Access to Derivatives of 4-(Arylthio)isocoumarins via Hydrogen Bonding Network Assisted Electrophilic Cyclization

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Content

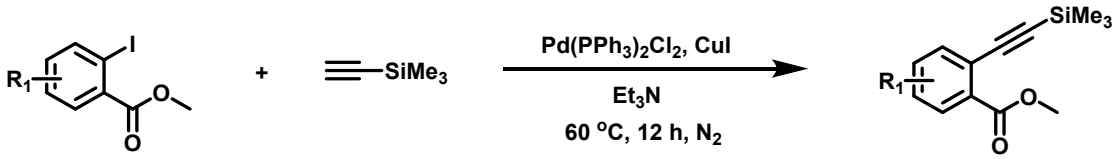
1. General

Commercial reagents and solvents were obtained from the commercial providers and used without further purification. The products were purified using a commercial flash chromatography system or a regular glass column. TLC was developed on silica gel 60 F254 glass plates. ^{1}H NMR (400 MHz) and ^{13}C NMR (100 MHz) spectra were recorded on a Bruker NMR apparatus. The chemical shifts are reported in δ (ppm) values (^{1}H and ^{13}C NMR relative to $CHCl_3$, δ 7.26 ppm for ^{1}H NMR and δ 77.0 ppm for ^{13}C NMR). Or alternatively, ^{1}H NMR chemical shifts were referenced to tetramethylsilane signal (0 ppm). Multiplicities are recorded by s (singlet), d (doublet), t (triplet), q (quartet), p (pentet), h (hextet), m (multiplet) and br (broad). Coupling constants (*J*), are reported in Hertz (Hz). HRMS data were obtained by using Thermo LTQ-Orbitrap XL mass spectrometer with ESI, ACPI or EI ionization sources by the service provided at Indiana University Bloomington Mass Spectral Facility. GC analyses were performed using a Shimadzu GC-2010 ultra gas chromatography–mass spectrometry instrument equipped with a Shimadzu AOC-20s autosampler.

2. General procedure for the preparation of *N*-thiosuccinimides

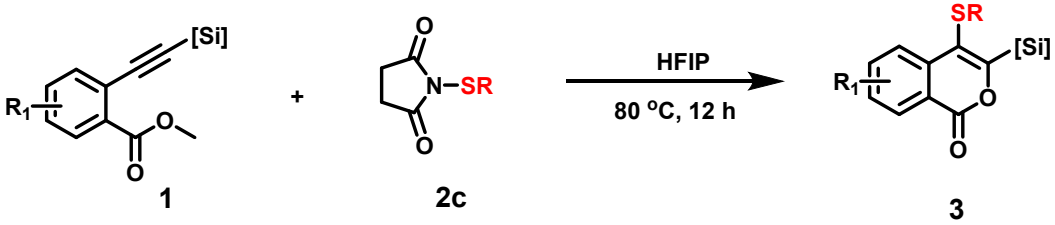
To a CH_2Cl_2 (15 mL) solution of NCS (1.01 g, 7.53 mmol) was dropwise added thiol (7.53 mmol, 1.0 equivalent) and Et_3N (1.05 mL, 7.53 mmol) at 0 °C. And then the mixture was stirring for 18 hours at room temperature. Subsequently, the solution was filtered and washed by saturated aqueous NH_4Cl. After evaporation of solvent, the residue was purified by column chromatography on silica gel eluted with hexane/EA to give the *N*-(benzenesulfenyl)succinimide.[1]

3. General procedure for the preparation of 2-silynylbenzoates



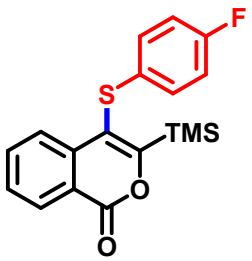
To an oven-dried vial charged with bis(triphenylphosphine)palladium(II) dichloride $Pd(PPh_3)Cl_2$ (36.1 mg, 0.05 mmol) and copper iodide (CuI) (10.0 mg, 0.05 mmol) was added a solution of 2-iodobenzoates (1.59 mmol) dissolved in dry triethylamine (9.0 mL) with stirring for 15 min under argon atmosphere. Then, ethynyltrimethylsilane (0.35 mL, 2.38 mmol) was also introduced into the above mixtures. Next, the reaction was heated to 60℃ and further stirred for 12 h. Subsequently, the solution was cooled to room temperature, filtered, and washed by ethyl acetate. After evaporation of solvent, the residue was purified by column chromatography on silica gel eluted with hexane to give 2-silynylbenzoates as pale yellow liquid. [2]

4. Procedure for preparation of 4-(arylthio)isocoumarins



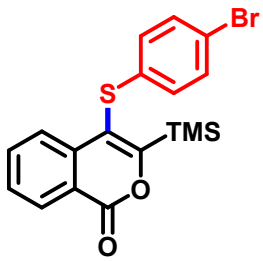
An oven-dried vial was charged with 2-silynylbenzoates (0.1 mmol, 1 equiv), *N*-

thiosuccinimide (0.12 mmol, 1.2 equiv) and HFIP (1.0 mL). After being sealed with a septum, the mixture was stirred at 80 °C for 12 h. This was followed by the addition of water; the aqueous phase was then extracted with ethyl acetate (3 x 10.0 mL). The combined organic layers were dried over Na_2SO_4 and concentrated. The crude product was purified by silica gel column chromatography.



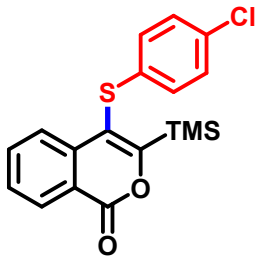
3a

4-((4-fluorophenyl)thio)-3-(trimethylsilyl)-1*H*-isochromen-1-one (3a). Following the standard procedure, the desired product was obtained after flash chromatography (PE as eluent) as yellow oil (26 mg, 77 %). ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.32 (d, *J* = 8.1 Hz, 1H), 7.72 – 7.62 (m, 2H), 7.57 – 7.50 (m, 1H), 7.10 – 7.03 (m, 2H), 6.94 (dd, *J* = 12.0, 5.3 Hz, 2H), 0.40 (s, 9H). ^{13}C NMR (151 MHz, $CDCl_3$) δ 170.9, 162.6, 161.2 (d, *J* = 246.1 Hz), 136.2, 135.0, 131.4 (d, *J* = 3.2 Hz), 129.7, 129.2, 127.46 (d, *J* = 7.9 Hz), 124.8, 121.9, 118.6, 116.4 (d, *J* = 22.6 Hz), -0.8.. HRMS (EI) m/z: $[M]^+$ Calcd for $C_{18}H_{17}FO_2SSi$ 344.0703, found 344.0710.



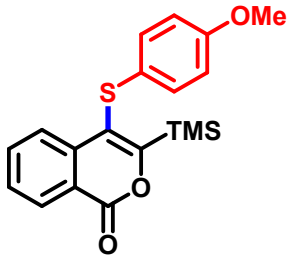
3b

4-((4-bromophenyl)thio)-3-(trimethylsilyl)-1*H*-isochromen-1-one (3b). Following the standard procedure, the desired product was obtained after flash chromatography (PE as eluent) as yellow oil (30 mg, 76 %). ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.33 (d, *J* = 7.9 Hz, 1H), 7.69 – 7.63 (m, 2H), 7.56-7.52 (m, 1H), 7.34 (d, *J* = 8.6 Hz, 2H), 6.95 (d, *J* = 8.6 Hz, 2H), 0.38 (s, 9H). ^{13}C NMR (151 MHz, $CDCl_3$) δ 171.3, 162.5, 136.1, 135.8, 135.1, 132.2, 129.8, 129.3, 127.2, 124.7, 121.9, 119.4, 117.9, -0.8. HRMS (EI) m/z: $[M]^+$ Calcd for $C_{18}H_{17}BrO_2SSi$ 403.9902, found 403.9908.



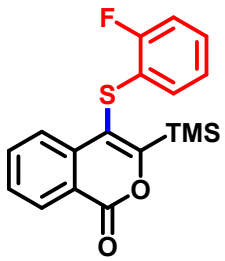
3c

4-((4-chlorophenyl)thio)-3-(trimethylsilyl)-1*H*-isochromen-1-one (3c). Following the standard procedure, the desired product was obtained after flash chromatography (PE as eluent) as yellow oil (25 mg, 70 %). ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.32 (d, *J* = 7.8 Hz, 1H), 7.66 (d, *J* = 3.7 Hz, 2H), 7.57 – 7.52 (m, 1H), 7.20 (d, *J* = 8.7 Hz, 2H), 7.01 (d, *J* = 8.7 Hz, 2H), 0.39 (s, 9H). ^{13}C NMR (101 MHz, $CDCl_3$) δ 172.1, 163.3, 136.9, 135.9, 135.8, 132.4, 130.6, 130.2, 130.1, 127.7, 125.5, 122.7, 118.8, 0.00. HRMS (EI) m/z: $[M]^+$ Calcd for $C_{18}H_{17}ClO_2SSi$ 360.0407, found 360.0408.



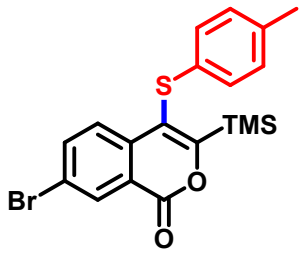
3d

4-((4-methoxyphenyl)thio)-3-(trimethylsilyl)-1*H*-isochromen-1-one (3d). Following the standard procedure, the desired product was obtained after flash chromatography (PE/EA= 20:1 as eluent) as yellow oil (29 mg, 81 %). ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.30 (dd, *J* = 7.9, 0.8 Hz, 1H), 7.72 (d, *J* = 7.6 Hz, 1H), 7.67 – 7.60 (m, 1H), 7.55 – 7.48 (m, 1H), 7.08 – 7.02 (m, 2H), 6.82 – 6.75 (m, 2H), 3.74 (s, 3H), 0.41 (s, 9H). ^{13}C NMR (151 MHz, $CDCl_3$) δ 170.1, 162.8, 158.1, 136.5, 134.8, 129.6, 129.0, 127.6, 126.7, 125.1, 121.9, 119.4, 114.9, 55.3, -0.7. HRMS (EI) m/z: $[M]^+$ Calcd for $C_{19}H_{20}O_3SSi$ 356.0902, found 356.0905.



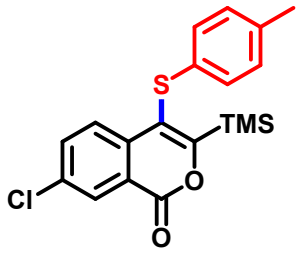
3e

4-((2-fluorophenyl)thio)-3-(trimethylsilyl)-1*H*-isochromen-1-one (3e). Following the standard procedure, the desired product was obtained after flash chromatography (PE as eluent) as colorless oil (23 mg, 68 %). ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.33 (d, *J* = 7.9 Hz, 1H), 7.74 – 7.64 (m, 2H), 7.60 – 7.51 (m, 1H), 7.14 – 7.05 (m, 2H), 6.97 – 6.89 (m, 1H), 6.72 (td, *J* = 7.9, 1.1 Hz, 1H), 0.39 (s, 9H). ^{13}C NMR (151 MHz, $CDCl_3$) δ 171.6, 162.5, 158.9 (d, *J* = 244.2 Hz), 136.2, 135.1, 129.7, 129.3, 127.1 (d, *J* = 3.0 Hz) 127.0, 124.8 (d, *J* = 3.0 Hz) 124.7, 123.9 (d, *J* = 16.6 Hz), 121.8, 116.8, 115.6 (d, *J* = 21.1 Hz), -0.8.HRMS (EI) m/z: $[M]^+$ Calcd for $C_{18}H_{17}FO_2SSi$ 344.0703, found 344.0700.



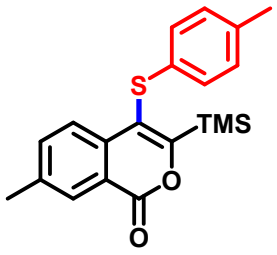
3f

7-bromo-4-(p-tolylthio)-3-(trimethylsilyl)-1*H*-isochromen-1-one (3f). Following the standard procedure, the desired product was obtained after flash chromatography (PE as eluent) as colorless oil (30 mg, 72 %). ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.43 (d, *J* = 1.9 Hz, 1H), 7.70 (dd, *J* = 8.6, 2.1 Hz, 1H), 7.57 (d, *J* = 8.6 Hz, 1H), 7.04 (d, *J* = 8.1 Hz, 2H), 6.96 (d, *J* = 8.3 Hz, 2H), 2.27 (s, 3H), 0.40 (s, 9H). ^{13}C NMR (101 MHz, $CDCl_3$) δ 171.8, 162.3, 138.8, 136.7, 136.2, 133.0, 132.9, 130.9, 127.8, 126.8, 124.0, 123.7, 119.2, 21.7, -0.0. HRMS (EI) m/z: $[M]^+$ Calcd for $C_{19}H_{19}BrO_2SSi$ 418.0058, found 418.0051.



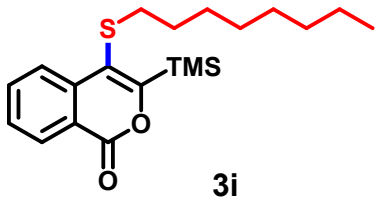
3g

7-chloro-4-(p-tolylthio)-3-(trimethylsilyl)-1*H*-isochromen-1-one (3g). Following the standard procedure, the desired product was obtained after flash chromatography (PE as eluent) as colorless oil (28 mg, 77 %). ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.23 (d, *J* = 8.4 Hz, 1H), 7.70 (d, *J* = 1.9 Hz, 1H), 7.46 (dd, *J* = 8.5, 2.0 Hz, 1H), 7.06 (d, *J* = 8.1 Hz, 2H), 6.98 (d, *J* = 8.3 Hz, 2H), 2.28 (s, 3H), 0.39 (s, 9H). ^{13}C NMR (151 MHz, $CDCl_3$) δ 172.4, 162.0, 141.9, 138.2, 135.9, 132.1, 131.3, 130.1, 129.6, 125.9, 124.8, 120.1, 117.9, 20.9, -0.8. HRMS (EI) m/z: $[M]^+$ Calcd for $C_{19}H_{19}ClO_2SSi$ 374.0564, found 374.0560.



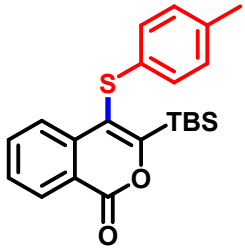
3h

7-methyl-4-(p-tolylthio)-3-(trimethylsilyl)-1*H*-isochromen-1-one (3h). Following the standard procedure, the desired product was obtained after flash chromatography (PE as eluent) as colorless oil (23 mg, 67 %). ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.12 (s, 1H), 7.59 (d, *J* = 8.2 Hz, 1H), 7.43 (dd, *J* = 8.2, 1.3 Hz, 1H), 7.02 (d, *J* = 8.2 Hz, 2H), 6.97 (d, *J* = 8.3 Hz, 2H), 2.43 (s, 3H), 2.26 (s, 3H), 0.39 (s, 9H). ^{13}C NMR (101 MHz, $CDCl_3$) δ 170.1, 163.8, 140.2, 136.9, 136.2, 134.8, 133.6, 130.7, 130.0, 126.6, 125.8, 122.5, 119.6, 22.0, 21.6, -0.0. HRMS (EI) m/z: $[M]^+$ Calcd for $C_{20}H_{22}O_2SSi$ 354.1110, found 354.1116.



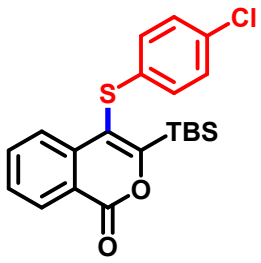
3i

4-(octylthio)-3-(trimethylsilyl)-1*H*-isochromen-1-one (3i). Following the standard procedure, the desired product was obtained after flash chromatography (PE as eluent) as colorless oil (20 mg, 57 %). ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.31 (dd, *J* = 7.9, 0.8 Hz, 1H), 8.01 (d, *J* = 8.0 Hz, 1H), 7.85 – 7.78 (m, 1H), 7.60 – 7.53 (m, 1H), 2.66 (t, *J* = 7.6 Hz, 2H), 1.64 (dd, *J* = 15.1, 7.3 Hz, 2H), 1.44 – 1.27 (m, 10H), 0.89 (d, *J* = 6.6 Hz, 3H), 0.45 (s, 9H). ^{13}C NMR (101 MHz, $CDCl_3$) δ 168.7, 163.4, 137.4, 135.1, 130.1, 129.3, 125.2, 122.7, 122.3, 37.4 32.2, 30.1, 30.0, 29.6, 29.5, 23.1, 14.5, 0.0. HRMS (EI) m/z: $[M]^+$ Calcd for $C_{20}H_{30}O_2SSi$ 362.1736, found 362.1731.



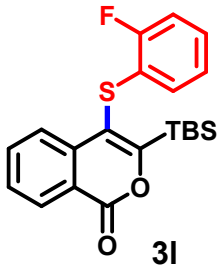
3j

3-(*tert*-butyldimethylsilyl)-4-(p-tolylthio)-1*H*-isochromen-1-one (3j) Following the standard procedure, the desired product was obtained after flash chromatography (PE as eluent) as colorless oil (25 mg, 66 %). ^{1}H NMR (600 MHz, $CDCl_3$) δ 8.31 (dd, *J* = 7.9, 1.1 Hz, 1H), 7.74 (d, *J* = 7.9 Hz, 1H), 7.65 – 7.60 (m, 1H), 7.54 – 7.48 (m, 1H), 7.03 (d, *J* = 8.1 Hz, 2H), 7.01 – 6.96 (m, 2H), 2.27 (s, 3H), 1.02 (s, 9H), 0.39 (s, 6H). ^{13}C NMR (151 MHz, $CDCl_3$) δ 169.9, 162.6, 136.7, 135.6, 134.9, 133.3, 130.1, 129.6, 129.2, 125.9, 125.6, 119.7, 29.8, 27.1, 18.2, 14.3. HRMS (EI) m/z: $[M]^+$ Calcd for $C_{22}H_{26}O_2SSi$ 382.1423, found 382.1422.



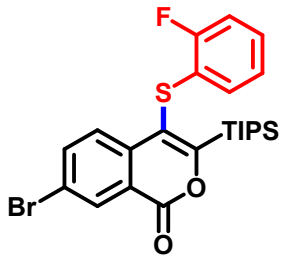
3k

3-(*tert*-butyldimethylsilyl)-4-((4-chlorophenyl)thio)-1*H*-isochromen-1-one (3k). Following the standard procedure, the desired product was obtained after flash chromatography (PE as eluent) as colorless oil (32 mg, 79 %). ^{1}H NMR (600 MHz, $CDCl_3$) δ 8.32 (dd, *J* = 7.9, 0.8 Hz, 1H), 7.71 – 7.68 (m, 1H), 7.68 – 7.63 (m, 1H), 7.57 – 7.52 (m, 1H), 7.22 – 7.17 (m, 2H), 7.05 – 6.94 (m, 2H), 1.02 (s, 9H), 0.37 (s, 6H). ^{13}C NMR (151 MHz, $CDCl_3$) δ 170.6, 162.3, 136.3, 135.5, 135.1, 131.6, 129.8, 129.5, 126.9, 125.3, 121.9, 118.9, 29.8, 27.1, 18.1. HRMS (EI) m/z: $[M]^+$ Calcd for $C_{21}H_{23}ClO_2SSi$ 402.0877, found 402.0880.



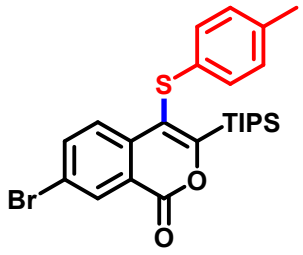
3l

3-(*tert*-butyldimethylsilyl)-4-((2-fluorophenyl)thio)-1*H*-isochromen-1-one (3l). Following the standard procedure, the desired product was obtained after flash chromatography (PE as eluent) as yellow oil (24 mg, 62 %). ^{1}H NMR (600 MHz, $CDCl_3$) δ 8.33 (dd, *J* = 7.9, 1.0 Hz, 1H), 7.73 (d, *J* = 7.8 Hz, 1H), 7.70 – 7.65 (m, 1H), 7.58 – 7.52 (m, 1H), 7.15 – 7.04 (m, 2H), 6.96 – 6.89 (m, 1H), 6.72 (td, *J* = 7.8, 1.4 Hz, 1H), 1.02 (s, 9H), 0.37 (s, 6H). ^{13}C NMR (151 MHz, $CDCl_3$) δ 170.9, 162.4, 158.9 (d, *J* = 244.6 Hz), 136.4, 135.2, 129.8, 129.5, 127.3 (d, *J* = 2.4 Hz), 127.1 (d, *J* = 7.5 Hz), 125.2, 124.9 (d, *J* = 3.4 Hz), 124.5, 124.4, 121.8, 115.7 (d, *J* = 21.1 Hz), 29.8, 27.1, 18.1. HRMS (EI) m/z: $[M]^+$ Calcd for $C_{21}H_{23}FO_2SSi$ 386.1172, found 386.1181.



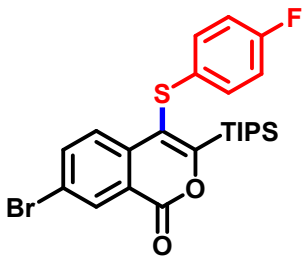
3m

7-bromo-4-((2-fluorophenyl)thio)-3-(triisopropylsilyl)-1*H*-isochromen-1-one (3m). Following the standard procedure, the desired product was obtained after flash chromatography (PE as eluent) as colorless oil (71 mg, 44 %). ^{1}H NMR (600 MHz, $CDCl_3$) δ 8.46 (d, *J* = 2.1 Hz, 1H), 7.74 (dd, *J* = 8.6, 2.1 Hz, 1H), 7.54 (d, *J* = 8.6 Hz, 1H), 7.13 – 7.05 (m, 2H), 6.93 – 6.88 (m, 1H), 6.63 (td, *J* = 7.8, 1.2 Hz, 1H), 1.63 (dt, *J* = 15.0, 7.5 Hz, 3H), 1.12 (d, *J* = 7.5 Hz, 18H). ^{13}C NMR (151 MHz, $CDCl_3$) δ 171.2, 161.2, 158.7 (d, *J* = 244.2 Hz), 138.1, 135.0, 132.1, 127.1 (d, *J* = 3.0 Hz), 127.0 (d, *J* = 7.5 Hz), 124.7 (d, *J* = 3.6 Hz), 123.1, 122.8, 115.6 (d, *J* = 19.6 Hz), 29.7, 18.9. HRMS (EI) m/z: $[M]^+$ Calcd for $C_{24}H_{28}BrFO_2SSi$ 506.0747, found 506.0740.



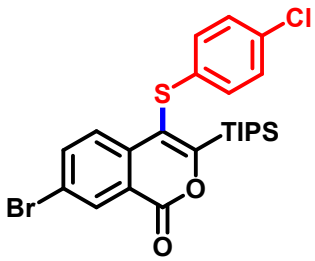
3n

7-bromo-4-(p-tolylthio)-3-(triisopropylsilyl)-1*H*-isochromen-1-one (3n). Following the standard procedure, the desired product was obtained after flash chromatography (PE as eluent) as colorless oil (36 mg, 72 %). ^{1}H NMR (600 MHz, $CDCl_3$) δ 8.44 (d, *J* = 2.1 Hz, 1H), 7.69 (dd, *J* = 8.7, 2.1 Hz, 1H), 7.55 (d, *J* = 8.7 Hz, 1H), 7.02 (d, *J* = 8.2 Hz, 2H), 6.91 (d, *J* = 8.2 Hz, 2H), 2.27 (s, 3H), 1.64 (dd, *J* = 10.0, 5.0 Hz, 3H), 1.14 (d, *J* = 7.5 Hz, 18H). ^{13}C NMR (151 MHz, $CDCl_3$) δ 170.0, 161.5, 138.0, 135.6, 135.4, 132.5, 132.0, 130.1, 127.8, 125.9, 123.0, 122.9, 119.5, 29.8, 19.0, 12.7. HRMS (EI) m/z: $[M]^+$ Calcd for $C_{25}H_{31}BrO_2SSi$ 502.0997, found 502.0990.



3o

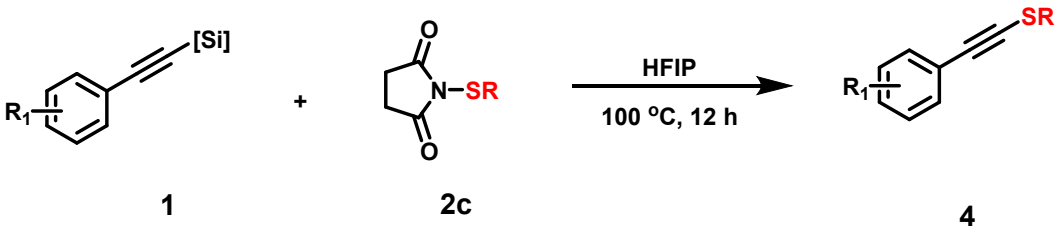
7-bromo-4-((4-fluorophenyl)thio)-3-(triisopropylsilyl)-1*H*-isochromen-1-one (3o). Following the standard procedure, the desired product was obtained after flash chromatography (PE as eluent) as colorless oil (33 mg, 66 %). ^{1}H NMR (600 MHz, $CDCl_3$) δ 8.45 (d, *J* = 2.1 Hz, 1H), 7.72 (dd, *J* = 8.6, 2.1 Hz, 1H), 7.53 (d, *J* = 8.6 Hz, 1H), 7.02 – 6.96 (m, 2H), 6.96 – 6.89 (m, 2H), 1.62 (dd, *J* = 15.0, 7.5 Hz, 3H), 1.13 (d, *J* = 7.5 Hz, 18H). ^{13}C NMR (151 MHz, $CDCl_3$) δ 170.6, 161.3, 161.2 (d, *J* = 246.1 Hz), 138.1, 135.1, 132.2, 131.3 127.5 (d, *J* = 7.1 Hz) 127.4, 123.2, 123.0, 119.2, 116.6 (d, *J* = 21.1 Hz), 29.8, 19.0. HRMS (EI) m/z: $[M]^+$ Calcd for $C_{24}H_{28}BrFO_2SSi$ 506.0747, found 506.0751.



3p

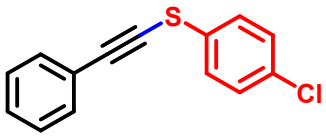
7-bromo-4-((4-chlorophenyl)thio)-3-(triisopropylsilyl)-1*H*-isochromen-1-one (3p). Following the standard procedure, the desired product was obtained after flash chromatography (PE as eluent) as colorless oil (47 mg, 72 %). ^{1}H NMR (600 MHz, $CDCl_3$) δ 8.48 (d, *J* = 2.1 Hz, 1H), 7.76 (dd, *J* = 8.6, 2.1 Hz, 1H), 7.53 (d, *J* = 8.6 Hz, 1H), 7.21 (d, *J* = 8.7 Hz, 2H), 6.97 (d, *J* = 8.7 Hz, 2H), 1.66 – 1.63 (m, 3H), 1.15 (s, 18H). ^{13}C NMR (151 MHz, $CDCl_3$) δ 170.9, 161.2, 138.2, 134.9, 134.8, 132.3, 131.7, 129.5, 127.4, 127.0, 123.3, 123.0, 118.6, 29.8, 19.0. HRMS (EI) m/z: $[M]^+$ Calcd for $C_{24}H_{28}BrClO_2SSi$ 522.0451, found 522.0457.

5. Procedure for preparation of (alkynyl)(aryl)sulfanes



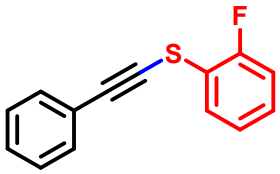
1 2c 4

An oven-dried vial was charged with aryl(trimethylsilyl)ethyne (0.1 mmol, 1 equiv), *N*-thiosuccinimide or *N*- (trifluoromethylthio)succinimide (0.12 mmol, 1.2 equiv) and HFIP (1.0 mL). After being sealed with a septum, the mixture was stirred at 100 °C for 12 h. This was followed by the addition of water; the aqueous phase was then extracted with ethyl acetate (3 x 10.0 mL). The combined organic layers were dried over Na_2SO_4 and concentrated. The crude product was purified by silica gel column chromatography.



4a

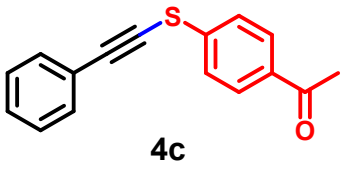
(4-chlorophenyl)(phenylethynyl)sulfane (4a). Following the standard procedure, the desired product was obtained after flash chromatography (PE as eluent) as white solid (16 mg, 66 %). ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.54 – 7.48 (m, 2H), 7.41 (d, *J* = 8.5 Hz, 2H), 7.34 (dd, *J* = 10.9, 6.7 Hz, 5H). ^{13}C NMR (151 MHz, $CDCl_3$) δ 132.5, 131.8, 131.6, 129.4, 128.9, 128.5, 127.5, 122.6, 98.4, 74.8.



4b

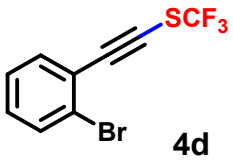
(2-fluorophenyl)(phenylethynyl)sulfane (4b). Following the standard procedure, the desired product was obtained after flash chromatography (PE as eluent) as white solid (16 mg, 70 %). ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.68 (dd, *J* = 11.0, 4.3 Hz, 1H), 7.57 – 7.49 (m, 2H), 7.35 (d, *J* = 4.5 Hz, 3H), 7.21 (dt, *J* = 14.2, 7.0 Hz, 2H), 7.07 (t, *J* = 9.0 Hz, 1H). ^{13}C NMR (151 MHz, $CDCl_3$) δ 158.9 (d, *J* = 246.1 Hz), 131.9, 128.9, 128.5,

128.2 (d, J = 3.0 Hz), 128.1 (d, J = 3.7 Hz), 125.0 (d, J = 3.4 Hz), 122.5, 120.5 (d, J = 16.3 Hz), 115.4 (d, J = 19.6 Hz), 98.3, 73.5. HRMS (EI) m/z: $[M]^+$ Calcd for $C_{14}H_9FS$ 228.0409, found 228.0400.



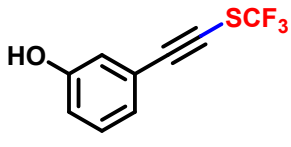
4c

1-(4-((phenylethynyl)thio)phenyl)ethan-1-one (4c). Following the standard procedure, the desired product was obtained after flash chromatography (PE/EA = 20:1 as eluent) as white solid (18 mg, 73 %). ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.94 (d, J = 8.3 Hz, 2H), 7.55 (t, J = 6.7 Hz, 4H), 7.38 (d, J = 5.0 Hz, 3H), 2.59 (s, 3H). ^{13}C NMR (151 MHz, $CDCl_3$) δ 197.01, 140.0, 135.2, 131.9, 129.1, 129.0, 128.5, 125.4, 122.4, 99.5, 73.6, 26.5. HRMS (EI) m/z: $[M]^+$ Calcd for $C_{16}H_{12}OS$ 252.0609, found 252.0600.



4d

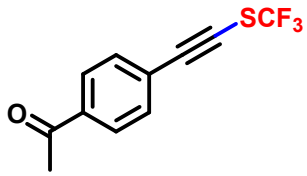
((2-bromophenyl)ethynyl)(trifluoromethyl)sulfane (4d). Following the standard procedure, the desired product was obtained after flash chromatography (PE as eluent) as colorless oil (17 mg, 61 %). ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.61 (d, J = 8.0 Hz, 1H), 7.53 – 7.46 (m, 1H), 7.30 (t, J = 7.4 Hz, 1H), 7.26 – 7.20 (m, 1H). ^{19}F NMR (377 MHz, $CDCl_3$) δ -43.07 (s). ^{13}C NMR (151 MHz, $CDCl_3$) δ 133.6, 132.6, 130.6, 127.9 (q, J = 318.6 Hz), 125.8, 123.9, 99.7, 71.63 (q, J = 4.1 Hz). HRMS (EI) m/z: $[M]^+$ Calcd for $C_9H_4BrF_3S$ 279.9169, found 279.9177.



4e

3-(((trifluoromethyl)thio)ethynyl)phenol (4e). Following the standard procedure, the desired product was obtained after flash chromatography (PE/EA = 8:1 as eluent)

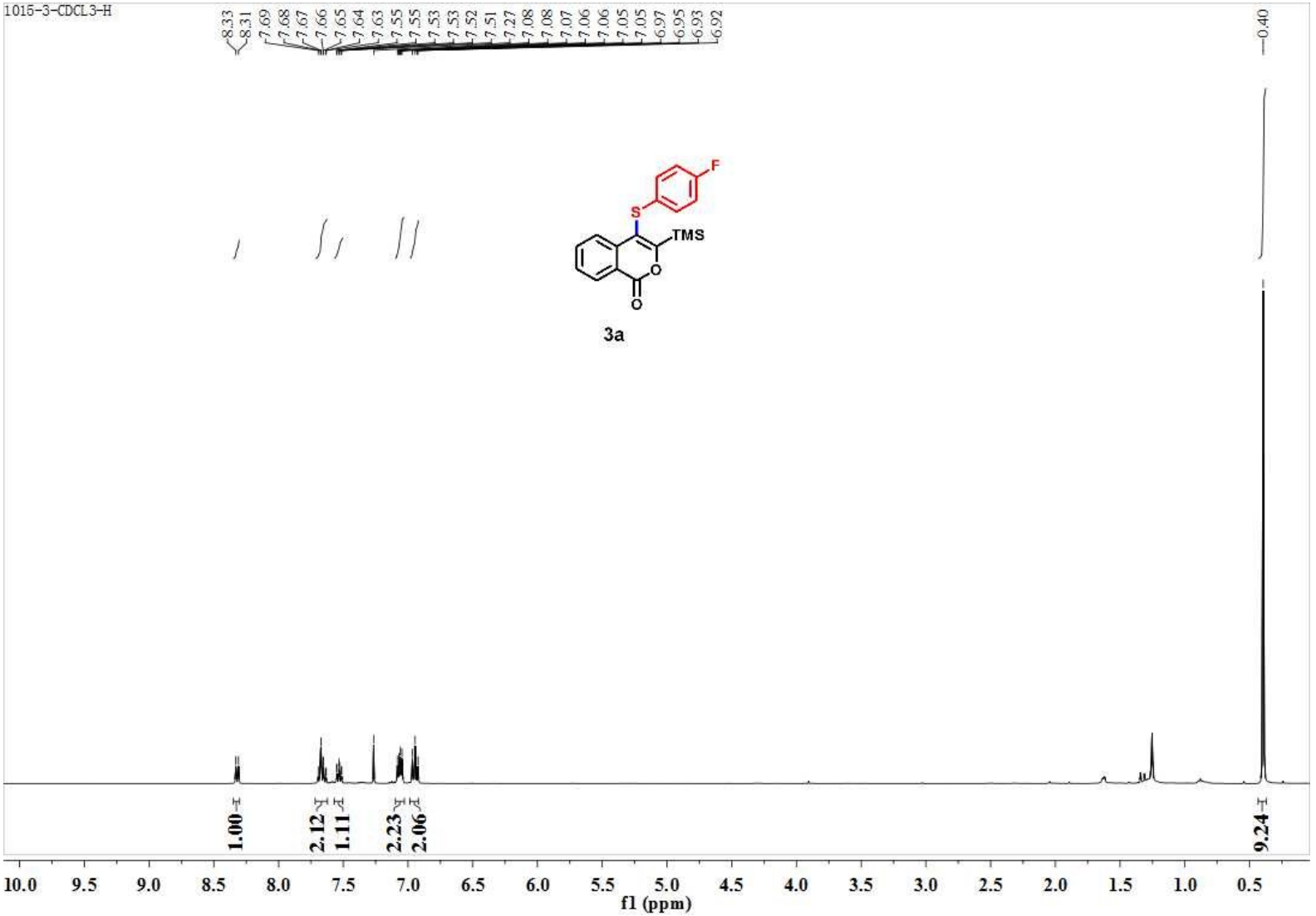
as colorless oil (13 mg, 58 %). ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.22 (t, J = 7.9 Hz, 1H), 7.07 (d, J = 7.6 Hz, 1H), 6.96 (s, 1H), 6.88 (d, J = 8.2 Hz, 1H), 3.08 (s, 1H). ^{19}F NMR (377 MHz, $CDCl_3$) δ -43.55 (s). ^{13}C NMR (151 MHz, $CDCl_3$) δ 155.5, 129.8, 128.1(q, J = 312.3 Hz), 124.8, 122.7, 118.7, 117.3, 100.9, 66.8 (q, J = 4.3 Hz). HRMS (EI) m/z: $[M]^+$ Calcd for $C_9H_5F_3OS$ 218.0013, found 218.0019.

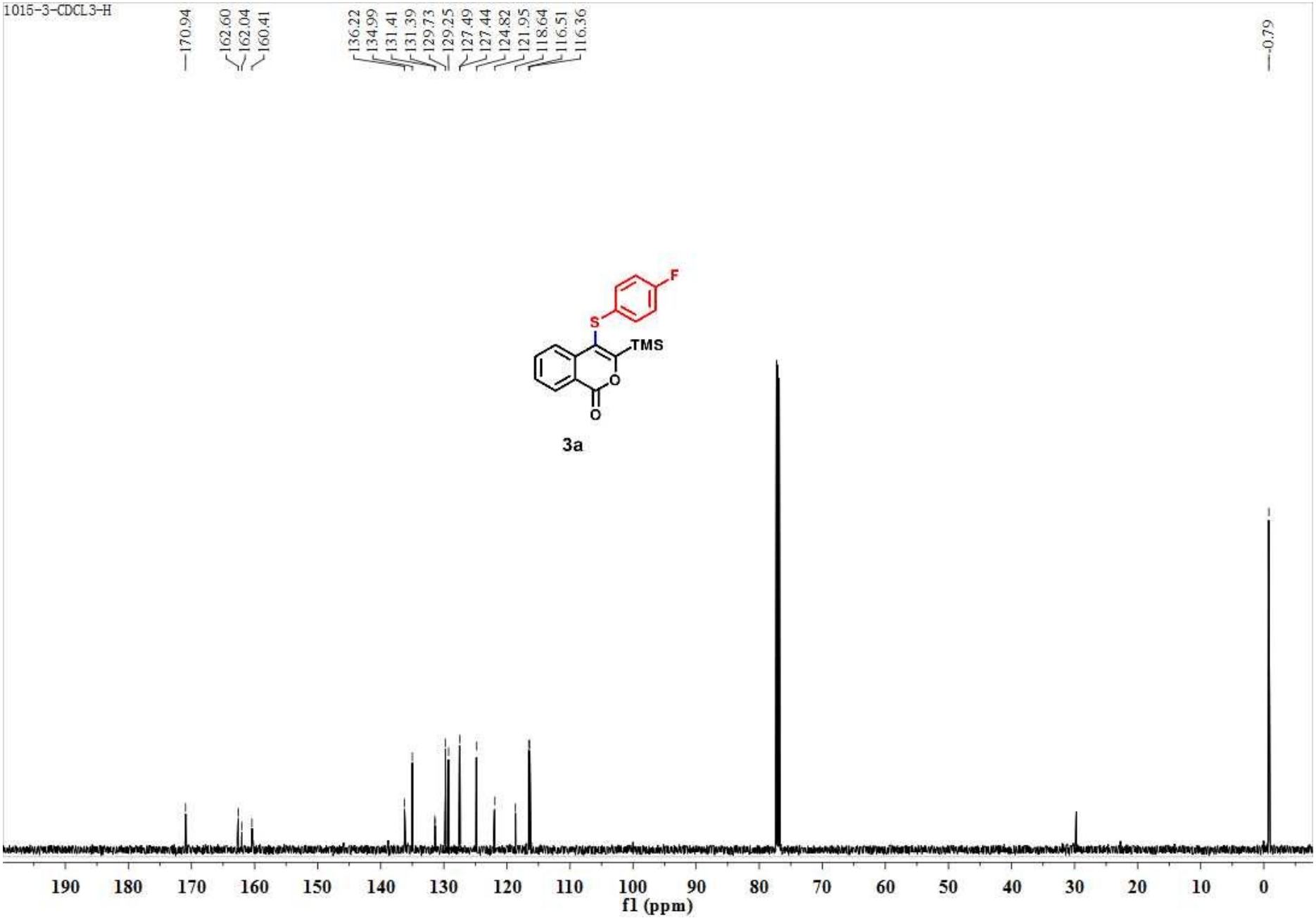


4f

1-(4-(((trifluoromethyl)thio)ethynyl)phenyl)ethan-1-one (4f). Following the standard procedure, the desired product was obtained after flash chromatography (PE/EA = 20:1 as eluent) as colorless oil (16 mg, 70 %). ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.94 (d, J = 8.1 Hz, 2H), 7.56 (d, J = 8.1 Hz, 2H), 2.61 (s, 3H). ^{19}F NMR (377 MHz, $CDCl_3$) δ -43.15 (s). ^{13}C NMR (151 MHz, $CDCl_3$) δ 197.1, 137.2, 131.9, 128.3, 127.9 (q, J = 312.6 Hz)126.1, 100.4, 70.4 (q, J = 4.2 Hz), 26.7. HRMS (EI) m/z: $[M]^+$ Calcd for $C_{11}H_7F_3OS$ 244.0170, found 244.0178.

6. Copies of NMR Spectra

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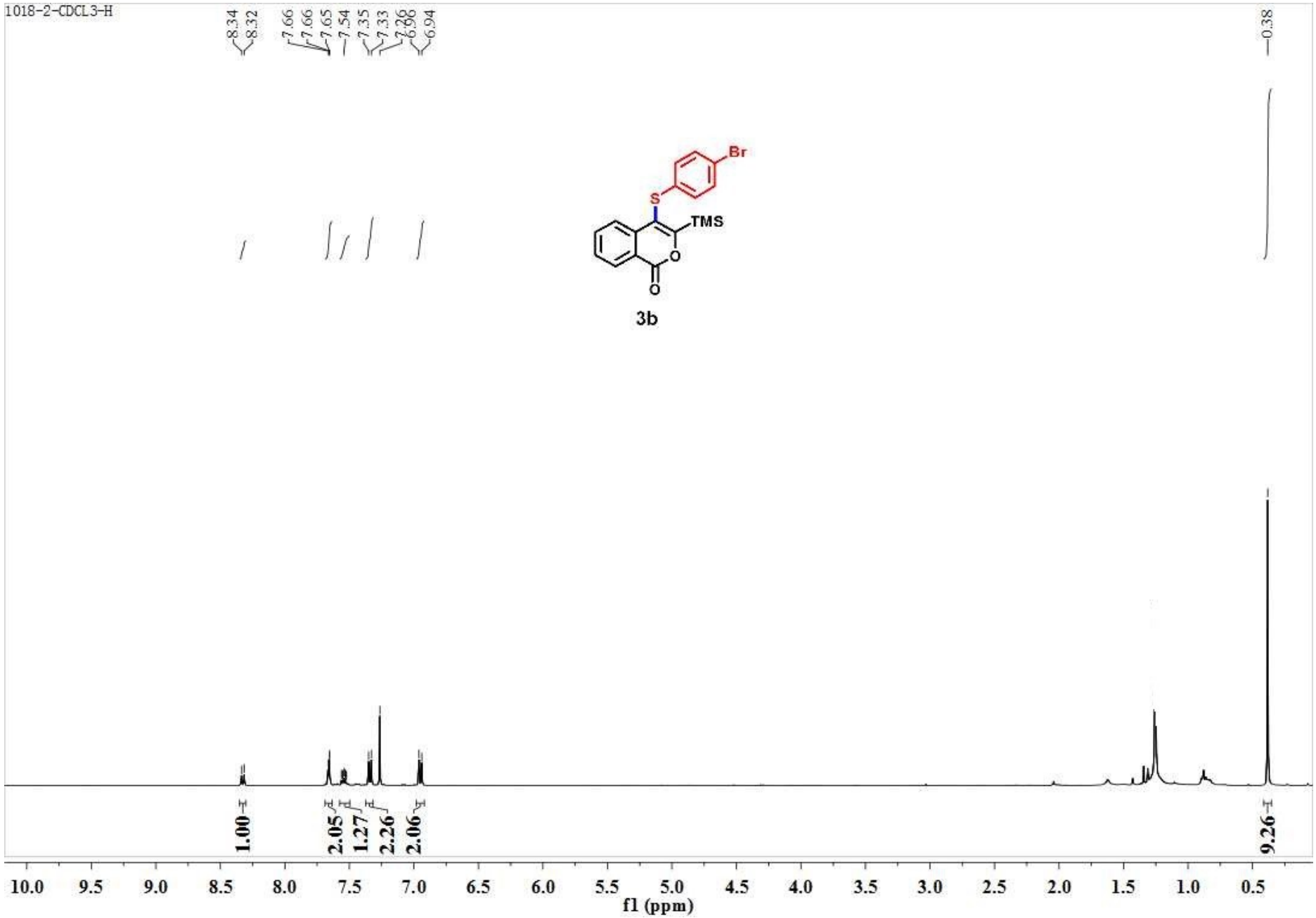
162.60
162.04
160.41
136.22
134.99
131.41
131.39
129.73
129.25
127.49
127.44
124.82
121.95
118.64
116.51
116.36
0.79
F
S
TMS
O
O
3a
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
f1 (ppm)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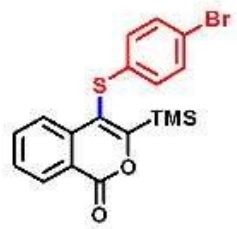
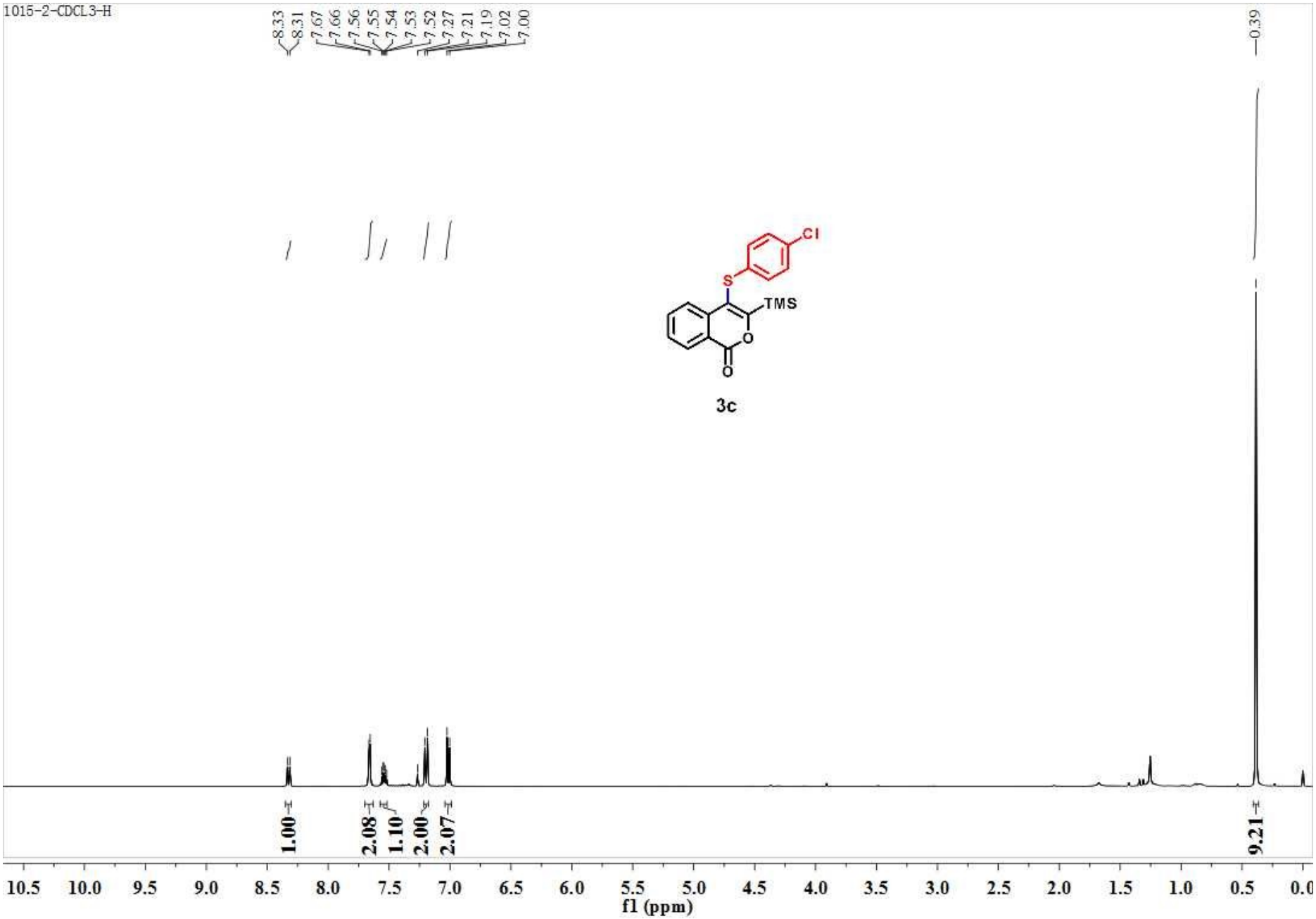
8.34
8.32
7.66
7.66
7.65
7.54
7.35
7.33
7.26
6.98
6.94
0.38
Br
S
TMS
O
O
3b
1.00
2.05
1.27
2.26
2.06
9.26
10.0
9.5
9.0
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
f1 (ppm)

3b-1018-2-4BR

171.34
162.52
136.08
135.78
135.08
132.26
129.79
129.34
127.23
124.72
121.91
119.40
117.91
-0.83



3b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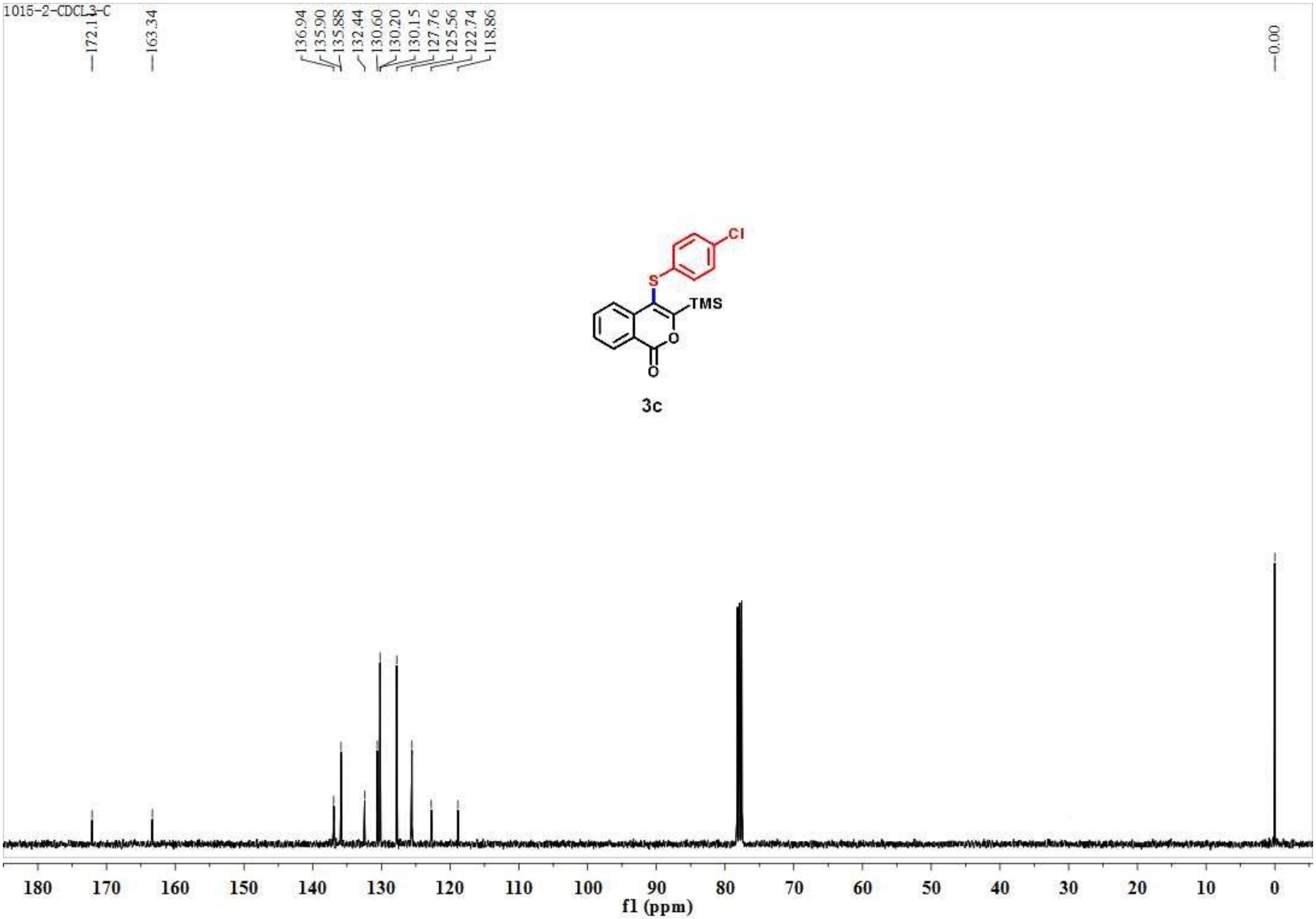
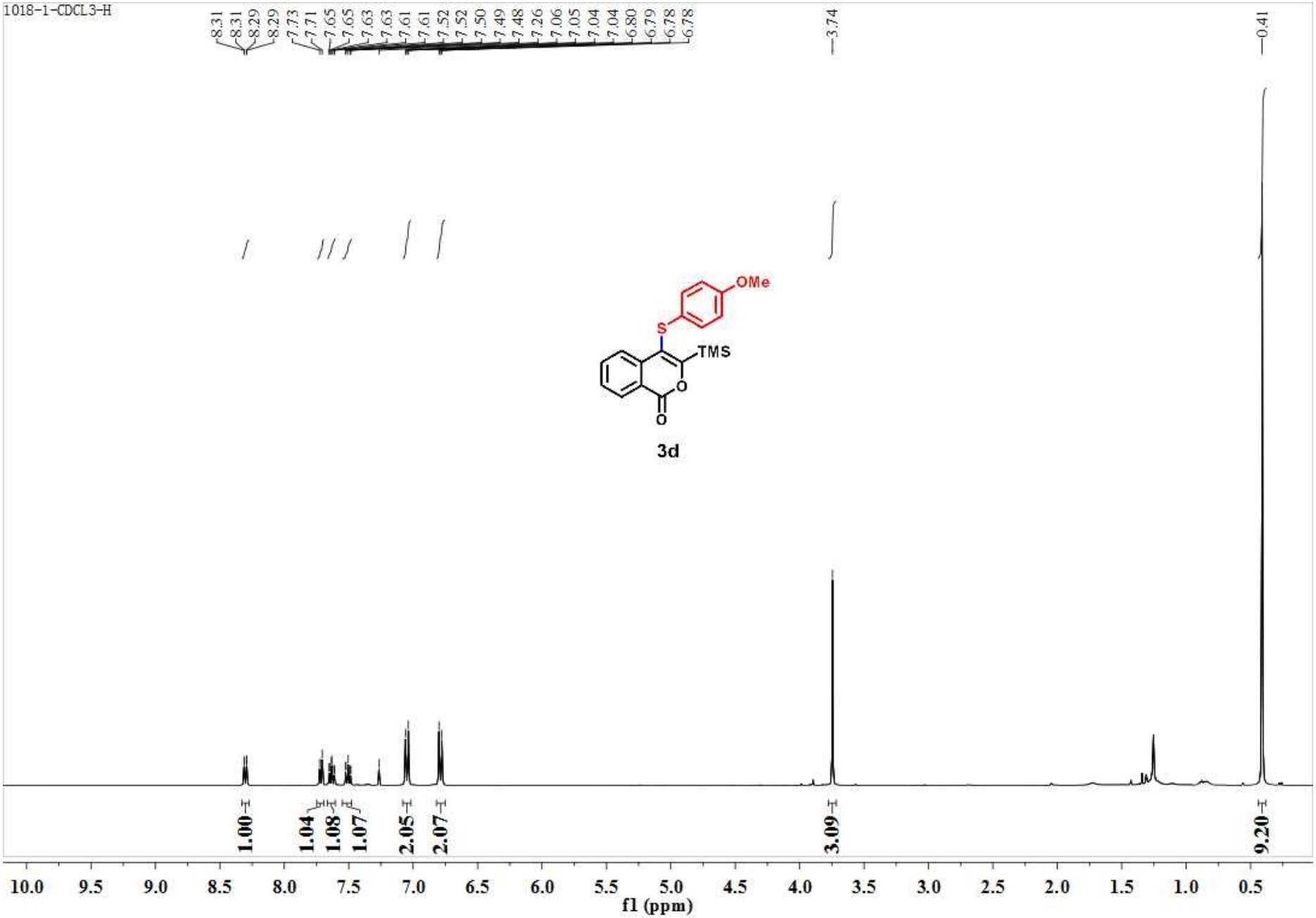
8.31
7.67
7.66
7.56
7.55
7.54
7.53
7.52
7.27
7.21
7.19
7.02
7.00
0.39
Cl
S
TMS
O
O
1.00
2.08
1.10
2.00
2.07
9.21
10.5 10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0
f1 (ppm)

3c


1015-2-CDCL3-C
172.11
163.34
136.94
135.90
135.88
132.44
130.60
130.20
130.15
127.76
125.56
122.74
118.86
0.00
Cl
S
TMS
O
O
3c
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
f1 (ppm)


1018-1-CDCL3-H
8.31
8.31
8.29
8.29
7.73
7.71
7.65
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7.63
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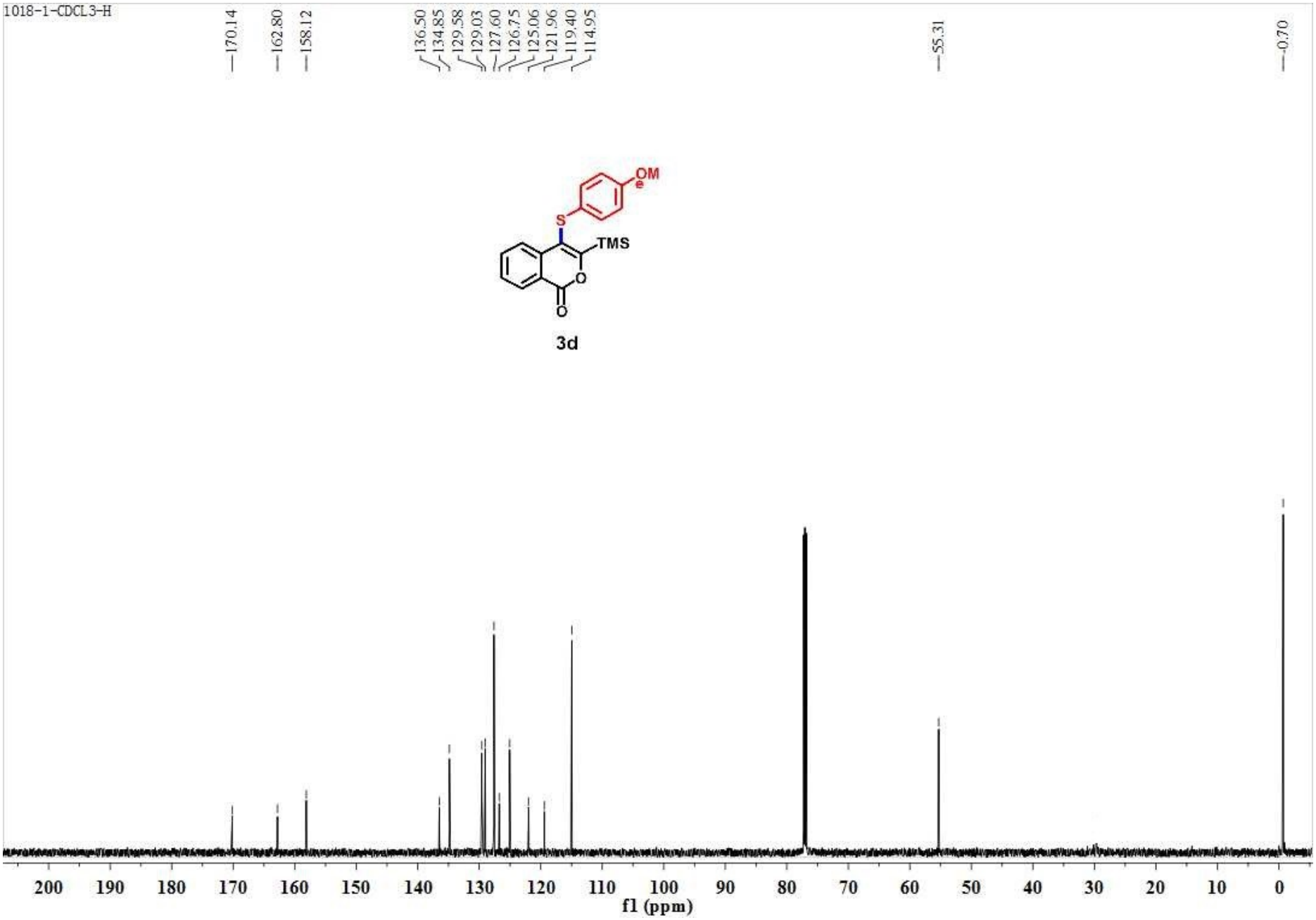
7.61
7.61
7.52
7.52
7.50
7.49
7.48
7.26
7.06
7.05
7.04
7.04
6.80
6.79
6.78
6.78
3.74
0.41
OMe
S
TMS
O
O
3d
1.00
1.04
1.08
1.07
2.05
2.07
3.09
9.20
10.0
9.5
9.0
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
f1 (ppm)


1018-1-CDCL3-H
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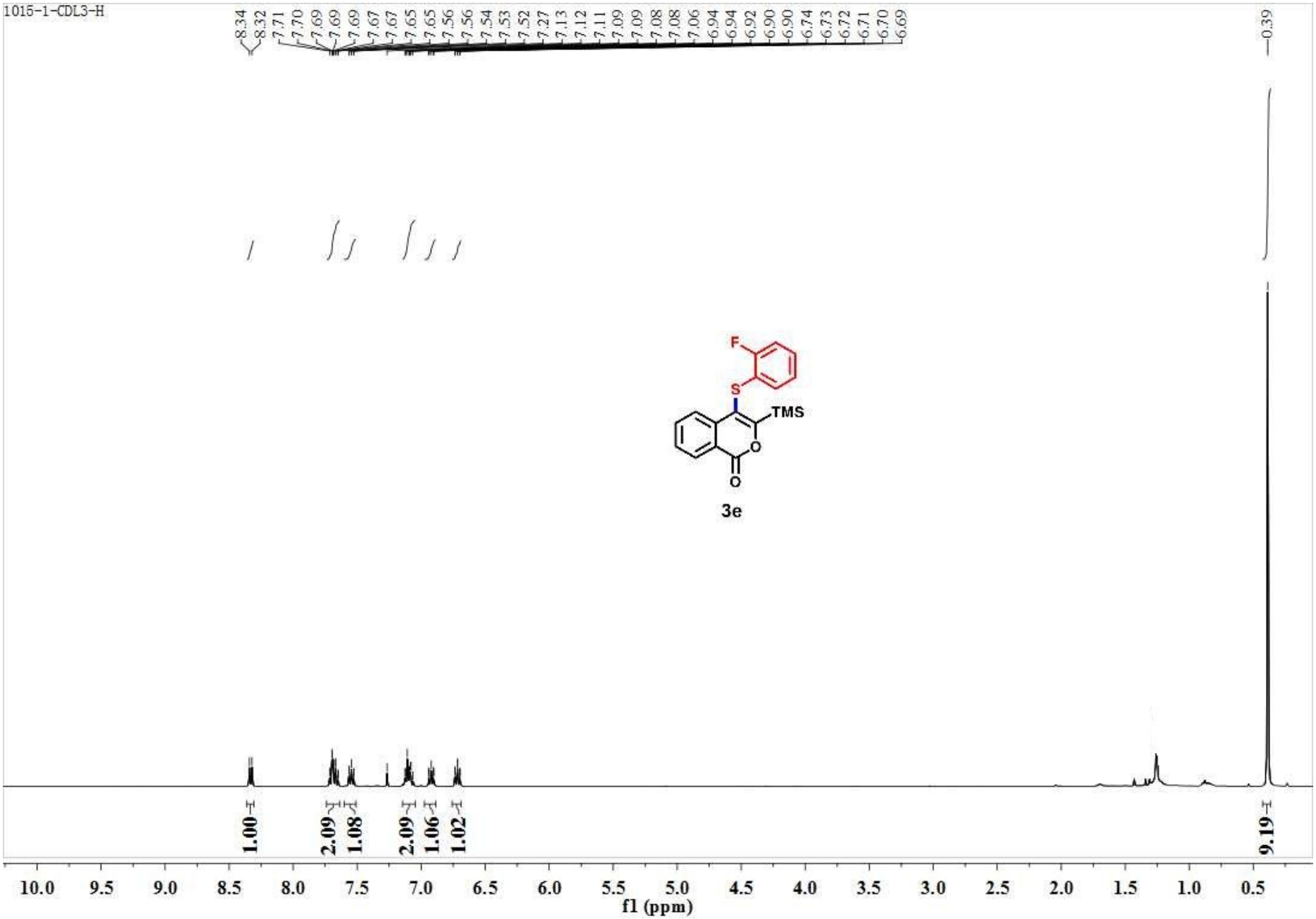
162.80
158.12
136.50
134.85
129.58
129.03
127.60
126.75
125.06
121.96
119.40
114.95
55.31
0.70
OMe
S
TMS
O
O
3d
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
f1 (ppm)


1015-1-CDL3-H
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8.32
7.71
7.70
7.69
7.69
7.69
7.67
7.67
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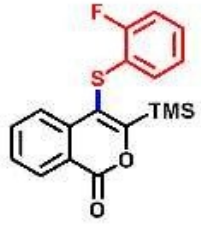
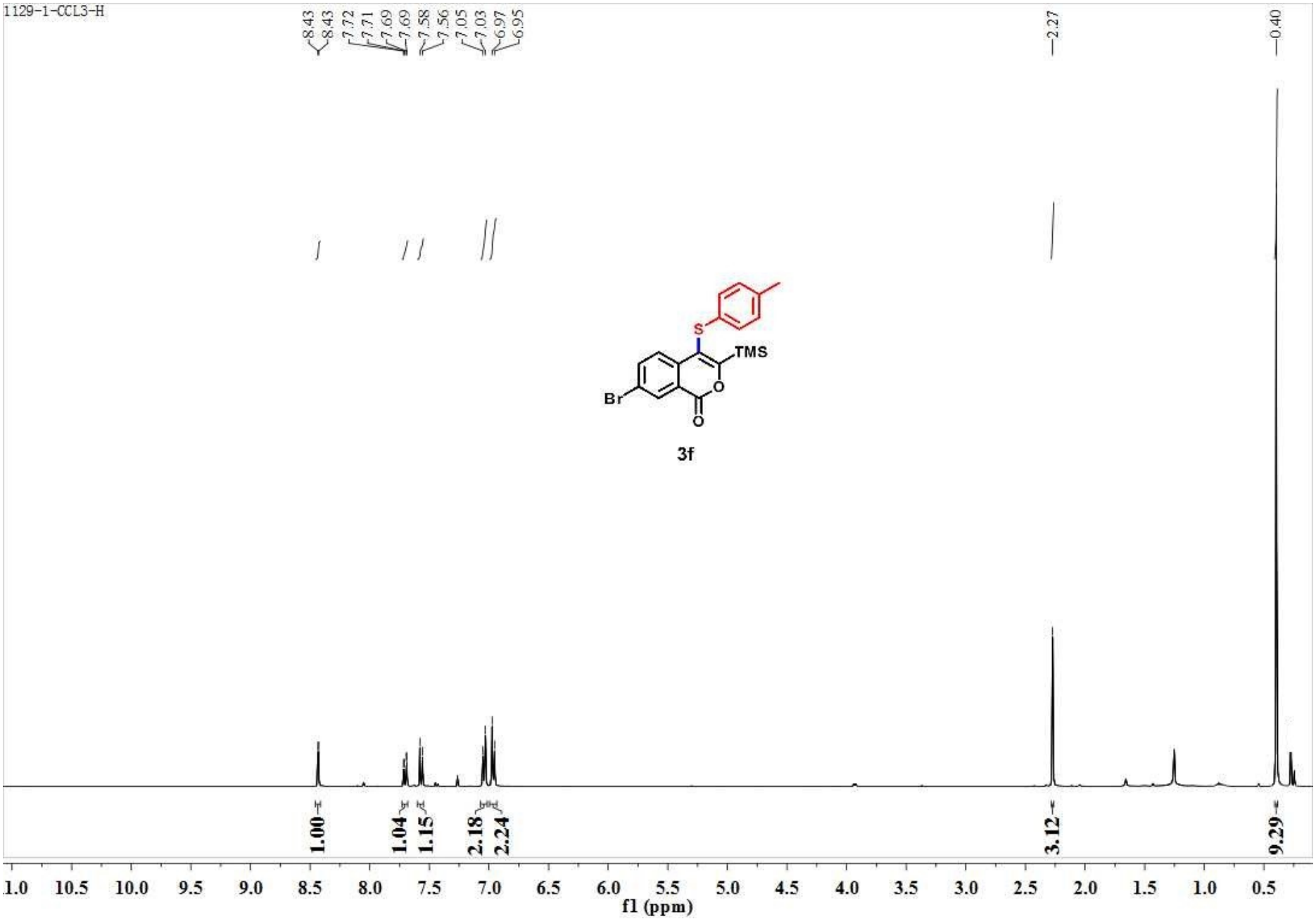
7.56
7.54
7.53
7.52
7.27
7.13
7.12
7.11
7.09
7.09
7.08
7.08
7.06
6.94
6.94
6.92
6.90
6.90
6.74
6.73
6.72
6.71
6.70
6.69
0.39
F
S
TMS
O
O
3e
1.00
2.09
1.08
2.09
1.06
1.02
9.19
10.0
9.5
9.0
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
f1 (ppm)

3e-1-2F

171.61
162.56
159.72
158.10
136.25
135.11
129.74
129.34
127.12
127.10
127.04
124.83
124.81
124.68
124.04
123.92
121.84
116.81
115.66
115.52
-0.87

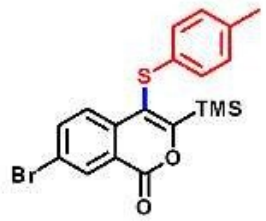


3e

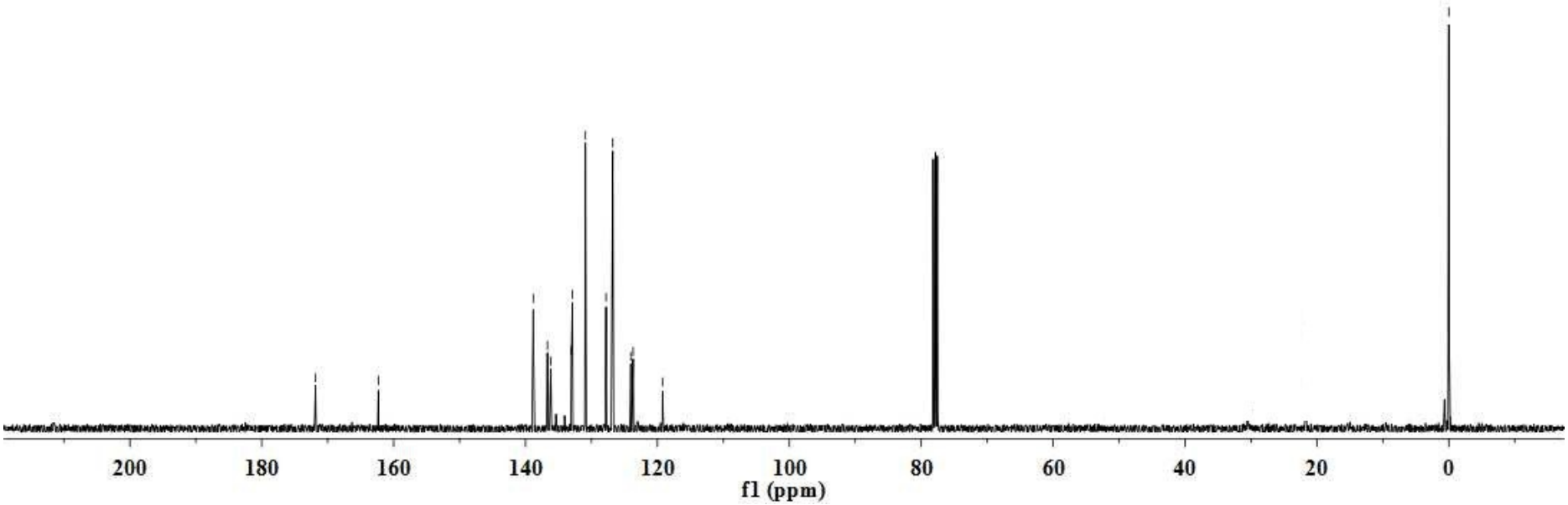

1129-1-CCL3-H
8.43
8.43
7.72
7.71
7.69
7.69
7.58
7.56
7.05
7.03
6.97
6.95
2.27
0.40
S
TMS
Br
O
O
3f
1.00
1.04
1.15
2.18
2.24
3.12
9.29
1.0 10.5 10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5
f1 (ppm)

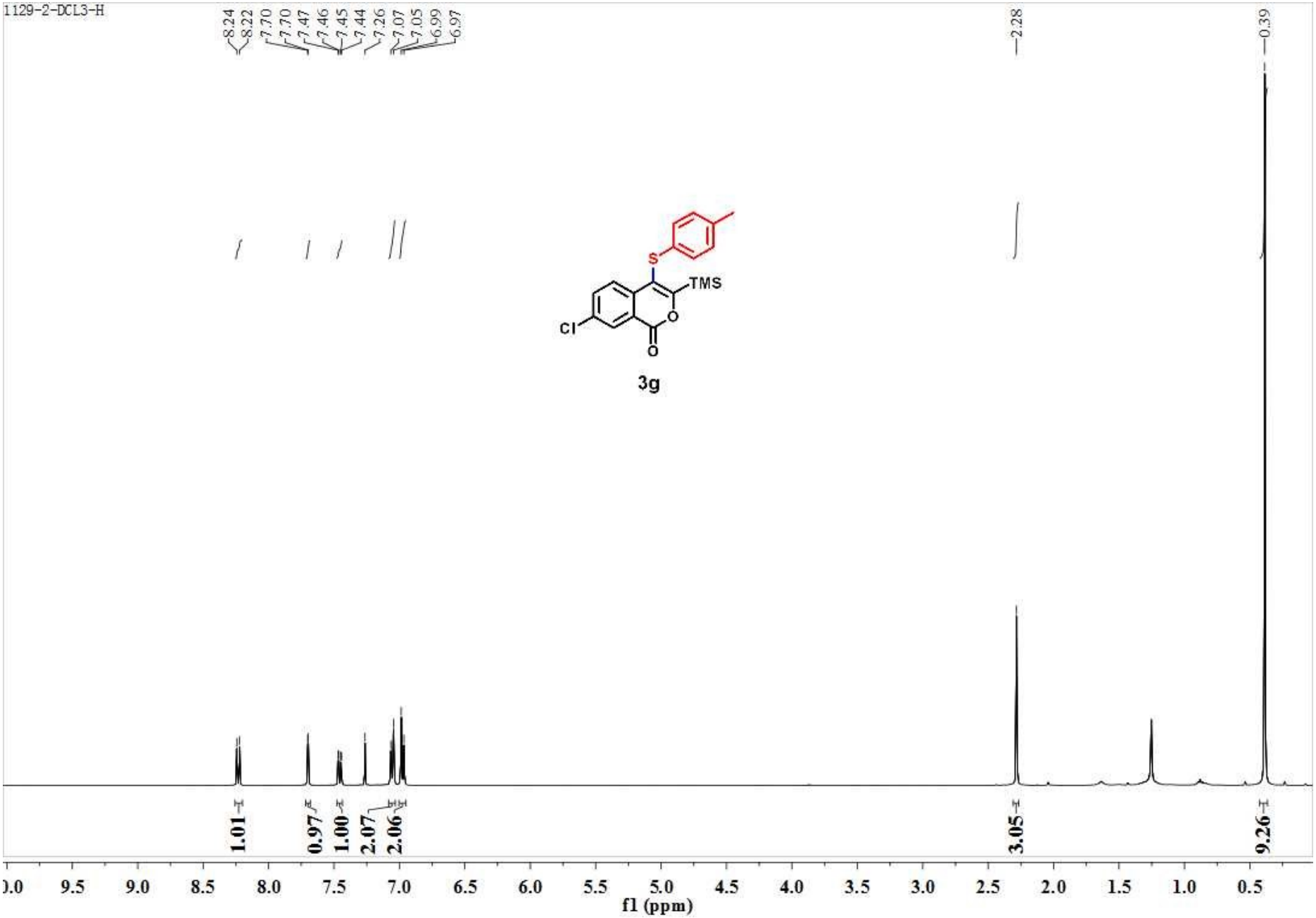
1129-1-CDCL3-C

171.85
162.32
138.82
136.68
136.17
133.06
132.89
130.91
127.78
126.77
124.05
123.68
119.23
21.74
0.00



3f

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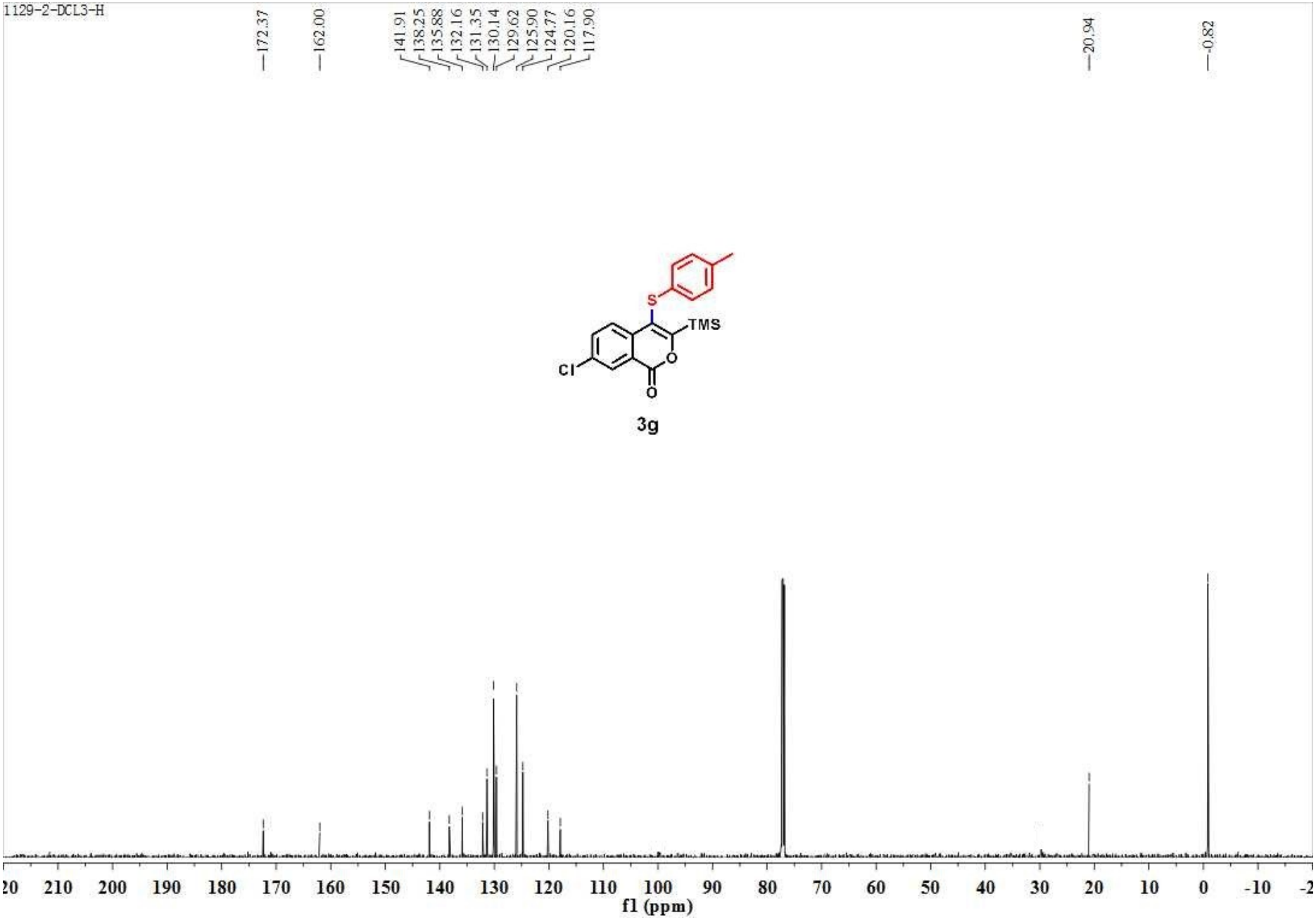
8.24
8.22
7.70
7.70
7.47
7.46
7.45
7.44
7.26
7.07
7.05
6.99
6.97
2.28
0.39
S
TMS
Cl
O
O
3g
1.01
0.97
1.00
2.07
2.06
3.05
9.26
f1 (ppm)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172.37
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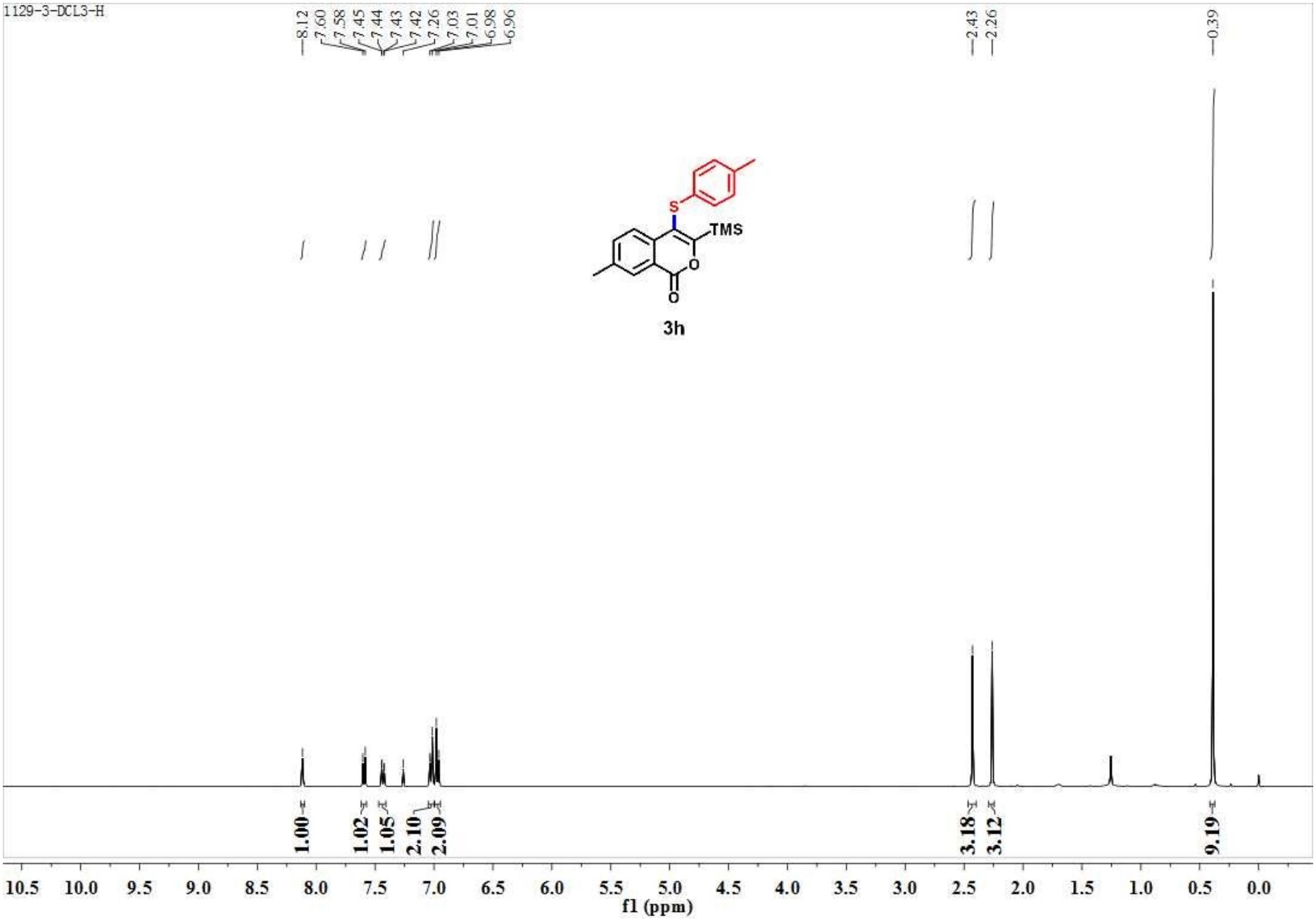
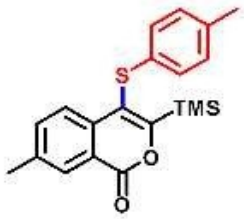
141.91
138.25
135.88
132.16
131.35
130.14
129.62
125.90
124.77
120.16
117.90
20.94
-0.82
S
TMS
Cl
O
O
3g
f1 (ppm)

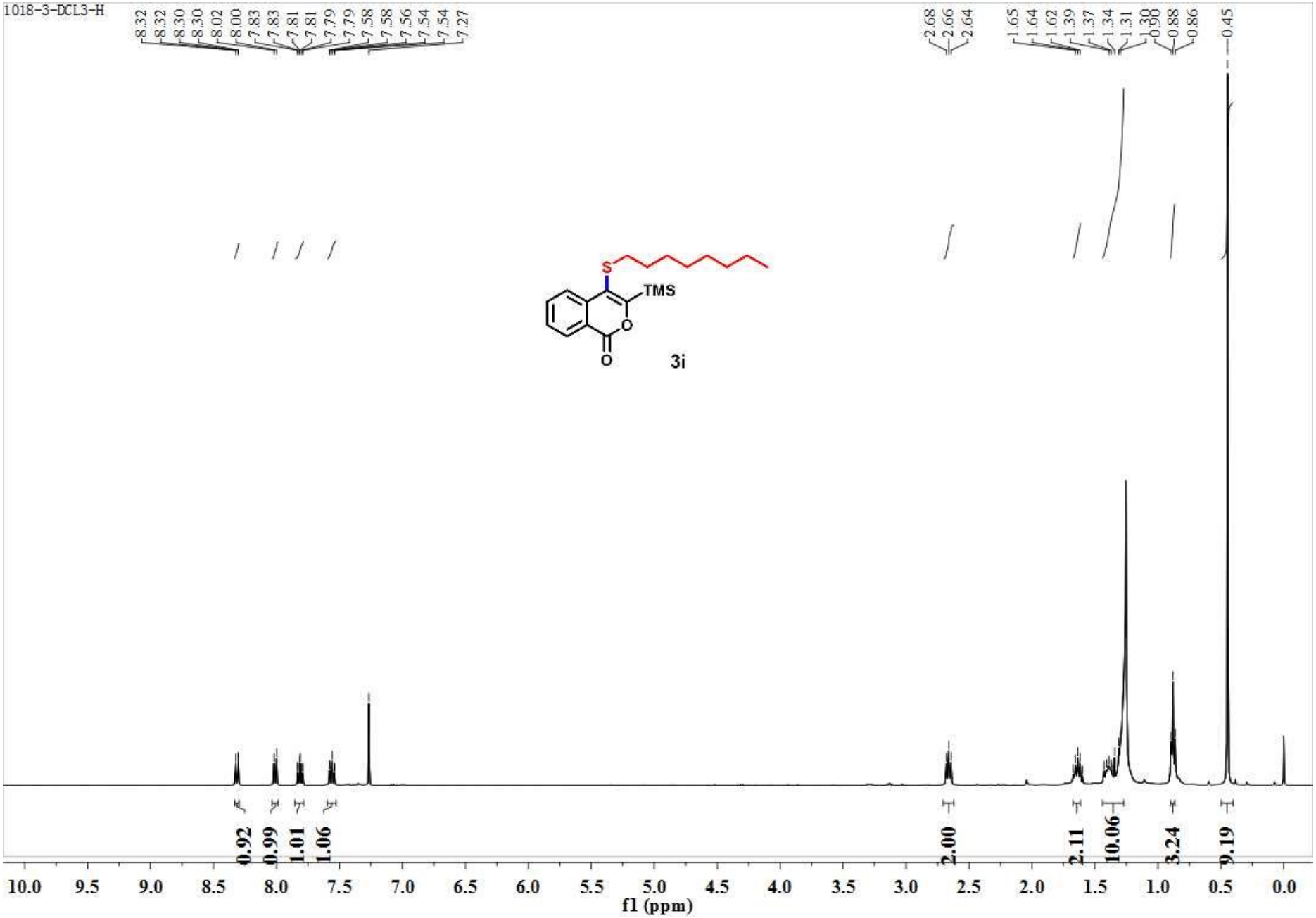

1129-3-DCL3-H
8.12
7.60
7.58
7.45
7.44
7.43
7.42
7.26
7.03
7.01
6.98
6.96
2.43
2.26
0.39
S
TMS
O
O
3h
1.00
1.02
1.05
2.10
2.09
3.18
3.12
9.19
10.5 10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0
f1 (ppm)

1129-3-CDCL3-C

170.07
163.77
140.23
136.88
136.20
134.85
133.65
130.67
130.04
126.60
125.76
122.48
119.61
22.05
21.64
0.00

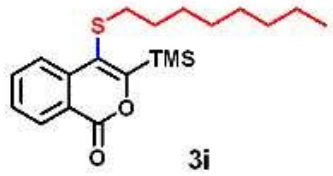


3h


1018-3-DCL3-H
8.32
8.32
8.30
8.30
8.02
8.00
7.83
7.83
7.81
7.81
7.79
7.79
7.58
7.58
7.56
7.54
7.54
7.27
2.68
2.66
2.64
1.65
1.64
1.62
1.39
1.37
1.34
1.31
1.30
0.90
0.88
0.86
0.45
S
TMS
O
O
3i
0.92
0.99
1.01
1.06
2.00
2.11
10.06
3.24
9.19
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)

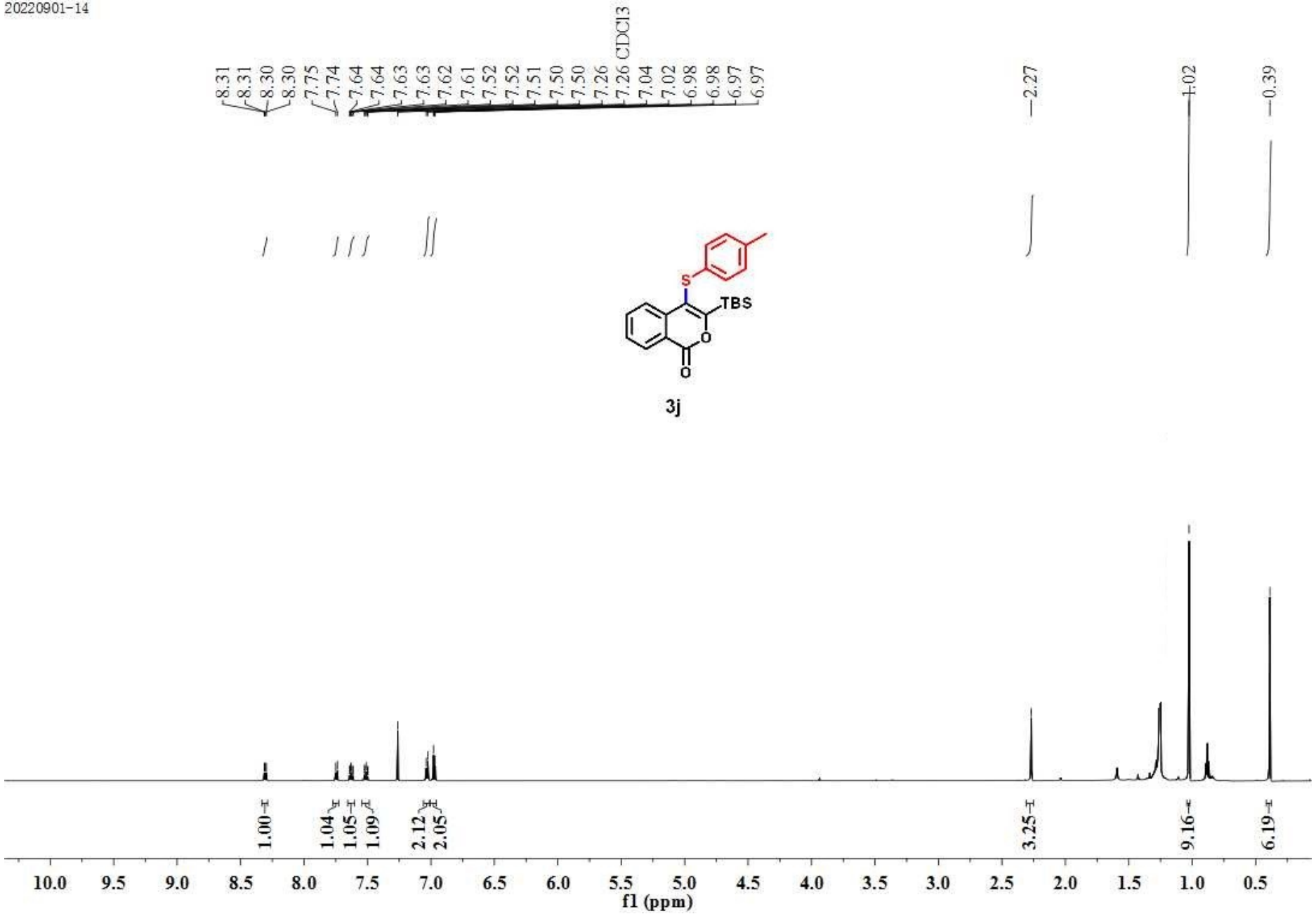
1018-3-CDCL3-C

168.75
163.40
137.45
135.15
130.15
129.29
125.19
122.76
122.28
37.36
32.21
30.14
29.64
29.60
29.49
23.06
14.52
0.00

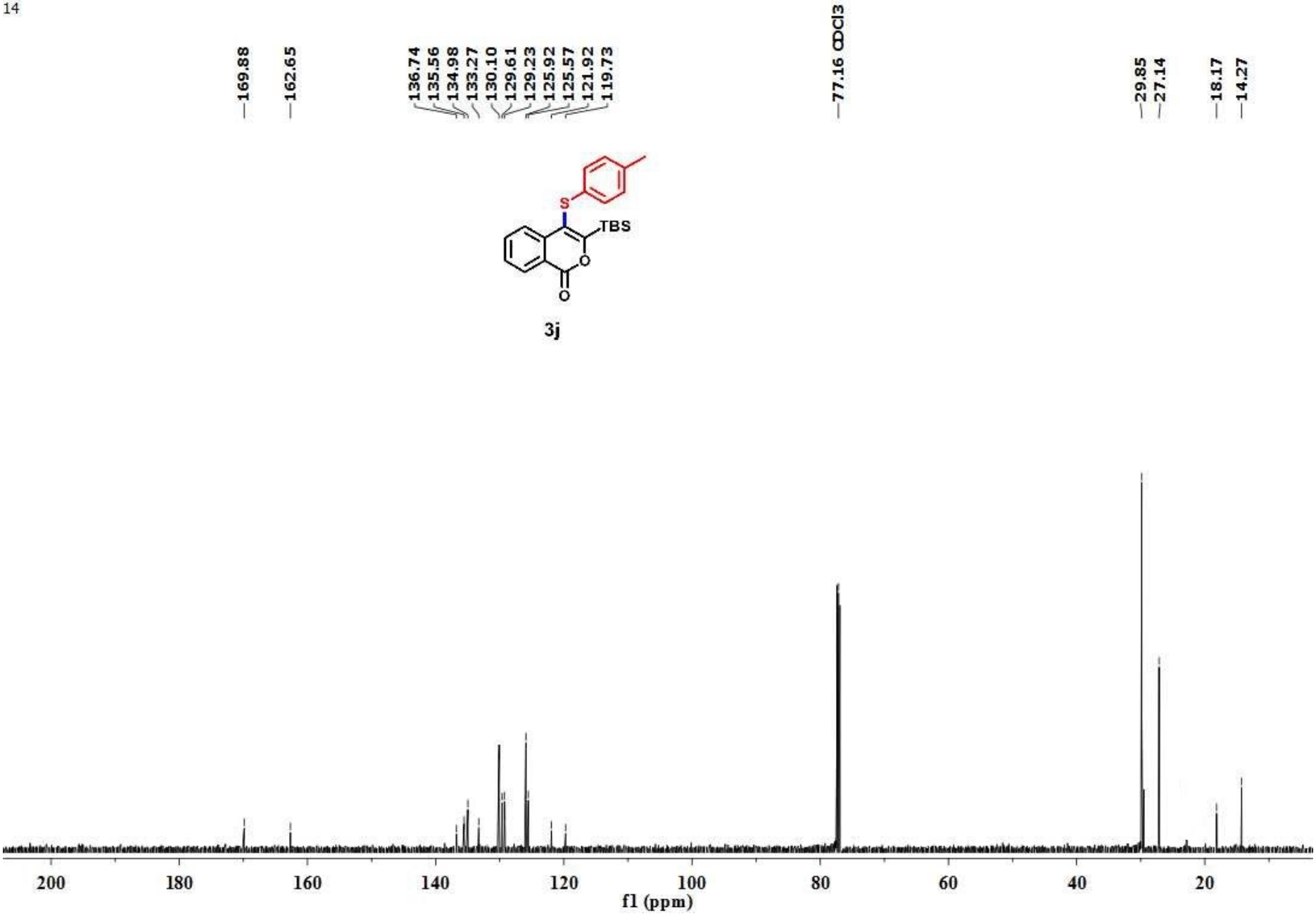


3i

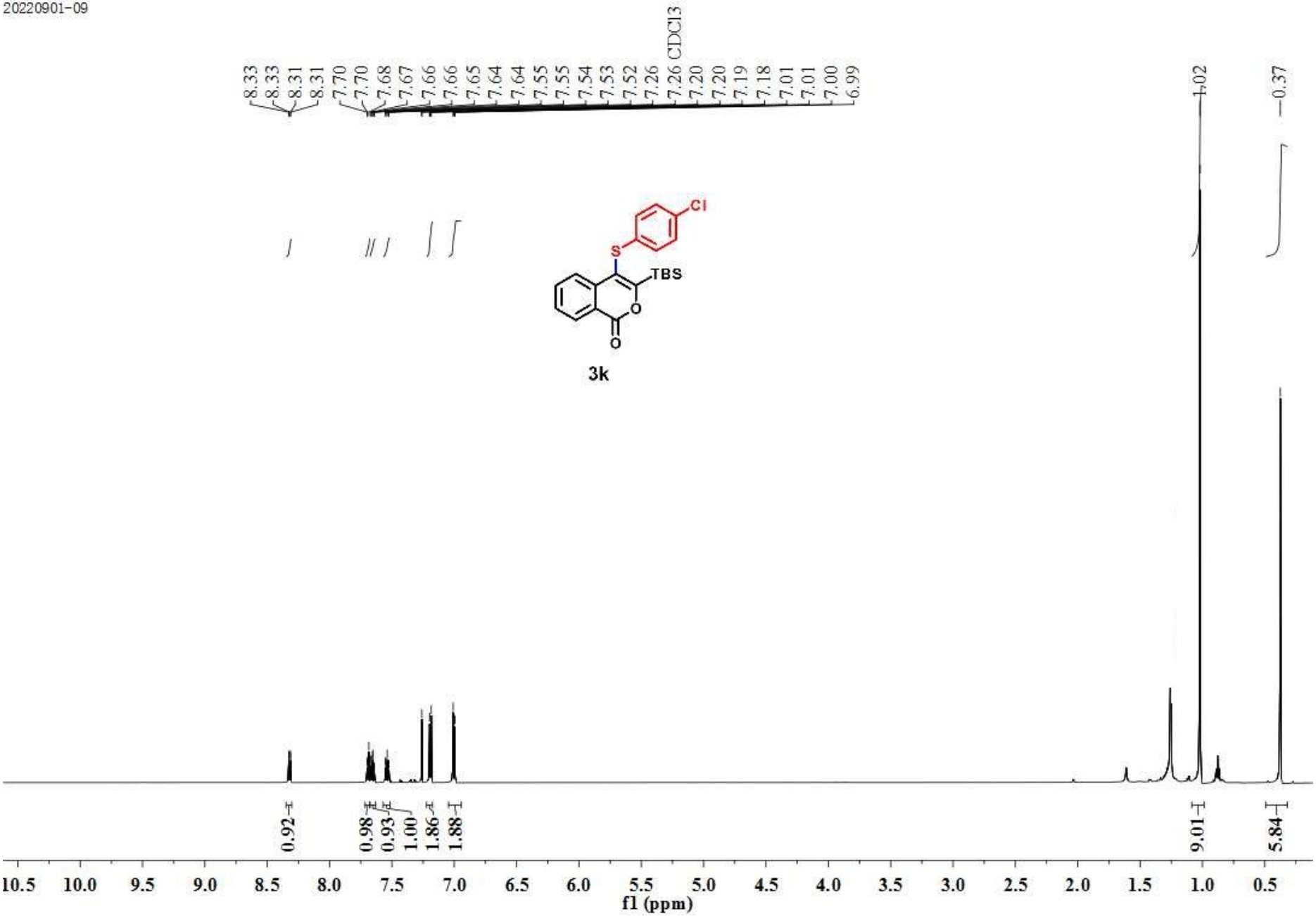
20220901-14



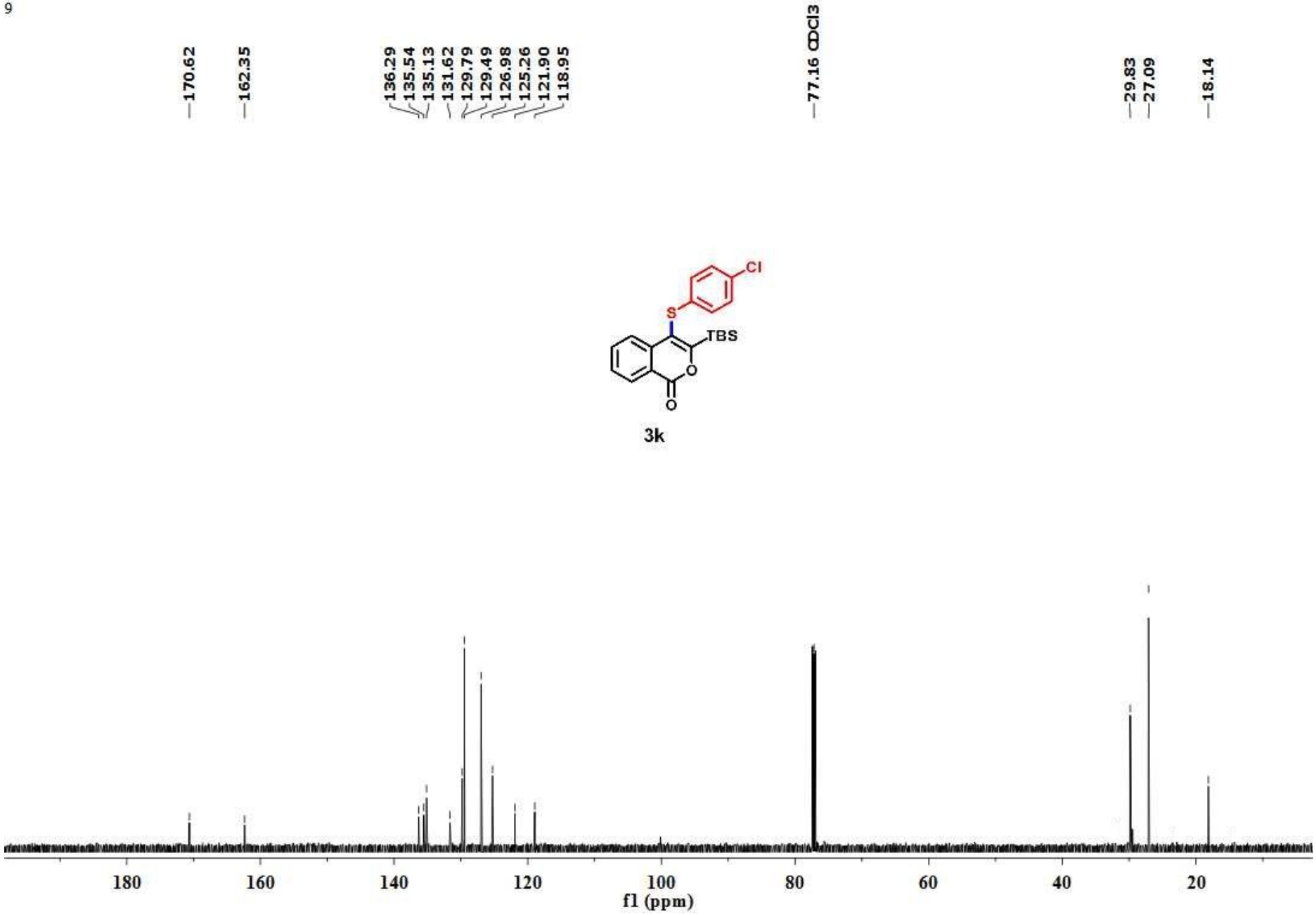
3j


169.88
162.65
136.74
135.56
134.98
133.27
130.10
129.61
129.23
125.92
125.57
121.92
119.73
77.16 CDCl3
29.85
27.14
18.17
14.27
S
TBS
O
O
3j
200
180
160
140
120
100
80
60
40
20
f1 (ppm)

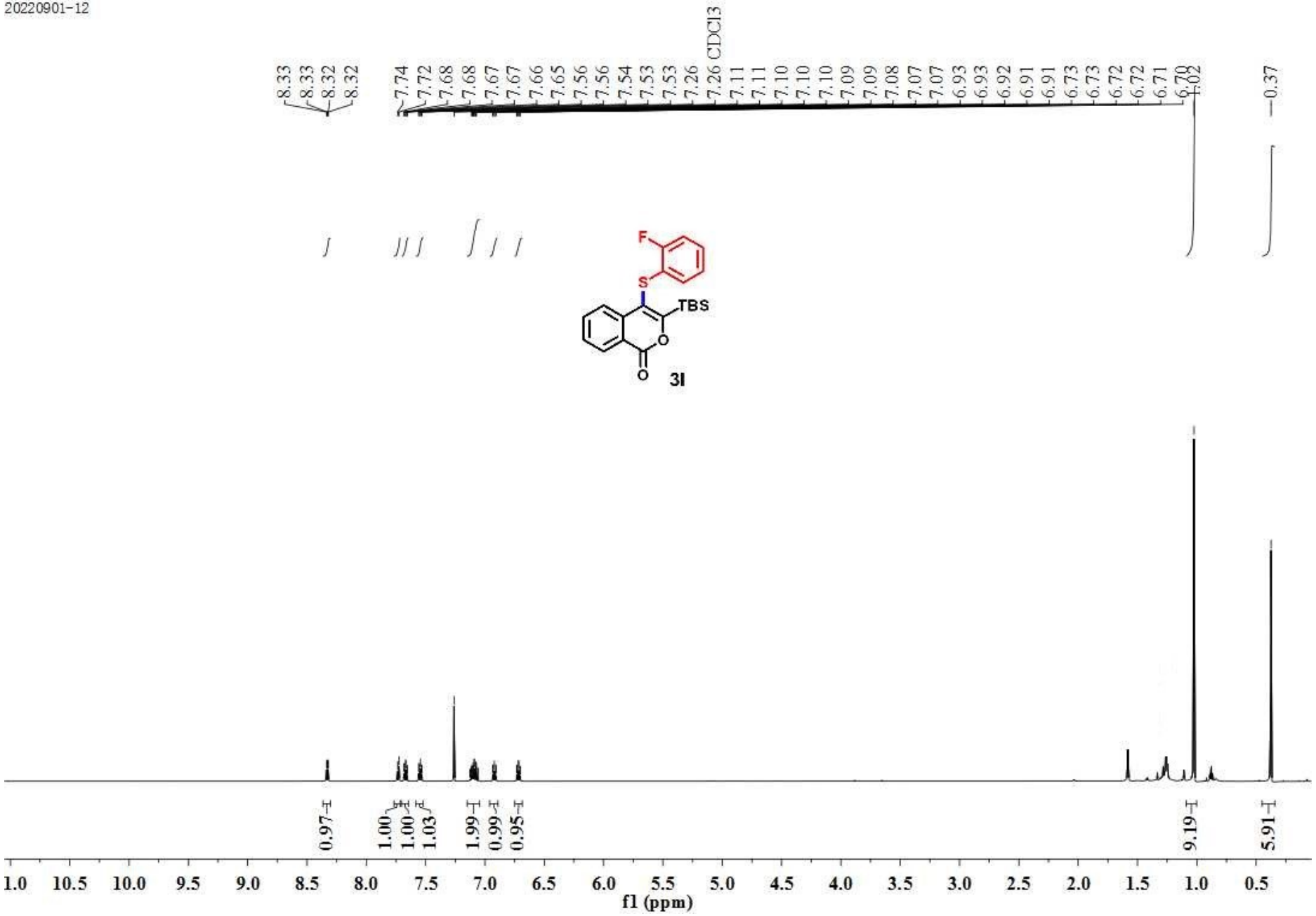
20220901-09

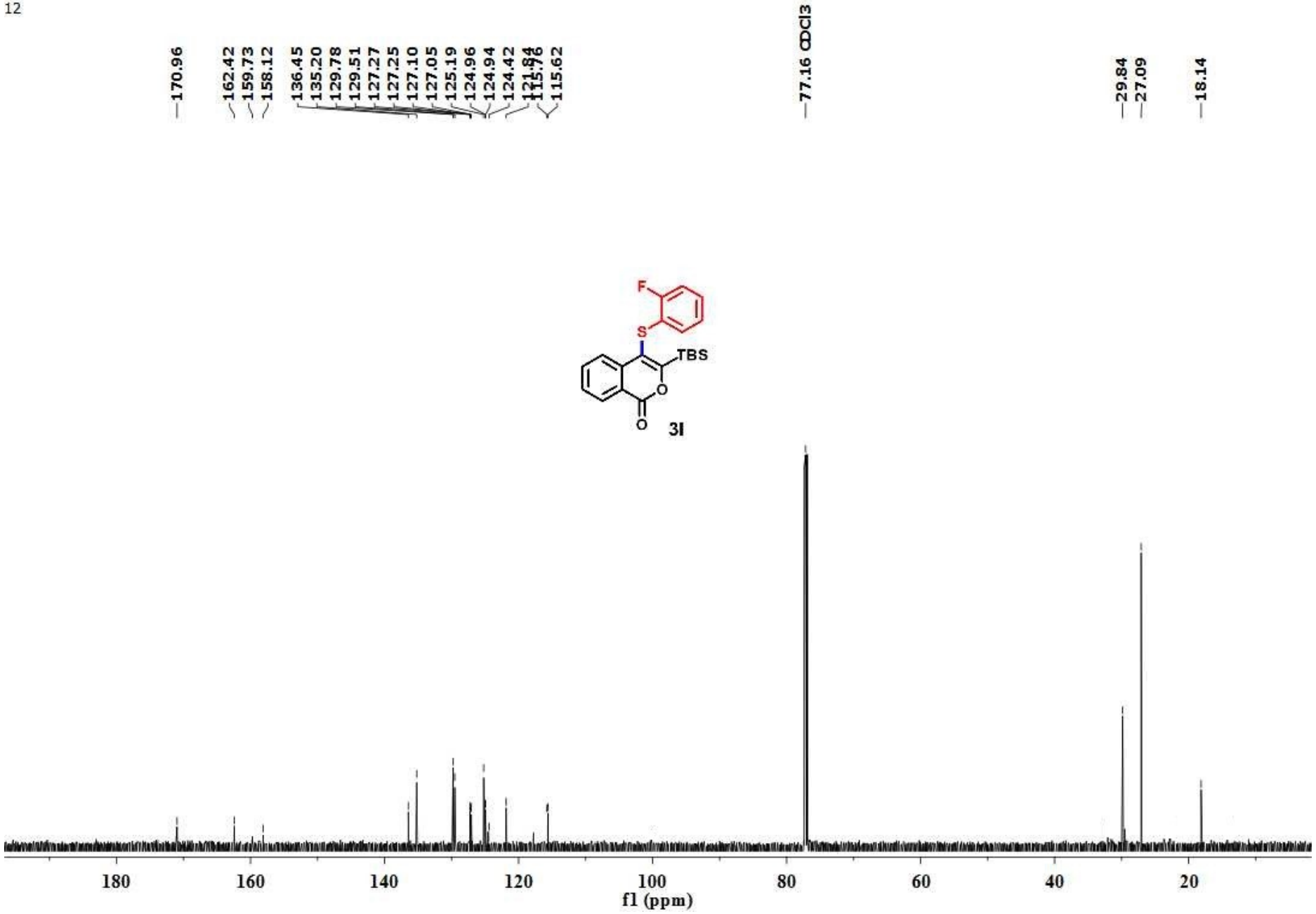


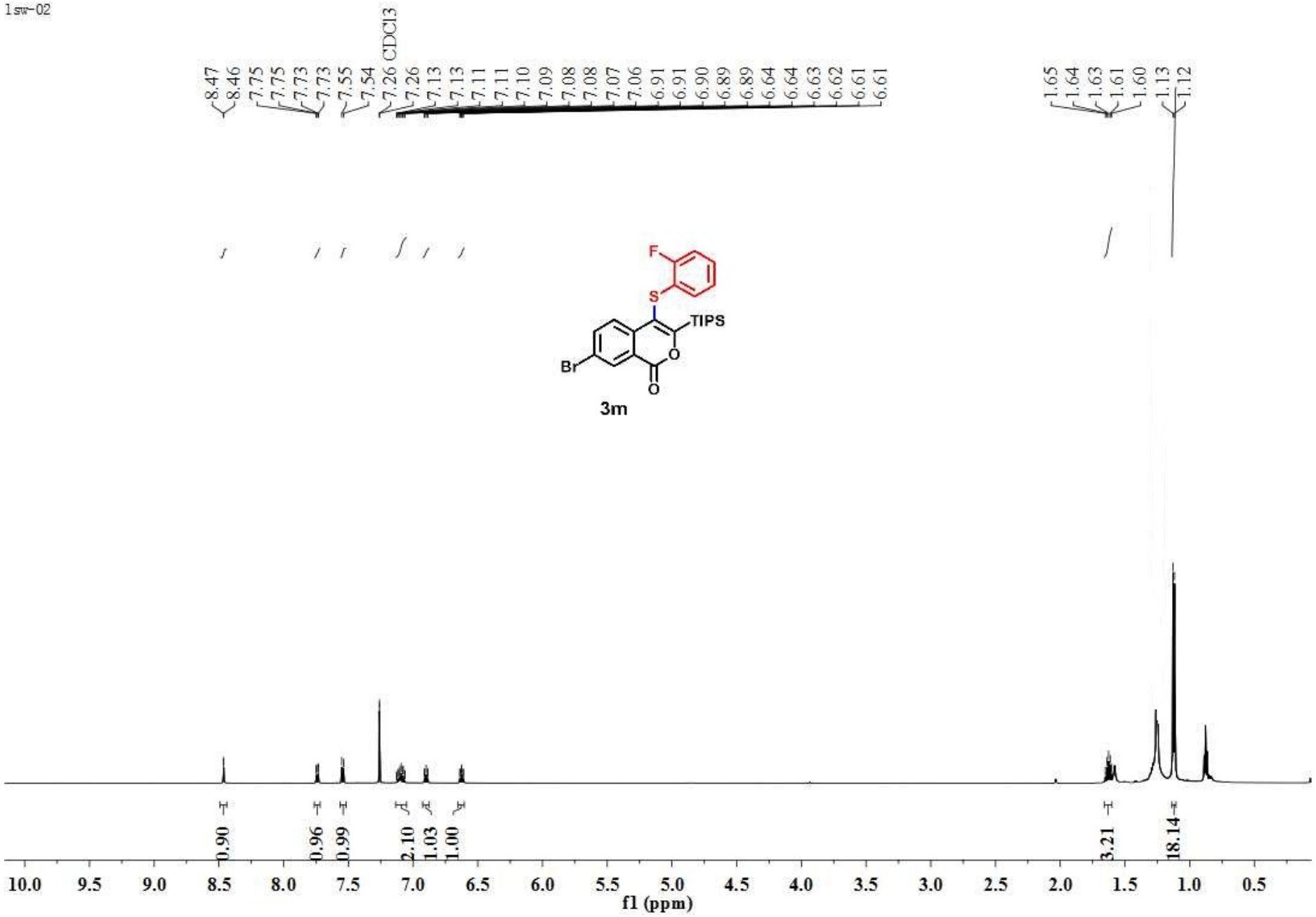
3k


170.62
162.35
136.29
135.54
135.13
131.62
129.79
129.49
126.98
125.26
121.90
118.95
77.16 CDCl3
29.83
27.09
18.14
Cl
S
TBS
O
O
3k
180
160
140
120
100
80
60
40
20
f1 (ppm)

20220901-12

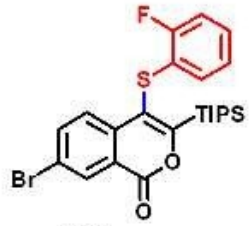

8.33
8.33
8.32
8.32
7.74
7.72
7.68
7.68
7.67
7.67
7.66
7.65
7.56
7.56
7.54
7.53
7.53
7.26 CDCl3
7.11
7.11
7.10
7.10
7.10
7.09
7.09
7.08
7.07
7.07
6.93
6.93
6.92
6.91
6.91
6.73
6.73
6.72
6.72
6.71
6.70
4.02
0.37
F
S
TBS
O
O
3l
0.97
1.00
1.00
1.03
1.99
0.99
0.95
9.19
5.91
1.0
10.5
10.0
9.5
9.0
8.5
8.0
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
f1 (ppm)


170.96
162.42
159.73
158.12
136.45
135.20
129.78
129.51
127.27
127.25
127.10
127.05
125.19
124.96
124.94
124.42
121.84
115.76
115.62
77.16 CDCl3
29.84
27.09
18.14
F
S
TBS
O
O
3l
180
160
140
120
100
80
60
40
20
f1 (ppm)

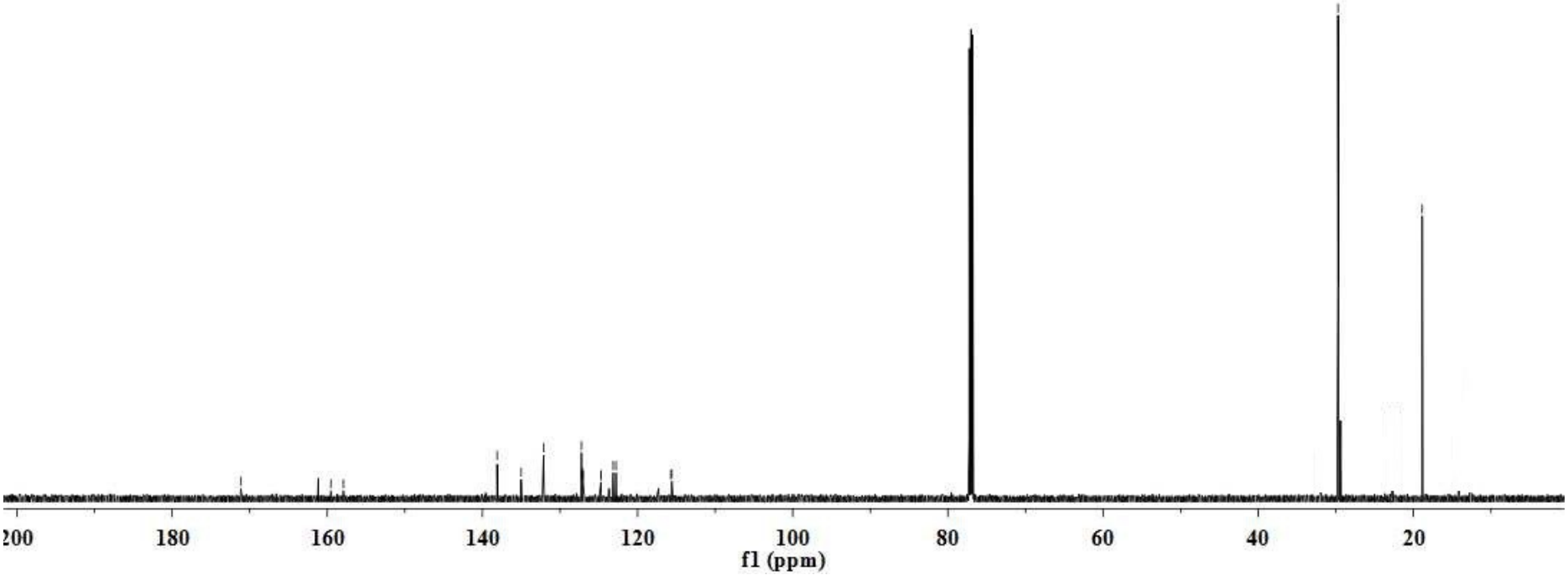

1sw-02
8.47
8.46
7.75
7.75
7.73
7.73
7.55
7.54
7.26 CDCl3
7.26
7.13
7.13
7.11
7.11
7.10
7.09
7.08
7.08
7.07
7.06
6.91
6.91
6.90
6.89
6.89
6.64
6.64
6.63
6.62
6.61
6.61
1.65
1.64
1.63
1.61
1.60
1.13
1.12
F
S
TIPS
Br
O
O
3m
0.90
0.96
0.99
2.10
1.03
1.00
3.21
18.14
10.0
9.5
9.0
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
f1 (ppm)

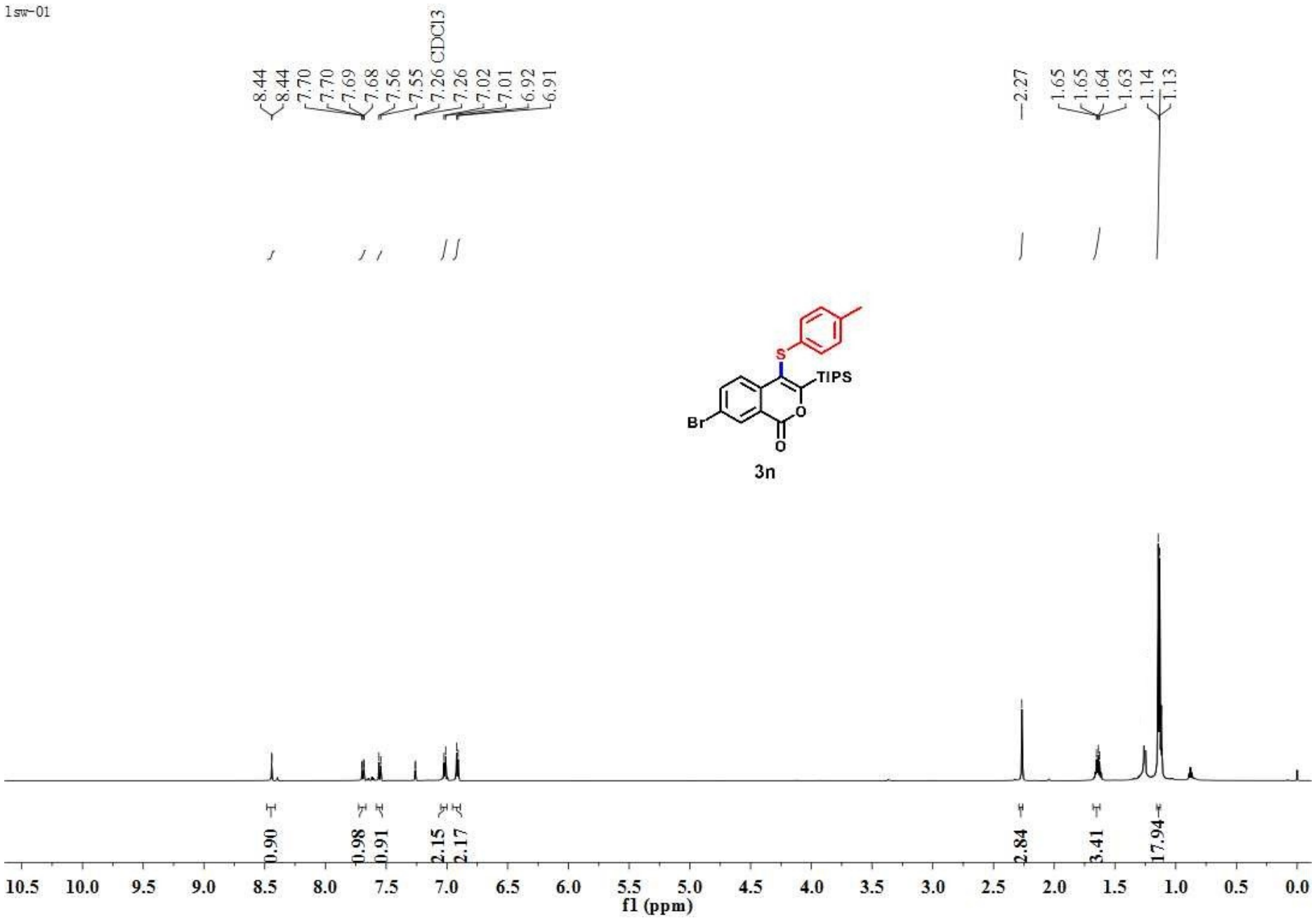
2

171.17
159.54
157.92
138.10
135.01
132.13
127.23
127.19
127.17
127.06
127.01
124.73
124.71
123.15
122.77
115.72
115.59
29.72
18.86

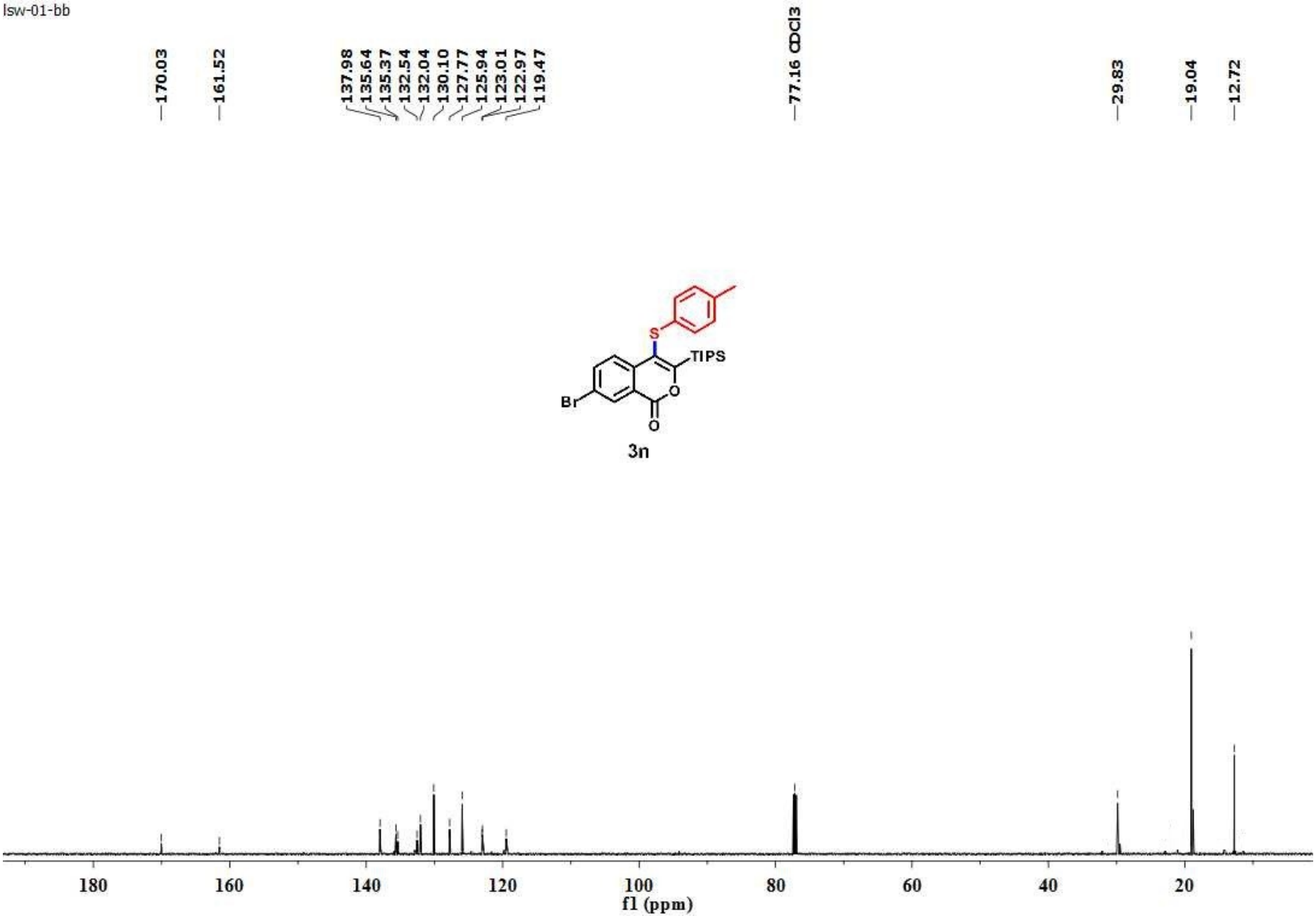


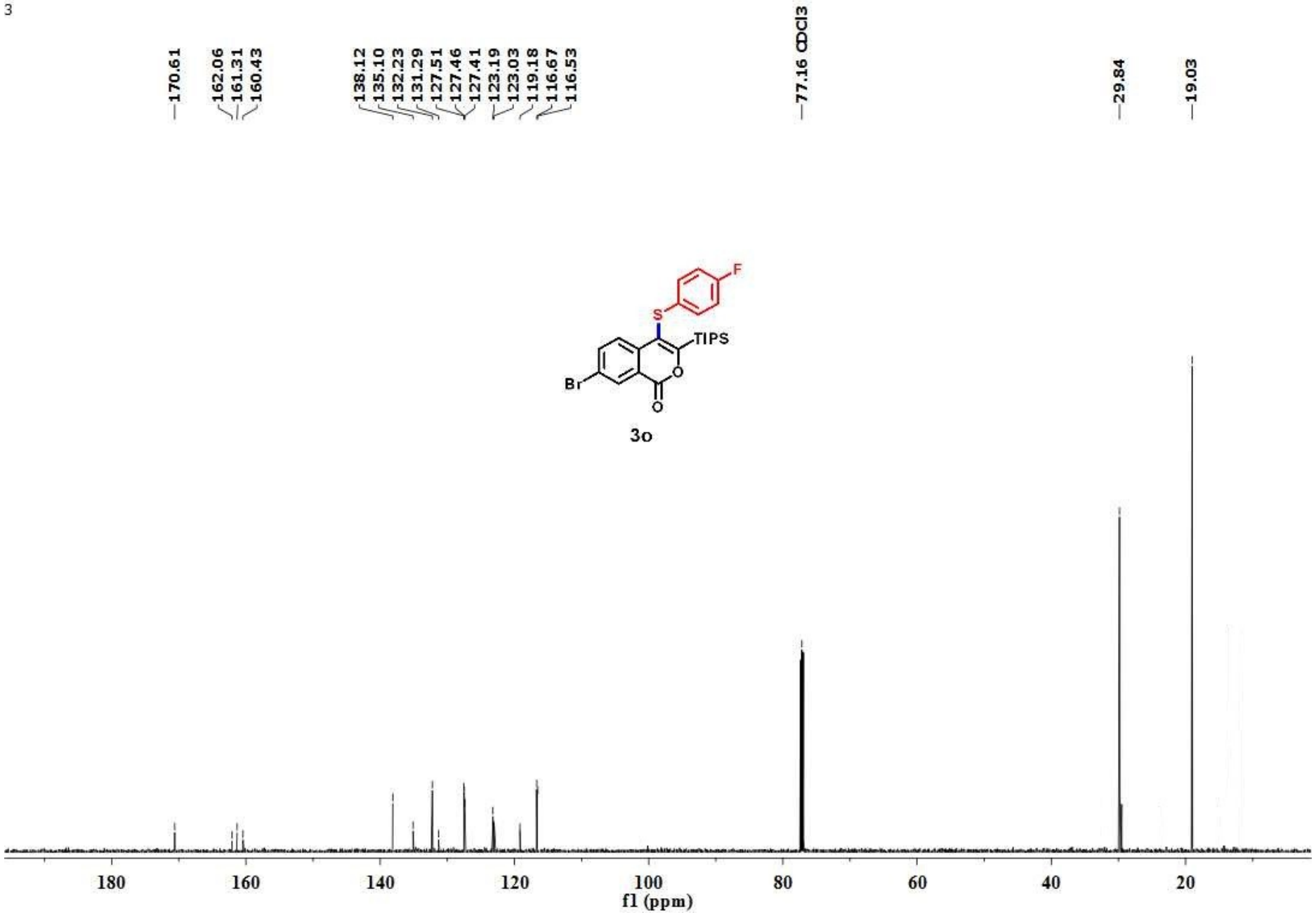
3m

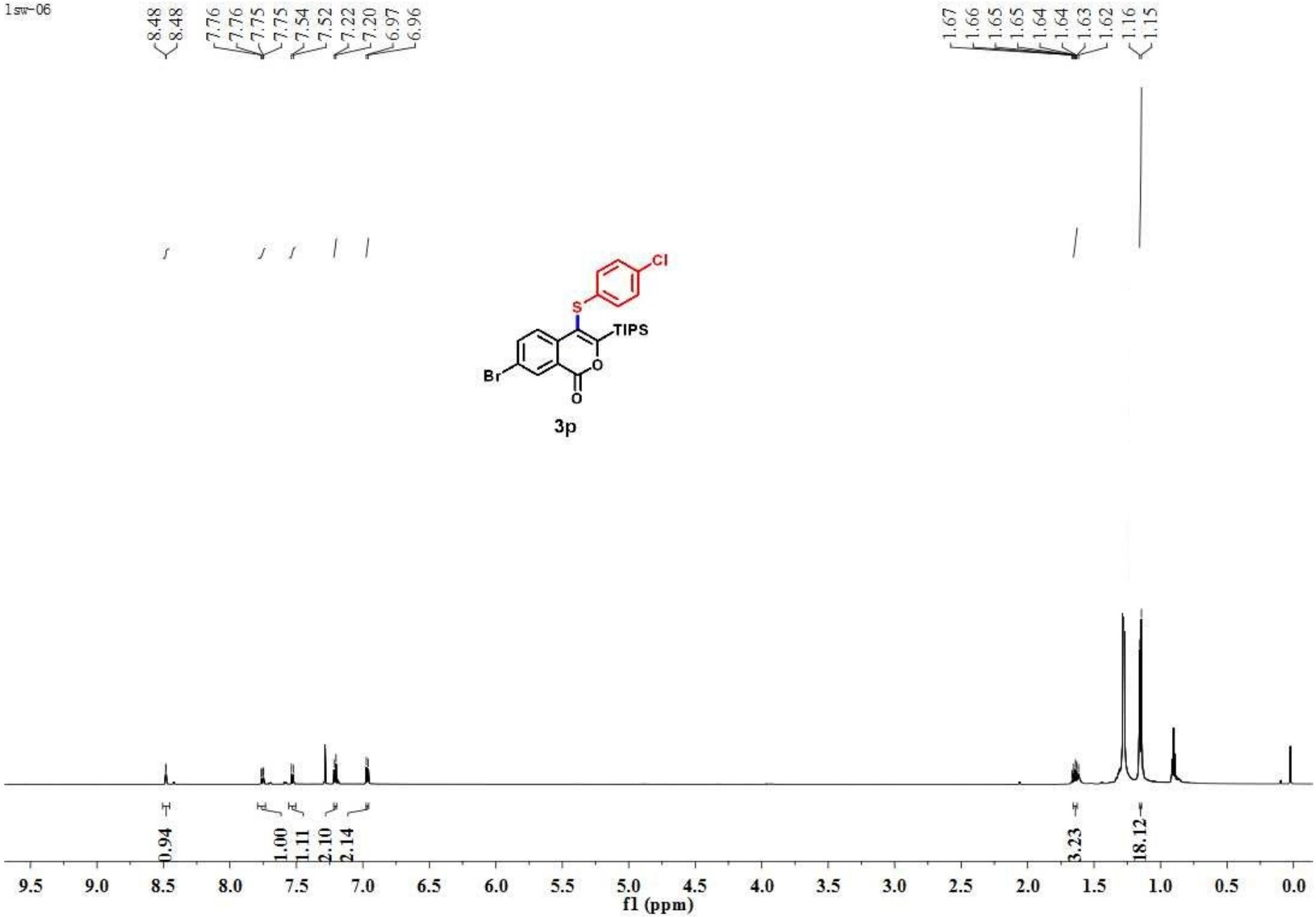


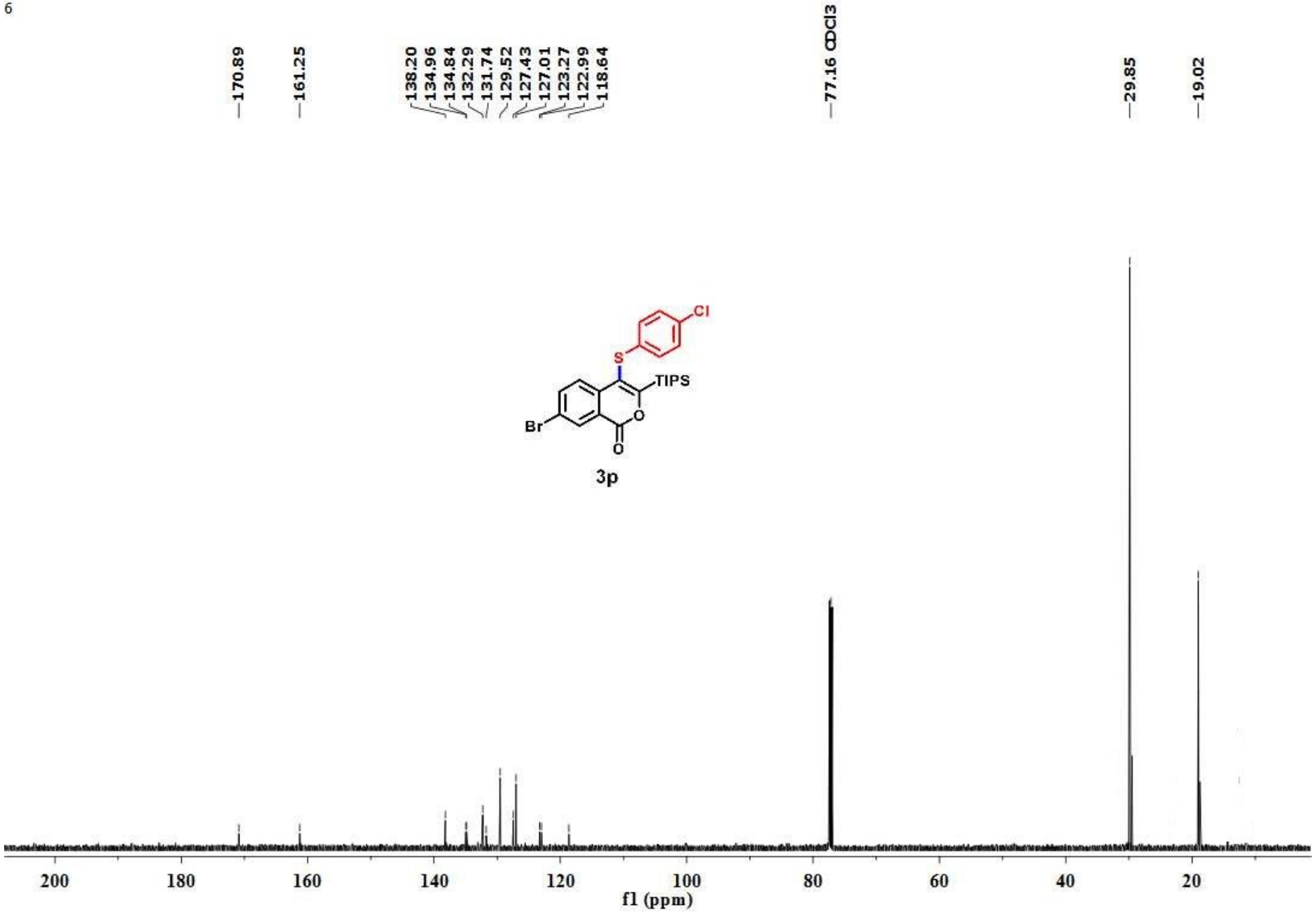

lsw-01
8.44
8.44
7.70
7.70
7.69
7.68
7.56
7.55
7.26 CDCl3
7.26
7.02
7.01
6.92
6.91
2.27
1.65
1.65
1.64
1.63
1.14
1.13
S
TIPS
Br
O
O
3n
0.90
0.98
0.91
2.15
2.17
2.84
3.41
17.94
10.5
10.0
9.5
9.0
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
f1 (ppm)

lsw-01-bb

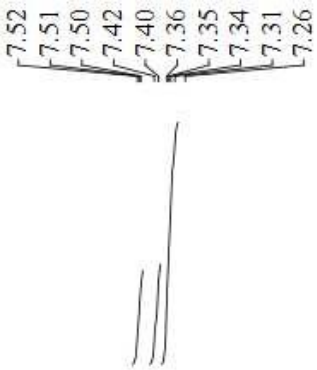

170.03
161.52
137.98
135.64
135.37
132.54
132.04
130.10
127.77
125.94
123.01
122.97
119.47
77.16 CDCl3
29.83
19.04
12.72
S
TIPS
Br
O
O
3n
180
160
140
120
100
80
60
40
20
f1 (ppm)

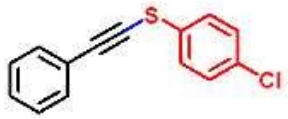

170.61
162.06
161.31
160.43
138.12
135.10
132.23
131.29
127.51
127.46
127.41
123.19
123.03
119.18
116.67
116.53
77.16 CDCl3
29.84
19.03
F
S
TIPS
Br
O
O
3o
180
160
140
120
100
80
60
40
20
f1 (ppm)


1sw-06
8.48
8.48
7.76
7.76
7.75
7.75
7.54
7.52
7.22
7.20
6.97
6.96
1.67
1.66
1.65
1.65
1.64
1.64
1.63
1.62
1.16
1.15
Cl
S
TIPS
Br
O
O
3p
0.94
1.00
1.11
2.10
2.14
3.23
18.12
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)

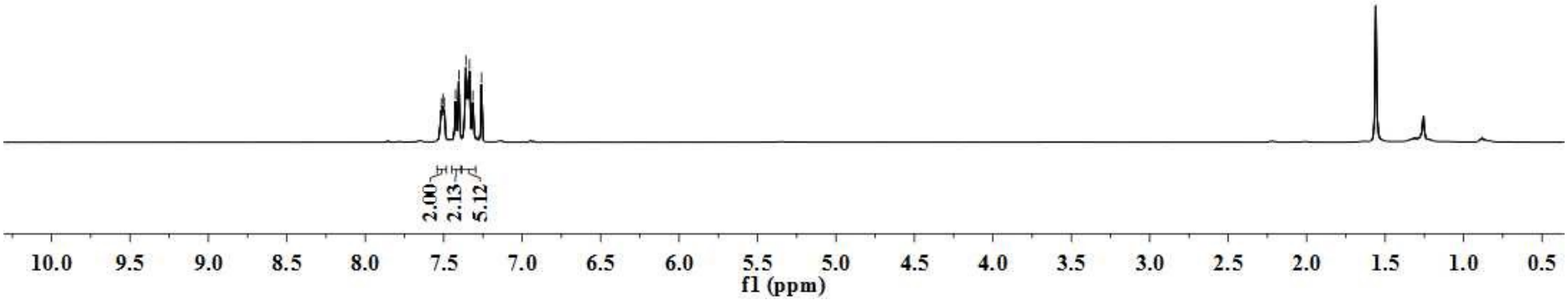

170.89
161.25
138.20
134.96
134.84
132.29
131.74
129.52
127.43
127.01
123.27
122.99
118.64
77.16 CDCl3
29.85
19.02
Cl
S
TIPS
Br
O
O
3p
200
180
160
140
120
100
80
60
40
20
f1 (ppm)

LSW-4H-S4CL

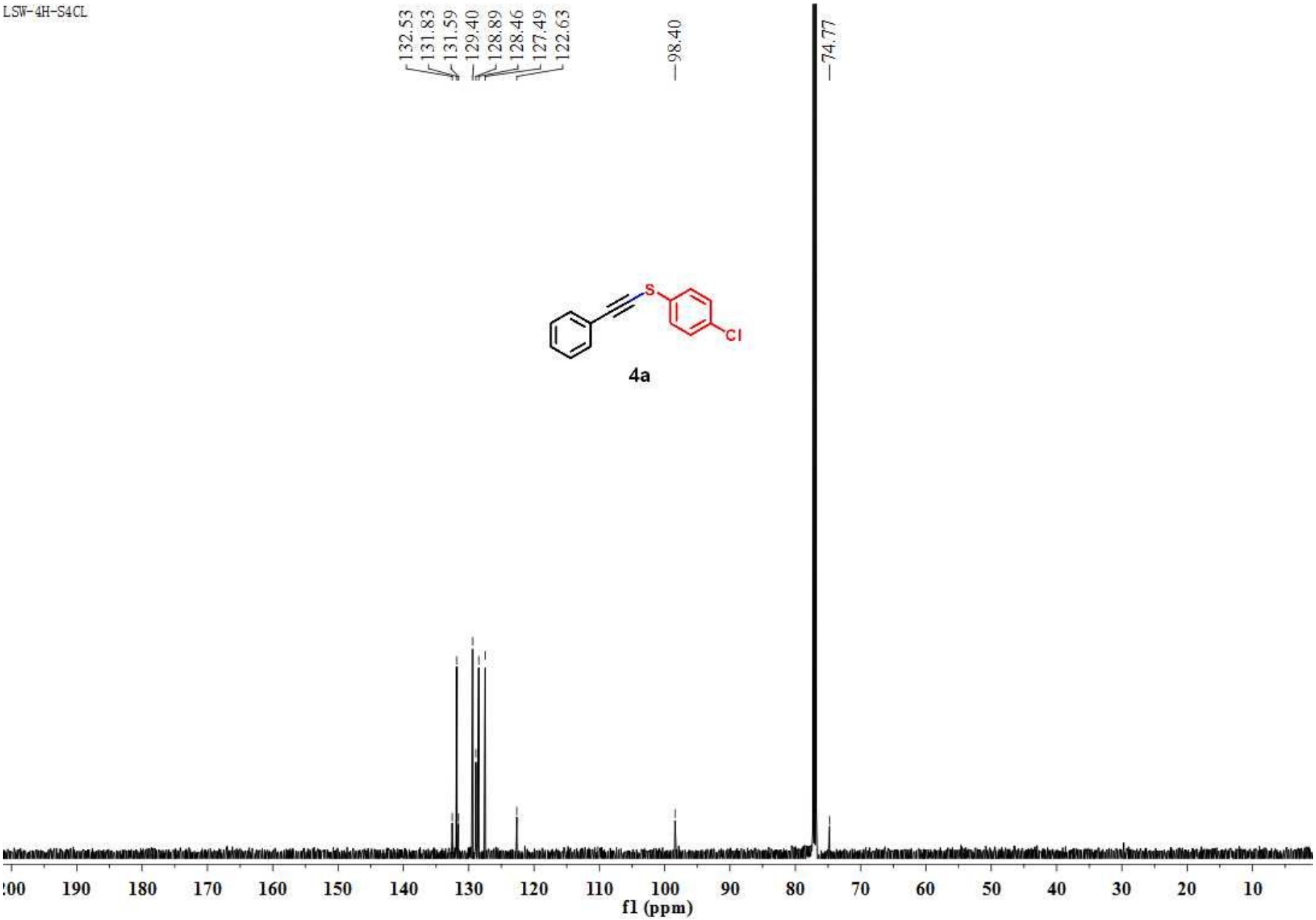




4a



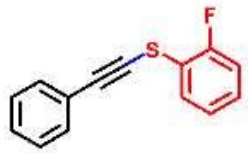
LSW-4H-S4CL


132.53
131.83
131.59
129.40
128.89
128.46
127.49
122.63
98.40
74.77
S
Cl
4a
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
f1 (ppm)

LSW-4H-S2F

7.70
7.69
7.67
7.67
7.53
7.52
7.51
7.36
7.35
7.26
7.24
7.22
7.21
7.19
7.17
7.09
7.07
7.04

1.56

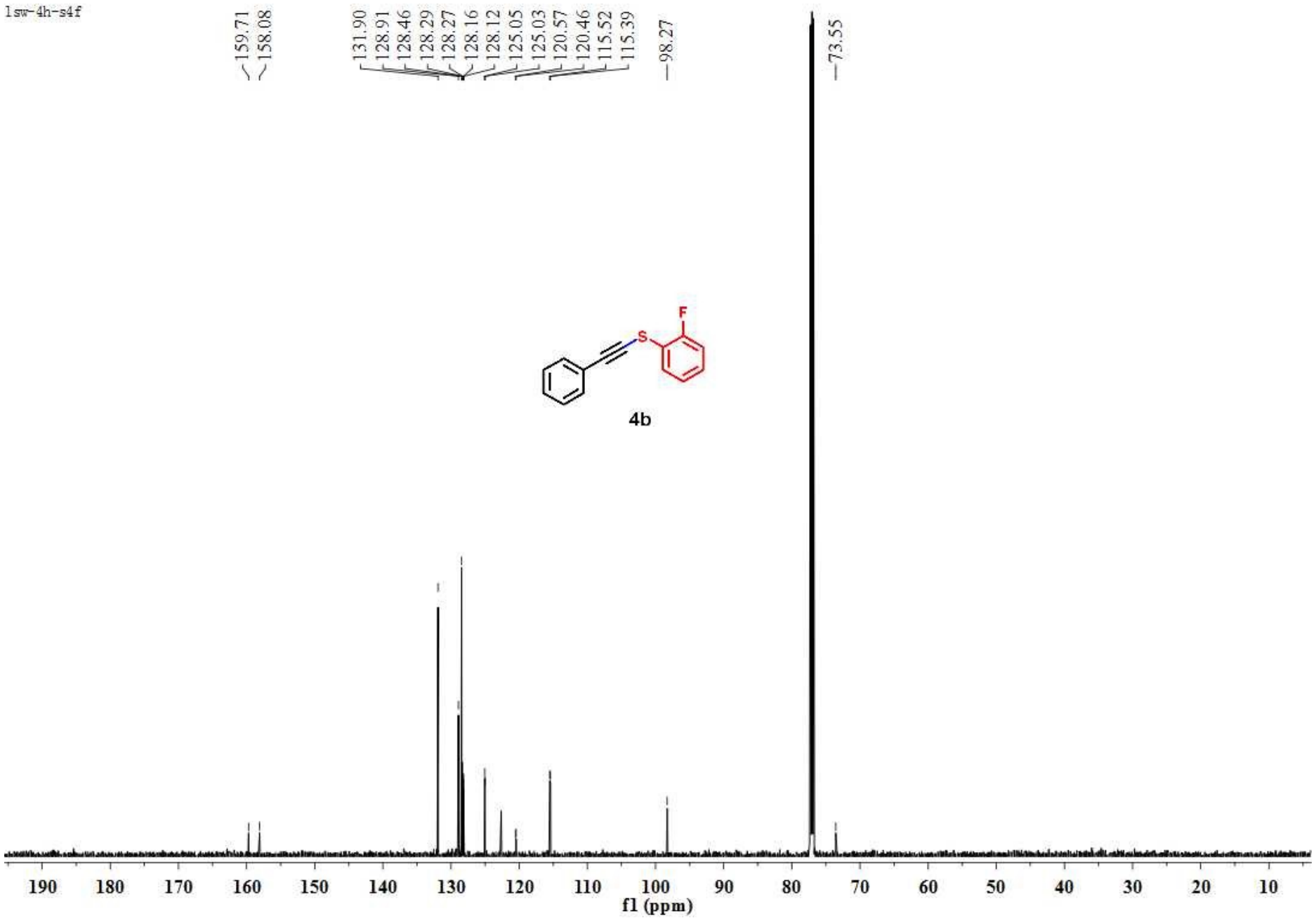


4b

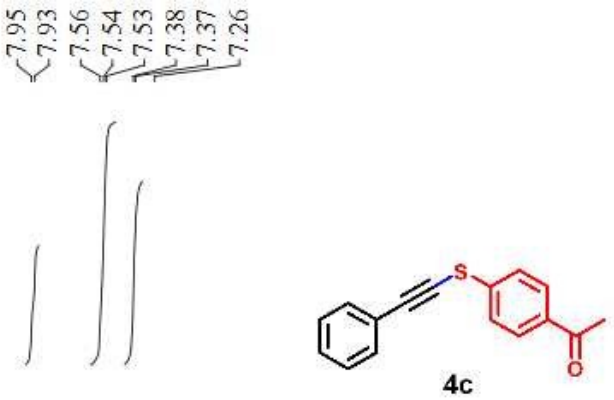
1.01
2.03
3.02
1.96
1.00

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

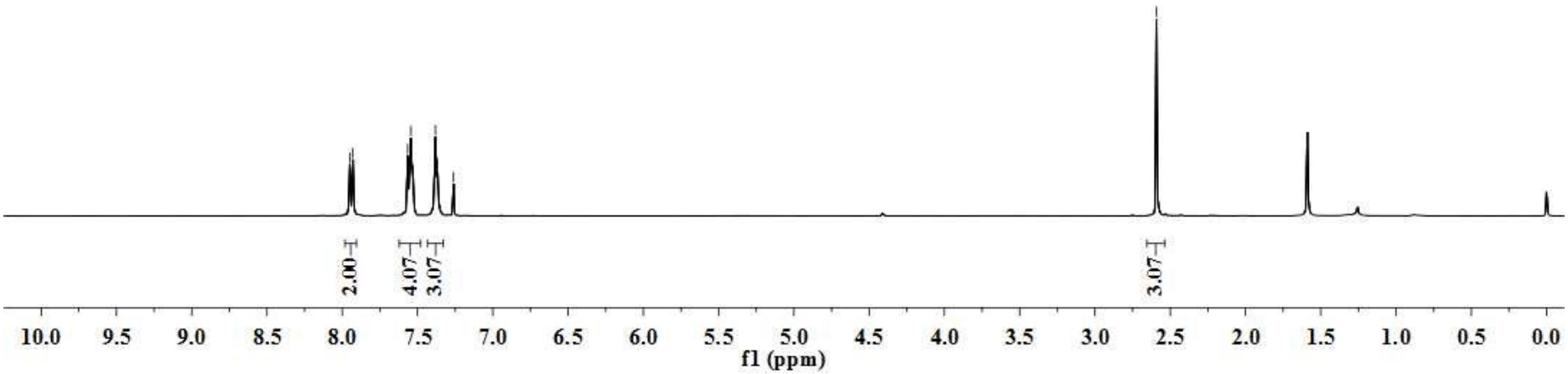
f1 (ppm)


1sw-4h-s4f
159.71
158.08
131.90
128.91
128.46
128.29
128.27
128.16
128.12
125.05
125.03
120.57
120.46
115.52
115.39
98.27
73.55
F
S
4b
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
f1 (ppm)

LSW-4H-S4AC



4c

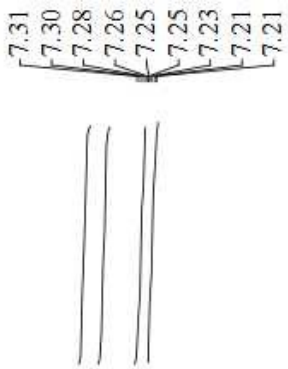


LSW-4H-SAC

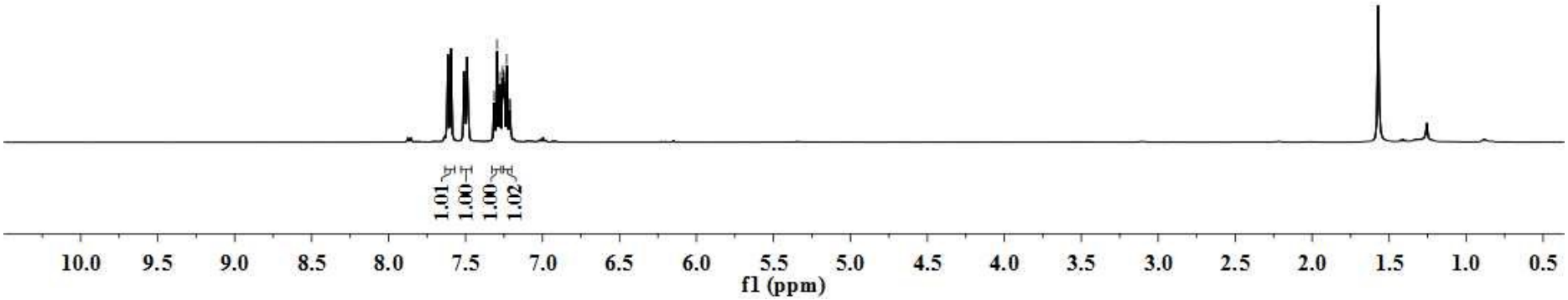
197.01
140.02
135.16
131.91
129.13
129.09
128.52
125.44
122.43
99.54
73.59
26.55

4c

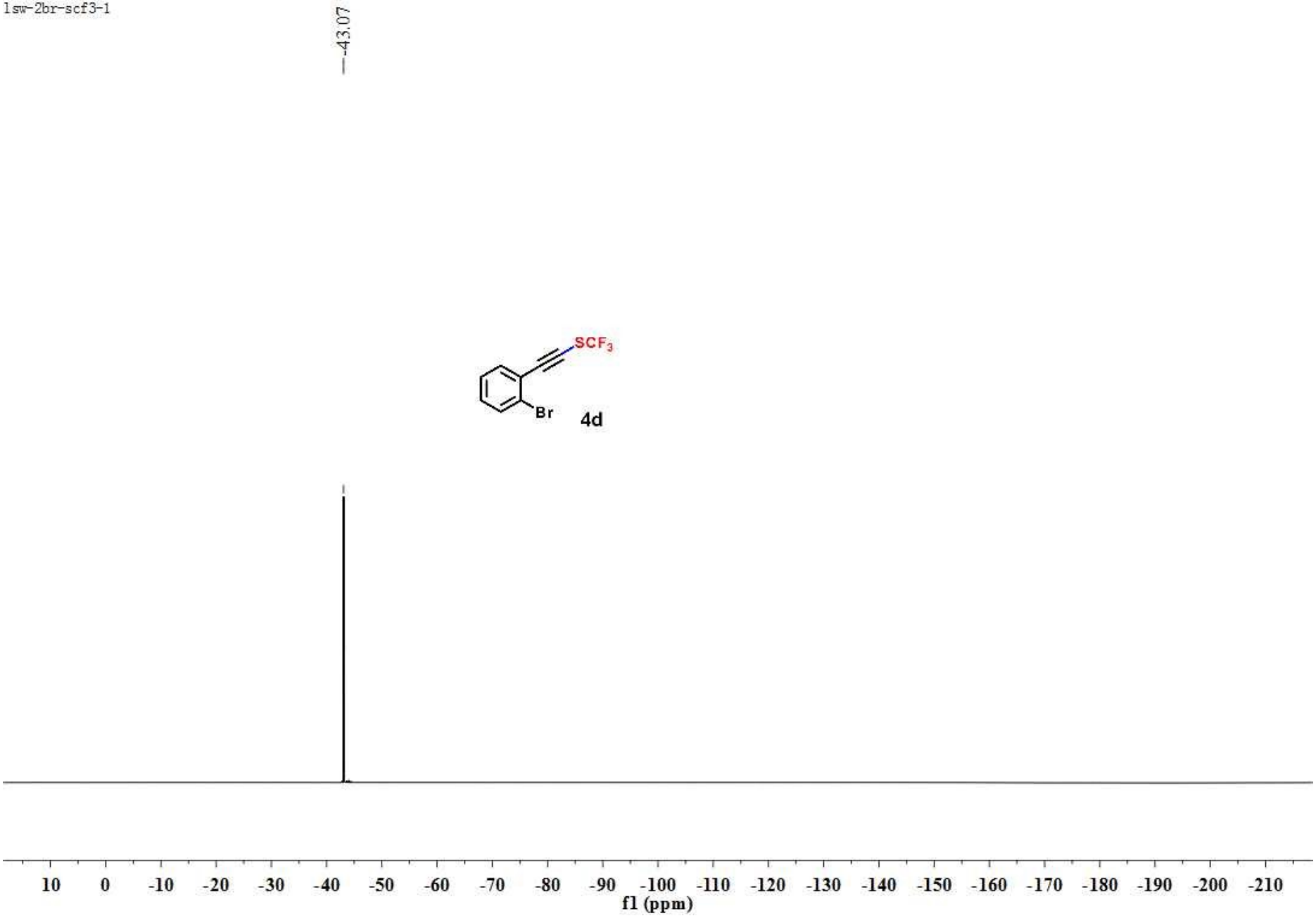
lsw-2br-scf3-1

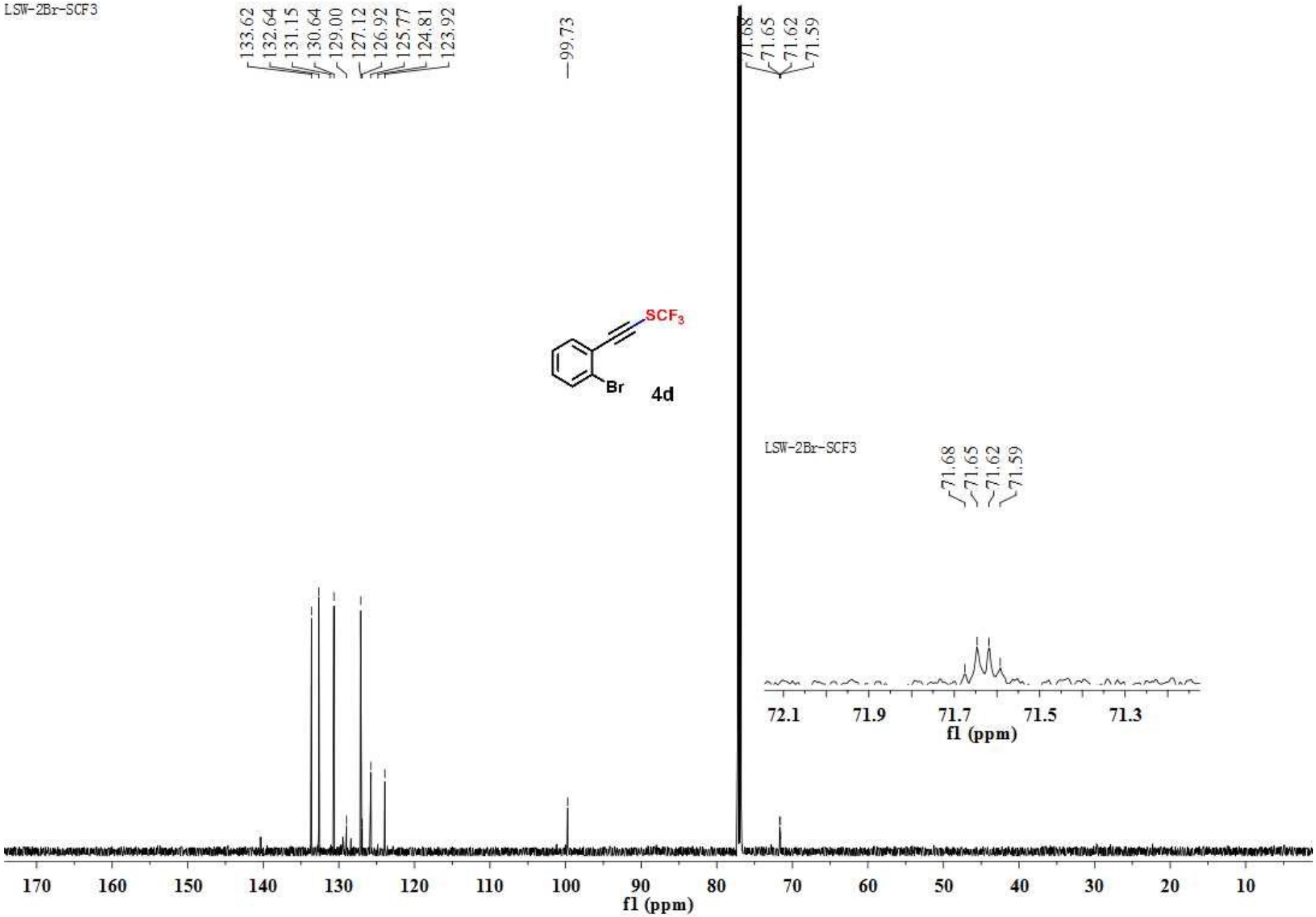


4d

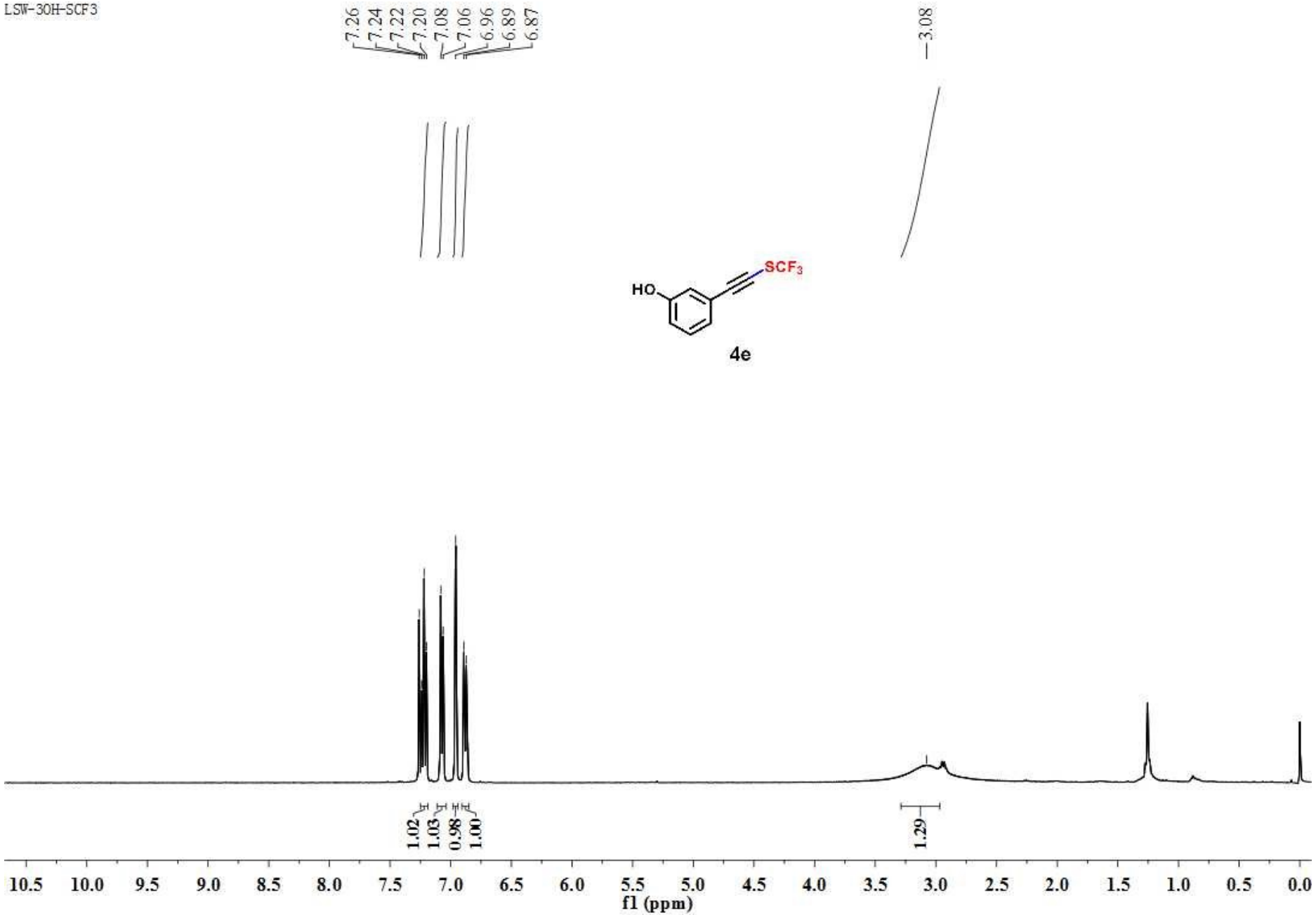


lsw-2br-scf3-1



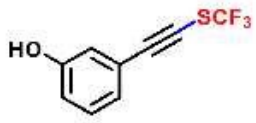

LSW-2Br-SCF3
133.62
132.64
131.15
130.64
129.00
127.12
126.92
125.77
124.81
123.92
99.73
71.68
71.65
71.62
71.59
SCF3
Br
4d
LSW-2Br-SCF3
71.68
71.65
71.62
71.59
72.1
71.9
71.7
71.5
71.3
f1 (ppm)
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
f1 (ppm)

LSW-3OH-SCF3

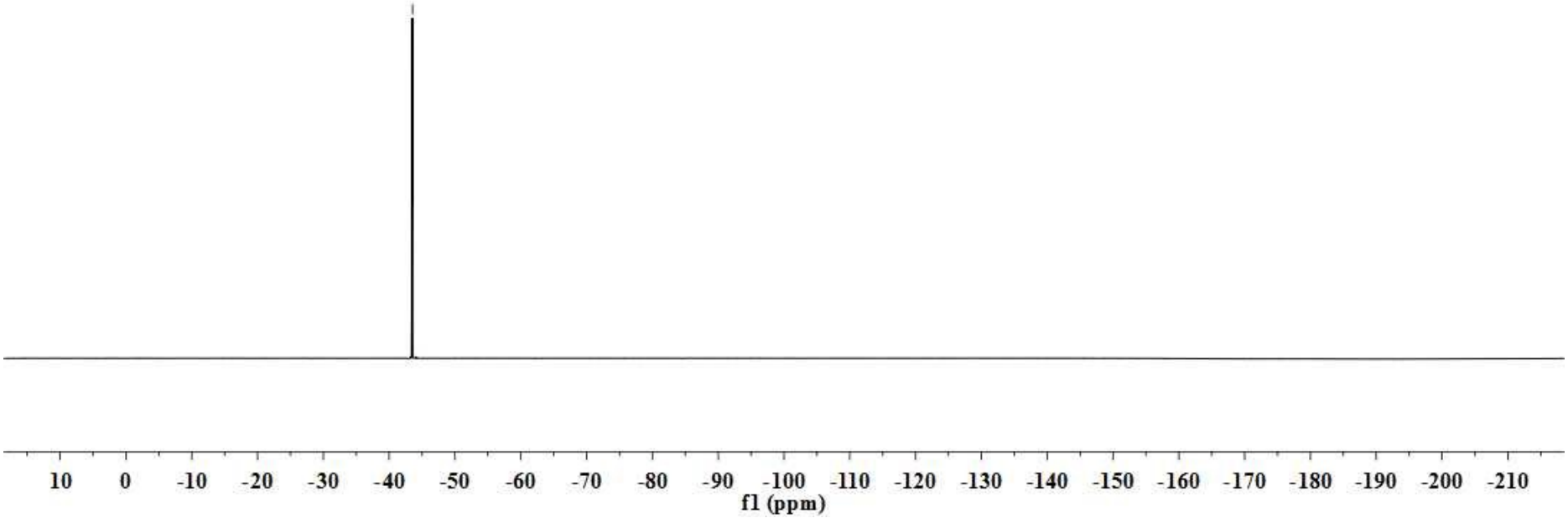

7.26
7.24
7.22
7.20
7.08
7.06
6.96
6.89
6.87
3.08
HO
SCF3
4e
1.02
1.03
0.98
1.00
1.29
10.5
10.0
9.5
9.0
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
f1 (ppm)

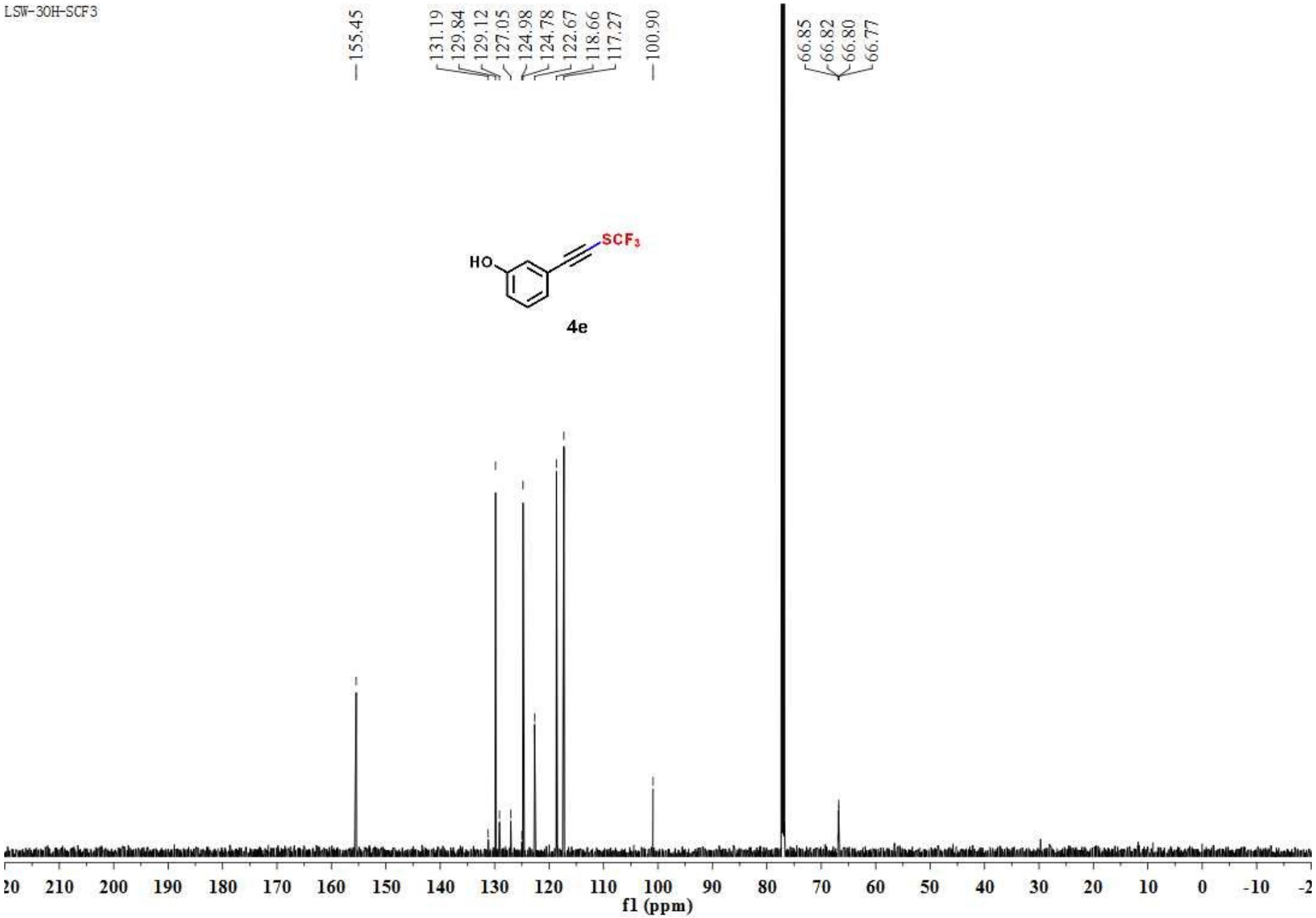
LSW-3OH-SCF3

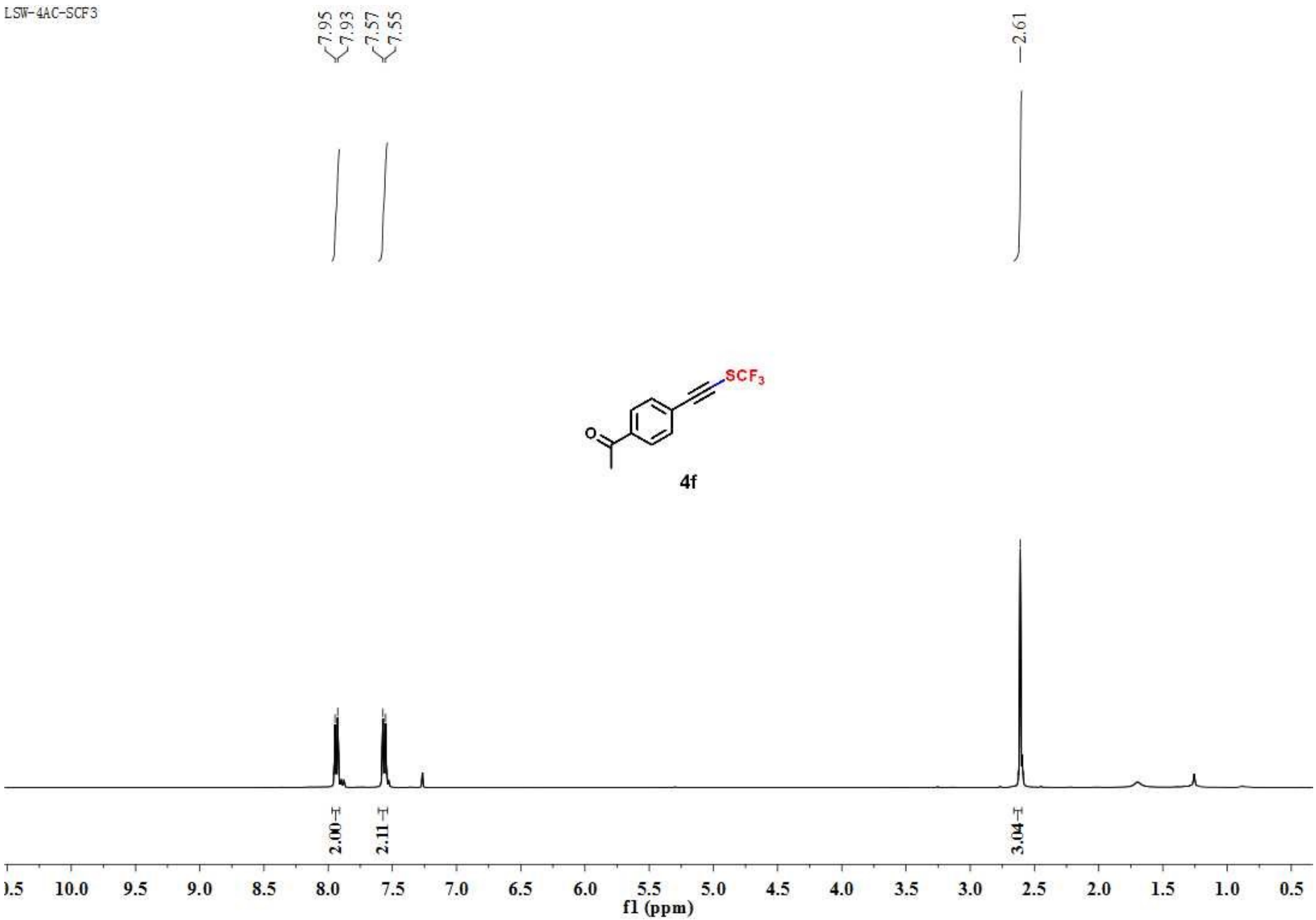
-43.55



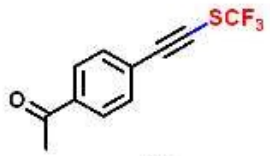
4e



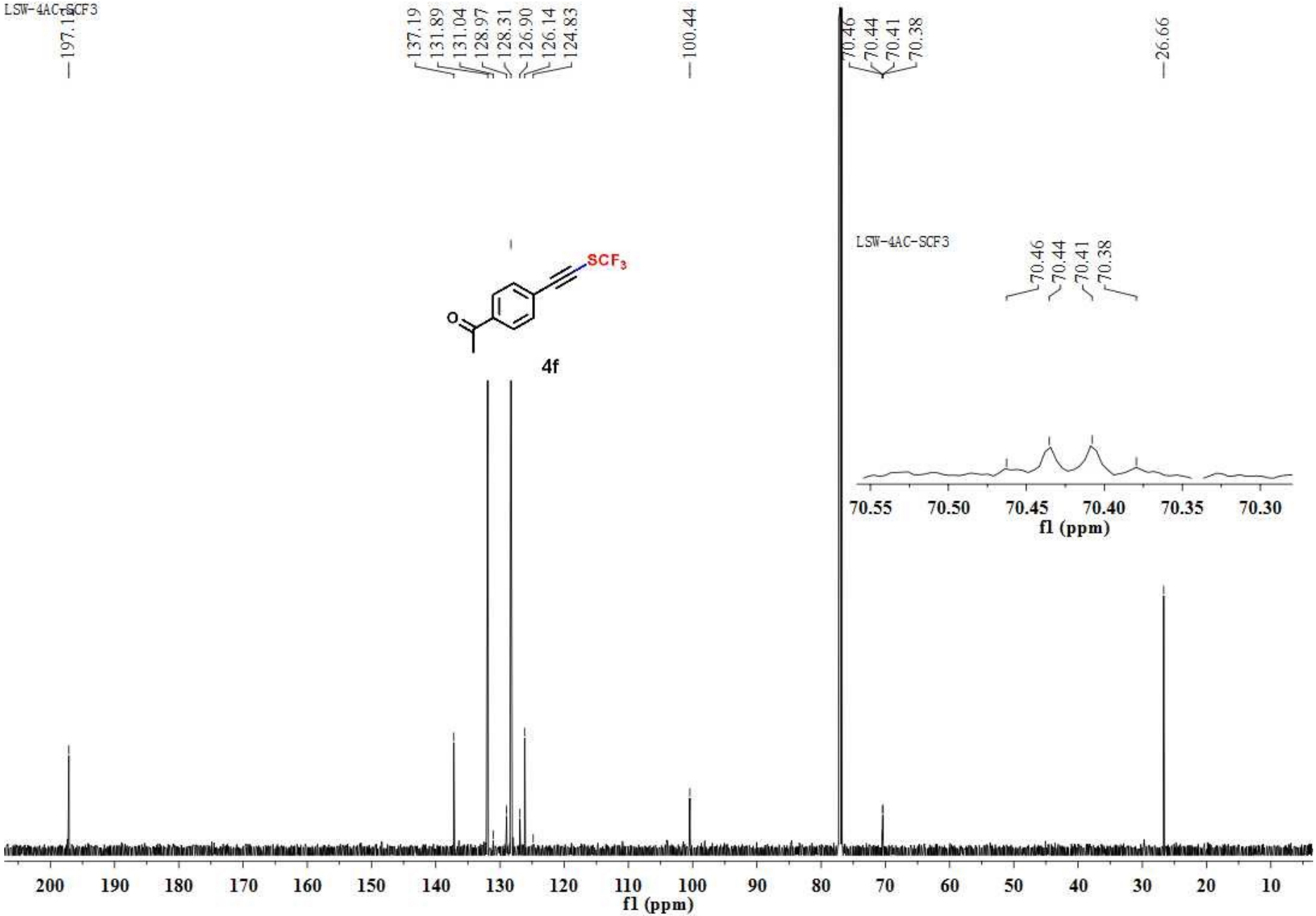

LSW-30H-SCF3
155.45
131.19
129.84
129.12
127.05
124.98
124.78
122.67
118.66
117.27
100.90
66.85
66.82
66.80
66.77
HO
SCF3
4e
f1 (ppm)


LSW-4AC-SCF3
7.95
7.93
7.57
7.55
2.61
SCF3
O
4f
2.00
2.11
3.04
f1 (ppm)

LSW-4AC-SCF3



4f


LSW-4AC-SCF3
197.13
137.19
131.89
131.04
128.97
128.31
126.90
126.14
124.83
100.44
70.46
70.44
70.41
70.38
26.66
SCF3
O
4f
LSW-4AC-SCF3
70.46
70.44
70.41
70.38
70.55
70.50
70.45
70.40
70.35
70.30
f1 (ppm)
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
f1 (ppm)

7. References

1. Shimada, H.; Kikuchi, S.; Okuda, S.; Haraguchi, K.; Tanaka, H. *Tetrahedron* **2009,** *65*, 6008-6016.
2. Hu, X.; Li, Z.; Ge, Y.; Liu, S.; Shi, C. *Colloids Surf. A Physicochem. Eng. Aspects* **2022,** *643*, 128782.