Supporting Information

Iron-catalysed 1,4-reduction of quinones for the synthesis of hydroquinones

Changpeng Lu, †[a] Mingyu Zhang, †[a] Tingting Bai, [a] Ziyao Yan, [a] Xiaoyun Pu, [a] Xiangzhong Huang, [a] Jiangping Chang, *[b] Ziliang Wang *[a] and Xishan Bai *[a]

[a] Key Laboratory of Chemistry in Ethnic Medicinal Resources, Ministry of Education, School of Ethnic Medicine, Yunnan Minzu University, Kunming 650500, China. E-mail: bai_xishan@126.com, zlwang3075@163.com

[b] KPC Pharmaceuticals, Inc. Clinical Research Center, Kunming 650500, China. E-mail: 13619657431@163.com

† These authors contributed equally to this work.

*Corresponding Authors: E-mail: bai_xishan@126.com (X. Bai), zlwang3075@163.com (Z. Wang), 13619657431@163.com (J. Chang)

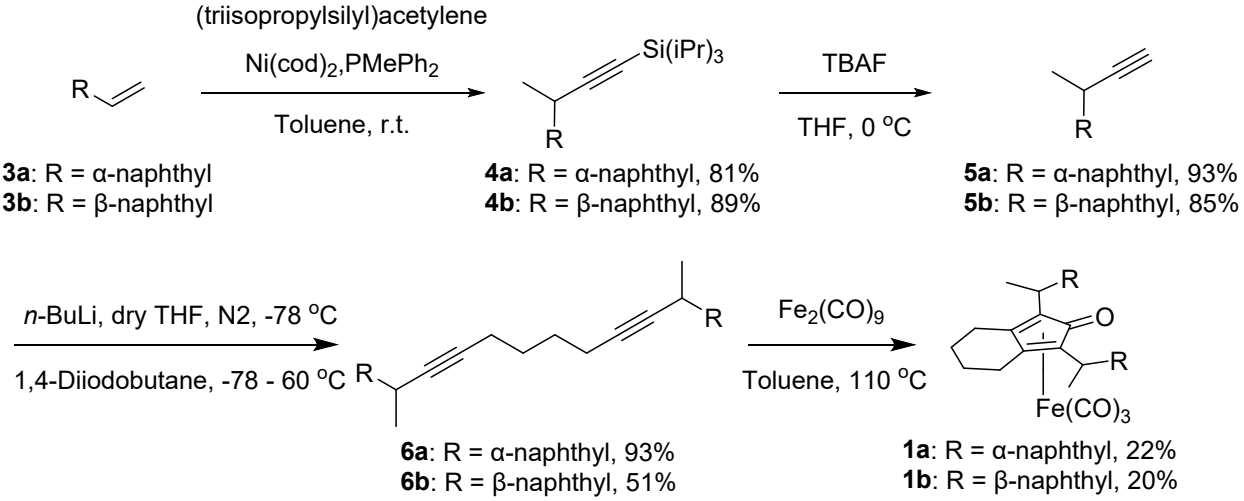
Table of contents

1. General Information.

All reactions involving the synthetic catalysts were carried out in anhydrous solvents under a nitrogen atmosphere. All glassware was baked and dried, and Schlenk tube techniques were employed. During the catalytic reactions, the feeding process was conducted under a nitrogen atmosphere, followed by the replacement of hydrogen. Reactions were monitored using thin-layer chromatography (TLC). Purification of the products was achieved by column chromatography using 100-200 mesh silica gel. Nuclear magnetic resonance (NMR) data were collected at (^{1}H: 400.0 or 600 MHz; ^{13}C: 100 or 150 MHz). Chemical shifts were reported in parts per million (ppm) relative to residual solvent peaks ($CDCl_3$, ^{1}H: 7.26 ppm, ^{13}C: 77.16 ppm; CD_3OD, ^{1}H: 3.31 ppm, ^{13}C: 49.00 ppm; and DMSO-d_6, ^{1}H: 2.50 ppm, ^{13}C: 39.52 ppm). The ^{13}C NMR spectra of compounds **4a**, **4b**, **5a**, **5b**, **6a**, **8aa-8ad**, **8af-8ar**, **8au-8ay**, **8ba**, **8bb**, **10**, and acetaminophen were measured using an attached proton test experiment. The others were measured using a proton noise decoupling experiment. Compounds **1a**, **1b**, **1c**, **1d**, **1e**, **7as**, **7at**, **7bb**, and **7bc** were synthesized in the laboratory, while all other reagents and substrates were purchased from Titan Reagent Platform. Solvents that did not require drying were purchased as technical grade. Dried solvents were freshly collected from a solvent purification system under a dry nitrogen atmosphere before use.

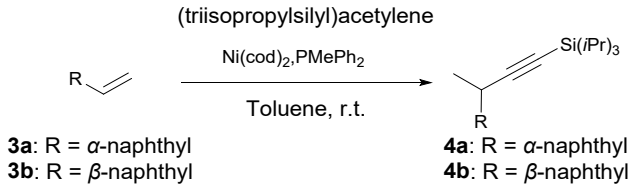
2. Experimental Procedure.

To obtain CICs **1a** and **1b**, we designed a synthesis route, as shown in Scheme 1.



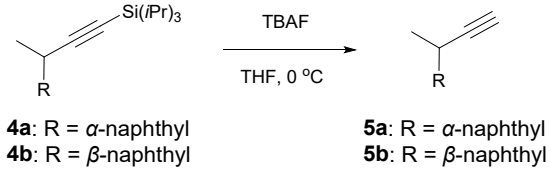
Scheme 1 Synthesis of CICs **1a** and **1b**.

General procedure for the synthesis of compounds 4a and 4b



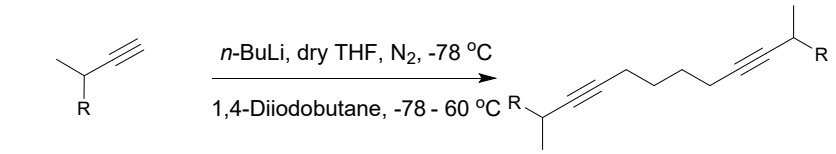
To prepare a 0.1 mol/L toluene solution (1.8 mL) of Ni/$PMePh_2$(= 1/2) catalyst, $PMePh_2$ (0.12 eq) was added to a solution of $Ni(cod)_2$ (0.06 eq) in dry toluene at room temperature under nitrogen, and stirred for 30 minutes. Then, it was added to a mixture of vinyl naphthalene (**3a** and **3b**, 6.0 mmol, 1 eq) and triisopropylsilylacetylene (12.0 mmol, 1 eq) at room temperature, and the mixture was stirred for 3 h. Then, triisopropylsilylacetylene (6.0 mmol, 0.5 eq) was added to this solution again at room temperature. After stirring for 8 h, the reaction mixture was passed through a short pad of silica gel (hexane) and then concentrated to give the crude product. It was purified by silica column chromatography (only using hexane) to provide the hydroalkynylation products **4a** and **4b** in yields of 81% and 89%, respectively.

General procedure for the synthesis of compounds 5a and 5b



Under nitrogen protection, compound **4** (5.35 mmol, 1 eq) was dissolved in dry THF (53.5 mL), and the solution was cooled to 0 °C and kept for 30 minutes. Then, a solution of tetrabutylammonium fluoride (TBAF) in THF (0.1 mol/L, 5.67 mL, 1.06 eq) was slowly injected into the solution using a syringe at 0 °C. After 6 h of reaction at the same temperature, the reaction mixture was quenched with water (50 mL). The mixture was extracted with ethyl acetate (EA, 3 × 50 mL). The combined organic layer was washed with saturated brine (50 mL), dried over anhydrous Na_2SO_4, filtered, and concentrated. The residue was purified by silica column chromatography, yielding product **5**. Compounds **5a** and **5b** were obtained in yields of 93% and 85%, respectively.

General procedure for the synthesis of CICs 6a and 6b

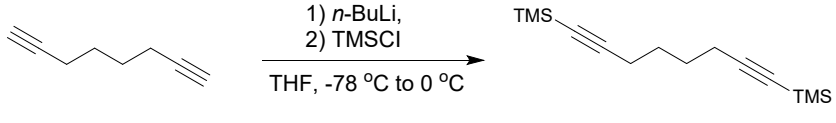


5a: R = *α*-naphthyl
5b: R = *β*-naphthyl

6a: R = *α*-naphthyl
6b: R = *β*-naphthyl

Under a nitrogen atmosphere, compound **5** (6 mmol, 4.0 eq) was dissolved in dry THF (20 mL), and the solution was cooled to –78 ℃. Then, a commercial solution of *n*-butyllithium (1.6 M in hexane; 9.1 mL, 5.7 mmol, 3.8 eq) was added dropwise over 10 min. After 1 h, the solution of 1,4-dibromoalkane (1.5 mmol, 1.0 eq) in dry THF (10 mL) was added at –78 ℃ under N_2, and the reaction mixture was slowly heated to 60 ℃. After 18 h, the reaction mixture was quenched with 20 mL of a saturated aqueous NH_4Cl solution, and 20 mL of EA was added for separation. The aqueous layer was extracted with EA (3 × 20 mL). The combined organic layer was dried over anhydrous $MgSO_4$, filtered, and concentrated to give the crude product. The residue was purified by silica column chromatography to yield **6**. Compounds **6a** and **6b** were obtained in yields of 93% and 51%, respectively.

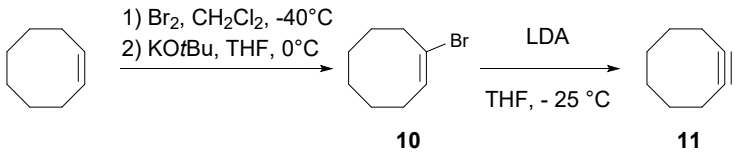
Procedure for the synthesis of 6c



6c

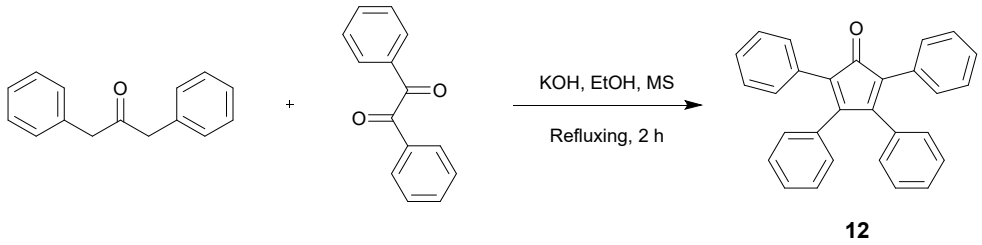
According to the reported method,[1] the solution of LiHMDS was prepared by dropwise addition of *n*-BuLi (1.6 M in hexanes, 47.1 mL, 2 eq) to a stirred solution of hexamethyldisilazane 15.7 mL, 75.34 mmol, 2 eq) in dry THF (20 mL) at –78 °C. Then, the LiHMDS solution cooled to –78 °C was transferred to a solution of 1, 7-octadiyne (5 mL, 37.67 mmol, 1 eq) in THF (54 mL) at –78 °C under N_2. After stirring for 0.5 h, chlorotrimethylsilane (TMSCl, 9.56 mL, 75.34 mmol, 2 eq) was added dropwise. The mixture was stirred for 10 min before it was allowed to reach ambient temperature. After stirring for 2 h at room temperature, the reaction was quenched with water (80 mL). The mixture was extracted with pentane (3 × 80 mL), and the combined extracts were successively washed with HCl (1 M, 80 mL), water (80 mL), and brine (80 mL) before they were dried over $MgSO_4$ and concentrated. Distillation of the crude product (bp 75 –78.5 °C, 7 mbar) gave compound **6c** as a colourless oil in a yield of 50%.

Procedure for the synthesis of 11



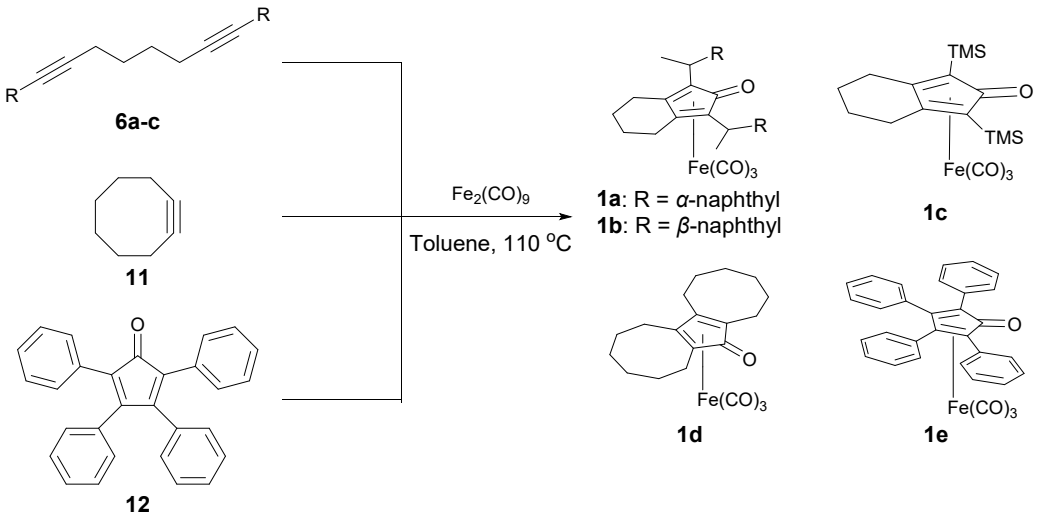
Following the reported procedures,[2] cyclooctene was used as the starting material to prepare cyclooctyne (**11**). Firstly, a solution of Br_2 (0.25 mol) in CH_2Cl_2 (12 mL) was added dropwise to a solution of cyclooctene (33.2 mL, 0.25 mol, 1 eq) in CH_2Cl_2 (100 mL) at -40 °C for the preparation of *trans*-1,2-dibromocyclootane. Secondly, a suspension of KO*t*Bu (41.07 g, 370 mmol, 1.52 eq) in THF (40 mL) was added to a solution of *trans*-1,2-dibromocyclootane (65.78 g, 244 mmol, 1 eq) in THF (100 mL) at 0 °C to synthesise (*E*)-1-bromocyclooct-1-ene (**10**), with a 71% yield. Finally, cyclooctyne was obtained by adding (*E*)-1-bromocyclooct-1-ene to the lithium diisopropylamide (LDA) solution cooled to -25 °C, affording a 66% yield.

Procedure for synthesis of 12



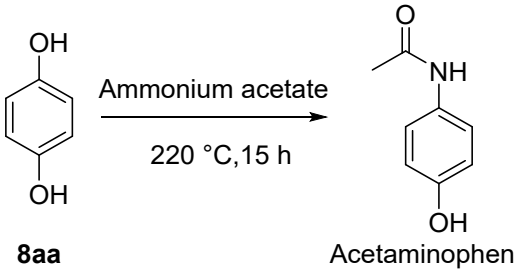
A solution of KOH (1 mmol, 0.5 eq) in dry ethanol (100 mL) was added to a mixture of benzil (2 mmol, 1 eq) and 1,3-diphenylacetone (2 mmol, 1 eq) in dry ethanol (4 mL), and then 400 mg molecular sieve (4 Å) was added. The resulting mixture was heated at reflux for 2 h. The mixture was concentrated under reduced pressure and purified by silica column chromatography using petroleum ether (PE)/EA as the eluent, yielding **12** in 61% yield.

General procedure for synthesis of CICs 1a-e



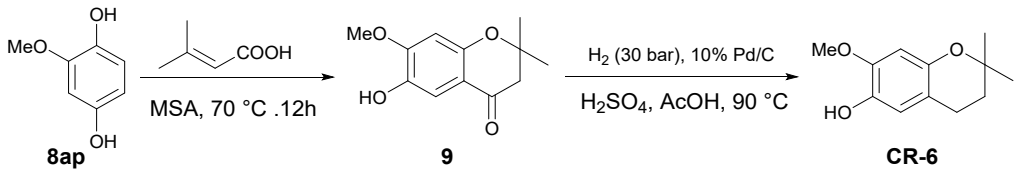
Compounds **6a-c**, **11** or **12** (3 mmol, 1 eq) and $Fe_2(CO)_9$ (7.5 mmol, 2.5 eq) were dissolved in dry toluene (21 mL), under argon, and heated to 110 °C overnight in a sealed Schlenk tube. The reaction mixture was cooled down to room temperature and filtered through Celite, rinsing with EA. After removing the solvent under reduced pressure, the residue was purified by flash column chromatography to give the CICs **1a-e**.

Procedures for the synthesis of acetaminophen



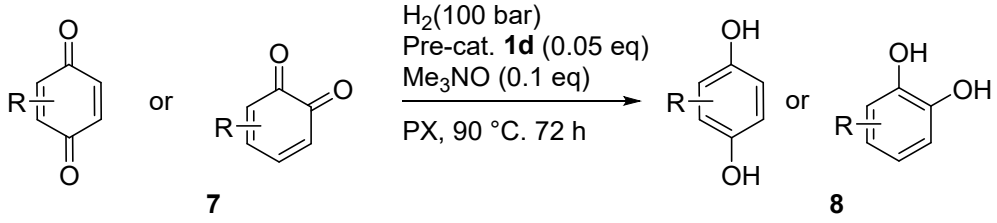
To a mixture of **8aa** (200 mg, 1.82 mmol, 1 eq) and acetic acid (0.57 mL) was added ammonium acetate (1.4 g, 18.2 mmol, 10 eq) under N_2. The reaction flask was sealed and heated in an oil bath at 220 ℃ for 15 hours. After concentration, the residue was purified by column chromatography using 1% MeOH in CH_2Cl_2 as the eluent, yielding acetaminophen with a 97% yield.

Procedures for the synthesis of CR-6



First, compound **8ap (**200 mg, 1.428 mmol, 1 eq) and 3,3-dimethylacrylic acid (172 mg, 1.7136 mmol, 1.2 eq) were stirred in methanesulfonic acid (20 mL) for 12 h at 70 ℃. Then, ice water (400 mL) was added to the mixture when it had cooled to room temperature. The mixture was extracted with EA (3 × 400 mL), and then the organic layer was washed with 1 M NaOH and water, and dried ($MgSO_4$). After concentration, the residue was purified by silica gel chromatography (CH_2Cl_2: MeOH: 99: 1) to give compound **9** in 84% yield. Secondly, compound **9** (100 mg, 0.44 mmol, 1 eq) and Pd/C (10%, 10 mg) were added to a solution of H_2SO_4 (1.19 μL, 0.0022 mmol, 0.004 eq.) in AcOH (1.6 mL), and the mixture was stirred at 80 ℃ for 12 h. The mixture was cooled and filtered, then water (10 mL) was added. After extracting with EA (3 × 10 mL), the organic layer was washed with brine, dried ($MgSO_4$), and concentrated. The residue was purified by silica gel chromatography (PE: EA = 5: 1) to give **CR-6** in a yield of 60%.

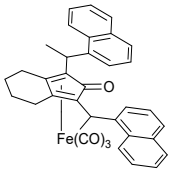
Hydrogenation of quinones



Trimethylamine oxide (0.045 mmol, 0.1 eq) was added to the solution of CICs (0.0225 mmol, 0.05 eq) in PX (3 mL) at room temperature under Ar. After 20 min, quinones (0.45 mmol, 1 eq) were added, and Ar was then exchanged for hydrogen three times. The reaction mixture was kept at 90 ºC under 100 bar of H_2 for 72 h. The mixture was filtered and washed with MeOH three times. After concentrating, the residue was purified by column chromatography to provide the target products.

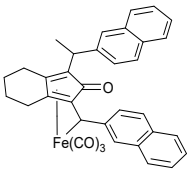
3. Analytical Data for Products.

CIC 1a



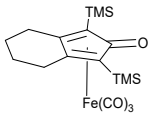
Purified by flash column chromatography on silica gel (PE: EA = 20: 1). Yield: 22%; light yellow solid; M.p. = 87-88 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.12 (dd, *J* = 6.6, 3.3 Hz, 2H), 7.87 – 7.84 (m, 2H), 7.78 – 7.75 (m, 4H), 7.49 – 7.47 (m, 6H), 4.83 (q, *J* = 7.2 Hz, 2H), 2.05 – 1.98 (m, 2H), 1.80 (d, *J* = 7.2 Hz, 6H), 1.40 – 1.33 (m, 4H), 1.26 – 1.20 (m, 2H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 209.3, 169.9, 139.9, 133.8, 131.9, 128.9, 127.5, 126.4, 125.7, 125.5, 125.0, 123.7, 100.6, 90.4, 29.5, 27.0, 23.9, 22.1, 21.6; HRESIMS *m/z* 583.1568 $[M+H]^+$ (calculated for $C_{36}H_{31}O_4Fe^+$: 583.1566).

CIC 1b



Purified by flash column chromatography on silica gel (PE: EA = 20: 1). Yield: 20%; light yellow solid; M.p. = 96-98 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.88 (s, 2H), 7.81 (d, *J* = 9.5 Hz, 8H), 7.44 (td, *J* = 8.2, 7.2, 4.3 Hz, 4H), 3.93 (q, *J* = 7.4 Hz, 2H), 2.55 – 2.48 (m, 2H), 2.27 – 2.22 (m, 2H), 1.72 (d, *J* = 7.4 Hz, 6H), 1.68 – 1.65 (m, 2H), 1.61 – 1.59 (m, 2H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 209.0, 171.3, 142.5, 133.4, 132.4, 128.1, 128.1, 127.7, 127.2, 126.1, 126.0, 125.6, 100.4, 88.3, 35.5, 22.0, 21.9, 21.1; HRESIMS *m/z* 583.1565 $[M+H]^+$ (calculated for $C_{36}H_{31}O_4Fe^+$: 583.1566).

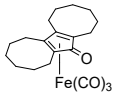
CIC 1c



Purified by flash column chromatography on silica gel (PE: EA = 15: 1). Yield: 64%; light yellow solid; M.p. = 135-136 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 2.56 – 2.50 (m, 4H), 1.82 (br s,

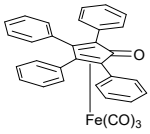
4H), 0.26 (s, 18H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 209.2, 181.4, 111.2, 71.9, 24.9, 22.6, – 0.1. The NMR data agree with those reported in the literature.[1]

CIC 1d



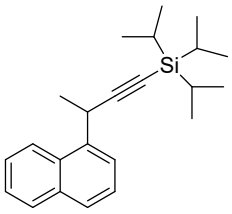
Purified by flash column chromatography on silica gel (PE: EA = 7: 3). Yield: 81%; light yellow solid; M.p. = 155-156 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 2.75 (d, *J* = 11.1 Hz, 2H), 2.59 (d, *J* = 13.9 Hz, 2H), 2.44 (d, *J* = 13.1 Hz, 2H), 1.89 – 1.72 (m, 8H), 1.62 – 1.42 (m, 10H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 209.4, 171.5, 102.5, 85.6, 31.4, 28.9, 26.3, 25.8, 23.8, 23.5. The NMR data agree with those reported in the literature.[2]

CIC 1e



Purified by flash column chromatography on silica gel (PE: EA = 20: 1). Yield: 80%; light yellow solid; M.p. = 173-174 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.67 – 7.64 (m, 4H), 7.37 – 7.32 (m, 8H), 7.28 – 7.23 (m, 8H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 208.7, 169.9, 132.0, 131.0, 130.4, 130.0, 128.9, 128.2, 128.2, 128.0, 104.2, 82.7. The NMR data agree with those reported in the literature.[3]

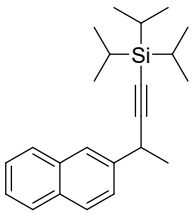
Triisopropyl(3-(naphthalen-1-yl)but-1-yn-1-yl)silane (4a)



Purified by flash column chromatography on silica gel (hexane). Yield: 81%; light yellow oil; ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.13 (dd, *J* = 8.6, 1.5 Hz, 1H), 7.92 – 7.85 (m, 2H), 7.78 (d, *J* = 8.2 Hz, 1H), 7.56 – 7.48 (m, 3H), 4.61 (q, *J* = 7.1 Hz, 1H), 1.68 (d, *J* = 7.1 Hz, 3H), 1.13 (d, *J* = 2.6

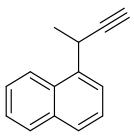
Hz, 21H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 139.0, 134.0, 130.6, 129.1, 127.5, 126.0, 125.8, 125.6, 124.5, 123.3, 111.6, 82.8, 29.8, 24.1, 18.8, 11.5. The NMR data agree with those reported in the literature.[4]

Triisopropyl(3-(naphthalen-2-yl)but-1-yn-1-yl)silane (4b)



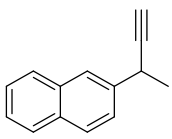
Purified by flash column chromatography on silica gel (hexane). Yield: 89%; light yellow oil; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.92 (d, *J* = 2.0 Hz, 1H), 7.84 – 7.80 (m, 3H), 7.54 (dd, *J* = 8.5, 1.9 Hz, 1H), 7.55 – 7.43 (m, 2H), 3.99 (q, *J* = 7.1 Hz, 1H), 1.60 (d, *J* = 7.1 Hz, 3H), 1.13 (d, *J* = 2.6 Hz, 21H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 140.8, 133.6, 132.4, 128.2, 127.9, 127.7, 126.2, 125.8, 125.7, 125.4, 111.3, 82.8, 33.2, 25.1, 18.8, 11.4. The NMR data agree with those reported in the literature.[5]

1-(But-3-yn-2-yl)naphthalene (5a)



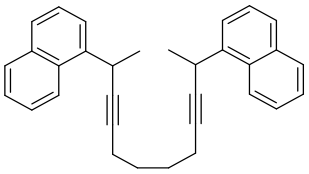
Purified by flash column chromatography on silica gel (hexane). Yield: 93%; light yellow oil; ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.12 (d, *J* = 8.4 Hz, 1H), 7.91 (dd, *J* = 7.9, 1.6 Hz, 1H), 7.80 (d, *J* = 7.6 Hz, 2H), 7.59 – 7.49 (m, 3H), 4.57 (qd, *J* = 7.1, 2.5 Hz, 1H), 2.36 (d, *J* = 2.5 Hz, 1H), 1.70 (d, *J* = 7.1 Hz, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 138.3, 134.1, 130.5, 129.1, 127.7, 126.2, 125.8, 125.7, 124.2, 123.1, 87.4, 70.6, 28.3, 23.2. The NMR data agree with those reported in the literature.[6]

2-(But-3-yn-2-yl)naphthalene (5b)



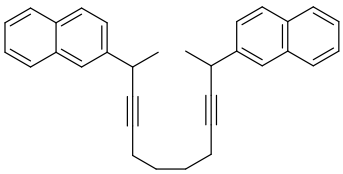
Purified by flash column chromatography on silica gel (hexane). Yield: 85%; light yellow oil; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.88 – 7.83 (m, 4H), 7.55 – 7.45 (m, 3H), 3.97 (qd, *J* = 7.2, 2.5 Hz, 1H), 2.36 (m, 1H), 1.62 (dd, *J* = 7.2, 1.5 Hz, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 140.1, 133.6, 132.5, 128.5, 127.9, 127.7, 126.3, 125.8, 125.5, 125.2, 87.2, 70.6, 31.9, 24.3. The NMR data agree with those reported in the literature.[5]

1,1'-(Dodeca-3,9-diyne-2,11-diyl)dinaphthalene (6a)



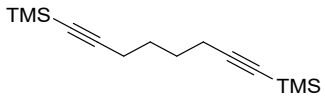
Purified by flash column chromatography on silica gel (hexane). Yield: 93%; colorless oil; ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.13 (d, *J* = 8.4 Hz, 2H), 7.87 (dd, *J* = 8.0, 1.6 Hz, 2H), 7.75 (dd, *J* = 7.7, 6.1 Hz, 4H), 7.55 – 7.44 (m, 6H), 4.51 (qt, *J* = 7.1, 2.3 Hz, 2H), 2.31 – 2.28 (m, 4H), 1.70 – 1.67 (m, 4H), 1.62 (d, *J* = 7.1 Hz, 6H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 139.7, 134.0, 130.6, 129.0, 127.4, 126.0, 125.8, 125.5, 124.2, 123.4, 83.5, 82.3, 28.6, 28.3, 23.8, 18.6; HRESIMS (ESI):*m/z* 437.2232 $[M+Na]^+$ (calculated for $C_{32}H_{30}Na^+$, 437.2240).

2,2'-(Dodeca-3,9-diyne-2,11-diyl)dinaphthalene (6b)



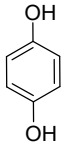
Purified by flash column chromatography on silica gel (hexane). Yield: 51%; colorless oil; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.84 – 7.73 (m, 8H), 7.52 (d, *J* = 8.5 Hz, 2H), 7.48 – 7.42 (m, 4H), 3.92 (q, *J* = 7.4 Hz, 2H), 2.33 (br s, 4H), 1.72 (br s, 4H), 1.55 (d, *J* = 7.1 Hz, 6H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 141.5, 133.6, 132.4, 128.2, 127.9, 127.7, 126.1, 125.8, 125.6, 125.1, 83.3, 82.4, 32.2, 28.3, 24.9, 18.6; HRESIMS (ESI):*m/z* 437.2246 $[M+Na]^+$ (calculated for $C_{32}H_{30}Na^+$, 437.2240).

1,8-Bis(trimethylsilyl)octa-1,7-diyne (6c)



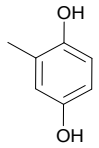
Purified by distillation. Yield: 50%; colorless oil; ^{1}H NMR (400 MHz, $CDCl_3$) δ 2.24 – 2.20 (m, 4H), 1.61 – 1.57 (m, 4H), 0.12 (s, 18H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 107.1, 84.8, 27.8, 19.5, 0.3. The NMR data agree with those reported in the literature.[1]

Hydroquinone (8aa)



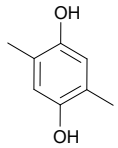
Purified by flash column chromatography on silica gel (CH_2Cl_2: MeOH = 99: 1). Yield: 99%; white solid; M.p. = 172-173 °C; ^{1}H NMR (400 MHz, CD_3OD) δ 6.61 (s, 4H); ^{13}C NMR (100 MHz, CD_3OD) δ 151.3, 116.8. The NMR data agree with those reported in the literature.[7]

2-Methylbenzene-1,4-diol (8ab)



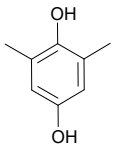
Purified by flash column chromatography on silica gel (CH_2Cl_2: MeOH = 99: 1). Yield: 99%; white solid; M.p. = 128-129 °C; ^{1}H NMR (400 MHz, CD_3OD) δ 6.57 (d, J = 8.5 Hz, 1H), 6.53 (d, J = 2.9 Hz, 1H), 6.43 (dd, J = 8.6, 3.0 Hz, 1H), 2.12 (s, 3H); ^{13}C NMR (100 MHz, CD_3OD) δ 151.0, 149.3, 126.5, 118.4, 116.3, 113.8, 16.4. The NMR data agree with those reported in the literature.[7]

2,5-Dimethylbenzene-1,4-diol (8ac)



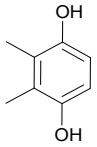
Purified by flash column chromatography on silica gel (CH_2Cl_2: MeOH = 99: 1). Yield: 99%; white solid; M.p. =212-214 °C; ^{1}H NMR (400 MHz, CD_3OD) δ 6.48 (s, 2H), 2.08 (s, 6H); ^{13}C NMR (100 MHz, CD_3OD) δ 148.9, 123.3, 118.1, 15.9. The NMR data agree with those reported in the literature.[7]

2,6-Dimethylbenzene-1,4-diol (8ad)



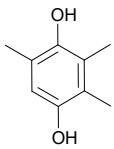
Purified by flash column chromatography on silica gel (CH_2Cl_2: MeOH = 99: 1). Yield: 85%; white solid; M.p. = 154-155 °C; ^{1}H NMR (400 MHz, CD_3OD) δ 6.38 (s, 2H), 2.14 (s, 6H); ^{13}C NMR (100 MHz, CD_3OD) δ 151.1, 146.9, 127.3, 115.7, 16.8. The NMR data agree with those reported in the literature.[7]

2,3-Dimethylbenzene-1,4-diol (8ae)



Purified by flash column chromatography on silica gel (CH_2Cl_2: MeOH = 99: 1). Yield: 88%; white solid; M.p. = 223-225 °C; ^{1}H NMR (400 MHz, DMSO-d_6) δ 8.37 (s, 2H), 6.43 (d, *J* = 1.9 Hz, 2H), 2.00 (s, 6H); ^{13}C NMR (100 MHz, DMSO-d_6) δ 147.6, 123.2, 111.9, 12.1. The NMR data agree with those reported in the literature.[8]

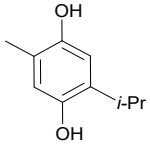
2,3,5-Trimethylbenzene-1,4-diol (8af)



Purified by flash column chromatography on silica gel (CH_2Cl_2: MeOH = 99: 1). Yield: 90%. white solid; M.p. = 169-171 °C; ^{1}H NMR (400 MHz, CD_3OD) δ 6.41 (s, 1H), 2.13 (s, 6H), 2.08

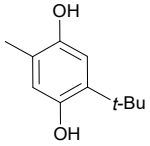
(s, 3H); ^{13}C NMR (100 MHz, CD_3OD) δ 149.3, 146.6, 126.5, 124.1, 122.1, 115.2, 16.7, 12.8, 12.2. The NMR data agree with those reported in the literature.[7]

2-Isopropyl-5-methylbenzene-1,4-diol (8ag)



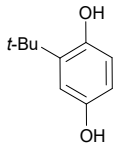
Purified by flash column chromatography on silica gel (CH_2Cl_2). Yield: 99%; white solid; M.p. =148-149 °C; ^{1}H NMR (400 MHz, CD_3OD) δ 6.58 (s, 1H), 6.49 (s, 1H), 3.18 (m, 1H), 2.09 (s, 3H), 1.16 (d, J = 6.9 Hz, 6H); ^{13}C NMR (100 MHz, CD_3OD) δ 149.1, 147.8, 134.2, 122.9, 118.4, 113.5, 27.6, 23.2, 15.9. The NMR data agree with those reported in the literature.[7]

2-(tert-Butyl)-5-methylbenzene-1,4-diol (8ah)



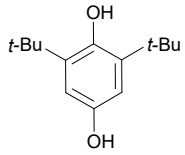
Purified by flash column chromatography on silica gel (CH_2Cl_2: MeOH = 99: 1). Yield: 99%; white solid; M.p. = 192.3 °C; ^{1}H NMR (400 MHz, DMSO-d_6) δ 8.45 (s, 1H), 8.31 (br s, 1H), 6.58 (s, 1H), 6.44 (s, 1H), 1.98 (s, 3H), 1.28 (s, 9H). ^{13}C NMR (100 MHz, DMSO-d_6) δ 147.8, 147.2, 133.0, 121.0, 118.2, 113.2, 33.9, 15.4. The NMR data agree with those reported in the literature.[9]

2-(tert-Butyl)benzene-1,4-diol (8ai)



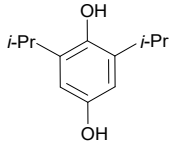
Purified by flash column chromatography on silica gel (CH_2Cl_2). Yield: 99%; white solid; M.p. = 127-128 °C; ^{1}H NMR (400 MHz, CD_3OD) δ 6.70 (d, J = 3.0 Hz, 1H), 6.55 (d, J = 8.5 Hz, 1H), 6.45 (dd, J = 8.5, 2.9 Hz, 1H), 1.36 (s, 9H); ^{13}C NMR (100 MHz, CD_3OD) δ 150.4, 150.2, 138.2, 117.6, 114.7, 113.5, 35.4, 29.9. The NMR data agree with those reported in the literature.[7]

2,6-Di-tert-butylbenzene-1,4-diol (8aj)



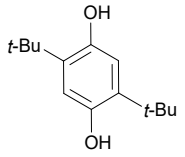
Purified by flash column chromatography on silica gel (CH_2Cl_2). Yield: 90%; white solid; M.p. = 101-102 °C; ^{1}H NMR (400 MHz, CD_3OD) δ 6.62 (d, *J* = 0.8 Hz, 2H), 1.39 (s, 18H); ^{13}C NMR (100 MHz, CD_3OD) δ 151.1, 148.1, 141.6, 112.3, 35.7, 30.9. The NMR data agree with those reported in the literature.[7]

2,6-Diisopropylbenzene-1,4-diol (8ak)



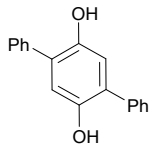
Purified by flash column chromatography on silica gel (CH_2Cl_2). Yield: 80%; pink solid; M.p. = 103-104 °C; ^{1}H NMR (400 MHz, CD_3OD) δ 6.48 (d, *J* = 1.4 Hz, 2H), 3.29 (m, 2H), 1.19 (d, *J* = 7.0 Hz, 12H); ^{13}C NMR (100 MHz, CD_3OD) δ 152.1, 144.2, 139.1, 110.7, 28.0, 23.5. The NMR data agree with those reported in the literature.[10]

2,5-Di-tert-butylbenzene-1,4-diol (8al)



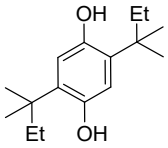
Purified by flash column chromatography on silica gel (CH_2Cl_2). Yield: 84%; white solid; M.p. = 216-218 °C; ^{1}H NMR (400 MHz, DMSO-d_6) δ 8.37 (s, 2H), 6.58 (s, 2H), 1.28 (s, 18H); ^{13}C NMR (100 MHz, DMSO-d_6) δ 147.5, 132.7, 114.5, 33.7, 29.4. The NMR data agree with those reported in the literature.[7]

[1,1':4',1''-Terphenyl]-2',5'-diol (8am)



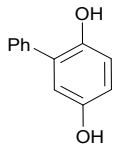
Purified by flash column chromatography on silica gel (CH_2Cl_2: MeOH = 99: 1). Yield: 99%; white solid; M.p. = 218-219 °C; ^{1}H NMR (400 MHz, DMSO-d_6) δ 8.98 (s, 2H), 7.55 (d, J = 7.7 Hz, 4H), 7.40 (t, J = 7.5 Hz, 4H), 7.30 (d, J = 7.4 Hz, 2H), 6.85 (s, 2H); ^{13}C NMR (100 MHz, DMSO-d_6) δ 147.0, 138.4, 128.9, 128.0, 127.4, 117.5. The NMR data agree with those reported in the literature.[7]

2,5-Di-tert-pentylbenzene-1,4-diol (8an)



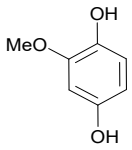
Purified by flash column chromatography on silica gel (PE: EA = 5:1). Yield: 46%; white solid; M.p. = 179-181 °C; ^{1}H NMR (400 MHz, CD_3OD) δ 6.54 (s, 2H), 1.85 (q, J = 7.5 Hz, 4H), 1.29 (s, 12H), 0.64 (t, J = 7.5 Hz, 6H); ^{13}C NMR (100 MHz, CD_3OD) δ 149.2, 133.1, 117.2, 38.6, 34.0, 28.2, 9.9. The NMR data agree with those reported in the literature.[11]

[1,1'-Biphenyl]-2,5-diol (8ao)



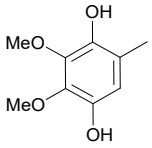
Purified by flash column chromatography on silica gel (CH_2Cl_2: MeOH = 99: 1). Yield: 91%; white solid; M.p. = 98-100 °C; ^{1}H NMR (400 MHz, DMSO-d_6) δ 8.88 (brs, 2H), 7.50 (d, J = 7.2 Hz, 2H), 7.37 (t, J = 7.6 Hz, 2H), 7.26 (t, J = 7.3 Hz, 1H), 6.76 (d, J = 8.6 Hz, 1H), 6.66 (d, J = 2.9 Hz, 1H), 6.58 (dd, J = 8.6, 2.9 Hz, 1H); ^{13}C NMR (100 MHz, DMSO-d_6) δ 150.1, 146.8, 138.9, 129.0, 128.1, 127.9, 126.5, 116.8, 116.5, 115.0. The NMR data agree with those reported in the literature.[7]

2-Methoxybenzene-1,4-diol (8ap)



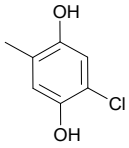
Purified by flash column chromatography on silica gel (CH_2Cl_2: MeOH = 99: 1). Yield: 76%; brown solid; M.p. = 88-91 °C; ^{1}H NMR (400 MHz, CD_3OD) δ 6.61 (d, *J* = 8.5 Hz, 1H), 6.42 (d, *J* = 2.7 Hz, 1H), 6.22 (dd, *J* = 8.5, 2.7 Hz, 1H), 3.79 (s, 3H); ^{13}C NMR (100 MHz, CD_3OD) δ 151.8, 149.5, 140.3, 116.4, 107.4, 101.2, 56.2. The NMR data agree with those reported in the literature.[12]

2,3-Dimethoxy-5-methylbenzene-1,4-diol (8aq)



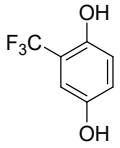
Purified by flash column chromatography on silica gel (CH_2Cl_2: MeOH = 99: 1). Yield: 95%; red solid; M.p. = 74-75 °C; ^{1}H NMR (400 MHz, CD_3OD) δ 6.35 (d, *J* = 0.8 Hz, 1H), 3.82 (s, 3H), 3.80 (s, 3H), 2.09 (d, *J* = 0.9 Hz, 3H); ^{13}C NMR (100 MHz, CD_3OD) δ 143.6, 142.3, 142.1, 140.2, 121.1, 113.3, 61.2, 61.1, 15.8. The NMR data agree with those reported in the literature.[7]

2-Chloro-5-methylbenzene-1,4-diol (8ar)



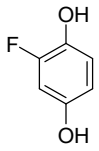
Purified by flash column chromatography on silica gel (CH_2Cl_2: MeOH = 99: 1). Yield: 30%; red solid; M.p. = 174-176 °C; ^{1}H NMR (400 MHz, CD_3OD) δ 6.68 (s, 1H), 6.65 (s, 1H), 2.10 (s, 3H); ^{13}C NMR (100 MHz, CD_3OD) δ 149.8, 146.6, 125.7, 119.5, 118.2, 116.4, 15.9. The NMR data agree with those reported in the literature.[13]

2-(Trifluoromethyl)benzene-1,4-diol (8as)



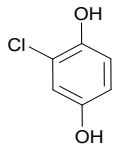
Purified by flash column chromatography on silica gel (CH_2Cl_2: MeOH = 95: 5). Yield: 37%; red solid; M.p. = 107-108 °C; ^{1}H NMR (400 MHz, CD_3OD) δ 6.90 (br s, 1H), 6.83 (dd, *J* = 8.8, 2.8 Hz, 1H), 6.77 (d, *J* = 8.8 Hz, 1H); ^{13}C NMR (100 MHz, CD_3OD) δ 150.8, 149.6 (d, *J* = 2.2 Hz), 125.2 (q, *J* = 271.3 Hz), 121.0, 118.8 (d, *J* = 3.1 Hz), 118.2 (q, *J* = 30.3 Hz), 113.7 (q, *J* = 7.3 Hz); ^{19}F NMR (376 MHz, CD_3OD) δ –63.75. The NMR data agree with those reported in the literature.[14]

2-Fluorobenzene-1,4-diol (8at)



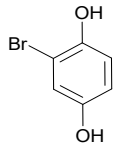
Purified by flash column chromatography on silica gel (CH_2Cl_2: PE = 10: 90). Yield: 40%; red solid; M.p. = 121-123 °C; ^{1}H NMR (400 MHz, CD_3OD) δ 6.73 (dd, *J* = 10.0, 8.7 Hz, 1H), 6.50 (dd, *J* = 12.6, 2.6 Hz, 1H), 6.42 (ddd, *J* = 8.7, 2.8, 1.4 Hz, 1H); ^{13}C NMR (100 MHz, CD_3OD) δ 152.9 (d, *J* = 244.8 Hz), 151.8 (d, *J* = 4.3 Hz), 138.5 (d, *J* = 13.2 Hz), 119.0 (d, *J* = 3.9 Hz), 111.7 (d, *J* = 3.3 Hz), 104.5 (d, *J* = 21.3 Hz); ^{19}F NMR (376 MHz, CD_3OD) δ –137.44. The NMR data agree with those reported in the literature.[15]

2-Chlorobenzene-1,4-diol (8au)



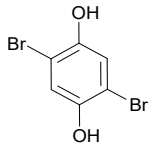
Purified by flash column chromatography on silica gel (CH_2Cl_2: MeOH = 99: 1). Yield: 36%; red solid; M.p. = 100-102 °C; ^{1}H NMR (400 MHz, CD_3OD) δ 6.74 (d, *J* = 8.6 Hz, 1H), 6.73 (d, *J* = 2.8 Hz, 1H), 6.56 (dd, *J* = 8.8, 2.9 Hz, 1H); ^{13}C NMR (100 MHz, CD_3OD) δ 151.7, 147.0, 121.6, 118.1, 117.3, 115.7. The NMR data agree with those reported in the literature.[16]

2-Bromobenzene-1,4-diol (8av)



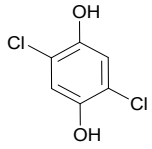
Purified by flash column chromatography on silica gel (CH_2Cl_2: MeOH = 99: 1). Yield: 32%; white solid; M.p. = 112-114 °C; ^{1}H NMR (400 MHz, CD_3OD) δ 6.90 (d, *J* = 2.8 Hz, 1H), 6.73 (d, *J* = 8.7 Hz, 1H), 6.61 (dd, *J* = 8.7, 2.8 Hz, 1H); ^{13}C NMR (100 MHz, CD_3OD) δ 152.0, 148.2, 120.2, 117.7, 116.4, 110.7. The NMR data agree with those reported in the literature.[17]

2,5-Dibromobenzene-1,4-diol (8aw)



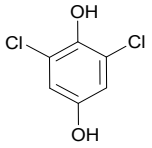
Purified by flash column chromatography on silica gel (CH_2Cl_2: MeOH = 99: 1). Yield: 10%; white solid; M.p. = 191-193 °C; ^{1}H NMR (400 MHz, CD_3OD) δ 7.01 (s, 2H); ^{13}C NMR (100 MHz, CD_3OD) δ 148.9, 120.7, 109.8. The NMR data agree with those reported in the literature.[18]

2,5-Dichlorobenzene-1,4-diol (8ax)



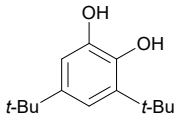
Purified by flash column chromatography on silica gel (CH_2Cl_2: MeOH = 99: 1). Yield: 51%; red solid; M.p. = 168-169 °C; ^{1}H NMR (400 MHz, DMSO-d_6) δ 9.78 (s, 2H), 6.91 (s, 2H); ^{13}C NMR (100 MHz, DMSO-d_6) δ 146.0, 118.4, 117.1. The NMR data agree with those reported in the literature.[7]

2,6-Dichlorobenzene-1,4-diol (8ay)



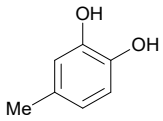
Purified by flash column chromatography on silica gel (CH_2Cl_2: MeOH = 99: 1). Yield: 51%; white solid; M.p. =157-158 °C; ^{1}H NMR (400 MHz, DMSO-d_6) δ 9.62 (s, 1H), 9.27 (s, 1H), 6.75 (s, 2H); ^{13}C NMR (100 MHz, DMSO-d_6) δ 150.6, 141.6, 123.1, 115.3. The NMR data agree with those reported in the literature.[7]

3,5-Di-tert-butylbenzene-1,2-diol (8ba)



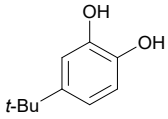
Purified by flash column chromatography on silica gel (CH_2Cl_2: MeOH = 99: 1). Yield: 15%; white solid; M.p. = 95-96 °C; ^{1}H NMR (400 MHz, CD_3OD) δ 6.75 (d, J = 2.3 Hz, 1H), 6.73 (d, J = 2.3 Hz, 1H), 1.38 (s, 9H), 1.25 (s, 9H); ^{13}C NMR (100 MHz, CD_3OD) δ 145.4, 142.8, 142.1, 136.1, 115.1, 111.0, 35.7, 35.1, 32.1, 30.1. The NMR data agree with those reported in the literature.[7]

4-Methylbenzene-1,2-diol (8bb)



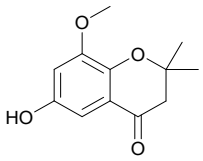
Purified by flash column chromatography on silica gel (CH_2Cl_2). Yield: 18%; white solid; M.p. = 65-66 °C; ^{1}H NMR (400 MHz, CD_3OD) δ 6.63 (d, J = 8.0 Hz, 1H), 6.58 (br s, 1H), 6.46 (dd, J = 8.1, 2.1 Hz, 1H), 2.17 (s, 3H); ^{13}C NMR (100 MHz, CD_3OD) δ 146.0, 143.9, 130.4, 121.1, 117.1, 116.2, 20.8. The NMR data agree with those reported in the literature.[19]

4-(tert-Butyl)benzene-1,2-diol (8bc)



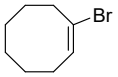
Purified by flash column chromatography on silica gel (CH_2Cl_2: PE = 10: 90). Yield: 18%; white solid; M.p. = 56-57 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 6.93 (d, *J* = 2.6 Hz, 1H), 6.85 – 6.80 (m, 2H), 1.26 (s, 9H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 145.1, 143.0, 140.9, 118.0, 115.2, 113.2, 34.3, 31.6. The NMR data agree with those reported in the literature.[20]

6-Hydroxy-8-methoxy-2,2-dimethylchroman-4-one (9)



Purified by flash column chromatography on silica gel (CH_2Cl_2: MeOH = 99: 1). Yield: 84%; white solid; M.p. = 136-138 °C; ^{1}H NMR (600 MHz, $CDCl_3$) δ 7.34 (s, 1H), 6.39 (s, 1H), 3.91 (s, 3H), 2.65 (s, 2H), 1.44 (s, 6H); ^{13}C NMR (150 MHz, $CDCl_3$) δ 191.3, 155.7, 153.8, 140.3, 113.5, 110.1, 100.0, 79.6, 56.3, 48.7, 26.7. The NMR data agree with those reported in the literature.[21]

(*E*)-1-Bromocyclooct-1-ene (10)

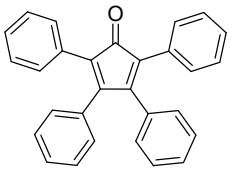


Purified by distillation. Yield: 71%; colorless oil; ^{1}H NMR (400 MHz, $CDCl_3$) δ 6.02 (t, *J* = 8.5 Hz, 1H), 2.62 – 2.59 (m, 2H), 2.12 – 2.07 (m, 2H), 1.62 (td, *J* = 8.5, 7.2, 4.5 Hz, 2H), 1.56 – 1.49 (m, 6H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 131.8, 124.9, 35.2, 30.0, 28.7, 27.6, 26.5, 25.6. The NMR data agree with those reported in the literature.[2]

Cyclooctyne (11)

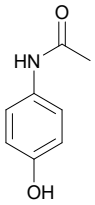
Purified by distillation. Yield: 66%; colorless oil; ^{1}H NMR (400 MHz, $CDCl_3$) δ 2.16 – 2.11 (m, 4H), 1.86 – 1.81 (m, 4H), 1.63 – 1.57 (m, 4H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 94.7, 34.8, 29.9, 21.1. The NMR data agree with those reported in the literature.[2]

2,3,4,5-Tetraphenylcyclopenta-2,4-dien-1-one (12)



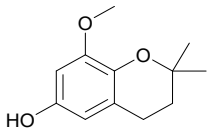
Purified by flash column chromatography on silica gel (PE: EA = 30: 1). Yield: 61%; purple solid; M.p. = 217-218 °C; ^{1}H NMR (400 MHz, DMSO-d_6) δ 7.29 – 7.20 (m, 12H), 7.17 – 7.15 (m, 4H), 6.98 – 6.95 (m, 4H); ^{13}C NMR (100 MHz, DMSO) δ 199.8, 154.8, 132.7, 130.5, 129.8, 128.9, 128.7, 128.1, 128.1, 127.6, 124.8. The NMR data agree with those reported in the literature.[22]

Acetaminophen



Purified by flash column chromatography on silica gel (CH_2Cl_2: MeOH = 99: 1). Yield: 97%; white solid; M.p. = 168-170 °C; ^{1}H NMR (400 MHz, DMSO-d_6) δ 9.65 (s, 1H), 9.15 (s, 1H), 7.33 (d, J = 8.9 Hz, 2H), 6.67 (d, J = 8.9 Hz, 1H), 1.97 (s, 3H); ^{13}C NMR (100 MHz, DMSO-d_6) δ 167.6, 153.1, 131.1, 120.8, 115.0, 23.8. The NMR data agree with those reported in the literature.[23]

8-Methoxy-2,2-dimethylchroman-6-ol (CR-6)



Purified by flash column chromatography on silica gel (PE: EA = 5: 1). Yield: 60%. M.p. = 115-116 °C; ^{1}H NMR (600 MHz, $CDCl_3$) δ 6.60 (s, 1H), 6.35 (s, 1H), 3.81 (s, 3H), 2.66 (t, J = 6.8 Hz, 2H), 1.76 (t, J = 6.8 Hz, 2H), 1.31 (s, 6H); ^{13}C NMR (150 MHz, $CDCl_3$) δ 147.1, 145.8, 139.0, 114.2, 112.6, 100.6, 74.0, 56.0, 33.1, 26.8, 22.1. The NMR data agree with those reported in the literature.[21]

4. DFT calculation details.

All data in this study were calculated with the Gaussian 16 software package and were optimised at the B3LYP level of density functional theory (DFT).[24] The basis set 6-31+G(d) was selected for all non-metal atoms. Vibrational frequency analysis was computed to ensure that the minimum points have no imaginary frequency and the saddle points have only one imaginary frequency. All the energetic values reported in this work are Gibbs free energies at 298.15 K.

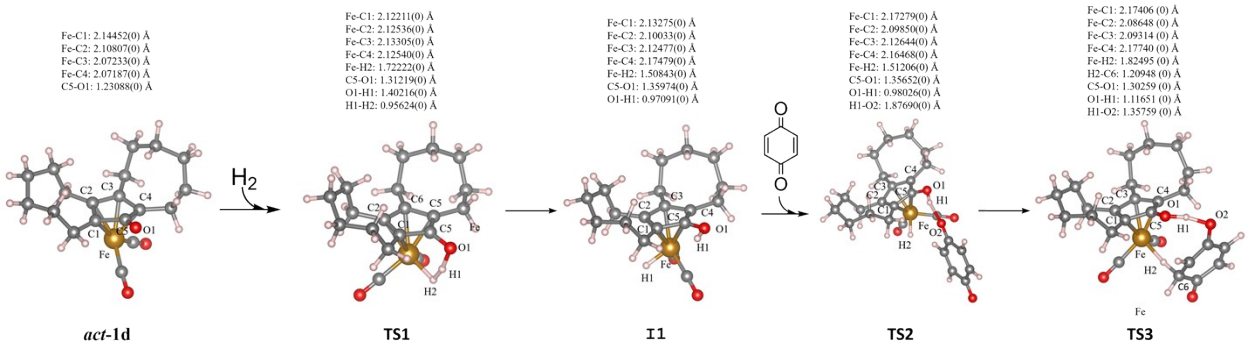


Figure S1. Optimised geometries of all species involved in the hydrogenation of quinone. The Gibbs energy changes are given in parentheses (kcal/mol).

5. Cartesian coordinates of the optimised structures.

***act*-1d**

C	-1.21500	0.53700	-0.55300
C	-0.84800	-0.39300	0.46600
C	-0.06500	0.62400	-1.49800
O	-0.04700	1.11400	-2.62700
C	1.09500	0.13700	-0.69700
C	0.56600	-0.65100	0.40400
C	1.30800	-1.67700	1.22700
C	1.53200	-3.01300	0.47700
C	2.10300	-2.89700	-0.94600
C	3.47700	-2.21800	-1.09700
C	3.58500	-0.71500	-0.74900
C	2.47100	0.17900	-1.32400
C	-1.80800	-1.00700	1.44800

C	-2.61900	-2.15200	0.76200
C	-4.11600	-1.86500	0.54200
C	-4.49200	-0.48400	-0.03600
C	-3.68800	0.03300	-1.25500
C	-2.57800	1.06900	-0.92500
H	2.33400	-0.05100	-2.39200
H	4.53700	-0.35500	-1.16100
H	3.67100	-0.56700	0.33300
H	1.37400	-2.38800	-1.59100
H	2.18900	-3.91500	-1.35100
H	4.22200	-2.76900	-0.50300
H	3.78100	-2.34000	-2.14600
H	2.19900	-3.63600	1.09100
H	0.57600	-3.55100	0.41800
H	0.75200	-1.88400	2.14900
H	-2.52900	-3.06800	1.36000
H	-1.26700	-1.39500	2.31600
H	-4.65000	-1.98300	1.49600
H	-2.49400	-0.24100	1.83100
H	-4.50700	-2.64900	-0.12100
H	-2.15100	-2.38200	-0.20300
H	-5.55500	-0.53700	-0.30600
H	-4.44100	0.27200	0.76100
H	-2.96300	1.73900	-0.14400
H	-4.38900	0.53500	-1.93300
H	-2.41400	1.69500	-1.81100
H	-3.26500	-0.80100	-1.83100
H	2.81700	1.22100	-1.31500
H	2.27100	-1.27900	1.55100
Fe	0.27100	1.37100	0.74900
C	0.22800	3.03500	0.08300
C	1.71200	1.52200	1.78400

O	0.25300	4.08600	-0.39000
O	2.66400	1.58900	2.43400

TS1

C	1.14200	-0.20800	-0.86400
C	0.72600	0.31900	0.41800
C	-0.04900	-0.36500	
O	-0.11800	-1.07400	-2.77600
C	-1.20000	0.00000	-0.87000
C	-0.70500	0.45100	0.41900
C	-1.51800	1.04600	1.54000
C	-1.93500	2.51500	1.28300
C	-2.57000	2.80300	-0.08700
C	-3.86100	2.03800	-0.43300
C	-3.76600	0.50600	-0.62600
C	-2.58500	0.02000	-1.48400
C	1.66500	0.85100	1.46600
C	2.21000	2.24500	1.02700
C	3.70700	2.28600	0.66500
C	4.25000	1.16400	-0.24400
C	3.44500	0.80800	-1.52000
C	2.53100	-0.44200	-1.40000
H	-2.52300	0.64200	-2.39100
H	-4.68800	0.18500	-1.12800
H	-3.77300	-0.01500	0.33800
H	-1.82600	2.63600	-0.87600
H	-2.79900	3.87700	-0.12500
H	-4.62600	2.25000	0.32900
H	-4.24600	2.46700	-1.37000
H	-2.63100	2.81000	2.08100
H	-1.05100	3.15900	1.39300

H	-0.94400	1.00200	2.47200
H	2.03100	2.97500	1.82600
H	1.15300	0.92700	2.42900
H	4.30100	2.27900	1.59000
H	2.49700	0.15400	1.62000
H	3.90500	3.25800	0.19000
H	1.62400	2.59700	0.16900
H	5.26400	1.46400	-0.53800
H	4.38600	0.24700	0.34700
H	3.06600	-1.19500	-0.80700
H	4.16300	0.59100	-2.32100
H	2.39100	-0.88000	-2.39500
H	2.86200	1.67100	-1.87000
H	-2.80400	-0.98600	-1.86000
H	-2.41200	0.44500	1.71900
Fe	-0.16000	-1.58500	0.09100
C	1.11000	-2.48000	0.97300
O	1.96100	-3.03200	1.52000
C	-1.54900	-2.25800	0.99200
O	-2.46300	-2.67200	1.55800
H	-0.27500	-2.76200	-1.16100
H	-0.22200	-2.17500	-1.91400

I1

C	1.21700	0.43200	0.61500
C	0.80100	-0.40600	-0.48200
C	0.05200	0.63400	1.42400
O	-0.03300	1.29000	2.61200
C	-1.09100	0.02900	0.83200
C	-0.60800	-0.65600	-0.35200
C	-1.41400	-1.55300	-1.26100

C	-1.70600	-2.95000	-0.66400
C	-2.29900	-2.96200	0.75400
C	-3.62800	-2.21200	0.96000
C	-3.61400	-0.67000	0.83300
C	-2.43800	0.03700	1.52800
C	1.74500	-1.07000	-1.44800
C	2.46000	-2.27900	-0.77400
C	3.96900	-2.10100	-0.51700
C	4.43600	-0.75800	0.08200
C	3.65900	-0.19400	1.29800
C	2.61100	0.90200	0.95300
H	-2.30200	-0.40700	2.52700
H	-4.53900	-0.29800	1.29400
H	-3.67100	-0.35500	-0.21400
H	-1.55200	-2.57800	1.46200
H	-2.46000	-4.01100	1.03800
H	-4.38600	-2.61600	0.27300
H	-3.98100	-2.45700	1.97300
H	-2.38900	-3.47200	-1.35100
H	-0.77600	-3.53400	-0.65200
H	-0.87600	-1.68400	-2.20600
H	2.32700	-3.17900	-1.38900
H	1.19600	-1.40000	-2.33400
H	4.51500	-2.24500	-1.46100
H	2.47900	-0.34300	-1.81100
H	4.29400	-2.91900	0.14300
H	1.95700	-2.49600	0.17600
H	5.48800	-0.89100	0.36900
H	4.45000	0.00900	-0.70500
H	3.00600	1.51700	0.13600
H	4.38800	0.26800	1.97600
H	2.54500	1.58900	1.81000

H	3.18600	-1.00300	1.87100
H	-2.71500	1.08000	1.71700
H	-2.35700	-1.07200	-1.53000
Fe	-0.23000	1.42000	-0.60100
C	-1.39000	1.64200	-1.89500
O	-2.13000	1.77400	-2.77600
C	-0.22200	3.10200	-0.09700
O	-0.17300	4.20900	0.23900
H	0.77600	1.86300	-1.63400
H	0.81200	1.72200	2.81700

TS2

C	-0.48300	1.01900	-0.39200
C	-1.64400	0.98700	0.45200
C	-0.46200	-0.21300	-1.10900
O	0.38400	-0.61800	-2.08900
C	-1.61300	-1.01100	-0.75300
C	-2.36000	-0.25600	0.20200
C	-3.68700	-0.62600	0.82000
C	-4.89400	-0.46000	-0.13100
C	-4.75300	-1.12400	-1.51000
C	-4.48600	-2.64100	-1.52700
C	-3.11800	-3.13800	-1.00000
C	-1.90000	-2.31900	-1.46100
C	-2.16100	2.16700	1.23100
C	-2.86700	3.19100	0.29300
C	-2.13600	4.53400	0.10300
C	-0.61200	4.48600	-0.13900
C	-0.07100	3.46700	-1.17200
C	0.50000	2.15100	-0.56700
H	-2.00800	-2.09200	-2.53300

H	-2.98200	-4.16400	-1.36700
H	-3.11600	-3.22300	0.09100
H	-3.96700	-0.61200	-2.08000
H	-5.68400	-0.94200	-2.06500
H	-5.28600	-3.16000	-0.97900
H	-4.57700	-2.97100	-2.57200
H	-5.78200	-0.86100	0.38000
H	-5.08500	0.61200	-0.28500
H	-3.85700	-0.00400	1.70600
H	-3.87500	3.40600	0.66900
H	-2.85600	1.82500	2.00500
H	-2.30800	5.16600	0.98600
H	-1.33600	2.64800	1.76900
H	-2.61500	5.05800	-0.73700
H	-3.01300	2.72000	-0.68800
H	-0.31200	5.49600	-0.45000
H	-0.09600	4.31800	0.81700
H	0.97700	2.38900	0.39100
H	0.75400	3.94500	-1.71500
H	1.30600	1.79800	-1.22000
H	-0.83100	3.23500	-1.93100
H	-1.00300	-2.94400	-1.40000
H	-3.65600	-1.65300	1.19100
Fe	-0.43400	-0.63000	1.02200
C	-0.91700	-0.78400	2.69900
O	-1.22000	-0.85400	3.81400
C	0.54200	-2.08400	0.96500
O	1.20000	-3.03700	0.91100
H	0.78300	0.04700	1.61100
H	1.28100	-0.23400	-1.99500
C	5.46700	-0.03200	-1.74200
C	4.07200	-0.05100	-1.24000

C	3.85200	-0.23400	0.21400
C	4.89300	-0.38000	1.05400
C	6.29500	-0.36000	0.56000
C	6.50700	-0.17800	-0.90100
H	5.58900	0.10100	-2.81300
H	2.82100	-0.24300	0.55700
H	4.76300	-0.51800	2.12400
H	7.54100	-0.17100	-1.23800
O	7.24500	-0.48500	1.32700
O	3.13000	0.08700	-2.02500

TS3

C	-1.22100	0.84500	-0.74200
C	-1.73900	0.12900	0.39700
C	-0.21400	0.01100	-1.35000
O	0.36900	0.33800	-2.46800
C	0.04600	-1.11500	-0.47400
C	-0.97100	-1.07700	0.55800
C	-1.29300	-2.17000	1.54600
C	-2.13500	-3.31500	0.92700
C	-1.65300	-3.84400	-0.43400
C	-0.24700	-4.47000	-0.47800
C	0.95900	-3.57000	-0.13200
C	1.02800	-2.21000	-0.85200
C	-3.01700	0.47000	1.11300
C	-4.24300	0.05400	0.24200
C	-5.07500	1.21900	-0.32600
C	-4.30800	2.39600	-0.96500
C	-3.17300	2.06700	-1.96600
C	-1.73500	2.11300	-1.37800
H	0.91800	-2.38000	-1.93300

H	1.86400	-4.11900	-0.42300
H	1.05000	-3.43300	0.95000
H	-1.71900	-3.04100	-1.18000
H	-2.36800	-4.61000	-0.76500
H	-0.22200	-5.34700	0.18500
H	-0.09600	-4.85800	-1.49600
H	-2.16900	-4.13900	1.65400
H	-3.17000	-2.96700	0.80900
H	-1.84800	-1.74400	2.38900
H	-4.91000	-0.58600	0.83300
H	-3.04900	-0.03300	2.08400
H	-5.70800	1.63200	0.47200
H	-3.05800	1.54300	1.32900
H	-5.76700	0.79800	-1.07000
H	-3.89000	-0.57200	-0.58600
H	-5.05700	3.01800	-1.47300
H	-3.89700	3.03900	-0.17400
H	-1.68600	2.94900	-0.66900
H	-3.20300	2.81500	-2.76700
H	-1.03500	2.35500	-2.18600
H	-3.34900	1.10000	-2.45800
H	2.04600	-1.82500	-0.74000
H	-0.37700	-2.57900	1.97500
Fe	0.24200	0.60400	0.84800
C	-0.19000	2.06900	1.75600
O	-0.52300	3.01200	2.32900
C	1.14500	-0.16100	2.17900
O	1.67400	-0.69800	3.05000
H	1.77500	1.47600	0.37900
H	1.37600	-0.04500	-2.76100
C	4.21400	-0.26100	-1.10700
C	3.18800	0.39900	-1.94400

C	2.71700	1.64400	-1.54600
C	2.74900	1.97700	-0.13400
C	3.87200	1.35700	0.70600
C	4.51800	0.15900	0.14300
H	4.69000	-1.13900	-1.53800
H	2.03100	2.17600	-2.19500
H	2.61100	3.02700	0.13300
H	5.27000	-0.32900	0.75900
O	4.19300	1.84200	1.78400
O	2.70200	-0.26900	-2.94700

I2

C	-0.70800	1.28300	-0.00000
C	0.64400	1.21300	0.00000
C	1.36800	-0.05400	0.00000
C	0.70600	-1.22700	-0.00000
C	-0.79400	-1.27600	0.00000
C	-1.53100	0.06300	0.00000
H	-1.23400	2.23300	-0.00000
H	1.22800	2.13400	0.00000
H	1.26100	-2.16100	-0.00100
H	-1.16000	-1.84400	-0.86900
O	2.74300	-0.03500	0.00000
H	3.07100	0.87600	-0.00000
O	-2.75800	0.11000	-0.00000
H	-1.15900	-1.84300	0.87000

1,4-Benzoquinone

C	0.69600	1.21900	0.00000
C	-0.69600	1.21900	0.00000

C	-1.40100	0.00900	0.00000
C	-0.70000	-1.19800	0.00000
C	0.70000	-1.19800	0.00000
C	1.40100	0.00900	-0.00000
H	1.25100	2.15200	0.00000
H	-1.25100	2.15200	-0.00000
H	-1.23600	-2.14600	0.00000
H	1.23600	-2.14600	-0.00000
O	-2.77600	0.07900	0.00000
H	-3.15100	-0.81500	-0.00000
O	2.77600	0.07900	-0.00000
H	3.15100	-0.81500	-0.00000

H_2

H	0.00000	0.00000	0.37100
H	0.00000	0.00000	-0.37100

6. References.

[1] A. Alexandridis, T. Rancon, A. Halliday, A. Kochem and A. Quintard, *Org. Lett.*, 2024, **26**, 5788-5793.

[2] S. Vailati Facchini, M. Cettolin, X. Bai, G. Casamassima, L. Pignataro, C. Gennari and U. Piarulli, *Adv. Synth. Catal.*, 2018, **360**, 1054-1059.

[3] C. A. M. R. van Slagmaat, T. Faber, K. C. Chou, A. J. Schwalb Freire, D. Hadavi, P. Han, P. J. L. M. Quaedflieg, G. K. M. Verzijl, P. L. Alsters and S. M. A. De Wildeman, *Dalton Trans.*, 2021, **50**, 10102-10112.

[4] L. Fu, Z. Zhang, P. Chen, Z. Lin and G. Liu, *J. Am. Chem. Soc.*, 2020, **142**, 12493-12500.

[5] Q. Ye, W. Huang, L. Wei and M. Cai, *J. Org. Chem.*, 2023, **88**, 2973-2984.

[6] M. Shirakura and M. Suginome, *Org. Lett.*, 2009, **11**, 523-526.

[7] J. Zhang, X. Xu, G. Zhao, H. You, R. Wang and F. Li, *Org. Lett.*, 2024, **26**, 1857-1862.

[8] X.-L. Xu and Z. Li, *Angew. Chem. Int. Ed.*, 2017, **56**, 8196-8200.

[9] O. R. Johnson-Ajinwo, I. Ullah, H. Mbye, A. Richardson, P. Horrocks and W.-W. Li, *Bioorg. Med. Chem. Lett.*, 2018, **28**, 1219-1222.

[10] R. Shah, L. A. Farmer, O. Zilka, A. T. M. Van Kessel and D. A. Pratt, *Cell Chem. Biol.*, 2019, **26**, 1594-1607.

[11] S. Paula, J. Abell, J. Deye, C. Elam, M. Lape, J. Purnell, R. Ratliff, K. Sebastian, J. Zultowsky and R. J. Kempton, *Bioorg. Med. Chem.*, 2009, **17**, 6613-6619.

[12] D. G. Aguila-Muñoz, G. Vázquez-Lira, E. Sarmiento-Tlale, M. C. Cruz-López, F. E. Jiménez-Montejo, V. E. López y López, C. H. Escalante, D. Andrade-Pavón, O. Gómez-García, J. Tamariz and A. Mendieta-Moctezuma, *Molecules*, 2023, **28**, 4180.

[13] N. I. Mikerova, L. M. Alekseeva, E. K. Panisheva, Y. N. Sheinker and V. G. Granik, *Chem. Heterocycl. Compd.*, 1990, **26**, 274-278.

[14] I. Cheng-Sánchez, J. A. Torres-Vargas, B. Martínez-Poveda, G. A. Guerrero-Vásquez, M. Á. Medina, F. Sarabia and A. R. Quesada, *Mar. Drugs*, 2019, **17**, 492.

[15] M. Essers and G. Haufe, *J. Chem. Soc., Perkin Trans. 1*, 2002, 2719-2728.

[16] W. Sun, L. Gao, X. Sun, H. Yang and G. Zheng, *Adv. Synth. Catal.*, 2019, **361**, 5210-5216.

[17] I. Cheng-Sánchez, J. A. Torres-Vargas, B. Martínez-Poveda, G. A. Guerrero-Vásquez, M. Á. Medina, F. Sarabia and A. R. Quesada, *Mar. Drugs*, 2019, **17**, 492.

[18] M. C. Baier, J. Huber and S. Mecking, *J. Am. Chem. Soc.*, 2009, **131**, 14267-14273.

[19] X. Yang, Y. Sun, Z. Chen and Y. Rao, *Adv. Synth. Catal.*, 2014, **356**, 1625-1630.

[20] F. Sprang, N. Schupp, P. J. Kohlpaintner, L. J. Gooßen and S. R. Waldvogel, *Green Chem.*, 2024, **26**, 5862-5868.

[21] P. Anastasis and P. E. Brown, *J. Chem. Soc., Perkin Trans. 1*, 1982, 2013-2018.

[22] B. A. G. Hammer, M. Baumgarten and K. Müllen, *Chem. Commun.*, 2014, **50**, 2034-2036.

[23] Y. Gao, J. Liu, Z. Li, T. Guo, S. Xu, H. Zhu, F. Wei, S. Chen, H. Gebru and K. Guo, *J. Org. Chem.*, 2018, **83**, 2040-2049.

[24] (a) A. D. Becke, *Physical Review A*, 1988, **38**, 3098-3100; (b) C. Lee, W. Yang and R. G. Parr, *Phys. Rev. B*, 1988, **37**, 785-789; (c) A. D. Becke, *J. Chem. Phys.*, 1993, **98**, 5648-5652.

7. NMR Spectra.

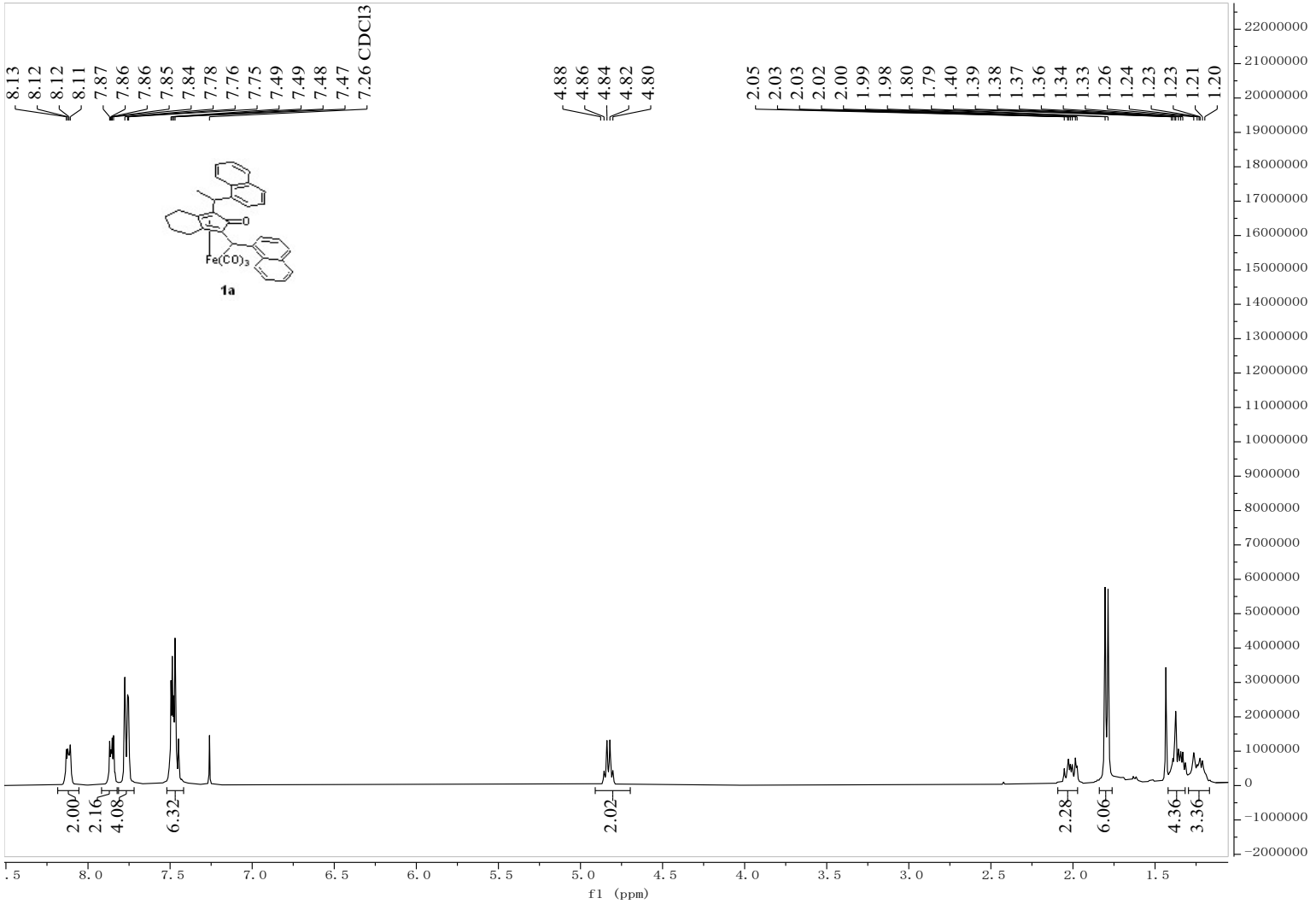


Figure S2. ^{1}H NMR spectrum of **1a** in $CDCl_3$ (400 MHz).

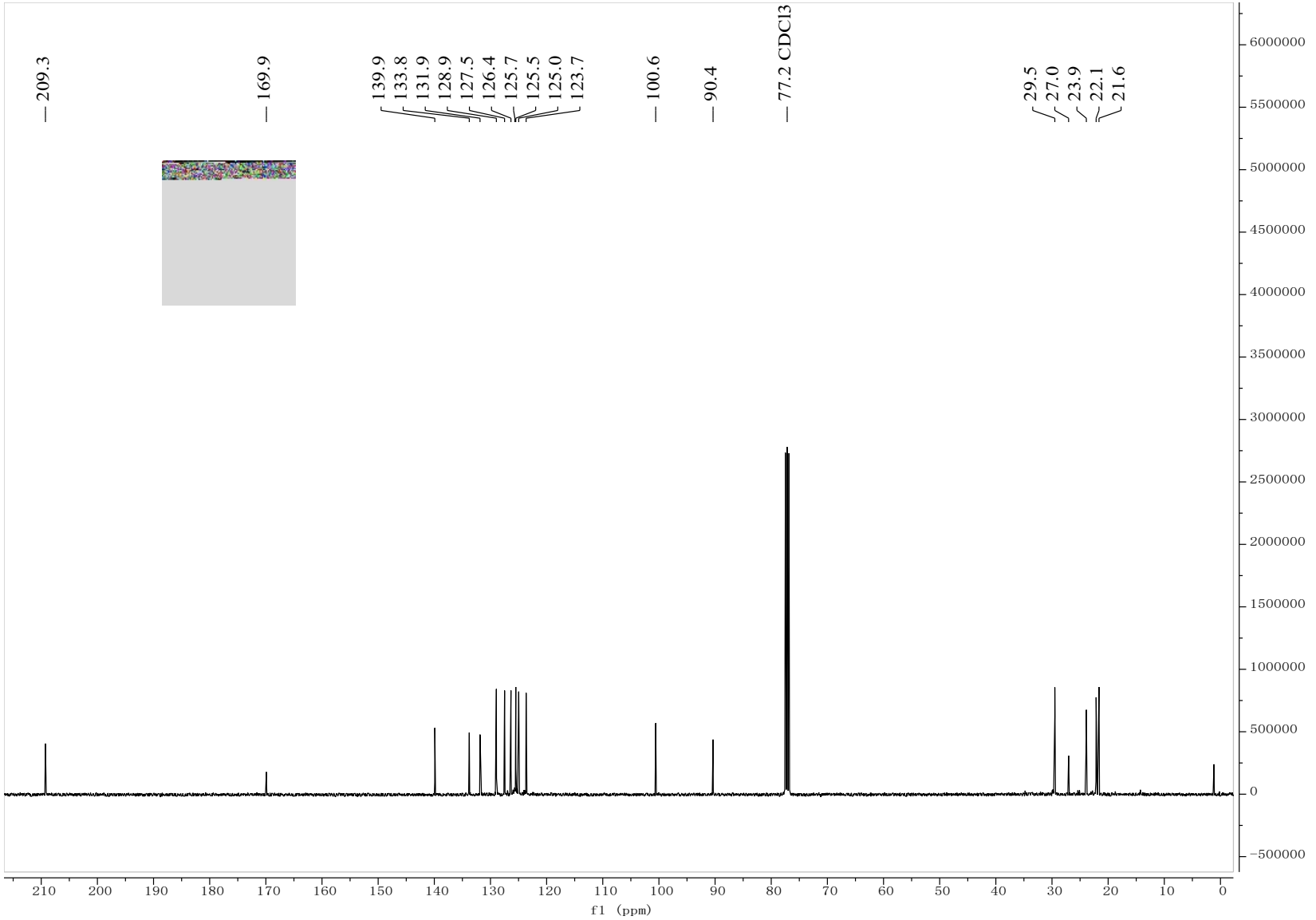


Figure S3. ^{13}C NMR spectrum of **1a** in $CDCl_3$ (100 MHz).

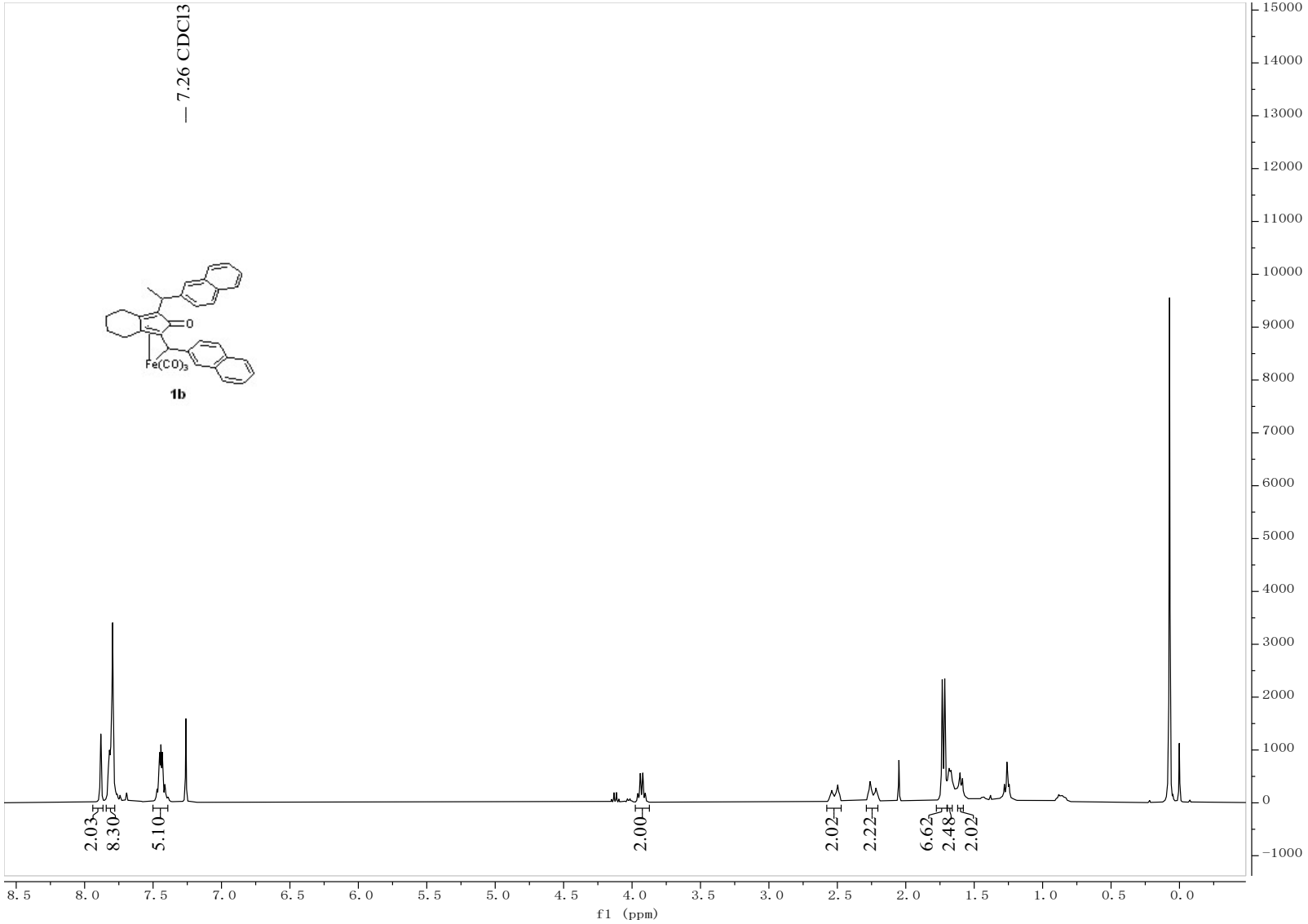


Figure S4. ^{1}H NMR spectrum of **1b** in $CDCl_3$ (400 MHz).

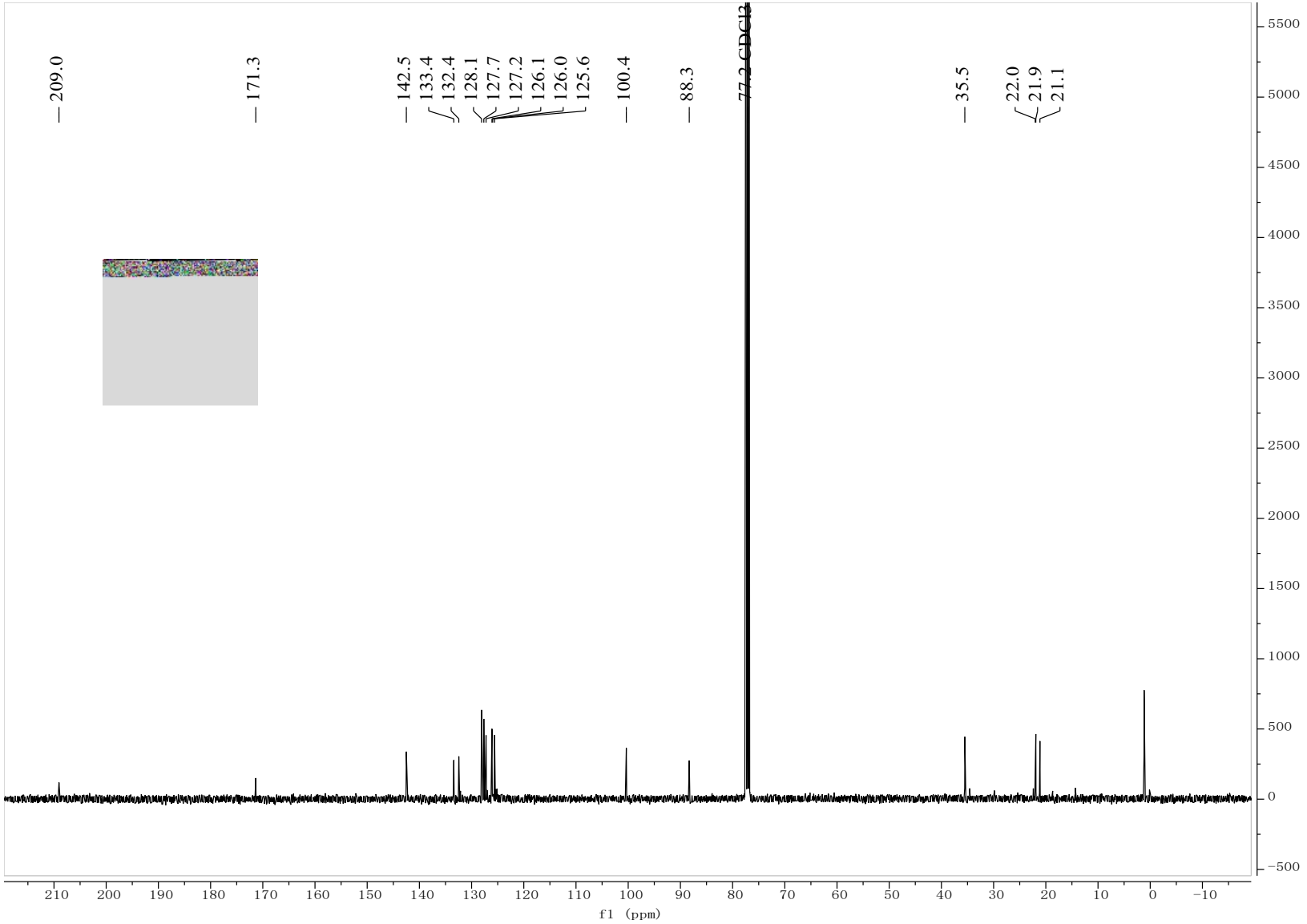


Figure S5. ^{13}C NMR spectrum of **1b** in $CDCl_3$ (100 MHz).

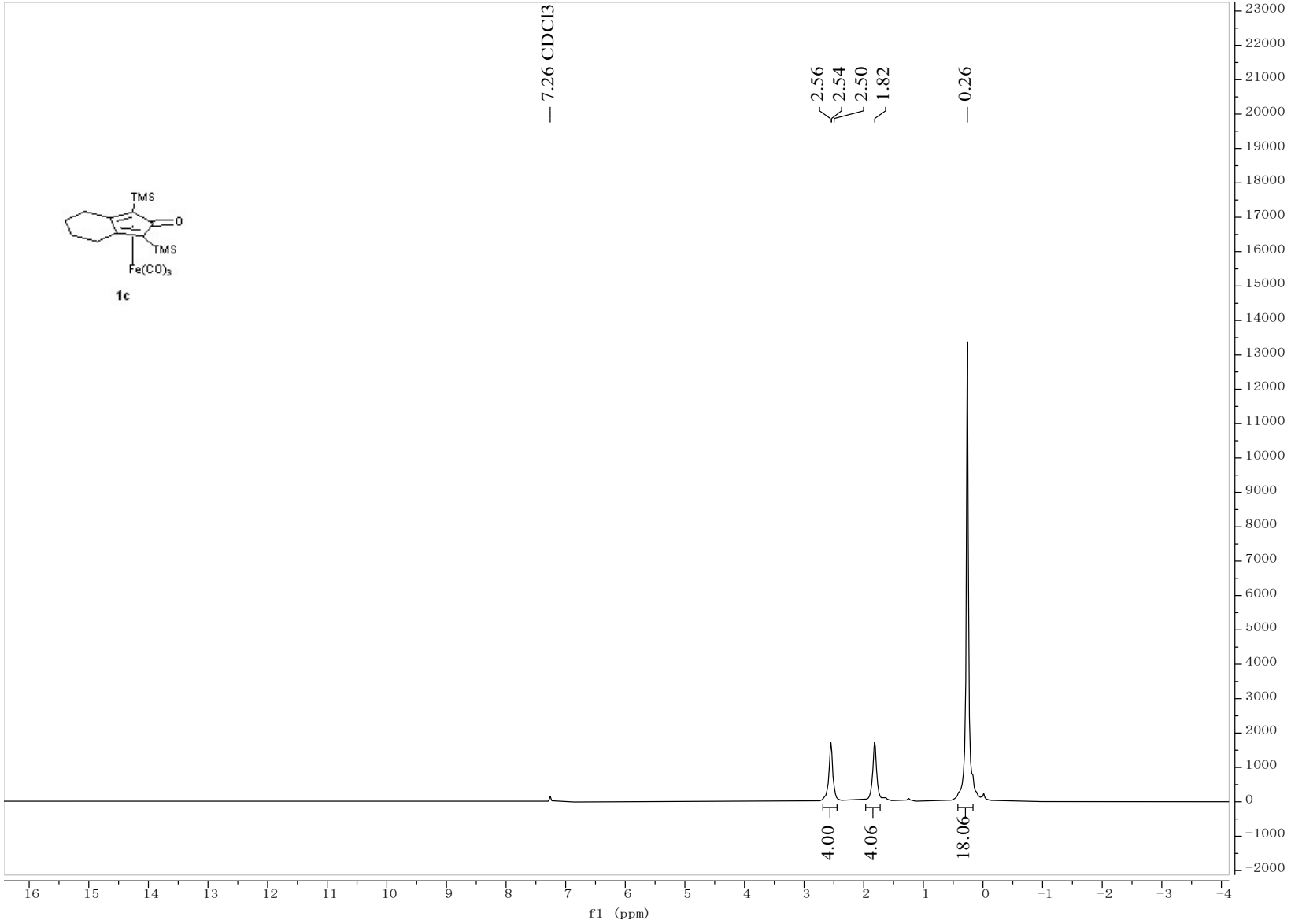


Figure S6. ^{1}H NMR spectrum of **1c** in $CDCl_3$ (400 MHz).

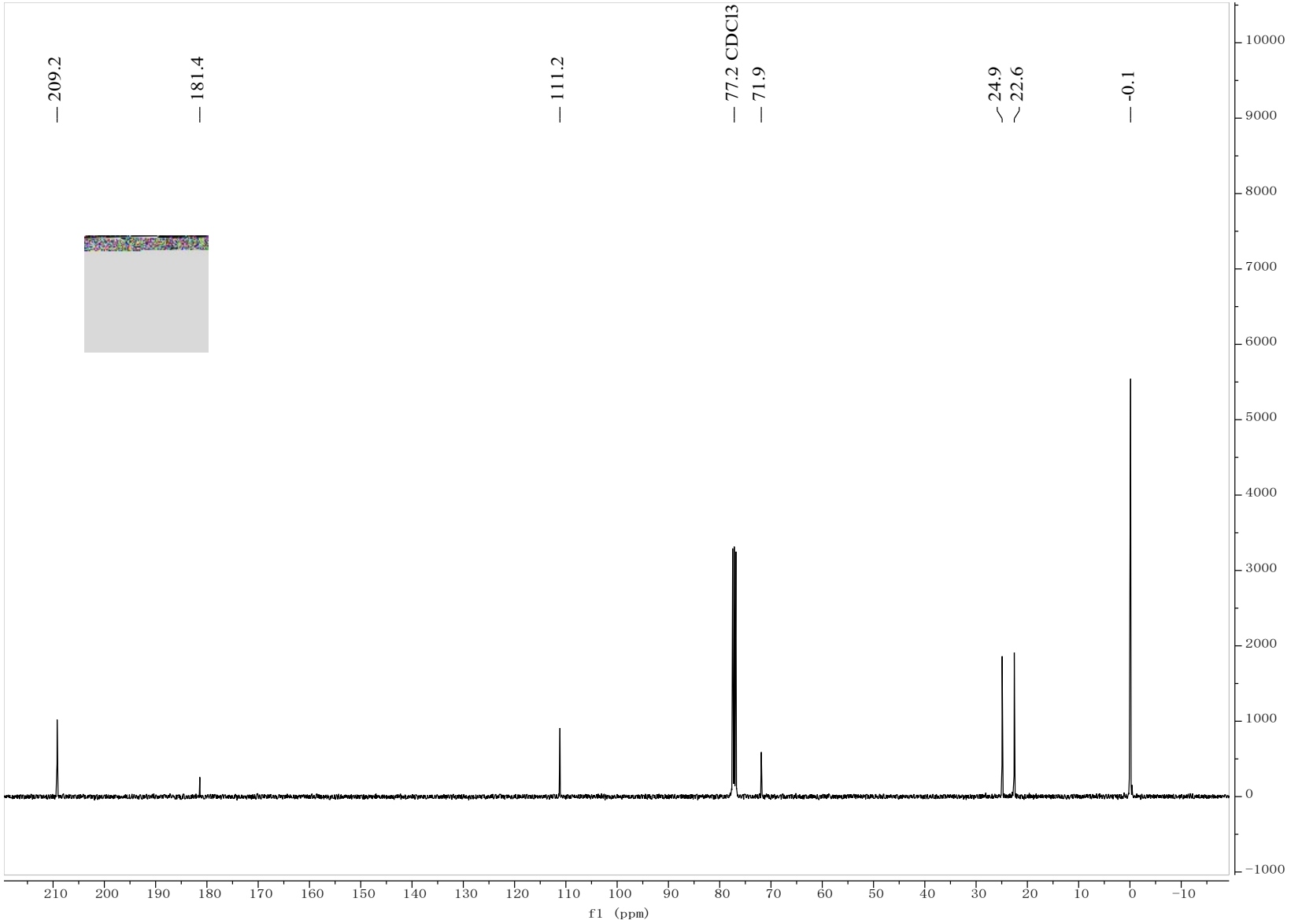


Figure S7. ^{13}C NMR spectrum of **1c** in $CDCl_3$ (100 MHz).

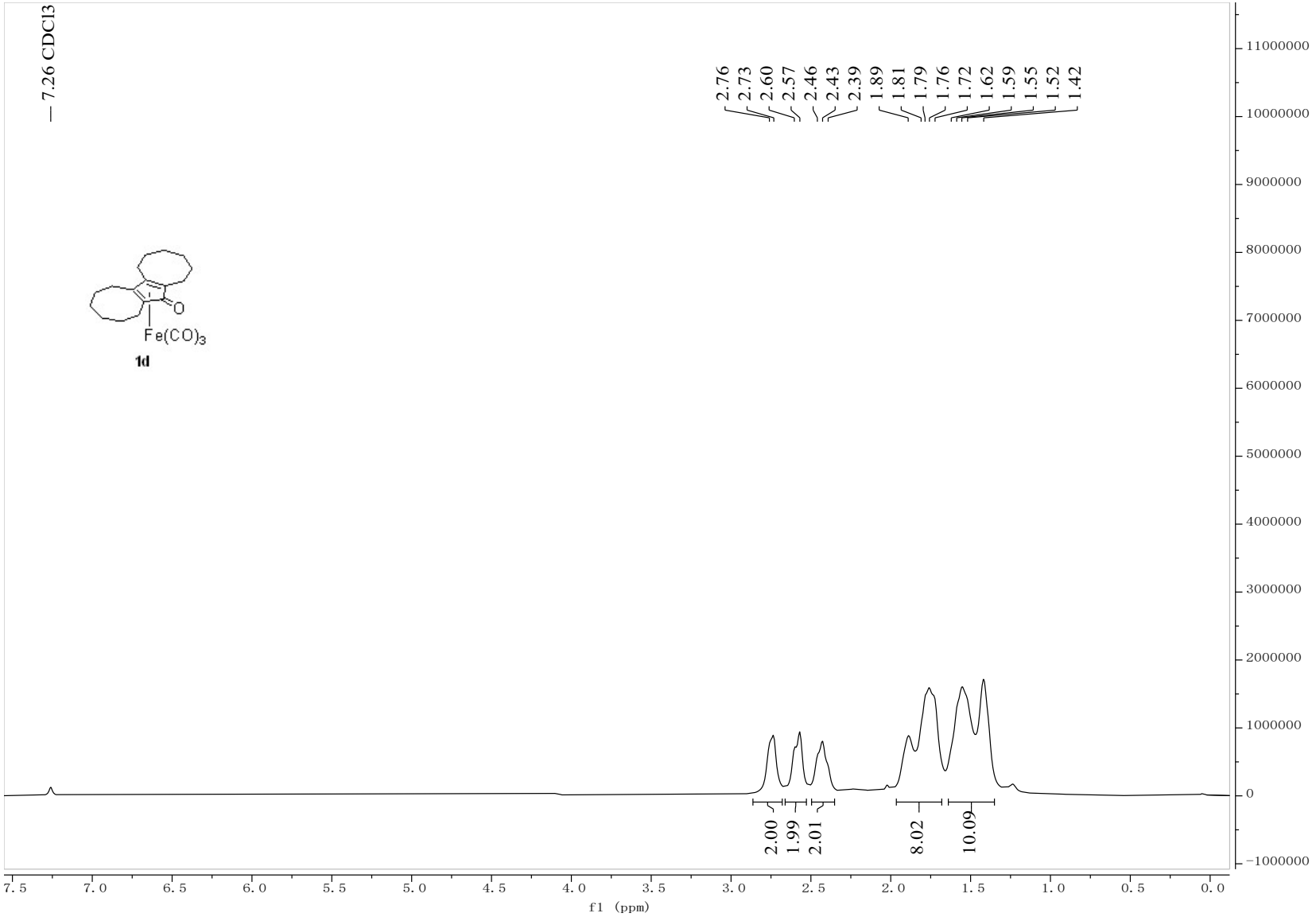


Figure S8. ^{1}H NMR spectrum of **1d** in $CDCl_3$ (400 MHz).

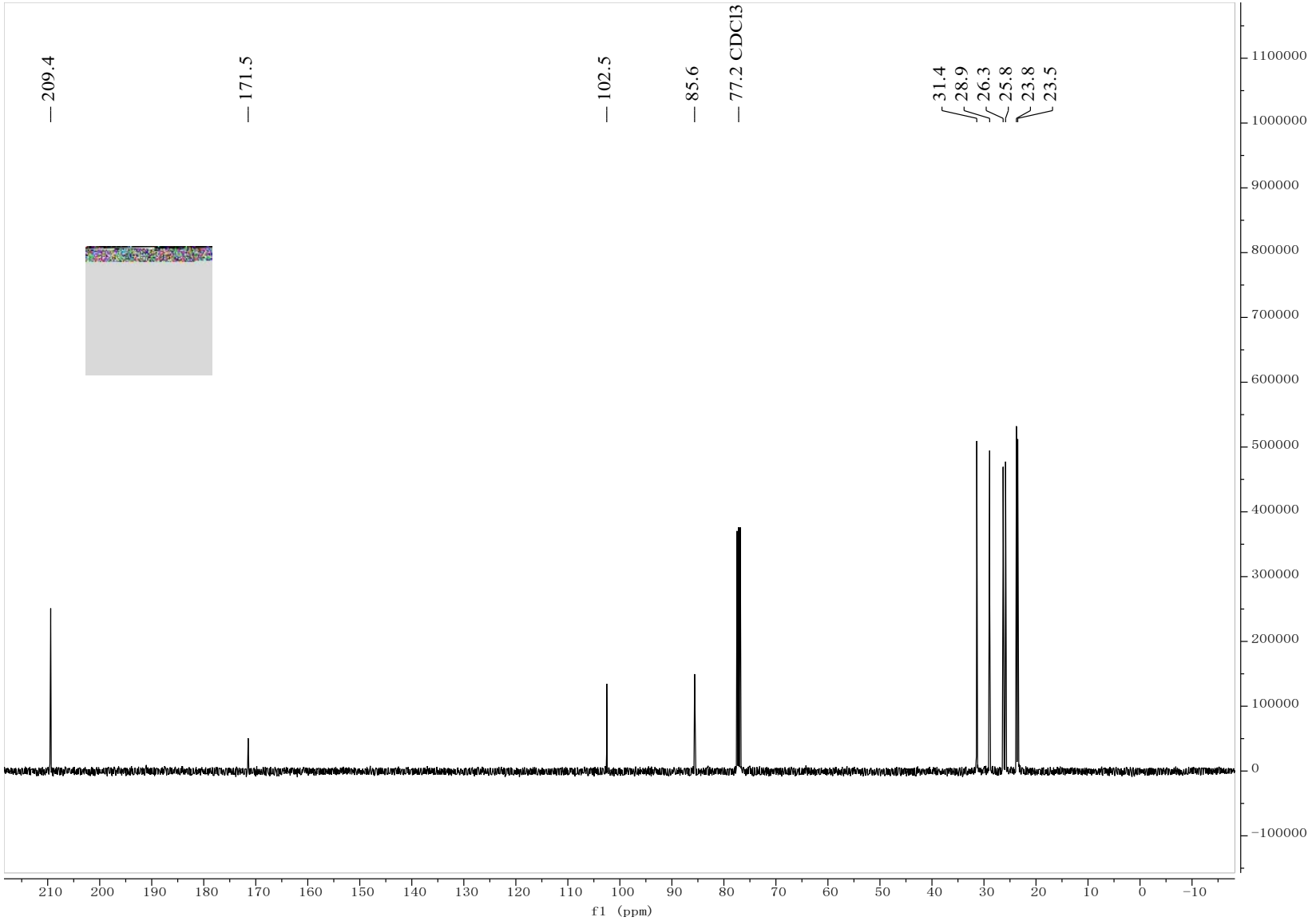


Figure S9. ^{13}C NMR spectrum of **1d** in $CDCl_3$ (100 MHz).

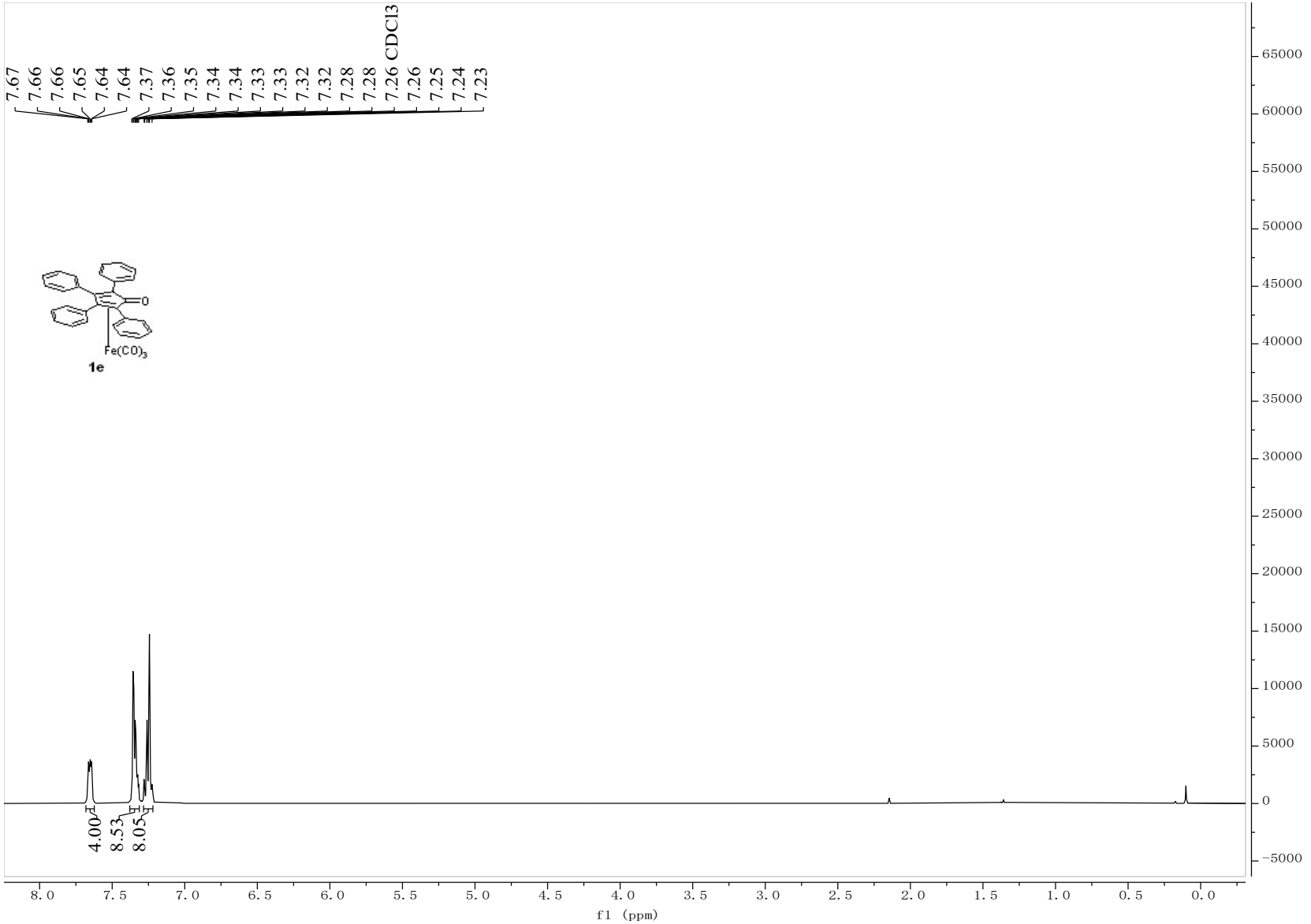


Figure S10. ^{1}H NMR spectrum of **1e** in $CDCl_3$ (400 MHz).

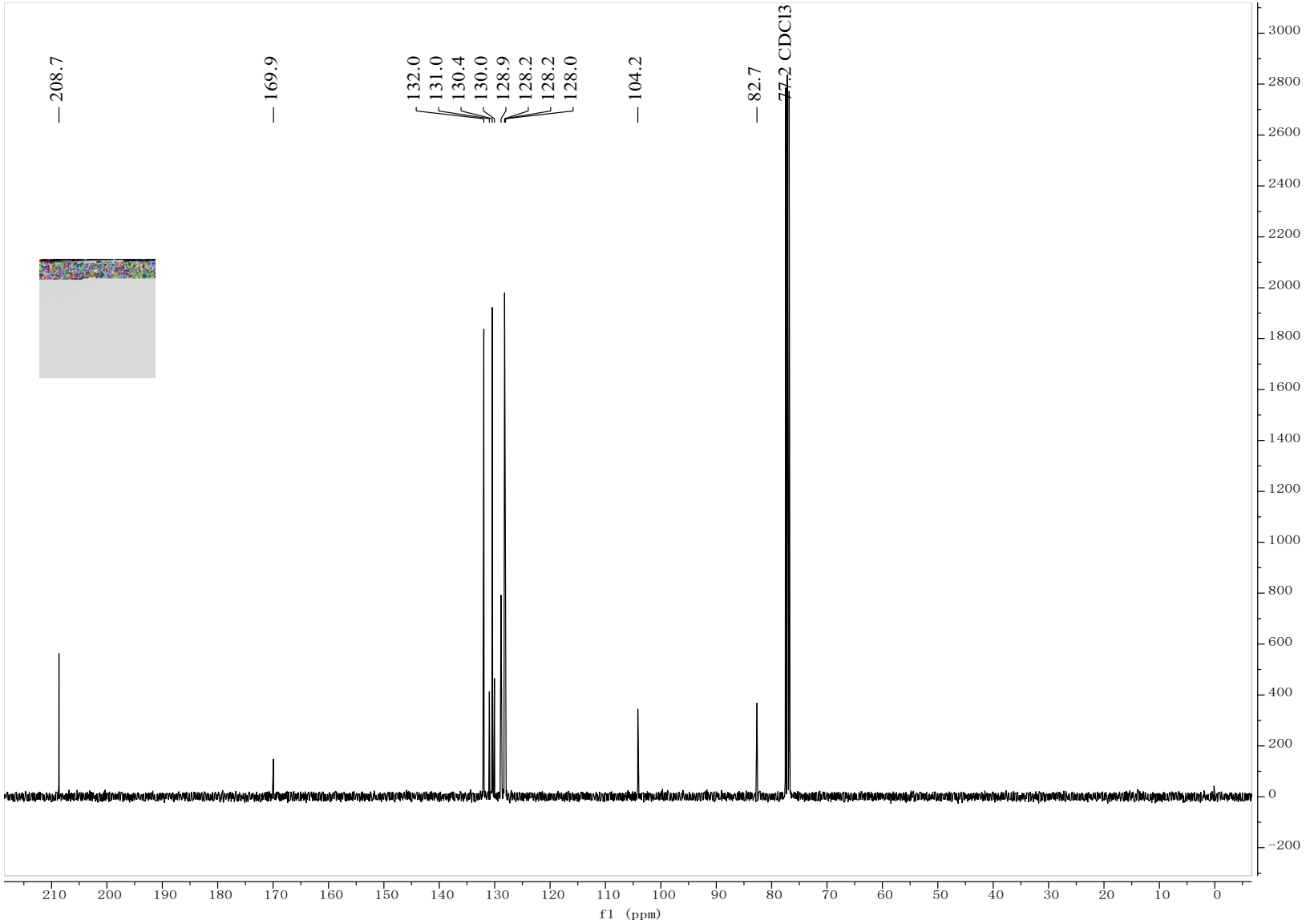


Figure S11. ^{13}C NMR spectrum of **1e** in $CDCl_3$ (100 MHz).

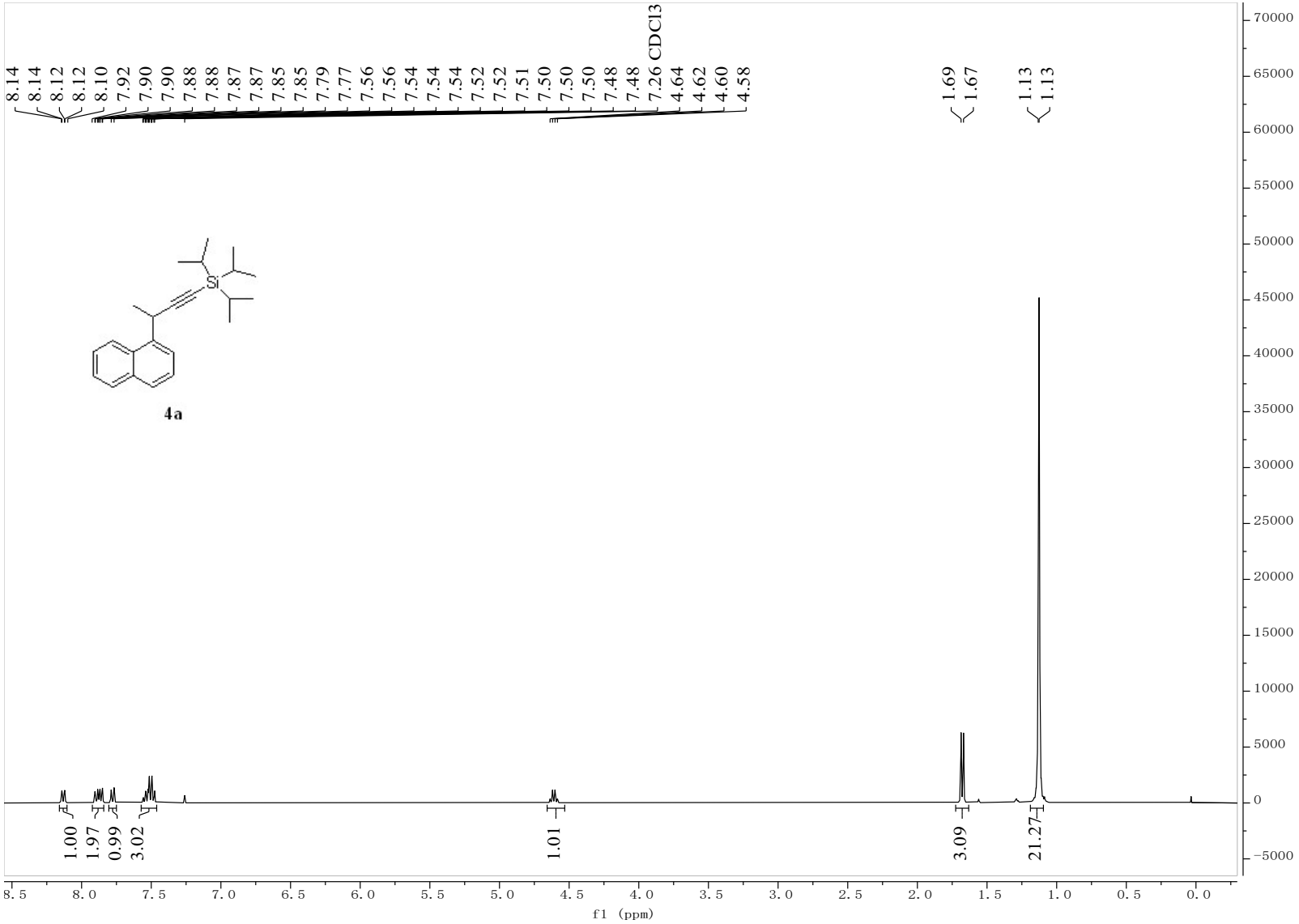


Figure S12. ^{1}H NMR spectrum of **4a** in $CDCl_3$ (400 MHz).

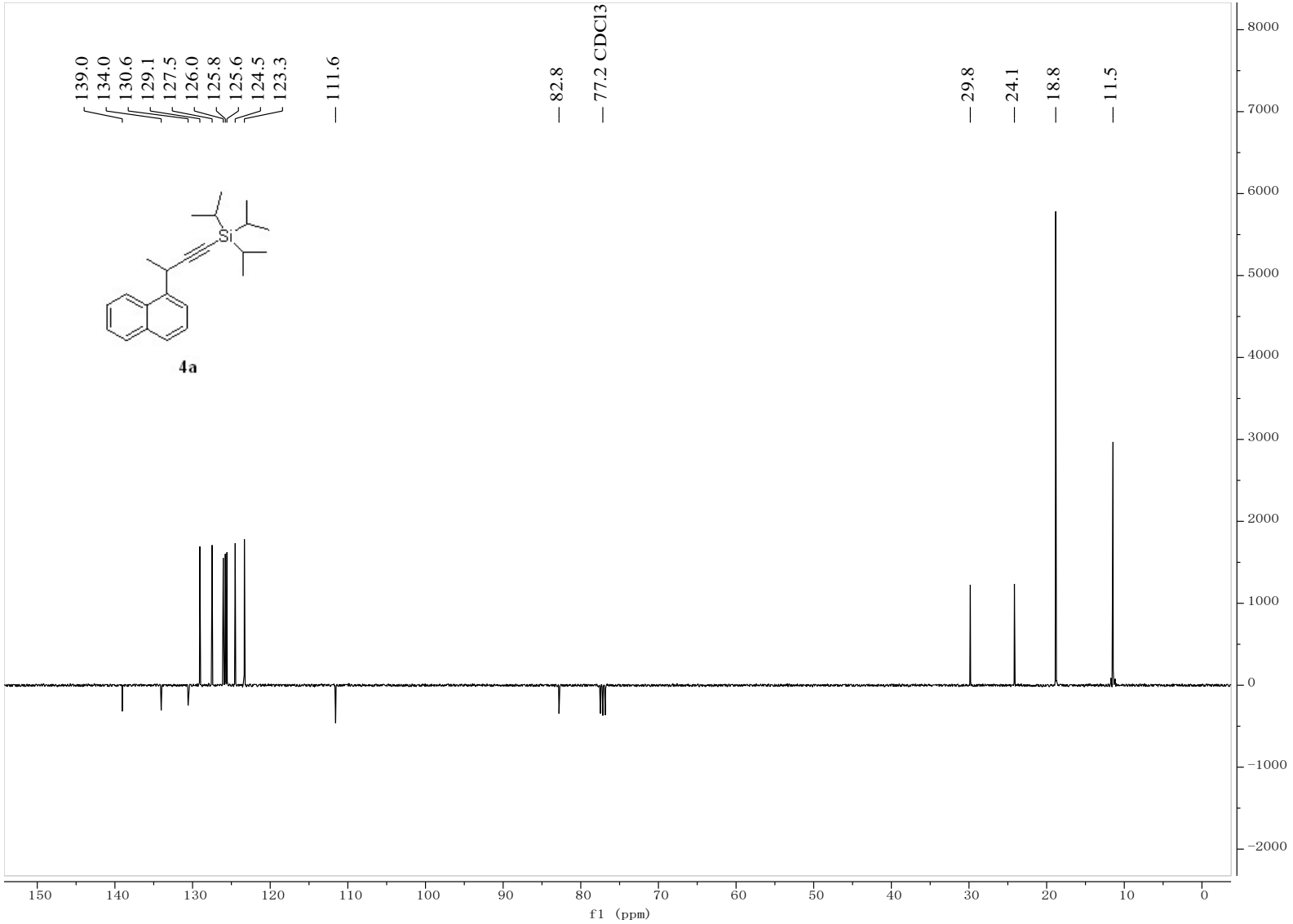


Figure S13. ^{13}C NMR spectrum of **4a** in $CDCl_3$ (100 MHz).

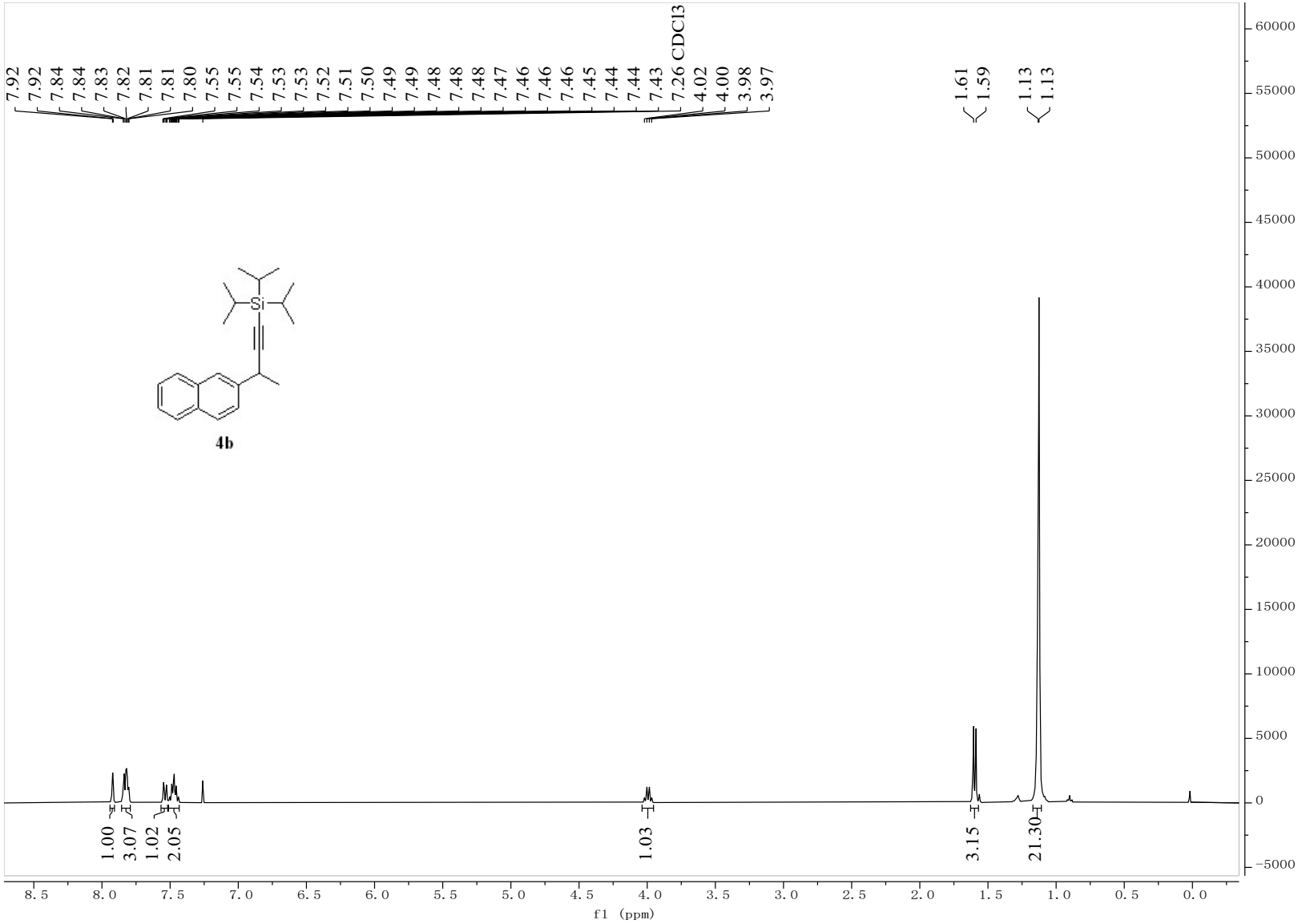


Figure S14. ^{1}H NMR spectrum of **4b** in $CDCl_3$ (400 MHz).

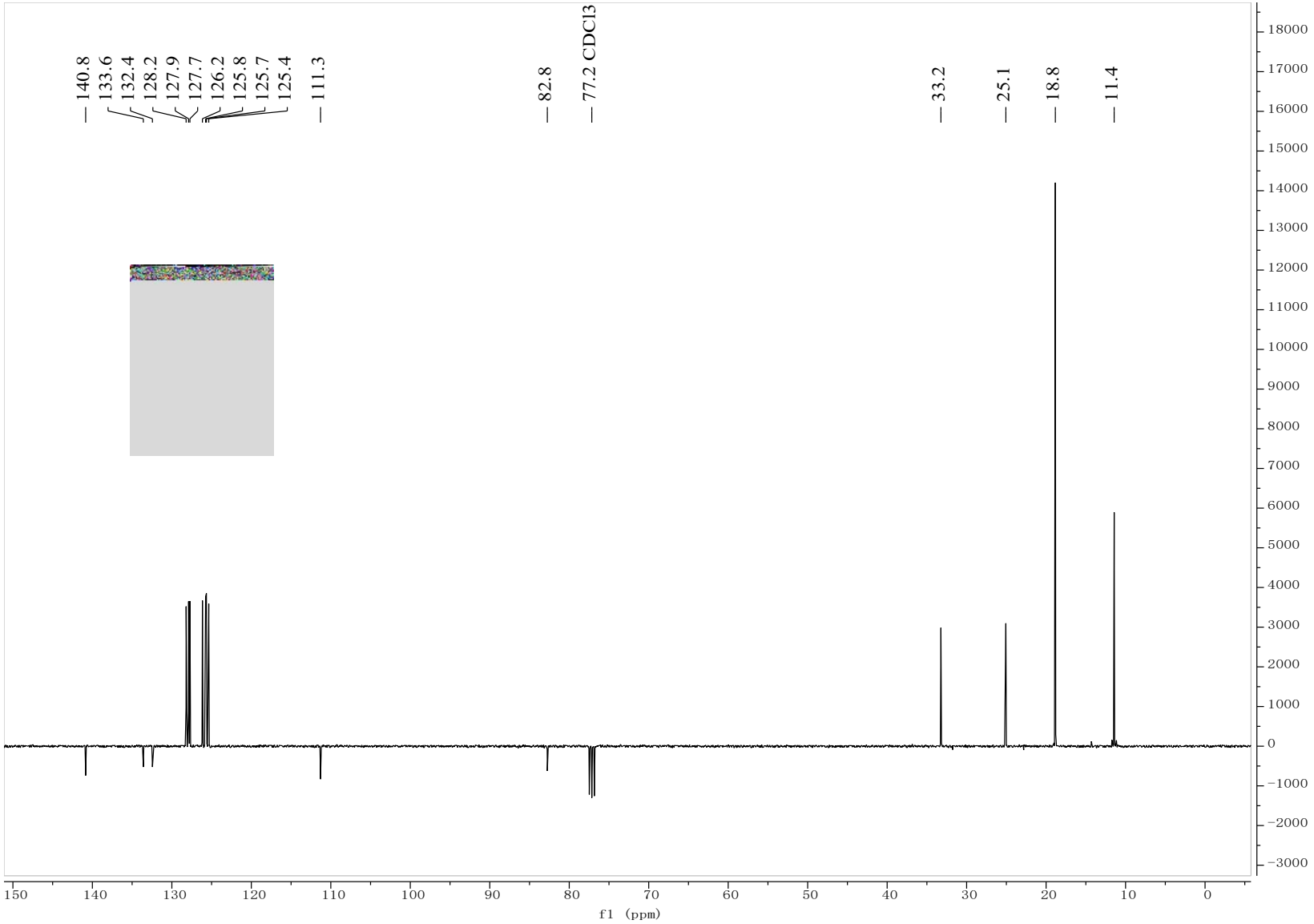


Figure S15. ^{13}C NMR spectrum of **4b** in $CDCl_3$ (100 MHz).

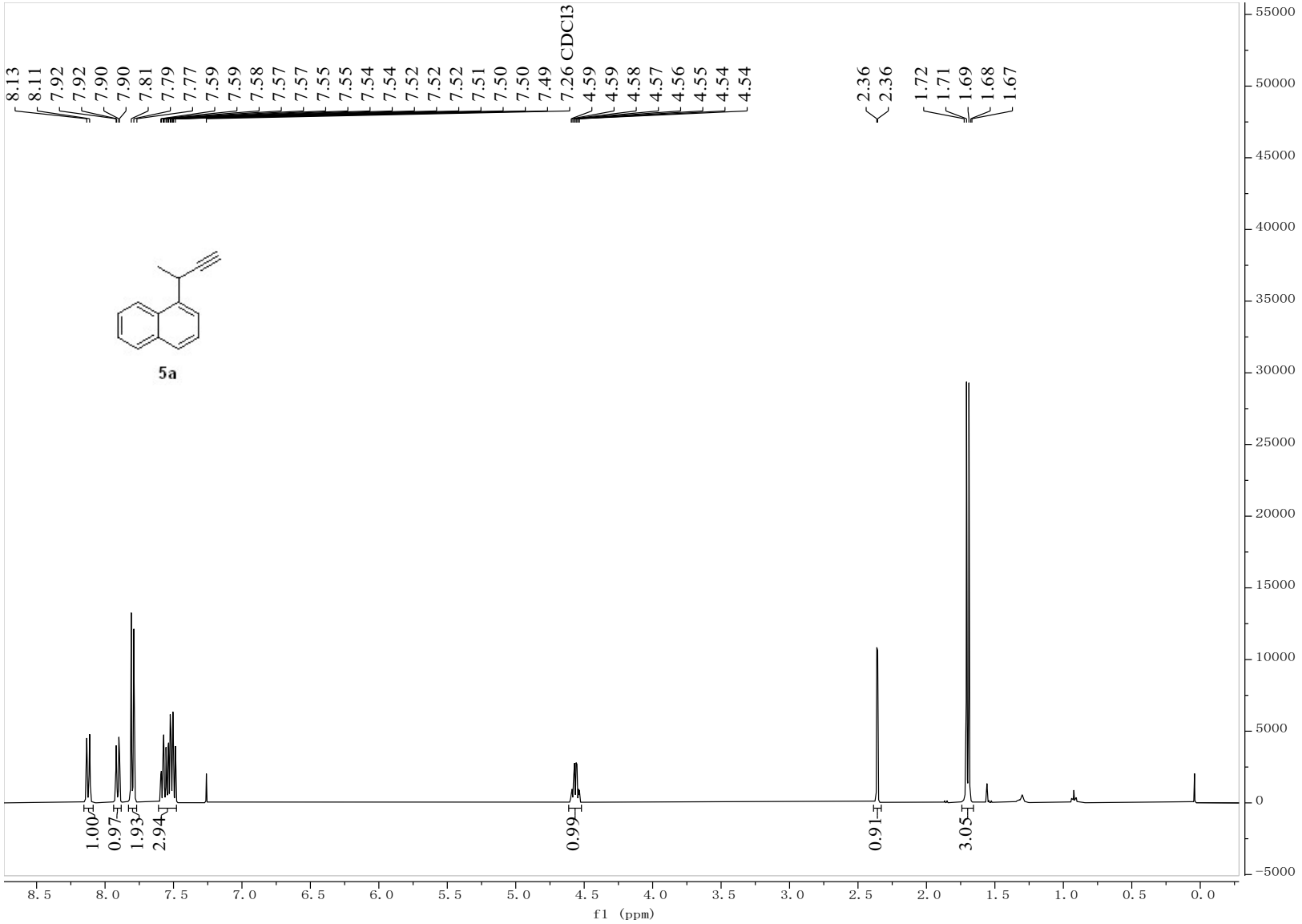


Figure S16. ^{1}H NMR spectrum of **5a** in $CDCl_3$ (400 MHz).

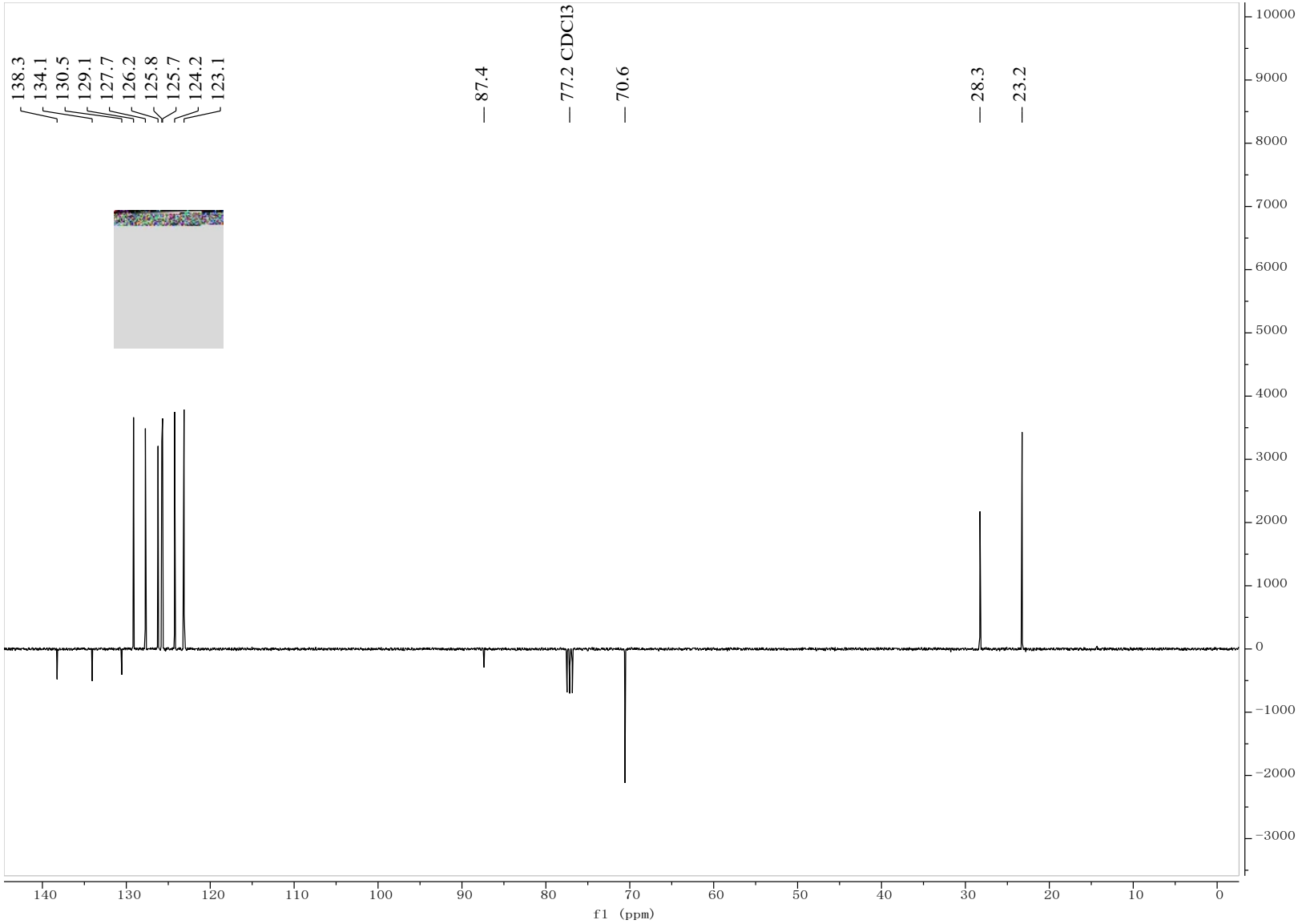


Figure S17. ^{13}C NMR spectrum of **5a** in $CDCl_3$ (100 MHz).

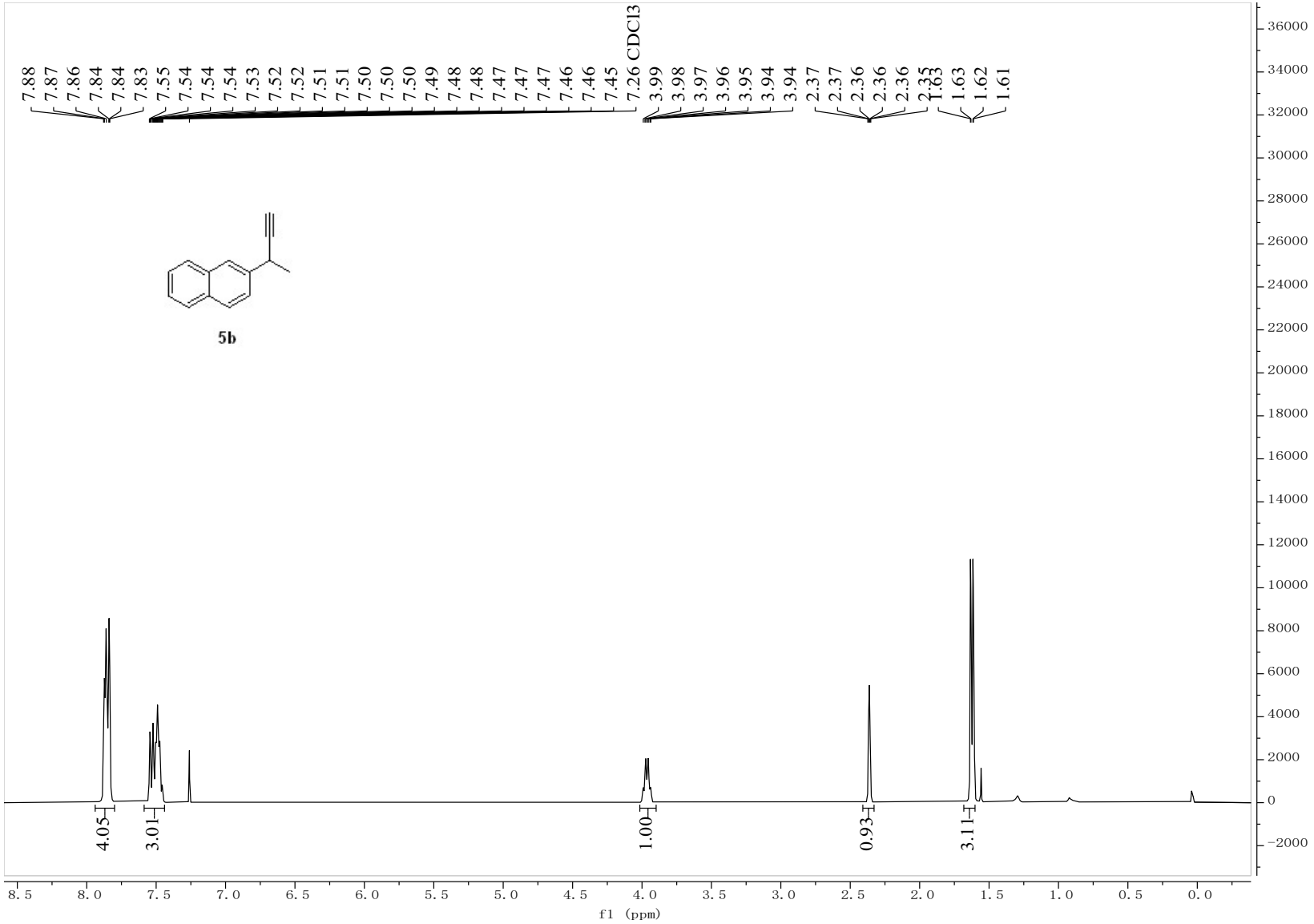


Figure S18. ^{1}H NMR spectrum of **5b** in $CDCl_3$ (400 MHz).

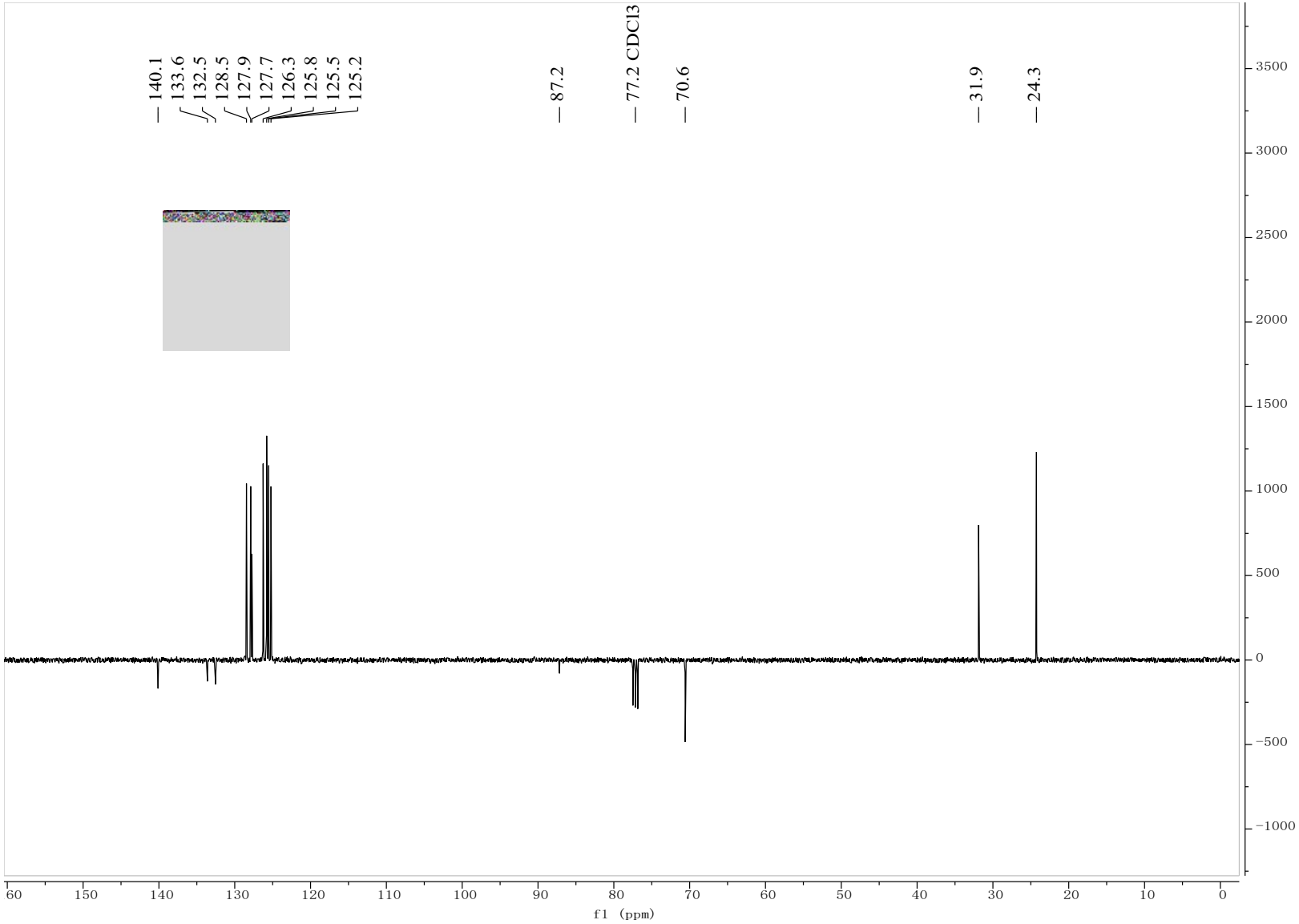


Figure S19. ^{13}C NMR spectrum of **5b** in $CDCl_3$ (100 MHz).

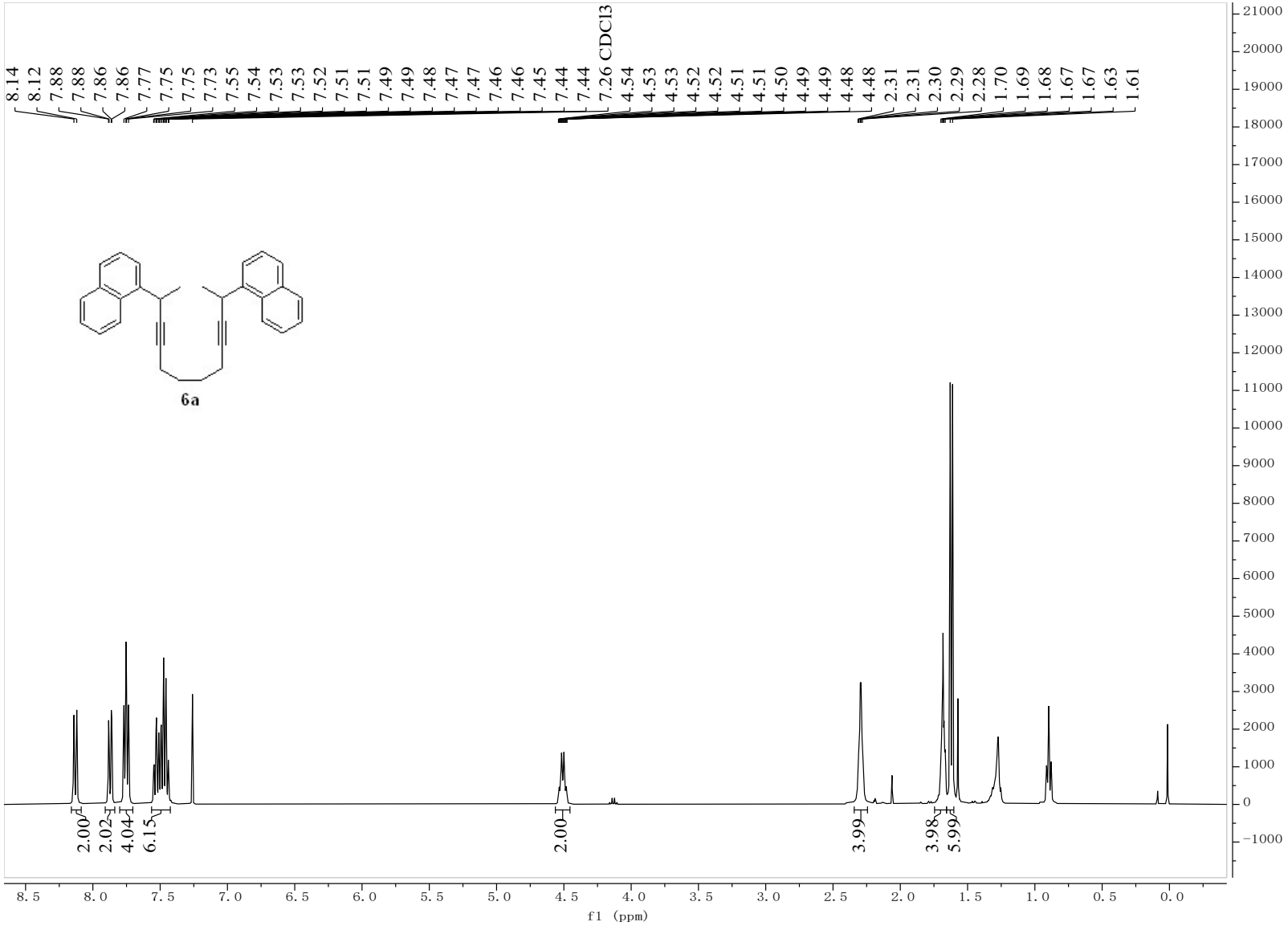


Figure S20. ^{1}H NMR spectrum of **6a** in $CDCl_3$ (400 MHz).

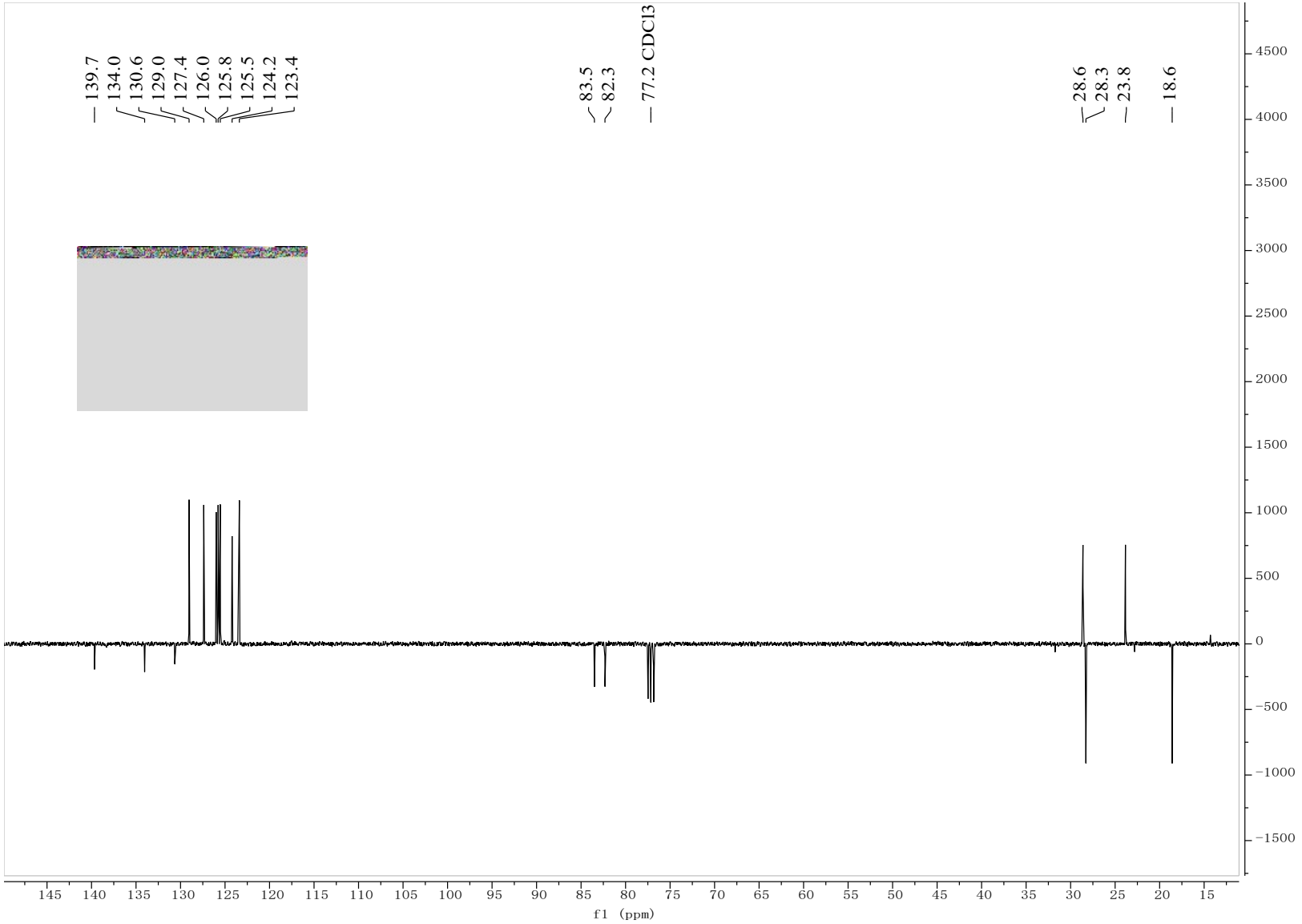


Figure S21. ^{13}C NMR spectrum of **6a** in $CDCl_3$ (100 MHz).

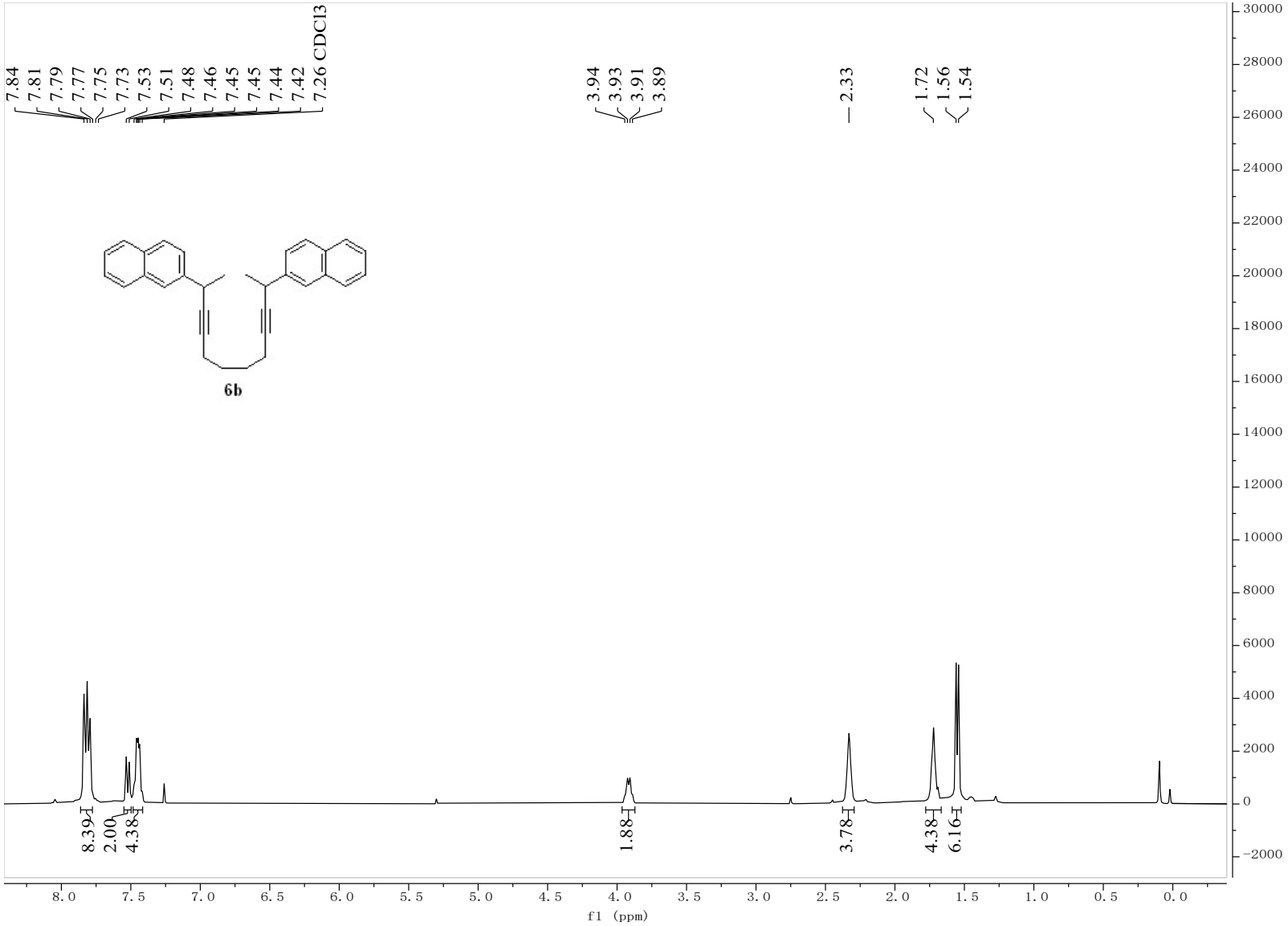


Figure S22. ^{1}H NMR spectrum of **6b** in $CDCl_3$ (400 MHz).

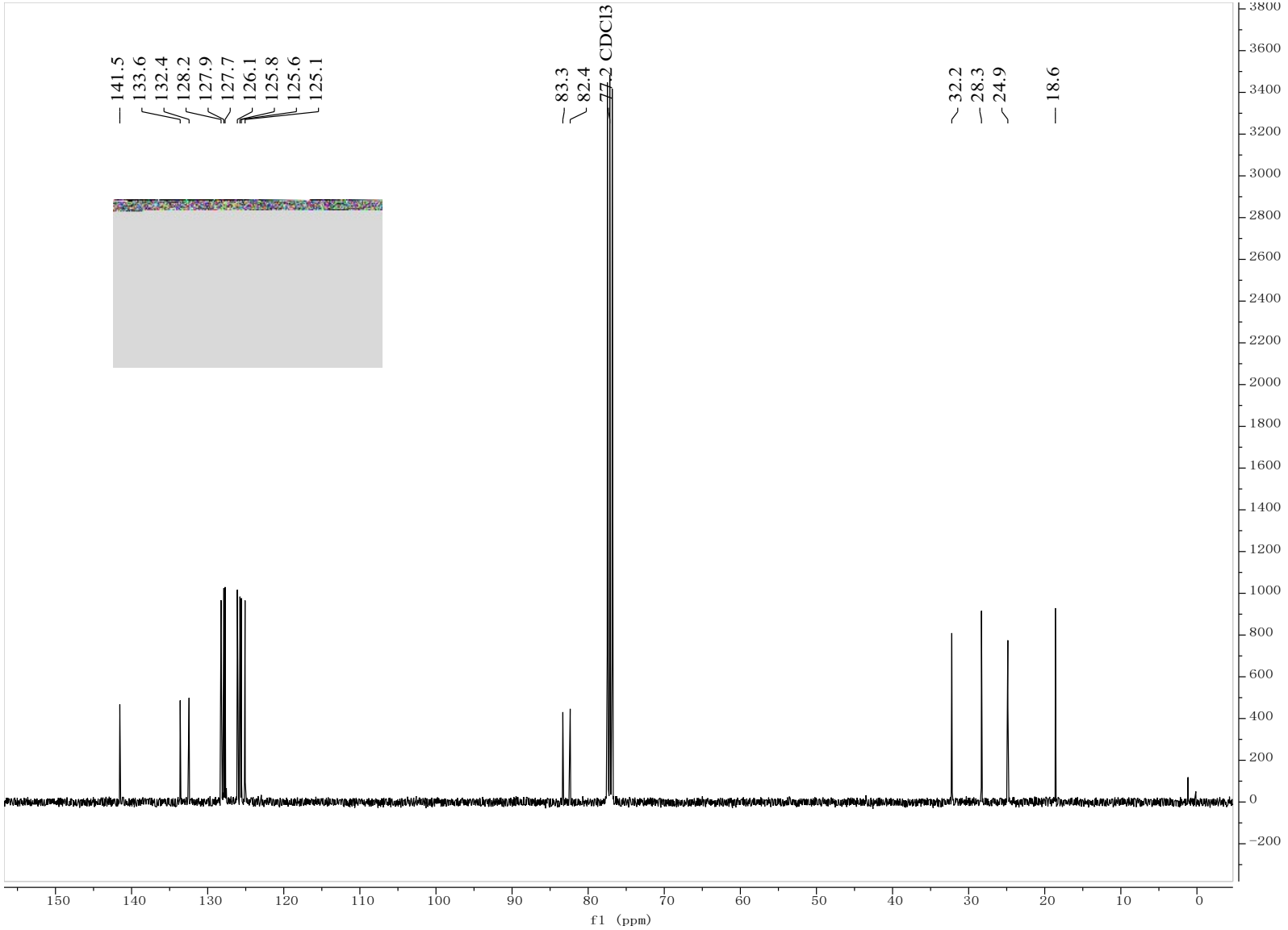


Figure S23. ^{13}C NMR spectrum of **6b** in $CDCl_3$ (100 MHz).

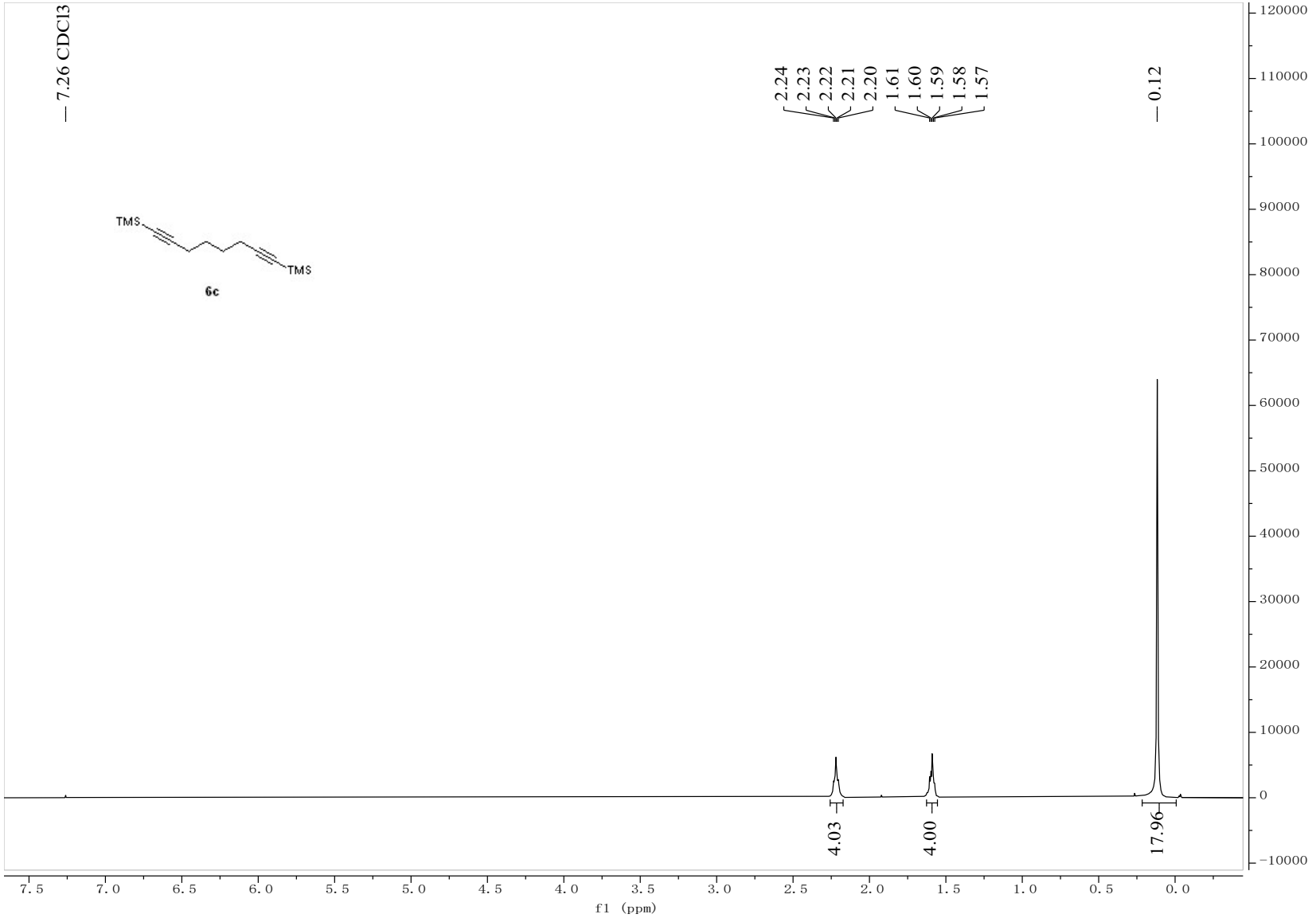


Figure S24. ^{1}H NMR spectrum of **6c** in $CDCl_3$ (400 MHz).

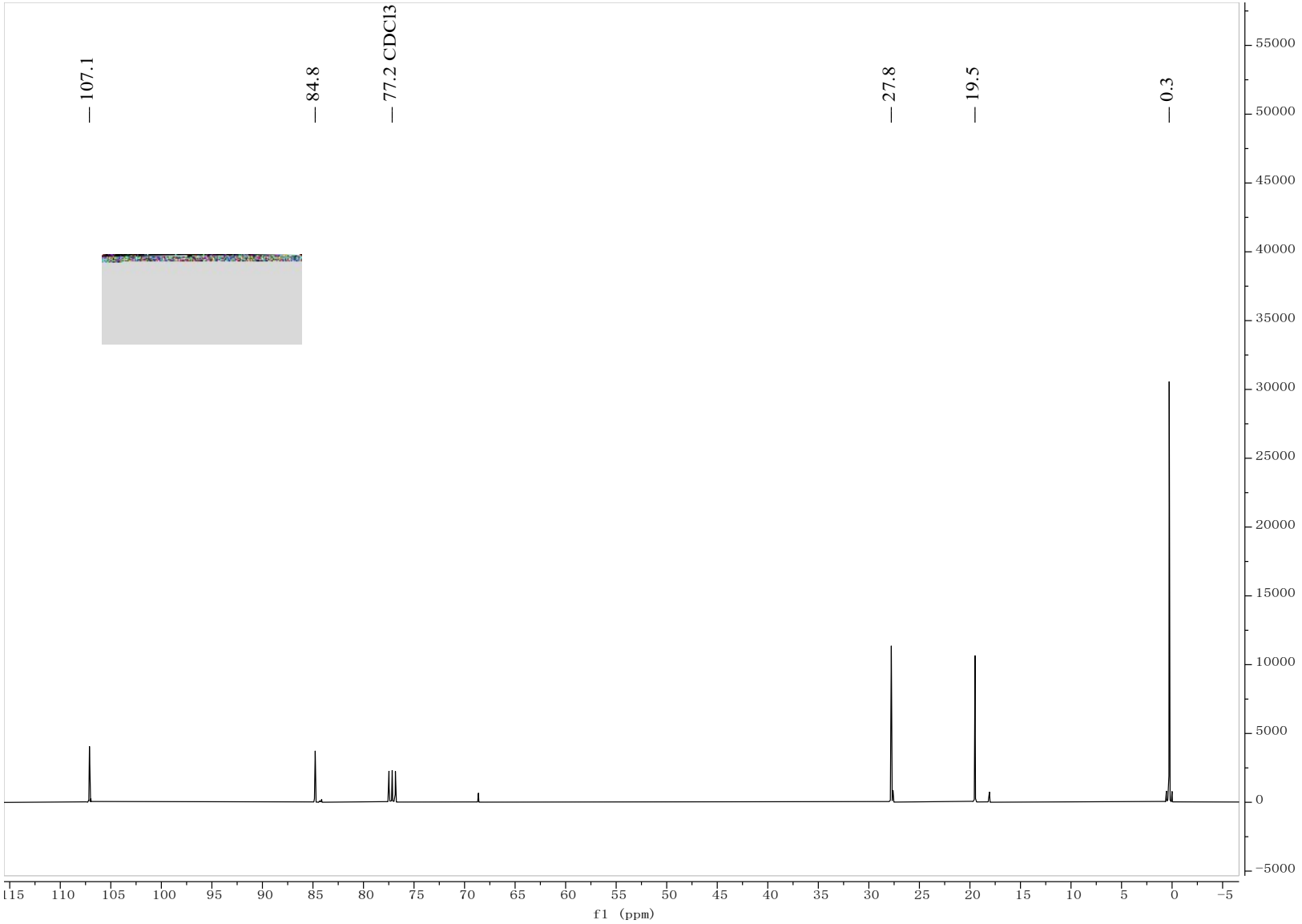


Figure S25. ^{13}C NMR spectrum of **6c** in $CDCl_3$ (100 MHz).

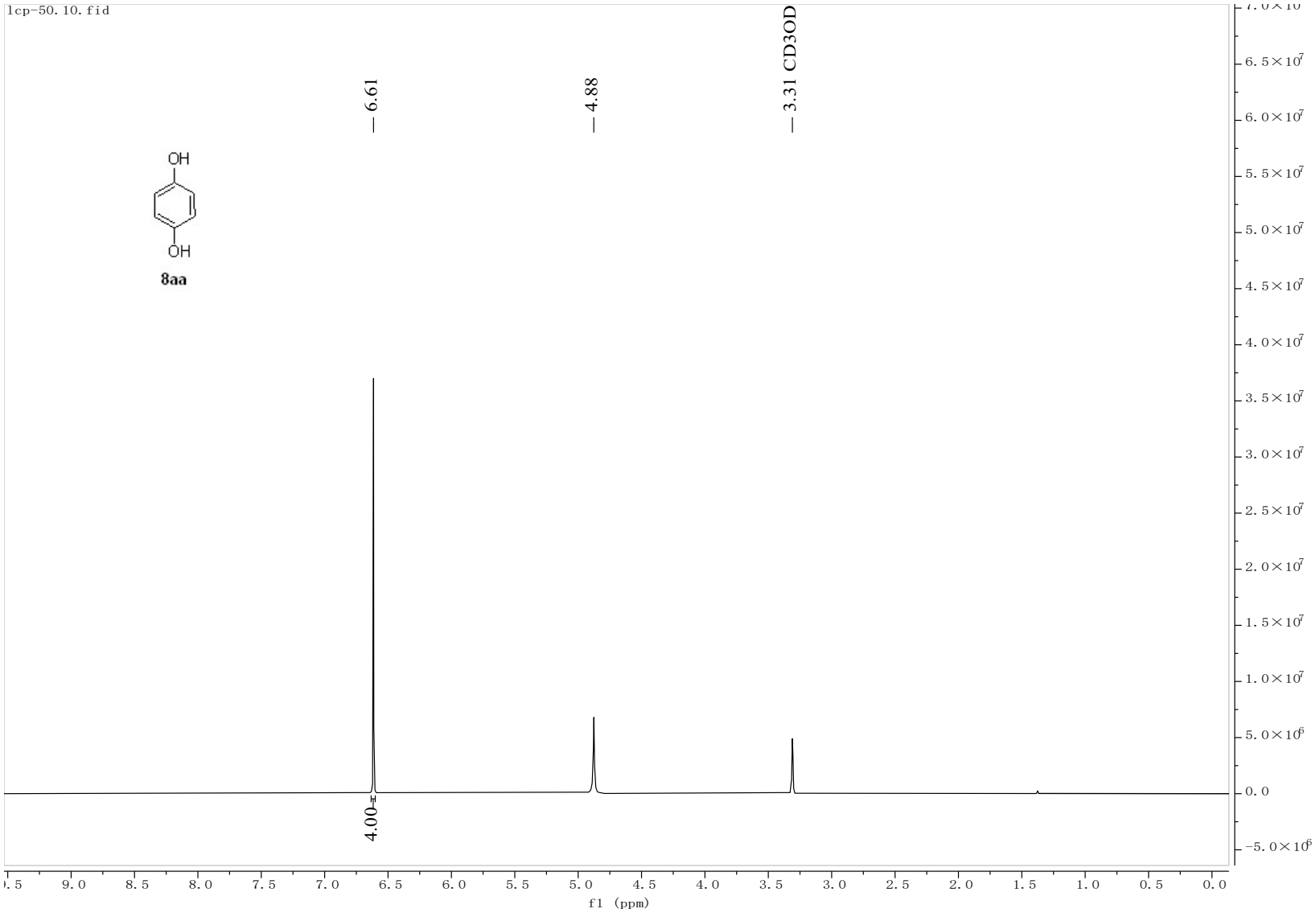


Figure S26. ^{1}H NMR spectrum of **8aa** in CD_3OD (400 MHz).

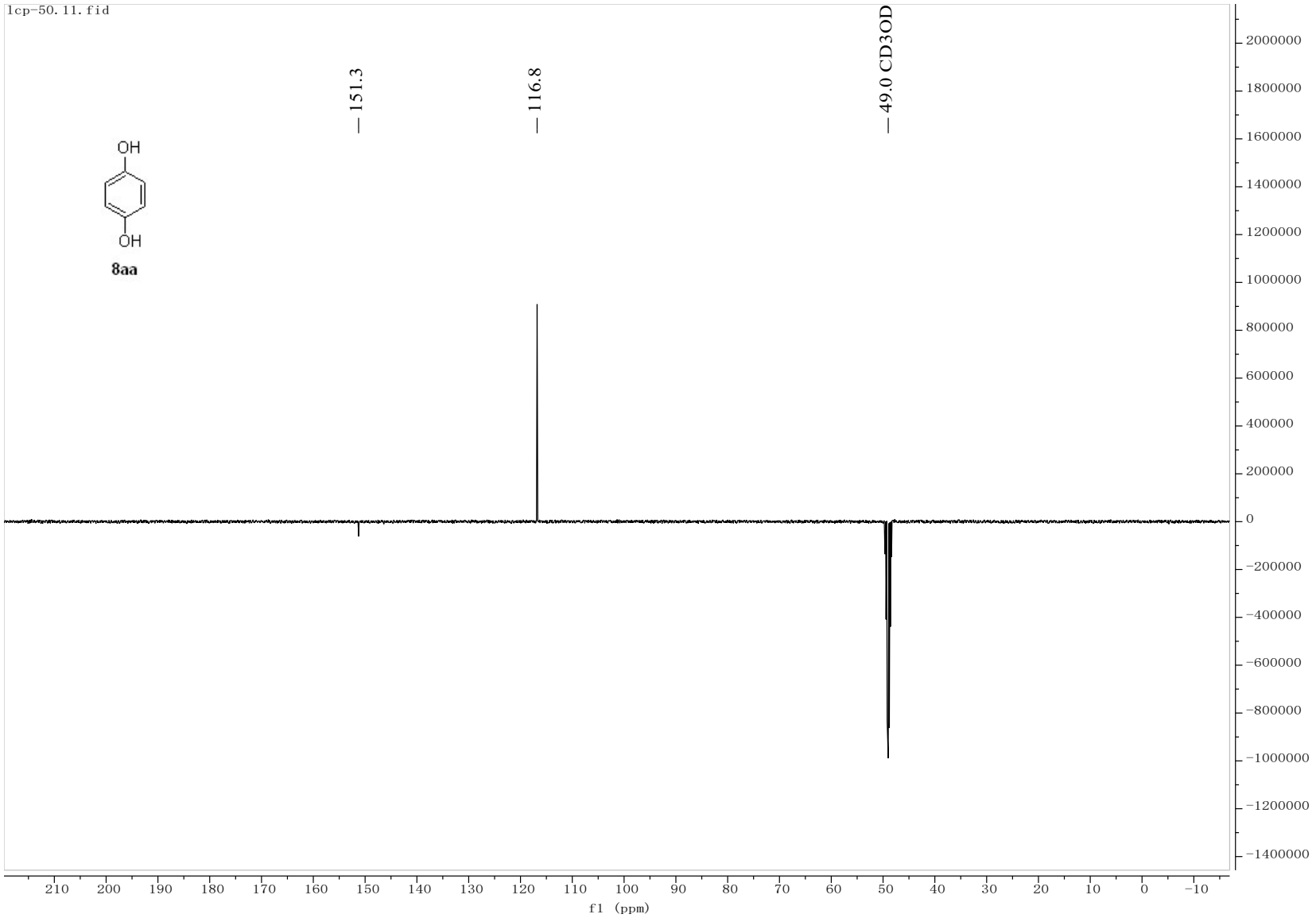


Figure S27. ^{13}C NMR spectrum of **8aa** in CD_3OD (100 MHz).

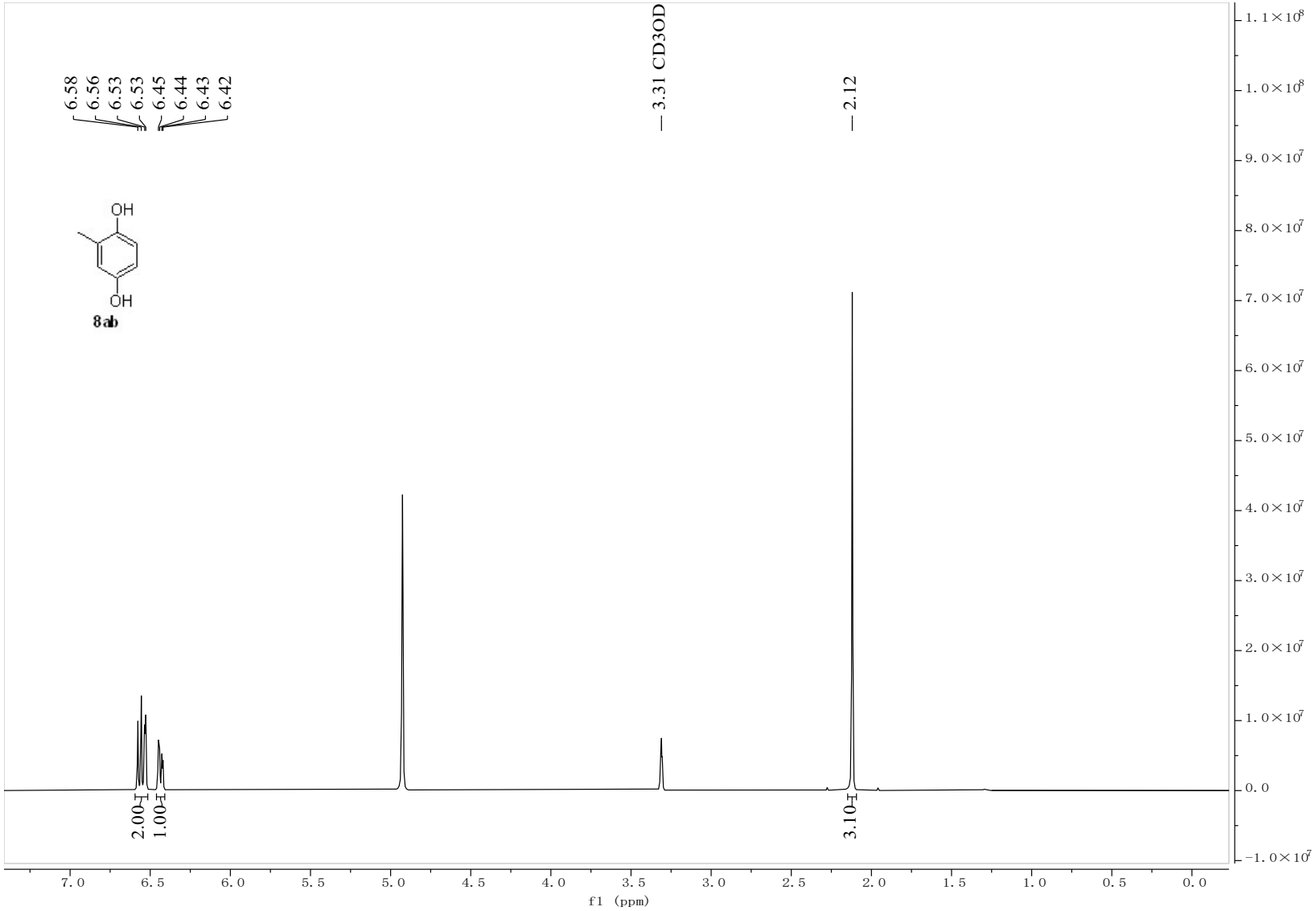


Figure S28. ^{1}H NMR spectrum of **8ab** in CD_3OD (400 MHz).

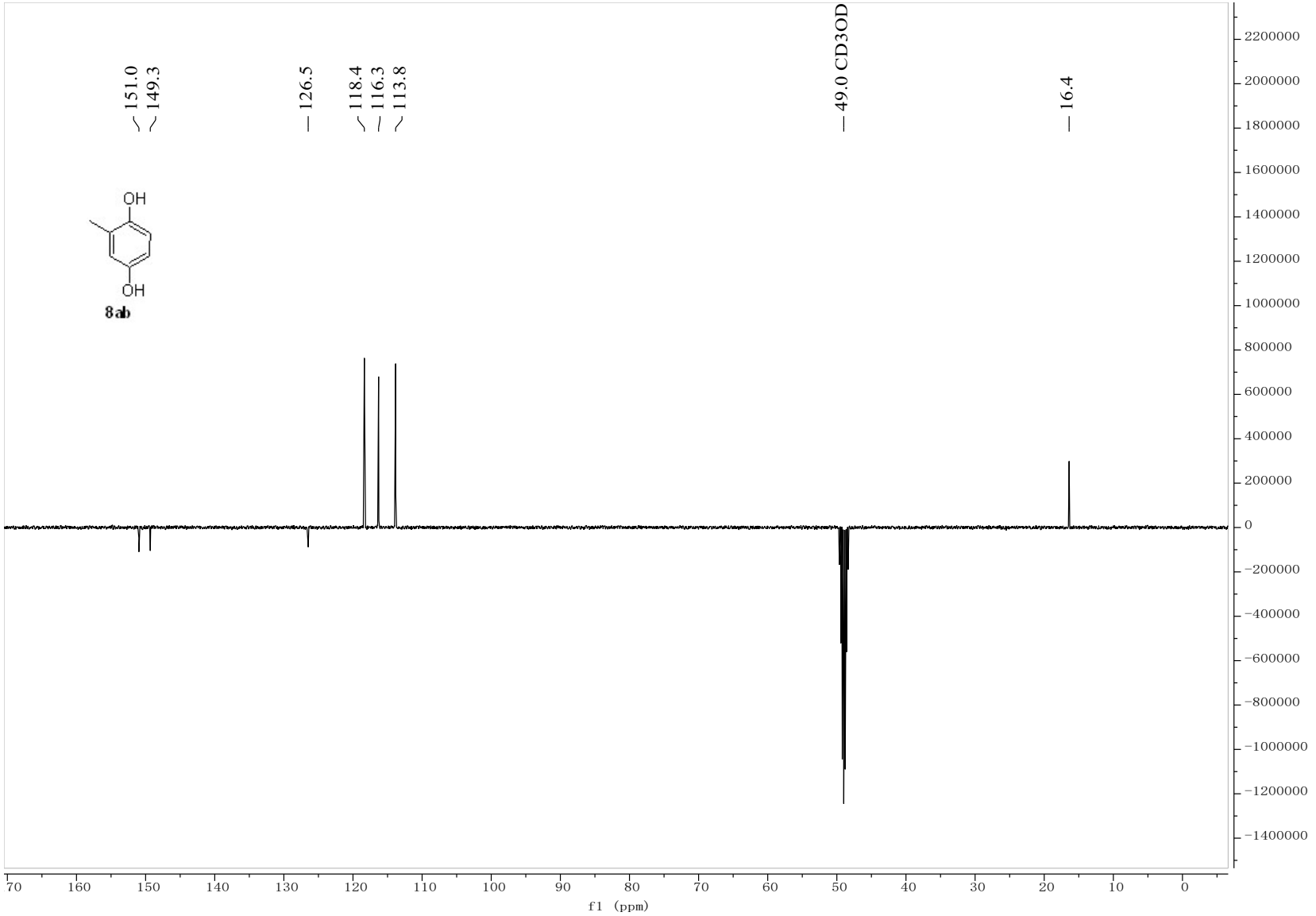


Figure S29. ^{13}C NMR spectrum of **8ab** in CD_3OD (100 MHz).

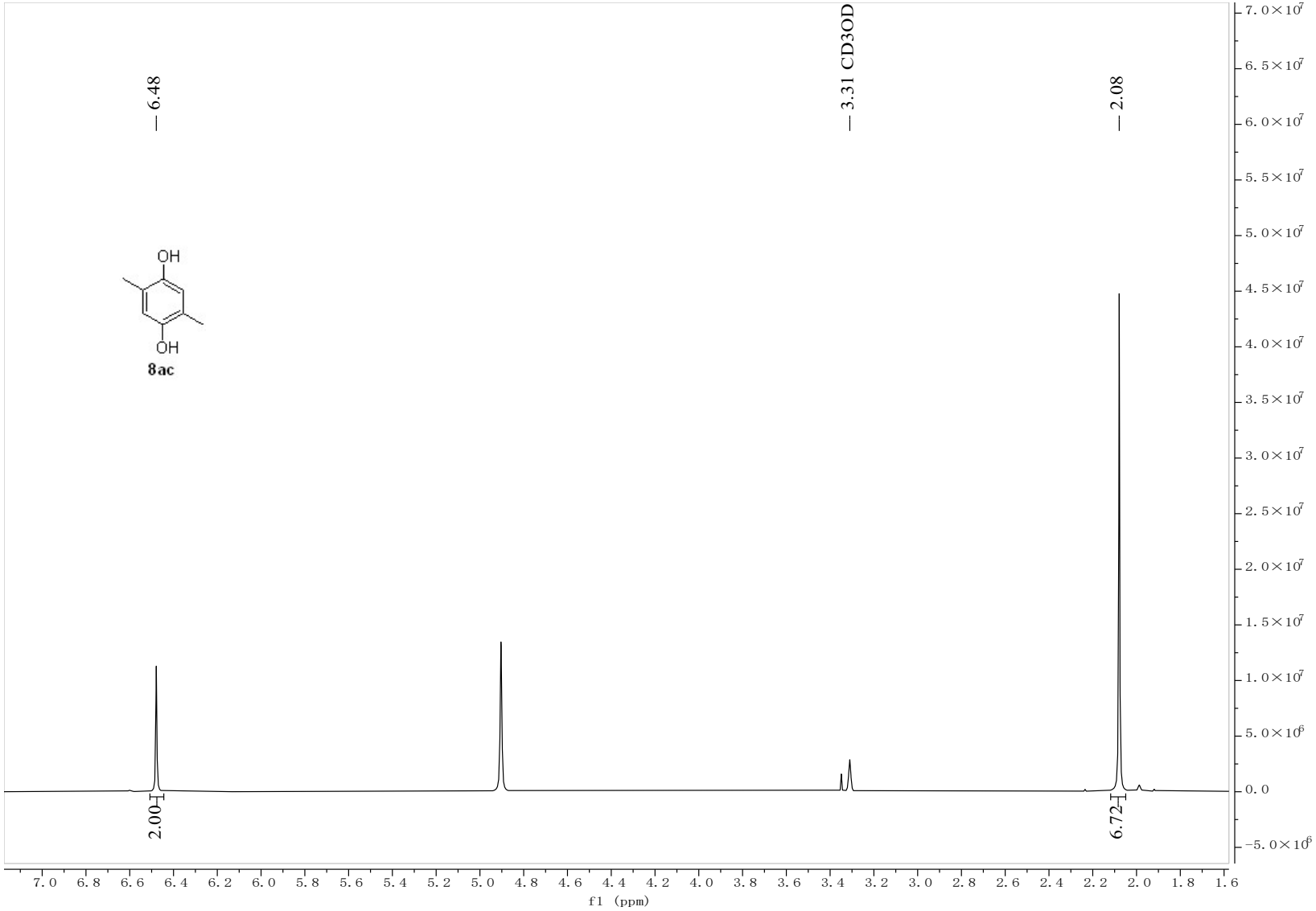


Figure S30. ^{1}H NMR spectrum of **8ac** in CD_3OD (400 MHz).

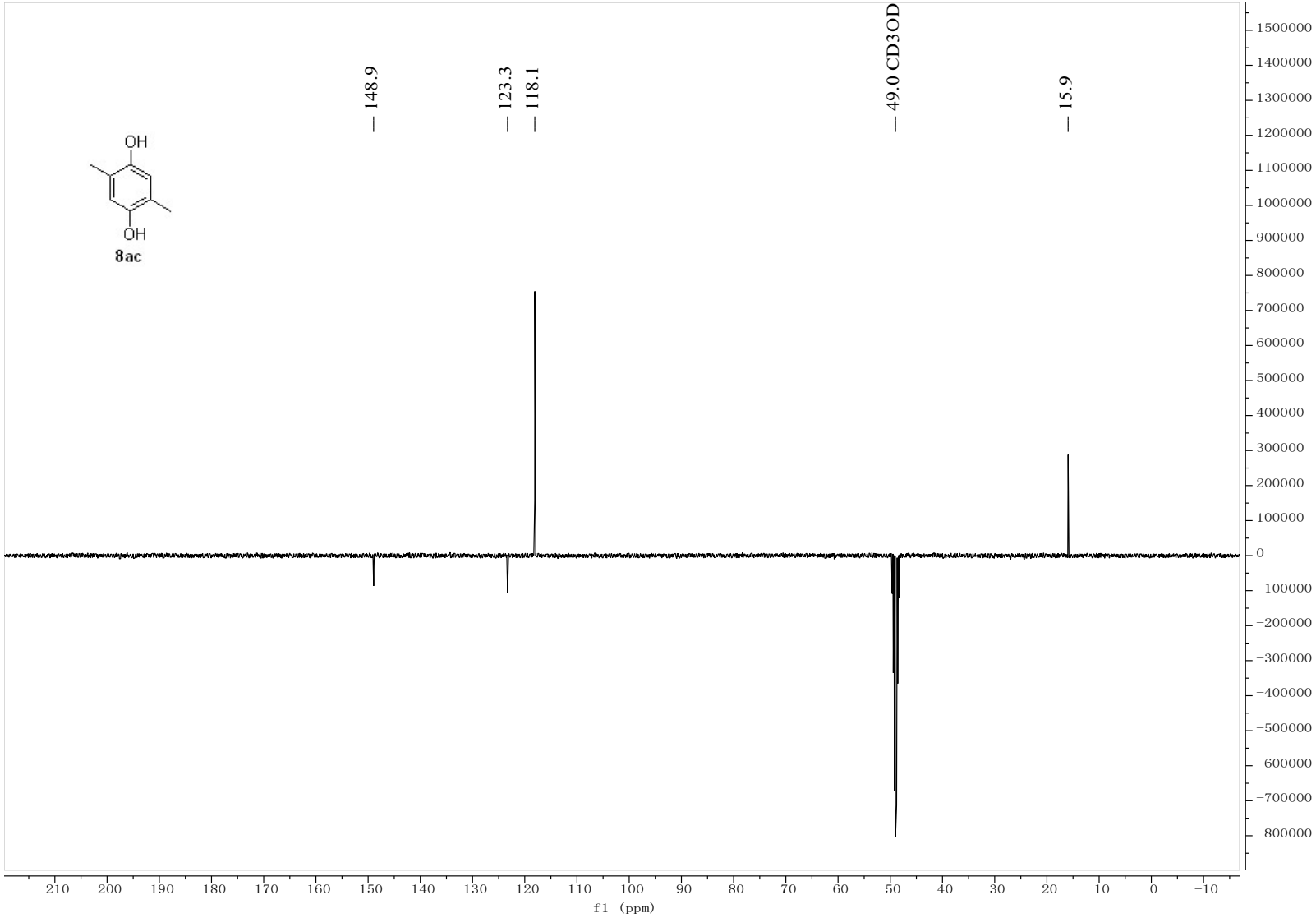


Figure S31. ^{13}C NMR spectrum of **8ac** in CD_3OD (100 MHz).

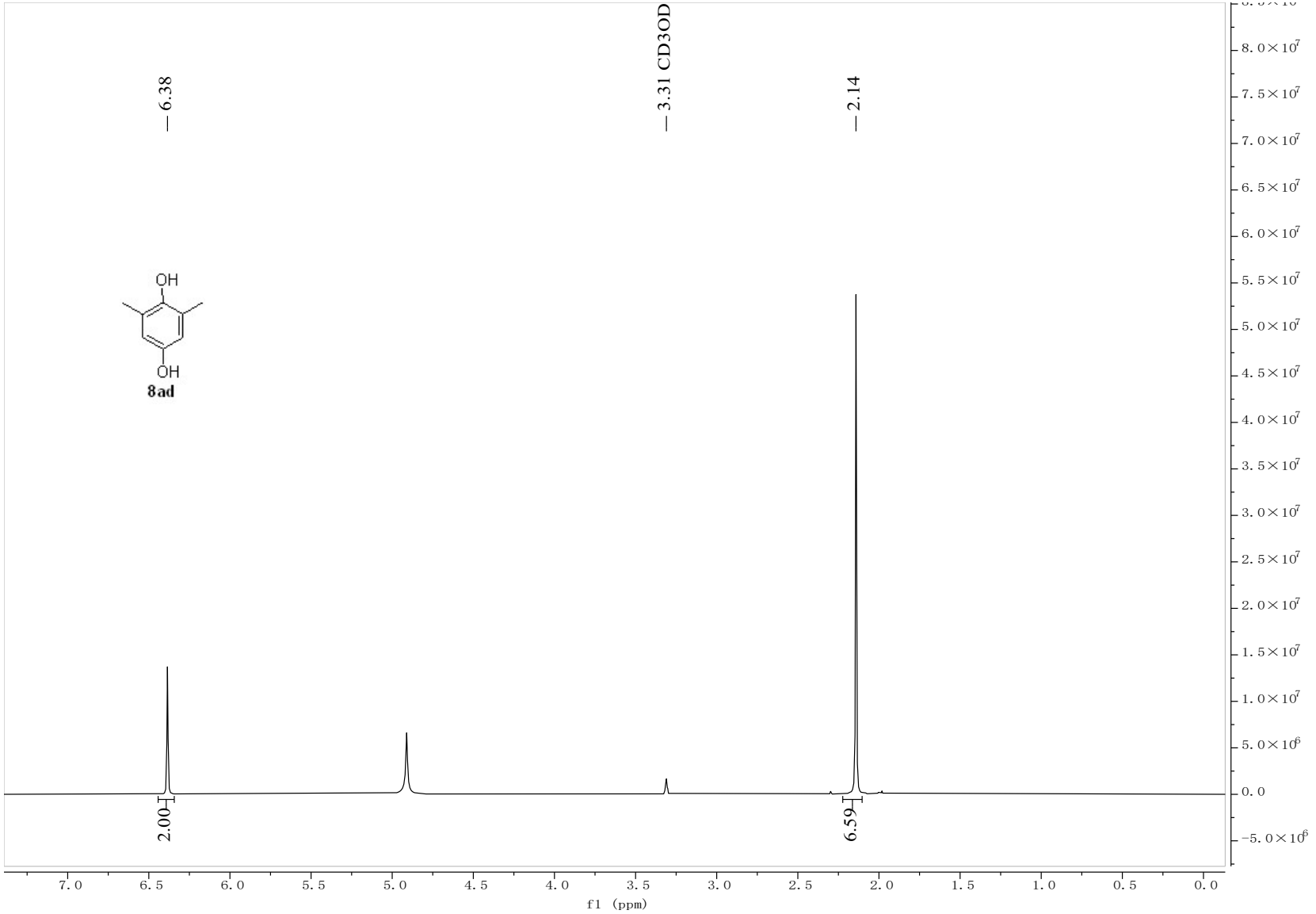


Figure S32. ^{1}H NMR spectrum of **8ad** in CD_3OD (400 MHz).

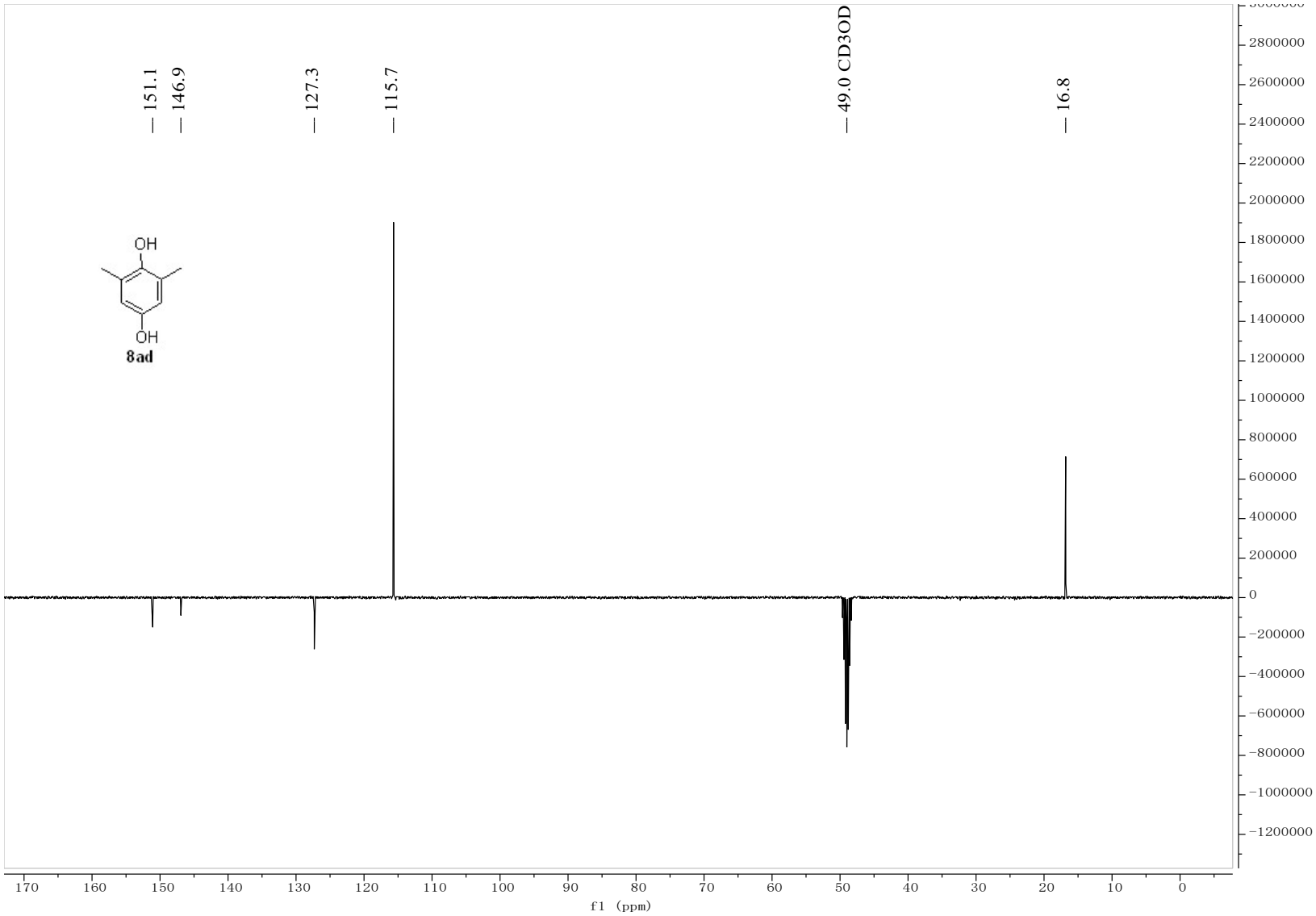


Figure S33. ^{13}C NMR spectrum of **8ad** in CD_3OD (100 MHz).

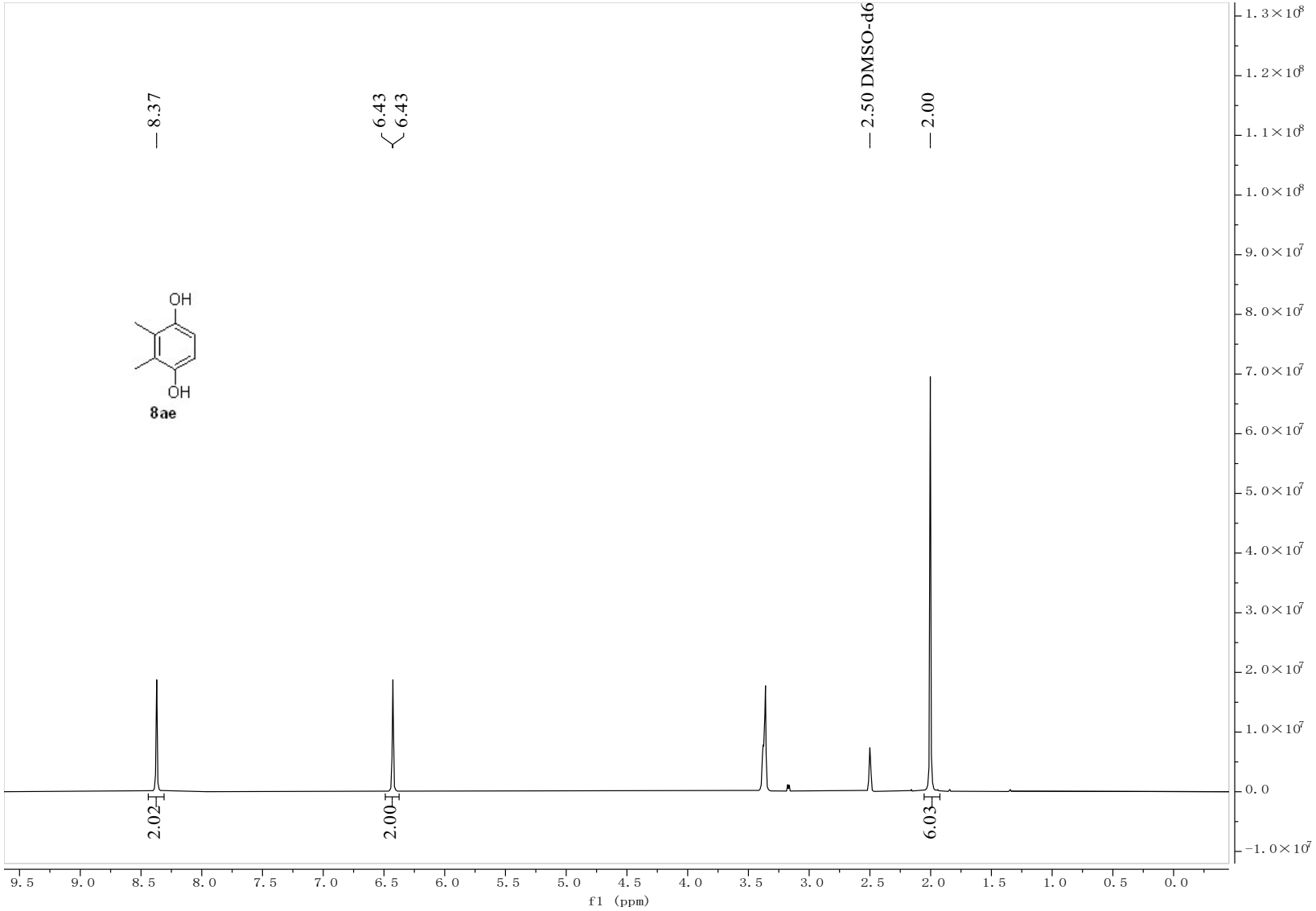


Figure S34. ^{1}H NMR spectrum of **8ae** in DMSO-d_6 (400 MHz).

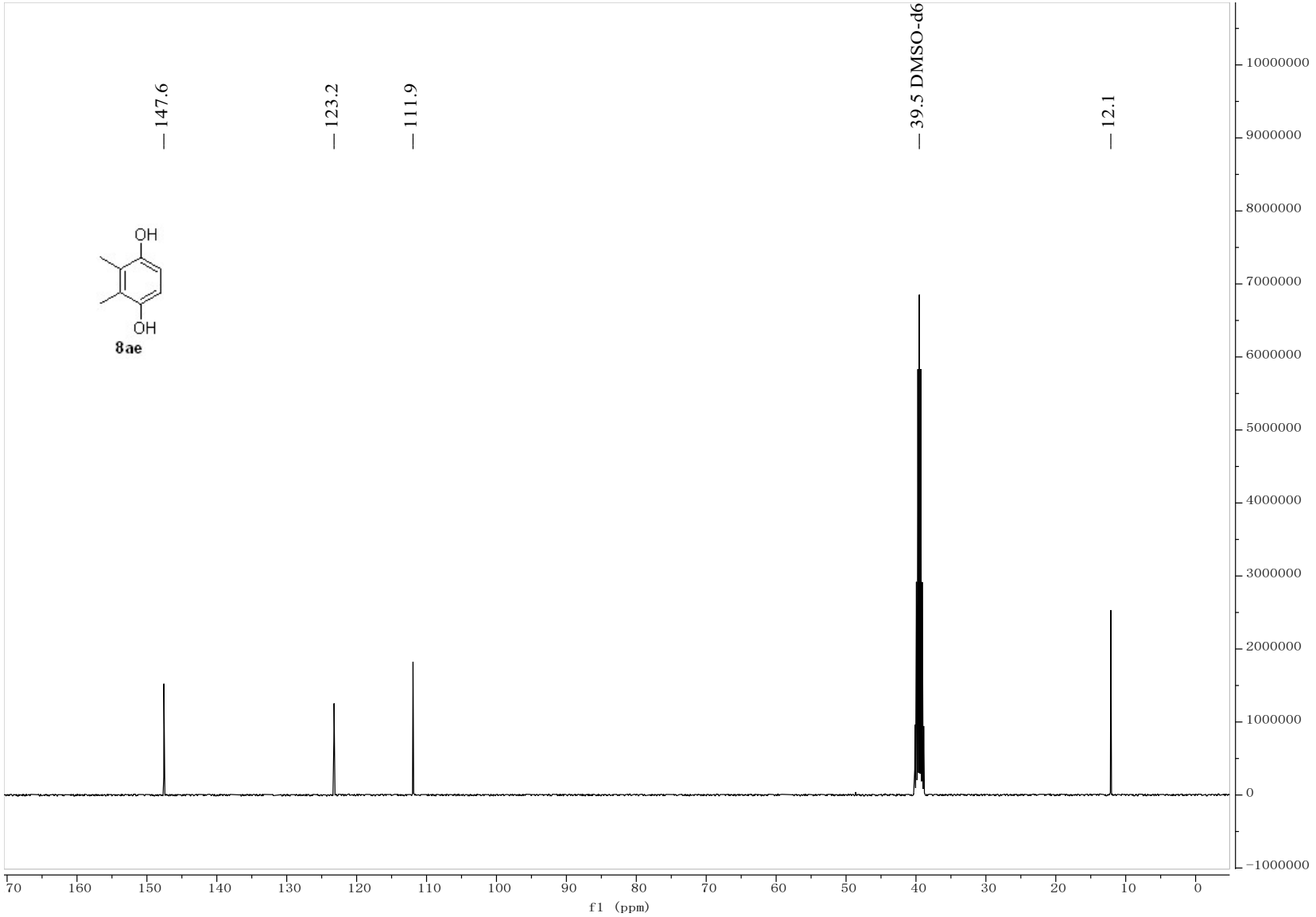


Figure S35. ^{13}C NMR spectrum of **8ae** in DMSO-d_6 (100 MHz).

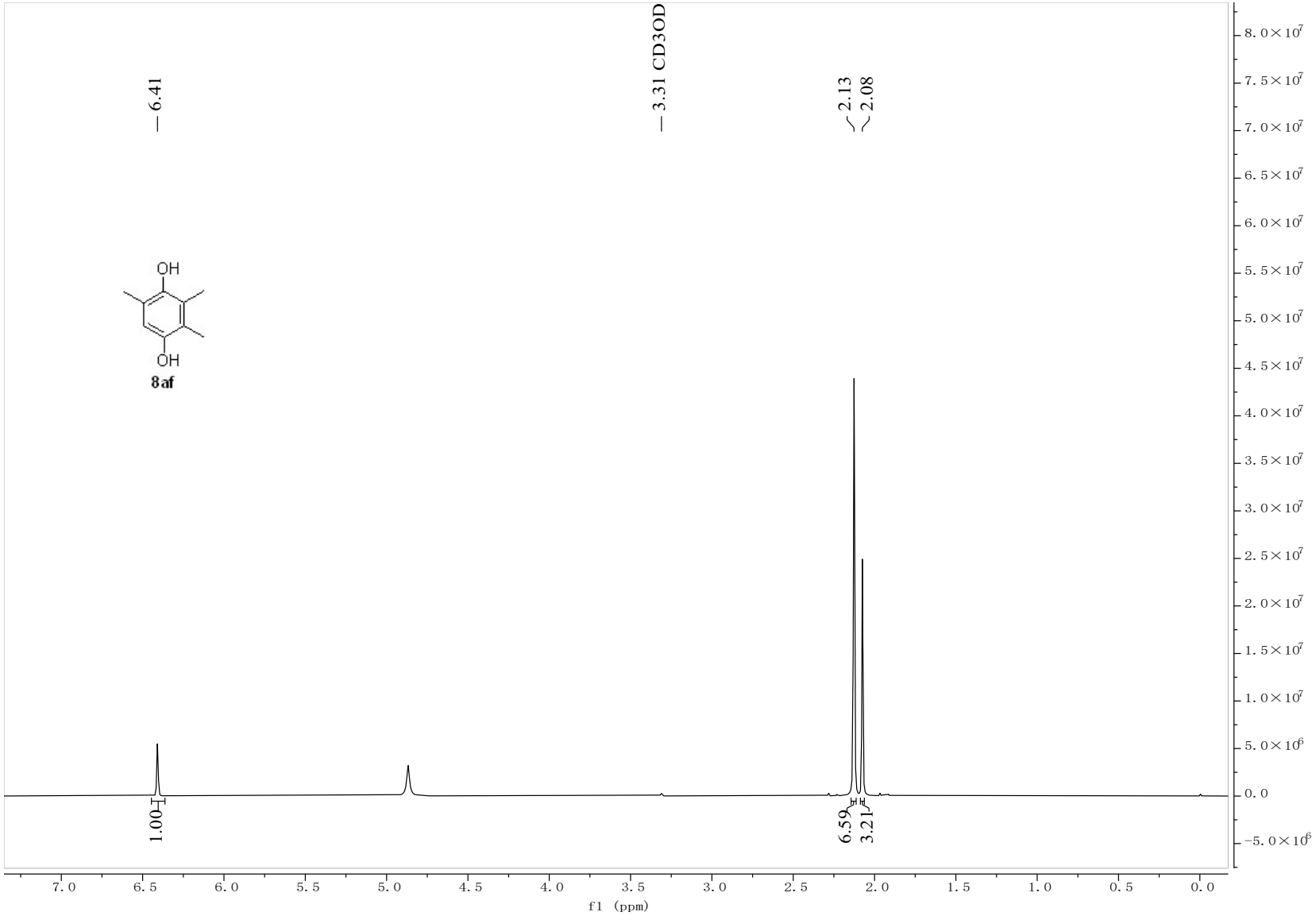


Figure S36. ^{1}H NMR spectrum of **8af** in CD_3OD (400 MHz).

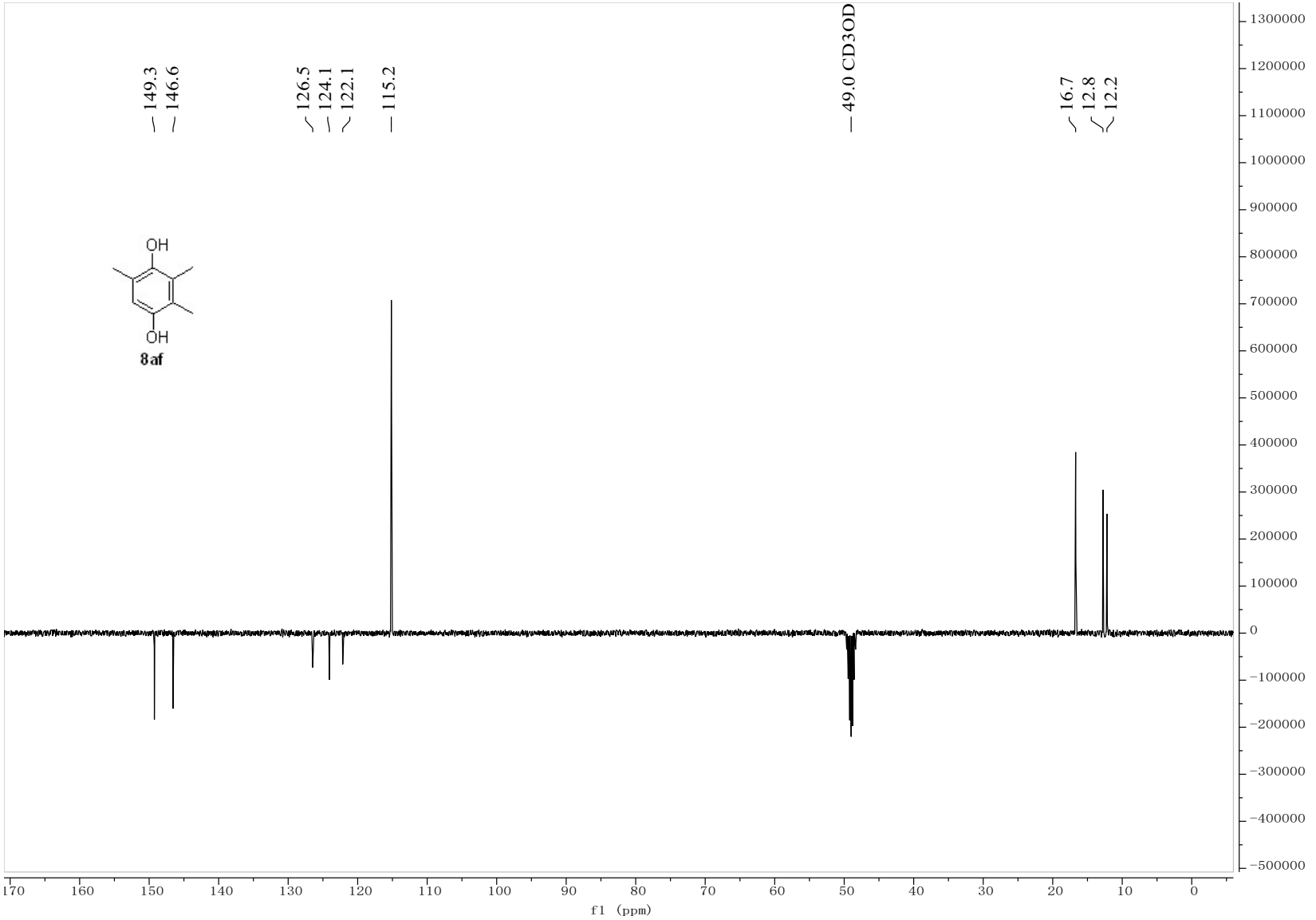


Figure S37. ^{13}C NMR spectrum of **8af** in CD_3OD (100 MHz).

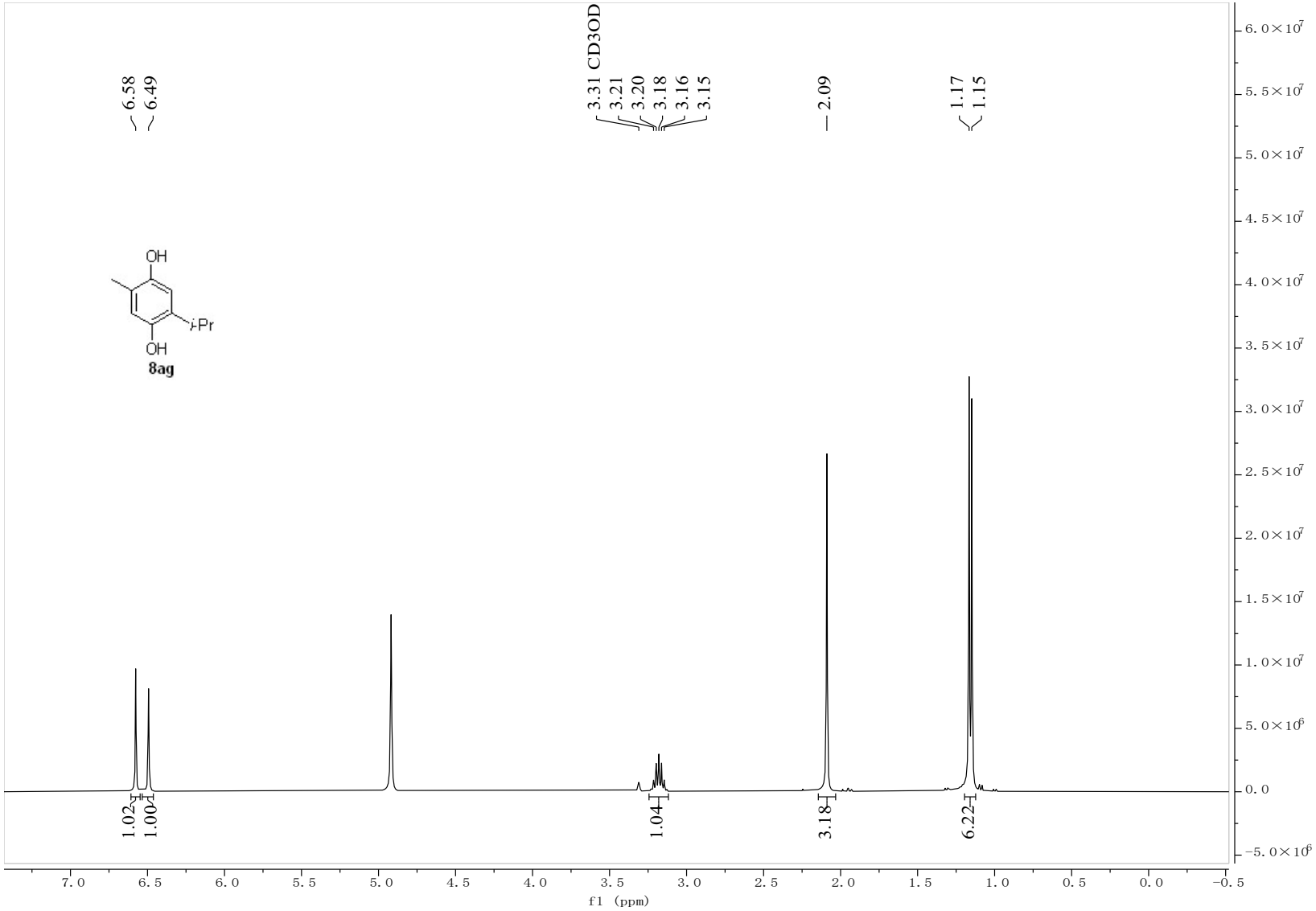


Figure S38. ^{1}H NMR spectrum of **8ag** in CD_3OD (400 MHz).

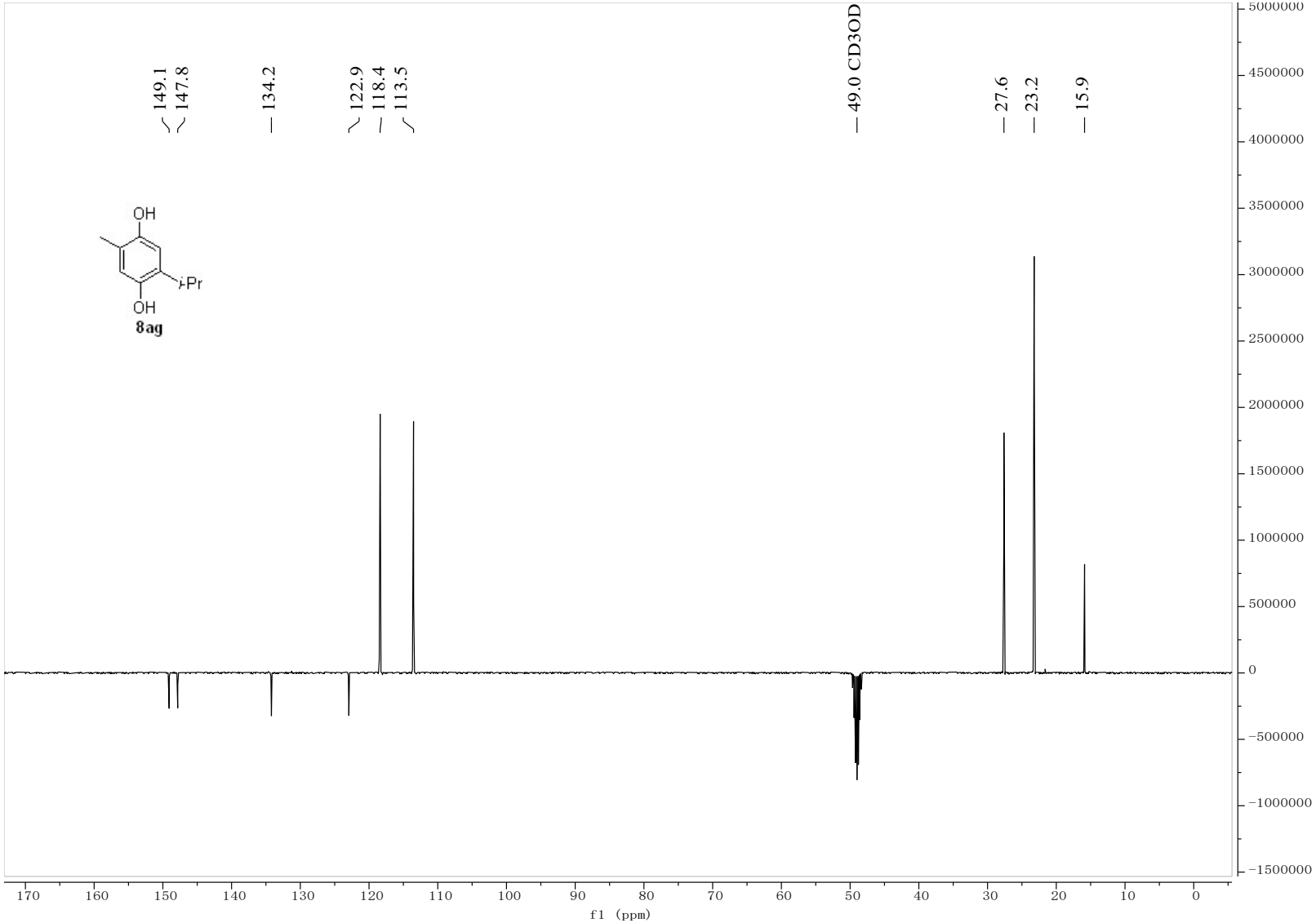


Figure S39. ^{13}C NMR spectrum of **8ag** in CD_3OD (100 MHz).

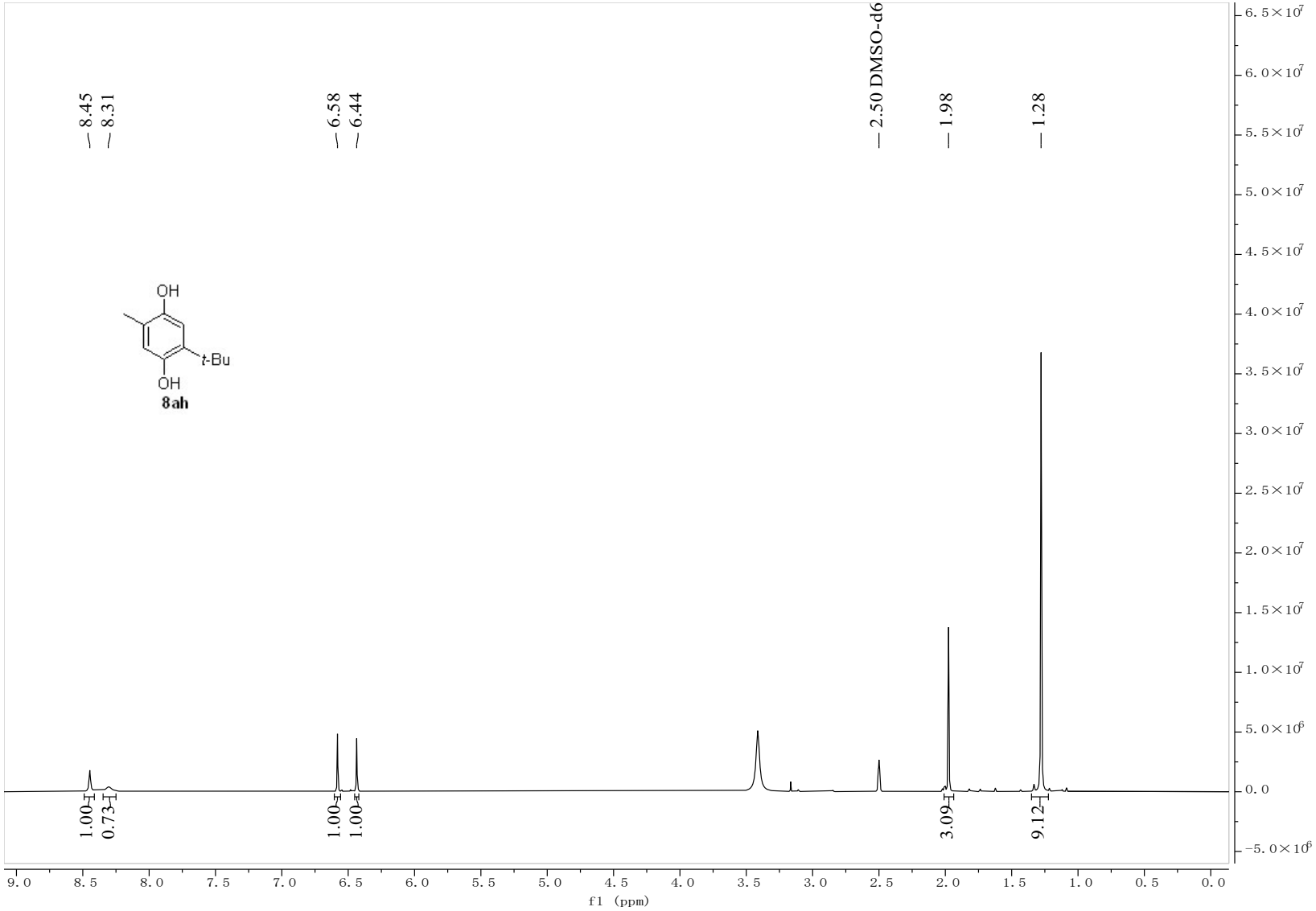


Figure S40. ^{1}H NMR spectrum of **8ah** in DMSO-d_6 (400 MHz).

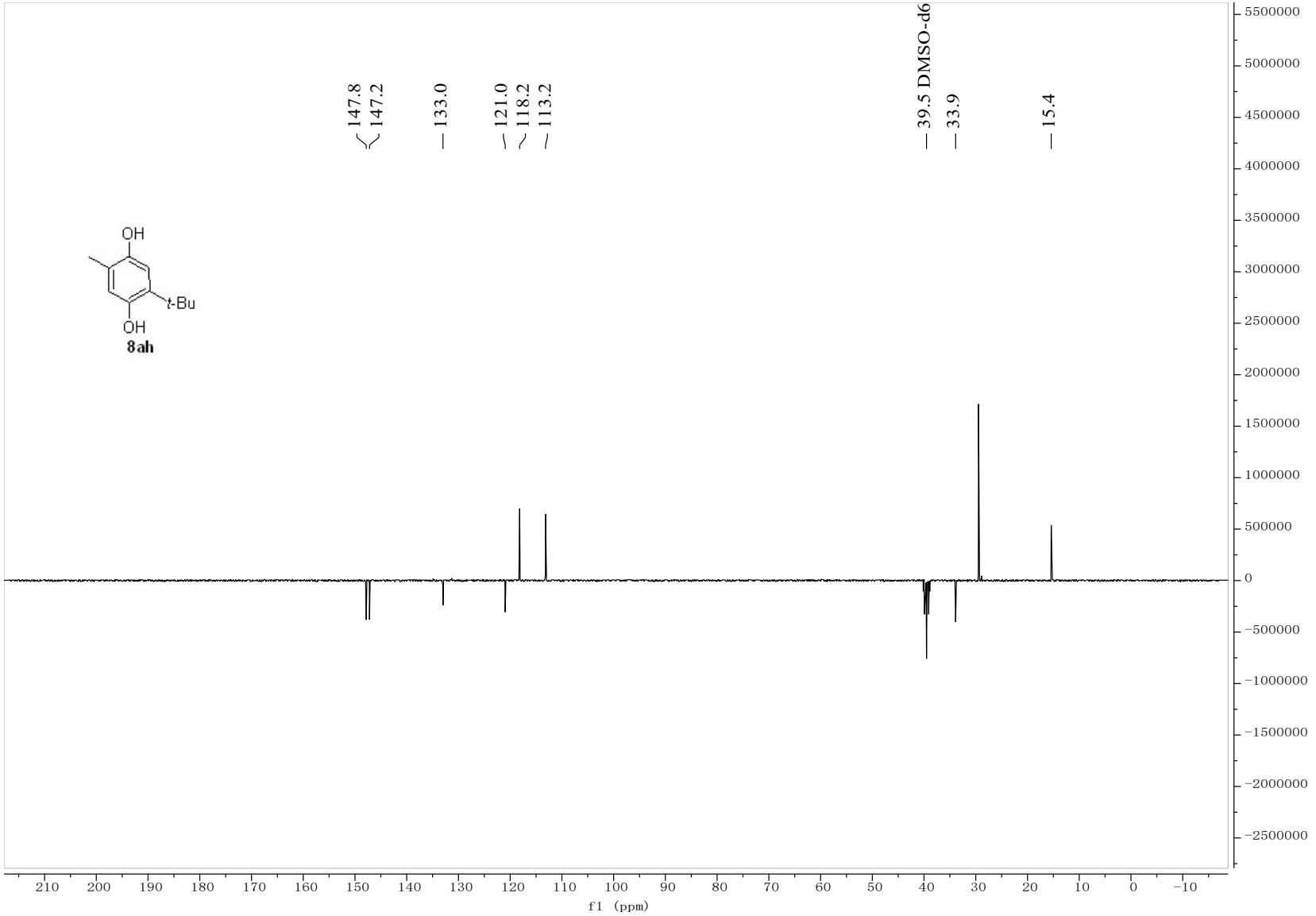


Figure S41. ^{13}C NMR spectrum of **8ah** in DMSO-d_6 (100 MHz).

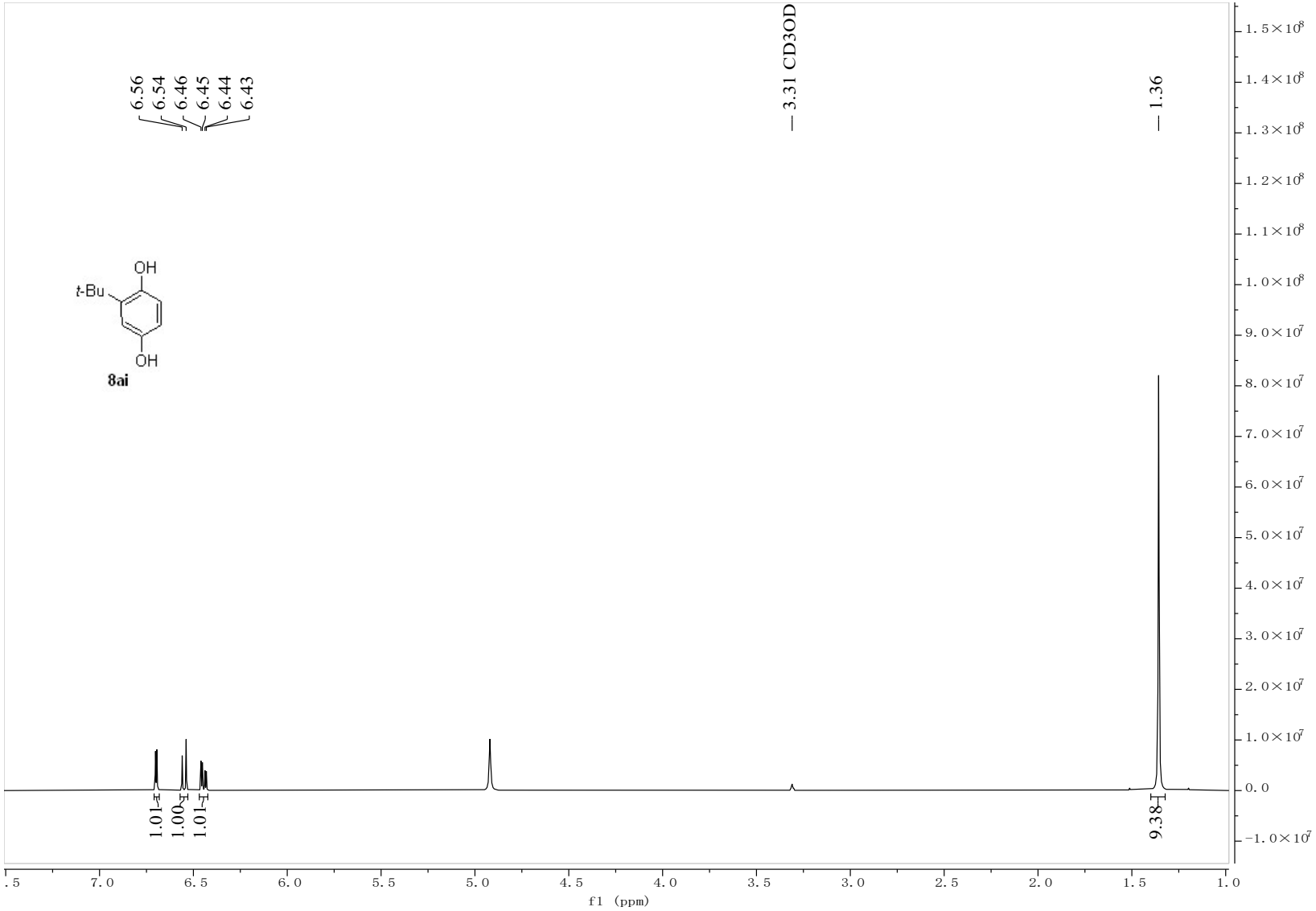


Figure S42. ^{1}H NMR spectrum of **8ai** in CD_3OD (400 MHz).

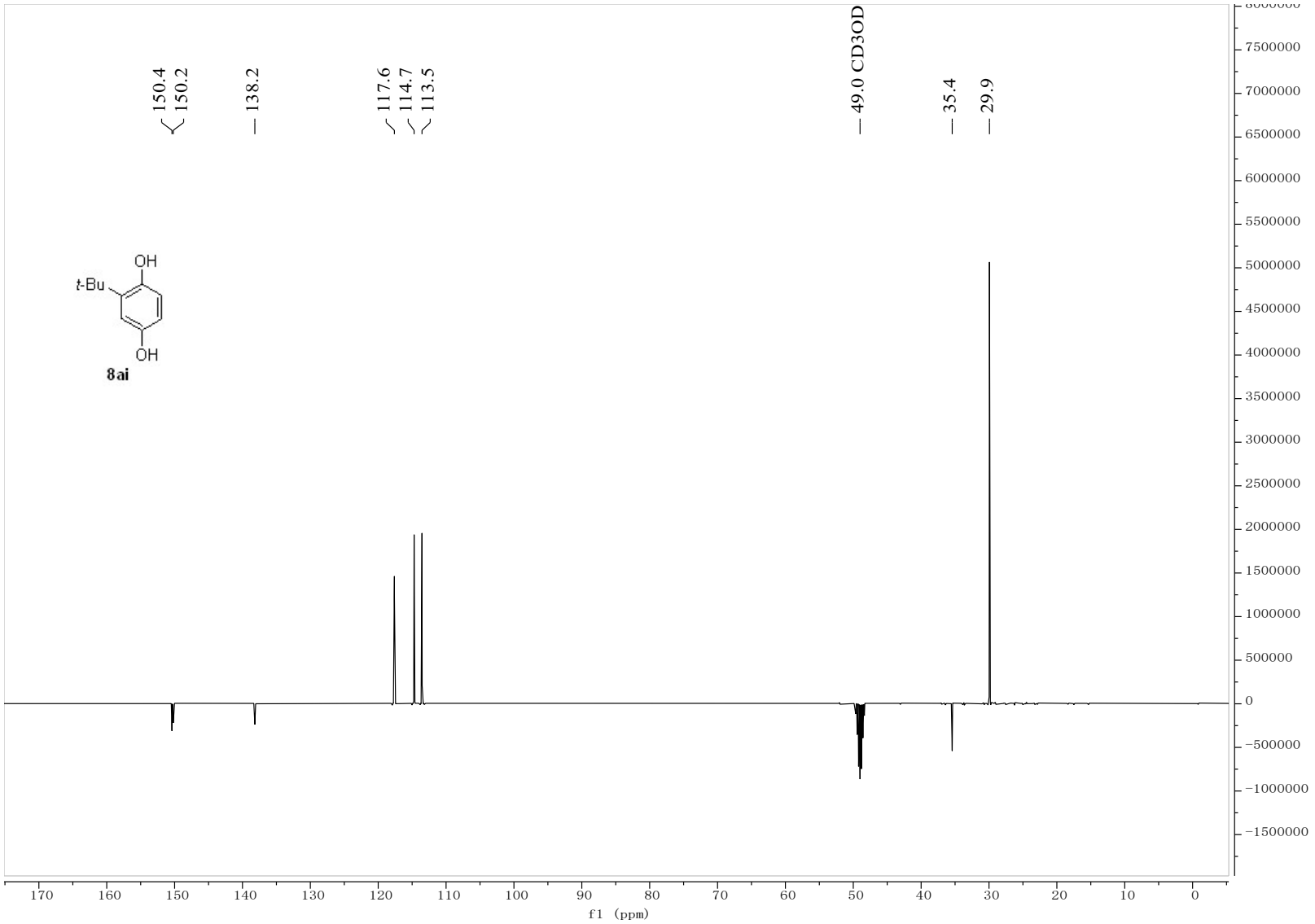


Figure S43. ^{13}C NMR spectrum of **8ai** in CD_3OD (100 MHz).

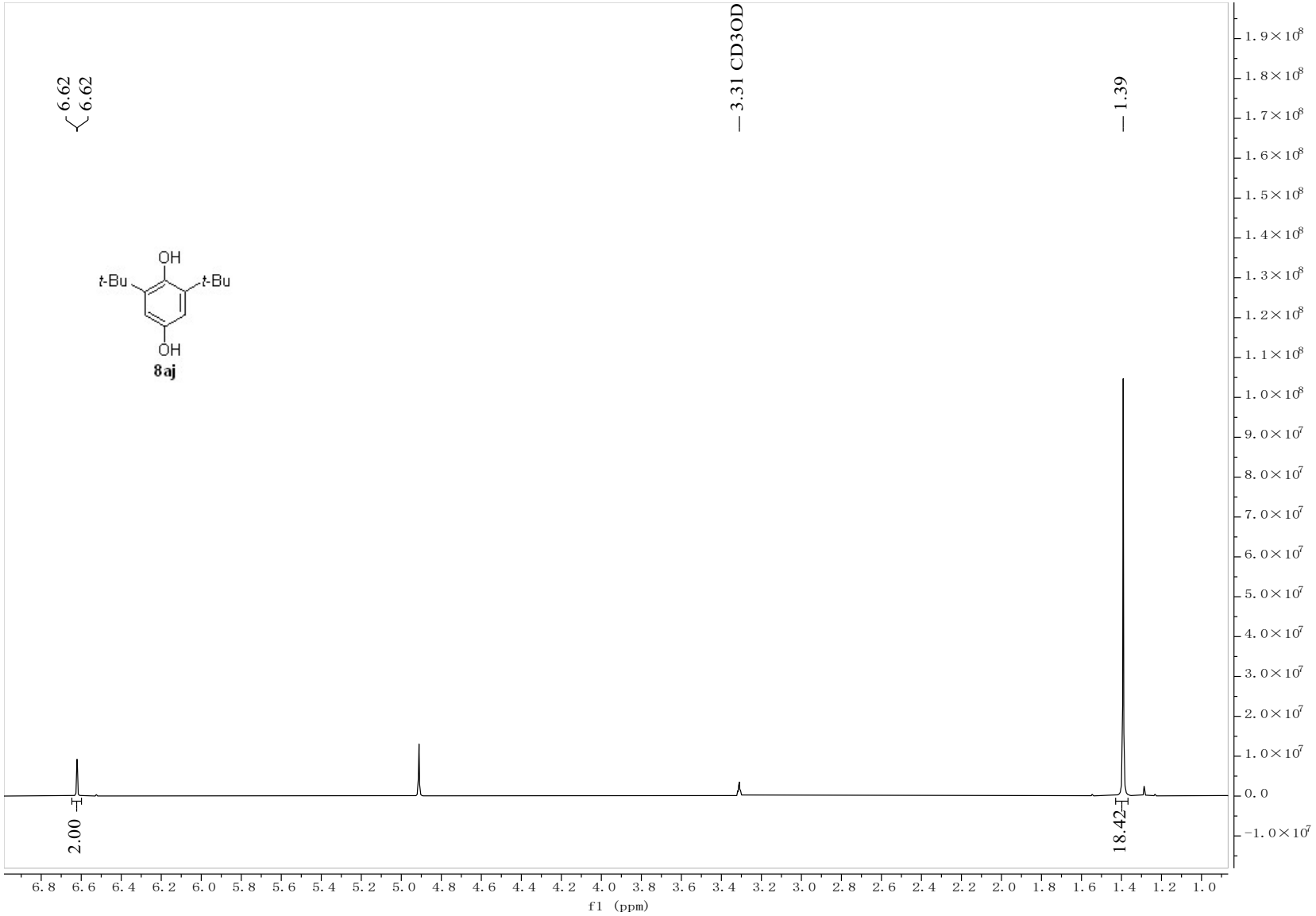


Figure S44. ^{1}H NMR spectrum of **8aj** in CD_3OD (400 MHz).

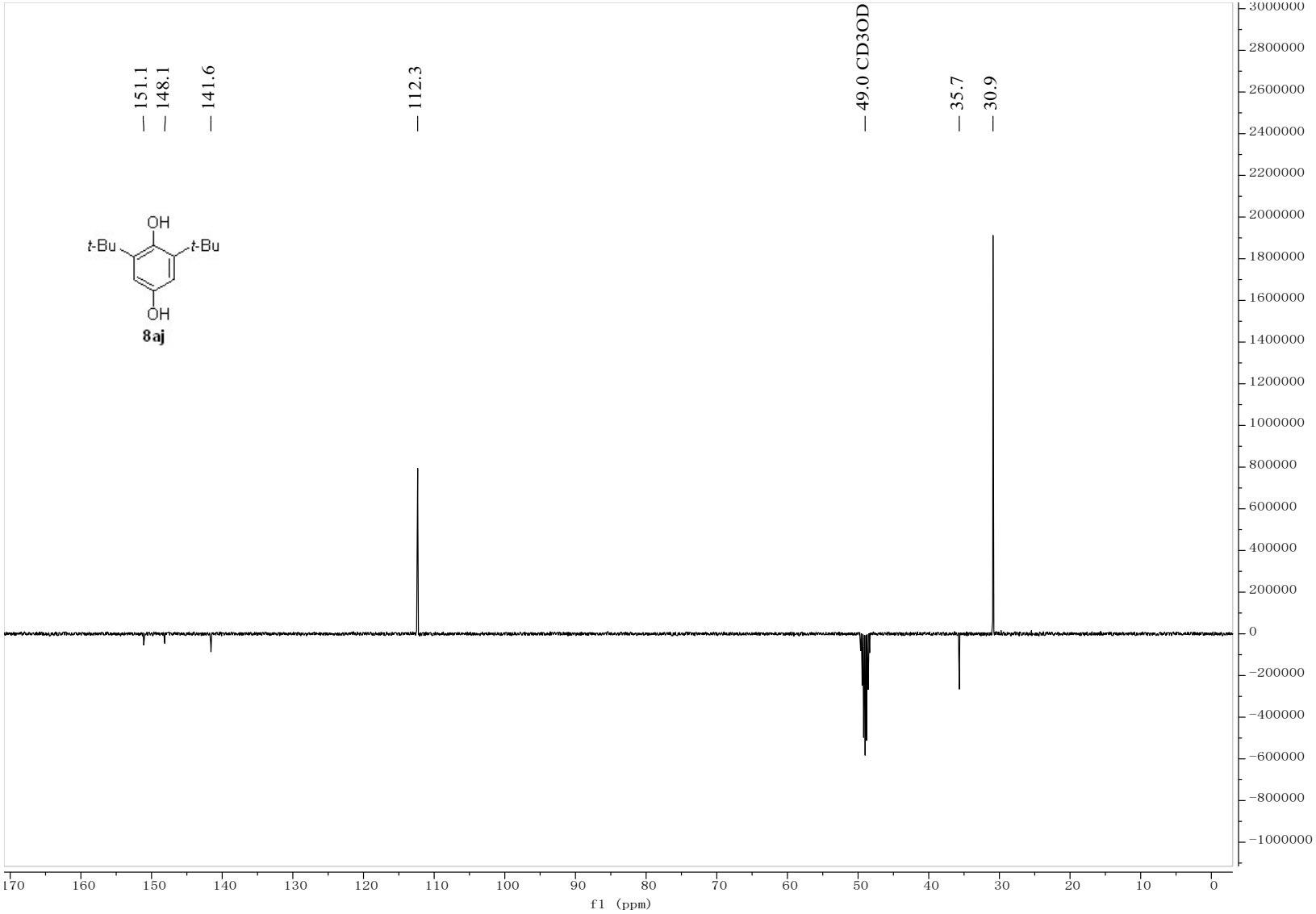


Figure S45. ^{13}C NMR spectrum of **8aj** in CD_3OD (100 MHz).

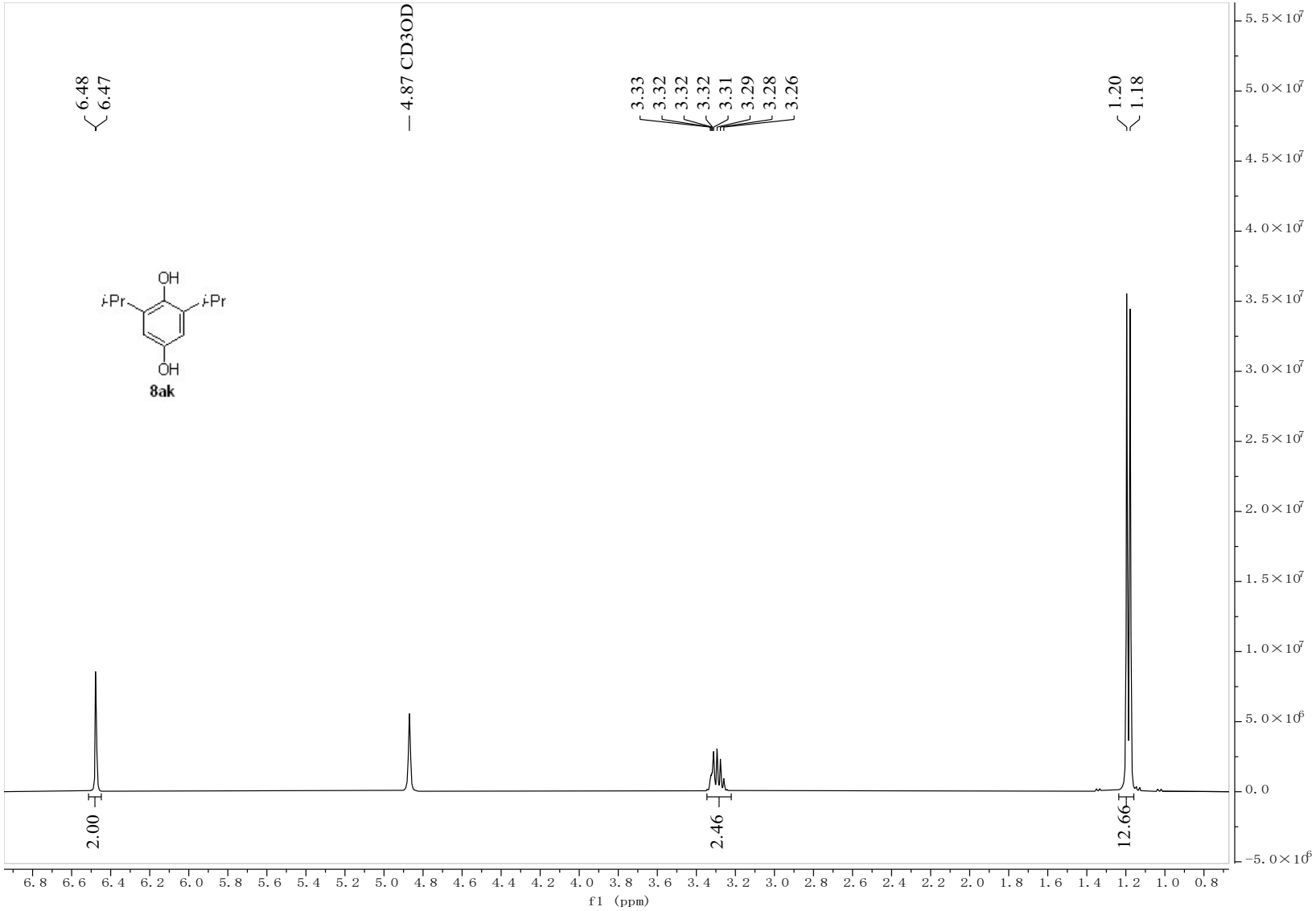


Figure S46. ^{1}H NMR spectrum of **8ak** in CD_3OD (400 MHz).

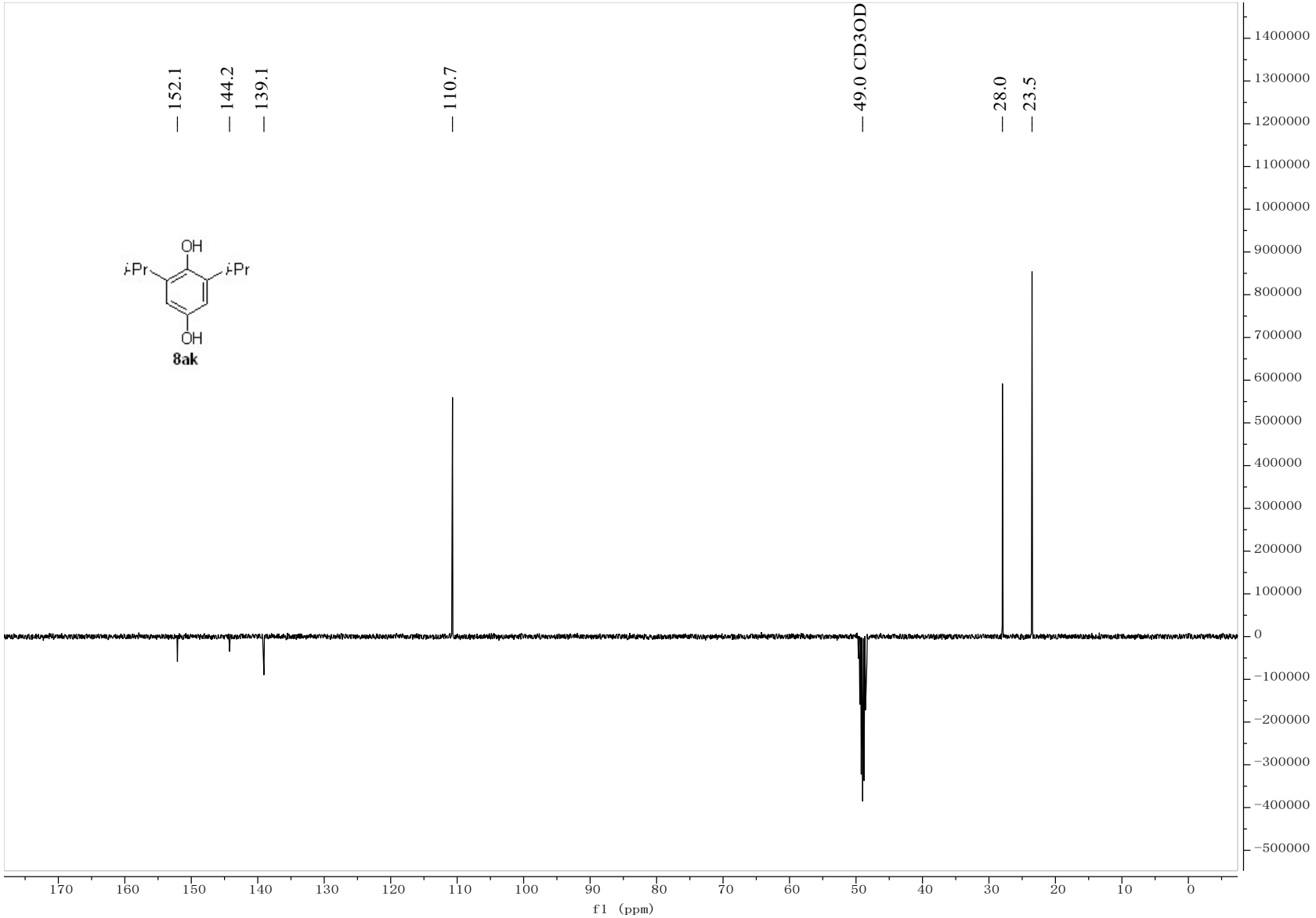


Figure S47. ^{13}C NMR spectrum of **8ak** in CD_3OD (100 MHz).

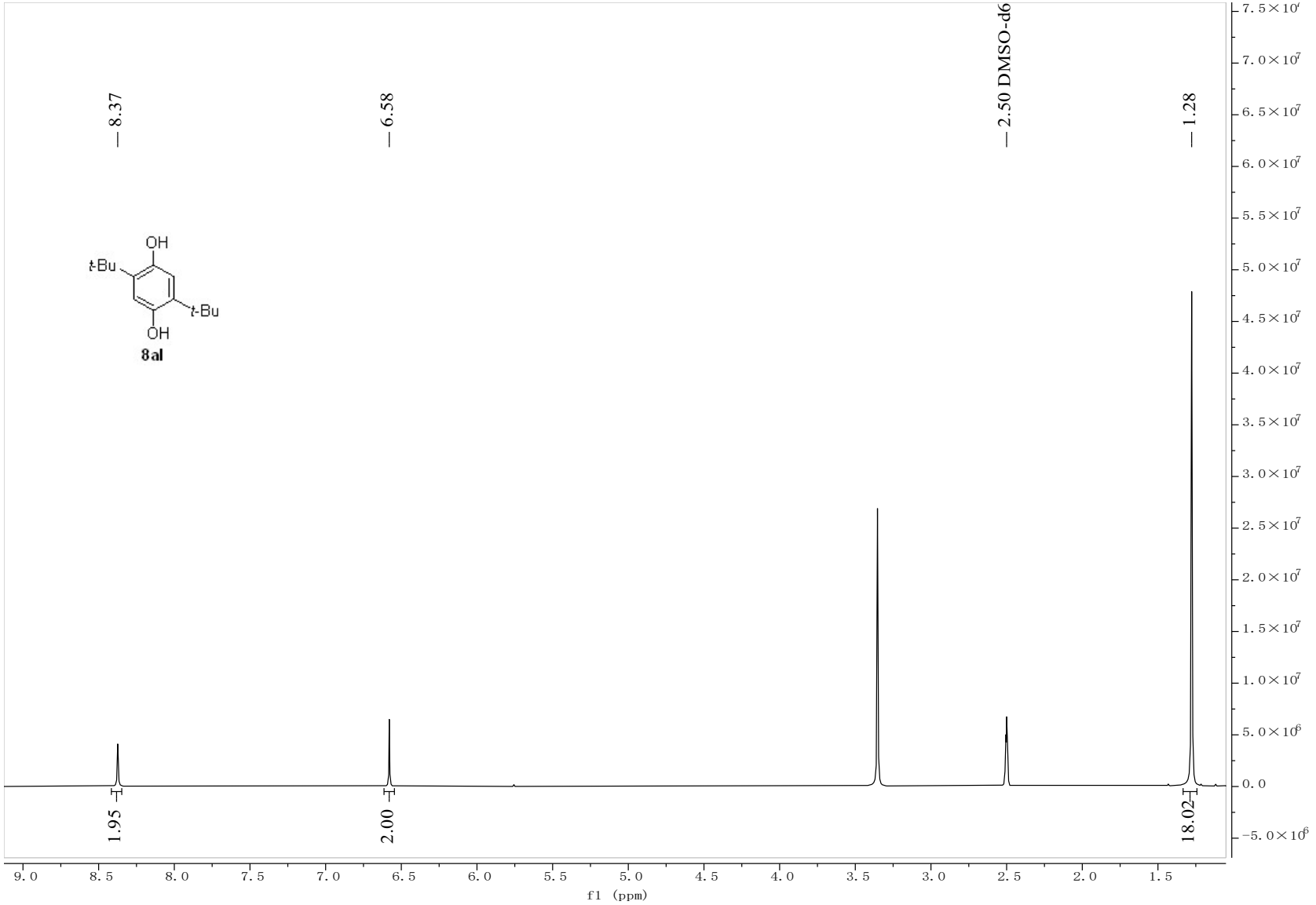


Figure S48. ^{1}H NMR spectrum of **8al** in DMSO-d_6 (400 MHz).

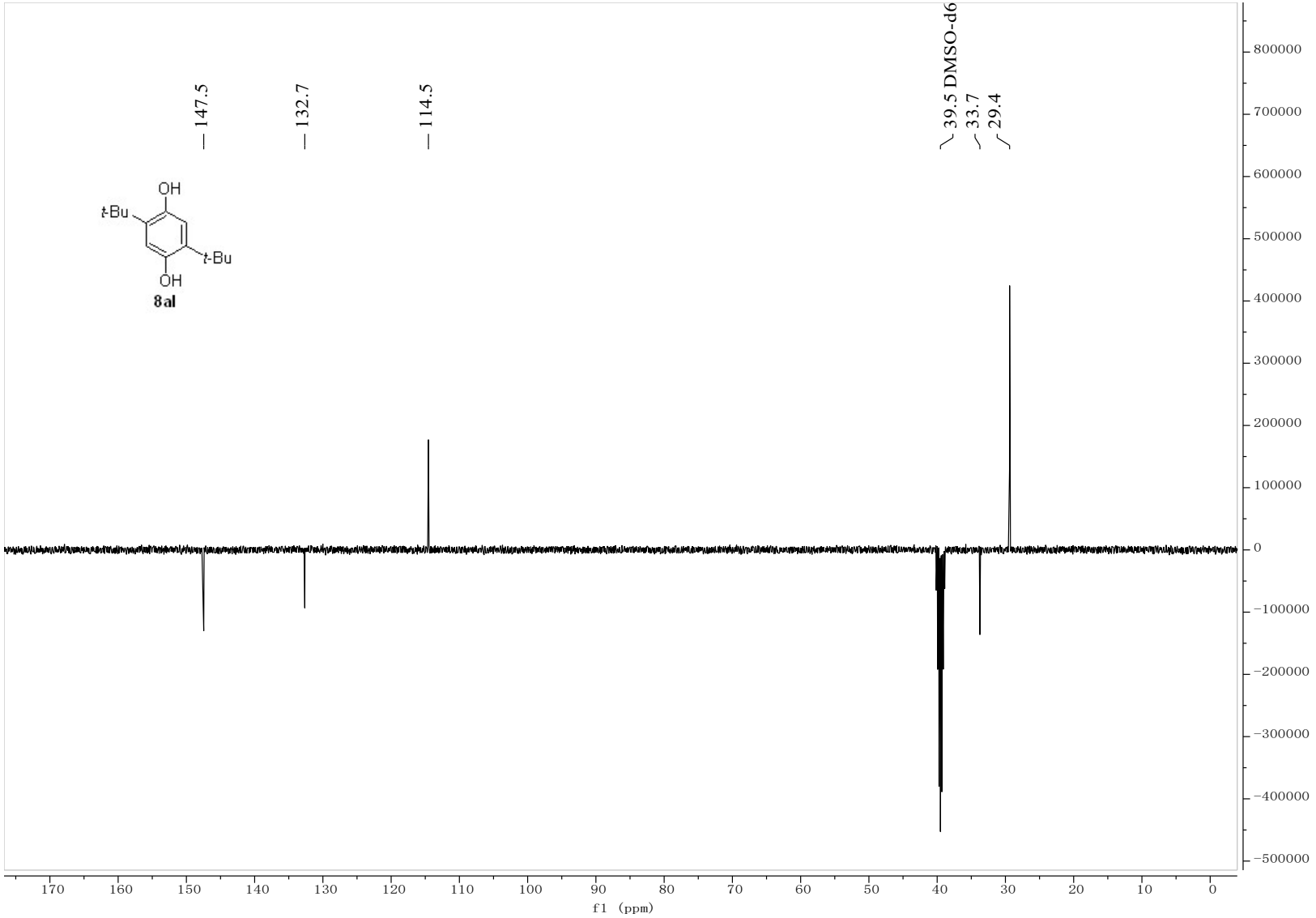


Figure S49. ^{13}C NMR spectrum of **8al** in DMSO-d_6 (100 MHz).

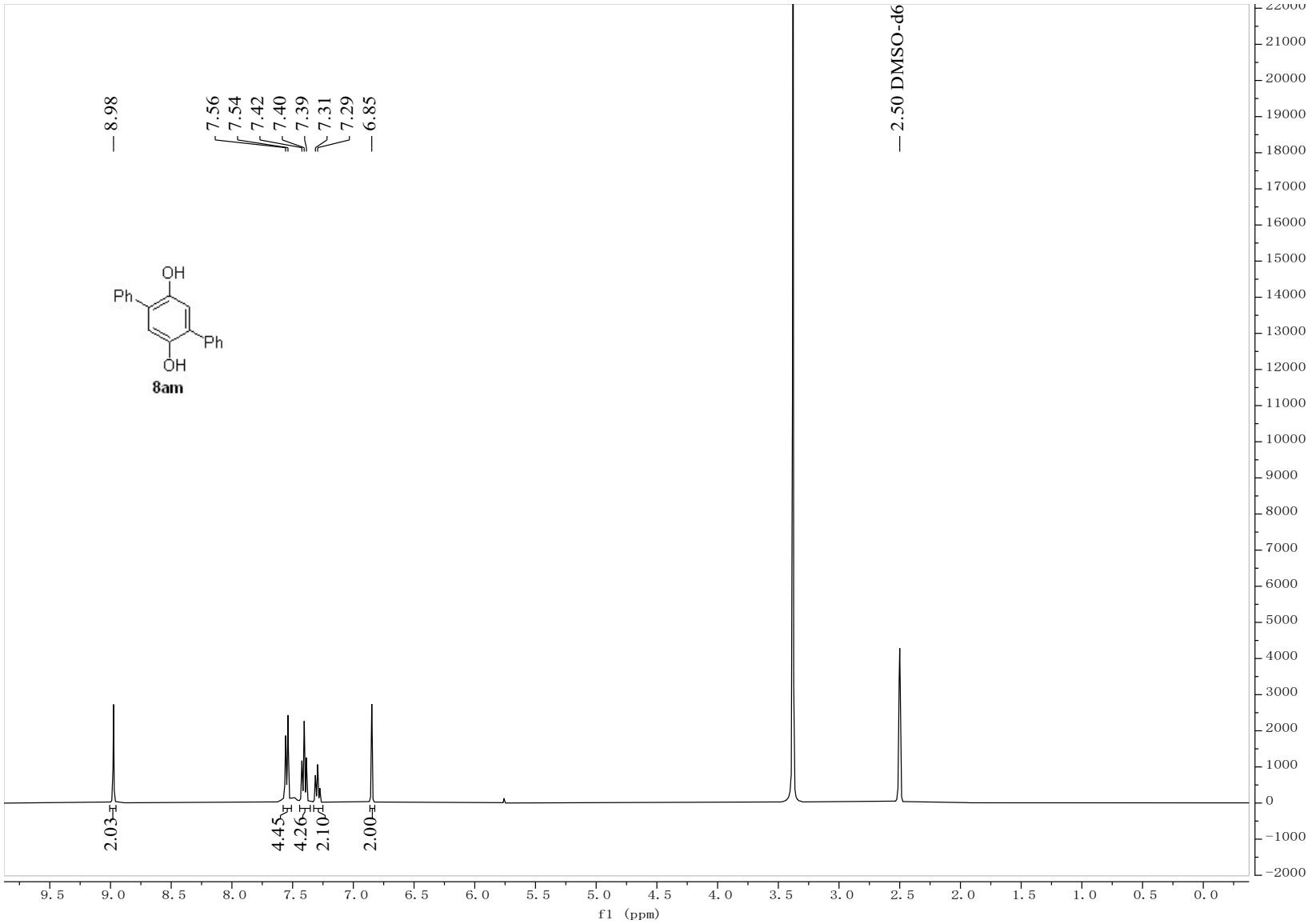


Figure S50. ^{1}H NMR spectrum of **8am** in DMSO-d_6 (400 MHz).

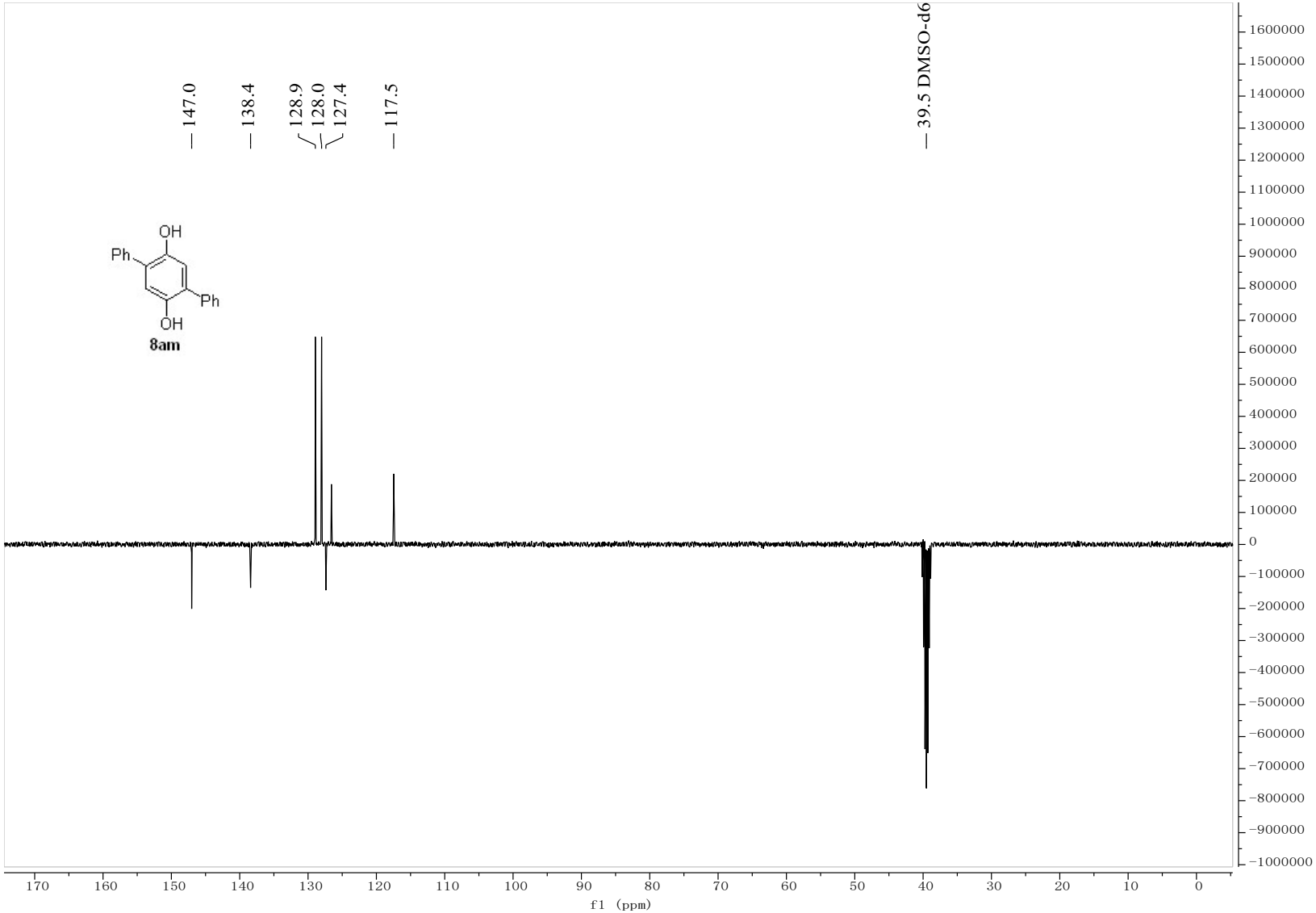


Figure S51. ^{13}C NMR spectrum of **8am** in DMSO-d_6 (100 MHz).

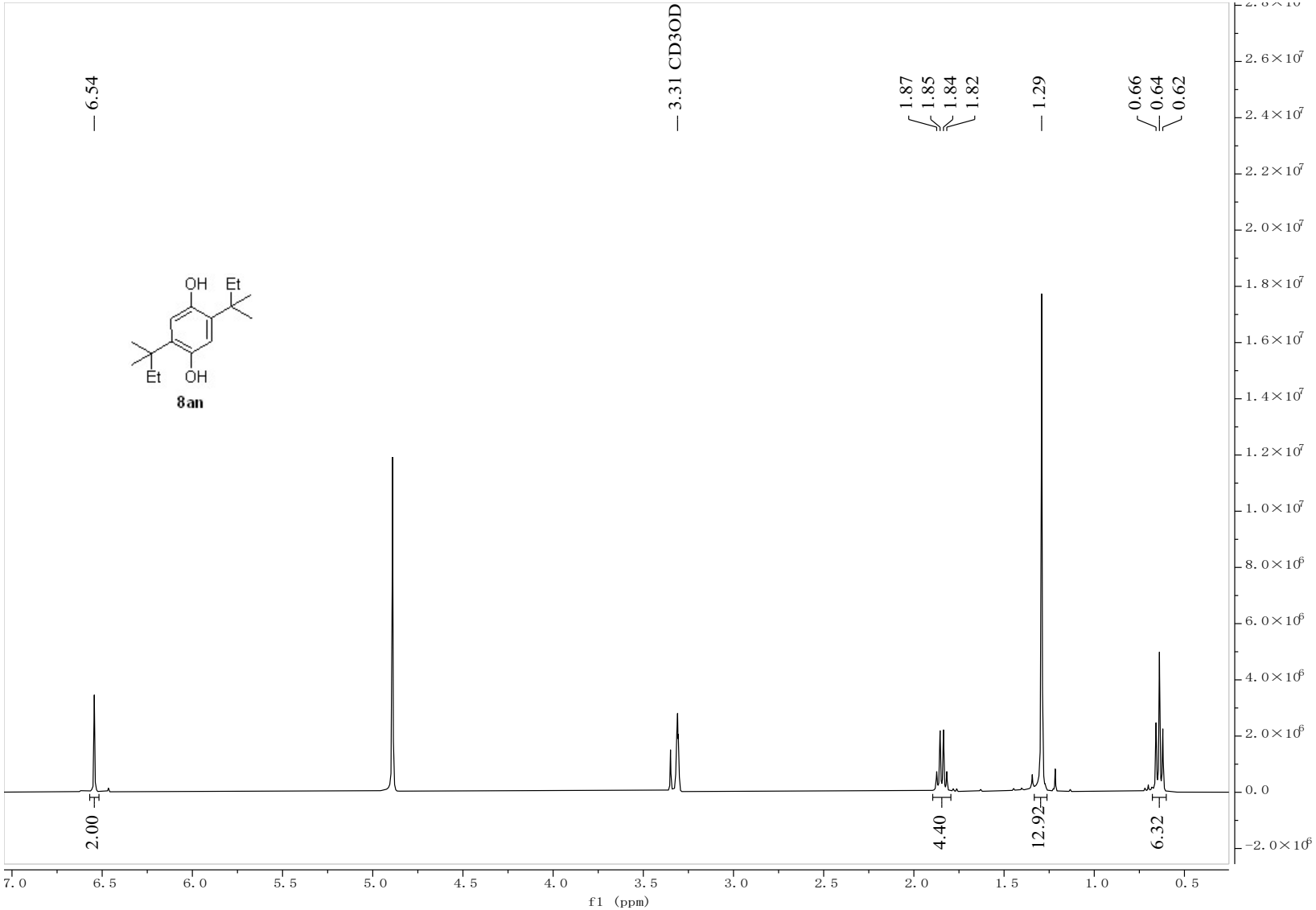


Figure S52. ^{1}H NMR spectrum of **8an** in CD_3OD (400 MHz).

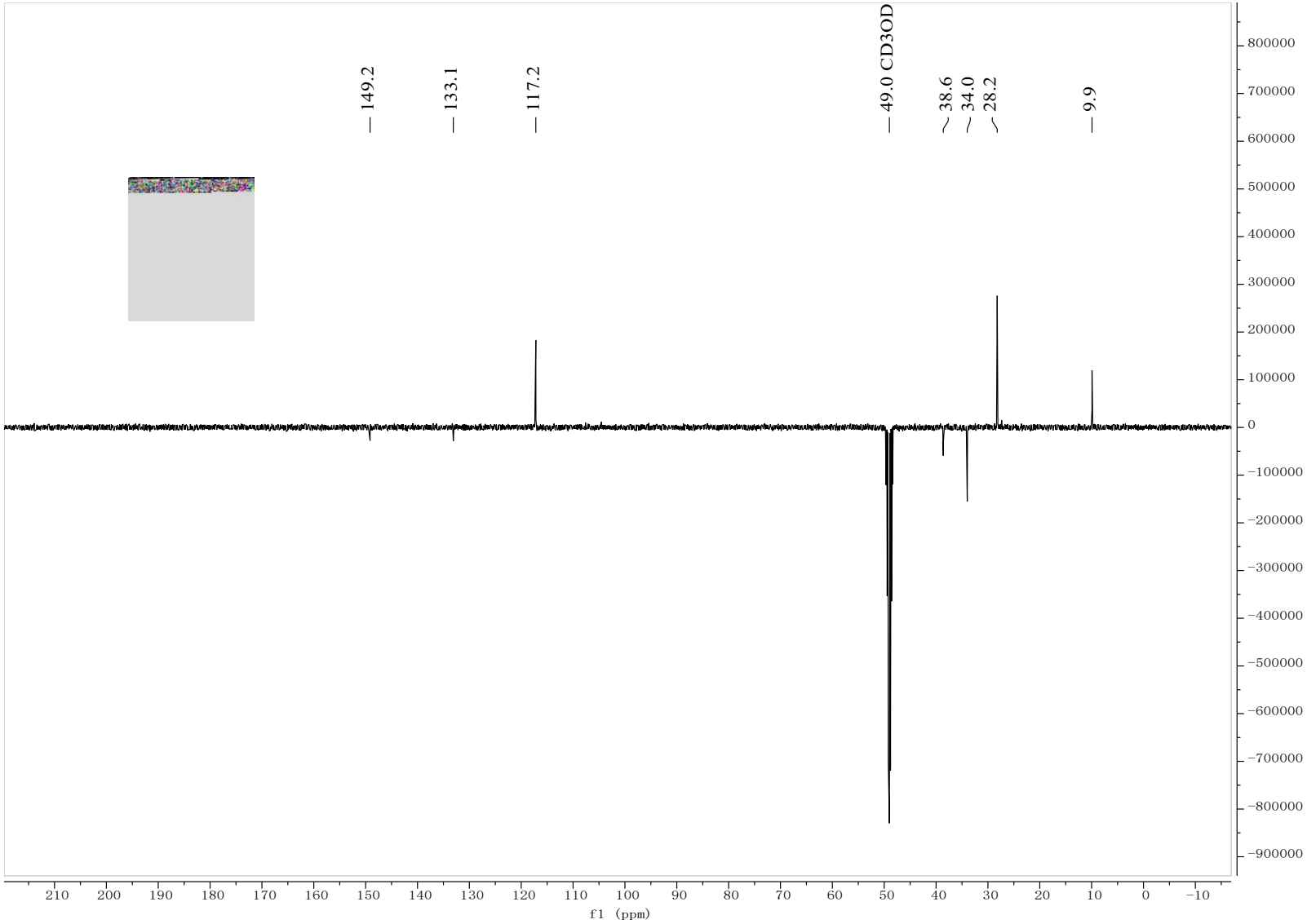


Figure S53. ^{13}C NMR spectrum of **8an** in CD_3OD (100 MHz).

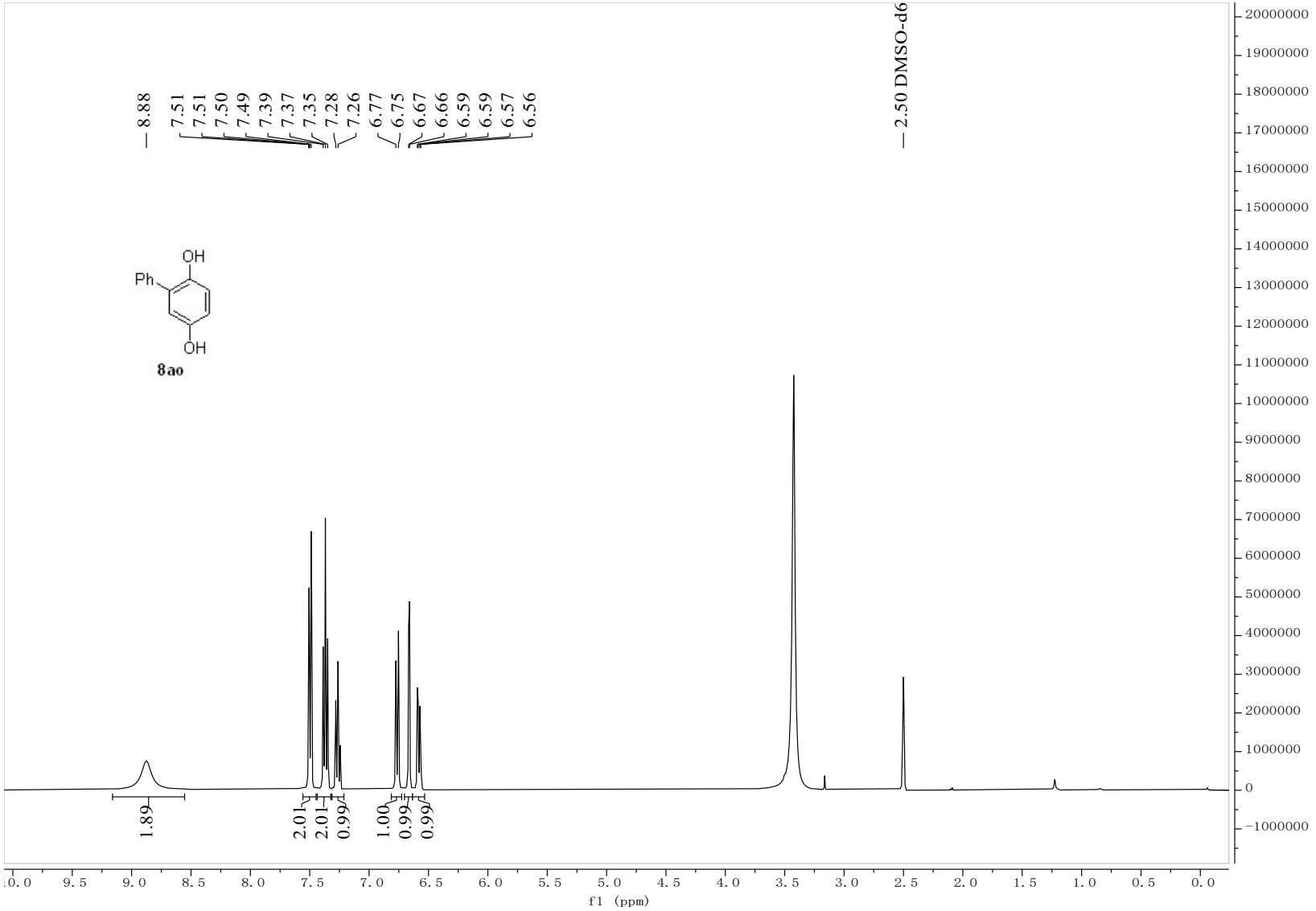


Figure S54. ^{1}H NMR spectrum of **8ao** in DMSO-d_6 (400 MHz).

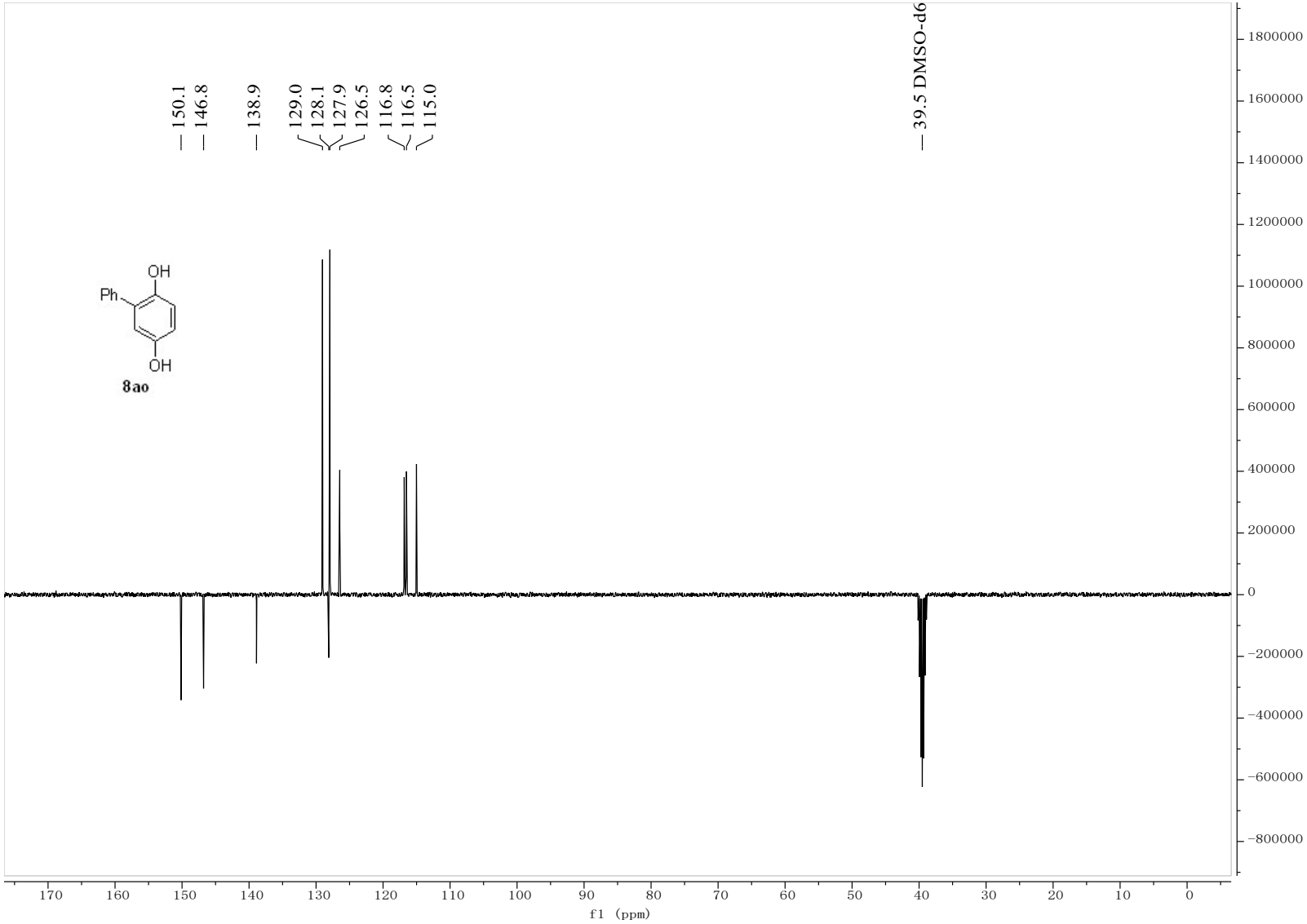


Figure S55. ^{13}C NMR spectrum of **8ao** in DMSO-d_6 (100 MHz).

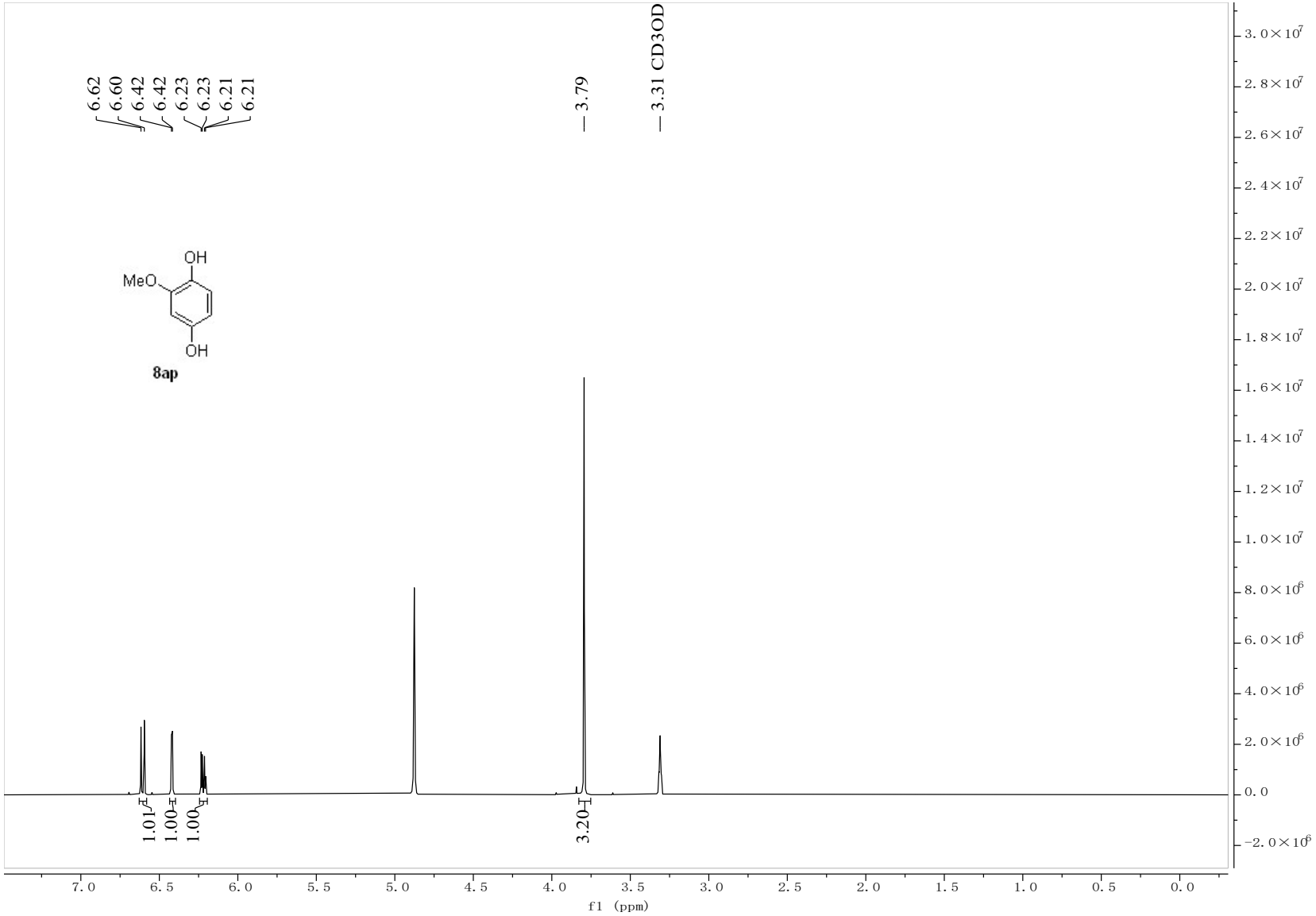


Figure S56. ^{1}H NMR spectrum of **8ap** in CD_3OD (400 MHz).

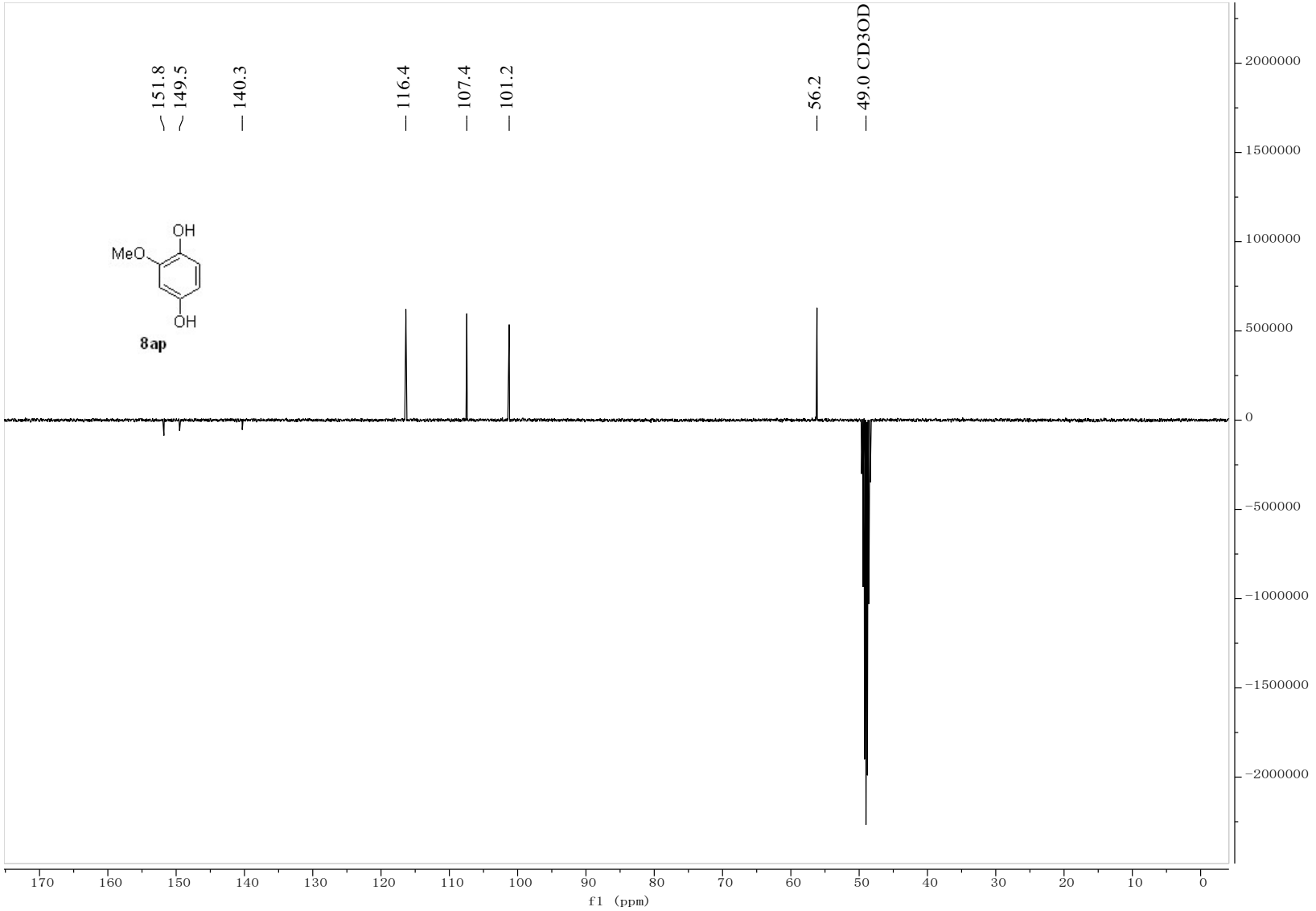


Figure S57. ^{13}C NMR spectrum of **8ap** in CD_3OD (100 MHz).

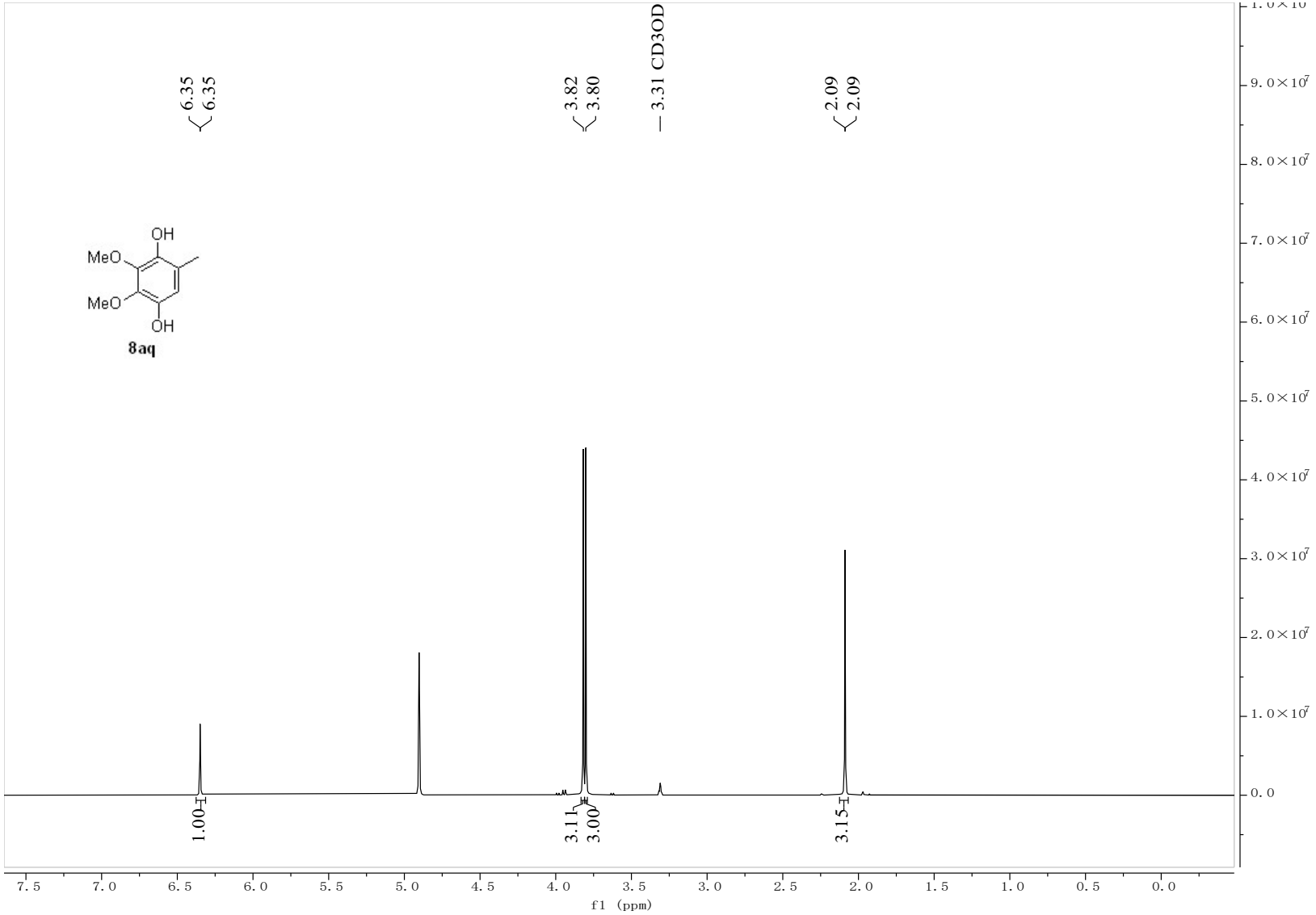


Figure S58. ^{1}H NMR spectrum of **8aq** in CD_3OD (400 MHz).

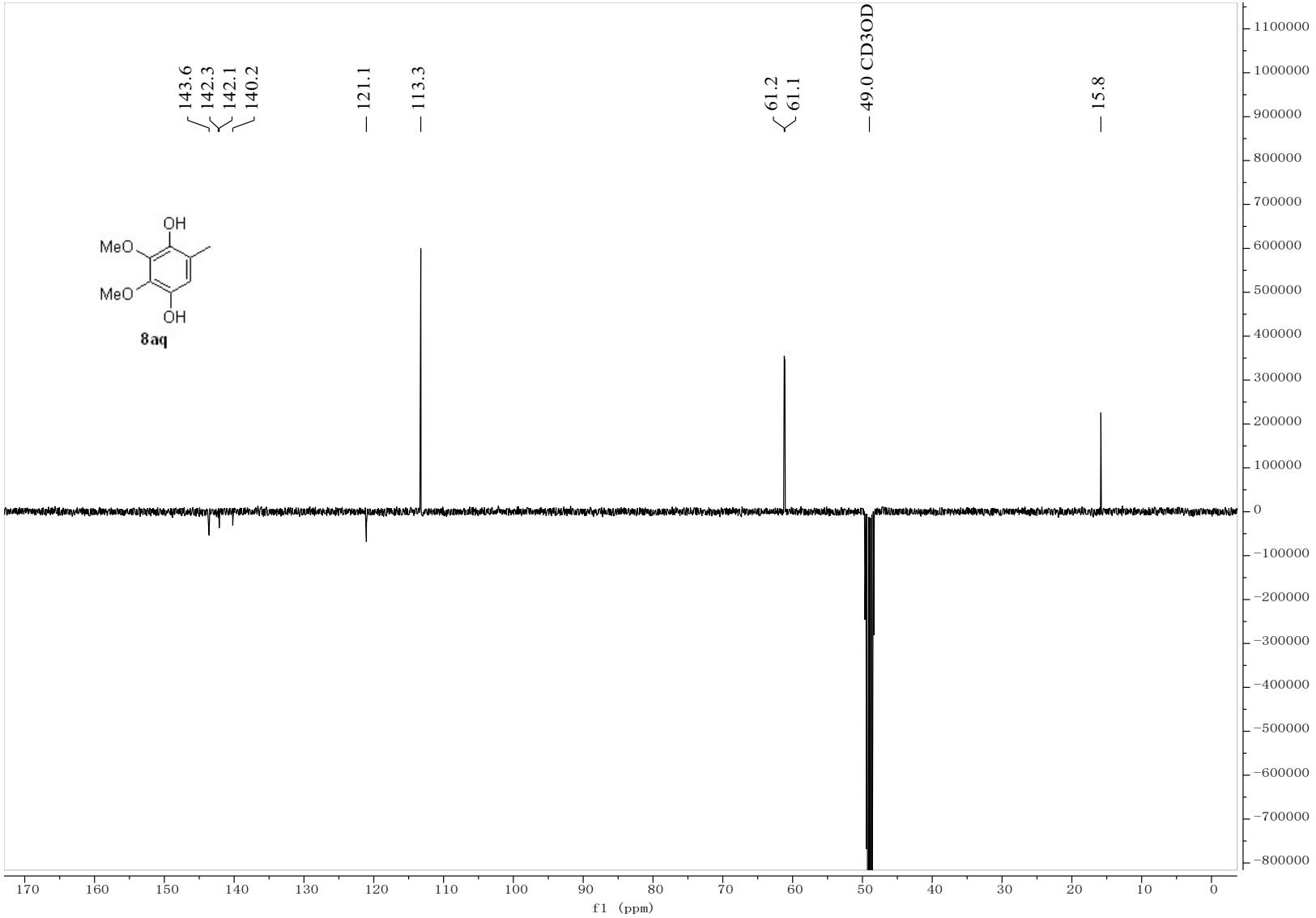


Figure S59. ^{13}C NMR spectrum of **8aq** in CD_3OD (100 MHz).

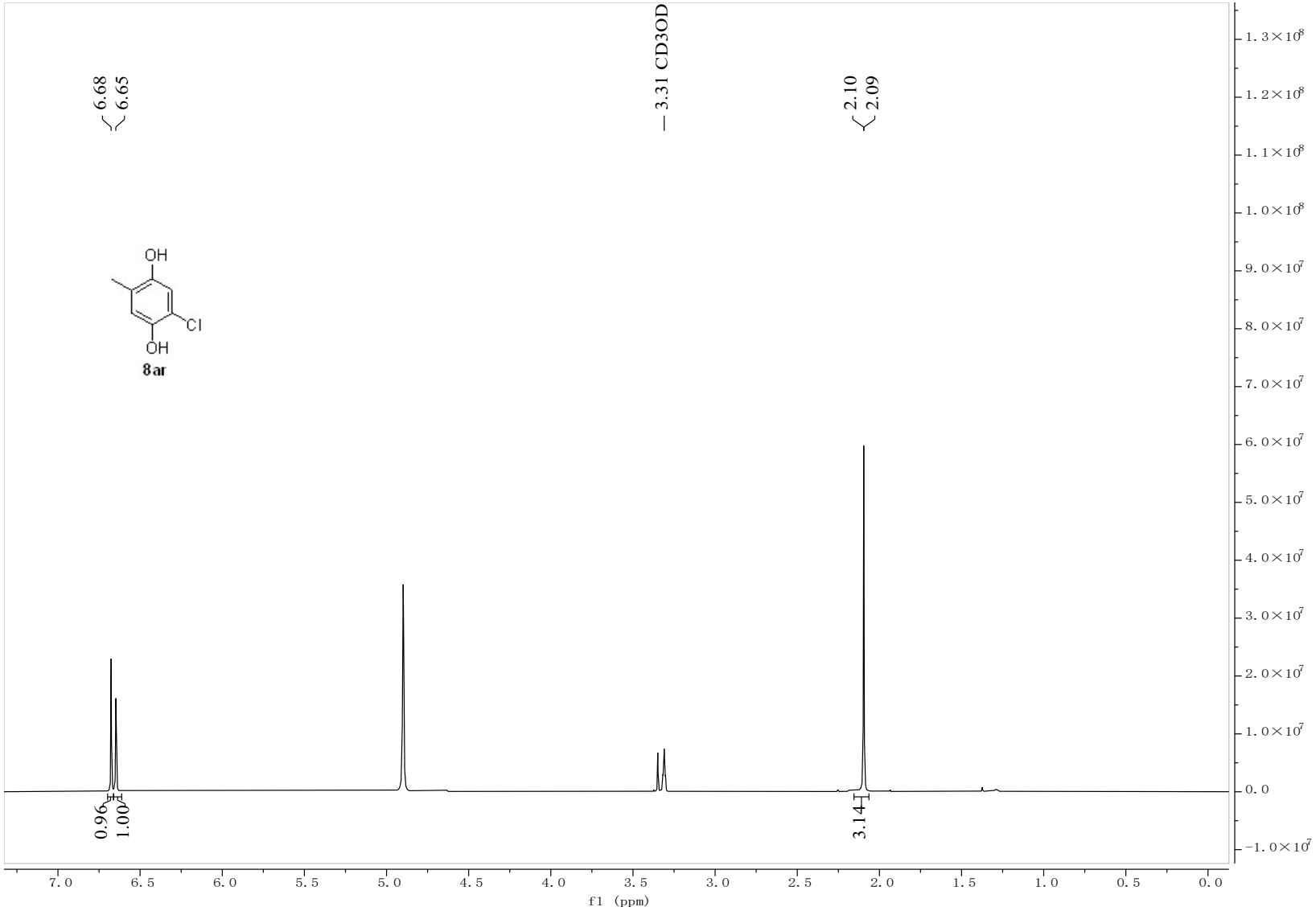


Figure S60. ^{1}H NMR spectrum of **8ar** in CD_3OD (400 MHz).

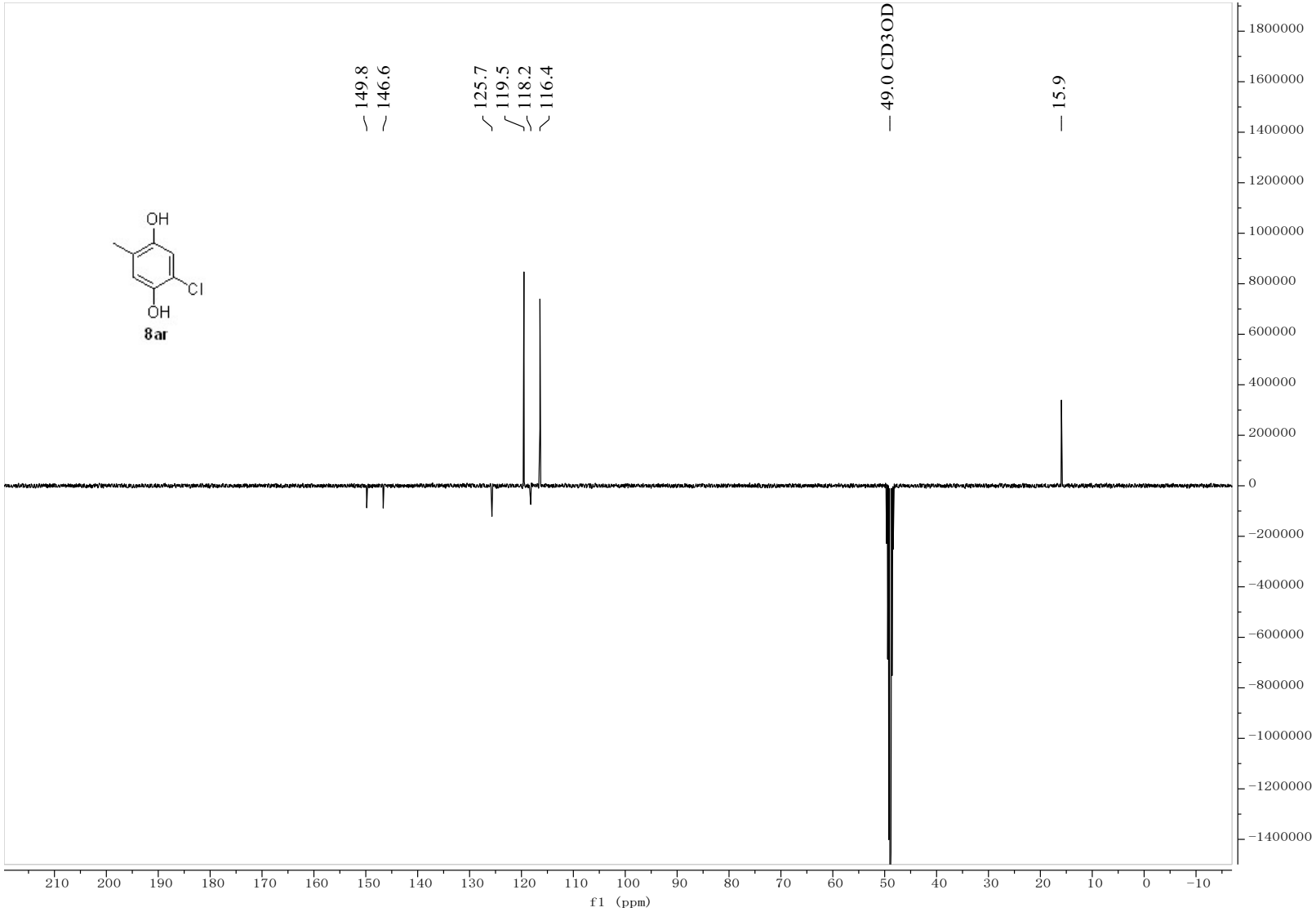


Figure S61. ^{13}C NMR spectrum of **8ar** in CD_3OD (100 MHz).

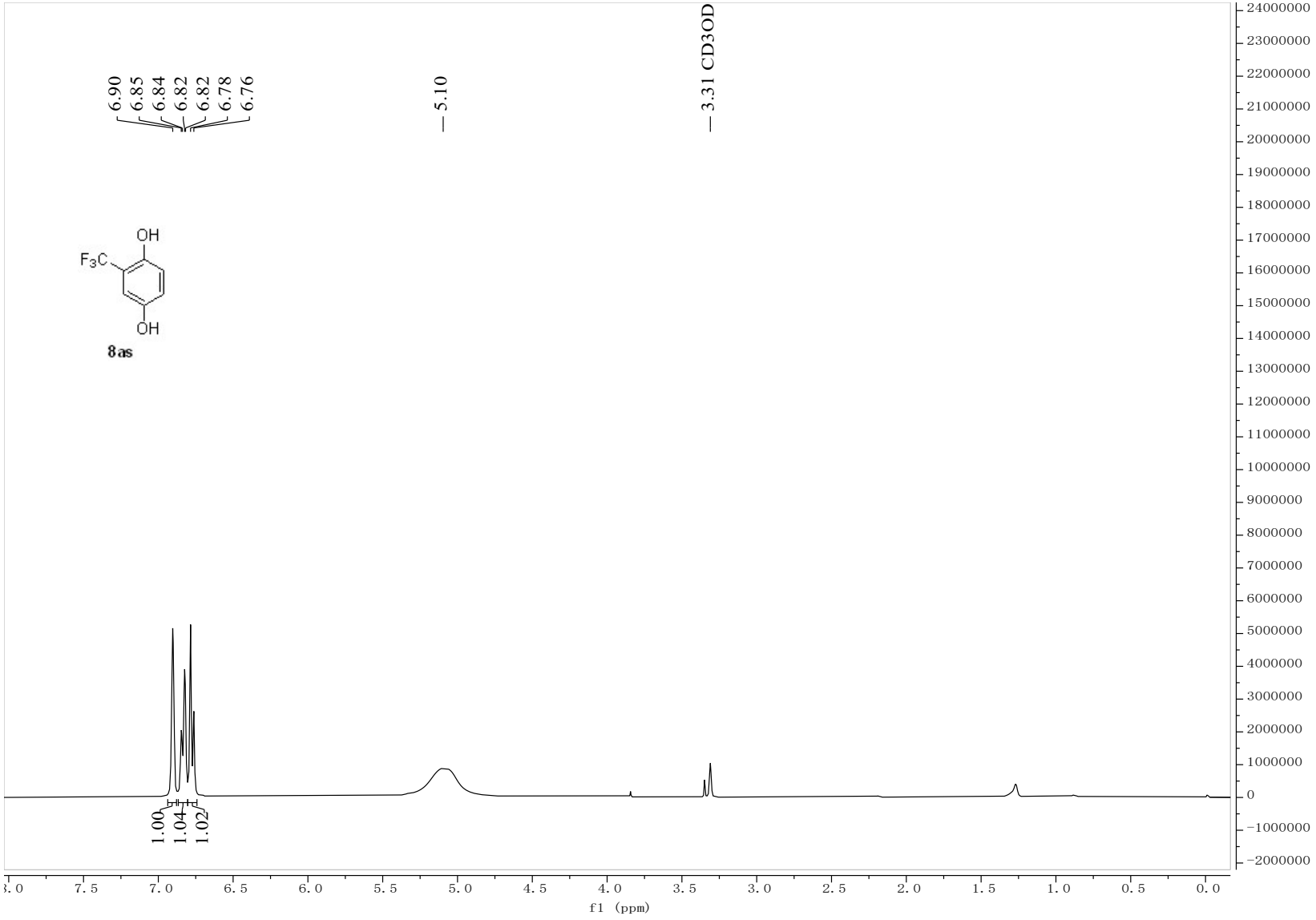


Figure S62. ^{1}H NMR spectrum of **8as** in CD_3OD (400 MHz).

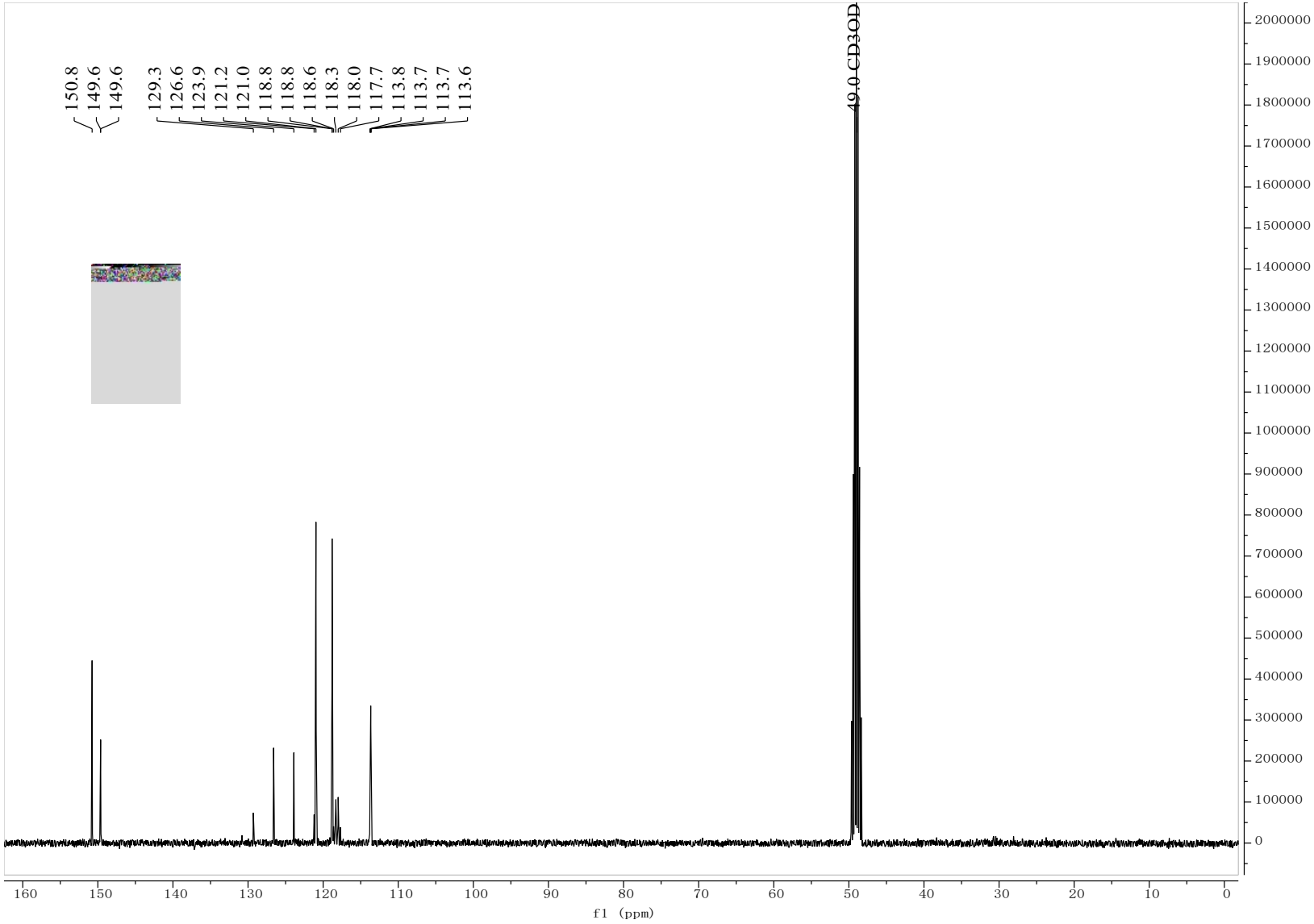


Figure S63. ^{13}C NMR spectrum of **8as** in CD_3OD (100 MHz).

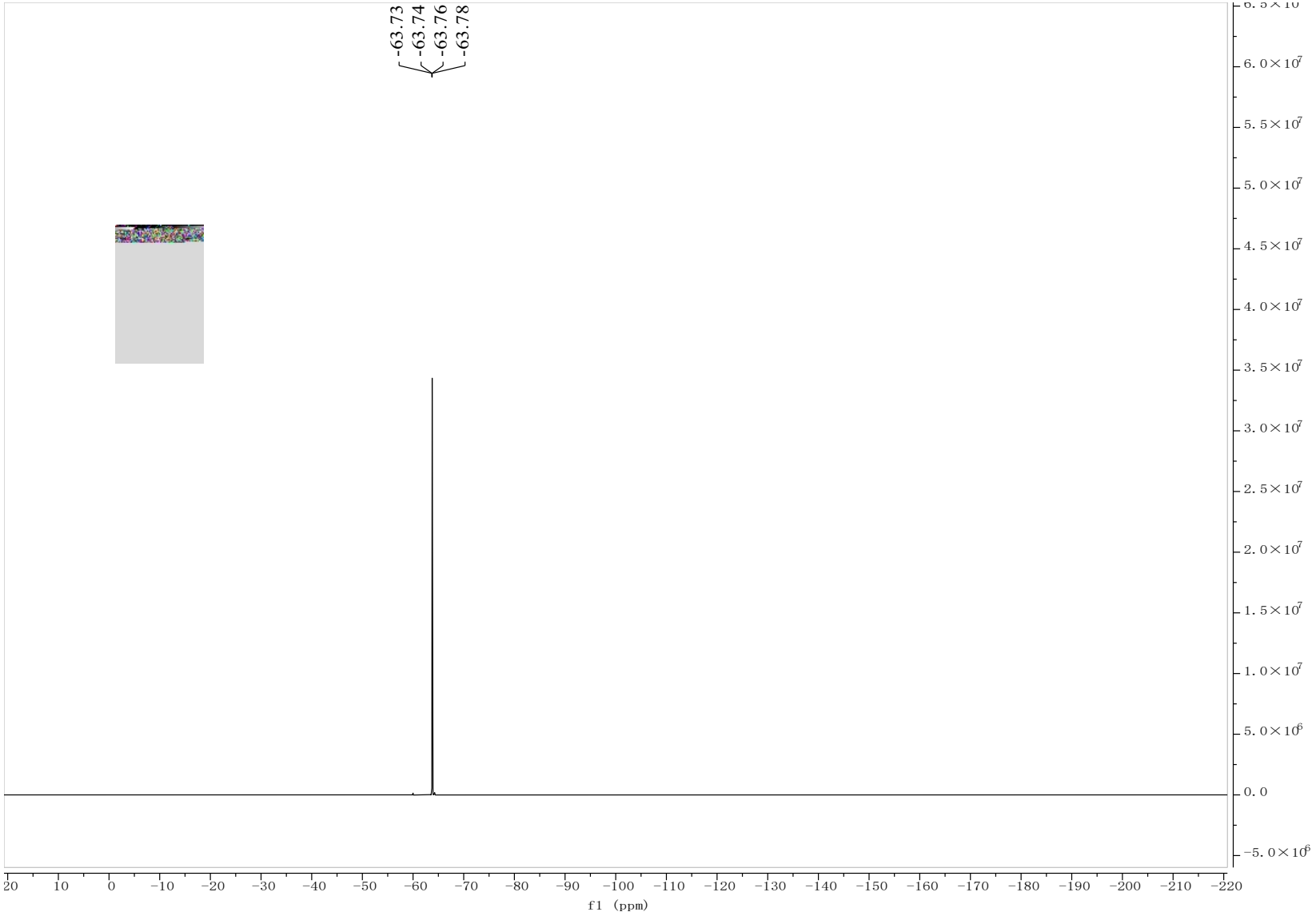


Figure S64. ^{19}F NMR spectrum of **8as** in CD_3OD (376 MHz).

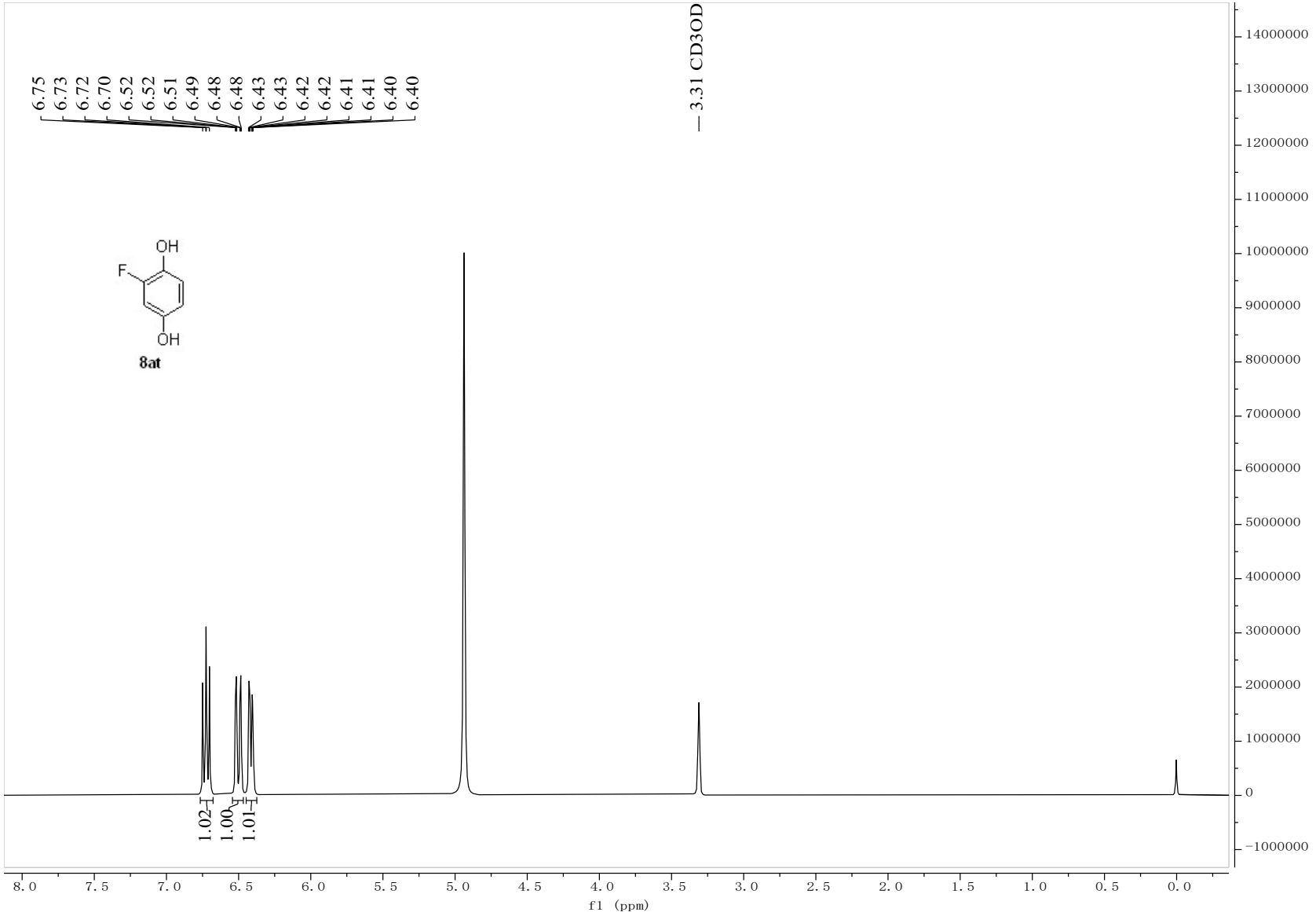


Figure S65. ^{1}H NMR spectrum of **8at** in CD_3OD (400 MHz).

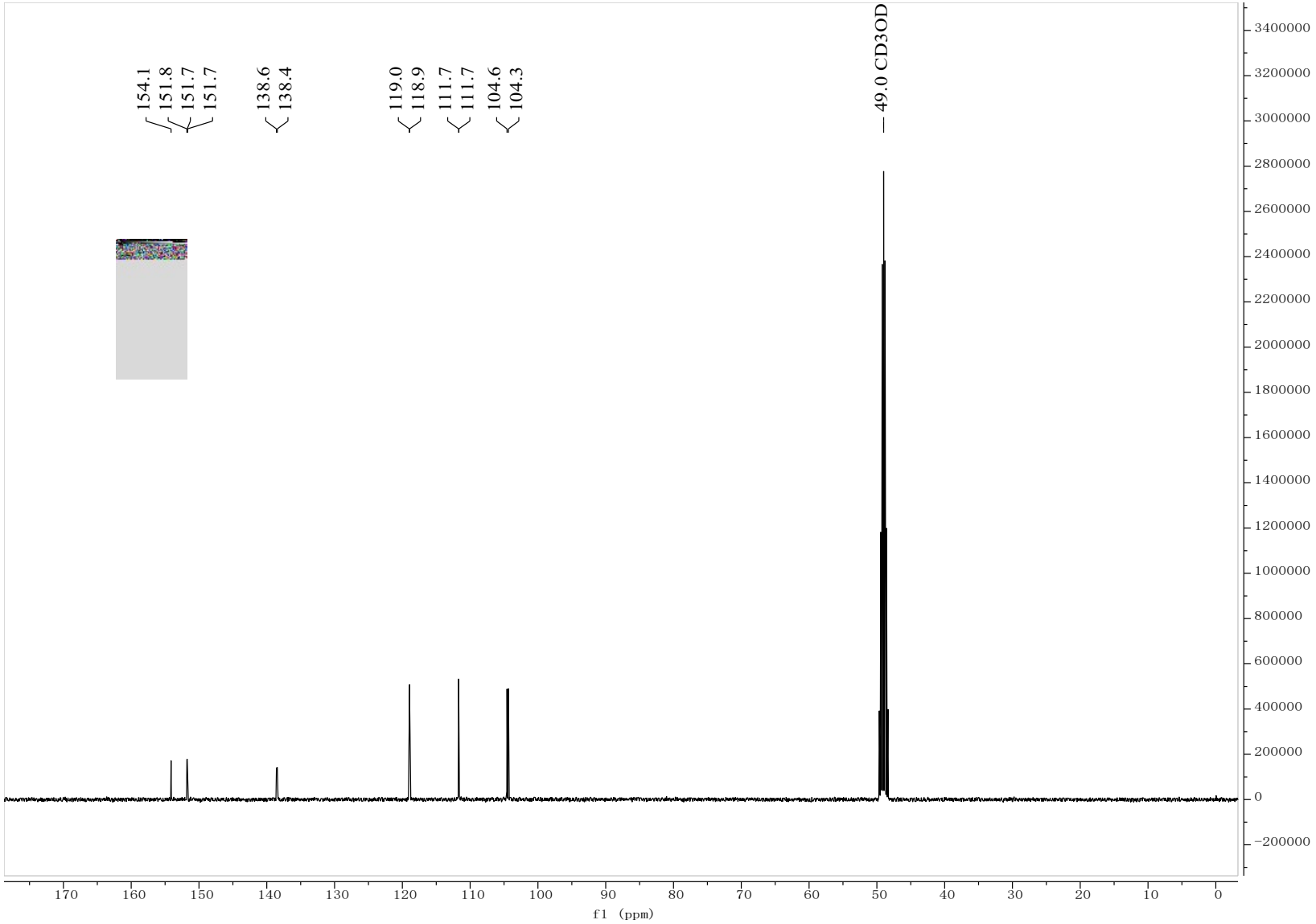


Figure S66. ^{13}C NMR spectrum of **8at** in CD_3OD (100 MHz).

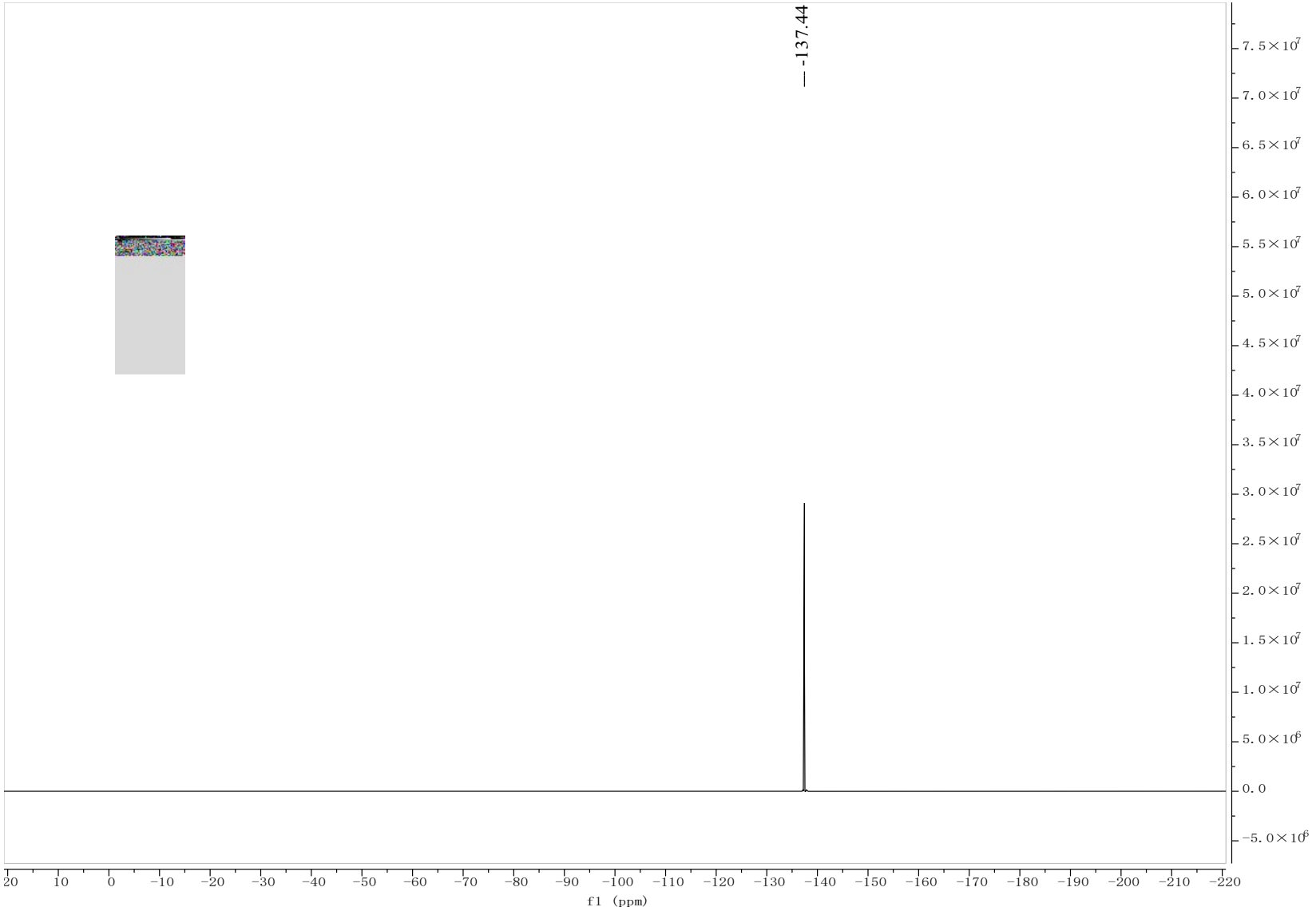


Figure S67. ^{19}F NMR spectrum of **8at** in CD_3OD (376 MHz).

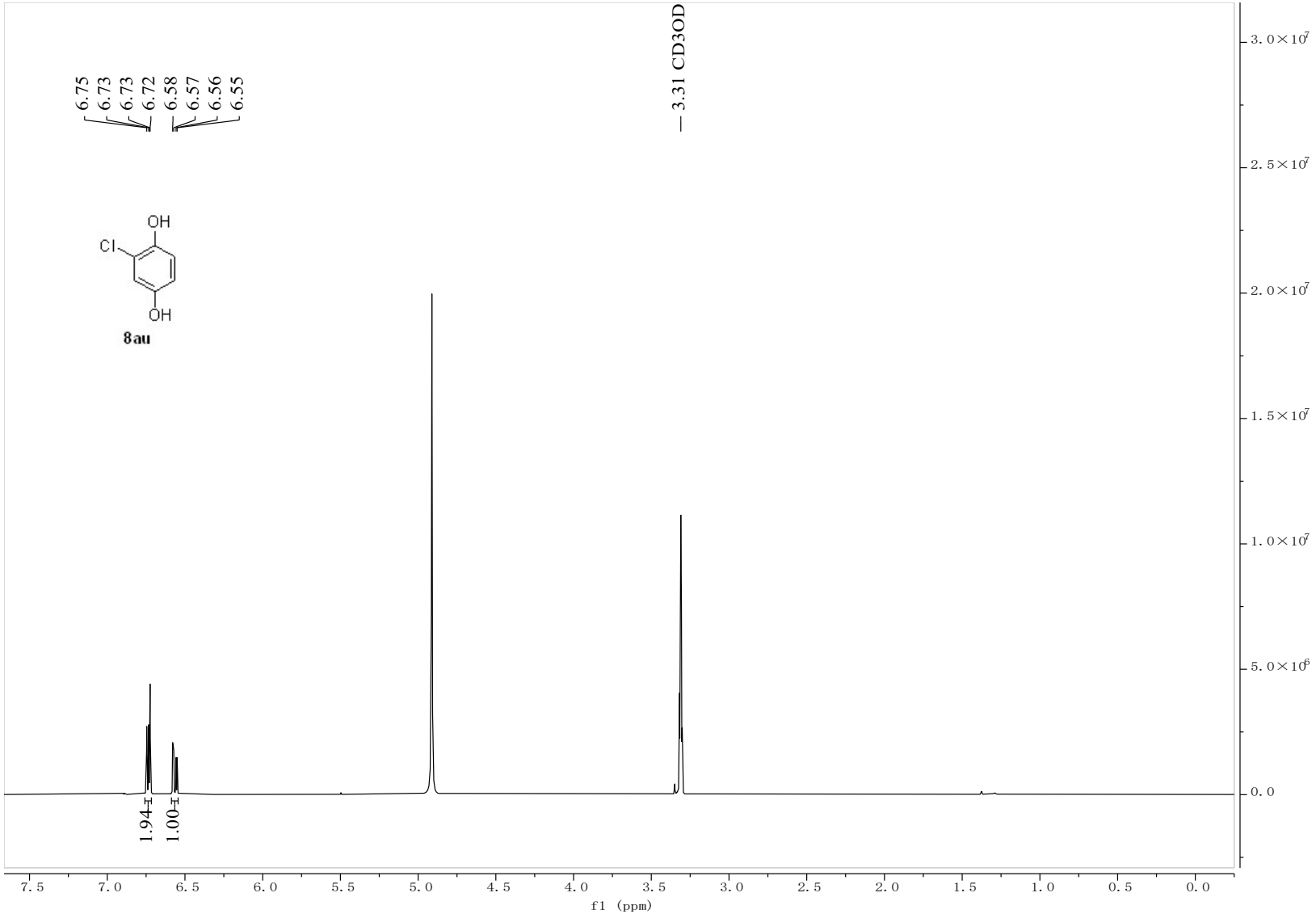


Figure S68. ^{1}H NMR spectrum of **8au** in CD_3OD (400 MHz).

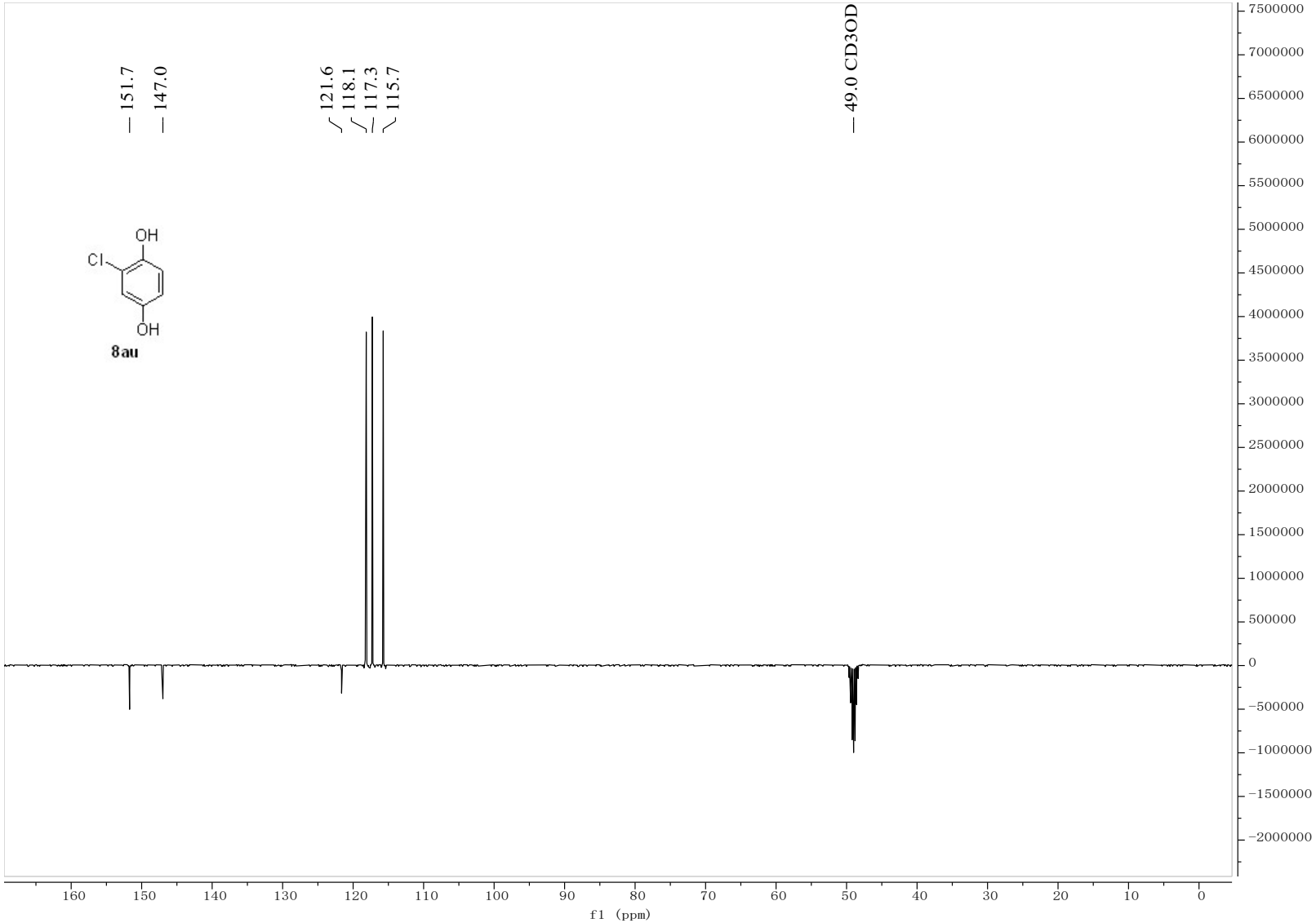


Figure S69. ^{13}C NMR spectrum of **8au** in CD_3OD (100 MHz).

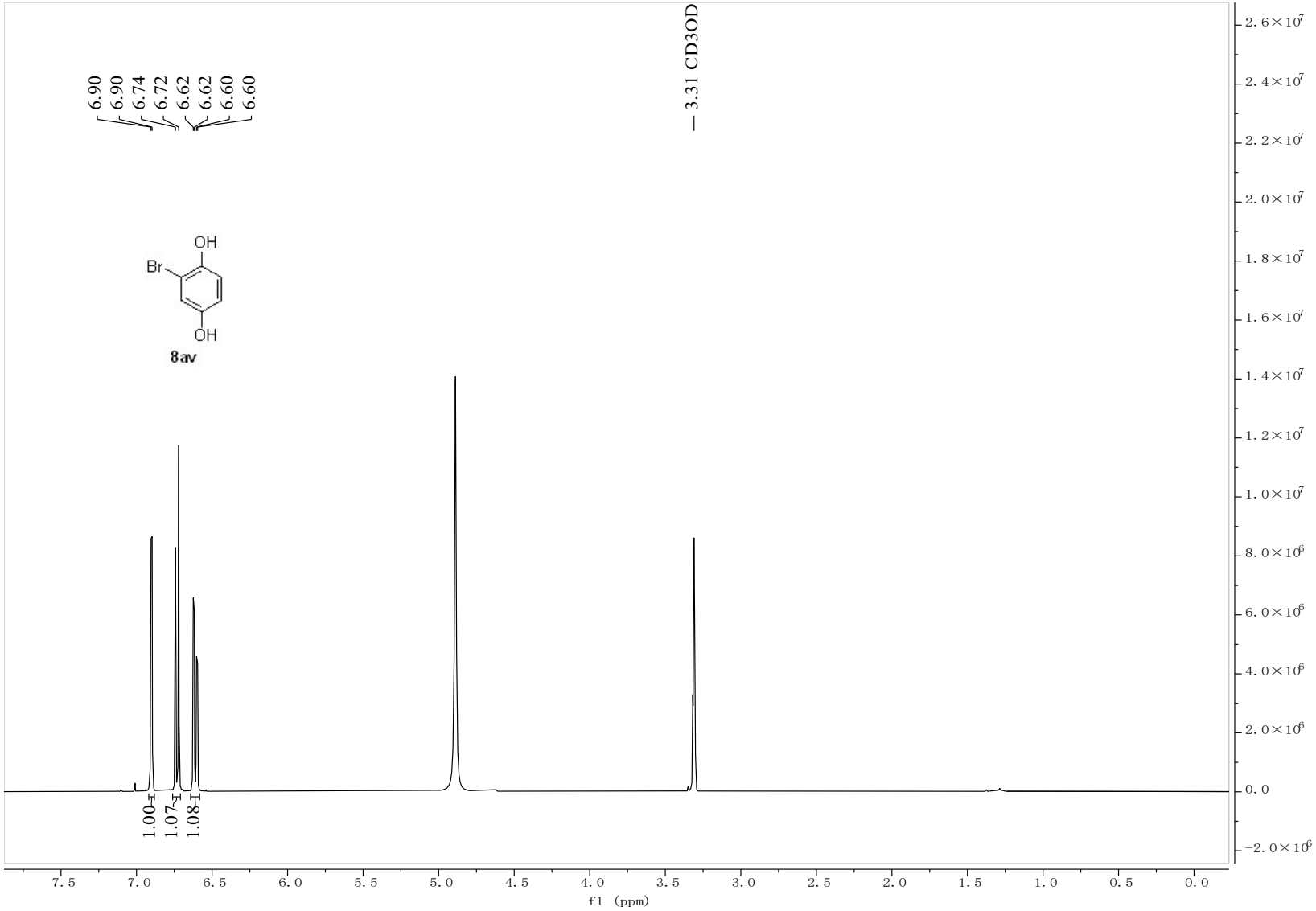


Figure S70. ^{1}H NMR spectrum of **8av** in CD_3OD (400 MHz).

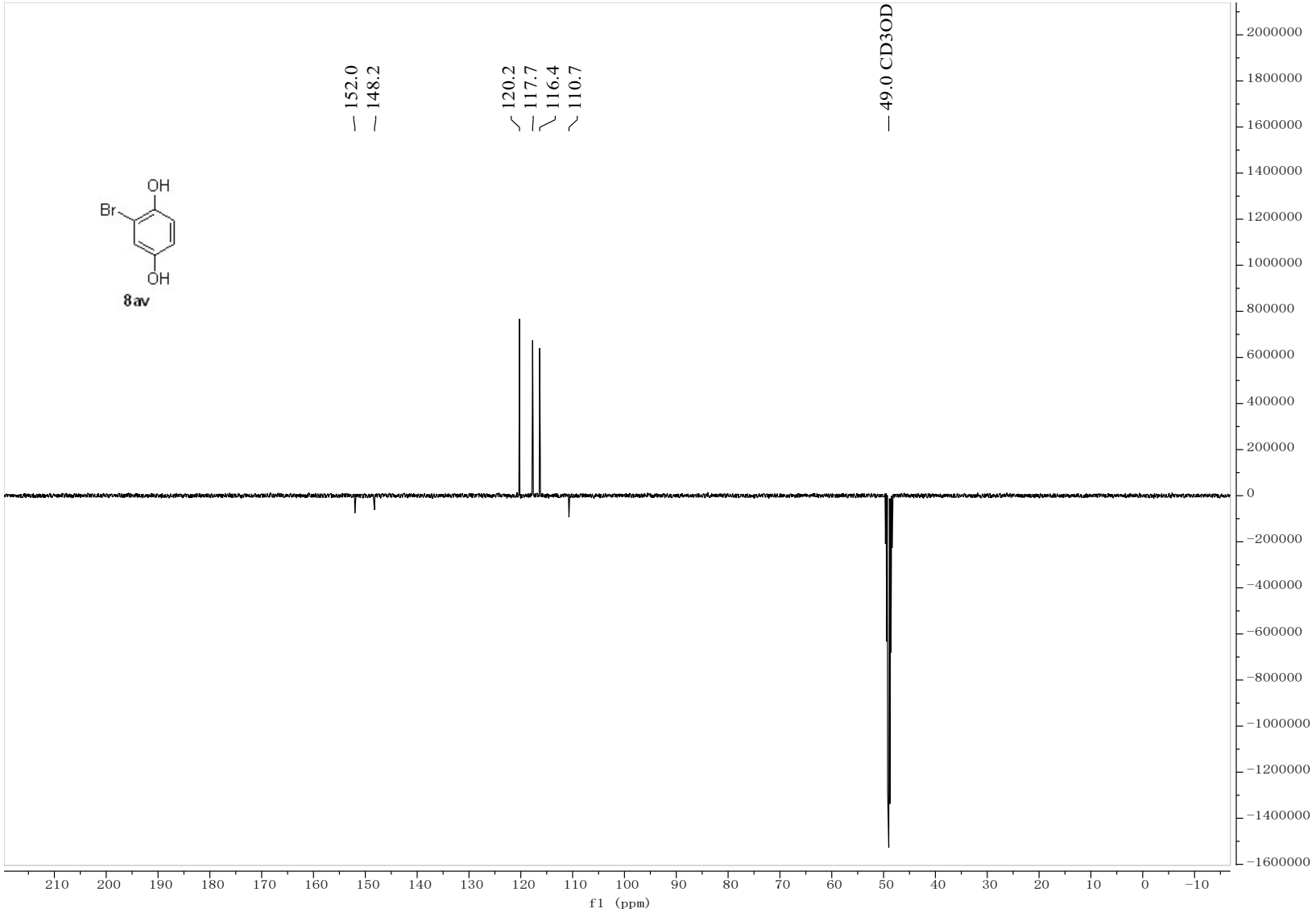


Figure S71. ^{13}C NMR spectrum of **8av** in CD_3OD (100 MHz).

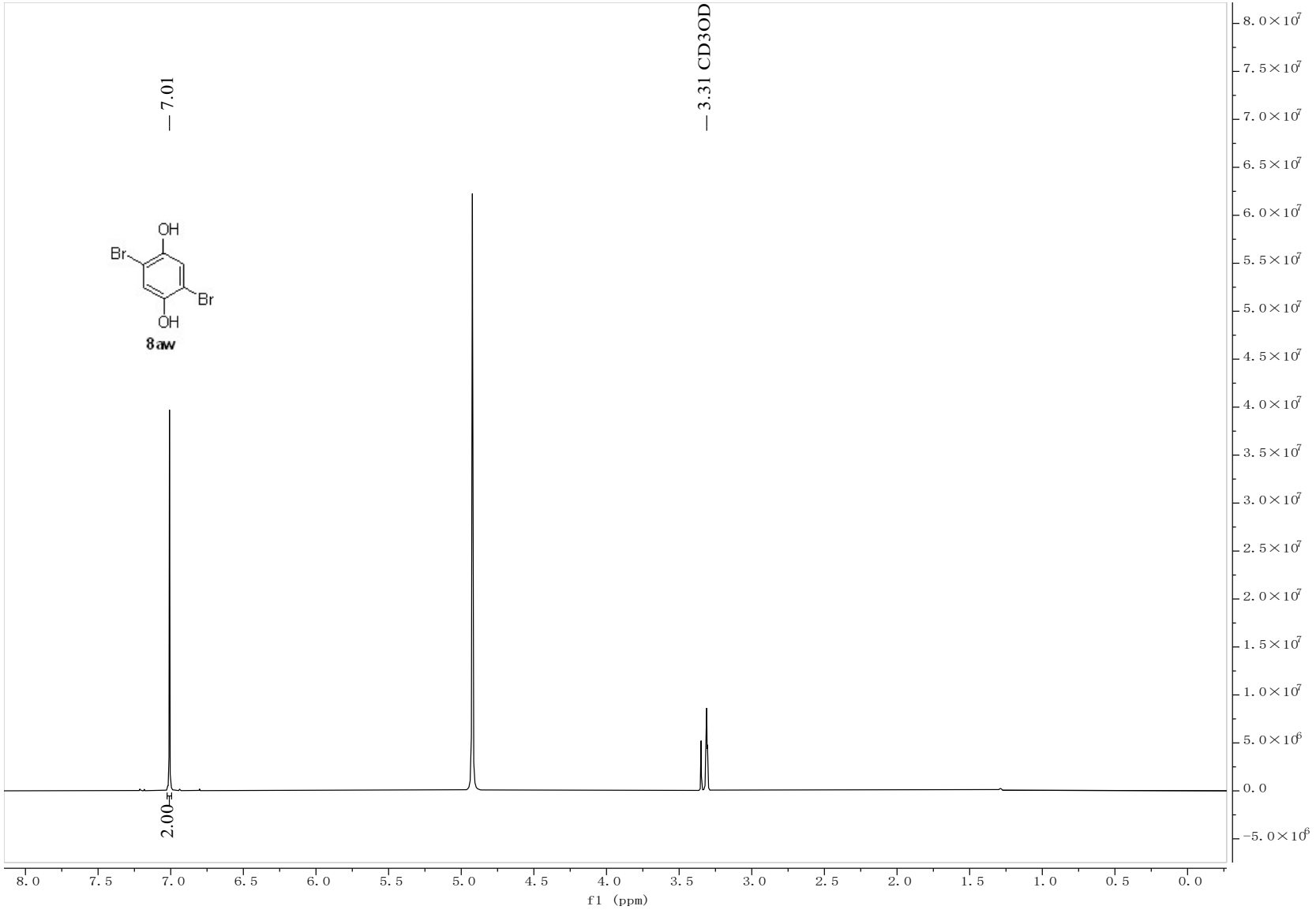


Figure S72. ^{1}H NMR spectrum of **8aw** in CD_3OD (400 MHz).

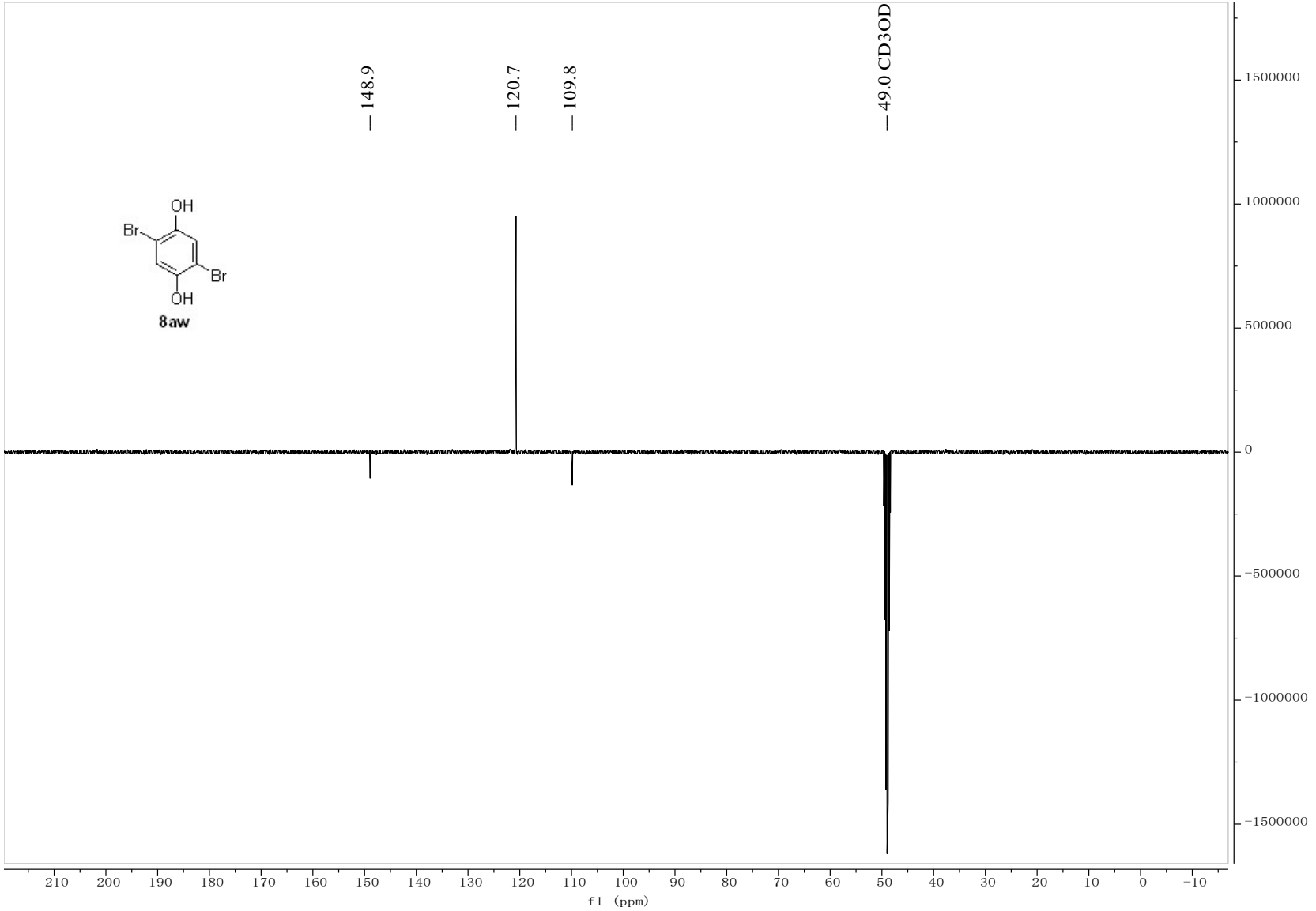


Figure S73. ^{13}C NMR spectrum of **8aw** in CD_3OD (100 MHz).

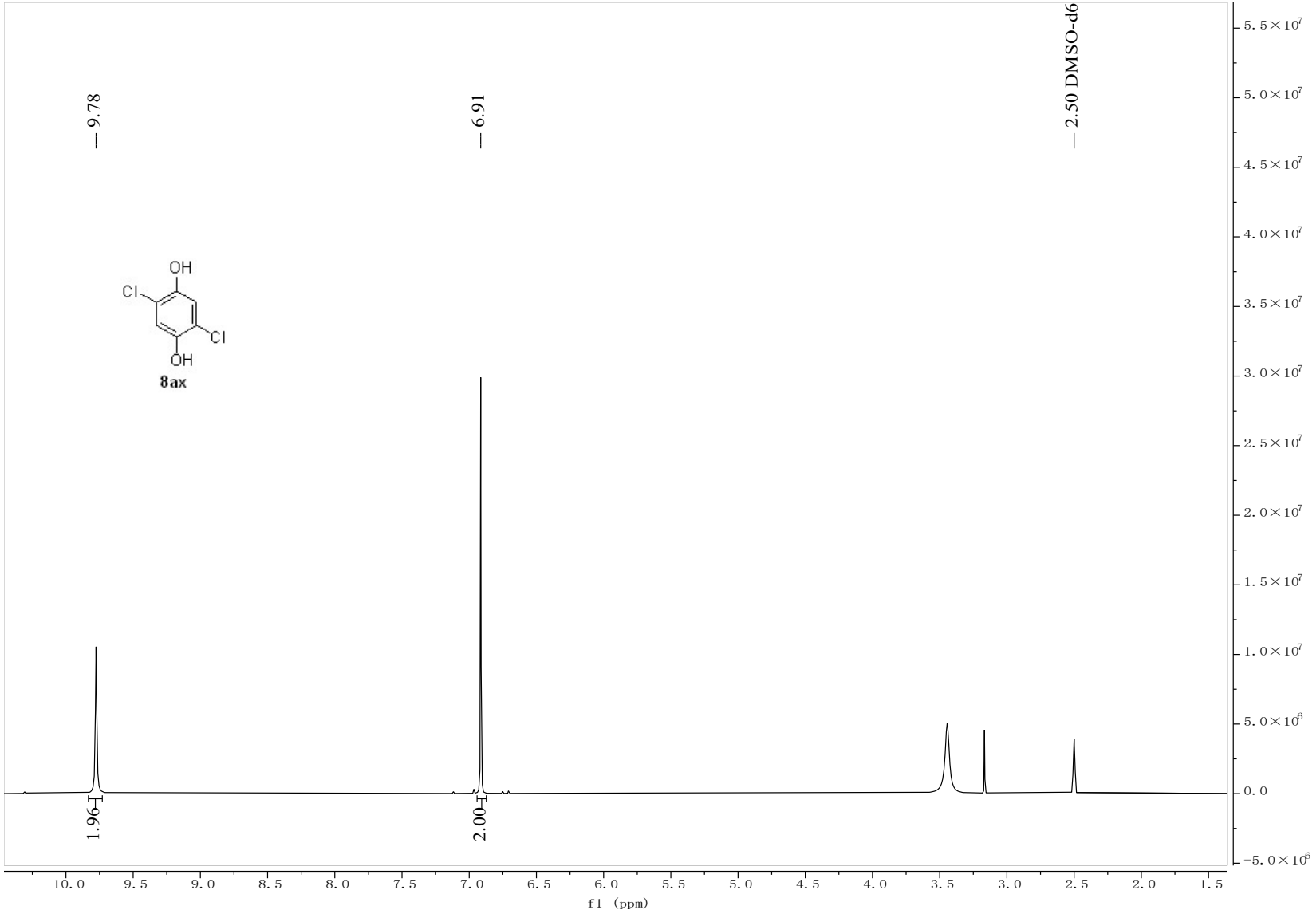


Figure S74. ^{1}H NMR spectrum of **8ax** in DMSO-d_6 (400 MHz).

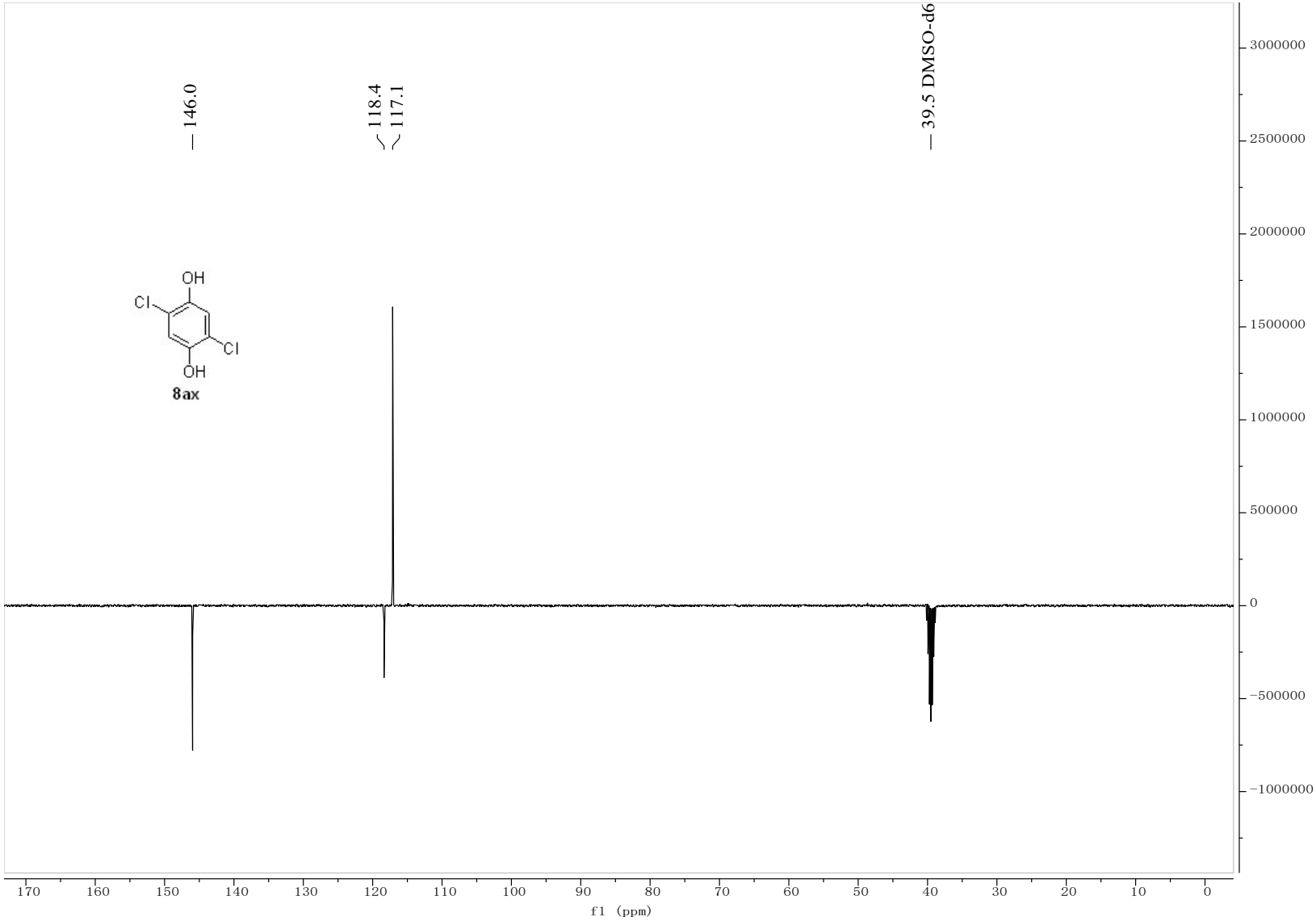


Figure S75. ^{13}C NMR spectrum of **8ax** in DMSO-d_6 (100 MHz).

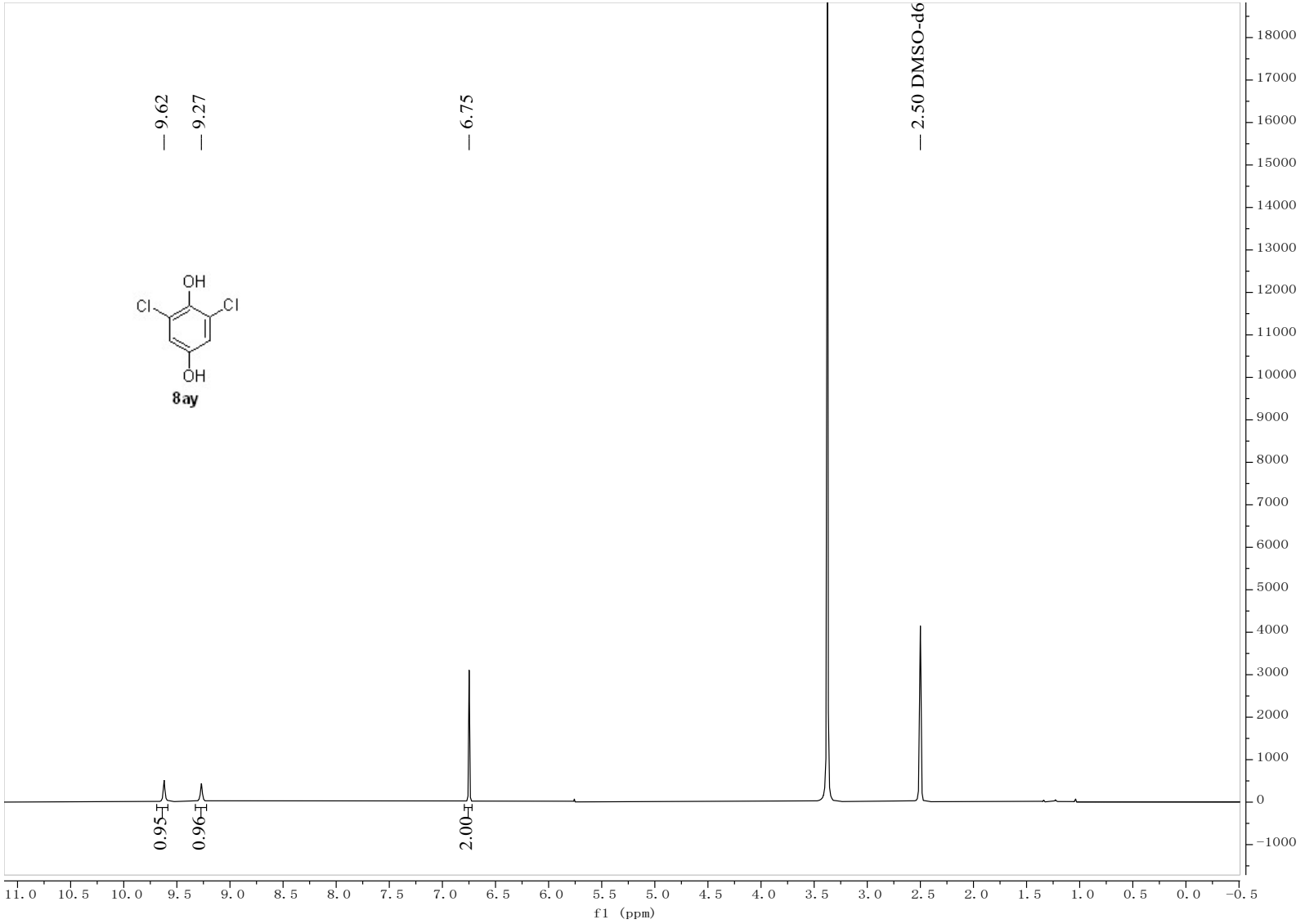


Figure S76. ^{1}H NMR spectrum of **8ay** in DMSO-d_6 (400 MHz).

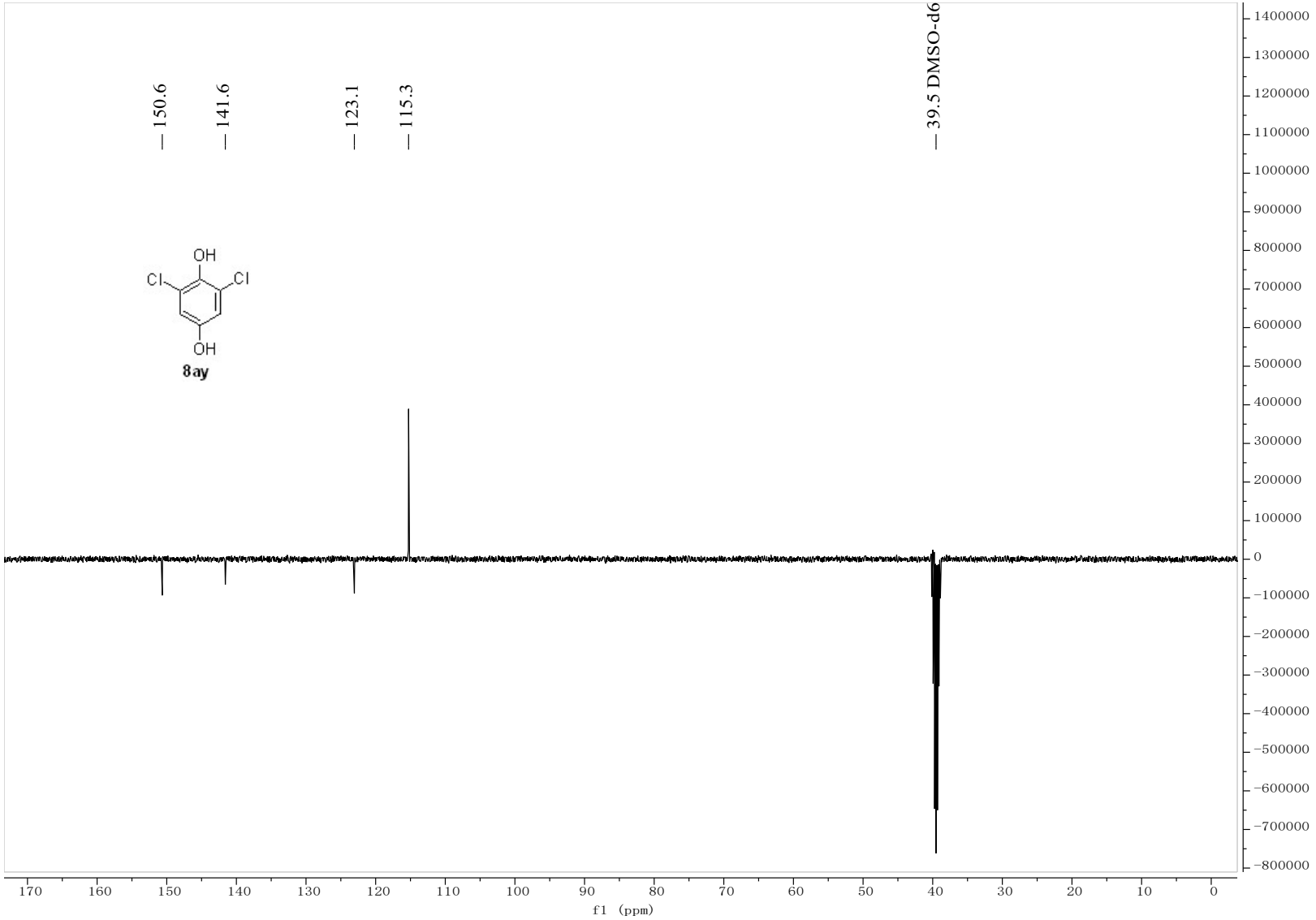


Figure S77. ^{13}C NMR spectrum of **8ay** in DMSO-d_6 (100 MHz).

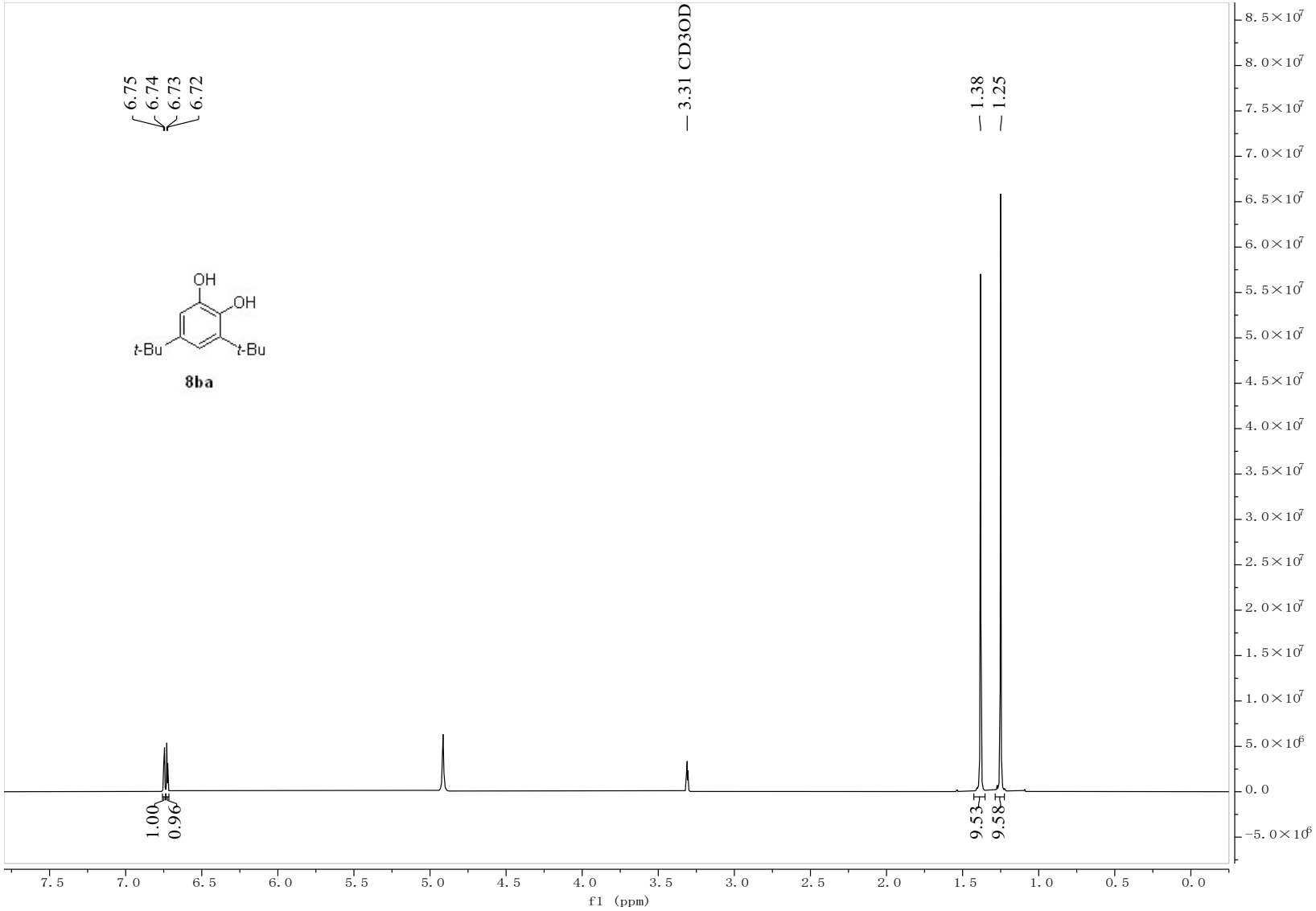


Figure S78. ^{1}H NMR spectrum of **8ba** in CD_3OD (400 MHz).

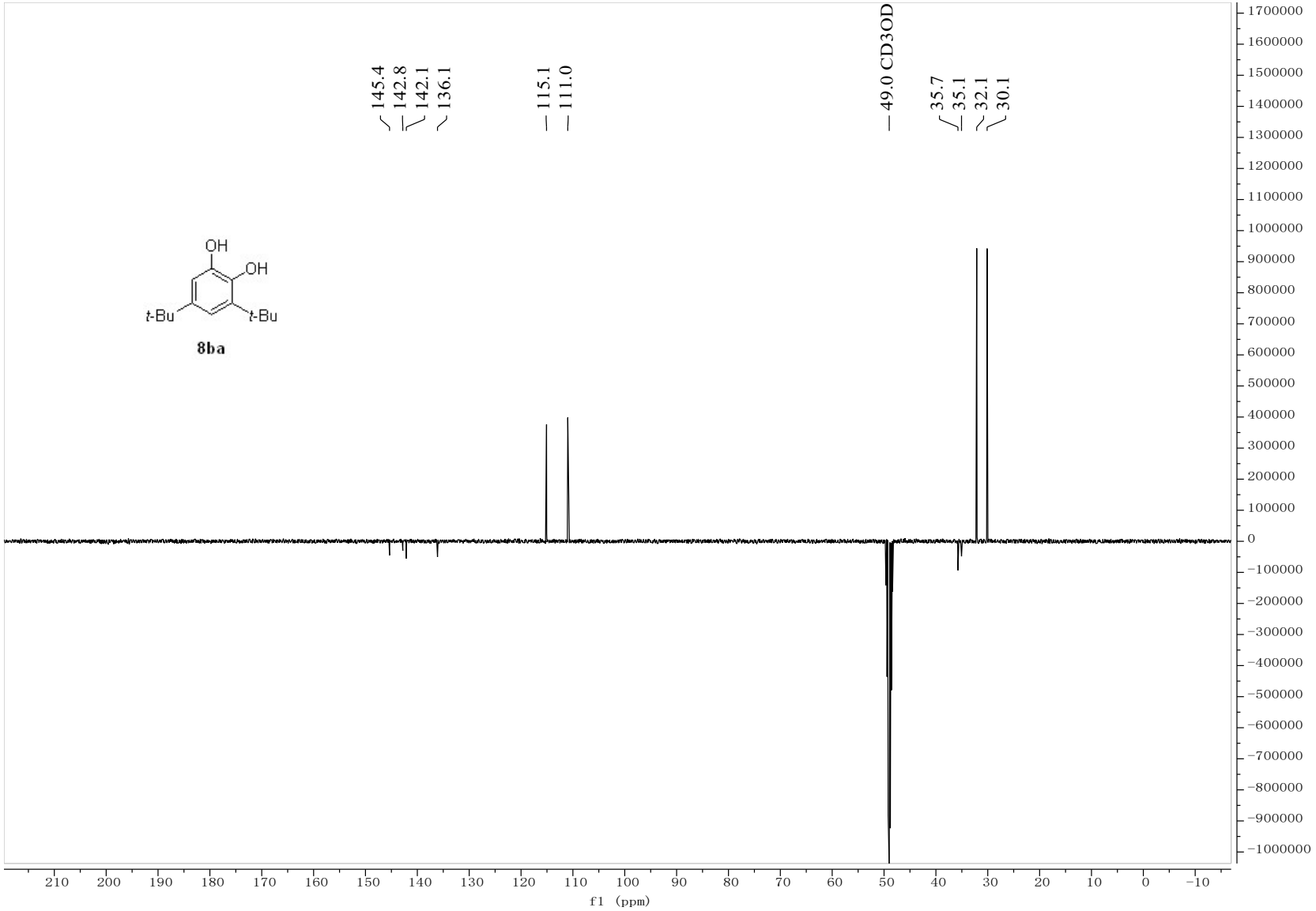


Figure S79. ^{13}C NMR spectrum of **8ba** in CD_3OD (100 MHz).

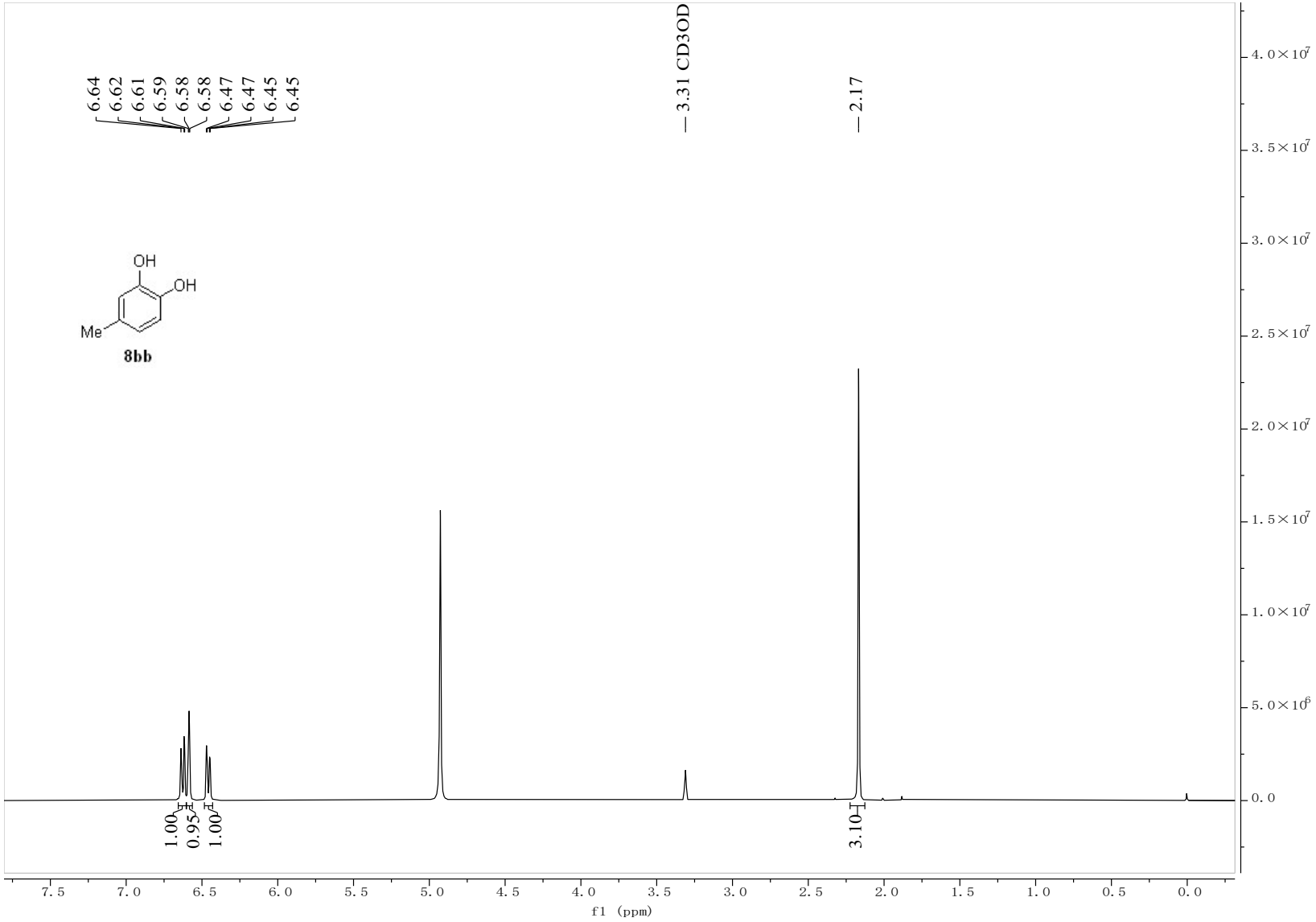


Figure S80. ^{1}H NMR spectrum of **8bb** in CD_3OD (400 MHz).

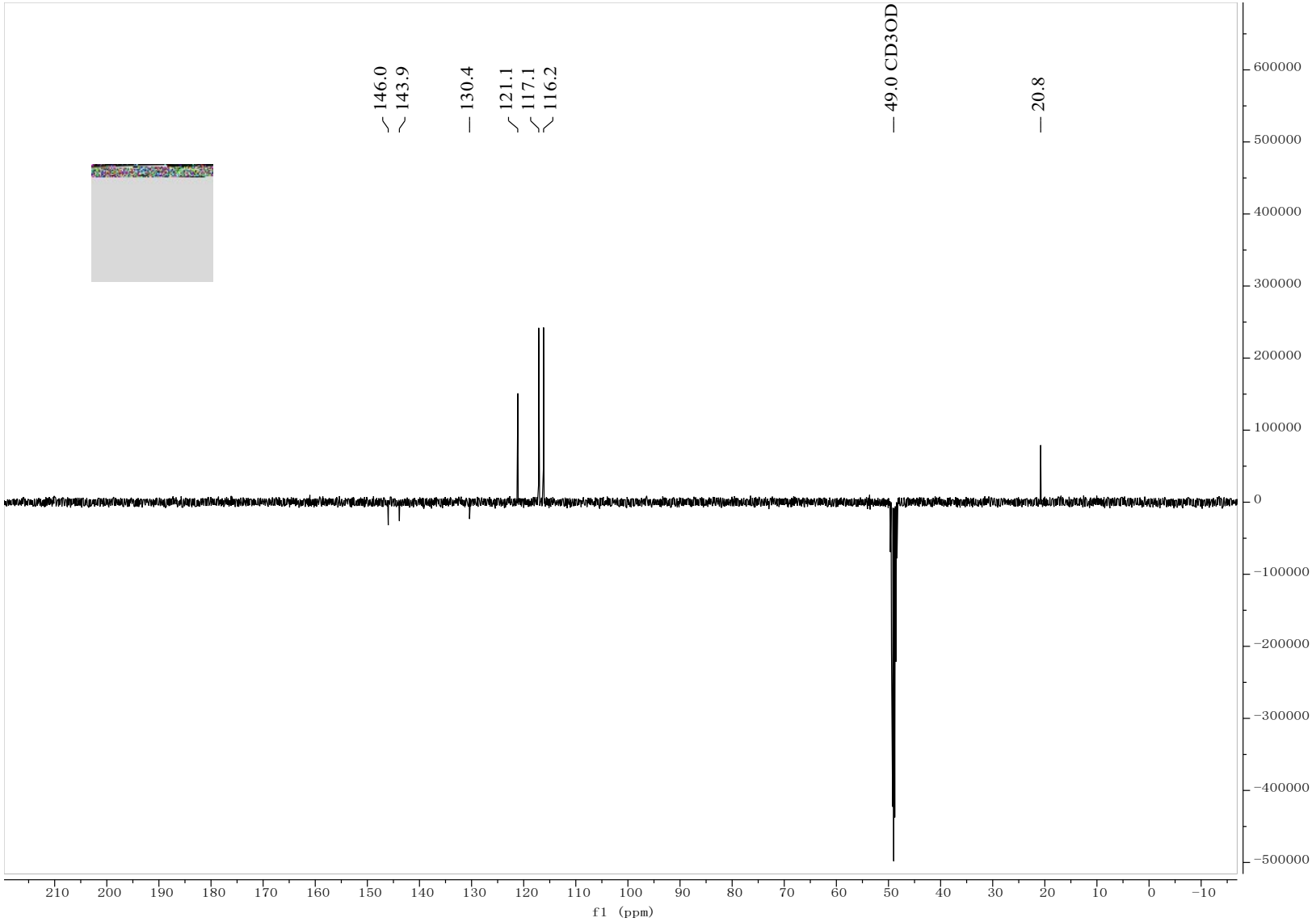


Figure S81. ^{13}C NMR spectrum of **8bb** in CD_3OD (100 MHz).

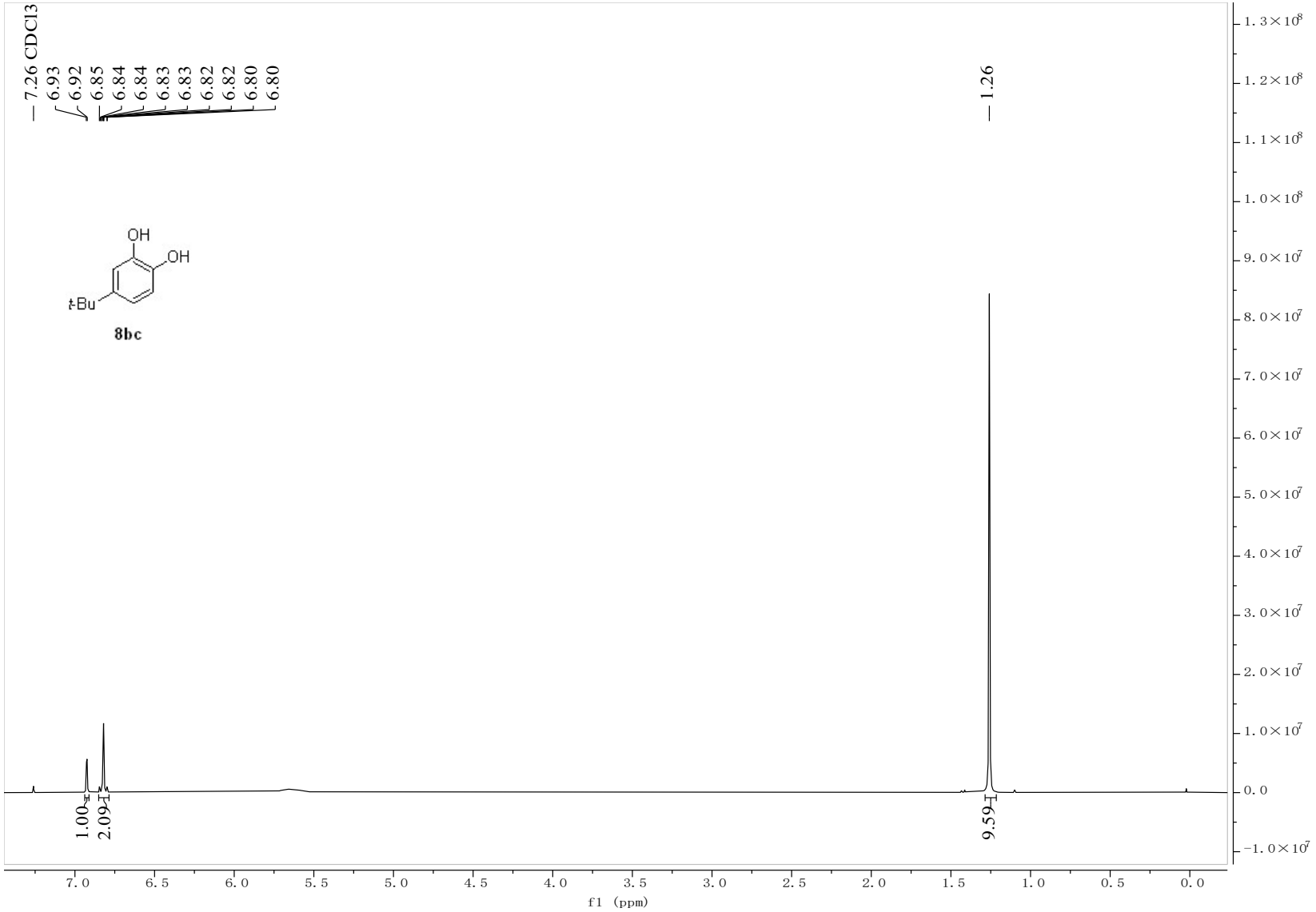


Figure S82. ^{1}H NMR spectrum of **8bc** in CD_3OD (400 MHz).

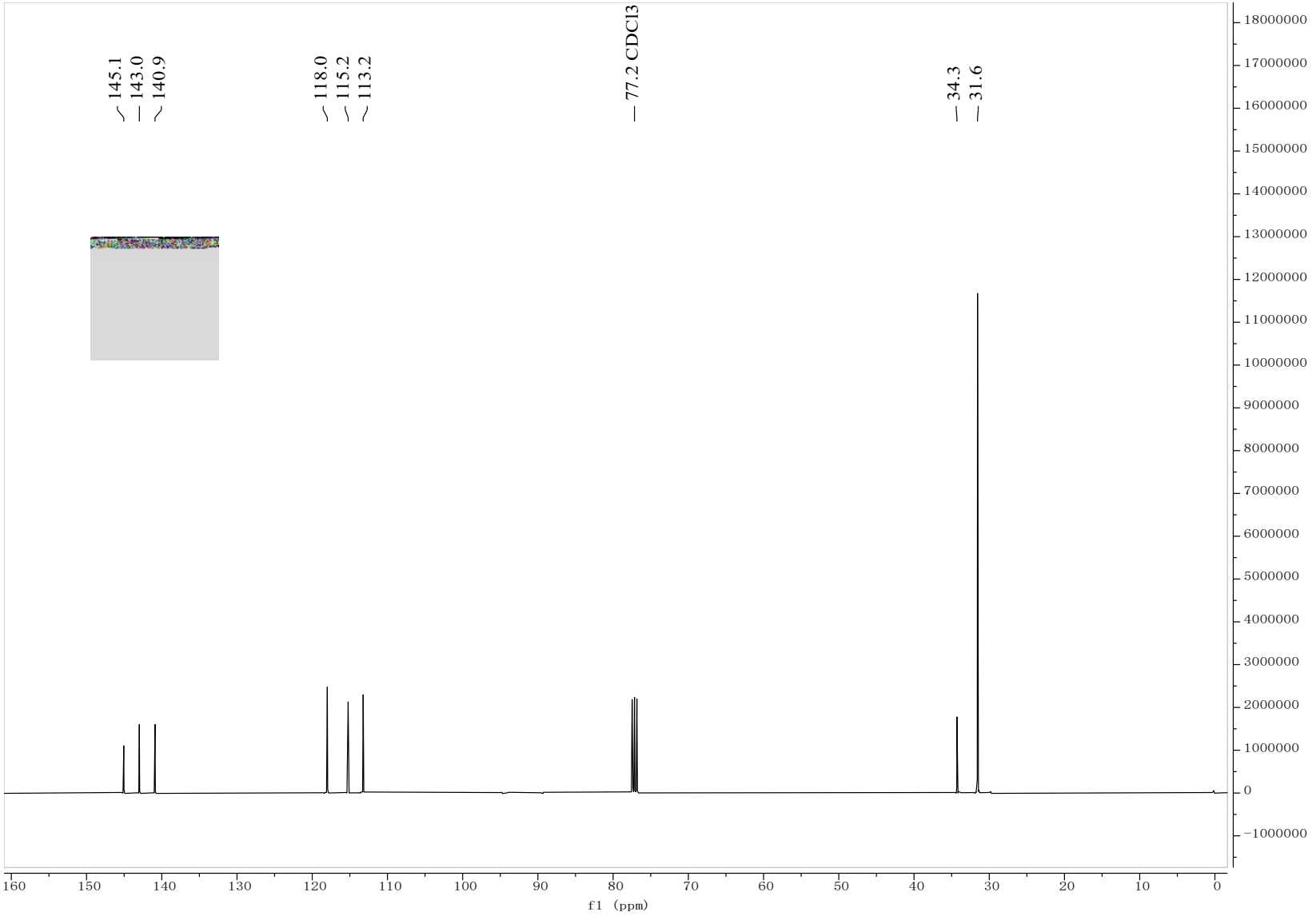


Figure S83. ^{13}C NMR spectrum of **8bc** in CD_3OD (100 MHz).

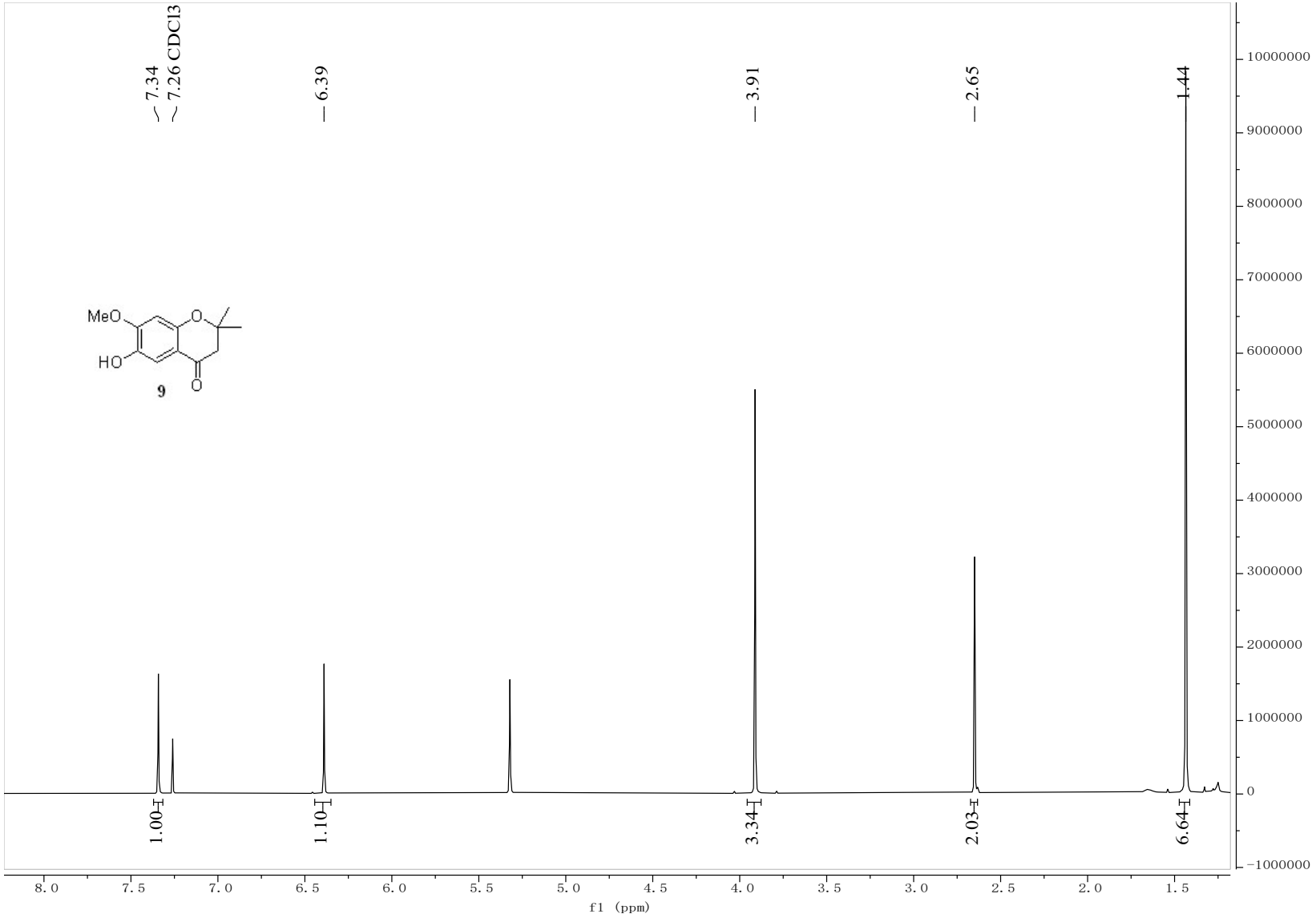


Figure S84. ^{1}H NMR spectrum of **9** in $CDCl_3$ (600 MHz).

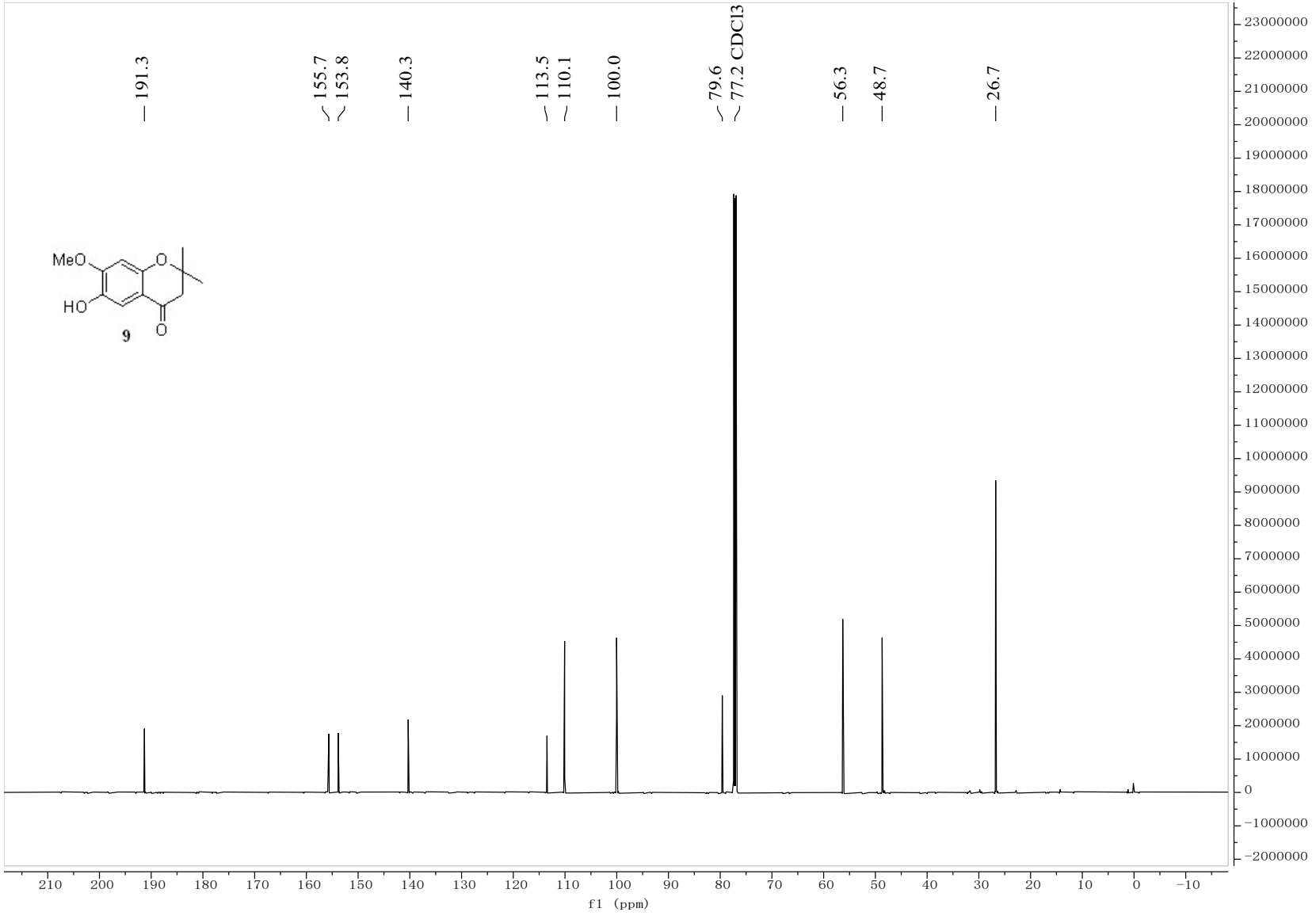


Figure S85. ^{13}C NMR spectrum of **9** in $CDCl_3$ (150 MHz).

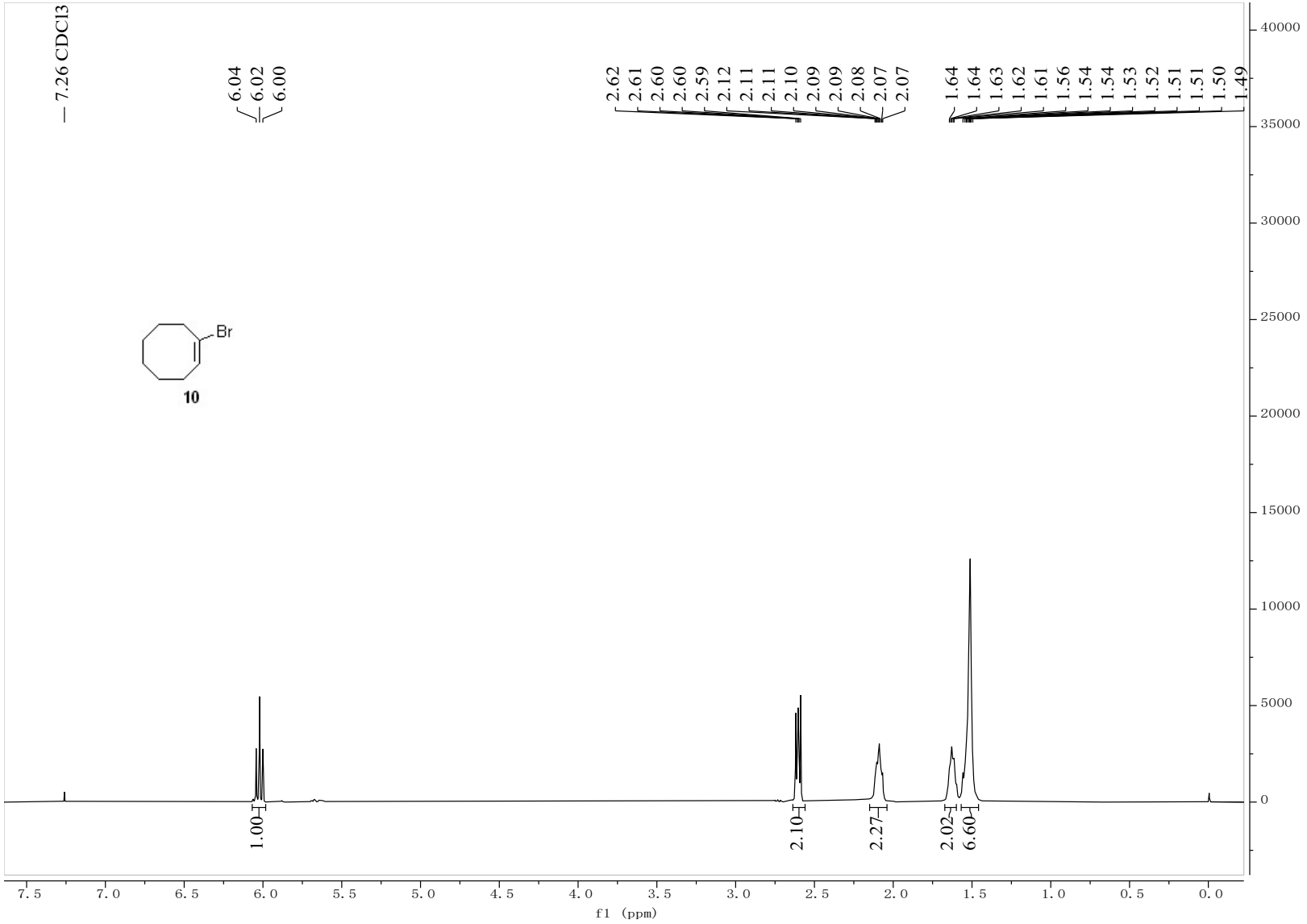


Figure S86. ^{1}H NMR spectrum of **10** in $CDCl_3$ (400 MHz).

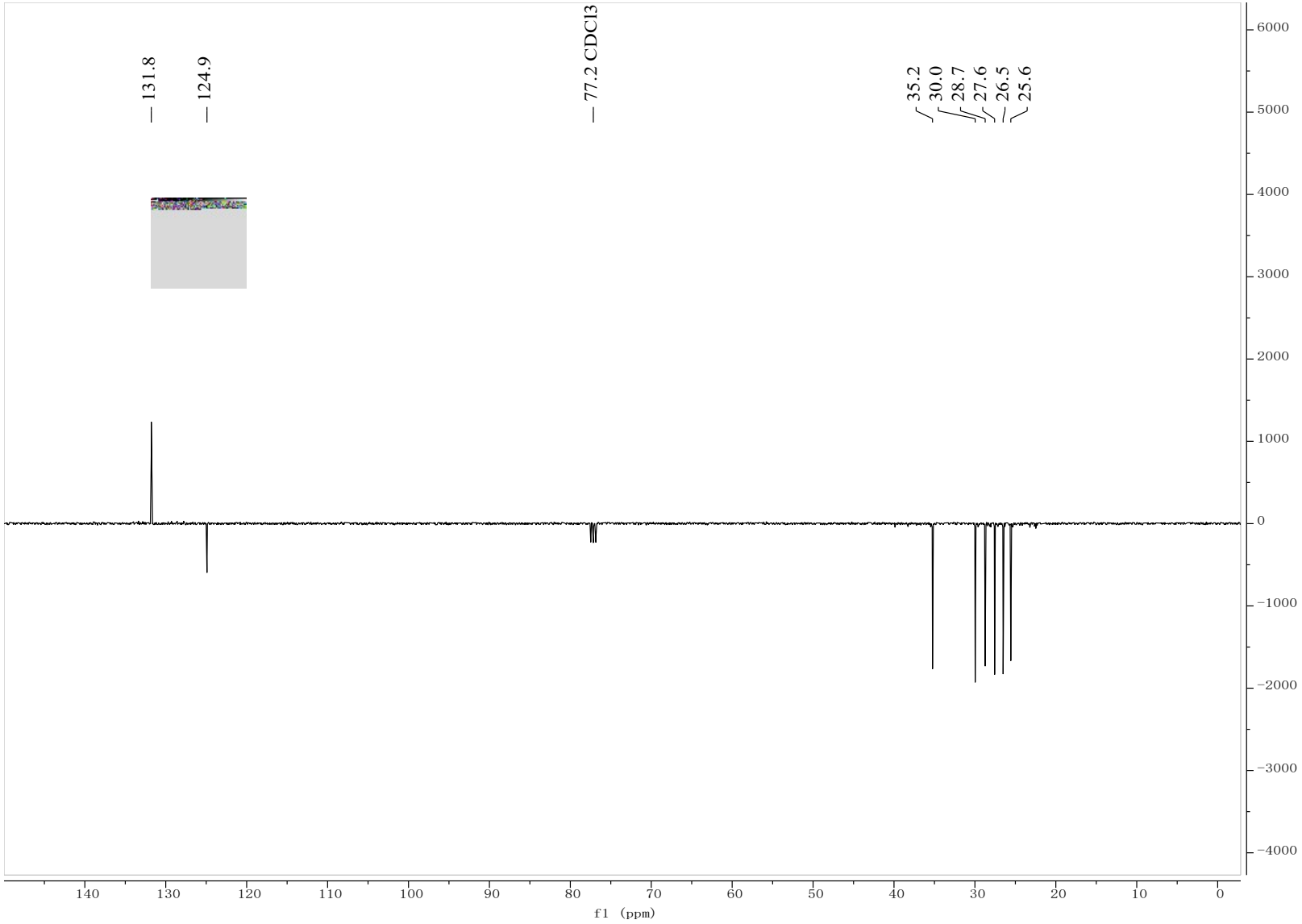


Figure S87. ^{13}C NMR spectrum of **10** in $CDCl_3$ (100 MHz).

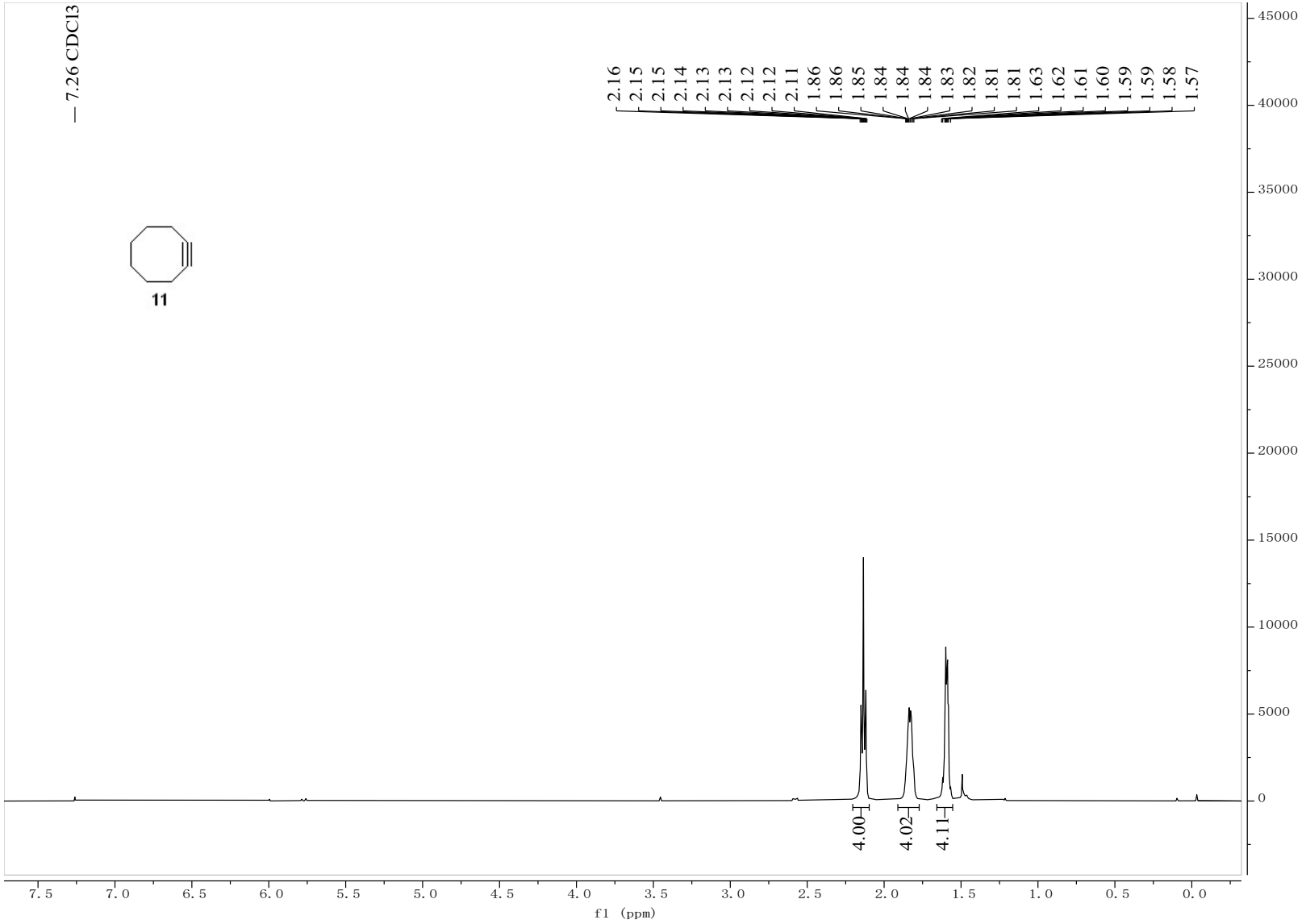


Figure S88. ^{1}H NMR spectrum of **11** in $CDCl_3$ (400 MHz).

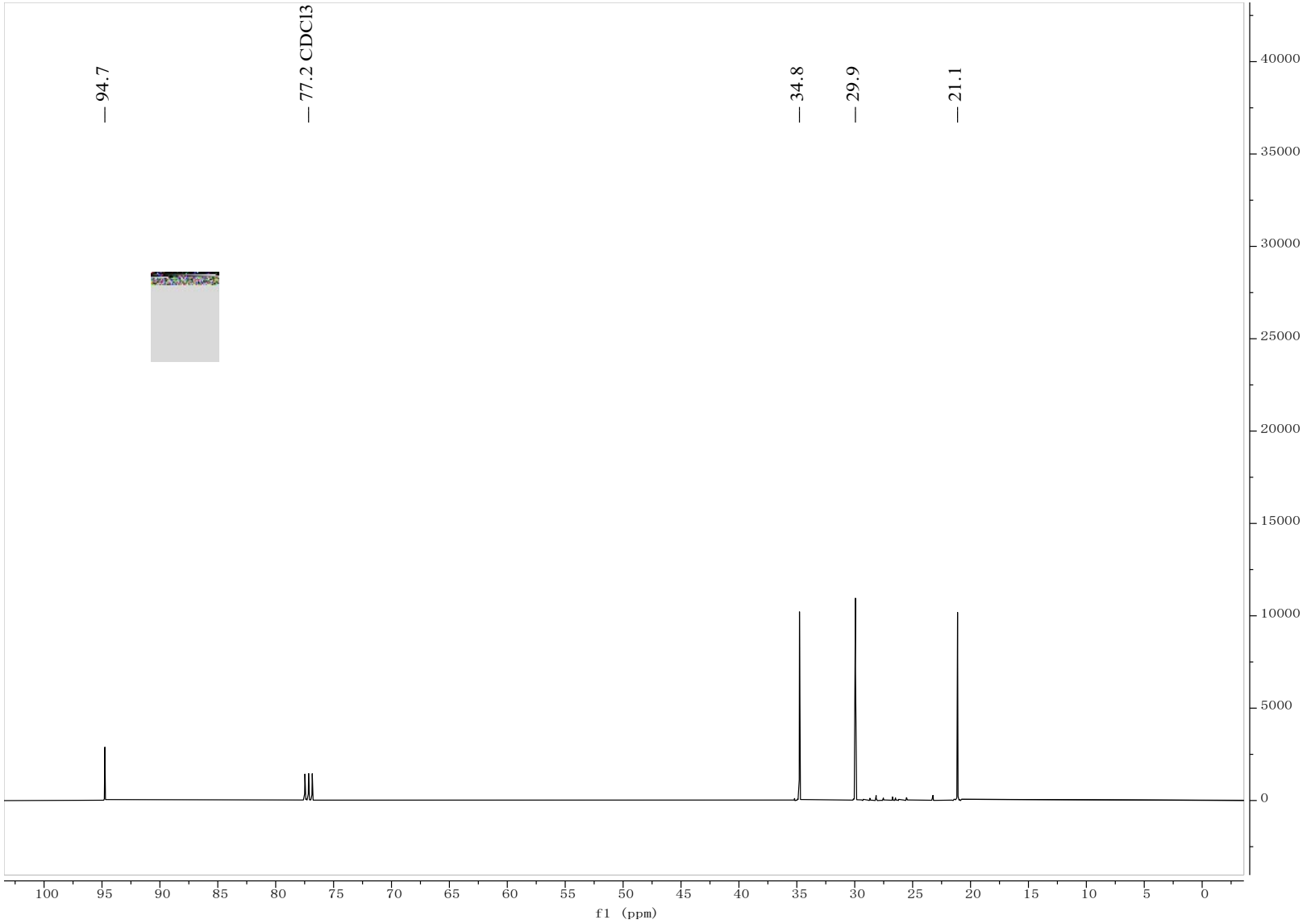


Figure S89. ^{13}C NMR spectrum of **11** in $CDCl_3$ (100 MHz).

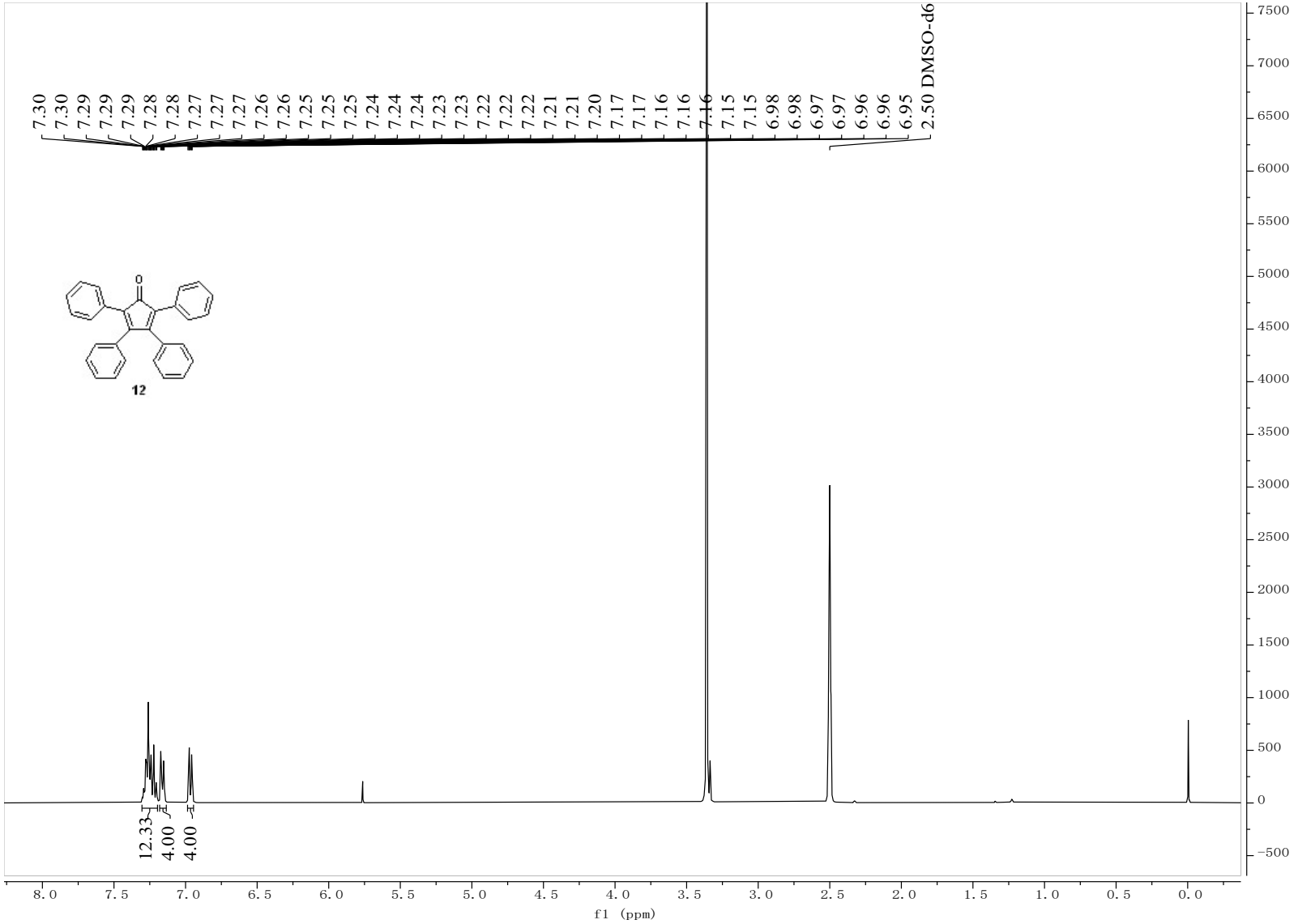


Figure S90. ^{1}H NMR spectrum of **12** in DMSO-d_6 (400 MHz).

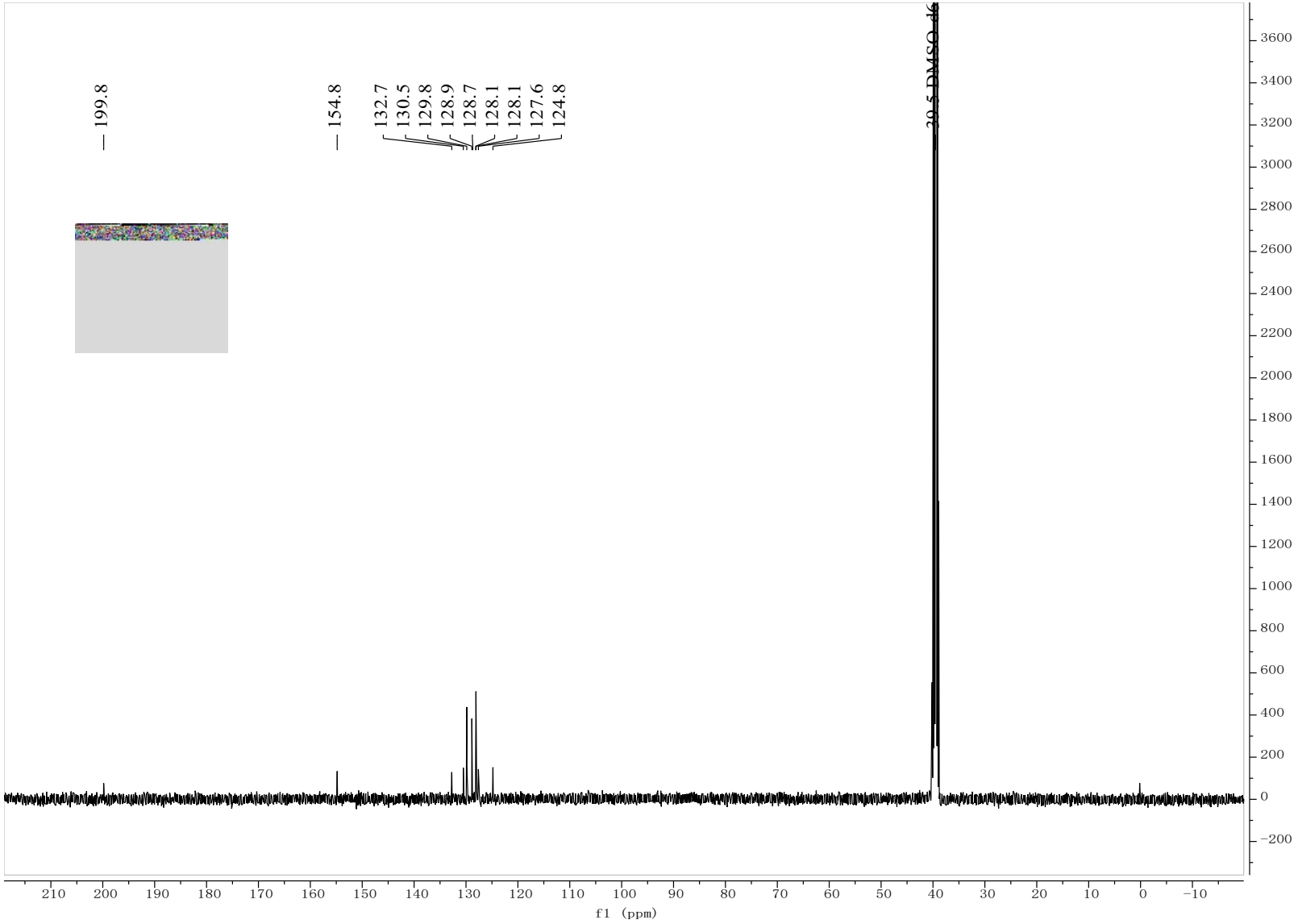


Figure S91. ^{13}C NMR spectrum of **12** in DMSO-d_6 (100 MHz).

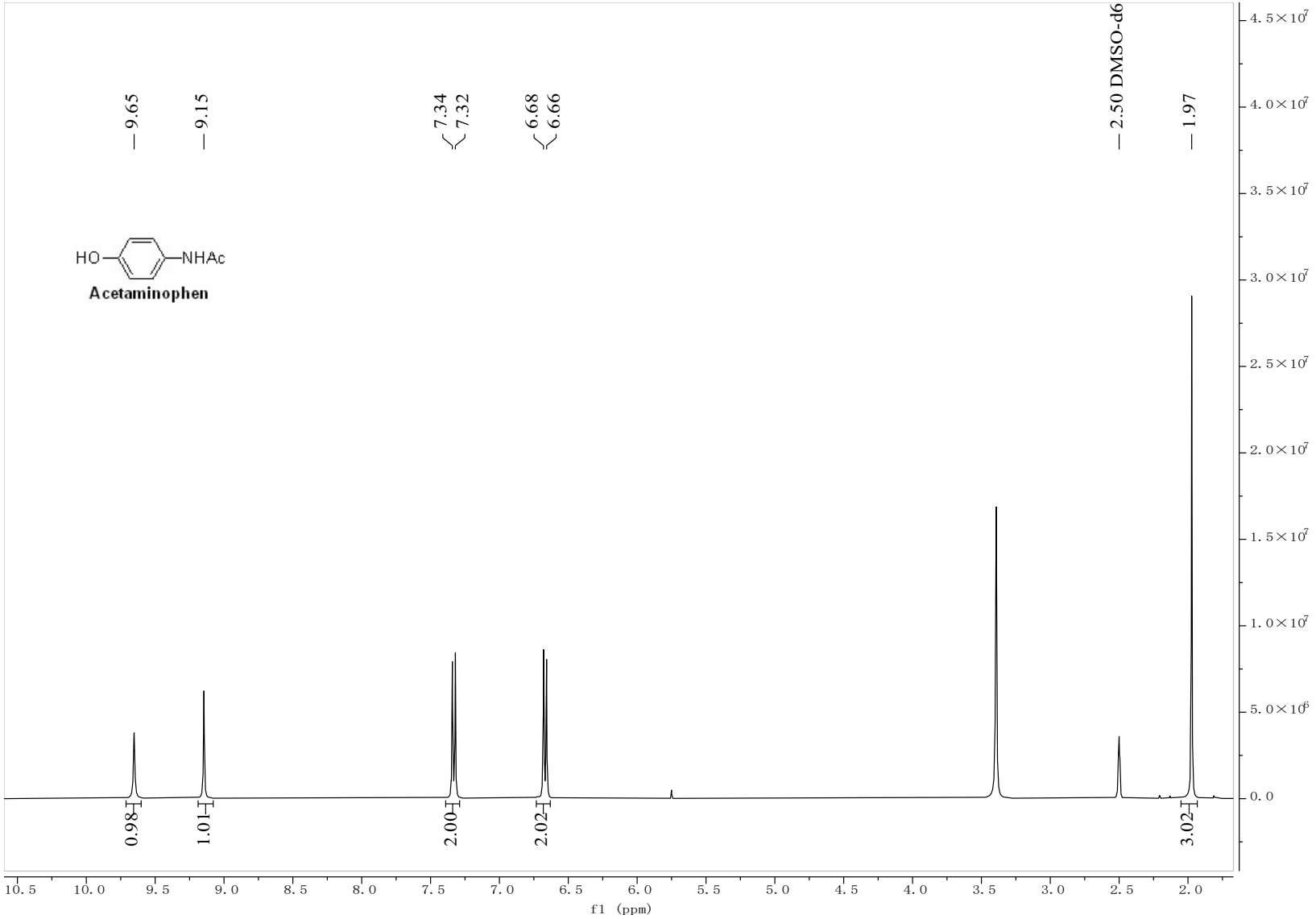


Figure S92. ^{1}H NMR spectrum of **acetaminophen** in DMSO-d_6 (400 MHz).

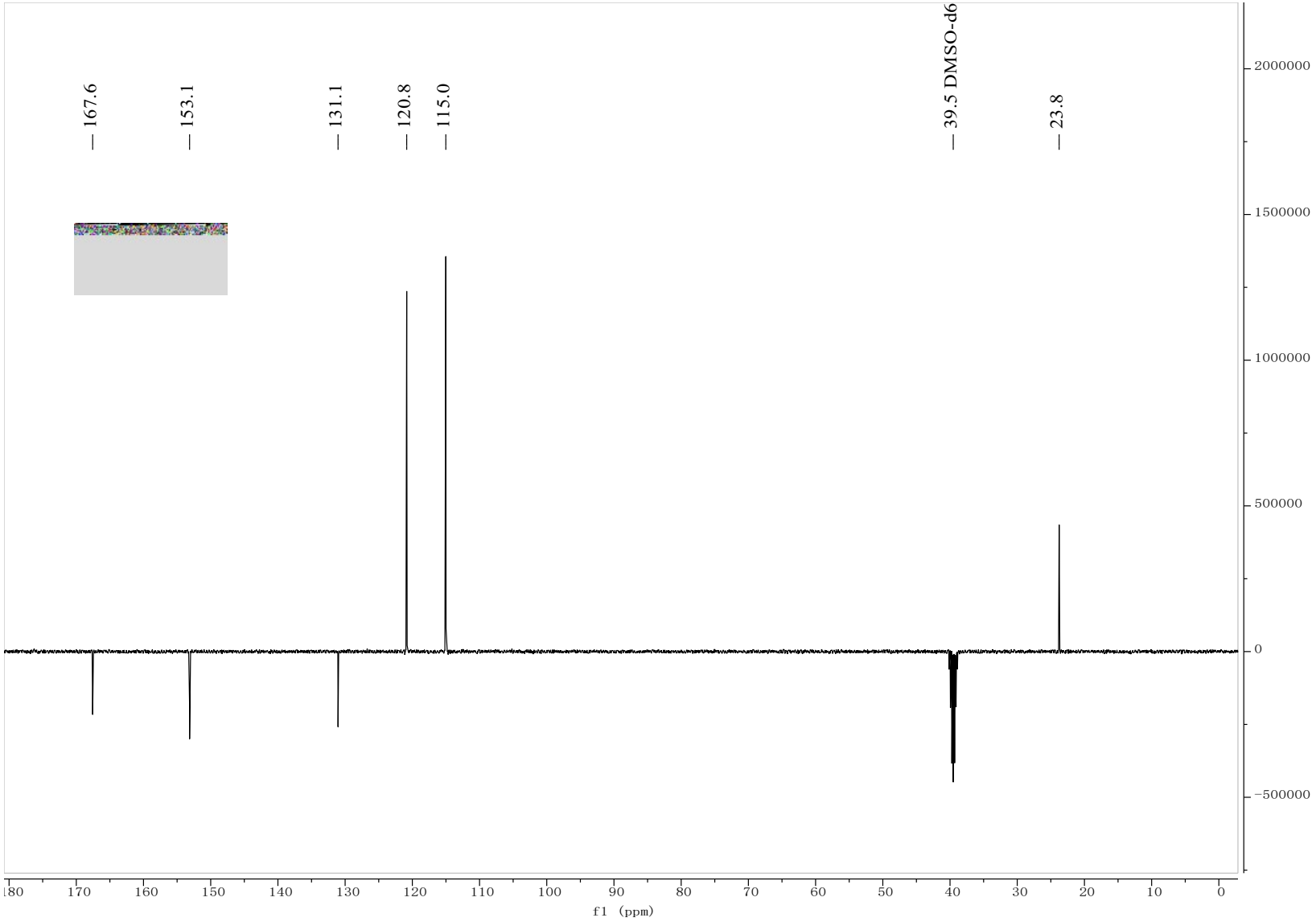


Figure S93. ^{13}C NMR spectrum of **acetaminophen** in DMSO-d_6 (100 MHz).

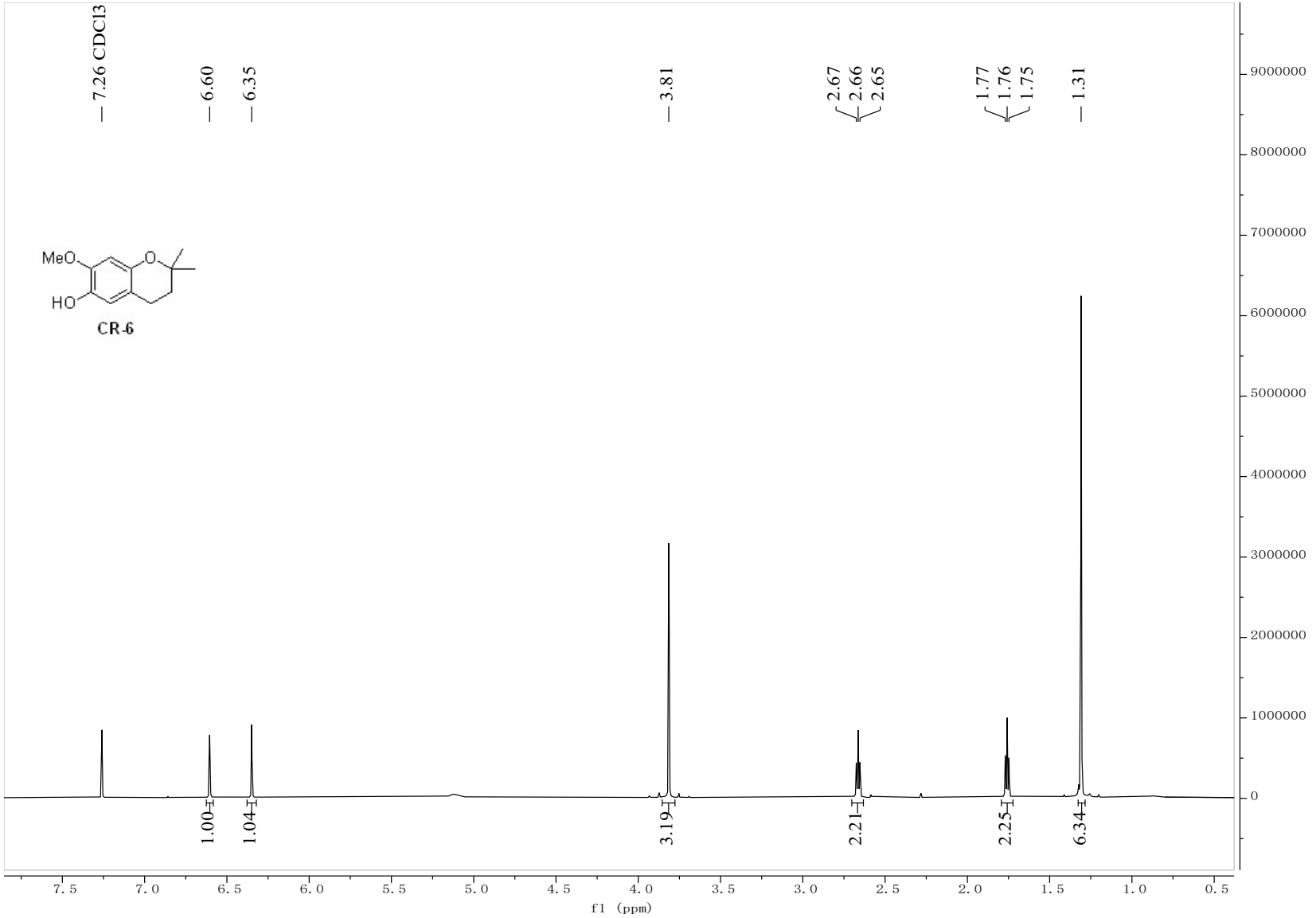


Figure S94. ^{1}H NMR spectrum of **CR-6** in $CDCl_3$ (600 MHz).

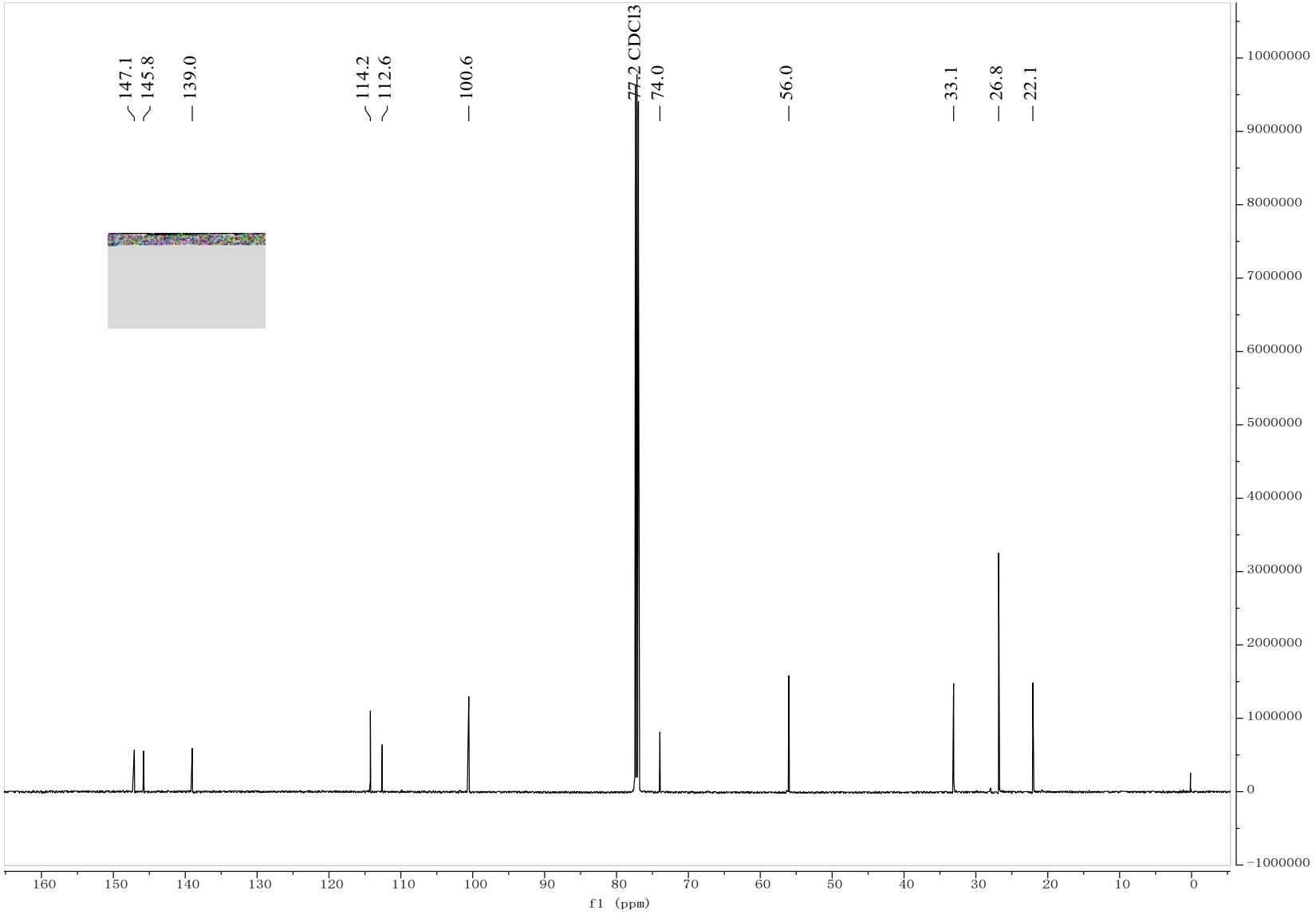


Figure S95. ^{13}C NMR spectrum of **CR-6** in $CDCl_3$ (150 MHz).