

**Electronic Supplementary Information**

**A Cp<sup>\*</sup>CoI<sub>2</sub>-dimer as a precursor for cationic Co(III)-catalysis: application to C-H phosphoramidation of indoles**

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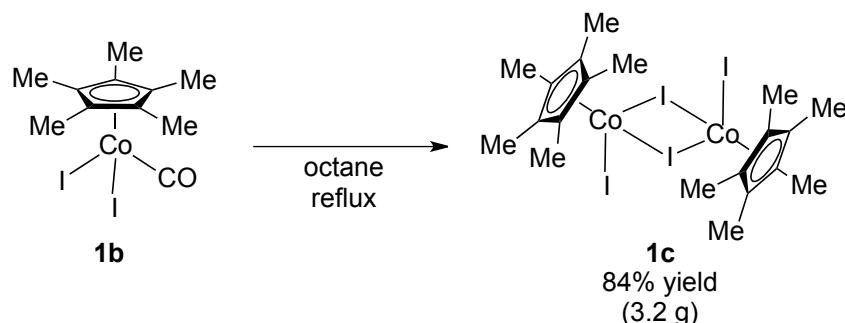
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**General:** Infrared (IR) spectra were recorded on a JASCO FT/IR 410 Fourier transform infrared spectrophotometer. NMR spectra were recorded on JEOL JNM-ECX500 spectrometers, operating at 500 MHz for <sup>1</sup>H NMR and 125 MHz for <sup>13</sup>C NMR or JNM-ECS400 spectrometers, operating at 400 MHz for <sup>1</sup>H NMR, 100 MHz for <sup>13</sup>C NMR and 158 MHz for <sup>31</sup>P NMR. All spectra were obtained at ambient temperature. The chemical shifts ( $\delta$ ) were recorded in parts per million (ppm). The coupling constants ( $J$ ) were shown in Hertz (Hz). Chemical shifts in CDCl<sub>3</sub> were reported the residual CHCl<sub>3</sub> (7.24 ppm for <sup>1</sup>H NMR, 77.0 ppm for <sup>13</sup>C NMR). ESI mass spectra for HRMS were measured on a JEOL JMS-T100LC AccuTOF spectrometer. 1,4-dioxane(Super Dehydrated) was purchased from Wako Ltd. and used without purification. 1-(Pyrimidin-2-yl)-1H-indole derivatives **2** were prepared by following the same procedure as described in the literature.<sup>[S1,S2]</sup> DPPA **3a** was purchased from Tokyo Chemical Industry Co., Ltd. and used without purification. Bis(4-methoxyphenyl)phosphoroazidate were prepared by following the same procedure as described in the literature.<sup>[S3]</sup>

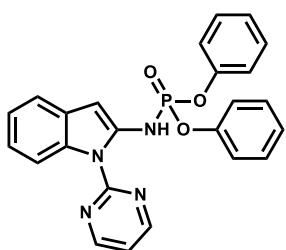
**Preparation of [Cp<sup>\*</sup>CoI<sub>2</sub>]<sub>2</sub> catalyst:<sup>[S4]</sup>**



To a round-bottomed flask was charged with *n*-octane (50 mL) and [Cp<sup>\*</sup>Co(CO)I<sub>2</sub>] (4.0 g). The mixture was heated to reflux under argon for 12 h. After cooling to room temperature, the solid precipitate was collected in a sintered-glass filtration funnel, washed with pentane, and dried under high vacuum to afford [Cp<sup>\*</sup>CoI<sub>2</sub>]<sub>2</sub> (3.2 g, 84%) as a black powder. <sup>1</sup>H NMR (500 MHz, CDCl<sub>3</sub>)  $\delta$  1.76 (s, 30H).

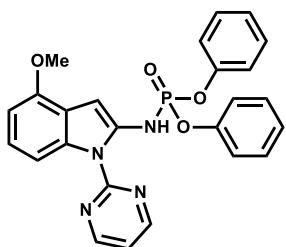
**General Procedure of Co-catalyzed C-H Amidation of Indoles:**

To a dried screw-capped vial were added indole **2** (0.80 mmol), phosphoryl azide **3** (0.40 mmol),  $[\text{Cp}^*\text{CoI}_2]_2$  (17.6 mg, 20  $\mu\text{mol}$ ),  $\text{AgSbF}_6$  (27.2 mg, 80  $\mu\text{mol}$ ), and 1,4-dioxane (0.20 mL) under Ar atmosphere. The vial was capped, and the mixture was heated at 60 °C for 36 h with stirring. The resulting mixture was cooled to room temperature, and directly purified by silica gel column chromatography (hexane:ethyl acetate = 1:1 for all compounds) to give product **4**.



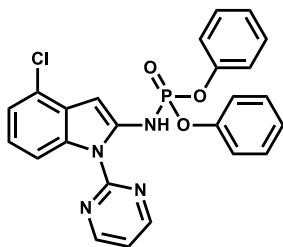
**Diphenyl (1-(pyrimidin-2-yl)-1H-indol-2-yl)phosphoramidate (4aa):**

colorless solid; IR (KBr)  $\nu$  3052, 2917, 1615, 1423, 1283, 1185, 951, 781, 687  $\text{cm}^{-1}$ ;  $^1\text{H}$  NMR (400 MHz,  $\text{CDCl}_3$ )  $\delta$  10.31 (d,  $J$  = 12.1 Hz, 1H), 8.55 - 8.49 (m, 3H), 7.43 - 7.39 (m, 1H), 7.22 - 7.16 (m, 8H), 7.16 - 7.09 (m, 2H), 7.09 - 7.02 (m, 2H), 6.92 (t,  $J$  = 4.9 Hz, 1H), 6.45 (s, 1H);  $^{13}\text{C}$  NMR (100 MHz,  $\text{CDCl}_3$ )  $\delta$  158.3, 157.5, 150.2 (d,  $J$  = 6.3 Hz), 136.4 (d,  $J$  = 7.2 Hz), 133.0, 129.7, 129.3, 125.4, 123.0, 121.8, 120.4 (d,  $J$  = 5.4 Hz), 119.0, 116.2, 115.9, 91.9;  $^{31}\text{P}$  NMR (158 MHz,  $\text{CDCl}_3$ )  $\delta$  -9.01; HRMS (ESI):  $m/z$  calculated for  $\text{C}_{24}\text{H}_{19}\text{N}_4\text{NaO}_3\text{P}^+ [\text{M}+\text{Na}^+]$  : 465.1087, found: 465.1089.



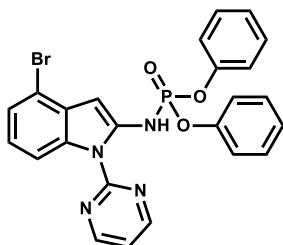
**Diphenyl (4-methoxy-1-(pyrimidin-2-yl)-1H-indol-2-yl)phosphoramidate (4ba):**

colorless solid; IR (KBr)  $\nu$  3067, 2955, 1568, 1367, 1270, 1194, 1014, 963, 689  $\text{cm}^{-1}$ ;  $^1\text{H}$  NMR (400 MHz,  $\text{CDCl}_3$ )  $\delta$  10.17 (d,  $J$  = 12.1 Hz, 1H), 8.58 (d,  $J$  = 4.9 Hz, 2H), 8.17 (d,  $J$  = 8.5 Hz, 1H), 7.26 - 7.19 (m, 8H), 7.12 - 7.07 (m, 3H), 6.97 (t,  $J$  = 4.9 Hz, 1H), 6.67 (d,  $J$  = 7.6 Hz, 1H), 6.62 (s, 1H), 3.91 (s, 3H);  $^{13}\text{C}$  NMR (100 MHz,  $\text{CDCl}_3$ )  $\delta$  158.4, 157.5, 151.7, 150.2 (d,  $J$  = 6.3 Hz), 134.9 (d,  $J$  = 6.3 Hz), 134.0, 129.7, 125.3 (d,  $J$  = 1.8 Hz), 122.5, 120.5 (d,  $J$  = 5.4 Hz), 119.3, 116.3, 109.1, 103.7, 89.3, 55.4;  $^{31}\text{P}$  NMR (158 MHz,  $\text{CDCl}_3$ )  $\delta$  -8.80; HRMS (ESI):  $m/z$  calculated for  $\text{C}_{25}\text{H}_{21}\text{N}_4\text{NaO}_4\text{P}^+ [\text{M}+\text{Na}^+]$  : 495.1193, found: 495.1183.



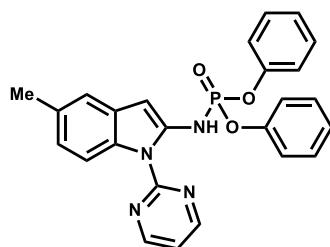
**Diphenyl (4-chloro-1-(pyrimidin-2-yl)-1H-indol-2-yl)phosphoramidate (4ca):**

colorless solid; IR (KBr)  $\nu$  3081, 2909, 1567, 1428, 1279, 1193, 1024, 954, 765 cm<sup>-1</sup>; <sup>1</sup>H NMR (500 MHz, CDCl<sub>3</sub>)  $\delta$  10.47 (d, *J* = 12.1 Hz, 1H), 8.67 (d, *J* = 4.6 Hz, 2H), 8.54 (d, *J* = 8.6 Hz, 1H), 7.37 - 7.29 (m, 8H), 7.28 - 7.23 (m, 1H), 7.21 - 7.16 (m, 2H), 7.15 - 7.09 (m, 2H), 6.64 (s, 1H); <sup>13</sup>C NMR (125 MHz, CDCl<sub>3</sub>)  $\delta$  158.2, 157.6, 150.2 (d, *J* = 7.2 Hz), 137.3 (d, *J* = 7.2 Hz), 133.5, 129.8, 128.1, 125.5, 124.1, 122.9, 122.3, 120.4 (d, *J* = 4.8 Hz), 116.7, 114.5, 89.9; <sup>31</sup>P NMR (158 MHz, CDCl<sub>3</sub>)  $\delta$  -9.45; HRMS (ESI): *m/z* calculated for C<sub>24</sub>H<sub>18</sub>ClN<sub>4</sub>NaO<sub>3</sub>P<sup>+</sup> [M+Na<sup>+</sup>] : 499.0697, found: 499.0689.



**Diphenyl (4-bromo-1-(pyrimidin-2-yl)-1H-indol-2-yl)phosphoramidate (4da):**

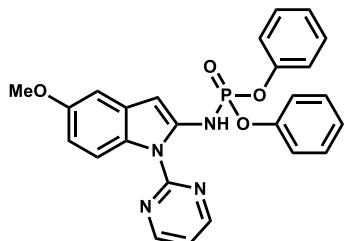
colorless solid; IR (KBr)  $\nu$  3039, 2914, 1567, 1447, 1280, 1192, 1020, 902, 757 cm<sup>-1</sup>; <sup>1</sup>H NMR (400 MHz, CDCl<sub>3</sub>)  $\delta$  10.37 (d, *J* = 12.1 Hz, 1H), 8.57 (d, *J* = 4.9 Hz, 2H), 8.49 (d, *J* = 8.5 Hz, 1H), 7.31 (d, *J* = 8.1 Hz, 1H), 7.25 - 7.17 (m, 8H), 7.11 - 7.05 (m, 2H), 7.02 (t, *J* = 4.9 Hz, 1H), 6.97 (dd, *J* = 8.5, 8.1 Hz, 1H), 6.50 (s, 1H); <sup>13</sup>C NMR (100 MHz, CDCl<sub>3</sub>)  $\delta$  158.2, 157.6, 150.2 (d, *J* = 7.2 Hz), 137.3 (d, *J* = 7.2 Hz), 133.1, 129.9, 129.8, 125.9, 125.5, 122.6, 120.4 (d, *J* = 4.5 Hz), 116.7, 115.1, 112.7, 91.7; <sup>31</sup>P NMR (158 MHz, CDCl<sub>3</sub>)  $\delta$  -9.51; HRMS (ESI): *m/z* calculated for C<sub>24</sub>H<sub>18</sub>BrN<sub>4</sub>NaO<sub>3</sub>P<sup>+</sup> [M+Na<sup>+</sup>] : 543.0192, found: 543.0198.



**Diphenyl (5-methyl-1-(pyrimidin-2-yl)-1H-indol-2-yl)phosphoramidate (4ea):**

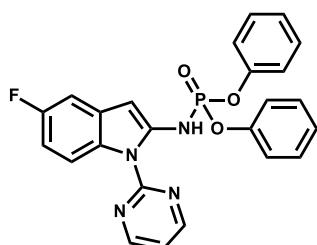
colorless solid; IR (KBr)  $\nu$  3041, 2915, 1561, 1480, 1274, 1012, 957, 788, 615 cm<sup>-1</sup>;

<sup>1</sup>H NMR (400 MHz, CDCl<sub>3</sub>) δ 10.36 (d, *J* = 12.6 Hz, 1H), 8.51 (d, *J* = 4.9 Hz, 2H), 8.41 (d, *J* = 8.5 Hz, 1H), 7.23 - 7.14 (m, 9H), 7.09 - 7.02 (m, 2H), 6.96 - 6.89 (m, 2H), 6.37 (s, 1H), 2.36 (s, 3H); <sup>13</sup>C NMR (100 MHz, CDCl<sub>3</sub>) δ 158.4, 157.4, 150.2 (d, *J* = 7.2 Hz), 136.5 (d, *J* = 7.2 Hz), 132.5, 131.1, 129.7, 129.5, 125.4, 123.0, 120.4 (d, *J* = 4.5 Hz), 119.1, 116.0, 115.7, 91.7, 21.3; <sup>31</sup>P NMR (158 MHz, CDCl<sub>3</sub>) δ -8.98; HRMS (ESI): *m/z* calculated for C<sub>25</sub>H<sub>21</sub>N<sub>4</sub>NaO<sub>3</sub>P<sup>+</sup> [M+Na<sup>+</sup>] : 479.1243, found: 479.1237.



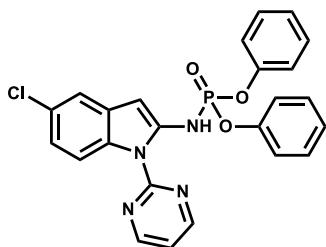
**Diphenyl (5-methoxy-1-(pyrimidin-2-yl)-1H-indol-2-yl)phosphoramidate (4fa):**

yellow solid; IR (KBr) ν 3062, 2995, 1582, 1424, 1212, 1089, 936, 779, 691 cm<sup>-1</sup>; <sup>1</sup>H NMR (400 MHz, CDCl<sub>3</sub>) δ 10.44 (d, *J* = 12.1 Hz, 1H), 8.52 (d, *J* = 4.9 Hz, 2H), 8.45 (d, *J* = 9.0 Hz, 1H), 7.23 - 7.15 (m, 8H), 7.09 - 7.04 (m, 2H), 6.94 - 6.89 (m, 2H), 6.73 - 6.70 (m, 1H), 6.39 (s, 1H), 3.78 (s, 3H); <sup>13</sup>C NMR (100 MHz, CDCl<sub>3</sub>) δ 158.3, 157.4, 156.1, 150.2 (d, *J* = 6.3 Hz), 137.2 (d, *J* = 7.2 Hz), 130.3, 129.7, 127.5, 125.4, 120.4 (d, *J* = 4.5 Hz), 117.0, 116.0, 109.7, 102.2, 91.8, 55.5; <sup>31</sup>P NMR (158 MHz, CDCl<sub>3</sub>) δ -9.05; HRMS (ESI): *m/z* calculated for C<sub>25</sub>H<sub>21</sub>N<sub>4</sub>NaO<sub>4</sub>P<sup>+</sup> [M+Na<sup>+</sup>] : 495.1193, found: 495.1197.



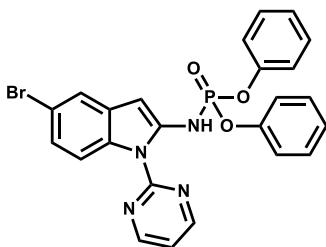
**Diphenyl (5-fluoro-1-(pyrimidin-2-yl)-1H-indol-2-yl)phosphoramidate (4ga):**

yellow solid; IR (KBr) ν 3063, 2923, 1597, 1495, 1285, 1200, 1024, 905, 767 cm<sup>-1</sup>; <sup>1</sup>H NMR (400 MHz, CDCl<sub>3</sub>) δ 10.45 (d, *J* = 12.1 Hz, 1H), 8.56 (d, *J* = 4.9 Hz, 2H), 8.51 (dd, *J* = 9.2, 4.5 Hz, 1H), 7.25 - 7.16 (m, 8H), 7.10 - 7.04 (m, 3H), 6.99 (t, *J* = 4.9 Hz, 1H), 6.82 (ddd, *J* = 9.2, 9.2, 2.7 Hz, 1H), 6.40 (s, 1H); <sup>13</sup>C NMR (100 MHz, CDCl<sub>3</sub>) δ 159.6 (d, *J* = 237.4 Hz), 158.2, 157.5, 150.1 (d, *J* = 6.3 Hz), 138.0 (d, *J* = 7.2 Hz), 130.4 (d, *J* = 9.9 Hz), 129.8, 129.2, 125.4 (d, *J* = 1.8 Hz), 120.4 (d, *J* = 4.5 Hz), 117.1 (d, *J* = 9.0 Hz), 116.4, 109.0 (d, *J* = 24.3 Hz), 104.6 (d, *J* = 24.3 Hz), 91.6 (d, *J* = 3.6 Hz); <sup>31</sup>P NMR (158 MHz, CDCl<sub>3</sub>) δ -9.31; HRMS (ESI): *m/z* calculated for C<sub>24</sub>H<sub>18</sub>FN<sub>4</sub>NaO<sub>3</sub>P<sup>+</sup> [M+Na<sup>+</sup>] : 483.0993, found: 483.0987.



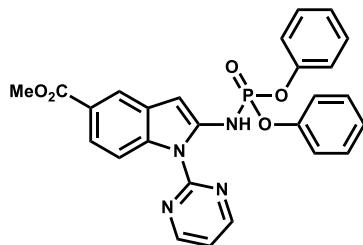
**Diphenyl (5-chloro-1-(pyrimidin-2-yl)-1H-indol-2-yl)phosphoramidate (4ha):**

colorless solid; IR (KBr)  $\nu$  3062, 2927, 1565, 1498, 1256, 1071, 983, 764, 652  $\text{cm}^{-1}$ ;  $^1\text{H}$  NMR (500 MHz,  $\text{CDCl}_3$ )  $\delta$  10.42 (d,  $J = 12.1$  Hz, 1H), 8.55 (d,  $J = 4.6$  Hz, 2H), 8.47 (d,  $J = 8.6$  Hz, 1H), 7.36 (d,  $J = 2.3$  Hz, 1H), 7.24 - 7.16 (m, 8H), 7.10 - 7.03 (m, 3H), 6.99 (t,  $J = 4.6$  Hz, 1H), 6.37 (s, 1H);  $^{13}\text{C}$  NMR (125 MHz,  $\text{CDCl}_3$ )  $\delta$  158.2, 157.6, 150.1 (d,  $J = 6.0$  Hz), 137.8 (d,  $J = 7.2$  Hz), 131.3, 130.7, 129.8, 128.5, 125.5, 121.7, 120.4 (d,  $J = 4.8$  Hz), 118.4, 117.2, 116.5, 91.1;  $^{31}\text{P}$  NMR (158 MHz,  $\text{CDCl}_3$ )  $\delta$  -9.36; HRMS (ESI):  $m/z$  calculated for  $\text{C}_{24}\text{H}_{18}\text{ClN}_4\text{NaO}_3\text{P}^+ [\text{M}+\text{Na}^+]$  : 499.0697, found: 499.0710.



**Diphenyl (5-bromo-1-(pyrimidin-2-yl)-1H-indol-2-yl)phosphoramidate (4ia):**

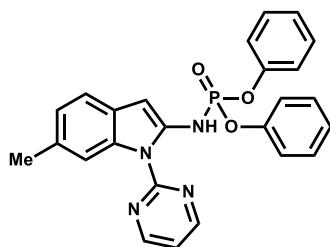
colorless solid; IR (KBr)  $\nu$  3042, 2924, 1582, 1492, 1276, 1163, 954, 771, 690  $\text{cm}^{-1}$ ;  $^1\text{H}$  NMR (400 MHz,  $\text{CDCl}_3$ )  $\delta$  10.42 (d,  $J = 12.1$  Hz, 1H), 8.55 (d,  $J = 4.9$  Hz, 2H), 8.41 (d,  $J = 9.0$  Hz, 1H), 7.51 (s, 1H), 7.25 - 7.15 (m, 9H), 7.10 - 7.04 (m, 2H), 6.99 (t,  $J = 4.9$  Hz, 1H), 6.37 (s, 1H);  $^{13}\text{C}$  NMR (100 MHz,  $\text{CDCl}_3$ )  $\delta$  158.2, 157.5, 150.1 (d,  $J = 6.3$  Hz), 137.7 (d,  $J = 7.2$  Hz), 131.6, 131.1, 129.8, 125.5 (d,  $J = 1.8$  Hz), 124.4, 121.4, 120.3 (d,  $J = 4.5$  Hz), 117.6, 116.5, 116.3, 90.9;  $^{31}\text{P}$  NMR (158 MHz,  $\text{CDCl}_3$ )  $\delta$  -9.39; HRMS (ESI):  $m/z$  calculated for  $\text{C}_{24}\text{H}_{18}\text{BrN}_4\text{NaO}_3\text{P}^+ [\text{M}+\text{Na}^+]$  : 543.0192, found: 543.0199.



**Methyl 2-((diphenoxypyrophoryl)amino)-1-(pyrimidin-2-yl)-1H-indole-5-carboxylate (4ja):**

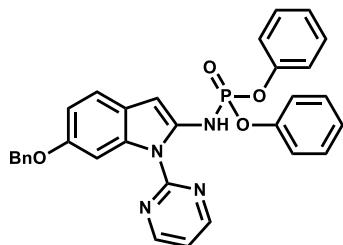
colorless solid; IR (KBr)  $\nu$  3057, 2953, 1704, 1564, 1491, 1292, 970, 767, 652  $\text{cm}^{-1}$ ;

<sup>1</sup>H NMR (400 MHz, CDCl<sub>3</sub>) δ 10.28 (d, *J* = 12.1 Hz, 1H), 8.60 -8.53 (m, 3H), 8.13 (d, *J* = 1.8 Hz, 1H), 7.81 (dd, *J* = 9.0, 1.8 Hz, 1H), 7.25 -7.16 (m, 8H), 7.09 -7.05 (m, 2H), 7.03 (t, *J* = 4.9 Hz, 1H), 6.50 (s, 1H), 3.86 (s, 3H); <sup>13</sup>C NMR (100 MHz, CDCl<sub>3</sub>) δ 167.6, 158.1, 157.7, 150.1 (d, *J* = 7.2 Hz), 137.6 (d, *J* = 7.2 Hz), 135.7, 129.8, 129.0, 125.5, 124.8, 123.3, 120.9, 120.3 (d, *J* = 4.5 Hz), 116.9, 115.6, 92.0, 51.9; <sup>31</sup>P NMR (158 MHz, CDCl<sub>3</sub>) δ -9.36; HRMS (ESI): *m/z* calculated for C<sub>26</sub>H<sub>21</sub>N<sub>4</sub>NaO<sub>5</sub>P<sup>+</sup> [M+Na<sup>+</sup>] : 523.1142, found: 523.1125.



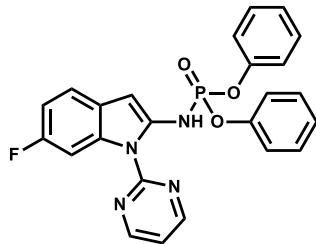
**Diphenyl (6-methyl-1-(pyrimidin-2-yl)-1H-indol-2-yl)phosphoramidate (4ka):**

colorless solid; IR (KBr) ν 3063, 2915, 1577, 1428, 1284, 1185, 954, 813, 691 cm<sup>-1</sup>; <sup>1</sup>H NMR (400 MHz, CDCl<sub>3</sub>) δ 10.17 (d, *J* = 12.6 Hz, 1H), 8.55 (d, *J* = 4.9 Hz, 2H), 8.35 (s, 1H), 7.30 (d, *J* = 7.6 Hz, 1H), 7.22 -7.14 (m, 8H), 7.08 -7.03 (m, 2H), 7.00 -6.97 (m, 1H), 6.94 (t, *J* = 4.9 Hz, 1H), 6.41 (s, 1H), 2.41 (s, 3H); <sup>13</sup>C NMR (100 MHz, CDCl<sub>3</sub>) δ 158.3, 157.5, 150.2 (d, *J* = 7.2 Hz), 135.7 (d, *J* = 7.2 Hz), 133.3, 131.7, 129.7, 126.9, 125.3, 124.3, 120.5 (d, *J* = 4.5 Hz), 118.7, 116.1, 116.0, 92.1, 22.0; <sup>31</sup>P NMR (158 MHz, CDCl<sub>3</sub>) δ -8.80; HRMS (ESI): *m/z* calculated for C<sub>25</sub>H<sub>21</sub>N<sub>4</sub>NaO<sub>3</sub>P<sup>+</sup> [M+Na<sup>+</sup>] : 479.1243, found: 479.1241.



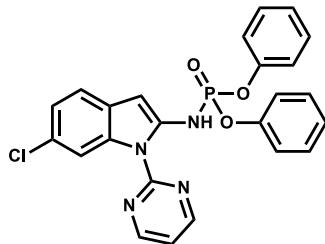
**Diphenyl (6-(benzyloxy)-1-(pyrimidin-2-yl)-1H-indol-2-yl)phosphoramidate (4la):**

yellow solid; IR (KBr) ν 3061, 2905, 1578, 1416, 1281, 1158, 953, 775, 695 cm<sup>-1</sup>; <sup>1</sup>H NMR (500 MHz, CDCl<sub>3</sub>) δ 10.12 (d, *J* = 14.1 Hz, 1H), 8.52 (d, *J* = 4.6 Hz, 2H), 8.30 (d, *J* = 2.3 Hz, 1H), 7.41 (brd, *J* = 7.5 Hz, 2H), 7.32 -7.27 (m, 3H), 7.25 -7.16 (m, 9H), 7.08 -7.02 (m, 2H), 6.94 (t, *J* = 4.6 Hz, 1H), 6.88 (dd, *J* = 8.6, 2.3 Hz, 1H), 6.38 (s, 1H), 5.05 (s, 2H); <sup>13</sup>C NMR (125 MHz, CDCl<sub>3</sub>) δ 158.3, 157.5, 155.2, 150.2 (d, *J* = 7.2 Hz), 137.5, 135.4 (d, *J* = 6.0 Hz), 133.8, 129.7, 128.5, 127.8, 127.6, 125.3, 123.3, 120.4 (d, *J* = 4.8 Hz), 119.2, 116.1, 111.5, 103.3, 92.1, 70.8; <sup>31</sup>P NMR (158 MHz, CDCl<sub>3</sub>) δ -8.83; HRMS (ESI): *m/z* calculated for C<sub>31</sub>H<sub>25</sub>N<sub>4</sub>NaO<sub>4</sub>P<sup>+</sup> [M+Na<sup>+</sup>] : 571.1506, found: 571.1531.



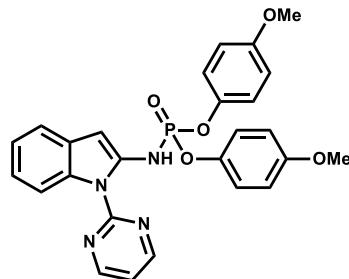
**Diphenyl (6-fluoro-1-(pyrimidin-2-yl)-1H-indol-2-yl)phosphoramidate (4ma):**

colorless solid; IR (KBr)  $\nu$  3065, 2911, 1577, 1496, 1283, 1197, 969, 809, 687  $\text{cm}^{-1}$ ;  $^1\text{H}$  NMR (400 MHz,  $\text{CDCl}_3$ )  $\delta$  10.22 (d,  $J = 12.1$  Hz, 1H), 8.56 (d,  $J = 4.9$  Hz, 2H), 8.35 (dd,  $J = 11.2, 2.2$  Hz, 1H), 7.33 - 7.28 (m, 1H), 7.24 - 7.16 (m, 8H), 7.09 - 7.04 (m, 2H), 6.99 (t,  $J = 4.9$  Hz, 1H), 6.94 - 6.88 (m, 1H), 6.41 (s, 1H);  $^{13}\text{C}$  NMR (100 MHz,  $\text{CDCl}_3$ )  $\delta$  159.3 (d,  $J = 234.7$  Hz), 158.2, 157.6, 150.2 (d,  $J = 6.3$  Hz), 136.7 (d,  $J = 3.6$  Hz), 136.6 (d,  $J = 3.6$  Hz), 132.9 (d,  $J = 12.6$  Hz), 129.7, 125.4, 120.4 (d,  $J = 4.5$  Hz), 119.2 (d,  $J = 9.9$  Hz), 116.5, 110.8 (d,  $J = 23.4$  Hz), 103.8 (d,  $J = 29.7$  Hz), 91.7;  $^{31}\text{P}$  NMR (158 MHz,  $\text{CDCl}_3$ )  $\delta$  -9.11; HRMS (ESI):  $m/z$  calculated for  $\text{C}_{24}\text{H}_{18}\text{FN}_4\text{NaO}_3\text{P}^+[\text{M}+\text{Na}^+]$ : 483.0993, found: 483.0976.



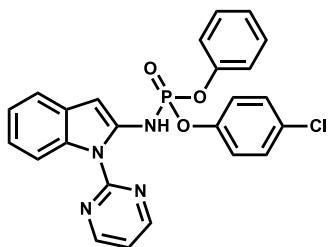
**Diphenyl (6-chloro-1-(pyrimidin-2-yl)-1H-indol-2-yl)phosphoramidate (4na):**

colorless solid; IR (KBr)  $\nu$  3054, 2919, 1577, 1496, 1281, 1194, 953, 770, 689  $\text{cm}^{-1}$ ;  $^1\text{H}$  NMR (400 MHz,  $\text{CDCl}_3$ )  $\delta$  10.31 (d,  $J = 12.1$  Hz, 1H), 8.61 (d,  $J = 1.8$  Hz, 1H), 8.57 (d,  $J = 4.9$  Hz, 2H), 7.31 (d,  $J = 8.5$  Hz, 1H), 7.24 - 7.16 (m, 8H), 7.14 - 7.11 (m, 1H), 7.10 - 7.05 (m, 2H), 7.01 (t,  $J = 4.9$  Hz, 1H), 6.41 (s, 1H);  $^{13}\text{C}$  NMR (100 MHz,  $\text{CDCl}_3$ )  $\delta$  158.2, 157.6, 150.1 (d,  $J = 7.2$  Hz), 137.1 (d,  $J = 7.2$  Hz), 133.2, 129.8, 127.8, 127.3, 125.4, 123.4, 120.4 (d,  $J = 4.5$  Hz), 119.5, 116.6, 116.3, 91.6;  $^{31}\text{P}$  NMR (158 MHz,  $\text{CDCl}_3$ )  $\delta$  -9.22; HRMS (ESI):  $m/z$  calculated for  $\text{C}_{24}\text{H}_{18}\text{ClN}_4\text{NaO}_3\text{P}^+[\text{M}+\text{Na}^+]$ : 499.0697, found: 499.0694.



**Bis(4-methoxyphenyl) (1-(pyrimidin-2-yl)-1H-indol-2-yl)phosphoramidate (4ab):**

colorless solid; IR (KBr)  $\nu$  3080, 2935, 1600, 1457, 1285, 1184, 955, 828, 743  $\text{cm}^{-1}$ ;  $^1\text{H}$  NMR (400 MHz,  $\text{CDCl}_3$ )  $\delta$  10.18 (d,  $J = 12.1$  Hz, 1H), 8.56 - 8.52 (m, 3H), 7.42 (dd,  $J = 6.3, 1.8$  Hz, 1H), 7.17 - 7.07 (m, 6H), 6.95 (t,  $J = 4.9$  Hz, 1H), 6.72 - 6.67 (m, 4H), 6.43 (s, 1H), 3.64 (s, 6H);  $^{13}\text{C}$  NMR (100 MHz,  $\text{CDCl}_3$ )  $\delta$  158.4, 157.5, 156.9, 143.7 (d,  $J = 6.3$  Hz), 136.6 (d,  $J = 6.3$  Hz), 133.0, 129.3, 123.0, 121.8, 121.3 (d,  $J = 4.5$  Hz), 119.0, 116.2, 115.9, 114.6, 91.9, 55.5;  $^{31}\text{P}$  NMR (158 MHz,  $\text{CDCl}_3$ )  $\delta$  -7.80; HRMS (ESI):  $m/z$  calculated for  $\text{C}_{26}\text{H}_{23}\text{N}_4\text{NaO}_5\text{P}^+$  [M+Na $^+$ ] : 525.1298, found: 525.1319.

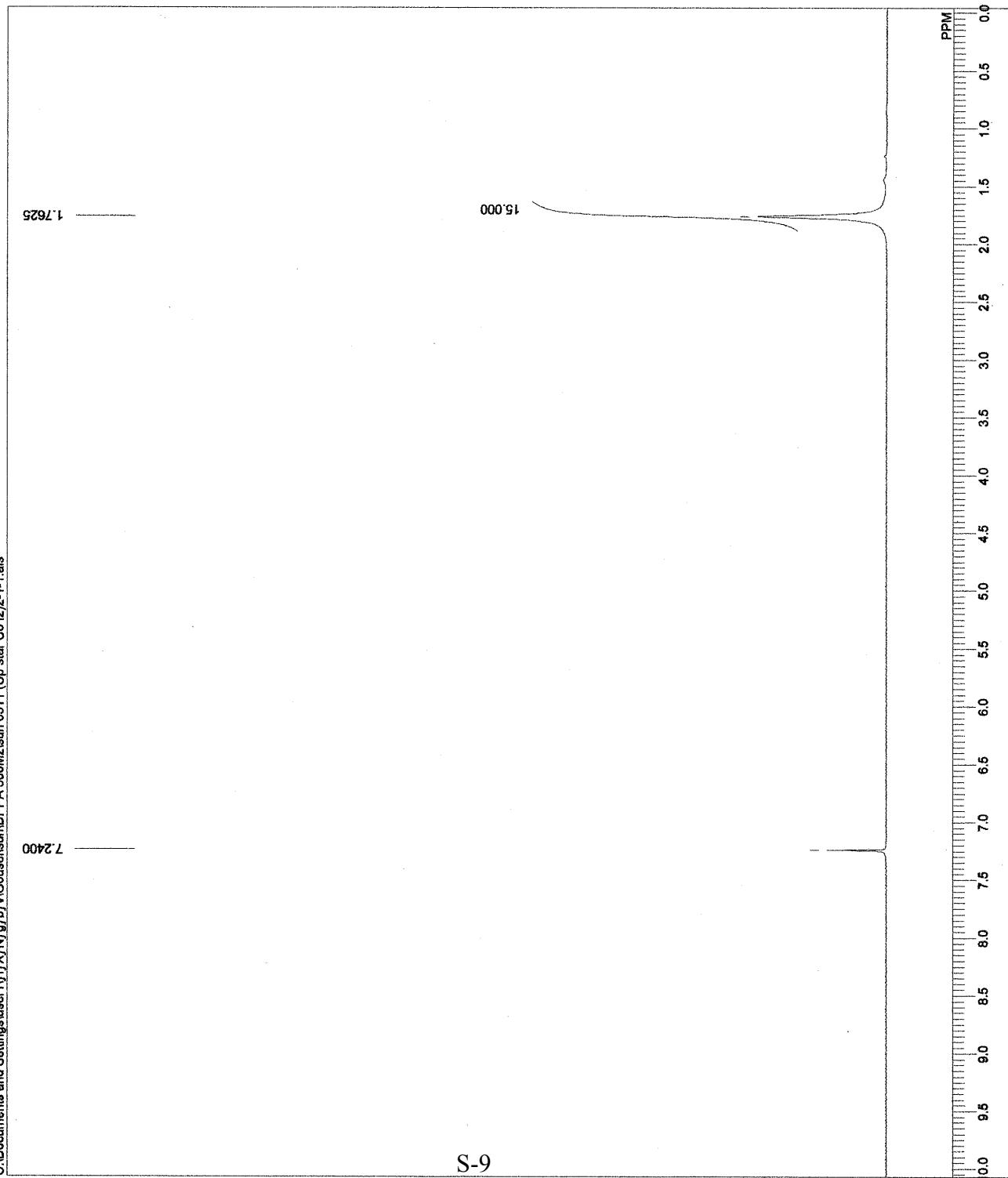


**4-chlorophenyl phenyl (1-(pyrimidin-2-yl)-1H-indol-2-yl)phosphoramidate (4ac):** yellow oil; IR (neat)  $\nu$  3057, 1583, 1485, 1427, 1352, 1190, 944, 747  $\text{cm}^{-1}$ ;  $^1\text{H}$  NMR (400 MHz,  $\text{CDCl}_3$ )  $\delta$  10.32 (d,  $J = 12.1$  Hz, 1H), 8.59 - 8.45 (m, 3H), 7.45 - 7.36 (m, 1H), 7.25 - 7.01 (m, 11H), 6.90 (td,  $J = 4.9, 1.3$  Hz, 1H), 6.41 (s, 1H);  $^{13}\text{C}$  NMR (125 MHz,  $\text{CDCl}_3$ )  $\delta$  158.3, 157.4, 150.0 (d,  $J = 7.2$  Hz), 148.6 (d,  $J = 7.2$  Hz), 136.1 (d,  $J = 7.2$  Hz), 133.0, 130.7, 129.7, 129.7, 129.1, 125.5, 123.1, 122.0, 121.8 (d,  $J = 3.6$  Hz), 120.3 (d,  $J = 4.8$  Hz), 119.0, 116.2, 116.0, 92.1;  $^{31}\text{P}$  NMR (158 MHz,  $\text{CDCl}_3$ )  $\delta$  -8.87; HRMS (ESI):  $m/z$  calculated for  $\text{C}_{24}\text{H}_{18}\text{ClN}_4\text{NaO}_3\text{P}^+$  [M+Na $^+$ ] : 499.0697, found: 499.0686.

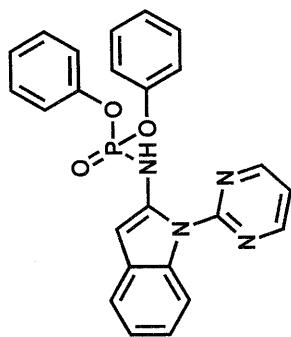
### Reference:

- [S1] L. Ackermann, A. V. Lygin. *Org. Lett.* **2011**, *13*, 3332.
- [S2] J. Shi, B. Zhou, Y. Yang, Y. Li. *Org. Biomol. Chem.* 2012, *10*, 8953.
- [S3] S. H. Kim, D. Y. Jung, S. Chang. *J. Org. Chem.*, **2007**, *72*, 9769.
- [S4] S. A. Frith, J. Spencer. *Inorganic Syntheses*. **1990**, *28*, 273.
- [S5] W. Li, L. Weng, G. Jin. *Inorg. Chem. Commun.* **2004**, *7*, 1174.

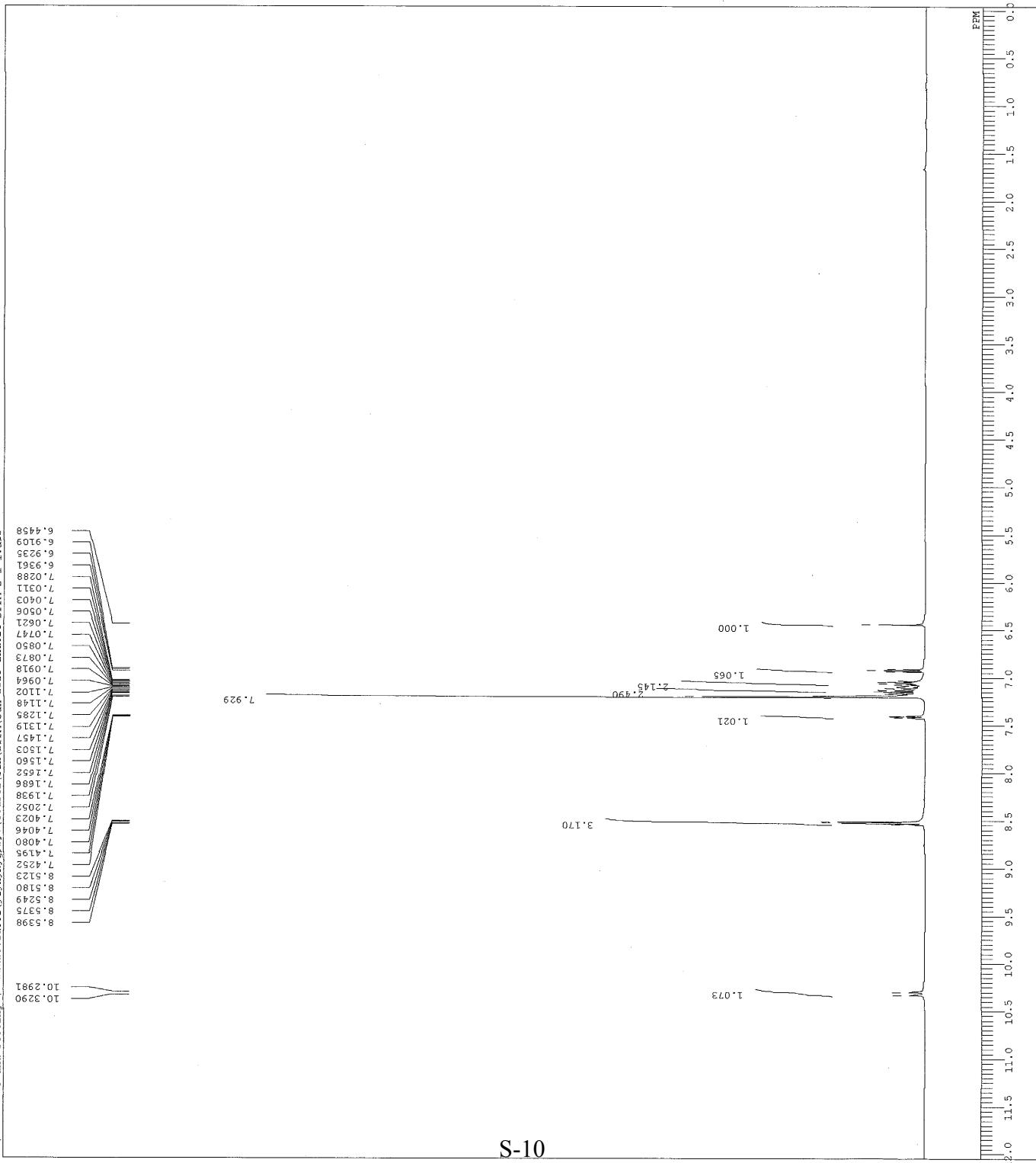
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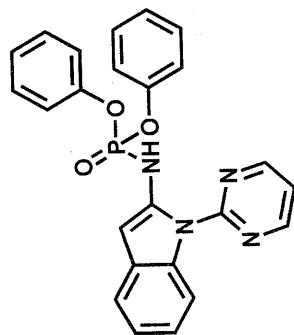
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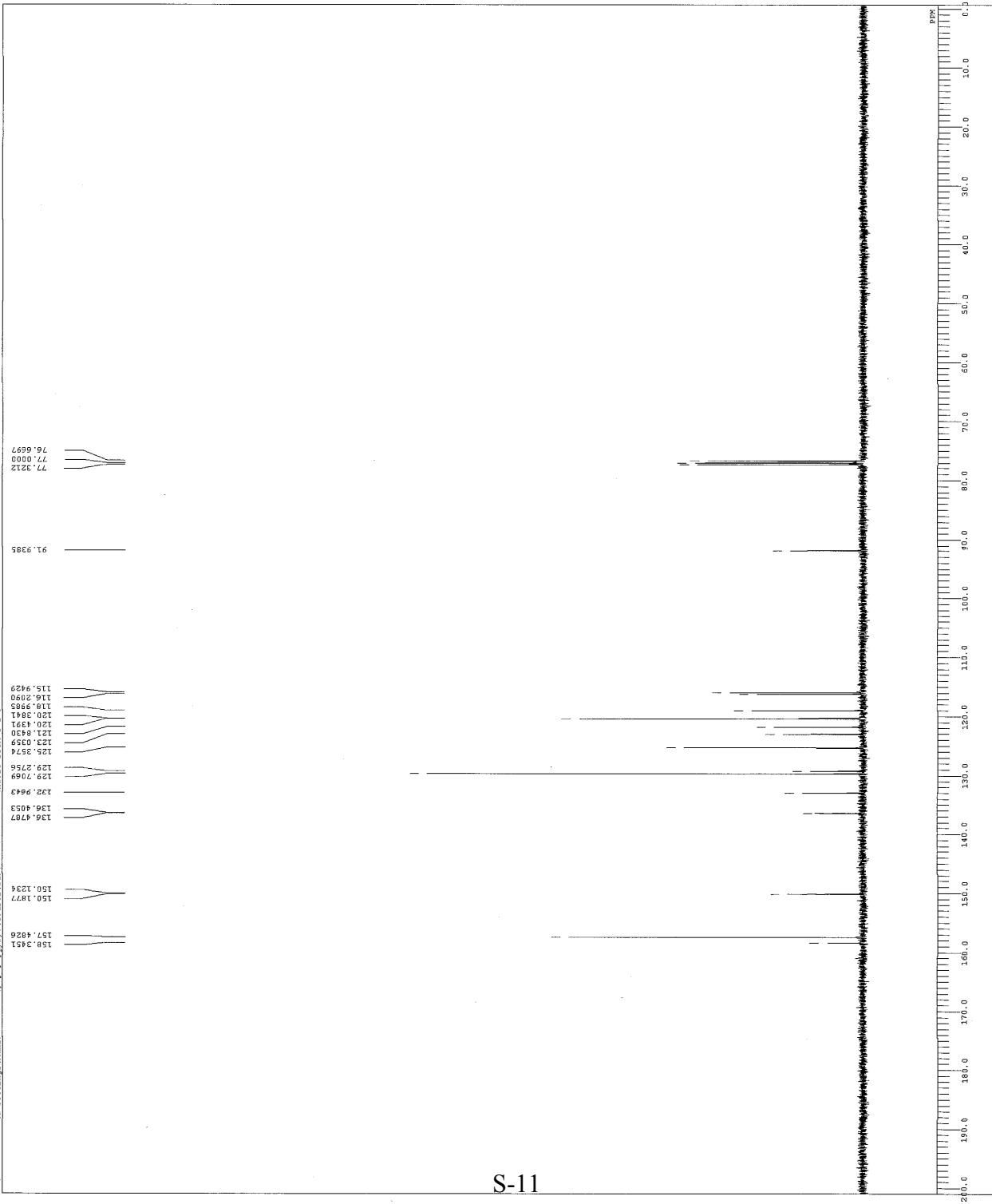
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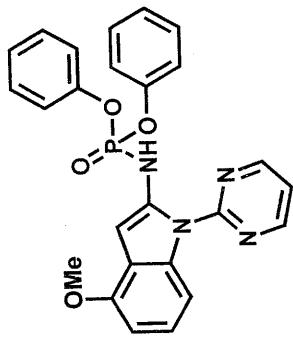
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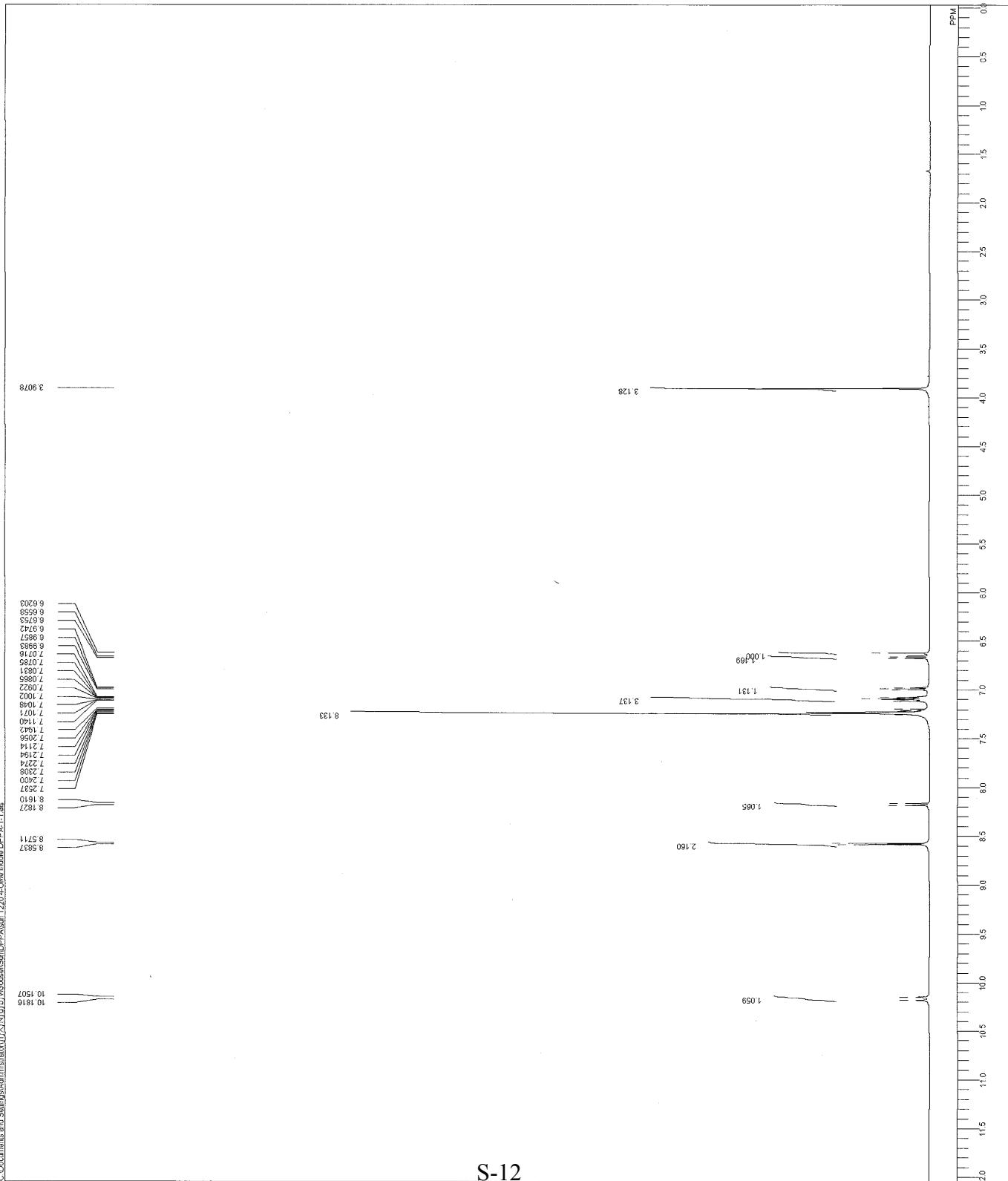
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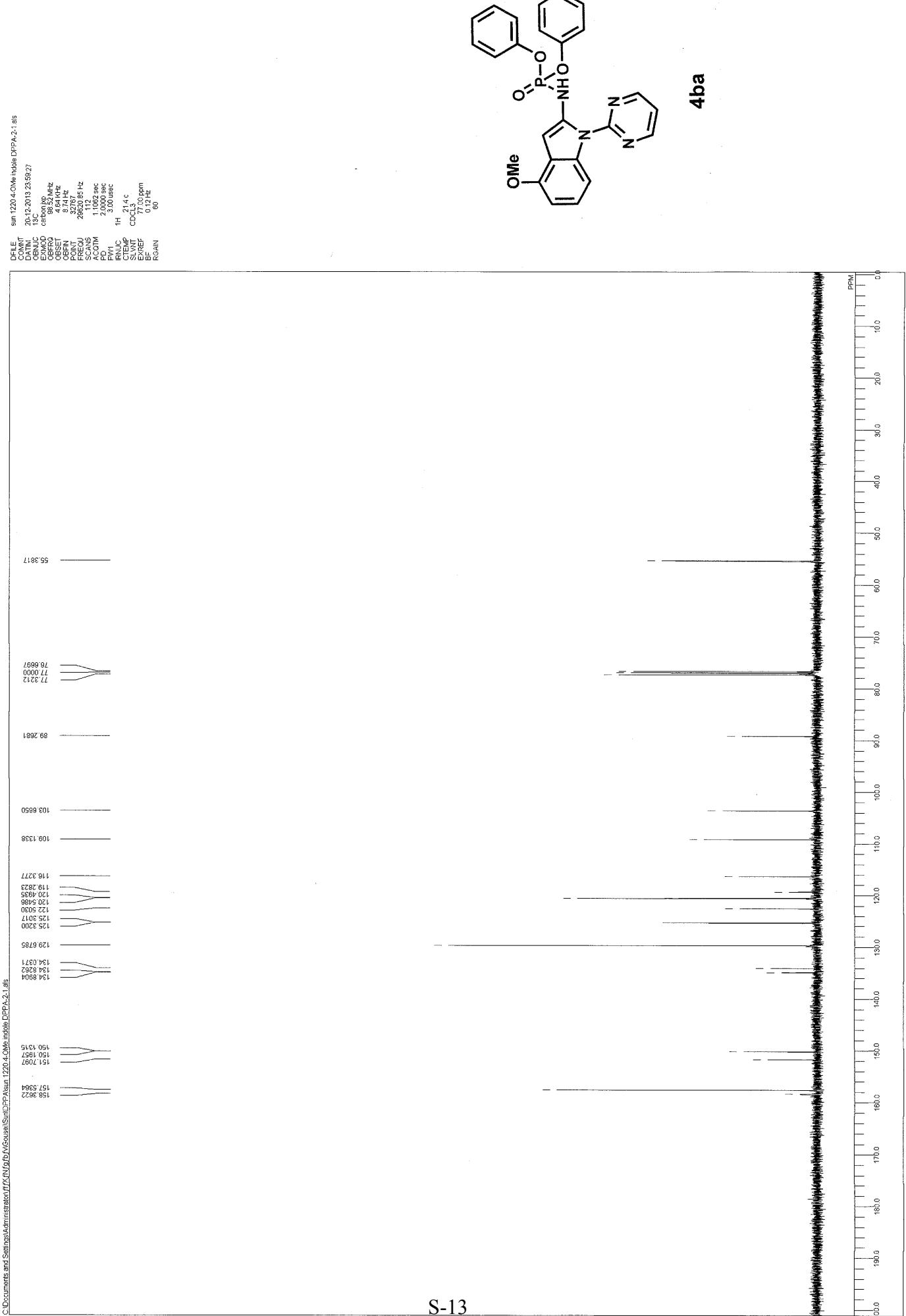


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4ba

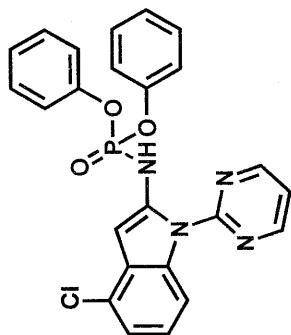




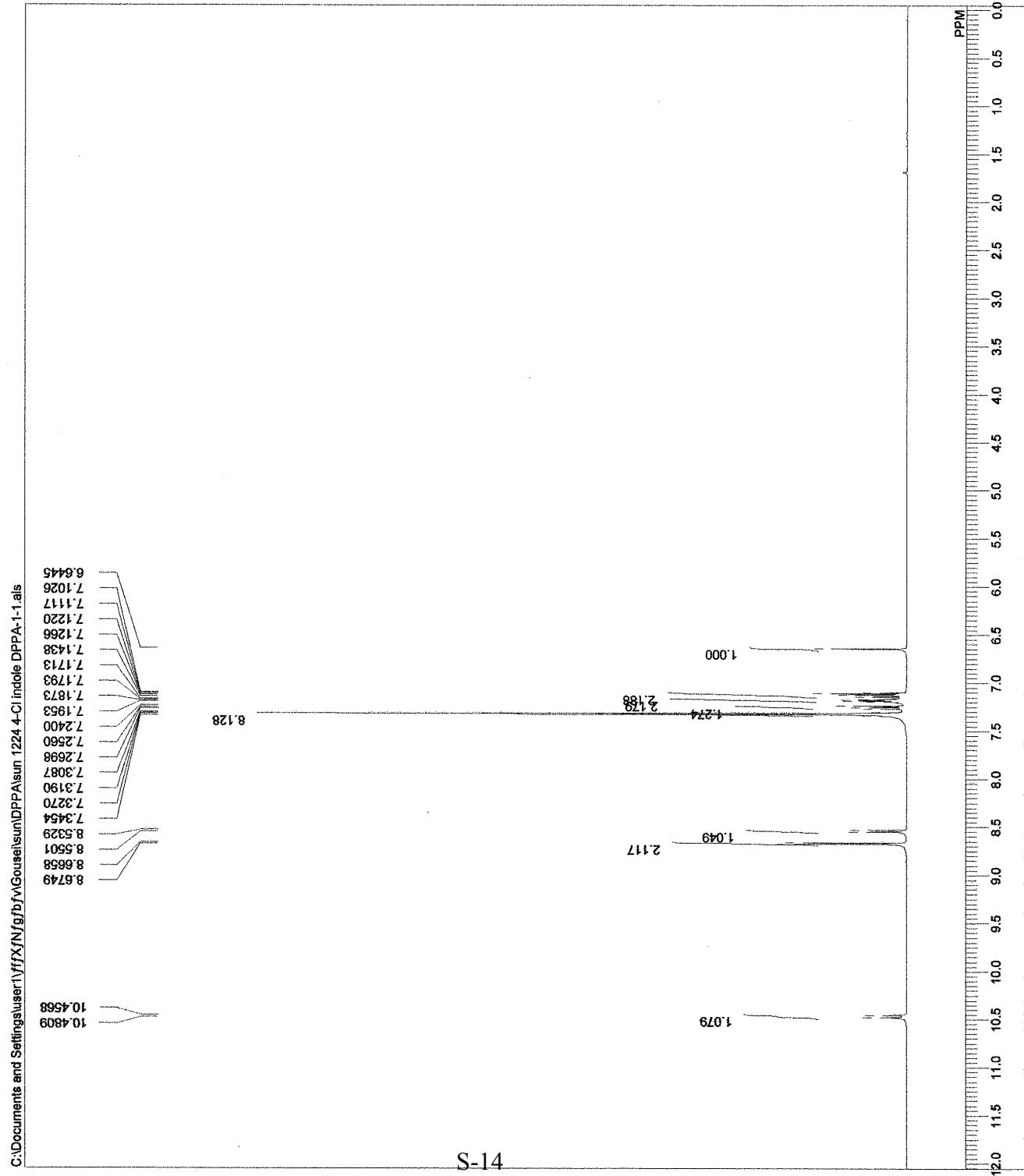
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RGAIN

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34



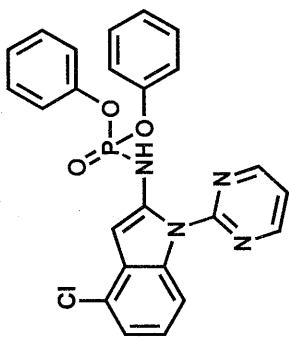
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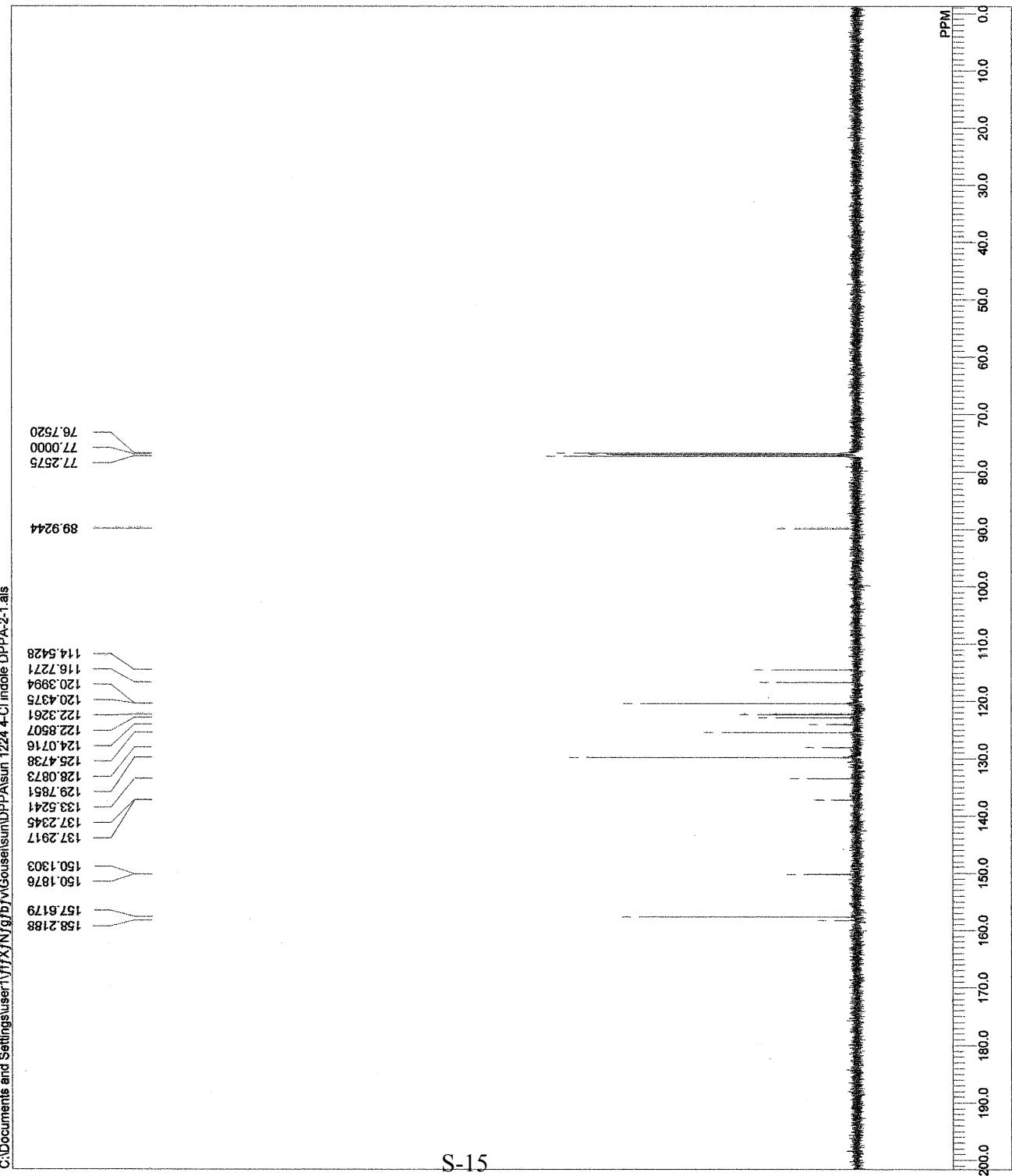
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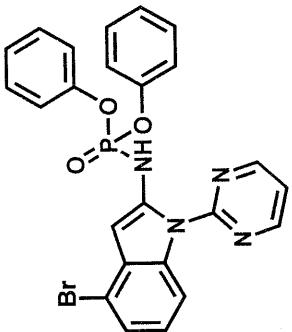
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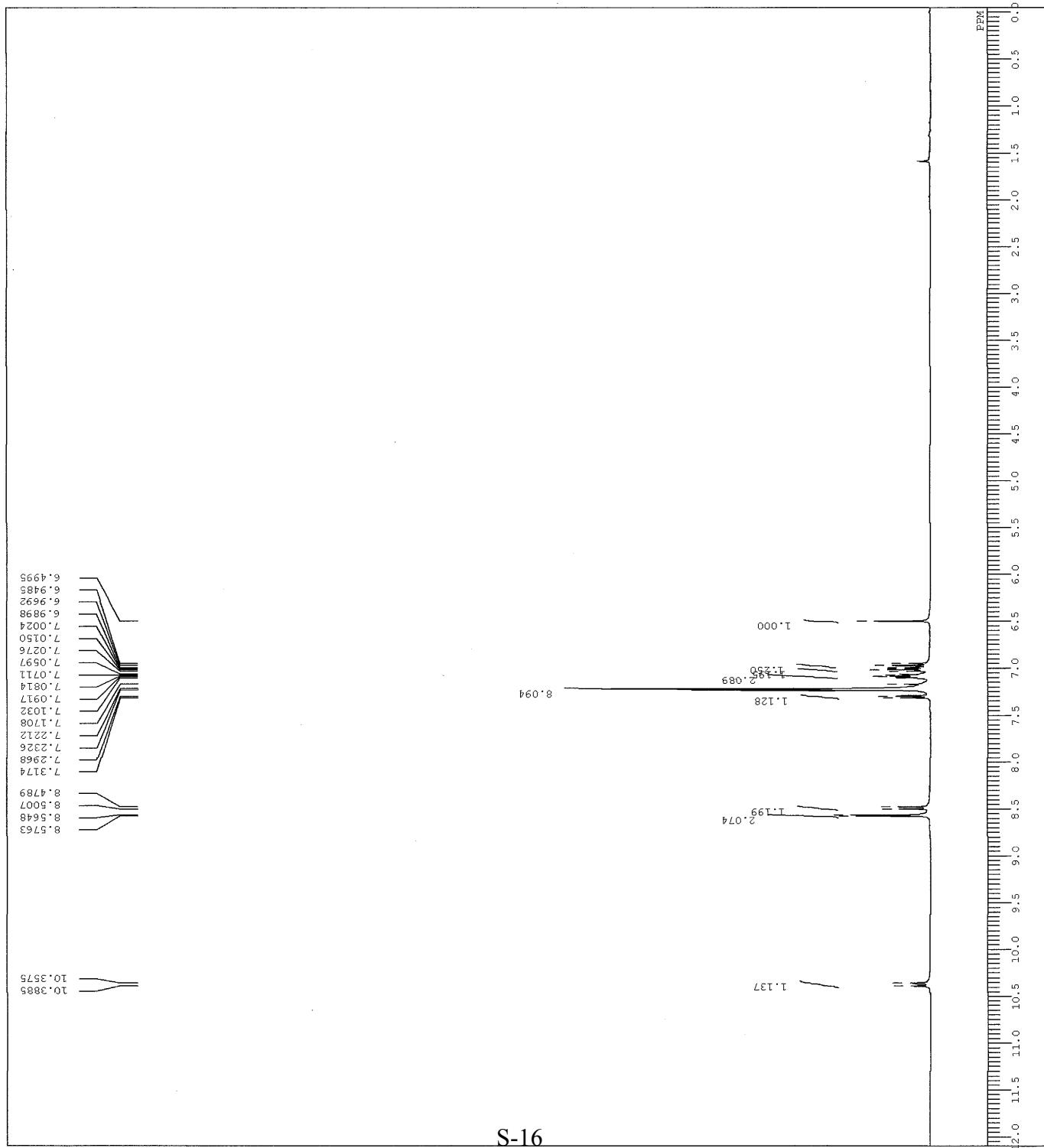


4ca

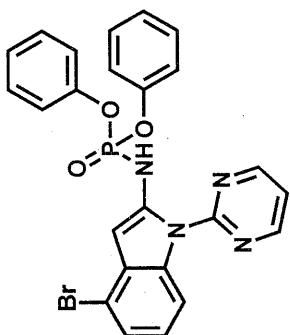




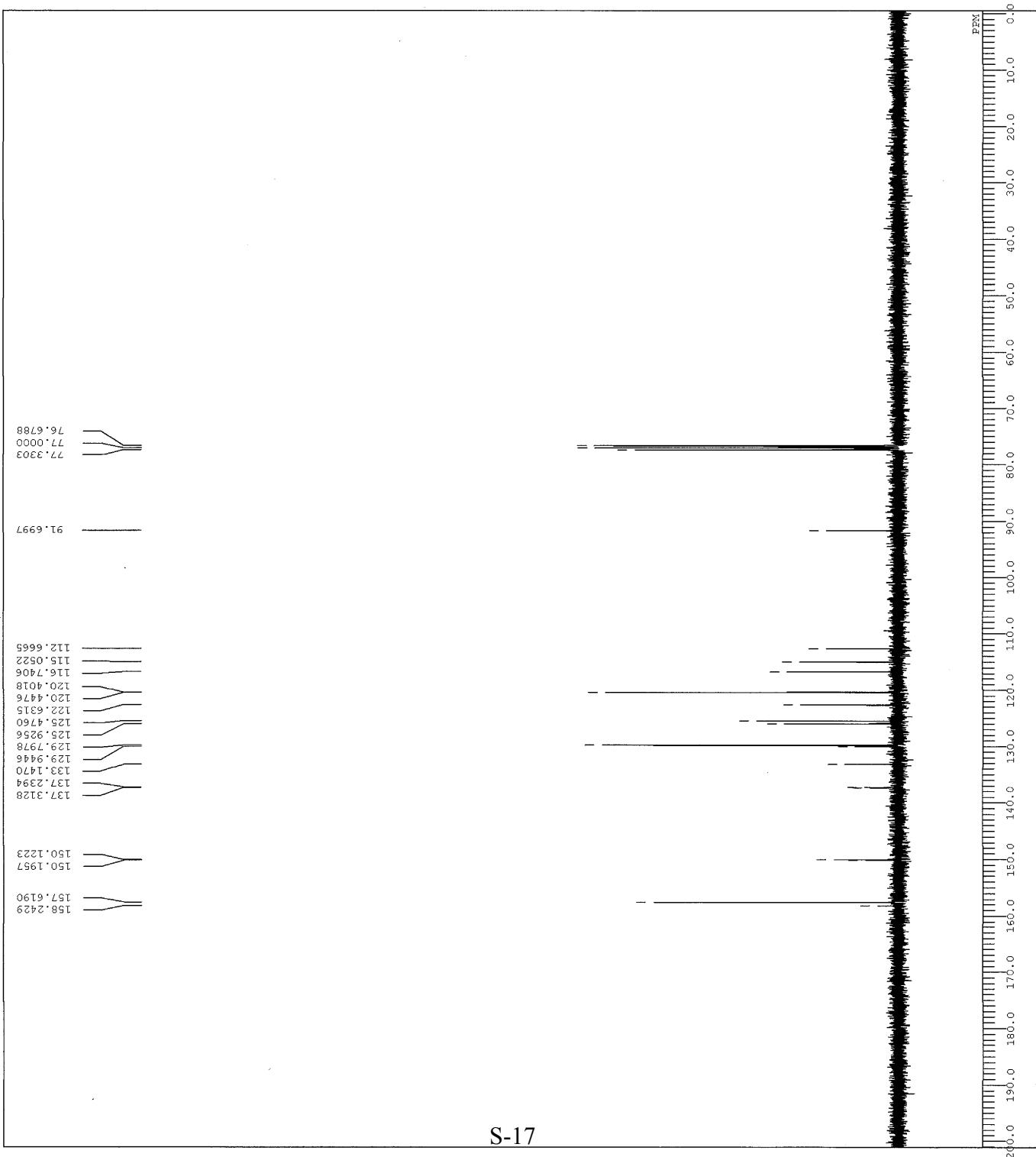
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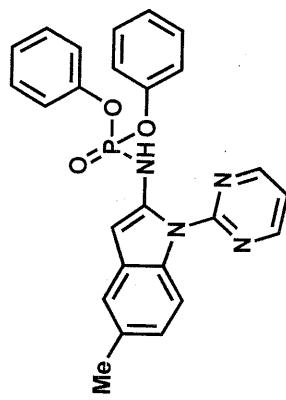
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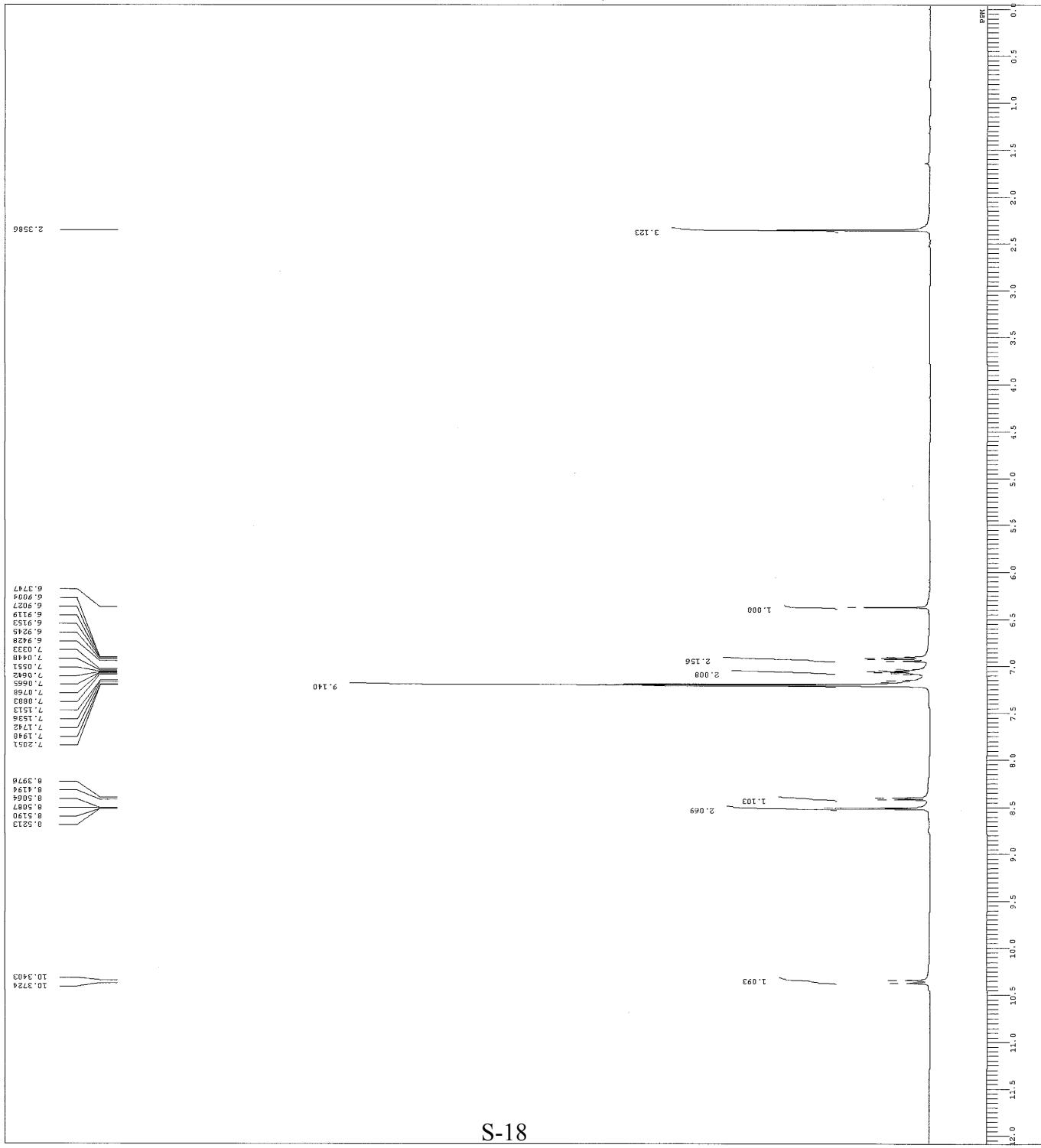
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4ea

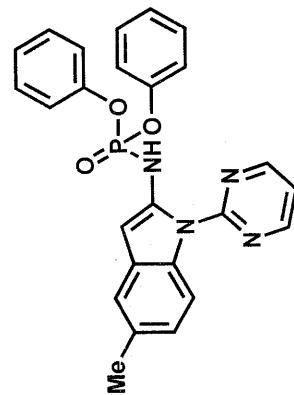


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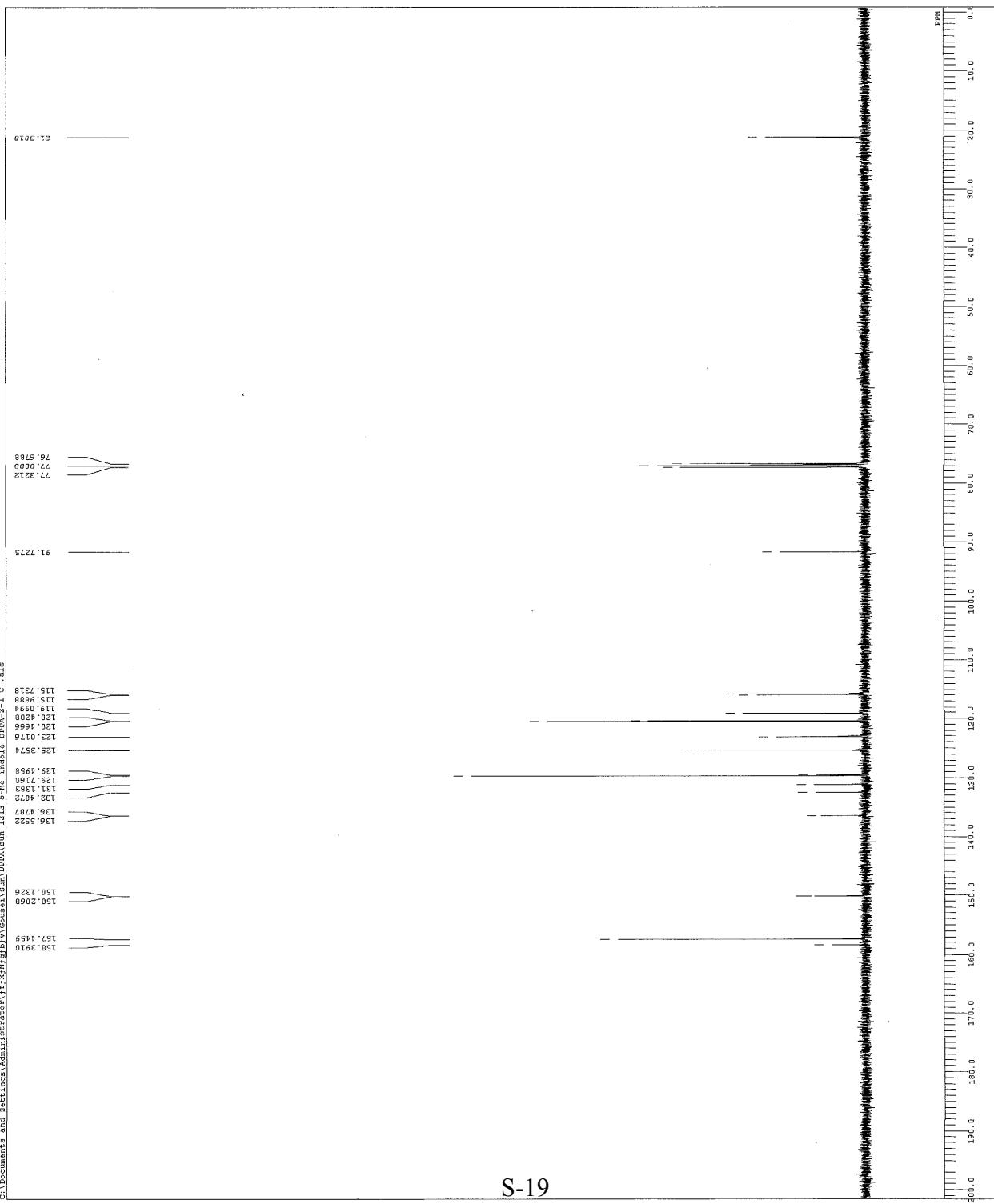
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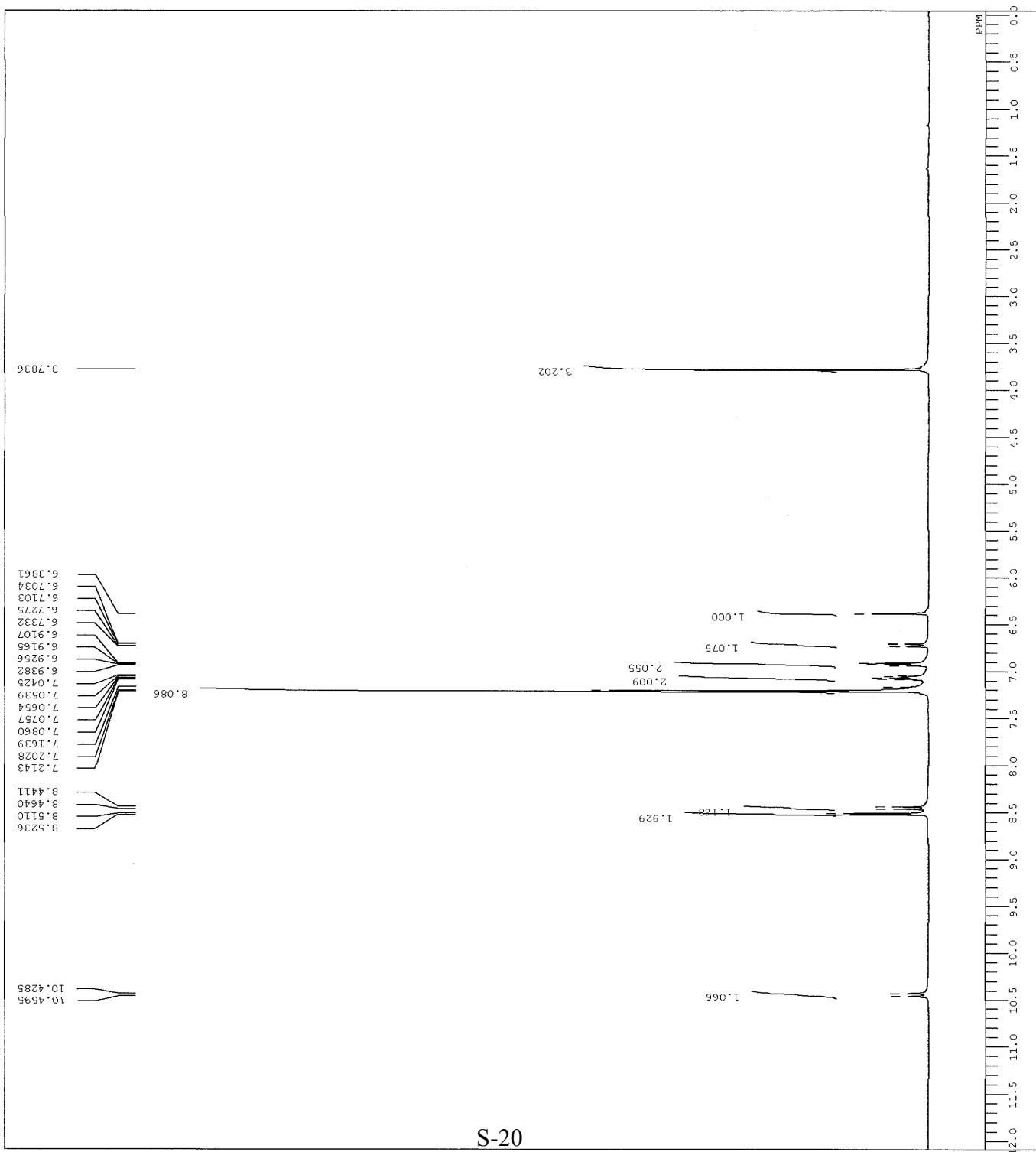
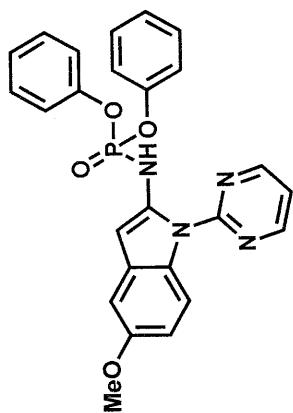
4ea



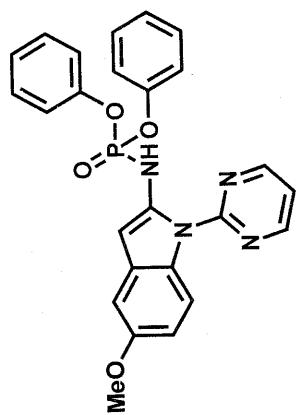
```

DFILE sun 1217 5-OMe indole DPPA-1.als
DATIM 17-12-2013 23:42:16
1H
OBNUC proton,90D
EXMOD 391.78 MHz
OBFQ 8.51 kHz
OBFIN 3.34 Hz
POINT 16384
FREQ0 7352.94 Hz
SCANS 6
ACQIM 2.2282 sec
PD 5.0000 sec
FW1 5.25 ussec
IRNUC 1H
CTEMP 21.3 °C
SLVNT CDCl3
EXREF 0.00 ppm
BF 0.12 Hz
RGAIN 28

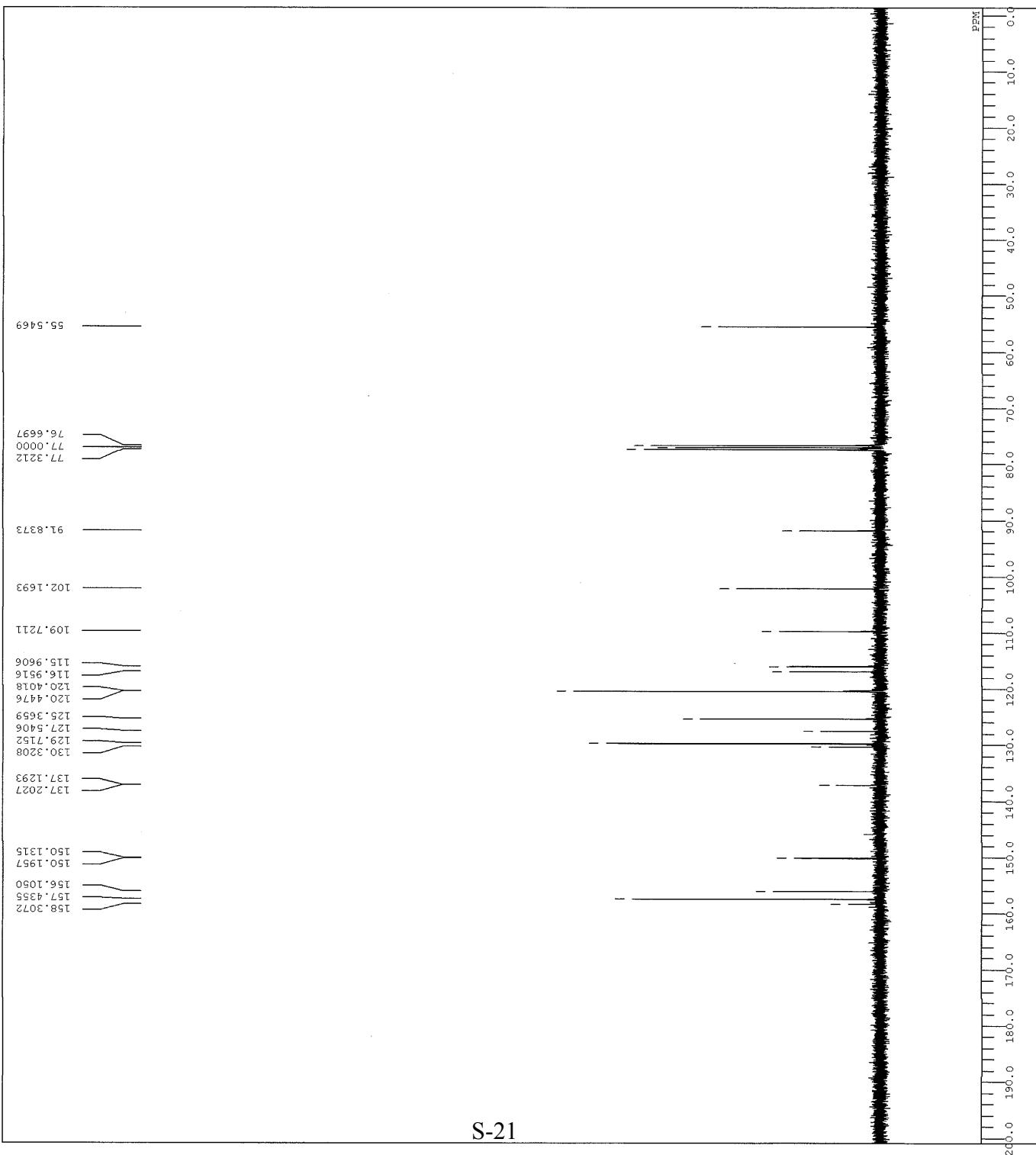
```



DFILE sun 1217 5-Ome indole DPPA-2-1.als  
 CNTM 17-12-2013 23:41:24  
 DATM 13C  
 OBNUC 13C  
 EXPD carbon\_J30  
 OBFRQ 96.52 MHz  
 OBSET 4.64 kHz  
 OBFIN 8.74 Hz  
 POINT 32767  
 FREQU 29620.85 Hz  
 SCANS 100  
 ACQIM 1.1062 sec  
 FD 2.0000 sec  
 PW1 3.00 usec  
 IRNUC 1H  
 CTMP 21.5 c  
 SLVNT CDCl<sub>3</sub>  
 EXREF 77.00 ppm  
 BF 0.12 Hz  
 RGAIN 60



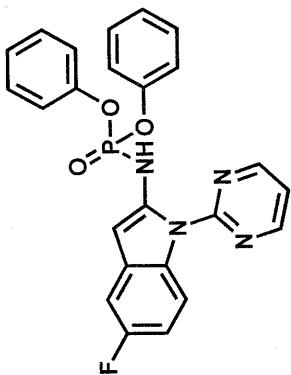
4fa



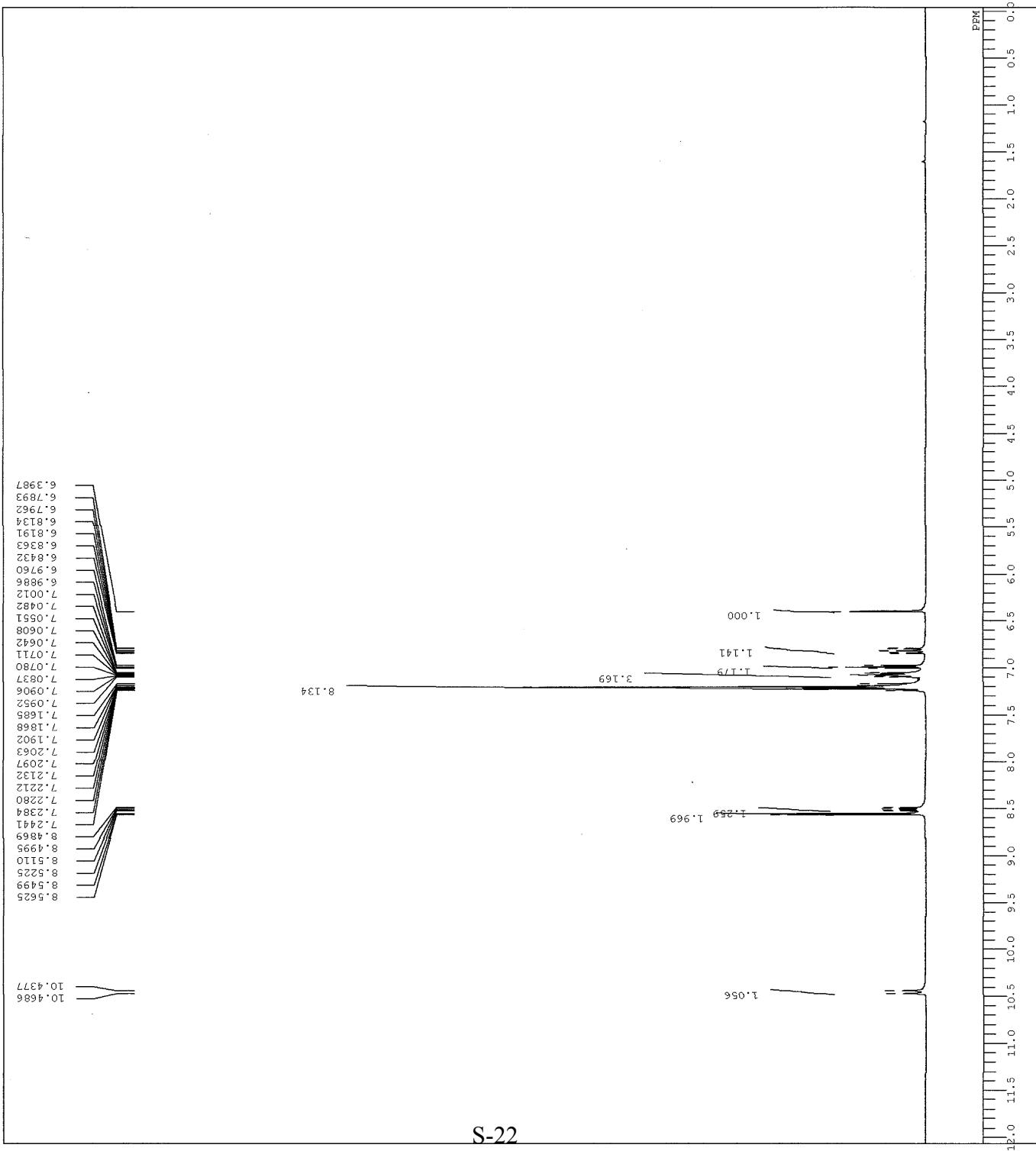
```

D:\FILE\ sun 12/17 5-F indole DPPg-1-1.als
D:\FILE\ 18-12-2013 00:12:51:1
D:\FILE\ 1H
D:\FILE\ OBUCB
D:\FILE\ proton,jxp
D:\FILE\ 391.78 MHz
D:\FILE\ OBFRQ
D:\FILE\ OBSET
D:\FILE\ OBSTIN
D:\FILE\ 6.51 kHz
D:\FILE\ POINT
D:\FILE\ 3.34 Hz
D:\FILE\ FRCQU
D:\FILE\ 7352.94 Hz
D:\FILE\ SCANS
D:\FILE\ 8
D:\FILE\ ACQTM
D:\FILE\ 2.2282 sec
D:\FILE\ FD
D:\FILE\ 5.0000 sec
D:\FILE\ FW1
D:\FILE\ 5.25 usec
D:\FILE\ IRUCN
D:\FILE\ 1H
D:\FILE\ SPLITNT
D:\FILE\ CDCL3
D:\FILE\ CTENCP
D:\FILE\ EXEKF
D:\FILE\ 0.00 ppm
D:\FILE\ BF
D:\FILE\ 0.12 Hz
D:\FILE\ 30
D:\FILE\ RGAIN

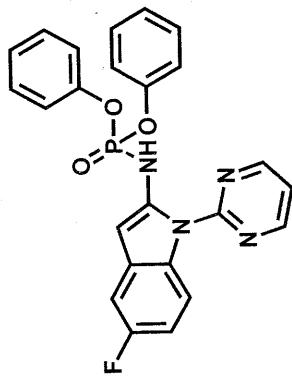
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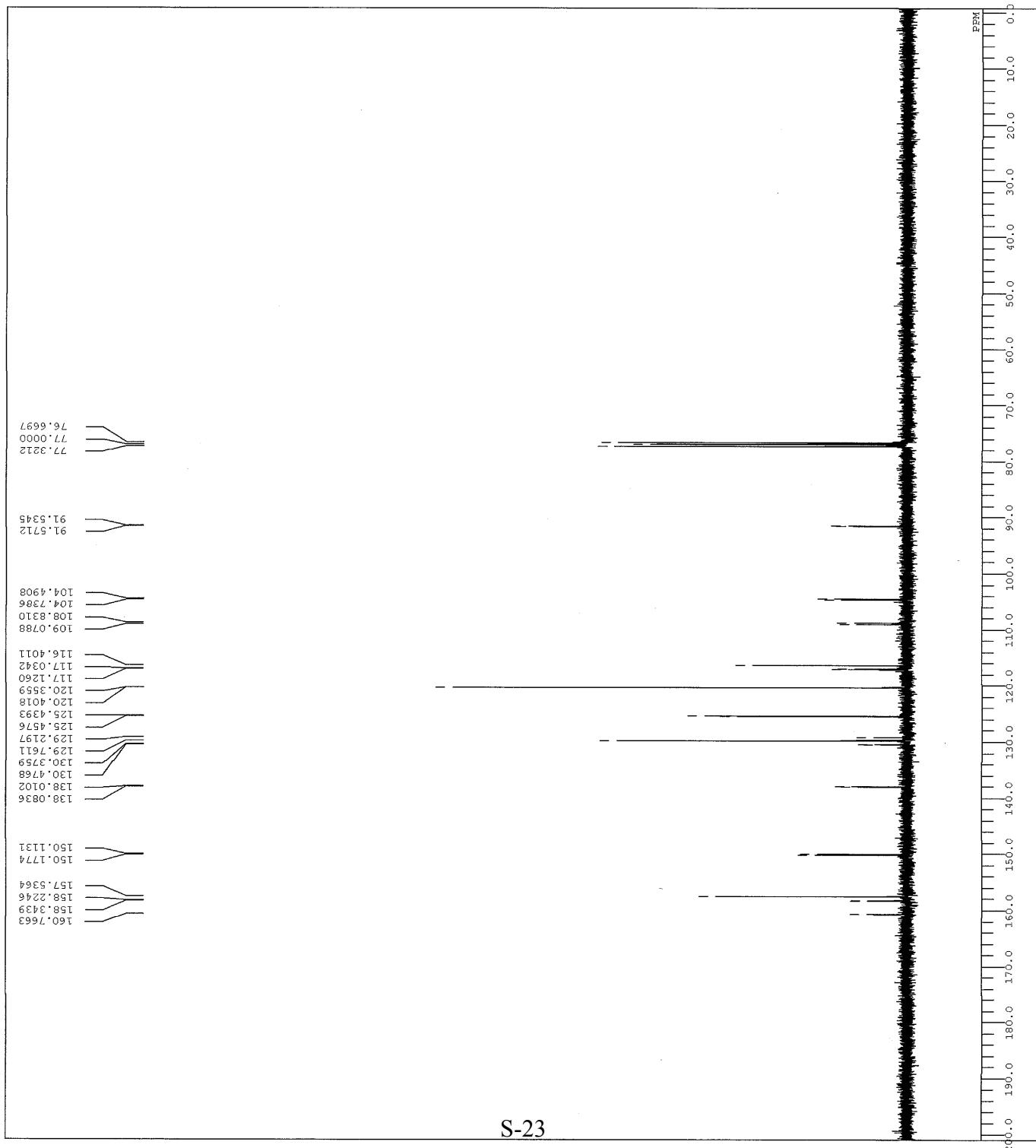
493



DFILE sun 1217 5-F indole DFPA-2-1.als  
 COMT 18-12-2013 00:15:15  
 DATUM 13C  
 OBNUC  
 EXMOD carbon-Jxp  
 OBFIQ 96.52 MHz  
 OBSET 4.64 kHz  
 OBFIN 8.74 Hz  
 POINT 32767  
 FREQU 29620.15 Hz  
 SCANS 150  
 ACQTM 1.1062 sec  
 PD 2.0000 sec  
 PW1 3.00 usc  
 TNUC 1H  
 CTENP 21.5 c  
 CDCL3 77.00 ppm  
 EXREF 0.12 Hz  
 BF 0.60  
 RGAIN



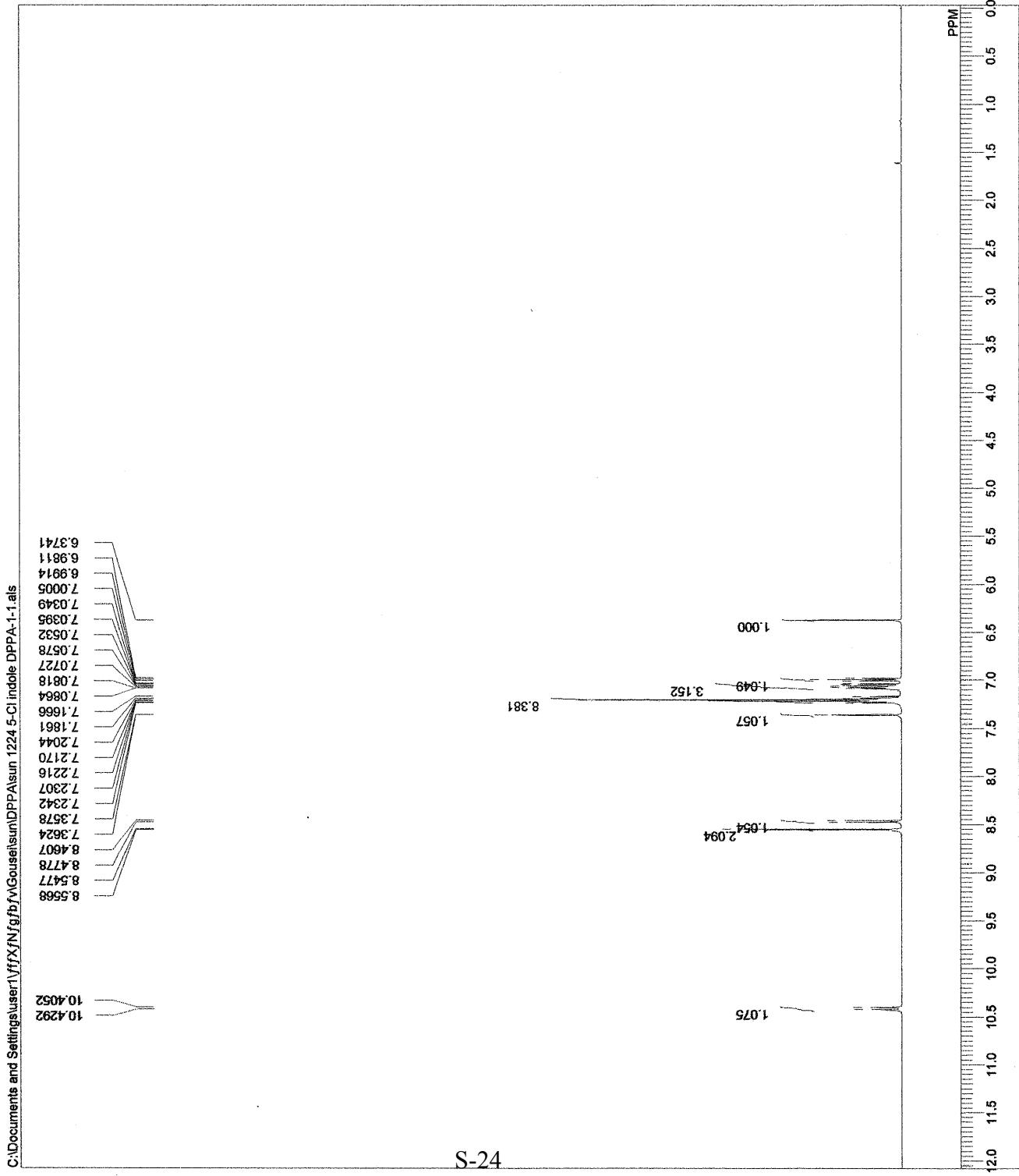
4ga



sun 1224 5-Cl indole DPPA-1.1.als

2013-12-24 23:22:24

DFILE  
COMINT  
DATIM  
OBNUC  
EXMOD  
proton:jx0  
1H  
OBFRQ  
500.16 MHz  
OBSET  
2.41 kHz  
OBFIN  
6.01 Hz  
POINT  
16384  
FREQU  
9384.38 Hz  
SCANS  
8  
ACQTM  
1.7459 sec  
PD  
5.0000 sec  
PW1  
5.55 usec  
IRNUC  
1H  
CTEMP  
21.3 c  
SLVNT  
CDCl3  
EXREF  
0.00 ppm  
BF  
0.12 Hz  
RGAIN  
34

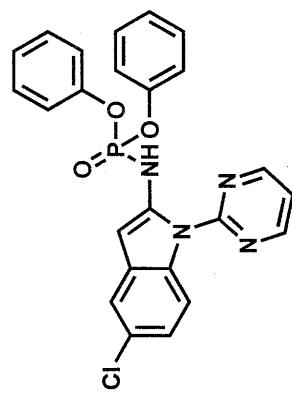


sun 1224 5-Chinole DPPA-2.1.als

DFILE COMNT DATIM OBNUC 13C carbon.kxp

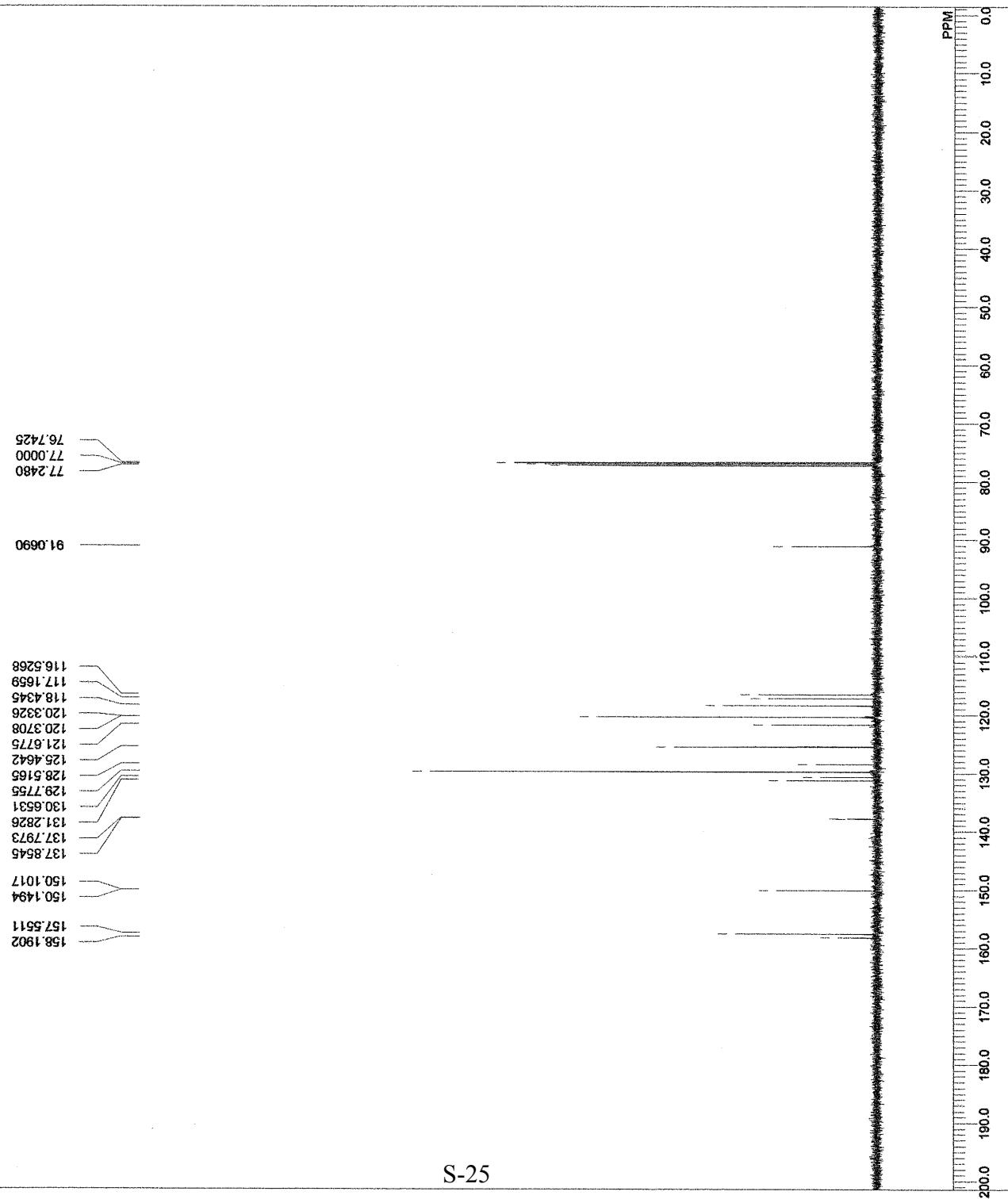
EXMOD OBFRQ 125.77 MHz  
OBSET 7.87 kHz  
OBFIN 4.21 Hz  
POINT 32767  
FREQU 39308.18 Hz  
SCANS 111  
ACQTM 0.8336 sec  
PD 3.0000 sec  
PW1 3.40 usec

IRNUC 1H  
CTEMP 21.7 c  
SLVNT CDCL<sub>3</sub>  
EXREF 77.00 ppm  
BF 0.12 Hz  
RGAIN 60

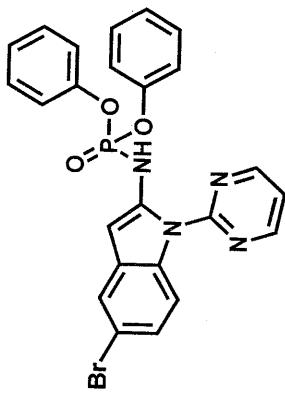


4ha

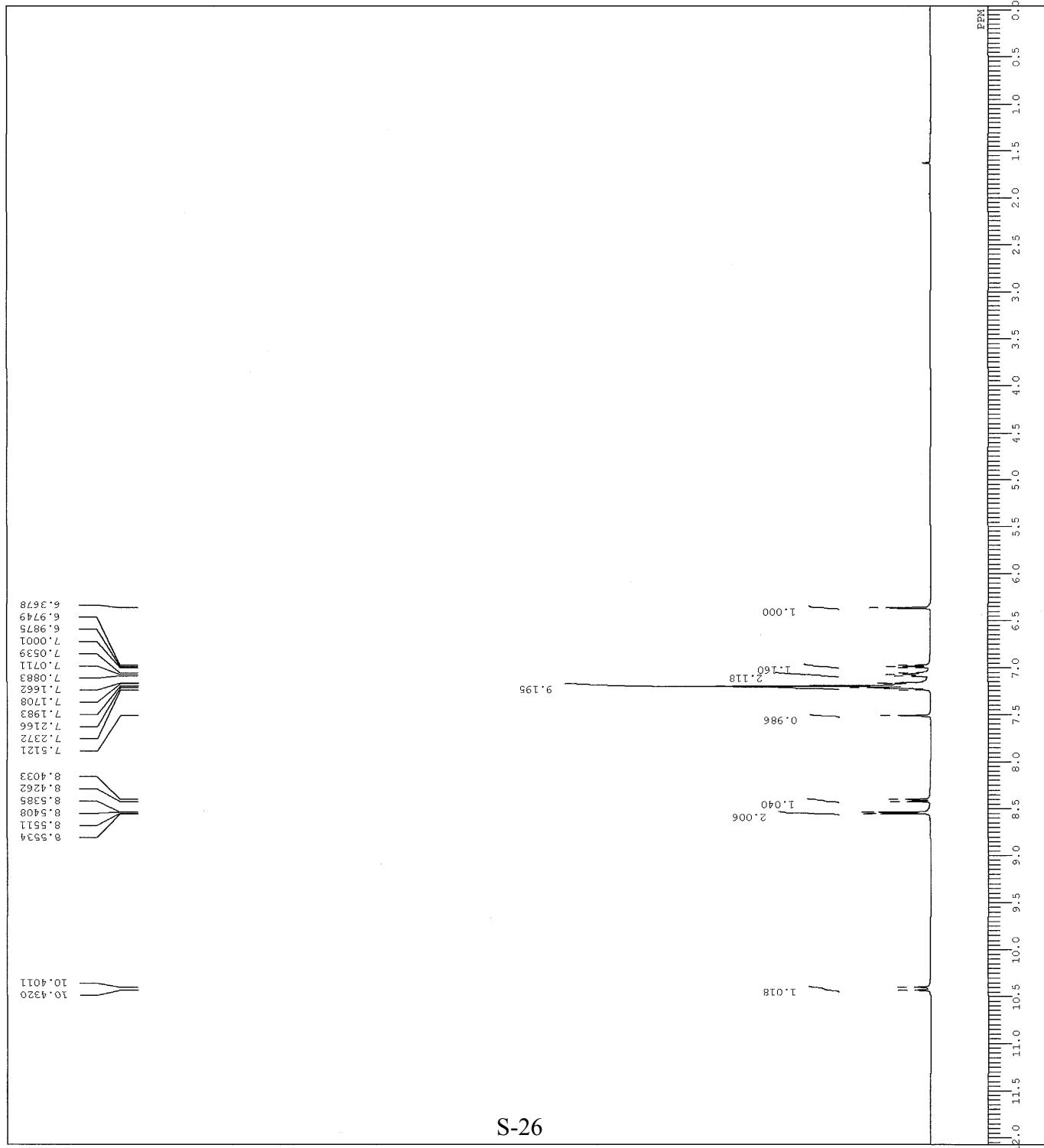
C:\Documents and Settings\user1\ffXfN\ffv\Gousel\sum\DPPIA\sum 1224 5-Chinole DPPA-2.1.als



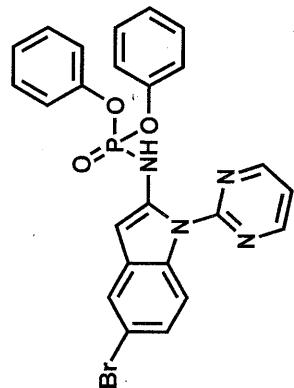
DFILE sun 1219 5-Br indole DFPA-1-1.als  
 CDMT 19-12-2013 23:13:07  
 1H  
 proton JRD  
 391.78 MHz  
 8.51 kHz  
 3.34 Hz  
 16384  
 7352.94 Hz  
 8  
 2.2282 sec  
 5.0000 sec  
 5.25 usec  
 1H  
 21.6 C  
 CDCl<sub>3</sub>  
 0.00 ppm  
 0.12 Hz  
 30  
 ACQTM  
 ED  
 TINUC  
 CTMP  
 SWANT  
 EREF  
 BF  
 RGAIN



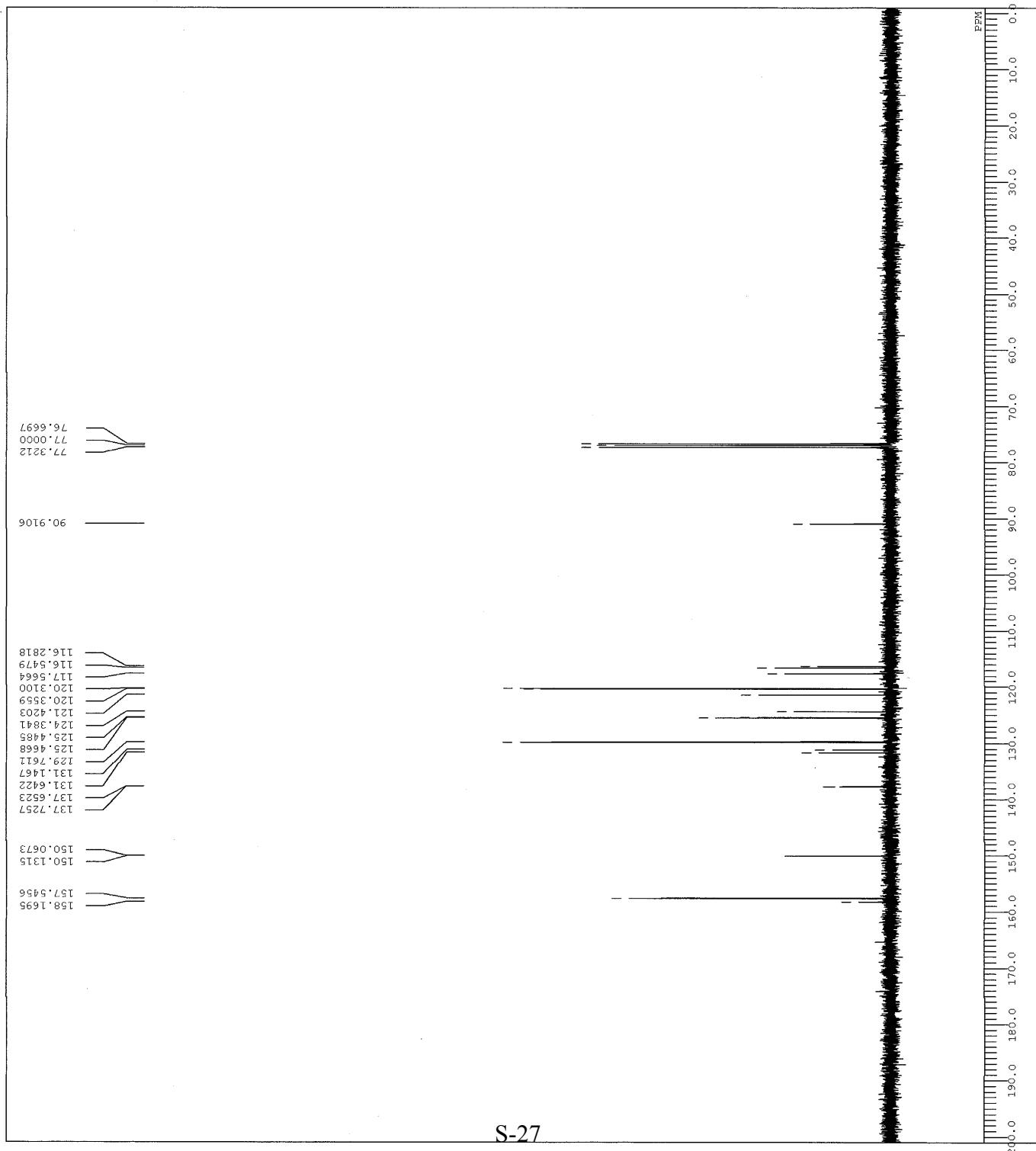
4ia



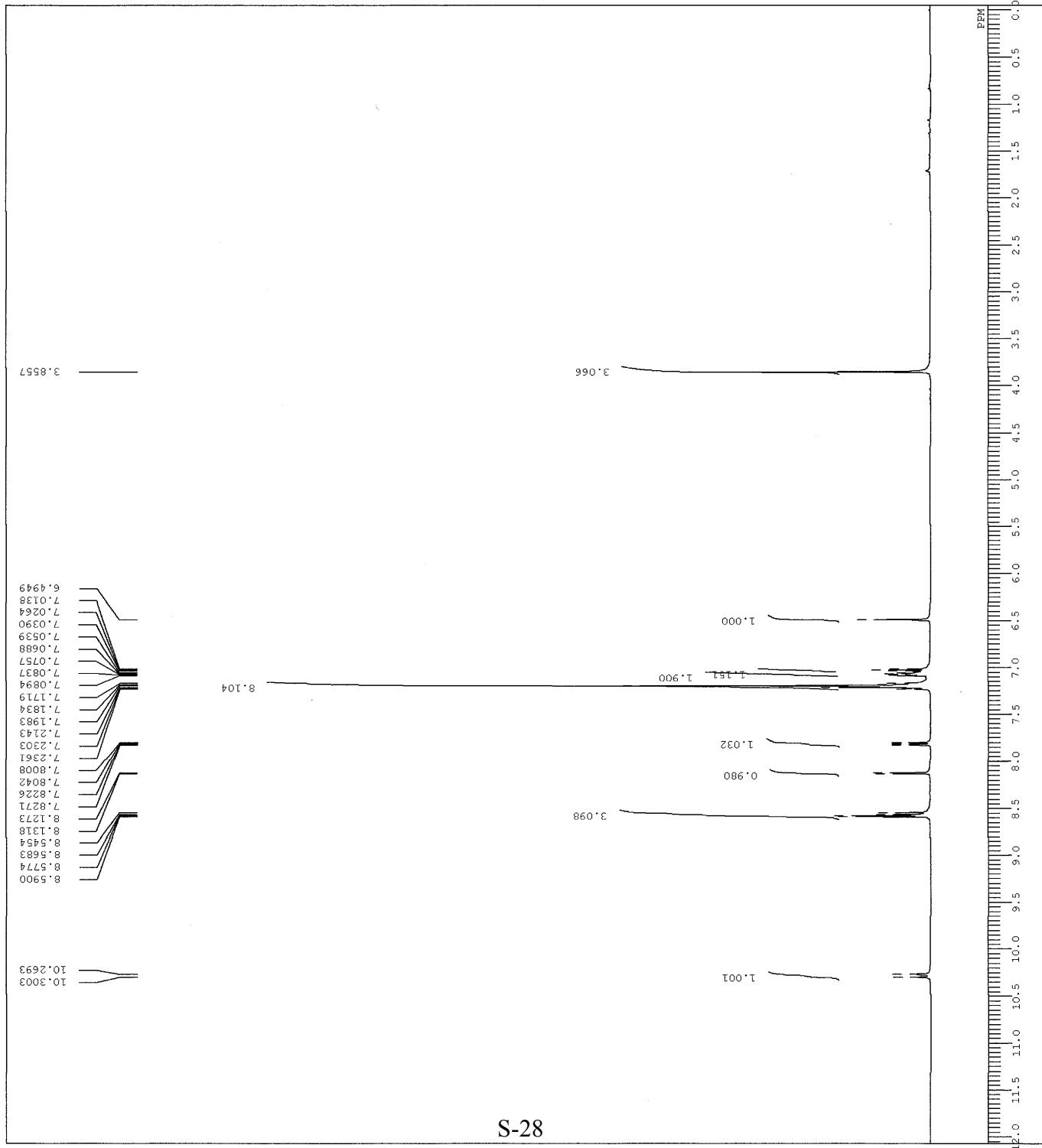
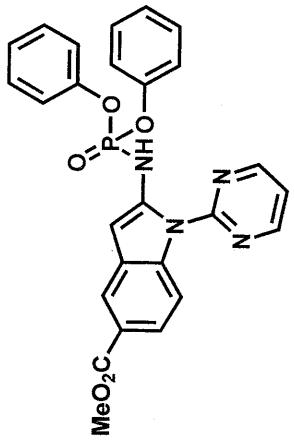
DFILE sun 1219 5-Br indole DPFA-2-1.ais  
 COMMENT 19-12-2013 23:15:01  
 DATUM 13C  
 OBNUC 13C  
 EXPMOD carbon,1exp  
 OBFREQ 98.52 MHz  
 OFFSET 4.64 kHz  
 OBFIN 8.74 Hz  
 POINT 32767  
 FREQU 23620.85 Hz  
 SCANS 96  
 ACQTM 1.1062 sec  
 PD 2.0000 sec  
 PW1 3.00 usec  
 IRNUC 1H  
 CTEMP 21.6 °C  
 SLVNT CDCl<sub>3</sub>  
 EXREF 77.00 ppm  
 RF 0.12 Hz  
 RGAIN 60



4ia



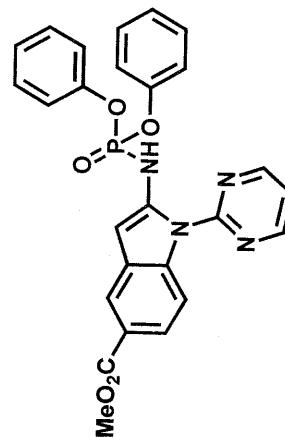
DFILE sun 1220 5-CO2R<sub>e</sub> Indole DPFA-2-1.als  
 CNT 20-12-2013 09:28:30  
 DATIM 1H  
 OBNUC proton,exp  
 EXMOD 1H  
 OBFRQ 391.78 MHz  
 OFFSET 8.51 Hz  
 D1 3.34 Hz  
 OBTIN 16384  
 POINT 7352.94 Hz  
 FREQU 8  
 SCANS 2.2282 sec  
 ACQTM 5.0000 sec  
 PD 5.25 usec  
 FID 1H 21.2 c  
 TINUC 1H CDCL<sub>3</sub>  
 CTMP 0.00 ppm  
 SVNT 0.12 Hz  
 EXREF BF  
 RGRIN 28



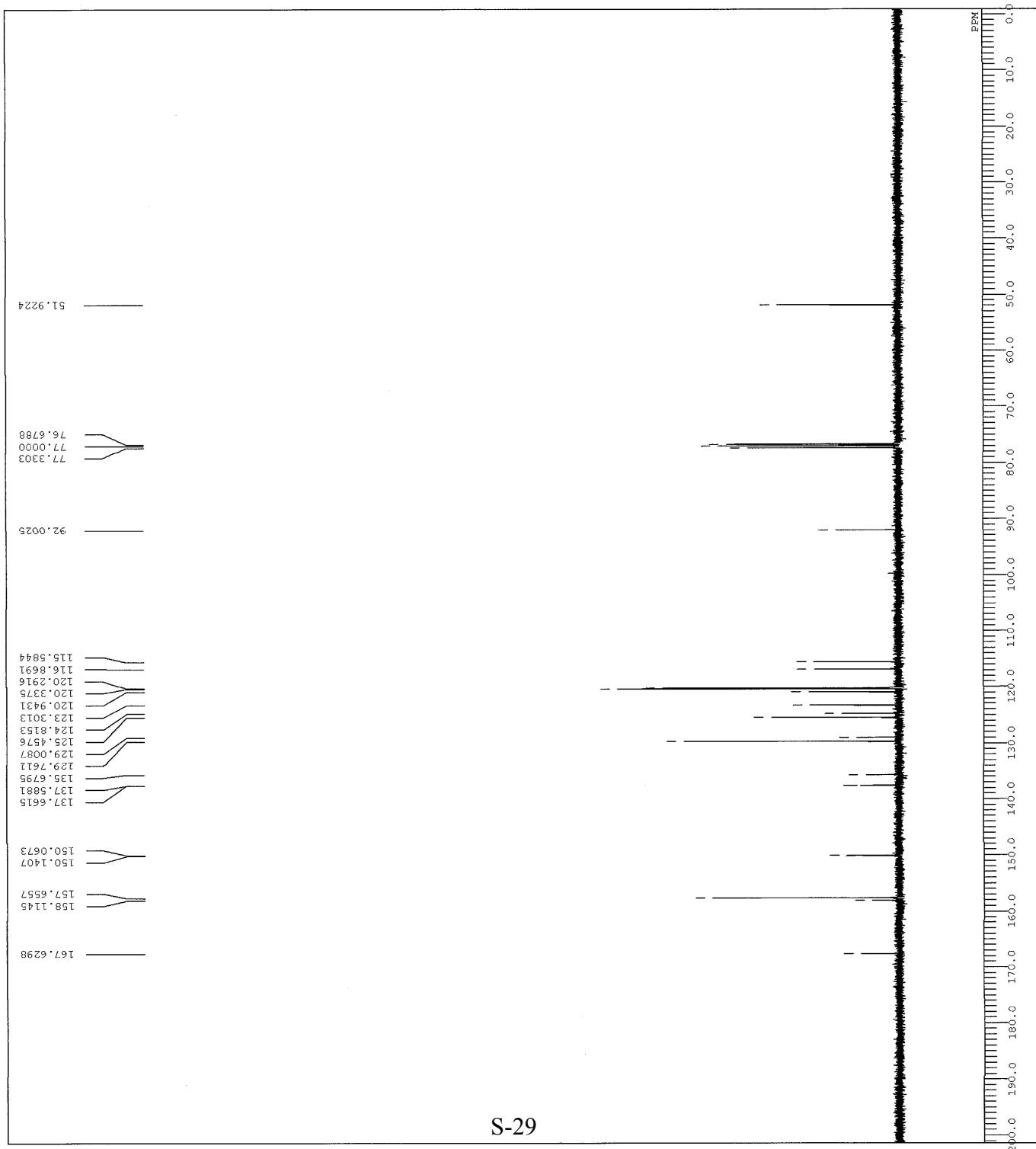
```

.DETILEL sun 1220 5-COMMe indole DPA-3-1.jdf
.COMMT 20-12-2013 09:31:13
.DATIM 13C
.DENMOD carbon-13p
.DESSET 98.52 MHz
.DOFIN 4.94 kHz
.DPOINT 8.74 Hz
.DREFEQN 32767
.DSCAMS 117
.DSQCPM 1.1062 sec
.DTPD 2.0000 sec
.DW1 3.00 usec
.DINDUC 1H
.DTEMP 21.2 °C
.DCDL3 CDCL3
.DZEREF 77.00 ppm
.BF 0.12 Hz
.BF 60
.BF

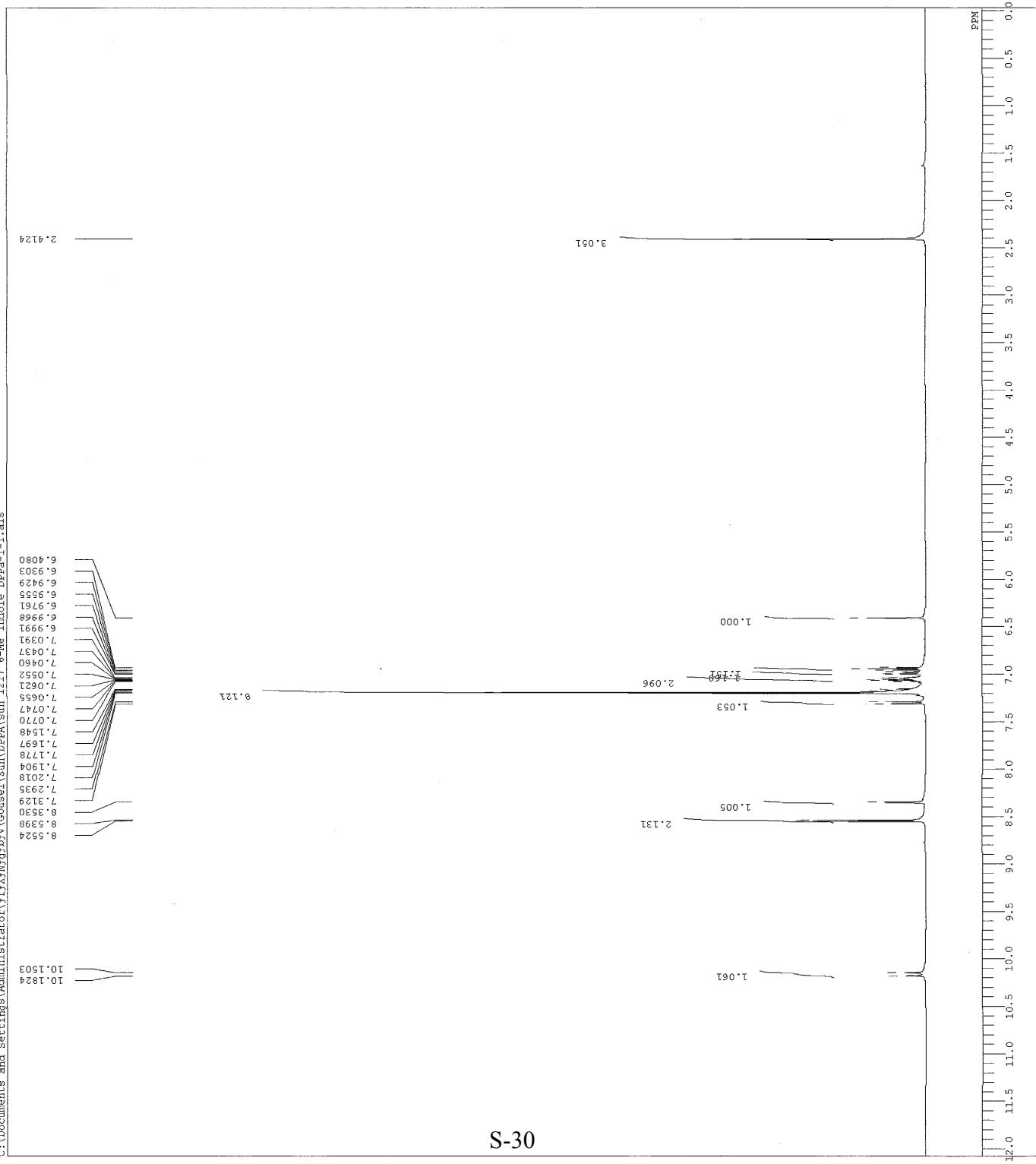
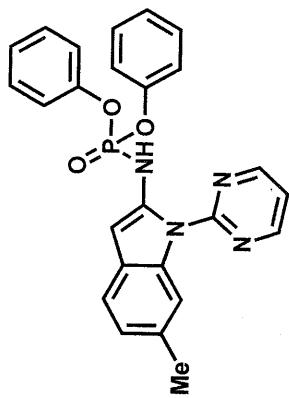
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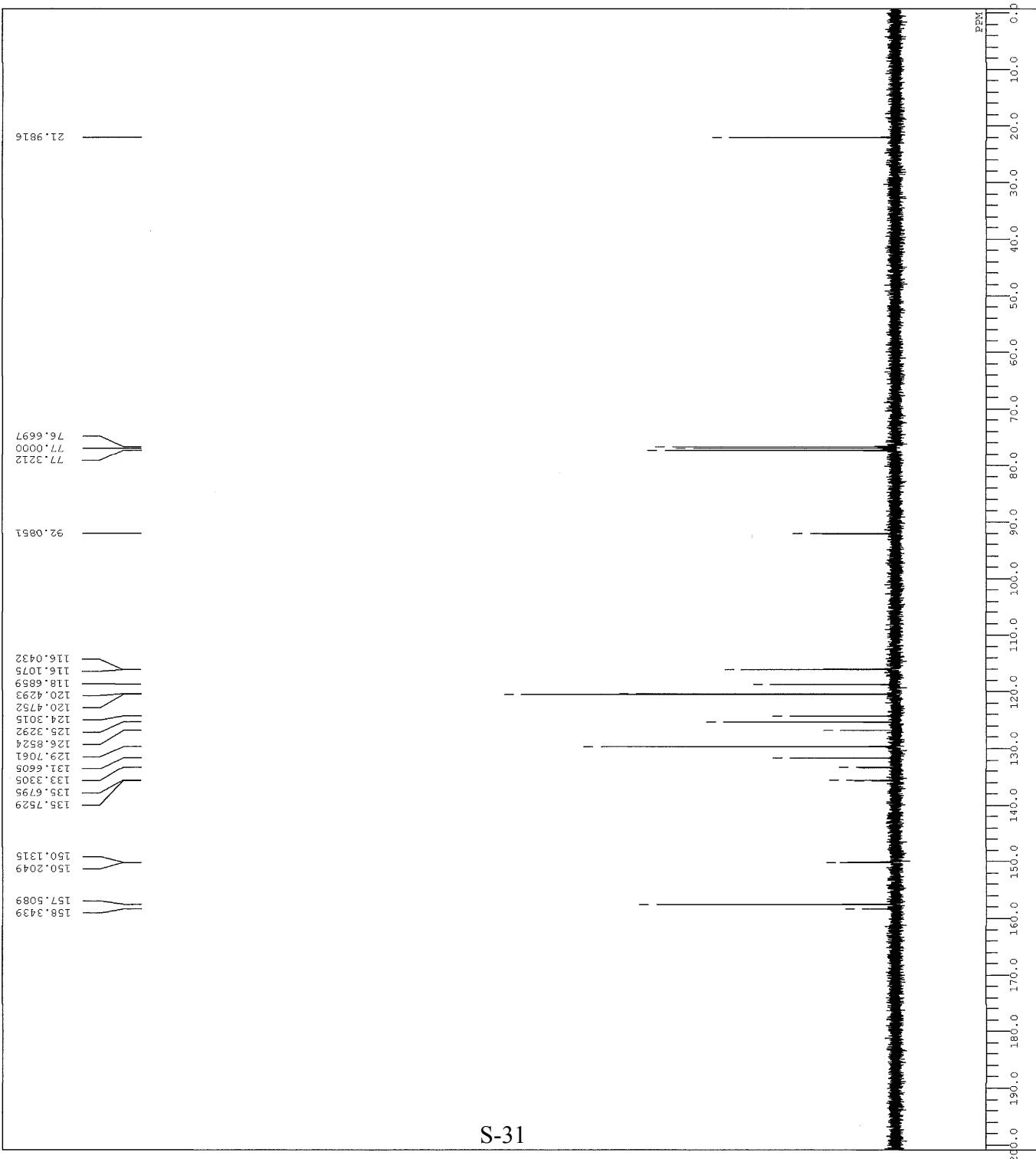
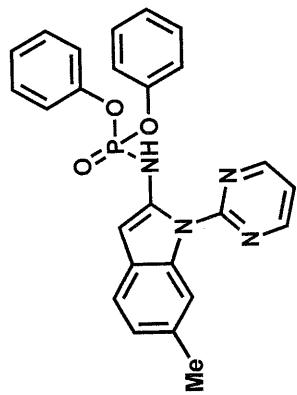
41



FILE: sun 1217 6-Me indole DEPA-1-1.als  
 COMMENT: 18-12-2013 00:00:11  
 OEMIC: 1H  
 EPGMD: proton-jsp  
 OFERQ: 391.78 MHz  
 OFFSET: 8.51 Hz  
 OFIN: 3.34 Hz  
 POINT: 13107  
 FREQU: 5882.35 Hz  
 SCANS: 8  
 ACQTM: 2.2282 sec  
 PD: 5.0000 sec  
 P1: 5.25 usec  
 T1EHC: 1H  
 C1EHP: 21.2 c  
 S1AVNT: CDCl<sub>3</sub>  
 ERREF: 0.00 ppm  
 BF: 0.12 Hz  
 RGAIN: 28

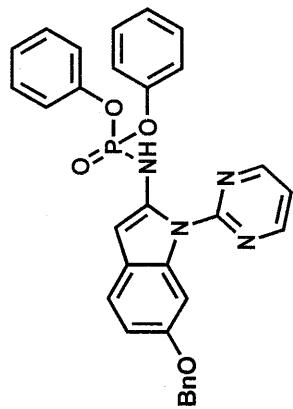


DFILE sun 1217 6-Me indole DPFA-2-1..als  
 CONN 18-12-2013 00:01:53  
 DFTM 13C  
 OBNUC carbon.jdp  
 GBRQ 98.52 MHz  
 OFFSET 4.64 kHz  
 OBTIN 8.74 Hz  
 POINT 337767  
 FREQ 29920.85 Hz  
 SCANS 63  
 ACQTM 1.1062 sec  
 PD 2.0000 sec  
 PW1 3.00 usec  
 IRNUC 1H  
 CTEMP 21.4 c  
 SLMNT CDCL3  
 EAREF 77.00 ppm  
 BF 0.12 Hz  
 RGAIN 60

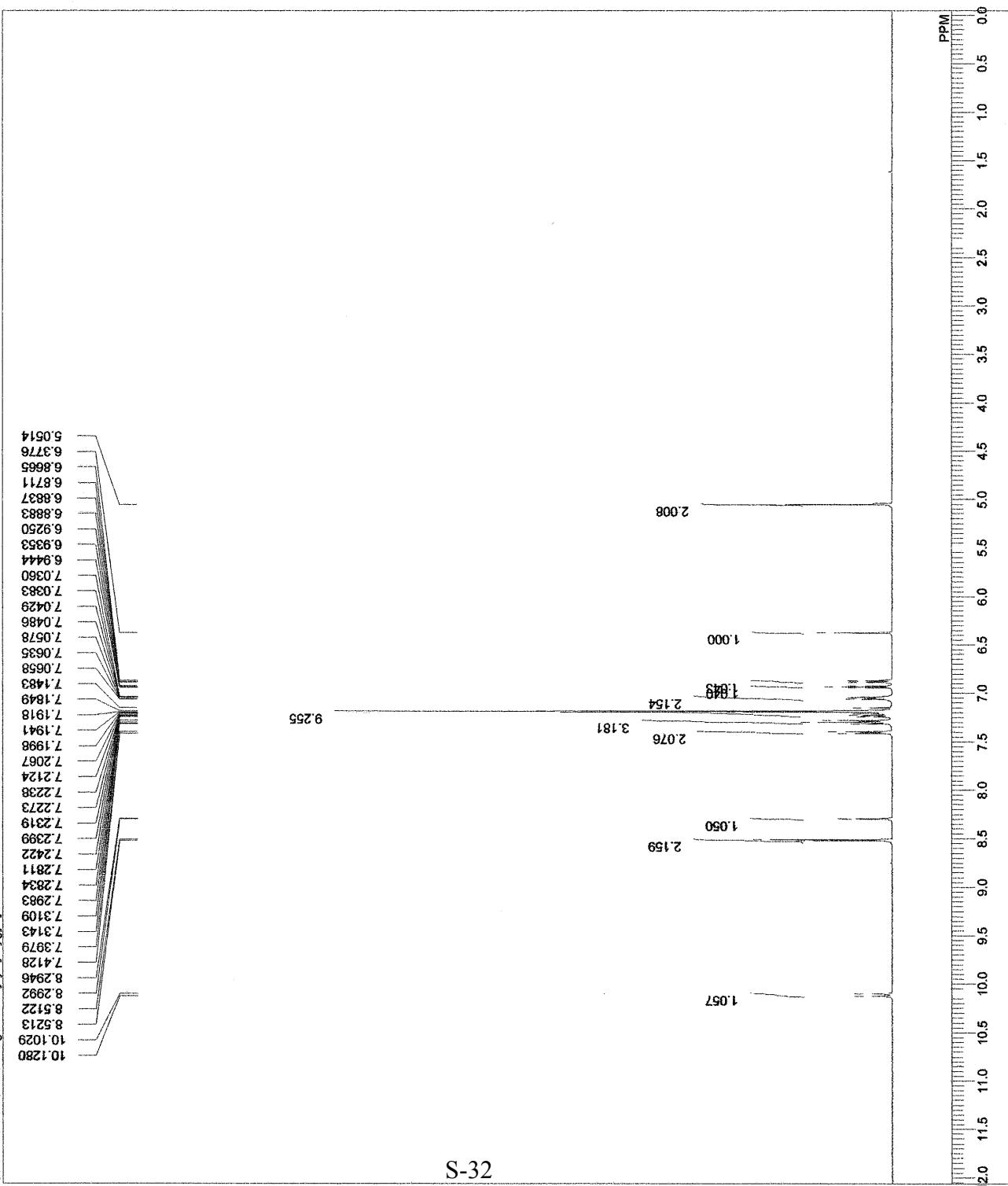


sun 1224 6-OBn indole DPPA-1-1.ais

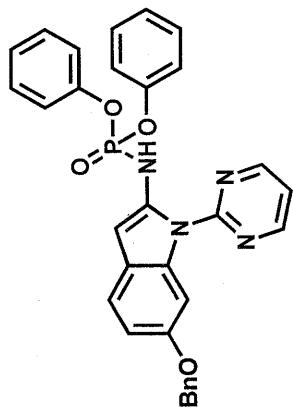
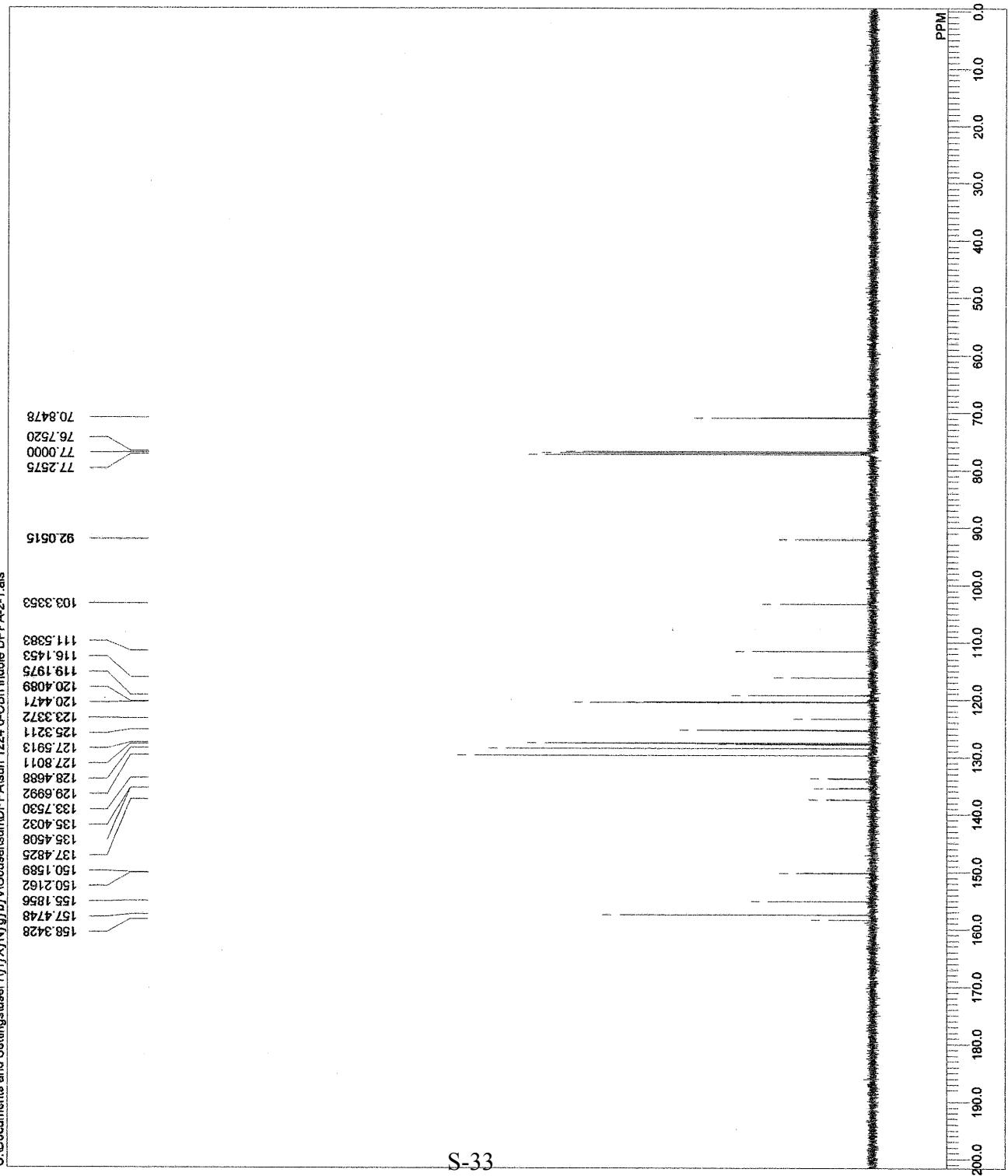
DFILE  
COMINT  
DATIM  
OBNUC  
EXMOD  
OBFRQ  
OBSET  
OBFIN  
POINT  
FREQU  
SCANS  
ACQTIM  
PD  
PW1  
IRNUC  
CTEMP  
SLVNT  
EXREF  
BF  
RGAIN



41

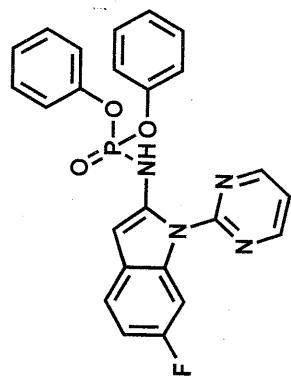


sun 1224 6-OBn indole DPAA-2-1.ais	
DFILE	sun 1224 6-OBn indole DPAA-2-1.ais
COMNT	
DATIM	2013-12-24 23:51:26
OBNUC	13C
EXMOD	carbon.jdp
OBFRQ	125.77 MHz
OBSET	7.87 kHz
OBFIN	4.21 Hz
POINT	32767
FREQU	39305.18 Hz

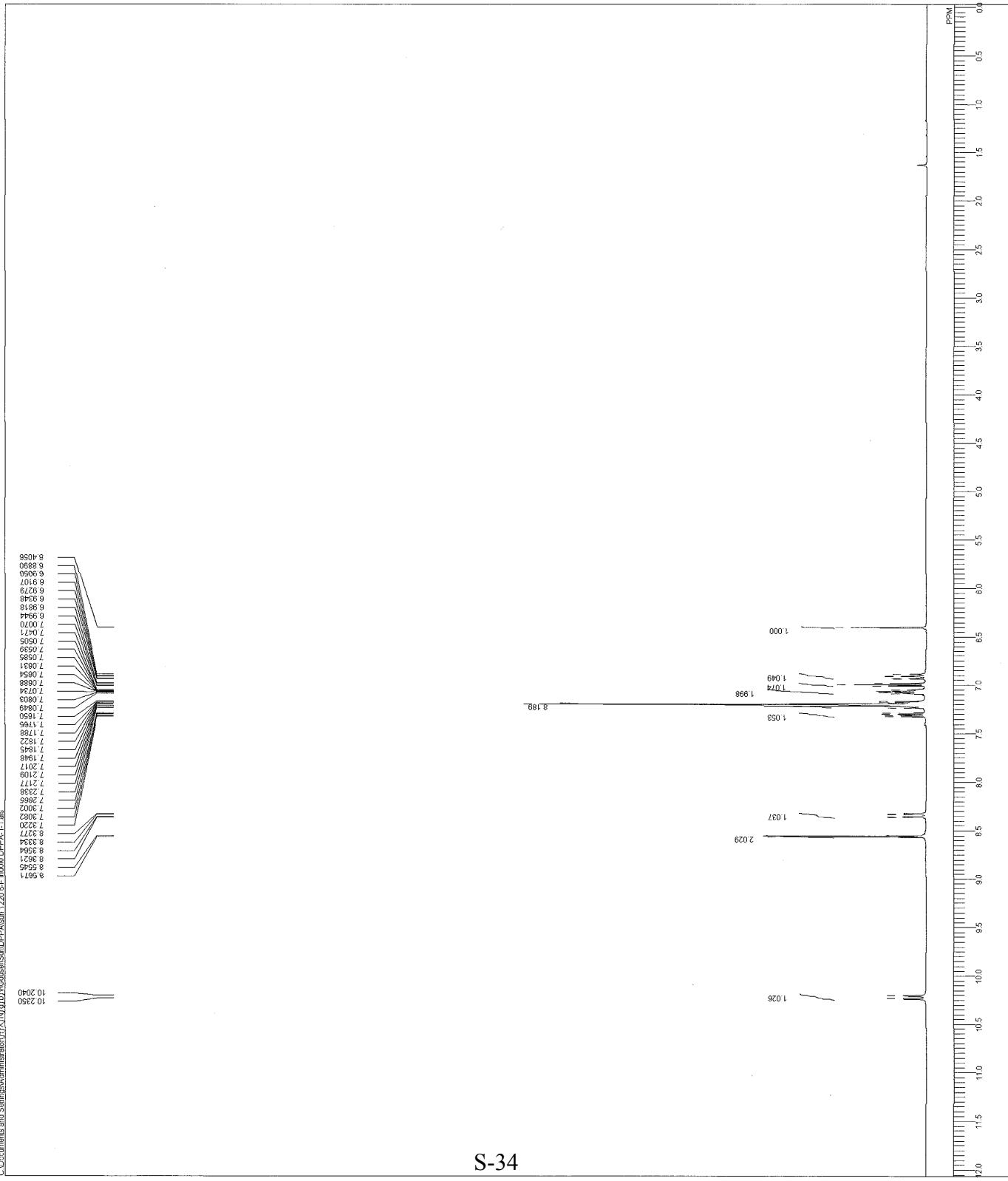


4|a

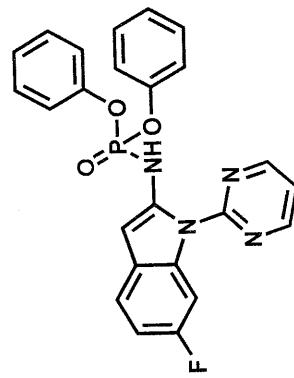
C:\Documents and Settings\Administrator\My Documents\GouseilSun\DPAA\sun1220\6.F.indd DPPA-1-1.xls



4ma



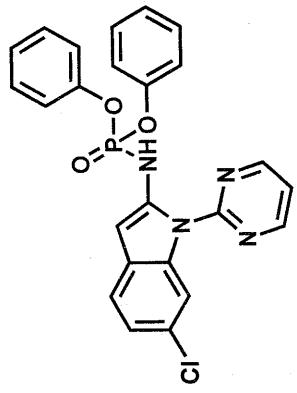
C:\Documents and Settings\administrator\My Documents\Gousei\SunDPPA\1sun1220 6.F inde DPPA-2-1.xls



4ma



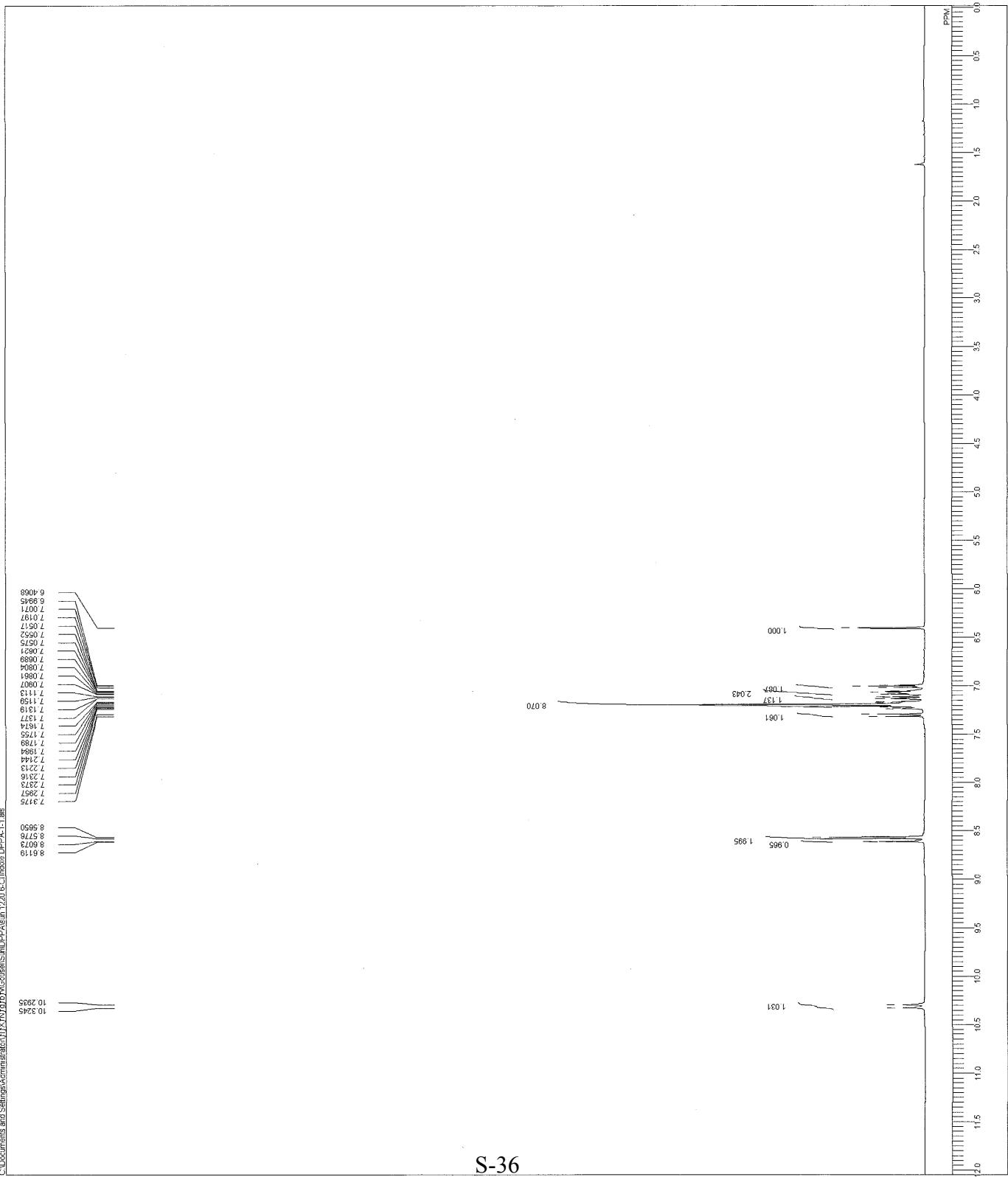
**4na**



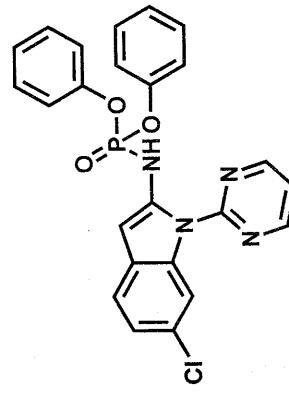
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FILE sun12206.C1ndole.DPFA-1.i.w5
COUNT 20,12,20,13,23,21,31
1H
proto100
39178 Hz
CBRQ 8.51 kHz
OBSET 3.5 kHz
CBIN 12.5 kHz
FREQ1 582.35 Hz
SCANS 6
ACQIM 2,222.28 sec
FD 5,030.08 sec
P1 1.25 usec
IRIC
CTEAD
SILNT
CDCL3 0.00 ppm
ESRF 0.17 Hz
EF 50
RGAIN

```

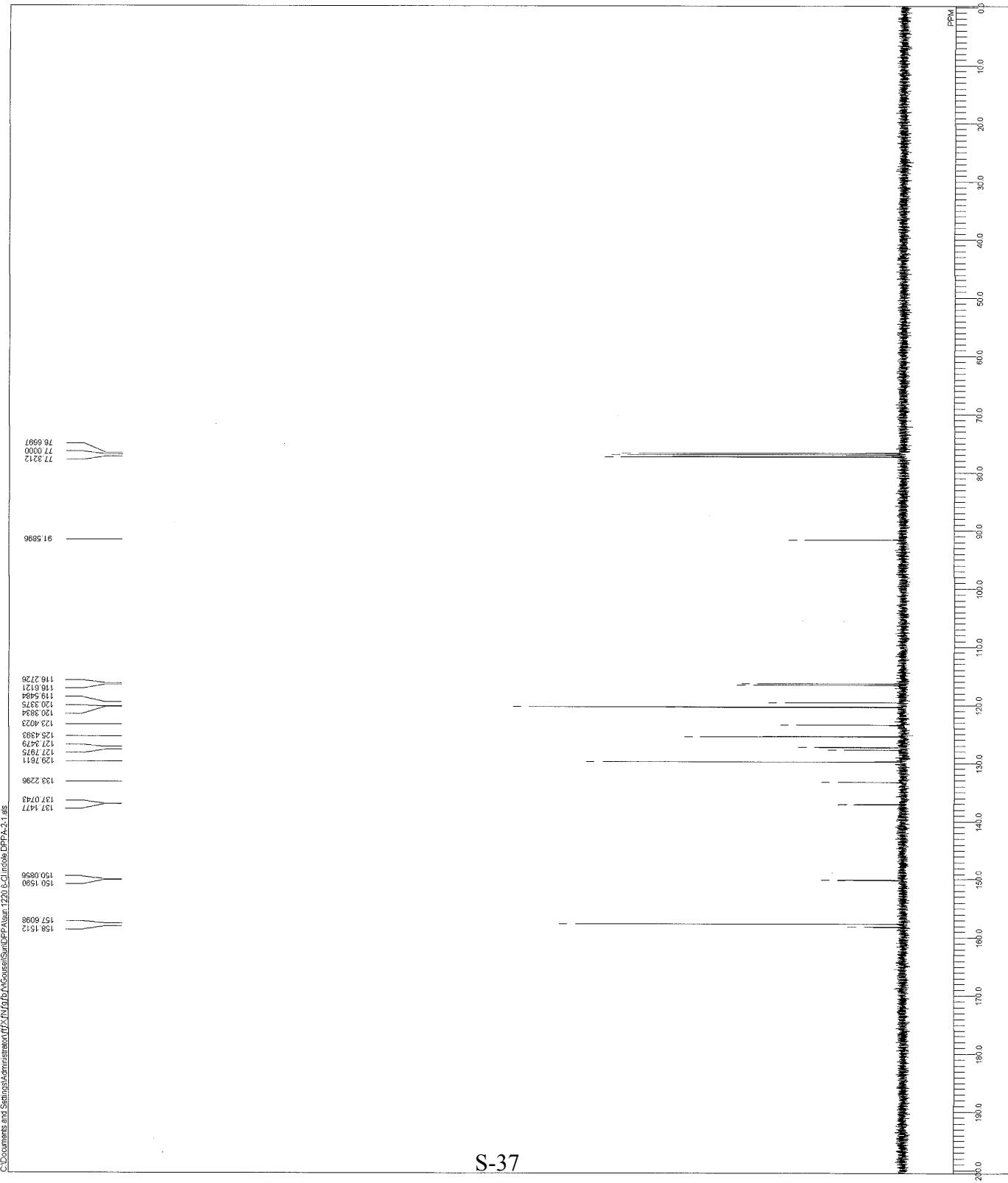


**4na**

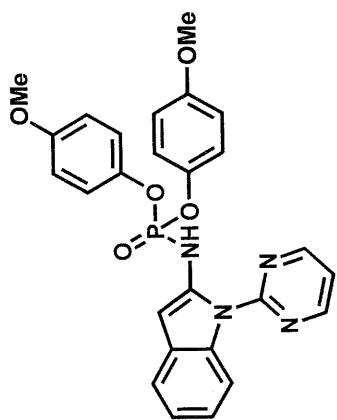


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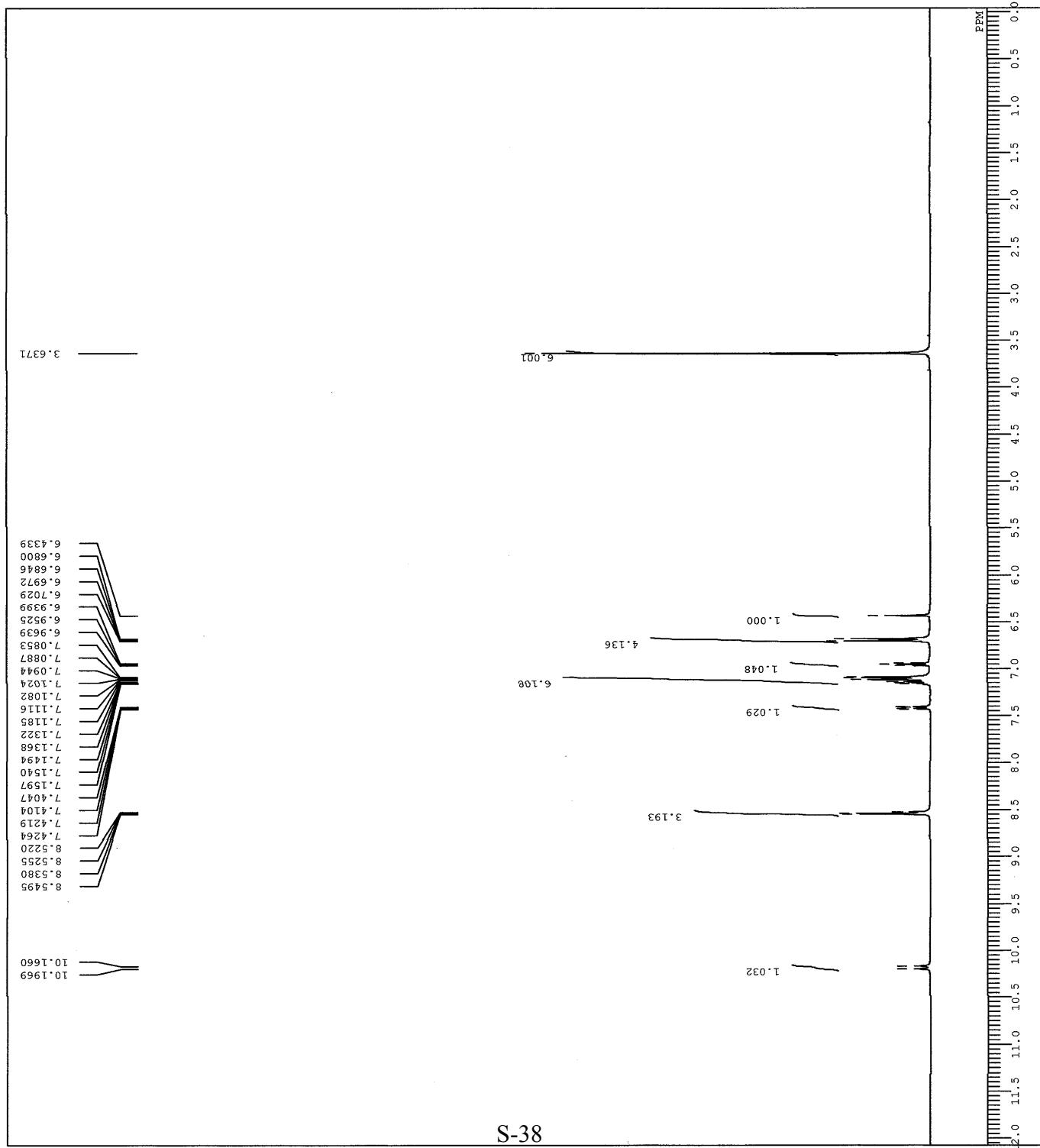
sun 1220 6-Chloro-1220 6-Chloro-DPPA-2,1-96
      COUNT    26-1-201:23-23:37
      DATIM    13C
      GBNUC
      carbon 13C
      EXMOD   12
      QNCQD   4.64 kHz
      ZFETW   8.74 Hz
      OFFSET  -3.2767 Hz
      2820.1815 Hz
      146.92 sec
      2.0000 sec
      3.00 usec
      POINT   1H
      11.61 ppm
      CDCl3
      IRNUC
      CTBPP
      SPC
      ESRFF
      71.00 ppm
      0.12 Hz
      RGAIN
  
```



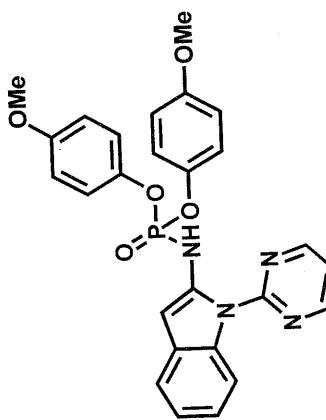
sun 0113 indole (4-O-MeO) 2B (O)-1-1.als  
 DFILE COUNT 13-01-2014 21:57:18  
 DATIM 1H  
 OBNUC proton,j,xp  
 EXMOD 331.78 MHz  
 OBFRQ  
 OBSBT 8.11 kHz  
 OBFIN 3.34 Hz  
 POINT 16384  
 FREQJ 7348.62 Hz  
 SCANS 12  
 ACQTM 2.225 sec  
 PD 5.0000 sec  
 PW1 5.25 usec  
 IRNUC 1H  
 CTEAR 25.0 c  
 SLYNT CDCL3  
 EXREF 0.00 ppm  
 BF 0.12 Hz  
 RGAIN 30



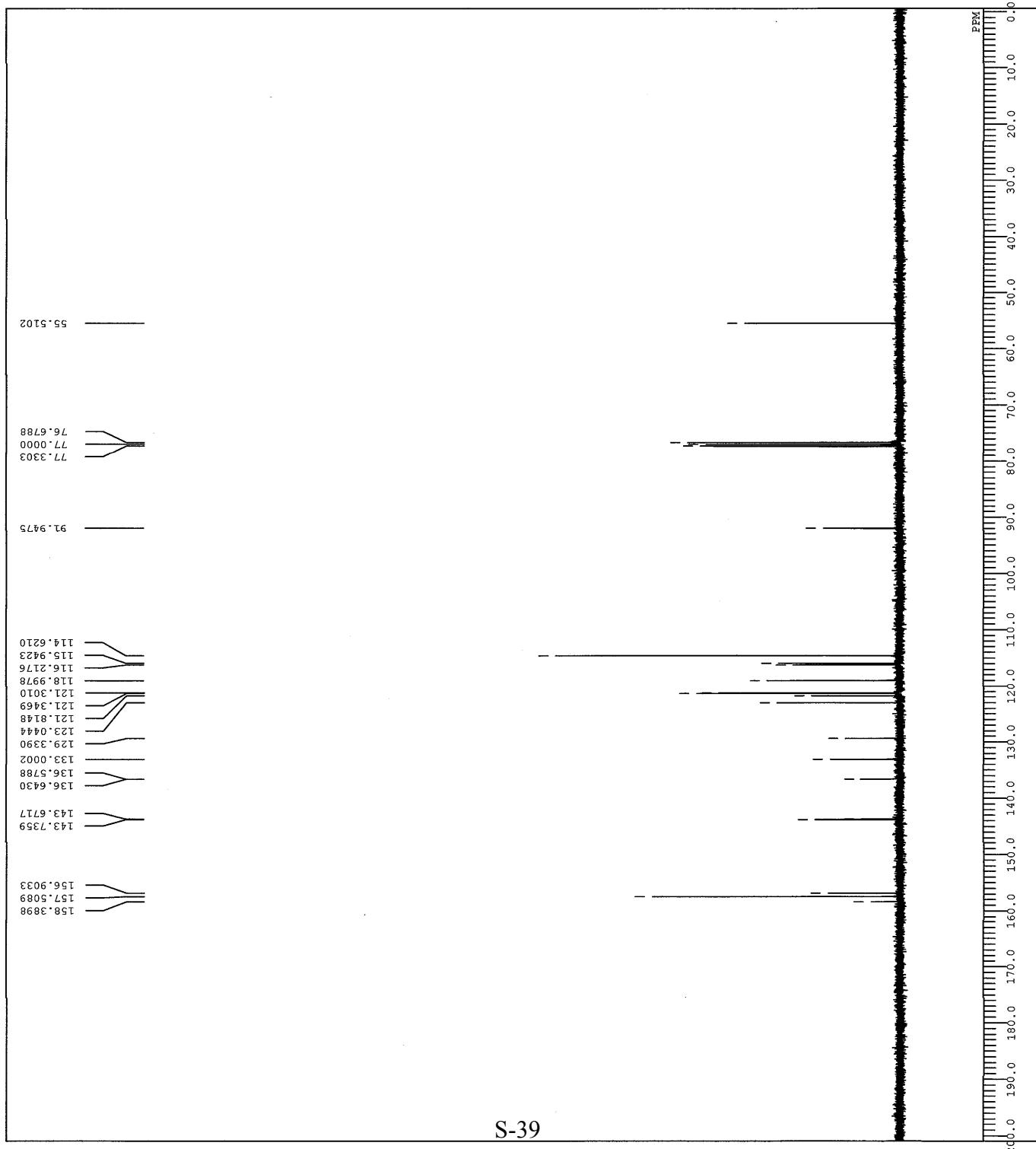
**4ab**



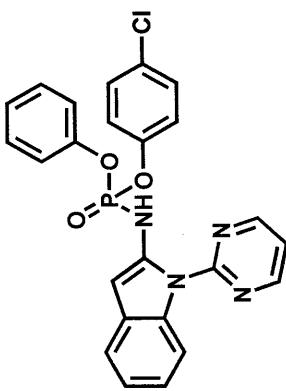
DFILE sun 0113 indole (4-MeO)2P(O)-2-1.als  
 COUNT 13-01-2014 21:59:58  
 DATIM 13C  
 QBNUC 13C  
 EXMOD carbon.jxp  
 OBFOQ 98.52 MHz  
 OBST 4.64 kHz  
 QBFIN 8.74 Hz  
 POINT 32767  
 FREQU 29620.05 Hz  
 SCANS 155  
 ACQTM 1.1062 sec  
 PD 2.0000 sec  
 PW1 3.00 usec  
 IRNUC 1H  
 CTECP  
 SLYNT CDCl<sub>3</sub>  
 EXREF 77.00 ppm  
 BF 0.12 Hz  
 RGAIN 60



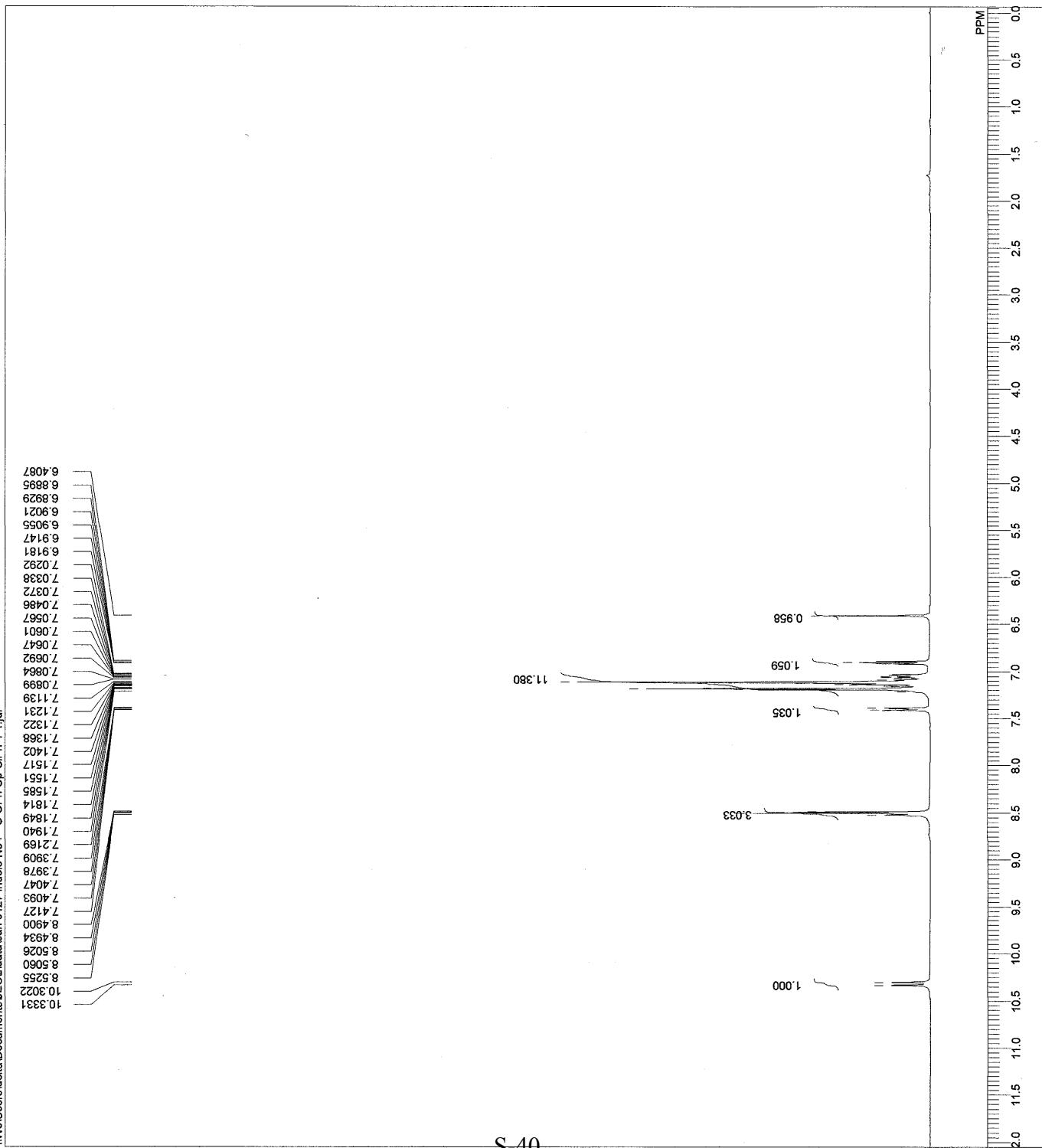
4ab



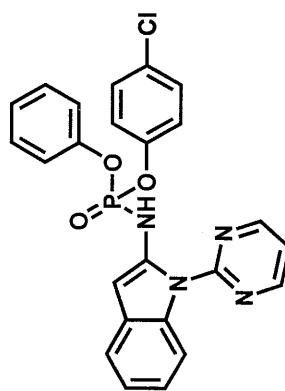
sun 0127 indole N3 P=O OPh Op-OPh-1-1.dif  
 DFILE  
 COMNT 27-01-2015 18:13:29  
 DATM 1H  
 OBNUC proton JXO  
 EXMOD 301.78 MHz  
 OBPPQ 8.51 kHz  
 OBSET 3.34 Hz  
 POINT 16384  
 FREQU 7348.62 Hz  
 SCANS 8  
 ACQTM 2.2295 sec  
 PD 5.0000 sec  
 RM1 6.50 usec  
 IRNUC 1H  
 CTEMP 460.0 c  
 SLVNT CDCl<sub>3</sub>  
 EXREF 0.00 ppm  
 BF 0.12 Hz  
 RGAIN 26



4ac



sun 0127 indole N3 P=O OPh Op-CiPh-1-  
 DFILE  
 COMNT 2015-01-27 18:09:19  
 DATIM 13C  
 EXMOD carbon,1JXP  
 OBFRQ 128.77 MHz  
 OBSET 7.87 kHz  
 OBFIN 4.21 Hz  
 POINT 32767  
 FREQU 39308.18 Hz  
 SCANS 216  
 ACQTM 0.8336 sec  
 PD 2.0000 sec  
 PW1 3.40 usec  
 IRNUC 1H  
 CTTEMP 23.7 C  
 SILVNT CDCL3  
 EXREF 77.00 ppm  
 BF 0.12 Hz  
 RGAIN 60



**4ac**

