

Supplementary Information

Photocluster Catalytic Oxidation Enabled by Structurally Precise

Copper-Hydride Nanoclusters

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A general note on CheckCif file B-level alerts for the cluster in this work.

[Cu₁₃(Dppm)₄(C₇H₄NS)₆H₆]

Alert level B

- 1) PLAT341_ALERT_3_B Low Bond Precision on C-C Bonds 0.01689 Ang.

Author Response: The data which arise from the ligand shell are similarly of low precision

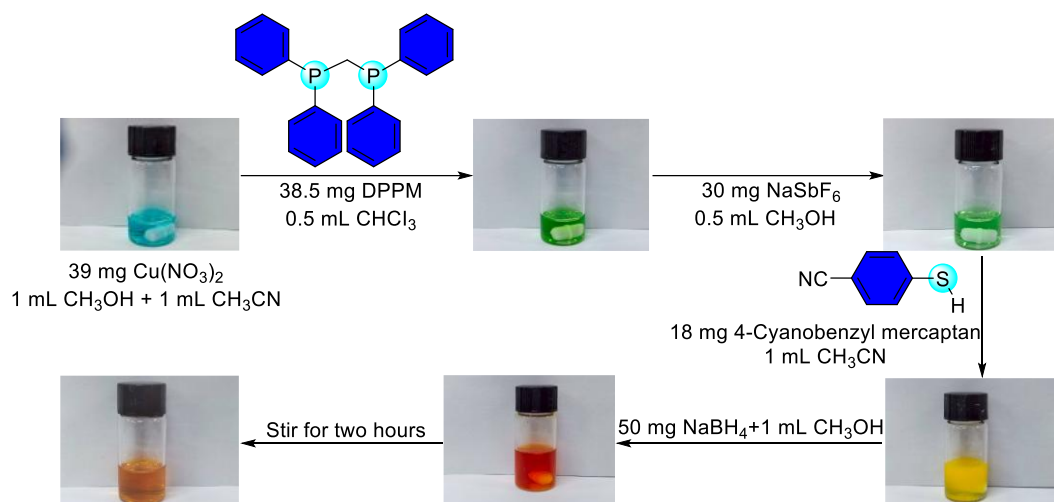


Figure S1. Synthesis process of the Cu_{13}H_6 cluster. Schematic illustration of the synthetic route for the Cu_{13}H_6 cluster from copper precursor and ligand under ambient conditions, with digital photographs of the reaction mixture taken before and after the reaction.

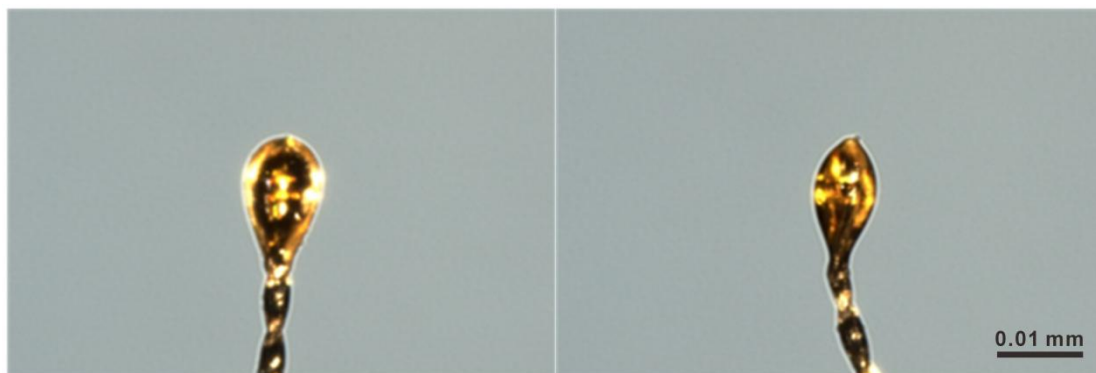


Figure S2. Digital photographs of crystals of the Cu_{13}H_6 cluster. Photos of the crystals were collected under a single-crystal diffractometer.

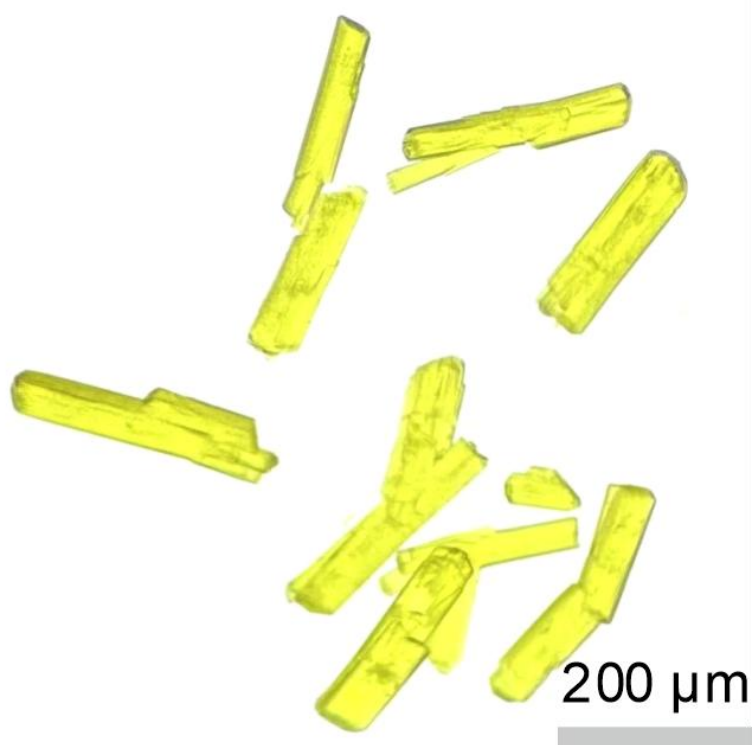


Figure S3. Digital photograph of crystals of the Cu_{13}H_6 cluster. Photos of the crystals were taken under a microscope.

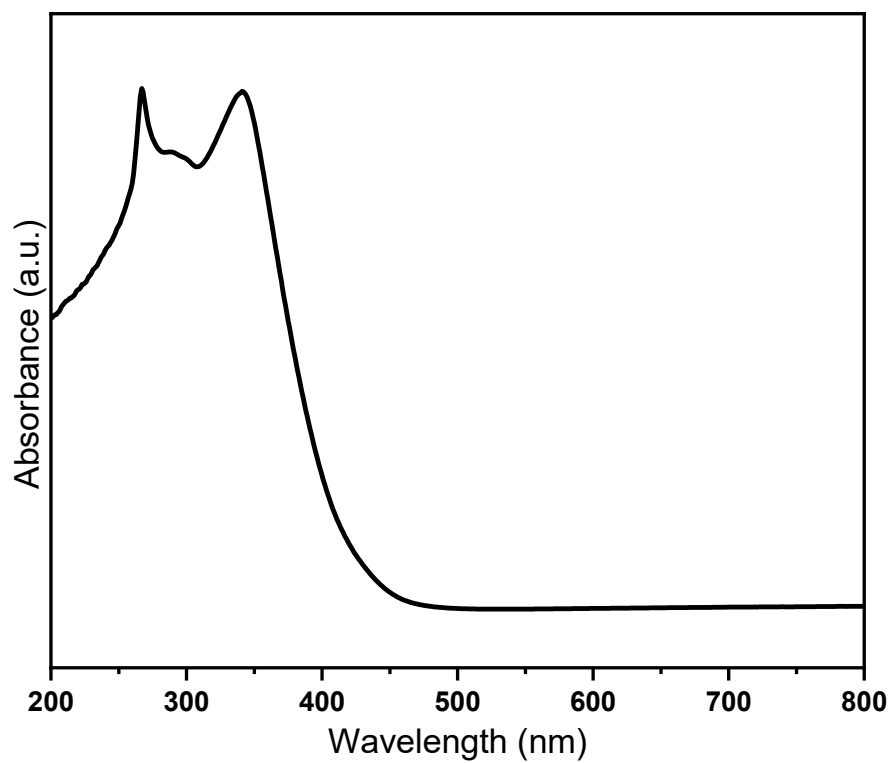


Figure S4. The UV-vis spectrum of Cu_{13}H_6 in DMF. The spectra was recorded at room temperature.

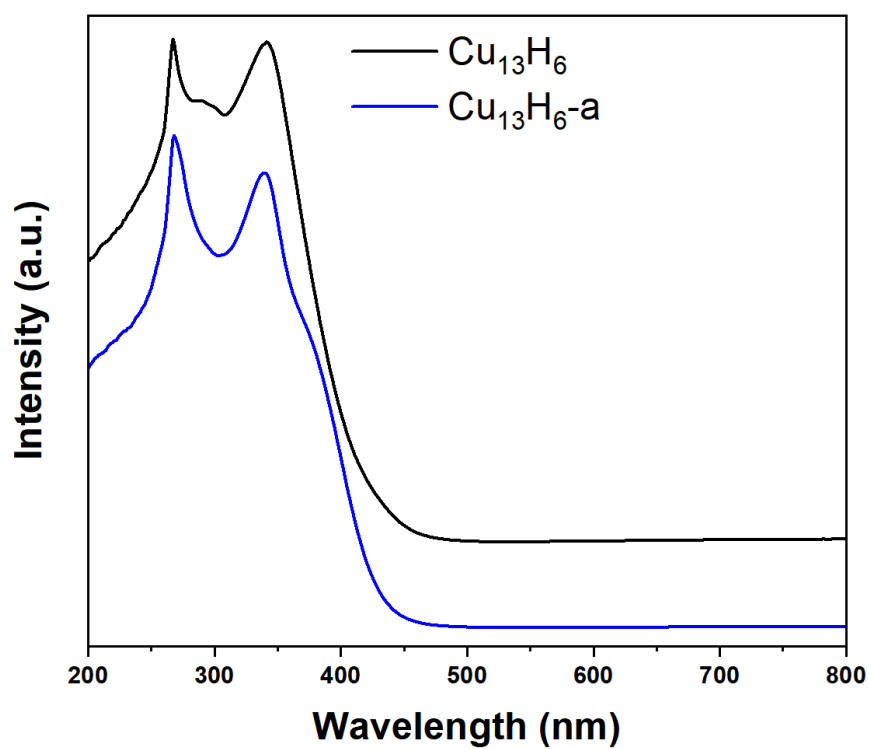


Figure S5. UV-vis spectra of the pure crystals (Cu_{13}H_6) and raw products of Cu_{13}H_6 ($\text{Cu}_{13}\text{H}_6\text{-a}$) in DMF. The high spectroscopic similarity between the pure crystals and the raw product indicates their high purity.



Figure S6. Digital photographs of Cu_{13}H_6 crystals. Crystal photographs were taken at room temperature.

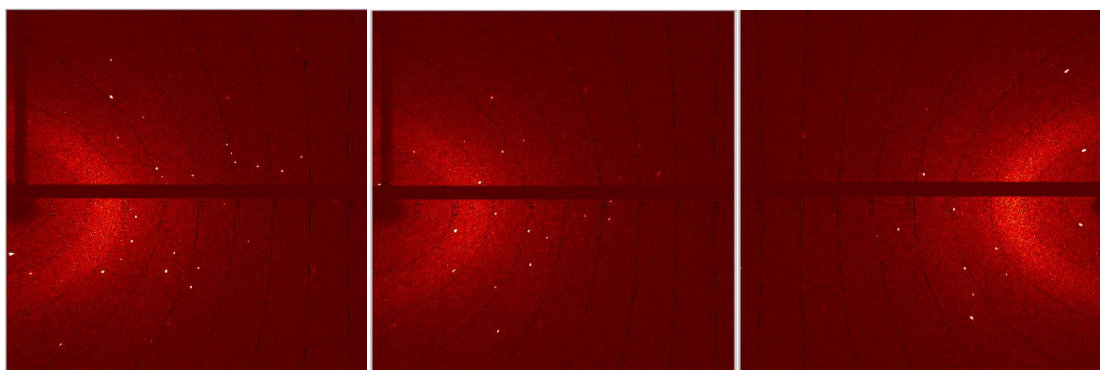


Figure S7. Single crystal X-ray diffraction patterns of the Cu₁₃H₆ cluster. Diffraction images were collected on a single-crystal diffractometer.

Table S1. Crystallographic data of Cu₁₃H₆. Further details see CCDC.

Identification code	[Cu ₁₃ (Dppm) ₄ (C ₇ H ₄ NS) ₆ H ₆]
Formula	[Cu ₁₃ (Dppm) ₄ (C ₇ H ₄ NS) ₆ H ₆]
Formula weight	3173.548
Temperature/K	100.00(10)
Crystal system	triclinic
Space group	<i>P</i> $\bar{1}$
a (Å)	16.733 (3)
b (Å)	16.908 (3)
c (Å)	28.425 (5)
α (°)	88.838(10)
β (°)	77.786(2)
γ (°)	66.650(2)
V (Å ³)	7198.2 (2)
Z	2
Dc / (g·cm ⁻³)	1.461
Radiation	Cu K α (λ = 1.54184 Å)
Theta (°) range	5.708 to 133.192
Index ranges	-19 $\leq$ h $\leq$ 19, -20 $\leq$ k $\leq$ 19, -33 $\leq$ l $\leq$ 33
Refls. Total	128437
Restraints	228
Parameters	1610
Rint	0.1035
R ₁ /wR ₂ [I>2 σ (I)]	0.1001/0.27120.0830
R ₁ /wR ₂ (all data)	0.1115/0.2788
Completeness	0.998
Goodness-of-fit on F ²	1.040

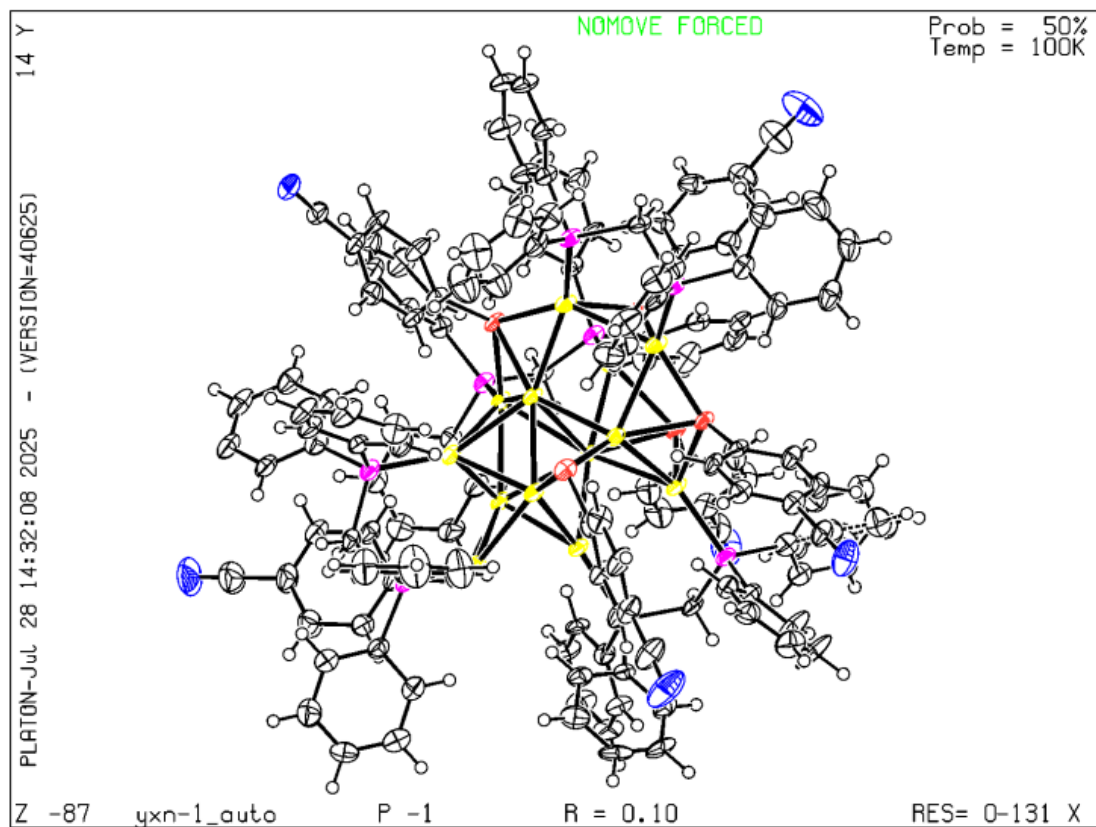


Figure S8. The thermal ellipsoids of the ORTEP diagram of the Cu_{13}H_6 cluster. CCDC number is 2501203.

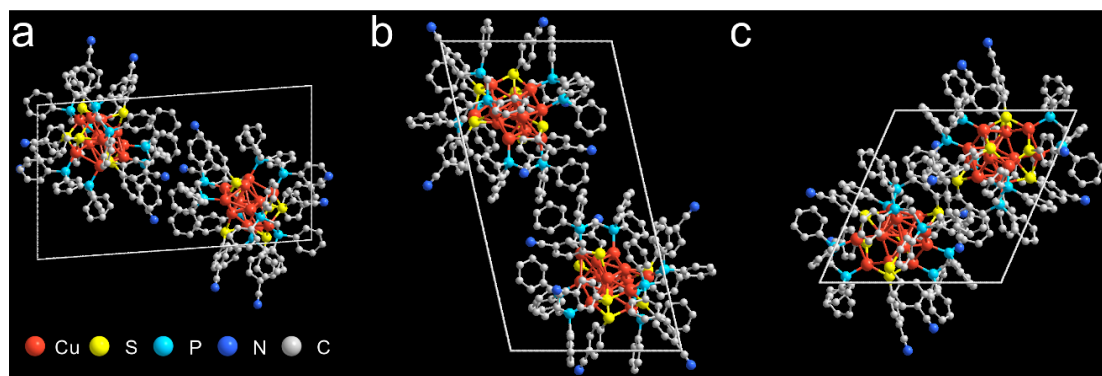


Figure S9. The packing structure of Cu_{13}H_6 clusters in the unit cell. All hydrogen atoms are omitted for clarity.

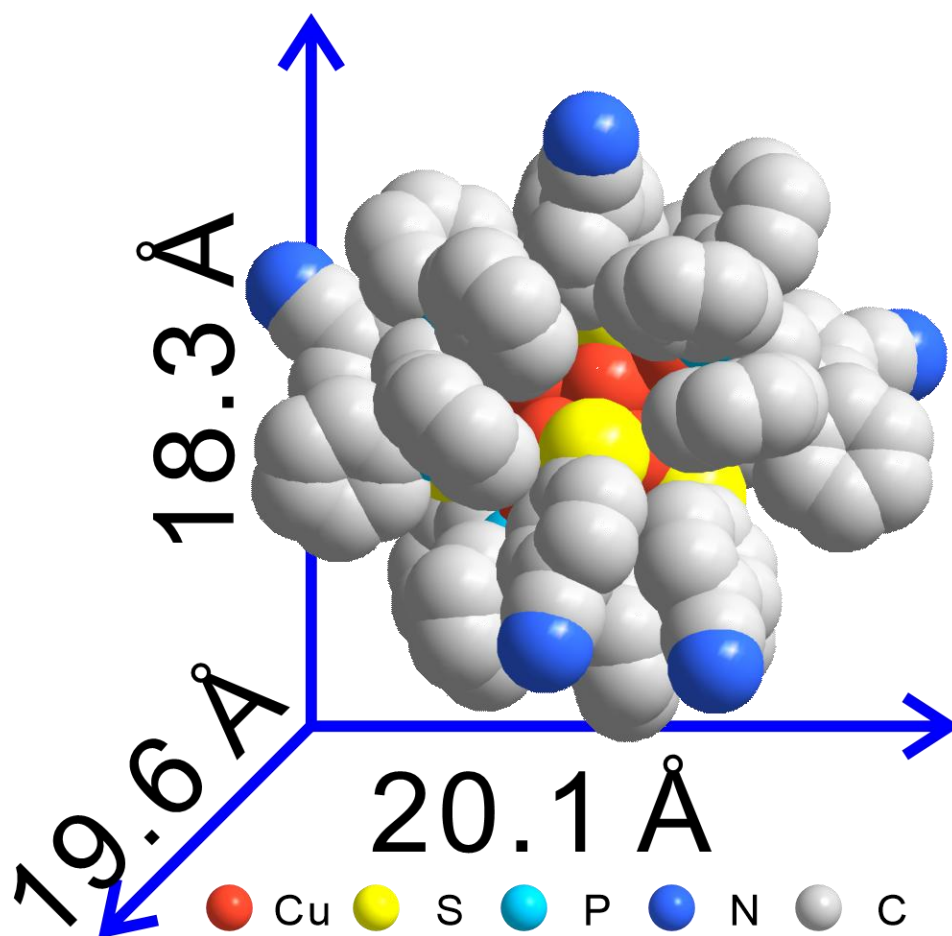


Figure S10. Total structure of Cu_{13}H_6 , related to the Figure 1. All hydrogen atoms are omitted for clarity.

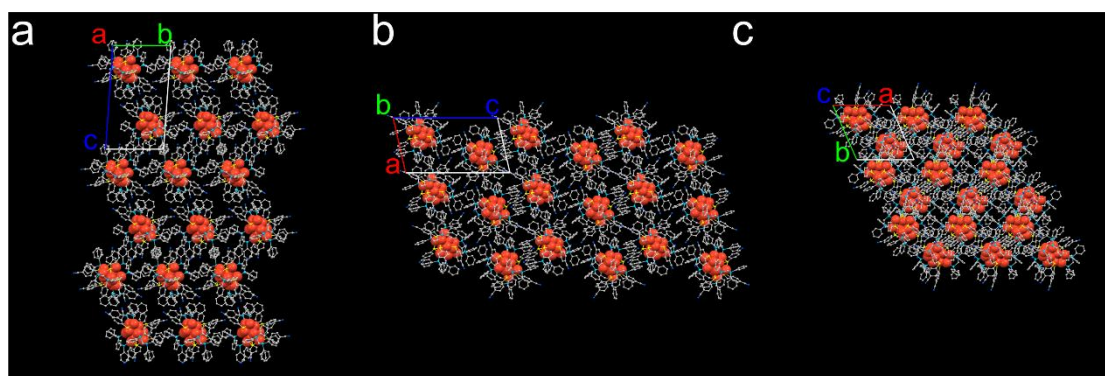


Figure S11. The packing structure of Cu_{13}H_6 along a-axis, b-axis and c-axis. No counterion was observed within the crystal lattice.

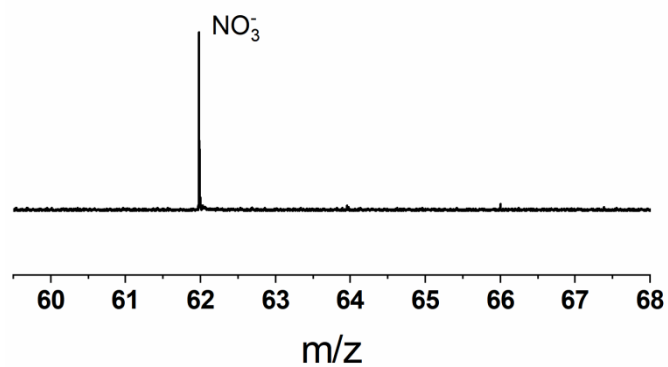


Figure S12. HRESI-MS of Cu₁₃H₆ in negative mode showing the peak of NO₃⁻. The presence of NO₃⁻ counterions in the crystal sample was detected.

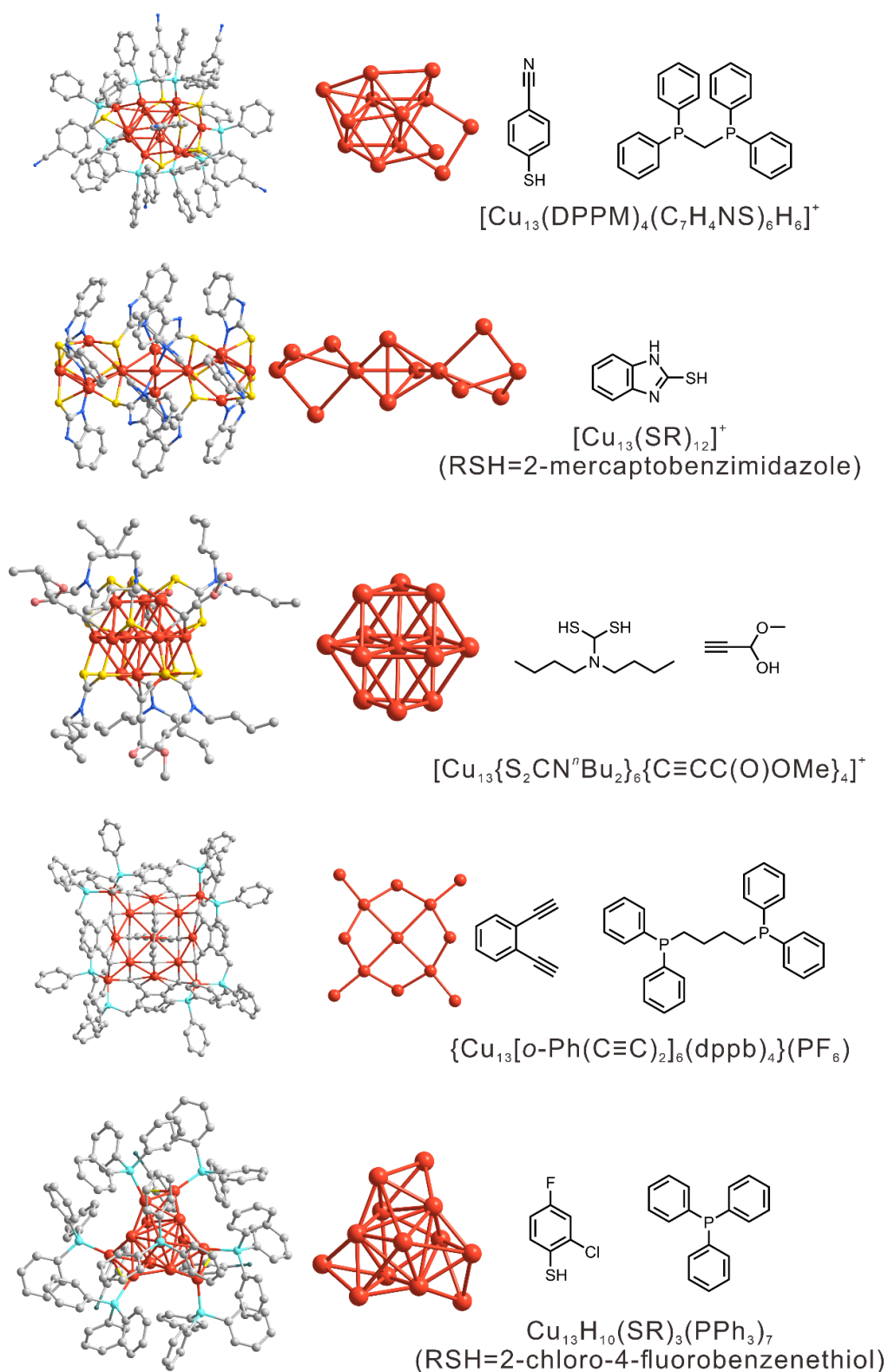


Figure S13. The Cu_{13}H_6 clusters with different cores. The structures were drawn from the literatures (Angew. Chem. Int. Ed. 2016, 55, 14704; Inorg. Chem. 2023, 62, 21091; Chem. Sci., 2023, 14, 994; 10.6023/A21050212).

Table S2. Selected bond lengths (Å) in Cu₁₃H₆.

<i>Bond types</i>	<i>Range</i>	<i>Average value</i>
Cu–Cu	2.487(1)-3.038(6)	2.657
Cu–S	2.260-2.446	2.341
Cu–P	2.211-2.250	2.229

Table S3. Selected bond lengths (Å) for compound [Cu₁₃(Dppm)₄(C₇H₄NS)₆H₆].

<i>Parameter</i>	<i>Value (Å)</i>	<i>Parameter</i>	<i>Value (Å)</i>
Cu1-P76	2.247(2)	Cu7-Cu11	2.678(19)
Cu2-Cu3	2.699(17)	Cu7-Cu12	2.577(18)
Cu2-Cu5	2.595(18)	Cu7-S29	2.271(2)
Cu2-Cu6	2.577(16)	Cu7-P155	2.246(3)
Cu2-Cu12	2.572(17)	Cu8-Cu9	2.962(18)
Cu2-Cu13	2.531(17)	Cu8-Cu11	2.617(17)
Cu2-S56	2.316(2)	Cu8-Cu12	2.560(17)
Cu3-Cu4	2.595(18)	Cu8-P103	2.232(2)
Cu3-Cu6	2.928(17)	Cu9-S20	2.366(2)
Cu3-Cu8	2.487(17)	Cu9-S38	2.376(3)
Cu3-Cu9	2.592(16)	Cu9-P101	2.215(2)
Cu3-Cu11	2.616(18)	Cu10-Cu13	2.612(17)
Cu3-Cu12	3.039(19)	Cu10-S20	2.307(2)
Cu3-S38	2.446(2)	Cu10-S47	2.362(2)
Cu4-S38	2.357(2)	Cu10-P128	2.218(2)
Cu4-S47	2.331(2)	Cu11-S29	2.260(3)
Cu4-P74	2.214(2)	Cu12-S65	2.331(2)
Cu5-Cu7	2.885(18)	Cu13-S47	2.413(3)
Cu5-Cu11	2.508(17)	Cu13-S56	2.335(2)
Cu5-Cu12	2.636(17)	Cu13-P130	2.211(2)
Cu5-P157	2.250(3)	Cu7-Cu8	2.748(18)
Cu6-Cu9	2.668(17)	Cu6-Cu12	2.530(18)
Cu6-Cu10	2.556(18)	Cu6-S20	2.301(2)
Cu6-S65	2.378(3)		

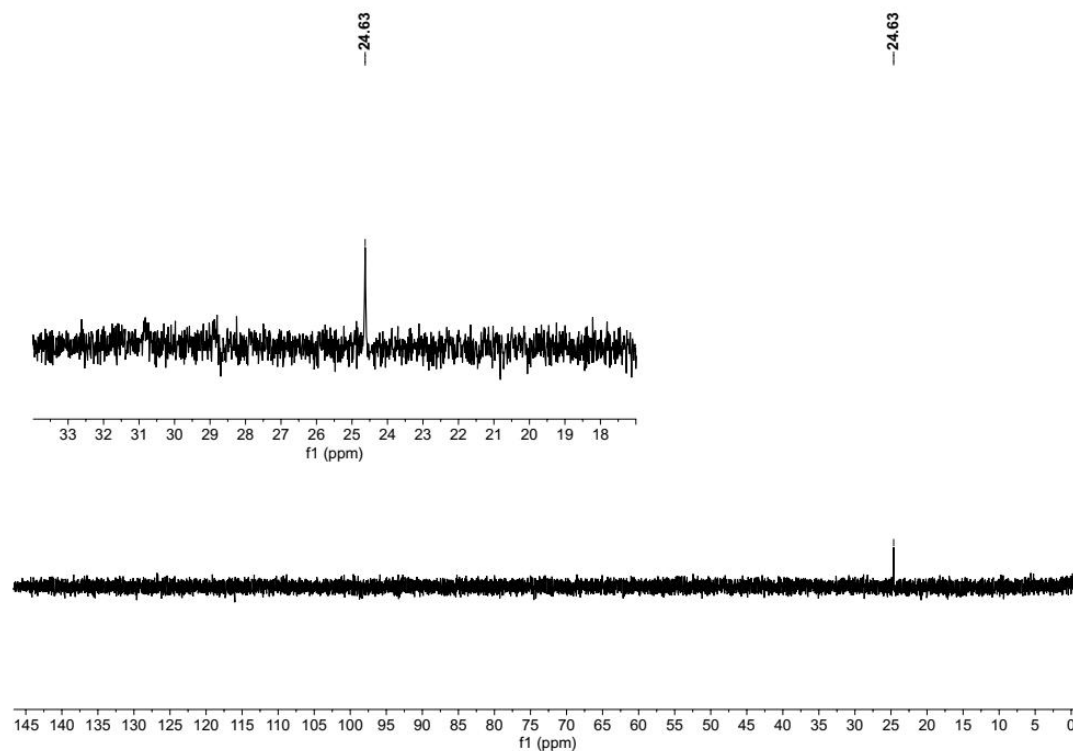


Figure S14. The proton-decoupled ^{31}P NMR spectrum of Cu_{13}H_6 in CDCl_3 (δ 24.63 ppm). The spectrum was recorded at room temperature, and the coordination geometry of DPPM ligands indicates they occupy similar chemical environments.

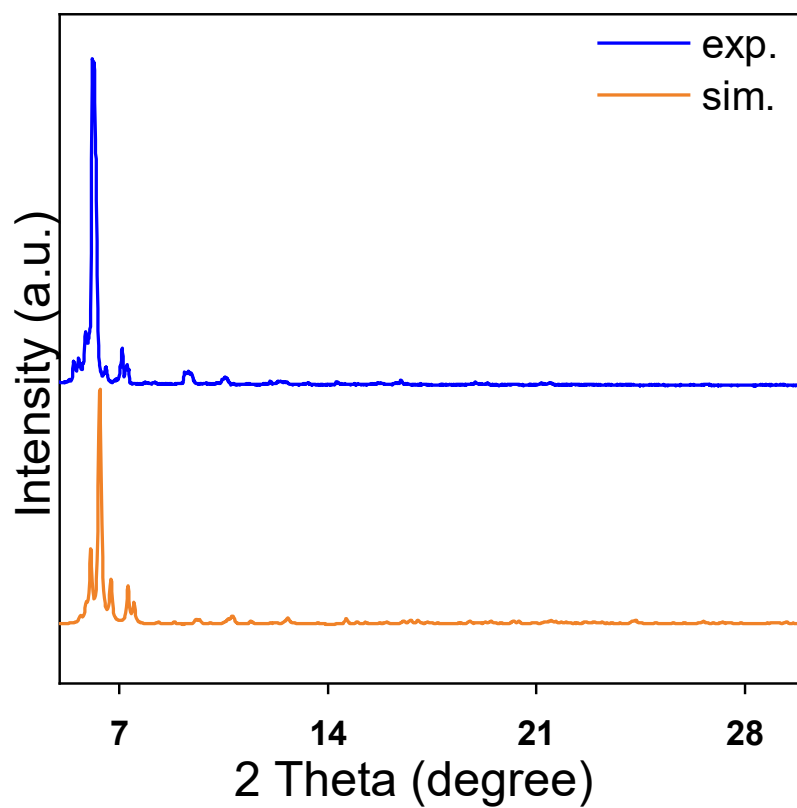


Figure S15. The PXRD of the Cu_{13}H_6 cluster. The good match between the simulated and experimental PXRD patterns indicates high crystallinity of the Cu_{13}H_6 cluster.

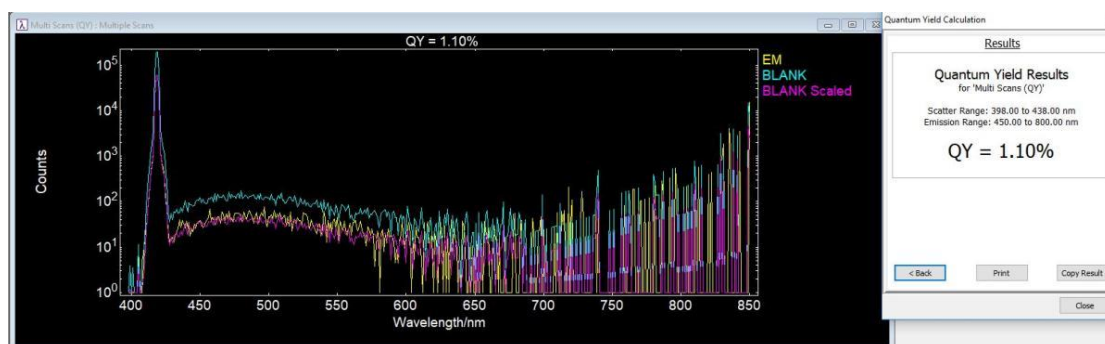


Figure S16. Quantum yield of Cu_{13}H_6 cluster. Room-temperature quantum yield of the Cu_{13}H_6 cluster was acquired with an FLS1000 spectrometer and determined to be 1.10%.

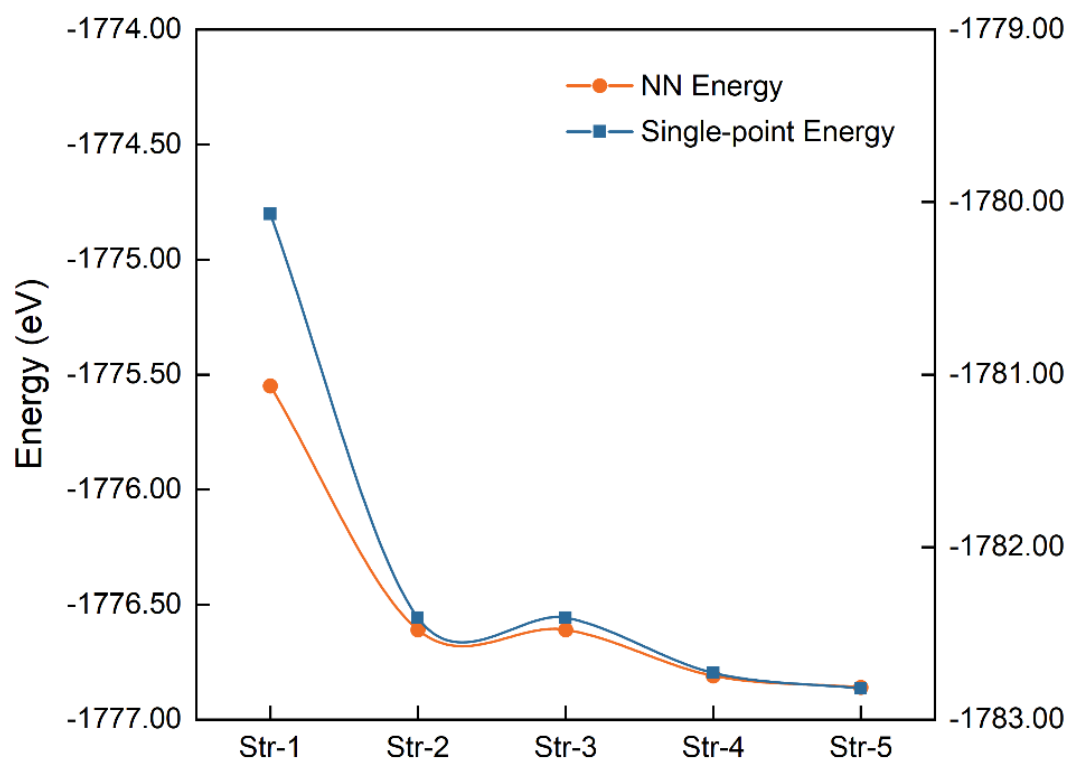


Figure S17. Trends of NN energy and DFT single-point energy. These five distinct low-energy structures confirm the consistency of the energetic trend.

Table S4. Deviations between NN energy and DFT single-point energy.

	<i>E_{SSW-NN}</i> (eV)	<i>E_{single-point}</i> (eV)	<i>E_{Optimization}</i> (eV)	<i>Error</i> (meV/atom)
Str-1	-1775.55	-1780.07	-1787.47	15.75
Str-2	-1776.61	-1782.41	-1789.16	20.21
Str-3	-1776.61	-1782.41	-1789.17	20.21
Str-4	-1776.81	-1782.72	-1789.45	20.59
Str-5	-1776.86	-1782.82	-1789.53	20.77

Table S5. Bader charge analysis of Cu atoms and hydrides in the Cu₁₃H₆ cluster.

<i>Atom</i>	<i>Bader charge e </i>	<i>Atom</i>	<i>Bader charge e </i>
Cu	0.28	Cu	0.28
Cu	0.29	Cu	0.27
Cu	0.23	Cu	0.31
Cu	0.35	H	-0.32
Cu	0.23	H	-0.28
Cu	0.27	H	-0.31
Cu	0.26	H	-0.31
Cu	0.20	H	-0.29
Cu	0.24	H	-0.30
Cu	0.33		

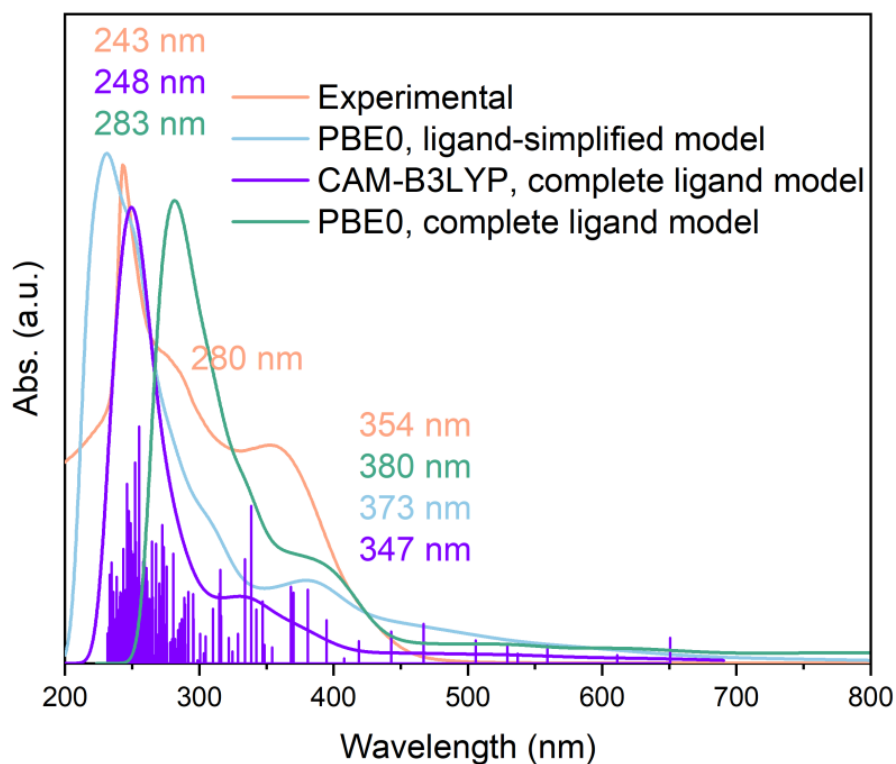


Figure S18. Experimental and TD-DFT-calculated UV-vis absorption spectra of the Cu_{13}H_6 cluster using different ligand models and exchange-correlation functionals. CAM-B3LYP (range-separated) calculations using the full ligand model yield better agreement with experimental spectra.

Table S6. Bond lengths among atoms after structural optimization.

<i>Atoms</i>	<i>Tag</i>	<i>Length/Å</i>	<i>Atoms</i>	<i>Tag</i>	<i>Length/Å</i>	<i>Atoms</i>	<i>Tag</i>	<i>Length/Å</i>
Cu-Cu	1-2	2.465	Cu-H	6-63	1.712	P-C	21-52	1.862
Cu-Cu	1-3	2.596	Cu-Cu	7-8	2.541	P-C	21-56	1.841
Cu-Cu	1-5	2.600	Cu-Cu	7-11	2.564	P-C	22-49	1.850
Cu-Cu	1-11	2.446	Cu-Cu	7-12	2.438	P-C	22-50	1.849
Cu-S	1-18	2.410	Cu-S	7-15	2.282	P-C	22-59	1.860
Cu-P	1-20	2.234	Cu-P	7-25	2.229	P-C	23-32	1.849
Cu-H	1-62	1.741	Cu-H	7-67	1.742	P-C	23-38	1.862
Cu-H	1-65	1.778	Cu-Cu	8-9	2.652	P-C	23-38	1.862
Cu-Cu	2-3	2.508	Cu-Cu	8-11	2.467	P-C	23-42	1.848
Cu-Cu	2-5	2.456	Cu-Cu	8-12	2.512	P-C	24-34	1.850
Cu-Cu	2-6	2.502	Cu-P	8-21	2.251	P-C	24-47	1.848
Cu-Cu	2-12	2.461	Cu-H	8-64	1.694	P-C	24-59	1.867
Cu-Cu	2-13	2.478	Cu-H	8-67	1.682	P-C	25-36	1.849
Cu-S	2-18	2.393	Cu-S	9-14	2.328	P-C	25-37	1.842
Cu-H	2-63	1.690	Cu-S	9-16	2.343	P-C	25-38	1.860
Cu-H	2-66	1.748	Cu-P	9-27	2.221	P-C	26-43	1.845
Cu-Cu	3-4	2.470	Cu-Cu	10-13	2.695	P-C	26-44	1.862
Cu-Cu	3-6	2.756	Cu-S	10-14	2.422	P-C	26-55	1.850
Cu-Cu	3-8	2.492	Cu-S	10-17	2.297	P-C	27-41	1.847
Cu-Cu	3-9	2.518	Cu-P	10-24	2.218	P-C	27-52	1.862
Cu-Cu	3-11	2.456	Cu-Cu	11-12	2.964	P-C	27-57	1.850
Cu-Cu	3-12	2.826	Cu-S	11-15	2.299	C-H	28-68	1.107
Cu-S	3-16	2.447	Cu-H	11-64	1.718	C-H	28-69	1.108
Cu-H	3-62	1.670	Cu-H	11-65	1.762	C-H	28-70	1.106
Cu-H	3-64	1.718	Cu-S	12-19	2.339	C-H	29-71	1.108
Cu-S	4-16	2.339	Cu-H	12-66	1.727	C-H	29-72	1.109

Cu-S	4-17	2.307	Cu-H	12-67	1.711	C-H	29-73	1.110
Cu-P	4-26	2.208	Cu-S	13-17	2.319	C-H	30-74	1.109
Cu-H	4-62	1.732	Cu-S	13-18	2.359	C-H	30-75	1.107
Cu-Cu	5-7	2.896	Cu-P	13-22	2.214	C-H	30-76	1.109
Cu-Cu	5-11	2.433	S-C	14-28	1.843	C-H	31-77	1.106
Cu-Cu	5-12	2.544	S-C	15-33	1.845	C-H	31-78	1.107
Cu-P	5-23	2.238	S-C	16-29	1.839	C-H	31-79	1.108
Cu-H	5-65	1.684	S-C	17-31	1.833	C-H	32-80	1.109
Cu-H	5-66	1.679	S-C	18-48	1.842	C-H	32-81	1.108
Cu-Cu	6-9	2.607	S-C	19-58	1.837	C-H	32-82	1.110
Cu-Cu	6-10	2.420	P-C	20-35	1.848	C-H	33-83	1.108
Cu-Cu	6-12	2.469	P-C	20-44	1.864	C-H	33-84	1.108
Cu-S	6-14	2.328	P-C	20-51	1.847	C-H	33-85	1.109
Cu-S	6-19	2.291	P-C	21-30	1.844	C-H	34-86	1.108

C-H	34-87	1.110	C-H	43-104	1.108	C-H	51-121	1.108
C-H	34-88	1.109	C-H	43-105	1.110	C-H	52-53	1.110
C-H	35-89	1.107	C-H	43-106	1.110	C-H	52-54	1.112
C-H	35-90	1.110	C-H	44-45	1.112	C-H	55-122	1.110
C-H	35-91	1.109	C-H	44-46	1.110	C-H	55-123	1.109
C-H	36-92	1.1082	C-H	47-107	1.109	C-H	55-124	1.109
C-H	36-93	1.109	C-H	47-108	1.108	C-H	56-125	1.107
C-H	36-94	1.110	C-H	47-109	1.109	C-H	56-126	1.109
C-H	37-95	1.108	C-H	48-110	1.106	C-H	56-127	1.109
C-H	37-96	1.108	C-H	48-111	1.108	C-H	57-128	1.108
C-H	37-97	1.109	C-H	48-112	1.107	C-H	57-129	1.108
C-H	38-39	1.110	C-H	49-113	1.110	C-H	57-130	1.110
C-H	38-40	1.113	C-H	49-114	1.108	C-H	58-131	1.106
C-H	41-98	1.109	C-H	49-115	1.109	C-H	58-132	1.108

C-H	41-99	1.107	C-H	50-116	1.109	C-H	58-133	1.109
C-H	41-100	1.107	C-H	50-117	1.109	C-H	59-60	1.113
C-H	42-101	1.107	C-H	50-118	1.108	C-H	59-61	1.111
C-H	42-102	1.108	C-H	51-119	1.109			

Table S7. Data of Kohn–Sham orbital energy level diagrams.

	<i>Cu-sp</i>	<i>Cu-d</i>	<i>C-sp</i>	<i>C-d</i>	<i>S-sp</i>	<i>S-d</i>	<i>P-sp</i>	<i>P-d</i>	<i>H-s</i>	<i>H-p</i>
HOMO-33	4.5360%	90.3692%	1.5515%	0.0031%	1.7166%	0.0513%	1.0483%	0.0756%	0.6439%	0.0044%
HOMO-32	5.8217%	86.0989%	2.2909%	0.0039%	2.7688%	0.0525%	1.4600%	0.0698%	1.4269%	0.0065%
HOMO-31	2.2871%	91.4009%	2.0416%	0.0034%	2.5175%	0.0349%	0.7152%	0.1030%	0.8913%	0.0051%
HOMO-30	3.2580%	90.7030%	1.7910%	0.0036%	1.2254%	0.0241%	1.9097%	0.0797%	0.9987%	0.0068%
HOMO-29	3.8900%	85.7000%	2.9659%	0.0041%	5.4656%	0.0351%	0.7965%	0.1511%	0.9859%	0.0057%
HOMO-28	8.3450%	77.0638%	3.2922%	0.0078%	6.6532%	0.0724%	3.1711%	0.0641%	1.3236%	0.0068%
HOMO-27	18.1052%	71.3374%	2.6343%	0.0072%	4.3388%	0.0380%	2.1996%	0.0631%	1.2697%	0.0068%
HOMO-26	4.4412%	86.8398%	2.2369%	0.0044%	3.8573%	0.0270%	1.5189%	0.0980%	0.9708%	0.0055%
HOMO-25	5.6295%	80.2540%	4.0345%	0.0074%	5.6378%	0.0640%	2.3368%	0.0730%	1.9575%	0.0056%
HOMO-24	6.2798%	85.0713%	2.2869%	0.0059%	3.9279%	0.0344%	1.0212%	0.0703%	1.2983%	0.0041%
HOMO-23	9.7405%	72.0771%	4.2302%	0.0131%	5.7041%	0.0562%	5.8414%	0.0515%	2.2756%	0.0102%
HOMO-22	6.9067%	80.4037%	2.6448%	0.0076%	7.2758%	0.0335%	1.0029%	0.0664%	1.6503%	0.0085%
HOMO-21	11.7796%	68.9863%	3.6825%	0.0113%	6.4925%	0.0266%	6.5511%	0.1095%	2.3533%	0.0073%
HOMO-20	19.8950%	58.7960%	2.8973%	0.0126%	11.1345%	0.0190%	4.6766%	0.0481%	2.5138%	0.0072%
HOMO-19	11.3686%	62.7616%	5.6262%	0.0170%	9.8458%	0.0590%	7.5286%	0.1124%	2.6702%	0.0107%
HOMO-18	14.1607%	51.0992%	5.4405%	0.0234%	12.9629%	0.0883%	12.3725%	0.0749%	3.7695%	0.0082%
HOMO-17	25.4321%	44.4405%	3.8946%	0.0201%	12.1948%	0.0252%	10.6093%	0.0411%	3.3318%	0.0106%
HOMO-16	22.4440%	35.1822%	4.9014%	0.0285%	20.9968%	0.0410%	11.4752%	0.0769%	4.8415%	0.0127%
HOMO-15	21.6955%	51.1623%	3.0944%	0.0181%	14.8633%	0.0316%	4.5826%	0.0694%	4.4746%	0.0083%
HOMO-14	27.2335%	40.3301%	3.9751%	0.0179%	19.0390%	0.0585%	5.2642%	0.0549%	4.0166%	0.0102%
HOMO-13	13.0319%	47.7798%	4.6112%	0.0242%	18.9127%	0.0383%	8.1280%	0.1372%	7.3271%	0.0097%
HOMO-12	31.8233%	31.8505%	3.1364%	0.0216%	18.4641%	0.0215%	10.4309%	0.0361%	4.2062%	0.0093%
HOMO-11	11.5036%	37.9152%	5.2943%	0.0256%	23.7143%	0.0508%	16.8260%	0.0979%	4.5625%	0.0098%
HOMO-10	21.2709%	30.8863%	4.5845%	0.0269%	25.7250%	0.0545%	12.9138%	0.0778%	4.4525%	0.0079%
HOMO-9	23.0974%	29.7883%	3.9428%	0.0263%	26.0132%	0.0201%	11.2682%	0.0625%	5.7704%	0.0108%
HOMO-8	27.4098%	29.6297%	2.9039%	0.0242%	31.0224%	0.0391%	3.5017%	0.0729%	5.3846%	0.0115%
HOMO-7	12.4433%	34.9594%	4.6154%	0.0327%	24.2082%	0.0455%	17.8489%	0.0429%	5.7925%	0.0112%

HOMO-6	23.3486%	31.3063%	5.4227%	0.0270%	17.6277%	0.0679%	15.3343%	0.0468%	6.8101%	0.0085%
HOMO-5	36.4842%	24.7286%	1.7720%	0.0180%	27.2831%	0.0135%	4.6565%	0.0257%	5.0121%	0.0062%
HOMO-4	17.8947%	31.2047%	5.1050%	0.0256%	15.5968%	0.0431%	22.7599%	0.0687%	7.2918%	0.0096%
HOMO-3	28.8833%	27.9893%	3.0190%	0.0245%	25.7744%	0.0277%	9.0501%	0.0432%	5.1790%	0.0095%
HOMO-2	22.7608%	29.4413%	2.8748%	0.0259%	29.5691%	0.0391%	10.0987%	0.0616%	5.1220%	0.0066%
HOMO-1	24.0311%	31.5371%	3.2933%	0.0248%	21.9288%	0.0220%	12.4148%	0.0524%	6.6859%	0.0097%
HOMO	39.3998%	26.8849%	2.4675%	0.0143%	19.3372%	0.0515%	2.4443%	0.0857%	9.3074%	0.0074%
LUMO	64.2332%	9.4627%	4.5226%	0.0074%	7.5010%	0.0634%	8.3352%	0.1088%	5.7556%	0.0102%
LUMO+1	72.7497%	7.0700%	7.7231%	0.0052%	2.4895%	0.0297%	5.9663%	0.1755%	3.7815%	0.0096%
LUMO+2	47.4096%	9.0992%	19.4578%	0.0094%	3.3333%	0.0869%	14.1637%	0.3099%	6.1166%	0.0136%
LUMO+3	78.2941%	2.9525%	7.1903%	0.0044%	1.9063%	0.0133%	6.2960%	0.1067%	3.2296%	0.0067%
LUMO+4	73.7809%	3.2309%	9.5916%	0.0048%	2.4189%	0.0276%	7.3390%	0.1102%	3.4875%	0.0087%
LUMO+5	71.9617%	4.2457%	9.2500%	0.0044%	3.6374%	0.0245%	6.8930%	0.0881%	3.8894%	0.0059%
LUMO+6	78.8281%	2.5678%	7.0248%	0.0034%	1.9654%	0.0131%	6.2071%	0.0648%	3.3207%	0.0048%
LUMO+7	61.1556%	4.5923%	14.2768%	0.0074%	3.2065%	0.0328%	10.8963%	0.1647%	5.6591%	0.0084%
LUMO+8	65.8158%	4.1170%	15.6759%	0.0045%	1.6850%	0.0528%	5.0410%	0.0916%	7.5096%	0.0067%
LUMO+9	87.7036%	1.4813%	4.9972%	0.0020%	0.9466%	0.0122%	2.5618%	0.0394%	2.2530%	0.0028%
LUMO+10	59.5921%	6.0507%	15.3694%	0.0051%	1.4734%	0.0295%	11.1214%	0.1185%	6.2324%	0.0075%

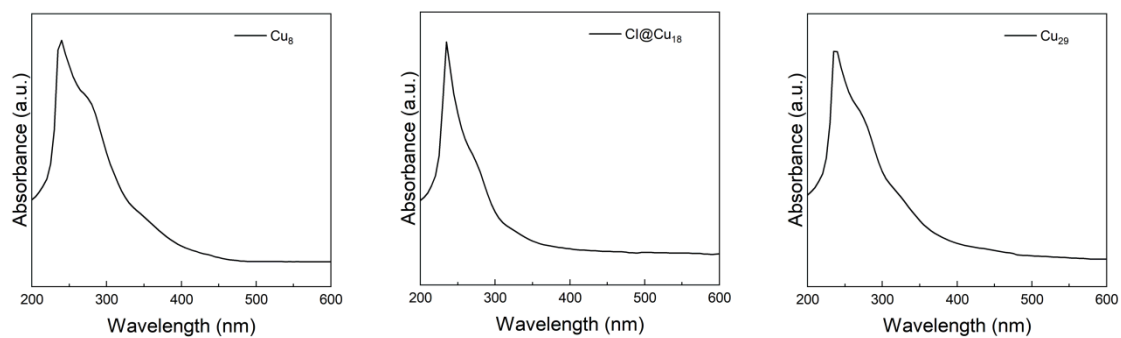


Figure S19. The UV-vis spectra of other copper nanoclusters . The spectra were recorded in dichloromethane at room temperature.

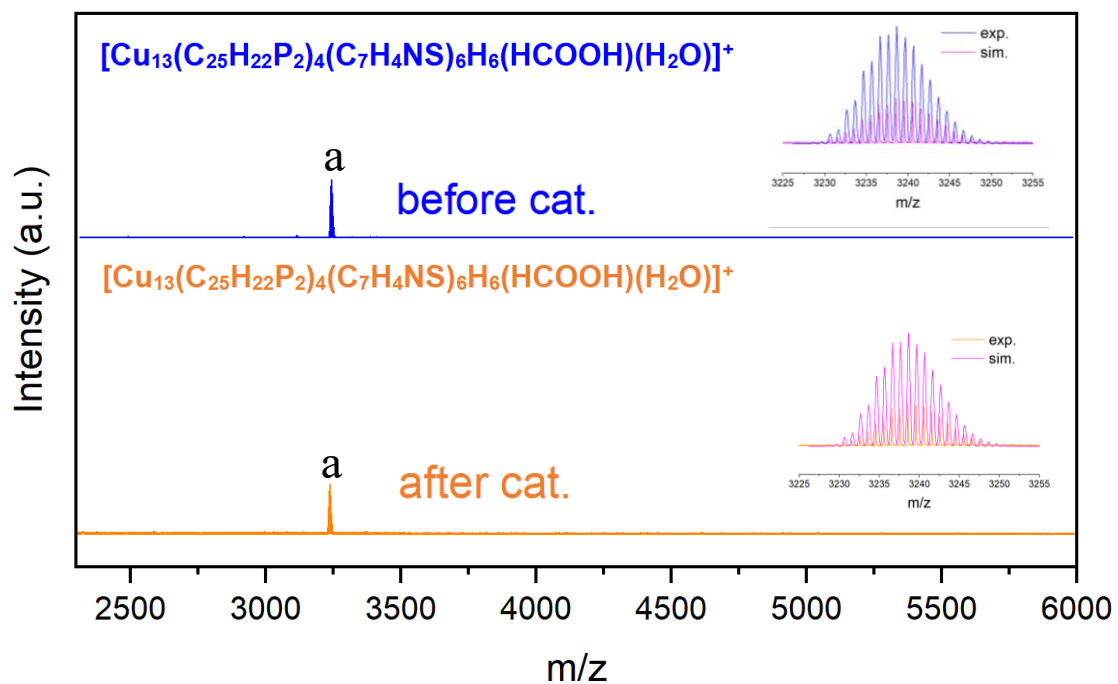


Figure S20. The ESI-MS spectra of reaction solution before and after catalysis.
The ESI-MS spectra of the catalysts preserved after catalysis.

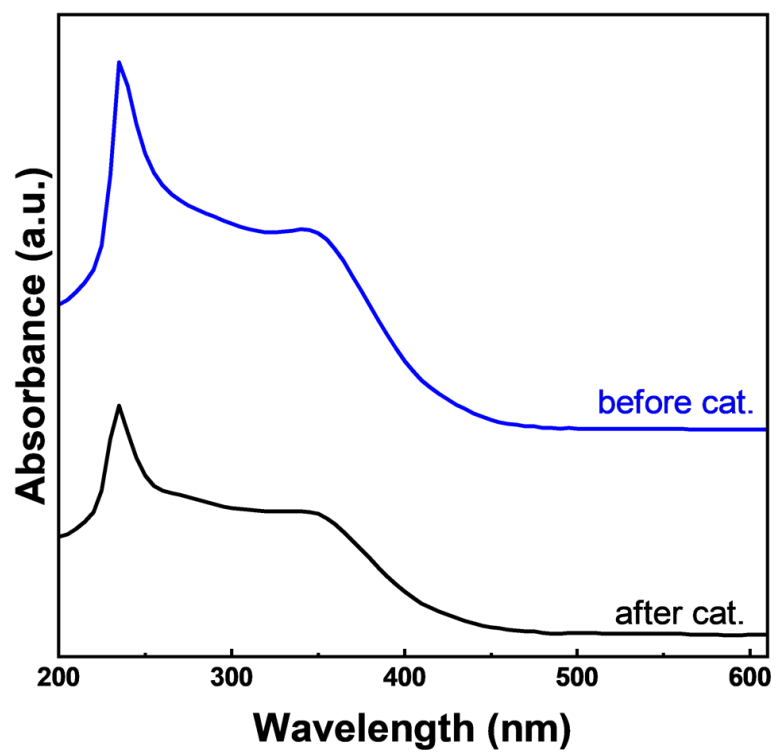


Figure S21. UV–vis absorption spectra of Cu_{13}H_6 nanocluster before and after catalysis. The UV-Vis spectra of the catalysts preserved after catalysis.

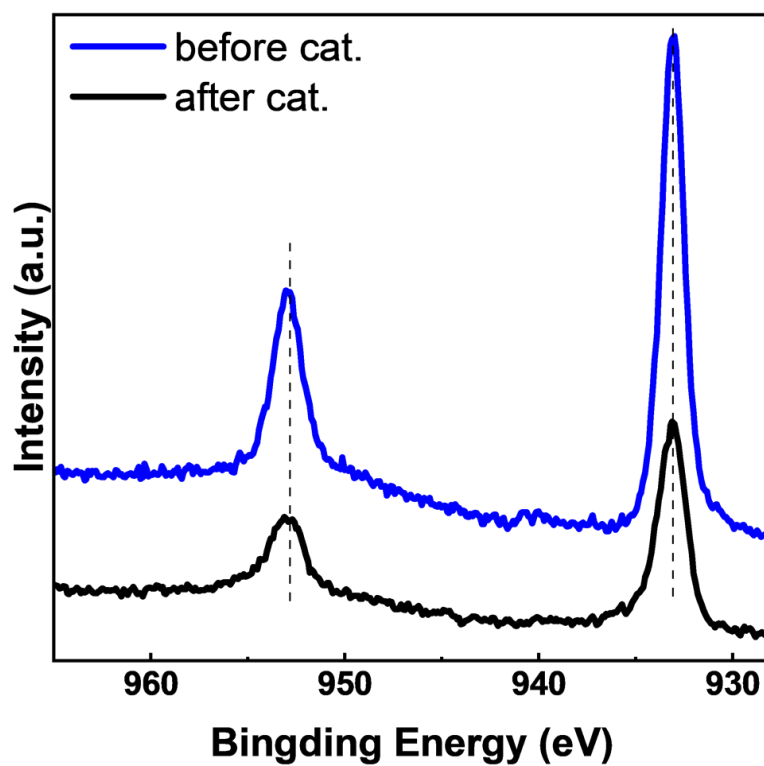


Figure S22. XPS of Cu $2p$ spectroscopy of Cu₁₃H₆ nanocluster before and after catalysis. The Cu oxidation state of the catalysts preserved after catalysis.

Supplementary Note 1: Recycling Experiments

To a 25-mL Schlenk tube under air atmosphere were added xanthene (37 mg, 0.2 mmol), Cu₁₃H₆ (10 mg, 0.003 mmol), DBU (10 μ L, 0.067 mmol) and DMF (3.0 mL) sequentially. The reaction mixture was stirred at room temperature under blue LED irradiation for 12 hours. Cu₁₃H₆ was precipitated by the addition of *n*-hexane (25 mL) to the solution. A following centrifugation gave Cu₁₃H₆ nanocluster. The remaining mixture was concentrated under vacuum. The crude product was purified by column chromatography isolation on silica gel via gradient elution with hexane to hexane/ethyl acetate (40:1 ~ 20:1) to give the product **3**. The recovered Cu₁₃H₆ catalyst was used for the recycling experiments.

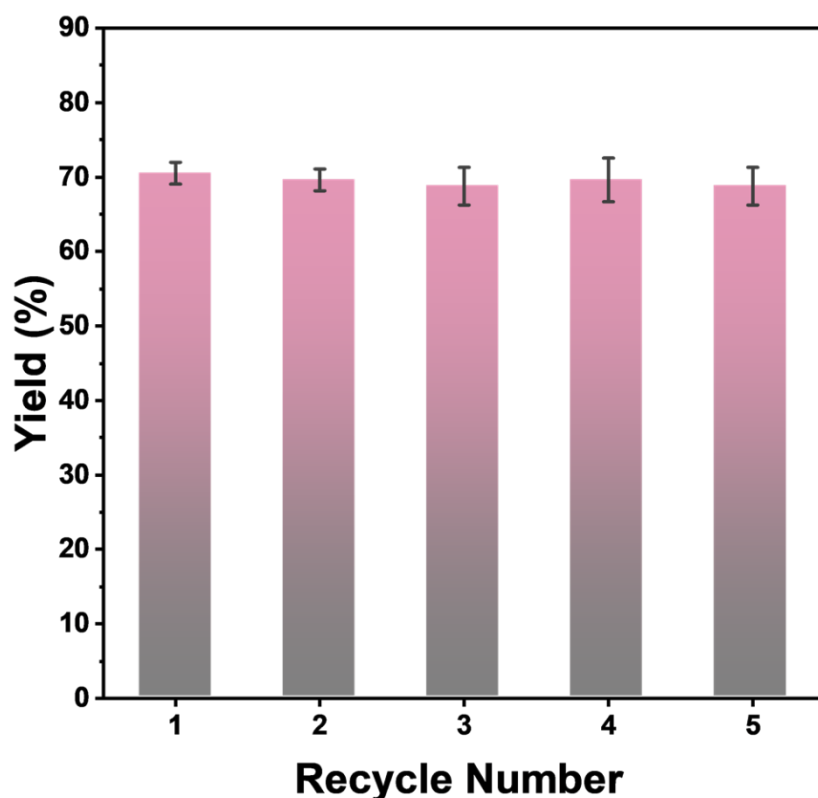


Figure S23. Recycled Cu₁₃H₆-catalyzed oxidation reaction. Error bars represent the mean $\pm$ S.D. (standard deviation) calculated from three independent catalytic experiments.

Elemental Composition Report

Page 1

Single Mass Analysis

Tolerance = 5.0 mDa / DBE: min = -1.5, max = 50.0

Element prediction: Off

Number of isotope peaks used for i-FIT = 3

Monoisotopic Mass, Even Electron Ions

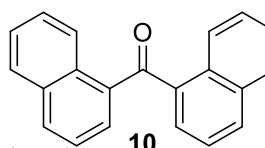
361 formula(e) evaluated with 1 results within limits (up to 50 best isotopic matches for each mass)

Elements Used:

C: 21-21 H: 15-15 N: 0-100 O: 0-50 Na: 0-1

47

251025-10-2 19 (0.125)



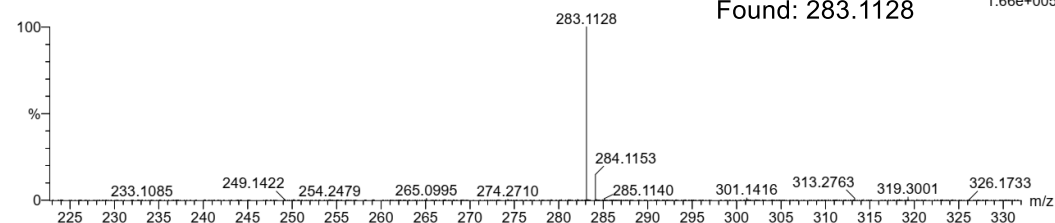
10

$[M+H]^+$

Calcd: 283.1118

Found: 283.1128

1: TOF MS ES+
1.66e+005



Minimum: -1.5
Maximum: 5.0 10.0 50.0

Mass	Calc. Mass	mDa	PPM	DBE	i-FIT	Norm	Conf (%)	Formula
283.1128	283.1123	0.5	1.8	14.5	393.1	n/a	n/a	C ₂₁ H ₁₅ O

Figure S24. HRMS of the product 10. HRMS m/z: calcd for C₂₁H₁₅O $[M + H]^+$: 283.1118; Found: 283.1128.

Elemental Composition Report

Page 1

Single Mass Analysis

Tolerance = 5.0 mDa / DBE: min = -1.5, max = 50.0

Element prediction: Off

Number of isotope peaks used for i-FIT = 3

Monoisotopic Mass, Even Electron Ions

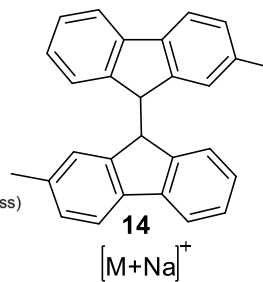
921 formula(e) evaluated with 1 results within limits (up to 50 closest results for each mass)

Elements Used:

C: 28-28 H: 22-22 N: 0-100 O: 0-50 Na: 0-2

52

250929-18-5 16 (0.109)



1: TOF MS ES+
1.26e+002

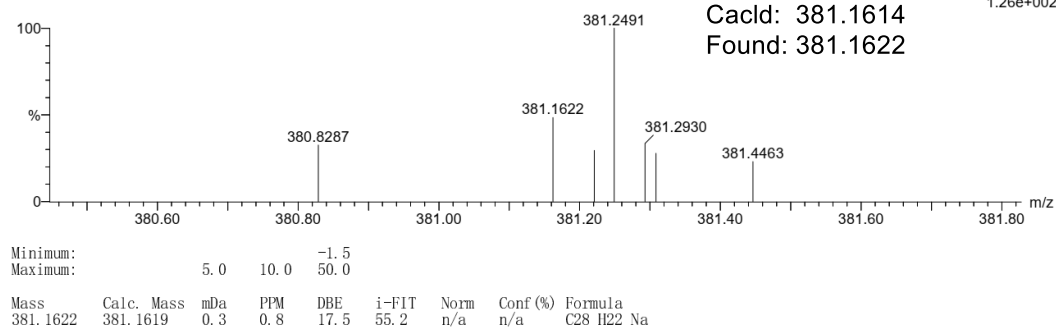


Figure S25. HRMS of the product 14. HRMS m/z: calcd for C₂₈H₂₂Na [M + Na]⁺: 381.1614; Found: 381.1622.

Elemental Composition Report

Single Mass Analysis

Tolerance = 5.0 mDa / DBE: min = -1.5, max = 50.0

Element prediction: Off

Number of isotope peaks used for i-FIT = 3

Monoisotopic Mass, Even Electron Ions

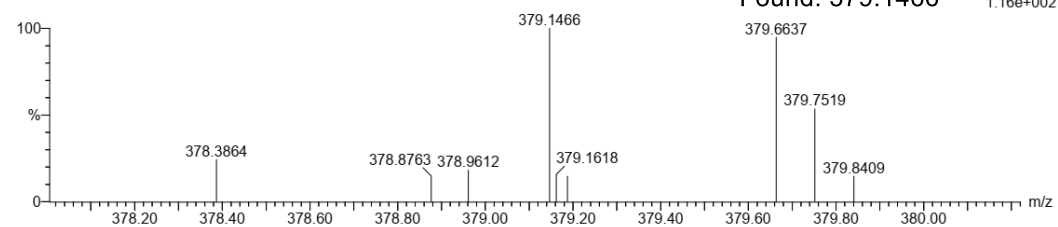
643 formula(e) evaluated with 1 results within limits (up to 50 best isotopic matches for each mass)

Elements Used:

C: 28-28 H: 20-20 N: 0-100 O: 0-100 Na: 0-1

30

251101-11-3 65 (0.382)



Minimum: -1.5
Maximum: 5.0 10.0 50.0

Mass	Calc. Mass	mDa	PPM	DBE	i-FIT	Norm	Conf (%)	Formula
379.1466	379.1463	0.3	0.8	18.5	53.7	n/a	n/a	C ₂₈ H ₂₀ Na

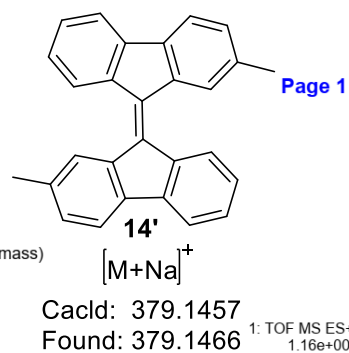


Figure S26. HRMS of the product 14'. HRMS m/z: calcd for C₂₈H₂₀Na [M + Na]⁺: 379.1457; Found: 379.1466.

Single Mass Analysis

Tolerance = 5.0 mDa / DBE: min = -1.5, max = 50.0

Element prediction: Off

Number of isotope peaks used for i-FIT = 3

Monoisotopic Mass, Even Electron Ions

2137 formula(e) evaluated with 1 results within limits (up to 50 closest results for each mass)

Elements Used:

C: 42-42 H: 50-50 N: 0-100 O: 0-50 Na: 0-2

52

250929-18-6 67 (0.392)

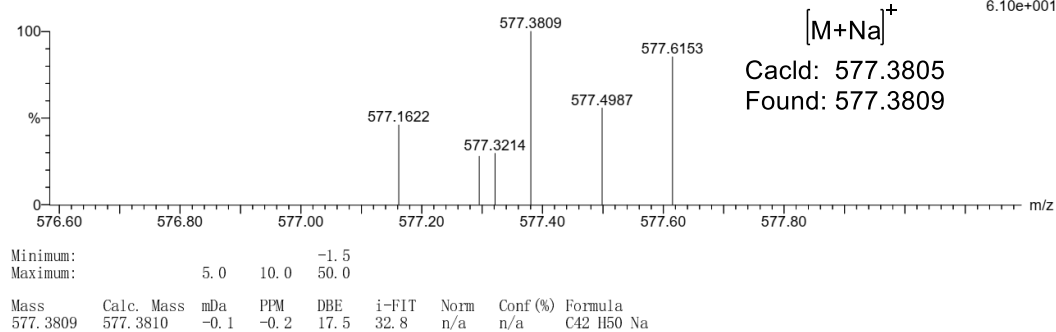


Figure S27. HRMS of the product 20. HRMS m/z: calcd for C₄₂H₅₀Na [M + Na]⁺: 577.3805; Found: 577.3809.

Single Mass Analysis

Tolerance = 5.0 mDa / DBE: min = -1.5, max = 50.0

Element prediction: Off

Number of isotope peaks used for i-FIT = 3

Monoisotopic Mass, Even Electron Ions

665 formula(e) evaluated with 1 results within limits (up to 50 best isotopic matches for each mass)

Elements Used:

C: 27-27 H: 17-17 N: 0-100 O: 0-50 Na: 0-1

47

251025-10-1 11 (0.083)

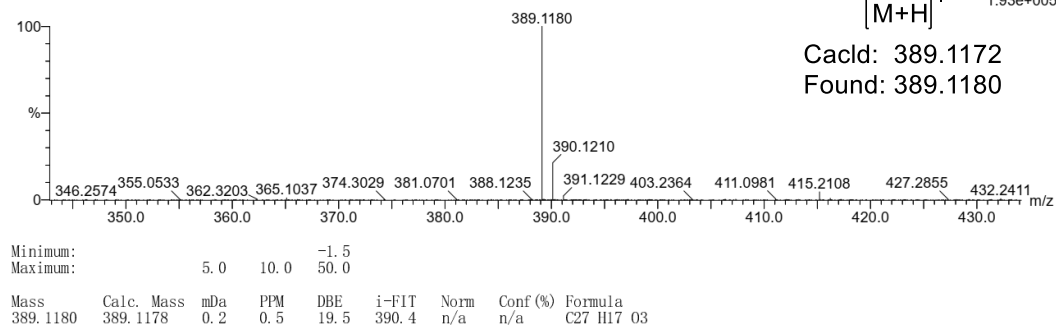


Figure S28. HRMS of the product 25. HRMS m/z: calcd for C₂₇H₁₇O₃ [M + H]⁺: 389.1172; Found: 389.1180.

Elemental Composition Report

Page 1

Single Mass Analysis

Tolerance = 5.0 mDa / DBE: min = -1.5, max = 50.0

Element prediction: Off

Number of isotope peaks used for i-FIT = 3

Monoisotopic Mass, Even Electron Ions

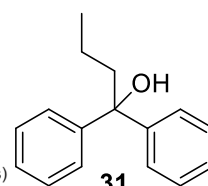
231 formula(e) evaluated with 1 results within limits (up to 50 best isotopic matches for each mass)

Elements Used:

C: 16-16 H: 19-19 N: 0-100 O: 0-50 Na: 0-1

47

251025-10-3 10 (0.077)

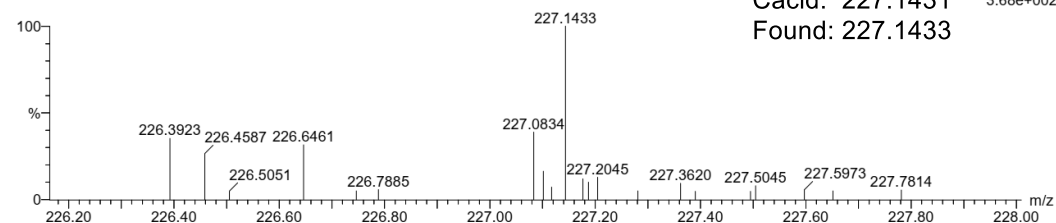


[M+H]⁺

Calcd: 227.1431

Found: 227.1433

1: TOF MS ES+
3.68e+002



Minimum: -1.5
Maximum: 50.0

Mass	Calc. Mass	mDa	PPM	DBE	i-FIT	Norm	Conf (%)	Formula
227.1433	227.1436	-0.3	-1.3	7.5	92.5	n/a	n/a	C16 H19 O

Figure S29. HRMS of the product 31. HRMS m/z: calcd for C₁₆H₁₉O [M + H]⁺: 227.1431; Found: 227.1433.

Elemental Composition Report

Page 1

Single Mass Analysis

Tolerance = 5.0 mDa / DBE: min = -1.5, max = 50.0

Element prediction: Off

Number of isotope peaks used for i-FIT = 3

Monoisotopic Mass, Even Electron Ions

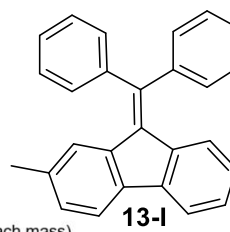
603 formula(e) evaluated with 1 results within limits (up to 50 best isotopic matches for each mass)

Elements Used:

C: 27-27 H: 20-20 N: 0-100 O: 0-100 Na: 0-1

4

251103-11-3 97 (0.558)



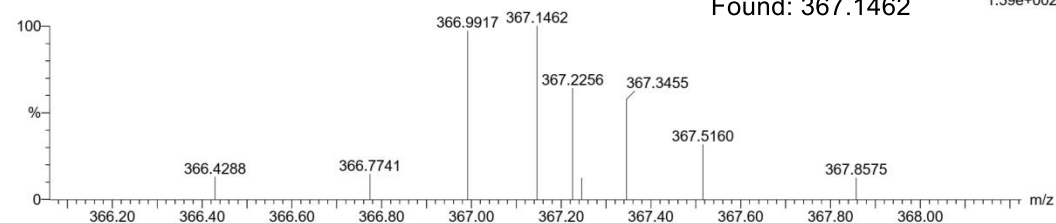
13-I

$[M+Na]^+$

Calcd: 367.1457

Found: 367.1462

1: TOF MS ES+
1.39e+002



Minimum: -1.5
Maximum: 5.0 10.0 50.0

Mass	Calc. Mass	mDa	PPM	DBE	i-FIT	Norm	Conf (%)	Formula
367.1462	367.1463	-0.1	-0.3	17.5	55.9	n/a	n/a	C ₂₇ H ₂₀ Na

Figure S30. HRMS of the product 13-I. HRMS m/z: calcd for C₂₇H₂₀Na [M + Na]⁺: 367.1457; Found: 367.1462.

Elemental Composition Report

Page 1

Single Mass Analysis

Tolerance = 5.0 mDa / DBE: min = -1.5, max = 50.0

Element prediction: Off

Number of isotope peaks used for i-FIT = 3

Monoisotopic Mass, Even Electron Ions

661 formula(e) evaluated with 1 results within limits (up to 50 best isotopic matches for each mass)

Elements Used:

C: 28-28 H: 33-33 N: 0-100 O: 0-100 Na: 0-1

4

251103-11-2 9 (0.072)

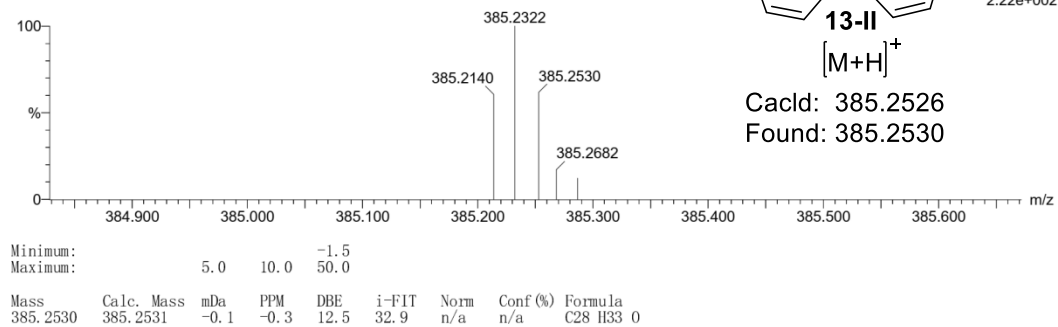


Figure S31. HRMS of the product 13-II. HRMS m/z: calcd for C₂₈H₃₃O [M + H]⁺: 385.2526; Found: 385.2530.

Elemental Composition Report

Page 1

Single Mass Analysis

Tolerance = 5.0 mDa / DBE: min = -1.5, max = 50.0

Element prediction: Off

Number of isotope peaks used for i-FIT = 3

Monoisotopic Mass, Even Electron Ions

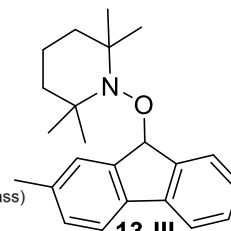
496 formula(e) evaluated with 1 results within limits (up to 50 best isotopic matches for each mass)

Elements Used:

C: 23-23 H: 30-30 N: 0-100 O: 0-100 Na: 0-1

4

251103-11-1 10 (0.077)



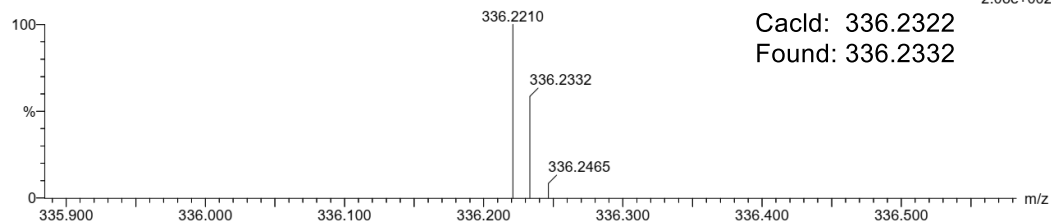
13-III

$[M+H]^+$

1: TOF MS ES+
2.08e+002

Calcd: 336.2322

Found: 336.2332



Minimum: -1.5
Maximum: 50.0

Mass	Calc. Mass	mDa	PPM	DBE	i-FIT	Norm	Conf (%)	Formula
336.2332	336.2327	0.5	1.5	9.5	24.1	n/a	n/a	C ₂₃ H ₃₀ N ₀ O

Figure S32. HRMS of the product 13-III. HRMS m/z: calcd for C₂₃H₃₀NO $[M + H]^+$: 336.2322; Found: 336.2332.

Elemental Composition Report

Page 1

Single Mass Analysis

Tolerance = 5.0 mDa / DBE: min = -1.5, max = 50.0

Element prediction: Off

Number of isotope peaks used for i-FIT = 3

Monoisotopic Mass, Even Electron Ions

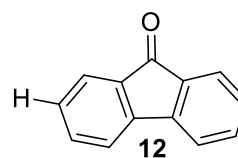
178 formula(e) evaluated with 1 results within limits (up to 50 best isotopic matches for each mass)

Elements Used:

C: 13-13 H: 8-8 N: 0-100 O: 0-100 Na: 0-1

30

251101-11-1 4 (0.046)

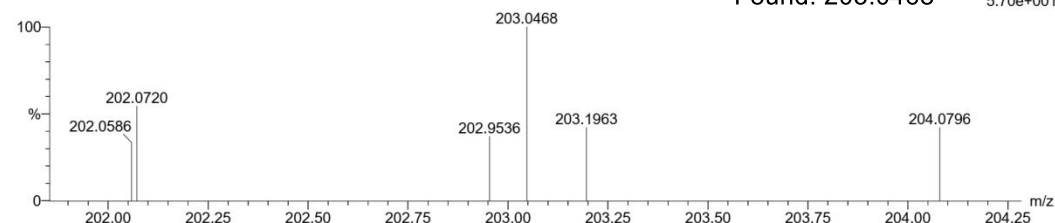


$[M+Na]^+$

Calcd: 203.0467

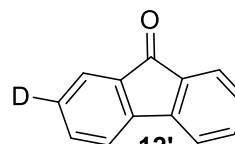
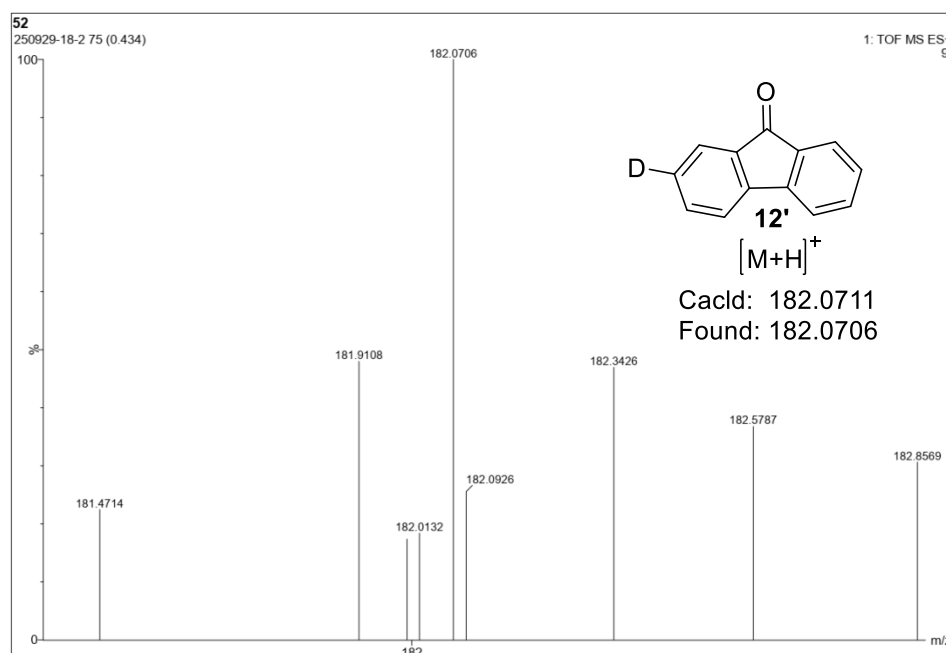
Found: 203.0468

1: TOF MS ES+
5.70e+001



Minimum: -1.5
Maximum: 5.0 10.0 50.0

Mass	Calc. Mass	mDa	PPM	DBE	i-FIT	Norm	Conf (%)	Formula
203.0468	203.0473	-0.5	-2.5	9.5	24.1	n/a	n/a	C13 H8 O Na



$[M+H]^+$

Calcd: 182.0711

Found: 182.0706

Figure S33. HRMS of the product 12 and 12'. HRMS m/z: calcd for $C_{13}H_8ONa [M + Na]^+$: 203.0467; Found: 203.0468; HRMS m/z: calcd for $C_{13}H_7DO [M + H]^+$: 182.0711; Found: 182.0706.

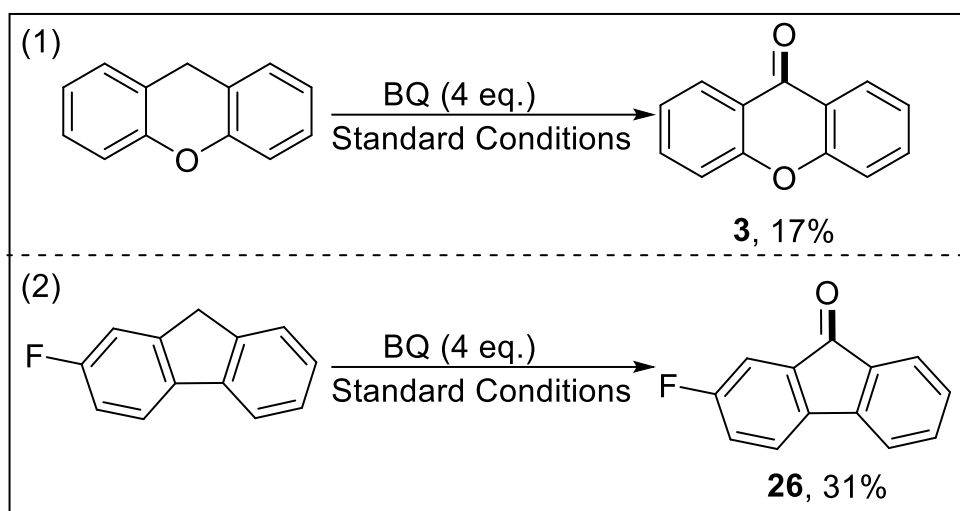
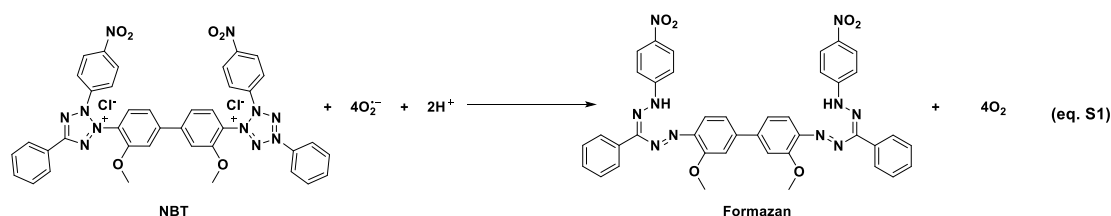


Figure S34. Radical inhibition experiments. Substantial suppression of catalytic activity by BQ addition.

Supplementary Note 2: Quantitative experiment of superoxide radical ($\text{O}_2^{\cdot-}$)

We use the nitro blue tetrazolium (NBT) method to quantitatively determine the formation of superoxide radical ($\text{O}_2^{\cdot-}$) in the system. As well documented in literatures, NBT can be oxidized to Formazan by $\text{O}_2^{\cdot-}$ in a quantitative manner (Angew. Chem. 2025, 137, e202502307). The product of Formazan has a characteristic absorption peak in the visible light region, and its formation amount is quantitatively related to the concentration of superoxide anion radicals ($\text{O}_2^{\cdot-}$), with a molar ratio of 4:1 between generated $\text{O}_2^{\cdot-}$ and Formazan, as described in the following equation (eq. S1). Therefore, this study uses the change in absorbance of Formazan as an indirect indicator for the generation of $\text{O}_2^{\cdot-}$. To satisfy the solubility requirements of both compounds in this catalytic reaction system, we employed a mixed solvent system consisting of DMF and water in a 5:1 volume ratio.



① **UV-vis absorption profile of Formazan.** Formazan was dissolved in a mixed solvent (DMF: H_2O = 5:1), with an absorption maximum at 530 nm (Figure S35).

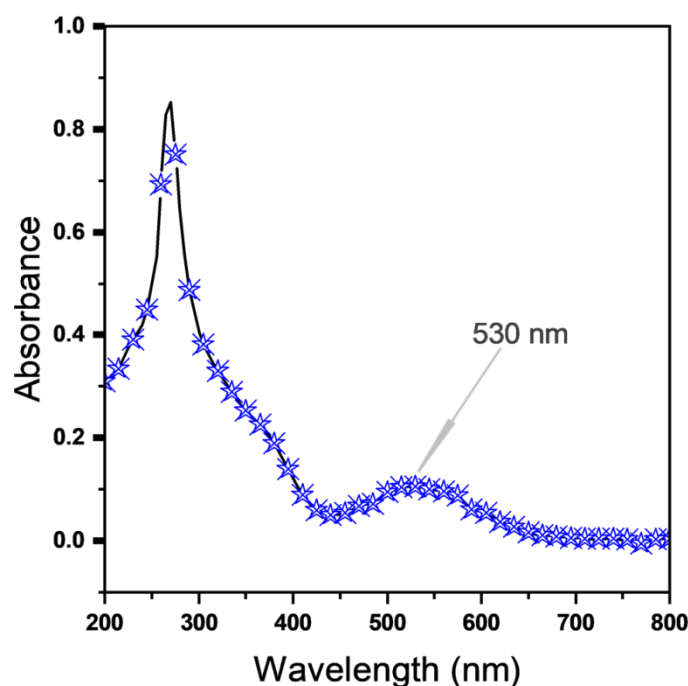


Figure S35. UV-vis spectra of Formazan solution (DMF: H_2O = 5:1). The spectra was recorded at room temperature.

② **Plotting the standard curve.** We prepare a Formazan standard solution with a concentration of $2.0 \times 10^{-5} \text{ mol} \cdot \text{L}^{-1}$ (DMF: H_2O = 5: 1, v/v; see Figure S36, A). The solution was then subjected to a series of serial dilutions (Figure S36, B), and the absorbance of each diluted sample was measured at $\lambda_{\text{max}} = 530 \text{ nm}$ using a UV-vis spectrophotometer (Figure S37). Based on these measurements, a standard curve of formazan concentration versus absorbance was plotted (Figure S38), yielding the equation: $y = 0.10531x - 0.00508$.



Figure S36. The photographs of Formazan standard solution (A), and the gradient dilution solution pictures (B). It shows the purple color of the solution.

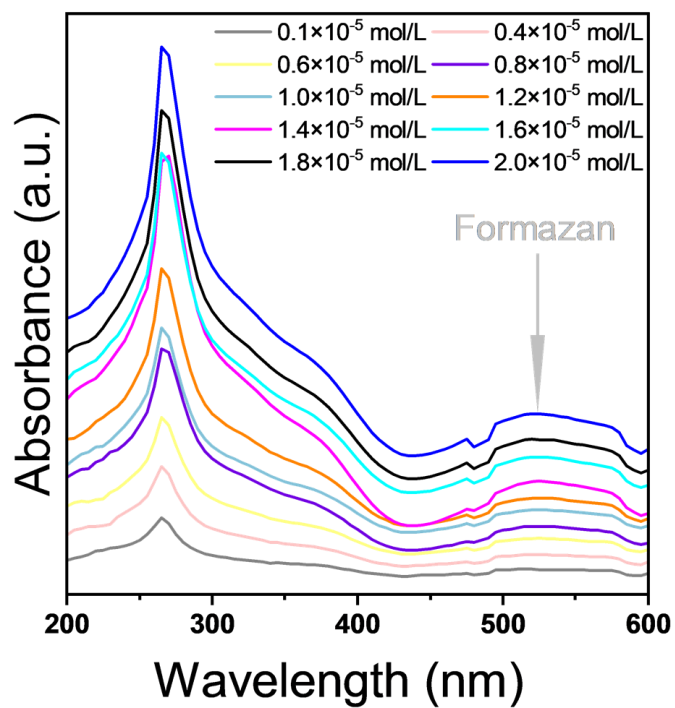


Figure S37. UV-vis spectra of the Formazan gradient dilution solution. UV-vis spectra acquired at room temperature were used to construct the calibration curve of absorbance versus formazan concentration for quantitative analysis.

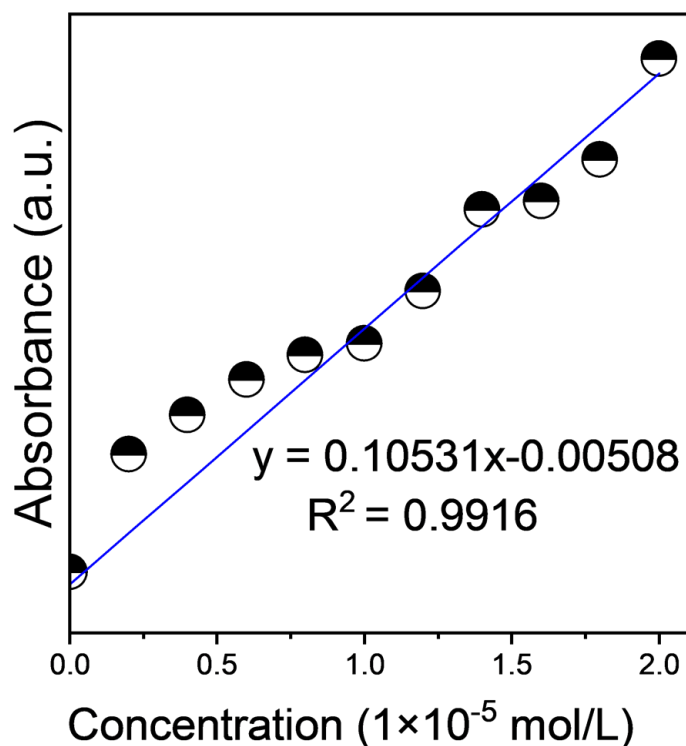


Figure S38. The concentration-absorbance standard curve of Formazan. The curve was employed to perform quantitative analysis.

③ **Quantitative testing.** First, a 2.0×10^{-5} M NBT solution (DMF: H_2O = 5: 1) was prepared. By using the standard solution described above as the reaction solvent, 3 mL of the reaction mixture was filtered through a filter at specified time intervals. The absorbance of the solution was then measured at 530 nm using a UV spectrophotometer (Figure S39). Quantification of $\text{O}_2^{\bullet-}$ revealed that its concentration remained low in the absence of Cu_{13}H_6 . However, when Cu_{13}H_6 was present in the system, the absorbance at a wavelength of 530 nm significantly increased over time (Figure S40).

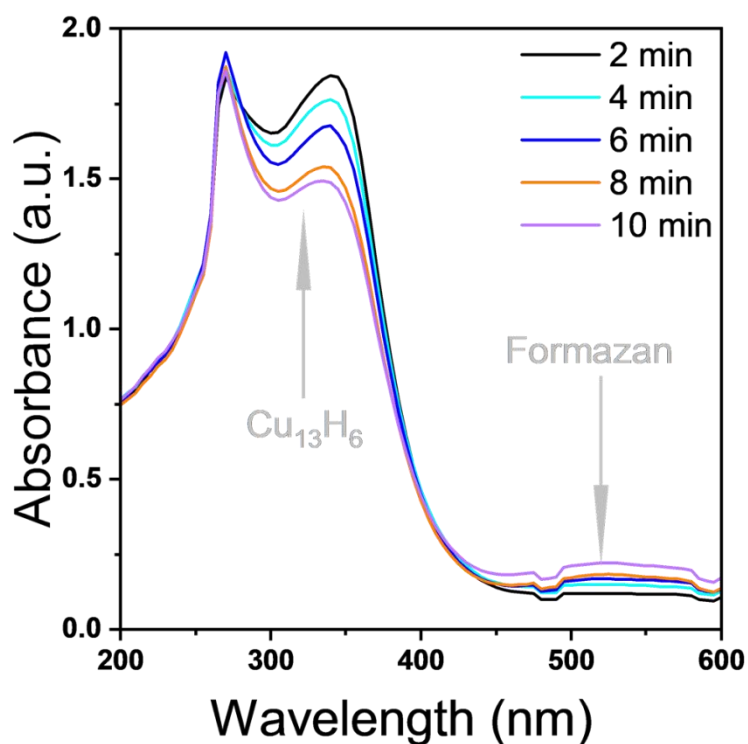


Figure S39. Absorption spectrum of the system at a wavelength of 530 nm at different time. Time-course absorption spectra of the system recorded at a wavelength of 530 nm at different time points.

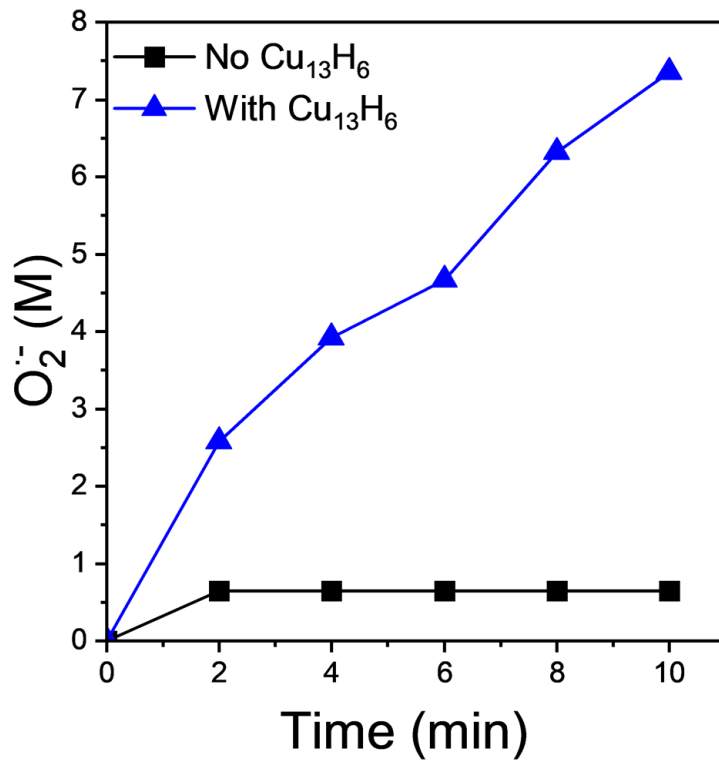


Figure S40. Quantitative experiments of $\text{O}_2^{\bullet-}$. Quantitative experiments to determine the yield of superoxide radical anion ($\text{O}_2^{\bullet-}$).

Supplementary Note 3: Computation of the redox potential of excited-state Cu₁₃H₆ catalysts

We estimated the redox potential of excited Cu₁₃H₆ using a Rehm-Weller equation (eq. S2), based on the redox potential of the ground-state Cu₁₃H₆ and its triplet energy E_T (Figure S41). The obtained values are shown in the Table S8. The thermodynamic feasibility assessment of single-electron transfer (SET) processes was shown in the following sections.

$$\begin{aligned} O_1[Cu_{13}H_6]^*(V) &= O_1[Cu_{13}H_6] - 1240/EW \\ R_1[Cu_{13}H_6]^*(V) &= R_1[Cu_{13}H_6] + 1240/EW \end{aligned} \quad \text{eq. S2}$$

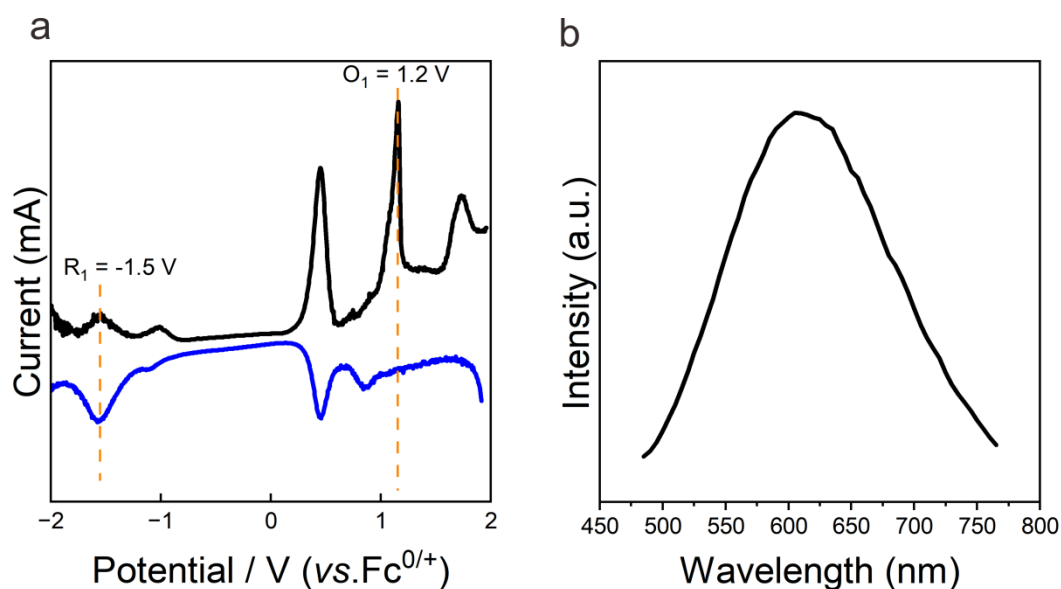


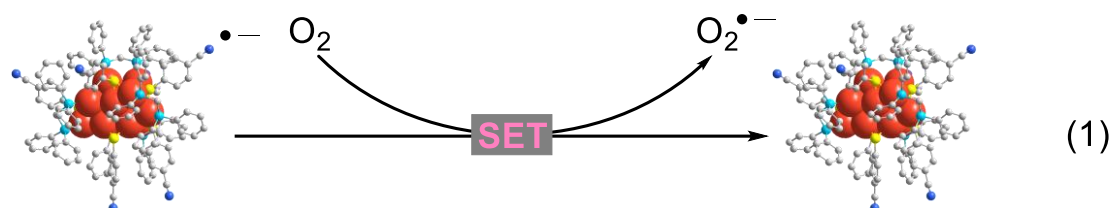
Figure S41. DPV (a) and emission spectra (b) of [Cu₁₃H₆] (solvent = DCM).

Note: The DPV test was always conducted in argon atmosphere.

Table S8. Calculation of oxidation potential of [Cu₁₃H₆]^{*}.

Emission Wavelength, EW (nm)	O ₁ [Cu ₁₃ H ₆] (V)	O ₁ [Cu ₁₃ H ₆] [*] (V)	R ₁ [Cu ₁₃ H ₆] (V)	R ₁ [Cu ₁₃ H ₆] [*] (V)
610	1.2	-0.833	-1.5	0.534

Supplementary Note 4: The single-electron transfer reaction between the reduced catalyst Cu₁₃H₆ and molecular oxygen



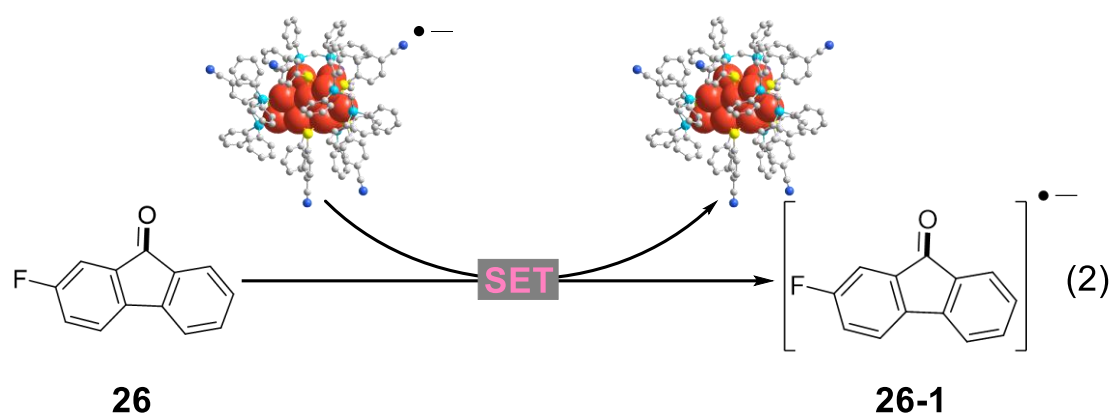
Process (1) represents the single-electron transfer reaction between the reduced catalyst Cu₁₃H₆ and molecular oxygen, resulting in the formation of the ground-state catalyst Cu₁₃H₆ and the superoxide radical (O₂^{•-}). During this process, O₂ acts as the oxidizing agent, while the reduced form of Cu₁₃H₆ acts as the reducing agent. Here,

$E(\text{Cu}_{13}\text{H}_6/[\text{Cu}_{13}\text{H}_6]^-) = -1.5 \text{ V}$, this value is much lower than the reduction potential of O₂ to superoxide radical anion O₂^{•-} ($E(\text{O}_2/[\text{O}_2]^-) = -0.91 \text{ V}$). During this reaction process,

$$\Delta E = E(\text{O}_2/[\text{O}_2]^-) - E(\text{Cu}_{13}\text{H}_6/[\text{Cu}_{13}\text{H}_6]^-) = -0.91 - (-1.5) = +0.59 \text{ V} > 0$$

Therefore, the corresponding Gibbs free energy change $\Delta G = -nF\Delta E < 0$, indicating that this single-electron transfer process is thermodynamically feasible.

Supplementary Note 5: The single-electron transfer reaction between the reduced catalyst Cu₁₃H₆ and the substrate 26



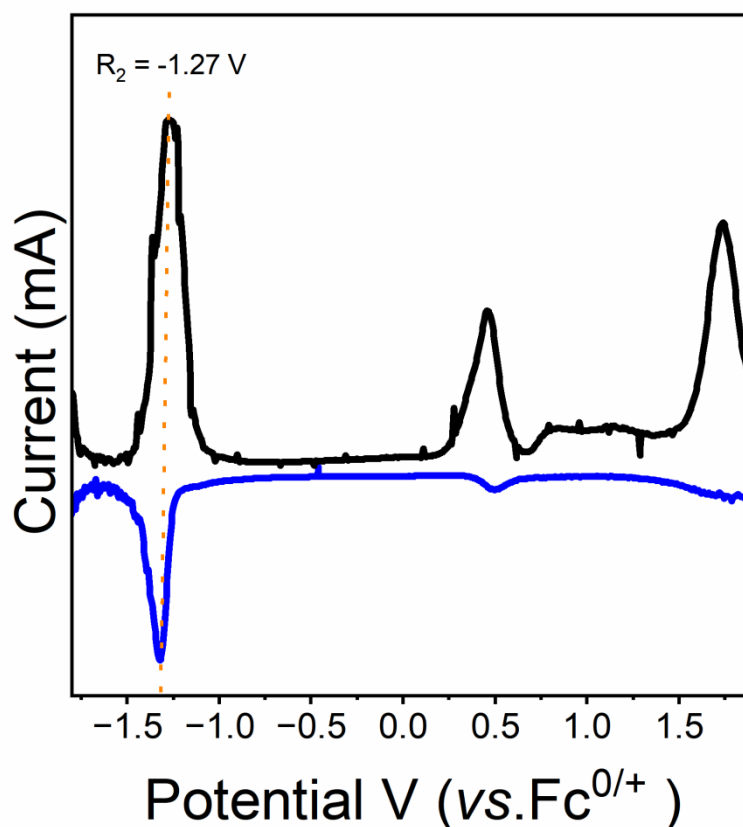


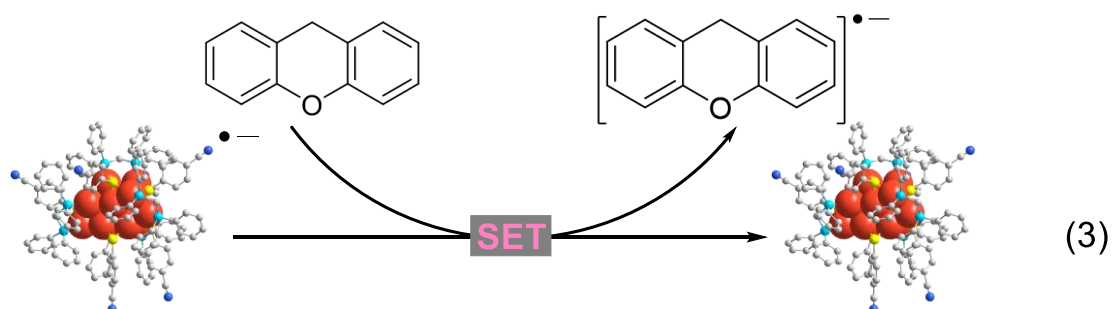
Figure S42. DPV of 26. The DPV test was performed under an argon atmosphere.

Process (2) is a single-electron transfer reaction between the reduced catalyst Cu_{13}H_6 and the substrate **26**, resulting in the formation of the ground-state catalyst Cu_{13}H_6 and the radical anion (**26-1**). During this reaction process,

$$\Delta E = E(26/[26]^-) - E(\text{Cu}_{13}\text{H}_6/[\text{Cu}_{13}\text{H}_6]^-) = -1.27 \text{ V} - (-1.5 \text{ V}) = +0.23 \text{ V} > 0.$$

Therefore, corresponding to the Gibbs free energy change $\Delta G = -nF\Delta E < 0$, it indicates that this single-electron transfer process is thermodynamically feasible.

Supplementary Note 6: The single-electron transfer reaction between the excited-state catalyst $[\text{Cu}_{13}\text{H}_6]^*$ and xanthene



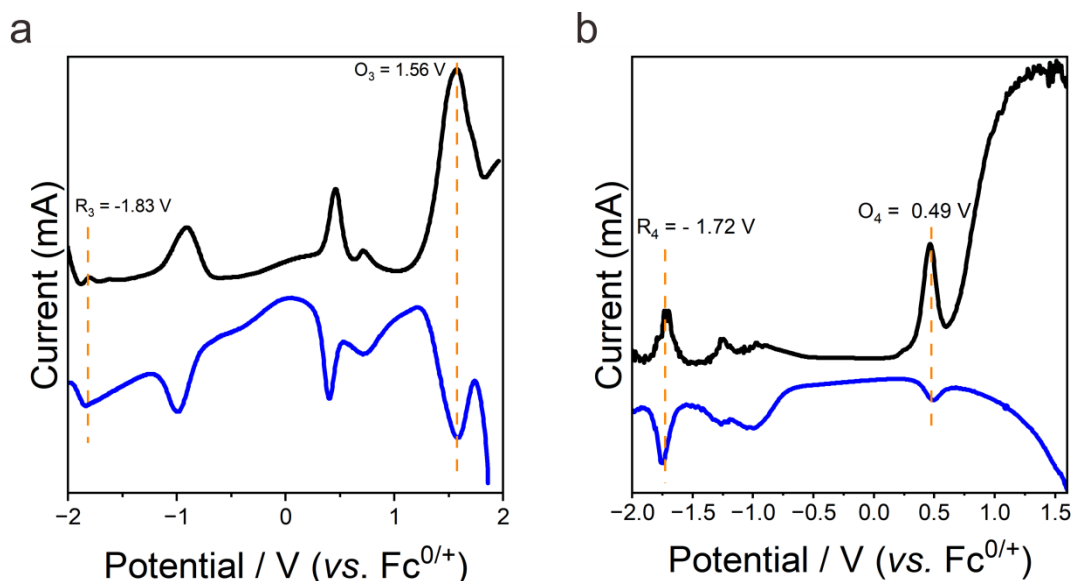


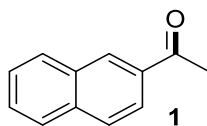
Figure S43. DPV of xanthene(a) and [xanthene + DBU] (b). The DPV test was performed under an argon atmosphere.

Process (3) involves a single electron transfer reaction between the excited-state catalyst [Cu₁₃H₆]^{*} and xanthene, resulting in the formation of the ground-state catalyst [Cu₁₃H₆] and a free radical cation. In this process, the substrate functions as the reducing agent, while the excited state [Cu₁₃H₆]^{*} acts as the oxidizing agent. To assess the feasibility of this process, an optimized oxygen heteroanthraquinone was selected, and its redox potential was measured. The DPV results indicate that the oxidation potential of the oxadiazole (Figure S43a) is significantly higher than the reduction potential of the excited-state catalyst [Cu₁₃H₆]^{*}. This process cannot occur spontaneously. Considering that DBU was added in our reaction, we measured the oxidation-reduction potential of the oxadiazole in the presence of DBU, as shown in Figure S43b. This oxidation potential is lower than the reduction potential of the excited-state catalyst. Here,

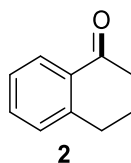
$$\Delta E = E([Cu_{13}H_6]^* / [Cu_{13}H_6]^-) - E(xanthene / [xanthene]^{+}) = 0.534 - 0.49 = + 0.044 \text{ V} > 0 .$$

Therefore, the corresponding Gibbs free energy change $\Delta G = - nF\Delta E < 0$. This indicates that the single-electron transfer process is thermodynamically feasible.

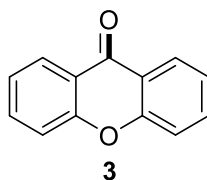
Analytical Data of the Products.



1; A known compound and the characterization data are in accordance with the literature¹. 1-(2-Naphthyl)ethanol (34 mg, 0.2 mmol), photocatalyst **1** Cu₁₃H₆ (10 mg, 0.003 mmol), and DBU (10 μ L, 0.067 mmol) in DMF (3 mL) were employed for 12 h to give the product **1** (14 mg) in 42% yield as a white powder. The crude product was purified by column chromatography isolation on silica gel via gradient elution with hexane to hexane/ethyl acetate (40:1 ~ 20:1) to give the product. ¹H NMR (600 MHz, CDCl₃): δ 8.38 (s, 1H), 7.95 (dd, J = 8.6, 1.3 Hz, 1H), 7.88 (d, J = 8.1 Hz, 1H), 7.80 (t, J = 8.7 Hz, 2H), 7.51 (t, J = 7.5 Hz, 1H), 7.47 (t, J = 7.4 Hz, 1H), 2.64 (s, 3H) ppm; ¹³C NMR (151 MHz, CDCl₃): δ 198.0, 135.6, 134.5, 132.5, 130.1, 129.5, 128.4, 128.4, 127.8, 126.7, 123.9, 26.6 ppm.

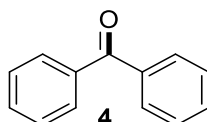


2; A known compound and the characterization data are in accordance with the literature². 1,2,3,4-Tetrahydro-1-Naphthol (27 μ L, 0.2 mmol), photocatalyst **1** Cu₁₃H₆ (10 mg, 0.003 mmol), and DBU (10 μ L, 0.067 mmol) in DMF (3 mL) were employed for 12 h to give the product **2** (15 mg) in 50% yield as a white powder. The crude product was purified by column chromatography isolation on silica gel via gradient elution with hexane to hexane/ethyl acetate (40:1 ~ 20:1) to give the product. ¹H NMR (600 MHz, CDCl₃): δ 7.95 (d, J = 7.8 Hz, 1H), 7.38 (t, J = 7.5 Hz, 1H), 7.22 (t, J = 7.6 Hz, 1H), 7.17 (d, J = 7.7 Hz, 1H), 2.88 (t, J = 6.1 Hz, 2H), 2.57 (t, 2H), 2.15 – 1.90 (m, 2H) ppm; ¹³C NMR (151 MHz, CDCl₃): δ 198.3, 144.4, 133.3, 132.6, 128.7, 127.1, 126.6, 39.1, 29.7, 23.2 ppm.

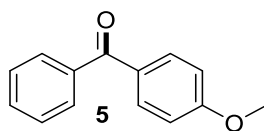


3; A known compound and the characterization data are in accordance with the literature². 9-Hydroxyxanthene (40 mg, 0.2 mmol), photocatalyst **1** Cu₁₃H₆ (10 mg, 0.003 mmol), and DBU (5 μ L, 0.033 mmol) in DMF (3 mL) were employed for 12 h

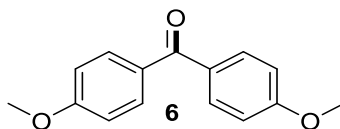
to give the product **3** (36 mg) in 92% yield as a white powder. The crude product was purified by column chromatography isolation on silica gel via gradient elution with hexane to hexane/ethyl acetate (40:1 ~ 20:1) to give the product. ^1H NMR (600 MHz, CDCl_3): δ 8.25 (dd, $J = 7.9, 1.5$ Hz, 2H), 7.70 – 7.57 (m, 2H), 7.40 (d, $J = 8.4$ Hz, 2H), 7.31 – 7.23 (m, 2H) ppm; ^{13}C NMR (151 MHz, CDCl_3): δ 177.1, 156.2, 134.7, 126.7, 123.9, 121.9, 117.9 ppm.



4; A known compound and the characterization data are in accordance with the literature². Diphenylmethanol (37 mg, 0.2 mmol), photocatalyst **1** Cu_{13}H_6 (10 mg, 0.003 mmol), and DBU (5 μL , 0.033 mmol) in DMF (3 mL) were employed for 12 h to give the product **4** (29 mg) in 81% yield as a white powder. The crude product was purified by column chromatography isolation on silica gel via gradient elution with hexane to hexane/ethyl acetate (40:1 ~ 20:1) to give the product. ^1H NMR (600 MHz, CDCl_3): δ 7.71 (d, $J = 7.6$ Hz, 4H), 7.48 (t, $J = 7.4$ Hz, 2H), 7.38 (t, $J = 7.7$ Hz, 4H) ppm; ^{13}C NMR (151 MHz, CDCl_3): δ 196.6, 137.6, 132.3, 130.0, 128.2 ppm.

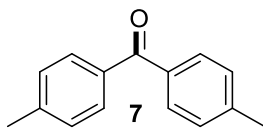


5; A known compound and the characterization data are in accordance with the literature³. 4-Methoxybenzhydrol (43 mg, 0.2 mmol), photocatalyst **1** Cu_{13}H_6 (10 mg, 0.003 mmol), and DBU (5 μL , 0.033 mmol) in DMF (3 mL) were employed for 12 h to give the product **5** (35 mg) in 83% yield as a white powder. The crude product was purified by column chromatography isolation on silica gel via gradient elution with hexane to hexane/ethyl acetate (40:1 ~ 20:1) to give the product. ^1H NMR (600 MHz, CDCl_3): δ 7.75 (d, $J = 8.8$ Hz, 2H), 7.70 – 7.64 (m, 2H), 7.48 (t, $J = 7.4$ Hz, 1H), 7.39 (t, $J = 7.7$ Hz, 2H), 6.88 (d, $J = 8.8$ Hz, 2H), 3.80 (s, 3H) ppm; ^{13}C NMR (151 MHz, CDCl_3): δ 195.5, 163.2, 138.3, 132.5, 131.8, 130.2, 129.7, 128.2, 113.5, 55.5 ppm.

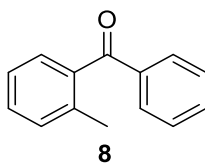


6; A known compound and the characterization data are in accordance with the literature². 4,4'-Dimethoxybenzhydrol (49 mg, 0.2 mmol), photocatalyst **1** Cu_{13}H_6 (10 mg, 0.003 mmol), and DBU (5 μL , 0.033 mmol) in DMF (3 mL) were employed for 12 h to give the product **6** (42 mg) in 87% yield as a white powder. The crude product was purified by column chromatography isolation on silica gel via gradient elution with hexane to hexane/ethyl acetate (40:1 ~ 20:1) to give the product. ^1H NMR (600 MHz,

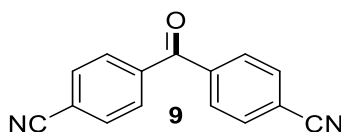
CDCl₃) δ 7.71 (d, J = 8.8 Hz, 4H), 6.89 (d, J = 8.8 Hz, 4H), 3.81 (s, 6H) ppm; ¹³C NMR (151 MHz, CDCl₃) δ 194.4, 162.8, 132.2, 130.8, 113.5, 55.4 ppm.



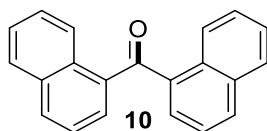
7; A known compound and the characterization data are in accordance with the literature². 4,4-Dimethylbenzhydrol (42 mg, 0.2 mmol), photocatalyst **1** Cu₁₃H₆ (10 mg, 0.003 mmol), and DBU (5 μ L, 0.033 mmol) in DMF (3 mL) were employed for 12 h to give the product **7** (35 mg) in 84% yield as a white powder. The crude product was purified by column chromatography isolation on silica gel via gradient elution with hexane to hexane/ethyl acetate (40:1 ~ 20:1) to give the product. ¹H NMR (600 MHz, CDCl₃) δ 7.58 (d, J = 8.0 Hz, 4H), 7.14 (d, J = 7.9 Hz, 4H), 2.30 (s, 6H) ppm; ¹³C NMR (151 MHz, CDCl₃) δ 196.0, 142.8, 135.1, 130.0, 128.8, 21.5 ppm.



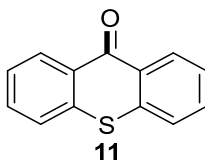
8; A known compound and the characterization data are in accordance with the literature³. 2-Methylbenzhydrol (40 mg, 0.2 mmol), photocatalyst **1** Cu₁₃H₆ (10 mg, 0.003 mmol), and DBU (5 μ L, 0.033 mmol) in DMF (3 mL) were employed for 12 h to give the product **8** (30 mg) in 76% yield as a colorless oil. The crude product was purified by column chromatography isolation on silica gel via gradient elution with hexane to hexane/ethyl acetate (40:1 ~ 20:1) to give the product. ¹H NMR (600 MHz, CDCl₃): δ 7.68 (d, J = 7.9 Hz, 2H), 7.44 (t, J = 7.3 Hz, 1H), 7.32 (t, J = 7.6 Hz, 2H), 7.26 (t, J = 7.5 Hz, 1H), 7.17 (dd, J = 15.6, 7.6 Hz, 2H), 7.11 (t, J = 7.5 Hz, 1H), 2.21 (s, 3H) ppm; ¹³C NMR (151 MHz, CDCl₃): δ 198.4, 138.5, 137.7, 136.6, 133.0, 130.9, 130.1, 130.0, 128.4, 128.3, 125.1, 19.8 ppm.



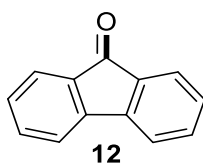
9; A known compound and the characterization data are in accordance with the literature⁴. Bis(4-Cyanophenyl)Methanol (47 mg, 0.2 mmol), photocatalyst **1** Cu₁₃H₆ (10 mg, 0.003 mmol), and DBU (5 μ L, 0.033 mmol) in DMF (3 mL) were employed for 12 h to give the product **9** (33 mg) in 70% yield as a yellow powder. The crude product was purified by column chromatography isolation on silica gel via gradient elution with hexane to hexane/ethyl acetate (40:1 ~ 20:1) to give the product. ¹H NMR (600 MHz, CDCl₃): δ 7.80 (d, J = 8.4 Hz, 2H), 7.76 (d, J = 8.4 Hz, 2H) ppm; ¹³C NMR (151 MHz, CDCl₃) δ 193.4, 139.8, 132.4, 130.2, 117.6, 116.6 ppm.



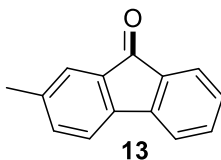
10; Di(Naphthalen-1-yl)Methanol (57 mg, 0.2 mmol), photocatalyst **1** Cu₁₃H₆ (10 mg, 0.003 mmol), and DBU (5 μ L, 0.033 mmol) in DMF (3 mL) were employed for 12 h to give the product **10** (47 mg) in 83% yield as a white powder. The crude product was purified by column chromatography isolation on silica gel via gradient elution with hexane to hexane/ethyl acetate (40:1 ~ 20:1) to give the product. ¹H NMR (600 MHz, CDCl₃): δ 7.52 (d, J = 7.3 Hz, 1H), 7.35 (d, J = 4.6 Hz, 3H), 7.27 (d, J = 7.5 Hz, 1H), 7.18 – 7.09 (m, 2H), 2.27 (s, 3H) ppm; ¹³C NMR (151 MHz, CDCl₃): δ 194.1, 144.6, 141.8, 139.2, 135.0, 134.6, 134.4, 134.2, 128.5, 124.9, 124.1, 120.1, 119.9, 21.3 ppm. HRMS m/z : calcd for C₂₁H₁₅O [M + H]⁺: 283.1118; Found: 283.1128.



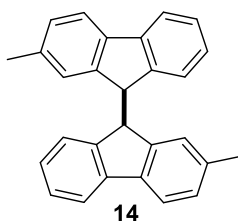
11; A known compound and the characterization data are in accordance with the literature⁵. Thioxanthene (43 mg, 0.2 mmol), photocatalyst **1** Cu₁₃H₆ (10 mg, 0.003 mmol), and DBU (5 μ L, 0.033 mmol) in DMF (3 mL) were employed for 12 h to give the product **11** (21 mg) in 50% yield as a yellow powder. The crude product was purified by column chromatography isolation on silica gel via gradient elution with hexane to hexane/ethyl acetate (40:1 ~ 20:1) to give the product. ¹H NMR (600 MHz, CDCl₃): δ 8.55 (dd, J = 8.1, 1.6 Hz, 2H), 7.57 – 7.52 (m, 2H), 7.50 (dd, J = 8.1, 1.5 Hz, 2H), 7.43 – 7.37 (m, 2H) ppm; ¹³C NMR (151 MHz, CDCl₃): δ 179.9, 137.3, 132.2, 129.9, 129.3, 126.3, 126.0 ppm.



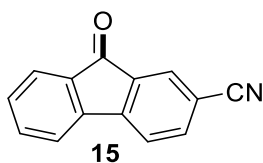
12; A known compound and the characterization data are in accordance with the literature⁶. Fluorene (34 mg, 0.2 mmol), photocatalyst **1** Cu₁₃H₆ (10 mg, 0.003 mmol), and DBU (5 μ L, 0.033 mmol) in DMF (3 mL) were employed for 12 h to give the product **12** (34 mg) in 96% yield as a yellow powder. The crude product was purified by column chromatography isolation on silica gel via gradient elution with hexane to hexane/ethyl acetate (40:1 ~ 20:1) to give the product. ¹H NMR (600 MHz, CDCl₃): δ 7.54 (dt, J = 7.4, 1.0 Hz, 2H), 7.41 – 7.33 (m, 4H), 7.18 (d, J = 1.5 Hz, 1H), 7.16 (d, J = 1.5 Hz, 1H) ppm; ¹³C NMR (151 MHz, CDCl₃): δ 193.8, 144.4, 134.6, 134.1, 129.0, 124.2, 120.2 ppm.



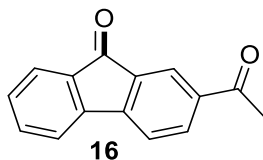
13; A known compound and the characterization data are in accordance with the literature⁷. 2-Methyl-9H-Fluorene (36 mg, 0.2 mmol), photocatalyst **1** Cu₁₃H₆ (10 mg, 0.003 mmol), and DBU (5 μ L, 0.033 mmol) in DMF (3 mL) were employed for 12 h to give the product **13** (31 mg) in 80% yield as a yellow powder. The crude product was purified by column chromatography isolation on silica gel via gradient elution with hexane to hexane/ethyl acetate (40:1 ~ 20:1) to give the product. ¹H NMR (600 MHz, CDCl₃): δ 7.52 (d, *J* = 7.3 Hz, 1H), 7.35 (d, *J* = 4.6 Hz, 3H), 7.27 (d, *J* = 7.5 Hz, 1H), 7.18 – 7.09 (m, 2H), 2.27 (s, 3H) ppm; ¹³C NMR (151 MHz, CDCl₃): δ 194.1, 144.6, 141.8, 139.2, 135.0, 134.6, 134.4, 134.2, 128.5, 124.9, 124.1, 120.1, 119.9, 21.3 ppm.



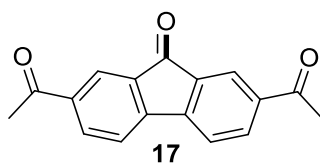
14; 2-Methyl-9H-Fluorene (36 mg, 0.2 mmol), photocatalyst Cu₁₃ NCs (10 mg, 0.003 mmol), and DBU (5 μ L, 0.033 mmol) in DMF (3 mL) were employed for 12 h to give the product **14**. The crude product was purified by column chromatography isolation on silica gel via gradient elution with hexane to hexane/ethyl acetate (100:1 ~ 50:1) to give the product **14** in about 5% yield as a white powder. ¹H NMR (600 MHz, CDCl₃): δ 7.67 (dd, *J* = 12.4, 7.4 Hz, 2H), 7.63 – 7.57 (m, 2H), 7.30 – 7.24 (m, 2H), 7.15 – 7.06 (m, 5H), 7.00 (d, *J* = 7.7 Hz, 3H), 4.89 (s, 2H), 2.26 (s, 6H) ppm. HRMS *m/z*: calcd for C₂₈H₂₂Na [M + Na]⁺: 381.1614; Found: 381.1622.



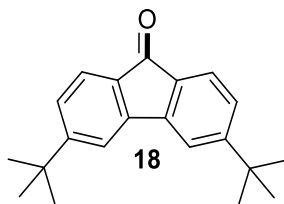
15; A known compound and the characterization data are in accordance with the literature⁷. 9H-Fluorene-2-carbonitrile (39 mg, 0.2 mmol), photocatalyst **1** Cu₁₃H₆ (10 mg, 0.003 mmol), and DBU (5 μ L, 0.033 mmol) in DMF (3 mL) were employed for 12 h to give the product **15** (38 mg) in 93% yield as a yellow powder. The crude product was purified by column chromatography isolation on silica gel via gradient elution with hexane to hexane/ethyl acetate (40:1 ~ 20:1) to give the product. ¹H NMR (600 MHz, CDCl₃): δ 7.52 (d, *J* = 7.3 Hz, 1H), 7.35 (d, *J* = 4.6 Hz, 3H), 7.27 (d, *J* = 7.5 Hz, 1H), 7.18 – 7.09 (m, 2H), 2.27 (s, 3H) ppm; ¹³C NMR (151 MHz, CDCl₃): δ 194.1, 144.6, 141.8, 139.2, 135.0, 134.6, 134.4, 134.2, 128.5, 124.9, 124.1, 120.1, 119.9, 21.3 ppm.



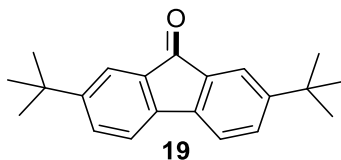
16; A known compound and the characterization data are in accordance with the literature⁷. 2-Acetylfluorene (42 mg, 0.2 mmol), photocatalyst **1** Cu₁₃H₆ (10 mg, 0.003 mmol), and DBU (5 μ L, 0.033 mmol) in DMF (3 mL) were employed for 12 h to give the product **16** (42 mg) in 95% yield as a yellow powder. The crude product was purified by column chromatography isolation on silica gel via gradient elution with hexane to hexane/ethyl acetate (40:1 ~ 20:1) to give the product. ¹H NMR (600 MHz, CDCl₃): δ 8.10 (s, 1H), 8.06 (dd, J = 7.8, 1.6 Hz, 1H), 7.63 (d, J = 7.4 Hz, 1H), 7.53 (t, J = 8.0 Hz, 2H), 7.46 (td, J = 7.4, 1.2 Hz, 1H), 7.30 (t, J = 7.4 Hz, 1H), 2.55 (s, 3H) ppm; ¹³C NMR (151 MHz, CDCl₃): δ 196.5, 192.6, 148.4, 143.2, 137.8, 135.0, 134.9, 134.3, 130.2, 124.6, 124.1, 121.2, 120.4, 26.7 ppm.



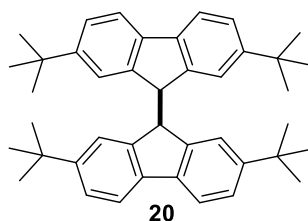
17; A known compound and the characterization data are in accordance with the literature⁸. 2,7-Diacetylfluorene (50 mg, 0.2 mmol), photocatalyst **1** Cu₁₃H₆ (10 mg, 0.003 mmol), and DBU (5 μ L, 0.033 mmol) in DMF (3 mL) were employed for 12 h to give the product **17** (45 mg) in 85% yield a yellow powder. The crude product was purified by column chromatography isolation on silica gel via gradient elution with hexane to hexane/ethyl acetate (1:3) to give the product. ¹H NMR (600 MHz, CDCl₃): δ 8.27 – 8.19 (m, 4H), 7.73 (d, J = 7.8 Hz, 2H), 2.66 (s, 6H) ppm.



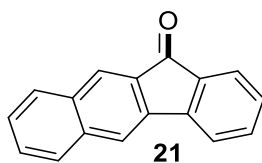
18; 3,6-Di-Tert-Butylfluorene (56 mg, 0.2 mmol), photocatalyst **1** Cu₁₃H₆ (10 mg, 0.003 mmol), and DBU (5 μ L, 0.033 mmol) in DMF (3 mL) were employed for 12 h to give the product **18** (47 mg) in 80% yield as a yellow powder. The crude product was purified by column chromatography isolation on silica gel via gradient elution with hexane to hexane/ethyl acetate (40:1 ~ 20:1) to give the product. ¹H NMR (600 MHz, CDCl₃): δ 7.52 – 7.41 (m, 4H), 7.22 (dd, J = 7.7, 1.7 Hz, 2H), 1.31 (s, 18H) ppm; ¹³C NMR (151 MHz, CDCl₃): δ 193.5, 158.7, 144.7, 132.4, 125.8, 124.0, 117.3, 35.6, 31.2 ppm.



19; A known compound and the characterization data are in accordance with the literature⁹. 2,7-Di-Tert-Butylfluorene (56 mg, 0.2 mmol), photocatalyst **1** Cu₁₃H₆ (10 mg, 0.003 mmol), and DBU (5 μ L, 0.033 mmol) in DMF (3 mL) were employed for 12 h to give the product **19** (41 mg) in 70% yield as a yellow powder. The crude product was purified by column chromatography isolation on silica gel via gradient elution with hexane to hexane/ethyl acetate (40:1 ~ 20:1) to give the product. ¹H NMR (600 MHz, CDCl₃) δ 7.62 (d, 2H), 7.41 (dd, *J* = 7.8, 1.4 Hz, 2H), 7.32 (d, *J* = 7.8 Hz, 2H), 1.27 (s, 18H) ppm; ¹³C NMR (151 MHz, CDCl₃) δ 194.9, 152.3, 141.9, 134.7, 131.4, 121.5, 119.7, 35.0, 31.2 ppm.

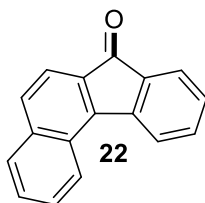


20; 2,7-Di-Tert-Butylfluorene (56 mg, 0.2 mmol), photocatalyst Cu₁₃ NCs (10 mg, 0.003 mmol), and DBU (5 μ L, 0.033 mmol) in DMF (3 mL) were employed for 12 h to give the product **20**. The crude product was purified by column chromatography isolation on silica gel via gradient elution with hexane to hexane/ethyl acetate (100:1 ~ 50:1) to give the product **20** in about 6% yield as a white powder. ¹H NMR (600 MHz, CDCl₃): δ 7.70 – 7.66 (m, 4H), 7.53 (d, *J* = 8.0 Hz, 4H), 7.40 (dd, *J* = 8.0, 1.9 Hz, 4H), 5.55 (d, *J* = 9.0 Hz, 2H), 1.37 (s, 36H) ppm. HRMS *m/z*: calcd for C₄₂H₅₀Na [*M* + Na]⁺: 577.3805; Found: 577.3809.

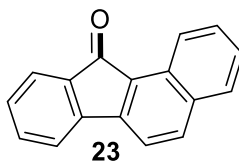


21; A known compound and the characterization data are in accordance with the literature¹⁰. 2,3-Benzofluorene (43 mg, 0.2 mmol), photocatalyst **1** Cu₁₃H₆ (10 mg, 0.003 mmol), and DBU (5 μ L, 0.033 mmol) in DMF (3 mL) were employed for 12 h to give the product **21** (43 mg) in 95% yield as a yellow powder. The crude product was purified by column chromatography isolation on silica gel via gradient elution with hexane to hexane/ethyl acetate (40:1 ~ 20:1) to give the product. ¹H NMR (600 MHz, CDCl₃) δ 7.62 (d, 2H), 7.41 (dd, *J* = 7.8, 1.4 Hz, 2H), 7.32 (d, *J* = 7.8 Hz, 2H), 1.27 (s, 18H) ppm; ¹³C NMR (151 MHz, CDCl₃) δ 194.9, 152.3, 141.9, 134.7, 131.4, 121.5,

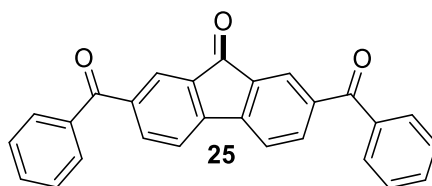
119.7, 35.0, 31.2 ppm.



22; A known compound and the characterization data are in accordance with the literature¹⁰. 7H-Benzo[c]fluorene (43 mg, 0.2 mmol), photocatalyst **1** Cu₁₃H₆ (10 mg, 0.003 mmol), and DBU (5 μ L, 0.033 mmol) in DMF (3 mL) were employed for 12 h to give the product **22** (41 mg) in 90% yield as a yellow powder. The crude product was purified by column chromatography isolation on silica gel via gradient elution with hexane to hexane/ethyl acetate (40:1 ~ 20:1) to give the product. ¹H NMR (600 MHz, CDCl₃): δ 8.33 (d, J = 8.3 Hz, 1H), 7.87 (d, J = 7.5 Hz, 1H), 7.75 (d, J = 8.1 Hz, 1H), 7.67 – 7.59 (m, 2H), 7.56 (d, J = 7.2 Hz, 1H), 7.47 (dt, J = 19.1, 7.1 Hz, 2H), 7.39 (t, J = 7.5 Hz, 1H), 7.22 – 7.14 (m, 1H) ppm; ¹³C NMR (151 MHz, CDCl₃): δ 194.3, 144.9, 142.8, 138.0, 134.5, 134.4, 131.8, 129.8, 129.6, 128.8, 128.6, 128.2, 127.7, 124.8, 124.0, 123.3, 119.8 ppm.

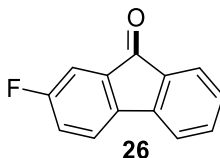


23; A known compound and the characterization data are in accordance with the literature⁹. 1,2-Benzofluorene (43 mg, 0.2 mmol), photocatalyst **1** Cu₁₃H₆ (10 mg, 0.003 mmol), and DBU (5 μ L, 0.033 mmol) in DMF (3 mL) were employed for 12 h to give the product **23** (35 mg) in 75% yield as a yellow powder. The crude product was purified by column chromatography isolation on silica gel via gradient elution with hexane to hexane/ethyl acetate (40:1 ~ 20:1) to give the product. ¹H NMR (600 MHz, CDCl₃): δ 8.88 (d, J = 8.5 Hz, 1H), 7.91 (d, J = 8.2 Hz, 1H), 7.71 (d, J = 8.3 Hz, 1H), 7.57 (d, J = 8.2 Hz, 1H), 7.54 – 7.48 (m, 2H), 7.41 (d, J = 7.3 Hz, 1H), 7.36 (t, J = 7.4 Hz, 2H), 7.20 (d, J = 7.4 Hz, 1H) ppm; ¹³C NMR (151 MHz, CDCl₃): δ 195.4, 146.1, 143.9, 135.9, 134.6, 134.4, 134.2, 130.2, 129.4, 129.2, 128.5, 126.9, 126.4, 124.3, 123.8, 119.9, 118.1 ppm.

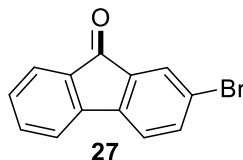


25; (9H-Fluorene-2,7-diyl)bis(phenylmethanone) (75 mg, 0.2 mmol), photocatalyst **1** Cu₁₃H₆ (10 mg, 0.003 mmol), and DBU (5 μ L, 0.033 mmol) in DMF (3 mL) were

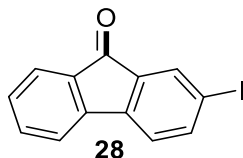
employed for 12 h to give the product **25** (63 mg) in 81% yield as a yellow powder. The crude product was purified by column chromatography isolation on silica gel via gradient elution with hexane to hexane/ethyl acetate (40:1 ~ 20:1) to give the product. ^1H NMR (600 MHz, CDCl_3): δ 8.07 – 7.98 (m, 4H), 7.78 – 7.68 (m, 6H), 7.57 (tt, J = 7.1, 1.4 Hz, 2H), 7.45 (t, J = 7.8 Hz, 4H) ppm; ^{13}C NMR (151 MHz, CDCl_3): δ 195.1, 191.6, 146.7, 139.4, 137.0, 136.9, 134.6, 132.9, 129.9, 128.6, 126.0, 121.2 ppm. HRMS m/z : calcd for $\text{C}_{27}\text{H}_{17}\text{O}_3$ $[\text{M} + \text{H}]^+$: 389.1172; Found: 389.1180.



26; A known compound and the characterization data are in accordance with the literature⁷. 2-Fluorofluorene (37 mg, 0.2 mmol), photocatalyst **1** Cu_{13}H_6 (10 mg, 0.003 mmol), and DBU (5 μL , 0.033 mmol) in DMF (3 mL) were employed for 12 h to give the product **26** (33 mg) in 83% yield as a yellow powder. The crude product was purified by column chromatography isolation on silica gel via gradient elution with hexane to hexane/ethyl acetate (40:1 ~ 20:1) to give the product. ^1H NMR (600 MHz, CDCl_3): δ 7.57 (d, J = 7.4 Hz, 1H), 7.44 – 7.34 (m, 3H), 7.25 (dd, J = 7.3, 2.5 Hz, 1H), 7.19 (td, J = 6.0, 2.0 Hz, 1H), 7.07 (td, J = 8.5, 2.5 Hz, 1H) ppm; ^{13}C NMR (101 MHz, CDCl_3): δ 192.50, 164.76, 162.27, 143.88, 140.14, 140.11, 136.31, 136.24, 135.03, 134.29, 134.27, 128.72, 124.59, 121.61, 121.53, 120.94, 120.71, 120.10, 112.04, 111.81 ppm.

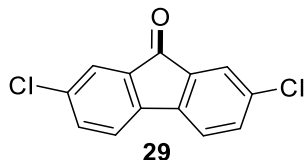


27; A known compound and the characterization data are in accordance with the literature⁷. 2-Iodo-9H-fluorene (50 mg, 0.2 mmol), photocatalyst **1** Cu_{13}H_6 (10 mg, 0.003 mmol), and DBU (5 μL , 0.033 mmol) in DMF (3 mL) were employed for 12 h to give the product **27** (42 mg) in 81% yield as a yellow powder. The crude product was purified by column chromatography isolation on silica gel via gradient elution with hexane to hexane/ethyl acetate (40:1 ~ 20:1) to give the product. ^1H NMR (600 MHz, CDCl_3) δ 7.70 (d, J = 2.2 Hz, 1H), 7.59 (d, J = 7.4 Hz, 1H), 7.54 (dd, J = 7.9, 2.0 Hz, 1H), 7.47 – 7.41 (m, 2H), 7.33 (d, J = 7.8 Hz, 1H), 7.29 – 7.21 (m, 1H) ppm.

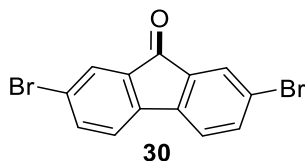


28; A known compound and the characterization data are in accordance with the literature⁷. 2-Iodo-9H-fluorene (59 mg, 0.2 mmol), photocatalyst **1** Cu_{13}H_6 (10 mg,

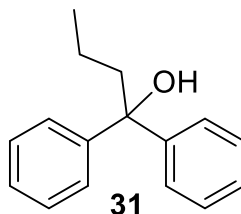
0.003 mmol), and DBU (5 μ L, 0.033 mmol) in DMF (3 mL) were employed for 12 h to give the product **28** (49 mg) in 80% yield as a yellow powder. The crude product was purified by column chromatography isolation on silica gel via gradient elution with hexane to hexane/ethyl acetate (40:1 ~ 20:1) to give the product. ^1H NMR (600 MHz, CDCl_3): δ 7.89 (d, J = 1.5 Hz, 1H), 7.75 (dd, J = 7.8, 1.6 Hz, 1H), 7.58 (dd, J = 6.9, 2.4 Hz, 1H), 7.47 – 7.39 (m, 2H), 7.28 – 7.19 (m, 2H) ppm.



29; A known compound and the characterization data are in accordance with the literature¹¹. 2,7-Dichlorofluorene (47 mg, 0.2 mmol), photocatalyst **1** Cu_{13}H_6 (10 mg, 0.003 mmol), and DBU (5 μ L, 0.033 mmol) in DMF (3 mL) were employed for 12 h to give the product **29** (45 mg) in 90% yield as a yellow powder. The crude product was purified by column chromatography isolation on silica gel via gradient elution with hexane to hexane/ethyl acetate (40:1 ~ 20:1) to give the product. ^1H NMR (600 MHz, CDCl_3): δ 7.50 (d, J = 2.0 Hz, 2H), 7.37 (dd, J = 7.9, 2.0 Hz, 2H), 7.33 (d, J = 7.9 Hz, 2H) ppm; ^{13}C NMR (151 MHz, CDCl_3): δ 191.0, 141.7, 135.4, 134.5, 124.9, 121.4 ppm.



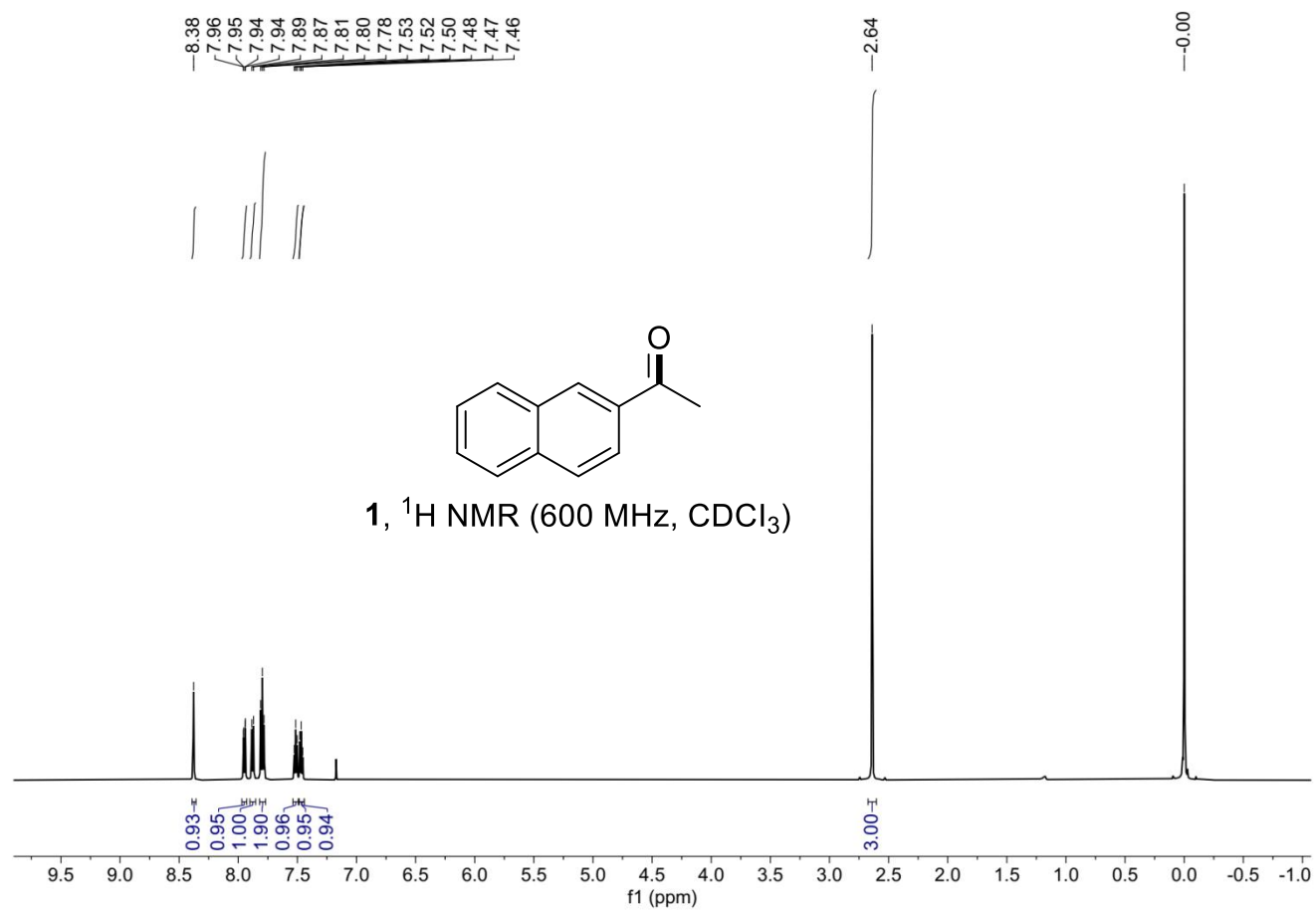
30; A known compound and the characterization data are in accordance with the literature⁷. 2,7-Dibromofluorene (65 mg, 0.2 mmol), photocatalyst **1** Cu_{13}H_6 (10 mg, 0.003 mmol), and DBU (5 μ L, 0.033 mmol) in DMF (3 mL) were employed for 12 h to give the product **30** (60 mg) in 89% yield as a yellow powder. The crude product was purified by column chromatography isolation on silica gel via gradient elution with hexane to hexane/ethyl acetate (40:1 ~ 20:1) to give the product. ^1H NMR (600 MHz, CDCl_3) δ 7.68 (d, J = 2.0 Hz, 2H), 7.55 (dd, J = 8.0, 1.9 Hz, 2H), 7.30 (d, J = 7.9 Hz, 2H) ppm; ^{13}C NMR (151 MHz, CDCl_3) δ 190.88, 142.26, 137.46, 135.29, 127.85, 123.33, 121.82 ppm.

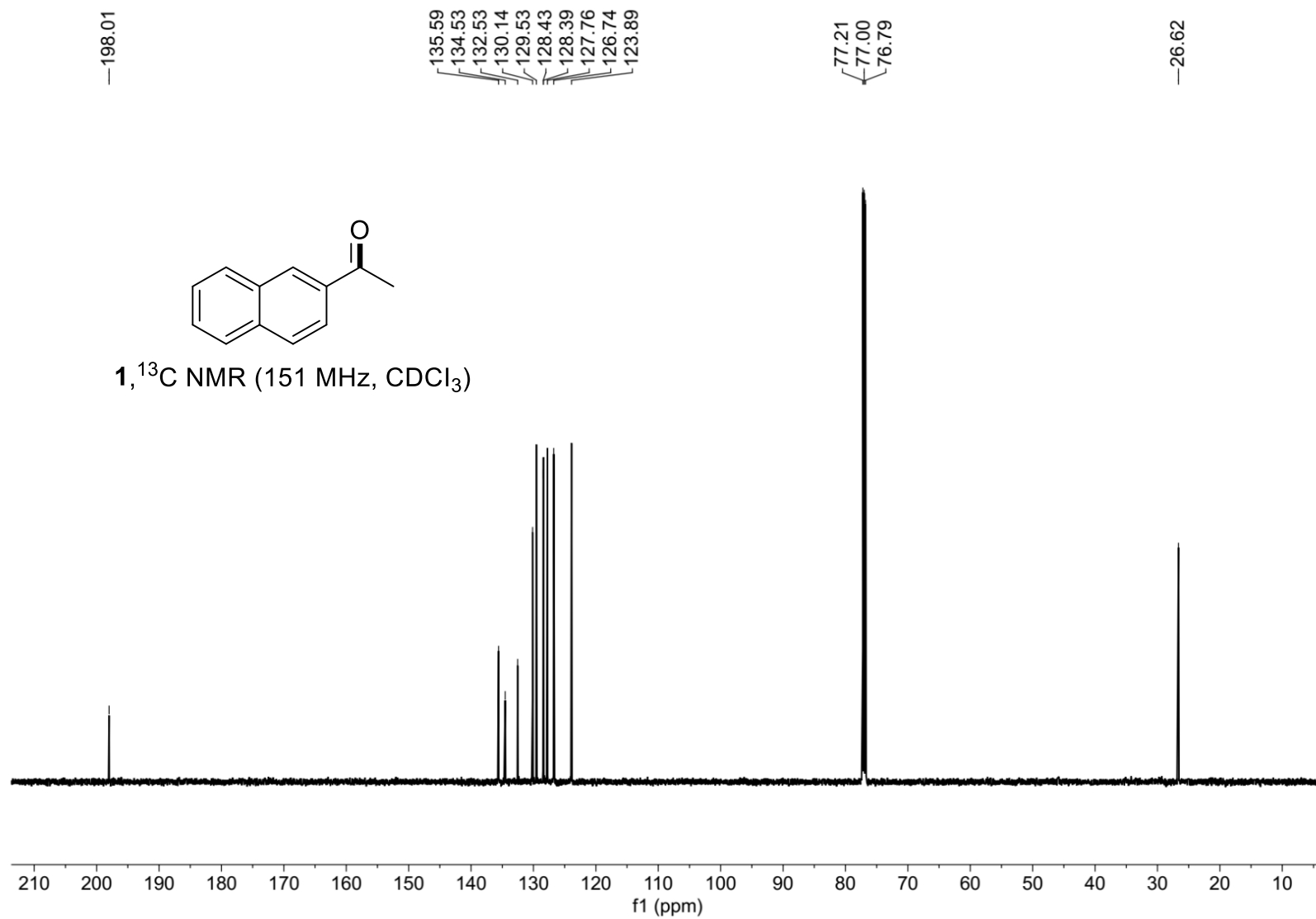


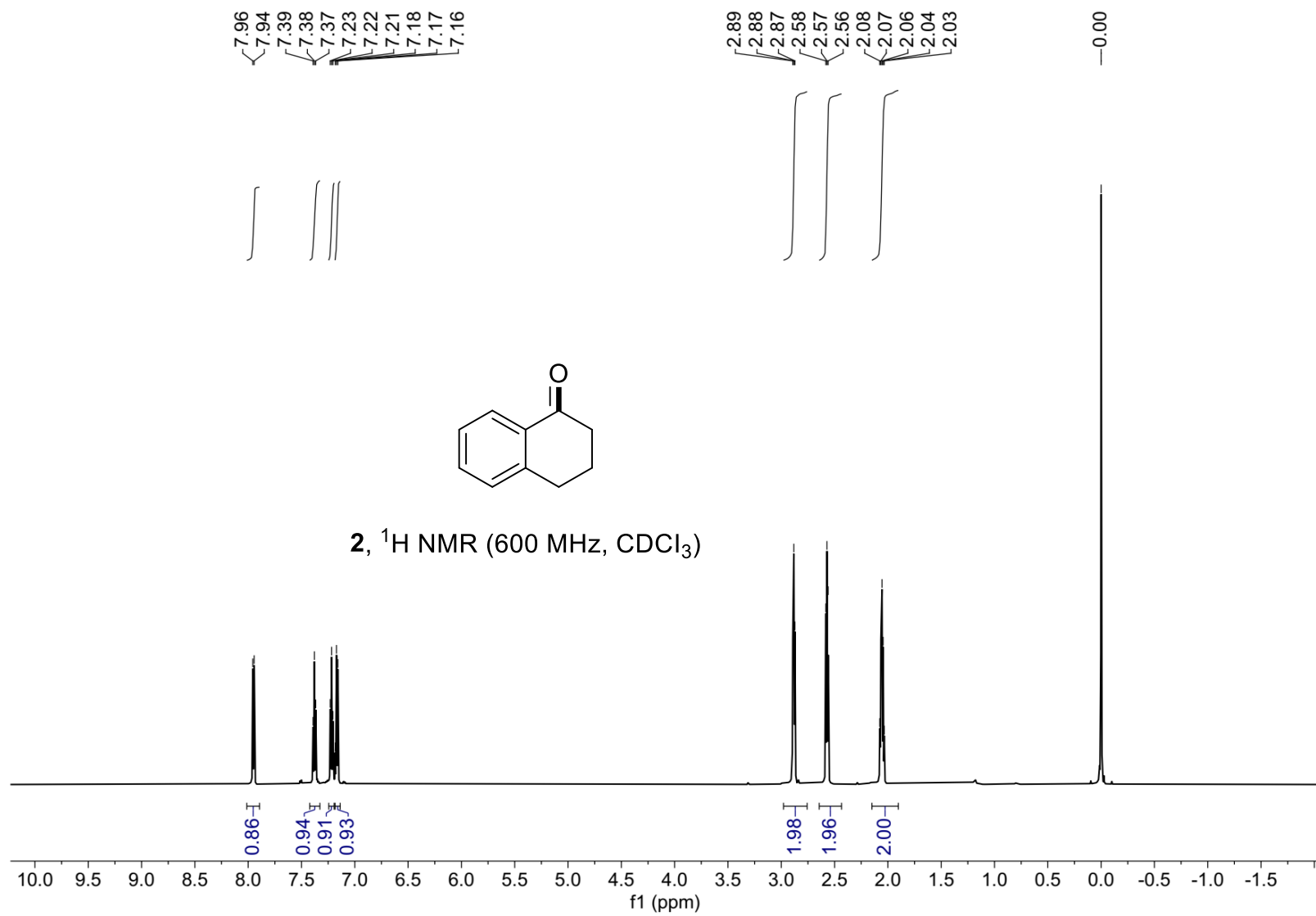
31; Cyclopropyldiphenylmethanol (45 mg, 0.2 mmol), photocatalyst Cu_{13} NCs (10 mg, 0.003 mmol), and DBU (10 μ L, 0.067 mmol) in DMF (3 mL) were employed for 12 h to give the product **31**. The crude product was purified by column chromatography

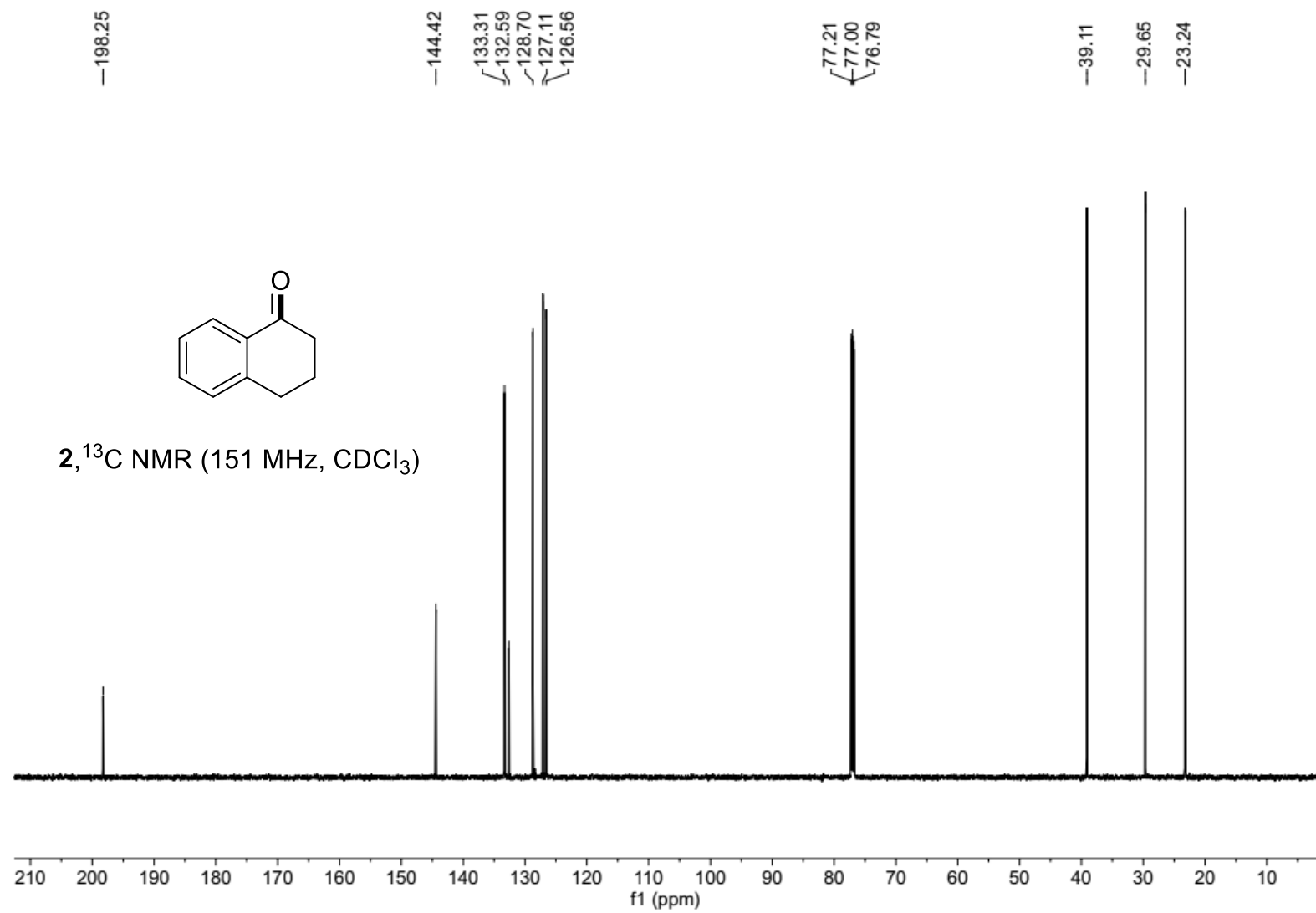
isolation on silica gel via gradient elution with hexane to hexane/ethyl acetate (100:1) to give the product **31** in about 5% yield as a colorless oil. ^1H NMR (600 MHz, CDCl_3): δ 7.40 (dd, $J = 8.1, 1.4$ Hz, 4H), 7.28 (t, $J = 7.8$ Hz, 4H), 7.23 – 7.15 (m, 2H), 2.28 – 2.19 (m, 2H), 2.14 (s, 1H), 1.34 – 1.22 (m, 2H), 0.92 (t, $J = 7.4$ Hz, 3H) ppm; ^{13}C NMR (151 MHz, CDCl_3): δ 147.2, 128.1, 126.7, 126.0, 78.3, 44.3, 17.1, 14.4 ppm. HRMS m/z : calcd for $\text{C}_{16}\text{H}_{19}\text{O}$ $[\text{M} + \text{H}]^+$: 227.1431; Found: 227.1433.

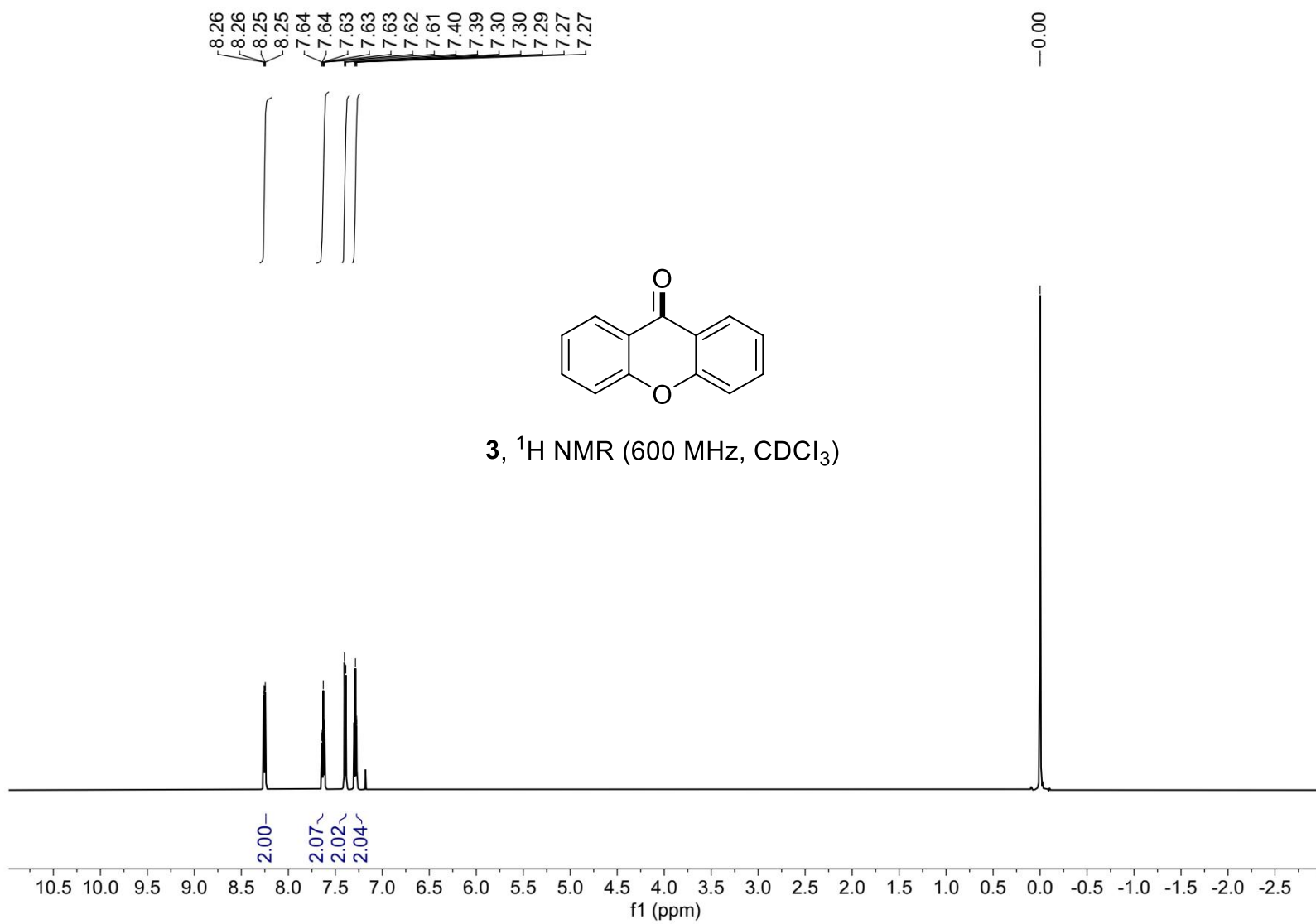
^1H , ^{13}C NMR Spectra of Products

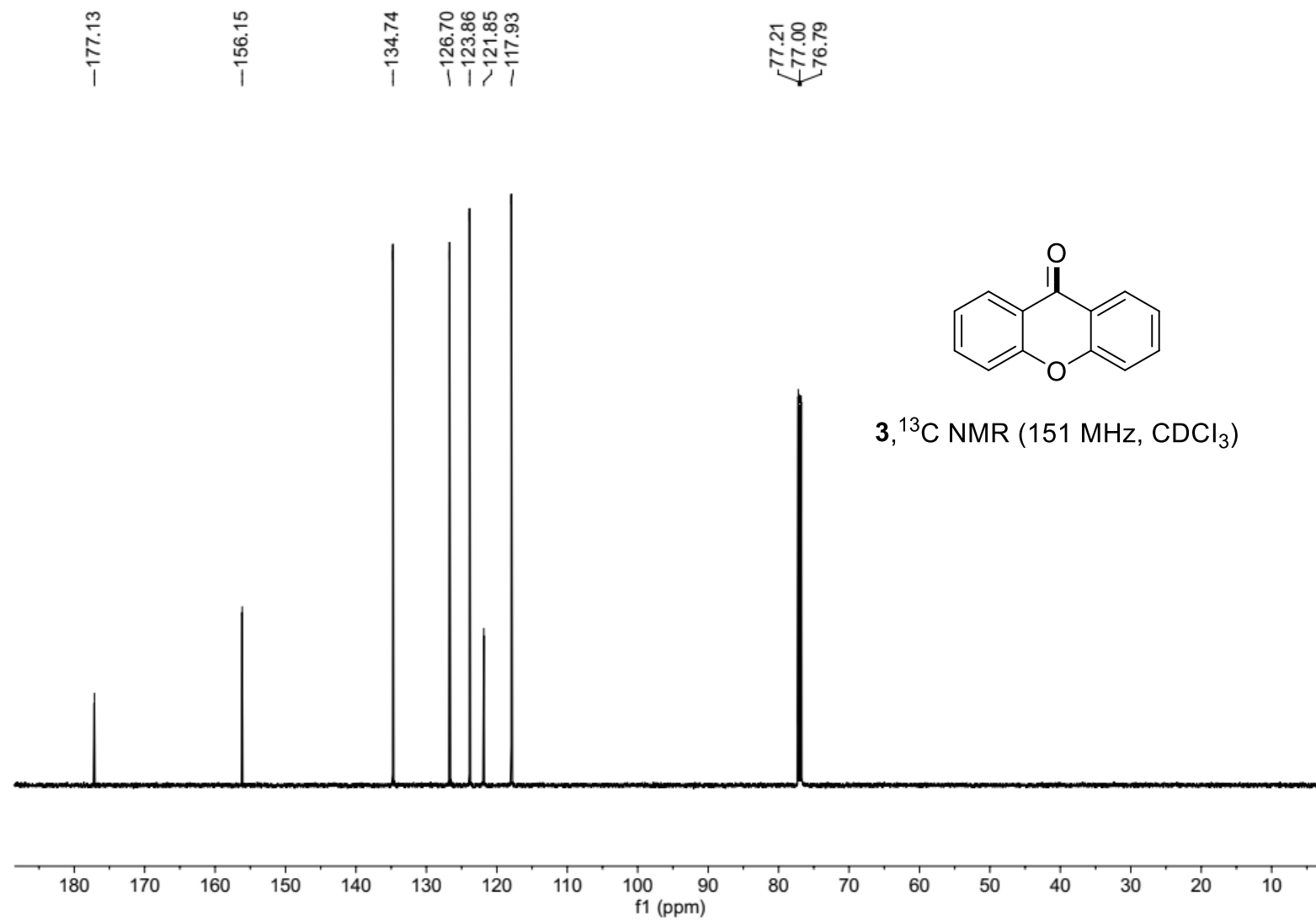


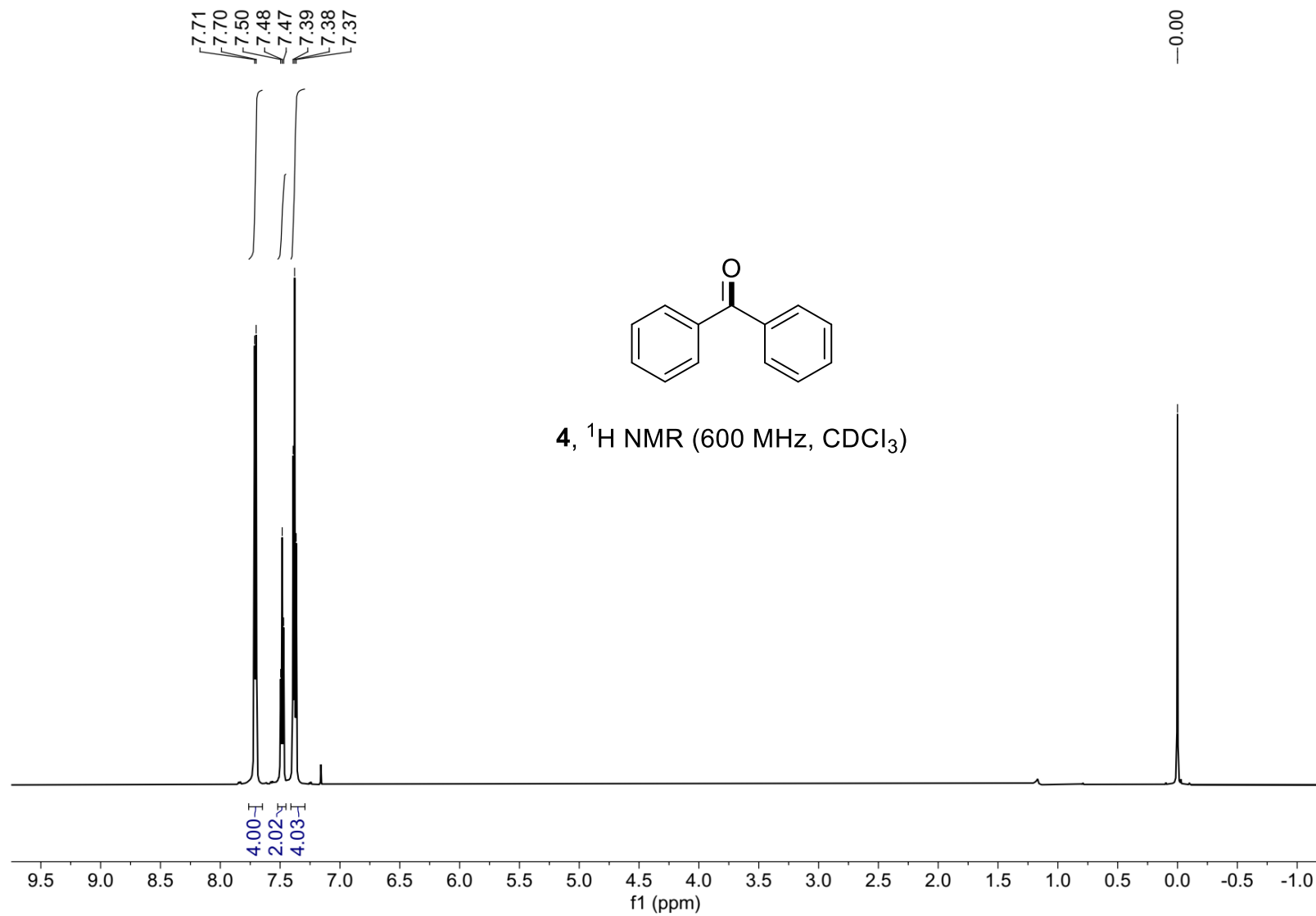


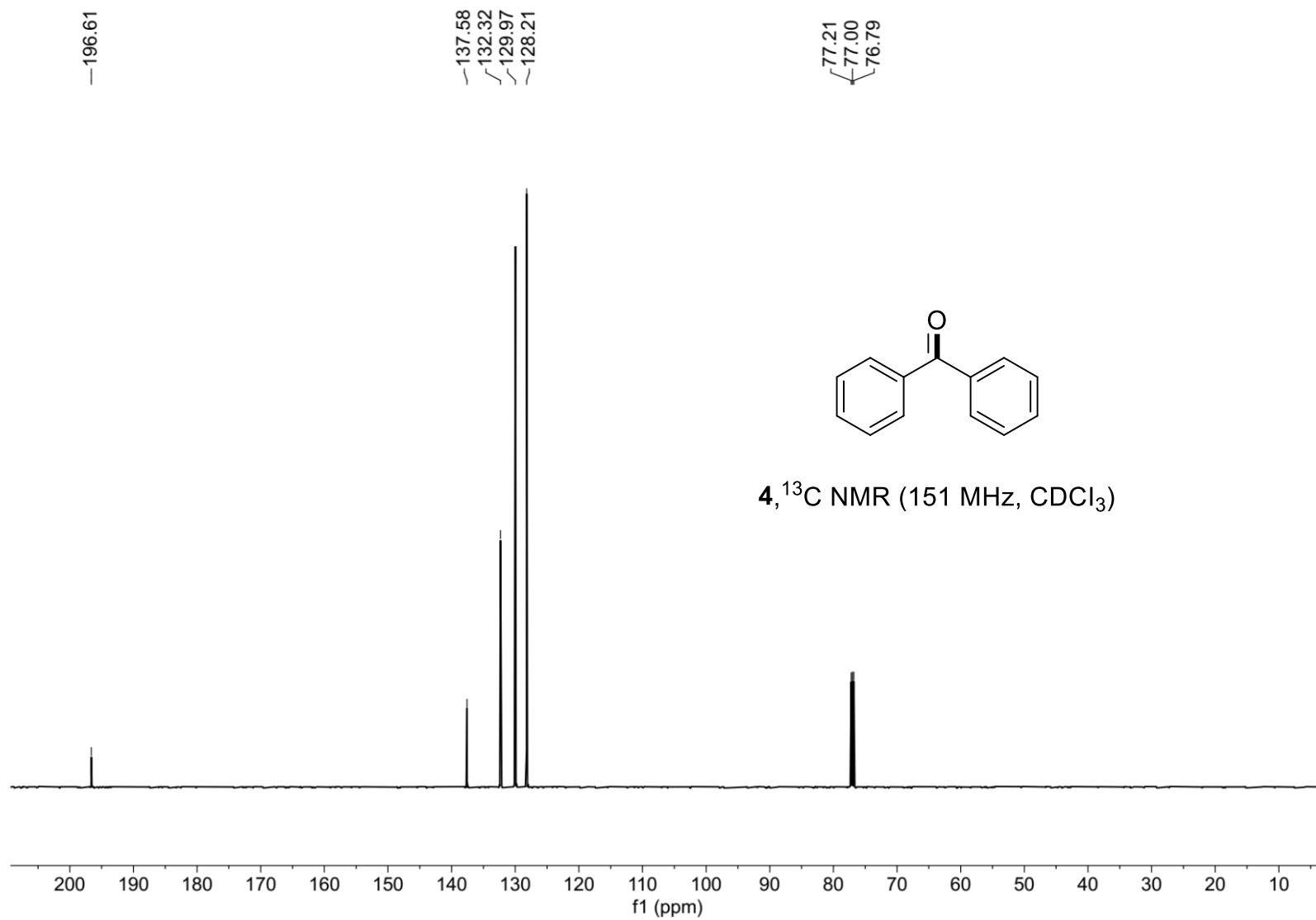


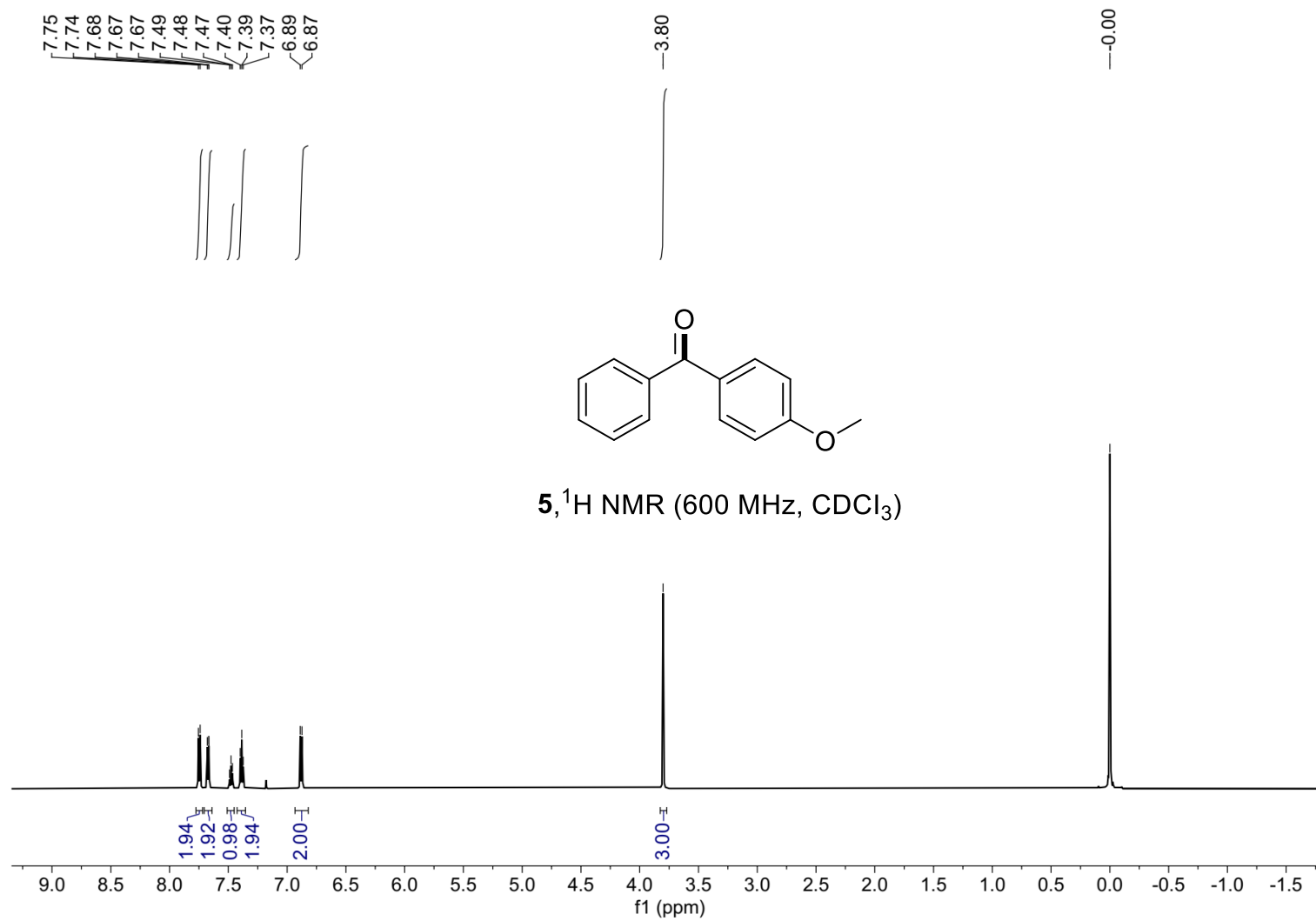


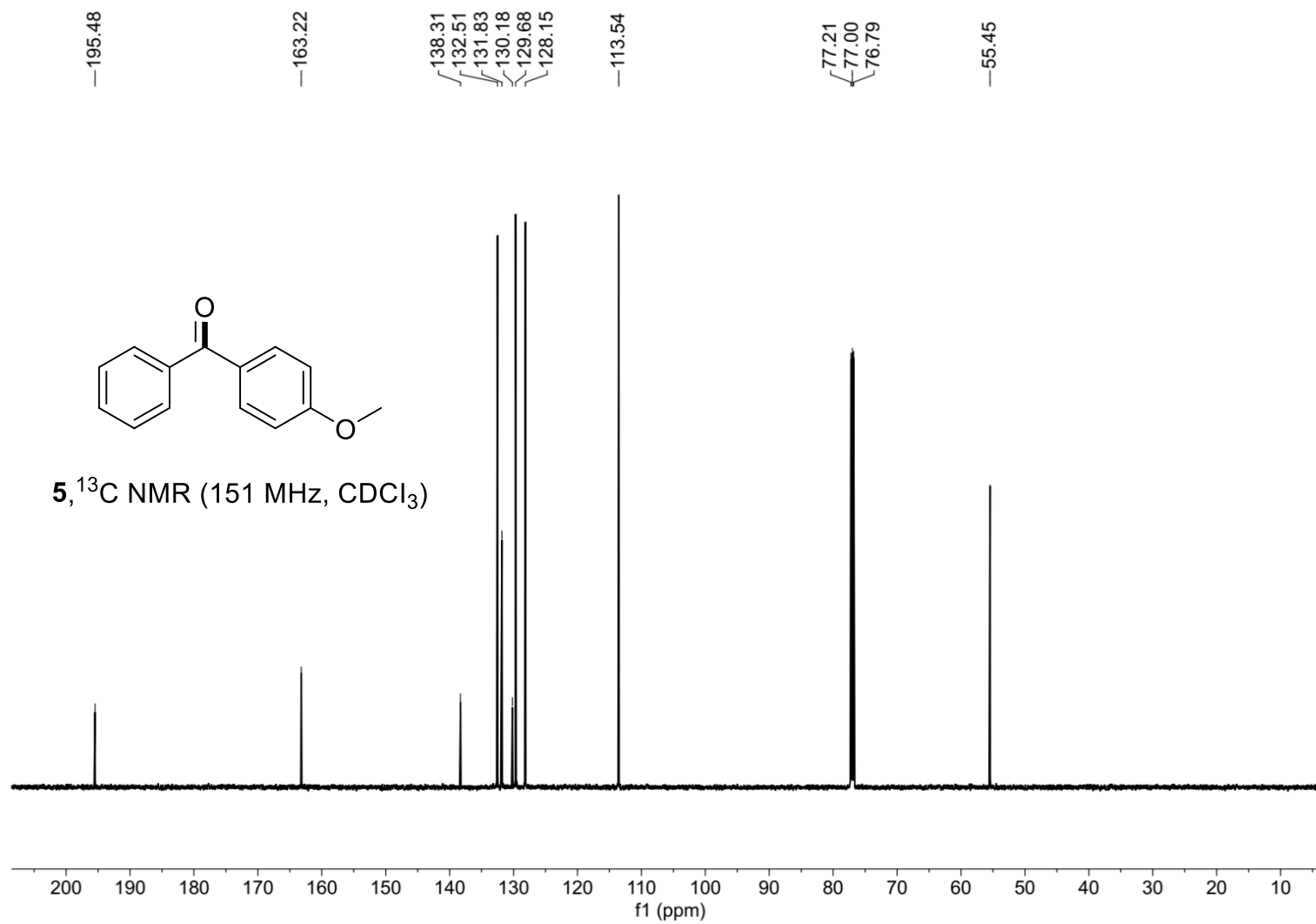


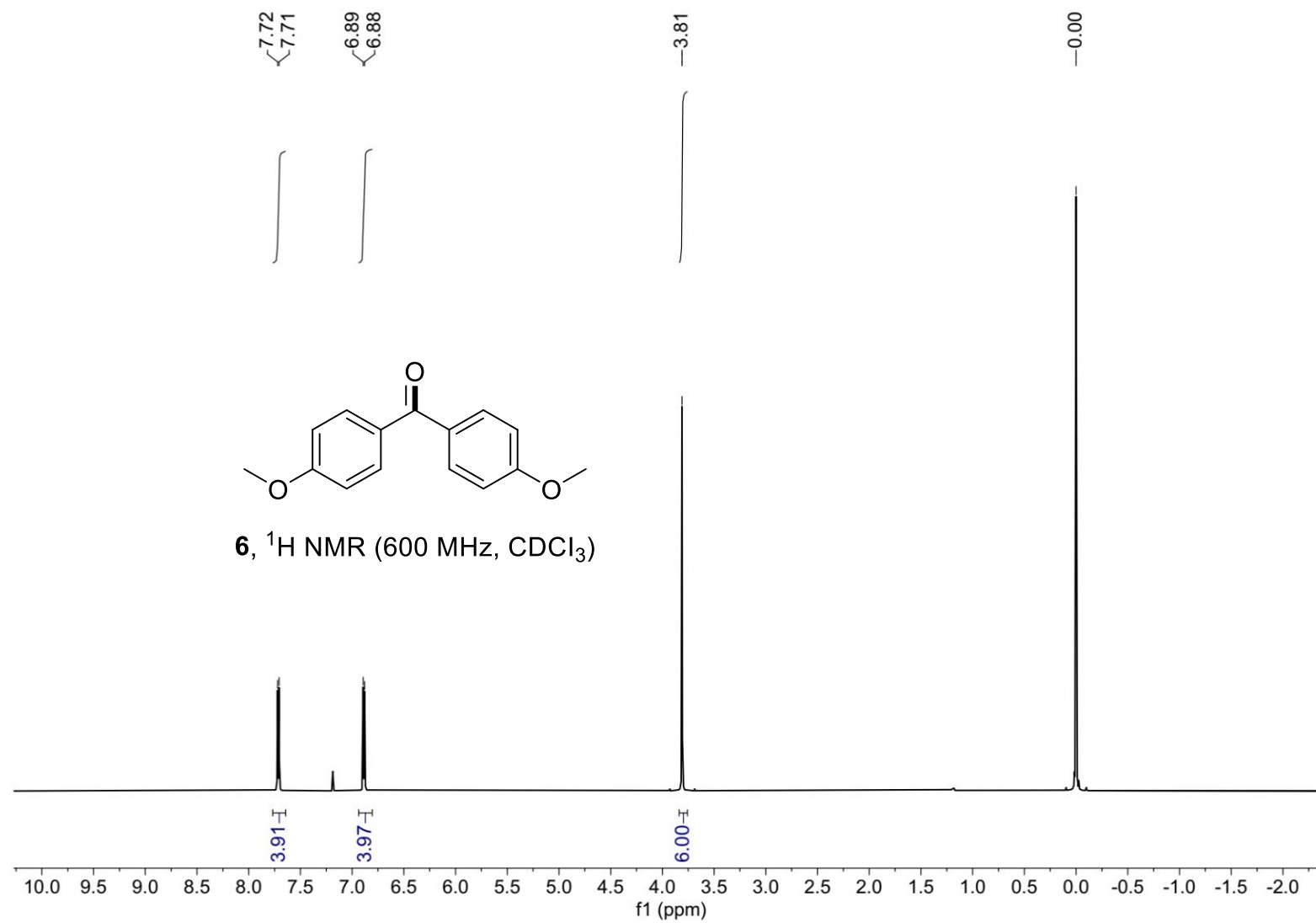


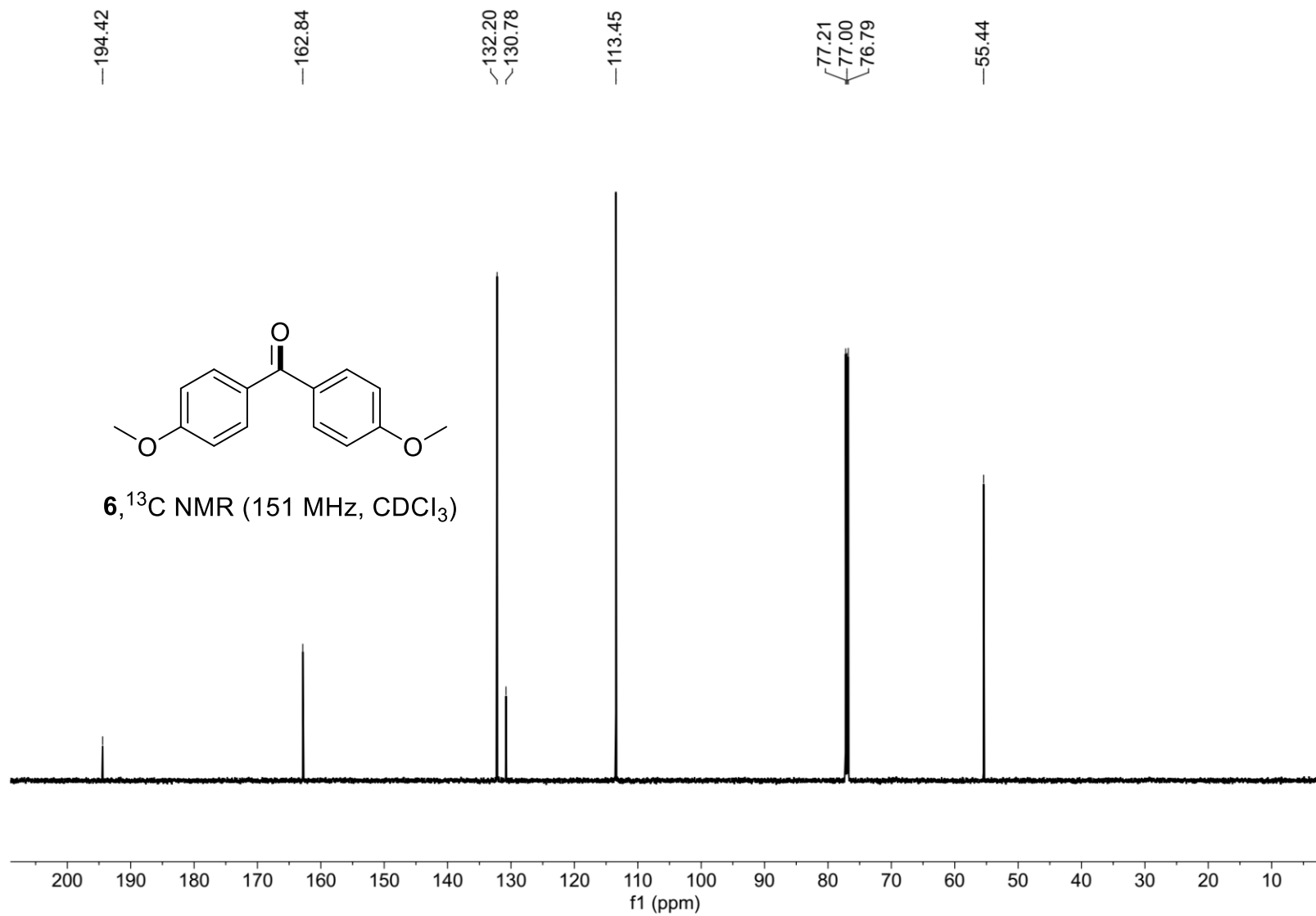


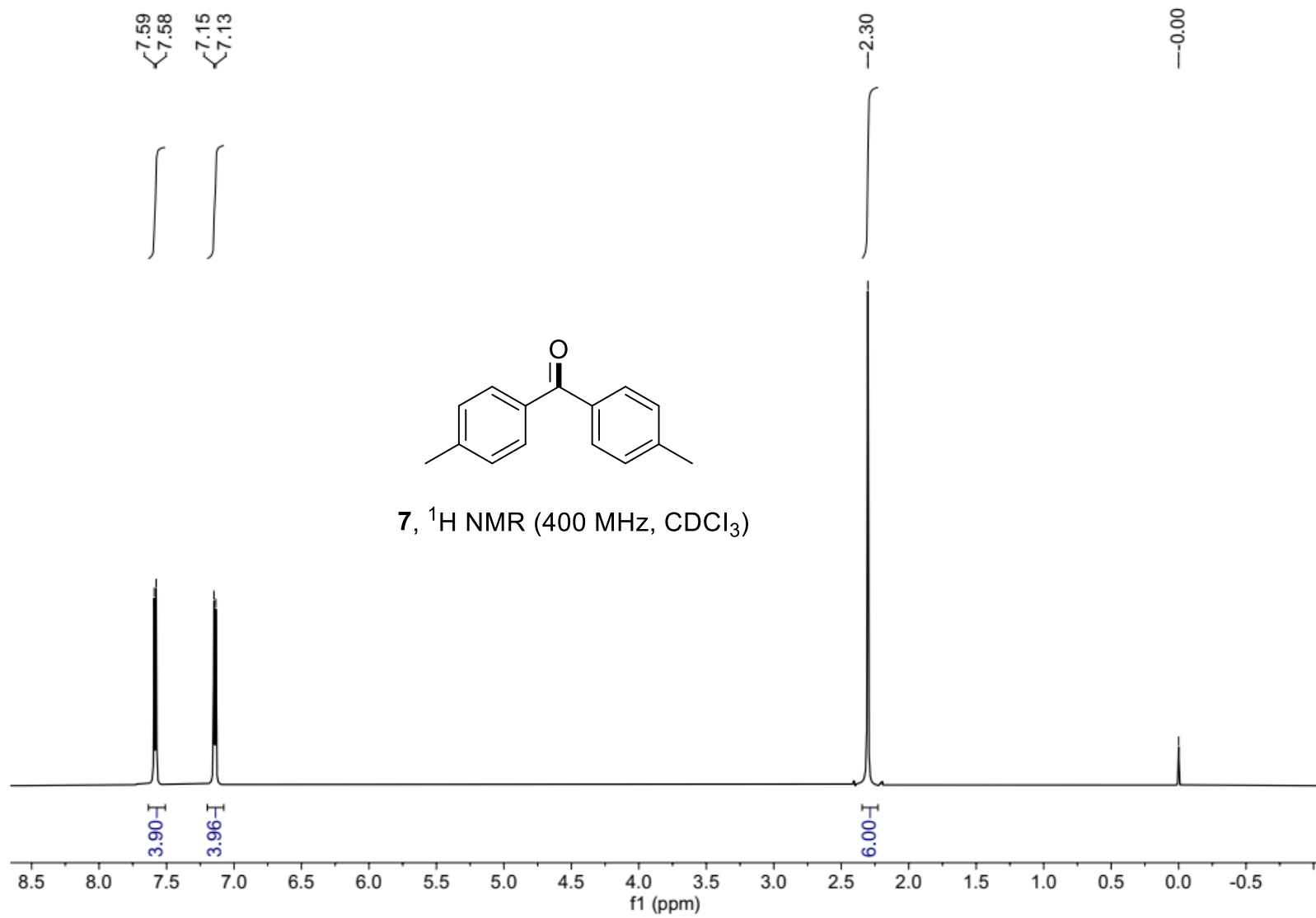


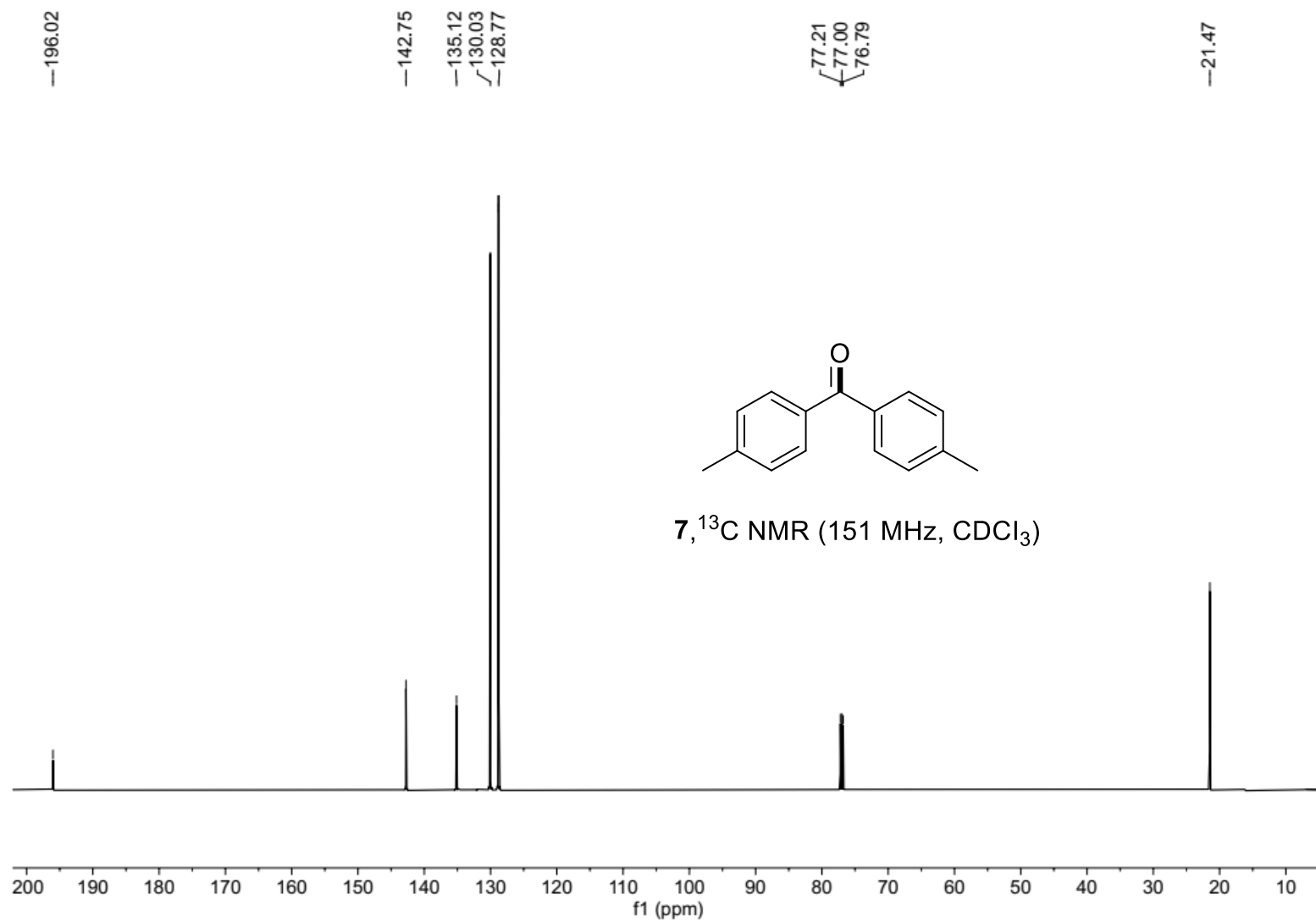


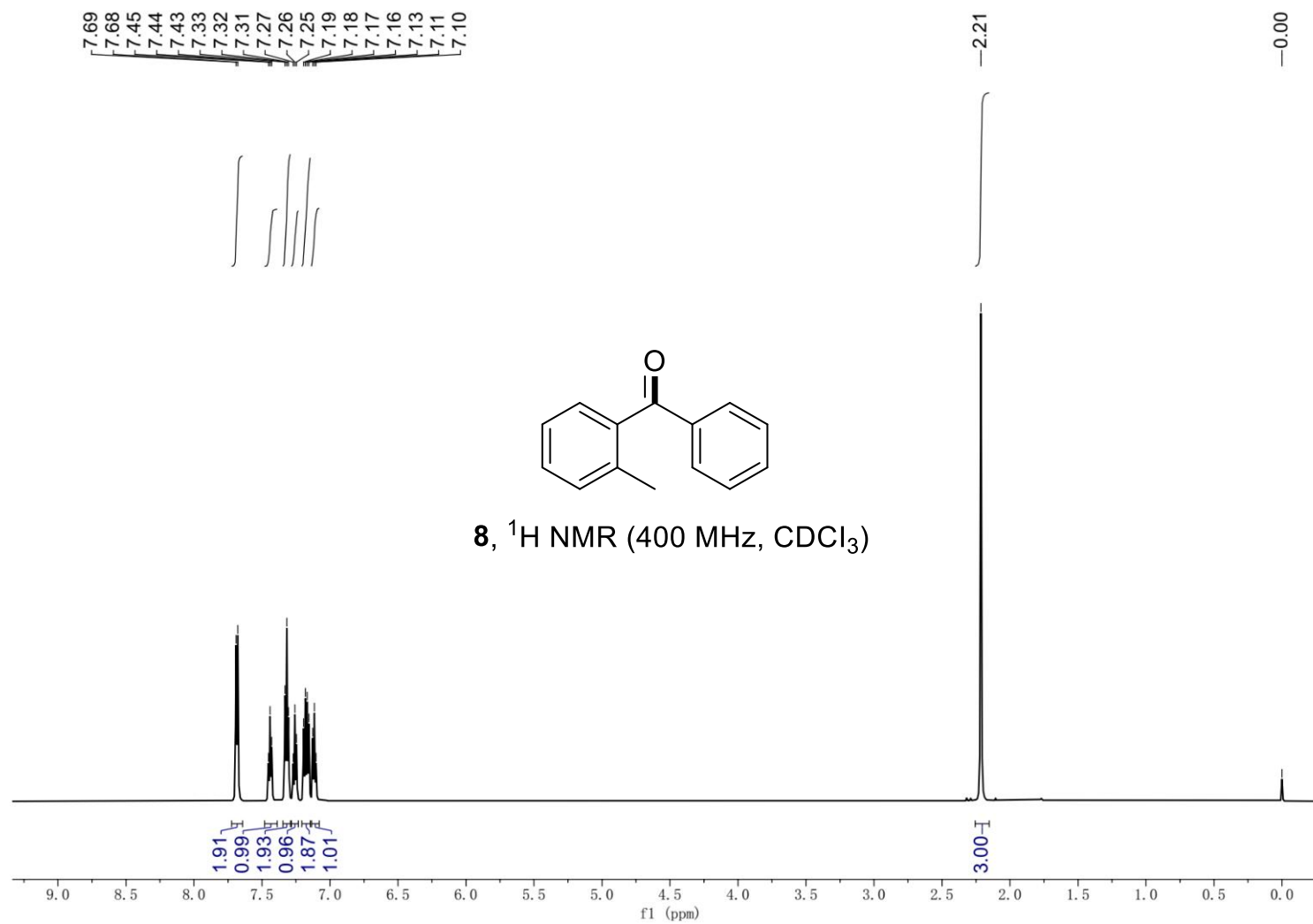


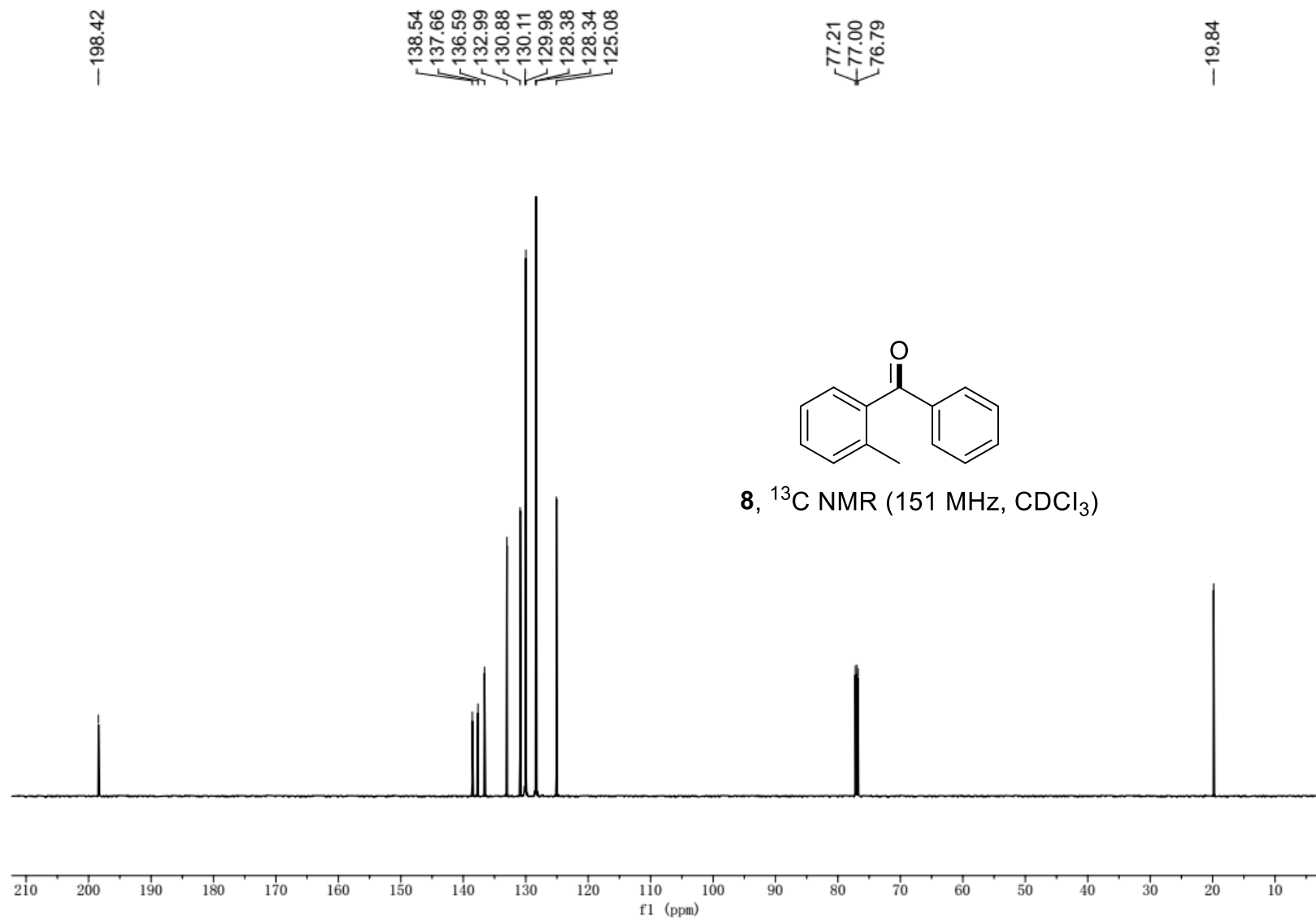


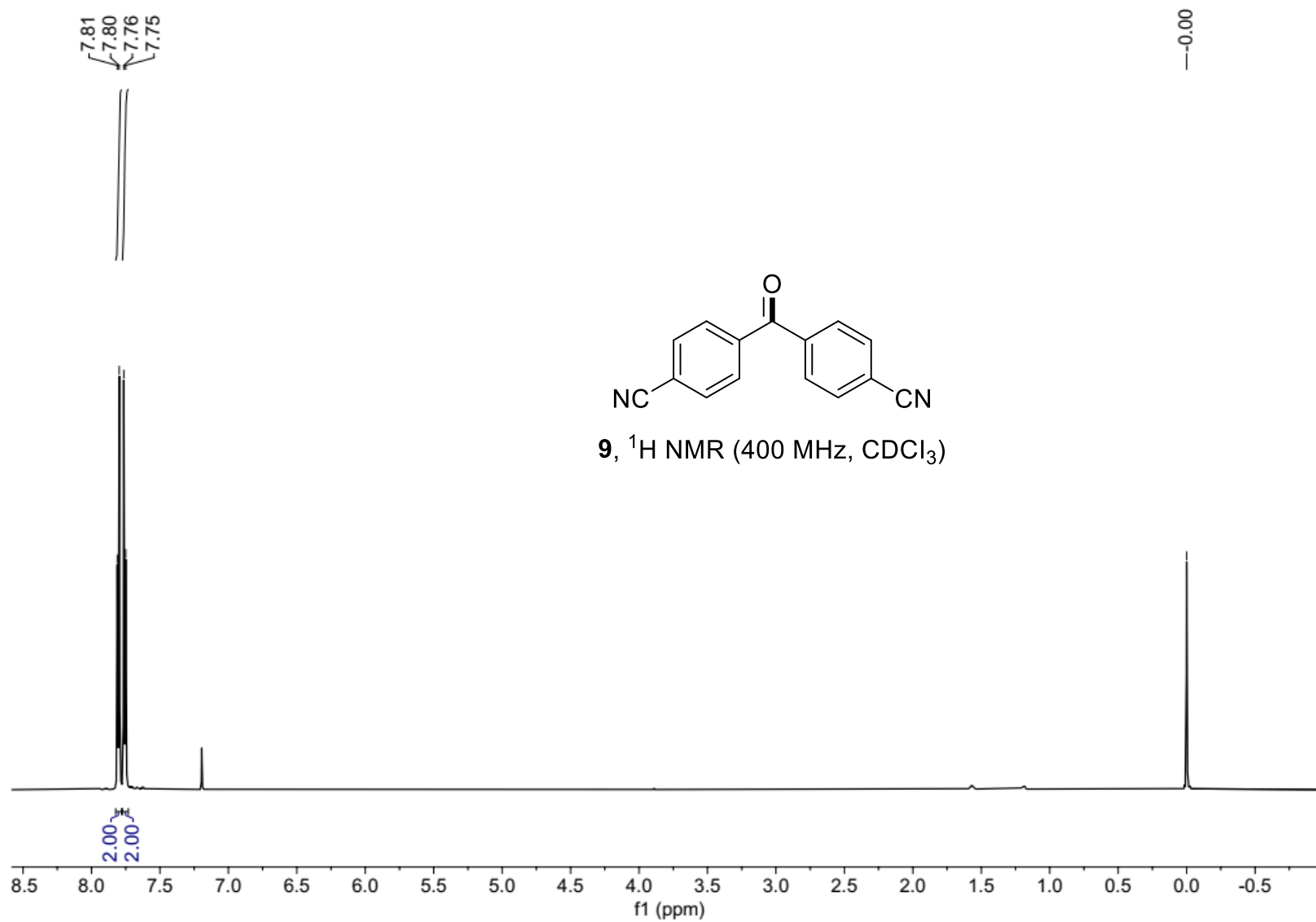


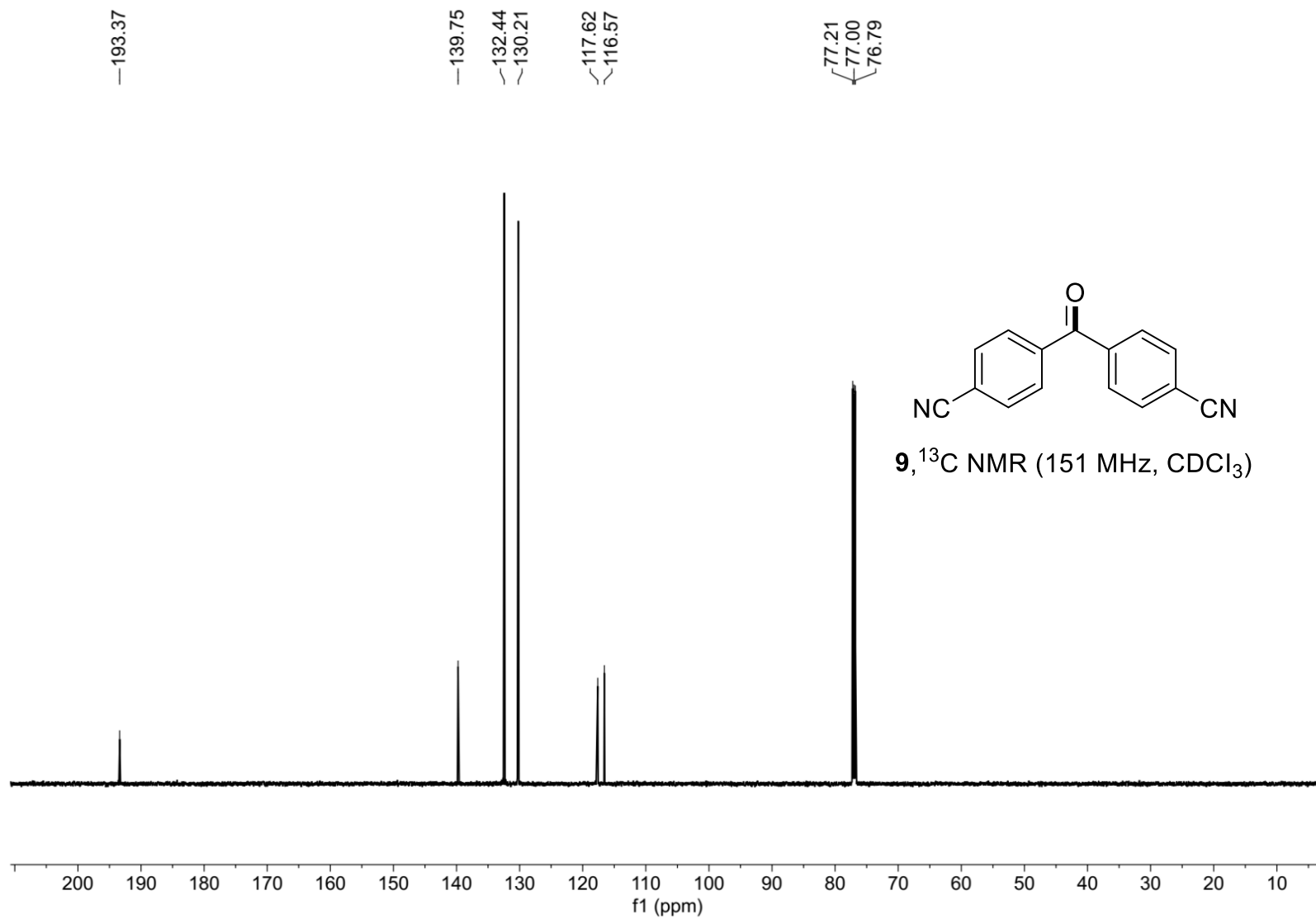


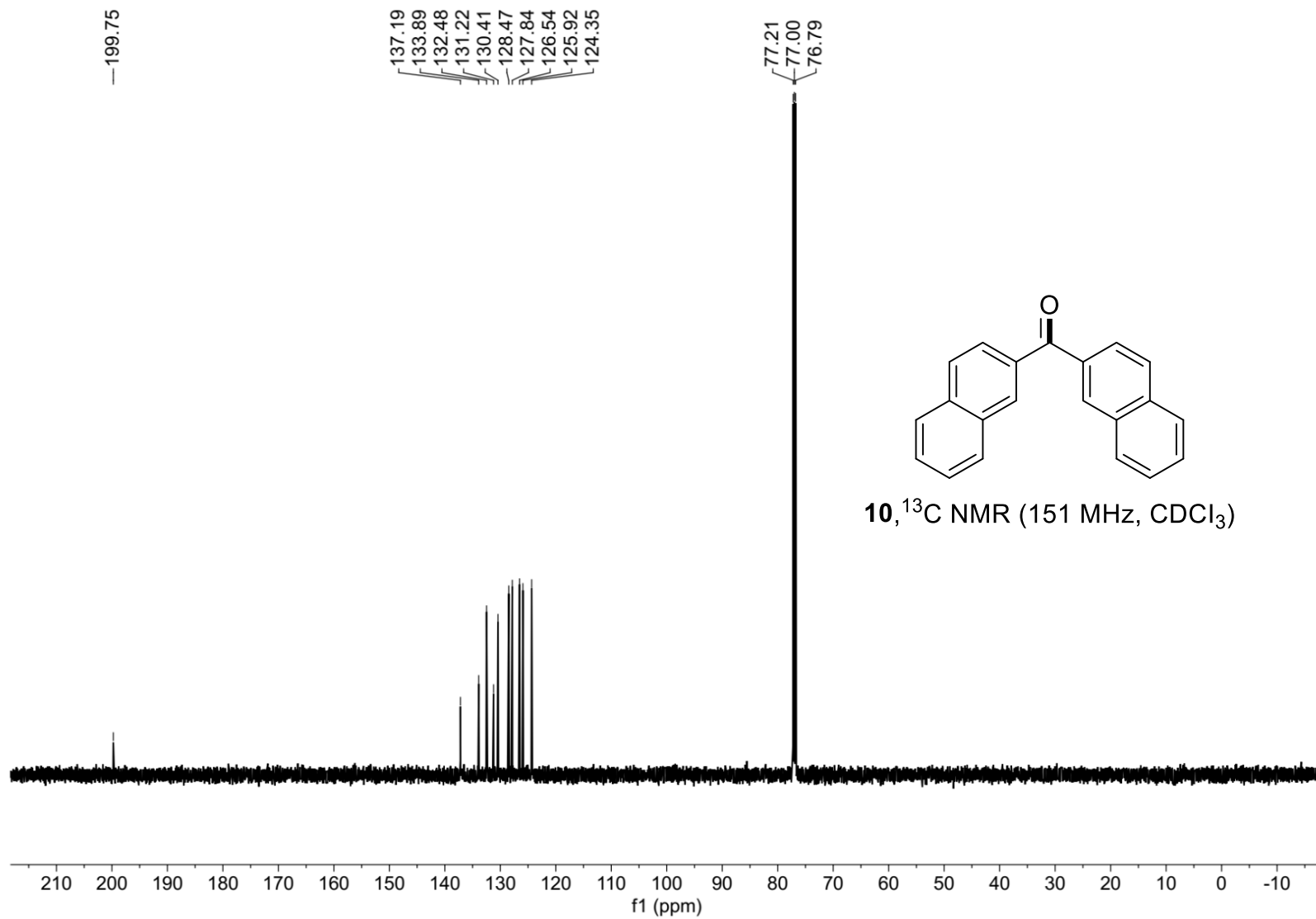


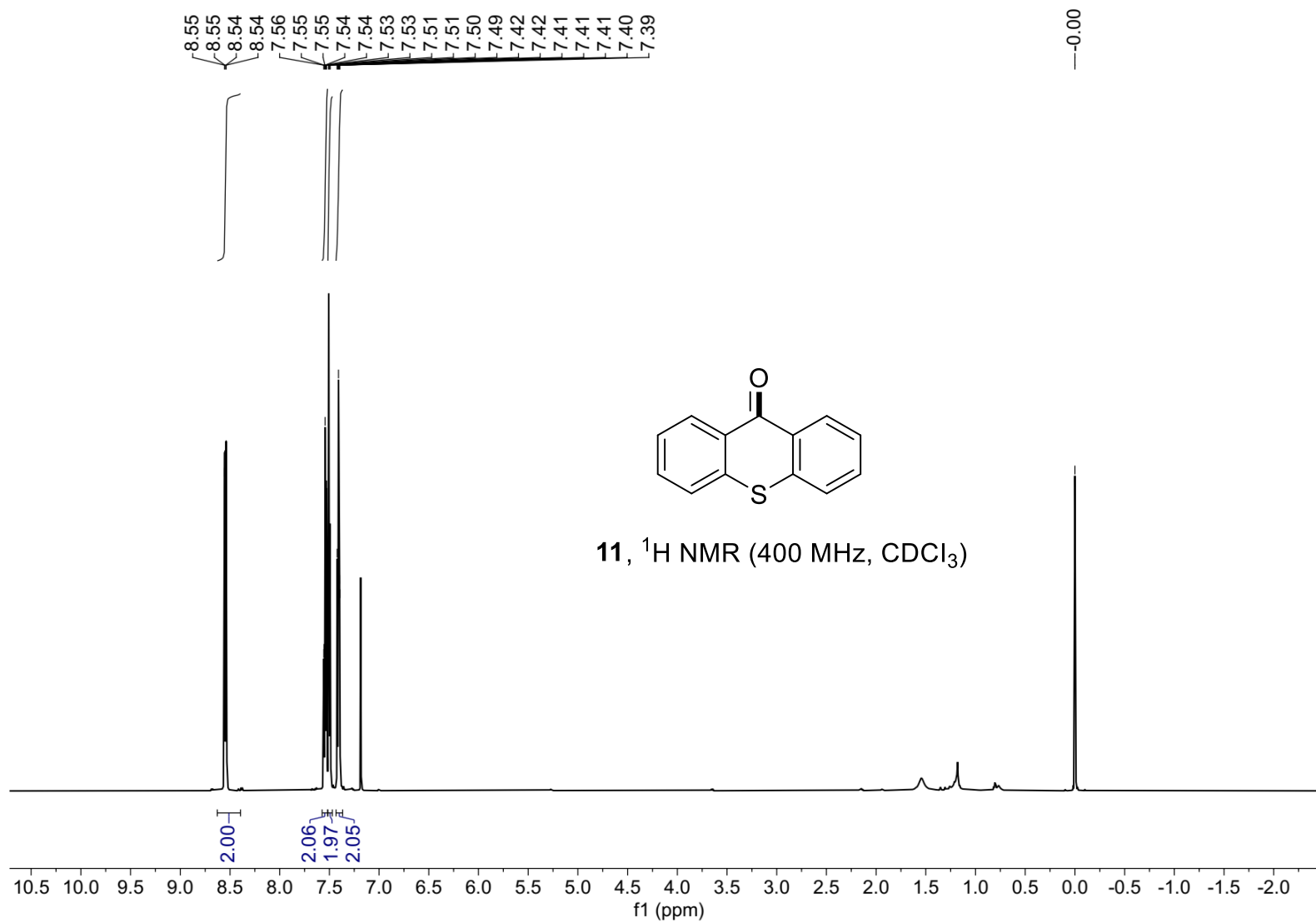


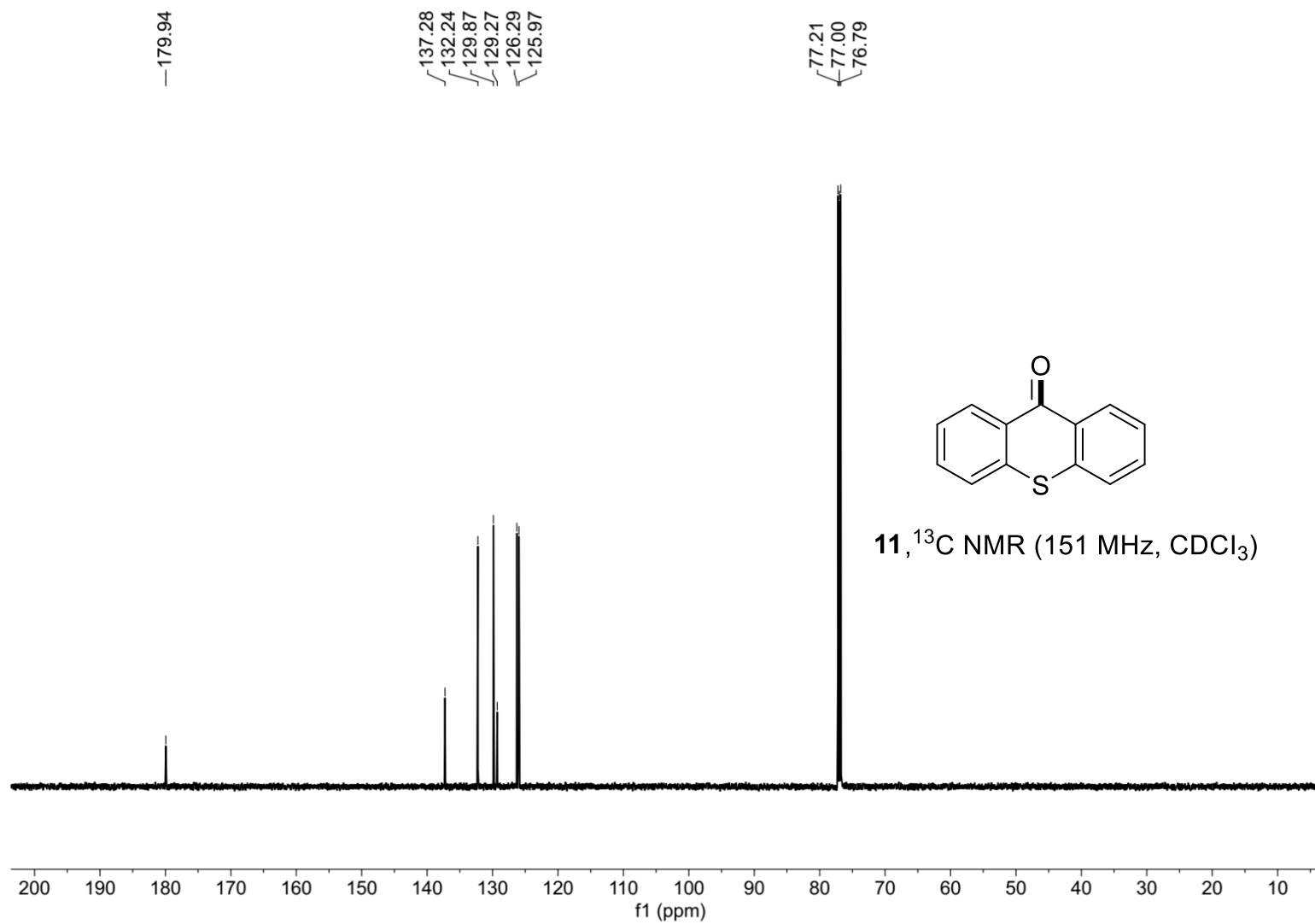


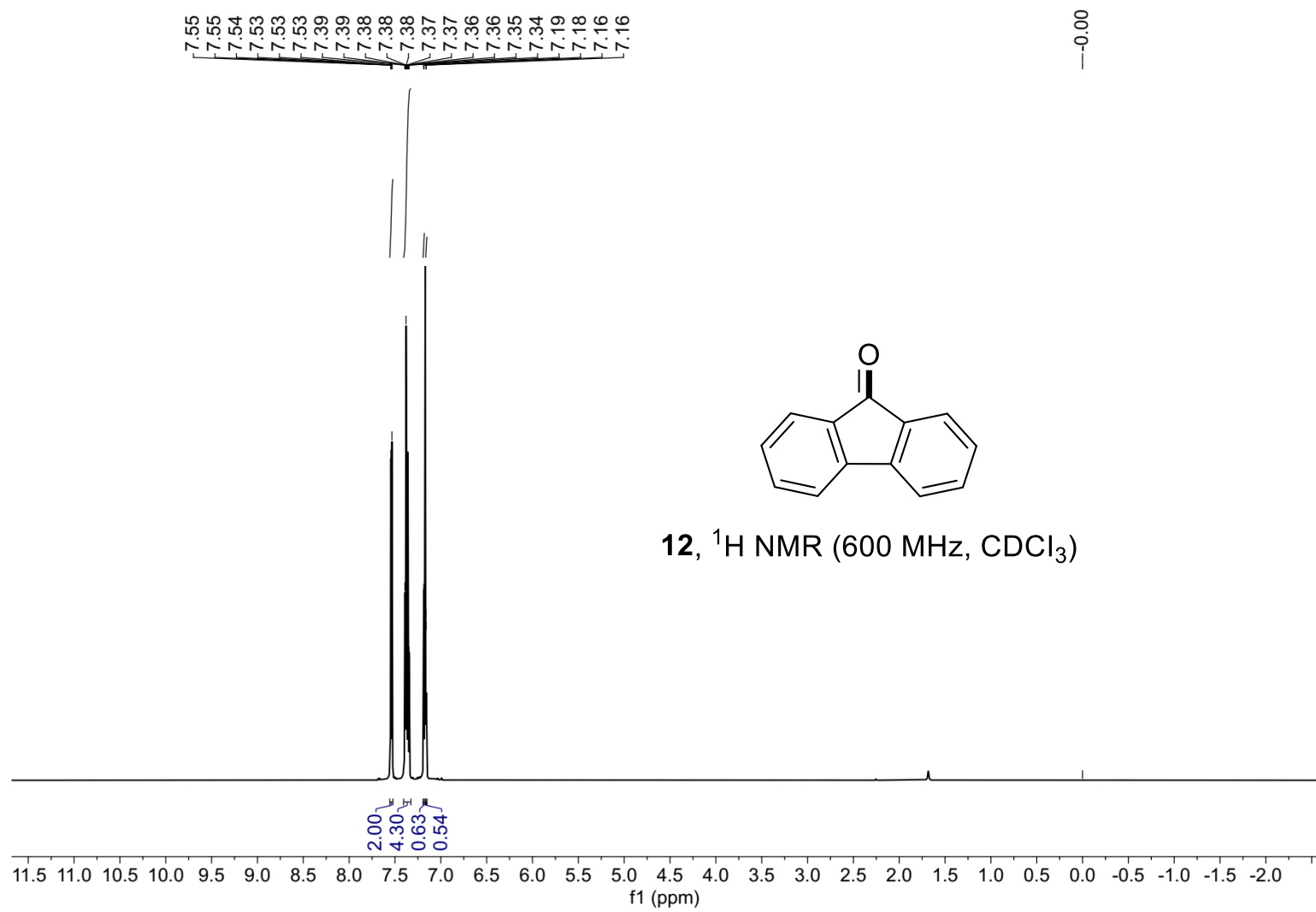


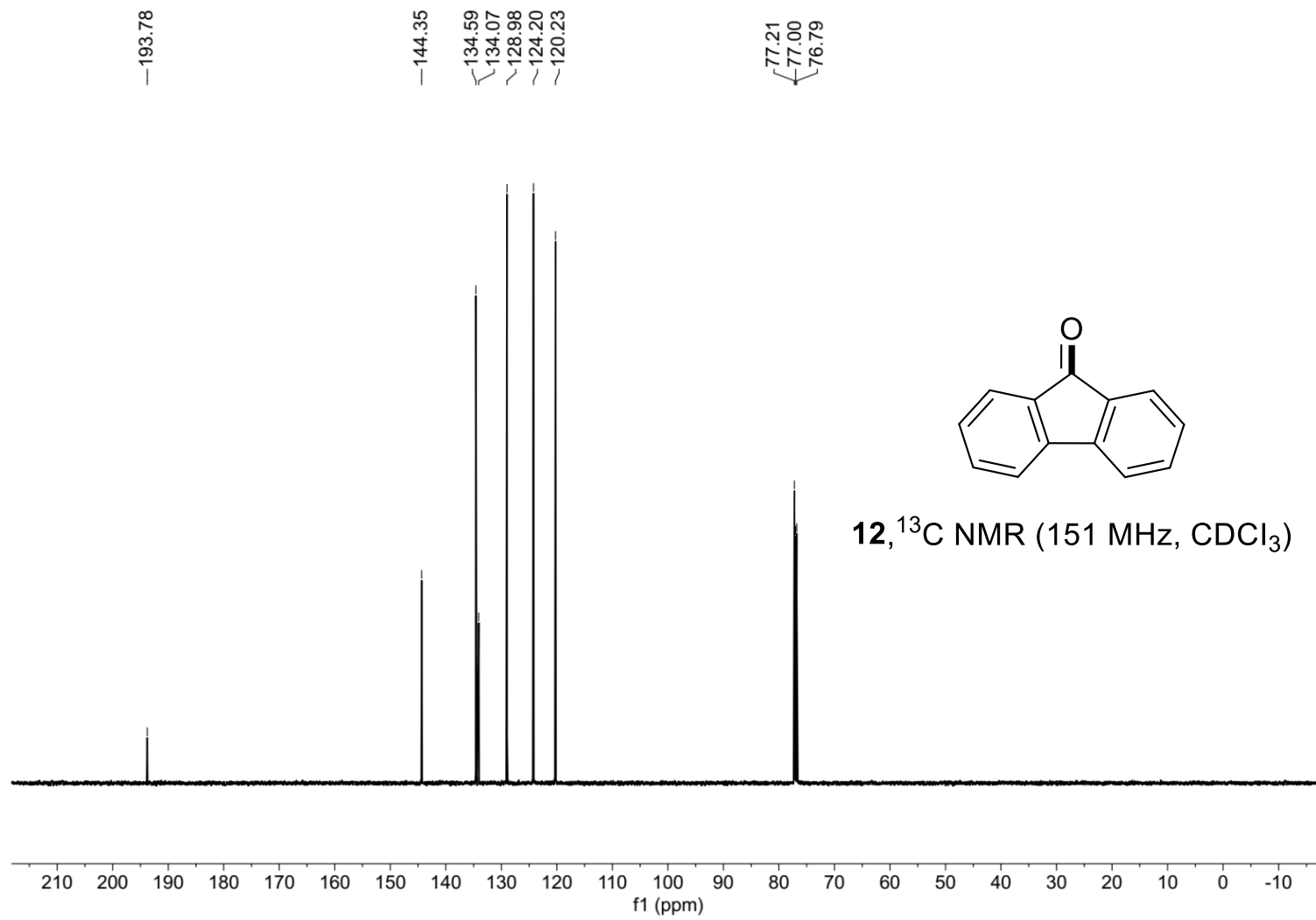


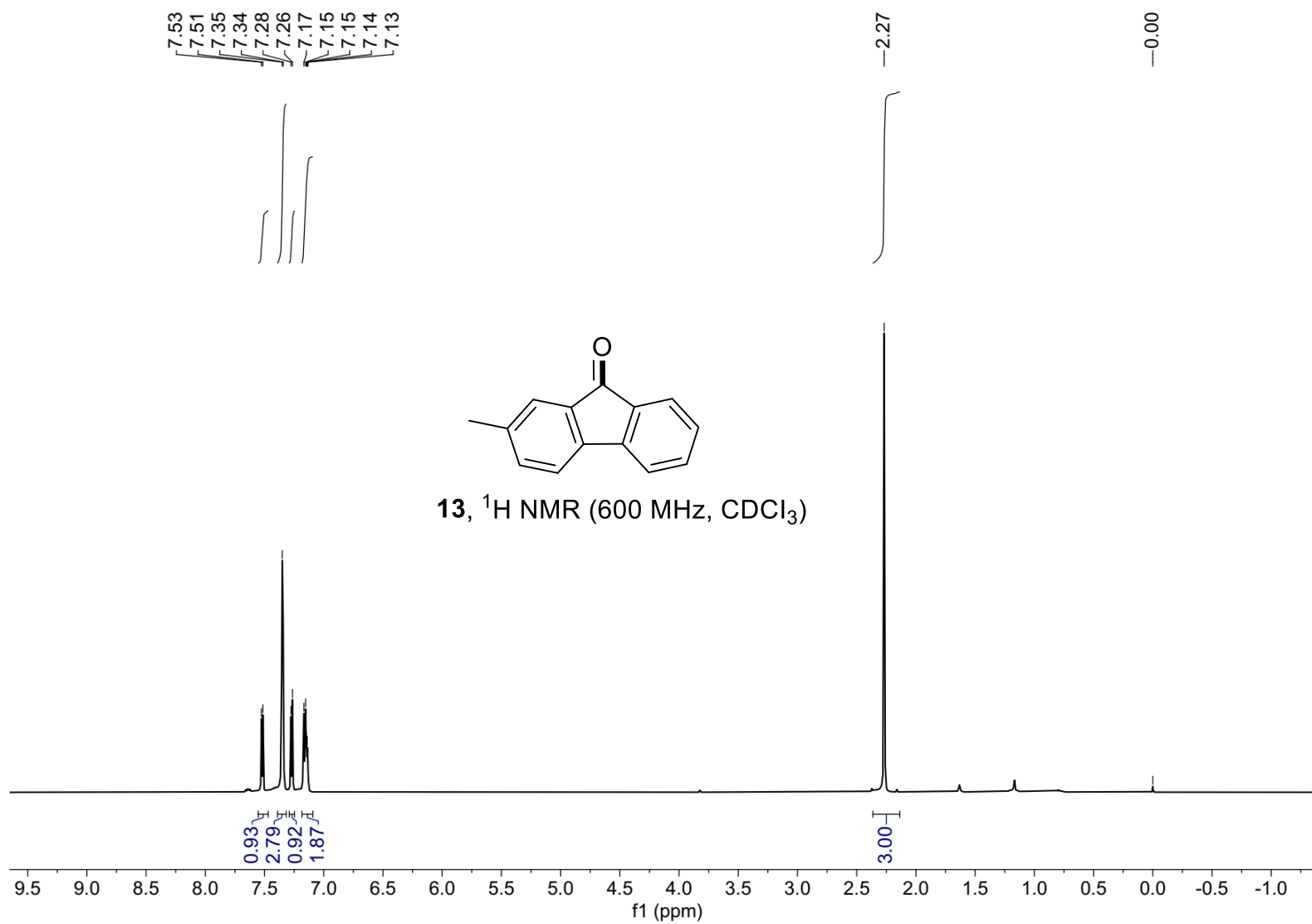


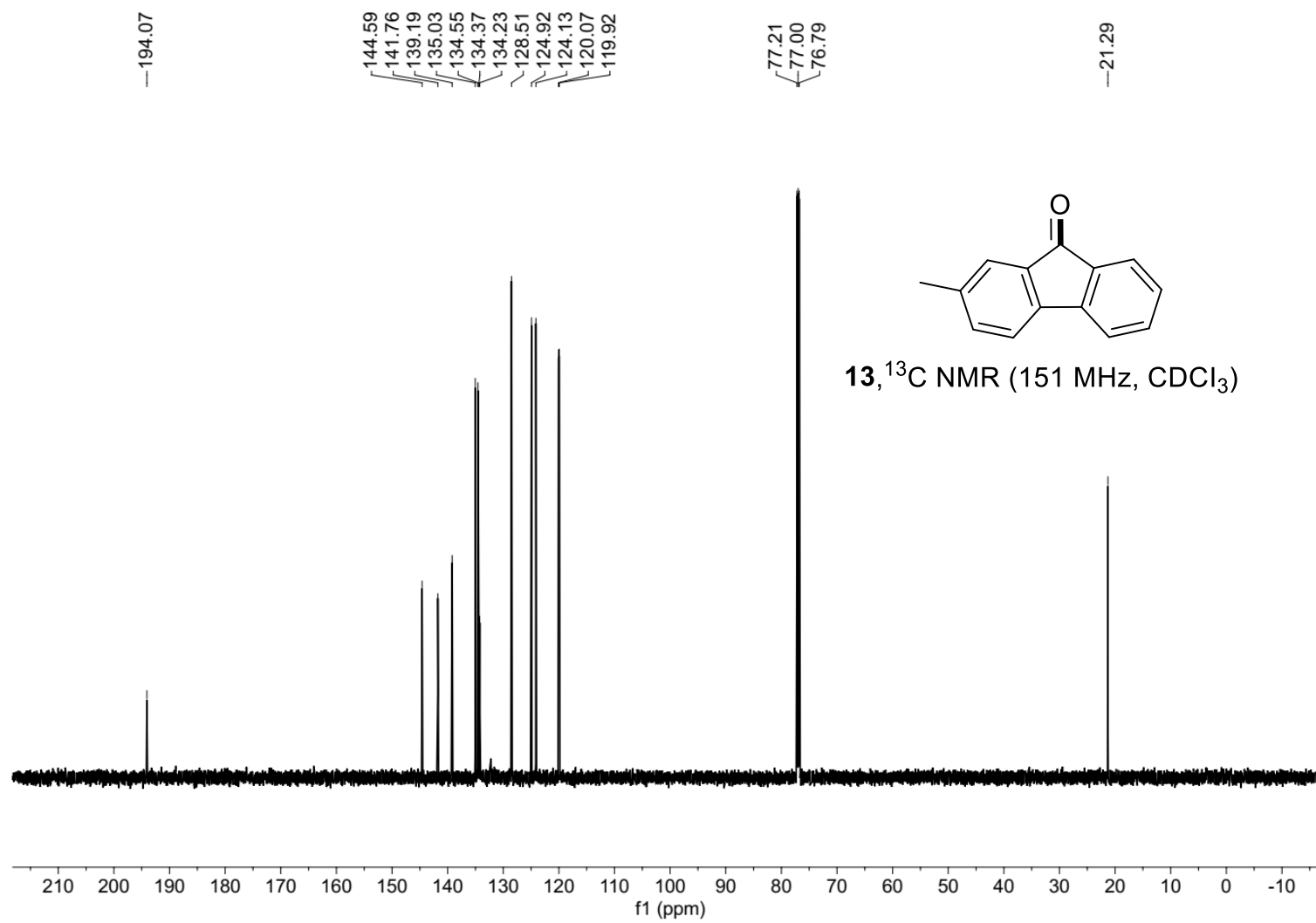


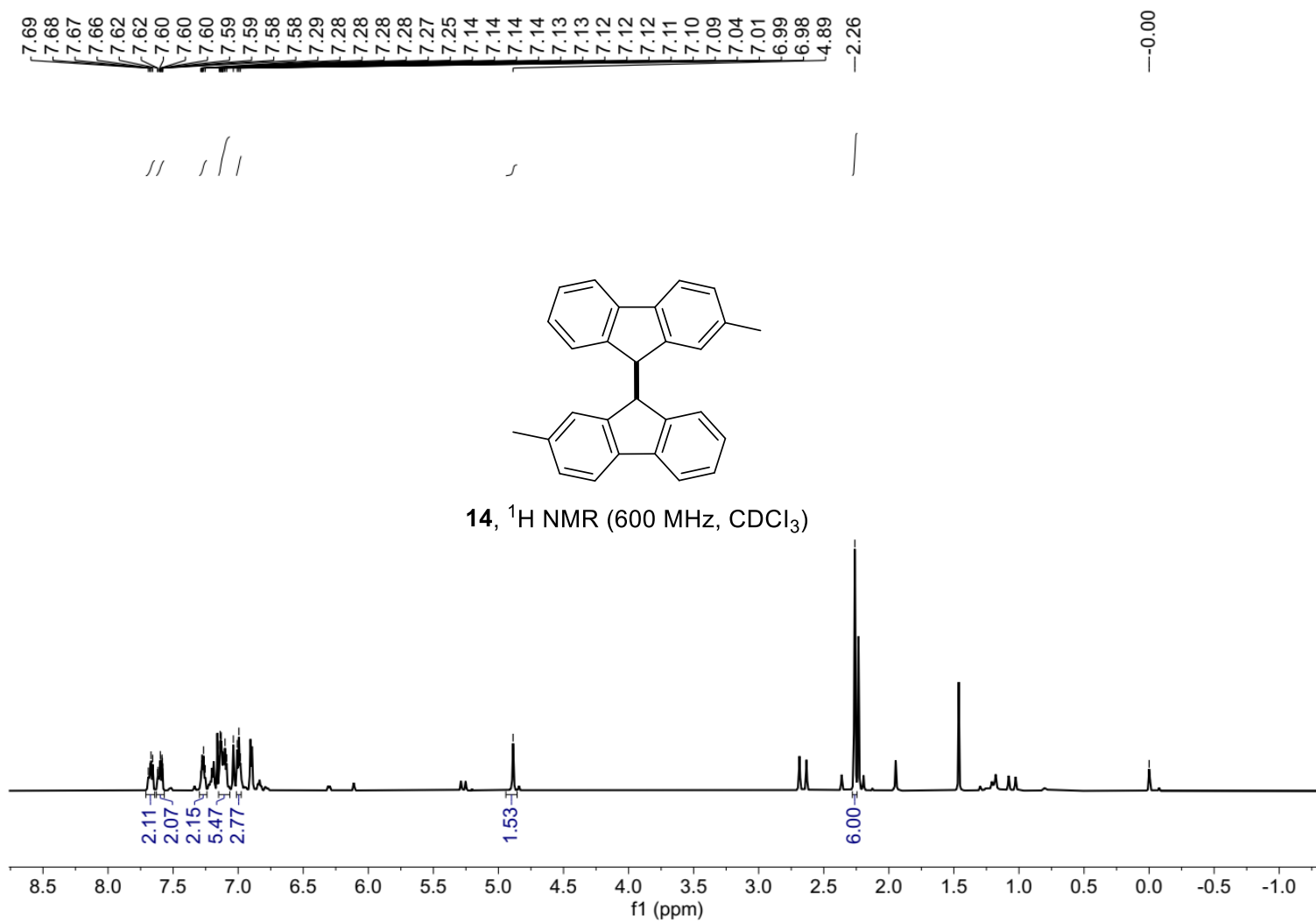


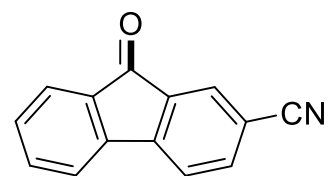
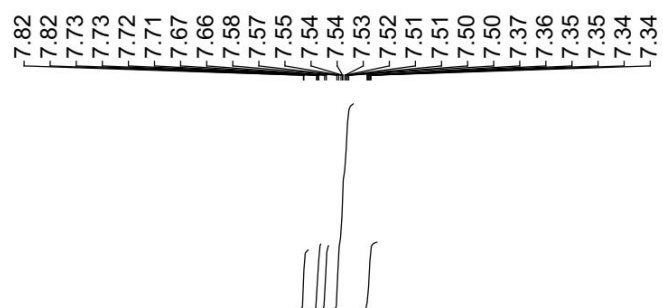




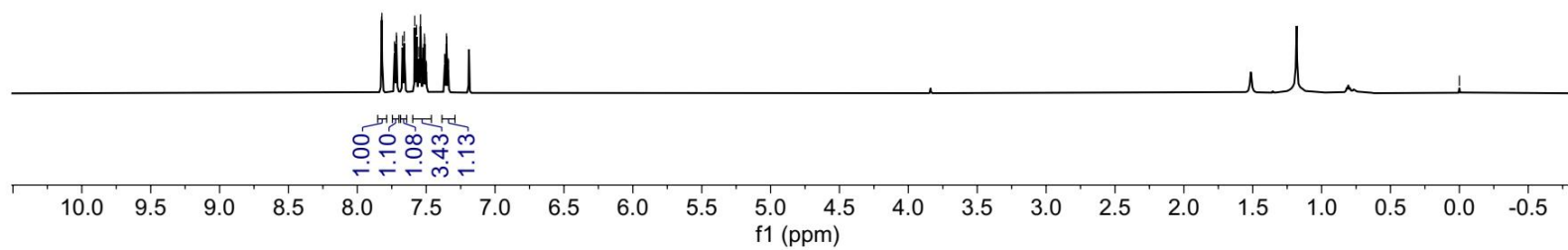


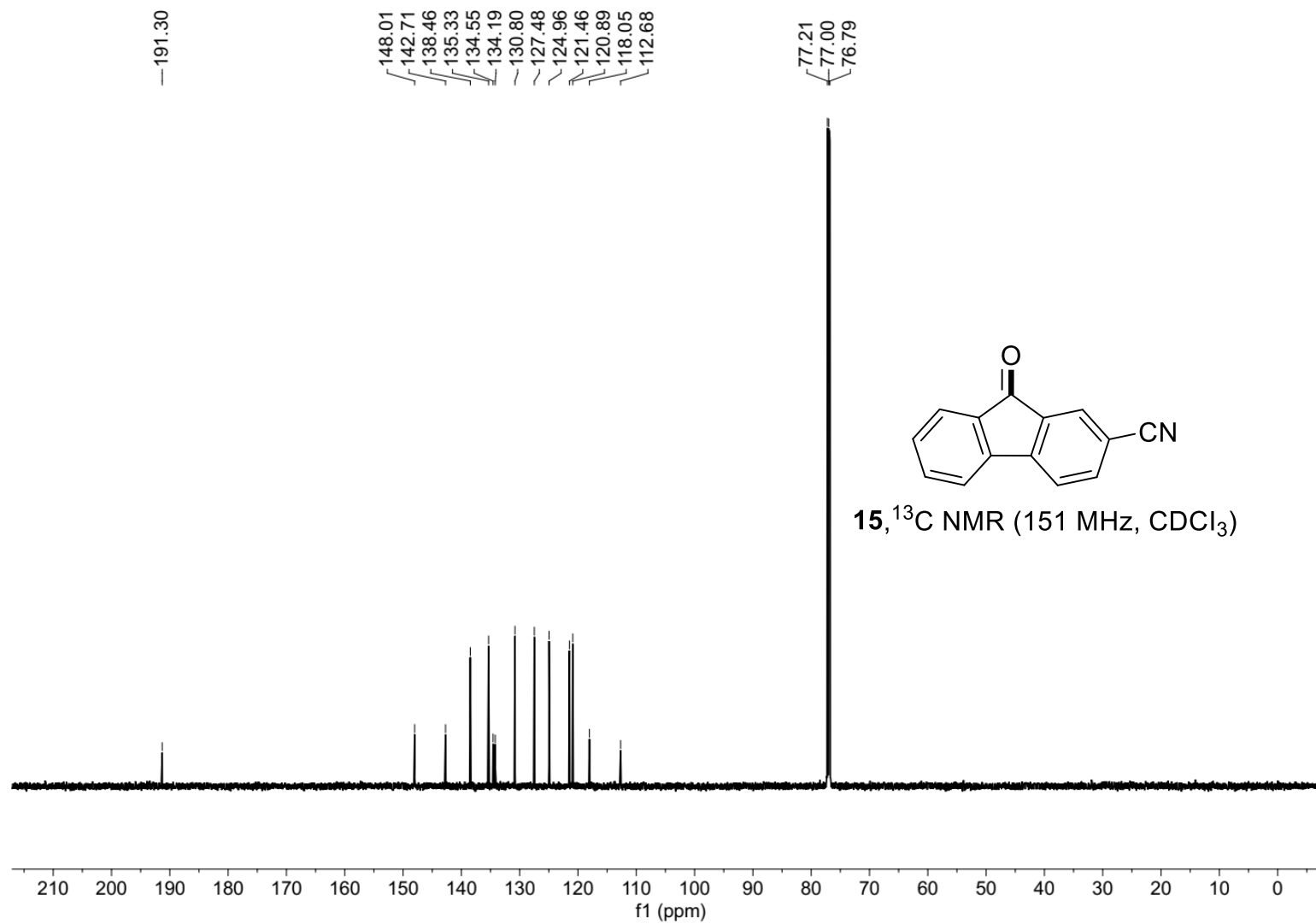


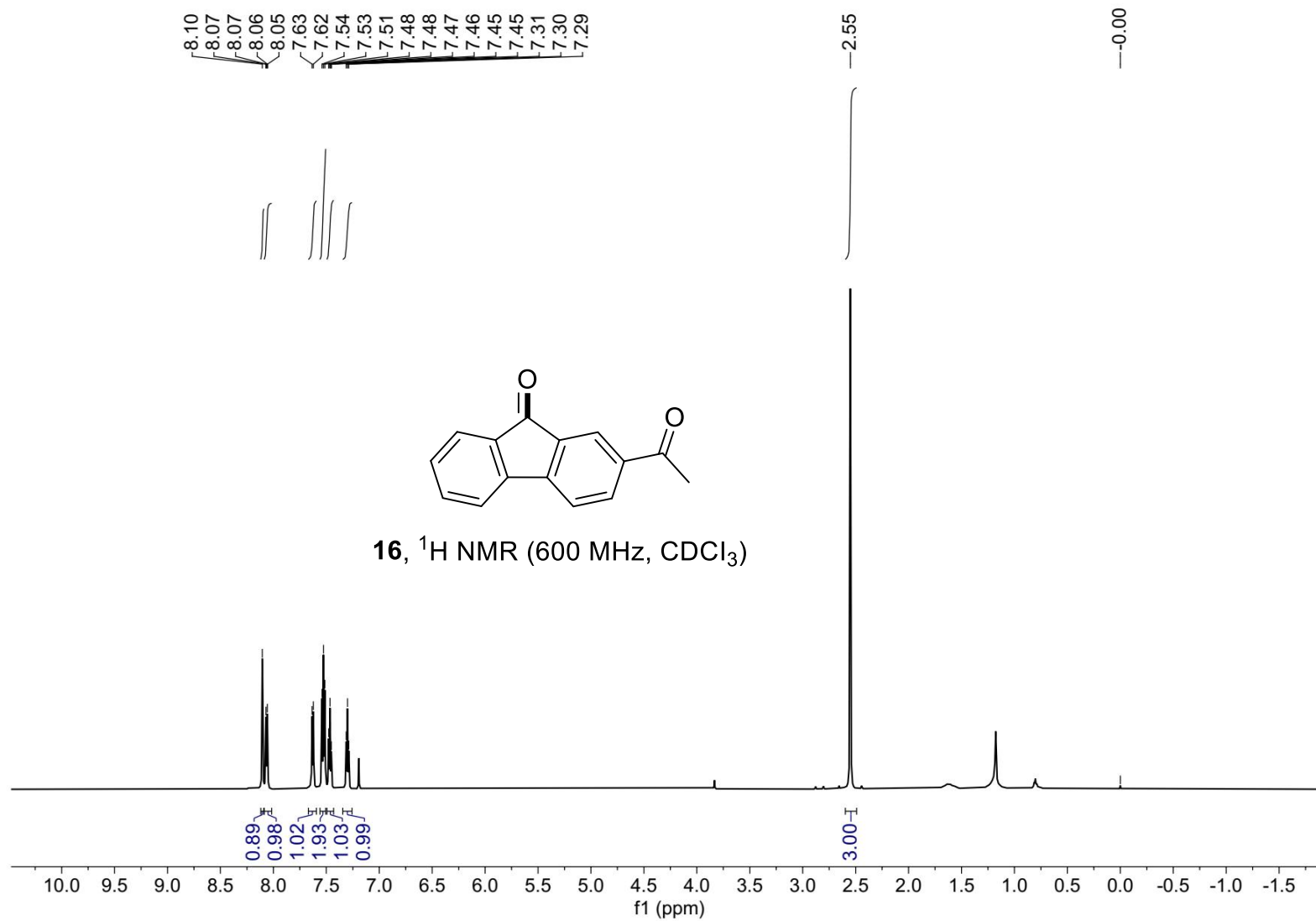


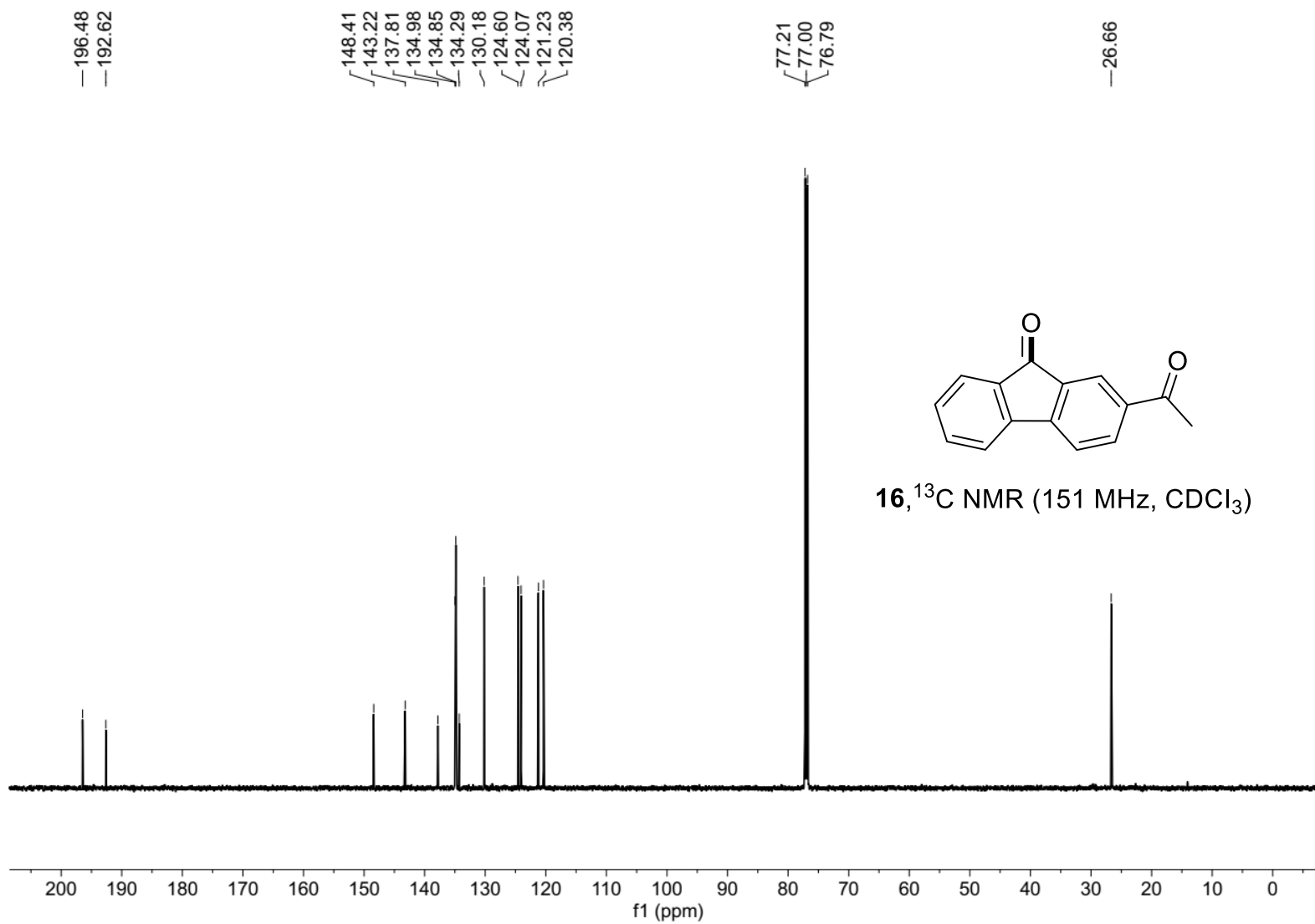


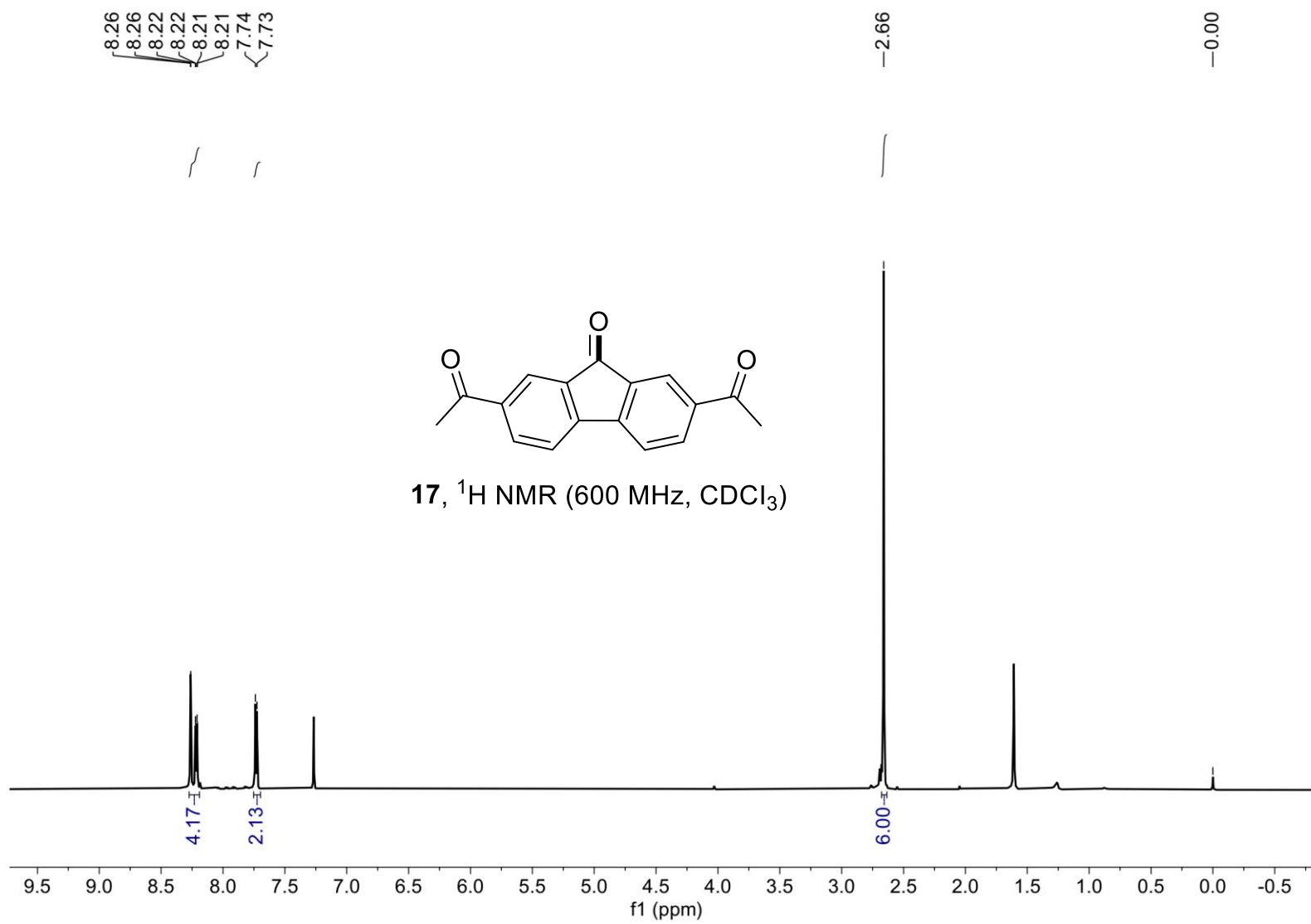
15, ^1H NMR (600 MHz, CDCl_3)

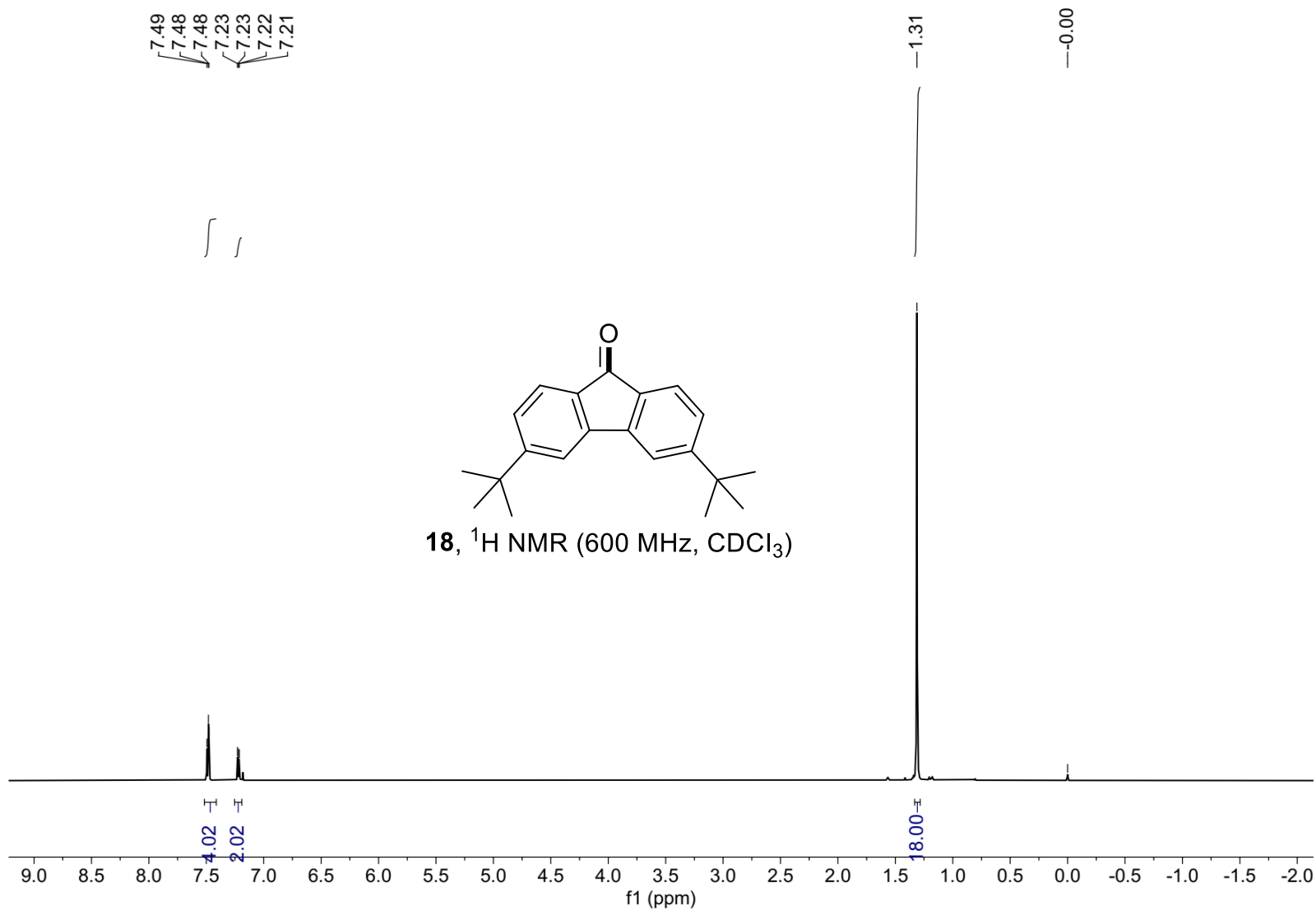


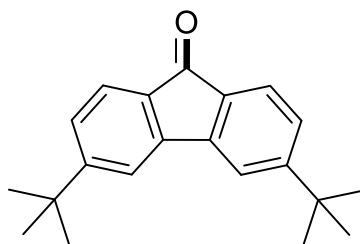




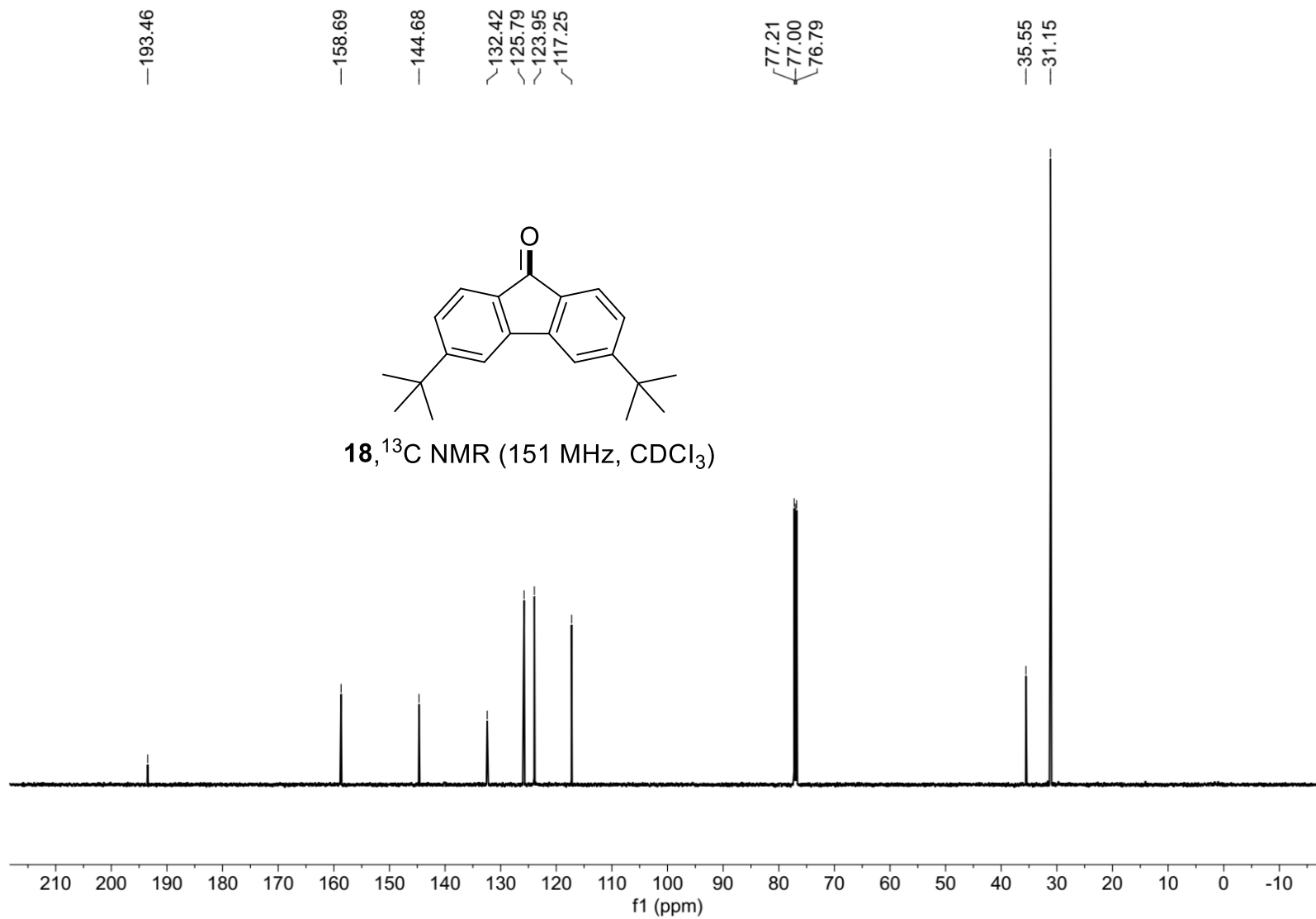


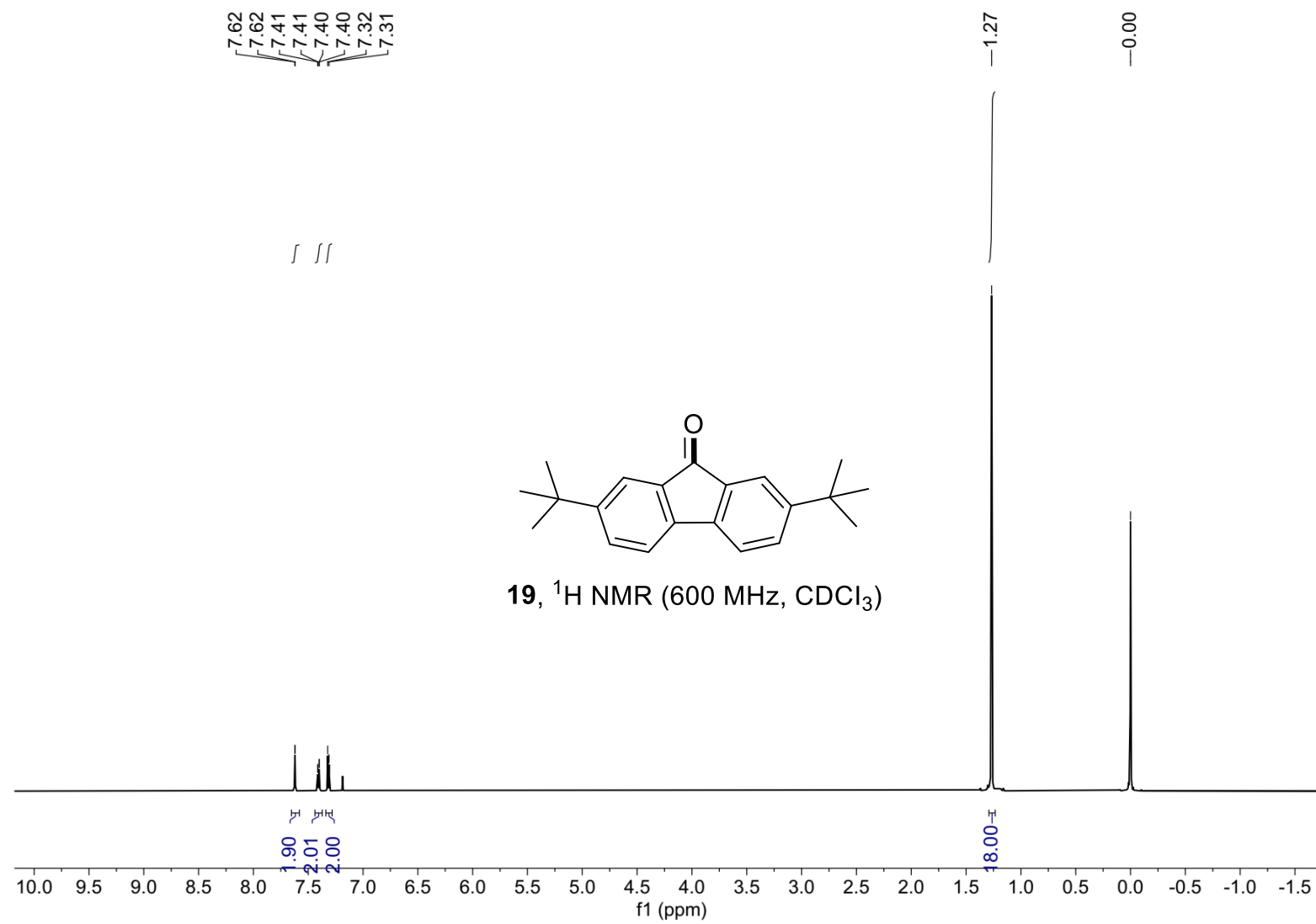


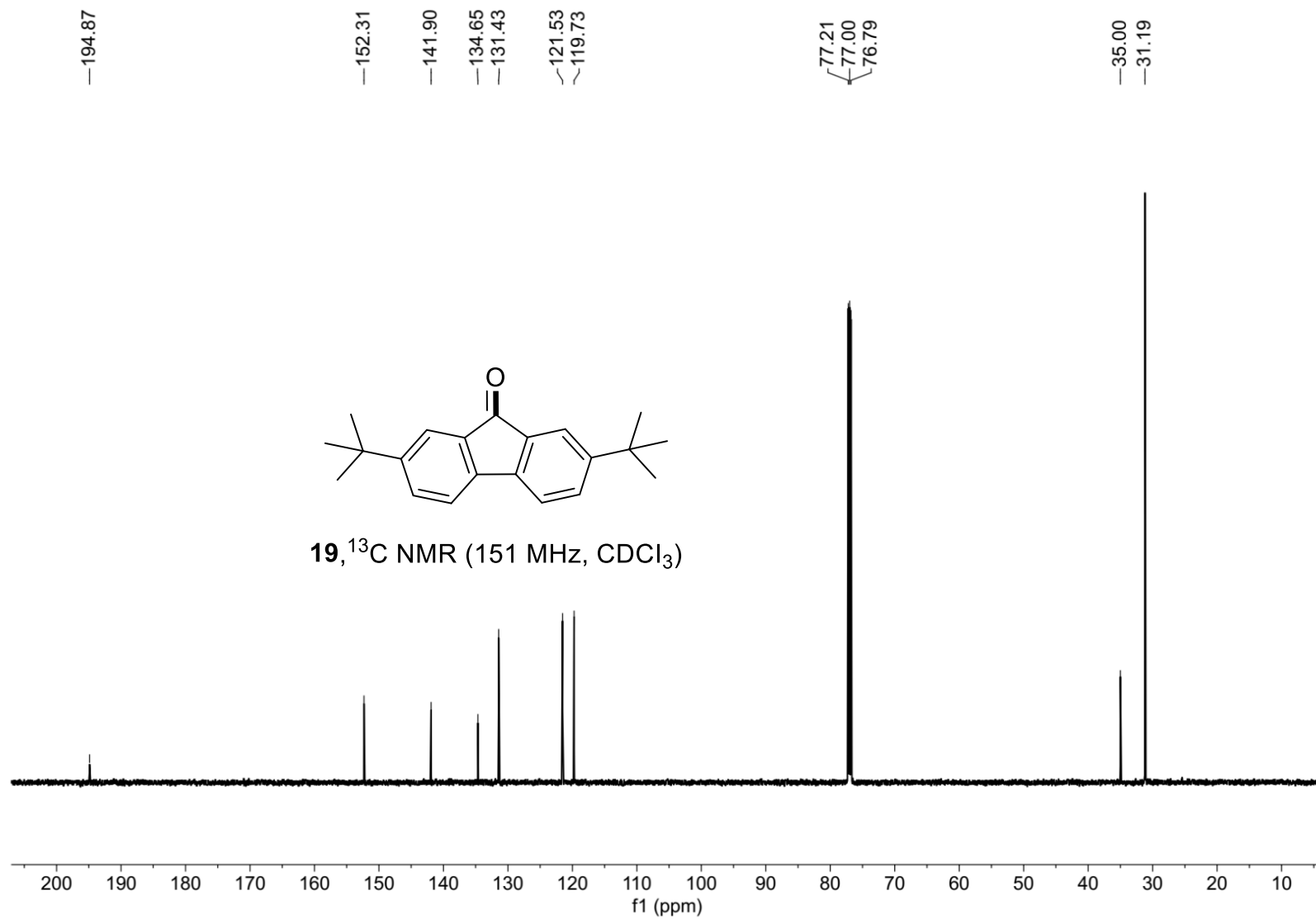


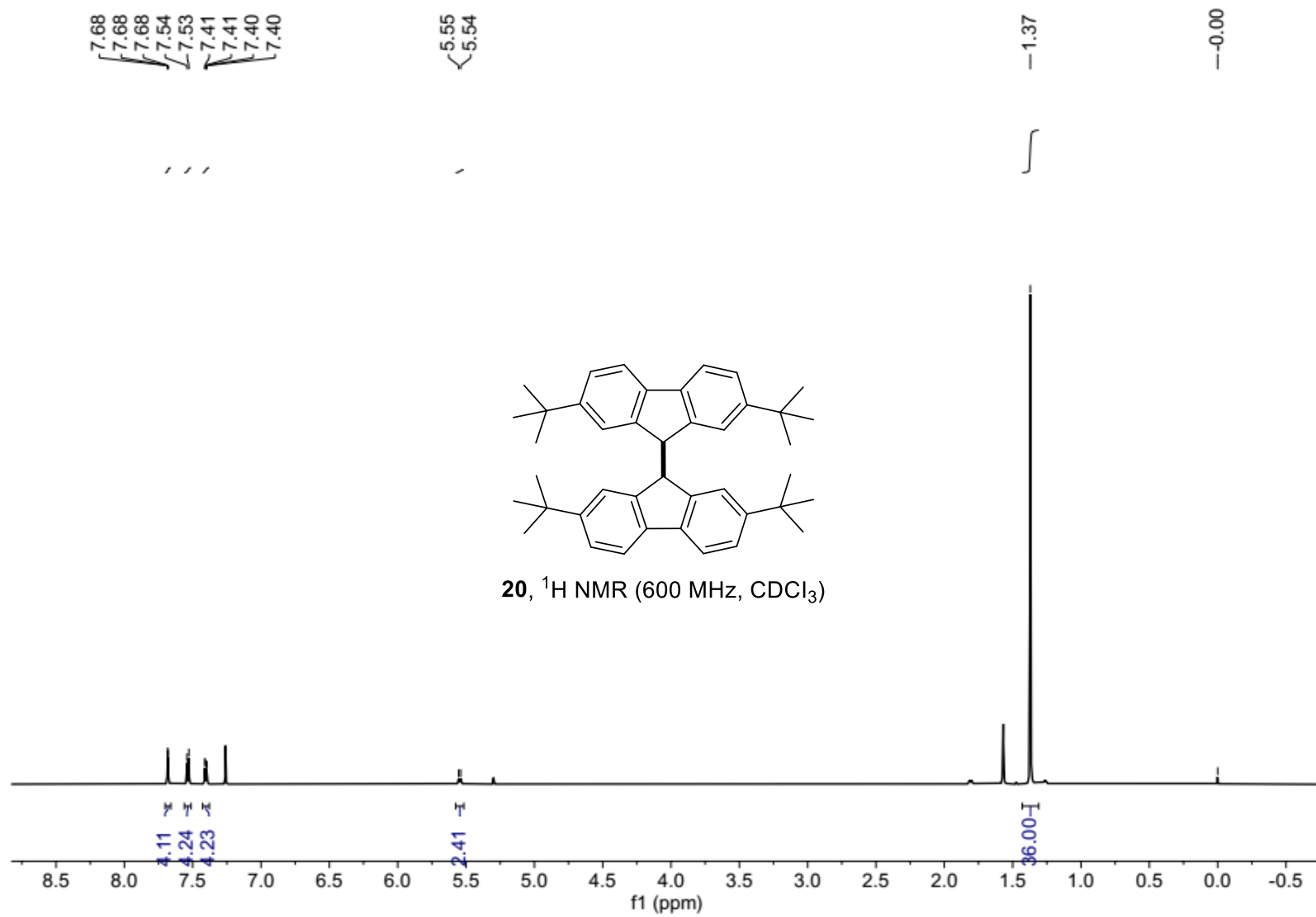


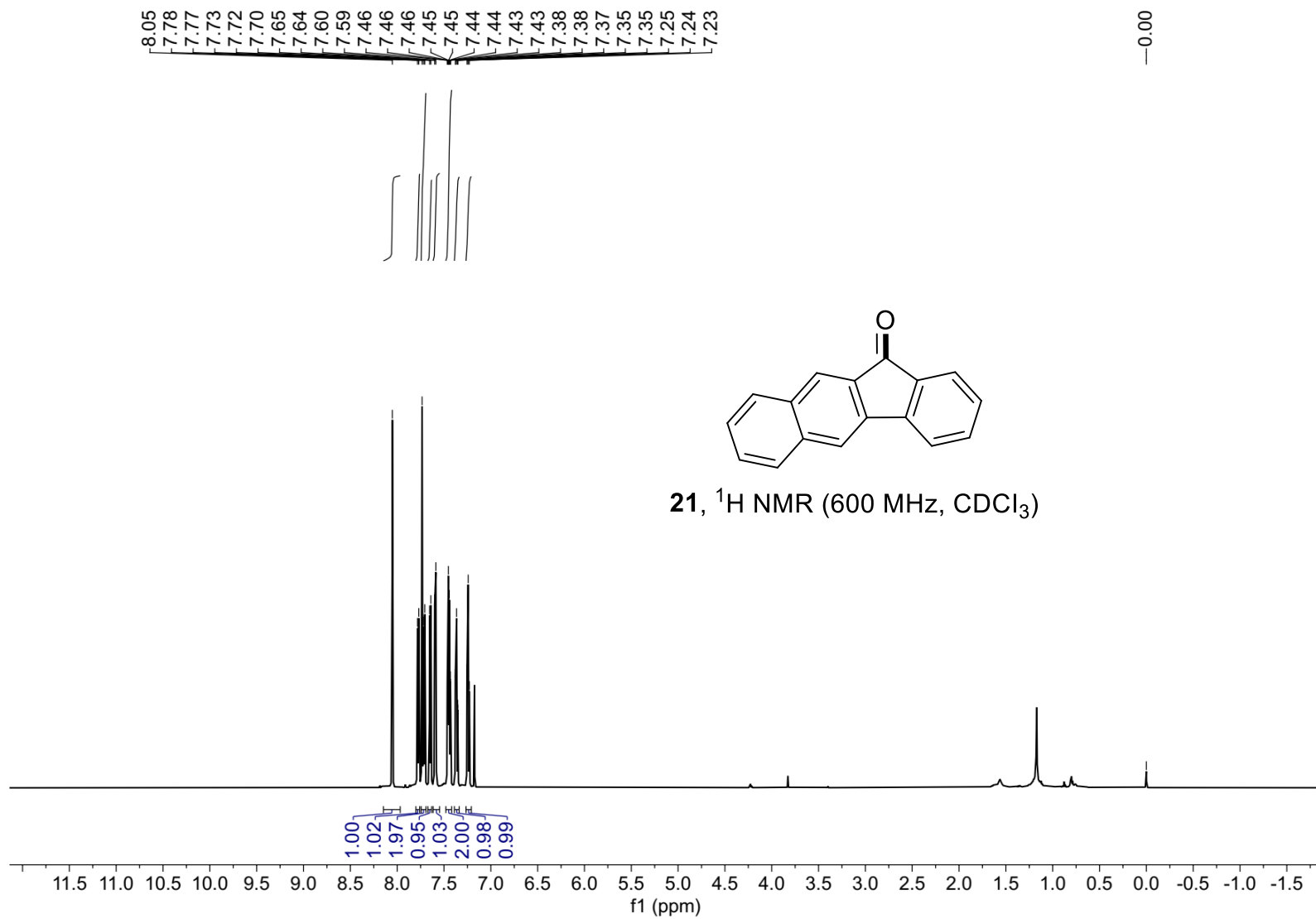
18, ^{13}C NMR (151 MHz, CDCl_3)

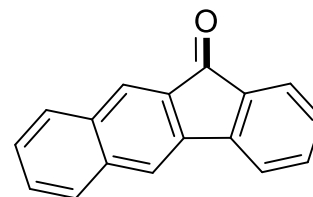




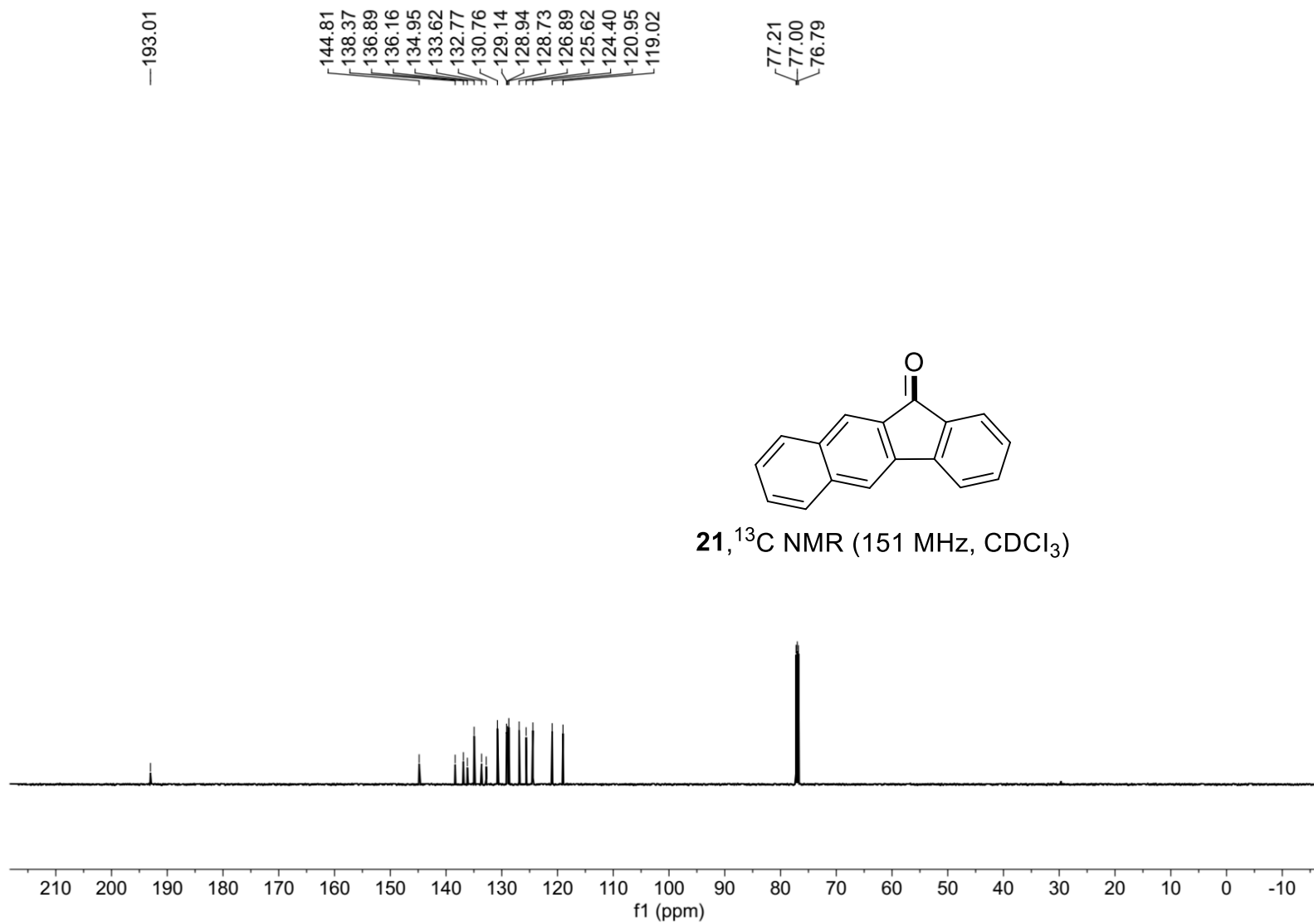


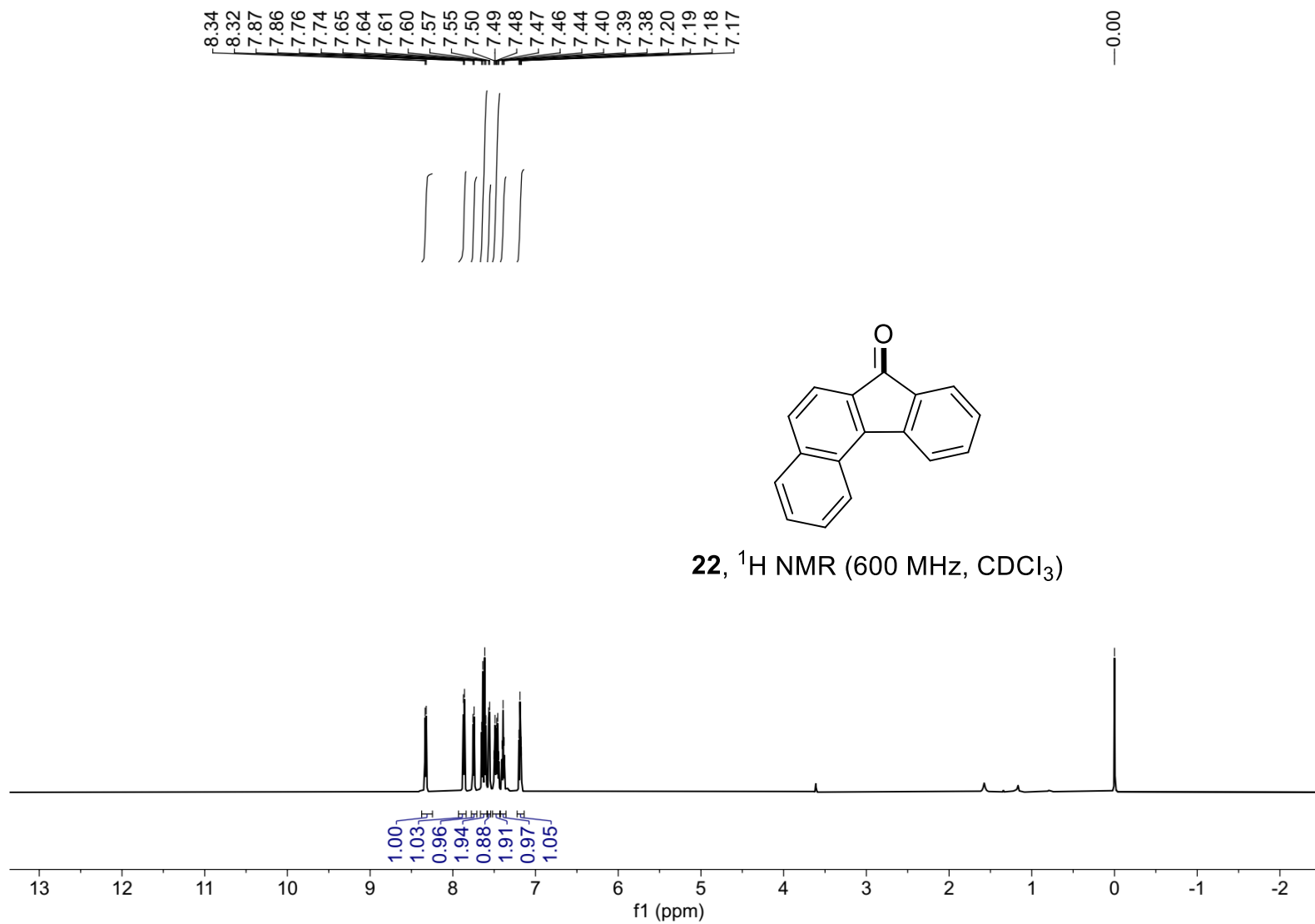


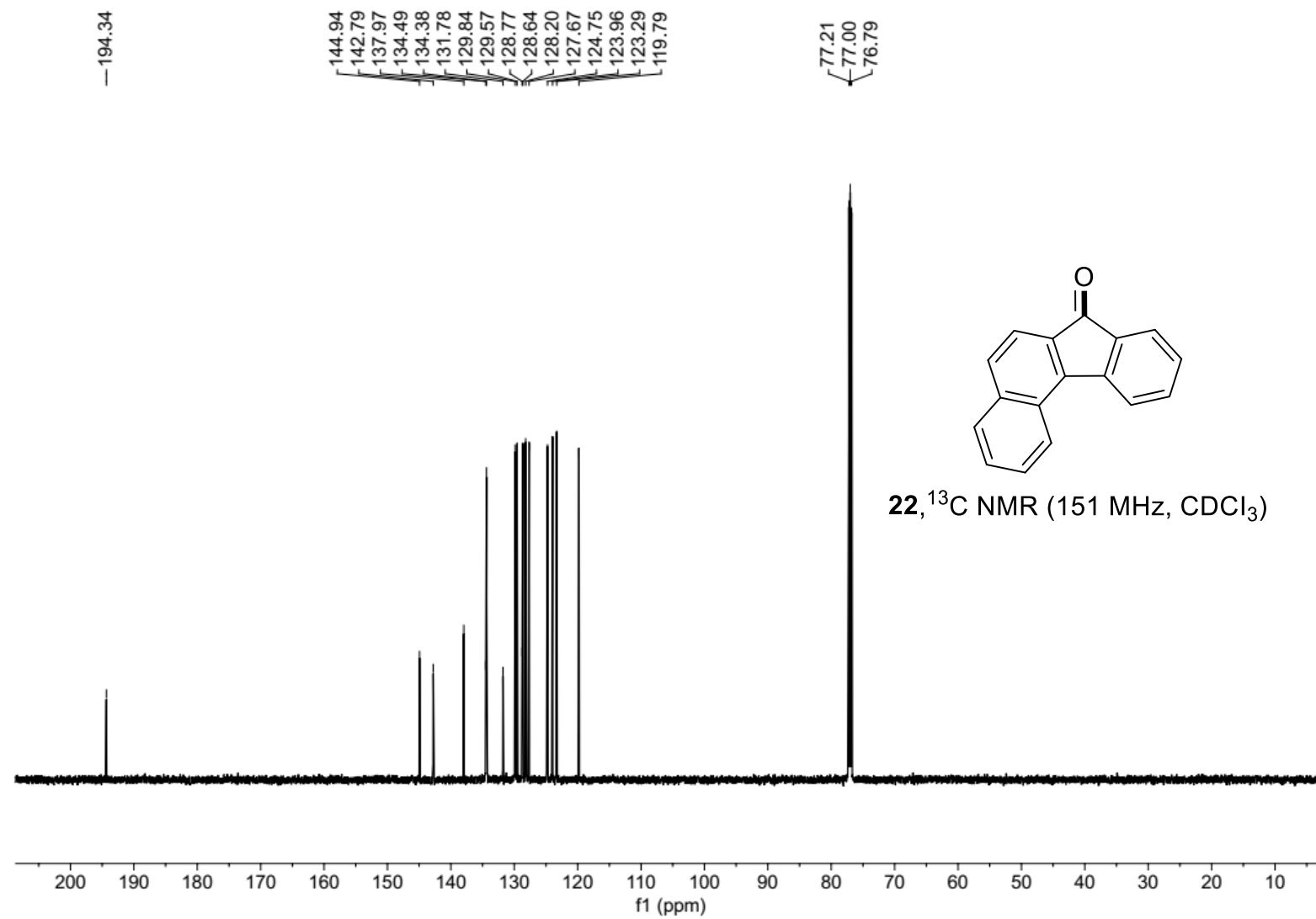


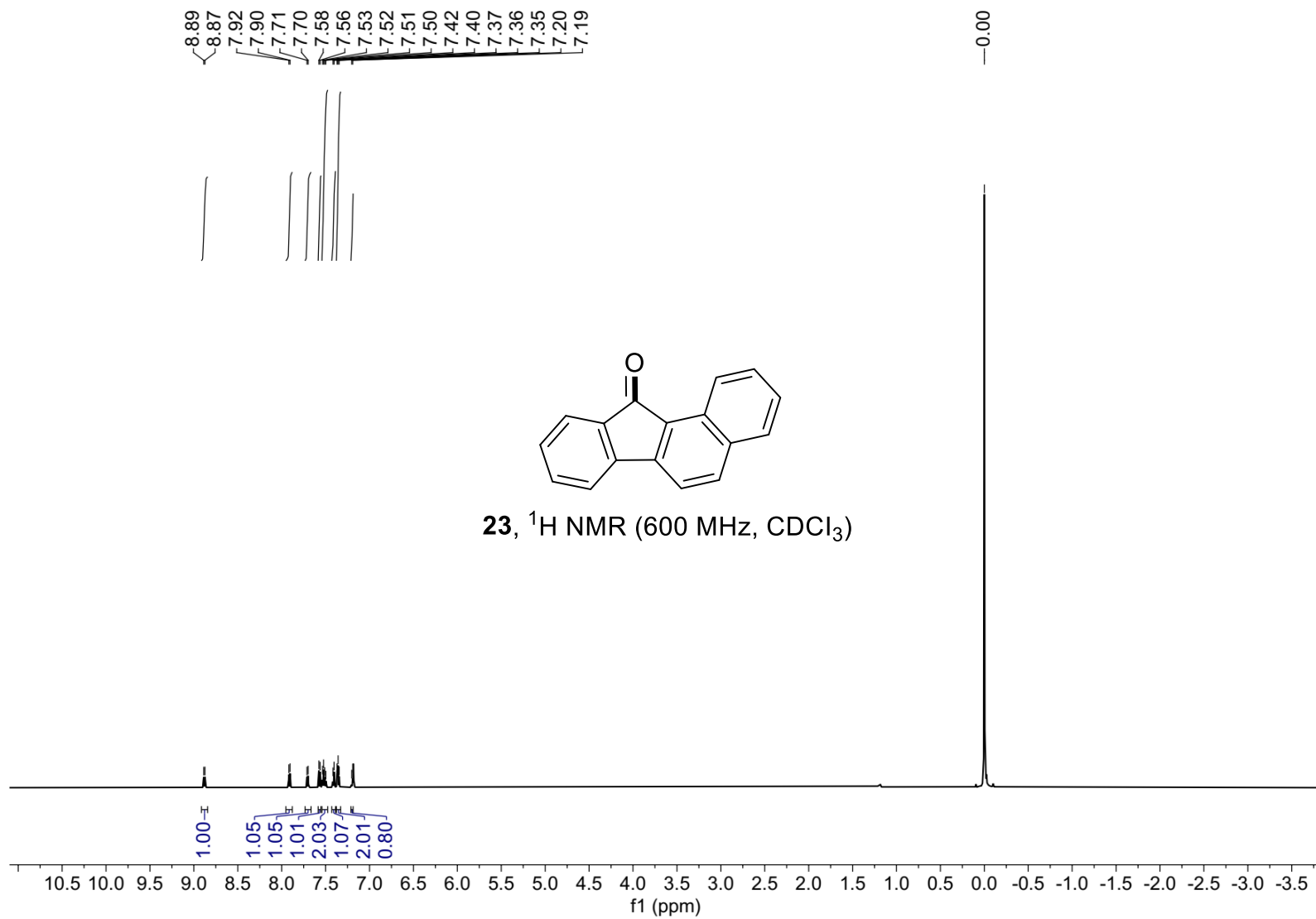


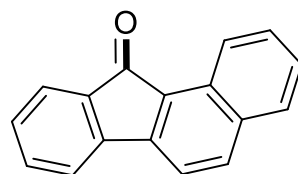
21, ^{13}C NMR (151 MHz, CDCl_3)



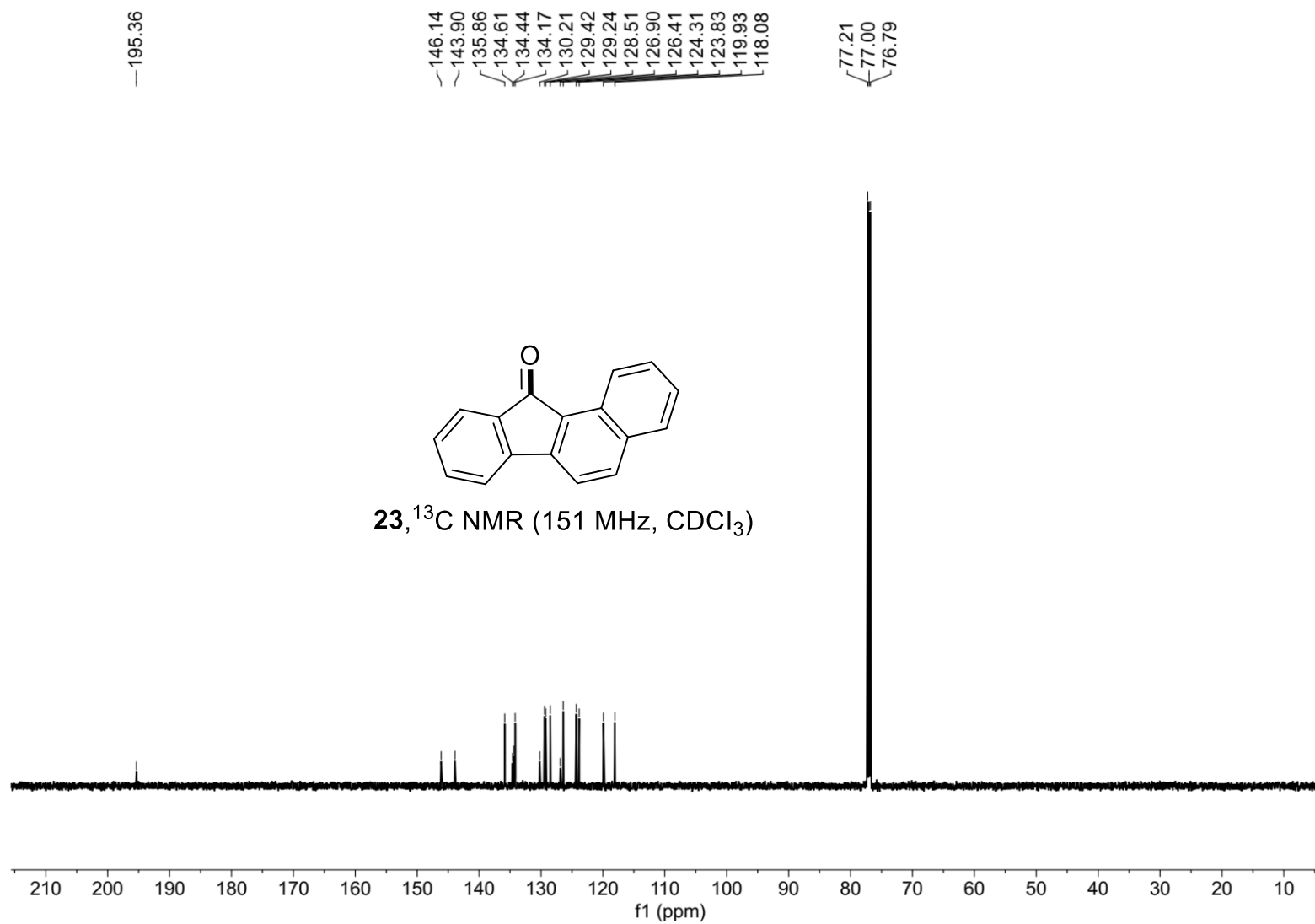


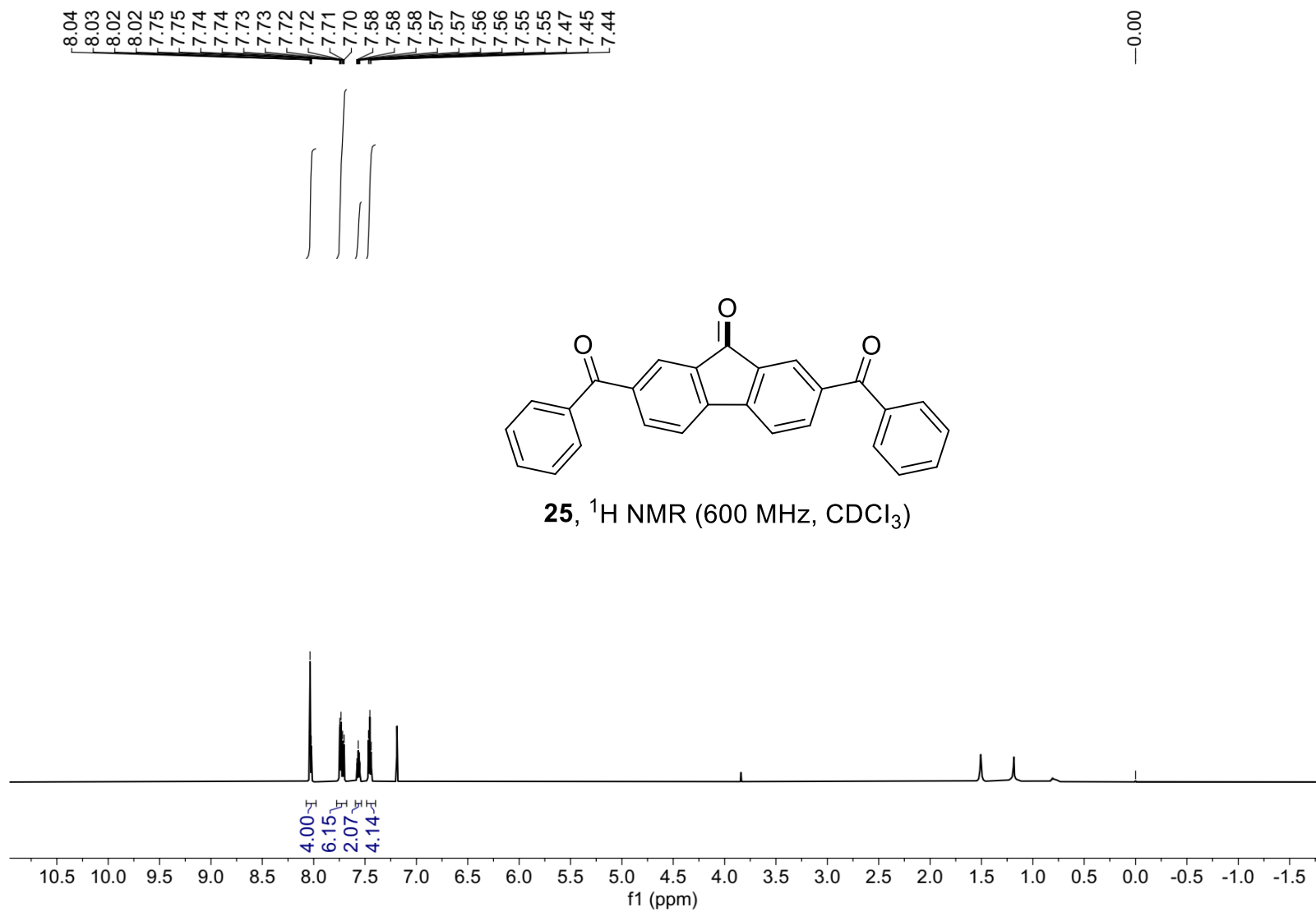


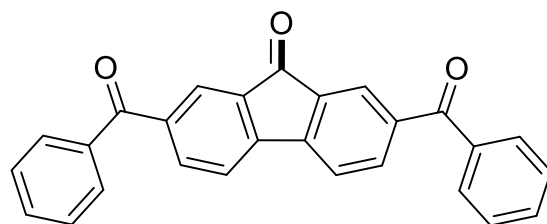




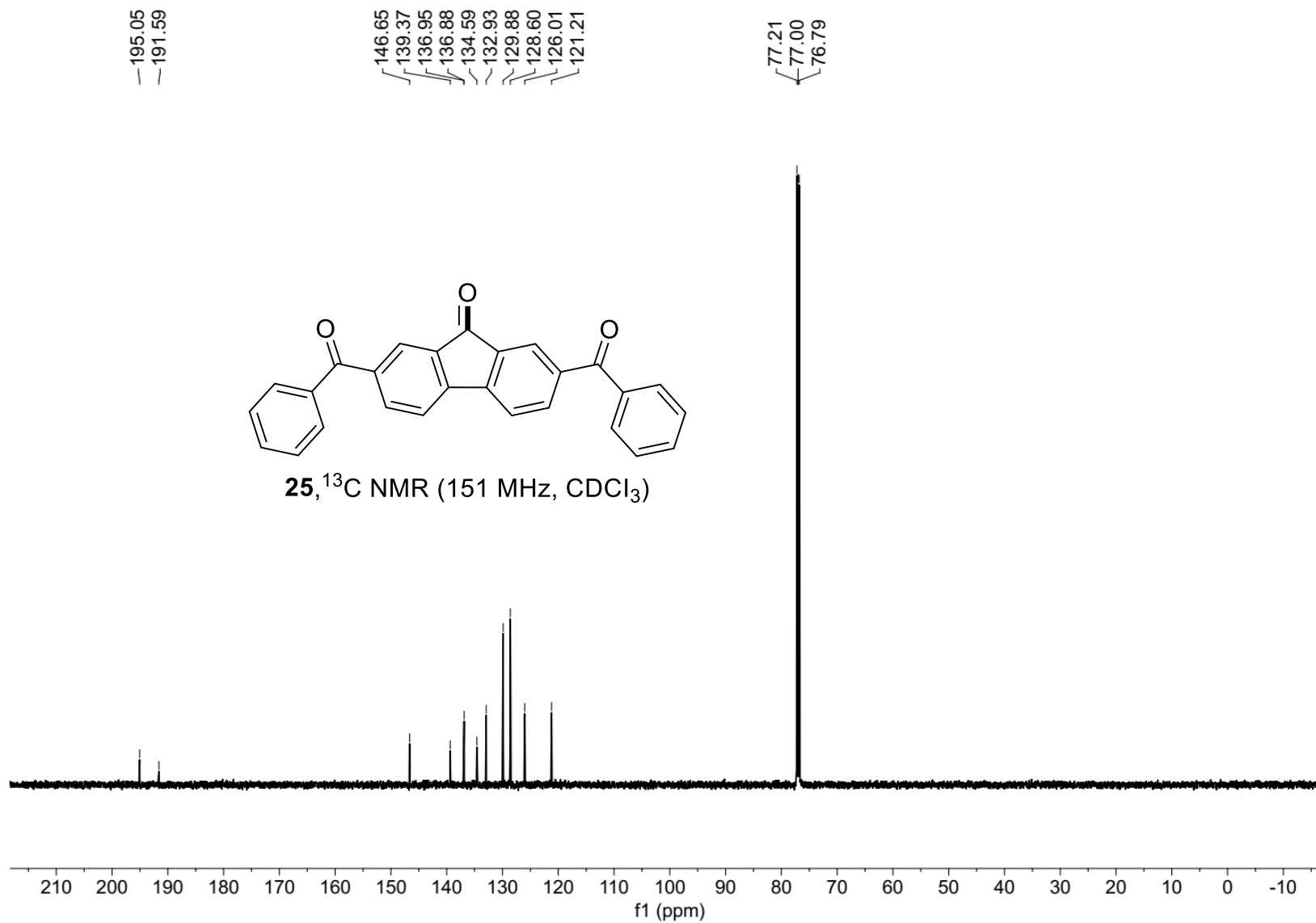
23, ^{13}C NMR (151 MHz, CDCl_3)

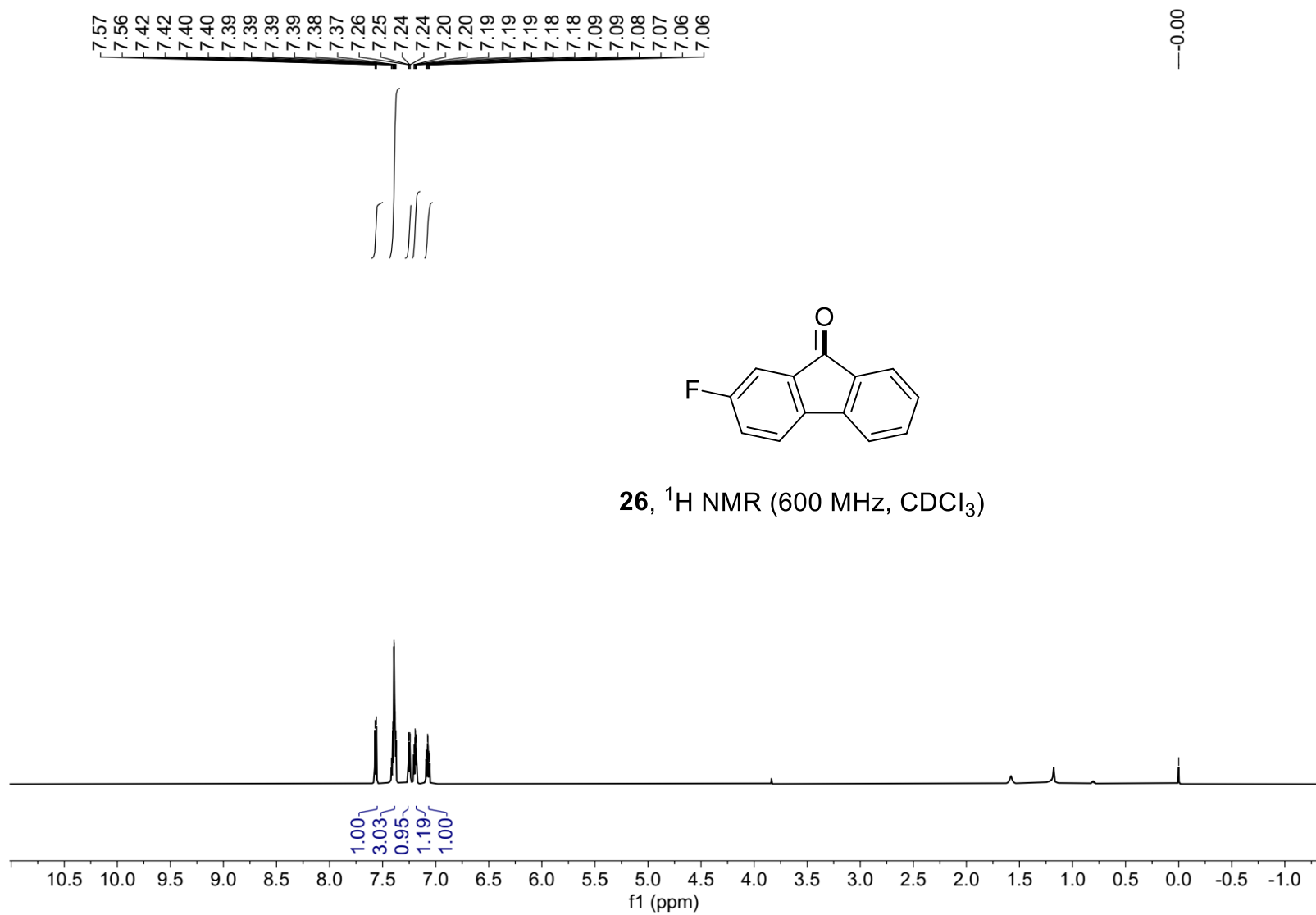


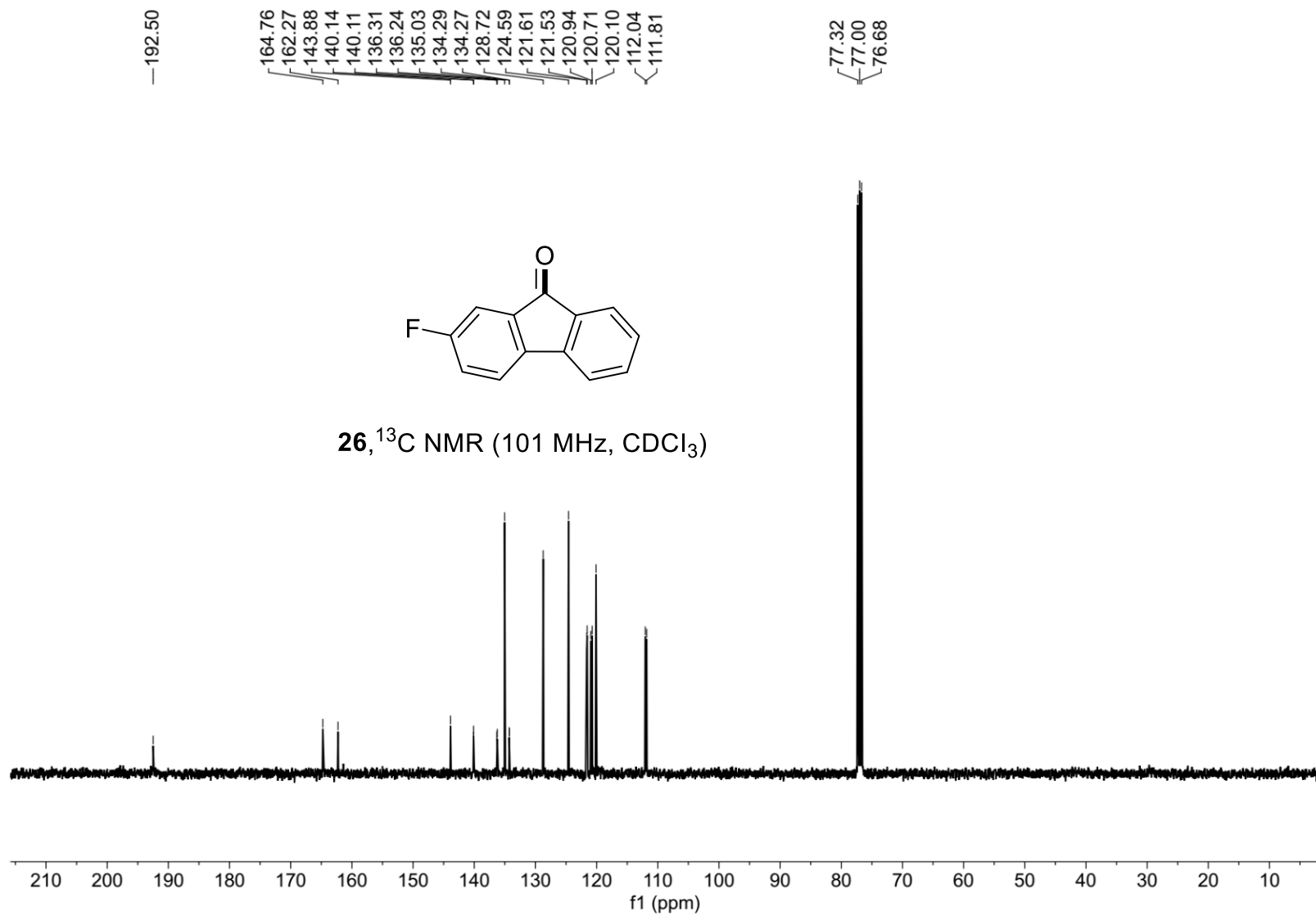


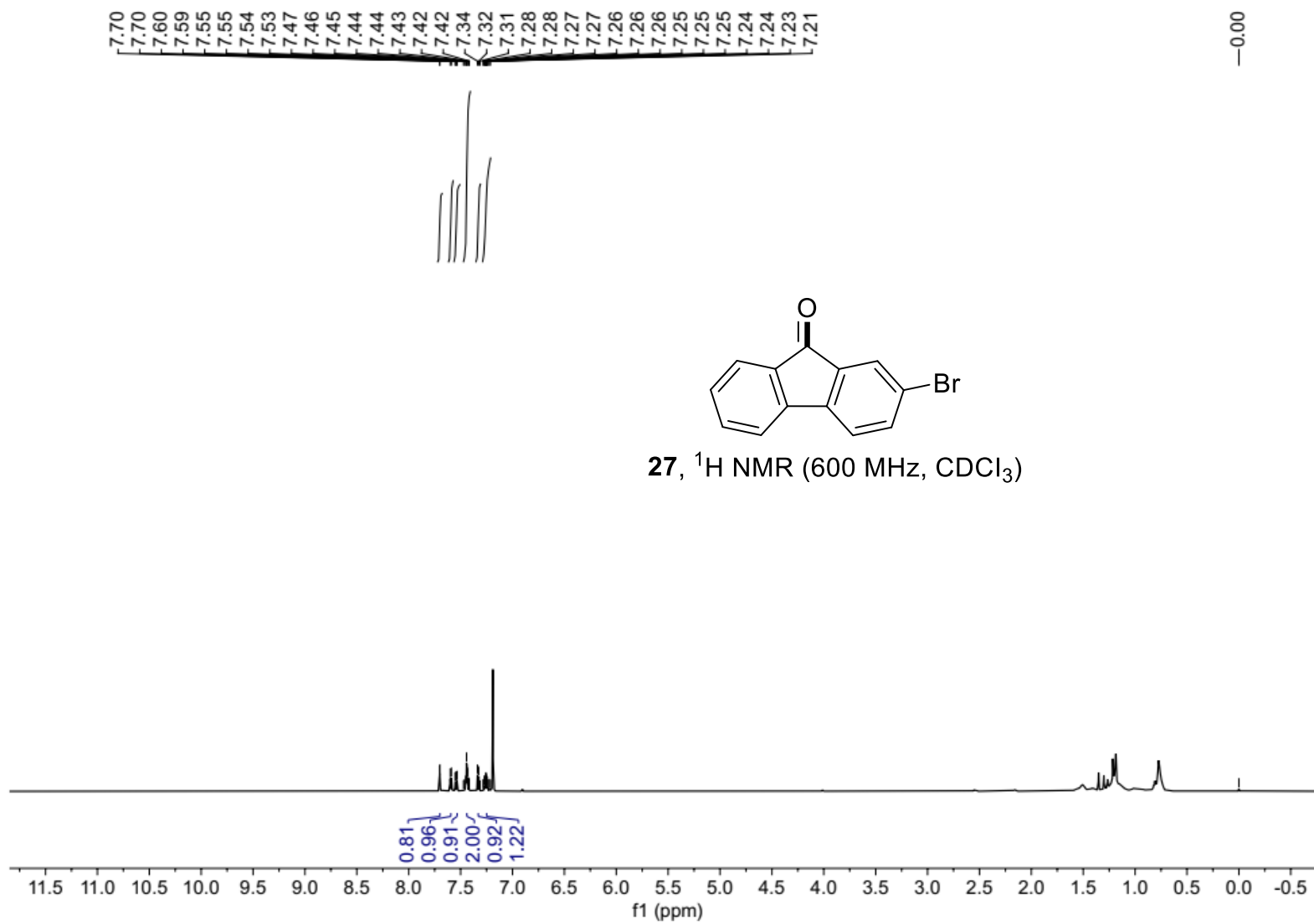


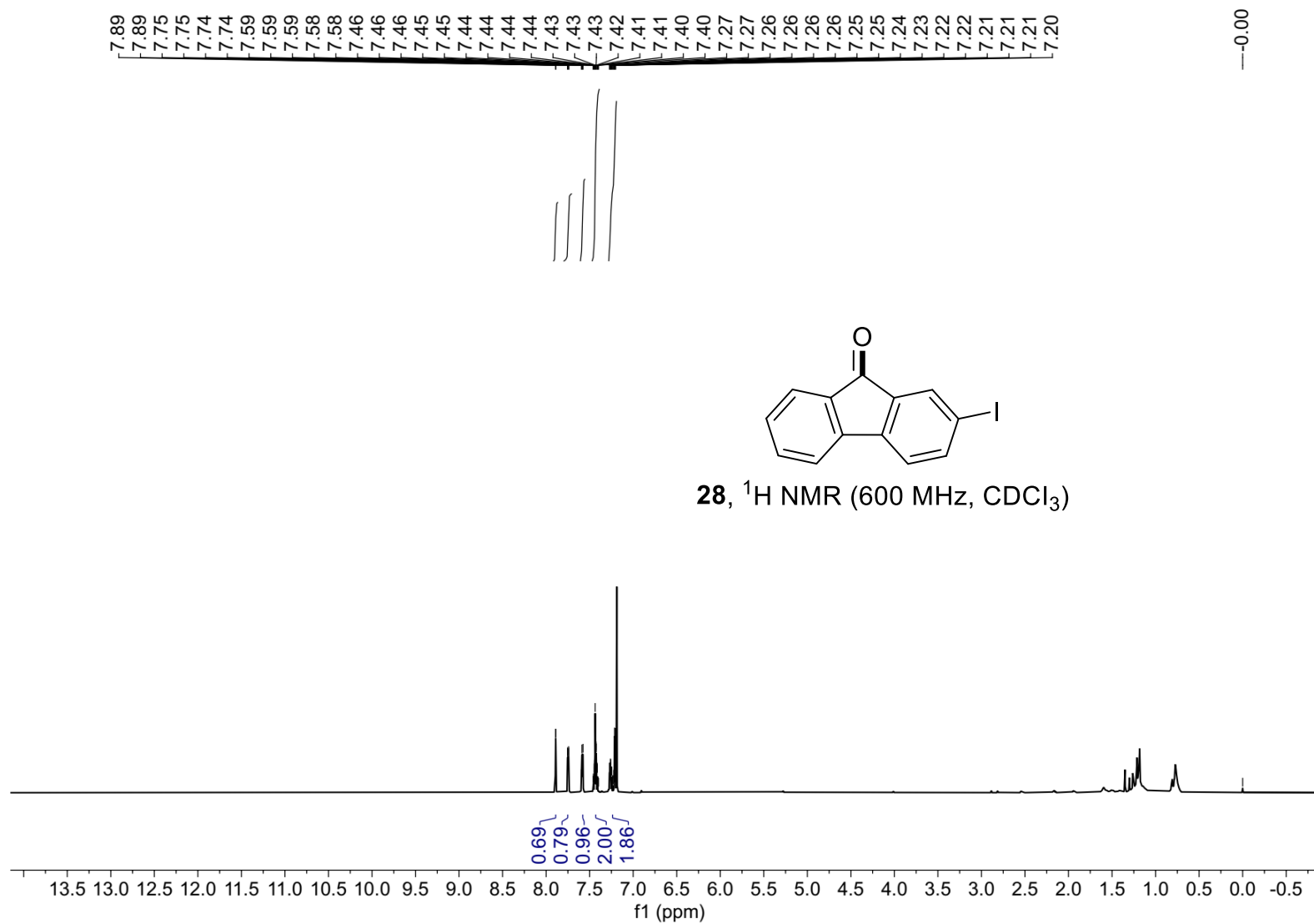
25, ^{13}C NMR (151 MHz, CDCl_3)

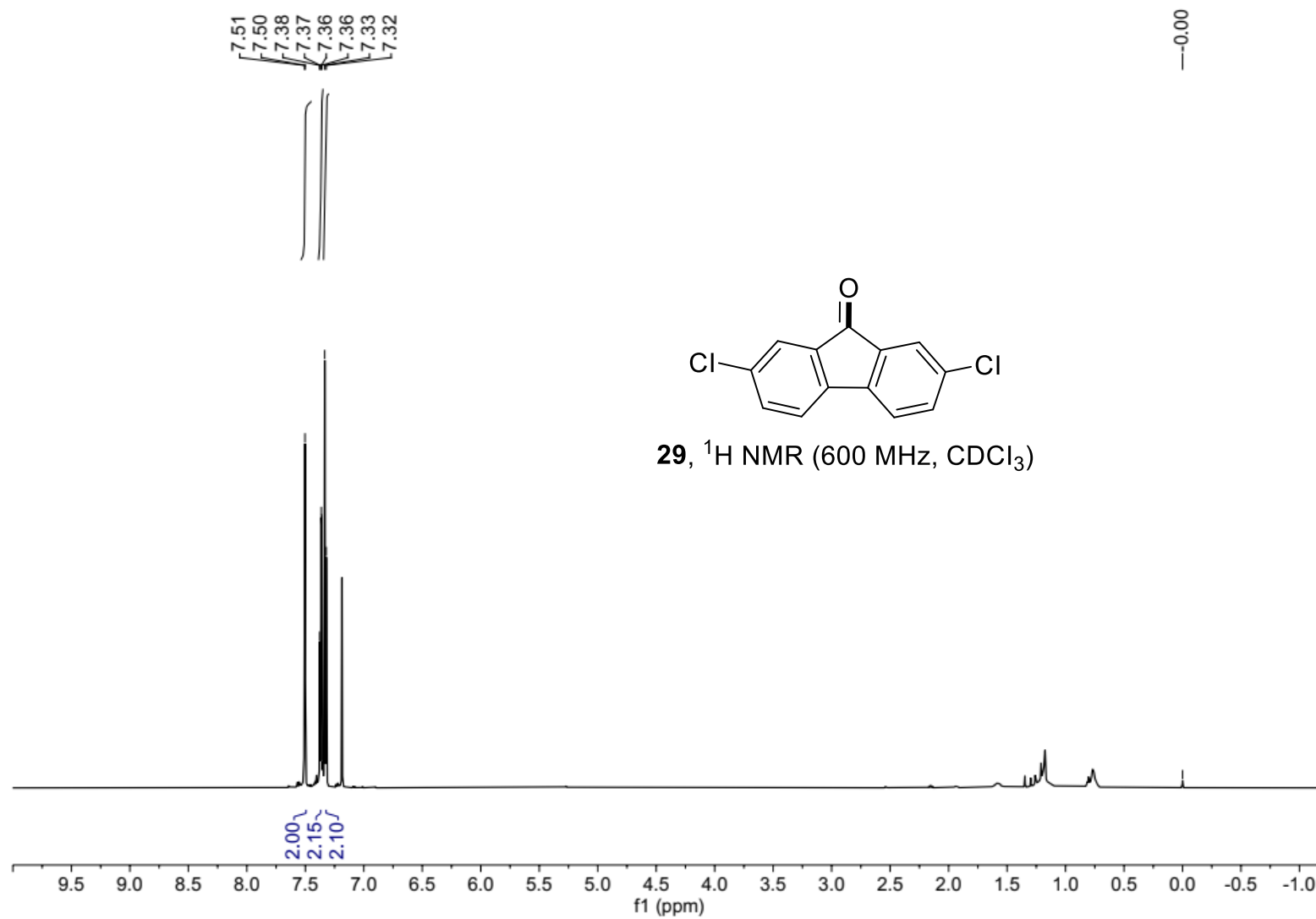


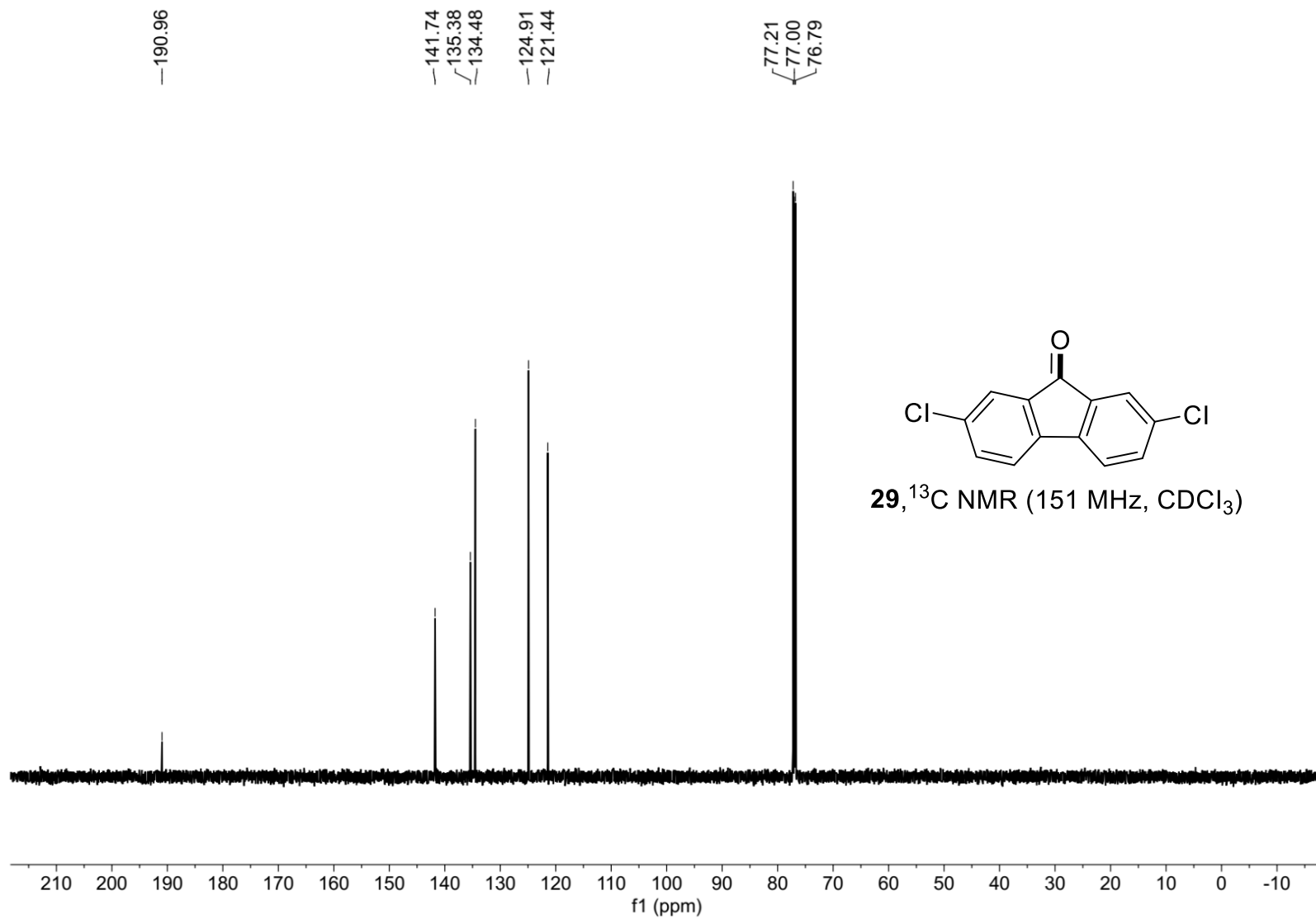


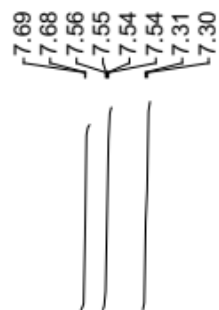




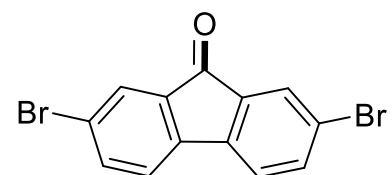




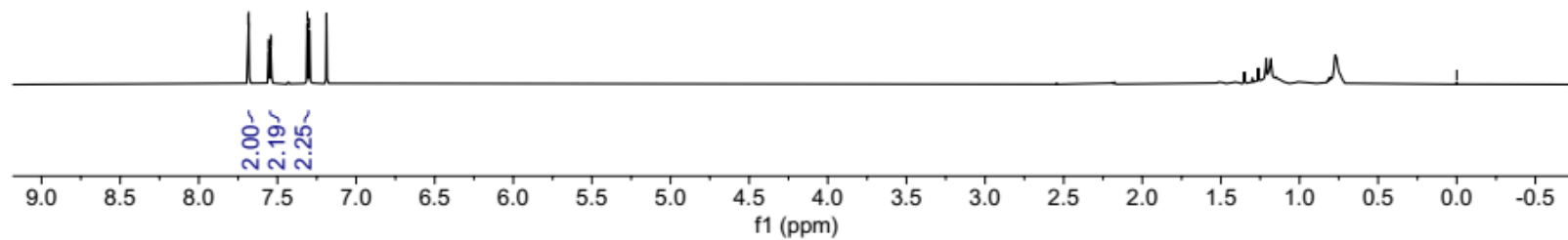


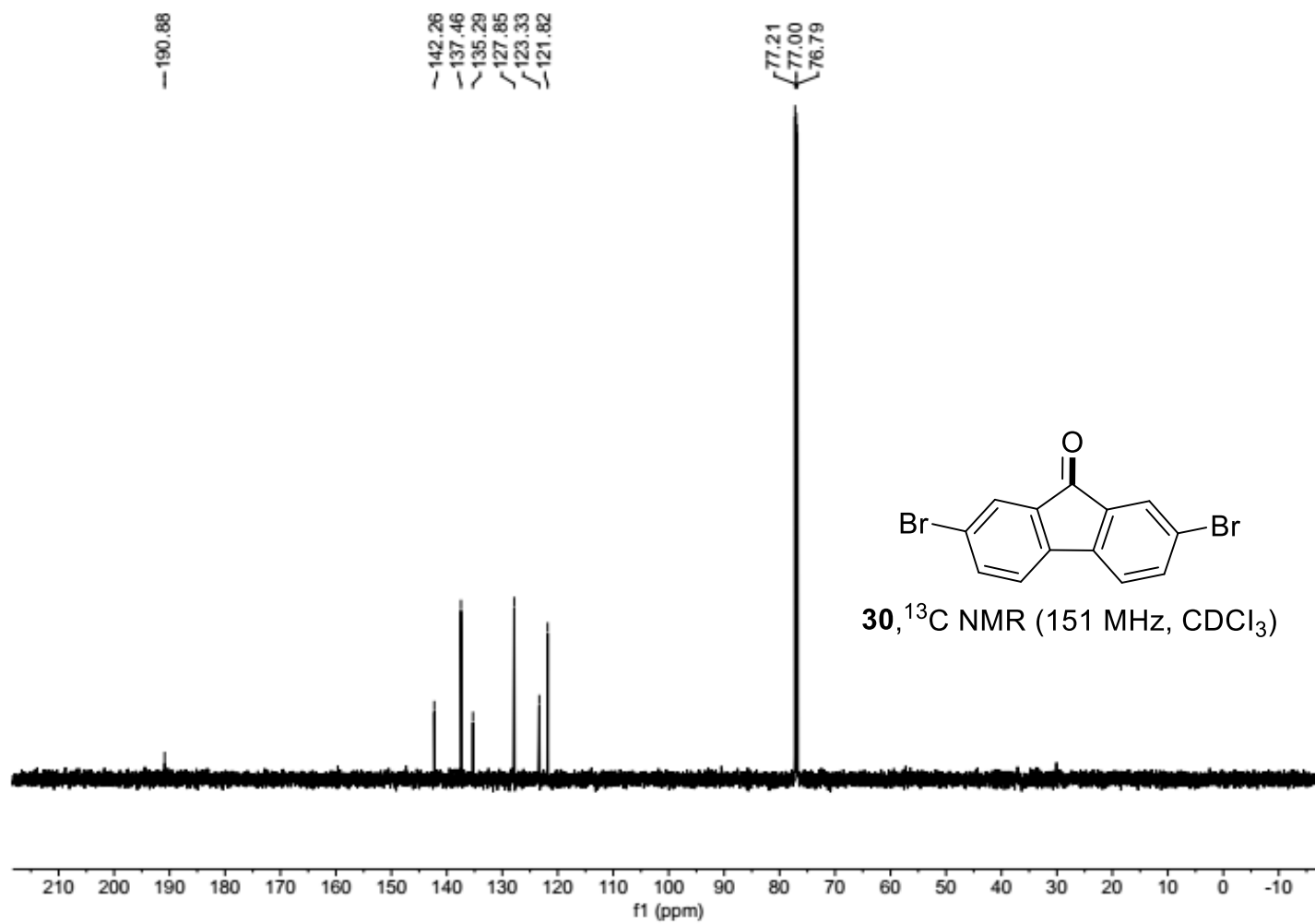


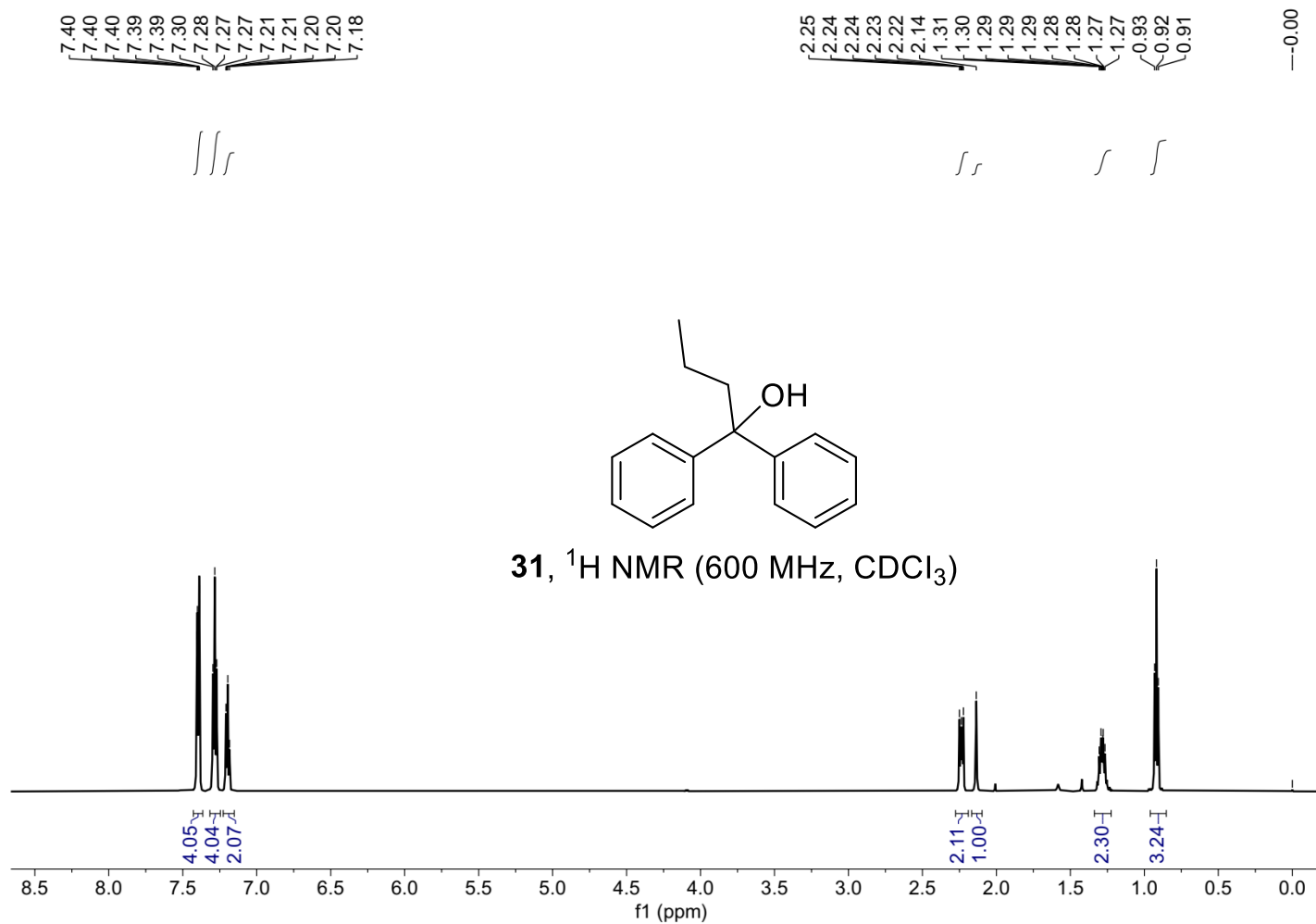
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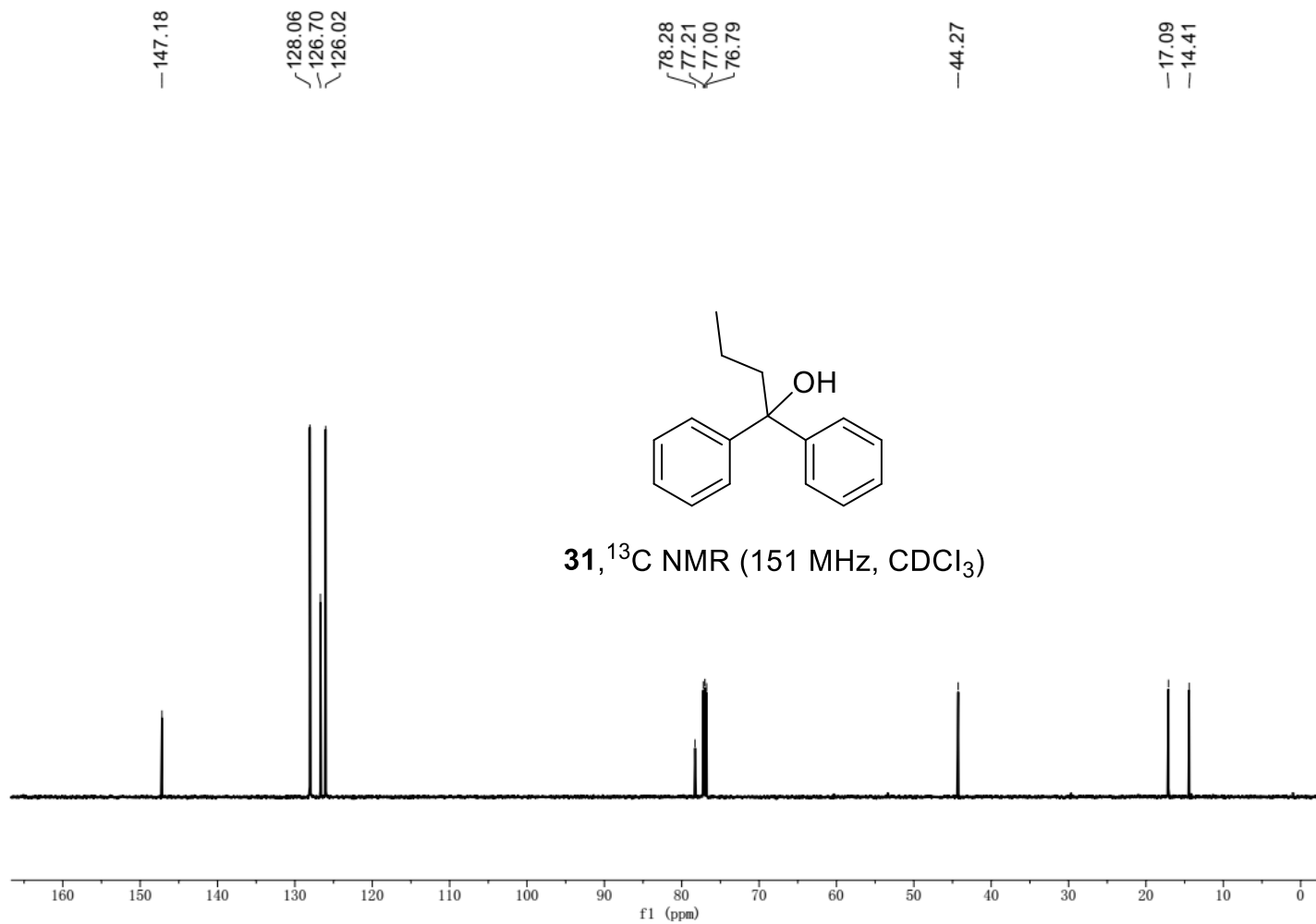


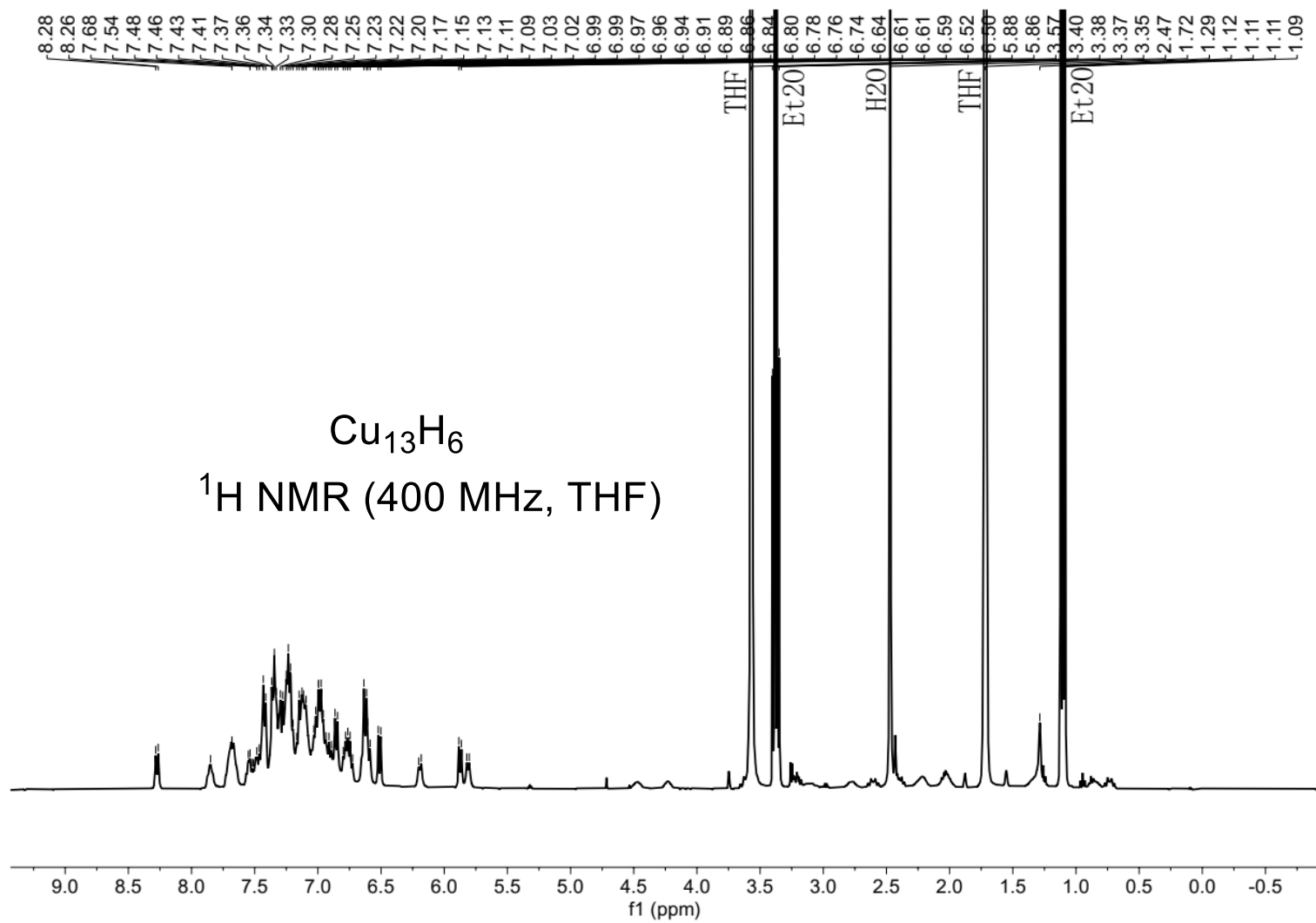
30, ^1H NMR (600 MHz, CDCl_3)

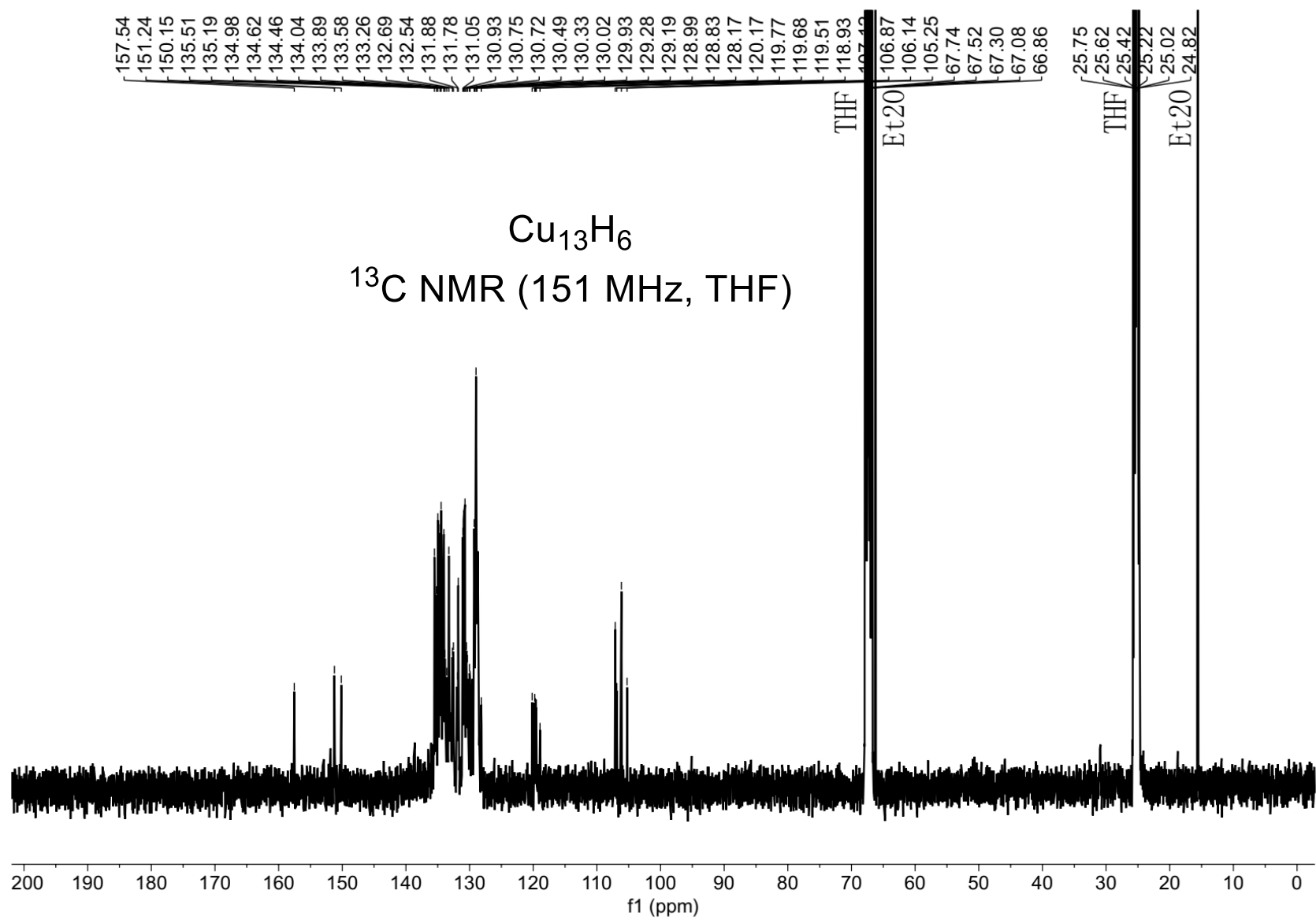












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