SUPPORTING INFORMATION

Synthesis of 9-Alkylidene-9*H*-flourenes by a Novel Palladium-Catalyzed Rearrangement

*Qingping Tian and Richard C. Larock**

Department of Chemistry, Iowa State University, Ames, Iowa 50011

Reagents. Iodobenzene, 2-iodobenzotrifluoride, 2-iodotoluene, 4-iodoanisole, 2-iodothiophene and diphenylacetylene were obtained from Aldrich Chemical Co., Inc. Ethyl 4-iodobenzoate was purchased from Lancaster Synthesis Inc. 4-Phenyl-2-methyl-3-butyn-2-ol was obtained from Farchan Scientific Co. 3,3-Dimethyl-1-phenyl-1-butyne,[1] 3-iodopyridine,[2] 1-*tert.*-butyl-2-iodobenzene[3] and 1-iodo-1,2,2-triphenylethylene[4] were prepared according to previous literature procedures.

General Procedure for the Palladium-catalyzed Reaction of Aryl Iodides and 1-Aryl-1-alkynes. Palladium acetate (2.8 mg, 0.0125 mmol), PPh_3 (6.7 mg, 0.0250 mmol), sodium acetate (42 mg, 0.5 mmol), *n*-Bu_4NCl (70 mg, 0.25 mmol), the aryl iodide (0.25 mmol), the alkyne (0.25 mmol), and 5 mL of DMF were placed in a 4 dram vial, which was heated in an oil bath at 100 °C for the period of time indicated in Table 1. The reaction mixture was cooled, diluted with ether, washed with saturated NH_4Cl, dried over anhydrous $MgSO_4$, and filtered. The solvent was evaporated under reduced pressure and the product was isolated by chromatography or preparative TLC. The following compounds were prepared by the above procedure.

9-Benzylidene-9*H*-fluorene (4) (Tables 1, entry 1). Obtained as a white solid in 62% yield from the reaction of 2-iodobenzene and diphenylacetylene after purification by column chromatography (hexanes): mp 73-74 °C (lit[5] mp 73-74 °C); ^{1}H NMR ($CDCl_3$) δ 7.06 (dt, *J* = 1.2, 7.5 Hz, 1 H), 7.29-7.50 (m, 6 H), 7.54-7.61 (m, 3 H), 7.70-7.74 (m, 3 H), 7.78-7.82 (m, 1 H); ^{13}C NMR ($CDCl_3$) δ 119.6, 119.7, 120.2, 124.4, 126.7, 127.0, 127.3, 128.1, 128.2, 128.6, 129.3, 136.5, 136.6, 136.9, 139.2, 139.5, 141.3 (one sp^2 C

missing due to overlap); IR ($CDCl_3$) 3053, 1490 cm^{-1}; HRMS *m/z* 254.1088 (calcd for $C_{20}H_{14}$, 254.1096).

9-(2,2-Dimethylpropylidene)-9*H*-fluorene (5) (Table 1, entry 2). Obtained as a light yellow oil in 61% yield from the reaction of 2-iodobenzene and 3,3-dimethyl-1-phenyl-1-butyne after purification by column chromatography (hexanes): ^1H NMR ($CDCl_3$) δ 1.52 (s, 9 H), 6.95 (s, 1 H), 7.27-7.40 (m, 4 H), 7.66-7.80 (m, 3 H), 8.05-8.08 (m, 1 H); ^{13}C NMR ($CDCl_3$) δ 30.4, 32.4, 119.2, 119.5, 119.7, 126.4, 126.9, 127.4, 127.6, 127.7, 134.8, 135.4, 138.2, 140.8, 141.7, 141.9; IR ($CDCl_3$) 3058, 2958, 1448 cm^{-1}; HRMS *m/z* 234.1412 (calcd for $C_{18}H_{18}$, 234.1408).

9-(2-Hydroxy-2-methylpropylidene)-9*H*-fluorene (6) (Table 1, entry 3). Obtained as a yellow oil in 55% yield from the reaction of 2-iodobenzene and 2-methyl-4-phenyl-3-butyn-2-ol after purification by column chromatography (20:1 hexanes/EtOAc): ^1H NMR ($CDCl_3$) δ 1.68 (s, 6 H), 6.82 (s, 1 H), 7.27-7.45 (m, 4 H), 7.62-7.73 (m, 3 H), 8.64 (d, J = 6.9 Hz, 1 H) (OH missing due to exchange); ^{13}C NMR ($CDCl_3$) δ 30.7, 71.1, 119.4, 119.9, 126.9, 127.0, 128.1, 128.4, 129.0, 135.4, 135.5, 136.4, 139.1, 140.0, 141.6 (one sp^2 C missing due to overlap); IR ($CDCl_3$) 3416 (OH), 3056, 1448 cm^{-1}; HRMS *m/z* 236.1206 (calcd for $C_{17}H_{16}O$, 236.1201).

9-Benzylidene-1-trifluoromethyl-9*H*-fluorene (7) (Table 1, entry 4). Obtained as a light yellow oil in 75% yield from the reaction of 2-iodobenzotrifluoride and diphenylacetylene after purification by column chromatography (hexanes): ^1H NMR ($CDCl_3$) δ 7.02 (dt, J = 1.2, 7.2 Hz, 1 H), 7.19(d, J = 7.2 Hz, 1 H), 7.31 (dt, J = 1.2, 7.5 Hz, 1 H), 7.41-7.52 (m, 6 H), 7.66 (d, J = 7.2 Hz, 1 H), 7.72 (d, J = 7.2 Hz, 1 H), 7.93 (d, J = 7.2 Hz, 1 H), 8.16 (s, 1 H); ^{13}C NMR ($CDCl_3$) δ 119.4, 123.0, 124.5 (q, $J^1_{C\text{-}F}$ = 271.5 Hz, CF_3), 124.9, 125.0, 125.1, 127.4, 127.7, 128.2, 128.3, 128.7, 128.8, 131.6, 135.2 (q, $J^3_{C\text{-}F}$ = 6.4 Hz), 137.1, 137.5, 139.2, 142.1 (one sp^2 C missing due to overlap); IR ($CDCl_3$) 3058, 4026, 1492 cm^{-1}; HRMS *m/z* 322.0965 (calcd for $C_{21}H_{13}F_3$, 322.0969).

9-Benzylidene-1-*tert.*-butyl-9*H*-fluorene (8) (Table 1, entry 5). Obtained as a yellow liquid in 35% yield from the reaction of 1-*tert.*-butyl-2-iodobenzene and diphenylacetylene after purification by column chromatography (hexanes): ^1H NMR ($CDCl_3$) δ 1.67 (s, 9 H), 6.91 (dt, J = 1.0, 7.8 Hz, 1 H), 7.00 (d, J = 7.8 Hz, 1 H), 7.20-7.48 (m, 8 H), 7.65-7.68 (m, 2 H), 8.12 (s, 1 H); ^{13}C NMR ($CDCl_3$) δ 30.9, 35.5, 117.8,

118.9, 125.0, 125.9, 126.3, 127.7, 127.8, 128.3, 128.7, 128.8, 135.8, 136.6, 137.4, 138.4, 138.5, 140.6, 141.9, 148.1; IR ($CDCl_3$) 3056, 2957, 1598 cm^{-1}; HRMS *m/z* 310.1719 (calcd for $C_{24}H_{22}$, 310.1721).

(*Z*/*E*)-9-Benzylidene-1-methyl-9*H*-fluorene (9a and 9b) (Table 1, entry 6). A yellow solid obtained in 61% yield as an inseparable mixture of *Z*/*E* isomers (40:60) from the reaction of 2-iodotoluene and diphenylacetylene after purification by column chromatography (hexanes). The assignment of isomers is based upon the presence of a singlet at δ 2.41 (CH_3) for the *Z* isomer and a singlet at δ 2.48 (CH_3) for the *E* isomer. Spectral data for the product mixture: ^{1}H NMR ($CDCl_3$) δ 2.41 (s, 3 H), 2.48 (s, 3 H), 6.89 (d, *J* = 8.1 Hz, 1 H), 7.06 (dt, *J* = 1.0, 7.8, Hz, 1 H), 7.15 (d, *J* = 7.5 Hz, 1 H), 7.28-7.72 (m, 22 H), 7.79 (d, *J* = 7.0 Hz, 1 H); ^{13}C NMR ($CDCl_3$) δ 21.7, 21.8, 119.4, 119.6, 120.0, 120.2, 120.3, 120.4, 124.2, 124.4, 126.3, 126.4, 126.6, 126.9, 127.6, 127.9, 128.0, 128.1, 128.4, 128.5, 129.3, 129.4, 134.0, 136.3, 136.4, 136.9, 137.0, 137.1, 138.2, 138.6, 139.2, 139.3, 140.0, 141.3, 141.5 (3 sp^2 C missing due to overlap); IR ($CDCl_3$) 3053, 3019, 2916, 1492, 1445 cm^{-1}; HRMS *m/z* 268.1247 (calcd for $C_{21}H_{16}$, 268.1252).

(*Z*)-9-Benzylidene-3-methoxy-9*H*-fluorene (10a) and (*E*)-9-benzylidene-3-methoxy-9*H*-fluorene (10b) (Table 1, entry 7). A yellow oil obtained in 45% yield (40:60 *Z*/*E* isomers) from the reaction of 4-iodoanisole and diphenylacetylene after purification by column chromatography (30:1 hexanes/EtOAc). The *Z*/*E* isomers were further separated by preparative TLC. **(*Z*)-9-Benzylidene-3-methoxy-9*H*-fluorene (10a)**: R_f = 0.36 (30:1 hexanes/EtOAc); ^{1}H NMR ($CDCl_3$) δ 3.87 (s, 3 H), 6.61 (dd, *J* = 2.4, 8.1 Hz, 1 H), 7.23 (d, *J* = 2.4, 1 H), 7.31-7.50 (m, 6 H), 7.56-7.60 (m, 3 H), 7.67-7.70 (m, 1 H), 7.76-7.80 (m, 1 H); ^{13}C NMR ($CDCl_3$) δ 55.5, 104.8, 112.7, 119.5, 120.2, 125.1, 125.4, 127.1, 127.8, 128.1, 128.5, 129.4, 129.5, 136.0, 127.1, 128.9, 140.5, 143.1, 160.5; IR ($CDCl_3$) 3050, 2951, 1607, 1455 cm^{-1}; HRMS *m/z* 284.1201 (calcd for $C_{21}H_{16}O$, 284.1201). **(*E*)-9-Benzylidene-3-methoxy-9*H*-fluorene (10b)**: R_f = 0.31 (30:1 hexanes/EtOAc); ^{1}H NMR ($CDCl_3$) δ 3.92 (s, 3 H), 6.89 (dd, *J* = 2.4, 8.4 Hz, 1 H), 7.06 (dt, *J* = 1.2, 7.5 Hz, 1 H), 7.24 (d, *J* = 2.4 Hz, 1 H), 7.31 (dt, *J* = 0.9, 7.5 Hz, 1 H), 7.40-7.48 (m, 3 H), 7.56-7.60 (m, 4 H), 7.66-7.71 (m, 2 H); ^{13}C NMR ($CDCl_3$) δ 55.6, 104.5, 113.4, 119.6, 121.3, 124.4, 125.6, 126.8, 127.8, 128.4, 128.5, 129.3, 132.4, 136.0, 137.1,

137.4, 140.7, 140.9, 160.5; IR ($CDCl_3$) 3051, 2952, 1607, 1454 cm^{-1}; HRMS *m/z* 284.1200 (calcd for $C_{21}H_{16}O$, 284.1201).

Compounds 11a and 11b (Table 1, entry 8). A yellow solid obtained in 45% yield (40:60 *Z/E* isomers) from the reaction of ethyl 4-iodobenzoate and diphenylacetylene after purification by column chromatography (50:1 hexanes/EtOAc). The *Z/E* isomers were further separated by preparative TLC. Compound **11a**: mp 124-125 °C (hexanes/EtOAc); ^1H NMR ($CDCl_3$) δ 1.41 (t, *J* = 1.2 Hz, 3 H), 4.41 (q, *J* = 1.2 Hz, 2 H), 7.37-7.50 (m, 5 H), 7.57-7.61 (m, 3 H), 7.75-7.83 (m, 4 H), 8.37 (d, *J* =1.0 Hz, 1 H); ^{13}C NMR ($CDCl_3$) δ 14.4, 61.0, 120.0, 120.2, 120.8, 124.0, 127.5, 128.0, 128.4, 128.5, 128.6, 129.3, 129.5, 130.2, 135.9, 136.4, 138.4, 139.5, 140.5, 141.3, 166.6; IR ($CDCl_3$) 3053, 2977, 2924, 1712, 1609, 1492 cm^{-1}; HRMS *m/z* 326.1304 (calcd for $C_{23}H_{18}O_2$, 326.1307). Compound **11b**: mp 104-105 °C; ^1H NMR ($CDCl_3$) δ 1.46 (t, *J* = 1.2 Hz, 3 H), 4.46 (q, *J* = 1.2 Hz, 2 H), 7.10 (dt, *J* = 1.0, 7.5 Hz, 1 H), 7.33-7.51 (m, 4 H), 7.59-7.62 (m, 3 H), 7.79-7.84 (m, 3 H), 8.04 (dd, *J* = 1.2, 7.5 Hz, 1 H), 8.39 (d, *J* = 1.2 Hz, 1 H); ^{13}C NMR ($CDCl_3$) δ 14.4, 61.1, 120.0, 120.1, 120.9, 124.4, 127.2, 128.4, 128.4, 128.6, 128.9, 129.2, 129.6, 130.1, 135.9, 136.4, 136.6, 139.2, 140.5, 143.6, 166.8; IR ($CDCl_3$) 3052, 2976, 2922, 1713, 1609, 1423 cm^{-1}; HRMS *m/z* 326.1304 (calcd for $C_{23}H_{18}O_2$, 326.1307).

(*Z*)-9-Benzylidene-4-aza-9*H*-fluorene (12a), (*E*)-9-benzylidene-4-aza-9*H*-fluorene (12b), (*Z*)-9-benzylidene-2-aza-9*H*-fluorene (12c) and (*E*)-9-benzylidene-2-aza-9*H*-fluorene (12d) (Table 1, entry 9). A yellow solid obtained in 76% yield as a 19:14:40:27 mixture of regioisomers and *Z/E* isomers from the reaction of 3-iodopyridine and diphenylacetylene after purification by column chromatography using 2:1 hexanes/EtOAc as eluant. The isomers were further separated by preparative TLC. The melting points and ^1H NMR spectra of these isomers match those in the literature.[6] **(*Z*)-9-Benzylidene-4-aza-9*H*-fluorene (12a)**: mp 64-65 °C (lit.[6b] mp 62-63 °C); ^1H NMR ($CDCl_3$) δ 6.98 (dd, *J* = 4.8, 7.5 Hz, 1 H), 7.42-7.58 (m, 7 H), 7.77 (dd, *J* = 1.5, 7.8 Hz, 1 H), 7.81 (s, 1 H), 7.85-7.88 (m, 1 H), 8.03-8.07 (m, 1 H), 8.50 (dd, *J* = 1.5, 4.8 Hz, 1 H); ^{13}C NMR ($CDCl_3$) δ 120.1, 120.6, 121.0, 128.5, 128.7, 128.8, 129.0, 129.3, 129.4, 130.6, 131.3, 133.8, 136.3, 138.2, 139.8, 149.2, 160.1. **(*E*)-9-Benzylidene-4-aza-9*H*-fluorene (12b)**: mp 99-100 °C (lit.[6b] mp 96-98 °C); ^1H NMR ($CDCl_3$) δ 7.16-7.25 (m, 2 H), 7.42-

7.51 (m, 4 H), 7.61-7.64 (m, 3 H), 7.70 (s, 1 H), 8.04 (dt, J = 1.5, 7.5 Hz, 2 H), 8.59 (dd, J = 1.5, 4.8 Hz, 1 H); ^{13}C NMR ($CDCl_3$) δ 120.6, 121.5, 124.3, 127.4, 128.5, 128.6, 128.7, 129.2, 129.3, 133.4, 133.7, 136.4, 137.0, 140.2, 149.2, 158.3 (one sp^2 C missing due to overlap). **(*Z*)-9-Benzylidene-2-aza-9*H*-fluorene (12c)**: mp 164-165 °C (lit.[6a] mp 165-166 °C); ^{1}H NMR ($CDCl_3$) δ 7.41-7.51 (m, 5 H), 7.59-7.63 (m, 3 H), 7.80-7.88 (m, 3 H), 8.52 (d, J = 5.1 Hz, 1 H), 8.83 (s, 1 H); ^{13}C NMR ($CDCl_3$) δ 114.6, 114.6, 120.7, 121.1, 128.5, 128.7, 128.8, 129.3, 129.5, 131.9, 134.7, 136.4, 136.8, 140.0, 145.6, 147.8, 149.0; HRMS *m/z* 255.1047 (calcd for $C_{19}H_{13}N$, 255.1048). **(*E*)-9-Benzylidene-2-aza-9*H*-fluorene (12d)**: mp 83-84 °C (lit.[6a] mp 82-83 °C); ^{1}H NMR ($CDCl_3$) δ 7.19-7.36 (m, 1 H), 7.36-7.51 (m, 4 H), 7.59-7.66 (m, 4 H), 7.80-7.84 (m, 2 H), 8.60 (d, J = 5.1 Hz, 1 H), 9.06 (s, 1 H); ^{13}C NMR ($CDCl_3$) δ 114.4, 121.3, 124.8, 128.6, 128.7, 128.9, 129.1, 129.2, 129.6, 134.6, 136.2, 137.1, 138.8, 142.2, 145.9, 148.7 (one sp^2 C missing due to overlap); HRMS *m/z* 255.1034 (calcd for $C_{19}H_{13}N$, 255.1048).

The following compound was prepared using the general procedure reported earlier, except that no alkyne was employed.

9-Benzylidene-9*H*-fluorene (4) (eq 3). Obtained as a white solid in 70% yield from the reaction of 1-iodo-1,2,2-triphenylethylene after purification by column chromatography (hexanes). The melting point and ^{1}H and ^{13}C NMR spectra were identical to those in the literature and those obtained from the reaction of iodobenzene and diphenylacetylene above..[7]

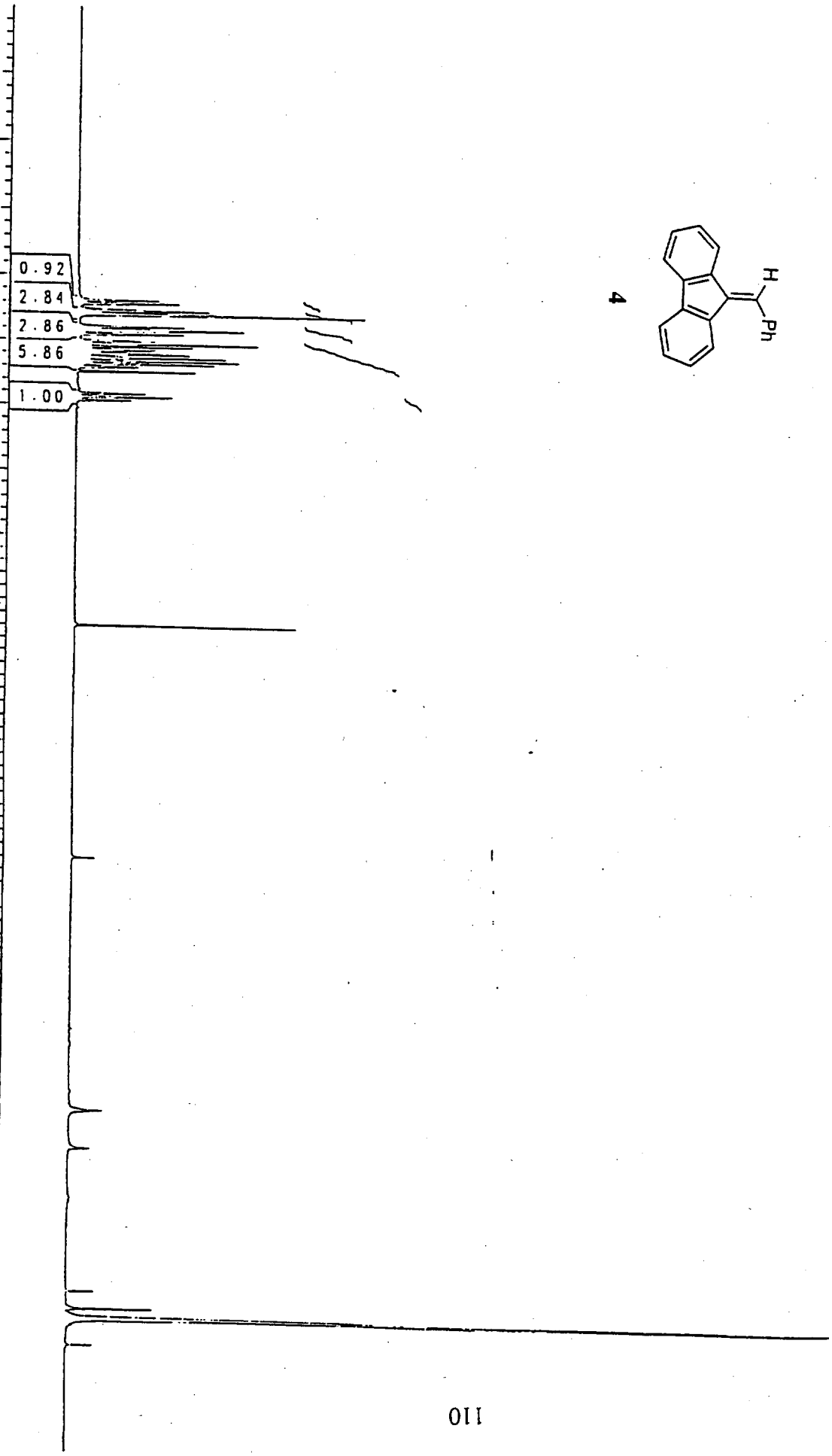
The ^{1}H and ^{13}C NMR for all Fluorenes described above follow (29 pages).

References

1. Larock, R. C.; Doty, M. J.; Cacchi, S. *J. Org. Chem.* **1993**, *58*, 4579.
2. Wang, Y. Ph. D. Dissertation, Iowa State University, **1995**.
3. Lesslie, M. S.; Mayer, U. J. H. *J. Chem. Soc.* **1961**, 611.
4. Miller, L. L.; Kaufman, D. A. *J. Am. Chem. Soc.* **1968**, *90*, 7282.
5. Sprinzak, Y. *J. Am. Chem. Soc.* **1956**, *78*, 466.

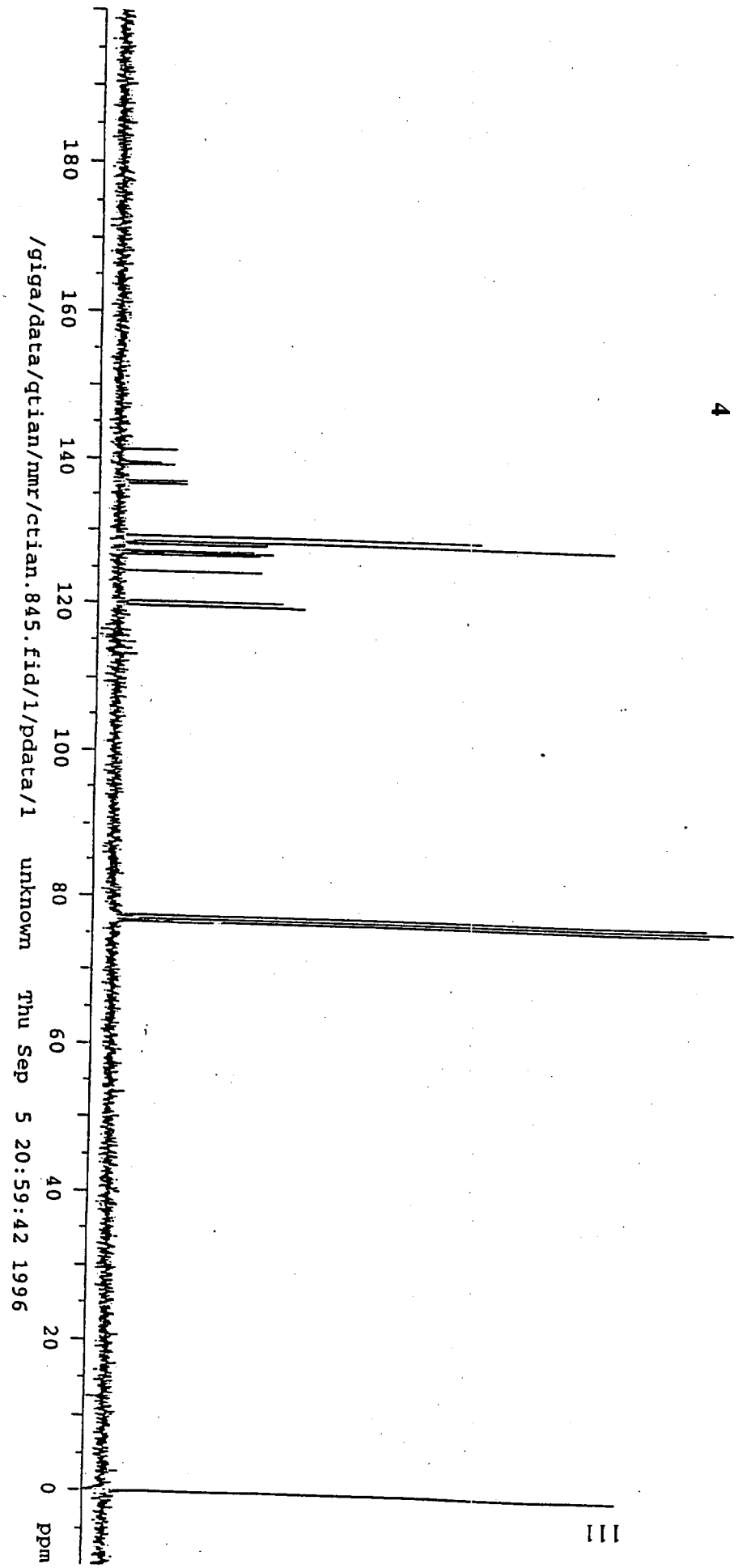
6. (a) Prostakov, N. S.; Moiz, S. S.; Soldatenkov, A. T.; Zvolinskii, V. P.; Cherenkova, G. I. *Khim. Geterotsikl. Soedin.* **1971**, 1398. (b) Prostakov, N. S.; Varlamov, A. V.; Anismov, B. N.; Mikhailova, N. M.; Vasil'ev, G. A.; Zakharov, P. I.; Galiullin, M. A. *Khim. Geterotsikl. Soedin.* **1978**, 1234.

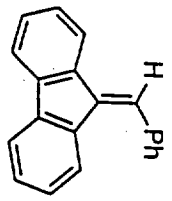
7. Sprinzak, Y. *J. Am. Chem. Soc.* **1956**, *78*, 466


0.92
2.84
2.86
5.86
1.00
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
ppm
/giga/data/qtian/nmr/htian.845.fid/1/pdata/1 unknown Thu Sep 5 22:19:11 1996

H
Ph

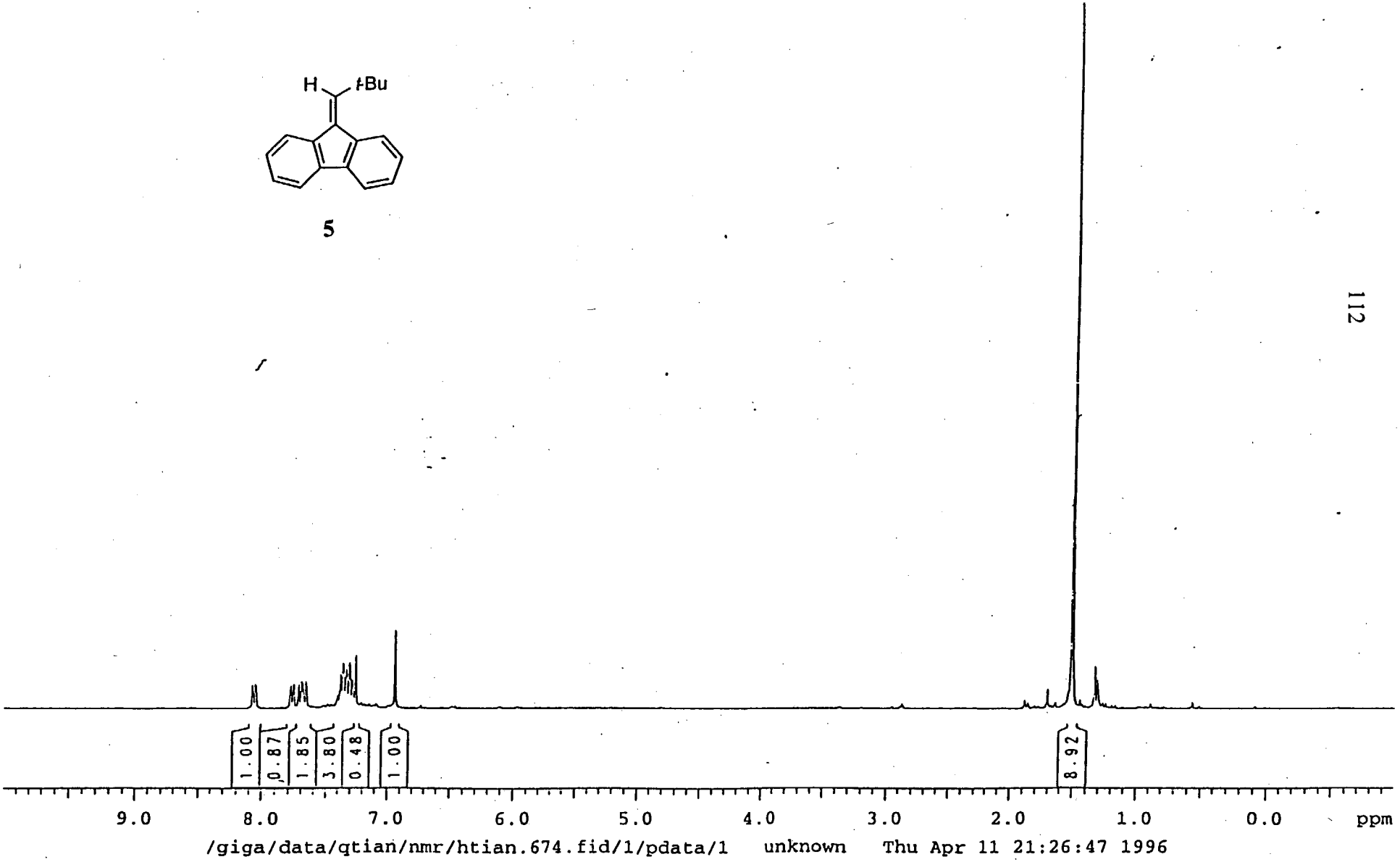
4


180
160
140
120
100
80
60
40
20
0
ppm
/giga/data/qtian/nmr/ctian.845.fid/1/pdata/1 unknown Thu Sep 5 20:59:42 1996

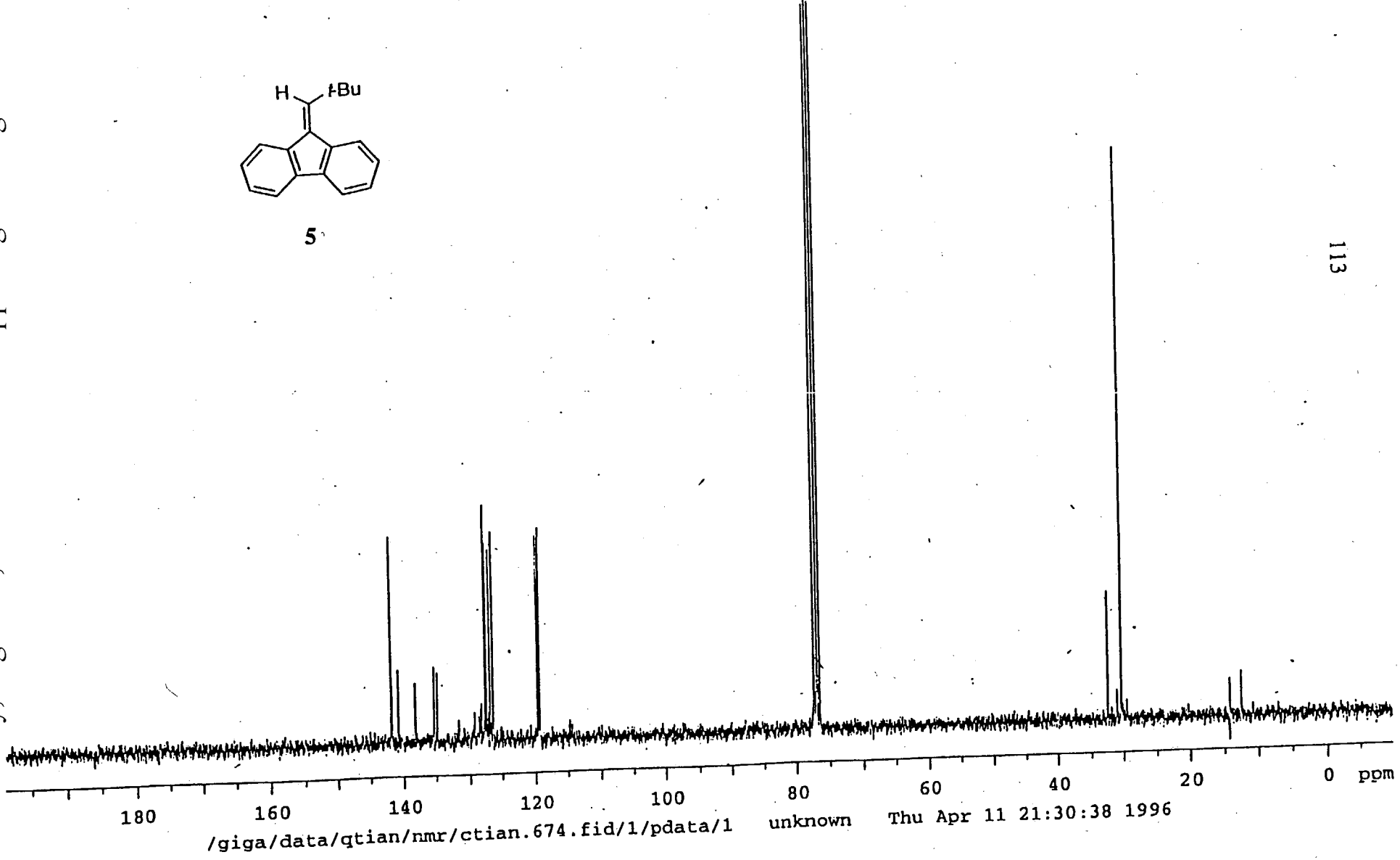

H
Ph

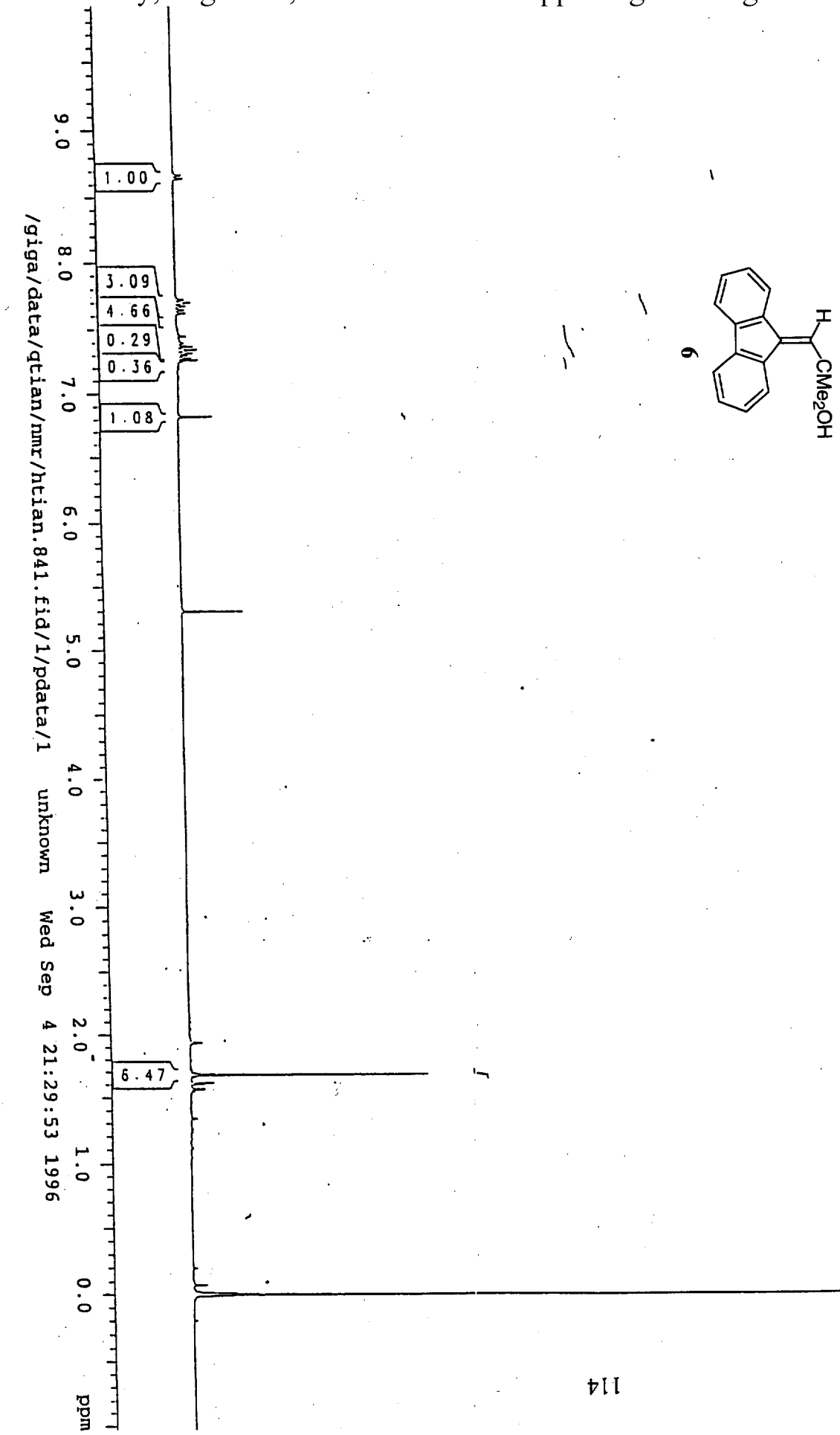
4

5

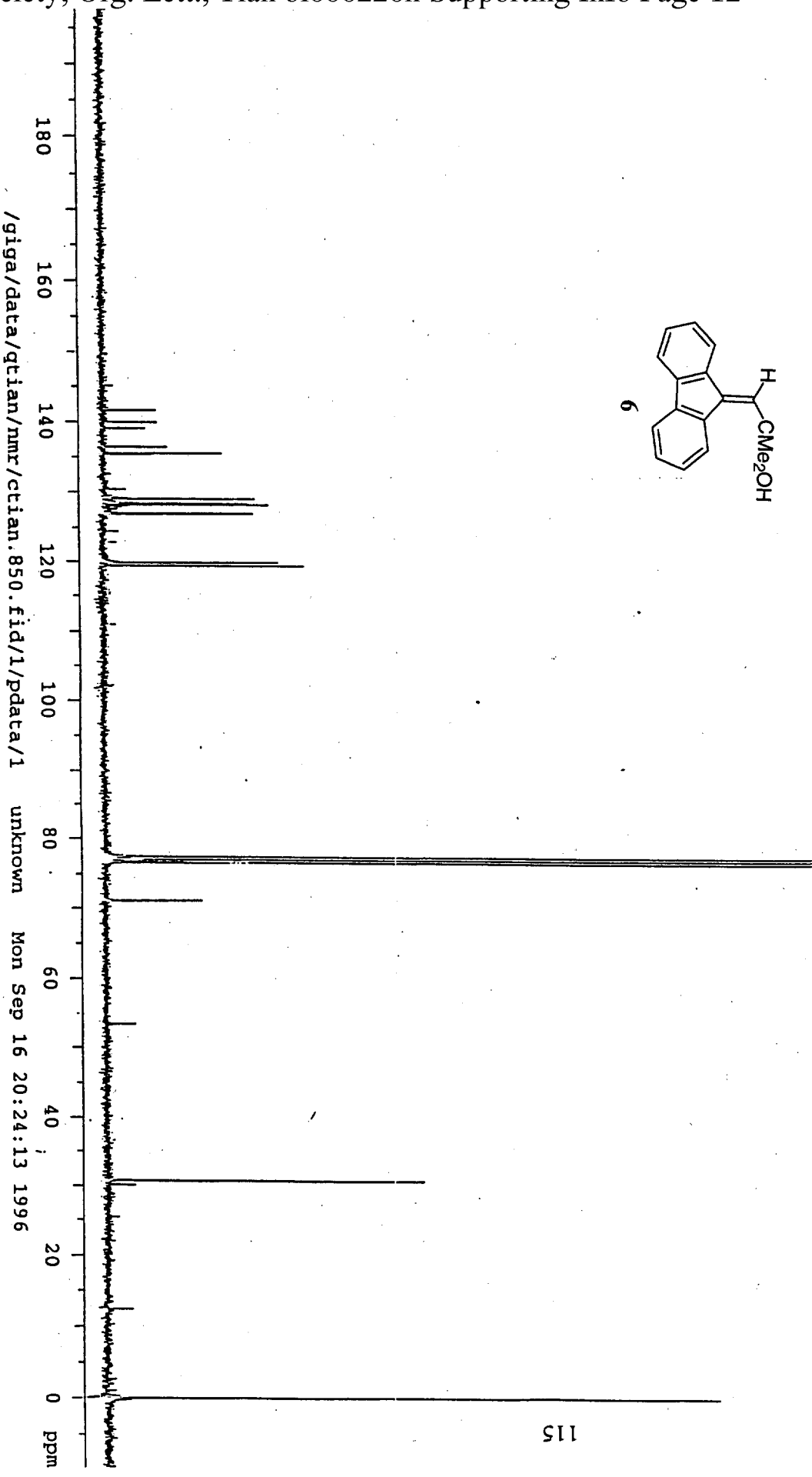


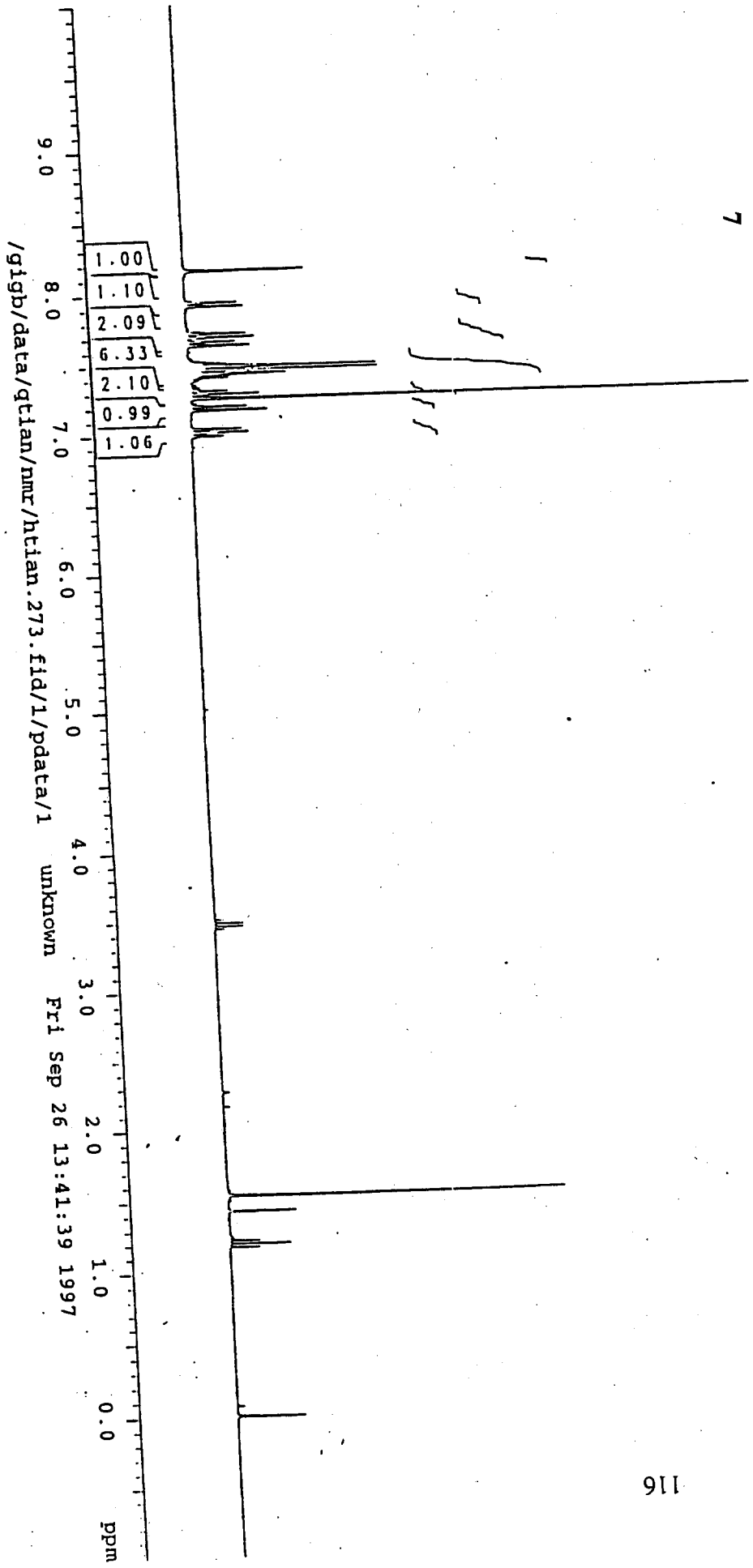
5

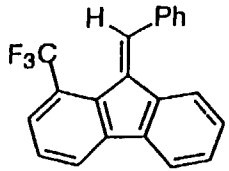




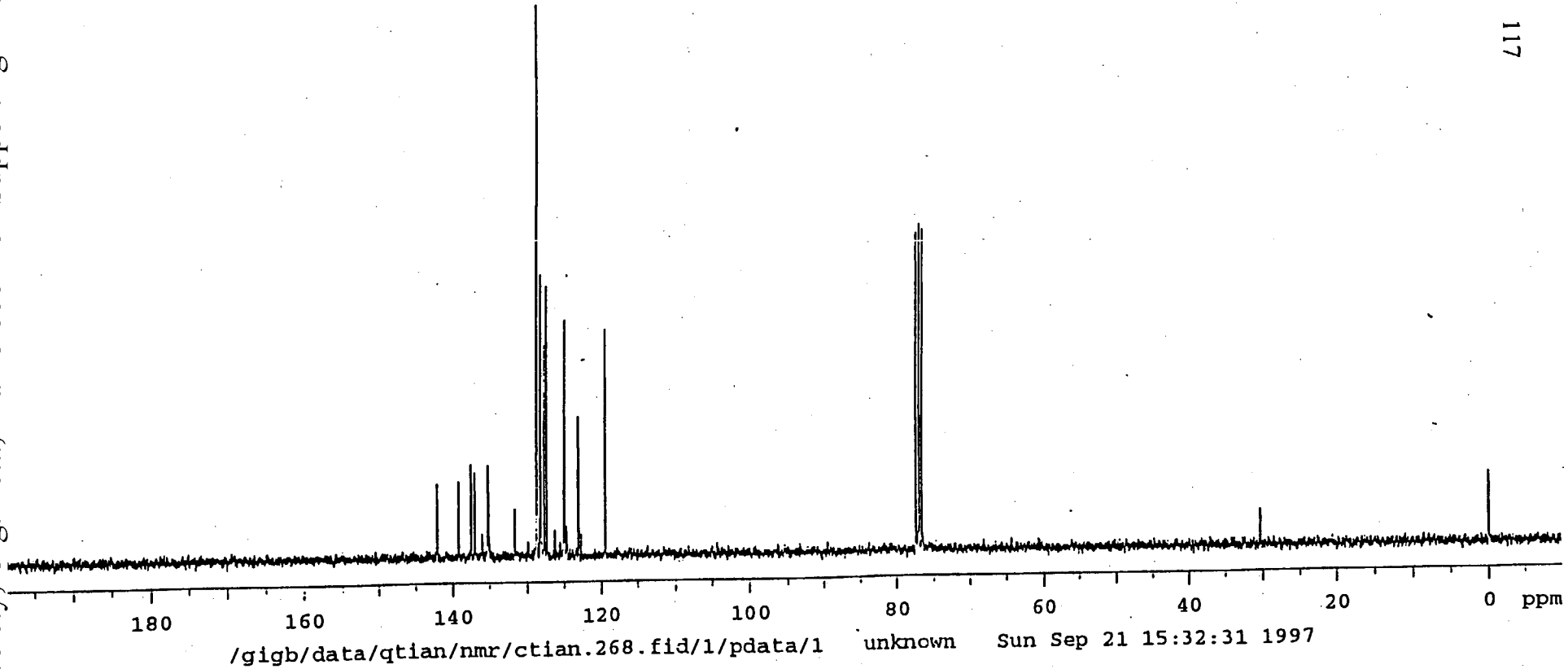
6




F3C
7
1.00
1.10
2.09
6.33
2.10
0.99
1.06
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
ppm
/glgb/data/qtian/nmr/htian.273.fid/1/pdata/1 unknown Fri Sep 26 13:41:39 1997

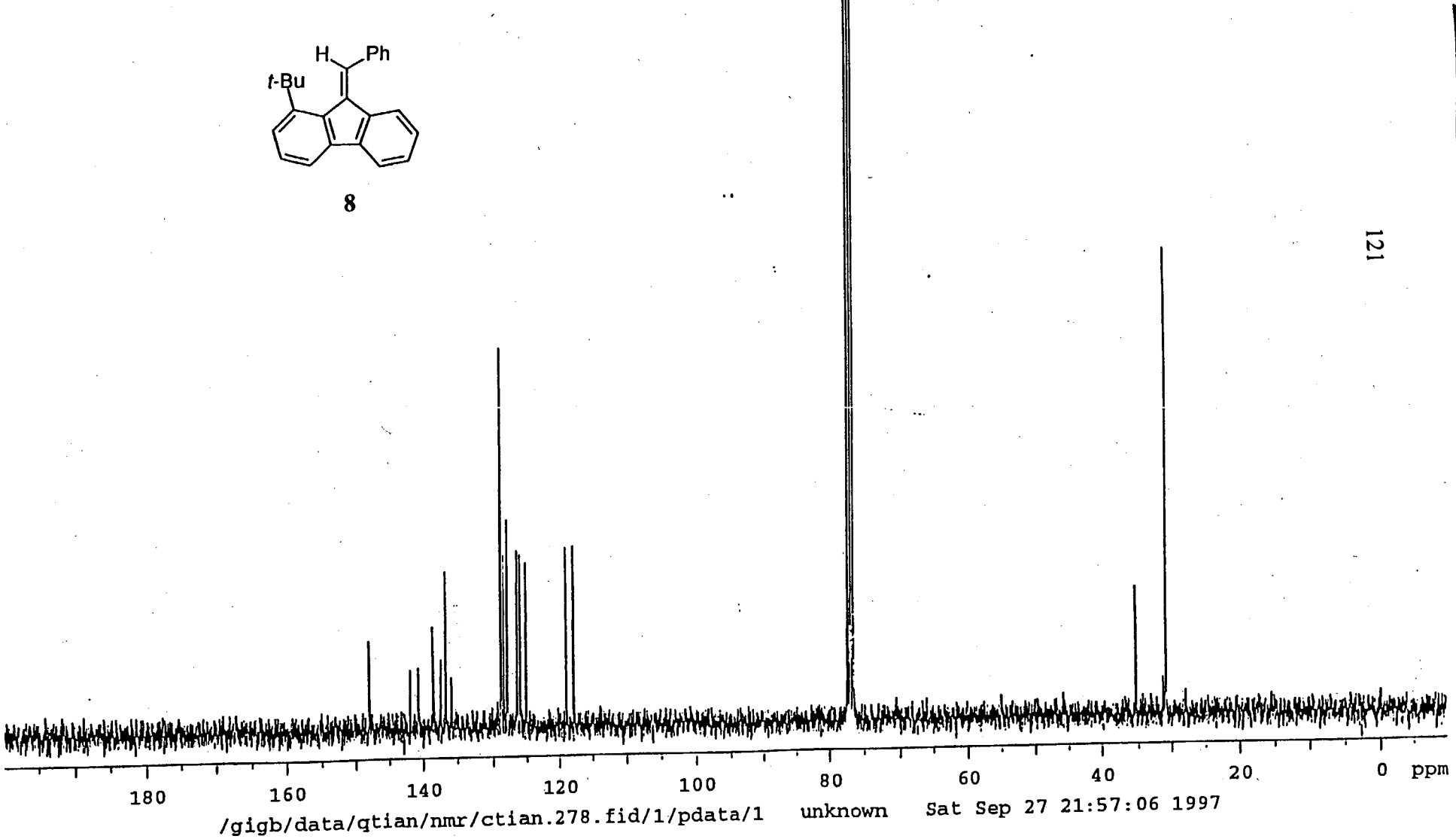


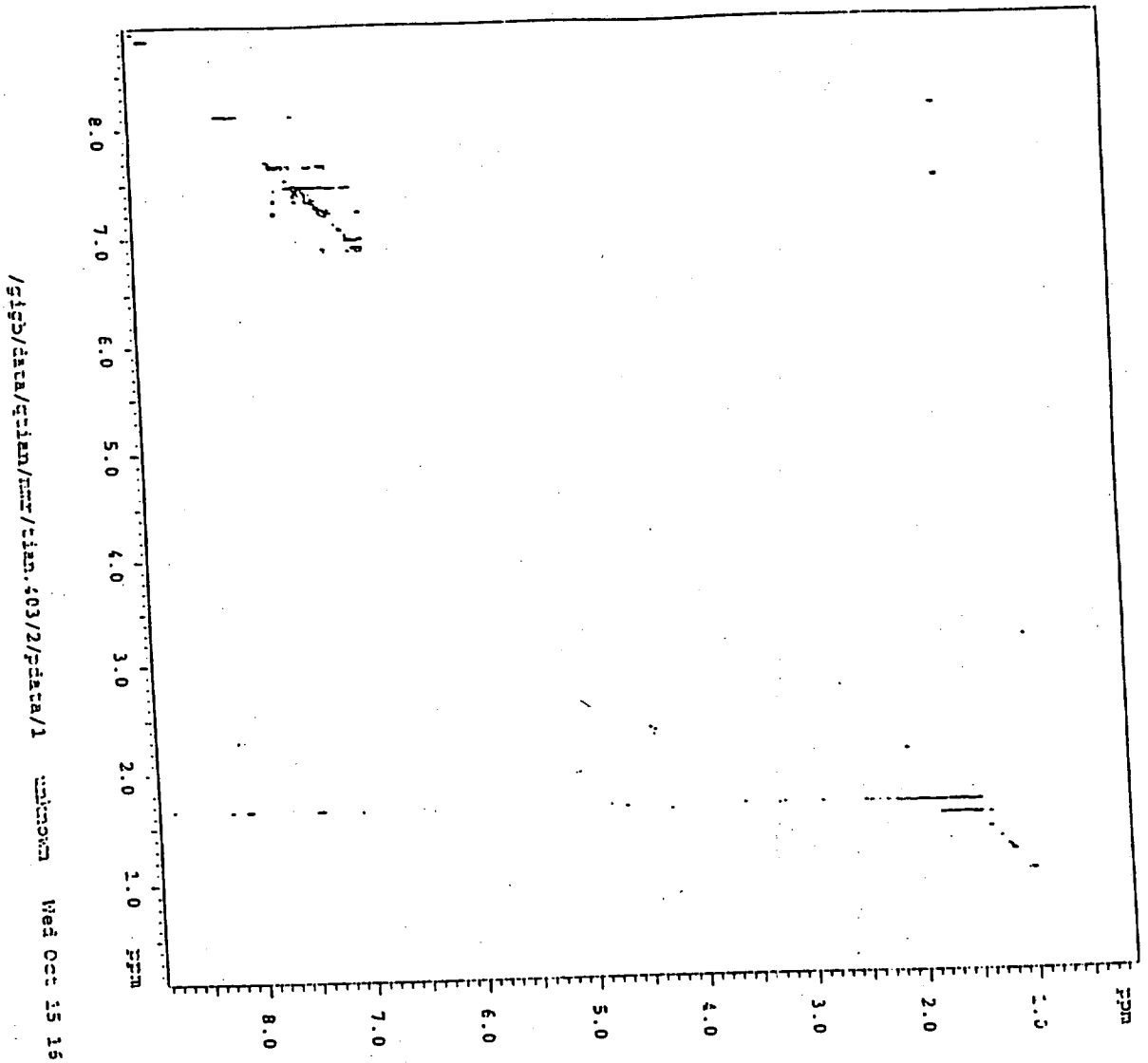
7

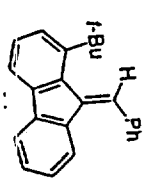


t-Bu
H
Ph
8
1.00
2.58
10.59
0.93
0.99
10.61
0.50
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
ppm
/glgb/data/qtian/nmr/htian.278.fid/1/pdata/1 unknown Sat Sep 27 21:47:00 1997
120

8

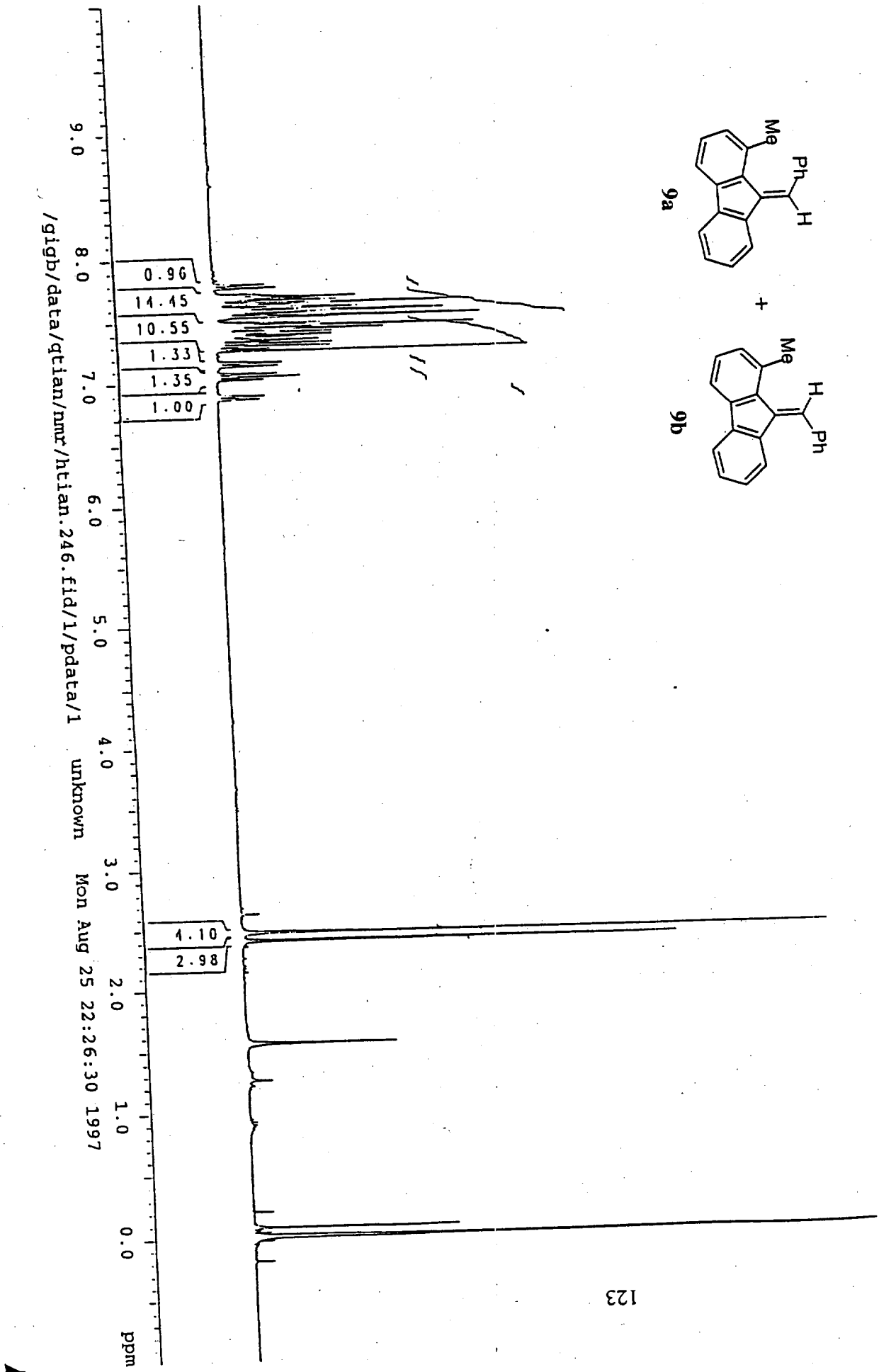






8

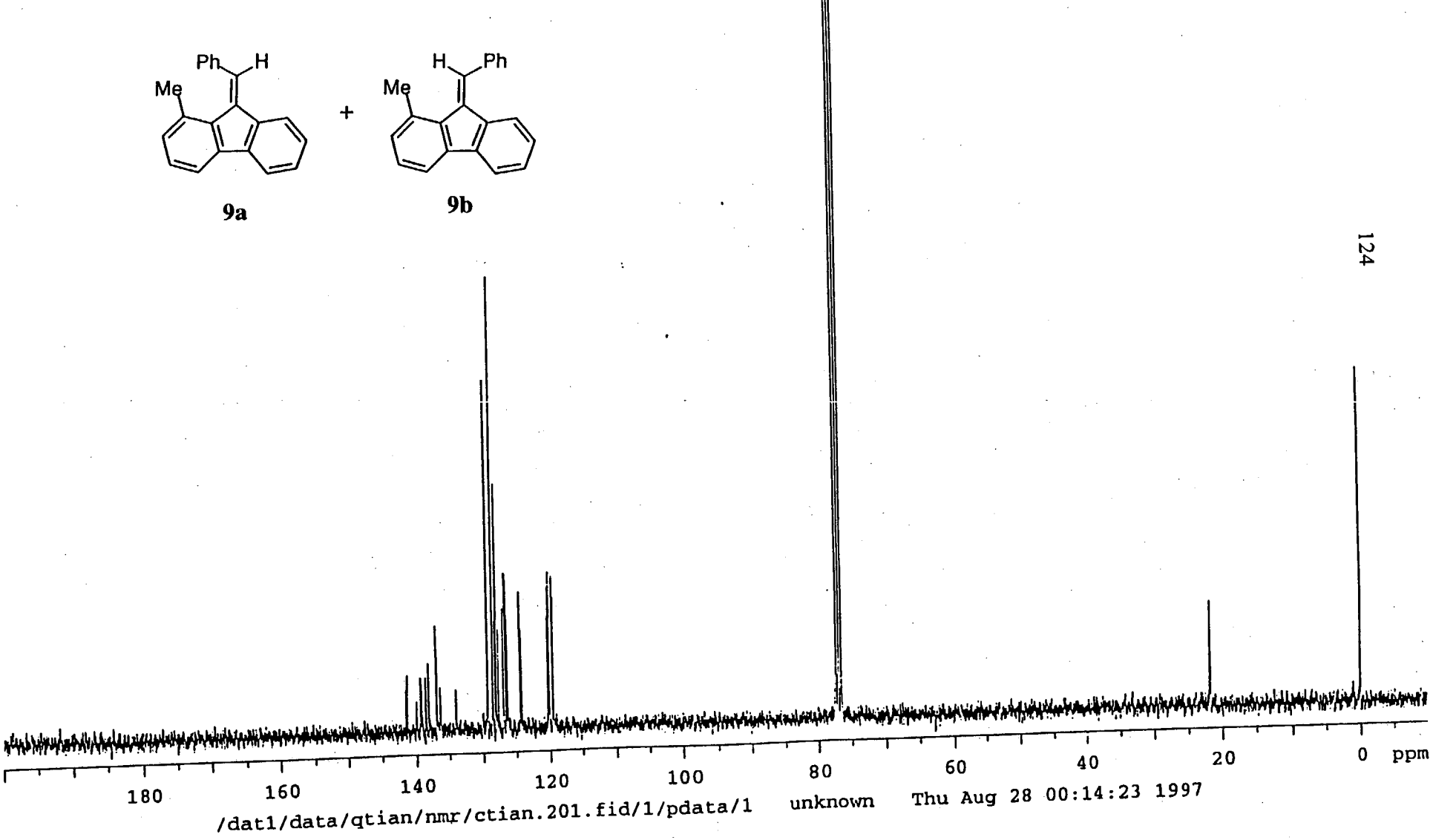
2D NOESY SPECTRUM

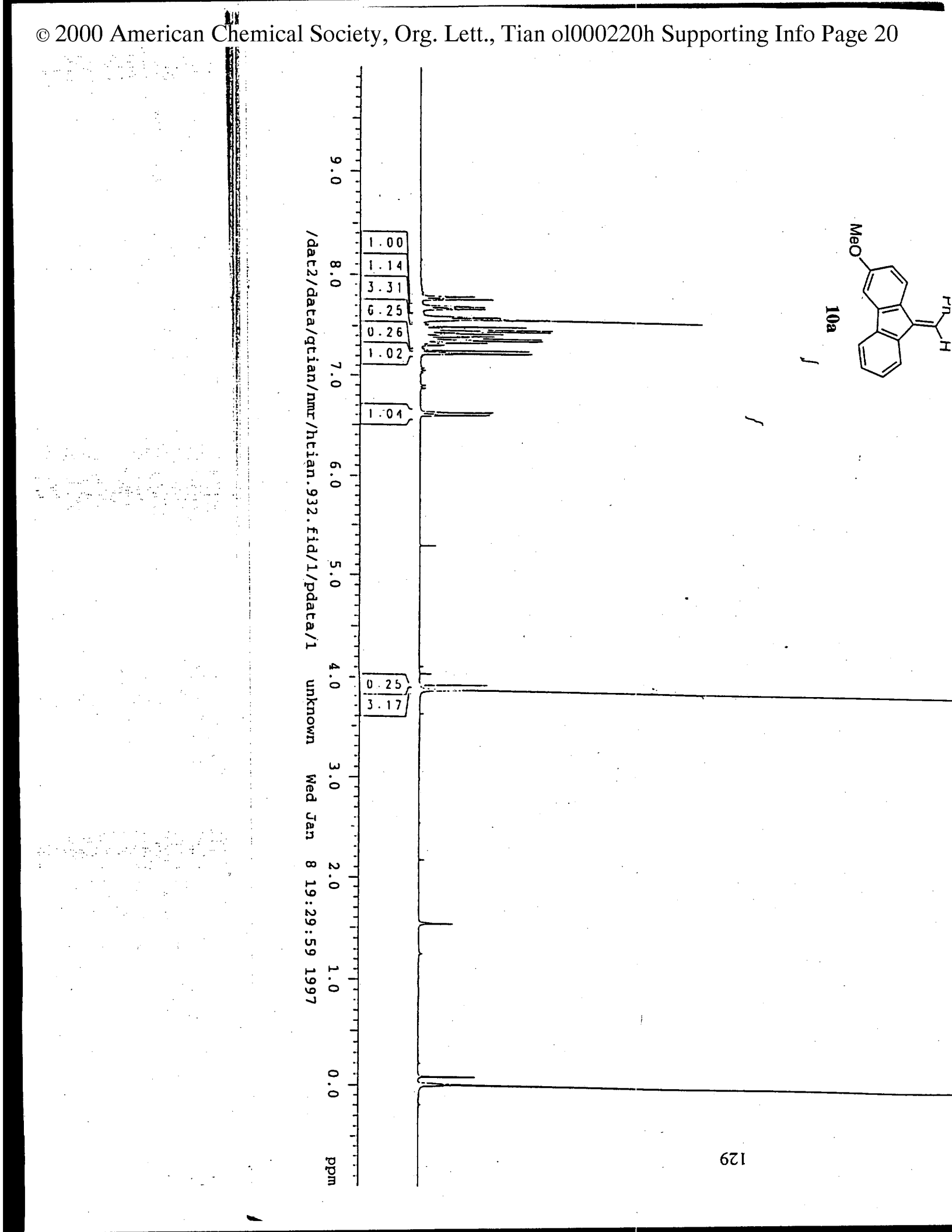

Me
Ph
H
9a
+
Me
H
Ph
9b
0.96
14.15
10.55
1.33
1.35
1.00
4.10
2.98
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
ppm
/gigb/data/qtian/nmr/htian.246.fid/1/pdata/1 unknown Mon Aug 25 22:26:30 1997

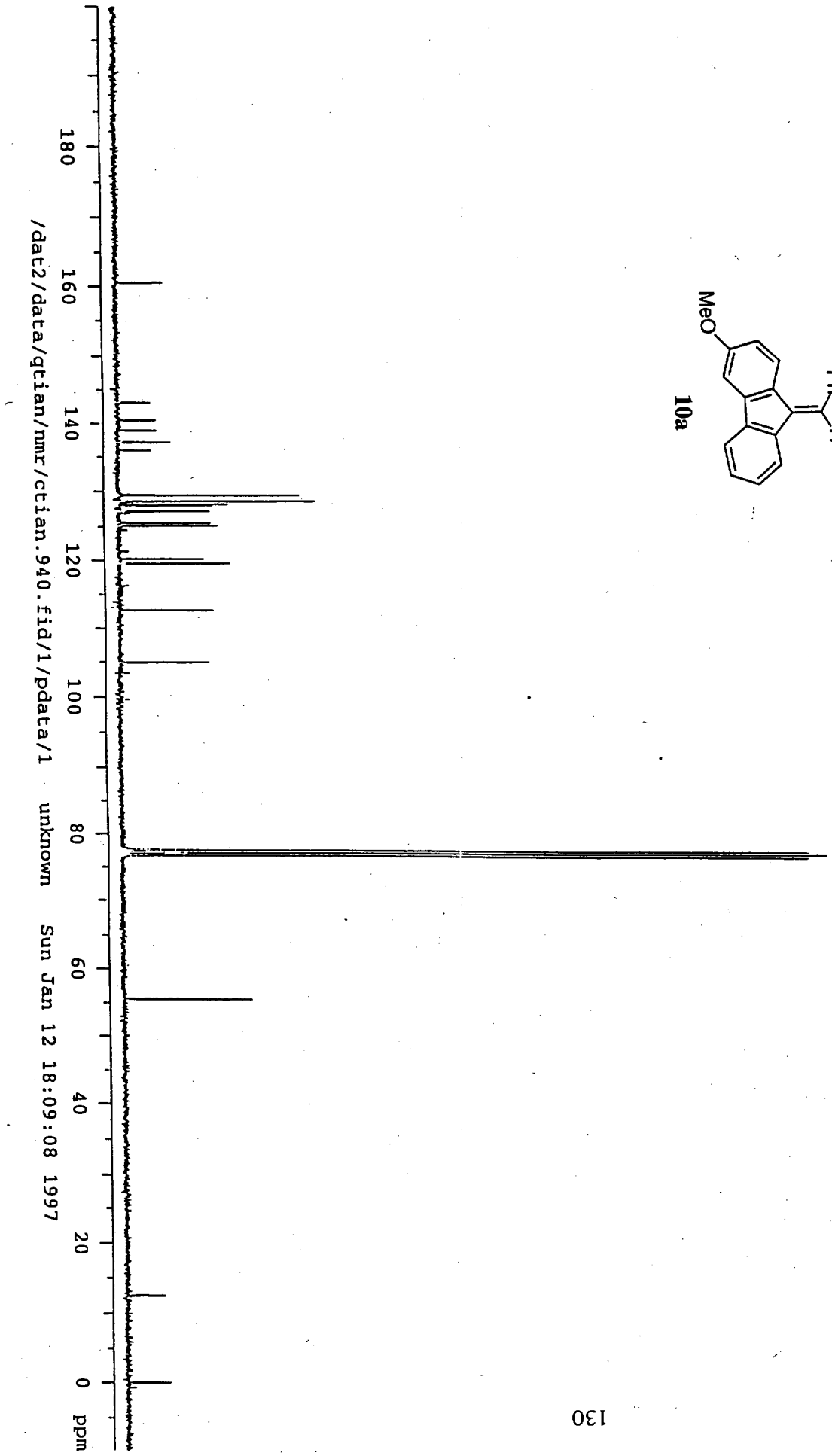
9a

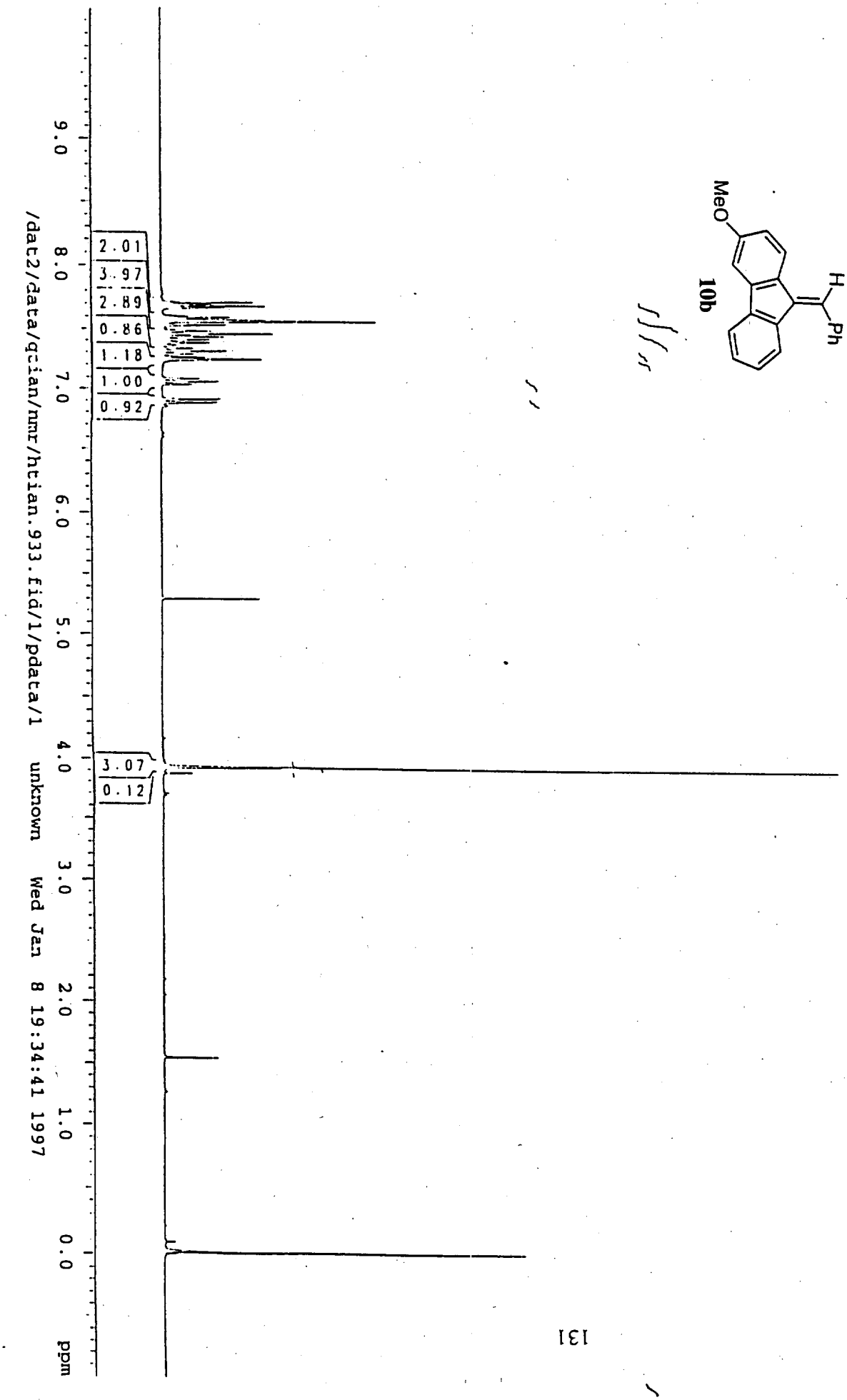
+

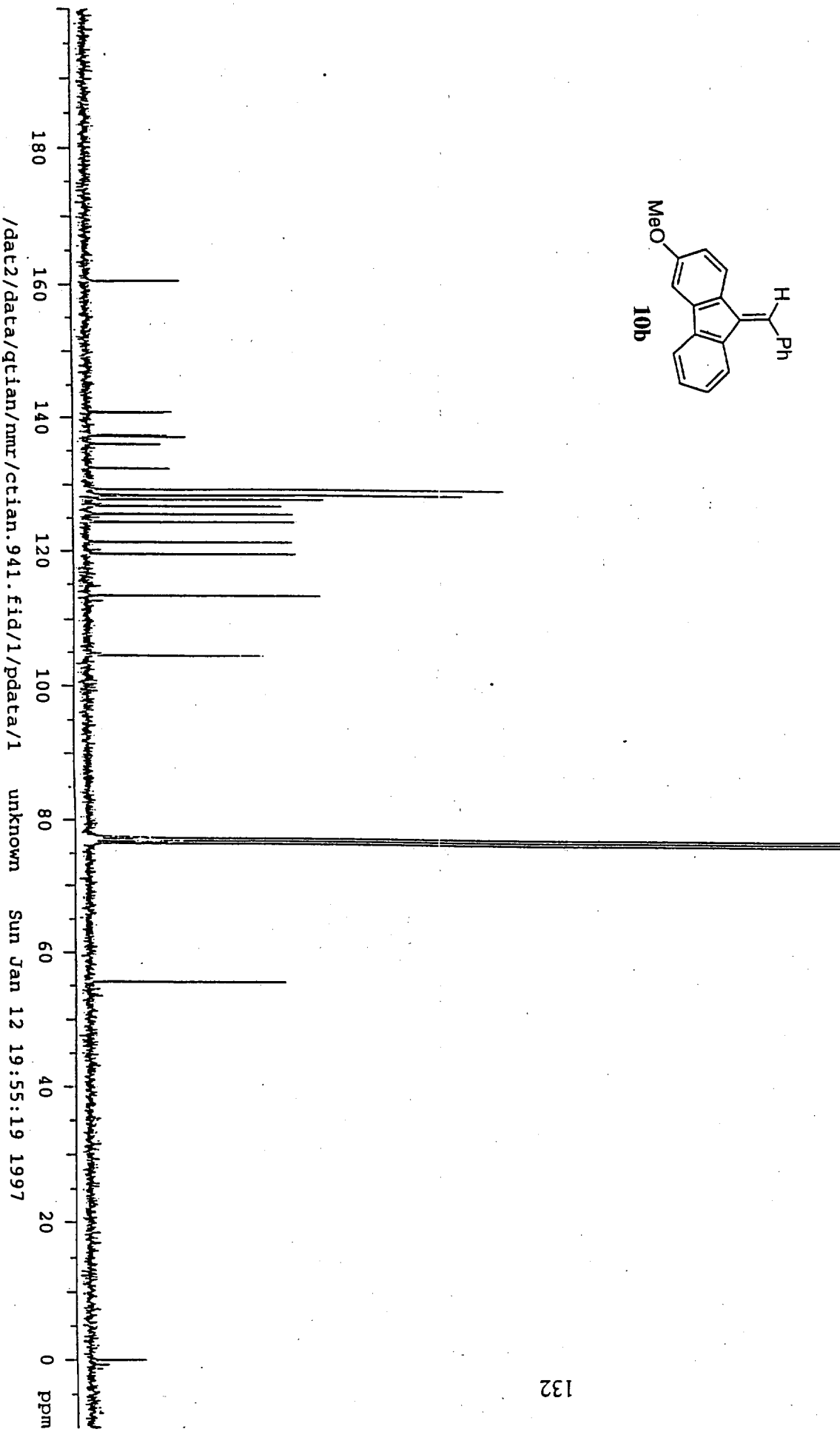
9b

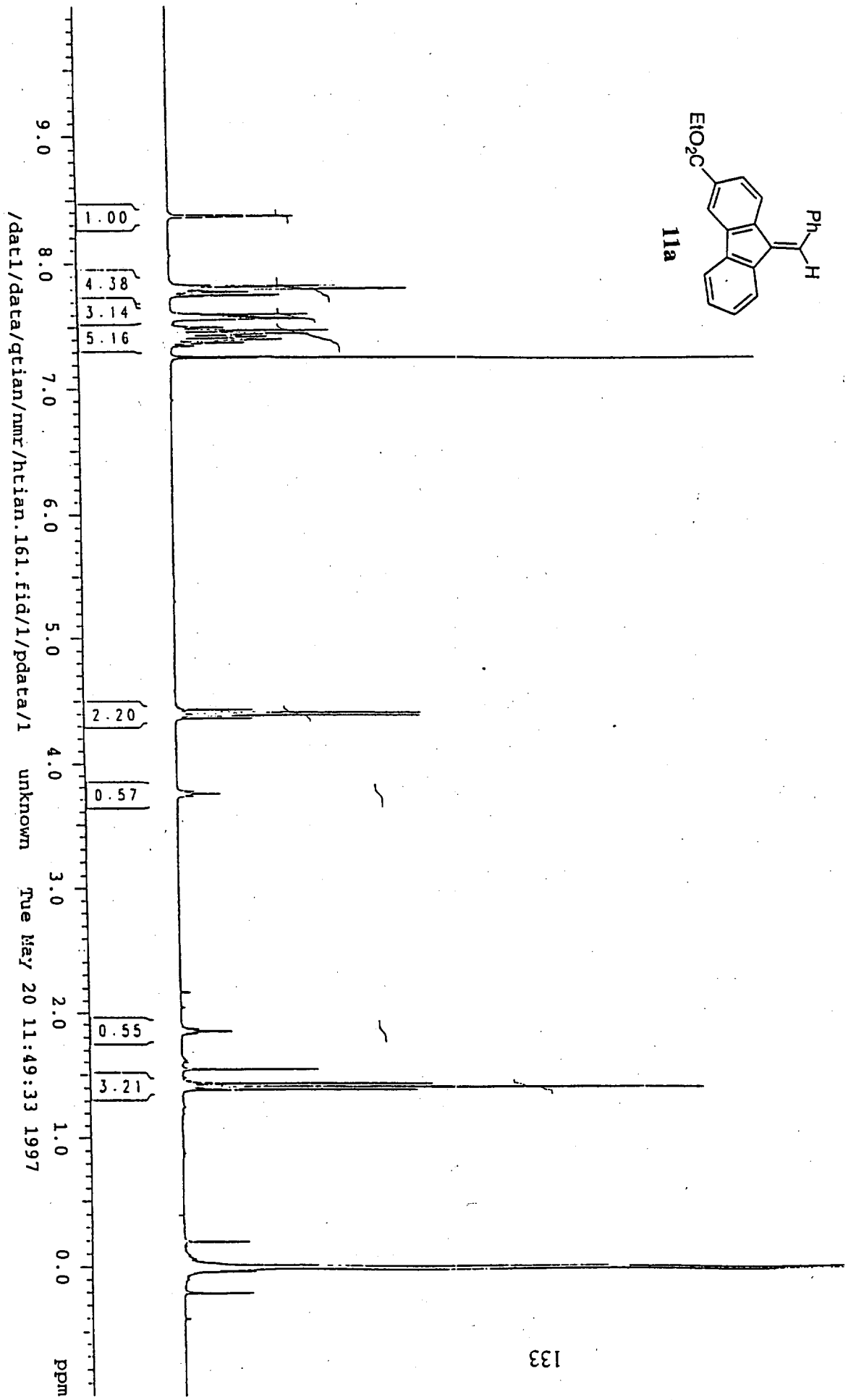


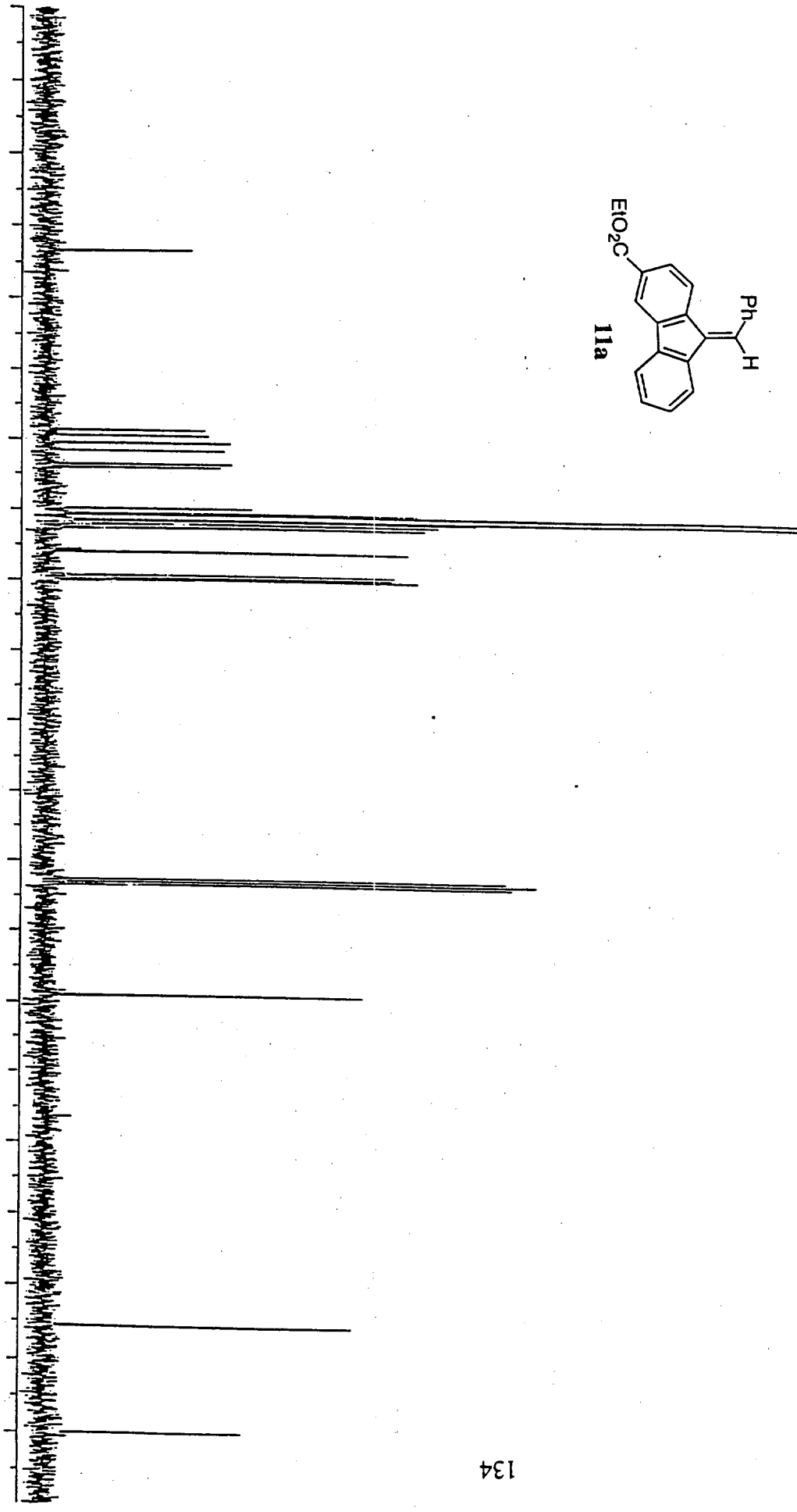


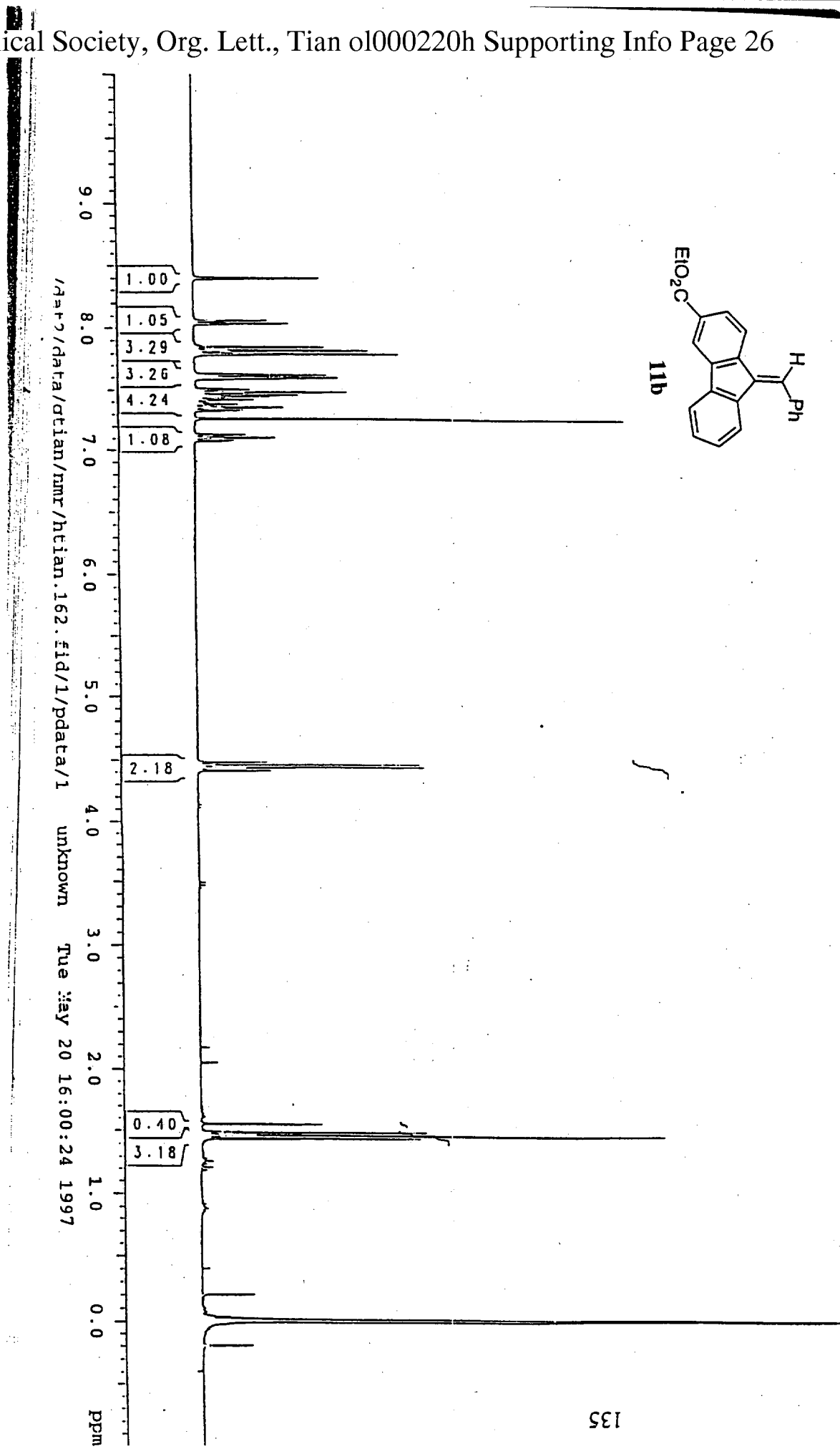


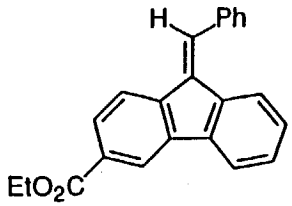

MeO
H
Ph
10b
2.01
3.97
2.89
0.86
1.18
1.00
0.92
3.07
0.12
/dat2/data/qcian/nmr/htian.933.fid/1/pdata/1 unknown Wed Jan 8 19:34:41 1997
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
ppm


MeO
H
Ph
10b
180
160
140
120
100
80
60
40
20
0
ppm
/dat2/data/qtian/nmr/ctian.941.fid/1/pdata/1 unknown Sun Jan 12 19:55:19 1997




EtO2C
Ph
H
11a
180
160
140
120
100
80
60
40
20
0
ppm
/gigb/data/qtian/nmr/ctian.240.fid/1/pdata/1 unknown Thu Aug 21 13:54:19 1997

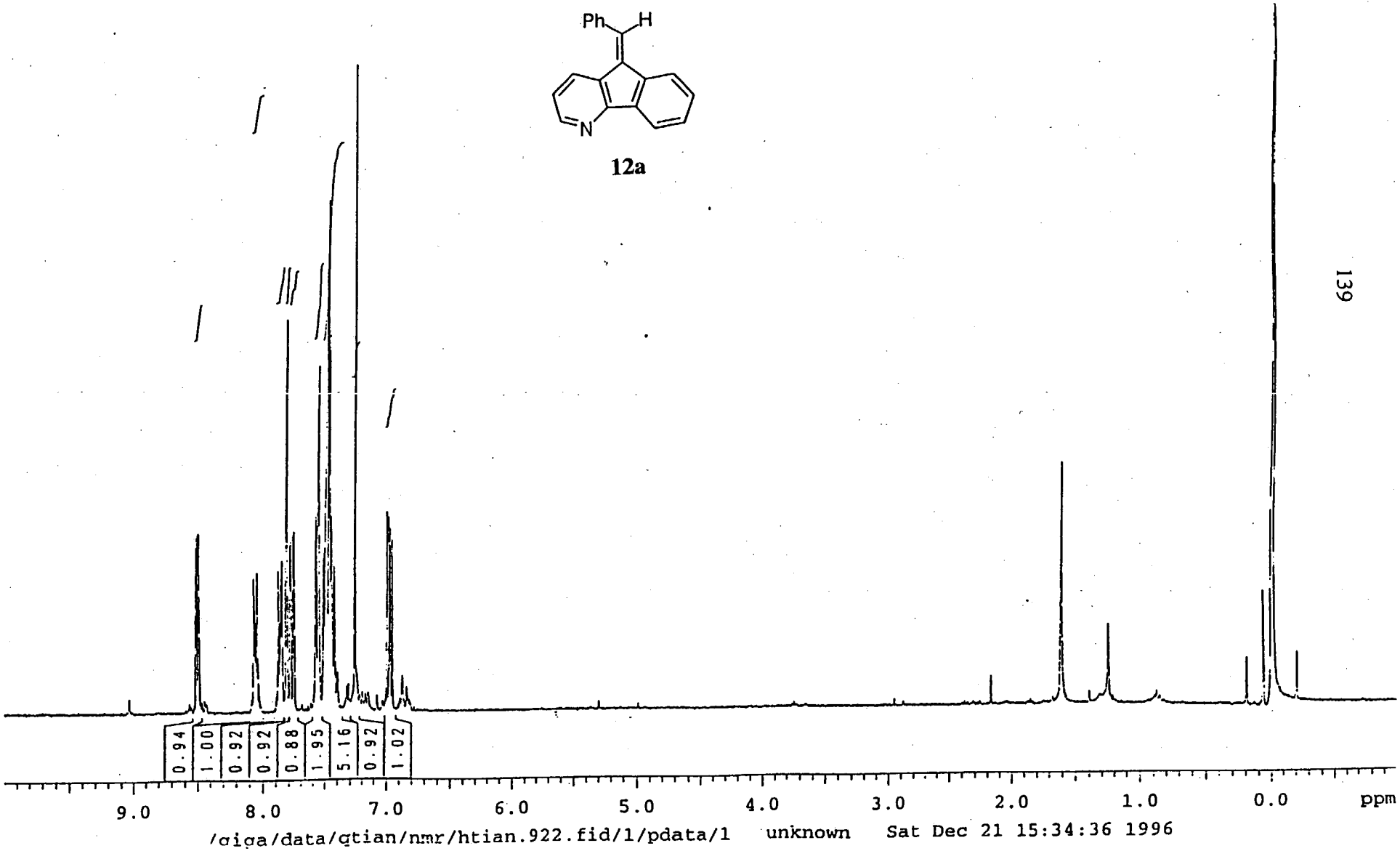


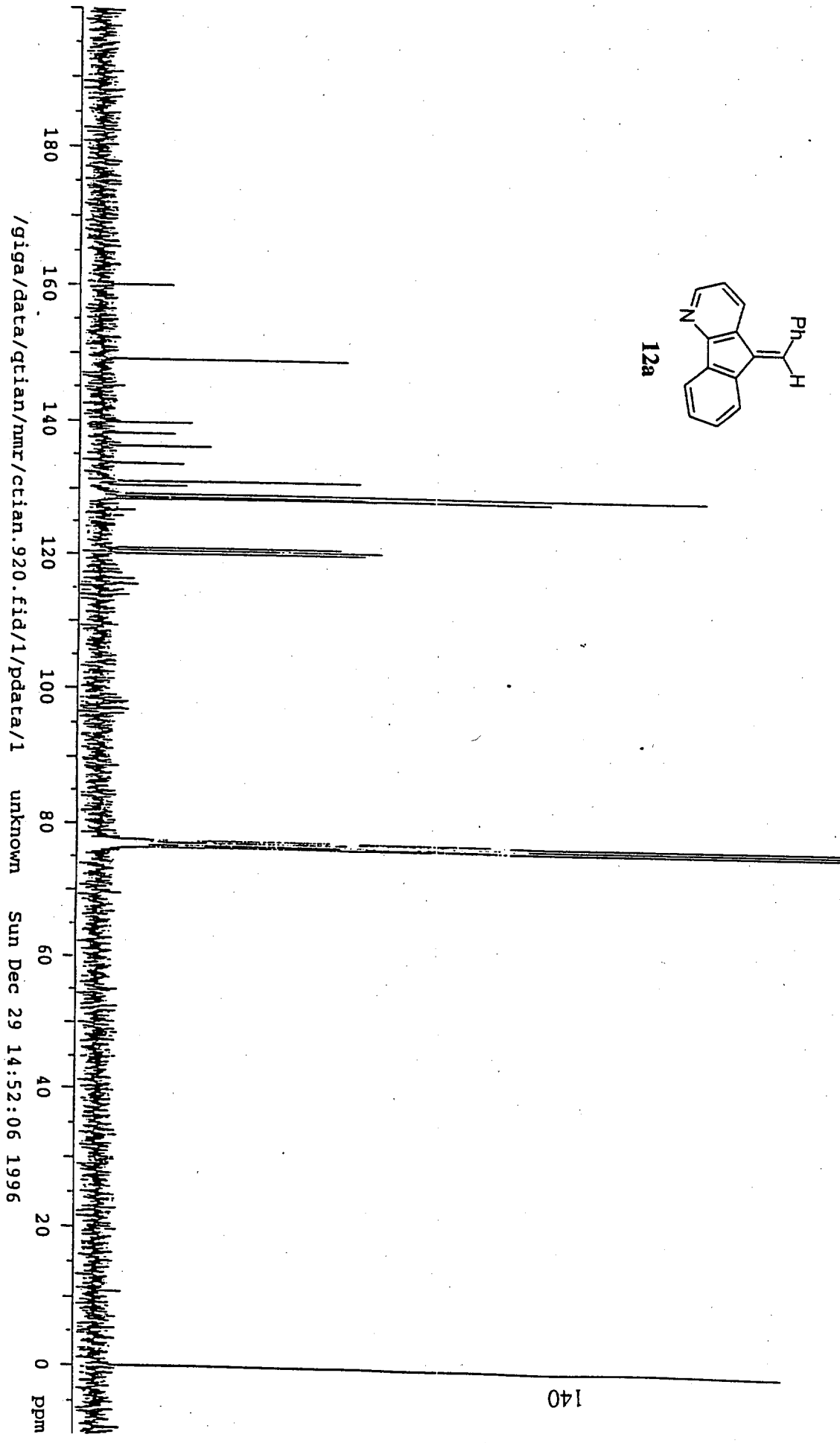


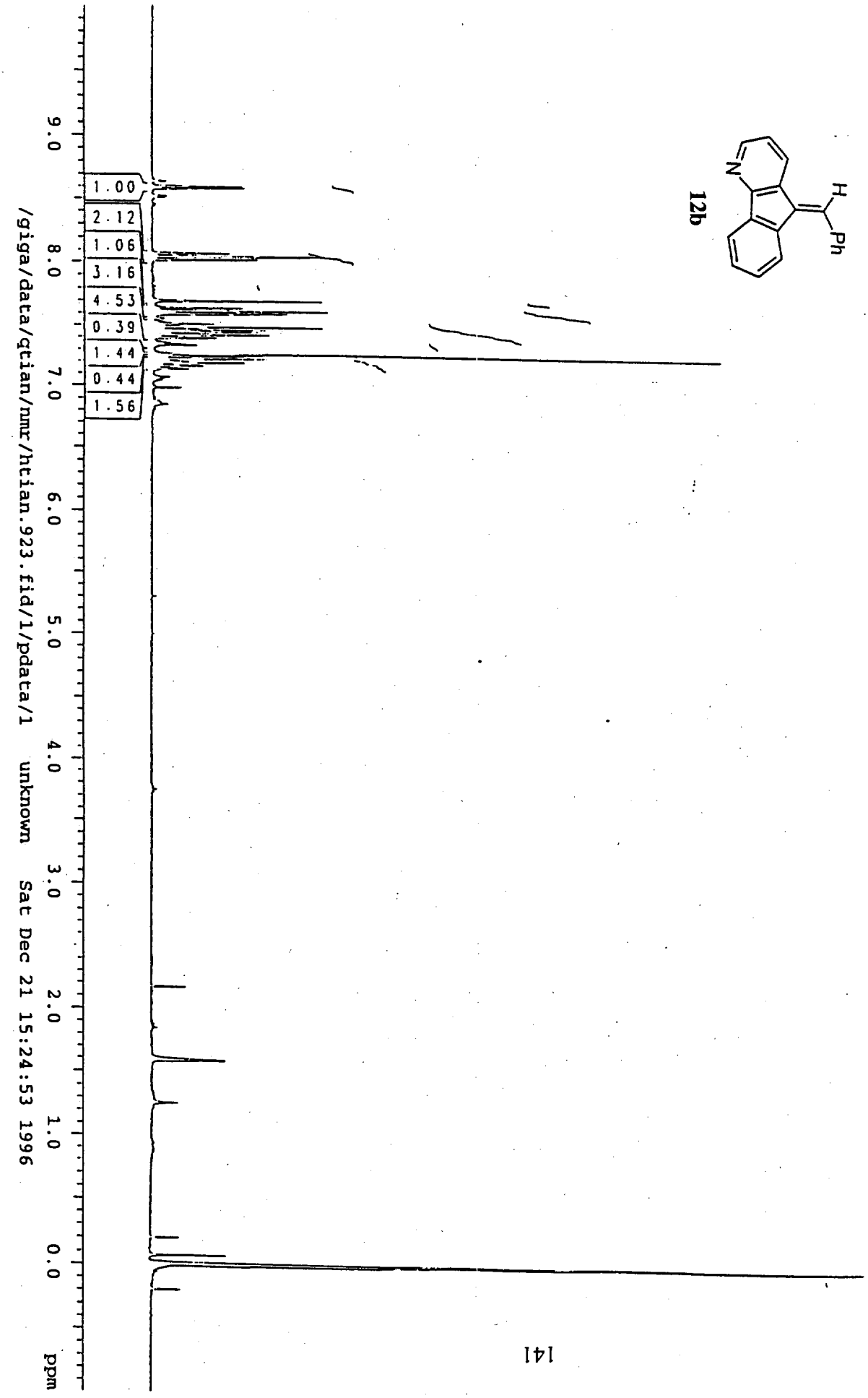
11b

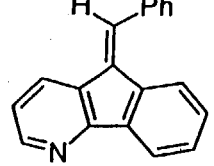
180 160 140 120 100 80 60 40 20 0 ppm

/gigb/data/qtian/nmr/ctian.245.fid/1/pdata/1 unknown Sat Aug 23 01:55:31 1997



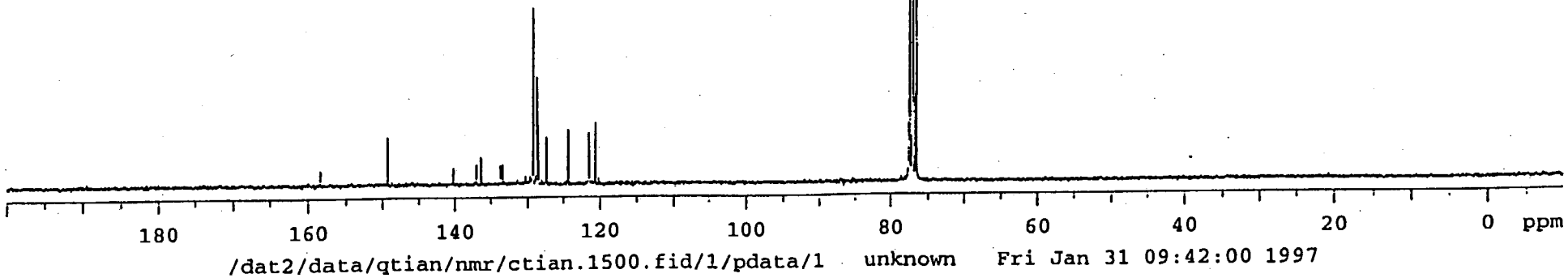




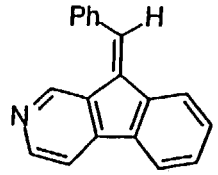


12b

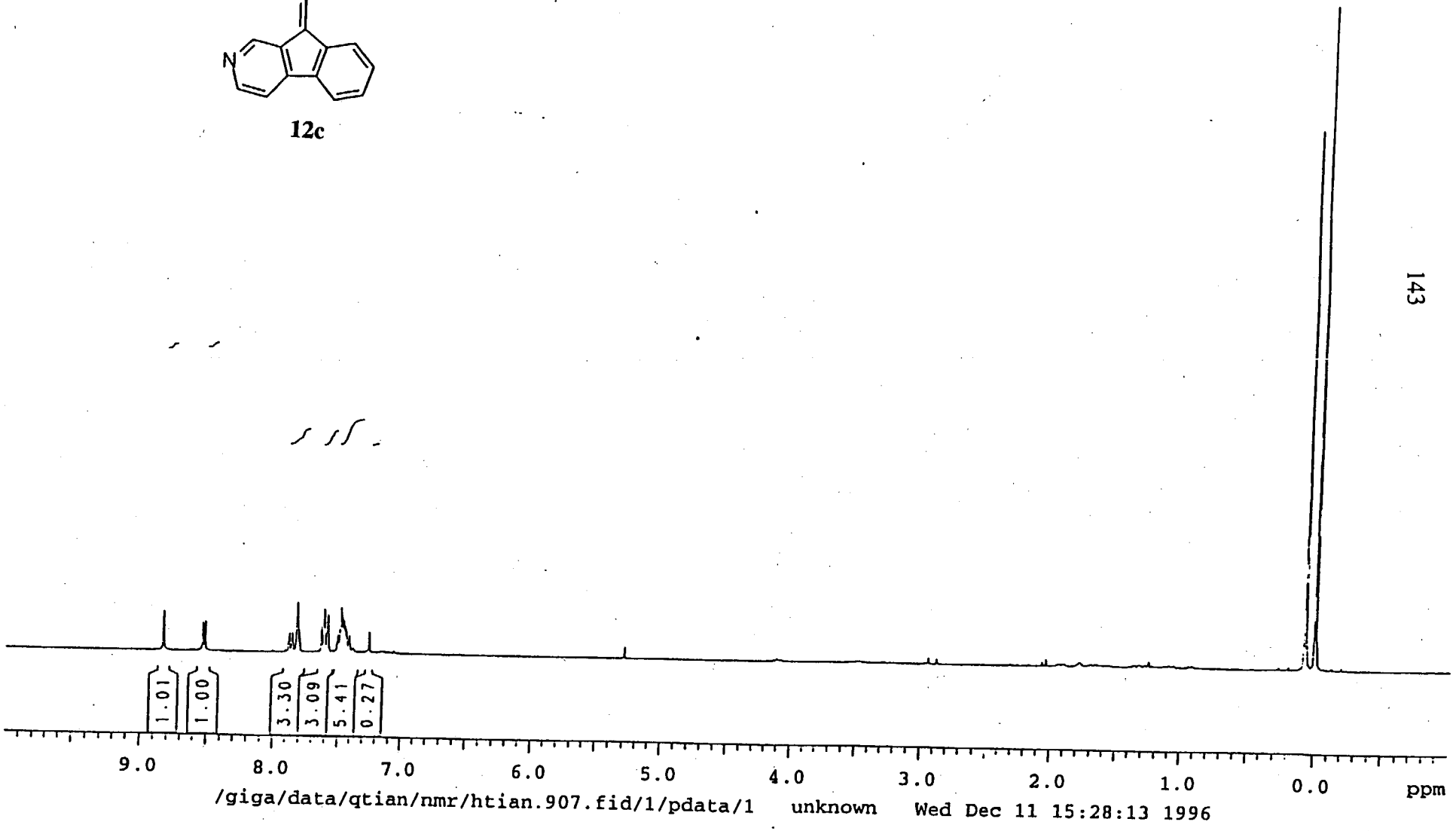
142

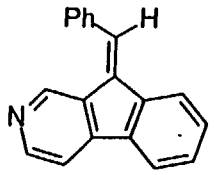


/dat2/data/qtian/nmr/ctian.1500.fid/1/pdata/1 unknown Fri Jan 31 09:42:00 1997



12c



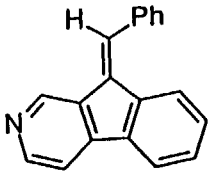


12c

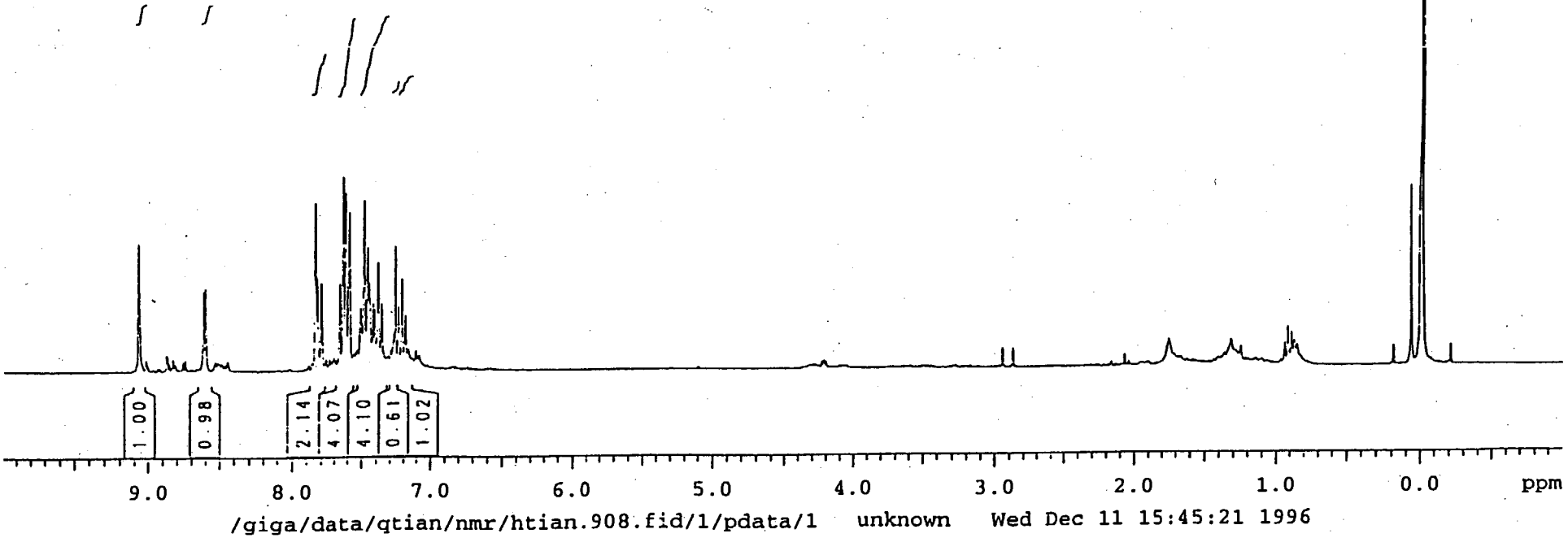
144

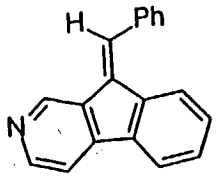
180 160 140 120 100 80 60 40 20 0 ppm

/giga/data/qtian/nmr/ctian.907.fid/1/pdata/1 unknown Thu Dec 12 08:39:32 1996



12d





12d

146

180 160 140 120 100 80 60 40 20 0 ppm

/dat2/data/qtian/nmr/ctian.975.fid/1/pdata/1 unknown Mon Jan 27 22:49:53 1997