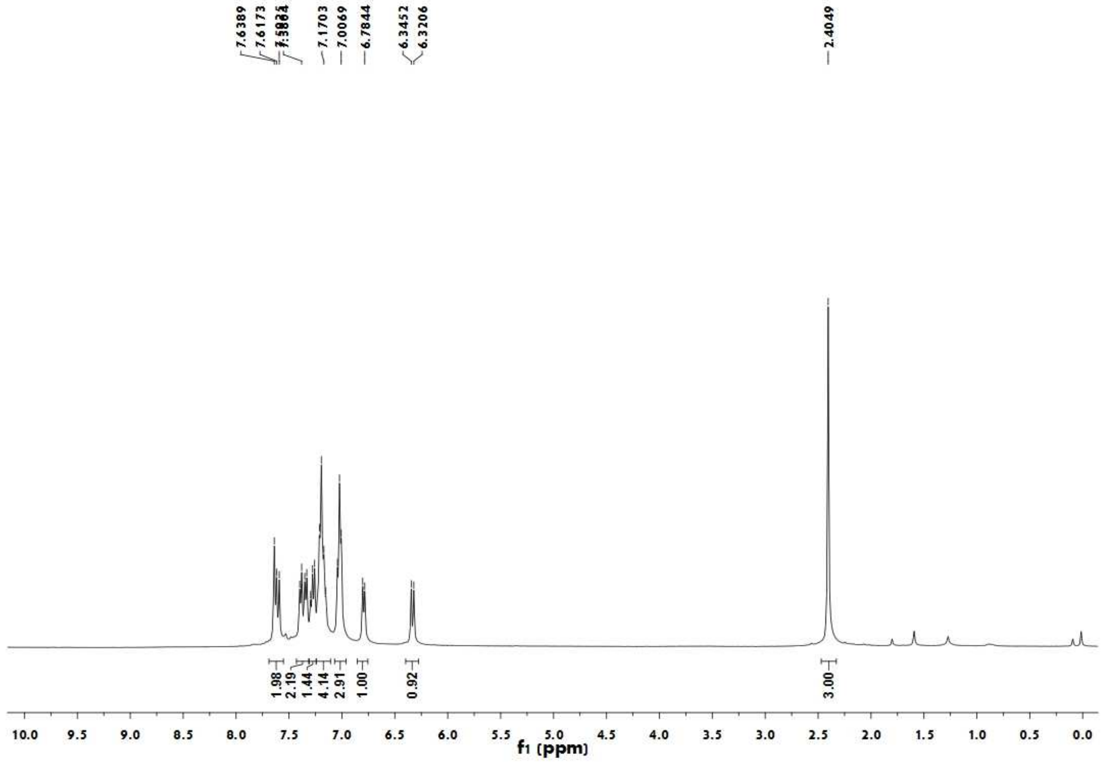
(**3i**)

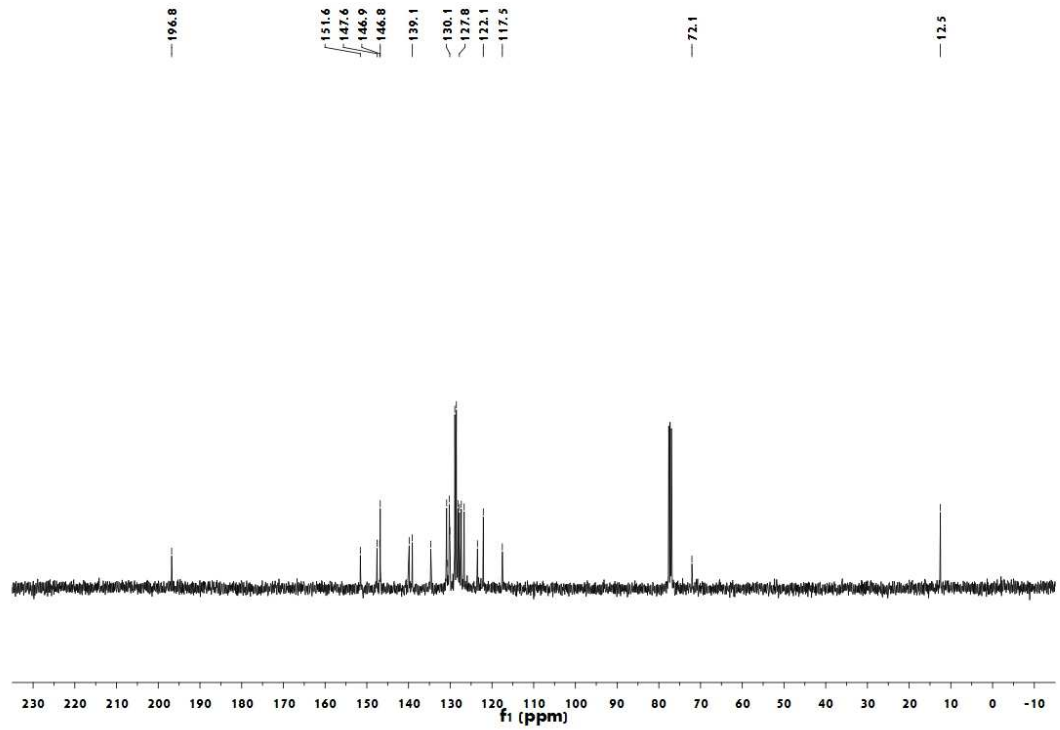

8.1
7.8
7.6
7.4
7.1
7.0
6.8
6.8
6.3
6.3
3.9
2.4
0.81
1.21
1.18
1.37
5.48
2.76
0.86
0.88
2.99
3.00
f1 (ppm)

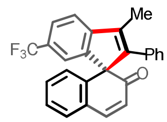

196.9
167.3
152.8
146.0
139.5
128.5
126.7
121.8
72.1
52.4
12.6
f1 (ppm)


F3C
Me
Ph
O

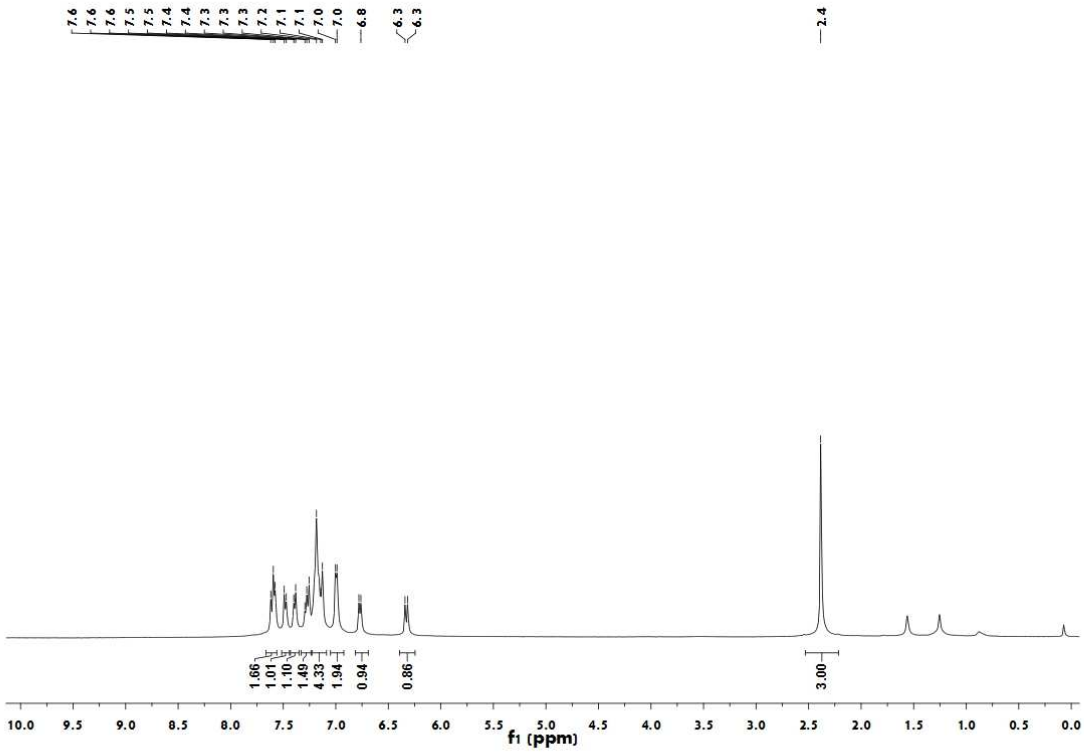
(**3j**)

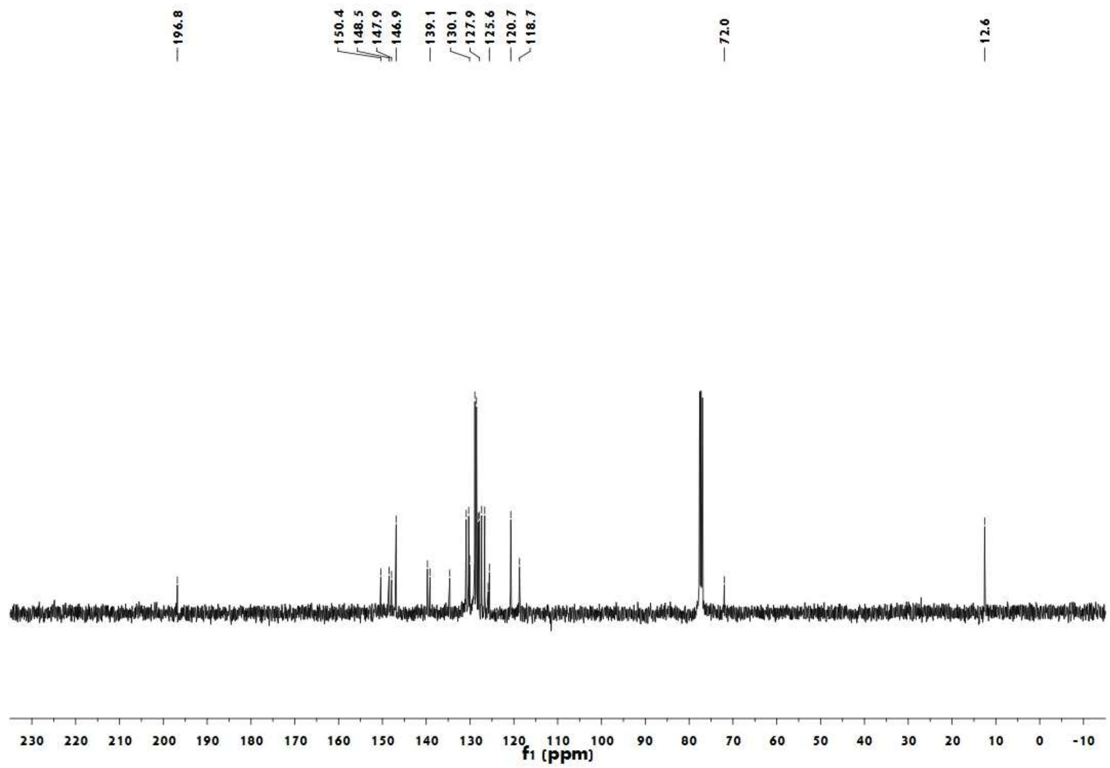

7.6389
7.6173
7.1703
7.0069
6.7844
6.3452
6.3206
2.4049
1.98
2.19
1.44
4.14
2.91
1.00
0.92
3.00
10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0
f1 (ppm)

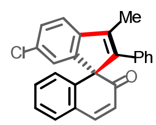

196.8
151.6
147.6
146.9
146.8
139.1
130.1
127.8
122.1
117.5
72.1
12.5
230 220 210 200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 -10
f1 (ppm)


Me
F3C
Ph
O

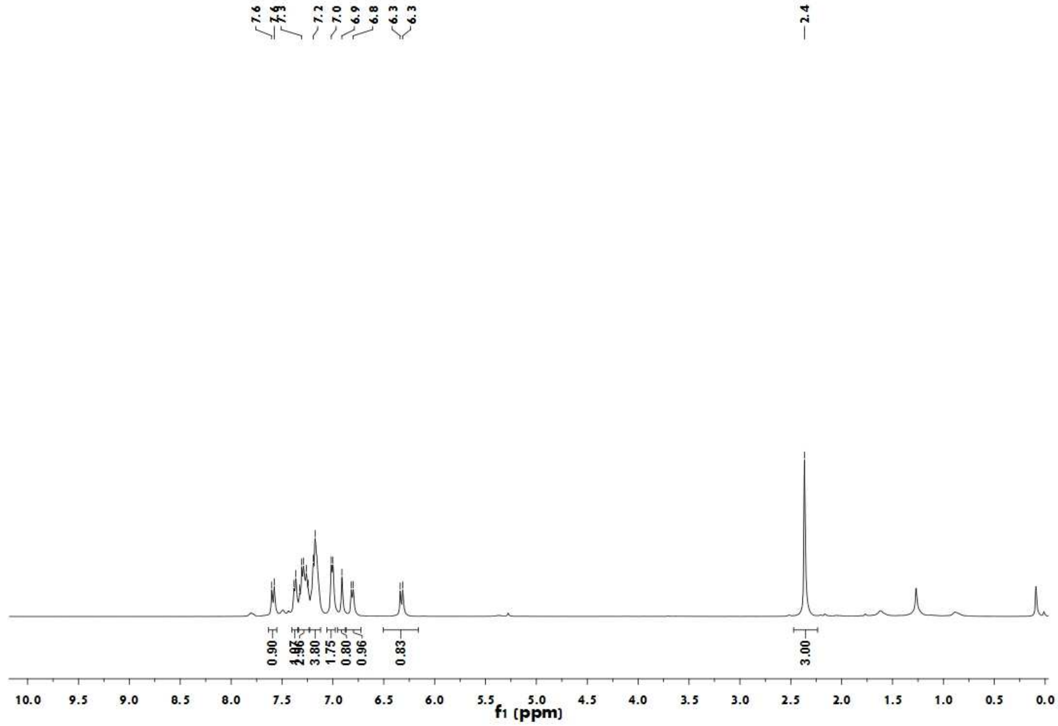
(**3k**)

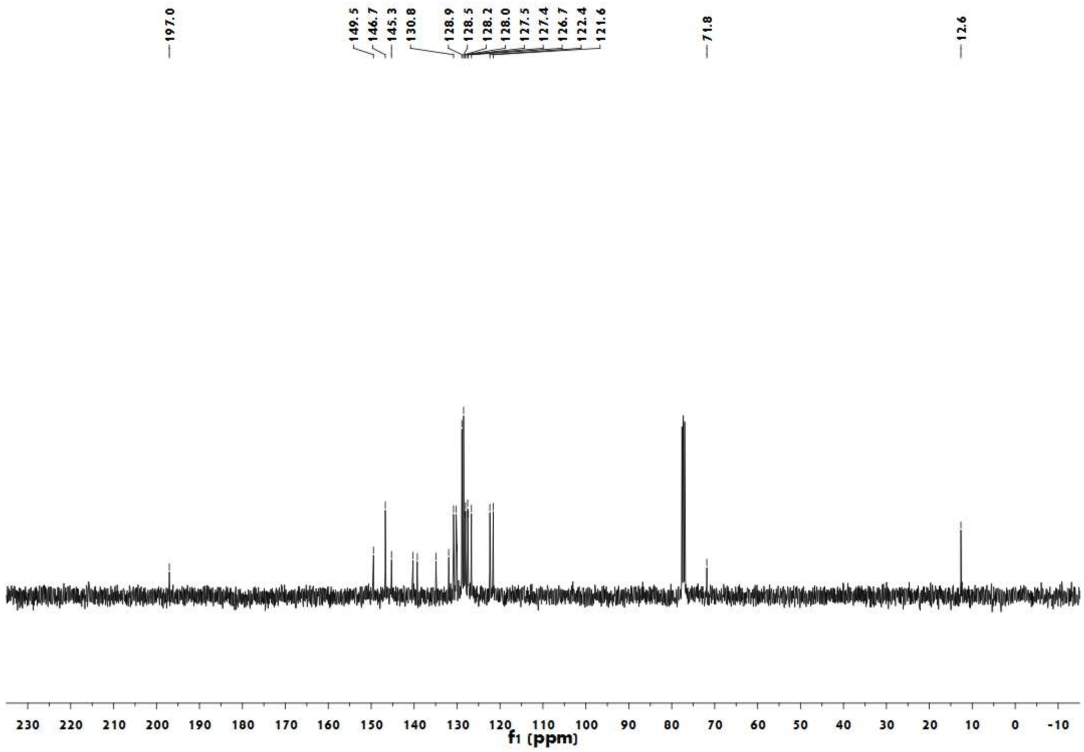

7.6
7.6
7.6
7.5
7.5
7.4
7.4
7.3
7.3
7.3
7.2
7.1
7.1
7.0
7.0
6.8
6.3
6.3
2.4
1.66
1.01
1.10
1.49
4.33
1.94
0.94
0.86
3.00
10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0
f1 (ppm)

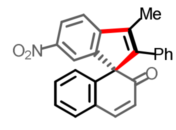

196.8
150.4
148.5
147.9
146.9
139.1
130.1
127.9
125.6
120.7
118.7
72.0
12.6
230 220 210 200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 -10
f1 (ppm)



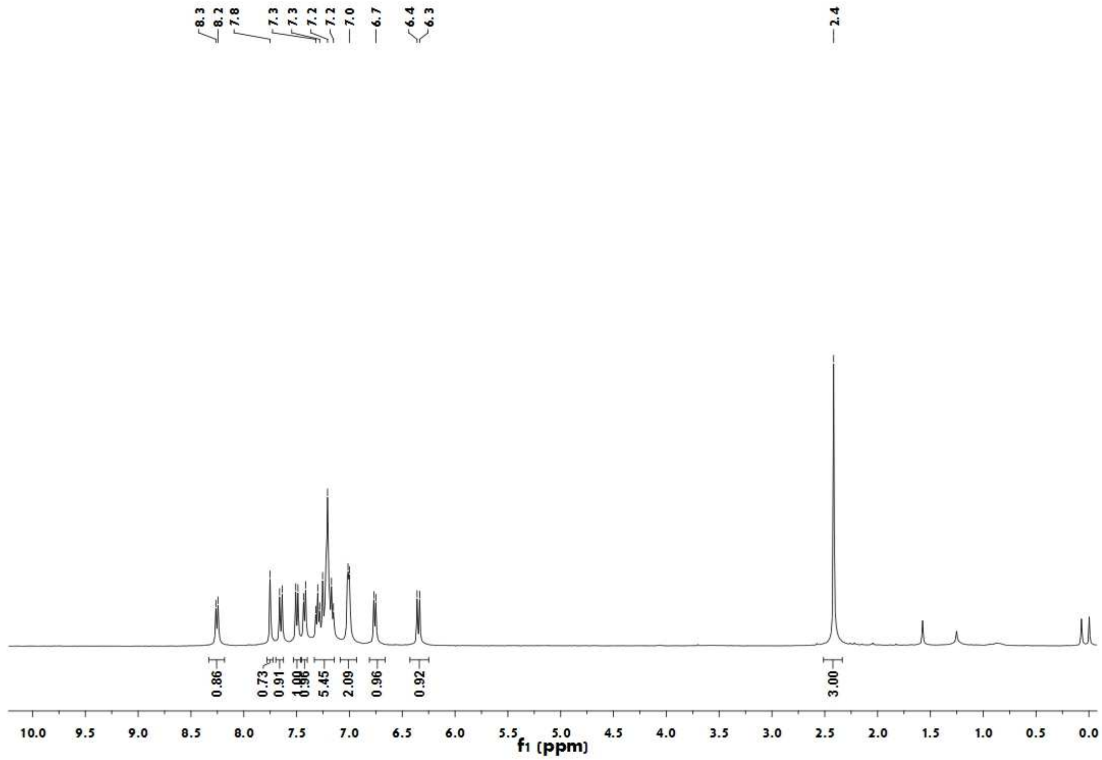
(3l)

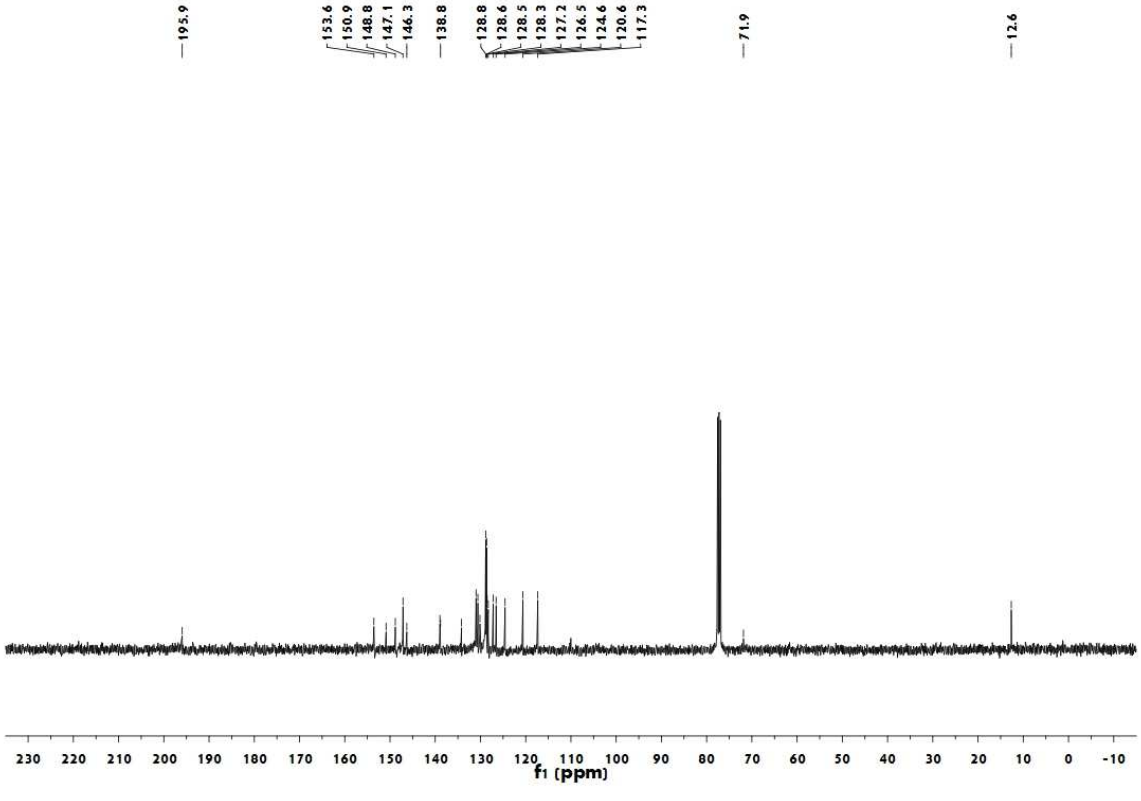

7.6
7.6
7.3
7.2
7.0
6.9
6.8
6.3
6.3
2.4
0.90
1.07
2.96
3.80
1.75
0.80
0.96
0.83
3.00
10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0
f1 (ppm)

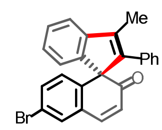

197.0
149.5
146.7
145.3
130.8
128.9
128.5
128.2
128.0
127.5
127.4
126.7
122.4
121.6
71.8
12.6
230 220 210 200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 -10
f1 (ppm)


Me
Ph
O_2N
O

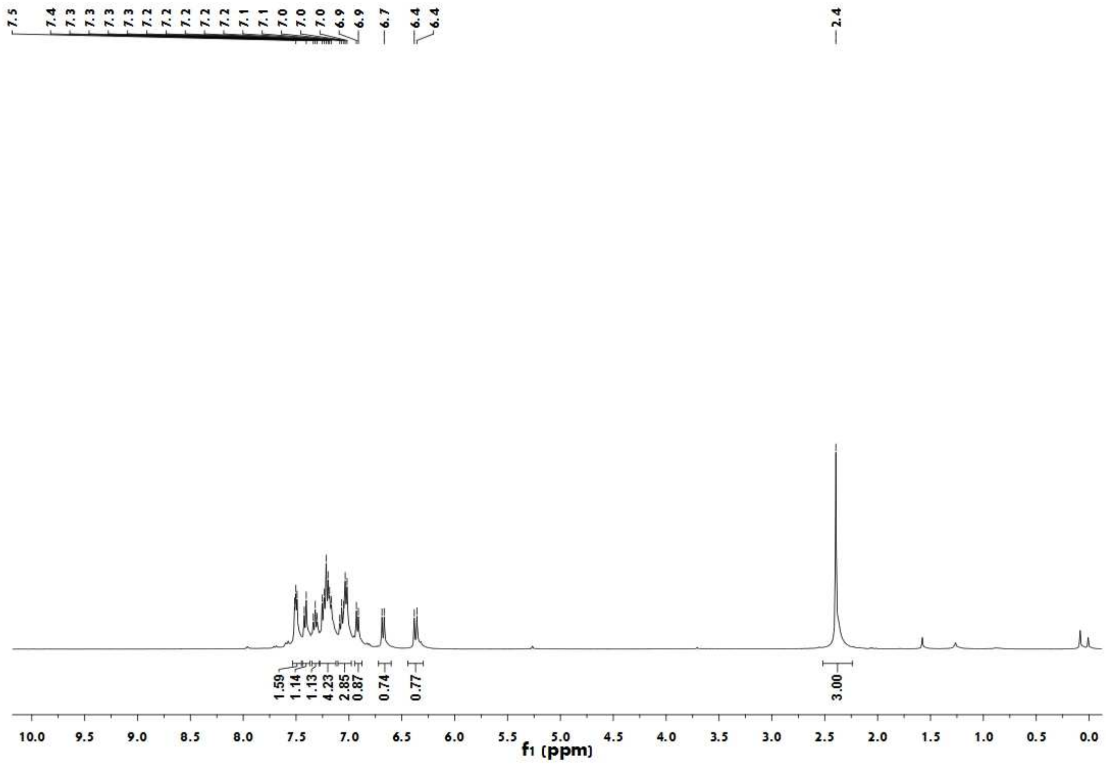
(**3m**)

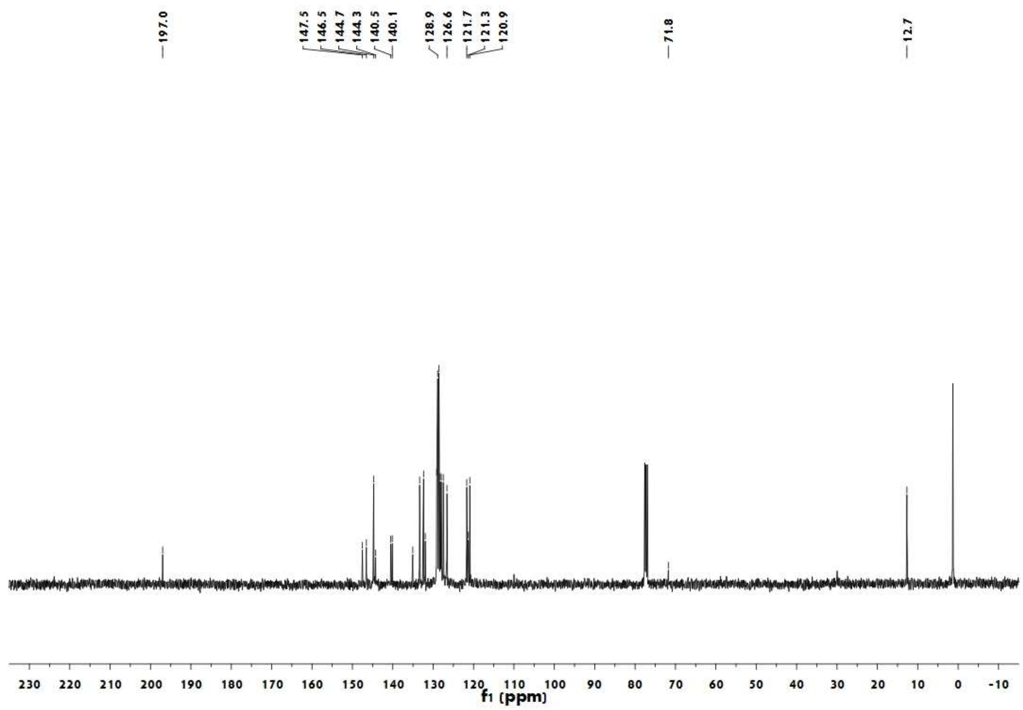

8.3
8.2
7.8
7.3
7.3
7.2
7.2
7.0
6.7
6.4
6.3
2.4
0.86
0.73
0.91
5.45
2.09
0.96
0.92
3.00
10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0
f1 (ppm)

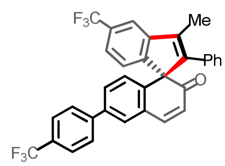

195.9
153.6
150.9
148.8
147.1
146.3
138.8
128.8
128.6
128.5
128.3
127.2
126.5
124.6
120.6
117.3
71.9
12.6
230 220 210 200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 -10
f1 (ppm)



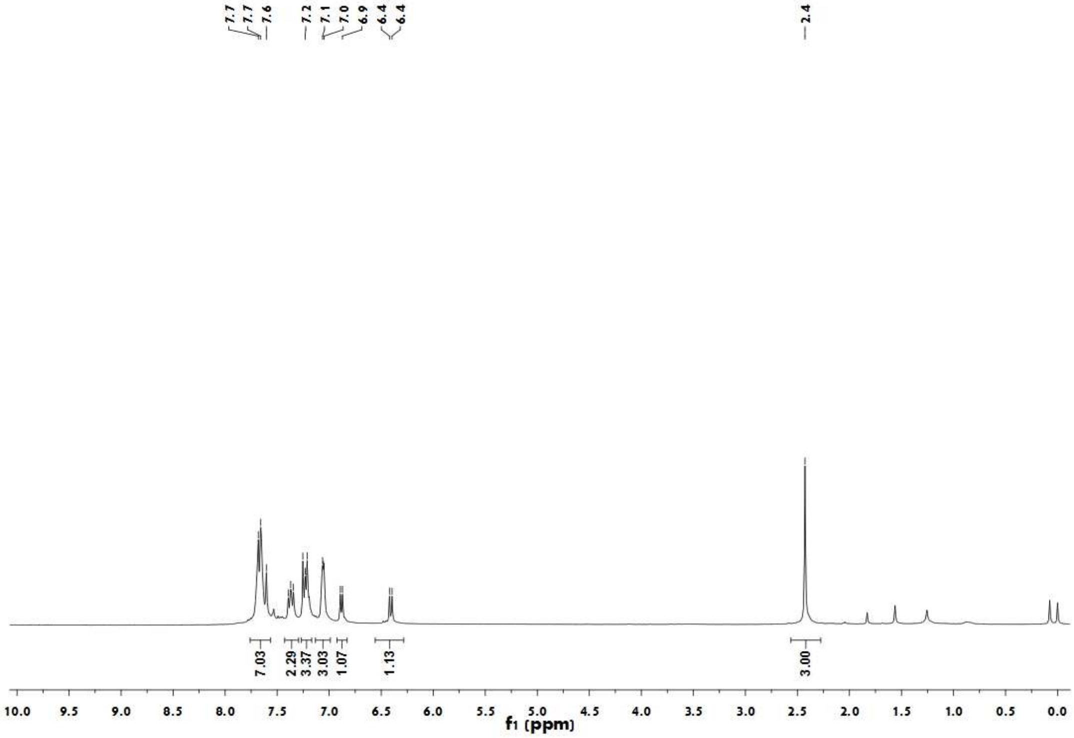
(**3n**)

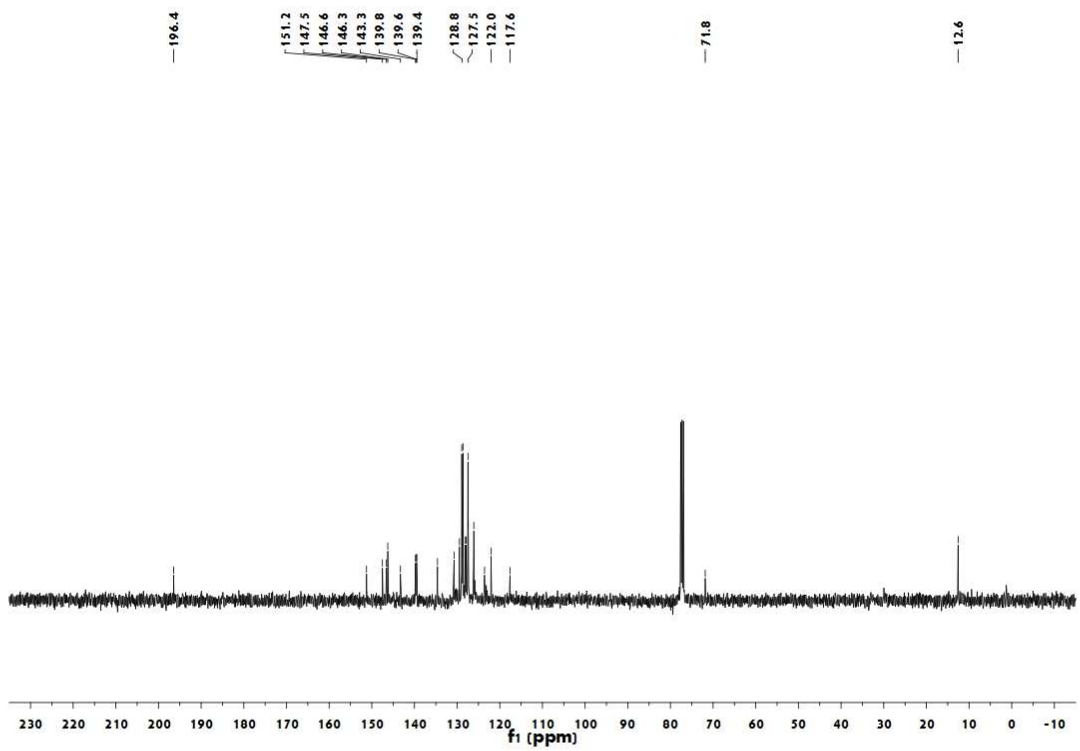


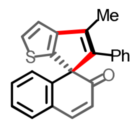



F3C
Me
Ph
O
F3C

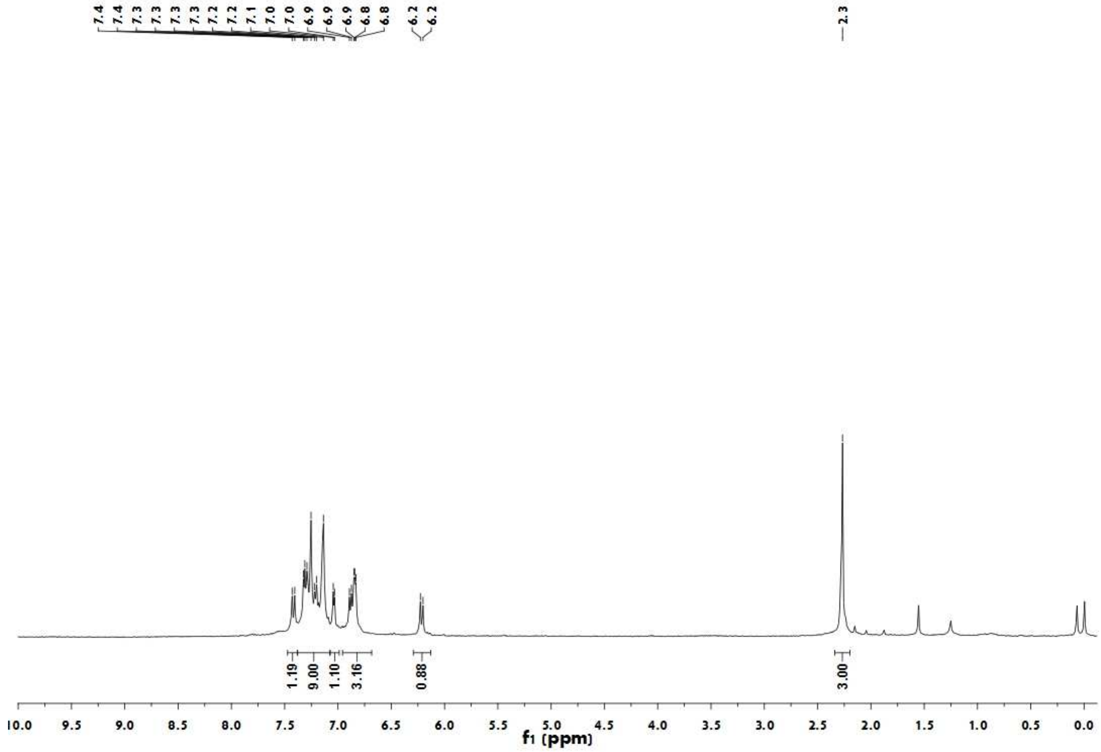
(**3o**)

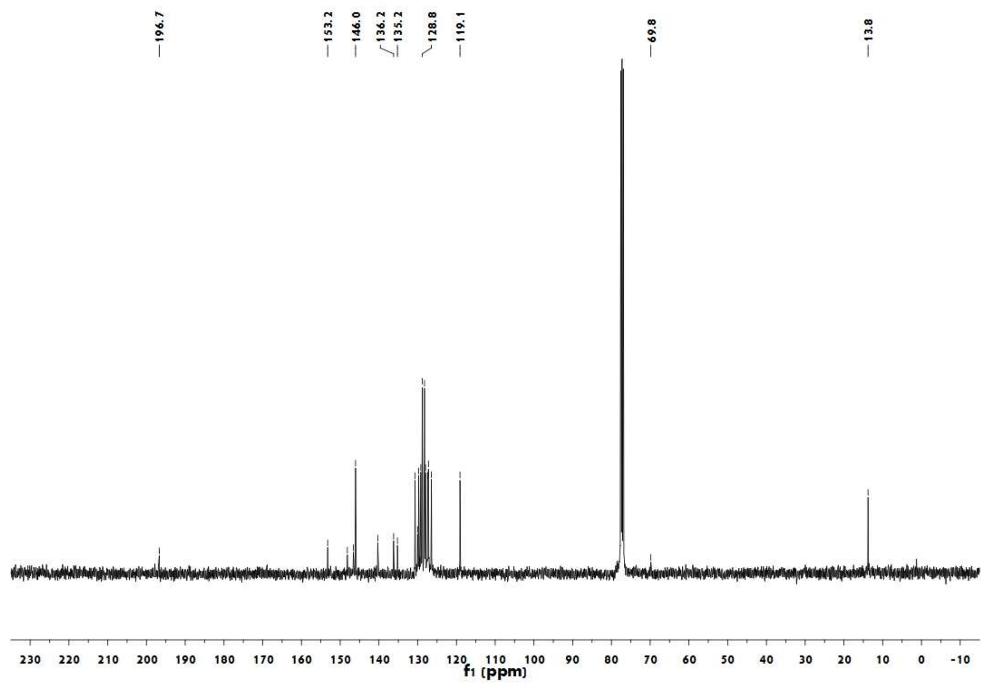

7.7
7.7
7.6
7.2
7.1
7.0
6.9
6.4
6.4
2.4
7.03
2.29
3.37
3.03
1.07
1.13
3.00
10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0
f1 (ppm)

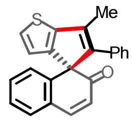

196.4
151.2
147.5
146.6
146.3
143.3
139.8
139.6
139.4
128.8
127.5
122.0
117.6
71.8
12.6
230 220 210 200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 -10
f1 (ppm)


Me
S
Ph
O

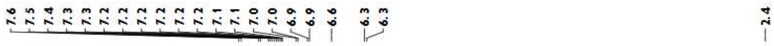
(**3p**)


7.4
7.4
7.3
7.3
7.3
7.3
7.2
7.2
7.1
7.0
7.0
6.9
6.9
6.9
6.8
6.8
6.2
6.2
2.3
1.19
9.00
1.10
3.16
0.88
3.00
10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0
f1 (ppm)


196.7
153.2
146.0
136.2
135.2
128.8
119.1
69.8
13.8
230 220 210 200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 -10
f1 (ppm)



(3q)



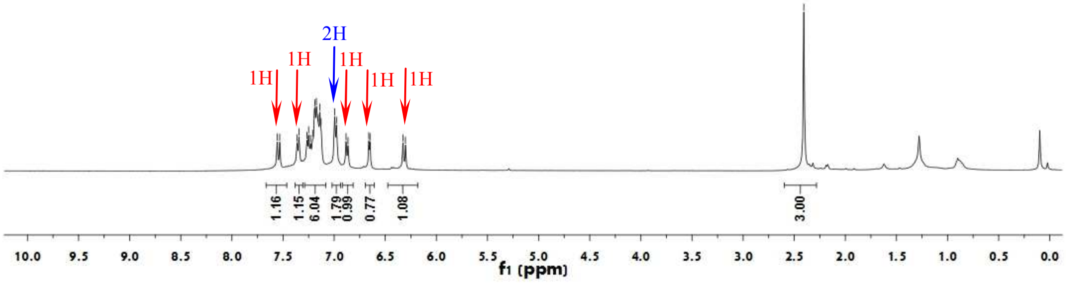
According to ^{1}H NMR of **3q**, its stereochemistry could be properly assigned.

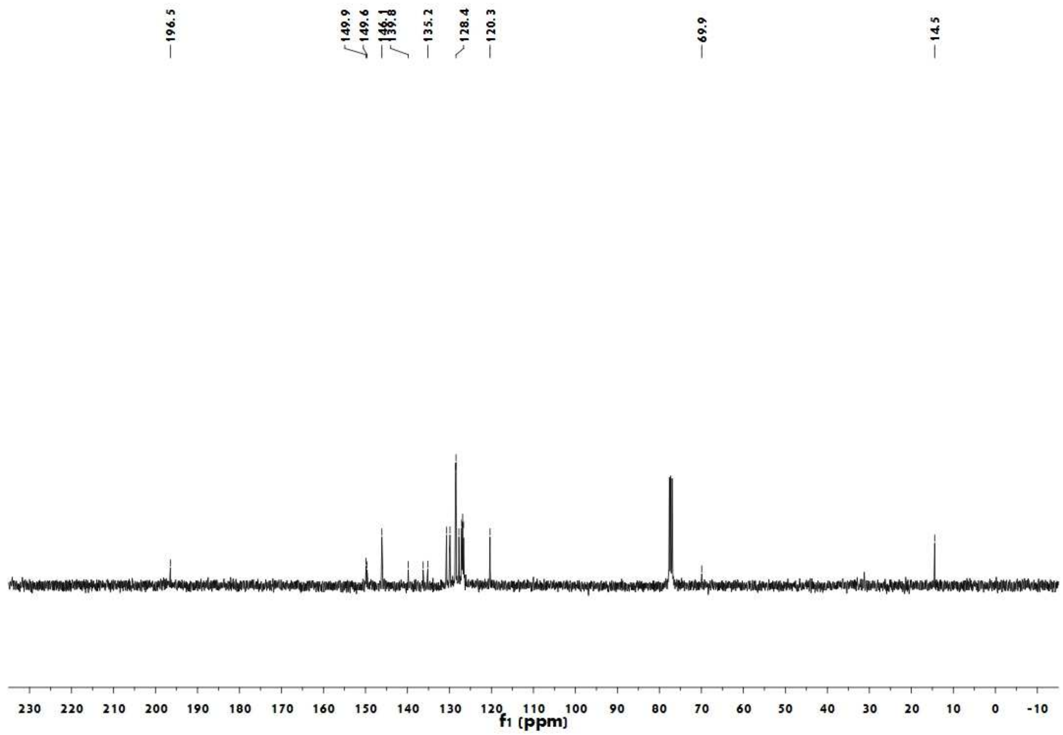
(1) For the regioselectivity of the C-H functionalization on the thiophene ring.

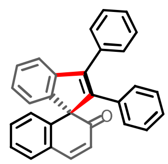
If the C-H functionalization occurred at the 4-position, there should be altogether five doublet peaks in the anticipated spectrum (1H+1H+1H+1H+2H). However, there are at least six doublet peaks in the recorded spectrum (1H+1H+1H+1H+1H+2H), so the C-H functionalization must occurred at the 2-position, because the corresponding compound should have seven doublet peaks in the spectrum.

(2) For the regioselectivity of the alkyne **2a** insertion.

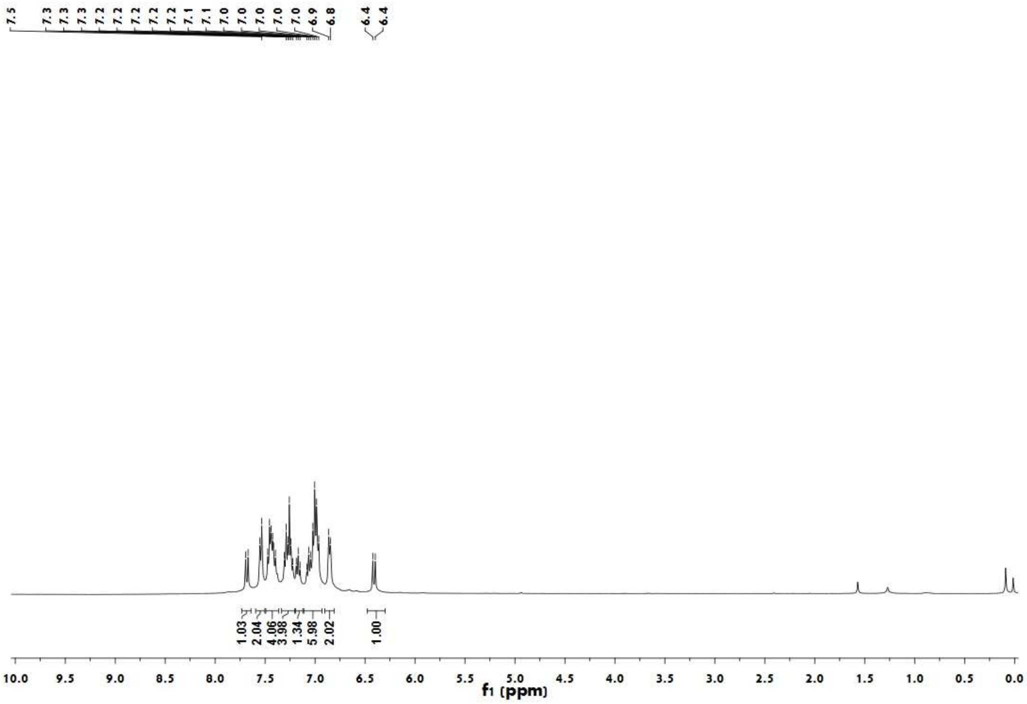
The other regioisomer of compound **3a** was also prepared by another method developed by us. The methyl group show very different chemical shift for **3a** (2.40 ppm) and its regioisomer (1.78 ppm). Looking at the methyl signal in the spectrum of **3q**, it shows a peak at 2.41 ppm, therefore the stereochemistry must be the same as **3a**.

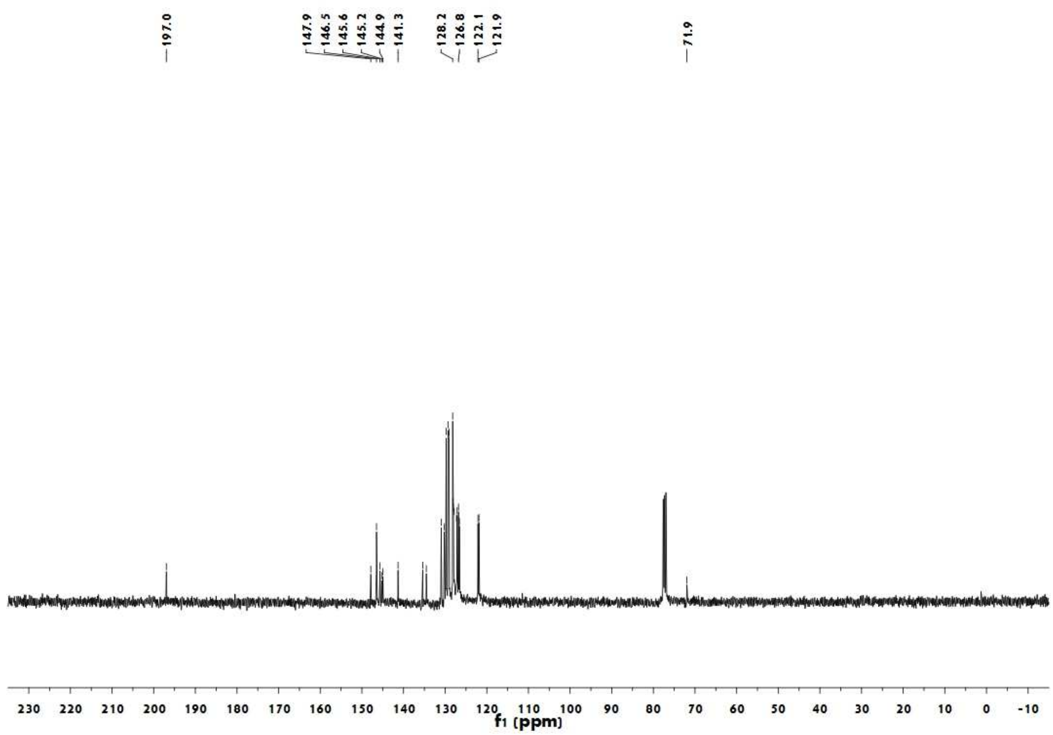


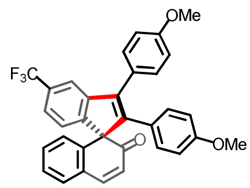




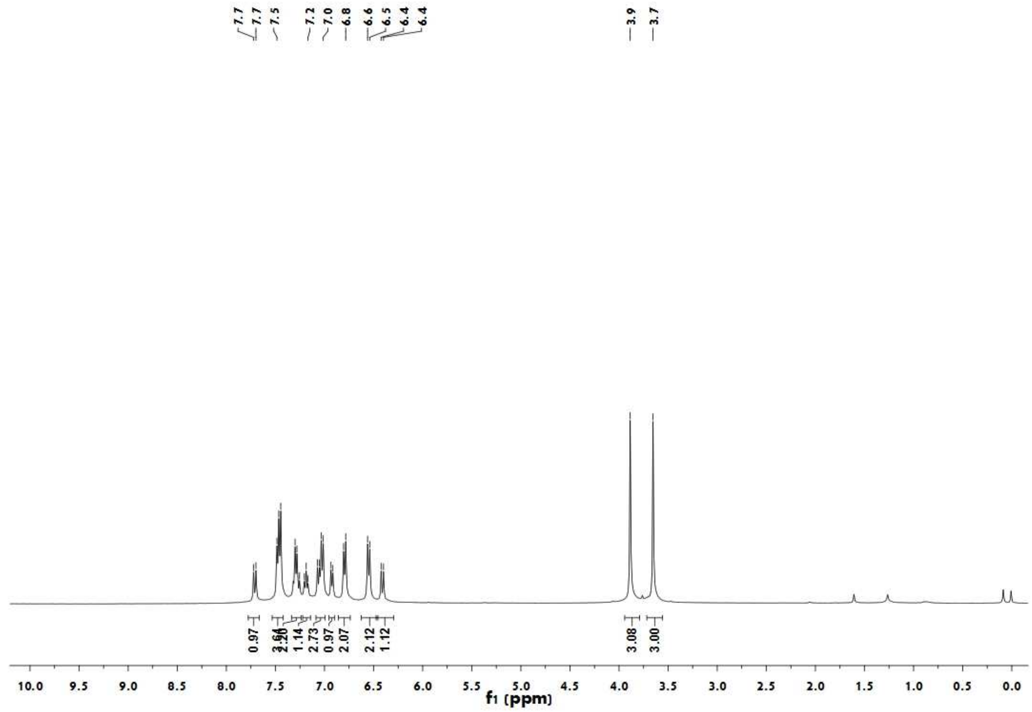
(3a')

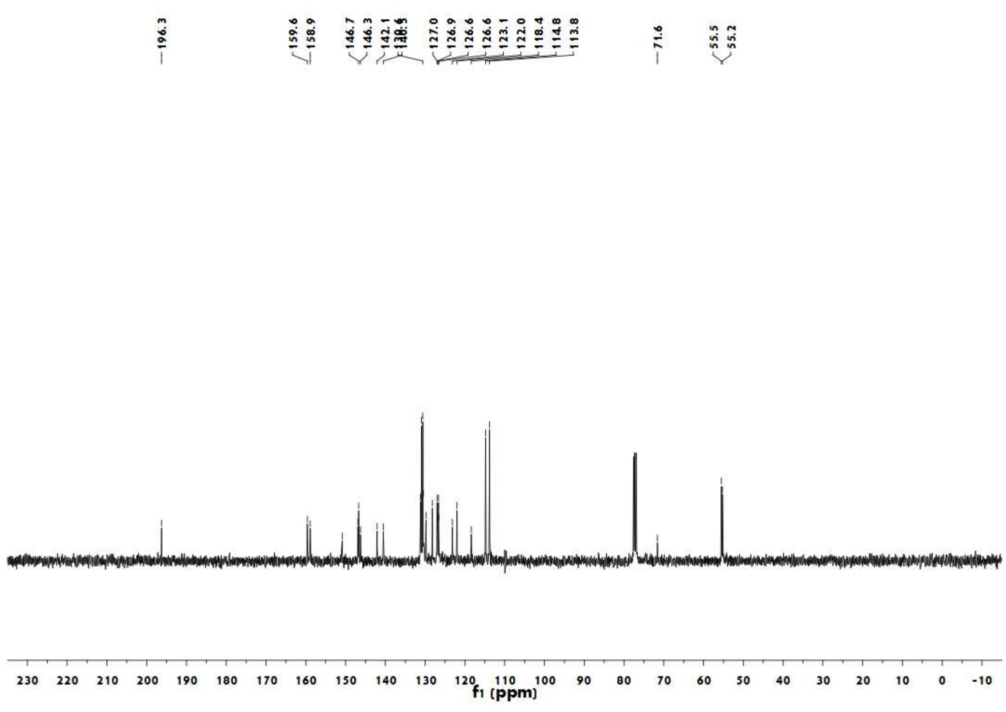

7.5
7.3
7.3
7.3
7.2
7.2
7.2
7.2
7.2
7.1
7.1
7.0
7.0
7.0
7.0
7.0
6.9
6.8
6.4
6.4
1.03
2.04
4.06
3.98
1.34
5.98
2.02
1.00
10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0
f1 (ppm)

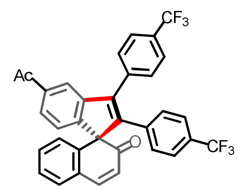

197.0
147.9
146.5
145.6
145.2
144.9
141.3
128.2
126.8
122.1
121.9
71.9
230 220 210 200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 -10
f1 (ppm)



(**3b'**)

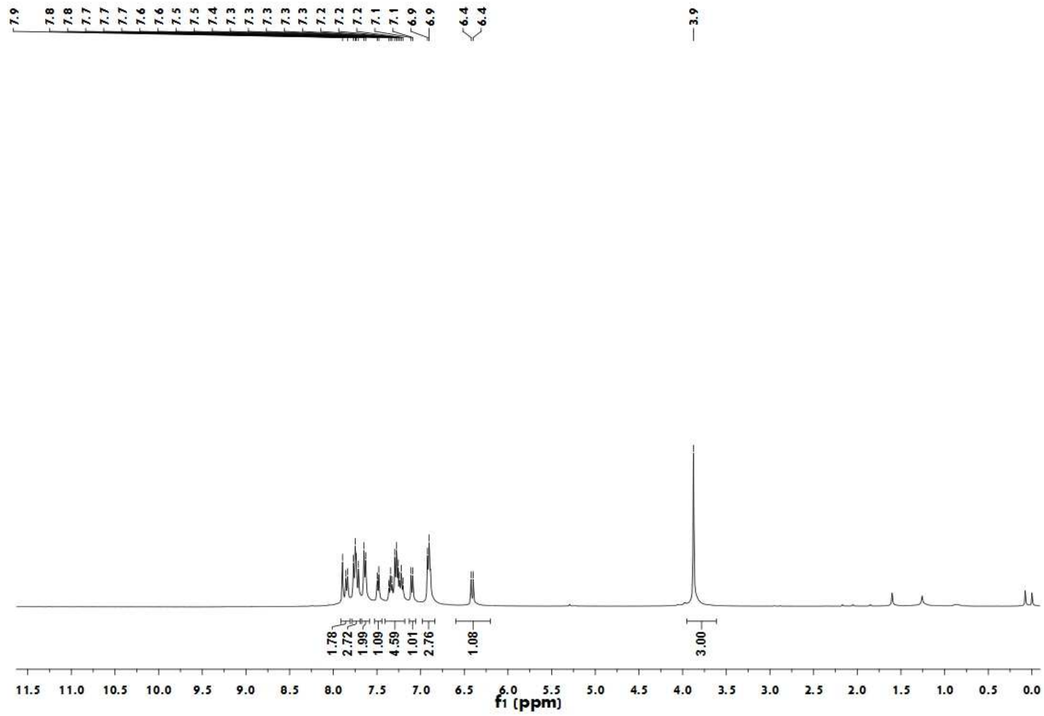




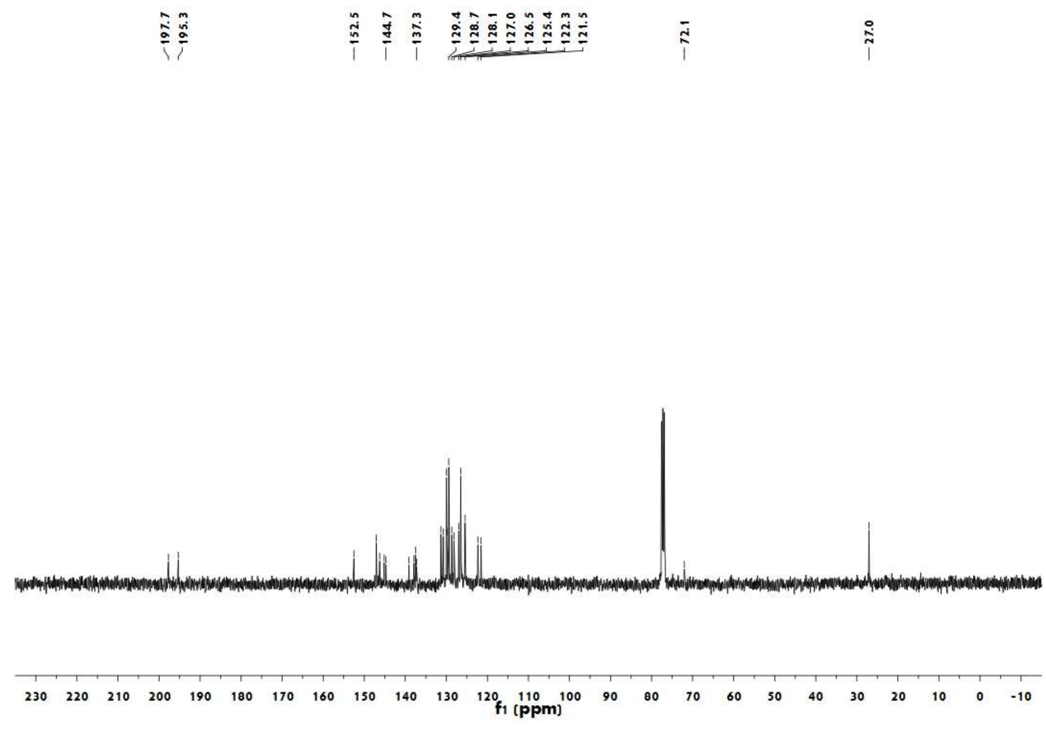


Ac
CF3
CF3
O

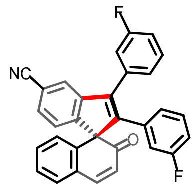
(3c')



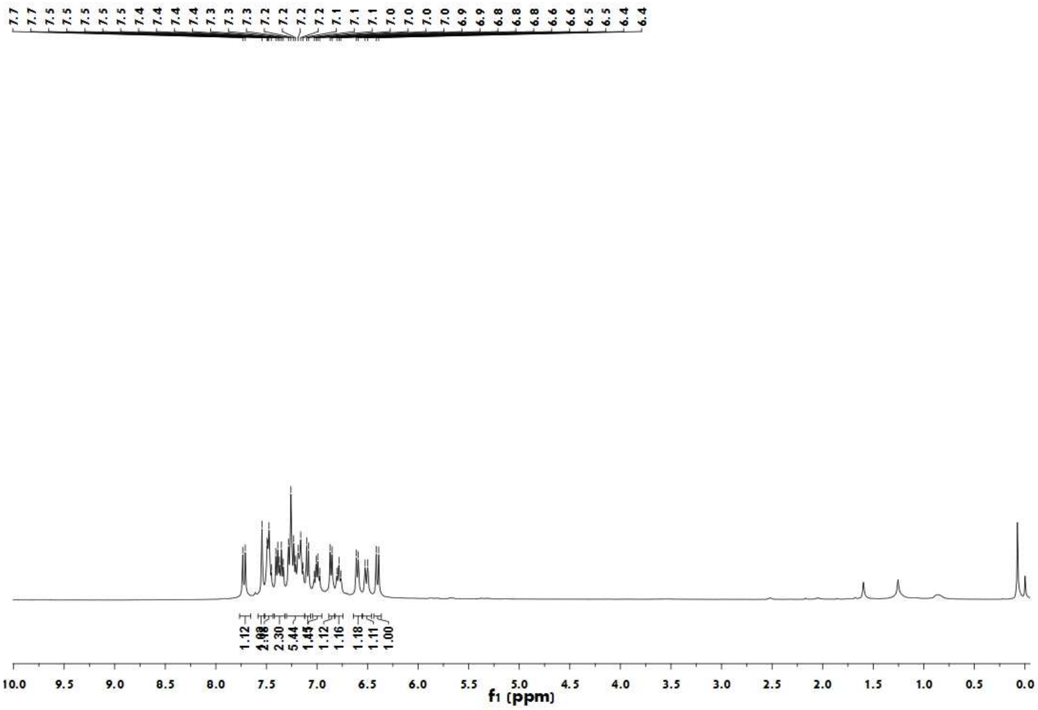
7.9
7.8
7.8
7.7
7.7
7.7
7.6
7.5
7.5
7.4
7.3
7.3
7.3
7.3
7.3
7.2
7.2
7.1
7.1
6.9
6.9
6.4
6.4
3.9
1.78
2.72
1.99
1.09
4.59
1.01
2.76
1.08
3.00
11.5 11.0 10.5 10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0
f1 (ppm)

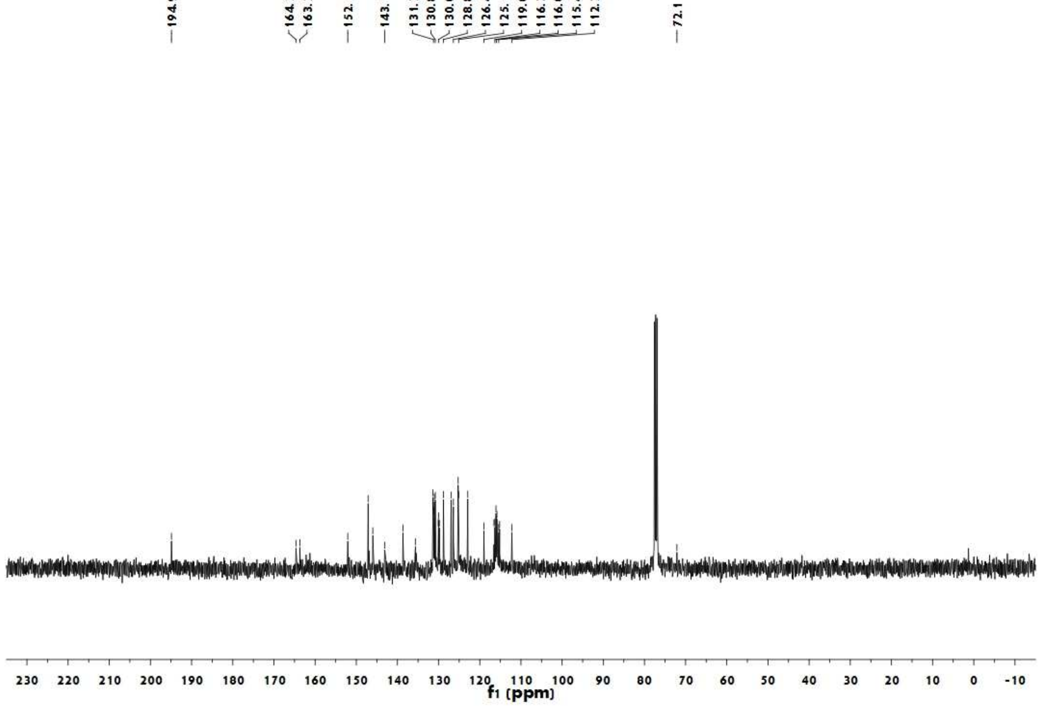


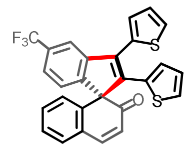
197.7
195.3
152.5
144.7
137.3
129.4
128.7
128.1
127.0
126.5
125.4
122.3
121.5
72.1
27.0
230 220 210 200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 -10
f1 (ppm)


NC
F
F
O

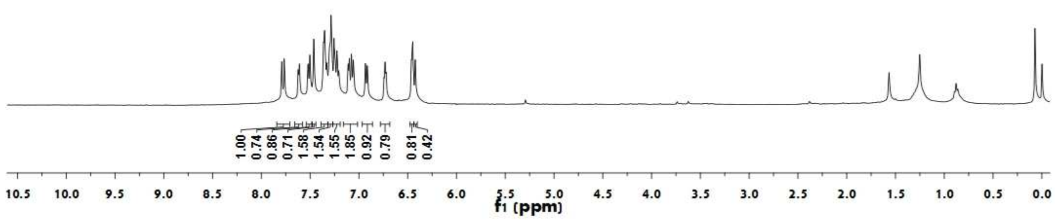
(**3d'**)

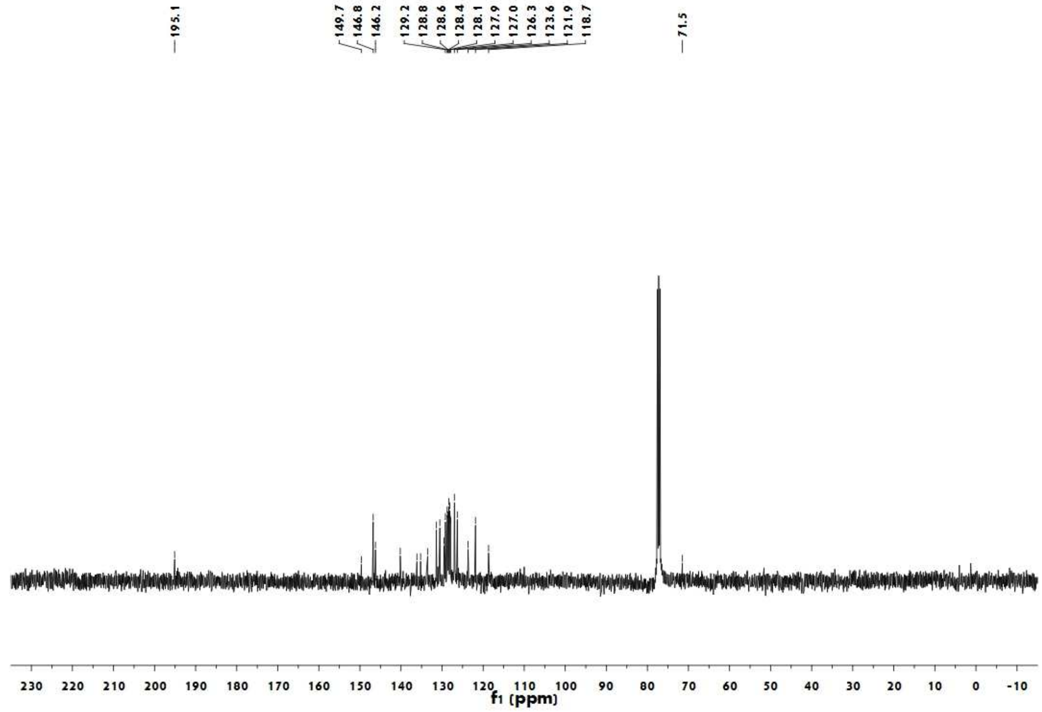

7.7 7.7 7.5 7.5 7.5 7.5 7.4 7.4 7.4 7.4 7.3 7.3 7.3 7.2 7.2 7.2 7.2 7.2 7.1 7.1 7.1 7.1 7.0 7.0 7.0 6.9 6.9 6.8 6.8 6.8 6.8 6.6 6.6 6.5 6.5 6.4 6.4
1.12
2.30
5.44
1.12
1.16
1.18
1.11
1.00
10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0
f1 (ppm)

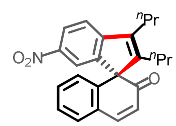

194.9
164.7
163.7
152.1
143.1
131.2
130.8
130.0
128.8
126.4
125.1
119.0
116.3
116.0
115.4
112.2
72.1
230 220 210 200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 -10
f1 (ppm)



(3e')

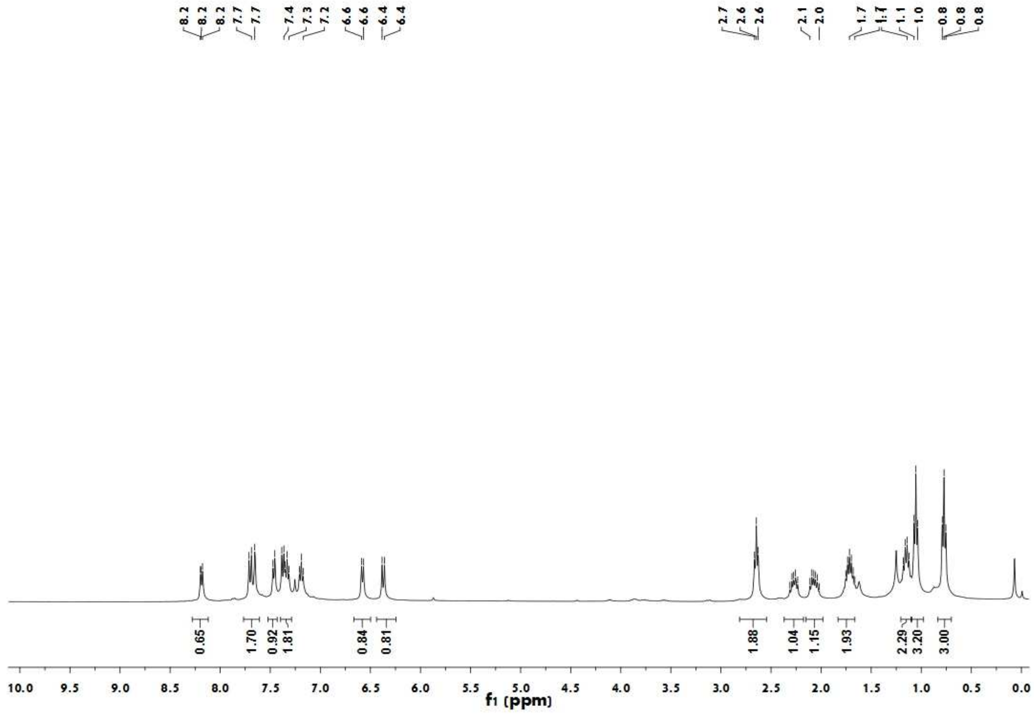




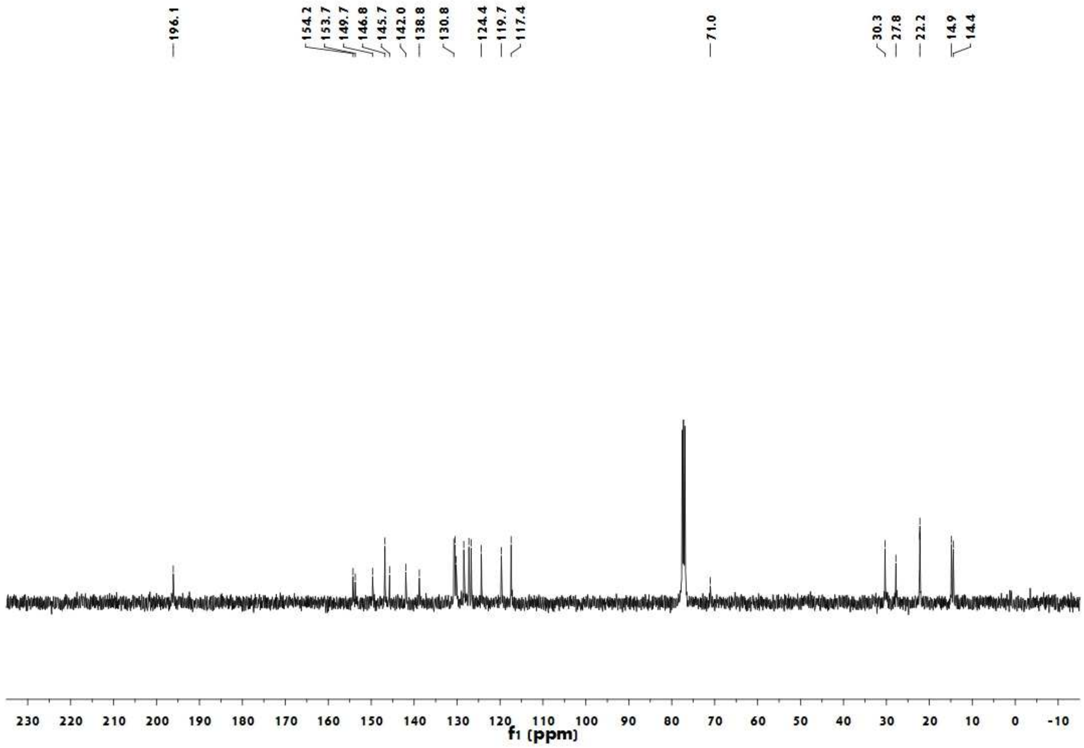


O2N
nPr
nPr
O

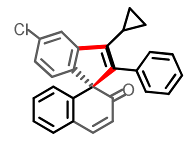
(3f ')



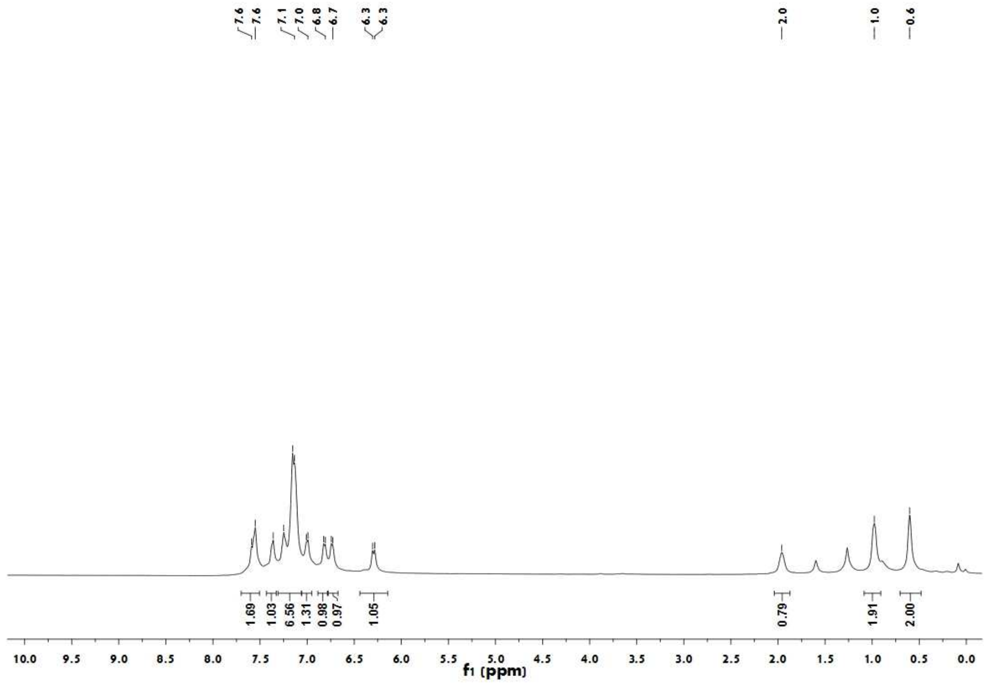
8.2
8.2
8.2
7.7
7.7
7.4
7.3
7.2
6.6
6.6
6.4
6.4
2.7
2.6
2.6
2.1
2.0
1.7
1.7
1.1
1.0
0.8
0.8
0.8
0.65
1.70
0.92
1.81
0.84
0.81
1.88
1.04
1.15
1.93
2.29
3.20
3.00
f1 (ppm)

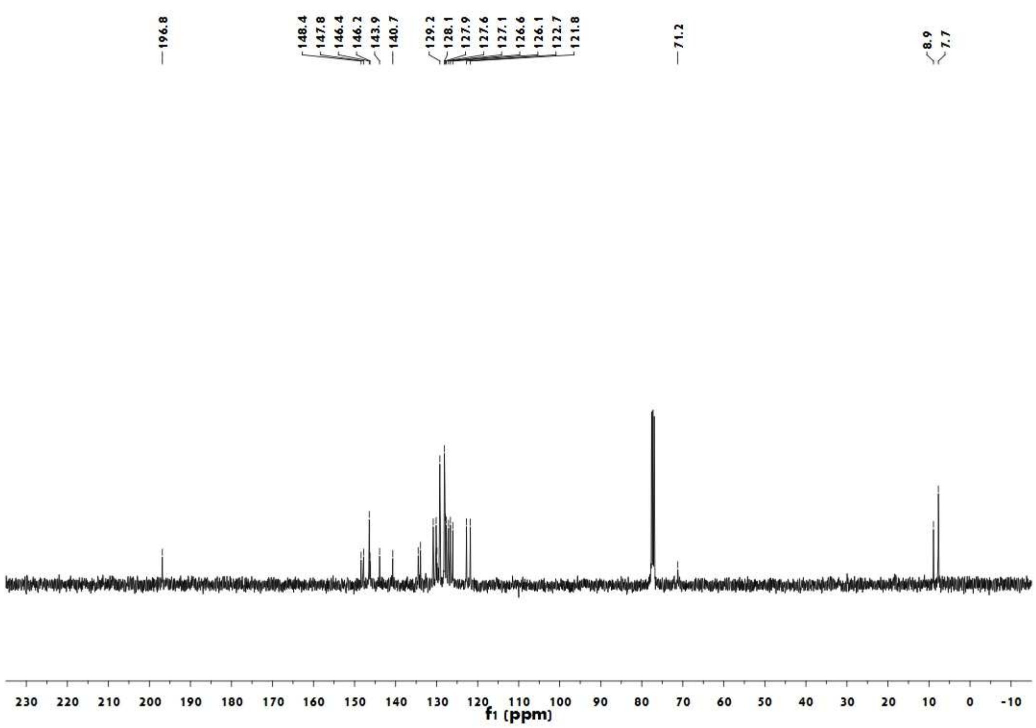


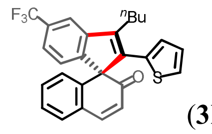
196.1
154.2
153.7
149.7
146.8
145.7
142.0
138.8
130.8
124.4
119.7
117.4
71.0
30.3
27.8
22.2
14.9
14.4
f1 (ppm)



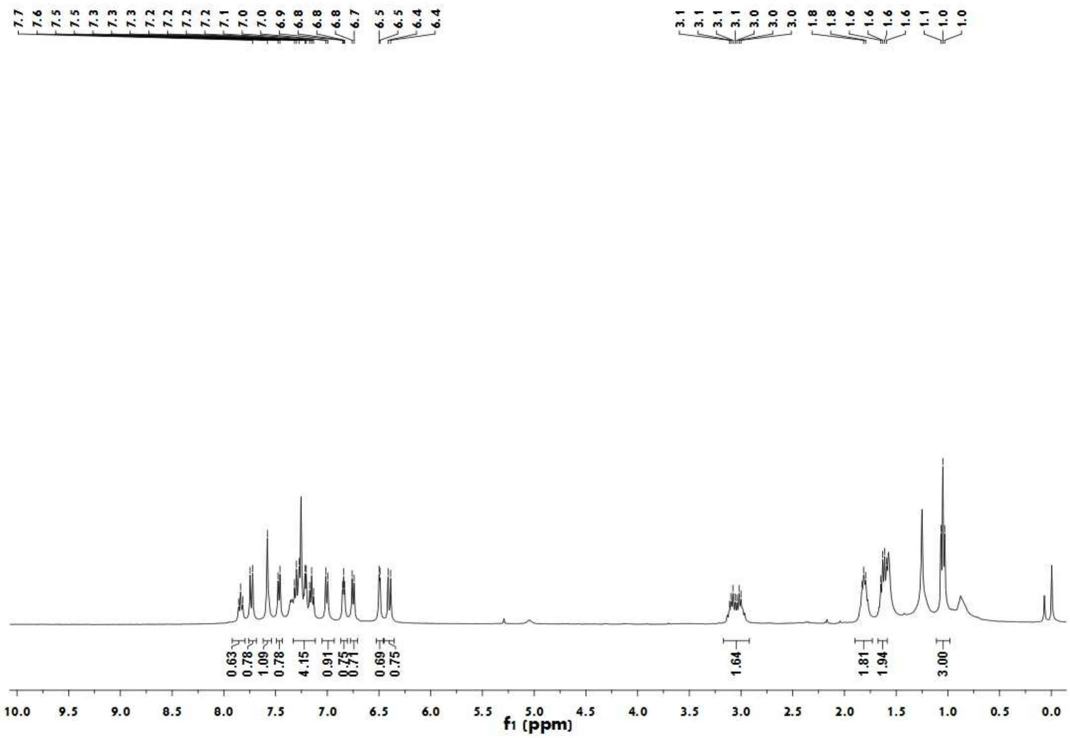
(3g')

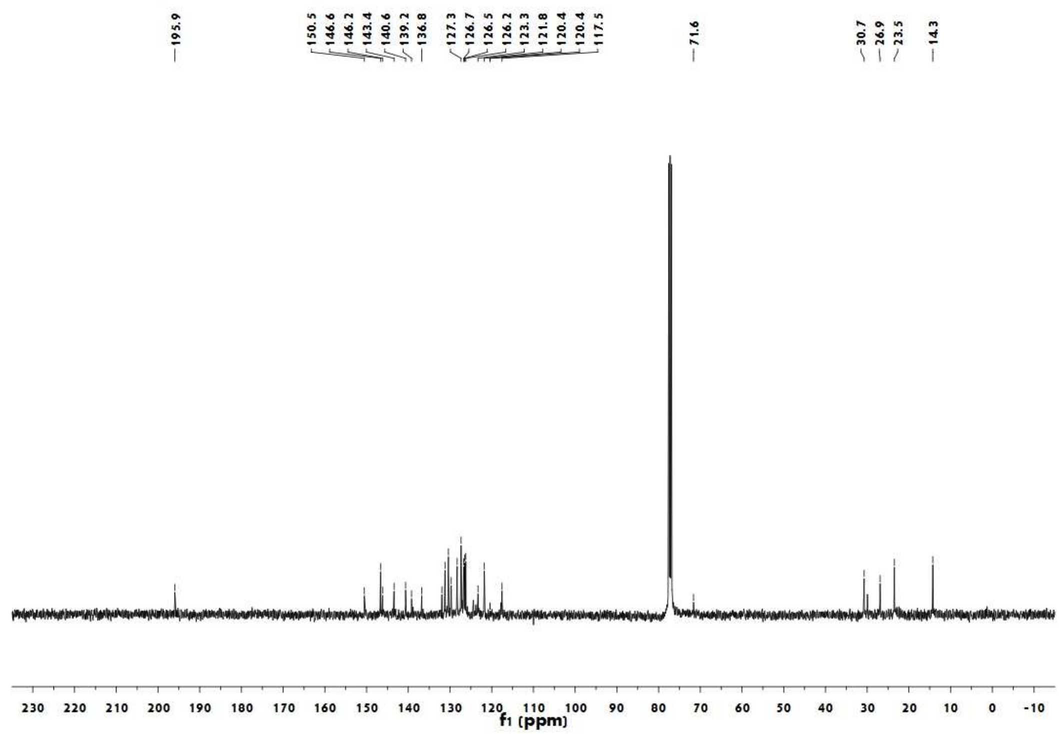


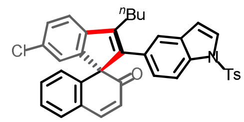




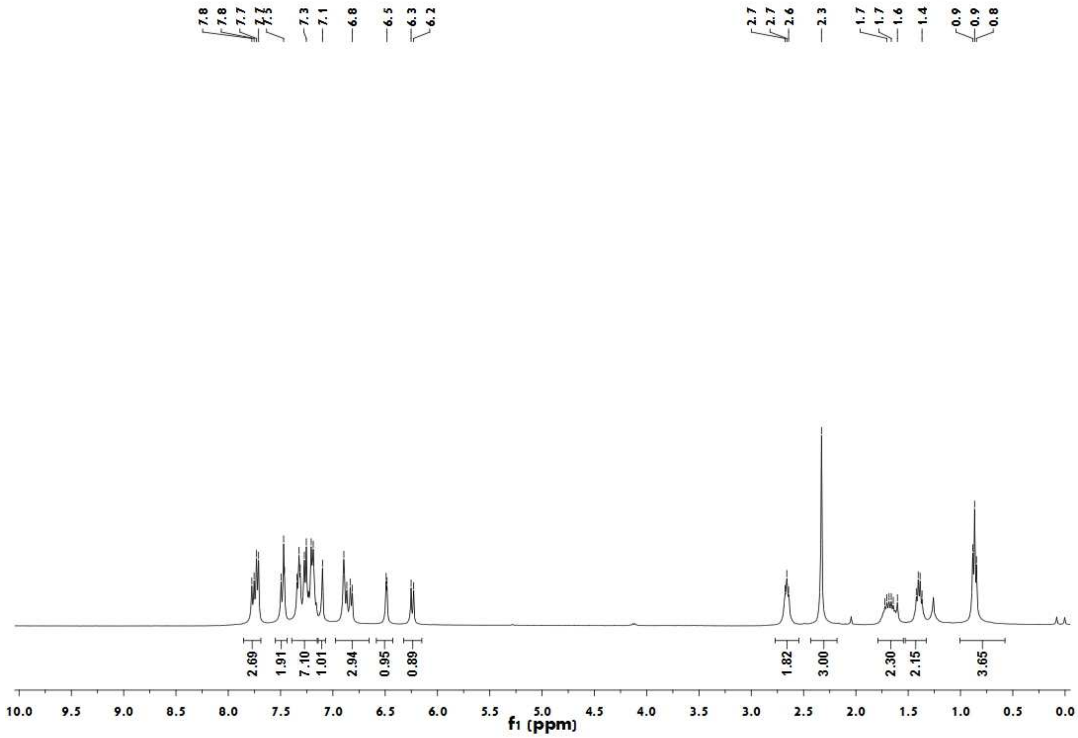
(3h')

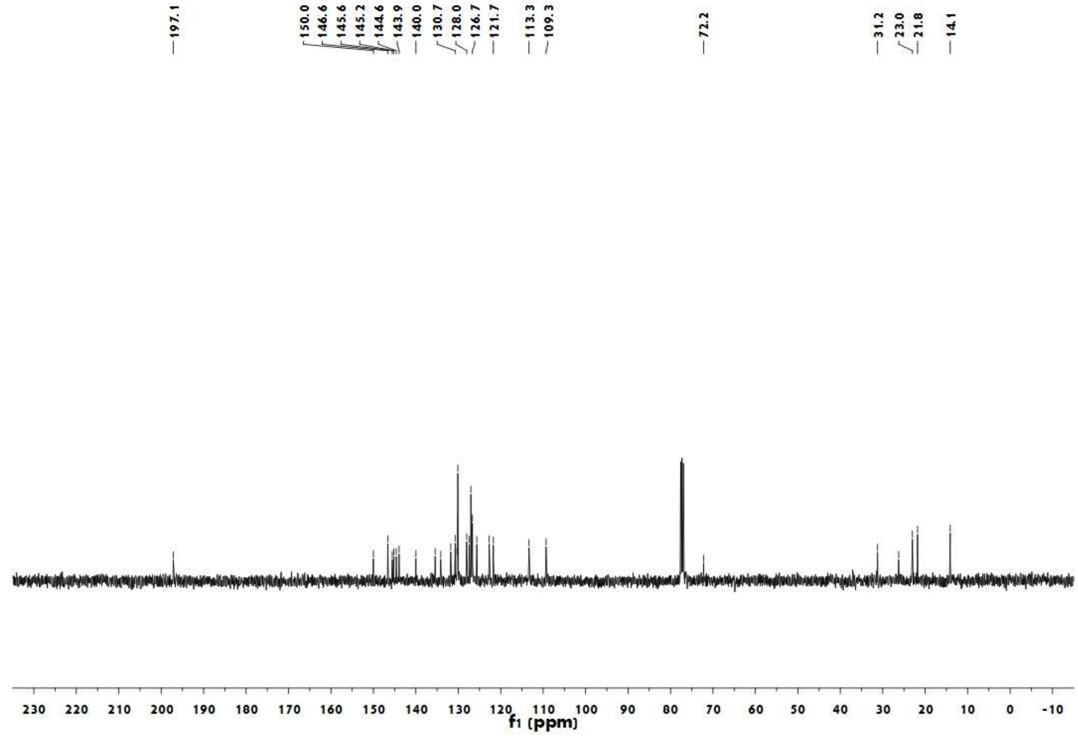






(**3i'**)


7.8 7.8 7.7 7.7 7.5 7.3 7.1 6.8 6.5 6.3 6.2 2.7 2.7 2.6 2.3 1.7 1.7 1.6 1.4 0.9 0.9 0.8
2.69 1.91 7.10 1.01 2.94 0.95 0.89 1.82 3.00 2.30 2.15 3.65
f1 (ppm)


197.1 150.0 146.6 145.6 145.2 144.6 143.9 140.0 130.7 128.0 126.7 121.7 113.3 109.3 72.2 31.2 23.0 21.8 14.1
f1 (ppm)