Supporting Information: Nanosecond Photoreduction of Cytochrome P450cam by Channel-Specific Ru-diimine Electron Tunneling Wires

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Syntheses

General: NMR spectra were taken on a General Electric QE300 or Varian Mercury 300. Electrospray mass spectral data were collected on a Finnigan LCQ quadrupole ion trap mass spectrometer.

$Ru(tmbpy)_2Cl_2$ (tmbpy = 4,4'5,5'-tetramethyl-2,2'-bipyridine) was synthesized by a standard procedure.[1] THF was purified by refluxing over calcium hydride for at least 3 days followed by distillation under Argon onto activated 3 Å molecular sieves. Dimethyl sulfoxide (DMSO) was stored over calcium hydride and distilled under argon immediately before use. All other reagents were obtained from the Aldrich Chemical Co. and used as received unless otherwise noted.

4-perfluorobiphenylmethyl-4'-methyl-2,2'-bipyridine (5). 0.50 g 4,4'-dimethyl-2,2'-bipyridine (Me_2bpy) (2.7 mmol) was dissolved in 100 mL dry THF. 1.4 mL LDA (2M) in ether (Aldrich Chemical Co.) was added dropwise under an argon atmosphere. In a separate flask, 1.36 g perfluorobiphenyl (4.07 mmol) was dissolved in 30 mL dry THF. The deprotonated Me_2bpy solution was cannulated into the perfluorobiphenyl solution with fast stirring at room temperature over 20 minutes. After the reaction mixture had stirred for several hours the solvent was removed under vacuum. The residue was then dissolved in 150 mL 1:2 (v/v) CH_2Cl_2/Et_2O and extracted with 150 mL brine. The aqueous layer was extracted with 2x150 mL Et_2O, and the

combined organics were concentrated to dryness under vacuum. The crude product was then purified by flash chromatography using a 20 to 50% ethyl acetate/hexanes gradient. The desired product was the second band that eluted from the column. Yield: 247 mg, 18.4%. ^{1}H NMR ($CDCl_3$, 300 MHz) 8.57 (IH, d, J=5 Hz) 8.49 (1H, d, 5 Hz) 8.32 (1H, s) 8.14 (1H, s) 7.15 (1H, d, J=4 Hz) 7.10 (1H, d, J=4 Hz) 4.17 (2H, s) 2.39 (3H, s) ^{19}F NMR ($CDCl_3$, 300 MHz) -137.62 (2F, m) -138.49 (2F, dd, J=20, 11 Hz) -141.78 (2F, dd, J=22, 12 Hz) -150.69 (1F, t, J=28 Hz) -160.95 (2F, m).

4-(4,4'-dimethyl-2,2'-bipyridine),4'-2-aminoadamantyl-octafluorobiphenyl (6). 100 mg **5** (0.200 mmol), 30.4 mg 2-amino-adamantane (0.200 mmol), and 32 mg K_2CO_3 were added to 0.2 mL dry DMSO. The reaction was heated under argon at 80 °C for 16 hours, then at 110 °C for 6 hours. The reaction mixture was diluted with 100 mL 1:2 v/v CH_2Cl_2/Et_2O, and extracted once with saturated aqueous Na_2CO_3. The organic phase was concentrated to dryness under reduced pressure. The crude product was purified by column chromatography using 2% MeOH in CH_2Cl_2 as the eluent. Yield: 99 mg (76.4 %). ^{1}H NMR ($CDCl_3$, 300 MHz) 8.55 (1H, d, J=5 Hz) 8.48 (1H, d, 5 Hz), 8.29 (1H, s) 8.14 (1H, s) 7.13 (1H, d, J=5 Hz) 7.08 (1H, d, J=4 Hz) 4.38 (1H, m) 4.19 (2H, s) 3.87 (1H, m) 2.43 (3H, s) 1.96 (2H, m) 1.83 (3H, m) 1.77 (1H, m) 1.69 (6 H, m) 1.61 (1H, m) 1.56 (1H, m) ^{19}F NMR ($CDCl_3$, 300 MHz) -138.91 (2F, dd, J=22, 11Hz) -141.59 (2F, m) -143.01 (2F, dd, J=21, 13 Hz) -160.77 (2F, d, J=19 Hz).

4-(4,4'-dimethyl-2,2'-bipyridine),4'-N-imidazole-octafluorobiphenyl (7). 40 mg **5** (0.08 mmol), 5.7 mg imidazole (0.08 mmol), and 13 mg K_2CO_3 were dissolved in 0.08 mL dry DMSO. The reaction was stirred at room temperature for 3 days, after which the reaction mixture was diluted with 10 mL each CH_2Cl_2 and H_2O. The aqueous layer was washed three times with 10

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[1] Mines, G. A.; Bjerrum, M. J.; Hill, M. G.; Casimiro, D. R.; Chang, I.-J.; Winkler, J. R.; Gray, H. B. *J. Am. Chem. Soc.* **1996**, *118*, 1961-1965.

mL CH_2Cl_2. The combined organics were evaporated to dryness under reduced pressure, and the crude product was purified by column chromatography using 4% MeOH in CH_2Cl_2 as the eluent. Yield: 26.8 mg (61%) ^{1}H NMR (CD_2Cl_2, 300 MHz) 8.59 (1H, d, J=5 Hz) 8.50 (1H, d, J=5 Hz) 8.39 (1H, s) 8.26 (1H, s) 7.81 (1H, m) 7.29 (1H, m) 7.26 (1H, m) 7.22 (1H, d, J=5 Hz) 7.15 (1H, d, J=4 Hz) 4.25 (2H, s) 2.42 (3H, s) ^{19}F NMR (CD_2Cl_2, 300 MHz) -135.38 (2F, dd, J=22, 11 Hz) -137.27 (2F, dd, 22, 11 Hz) -140.49 (2F, J=22, 11 Hz) -146.80 (2F, J=25, 11 Hz).

[Ru-F$_8$bp-Ad](NO$_3$)$_2$ (1). 24.5 mg $Ru(bpy)_2Cl_2$ (0.048 mmol) and 30 mg **6** (0.048 mmol) were dissolved in 3 mL 6:3:1 ethanol:chloroform:water. Oxygen was removed by three cycles of freeze-pump-thawing. The reaction mixture was heated to 80° C for 14 h, after which the solvent was removed under vacuum. The desired product was isolated using flash chromatography, using 12:2:3 acetonitrile:water:ethanol saturated with KNO_3 as eluent. The fractions containing product were concentrated to dryness under reduced pressure, and the product was extracted from the resulting salt with CH_2Cl_2. The resulting solution was filtered, then evaporated to dryness. The product was redissolved in CH_2Cl_2 and filtered over a 0.45 μM teflon filter (Amicon). Removal of the solvent gave the product as a red, amorphous solid. Yield: 40 mg (70 %). ^{1}H NMR (CD_2Cl_2, 300 MHz) 8.56 (4H, m) 8.46 (1H, s) 8.37 (1H, s) 8.03 (4H, m) 7.74 (4H, m) 7.64 (1H, d, J=6 Hz) 7.57 (1H, d, J=6 Hz) 7.41 (4H, m) 7.28 (2H, t, J=5 Hz) 4.53 (1H, m) 4.38 (2H, s) 3.97 (1H, m) 2.56 (3H, s) 2.01 (2H, m) 1.85 (4H, m) 1.77 (2H, m) 1.73 (4H, m) 1.68 (1H, s) 1.63 (1H, s) ^{19}F NMR (CD_2Cl_2, 300 MHz) -137.21 (2F, dd, J=22, 11) -140.71 (2F, dd, J=24, 11 Hz) -141.11 (2F, dd, J=22, 13) -159.18 (2F, d, J=15 Hz) ESI-MS m/z 521.7 (M+2).

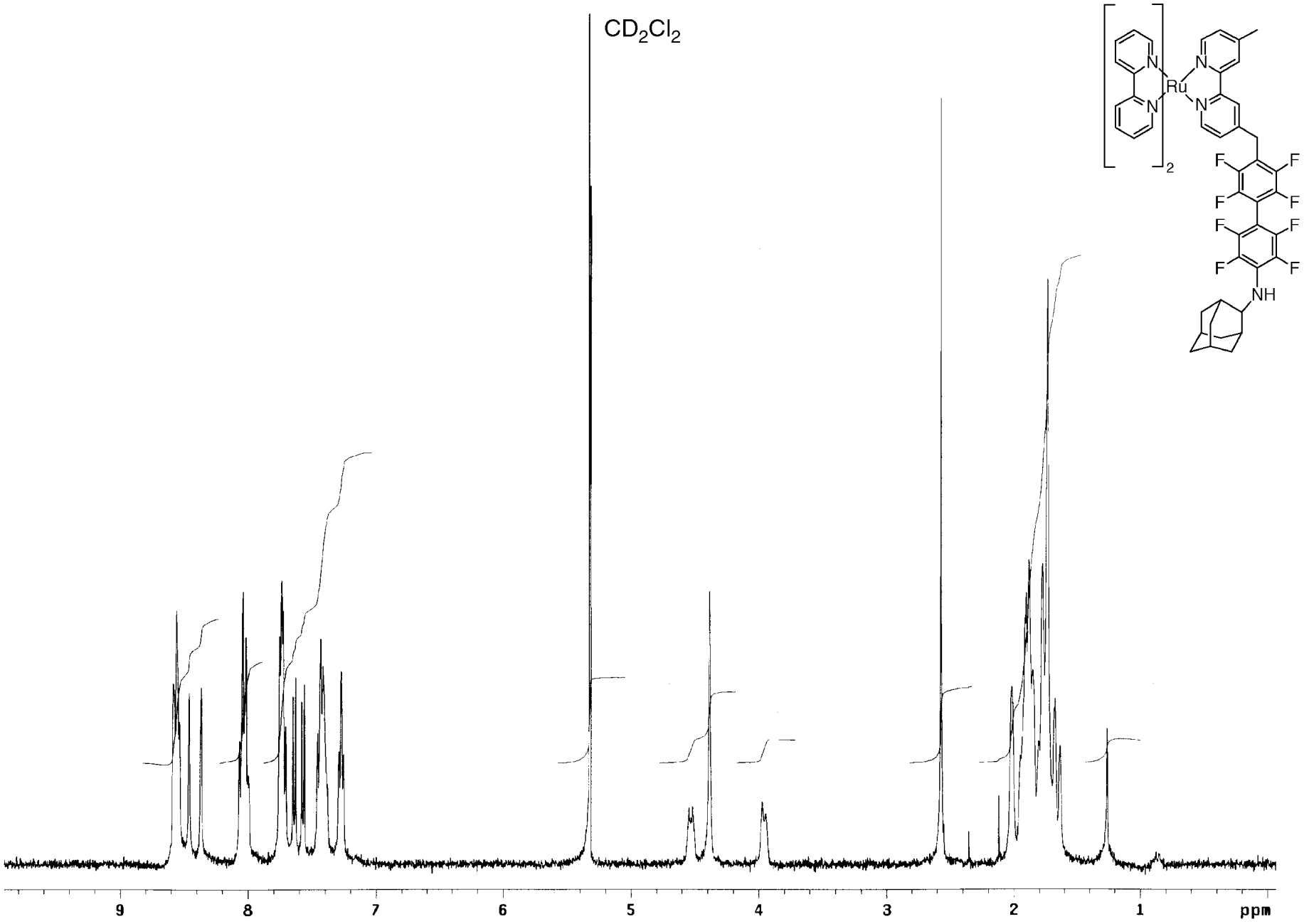
[Ru-F$_8$bp-im](NO$_3$)$_2$ (2). This compound was synthesized in analogy to **1** from 26.8 mg **7** (0.049 mmol) and 25.5 mg $Ru(bpy)_2Cl_2$ (0.049 mmol). Yield: 15.3 mg (28.8%) ^{1}H NMR (acetone, 300 MHz) 8.61 (4H, m) 8.50 (1H, s) 8.50 (1H, s) 8.06 (4H, m) 7.79 (1H, d, J=6 Hz)

7.76 (1H, s) 7.74 (4H, m) 7.64 (1H, d, J=6 Hz) 7.54 (1H, d, J=6 Hz) 7.49 (4H, m) 7.29 (1H, m) 7.25 (1H, s) 4.45 (2H, s) 2.58 (3H, s) ^{19}F NMR (CD_2Cl_2, 300 MHz) -135.43 (2F, dd, J=22, 11) -136.51 (2F, d, J=22, 11 Hz) -139.74 (2F, dd, J=22, 11 Hz) -146.55 (2F, dd, J=22, 10.0 Hz) ESI-MS m/z 480 (M+2).

[tmRu-F$_8$bp-im](Cl)$_2$ (3). 17.6 mg Ru(tmbpy)$_2$Cl$_2$ (29.8 μmol) and 15.2 mg **7** (29.8 μmol) were dissolved in a mixture of 1mL THF, 1mL EtOH, and 0.25 mL water. The reaction mixture was deaerated using 3 freeze-pump-thaw cycles and heated to 60 °C under argon for 12 h. The reaction mixture was concentrated under reduced pressure, and purified using flash chromatography with a mixture of 18:1:1 acetonitrile:EtOH:water saturated with KNO_3 as eluent. The fractions containing product were pooled and concentrated to dryness, then extracted with CH_2Cl_2 to yield the product. Yield: 10.4 mg (30%). The nitrate counterion was exchanged for chloride using a CM Sepharose cation exchange column (2x13 cm) and 1M NaCl as eluent. The fractions containing product were diluted by 1/3 with brine and extracted with two 100-mL portions of CH_2Cl_2. The CH_2Cl_2 solutions were pooled and concentrated to dryness. ^{1}H NMR (acetone D_6, 300 MHz) 9.58 (1H, s) 9.27 (1H, s) 9.08 (2H, s) 9.07 (1H, s) 9.06(1H, s) 8.03 (1H, s) 7.83 (1H, d, J=6 Hz) 7.80 (1H, d, J=6 Hz) 7.66 (1H, s) 7.61 (1H, s) 7.59 (1H, s) 7.58 (1H, m) 7.48 (1H, s) 7.37 (1H, d, J=7 Hz) 7.35 (1H, d, J=7 Hz) 7.25 (1H, m) 4.63 (2H, s) 2.56 (3H, s) 2.49 (6H, s) 2.48 (6H, s) 2.10 (12H, m) ^{19}F NMR (acetone D_6, 300 MHz) -139.85 (2F, dd, J=22, 11 Ha) -140.52 (2F, dd, J=22, 11 Hz) -142.68 (2F, dd, J=19, 11 Hz) -149.72 (2F, dd, J=22, 11 Hz) ESI-MS m/z 536.2 (M+2).

[tmRu-F$_9$bp(Cl)$_2$ (4). 20 mg Ru(tmbpy)$_2$Cl$_2$ (31.6 μmol) and 16.5 mg **5** (33.2 μmol) were dissolved in a mixture of 1mL THF, 1mL EtOH and 0.25 mL water. Oxygen was removed using three freeze-pump-thaw cycles. The reaction was then heated to 65 °C under argon for 16 h. The reaction mixture was diluted with 50 mL CH_2Cl_2, and washed with 50 mL sat. NaCl

solution. The aqueous phase was washed with 3 25-mL portions of CH_2Cl_2, and the combined CH_2Cl_2 solutions were concentrated to dryness under vacuum. The product was purified by flash chromatography using 83:10:7 acetonitrile:ethanol:water saturated with KNO_3 as eluent. The fractions containing product were pooled and concentrated under reduced pressure until only water remained, diluted with 15 mL saturated NaCl solution, and washed with 3 25-mL portions of CH_2Cl_2. The CH_2Cl_2 solutions were combined and concentrated under reduced pressure to give the red, luminescent product. Yield was > 90 %. ^{1}H NMR (acetone D_6, 300 MHz) 9.20 (1H, s) 9.11 (1H, s) 8.95 (1H, s) 7.85 (4H, s) 7.84 (1H, d, J=4 Hz) 7.81 (1H, d, J=6 Hz) 7.68 (1H, s) 7.61 (1H, s) 7.60 (1H, s) 7.47 (1H, s) 7.37 (1H, d, J=7 Hz) 7.35 (1H, d, J=7 Hz) 4.60 (2H, s) 2.55 (3H, s) 2.48 (6H, s) 2.47 (6H, s) 2.09 (12H, m) ^{19}F NMR (acetone D_6, 300 MHz) -140.05 (2F, m) -140.63 (2F, m) -142.82 (2F, m) -143.92 (1F, t, J = 21 Hz) -153.82 (2F, m). ESI-MS m/z 512 (M+2).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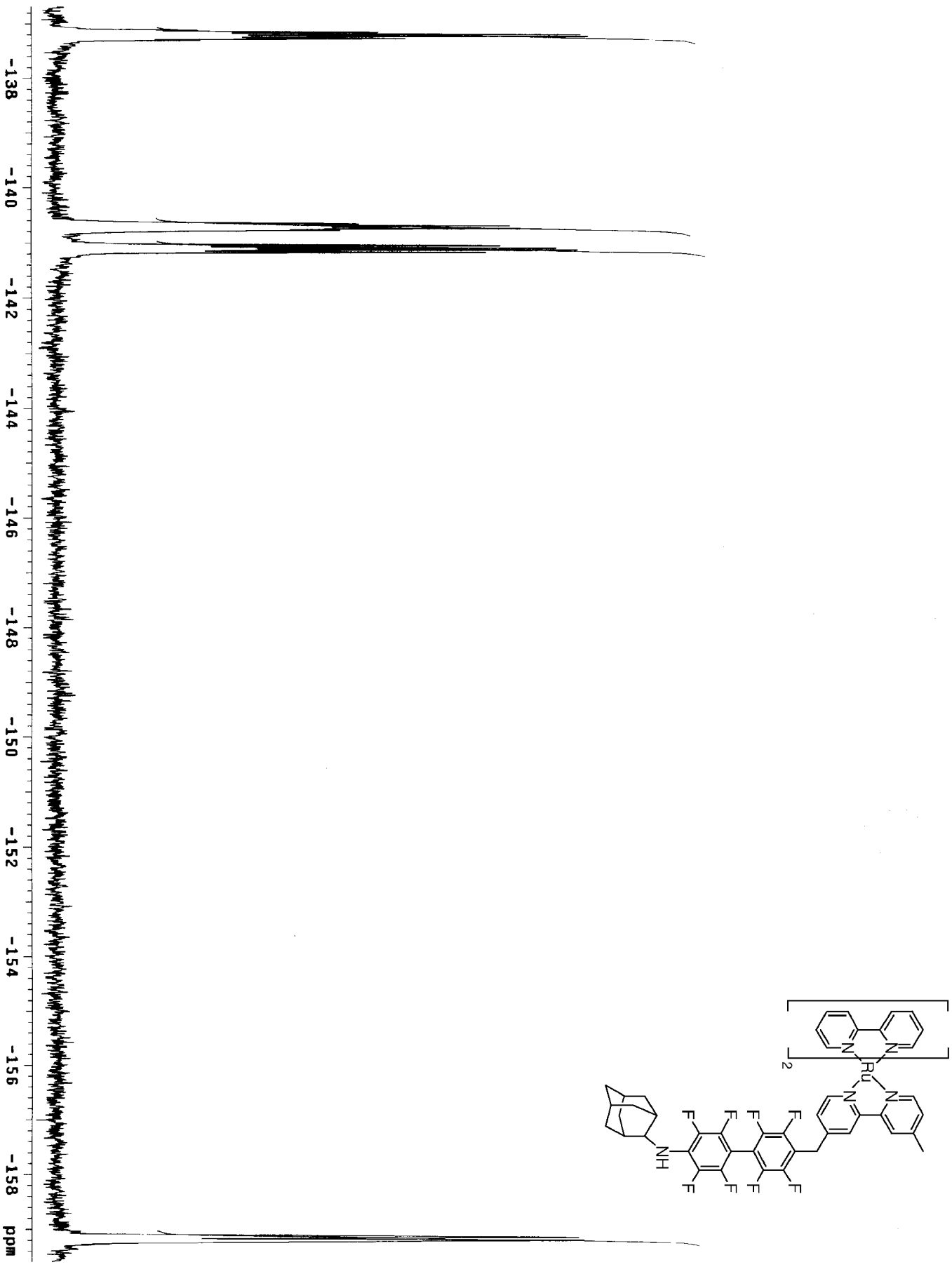
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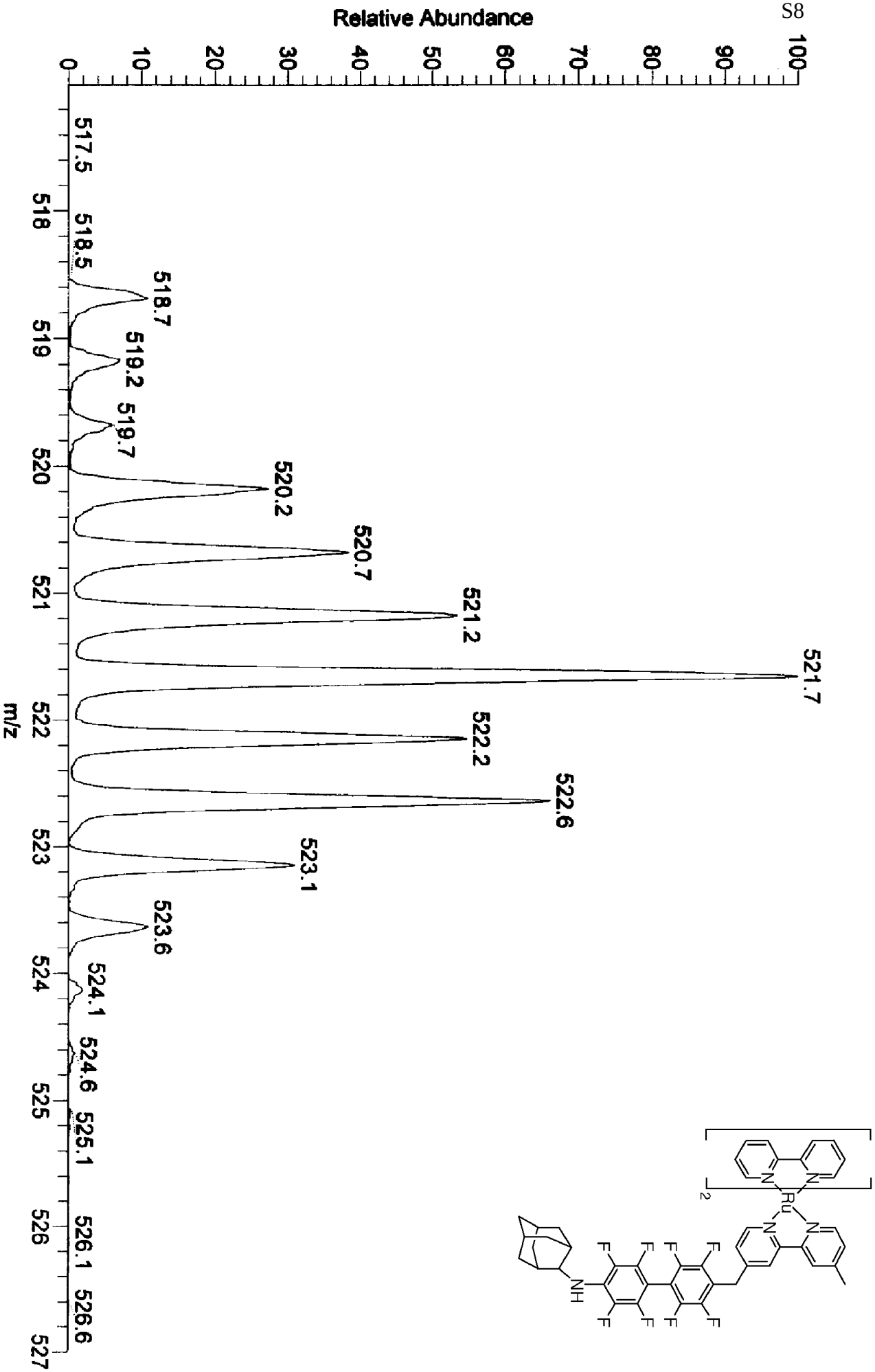
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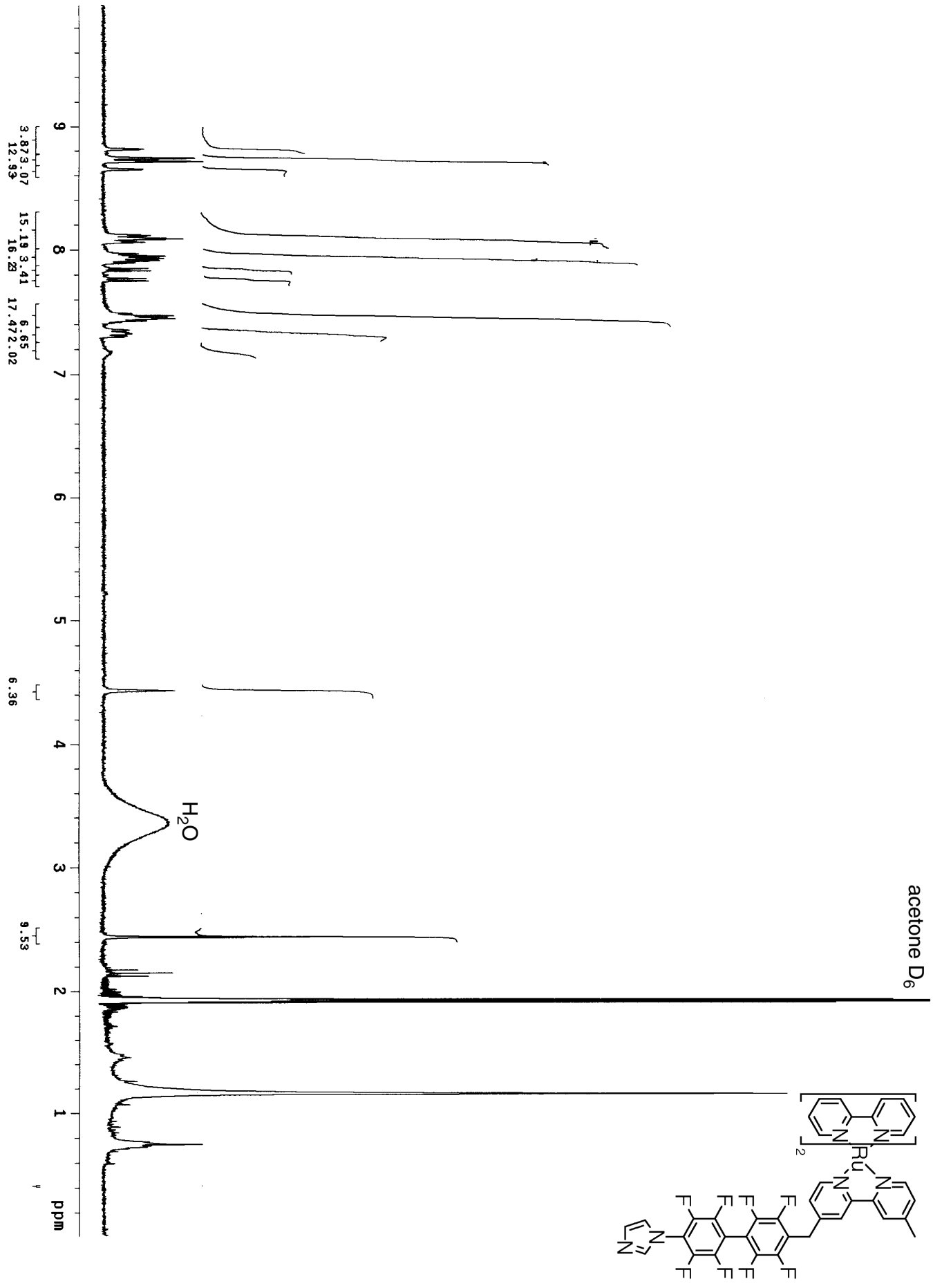
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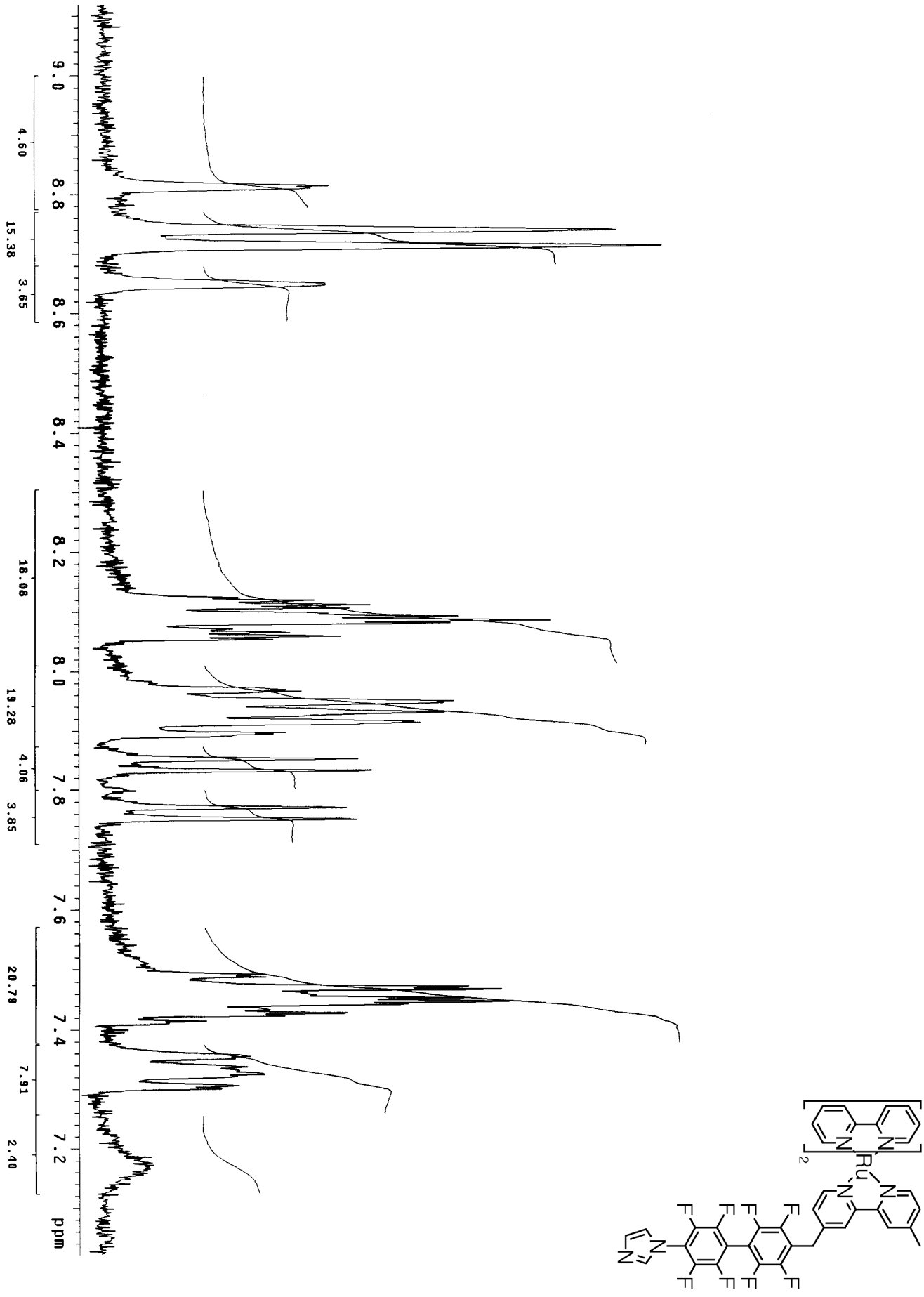
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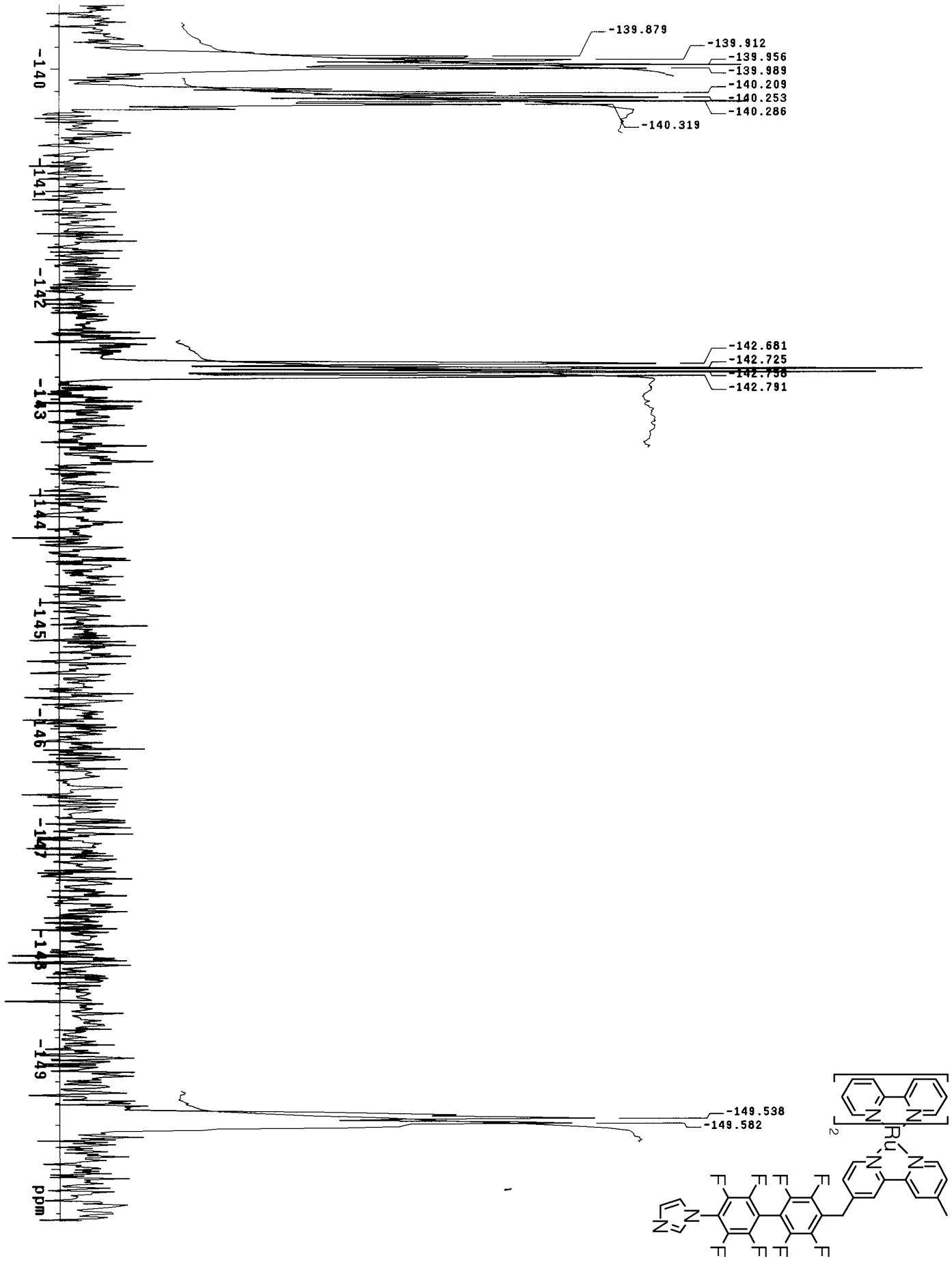
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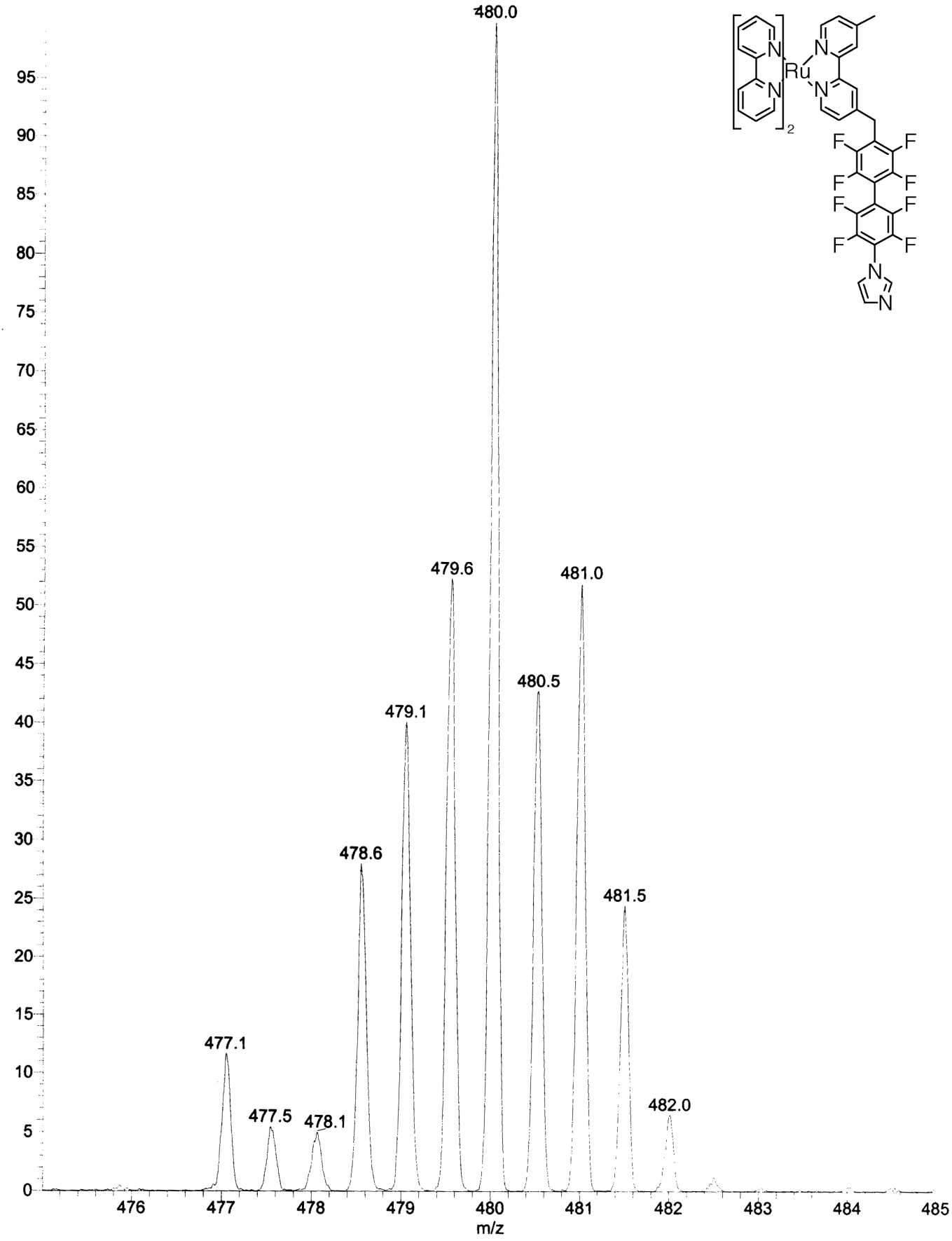
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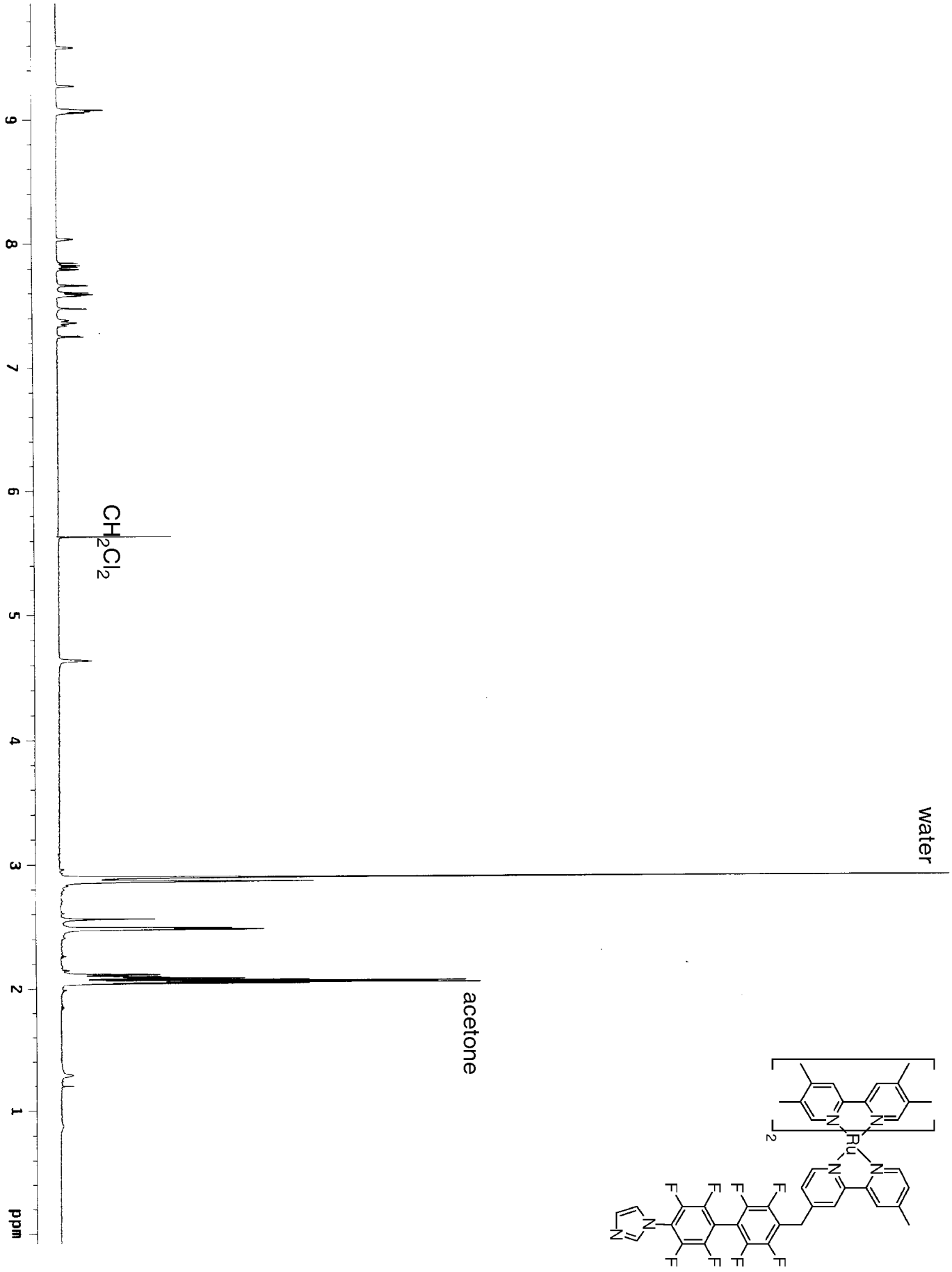
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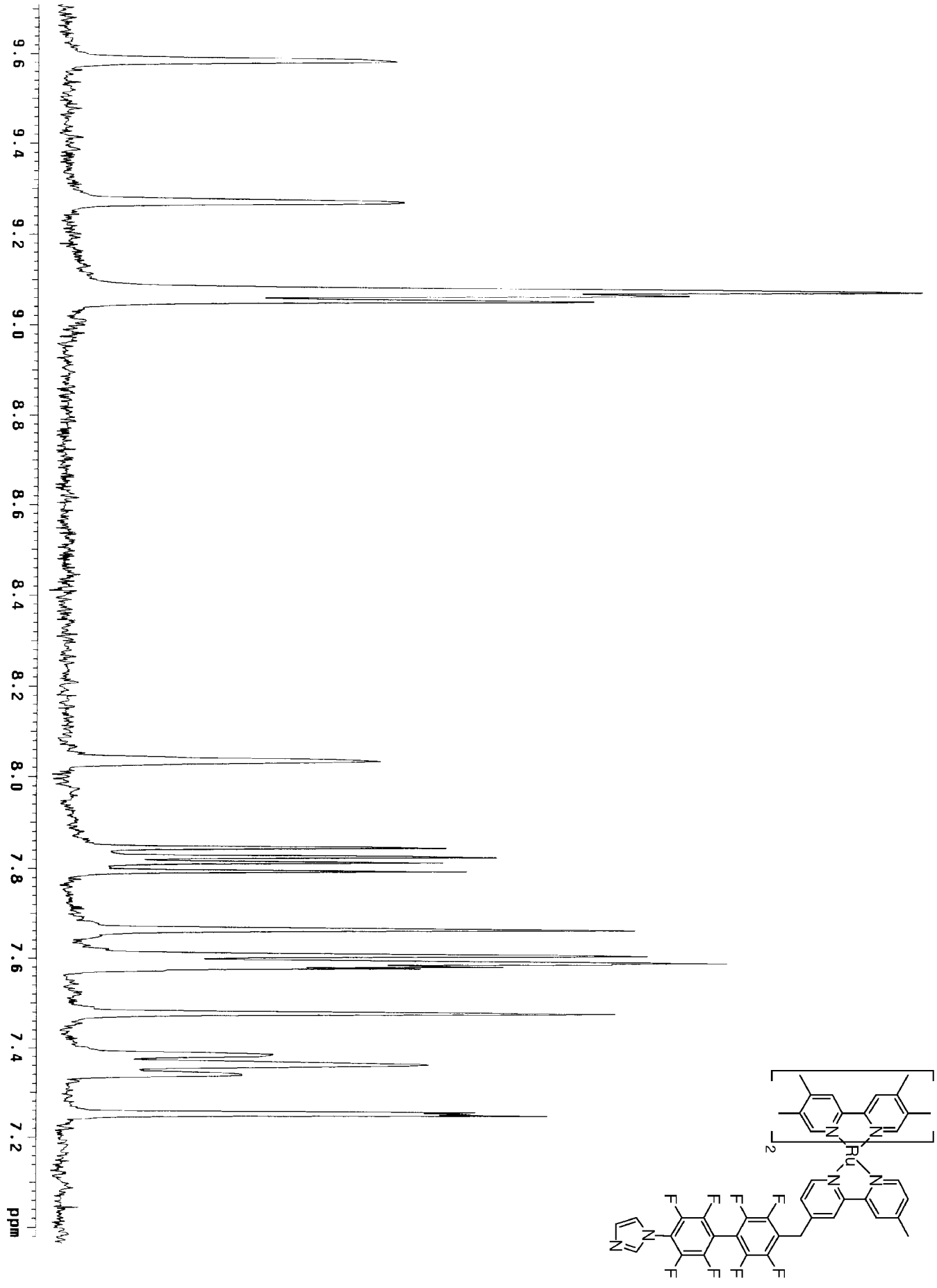
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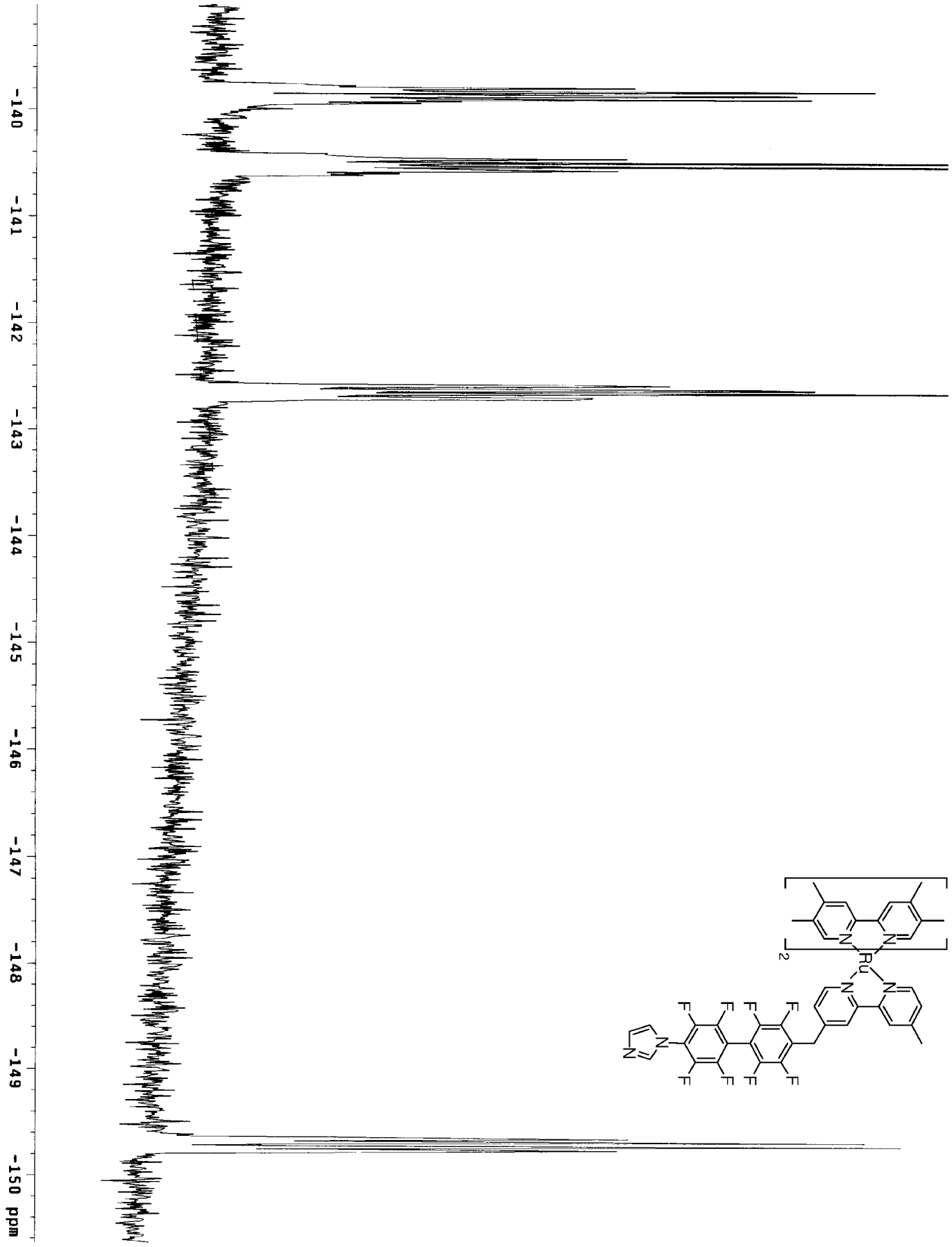
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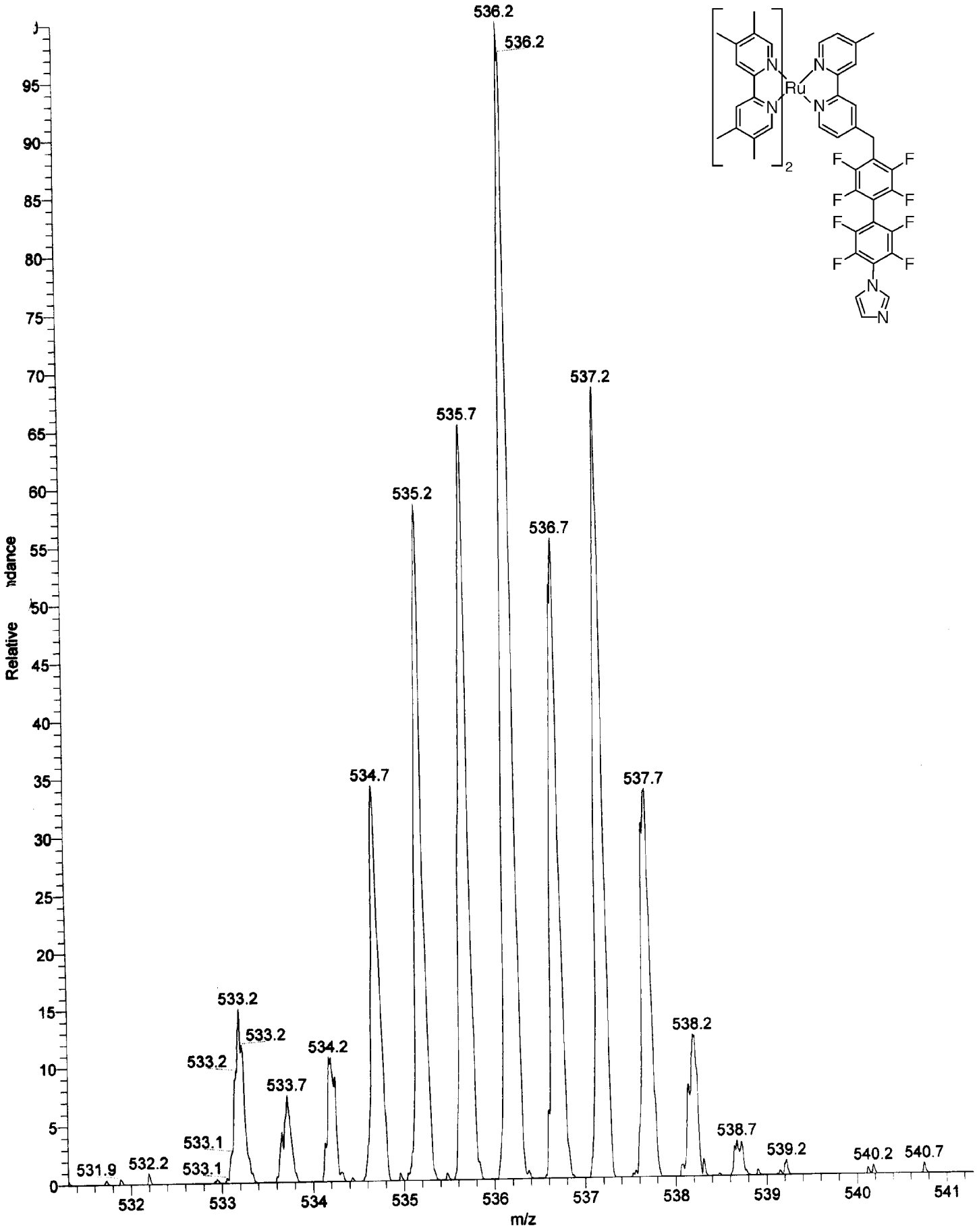
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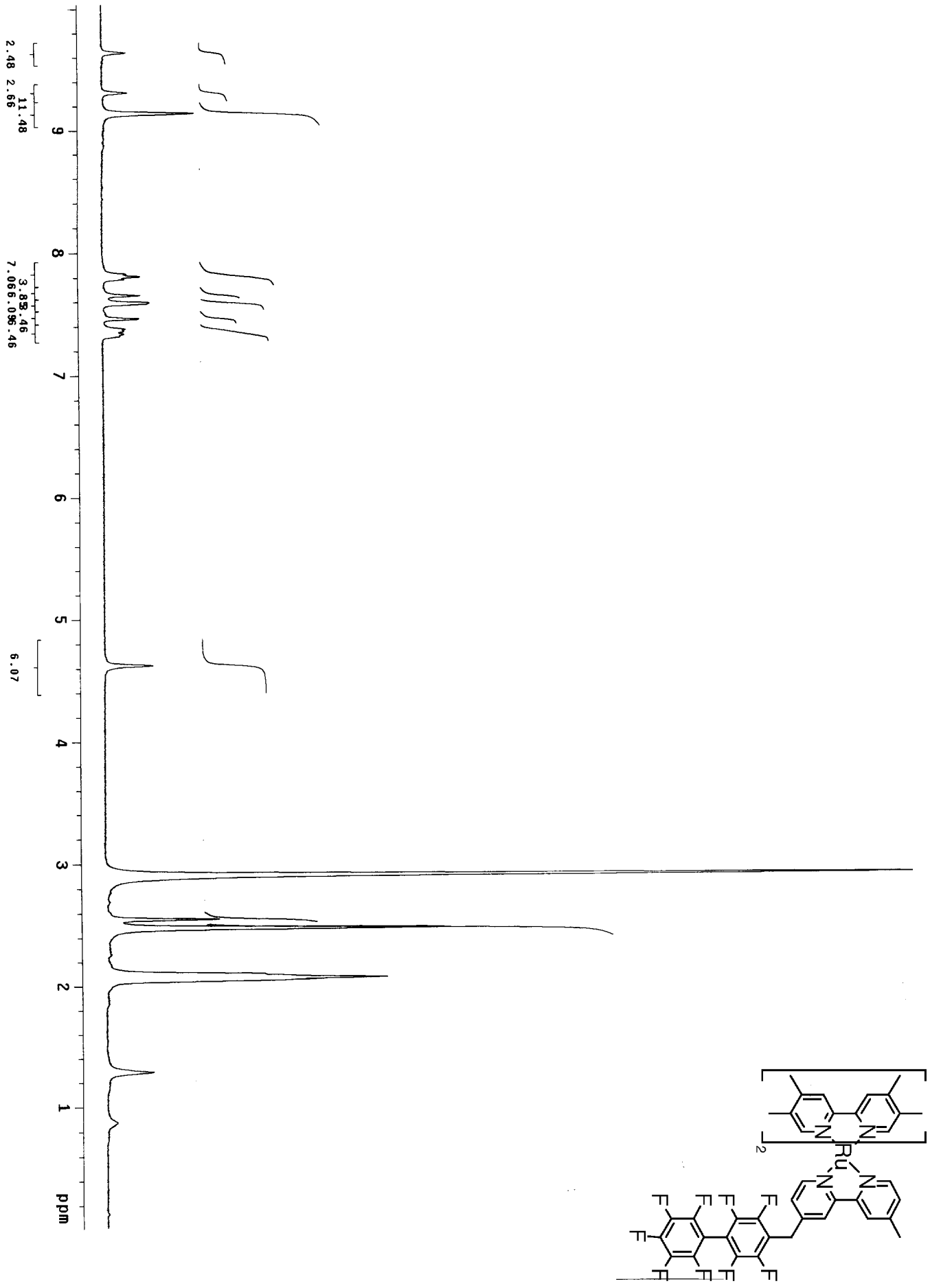
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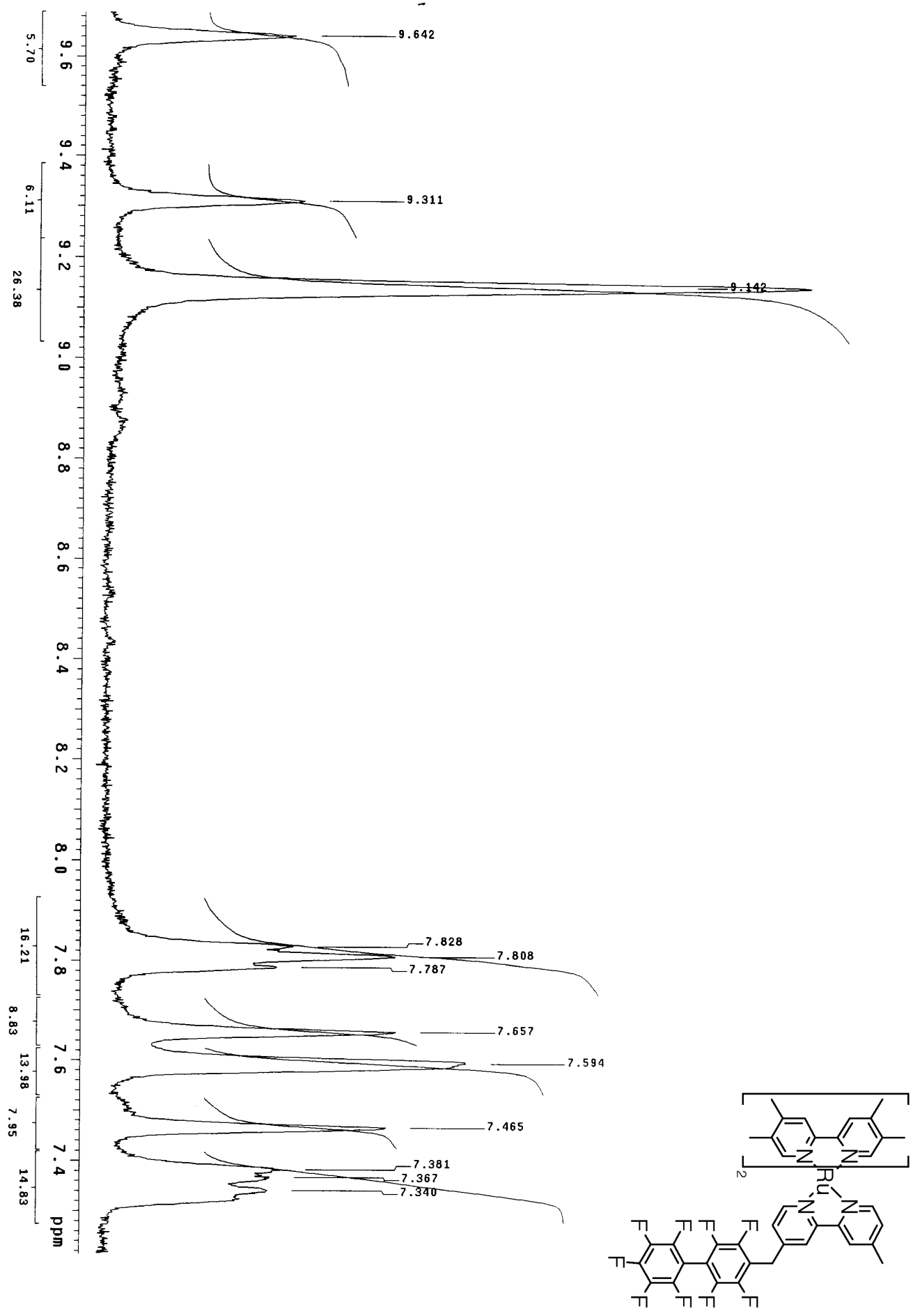
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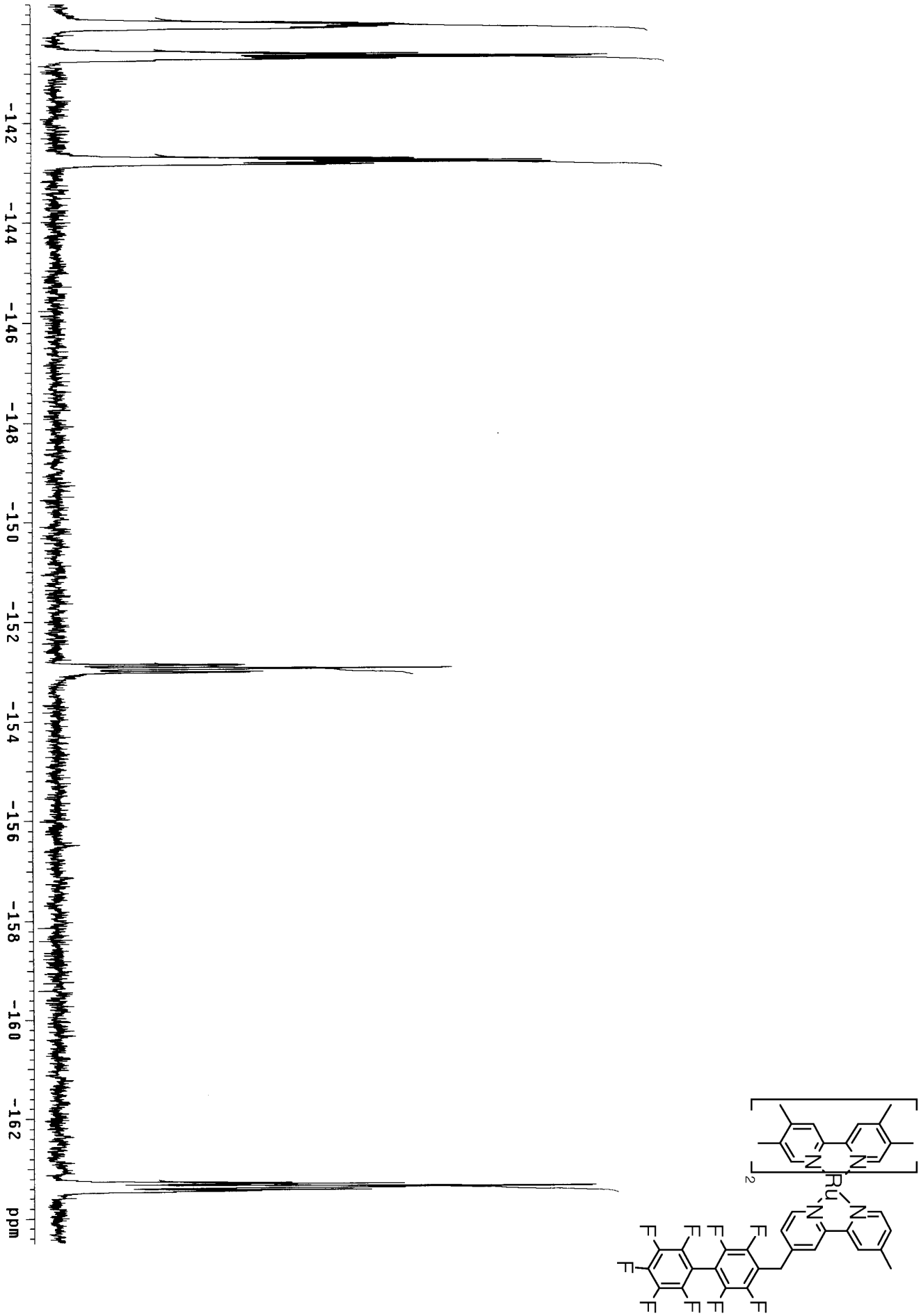
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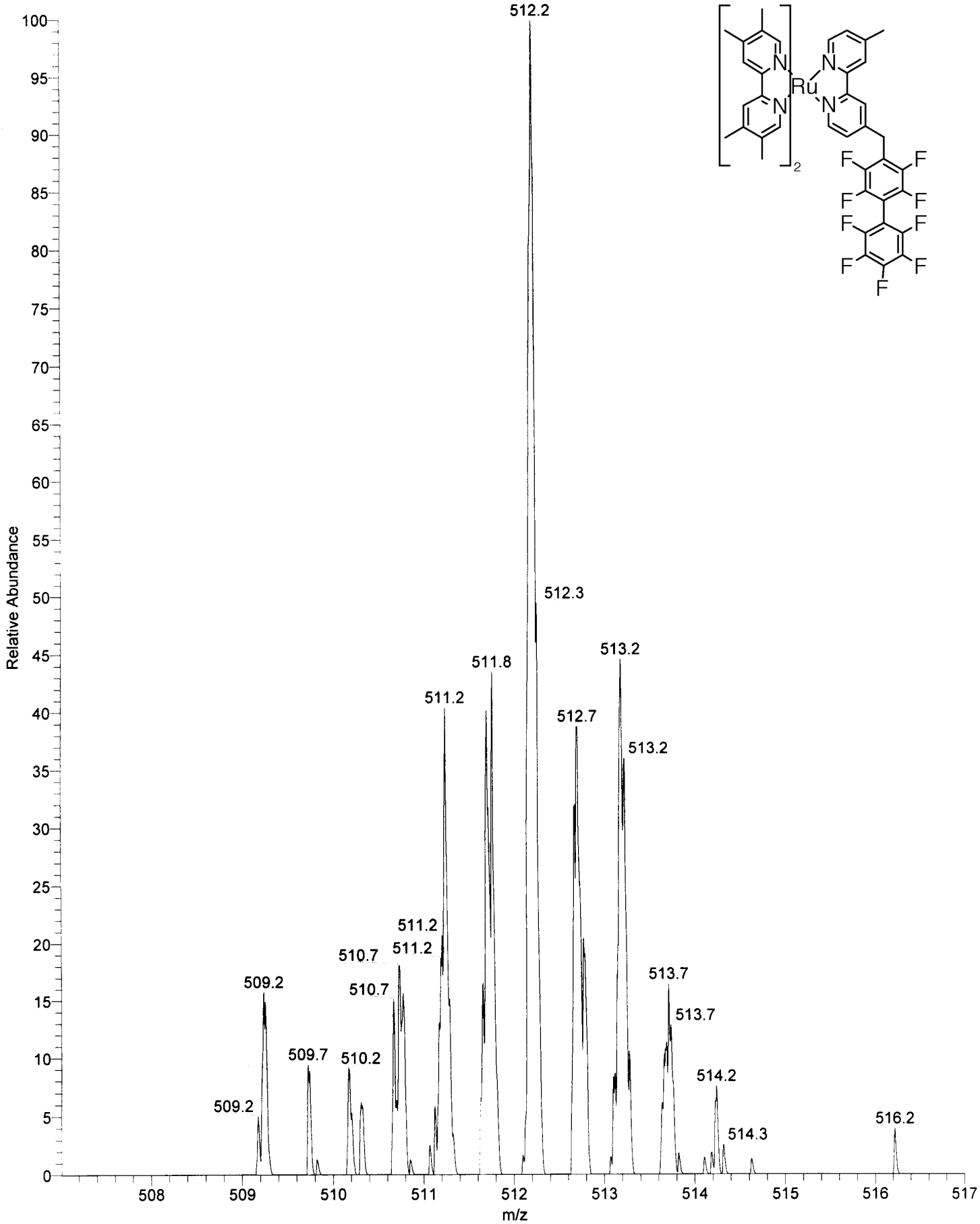
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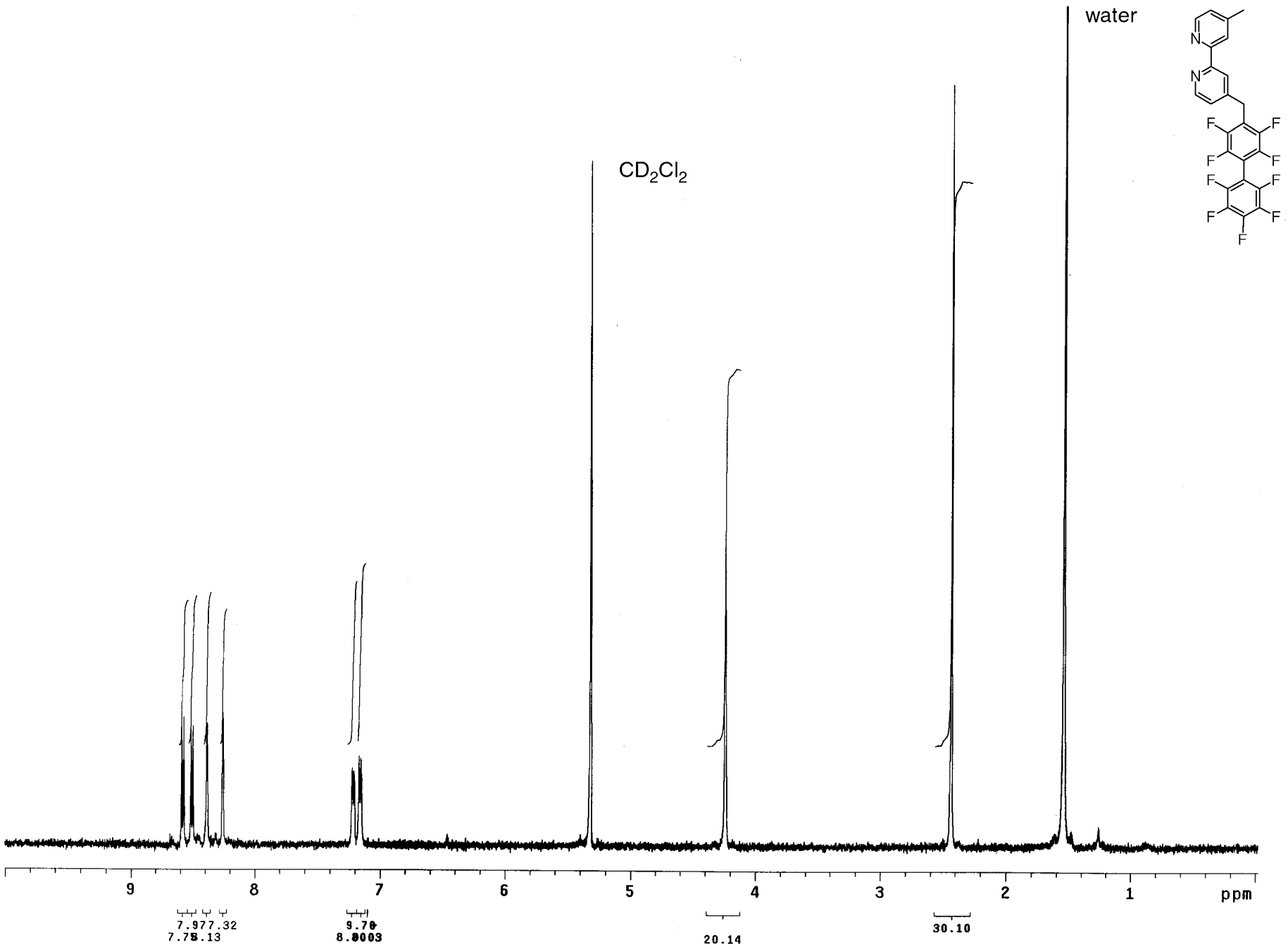
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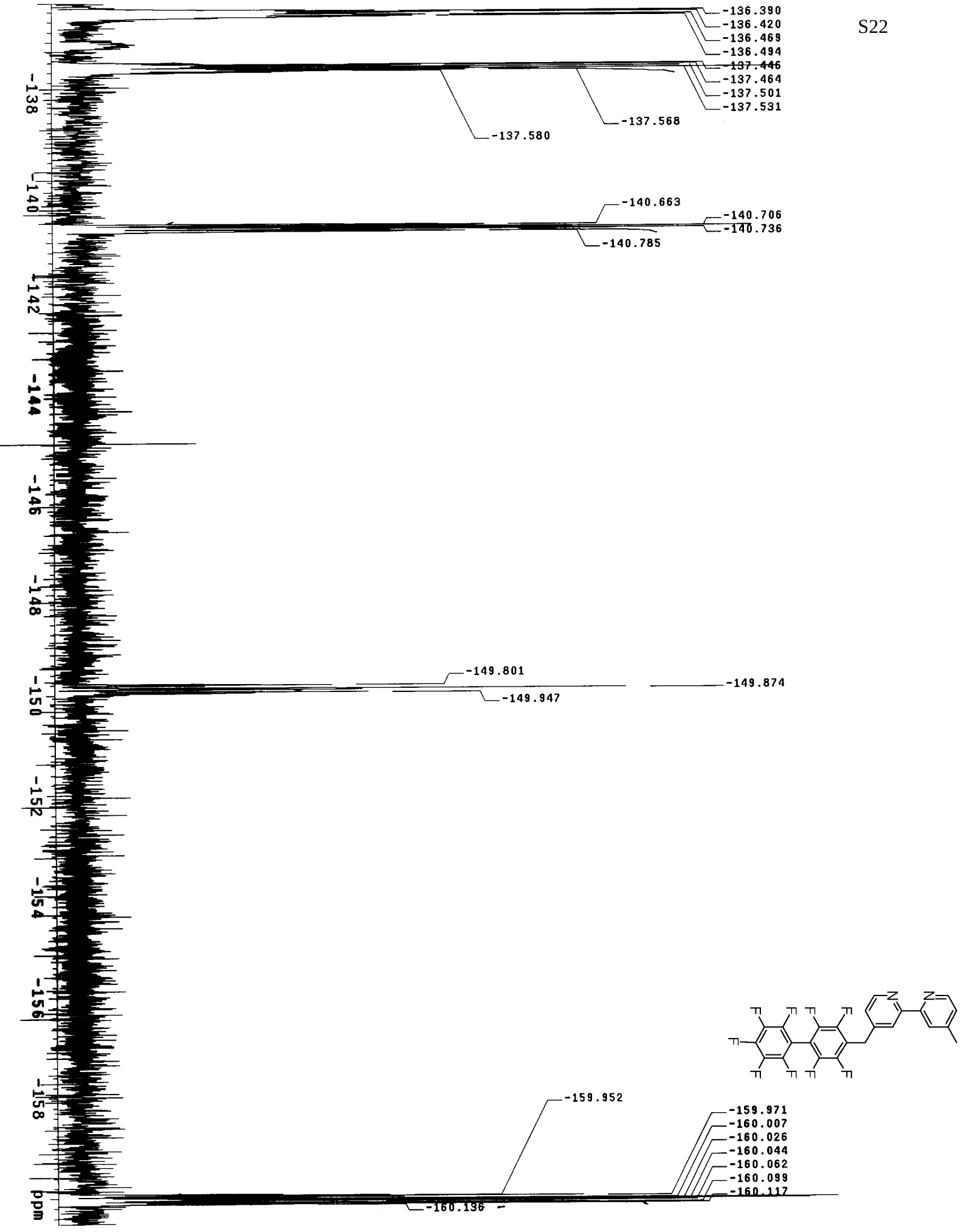
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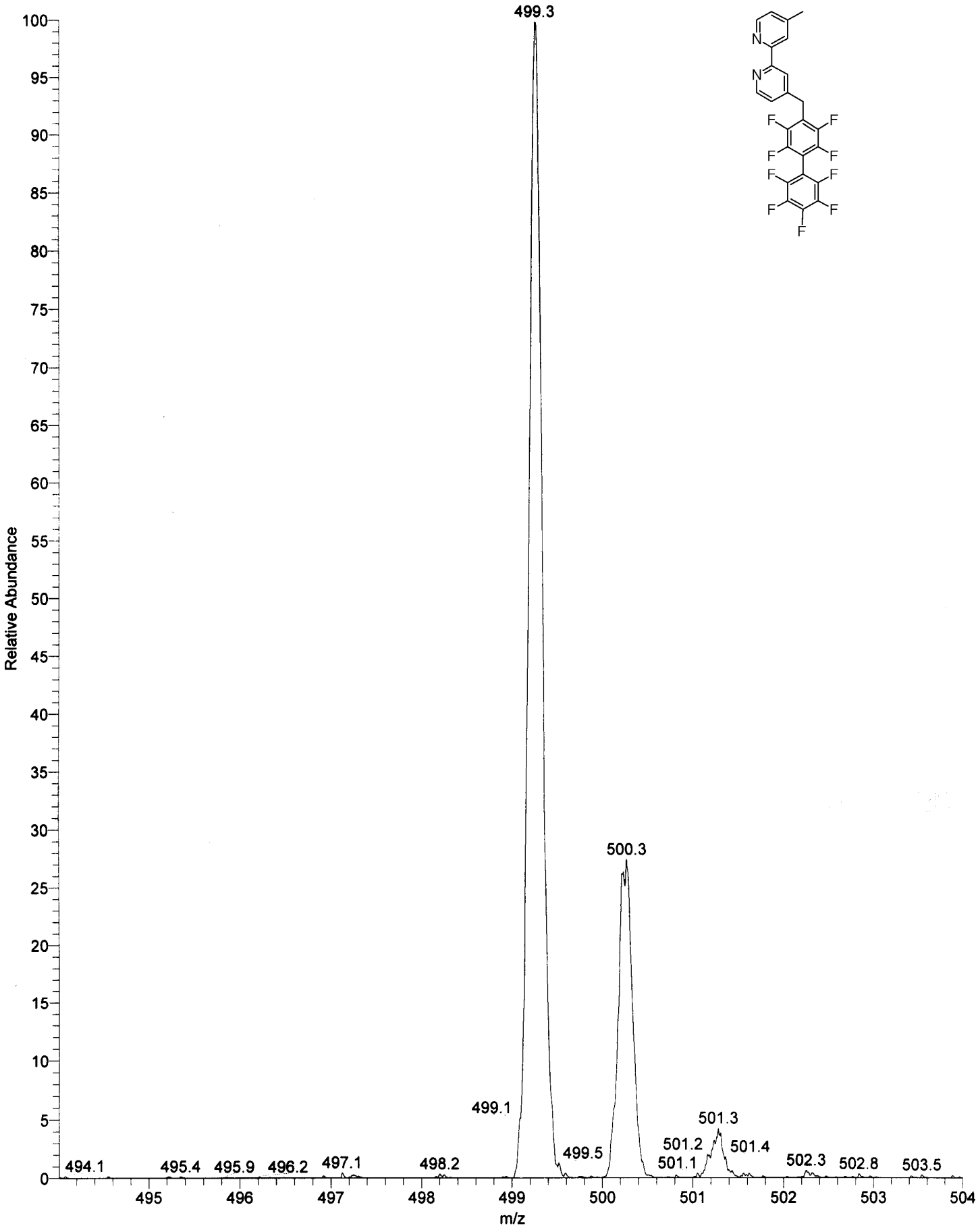
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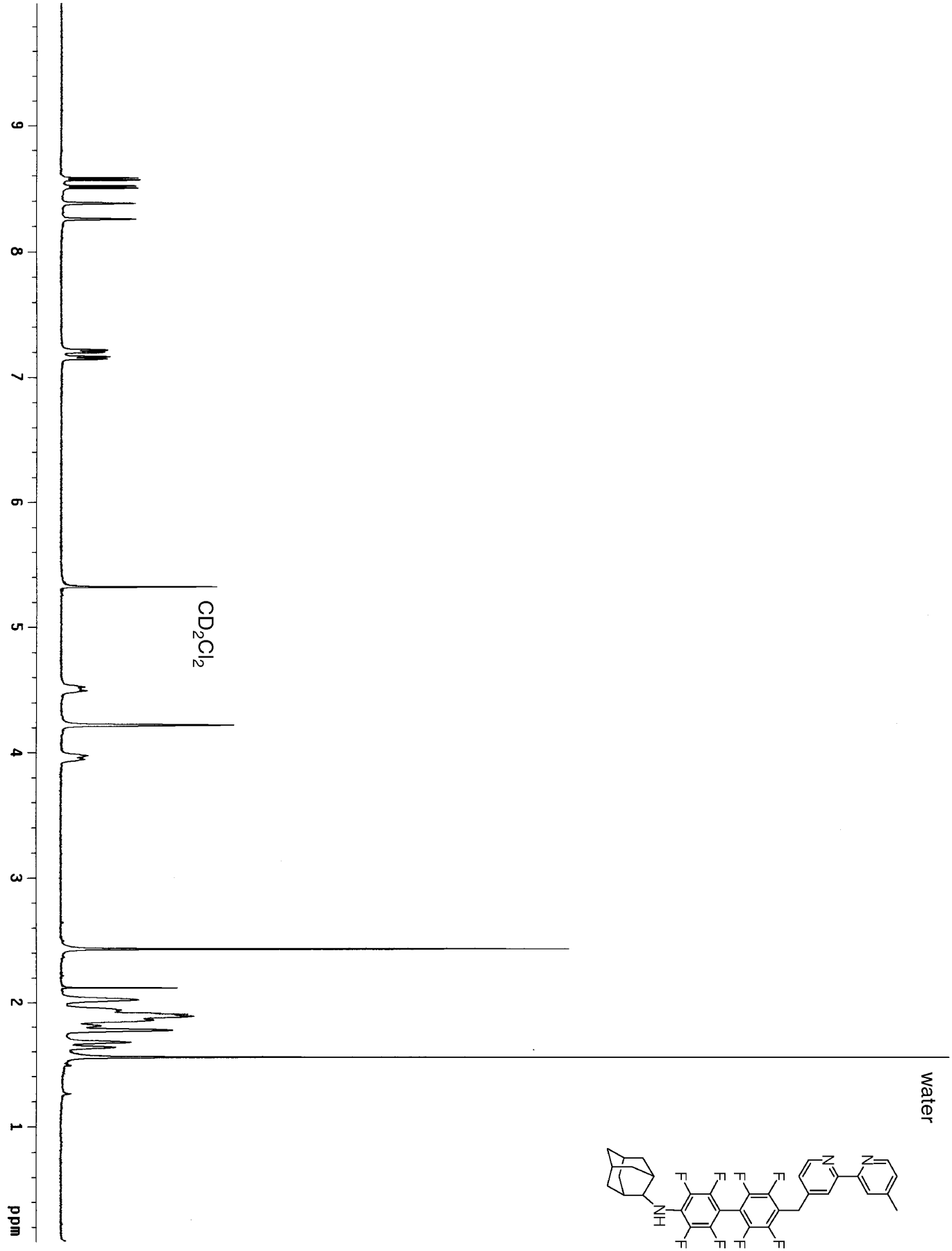
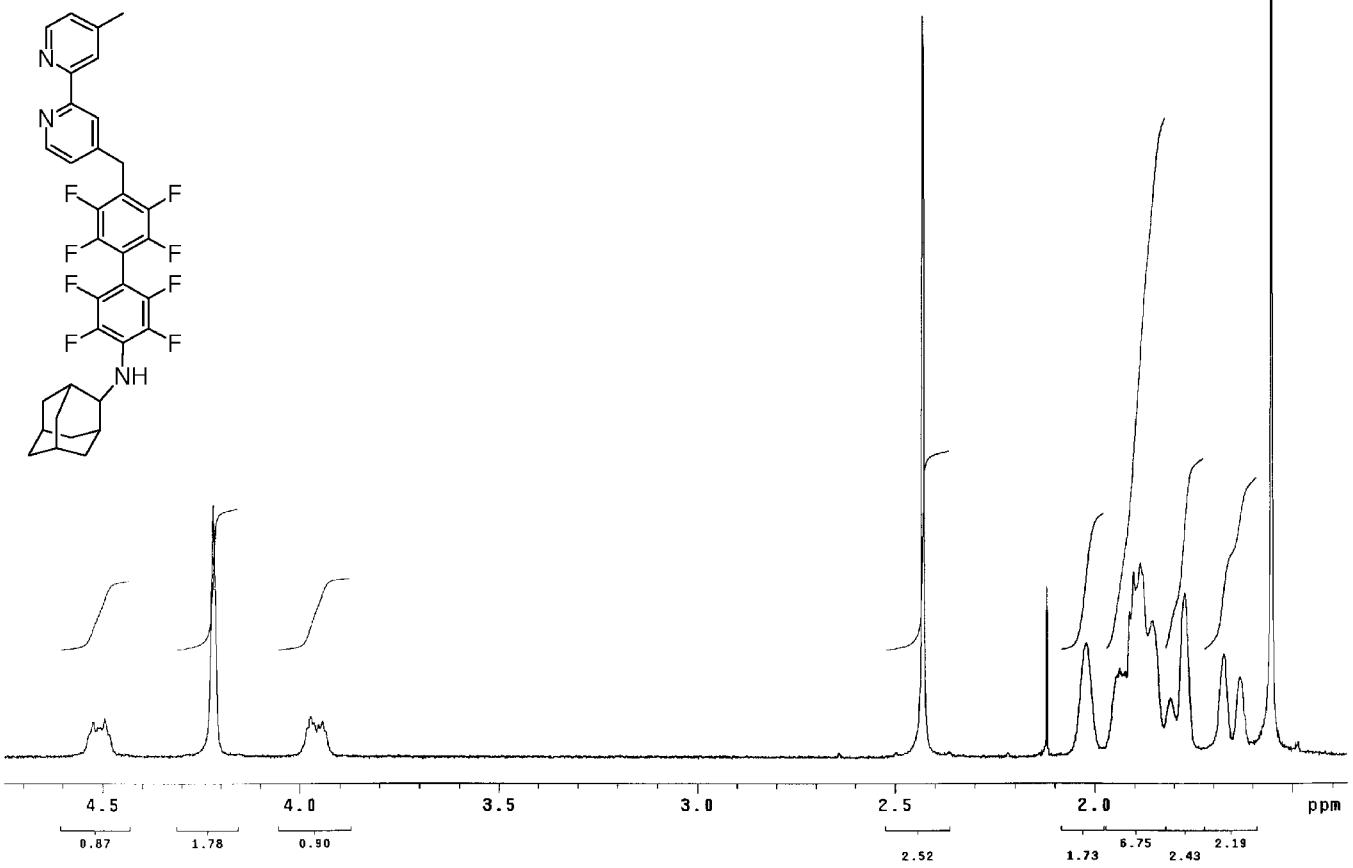
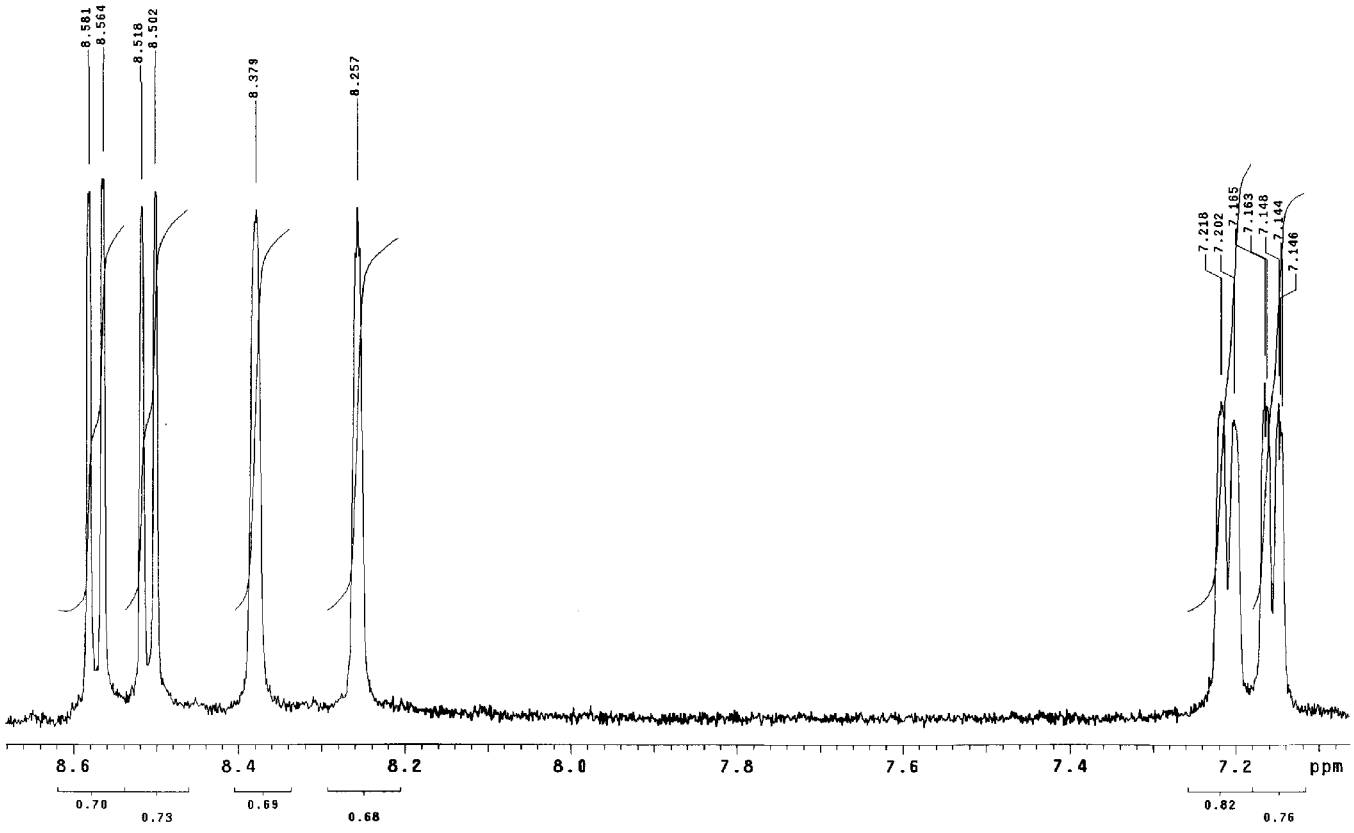
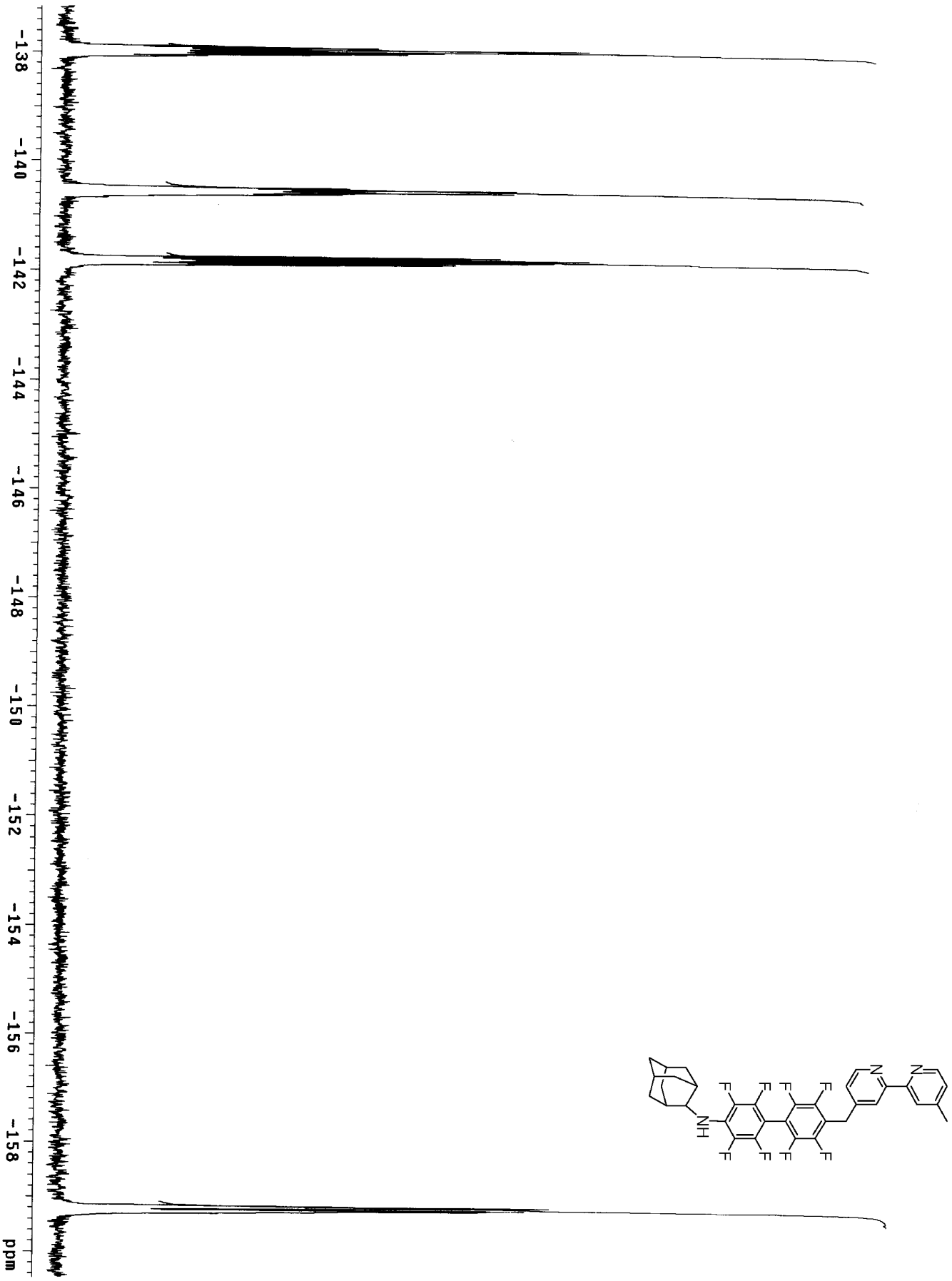
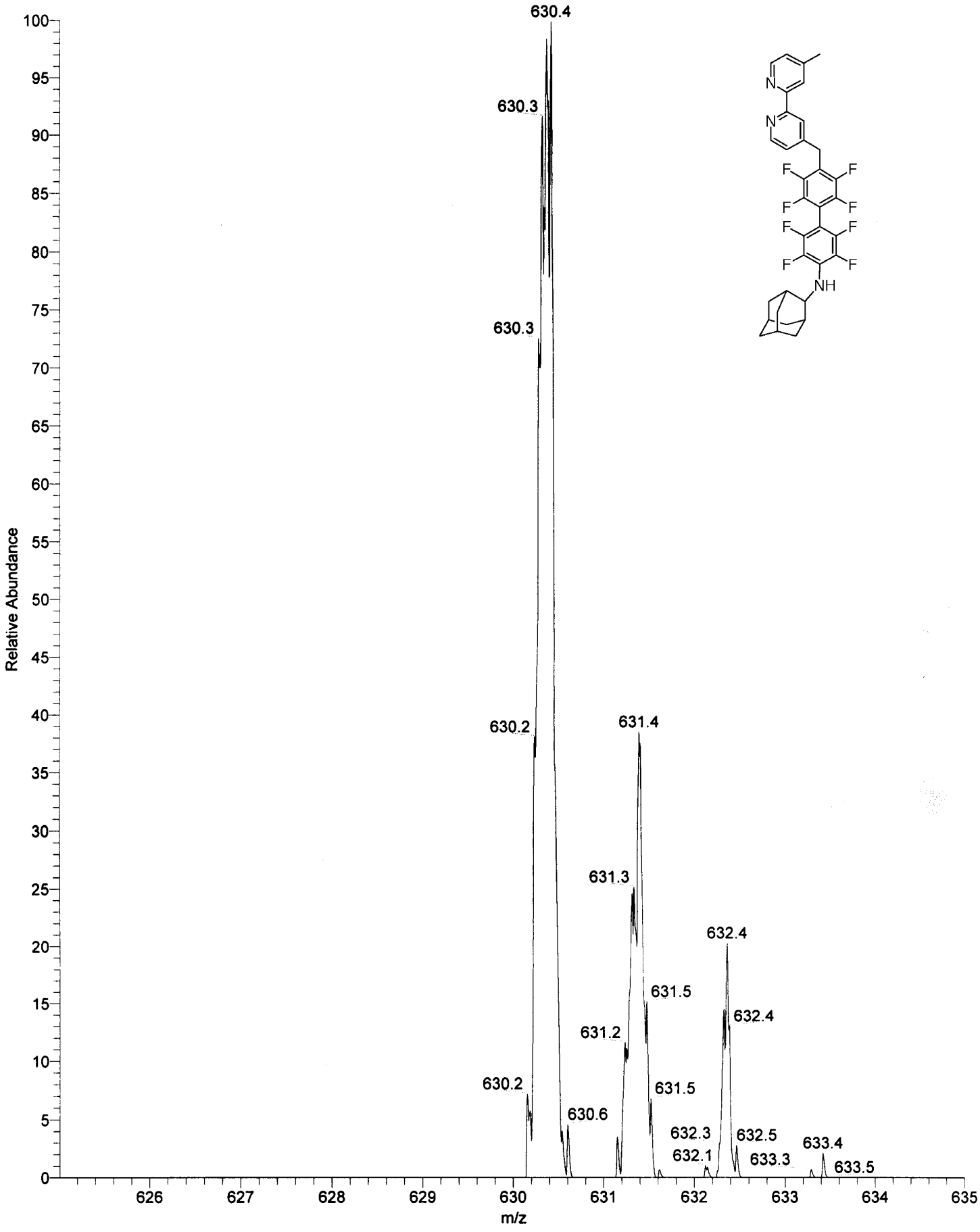
502.3
502.8
503.5
Relative Abundance
m/z
N
N
F

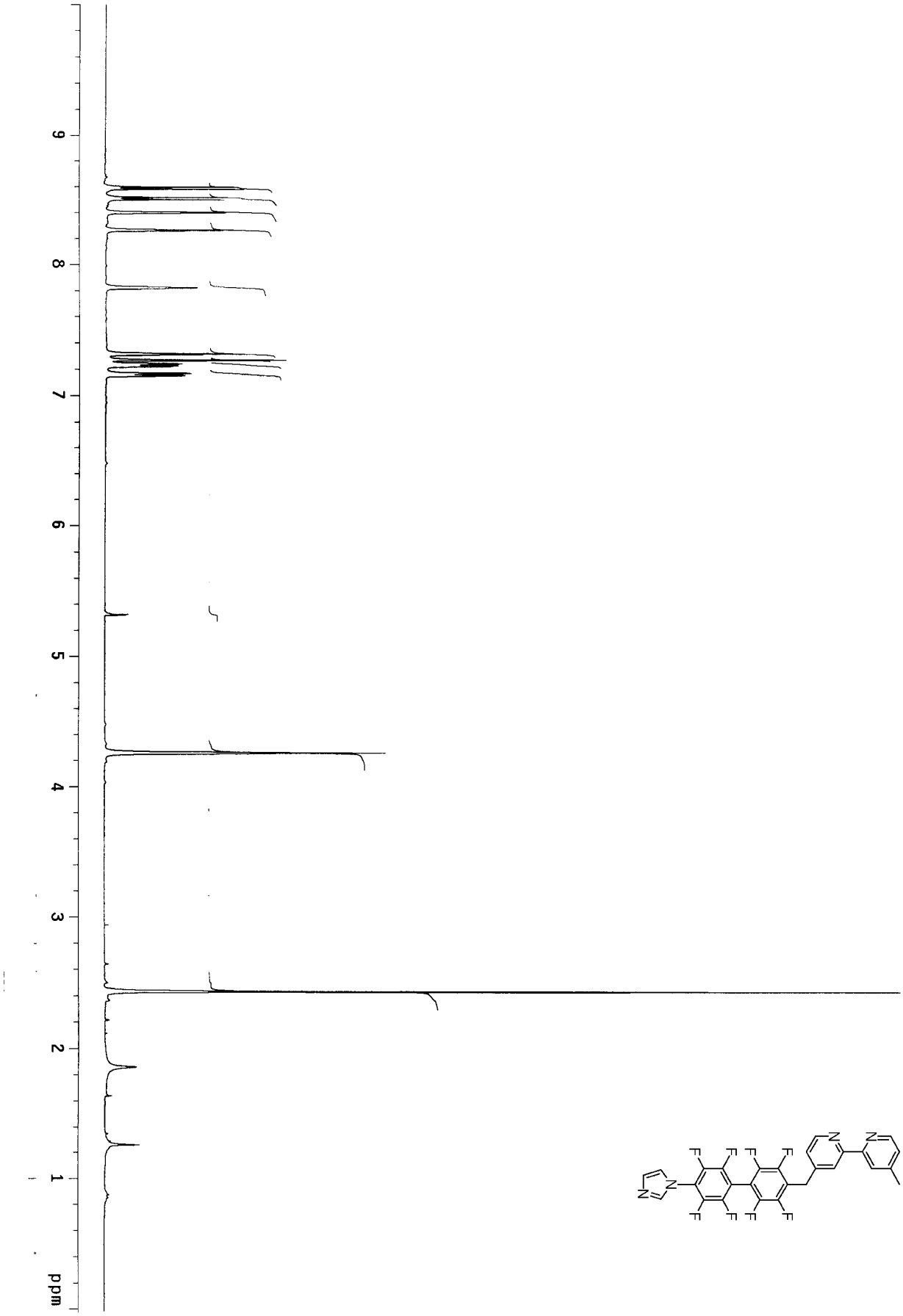

9
8
7
6
5
4
3
2
1
ppm
CD2Cl2
water
NH
F
N

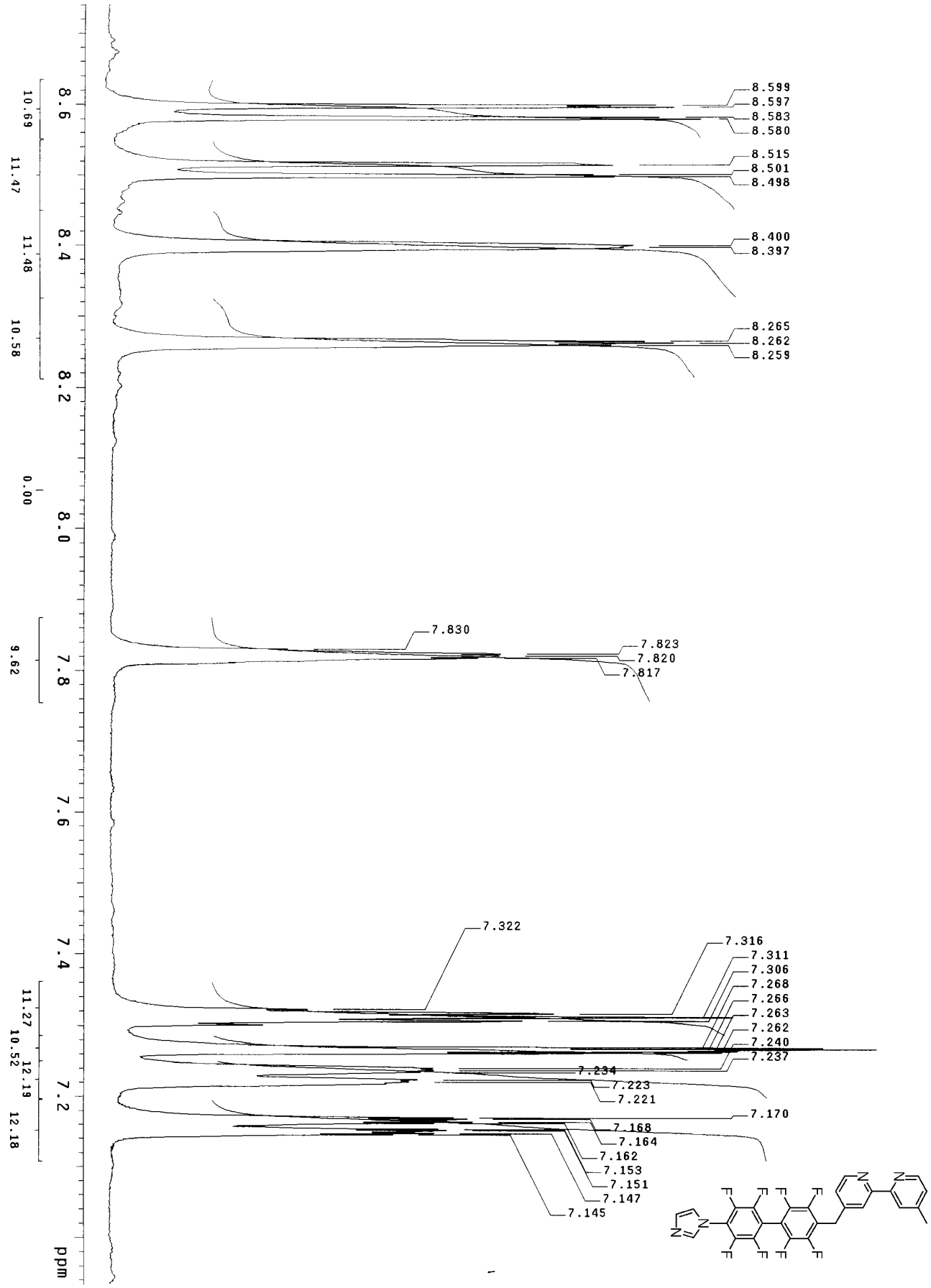

N
N
F
F
F
F
F
F
F
F
NH
4.5
4.0
3.5
3.0
2.5
2.0
ppm
0.87
1.78
0.90
2.52
1.73
6.75
2.43
2.19

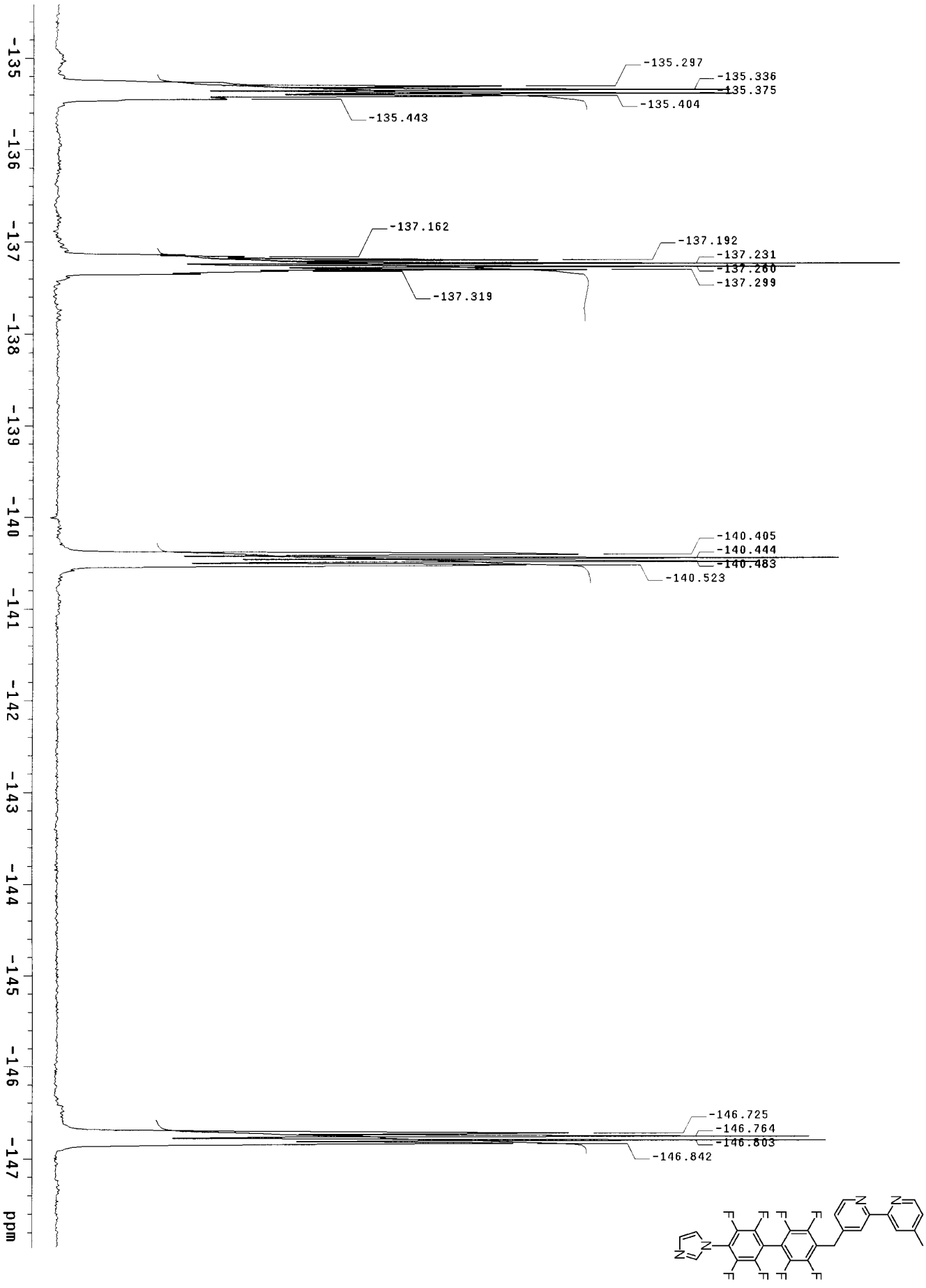

8.581
8.564
8.518
8.502
8.379
8.257
7.218
7.202
7.185
7.163
7.148
7.144
7.146
8.6
8.4
8.2
8.0
7.8
7.6
7.4
7.2
ppm
0.70
0.73
0.69
0.68
0.82
0.76

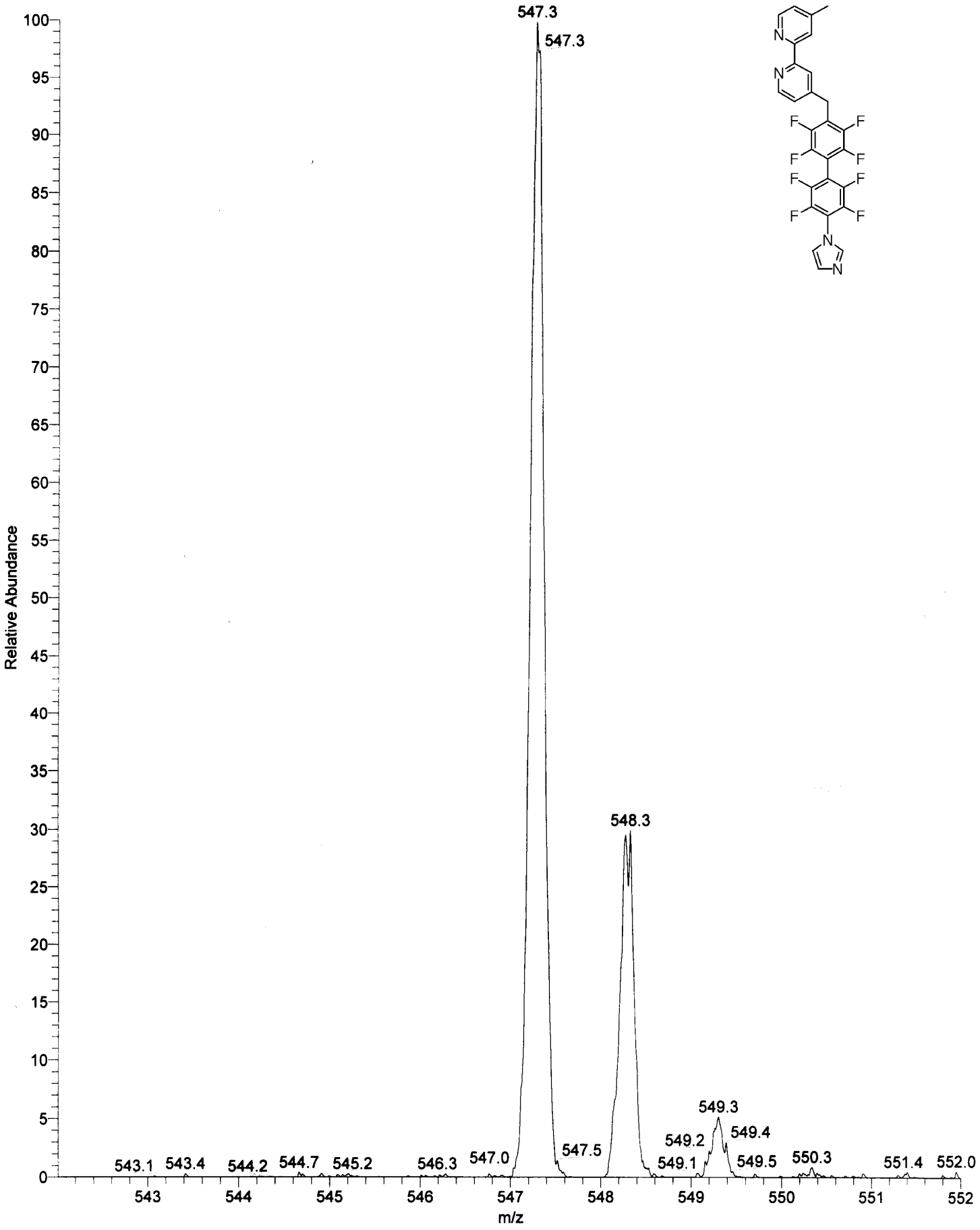

-138
-140
-142
-144
-146
-148
-150
-152
-154
-156
-158
ppm
NH
F
N


630.4
630.3
630.3
630.2
631.4
631.3
632.4
631.5
632.4
631.2
630.2
631.5
630.6
632.3
632.5
633.4
632.1
633.3
633.5
Relative Abundance
m/z
N
N
F
F
F
F
F
F
F
F
NH


9
8
7
6
5
4
3
2
1
ppm
F
F
F
F
F
F
F
F
N
N
N
N


8.599
8.597
8.583
8.580
8.515
8.501
8.498
8.400
8.397
8.265
8.262
8.259
7.830
7.823
7.820
7.817
7.322
7.316
7.311
7.306
7.268
7.266
7.263
7.262
7.240
7.237
7.234
7.223
7.221
7.170
7.168
7.164
7.162
7.153
7.151
7.147
7.145
ppm


-135.297
-135.336
-135.375
-135.404
-135.443
-137.162
-137.192
-137.231
-137.260
-137.299
-137.319
-140.405
-140.444
-140.483
-140.523
-146.725
-146.764
-146.803
-146.842
-135
-136
-137
-138
-139
-140
-141
-142
-143
-144
-145
-146
-147
ppm


547.3
547.3
548.3
549.3
549.4
549.2
549.1
549.5
550.3
547.5
547.0
546.3
544.7
545.2
544.2
543.1
543.4
551.4
552.0
Relative Abundance
m/z
100
95
90
85
80
75
70
65
60
55
50
45
40
35
30
25
20
15
10
5
0
543
544
545
546
547
548
549
550
551
552
N
N
F
F
F
F
F
F
F
F
N
N