Supporting Information for

Copper-Catalyzed Homocoupling of Ketoxime Carboxylates for Synthesis of Symmetrical Pyrroles

Longfei Ran, Zhi-Hui Ren, Yao-Yu Wang and Zheng-Hui Guan*

Key Laboratory of Synthetic and Natural Functional Molecule Chemistry of Ministry of Education, Department of Chemistry & Materials Science, Northwest University, Xi'an 710069, P. R. China

E-mail: guanzhh@nwu.edu.cn

CONTENTS

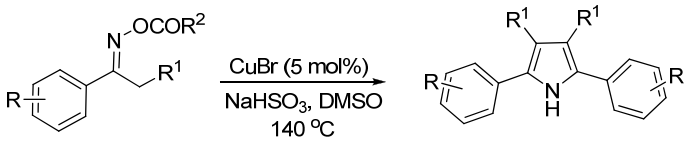
1. General Information

Column chromatography was carried out on silica gel. 1H NMR spectra were recorded on 400 MHz in $CDCl_3$, and ^{13}C NMR spectra were recorded on 100 MHz in $CDCl_3$. The following abbreviations were used to explain multiplicities: s = singlet, d = doublet, t = triplet, q = quartet, m = multiplet. Unless otherwise stated, all reagents and solvents were purchased from commercial suppliers and used without further purification. Ketoxime acetates were synthesized by the following procedure.

2. General Procedures for the Preparation of Ketoxime Carboxylates

The mixture of ketoxime (3.0 mmol), anhydride (6.0 mmol, 2.0 eq), was stirred at room temperature to 100 ^oC for 3h. The reaction mixture was cooled to room temperature, diluted with EtOAc (25 mL) and washed with H_2O (20 mL) and brine (10 mL). The organic layers were dried over anhydrous Na_2SO_4 and evaporated in vacuo. The residue was purified by column chromatography on silica gel to afford the ketoxime carboxylates **1** with hexane/ethyl acetate as the eluent.

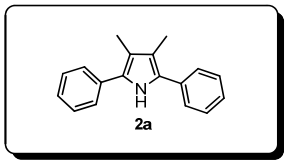
3. Typical Procedure for Copper-Catalyzed Homocoupling of Ketoxime Carboxylates for Synthesis of Symmetrical Pyrroles



1 **2**

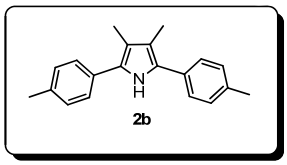
In a 25 mL round bottom flask, the ketoxime acetate **1** (0.3 mmol), CuBr (5 mol%, 2.2 mg) and $NaHSO_3$ (0.36 mmol, 37.5 mg) was stirred in DMSO (3.0 mL) at 140 ^oC under Ar for 2h. When the reaction was completed (detected by TLC), the mixture was cooled to room temperature. The reaction was quenched with H_2O (10 mL) and extracted with EtOAc (3 × 10 mL). The combined organic layers were dried over anhydrous Na_2SO_4 and then evaporated in vacuo. The residue was purified by column chromatography on silica gel to afford the corresponding pyrrole **2** with hexane/ethyl acetate as the eluent.

4. Characterization Data of the Products



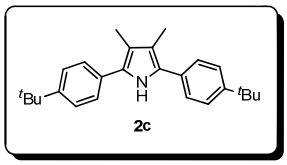
2a

2a: ^{1}H NMR ($CDCl_3$, 400 MHz): δ = 7.89 (s, 1 H), δ = 7.38-7.29 (m, 8 H), δ = 7.17-7.14 (t, *J* = 7.2 Hz, 2 H), δ = 2.14 (s, 6 H); ^{13}C NMR ($CDCl_3$, 100 MHz): δ = 133.5, 128.7, 126.6, 126.1, 117.3, 10.4. HRMS Calcd (ESI) m/z for $C_{18}H_{16}N$: $[M-H]^-$ 246.1277, found: 246.1275.



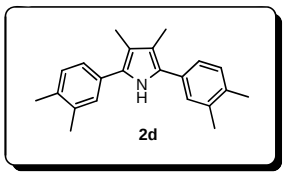
2b

2b: ^{1}H NMR ($CDCl_3$, 400 MHz): δ = 7.85 (s, 1 H), δ = 7.26 (s, 4 H), δ = 7.13 (d, *J* = 5.6 Hz, 4 H), δ = 2.28 (s, 6 H), δ = 2.13 (s, 6 H); ^{13}C NMR ($CDCl_3$, 100 MHz): δ = 135.7, 130.8, 129.4, 126.5, 116.8, 21.1, 10.4. HRMS Calcd (ESI) m/z for $C_{20}H_{20}N$: $[M-H]^-$ 274.1590, found: 274.1597.



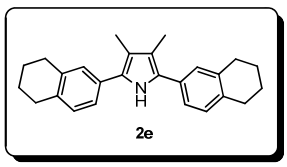
2c

2c: ^{1}H NMR (DMSO-d^6, 400 MHz): δ = 10.61 (s, 1 H), δ = 7.45-7.40 (m, 8 H), δ = 2.10 (s, 6 H), δ = 1.29 (s, 18 H); ^{13}C NMR (DMSO-d^6, 100 MHz): δ = 147.7, 131.1, 128.1, 126.6, 125.1, 115.6, 34.2, 31.2, 10.6. HRMS Calcd (ESI) m/z for $C_{26}H_{32}N$: $[M-H]^-$ 358.2529, found: 358.2535.



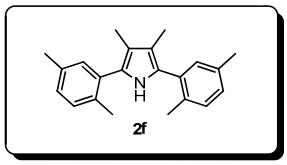
2d

2d: ^{1}H NMR ($CDCl_3$, 400 MHz): δ = 7.83 (s, 1 H), δ = 7.13-7.04 (m, 6 H), δ = 2.19 (s, 12 H), δ = 2.11 (s, 6 H); ^{13}C NMR ($CDCl_3$, 100 MHz): δ = 136.8, 134.4, 131.3, 129.9, 128.3, 127.8, 124.1, 116.6, 19.9, 19.4, 10.4. HRMS Calcd (ESI) m/z for $C_{22}H_{24}N$: $[M-H]^-$ 302.1903, found: 302.1908.

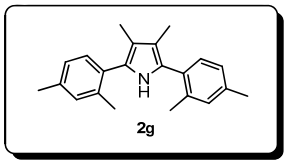


2e

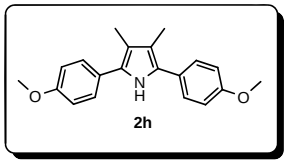
2e: ^{1}H NMR ($CDCl_3$, 400 MHz): δ = 7.84 (s, 1 H), δ =7.12 (d, *J* = 5.6 Hz, 2 H), δ = 7.07 (s, 2 H), δ = 7.02 (d, *J* = 7.2 Hz, 2 H), δ = 2.72 (s, 8 H), δ = 2.12 (s, 6 H), δ = 1.73 (s, 8 H); ^{13}C NMR ($CDCl_3$, 100 MHz): δ = 137.3, 135.0, 130.9, 129.4, 128.3, 127.1, 124.0, 116.6, 29.5, 29.1, 23.1, 10.4. HRMS Calcd (ESI) m/z for $C_{26}H_{28}N$: $[M-H]^-$ 354.2216, found: 354.2204.



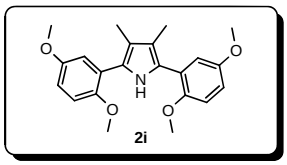
2f: ^{1}H NMR ($CDCl_3$, 400 MHz): δ = 7.47 (s, 1 H), δ = 7.08-7.04 (m, 4 H), δ = 6.96 (d, *J* = 7.6 Hz, 2 H), δ = 2.25 (s, 6 H), δ = 2.19 (s, 6 H), δ = 1.91 (s, 6 H); ^{13}C NMR ($CDCl_3$, 100 MHz): δ = 134.8, 133.7, 133.2, 131.2, 130.2, 127.9, 127.4, 116.1, 20.8, 19.8, 10.2. HRMS Calcd (ESI) m/z for $C_{22}H_{24}N$: $[M-H]^-$ 302.1903, found: 302.1892.



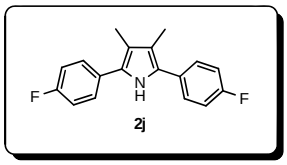
2g: ^{1}H NMR ($CDCl_3$, 400 MHz): δ = 7.46 (s, 1 H), δ = 7.12 (d, *J* = 7.6 Hz, 2 H), δ = 7.01 (s, 2 H), δ = 6.97-6.94 (t, *J* = 4.0 Hz, 2 H), δ = 2.27 (s, 6 H), δ = 2.20 (s, 6 H), δ = 1.90 (s, 6 H); ^{13}C NMR ($CDCl_3$, 100 MHz): δ = 136.9, 136.8, 131.1, 130.5, 127.2, 126.3, 124.1, 116.1, 21.1, 20.3, 10.2. HRMS Calcd (ESI) m/z for $C_{22}H_{24}N$: $[M-H]^-$ 302.1903, found: 302.1906.



2h: ^{1}H NMR (DMSO-*d*^{6}, 400 MHz): δ = 10.56 (s, 1 H), δ = 7.43 (d, *J* = 8.0 Hz, 4 H), δ = 6.97 (d, *J* = 8.0 Hz, 4 H), δ = 3.76 (s, 6 H), δ = 2.08 (s, 6 H); ^{13}C NMR (DMSO-*d*^{6}, 100 MHz): δ = 157.3, 128.0, 127.5, 126.5, 114.8, 113.9, 55.1, 10.6. HRMS Calcd (ESI) m/z for $C_{20}H_{20}NO_2$: $[M-H]^-$ 306.1489, found: 306.1485.

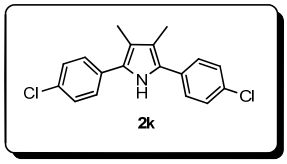


2i: ^{1}H NMR ($CDCl_3$, 400 MHz): δ = 9.65 (s, 1 H), δ = 6.97 (d, *J* = 2.4 Hz, 2 H), δ = 6.78 (d, *J* = 9.2 Hz, 2 H), δ = 6.65-6.62 (m, 2 H), δ = 3.72 (s, 6 H), δ = 3.69 (s, 6 H), δ = 2.14 (s, 6 H); ^{13}C NMR ($CDCl_3$, 100 MHz): δ = 153.5, 150.3, 124.2, 123.0, 117.4, 115.4, 112.2, 111.2, 56.2, 55.6, 11.1. HRMS Calcd (ESI) m/z for $C_{22}H_{25}NNaO_4$: $[M+Na]^+$ 390.1676, found: 390.1685.



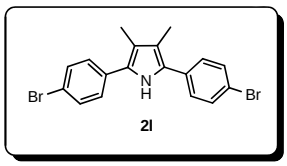
2j: ^{1}H NMR (DMSO-*d*^{6}, 400 MHz): δ = 10.78 (s, 1 H), δ = 7.50 (d, *J* = 4.8 Hz, 4 H), δ = 7.24-7.20 (m, 4 H), δ = 2.07 (s, 6 H); ^{13}C NMR (DMSO-*d*^{6}, 100 MHz): δ = 160.5 (d, J_F = 241.3 Hz), 130.1, 128.6 (d, J_F = 8.4 Hz), 127.3, 115.9, 115.2 (d, J_F = 20.5 Hz), 10.5. HRMS Calcd (ESI)

m/z for $C_{18}H_{14}F_2N$: $[M-H]^-$ 282.1089, found: 282.1090.



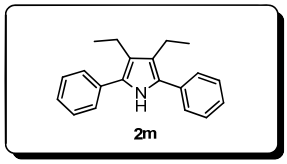
2k

2k: ^{1}H NMR (DMSO-d^6, 400 MHz): δ = 10.88 (s, 1 H), δ = 7.52 (d, J = 8.0 Hz, 4 H), δ = 7.43 (d, J = 8.0 Hz, 4 H), δ = 2.08 (s, 6 H); ^{13}C NMR (DMSO-d^6, 100 MHz): δ = 132.2, 130.1, 128.4, 128.3, 127.6, 116.9, 10.6. HRMS Calcd (ESI) m/z for $C_{18}H_{14}Cl_2N$: $[M-H]^-$ 314.0498, found: 314.0489.



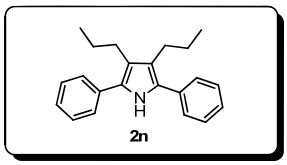
2l

2l: ^{1}H NMR (DMSO-d^6, 400 MHz): δ = 10.88 (s, 1 H), δ = 7.56 (d, J = 8.0 Hz, 4 H), δ = 7.45 (d, J = 8.0 Hz, 4 H), δ = 2.08 (s, 6 H); ^{13}C NMR (DMSO-d^6, 100 MHz): δ = 132.5, 131.3, 128.6, 127.6, 118.5, 117.0, 10.5. HRMS Calcd (ESI) m/z for $C_{18}H_{14}Br_2N$: $[M-H]^-$ 401.9488, found: 401.9482.



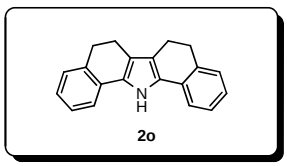
2m

2m: ^{1}H NMR ($CDCl_3$, 400 MHz): δ = 7.90 (s, 1 H), δ = 7.37 (d, J = 7.2 Hz, 4 H), δ = 7.32-7.29 (t, J = 7.2 Hz, 4 H), δ = 7.17-7.14 (t, J = 6.4 Hz, 2 H), δ = 2.61-2.56 (m, 4 H), δ = 1.16-1.13 (t, J = 7.2 Hz, 6 H); ^{13}C NMR ($CDCl_3$, 100 MHz): δ = 133.7, 128.7, 128.4, 126.6, 126.2, 123.5, 17.8, 16.2. HRMS Calcd (ESI) m/z for $C_{20}H_{20}N$: $[M-H]^-$ 274.1590, found: 274.1591.



2n

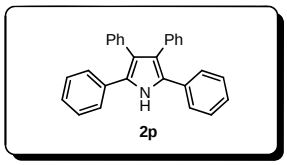
2n: ^{1}H NMR ($CDCl_3$, 400 MHz): δ = 8.03 (s, 1 H), δ = 7.50 (d, J = 7.6 Hz, 4 H), δ = 7.46-7.42 (t, J = 7.2 Hz, 4 H), δ = 7.30-7.27 (t, J = 7.6 Hz, 2 H), δ = 2.66-2.62 (t, J = 8.0 Hz, 4 H), δ = 1.69-1.62 (m, 4 H), δ = 1.04-1.00 (t, J = 7.6 Hz, 6 H); ^{13}C NMR ($CDCl_3$, 100 MHz): δ = 133.9, 128.7, 128.5, 126.5, 126.1, 122.3, 27.2, 24.9, 14.6. HRMS Calcd (ESI) m/z for $C_{22}H_{24}N$: $[M-H]^-$ 302.1903, found: 302.1904.



2o

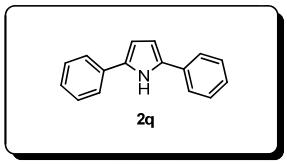
2o: ^{1}H NMR ($CDCl_3$, 400 MHz): δ = 8.25 (s, 1 H), δ = 7.10-7.08 (m, 6 H), δ = 6.95 (s, 6 H), δ = 2.85-2.82 (t, J = 7.6 Hz, 4 H), δ = 2.58 (d, J = 6.0 Hz, 4 H); ^{13}C NMR ($CDCl_3$, 100 MHz): δ =

134.9, 130.9, 129.0, 128.3, 126.5, 125.0, 119.1, 118.3, 29.7, 19.9. HRMS Calcd (ESI) m/z for $C_{20}H_{16}N$: $[M-H]^-$ 270.1277, found:270.1285.



2p

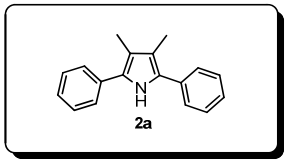
2p: ^{1}H NMR ($CDCl_3$, 400 MHz): δ = 8.38 (s, 1 H), δ = 7.18 (d, *J* = 4.0 Hz, 10 H), δ = 7.08-7.06 (m, 6 H), δ = 7.01-6.99 (m, 4 H); ^{13}C NMR ($CDCl_3$, 100 MHz): δ = 135.3, 132.7, 130.9, 128.9, 128.5, 127.9, 127.2, 126.6, 125.9, 123.1. HRMS Calcd (ESI) m/z for $C_{28}H_{20}N$: $[M-H]^-$ 370.1590, found: 370.1606.

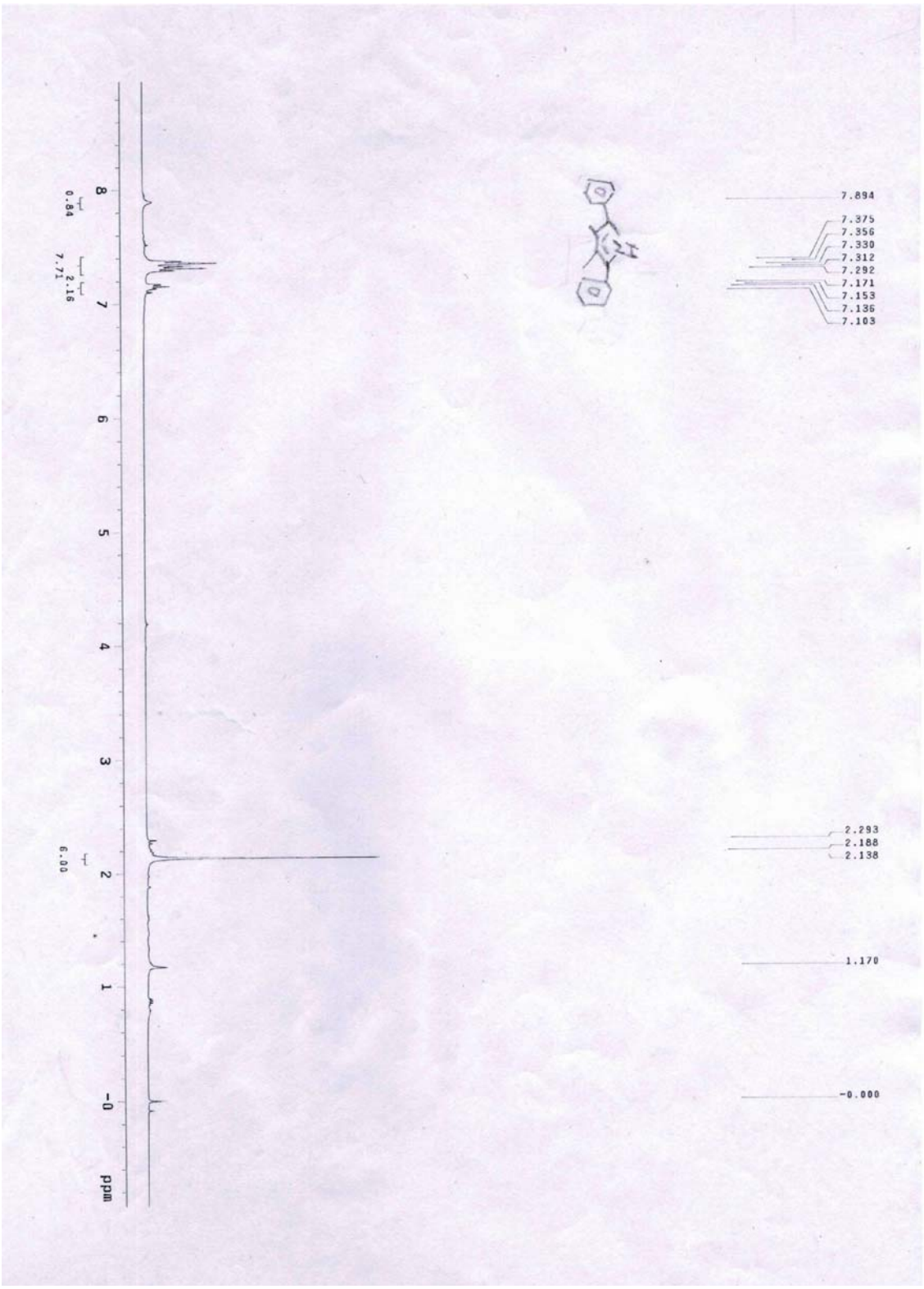


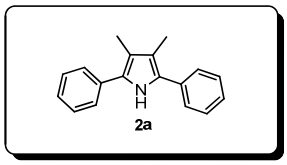
2q

2q: ^{1}H NMR ($CDCl_3$, 400 MHz): δ = 8.78 (s, 1 H), δ = 7.59 (d, *J* = 7.6 Hz, 4 H), δ = 7.45-7.41 (t, *J* = 7.2 Hz, 4 H), δ = 7.29-7.26 (t, *J* = 7.6Hz, 2 H), δ = 6.64 (d, *J* = 2 Hz, 2 H); ^{13}C NMR ($CDCl_3$, 100 MHz): δ = 133.1, 132.4, 128.8, 126.2, 123.7, 107.8. HRMS Calcd (ESI) m/z for $C_{16}H_{14}N$: $[M+H]^+$ 220.1120, found: 220.1109.

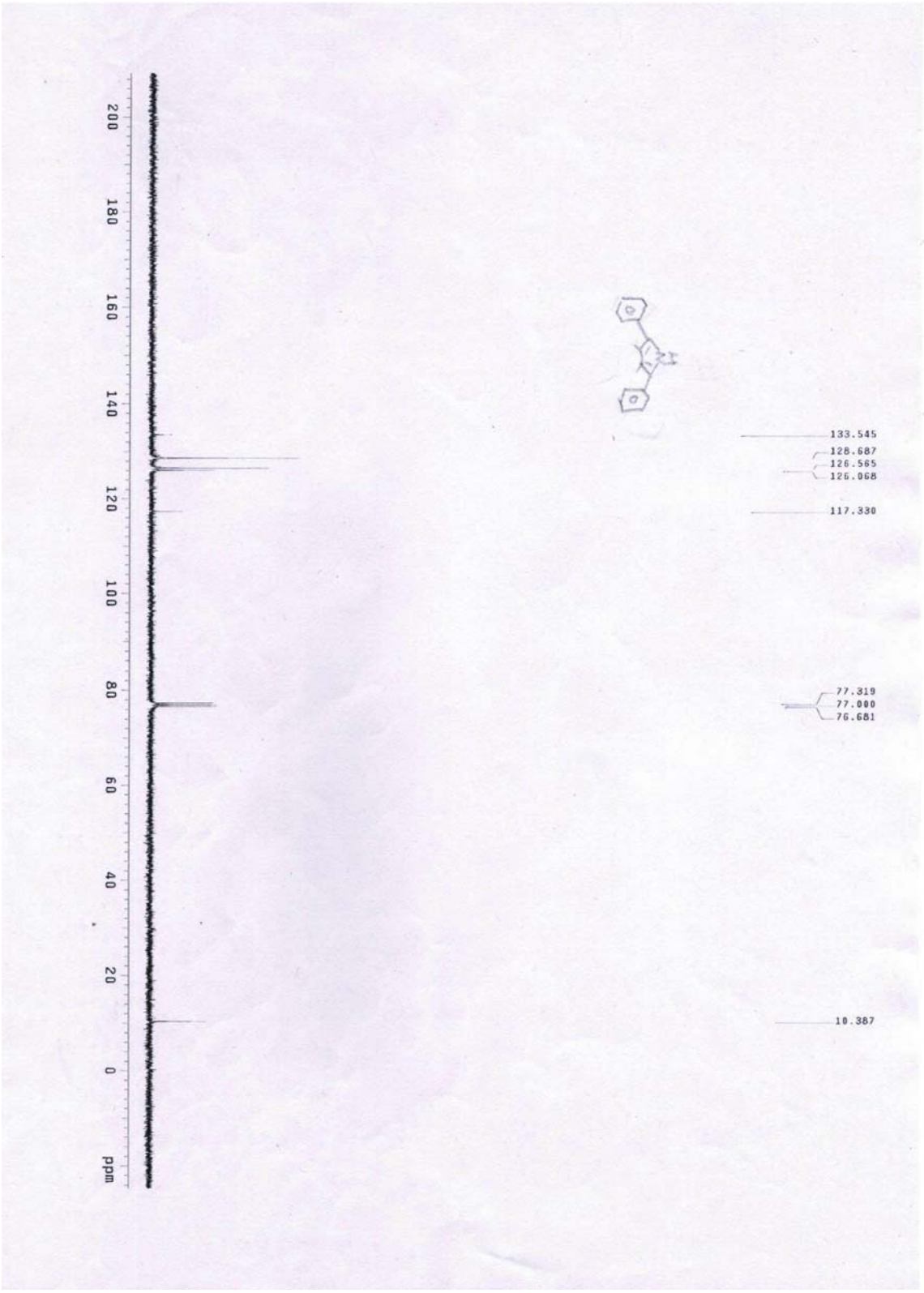
5. Copies of ^{1}H and ^{13}C NMR Spectra

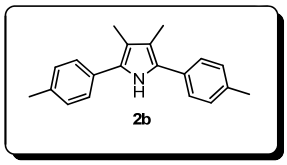


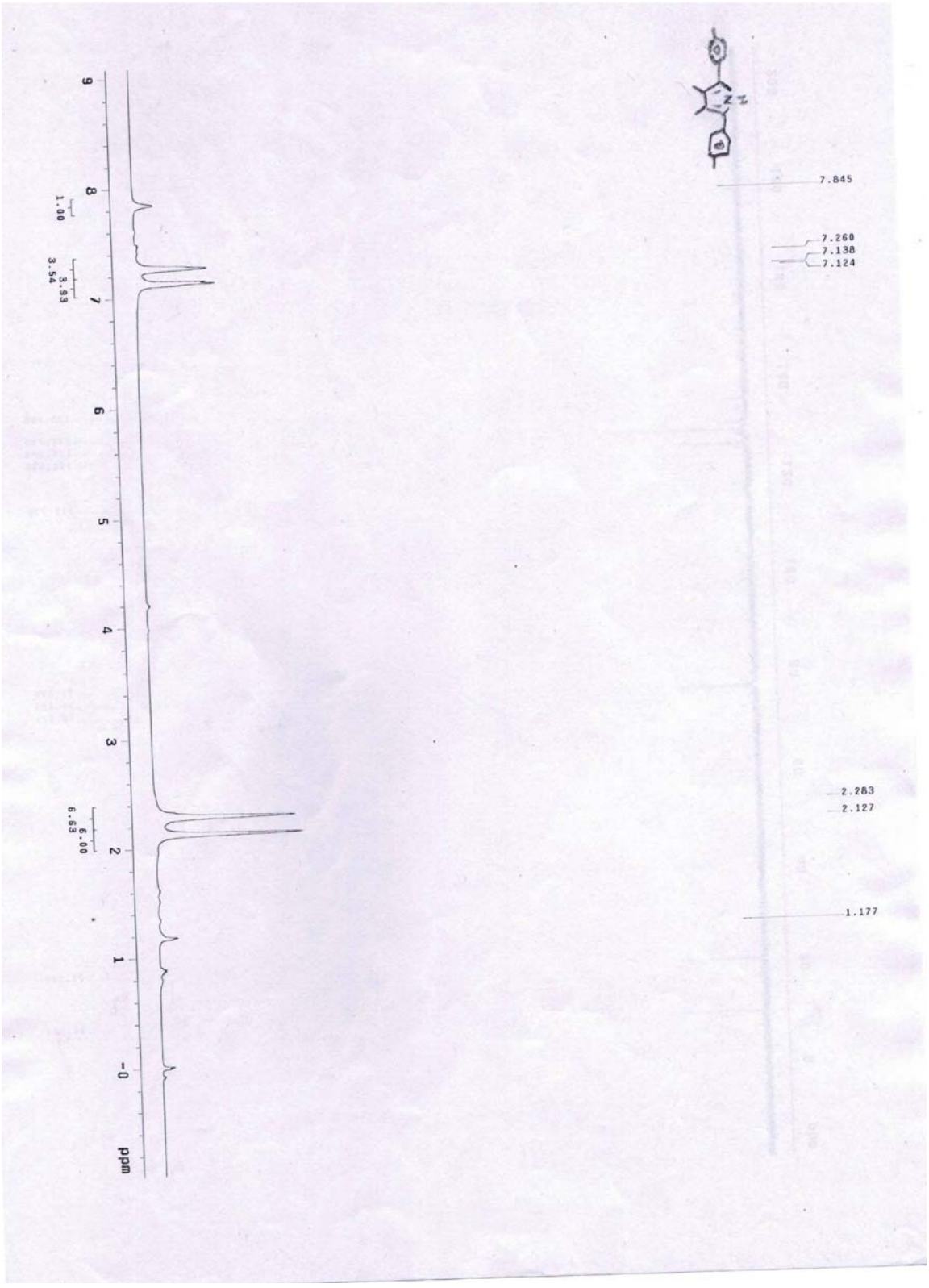


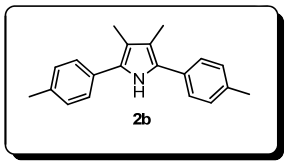


2a

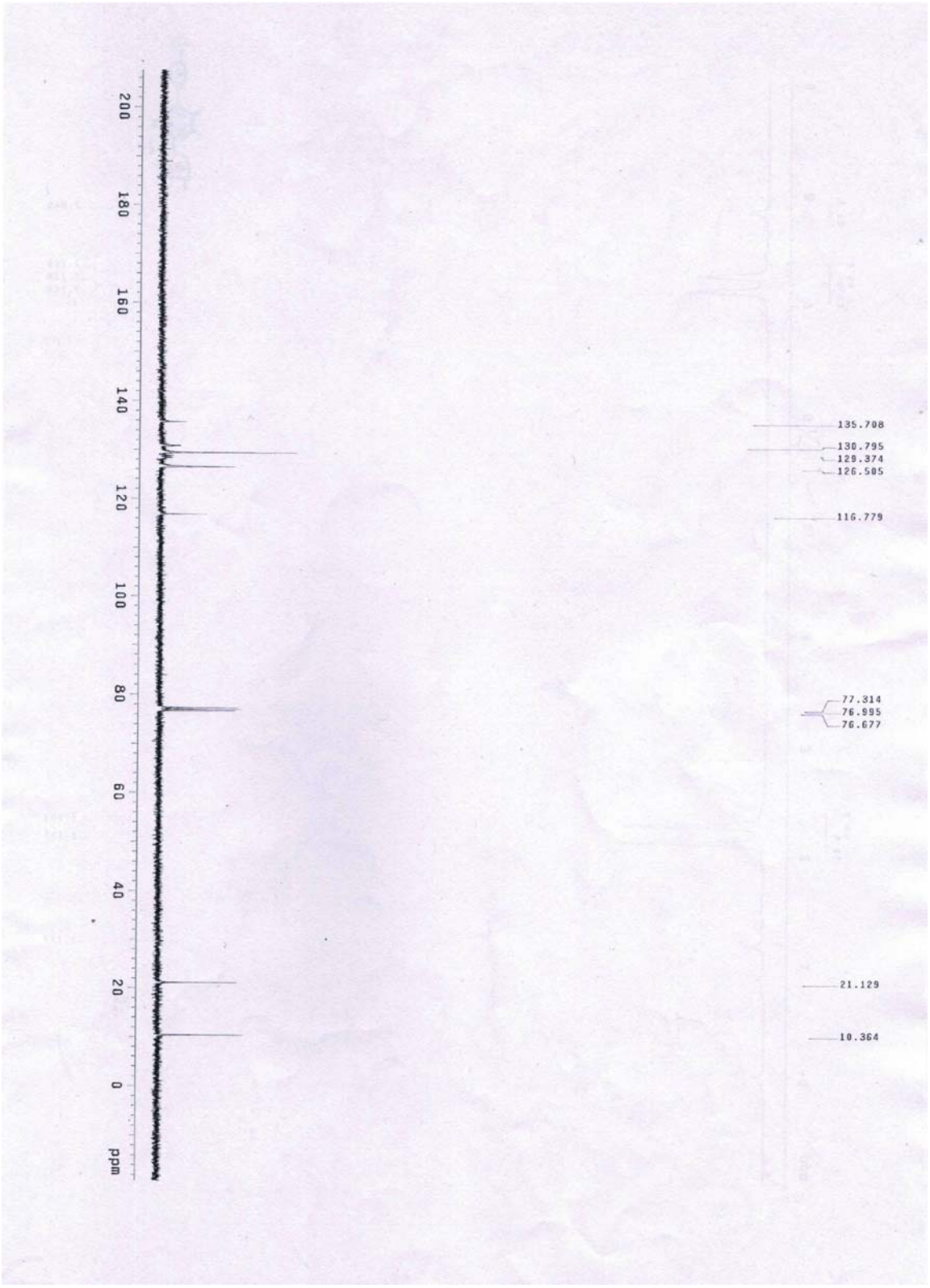


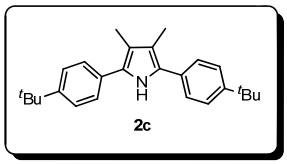




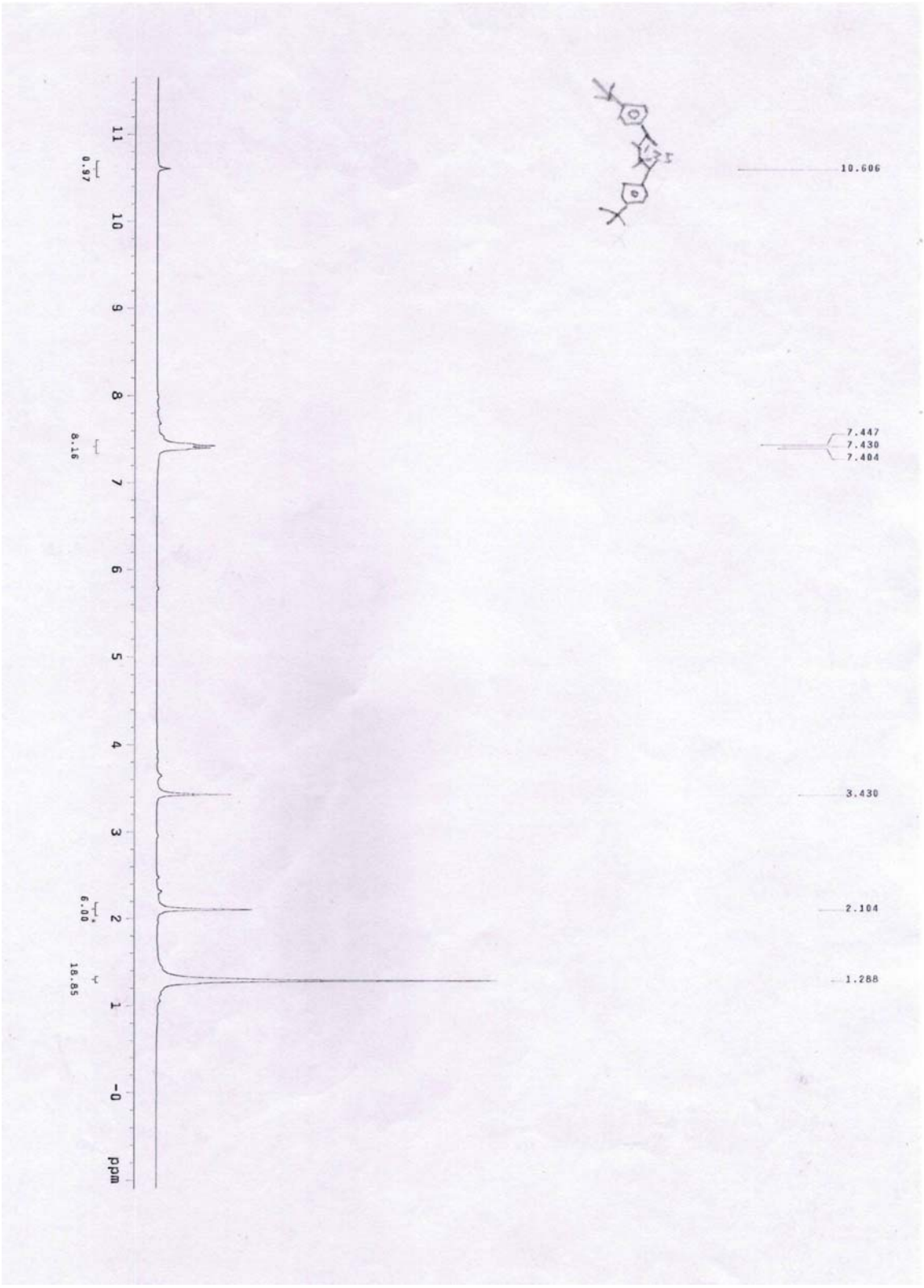


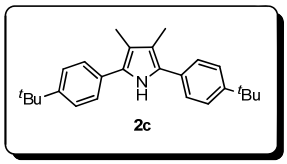
2b



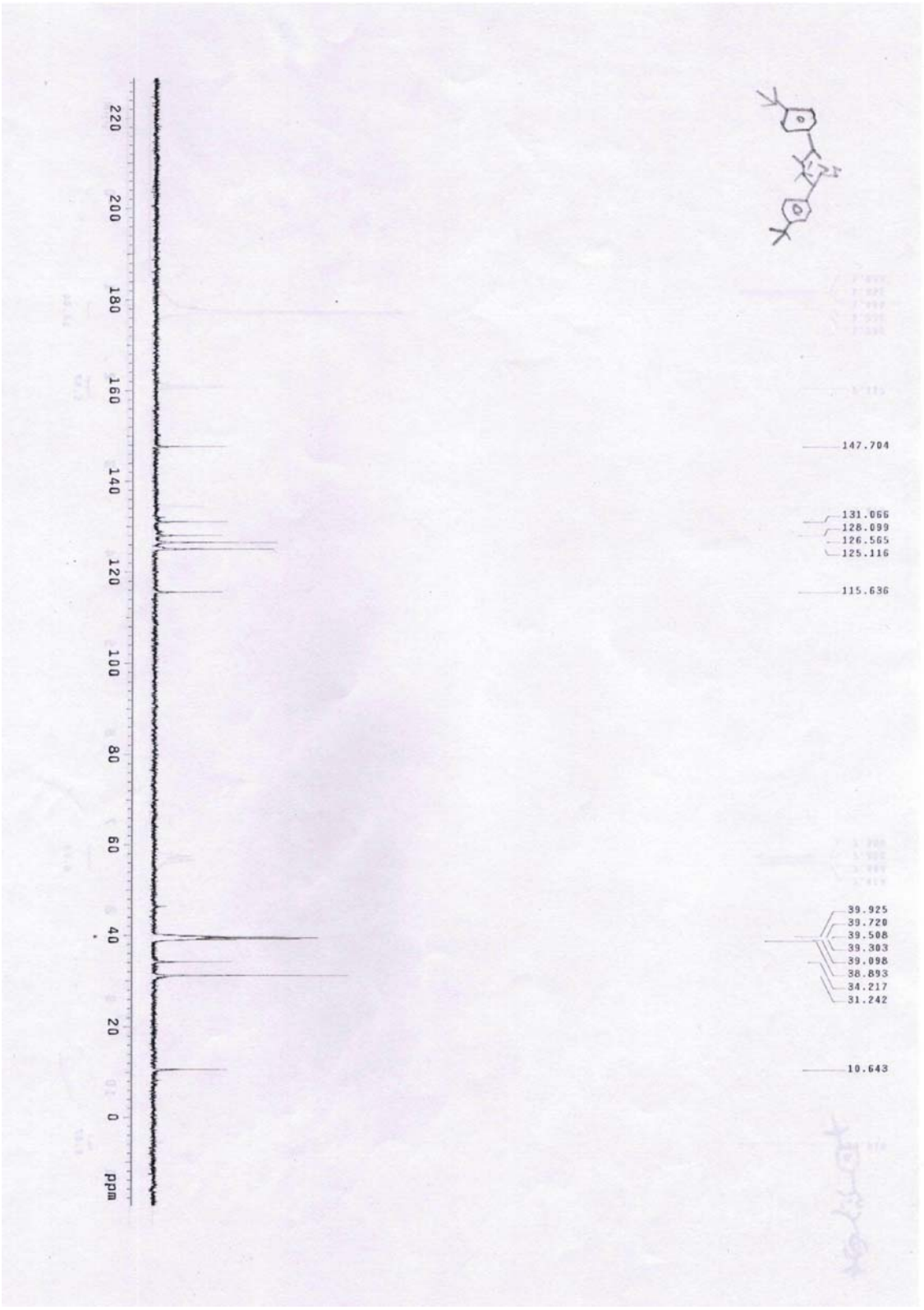


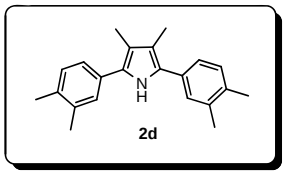
2c



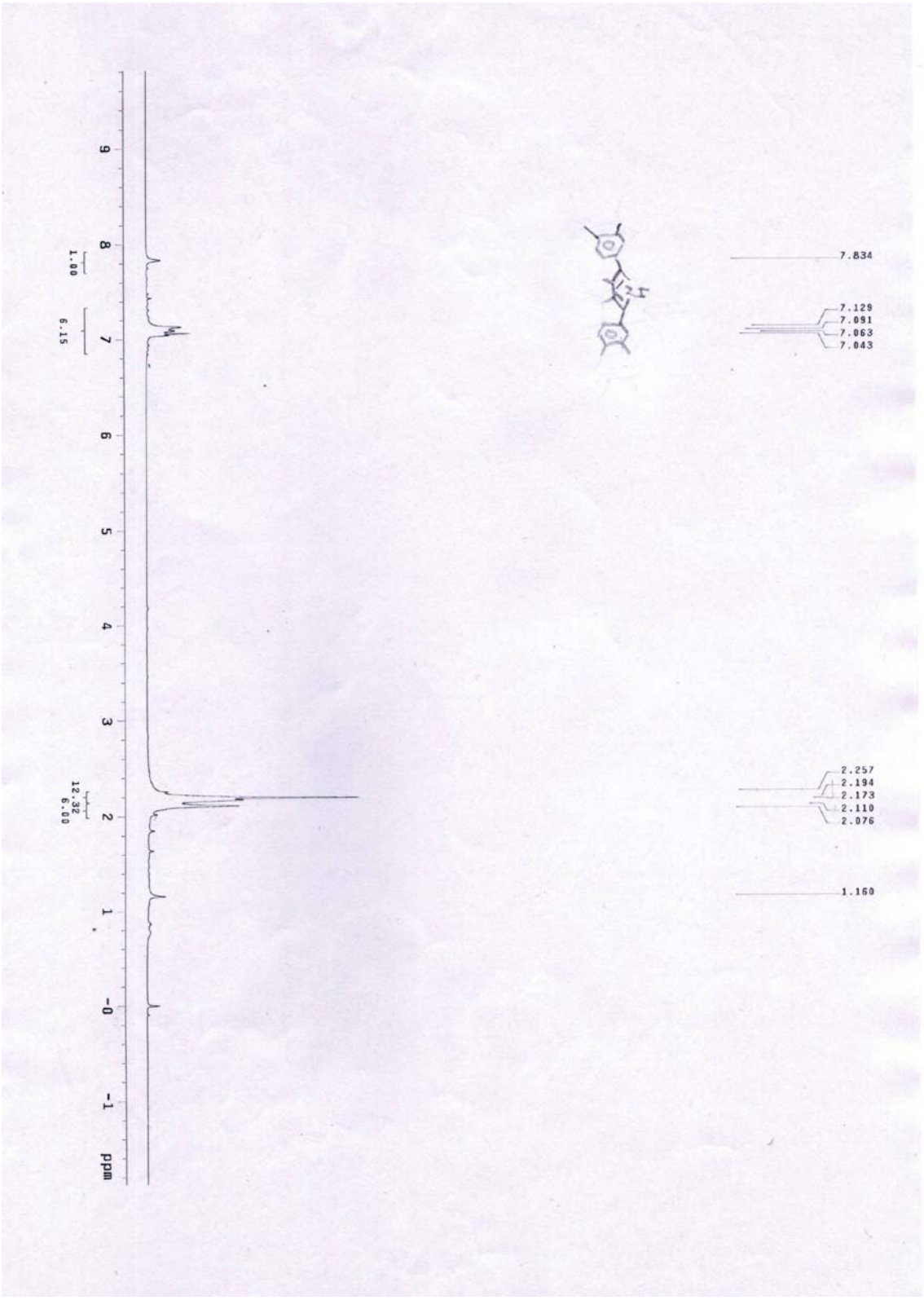


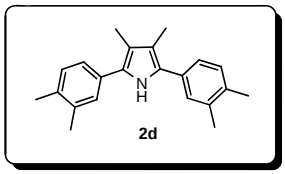
2c



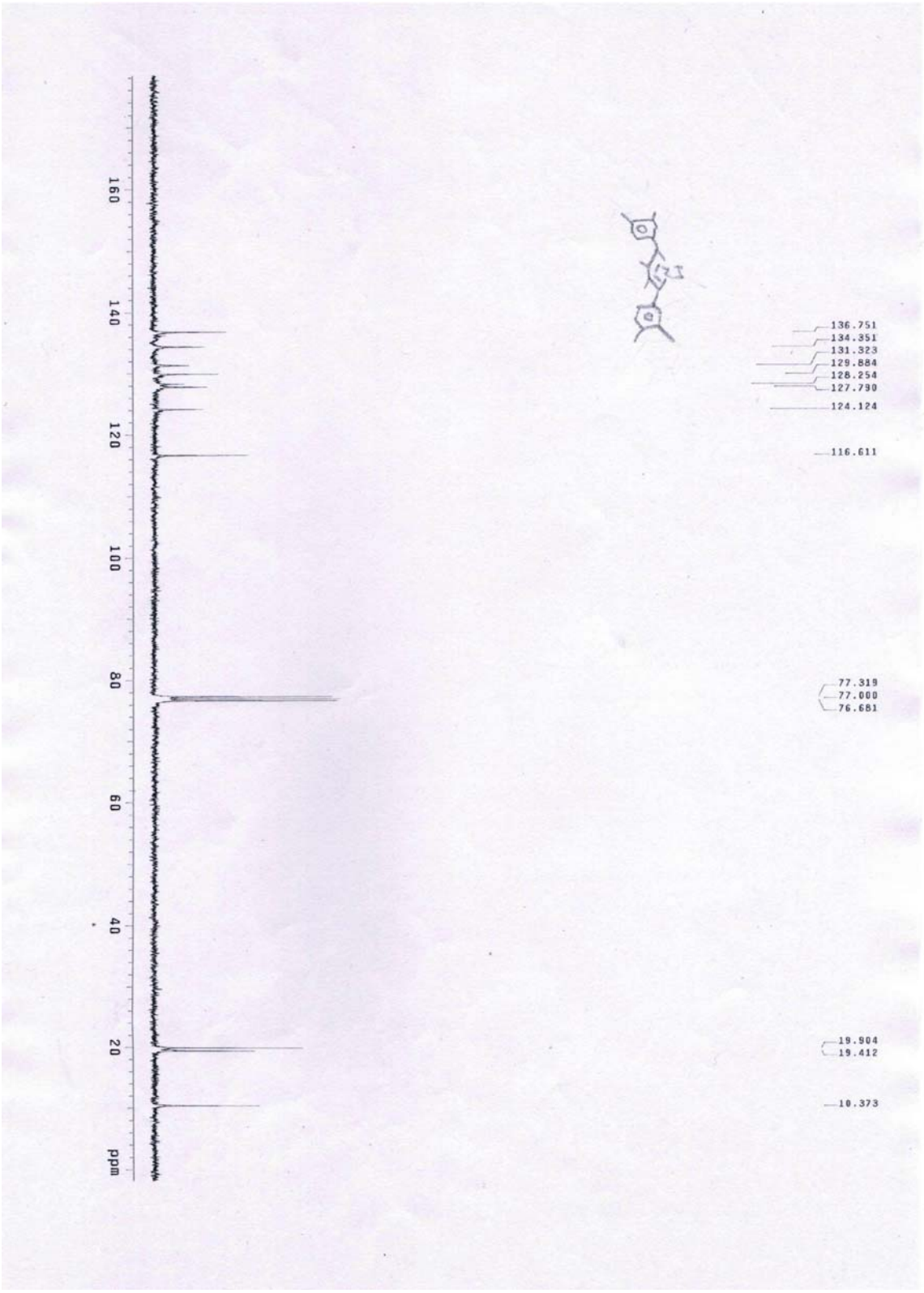


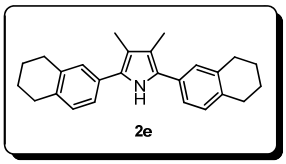
2d



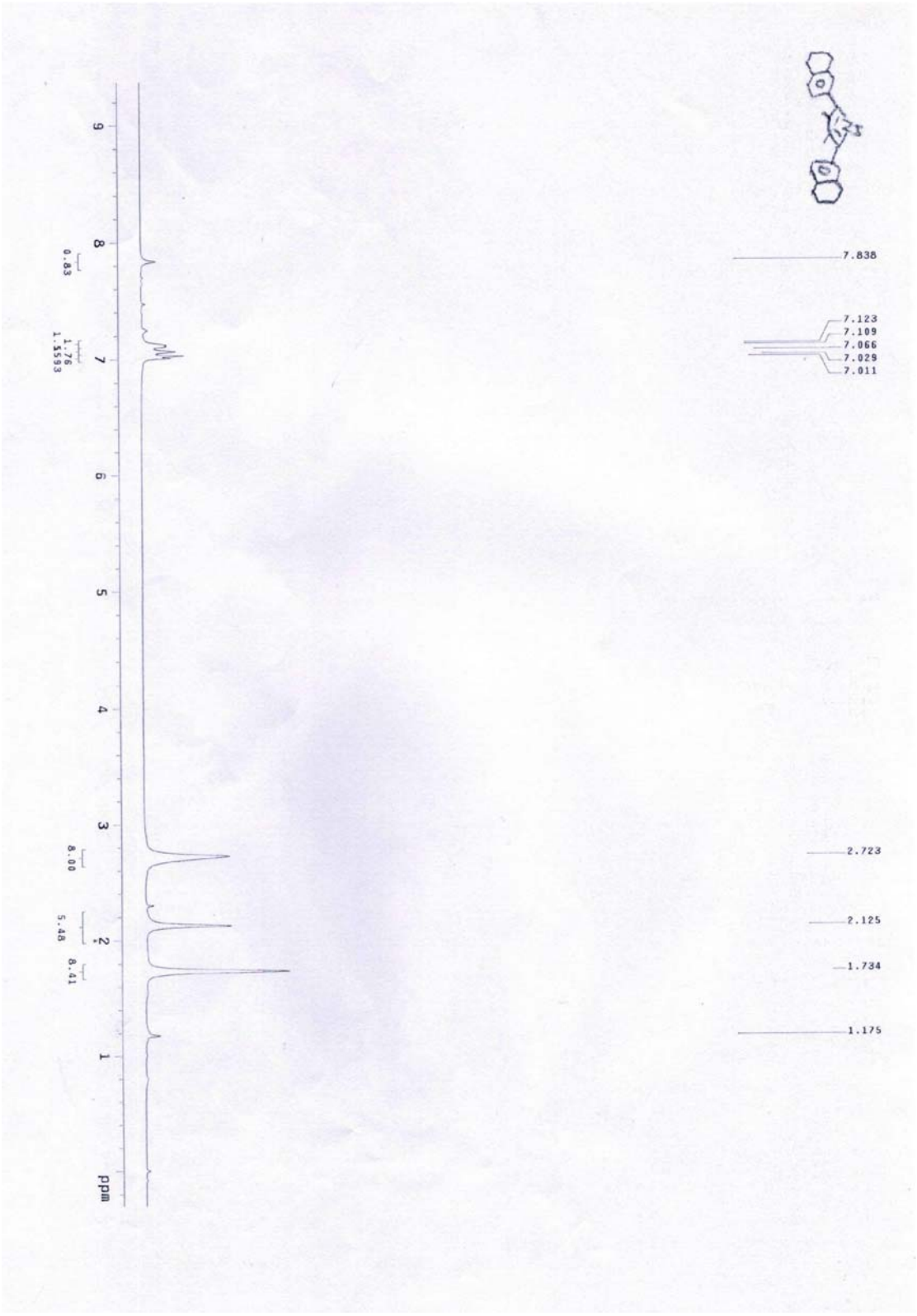


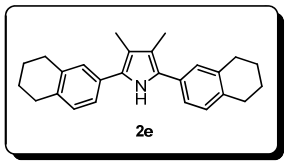
2d



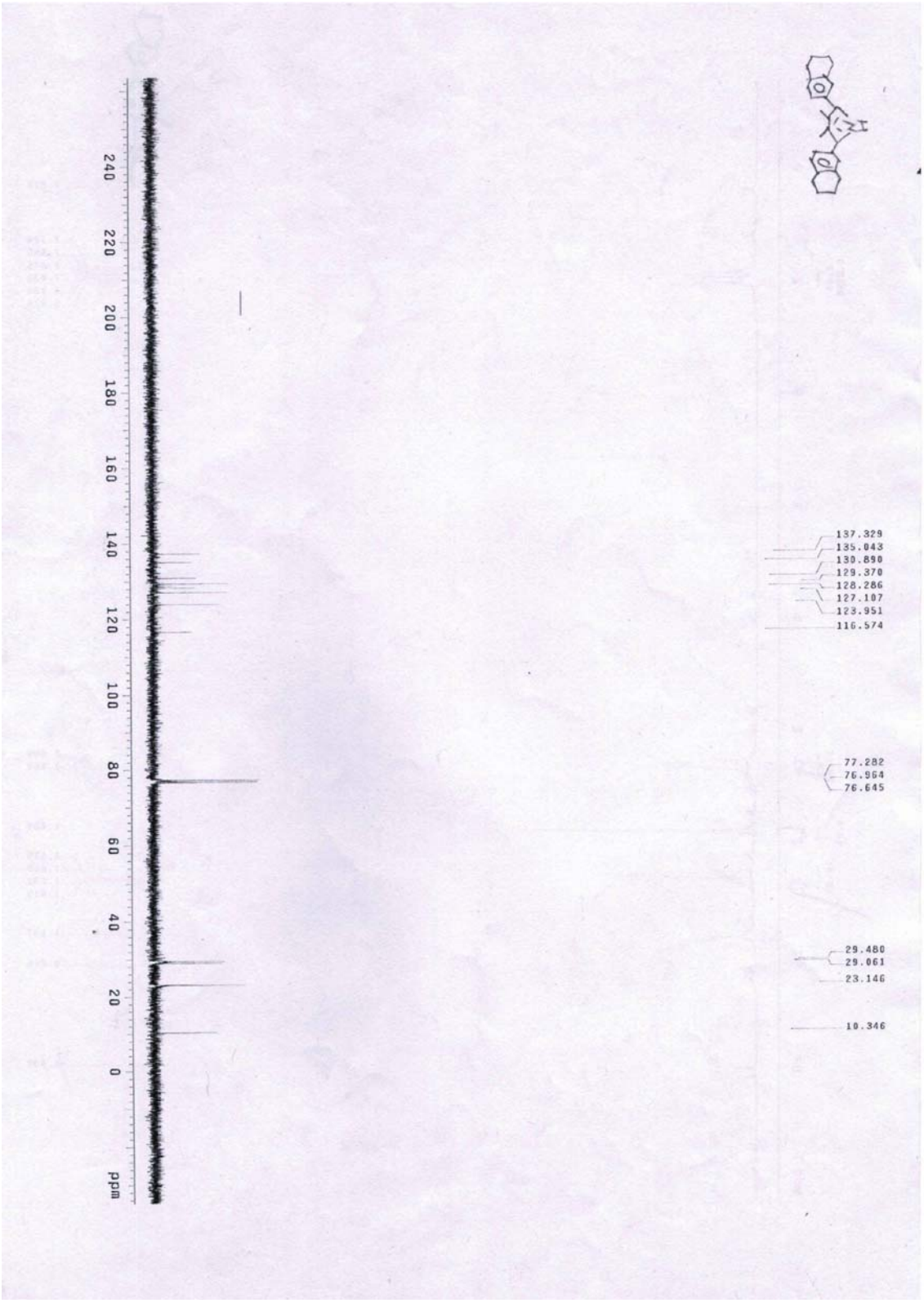


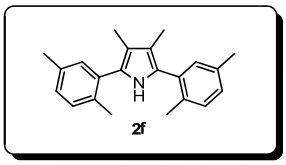
2e

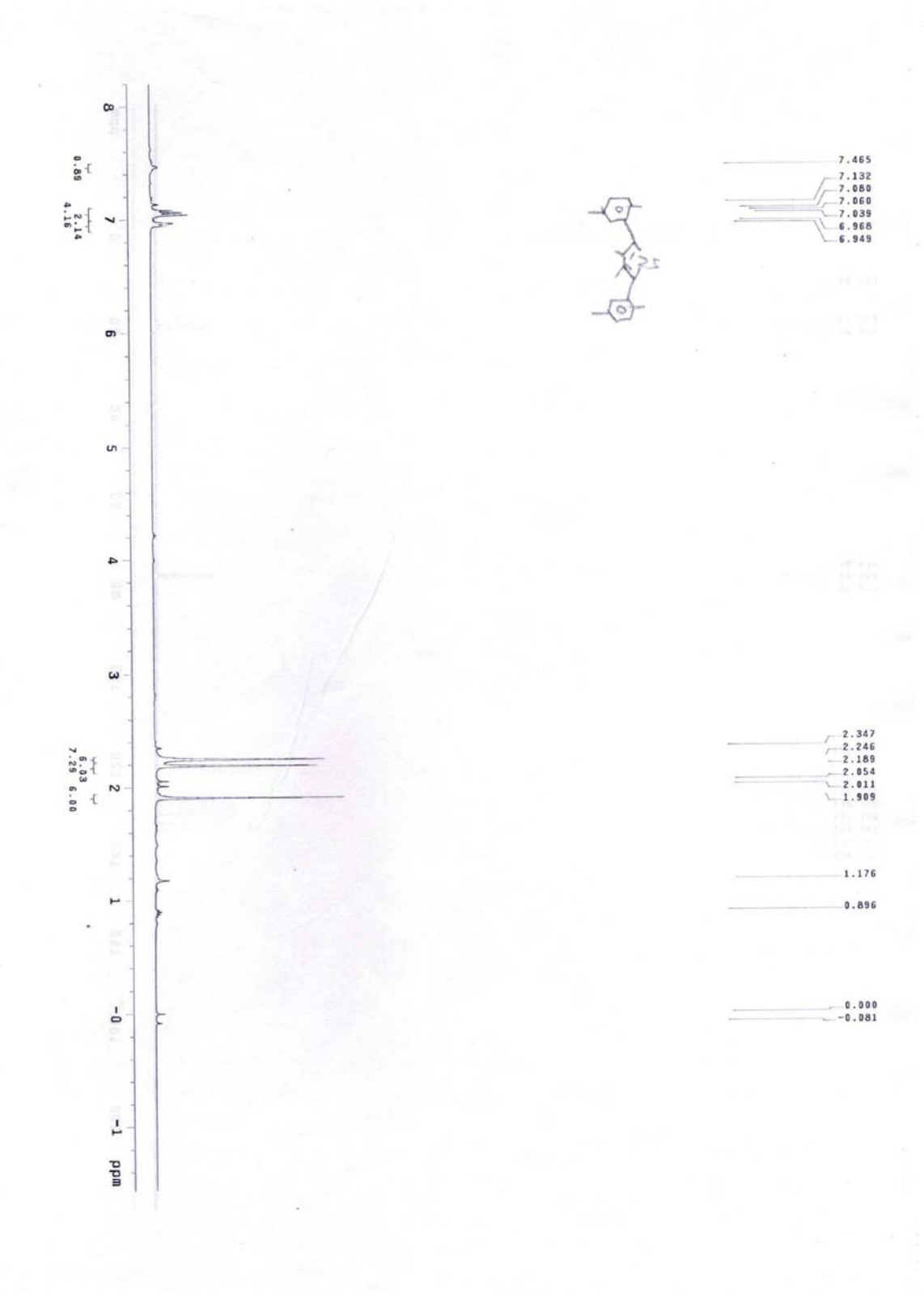


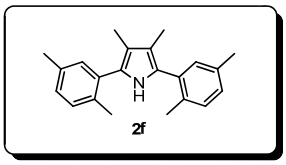


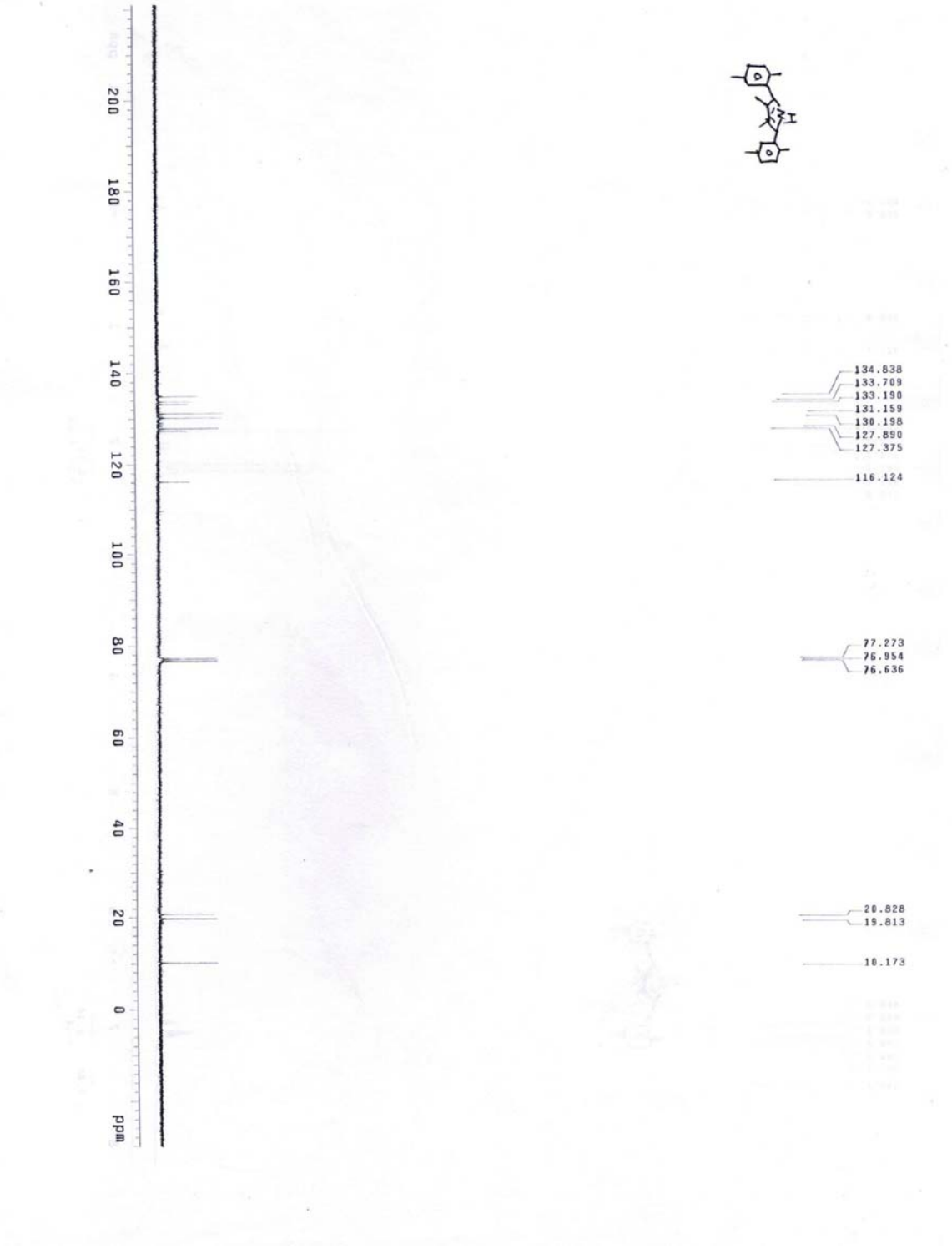
2e

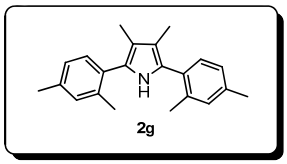


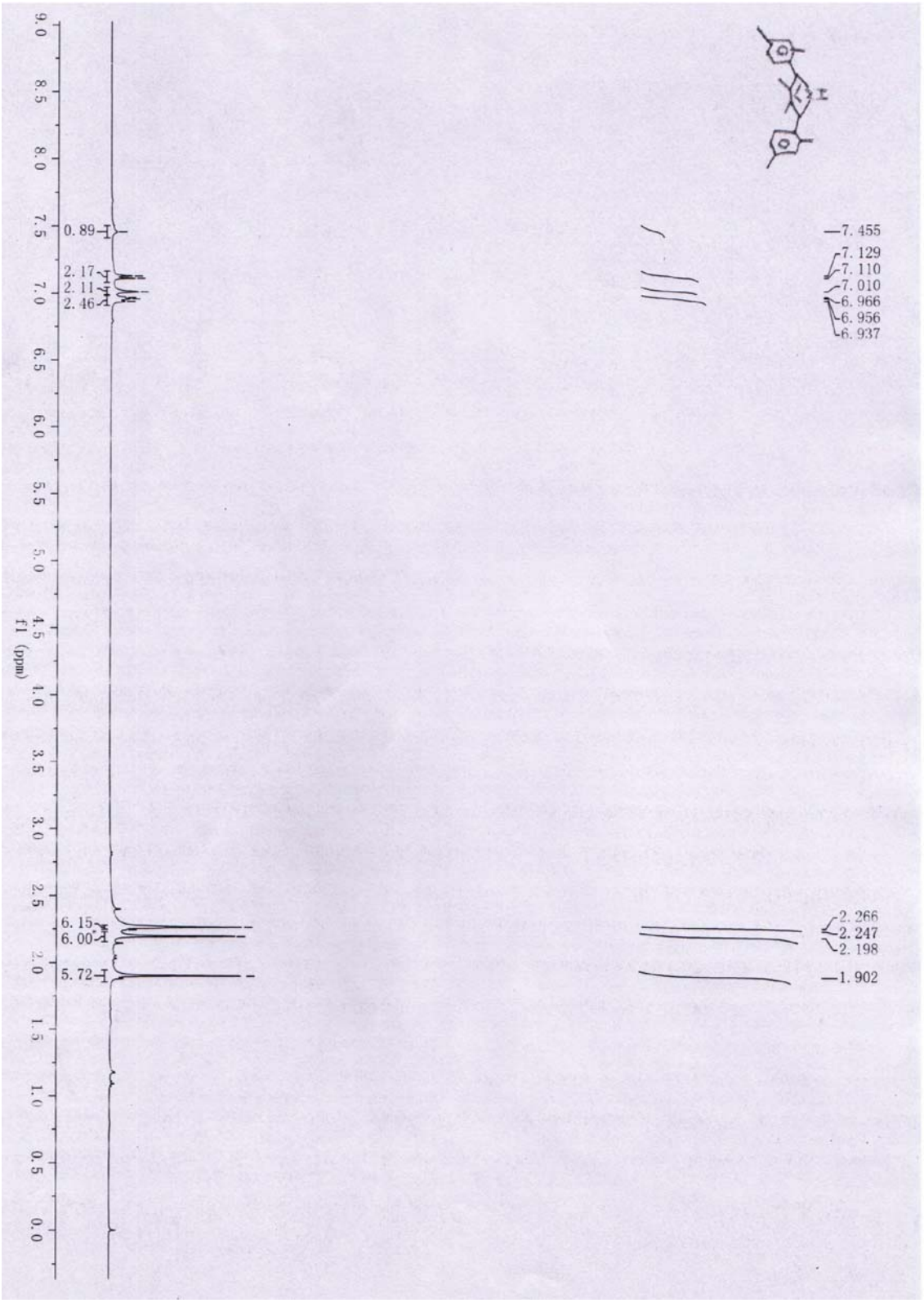


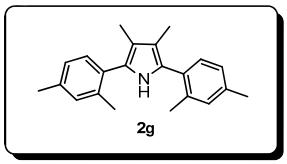




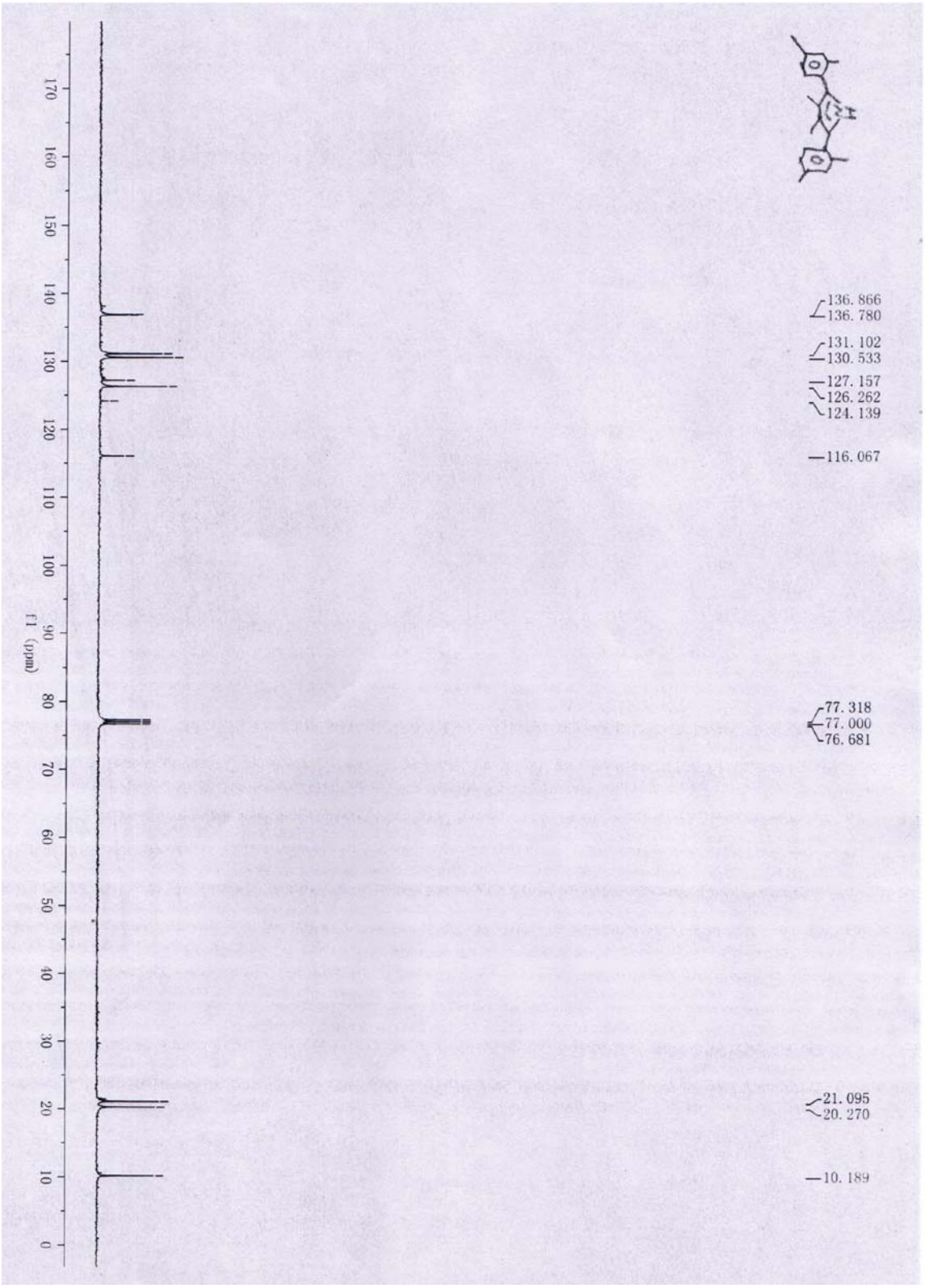


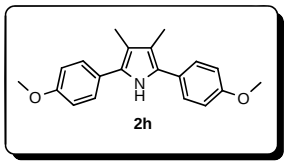

2g


0.89
2.17
2.11
2.46
6.15
6.00
5.72
7.455
7.129
7.110
7.010
6.966
6.956
6.937
2.266
2.247
2.198
1.902
f1 (ppm)

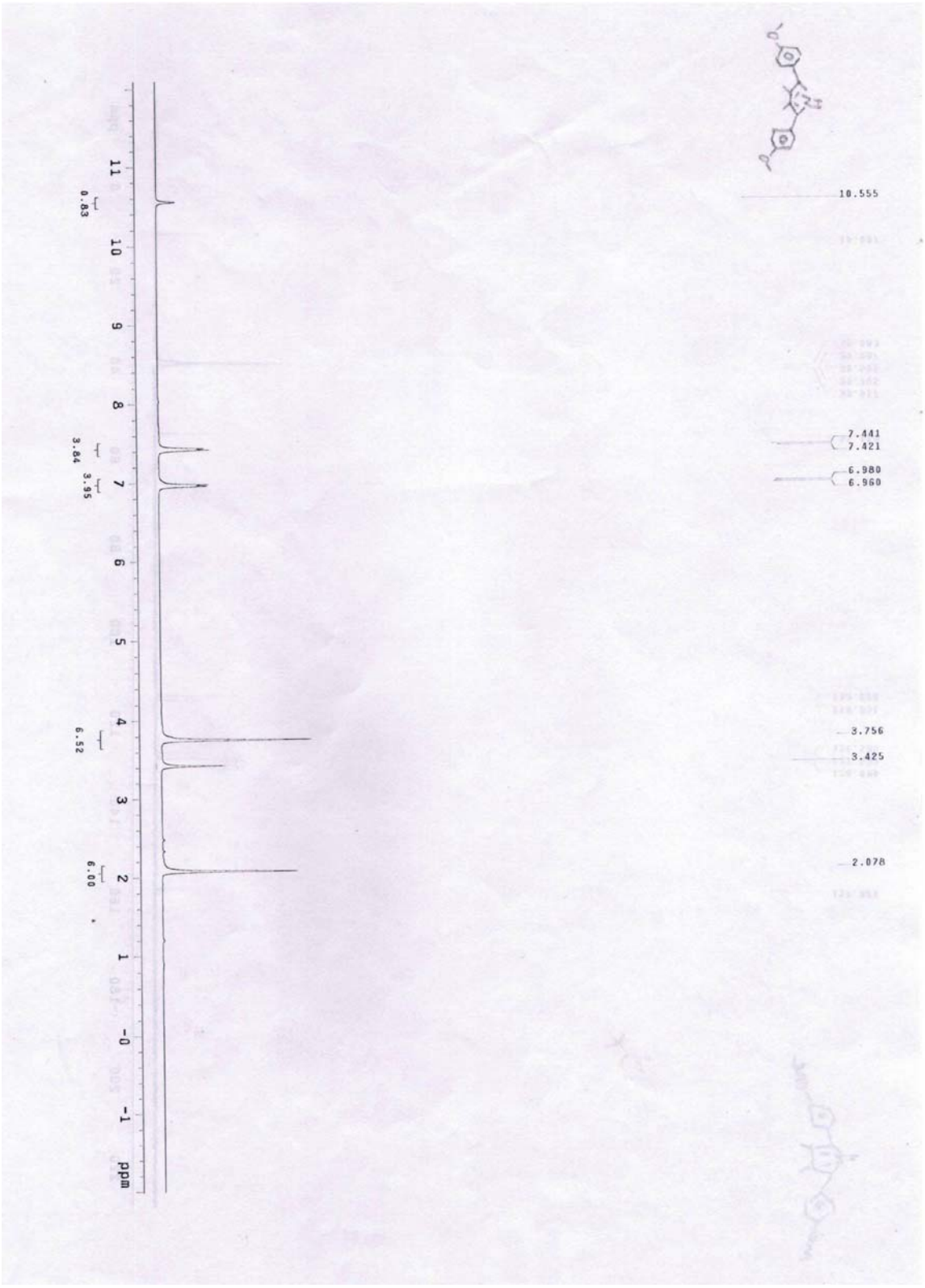


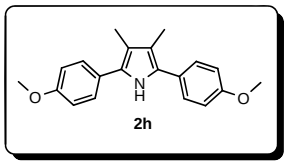
2g



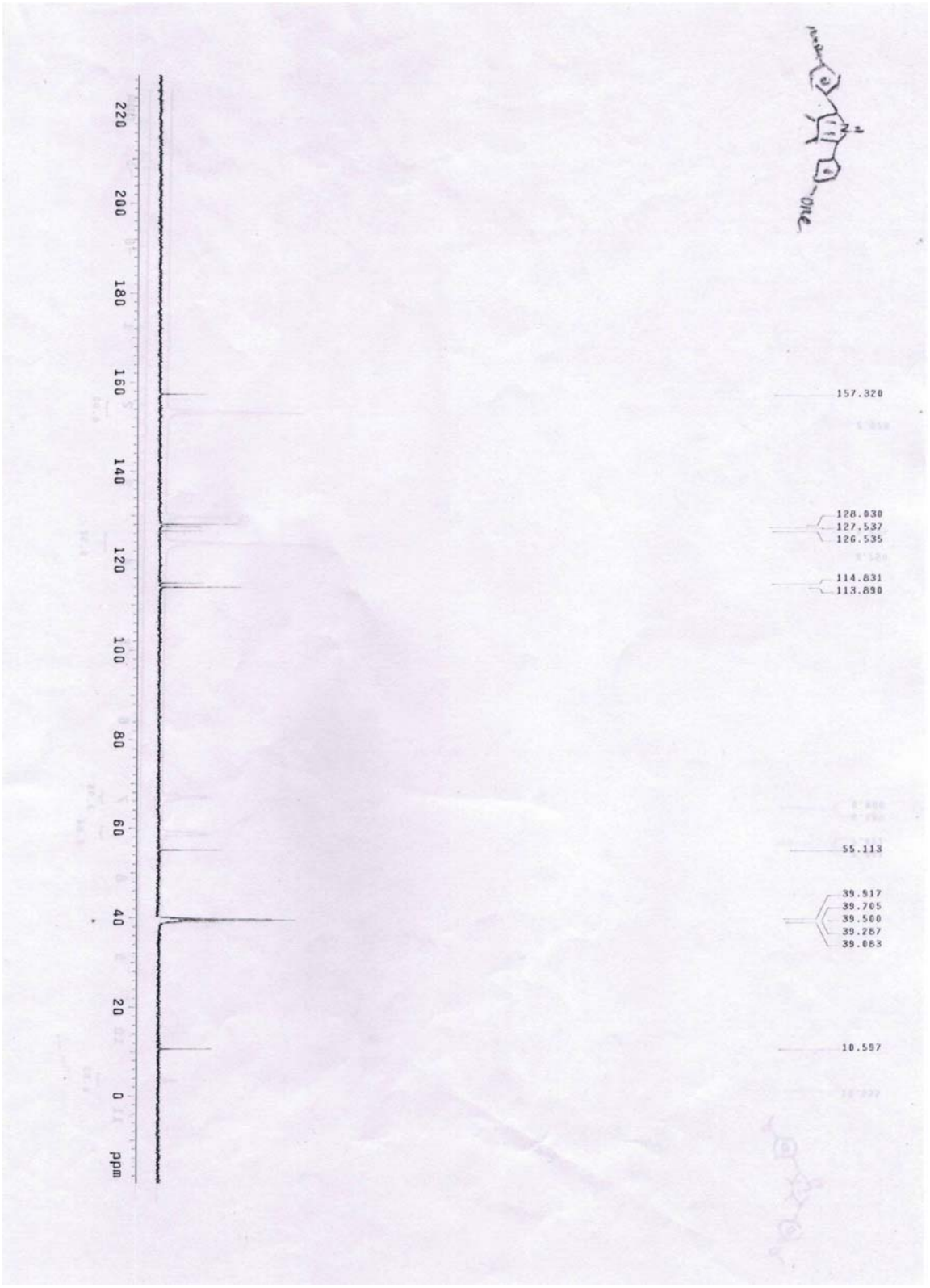


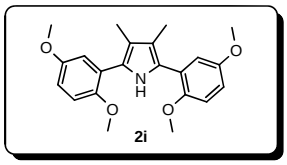
2h

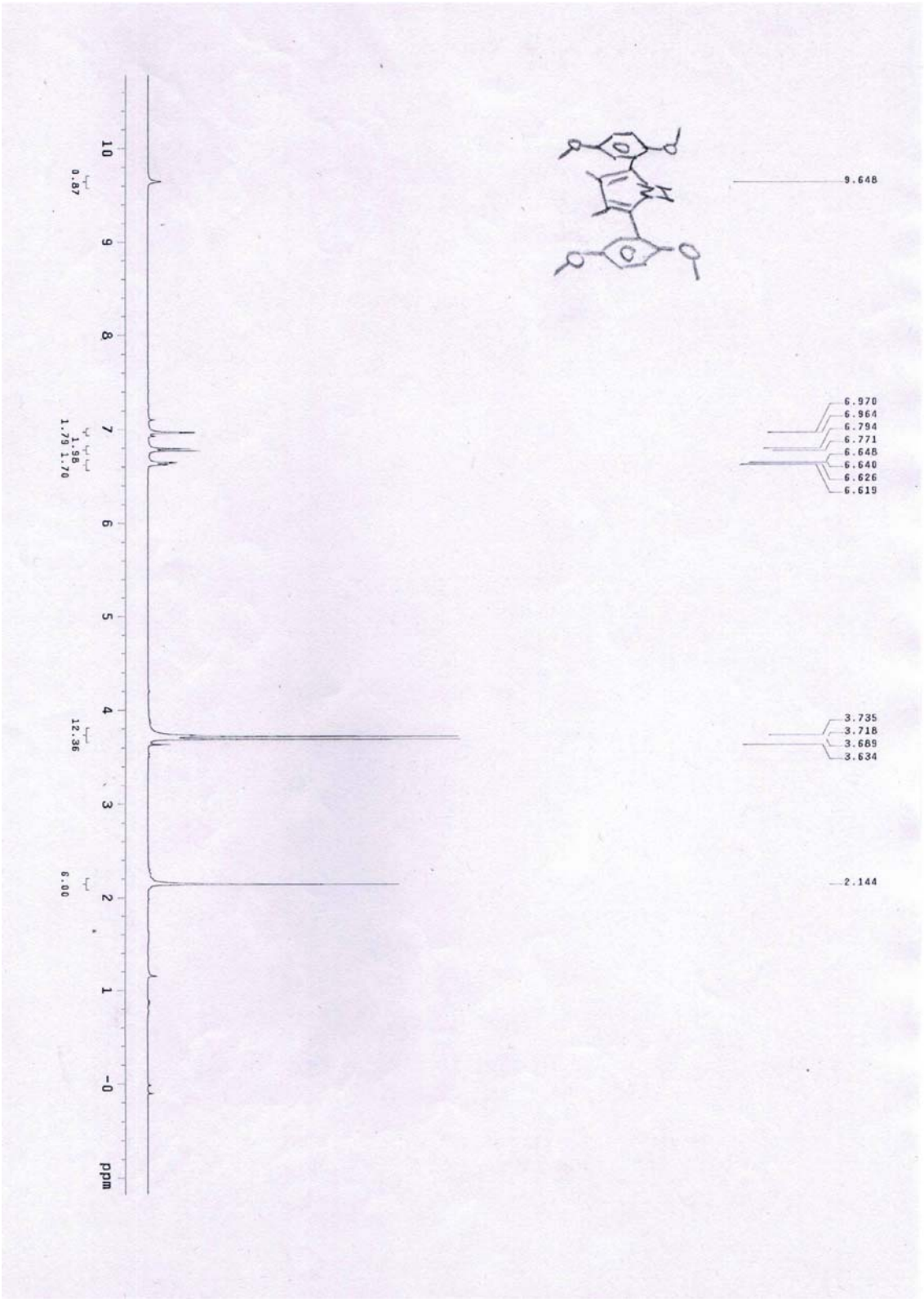


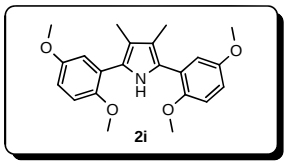

O
N
H
O

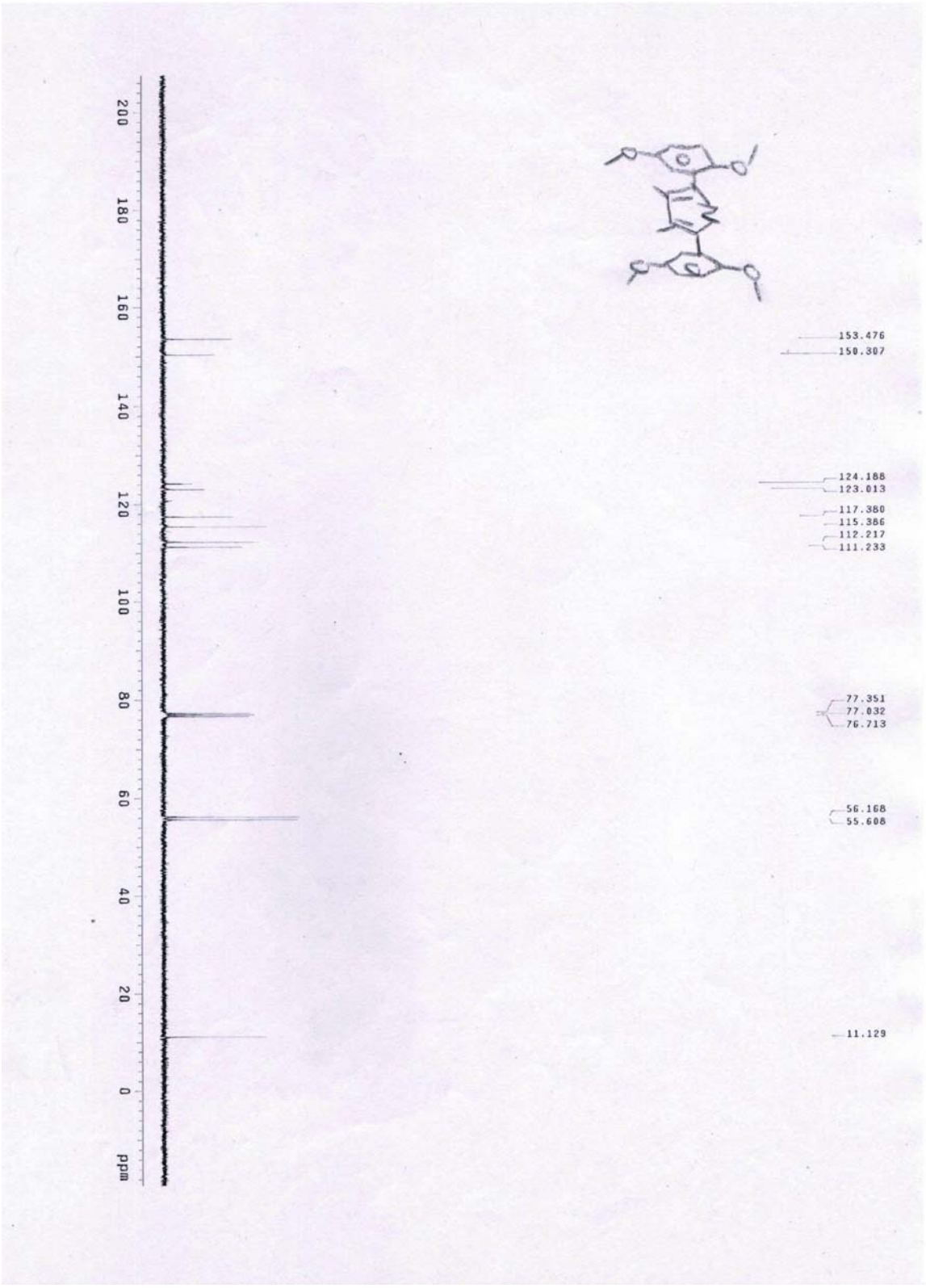
2h

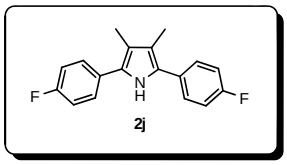

220
200
180
160
140
120
100
80
60
40
20
0
ppm
157.320
128.030
127.537
126.535
114.831
113.890
55.113
39.917
39.705
39.500
39.287
39.083
10.597



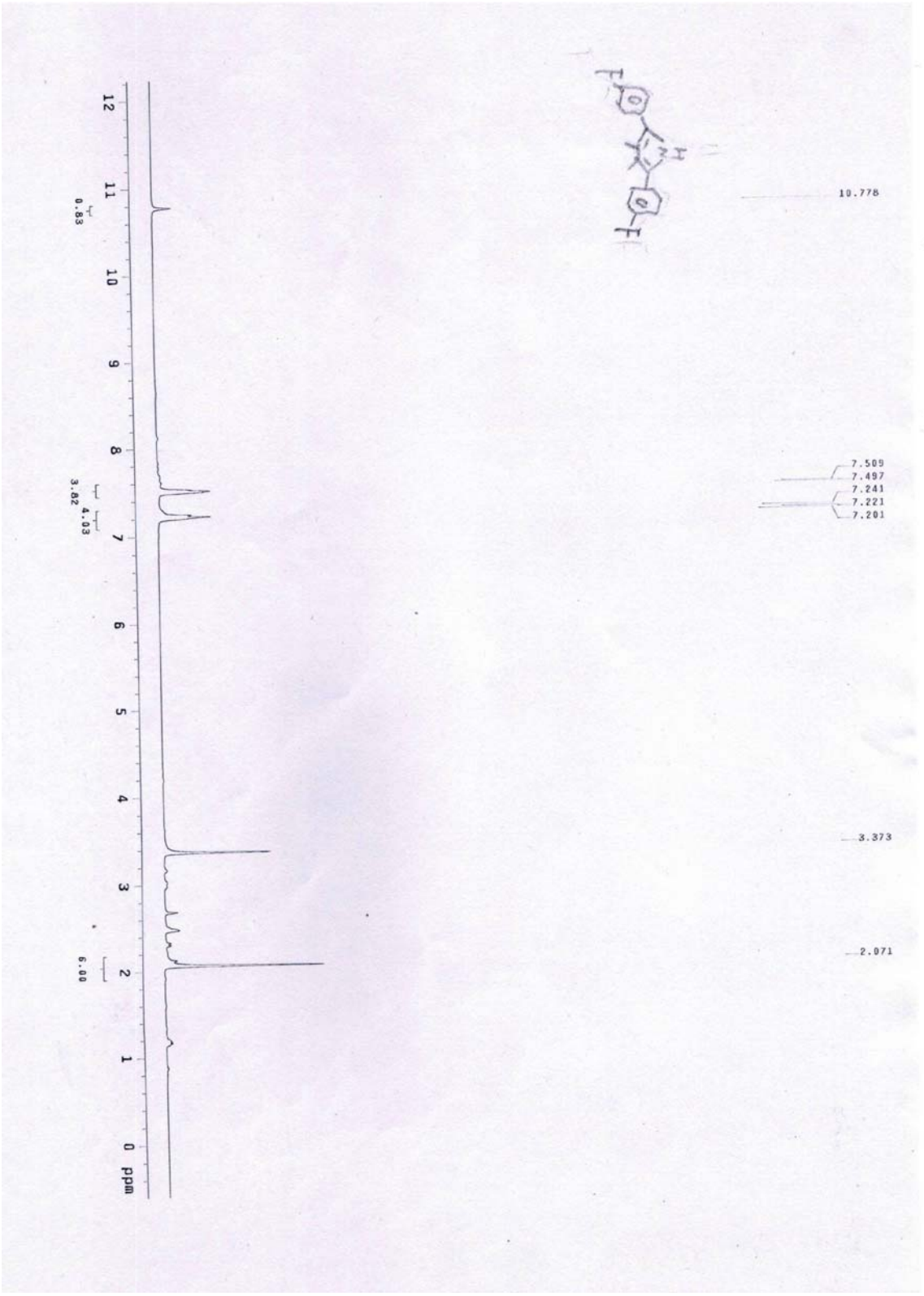


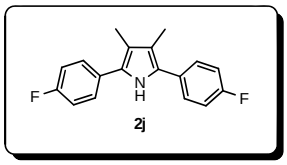




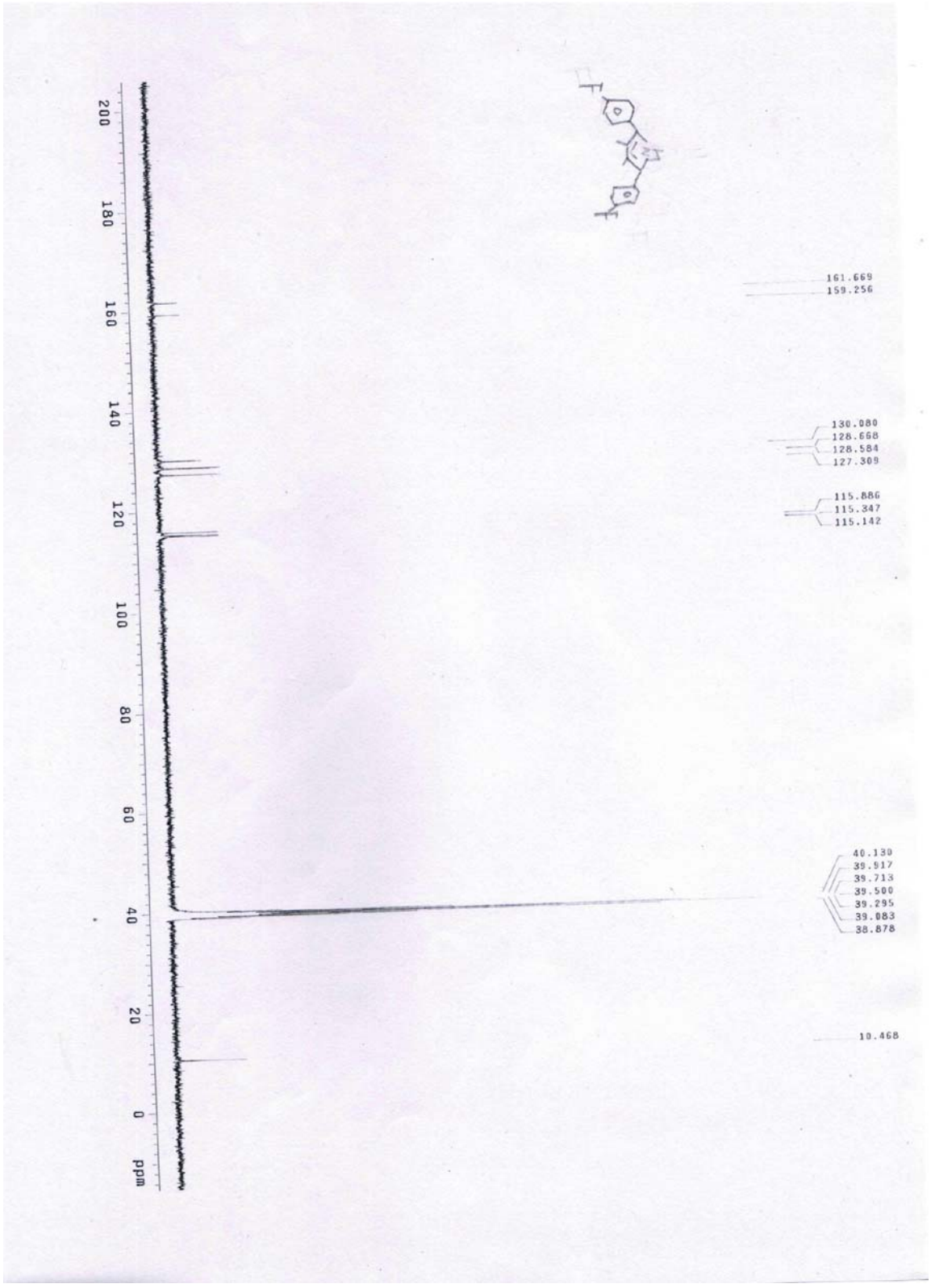


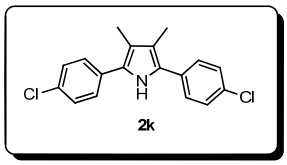
2j



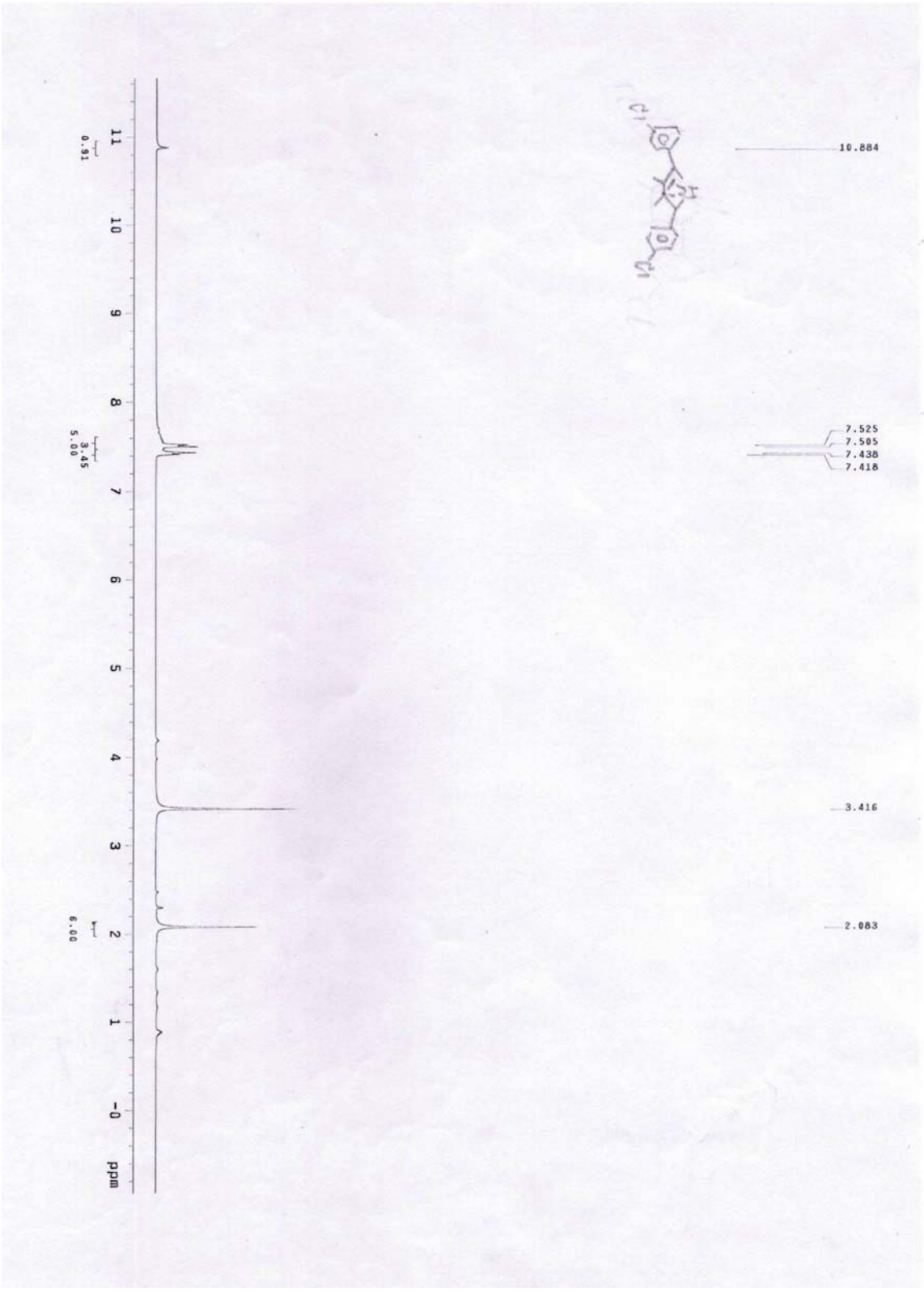

F
N
H
F

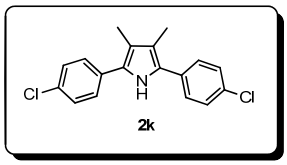
2j


161.669
159.256
130.080
128.668
128.584
127.309
115.886
115.347
115.142
40.130
39.917
39.713
39.500
39.295
39.083
38.878
10.468
200
180
160
140
120
100
80
60
40
20
0
ppm

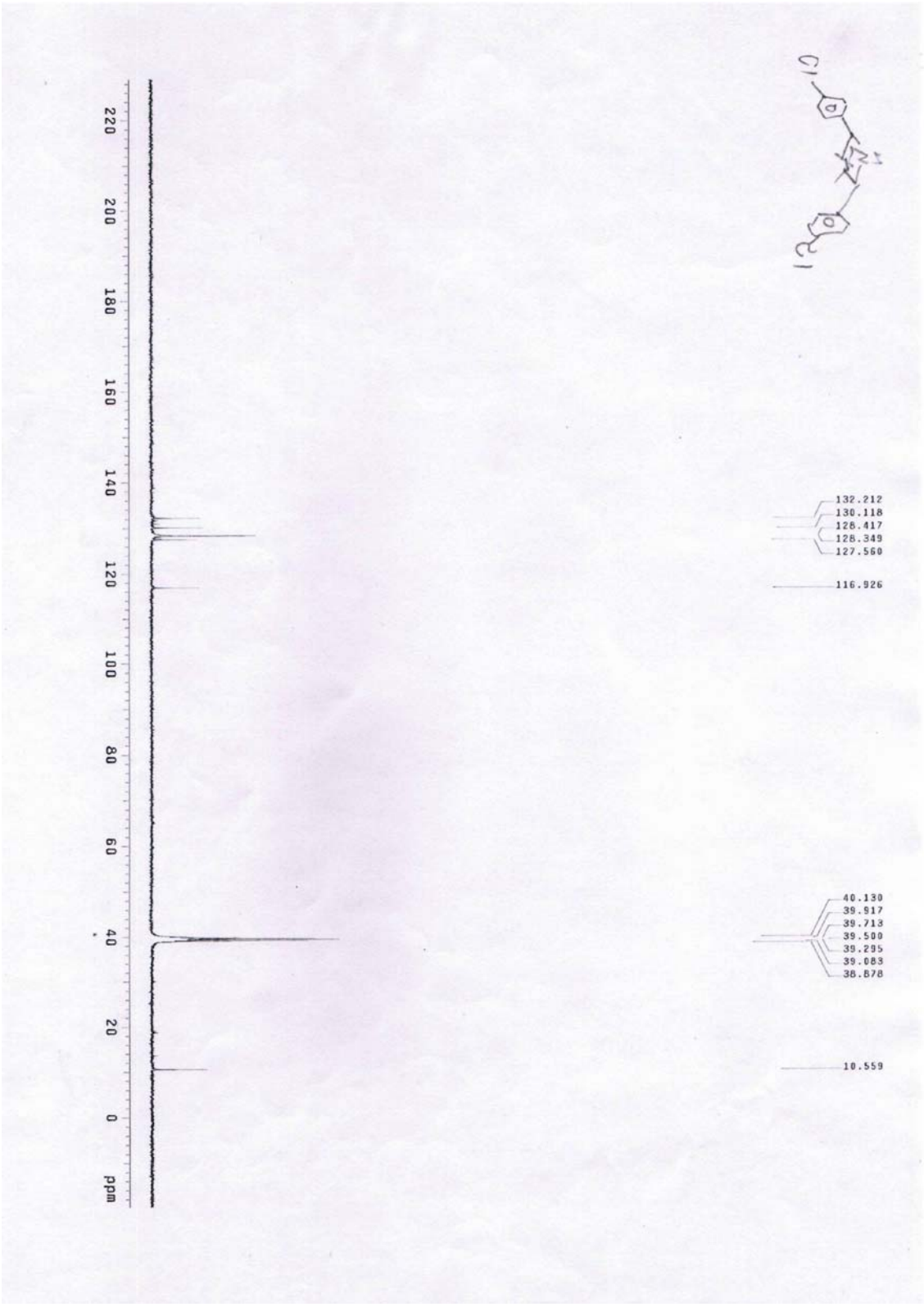


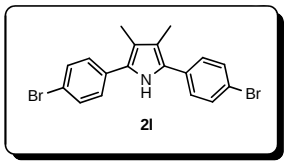
2k



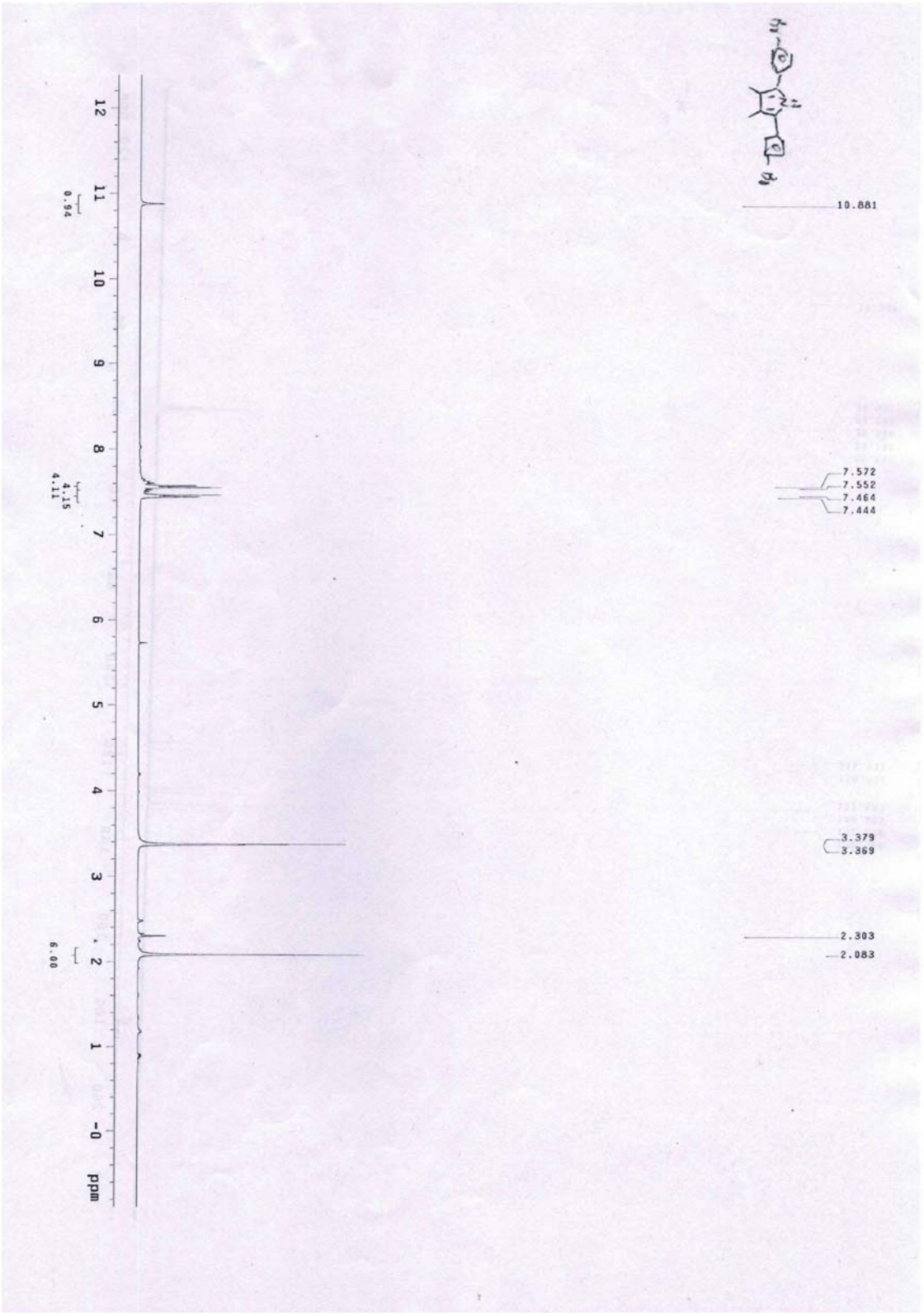


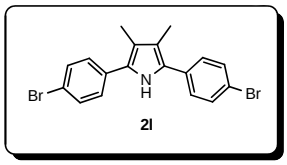
2k



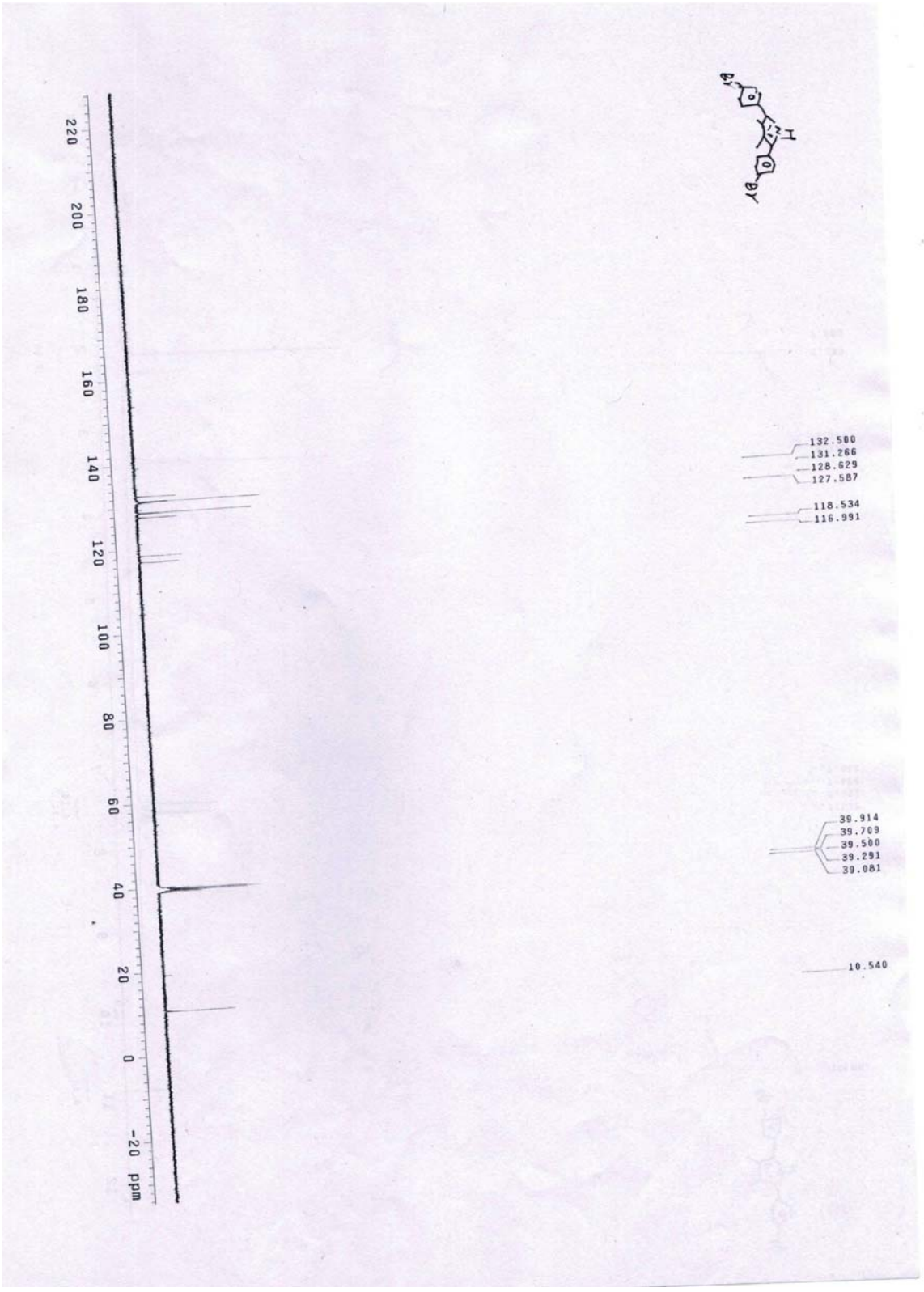

Br
N
H
Br

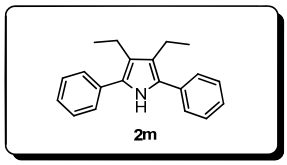
2l

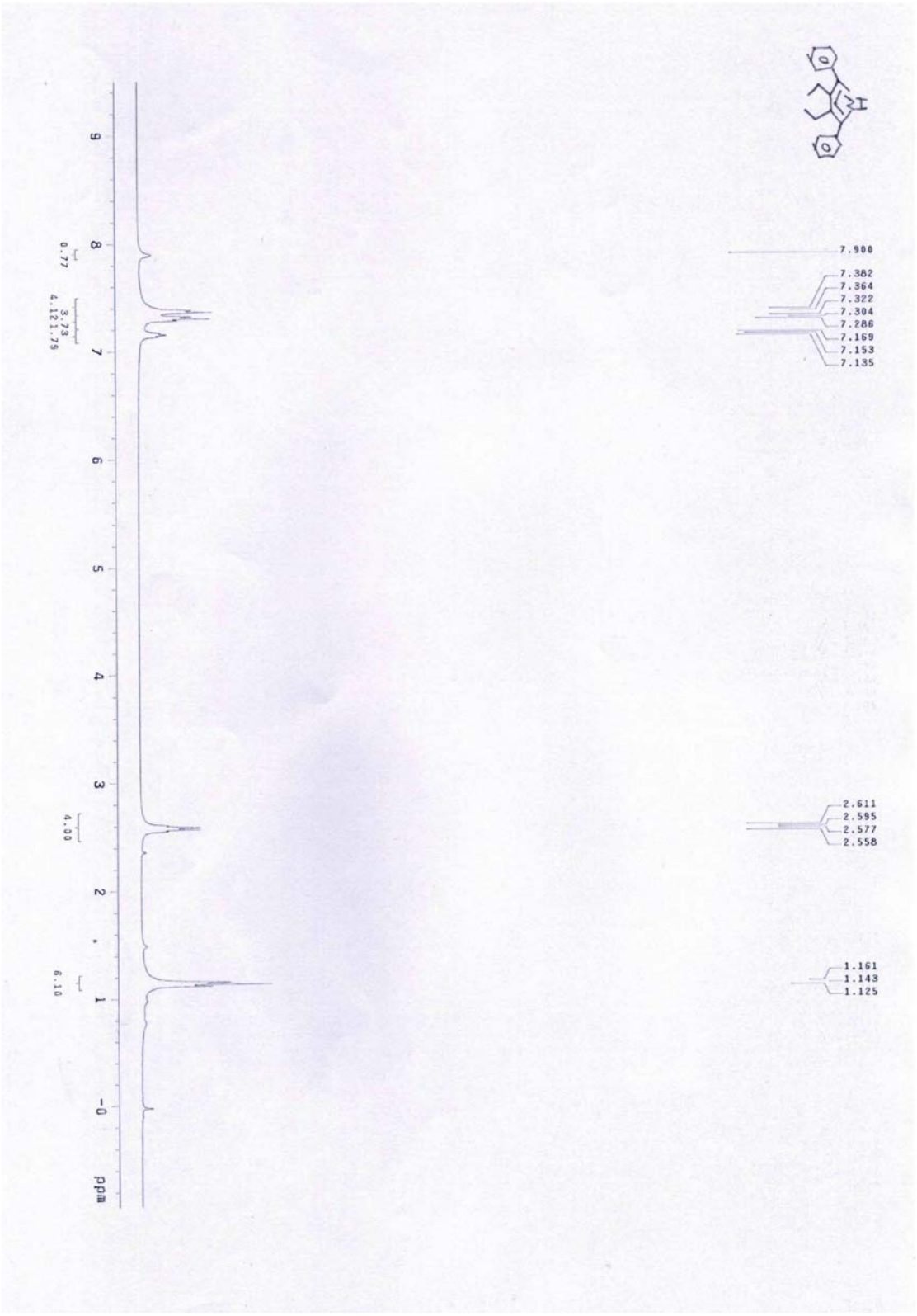

10.881
7.572
7.552
7.464
7.444
3.379
3.369
2.303
2.083
0.94
4.15
4.11
6.00
ppm

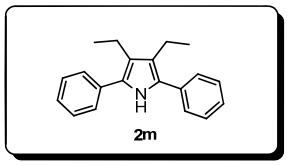

Br
N
H
Br

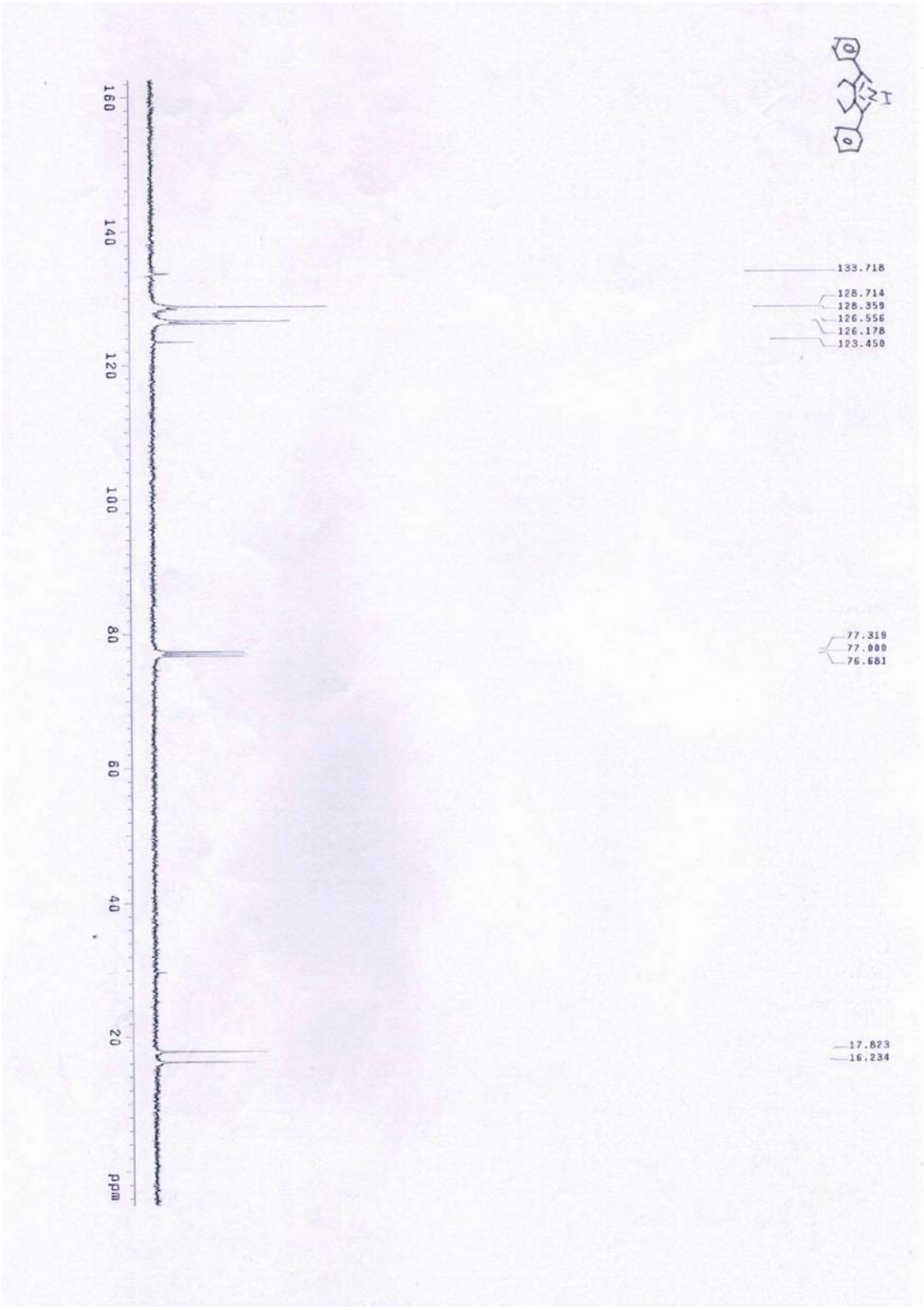
2l

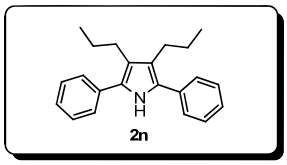

132.500
131.266
128.629
127.587
118.534
116.991
39.914
39.709
39.500
39.291
39.081
10.540
220
200
180
160
140
120
100
80
60
40
20
0
-20
ppm

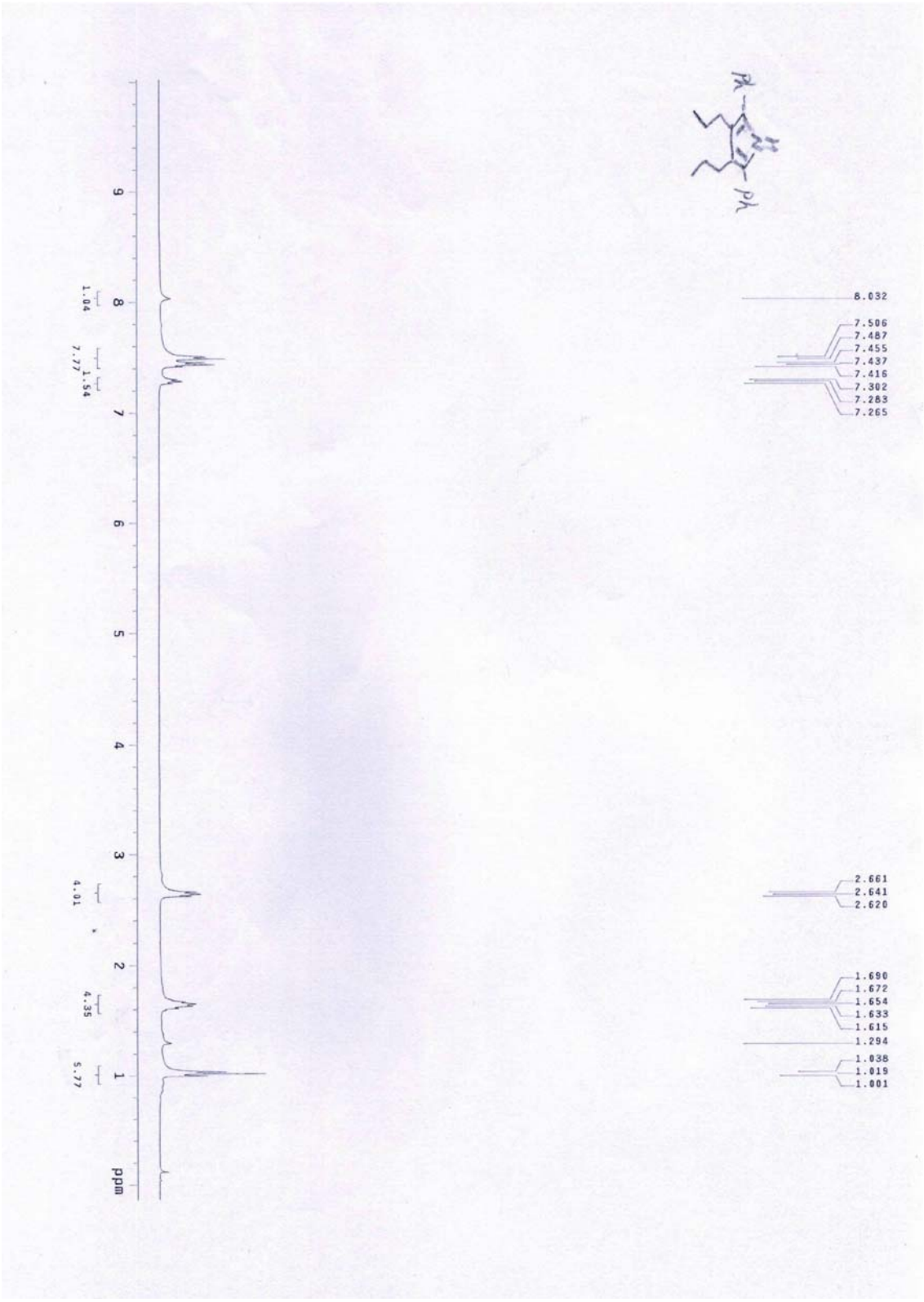


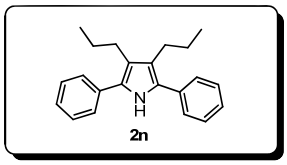




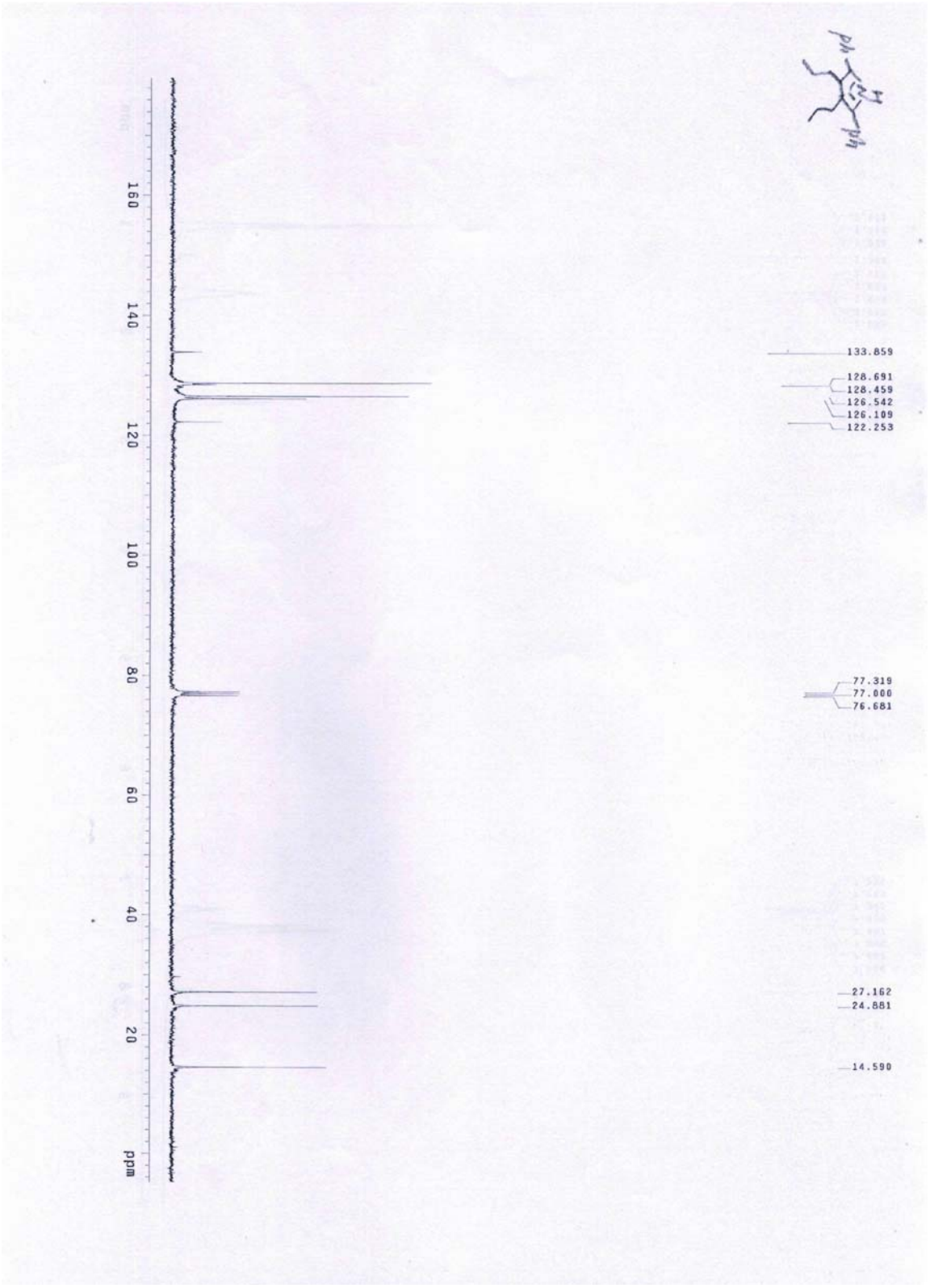


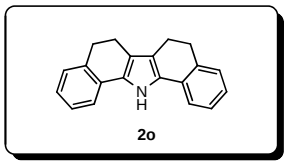




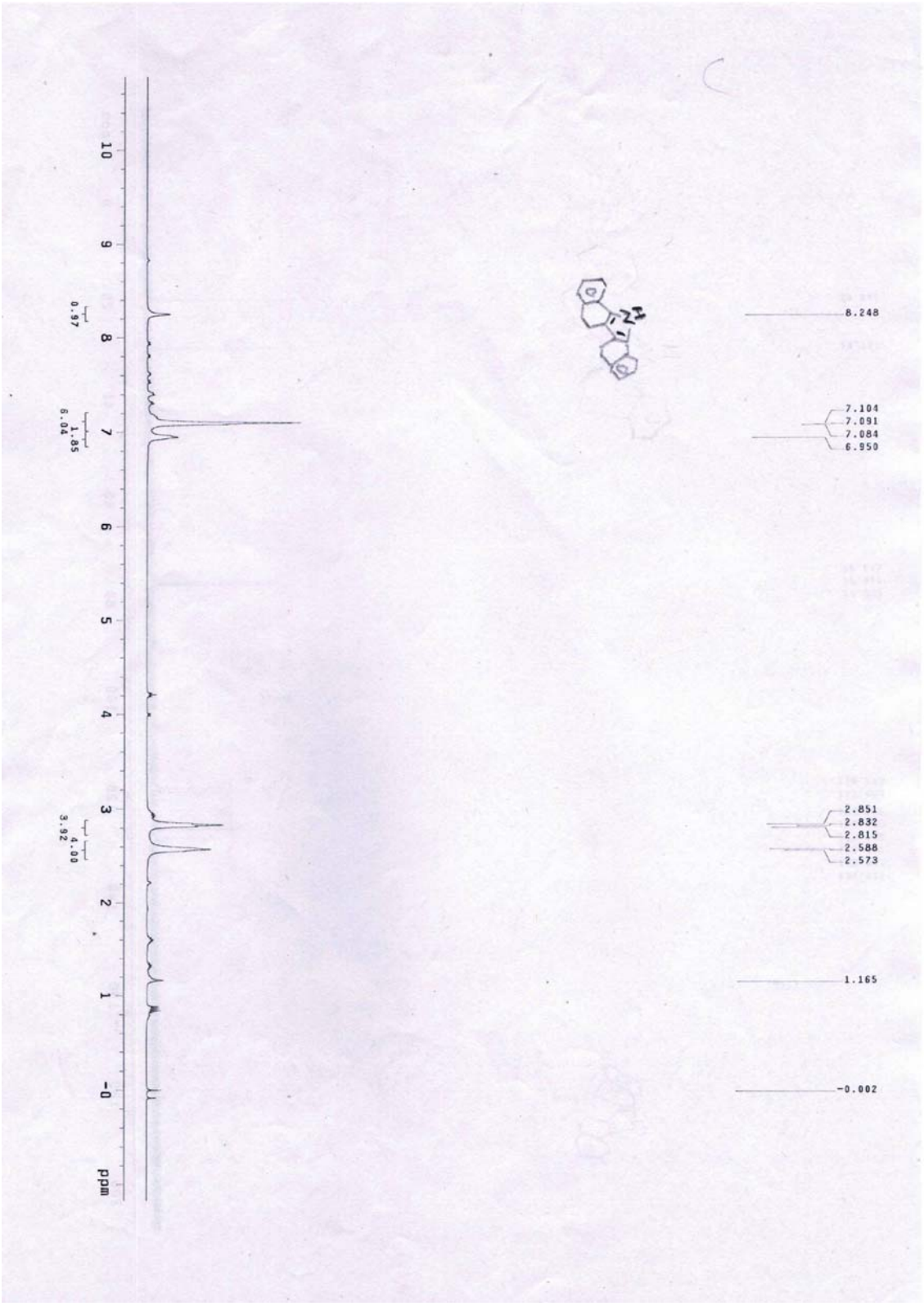


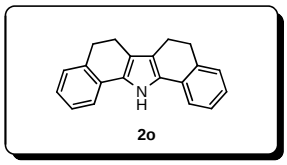
2n



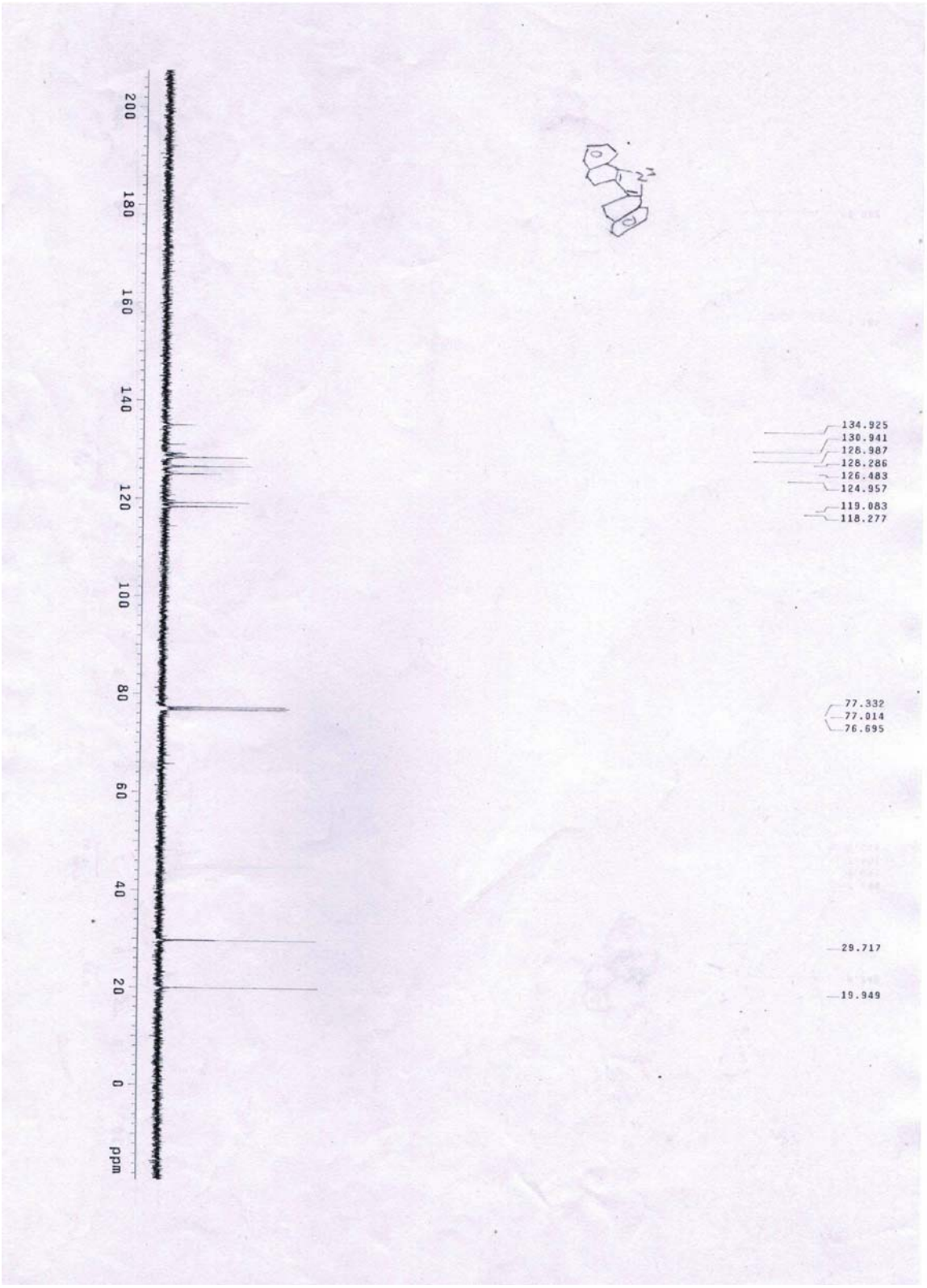


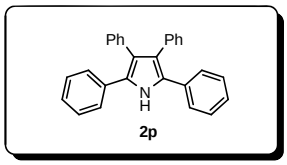
2o



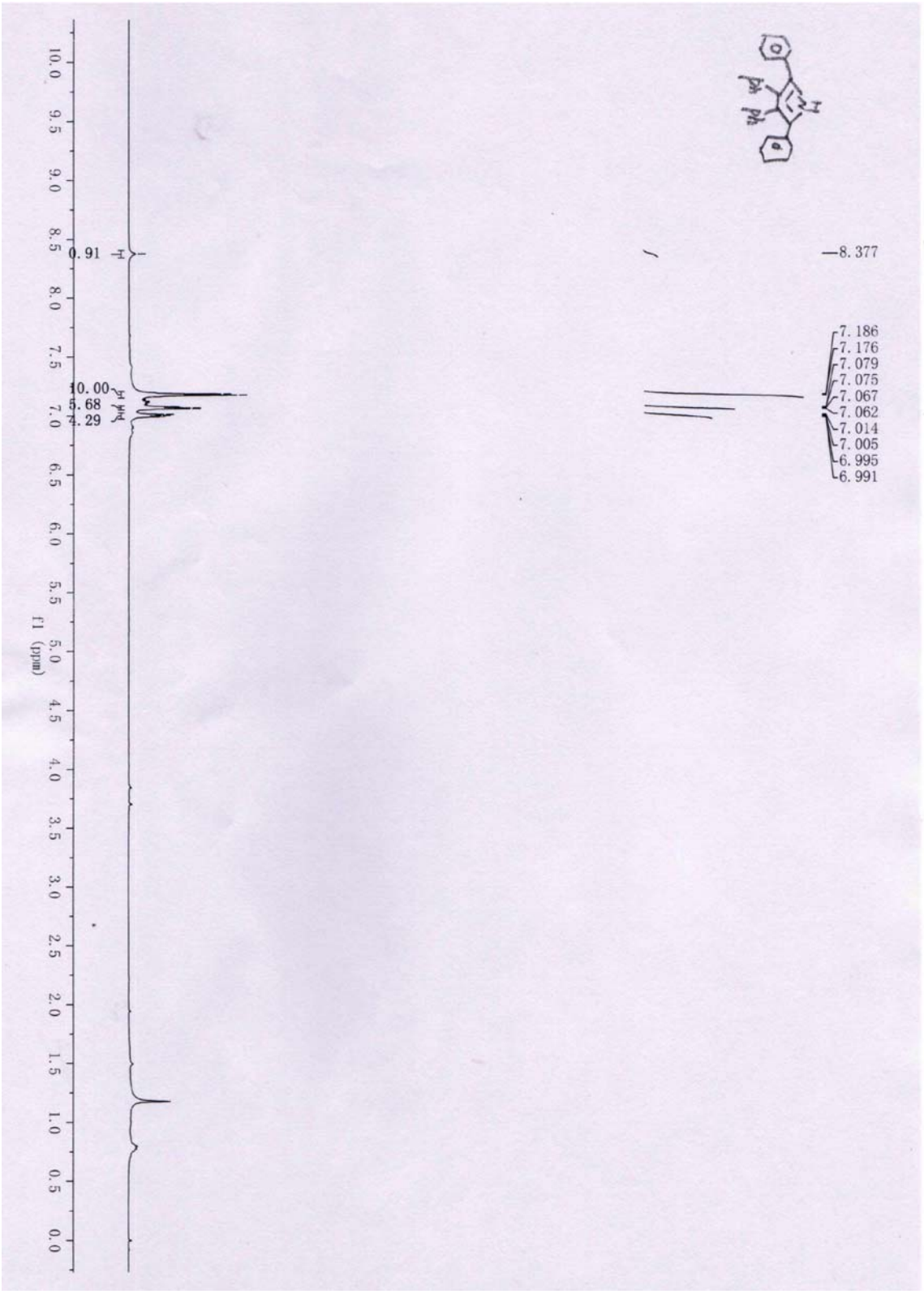


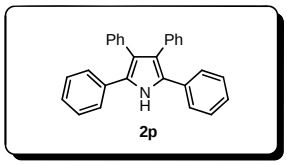
2o



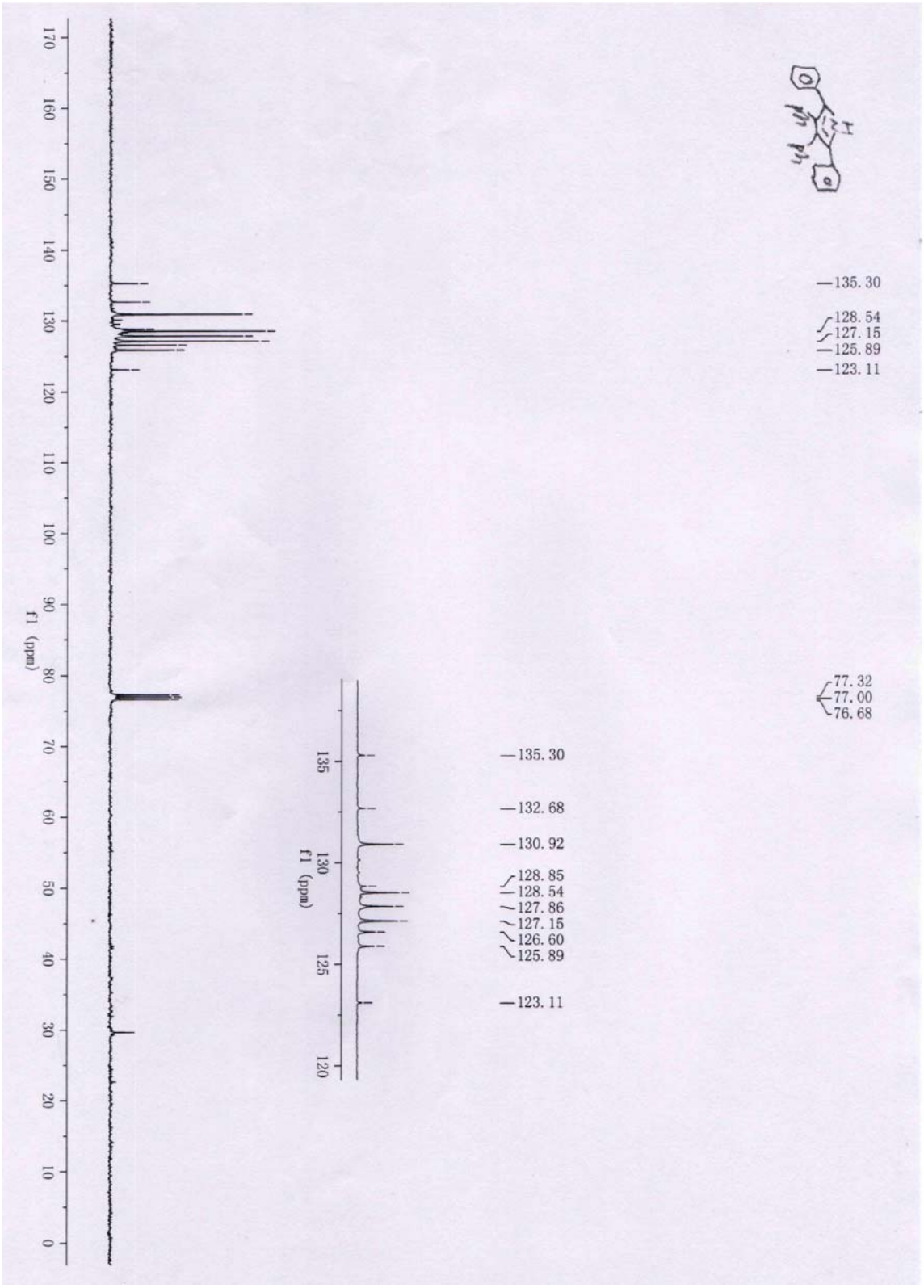


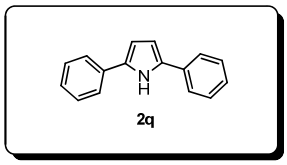
2p



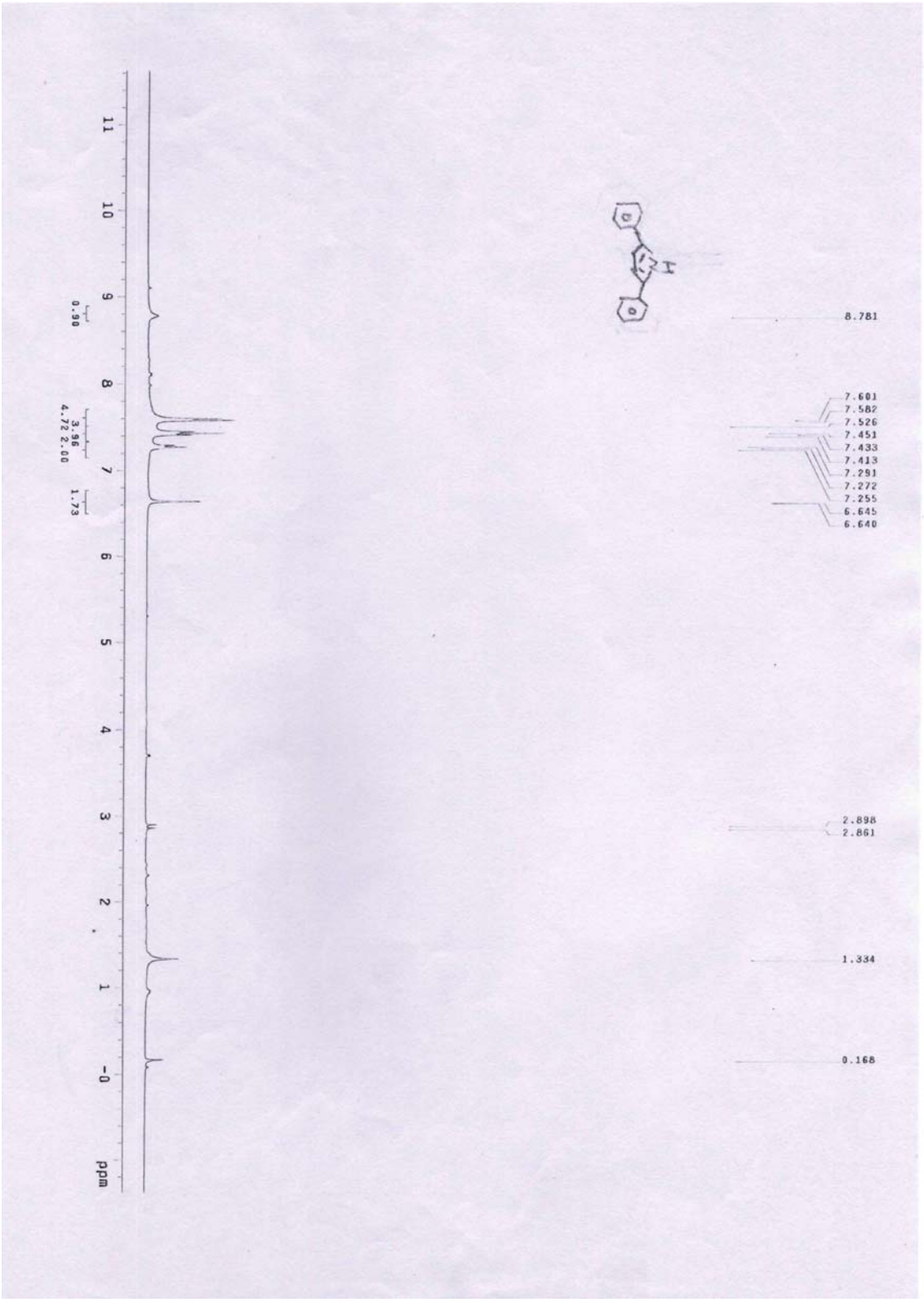


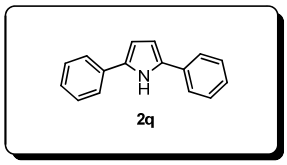
2p





2q





2q