Electronic Supplementary Information for:

Enhanced upconversion emission in air using novel stretched poly(vinyl alcohol) thin films

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I. Orientation in UC-PVA films

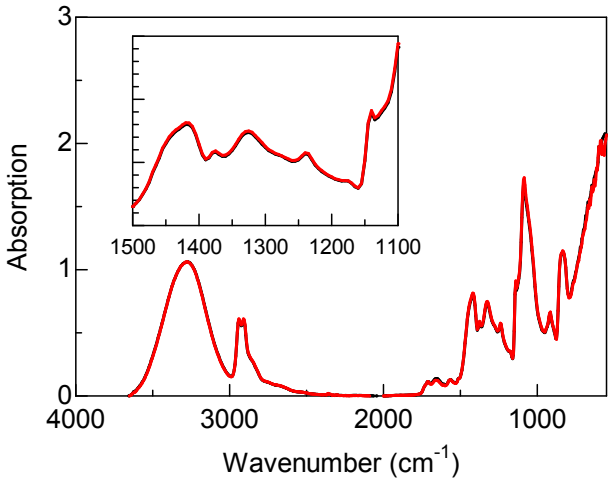
Orientation function values (P) were determined by polarized infrared measurement as previous report.[1] We used following equations.

$$D = \frac{A_{\parallel}}{A_{\perp}}$$

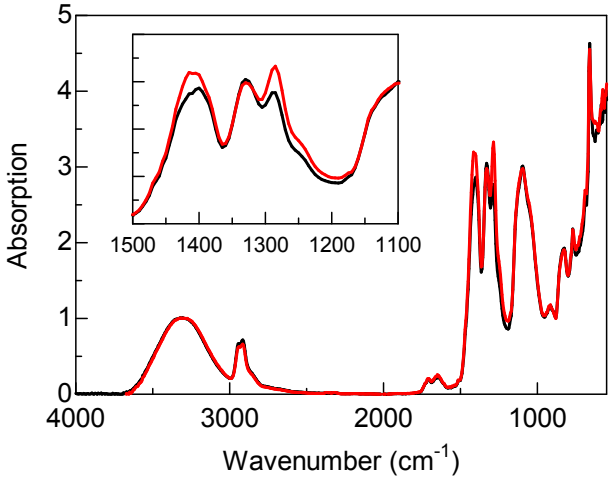
$$P = \frac{2(1 - D)}{(D + 2)}$$

Where D is the dichroic ratio, $A_{\parallel}$ and $A_{\perp}$ is the absorptions for the parallel and perpendicular irradiations, respectively.

a)



b)



c)

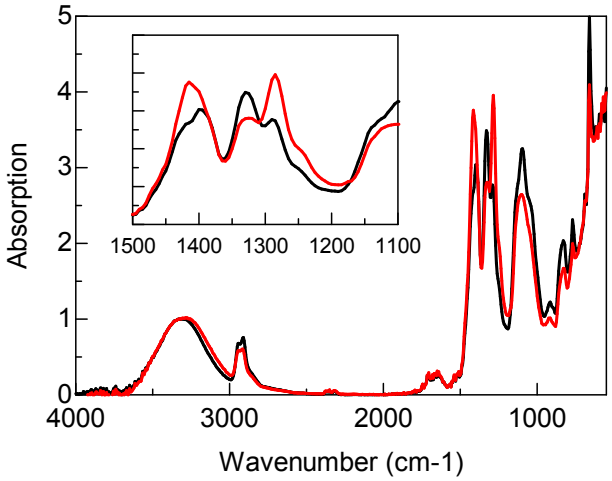


Fig S1. FTIR spectra of UC-PVA films. a): Unstretched film, b): 200% elongation, c): 400% elongation, red line: parallel, black line: perpendicular.

Table S1. Orientation function of UC-PVA determined from FTIR measurements (at 1325 cm^{-1}).

Film elongation	*P*
Unstretched	-0.015
200%	0.063
400%	0.276

II. DSC curves

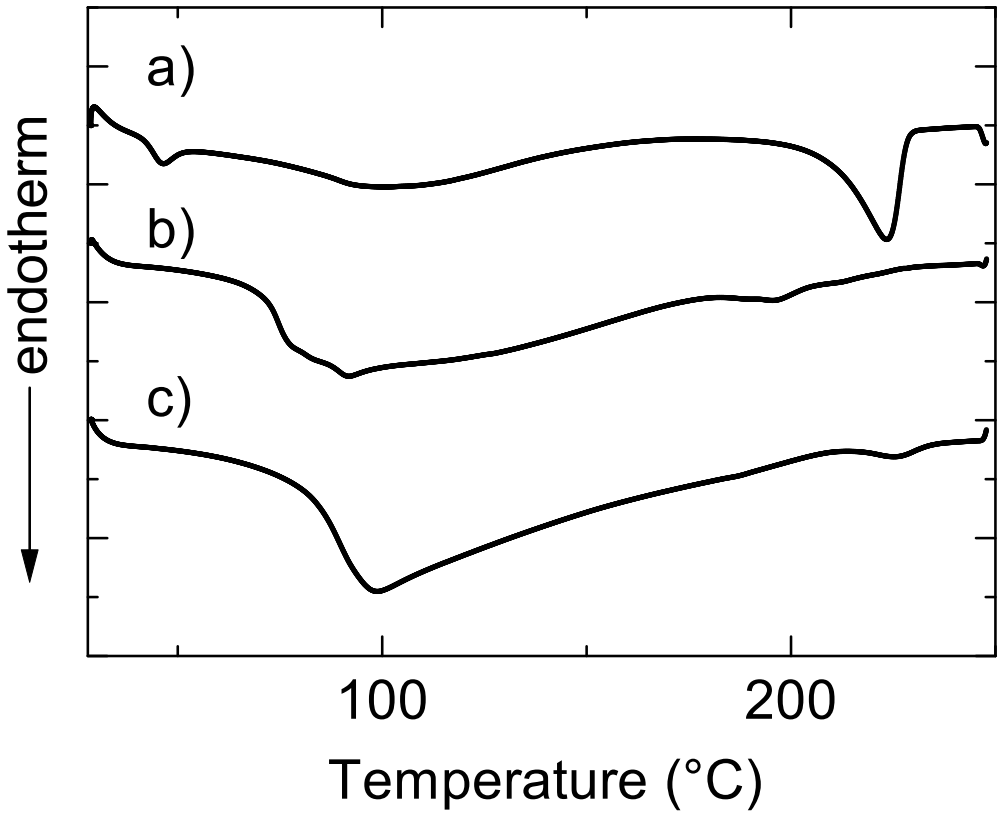


Fig S2. DSC curves of a) non-stretched film, b) 200% stretched film, c) 400% stretched film.

III. Length, thickness and width of the films

Table S2. Measured values of the PVA films.

Elongation (%)	Before stretching			After stretching		
	Length (mm)	Thickness (μm)	Width (mm)	Length (mm)	Thickness (μm)	Width (mm)
Unstretched	30	35	20			
200	20[a]	45	20	40	35	15
400	20[a]	33	20	80	21	12

[a] The length of initial film was 30 mm. When stretching, 5 mm from both of the shorter edges were overlapped with an attachment for chucking. Therefore, 20mm-length film was stretched.

IV. Polarized absorption of UC-PVA films

Dichroic ratio was determined from the absorption intensity at 414 nm. The following equation was used.[2]

$$D = \frac{I_{\parallel}}{I_{\perp}}$$

Where $I_{\parallel}$ and $I_{\perp}$ is the absorptions for the parallel and perpendicular irradiations, respectively.

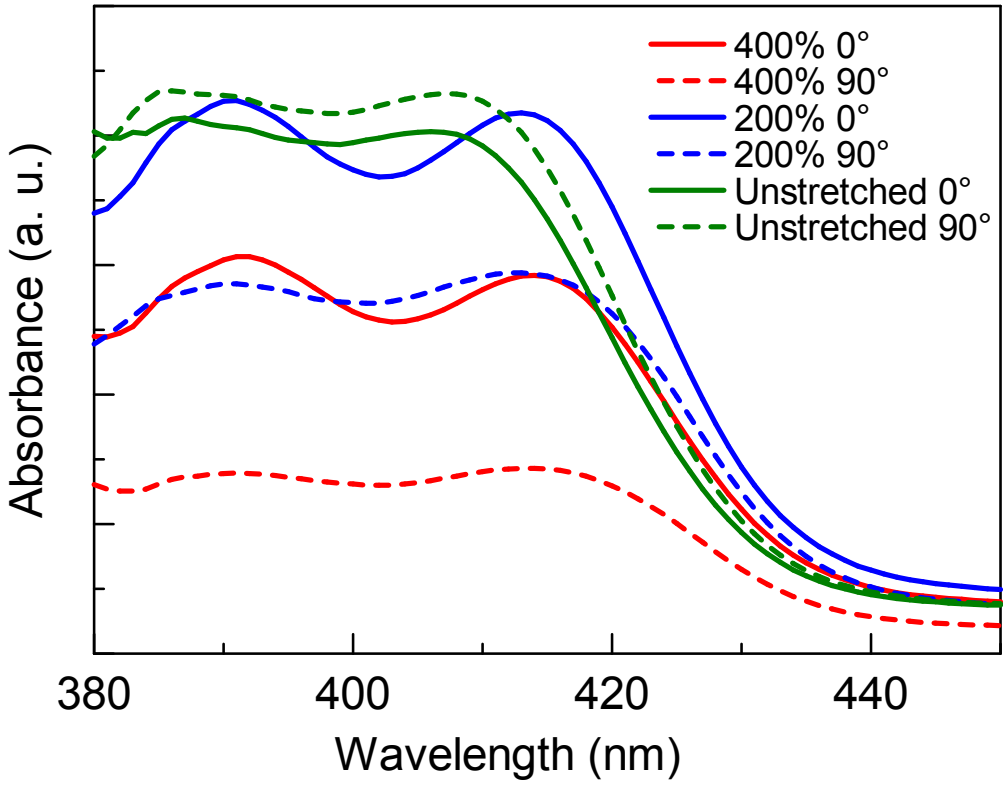
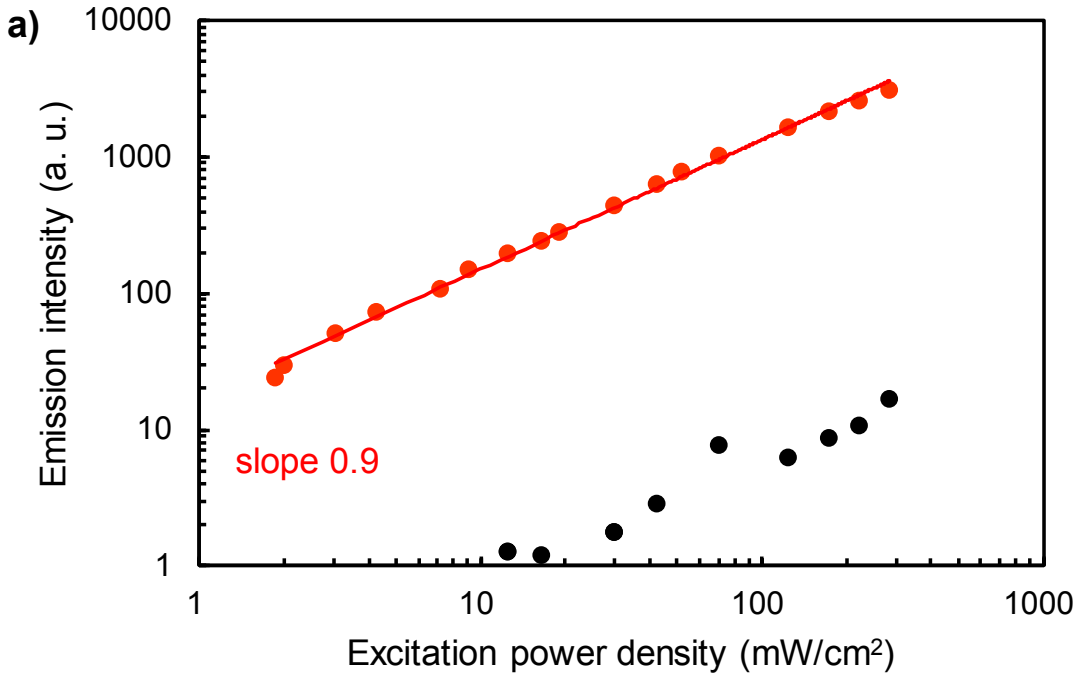
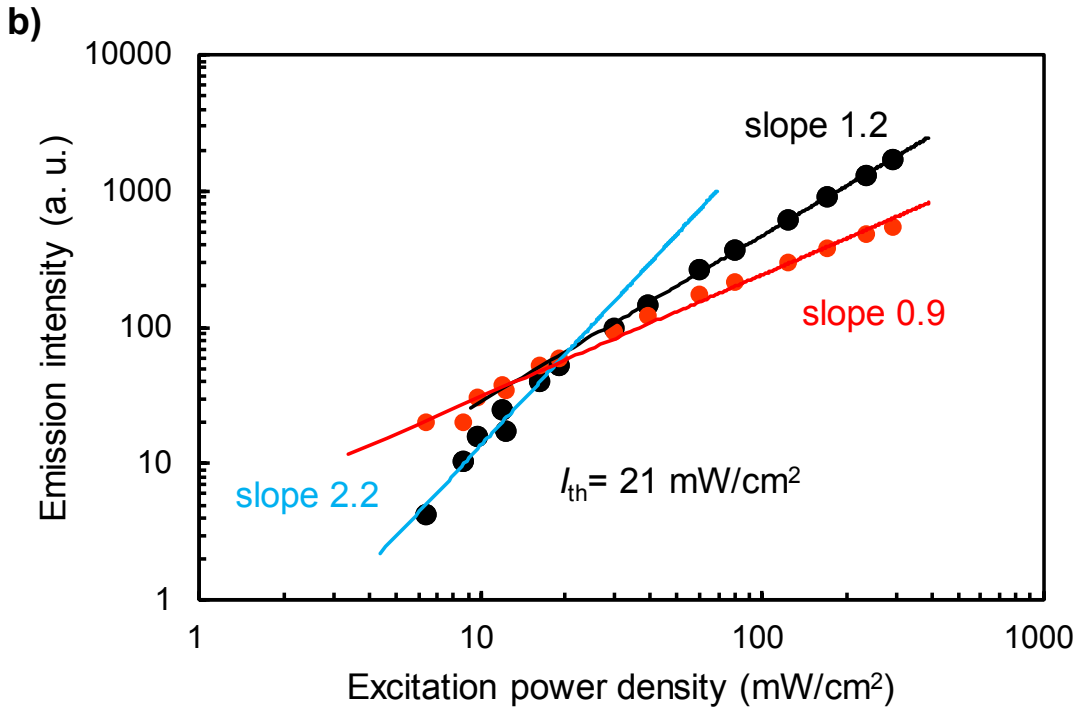


Fig S3. Polarized absorption spectra of UC-PVA films. The direction of stretching and incident polarized light were parallel (0°) or perpendicular (90°).

V. Dependence of UC emission and phosphorescence vs excitation power density





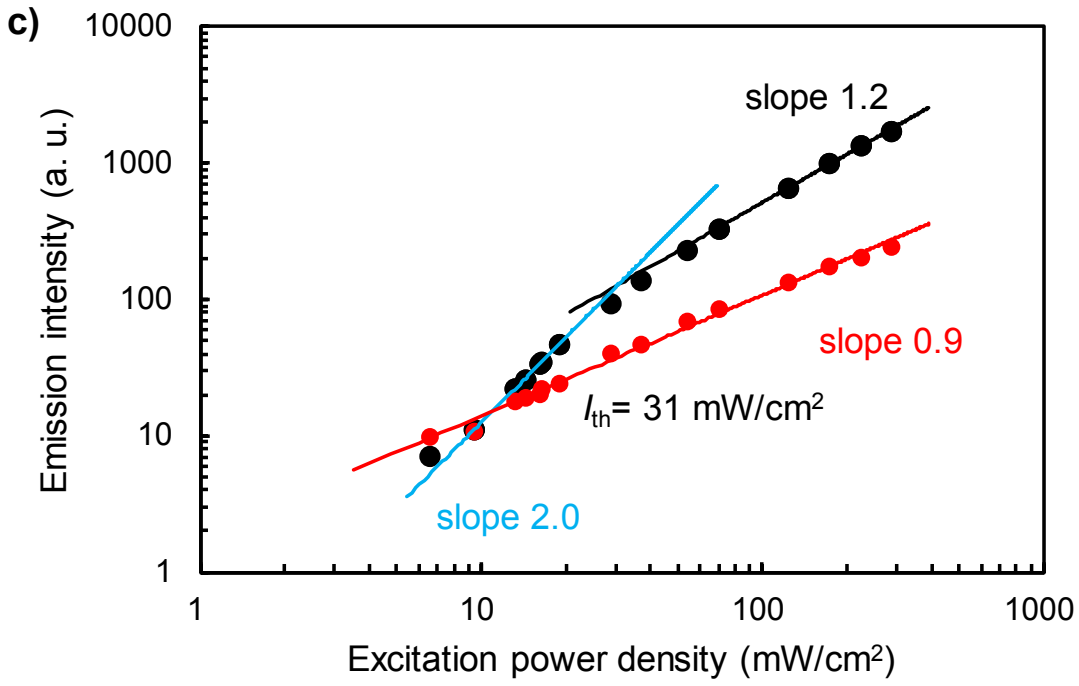
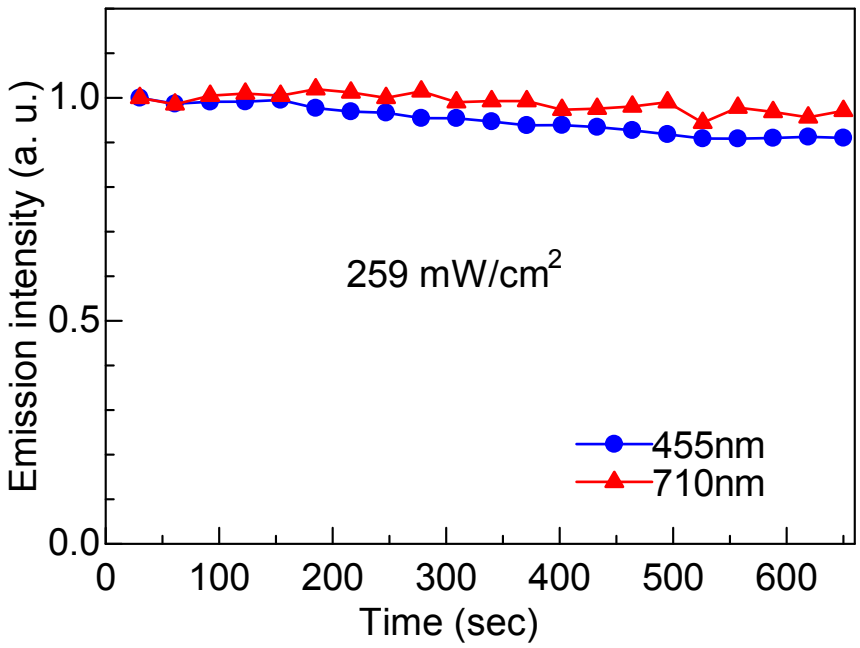


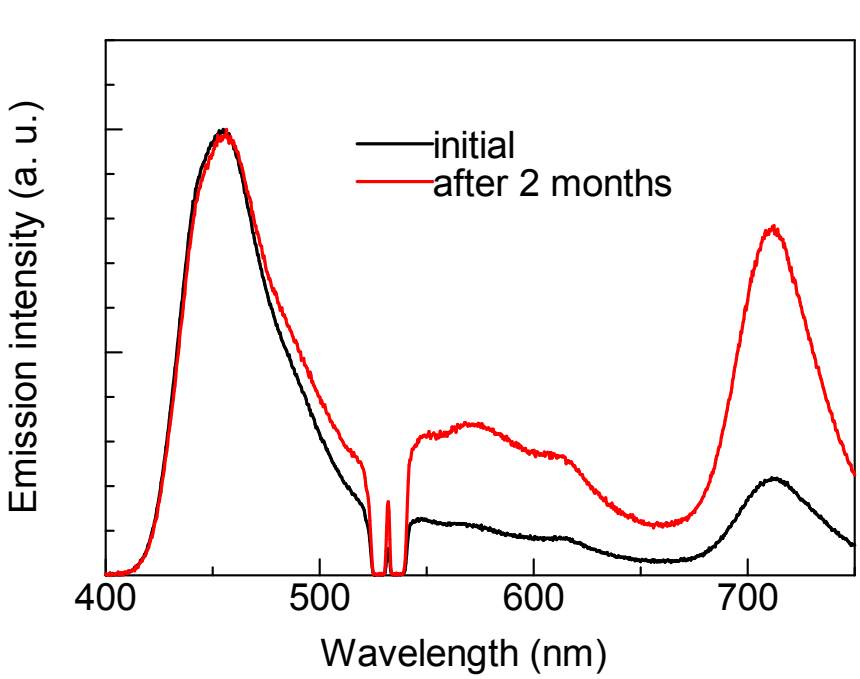
Fig S4. UC emission (455 nm: black) and phosphorescence (710 nm: red) intensity as a function of 532 nm excitation power density of the UC-PVA films. a) Unstretched film, b) 200%-elongated, c) 400%-elongated.

VI. Stability of the UC-PVA film

a)



b)



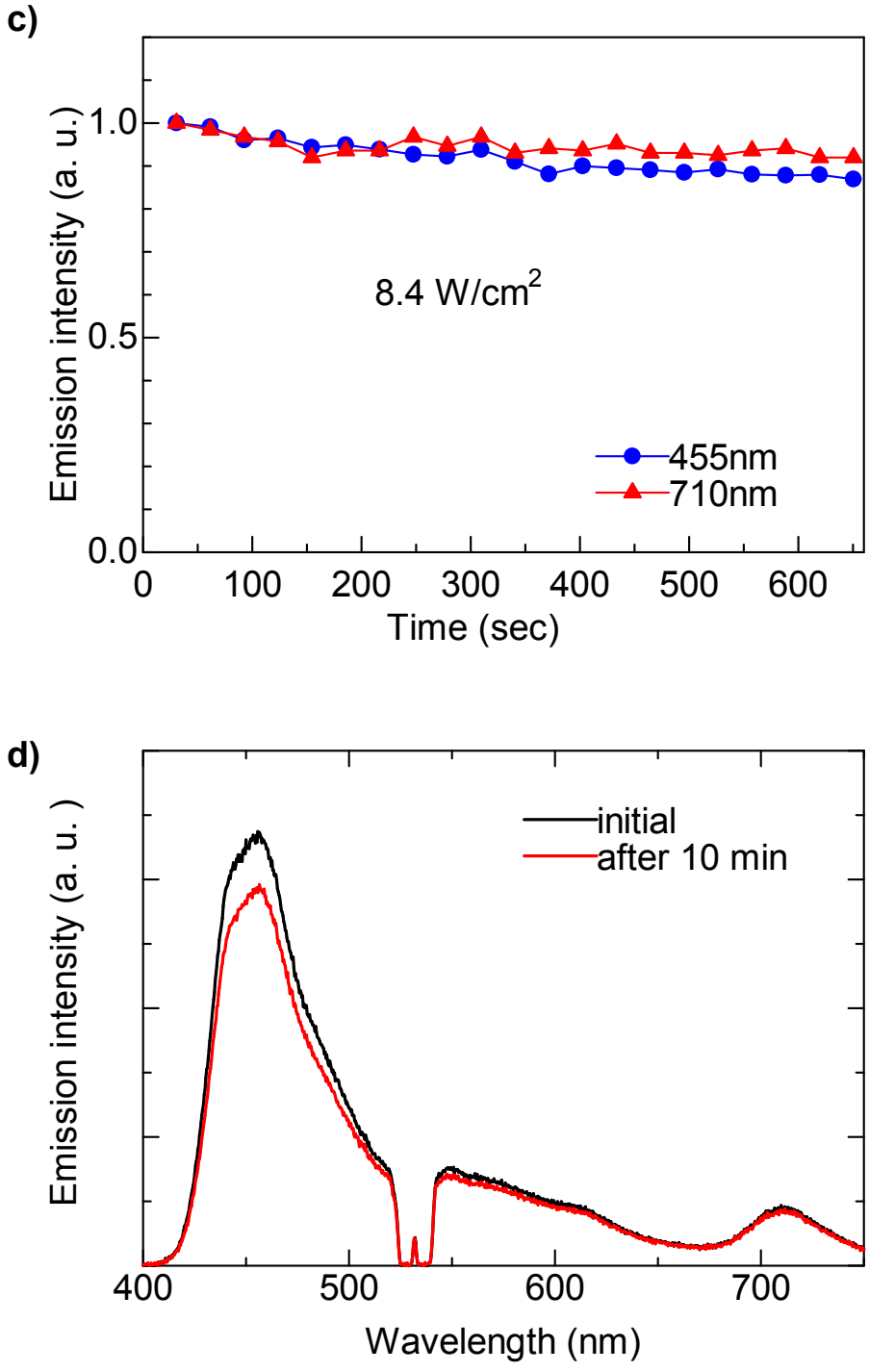


Fig S5. The changes in emission intensity and spectra upon excitation at 532 nm. The excitation power density is 259 mW/cm^2 for a) and b), 8.4 W/cm^2 for c) and d).

VII. Reference

1 G. Voyiatzis, G. Petekidis, D. Vlassopoulos, E. I. Kamitsos and A. Bruggeman, *Macromolecules*, 1996, **29**, 2244–2252.

2 X. Zhang, H. Gorohmaru, M. Kadowaki, T. Kobayashi, T. Ishi-i, T. Thiemann and S. Mataka, *J. Mater. Chem.*, 2004, **14**, 1901–1904.

^{1}H NMR and ^{13}C NMR

ppm
0
1
2
3
4
5
6
7
8
9
10
5.77
7.75
3.85
8.63
4.00
3.90
3.92
4.00
-0.00
1.24
1.26
1.28
1.29
1.31
1.57
1.71
1.91
1.92
1.92
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4.15
4.16
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7.11
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7.14
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7.75

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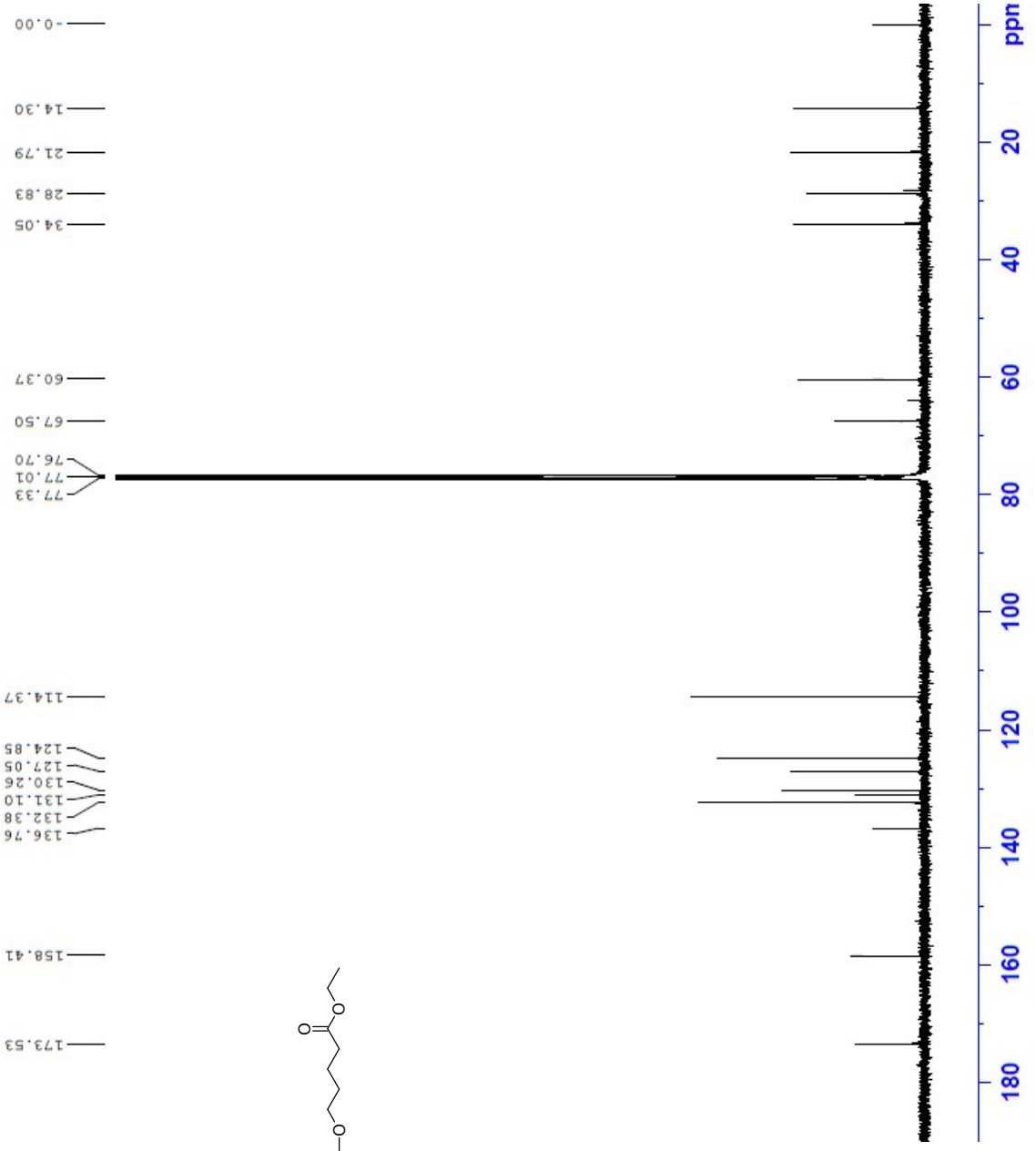
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127.05
130.26
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132.38
136.76
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173.53
ppm
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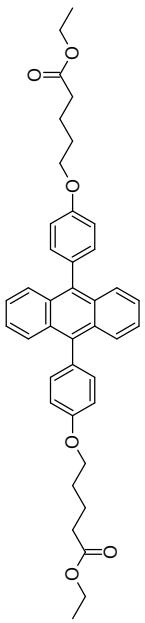

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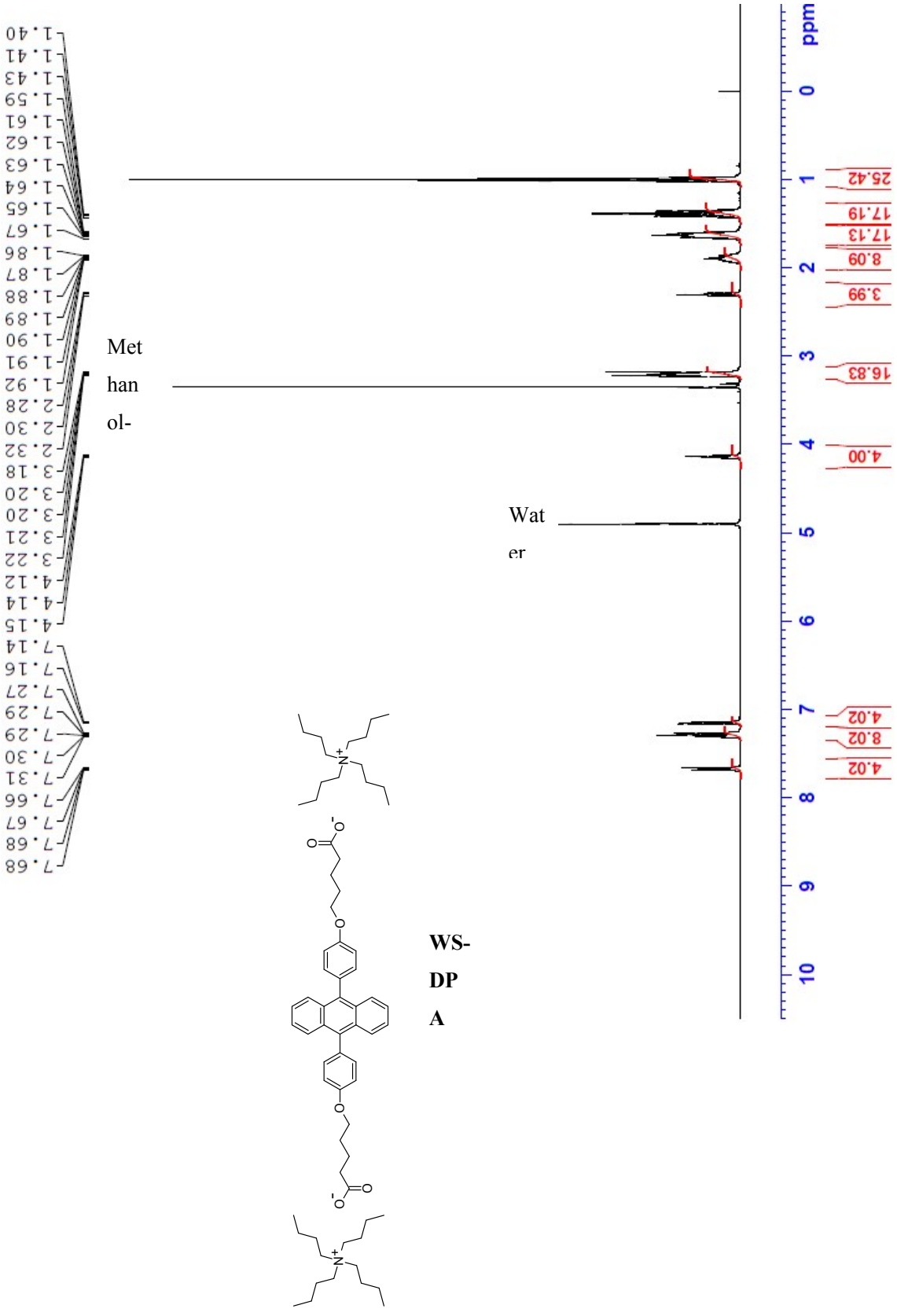
Met
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ppm
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1
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3
4
5
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7
8
9
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17.19
17.13
8.09
3.99
16.83
4.00
4.02
8.02
4.02
1.40
1.41
1.43
1.59
1.61
1.62
1.63
1.64
1.65
1.67
1.86
1.87
1.88
1.89
1.90
1.91
1.92
2.28
2.30
2.32
3.18
3.20
3.20
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4.12
4.14
4.15
7.14
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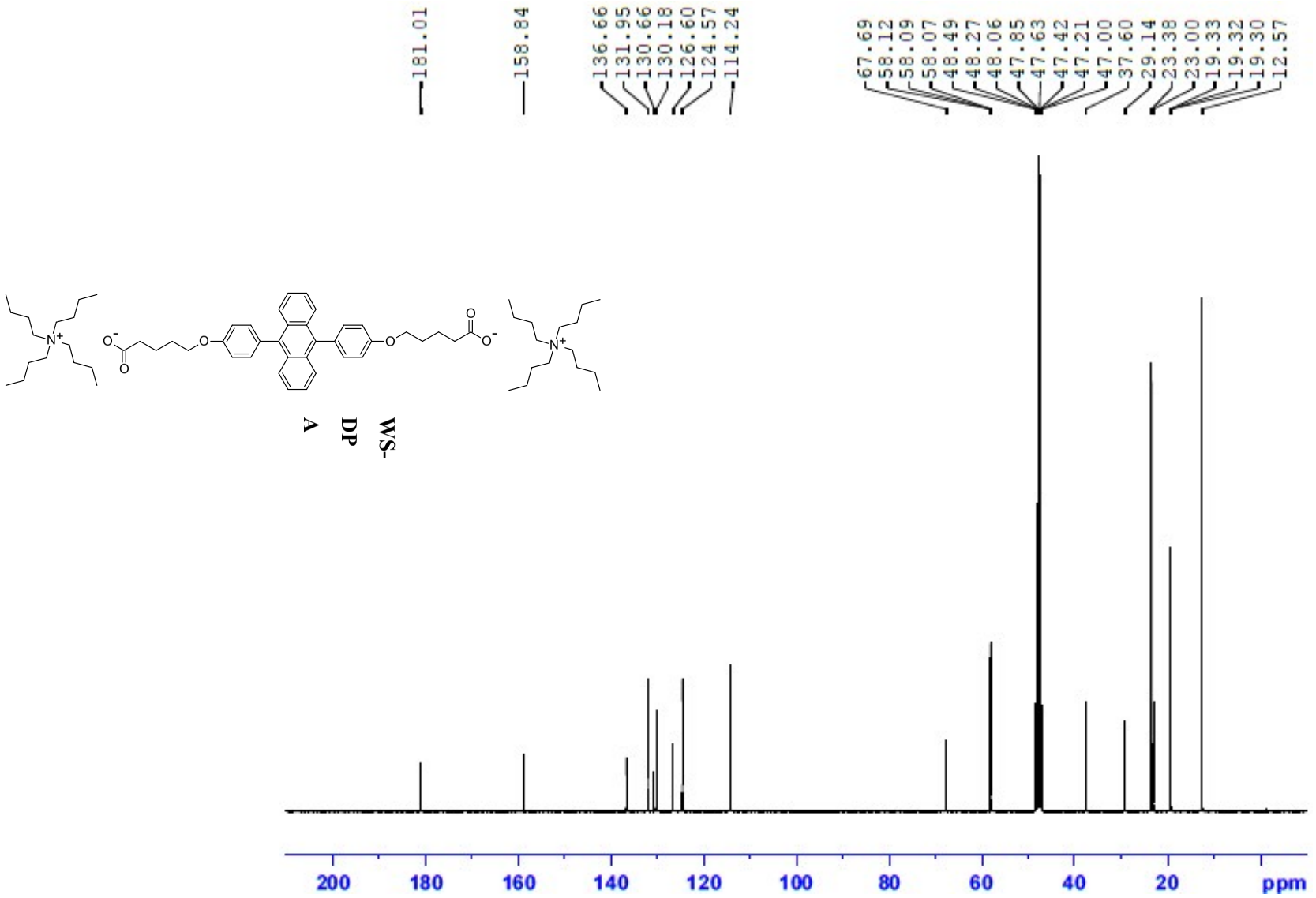
WS-DPA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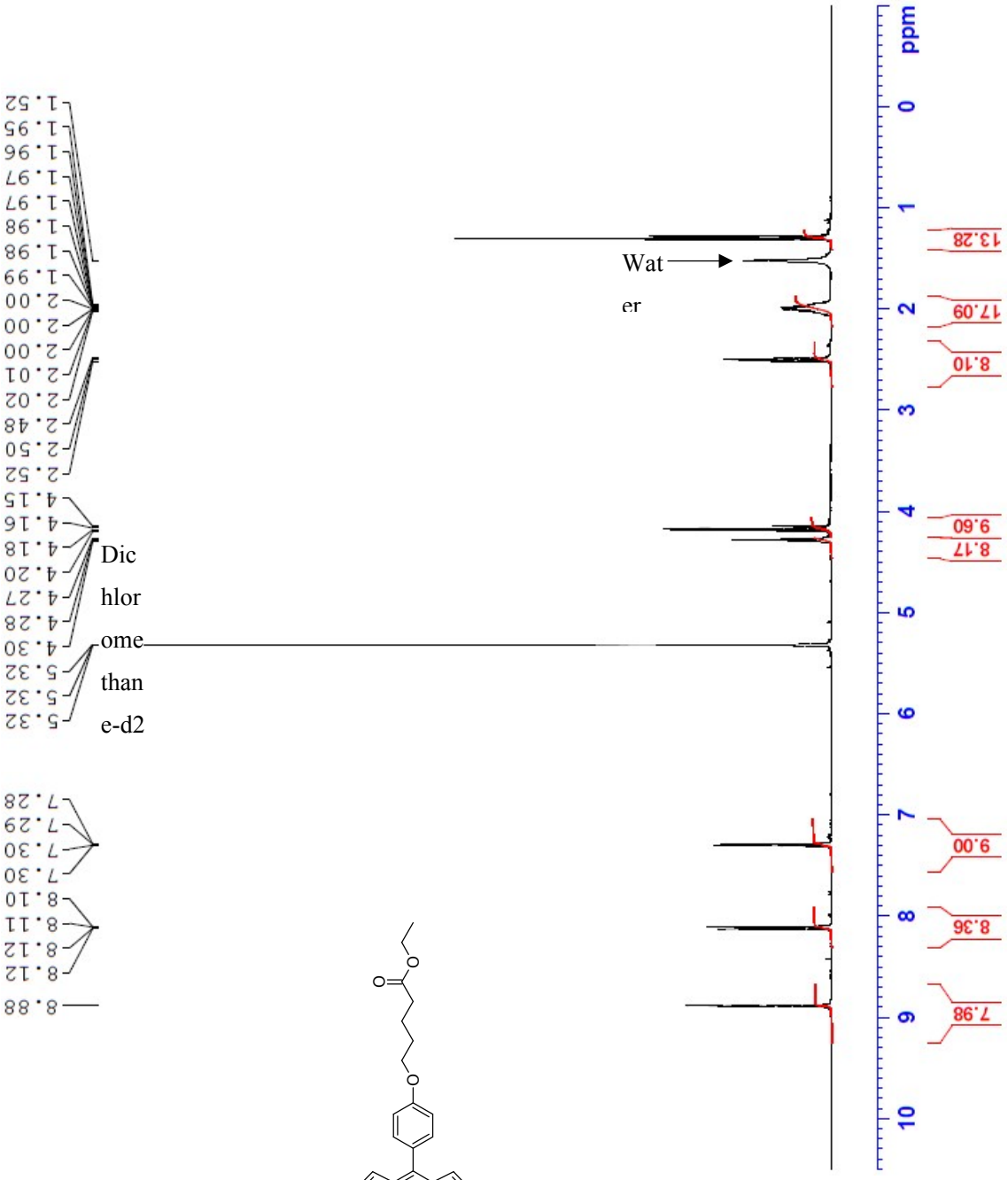
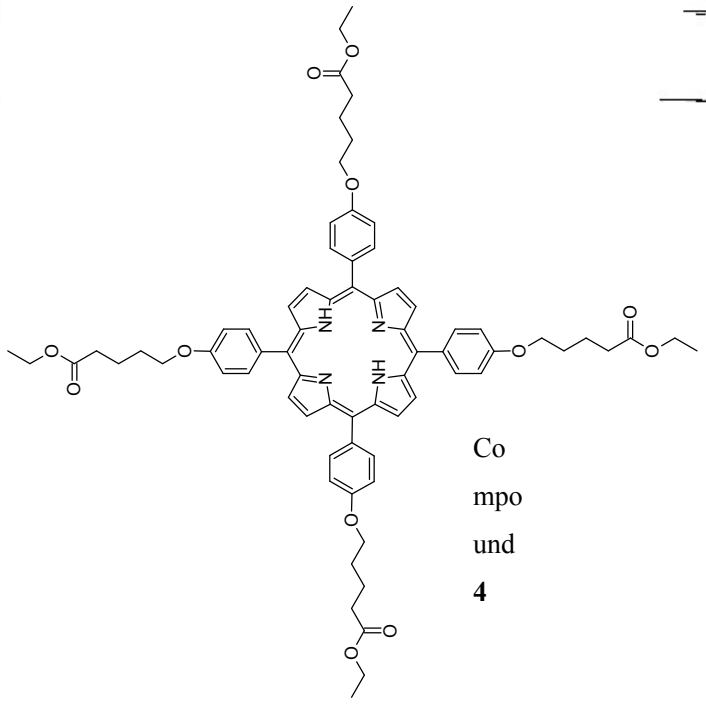
58.07
48.49
48.27
48.06
47.85
47.63
47.42
47.21
47.00
37.60
29.14
23.38
23.00
19.33
19.32
19.30
12.57
WS-DPA
200
180
160
140
120
100
80
60
40
20
ppm





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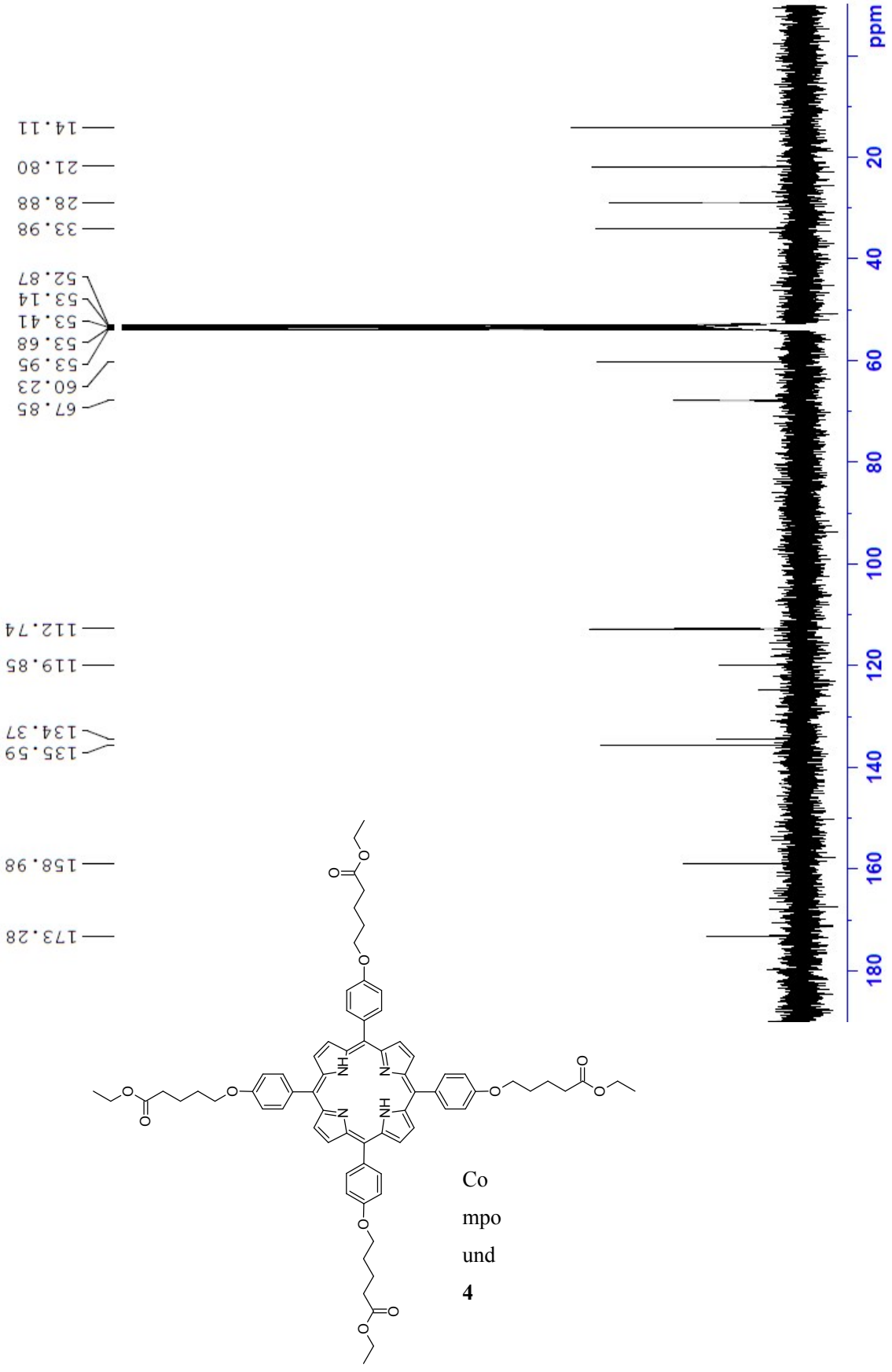
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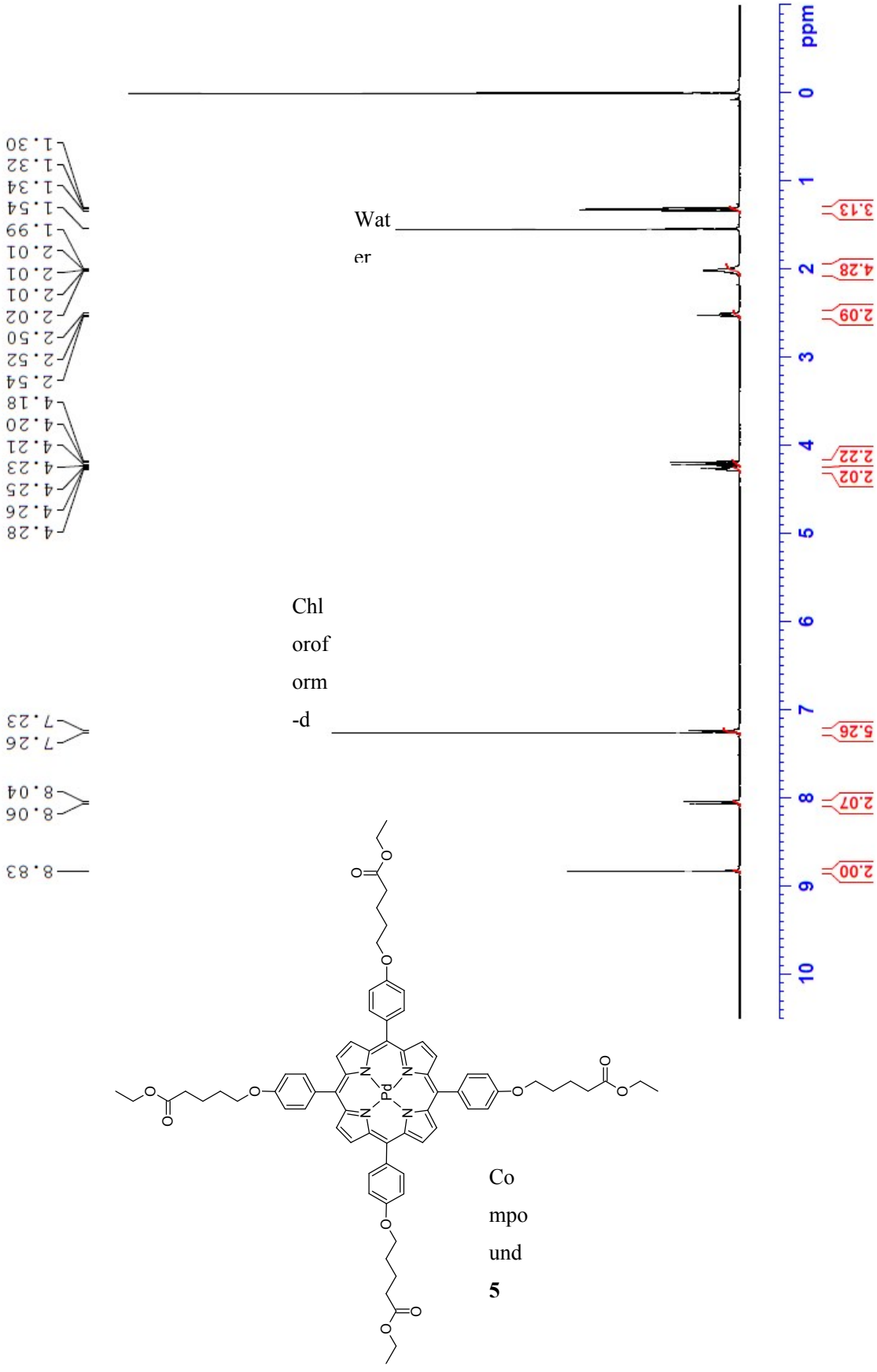
180

Compound **4**


Water
Chloroform-d
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1.34
1.54
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2.01
2.01
2.02
2.50
2.52
2.54
4.18
4.20
4.21
4.23
4.25
4.26
4.28
7.23
7.26
8.04
8.06
8.83
3.13
4.28
2.09
2.22
2.02
5.26
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Pd

Compound 5

14.33
21.86
28.92
34.11
60.40
67.67
112.69
121.39
130.88
134.16
135.11
141.88
158.77
173.55
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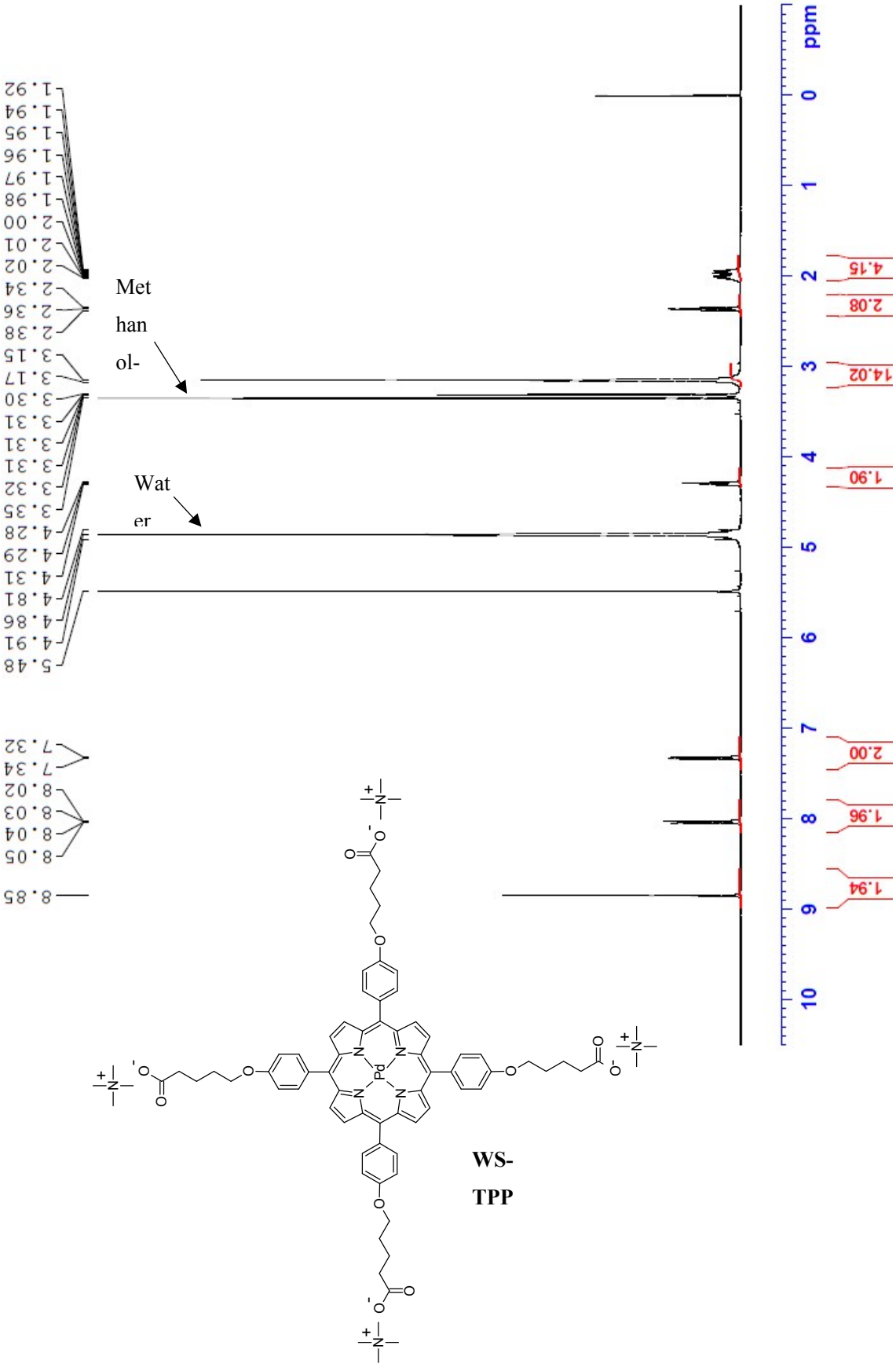
Compound **5**


Met
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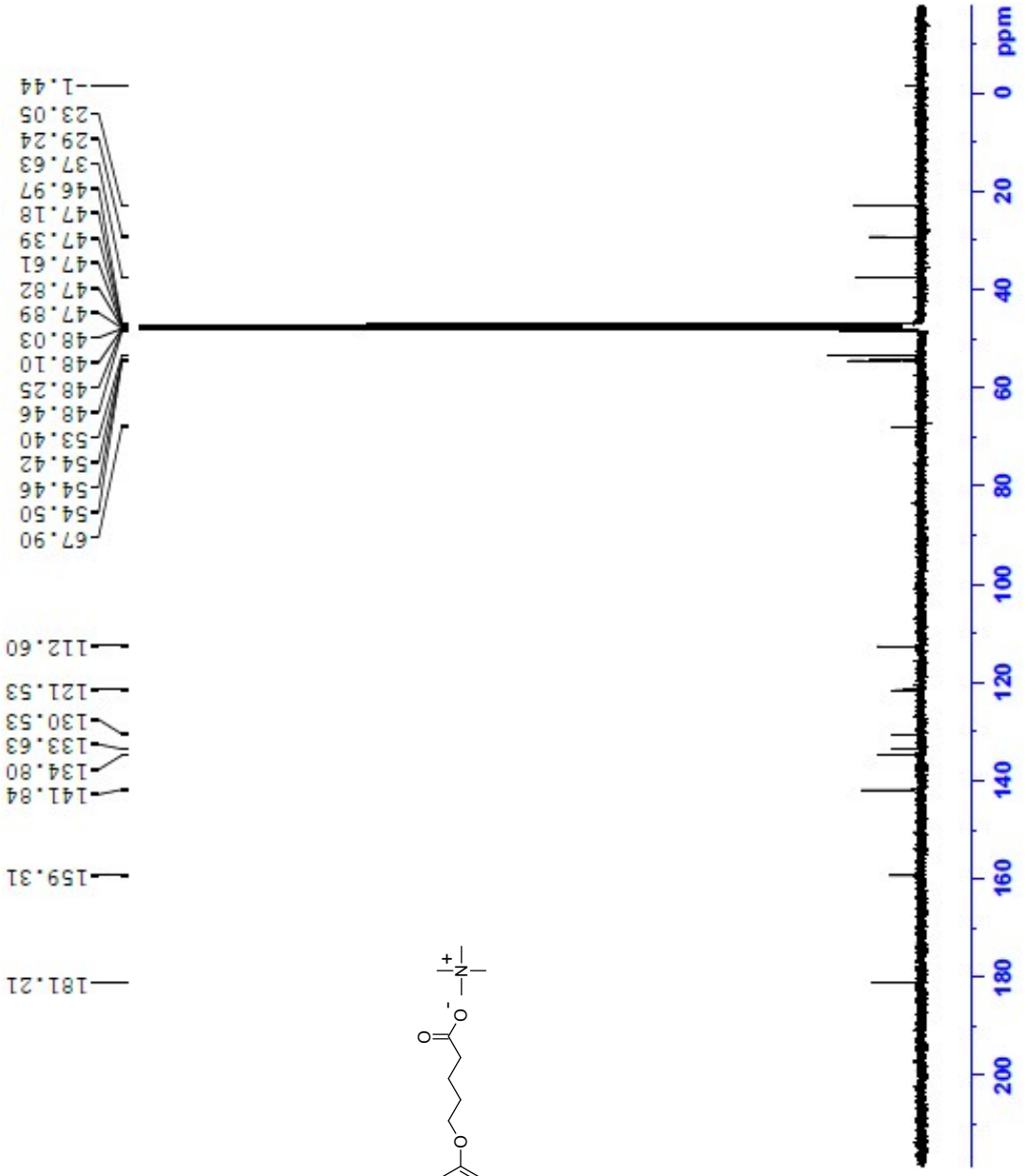
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130.53
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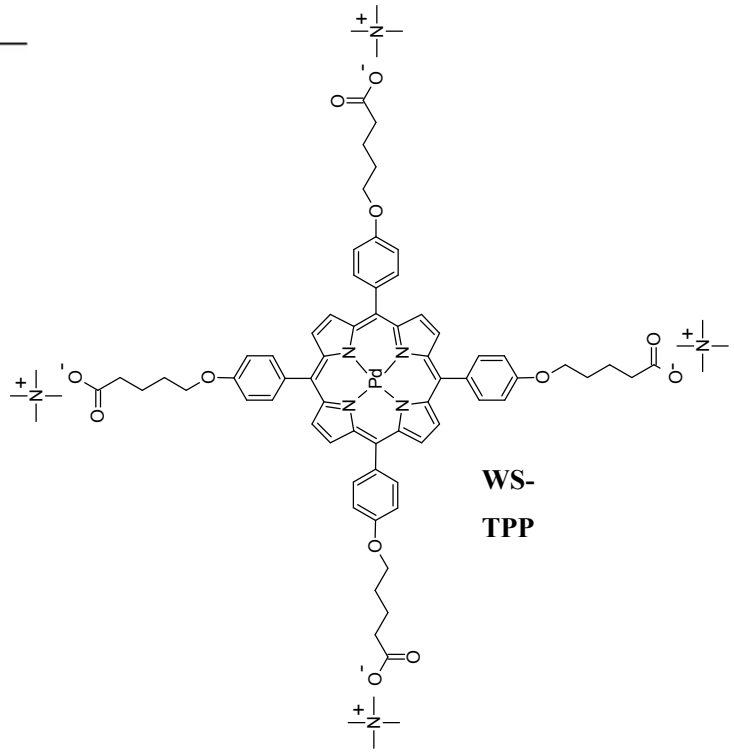
Pd

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