Cu(I)-Catalyzed Regioselective Diamination of Conjugated Dienes via Dual Mechanistic Pathways

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Supporting Information

Reference 14a: Ribas, X.; Jackson, D. A.; Donnadieu, B.; Mahía, J.; Parella, T.; Xifra, R.; Hedman, B.; Hodgson, K. O.; Llobet, A.; Stack, T. D. P. *Angew. Chem., Int. Ed.* **2002**, *41*, 2991.
Reference 14b: Xifra, R.; Ribas, X.; Llobet, A.; Poater, A.; Duran, M.; Solà, M.; Stack, T. D. P.; Benet-Buchholz, J.; Donnadieu, B.; Mahía, J.; Parella, T. *Chem. Eur. J.* **2005**, *11*, 5146.

General Methods. All commercially available reagents were used without further purification. Benzene-d_6 was freshly distilled from sodium-benzophenone under argon atmosphere. Column chromatography was performed on silica gel (200-400 mesh). ^{1}H NMR spectra were recorded on a 300 MHz or 400 MHz NMR spectrometer and ^{13}C NMR spectra were recorded on a 75 MHz or 100 MHz NMR spectrometer. IR spectra were recorded on a FT-IR spectrometer.

Terminal diamination of 1b (Table 1, entry 7). To a 1.5 mL vial equipped with a stir bar were added CuCl (0.002 g, 0.020 mmol) and tri(cyclohexyl)phosphine (0.0084 g, 0.030 mmol). The sealed vial was evacuated and filled with Ar three times, followed by the addition of C_6D_6 (0.2 mL). Upon stirring at rt for 1 h, a solution of 3-methyl-1-phenylbutadiene (**1b**) (0.029 g, 0.20 mmol) in C_6D_6 (0.05 mL) was added via syringe, followed by the addition of di-*tert*-butyldiaziridinone (0.068 g, 0.40 mmol). The reaction mixture was stirred at rt for 10 h and purified by chromatography on silica gel (hexanes/ethyl acetate, 10:1) to give terminal diamination product **3b** as a colorless oil (0.062 g, 99%).

Representative internal diamination (Table 2, entry 1). To a 1.5 mL vial equipped with a stir bar was added CuBr (0.0015 g, 0.010 mmol). The sealed vial was evacuated and filled with Ar three times, followed by the addition of $CDCl_3$ (0.4 mL) and (*E*)-deca-1,3-diene (**1c**) (0.023 g, 0.19 mmol). After the mixture was cooled to 0 °C in an ice bath, di-*tert*-butyldiaziridinone (**2**) (0.0374 g, 0.22 mmol) was added. The reaction mixture was stirred at 0 °C for 20 h and purified by chromatography on silica gel (hexanes/ethyl acetate, 10:1) to give diamination product **4c** as a colorless oil (0.053 g, 97%, **4c**:**3c** = 96:4).

Large scale diamination and subsequent deprotection (Scheme 2). To a 500 mL round-bottomed flask equipped with a stir bar was added CuBr (0.994 g, 6.95 mmol). The sealed flask was evacuated and filled with Ar three times, followed by the addition of $CHCl_3$ (280 mL) and (*E*)-deca-1,3-diene (**1c**) (17.0 g, 137.1 mmol). After the mixture was cooled down to -10 ºC, di-*tert*-butyldiaziridinone (**2**) (26.0 g, 153.0 mmol) was added. The reaction mixture was stirred at -10 ºC for 30 h, concentrated, and purified by chromatography on silica gel (hexanes/ethyl acetate, 10:1) to give diamination product **4c** as colorless oil (38.2 g, 95%, **4c**:**3c** = 95:5).

Diamination product **4c** (38.2 g, 130.0 mmol) was refluxed in conc. HCl (700 mL) for 30 h. Upon removal of one third of the volume by rotary evaporation, the reaction mixture was cooled to room temperature, then washed with ether (200 mL) and hexanes (100 mL). After the aqueous solution was concentrated by rotary evaporation, an aqueous NaOH solution (4 M, 100 mL) was added. The resulting mixture was stirred at rt for 0.5 h, extracted with CH_2Cl_2 (150 mL × 4), dried over (Na_2SO_4), filtered, and concentrated to give free diamine **5** as a pale yellow oil (20.3 g, 100%).

Resolution of racemic diamine (±)-5 (Scheme 2). To a stirred solution of racemic diamine (±)-**5** (19.5 g, 125.0 mmol) in methanol (50 mL) immersed in a 60 ºC oil bath was added a hot homogenous solution of L-(+)-tartaric acid (14.1 g, 94.0 mmol) in methanol (50 mL) over 10 min, followed by the addition of glacial acetic acid (3.75 g, 62.5 mmol). At this point, a large amount of solid precipitated. The suspension was cooled to rt with vigorous stirring over 1 h, heated to reflux for 3 min using a heat gun, and cooled again to rt without stirring. After 2 h at rt, the mixture was filtered to give a white solid. The solid was washed with cold methanol (100 mL), dried under reduced pressure, and dissolved in hot water (25 mL). To the hot homogenous solution was added hot methanol (50 mL). A white solid precipitated immediately. The mixture stayed at rt for 12 h. The solid was collected by filtration, washed with cold

methanol (100 mL), and dried under reduced pressure to give the L-(+)-tartaric acid salt (14.8 g). The salt was treated with NaOH solution (4 M, 50 mL, 200.0 mmol) and the resulting mixture was extracted with CH_2Cl_2 (50 mL × 4). The combined organic layer was dried over Na_2SO_4, filtered, and concentrated to give diamine (*R*,*R*)-**5** as a colorless oil (7.4 g, 76%, > 99% ee). $[\alpha]_D^{25} = 42.0$ ($CHCl_3$, *c* 1.0).

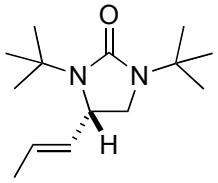
All the filtrates were combined and concentrated by rotary evaporation. The resulting residue was treated with NaOH solution (4 M, 100 mL, 400.0 mmol) and the resulting mixture was extracted with CH_2Cl_2 (100 mL × 4). The combined organic layer was dried over Na_2SO_4, filtered, and concentrated to give enriched diamine (*S*,*S*)-**5** as a pale yellow oil, which was then dissolved in methanol (50 mL). To the stirred solution immersed in a 60 ºC oil bath was added a hot homogenous solution of D-(-)-tartaric acid (10.5 g, 70.0 mmol) in methanol (50 mL) over 10 min, followed by the addition of glacial acetic acid (0.9 g, 15.0 mmol). At this point, a large amount of solid precipitated. The suspension was cooled to rt with vigorous stirring over 1 h, heated to reflux for 3 min using a heat gun, and cooled again to rt without stirring. After 2 h at rt, the mixture was filtered to give a white solid. The solid was washed with cold methanol (100 mL), dried under reduced pressure, and dissolved in hot water (25 mL). To the hot homogenous solution was added hot methanol (50 mL). A white solid precipitated immediately. The mixture stayed at rt for 12 h. The solid was collected by filtration, washed with cold methanol (100 mL), and dried under reduced pressure to give the D-(-)-tartaric acid salt (14.0 g). The salt was treated with NaOH solution (4 M, 50 mL, 200.0 mmol) and the resulting mixture was extracted with CH_2Cl_2 (50 mL × 4). The combined organic layer was dried over Na_2SO_4, filtered, and concentrated to give diamine (*S*,*S*)-**5** as a colorless oil (7.1 g, 73%, > 99% ee). $[\alpha]_D^{25} = -40.8$ ($CHCl_3$, *c* 1.0).

(a) Pikul, S.; Corey, E. J. *Org. Synth.* **1993**, *71*, 22. (b) Larrow, J. F.; Jacobsen, E. N. *Org. Synth.* **1998**, *75*, 1.

The enantiomeric purity of the diamine was determined by chiral HPLC (chiralpak AD-column) after the derivatization to di-*m*-toluoyl amide by the following procedure: To a 5

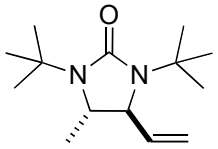
mL vial charged with diamine **5** (0.016 g, 0.1 mmol) or the tartaric acid salt (0.031 g, 0.1 mmol) were added NaOH solution (1.0 M, 1.2 mL, 1.2 mmol) and CH_2Cl_2 (2.4 mL). Upon stirring for 2 min, *m*-toluoyl chloride (0.034 g, 0.22 mmol) was added via syringe and the resulting mixture was stirred at rt for 5 min. A portion (60 uL) of the organic layer was diluted with 2-propanol (2 mL) and submitted to HPLC analysis.

Table 1, entry 4



3a, Colorless oil; IR (film) 1692 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$) δ 5.69-5.50 (m, 2H), 3.94 (ddd, *J* = 8.1, 7.8, 2.1 Hz, 1H), 3.32 (t, *J* = 8.1 Hz, 1H), 2.89 (dd, *J* = 8.1, 2.1 Hz, 1H), 1.69 (d, *J* = 5.1 Hz, 3H), 1.34 (s, 9H), 1.30 (s, 9H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 160.8, 133.5, 126.7, 55.2, 53.8, 53.0, 48.5, 29.0, 27.6, 17.9; Anal. Calcd for $C_{14}H_{26}N_2O$: C, 70.54; H, 10.99; N, 11.75. Found: C, 70.73; H, 10.84; N, 11.94.

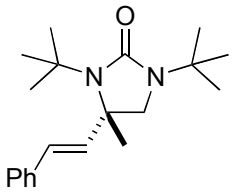
Table 1, entry 6



4a, Colorless oil; IR (film) 1688 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$) δ 5.91 (ddd, *J* = 17.1, 10.2, 8.4 Hz, 1H), 5.18 (d, *J* = 17.1 Hz, 1H), 5.08 (d, *J* = 10.2 Hz, 1H), 3.50 (d, *J* = 8.4 Hz, 1H), 3.26 (q, *J* = 6.0, 1H), 1.35 (s, 9H), 1.34 (s, 9H), 1.20 (d, *J* = 6.0 Hz, 3H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 158.0, 140.2, 115.6, 63.7, 55.4, 53.1, 52.6, 29.2, 29.0, 21.3.

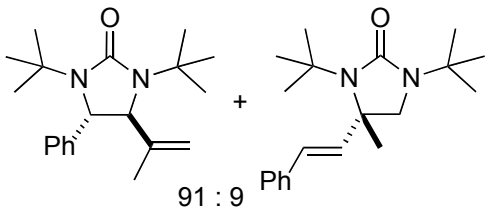
Du, H.; Zhao, B.; Shi, Y. *J. Am. Chem. Soc.* **2007**, *129*, 762.

Table 1, entry 7



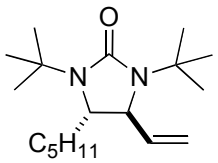
3b, Colorless oil; IR (film) 1690 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$) δ 7.41-7.22 (m, 5H), 6.39 (s, 2H), 3.04 (d, *J* = 8.1 Hz, 1H), 2.91 (d, *J* = 8.1 Hz, 1H), 1.64 (s, 3H), 1.41 (s, 9H), 1.32 (s, 9H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 160.7, 137.0, 136.9, 128.9, 127.9, 127.5, 126.5, 60.2, 55.9, 55.7, 53.0, 30.1, 27.6, 23.6; Anal. Calcd for $C_{20}H_{30}N_2O$: C, 76.39; H, 9.62; N, 8.91. Found: C, 75.98; H, 9.46; N, 8.56.

Table 1, entry 8



4b, Colorless oil; IR (film) 1687 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$) δ 7.39-7.23 (m, 5H), 4.89 (s, 1H), 4.86-4.81 (m, 1H), 4.11 (d, *J* = 2.1 Hz, 1H), 3.61 (d, *J* = 2.1 Hz, 1H), 1.83 (s, 3H), 1.34 (s, 9H), 1.26 (s, 9H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 159.6, 147.6, 145.4, 129.1, 127.8, 125.6, 112.1, 66.9, 62.8, 53.8, 29.0, 28.7, 18.0; Anal. Calcd for $C_{20}H_{30}N_2O$: C, 76.39; H, 9.62; N, 8.91. Found: C, 76.46; H, 9.54; N, 8.67.

Table 2, entry 1

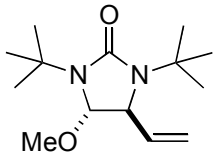


4c, Colorless oil; IR (film) 1689 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$) δ 5.91 (ddd, *J* = 16.8, 10.2, 8.4 Hz, 1H), 5.17 (d, *J* = 16.8 Hz, 1H), 5.07 (d, *J* = 10.2 Hz, 1H), 3.65 (d, *J* = 8.4 Hz, 1H),

3.09 (dd, J = 8.4, 3.3 Hz, 1H), 1.58-1.48 (m, 2H), 1.44-1.21 (m, 6H), 1.35 (s, 9H), 1.34 (s, 9H), 0.89 (t, J = 6.9 Hz, 3H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 158.4, 140.8, 115.2, 60.7, 59.8, 53.1, 52.7, 34.4, 32.0, 29.2, 29.0, 24.6, 22.9, 14.2.

Du, H.; Zhao, B.; Shi, Y. *J. Am. Chem. Soc.* **2007**, *129*, 762.

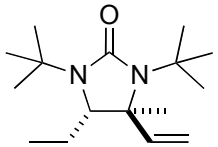
Table 2, entry 2



4d, Colorless oil; IR (film) 1701 cm^{-1}; ^{1}H NMR (300 MHz, C_6D_6) δ 5.58 (ddd, J = 17.4, 10.5, 8.1 Hz, 1H), 5.03 (d, J = 17.4 Hz, 1H), 4.88 (d, J = 10.5 Hz, 1H), 4.28 (s, 1H), 3.74 (d, J = 8.1 Hz, 1H), 2.92 (s, 3H), 1.49 (s, 9H), 1.41 (s, 9H); ^{13}C NMR (75 MHz, C_6D_6) δ 158.2, 139.7, 116.6, 90.5, 60.5, 53.9, 53.2, 51.1, 29.1, 28.9.

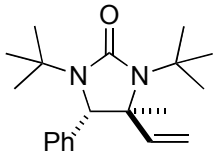
Du, H.; Zhao, B.; Shi, Y. *J. Am. Chem. Soc.* **2007**, *129*, 762.

Table 2, entry 3



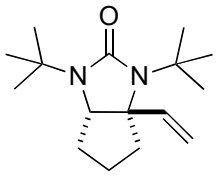
4e, Colorless oil; IR (film) 1686 cm^{-1}; ^{1}H NMR (300 MHz, $CDCl_3$) δ 6.12 (dd, J = 17.4, 10.5 Hz, 1H), 5.12 (d, J = 17.4 Hz, 1H), 5.02 (d, J = 10.5 Hz, 1H), 3.03 (t, J = 3.6 Hz, 1H), 1.72-1.60 (m, 2H), 1.51 (s, 3H), 1.38 (s, 9H), 1.36 (s, 9H), 1.00 (t, J = 7.5 Hz, 3H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 160.1, 144.6, 112.3, 64.2, 63.8, 56.4, 52.7, 30.2, 28.9, 24.8, 20.1, 9.4; HRMS Calcd for $C_{16}H_{31}N_2O$ ($M + H^+$): 267.2431. Found: 267.2432.

Table 2, entry 4



4f, Colorless oil; IR (film) 1687 cm^{-1}; ^{1}H NMR (300 MHz, $CDCl_3$) δ 7.49 (d, *J* = 7.8 Hz, 1H), 7.36-7.20 (m, 3H), 7.02-6.97 (m, 1H), 6.24 (dd, *J* = 17.4, 10.8 Hz, 1H), 5.13 (d, *J* = 10.8 Hz, 1H), 5.09 (d, *J* = 17.4 Hz, 1H), 4.04 (s, 1H), 1.42 (s, 9H), 1.23 (s, 9H), 0.97 (s, 3H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 160.8, 144.9, 140.7, 129.2, 128.4, 128.1, 128.0, 113.0, 69.0, 64.8, 56.3, 54.2, 30.0, 28.8, 23.0; Anal. Calcd for $C_{20}H_{30}N_2O$: C, 76.39; H, 9.62; N, 8.91. Found: C, 76.48; H, 9.51; N, 8.75.

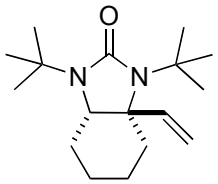
Table 2, entry 5



4g, Colorless oil; IR (film) 1681 cm^{-1}; ^{1}H NMR (300 MHz, $CDCl_3$) δ 6.01 (dd, *J* = 17.7, 10.5 Hz, 1H), 5.13 (d, *J* = 17.7 Hz, 1H), 5.04 (d, *J* = 10.5 Hz, 1H), 3.37 (dd, *J* = 7.2, 6.6 Hz, 1H), 2.31-2.21 (m, 1H), 2.13-2.02 (m, 1H), 1.96-1.85 (m, 1H), 1.81-170 (m, 1H), 1.62-1.30 (m, 2H), 1.41 (s, 9H), 1.35 (s, 9H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 159.0, 145.6, 112.0, 69.6, 67.1, 54.9, 53.3, 39.4, 37.6, 29.8, 29.0, 24.4.

Du, H.; Zhao, B.; Shi, Y. *J. Am. Chem. Soc.* **2007**, *129*, 762.

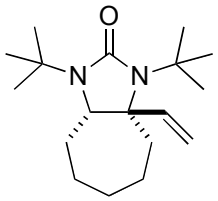
Table 2, entry 6



4h, Colorless oil; IR (film) 1686 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$) δ 6.16 (dd, *J* = 17.4, 11.1 Hz, 1H), 5.15 (d, *J* = 17.4 Hz, 1H), 5.08 (d, *J* = 11.1 Hz, 1H), 3.05 (dd, *J* = 9.3, 4.8 Hz, 1H), 2.31-2.21 (m, 1H), 1.83-1.20 (m, 7H), 1.39 (s, 9H), 1.36 (s, 9H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 160.1, 143.2, 113.1, 64.3, 60.1, 56.4, 52.6, 30.5, 29.8, 29.0, 28.9, 21.3, 19.9.

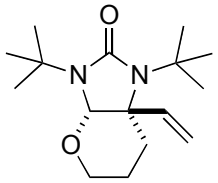
Du, H.; Zhao, B.; Shi, Y. *J. Am. Chem. Soc.* **2007**, *129*, 762.

Table 2, entry 7



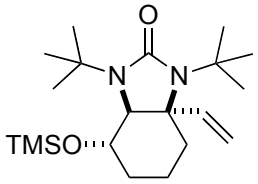
4i, Colorless oil; IR (film) 1686 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$) δ 6.03 (dd, *J* = 17.7, 10.5 Hz, 1H), 5.10 (d, *J* = 17.7 Hz, 1H), 5.08 (d, *J* = 10.5 Hz, 1H), 3.17 (d, *J* = 8.7 Hz, 1H), 2.48-2.39 (m, 1H), 1.98-1.85 (m, 1H), 1.80-1.13 (m, 8H), 1.36 (s, 9H), 1.35 (s, 9H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 159.8, 142.4, 112.7, 68.6, 64.9, 56.5, 52.9, 34.3, 30.7, 30.2, 29.1, 26.5, 24.4; Anal. Calcd for $C_{18}H_{32}N_2O$: C, 73.92; H, 11.03; N, 9.58. Found: C, 73.76; H, 10.93; N, 9.37.

Table 2, entry 8



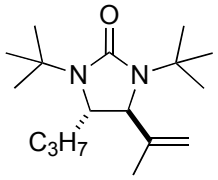
4j, Colorless oil; IR (film) 1694 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$) δ 5.94 (dd, *J* = 18.0, 10.8 Hz, 1H), 5.23 (d, *J* = 18.0 Hz, 1H), 5.19 (d, *J* = 10.8 Hz, 1H), 4.55 (s, 1H), 3.75-3.56 (m, 2H), 2.16-1.60 (m, 4H), 1.41 (s, 9H), 1.40 (s, 9H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 159.9, 141.9, 114.9, 88.0, 62.7, 57.4, 56.0, 53.0, 29.4, 28.5, 25.1, 19.7; HRMS Calcd for $C_{16}H_{29}N_2O_2$ (M + H^+): 281.2224. Found: 281.2229.

Table 2, entry 9



4k, Colorless oil; IR (film) 1688 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$) δ 6.06 (dd, *J* = 17.7, 10.8 Hz, 1H), 5.11 (d, *J* = 17.7 Hz, 1H), 5.05 (d, *J* = 10.8 Hz, 1H), 3.78-3.73 (m, 1H), 3.00 (d, *J* = 2.7 Hz, 1H), 2.15-2.06 (m, 1H), 2.00-1.75 (m, 2H), 1.72-1.22 (m, 3H), 1.37 (s, 18H), 0.08 (s, 9H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 160.1, 144.2, 112.9, 72.8, 66.2, 64.4, 56.3, 53.1, 29.4, 29.1, 26.2, 25.9, 16.6, 0.75; Anal. Calcd for $C_{20}H_{38}N_2O_2Si$: C, 65.52; H, 10.45; N, 7.64. Found: C, 65.59; H, 10.24; N, 7.41.

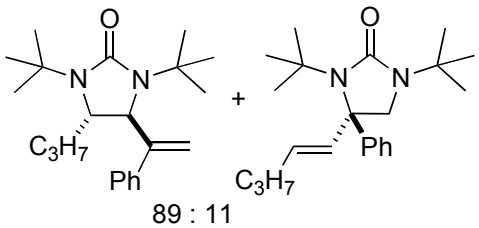
Table 2, entry 10



4l, Colorless oil; IR (film) 1687 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$) δ 4.92-4.88 (m, 1H), 4.81-4.78 (m, 1H), 3.61 (s, 1H), 3.10 (dd, *J* = 6.9, 3.0 Hz, 1H), 1.73 (s, 3H), 1.56-1.28 (m, 4H), 1.36 (s, 9H), 1.35 (s, 9H), 0.95 (t, *J* = 7.2 Hz, 3H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 158.7, 147.5, 111.7, 62.6, 58.9, 53.4, 52.6, 38.2, 29.2, 28.9, 18.2, 17.8, 14.4.

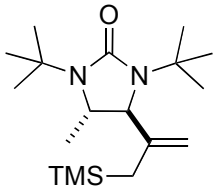
Du, H.; Zhao, B.; Shi, Y. *J. Am. Chem. Soc.* **2007**, *129*, 762.

Table 2, entry 11



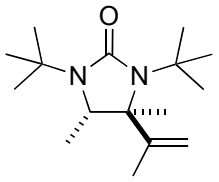
4m, Colorless oil; IR (film) 1686 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$) δ 7.51-7.29 (m, 5H), 5.32 (s, 2H), 4.14 (s, 1H), 3.08 (t, *J* = 5.4 Hz, 1H), 1.52-0.94 (m, 4H), 1.44 (s, 9H), 1.31 (s, 9H), 0.74 (t, *J* = 7.2 Hz, 3H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 158.9, 149.9, 140.0, 128.7, 128.0, 127.2, 113.5, 60.1, 59.1, 53.5, 52.5, 38.1, 29.1, 17.7, 14.1; HRMS Calcd for $C_{22}H_{35}N_2O$ ($M + H^+$): 343.2744. Found: 343.2751.

Table 2, entry 12



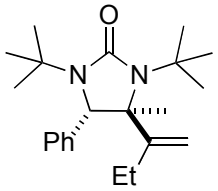
4n, Colorless oil; IR (film) 1687 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$) δ 4.97 (d, *J* = 1.2 Hz, 1H), 4.71 (d, *J* = 1.2 Hz, 1H), 3.32 (s, 1H), 3.25 (q, *J* = 6.0 Hz, 1H), 1.55 (d, *J* = 15.0 Hz, 1H), 1.35 (s, 9H), 1.32 (s, 9H), 1.30 (d, *J* = 15.0 Hz, 1H), 1.21 (d, *J* = 6.0 Hz, 3H), 0.05 (s, 9H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 158.8, 147.0, 109.0, 65.7, 54.6, 53.1, 52.4, 29.15, 29.07, 24.0, 22.5, -0.62; HRMS Calcd for $C_{18}H_{37}N_2OSi$ ($M + H^+$): 325.2670. Found: 325.2674.

Table 2, entry 13



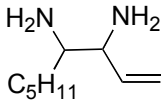
4o, Colorless oil; IR (film) 1685 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$) δ 4.95 (s, 1H), 4.89 (s, 1H), 3.25 (q, *J* = 6.0 Hz, 1H), 1.82 (s, 3H), 1.43 (s, 9H), 1.36 (s, 9H), 1.11 (t, *J* = 6.0 Hz, 3H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 160.6, 148.9, 112.7, 66.5, 57.4, 55.8, 54.0, 29.8, 29.0, 20.9, 20.0, 17.8; Anal. Calcd for $C_{16}H_{30}N_2O$: C, 72.13; H, 11.35; N, 10.51. Found: C, 72.32; H, 11.19; N, 10.44.

Table 2, entry 14



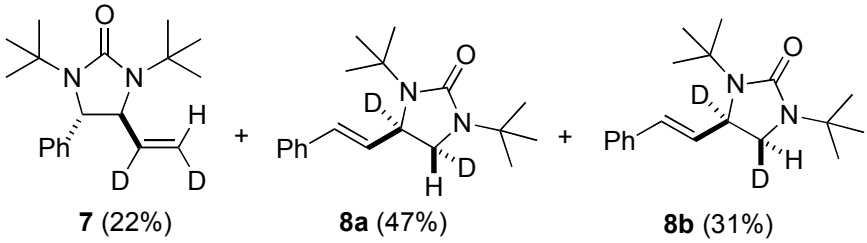
4p, Colorless oil; IR (film) 1687 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$) δ 7.52 (d, *J* = 7.5 Hz, 1H), 7.36-7.18 (m, 3H), 6.89 (dt, *J* = 6.6, 1.8 Hz, 1H), 4.96 (s, 1H), 4.87 (s, 1H), 4.22 (s, 1H), 2.26 (q, *J* = 6.9 Hz, 2H), 1.42 (s, 9H), 1.22 (s, 9H), 1.20 (t, *J* = 6.9 Hz, 3H), 0.96 (s, 3H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 161.7, 154.9, 141.4, 128.3, 128.2, 128.0, 127.9, 127.7, 110.1, 67.1, 66.9, 56.0, 55.3, 29.6, 28.9, 24.4, 23.8, 12.9; Anal. Calcd for $C_{22}H_{34}N_2O$: C, 77.14; H, 10.01; N, 8.18. Found: C, 77.51; H, 9.75; N, 8.15.

Scheme 2



(±)-5, Colorless oil; IR (film) 3281, 3077, 1580, 1466 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$) δ 5.82 (ddd, *J* = 17.4, 10.5, 6.6 Hz, 1H), 5.18 (ddd, *J* = 17.4, 1.5, 1.2 Hz, 1H), 5.12 (ddd, *J* = 10.5, 1.5, 0.9 Hz, 1H), 3.20-3.13 (m, 1H), 2.64-2.56 (m, 1H), 1.60-1.09 (m, 12H), 0.88 (t, *J* = 6.6 Hz, 3H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 141.4, 115.0, 59.0, 55.5, 34.4, 32.1, 26.3, 22.7, 14.2; Anal. Calcd for $C_9H_{20}N_2$: C, 69.17; H, 12.90; N, 17.93. Found: C, 69.48; H, 12.96; N, 17.84.

Scheme 3, compounds 7, 8a, and 8b

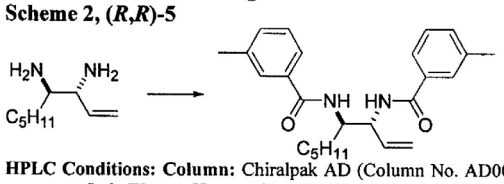


7 (22%) **8a** (47%) **8b** (31%)

Colorless oil; IR (film) 1688 cm^{-1}; ^{1}H NMR (300 MHz, $CDCl_3$) **7**: δ 7.40-7.24 (m, 5H), 5.18 (s, 1H), 4.16 (s, 1H), 3.65 (s, 1H), 1.33 (s, 9 H), 1.28 (s, 9H); **8a**: δ 7.40-7.24 (m, 5H), 6.50 (d, *J* = 15.9 Hz, 1H), 6.36 (d, *J* = 15.9 Hz, 1H), 2.99 (s, 1H), 1.38 (s, 9H), 1.33 (s, 9H); **8b**: δ 7.40-7.24 (m, 5H), 6.50 (d, *J* = 15.9 Hz, 1H), 6.36 (d, *J* = 15.9 Hz, 1H), 3.41 (s, 1H), 1.38 (s, 9H), 1.33 (s, 9H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 160.8, 159.2, 144.2, 140.8, 140.6, 140.4, 136.8, 131.8, 131.7, 130.9, 129.0, 128.9, 128.1, 127.9, 126.6, 125.9, 115.7, 115.4, 115.2, 64.9, 63.4, 55.3, 55.1, 54.8, 54.0, 53.7, 53.5, 53.2, 48.2, 48.0, 47.8, 29.1, 28.9, 27.7; HRMS Calcd for $C_{19}H_{27}D_2N_2O$ ($M + H^+$): 303.2400. Found: 303.2404.

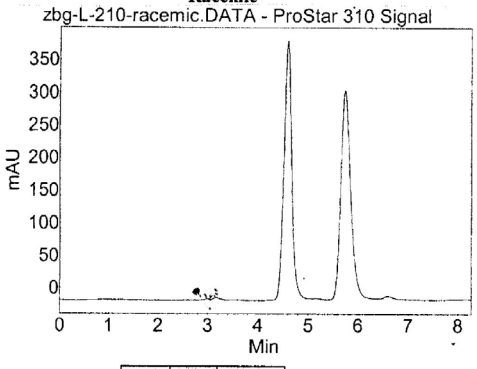
The chromatograms for the determination of enantioselectivity

Scheme 2, (*R*,*R*)-5



HPLC Conditions: Column: Chiralpak AD (Column No. AD00CE-EA001), Daicel Chemical Industries, Ltd.. **Eluent**: Hexanes/IPA (90/10); **Flow rate:** 1.0 mL/min; **Detection:** UV210 nm

Racemic



Index	Time [Min]	Area % [%]
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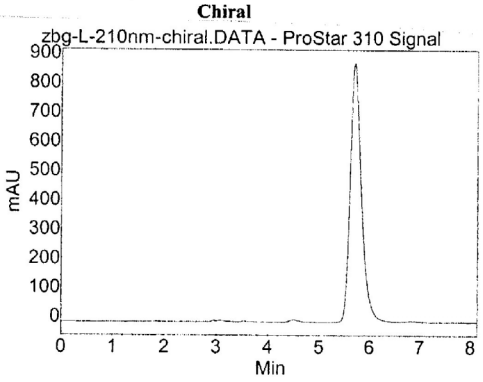
2	5.74	50.443
Total		100.000

Chiral



Index	Time [Min]	Area % [%]
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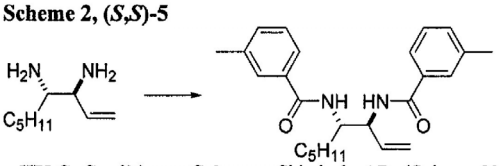
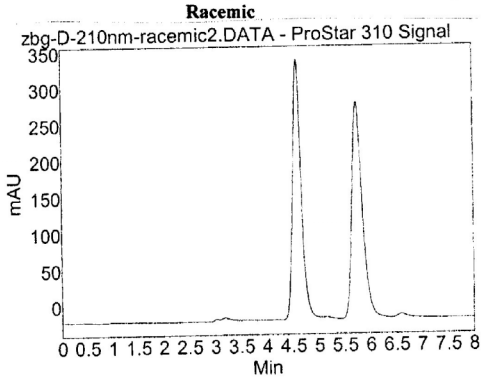
2	5.70	99.580
Total		100.000

Scheme 2, (*S*,*S*)-5



HPLC Conditions: Column: Chiralpak AD (Column No. AD00CE-EA001), Daicel Chemical Industries, Ltd.. **Eluent**: Hexanes/IPA (90/10); **Flow rate:** 1.0 mL/min; **Detection:** UV210 nm

Racemic



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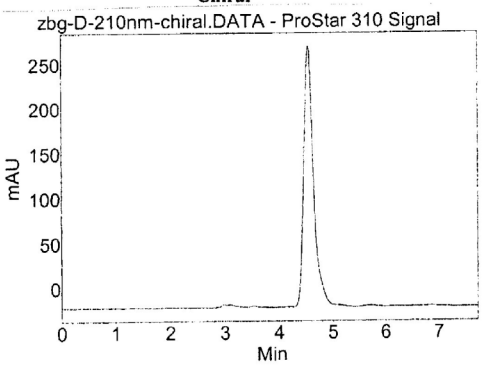
Chiral



Index	Time [Min]	Area % [%]
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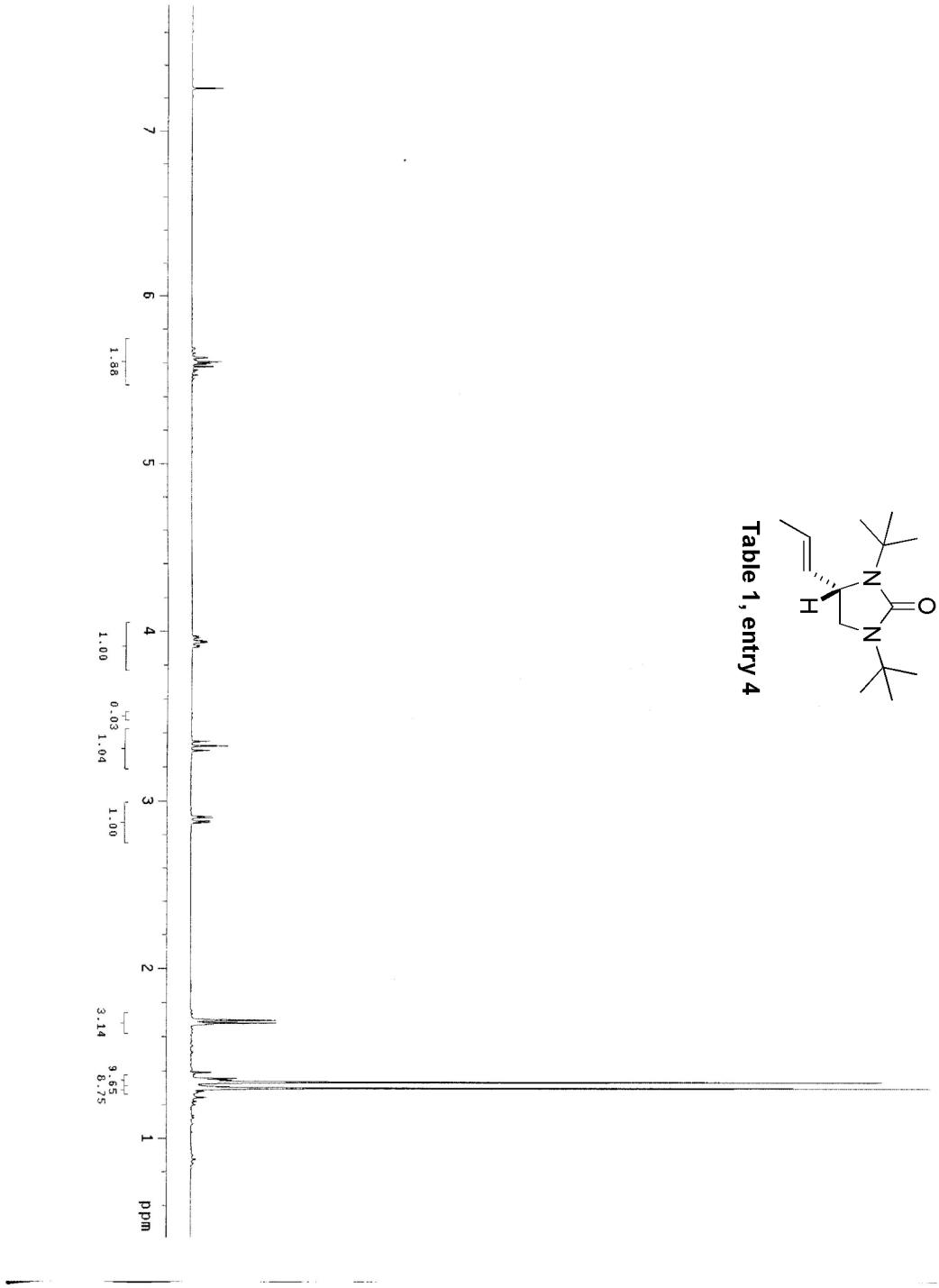
Table 1, entry 4
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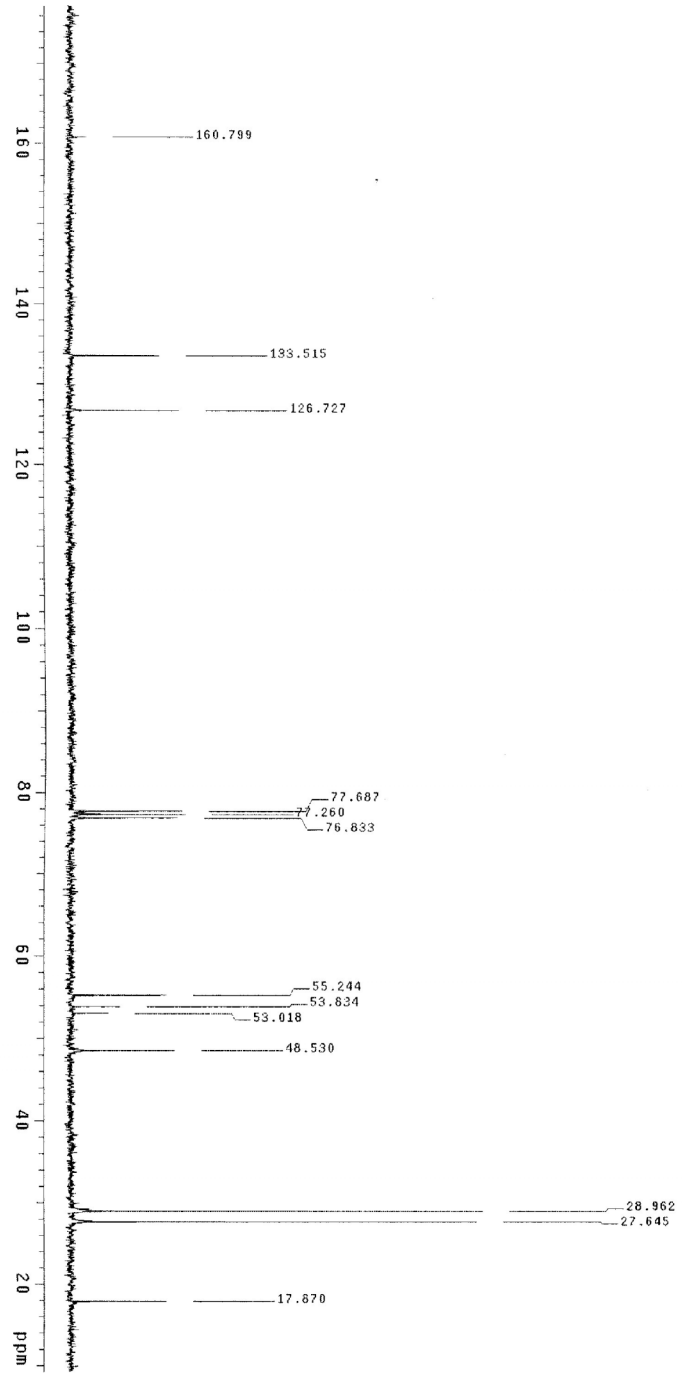

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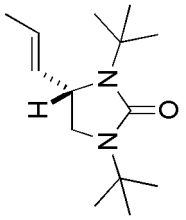


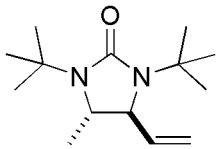
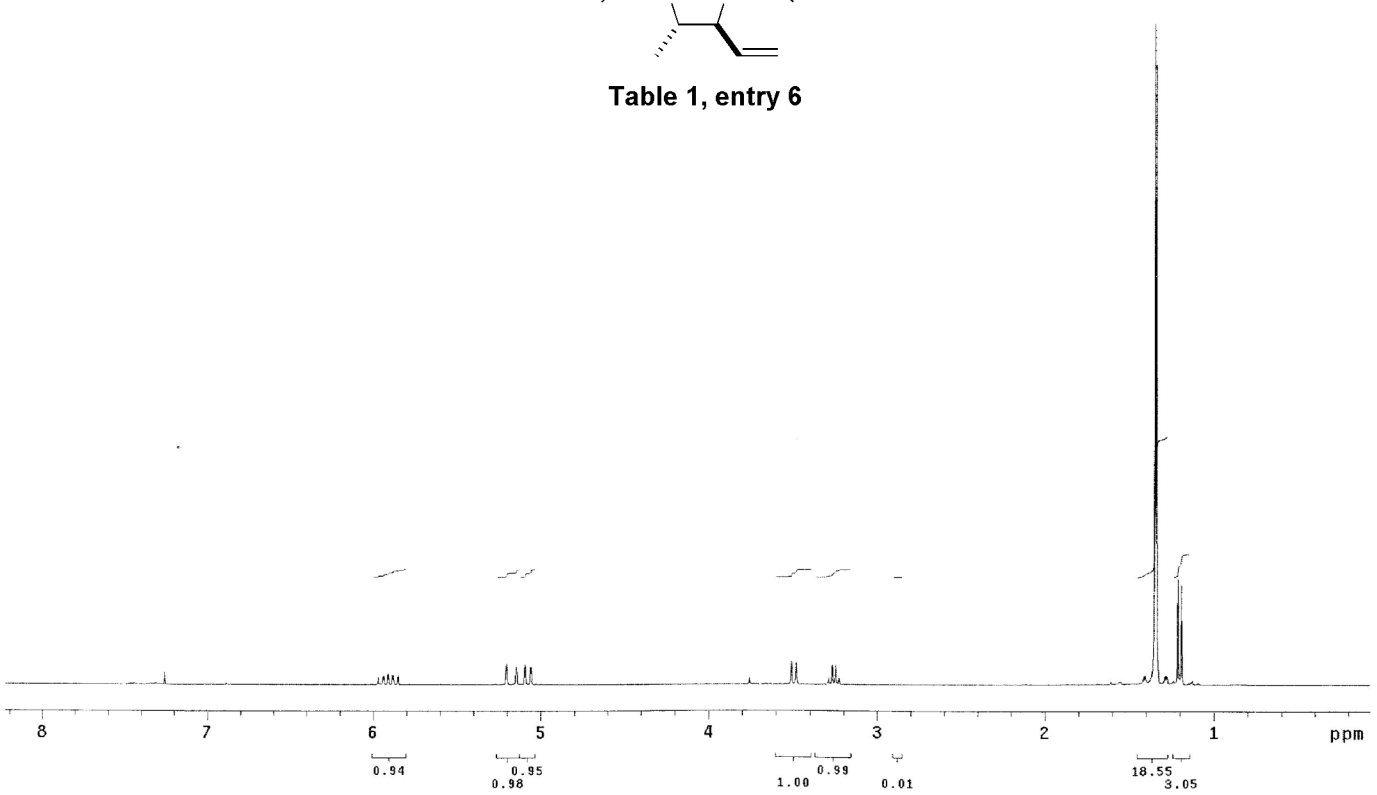


Table 1, entry 6



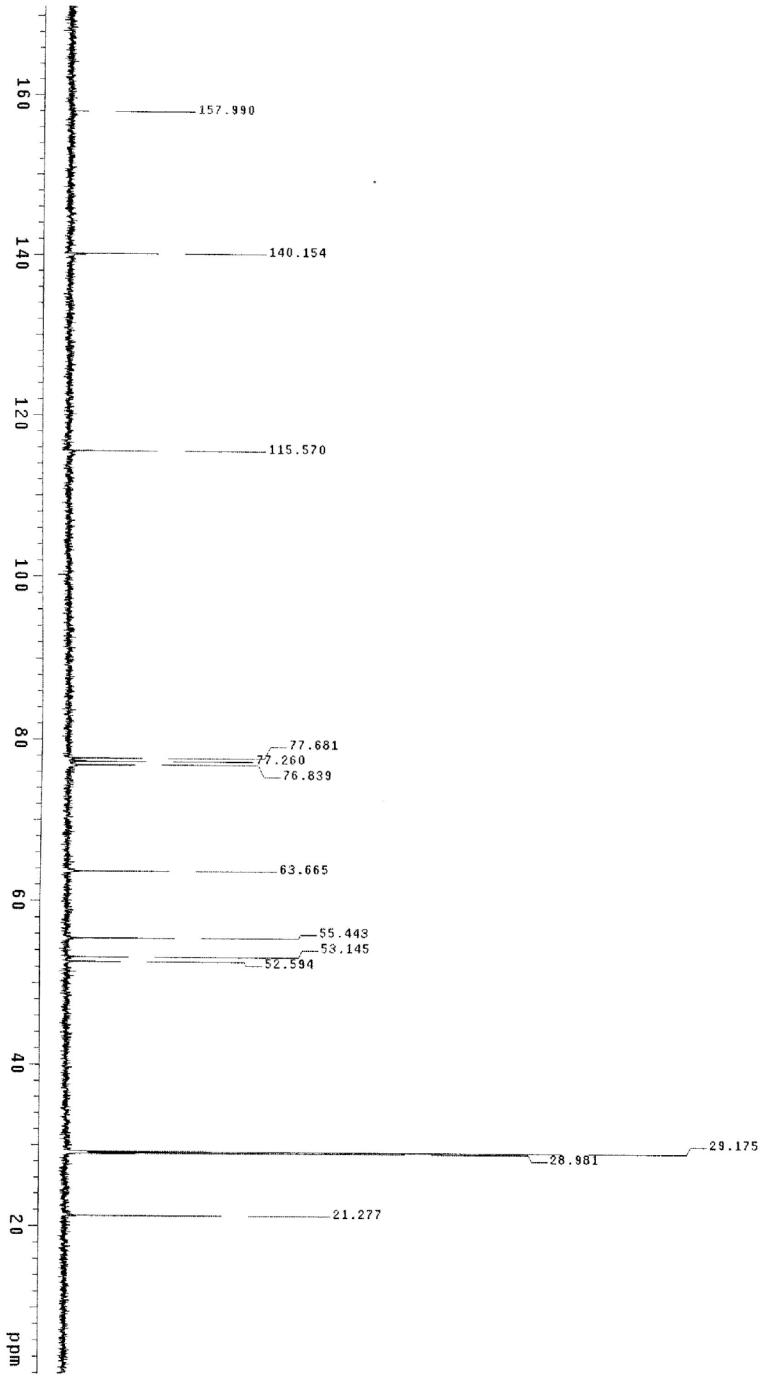
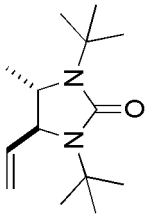
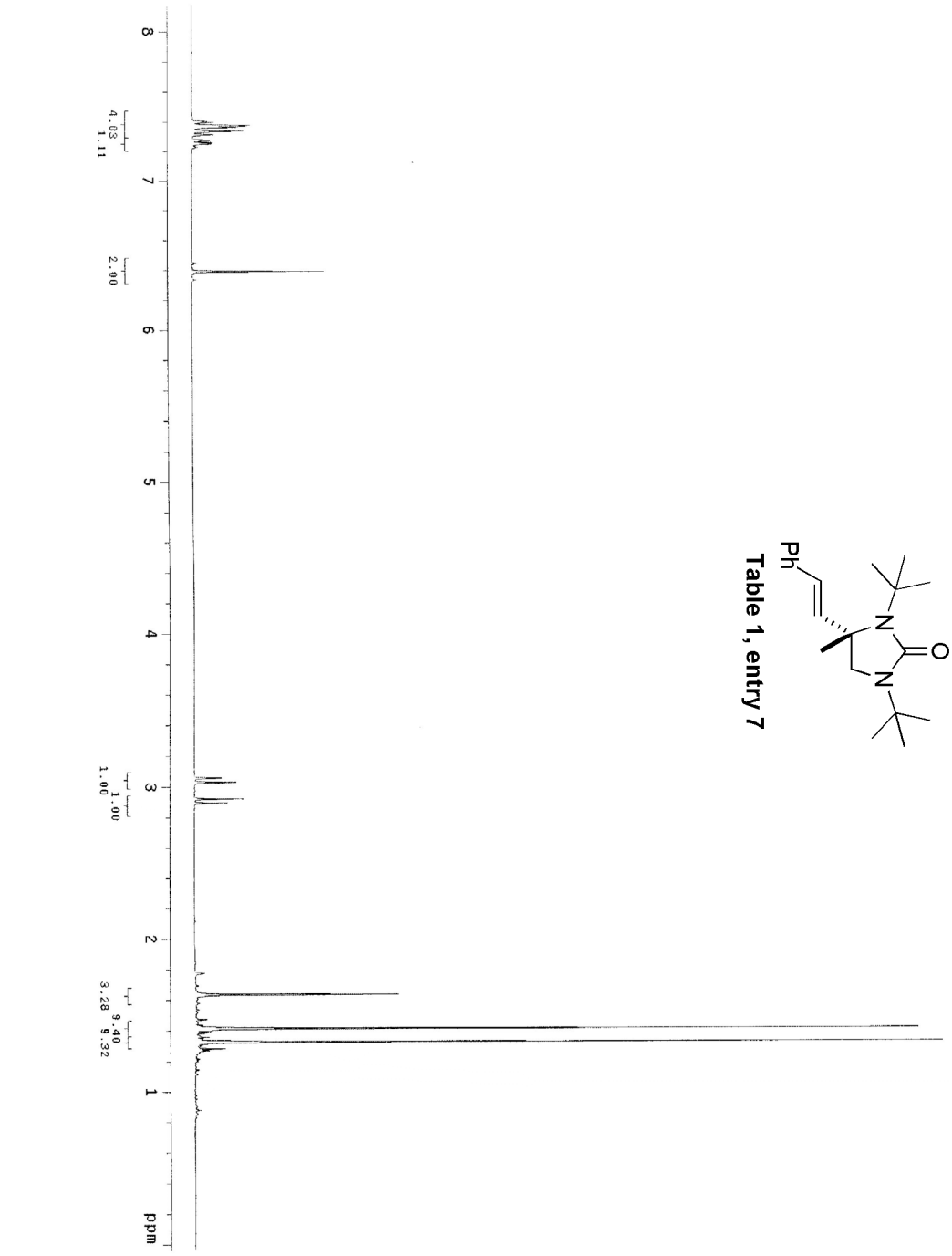


Table 1, entry 6

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N
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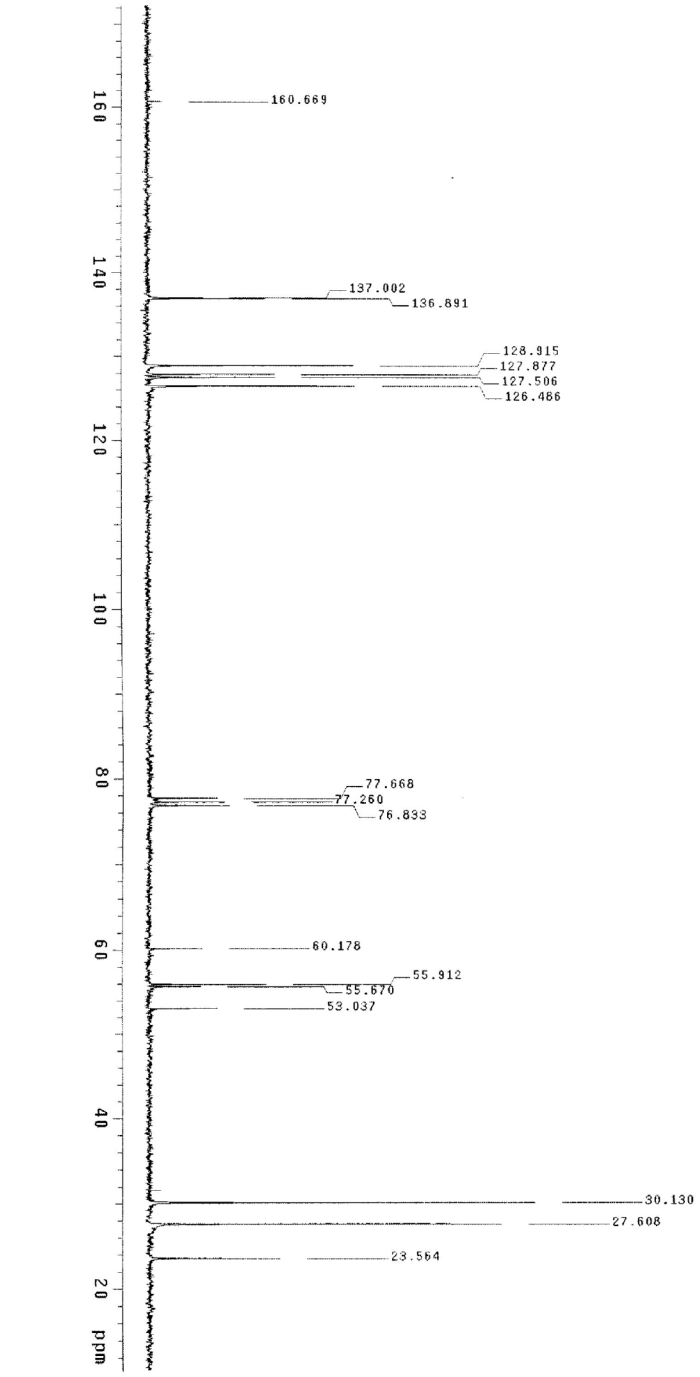
9.32



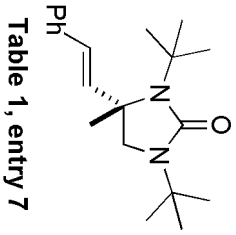
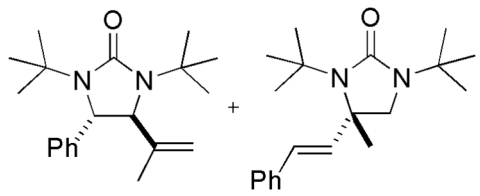


Table 1, entry 7



91:9

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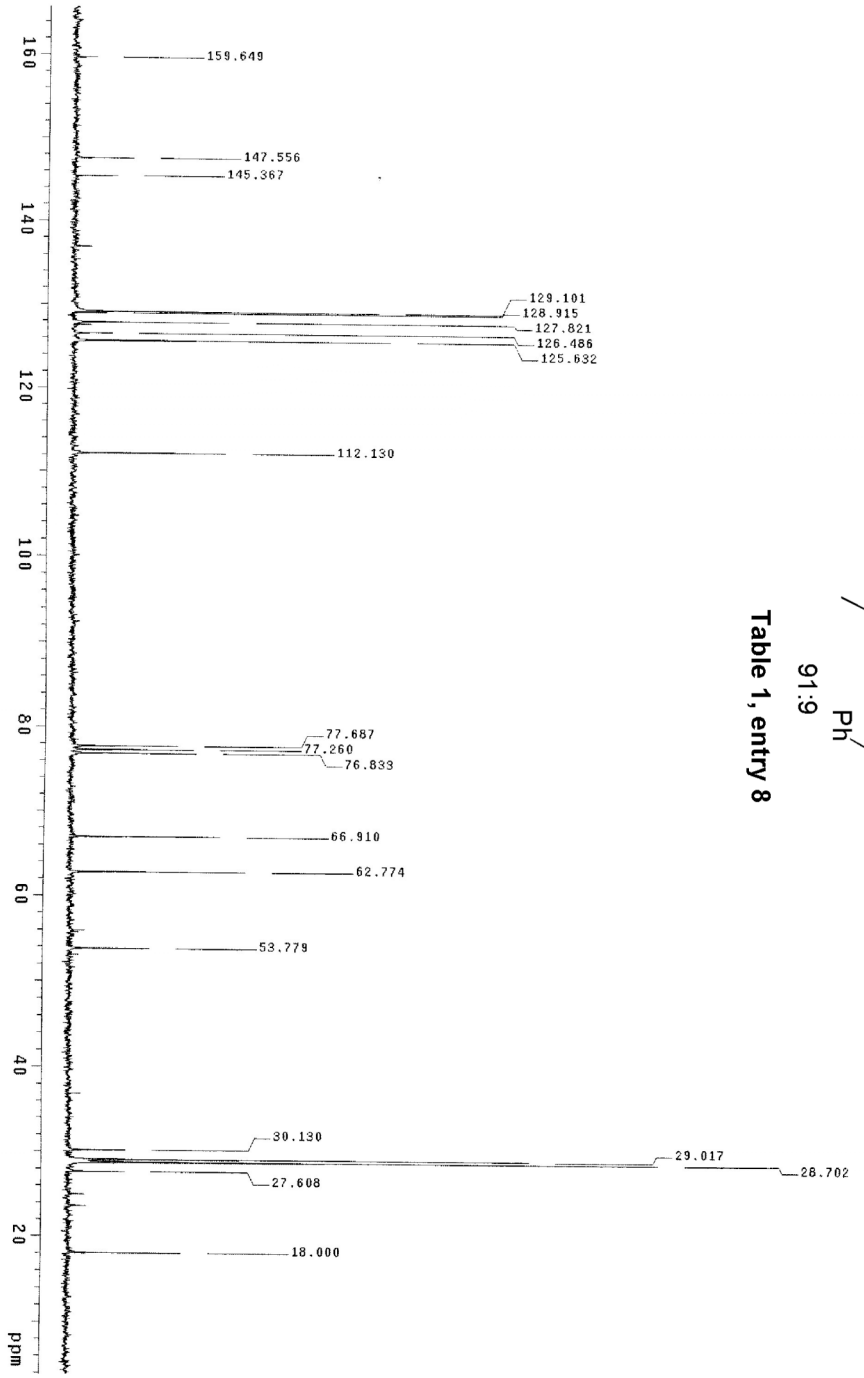
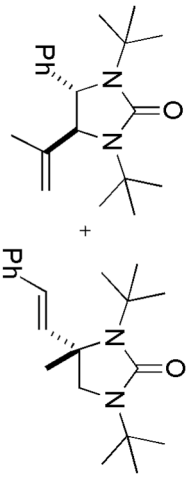
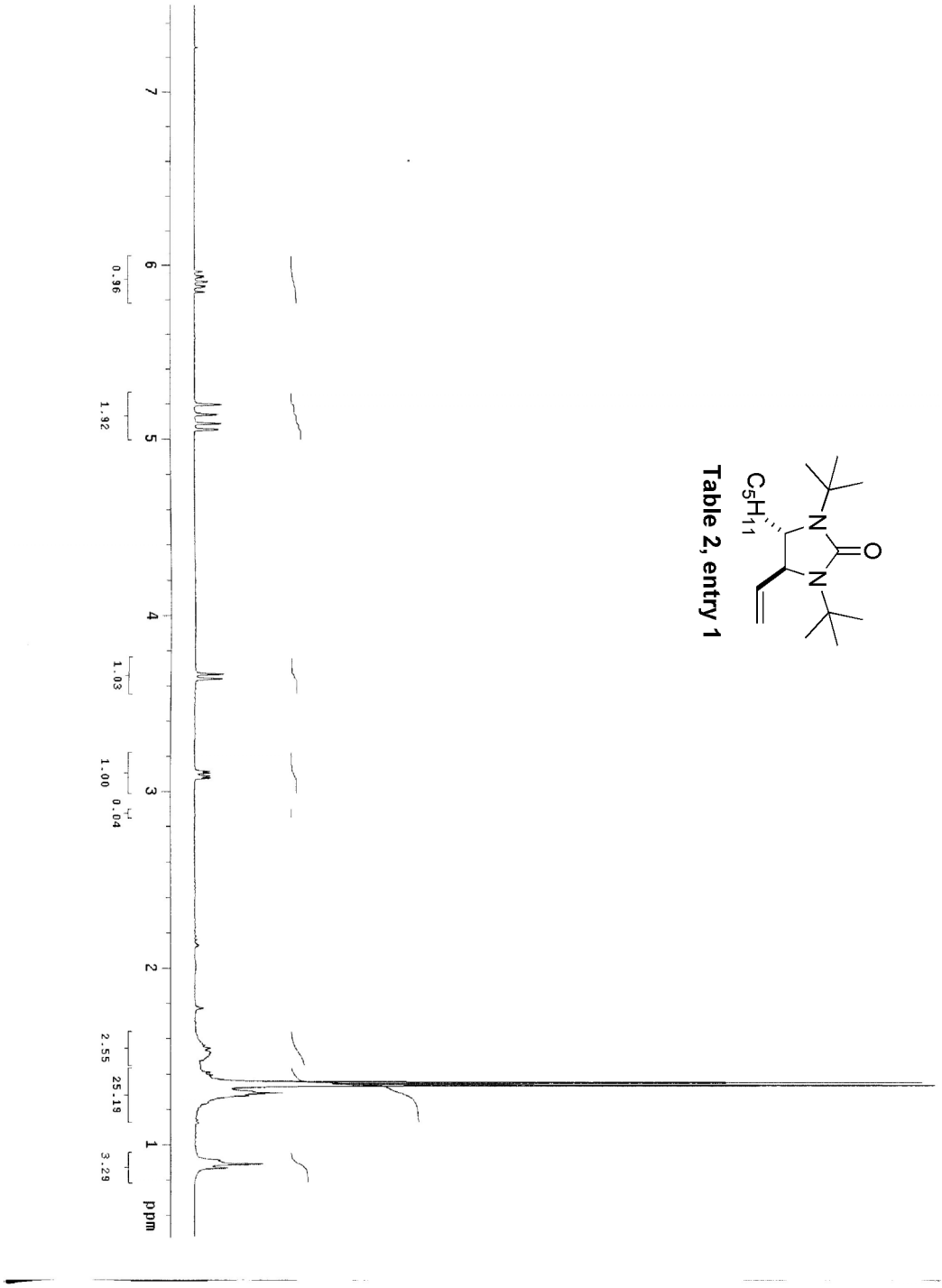




91:9

Table 1, entry 8



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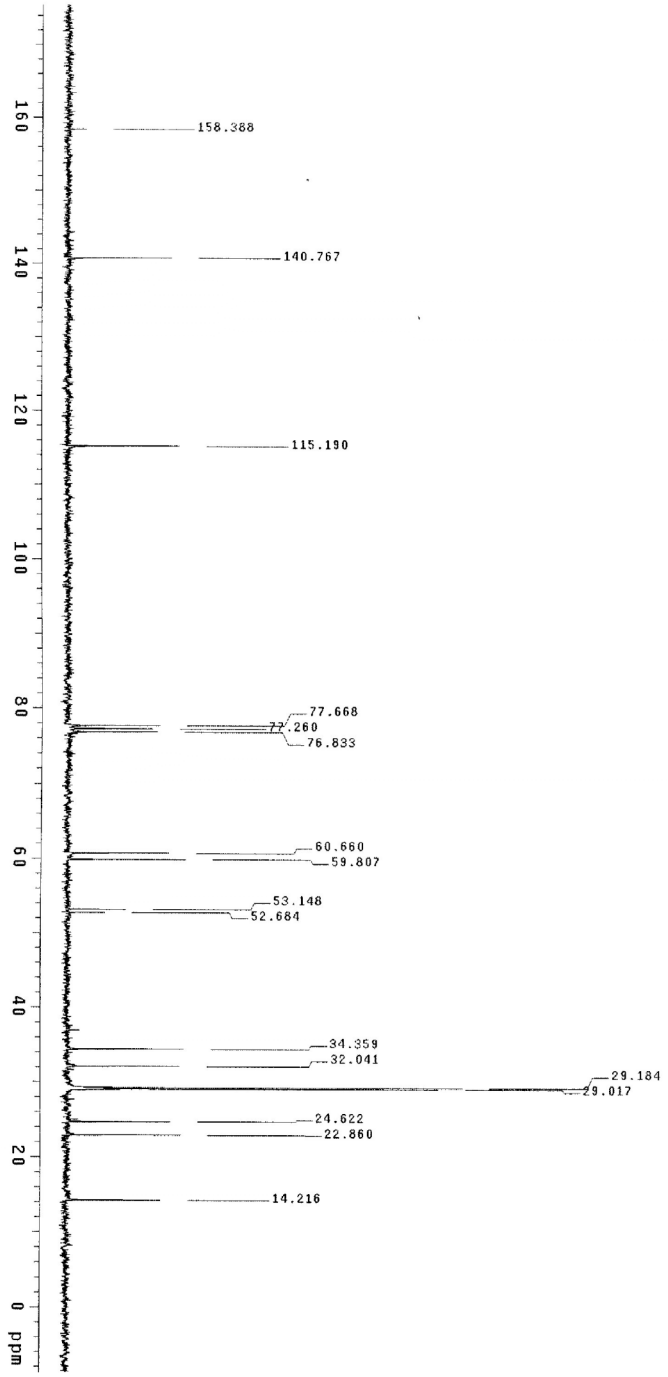

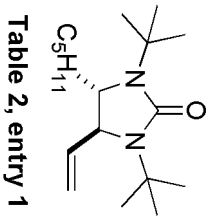

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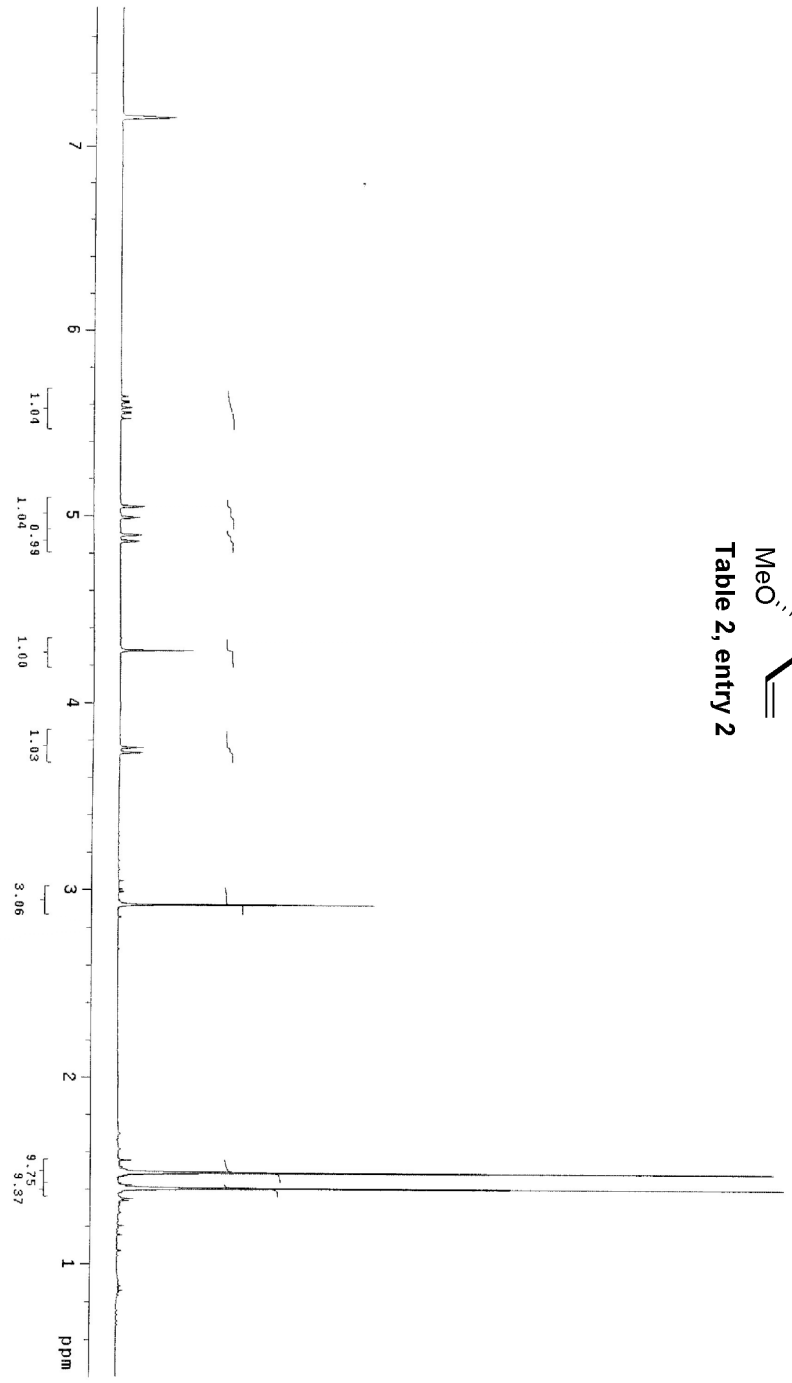

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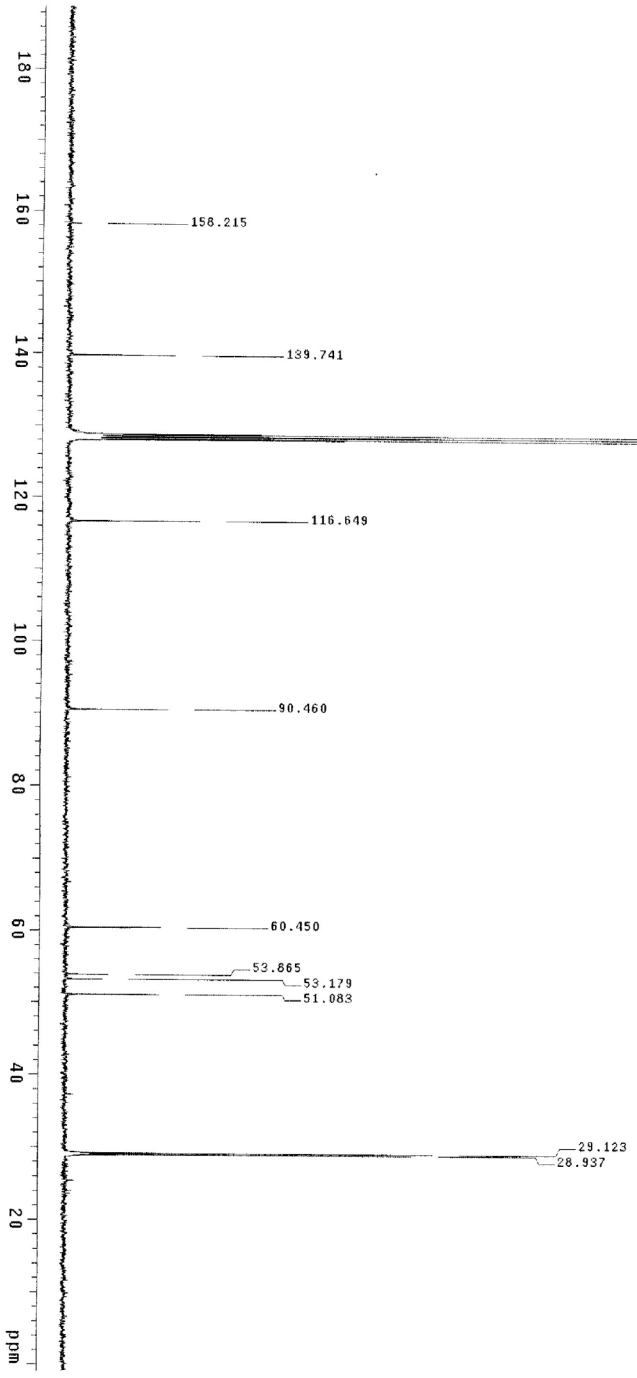

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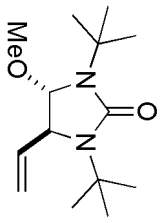

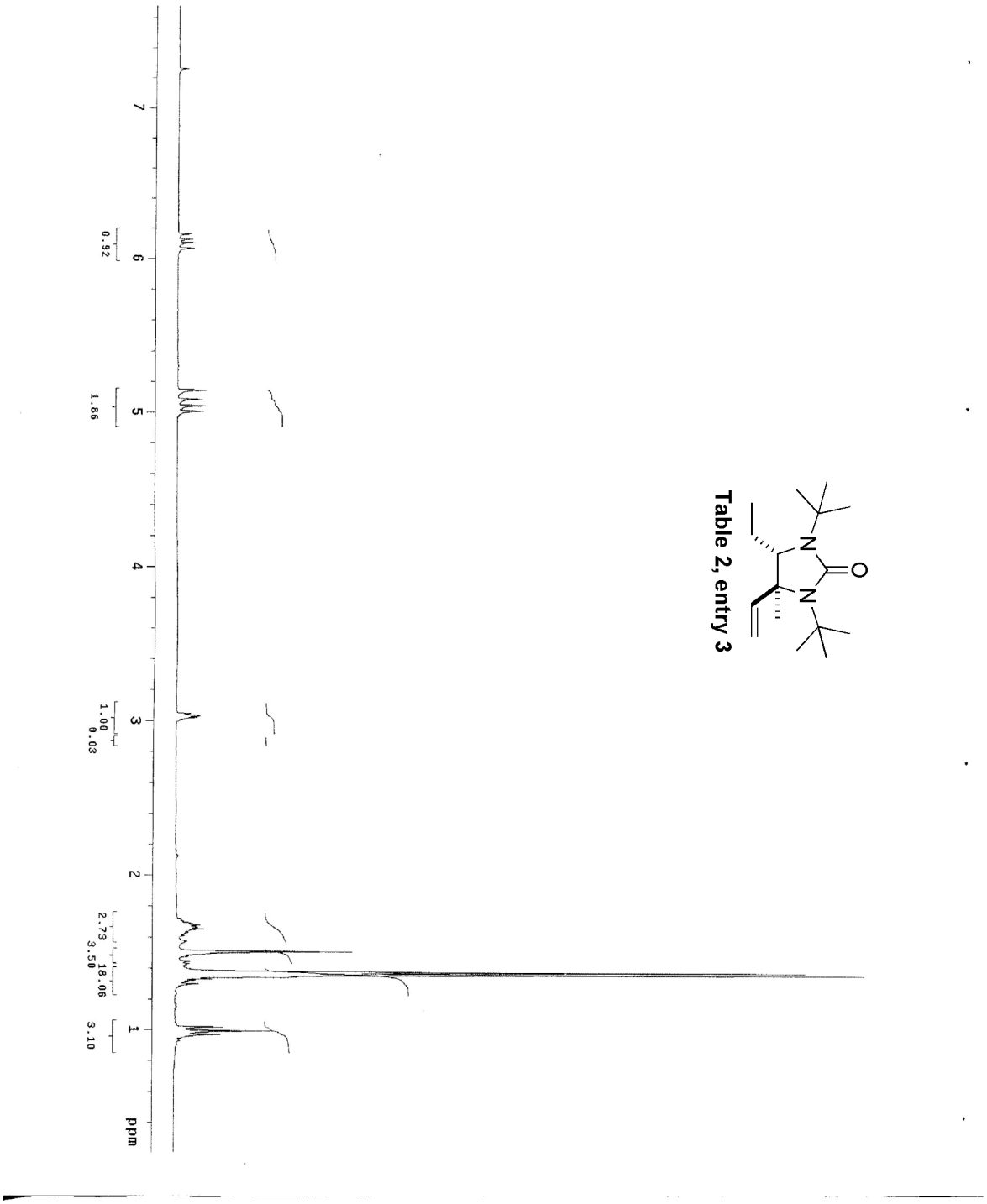
Table 2, entry 3
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4
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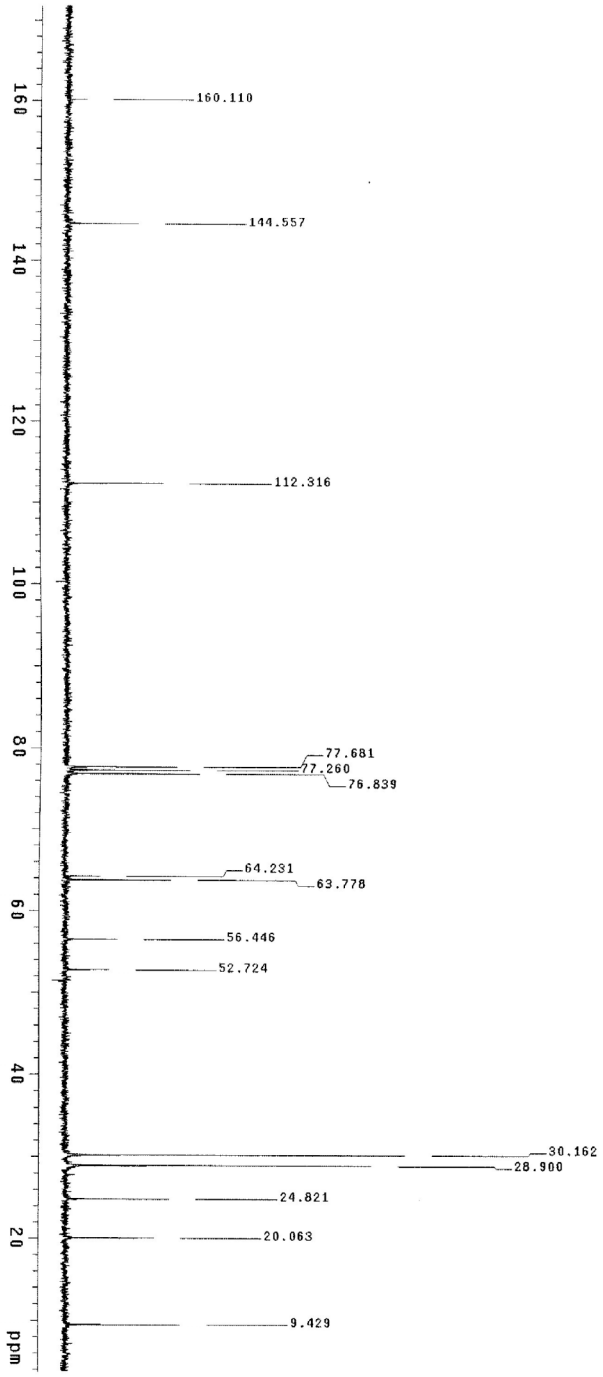

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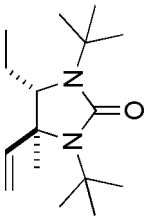


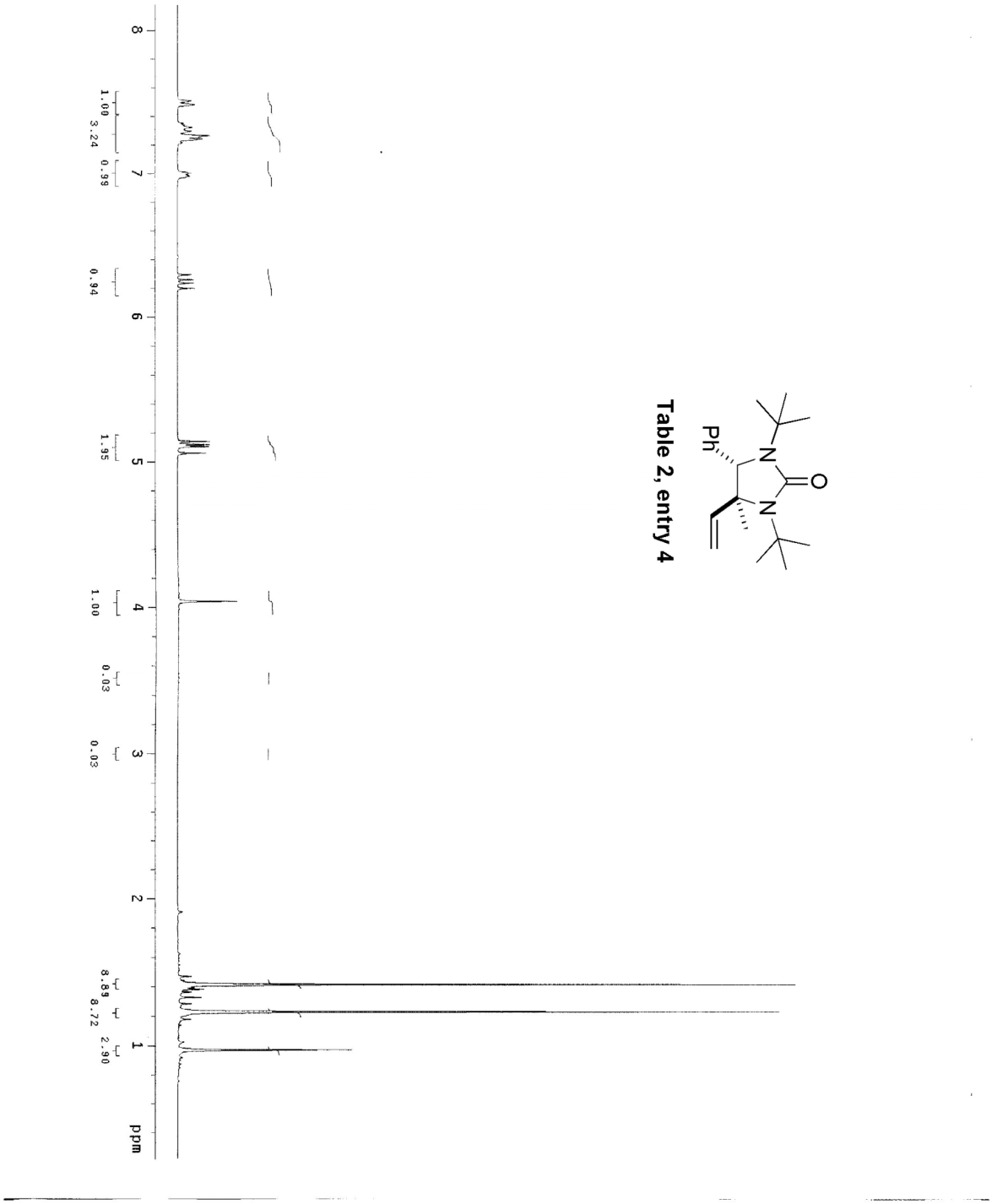


Table 2, entry 4

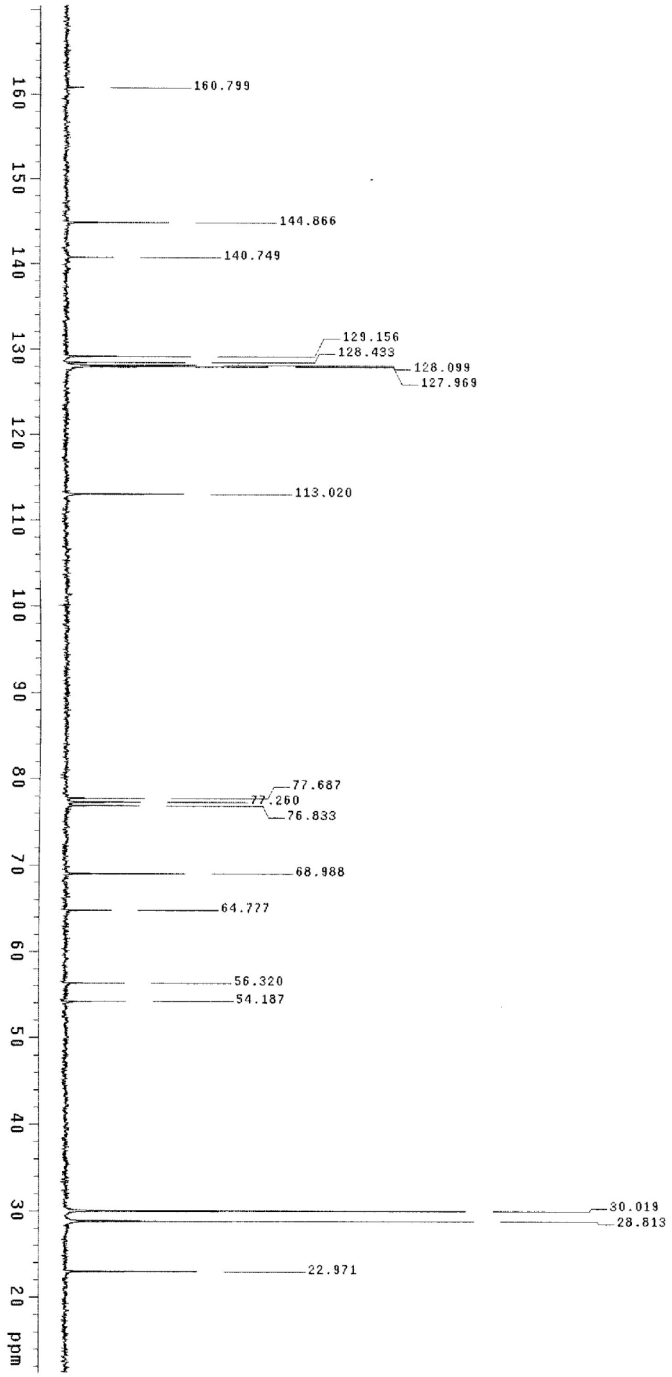
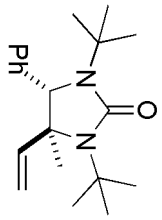
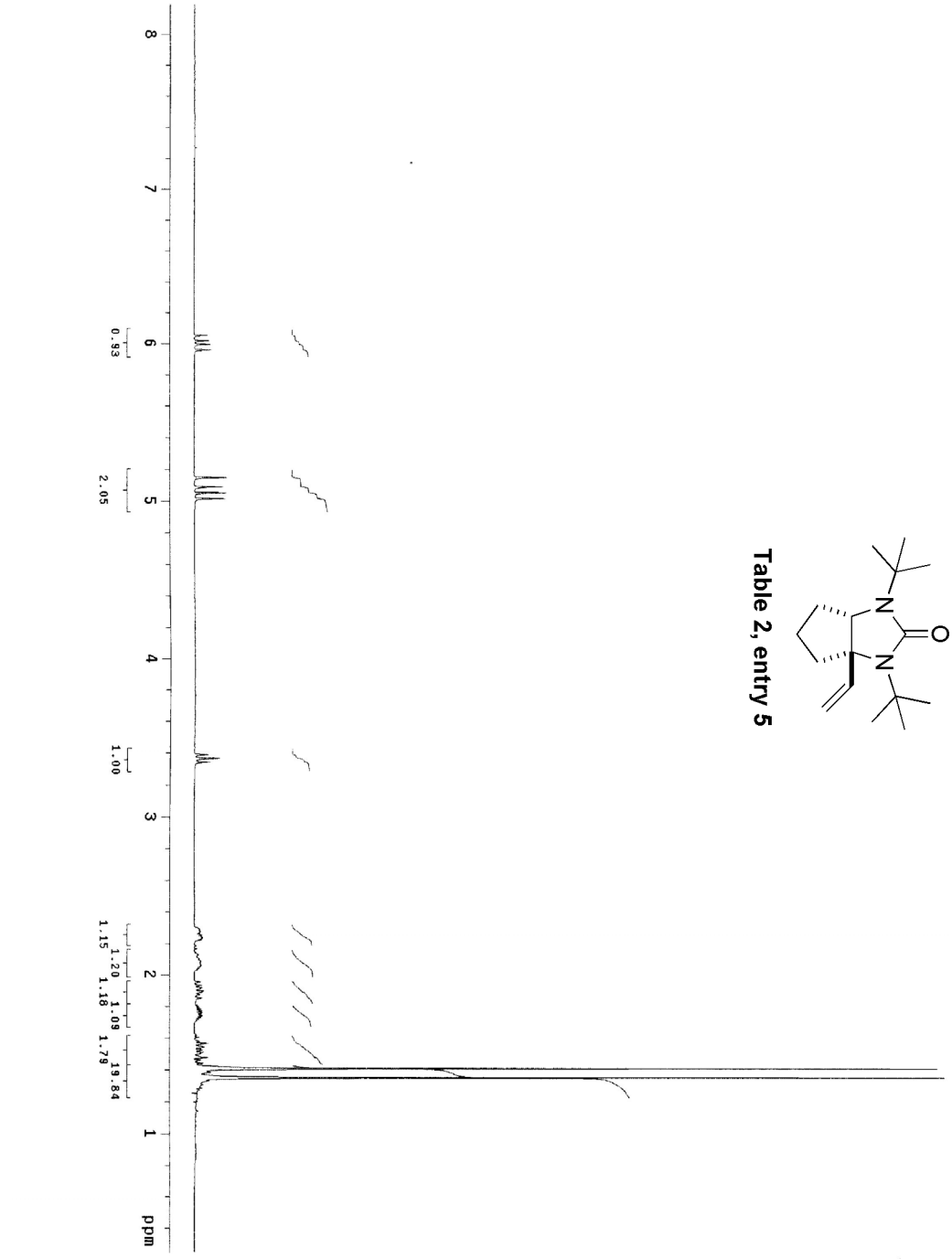


Table 2, entry 4

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1.09
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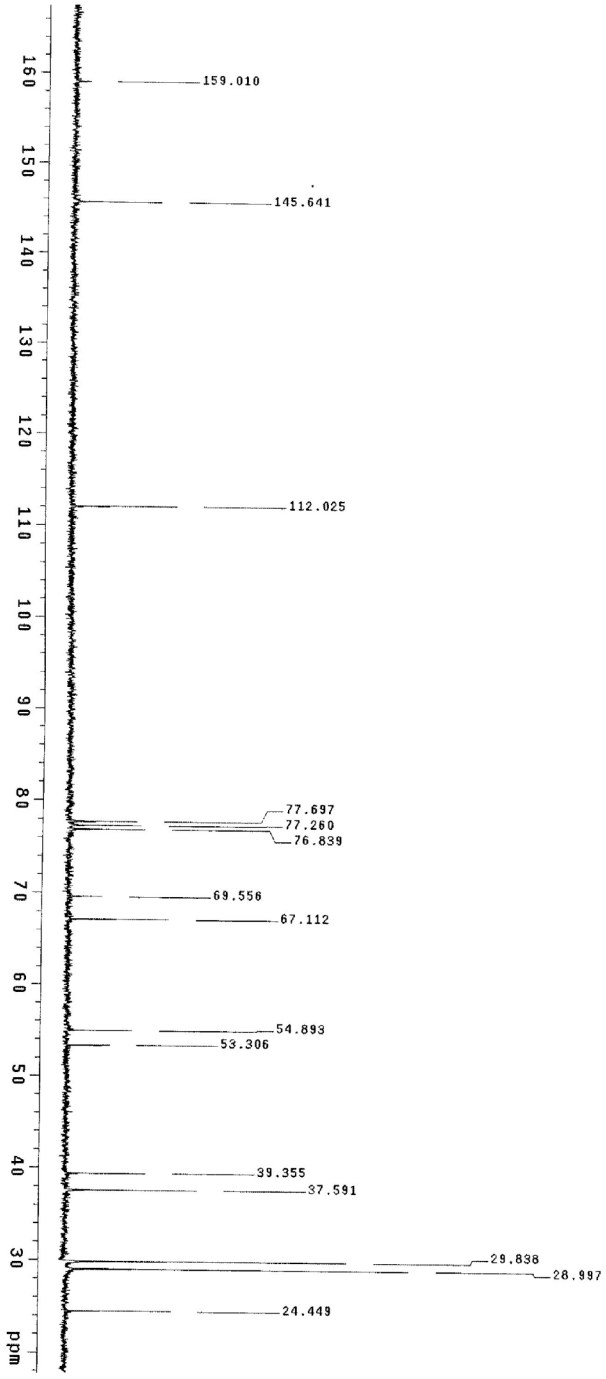
19.84



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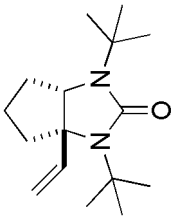

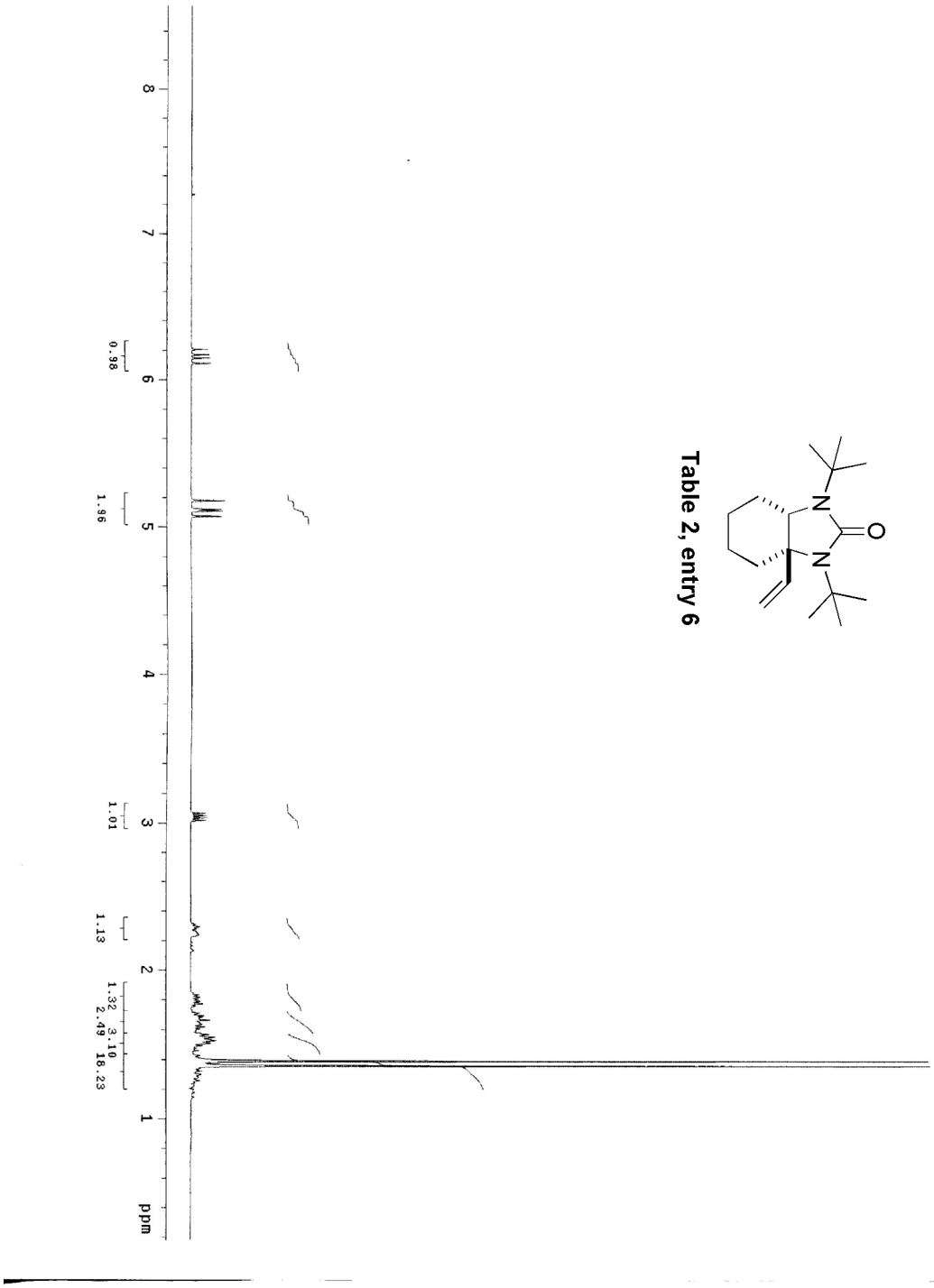
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3.10
16.23

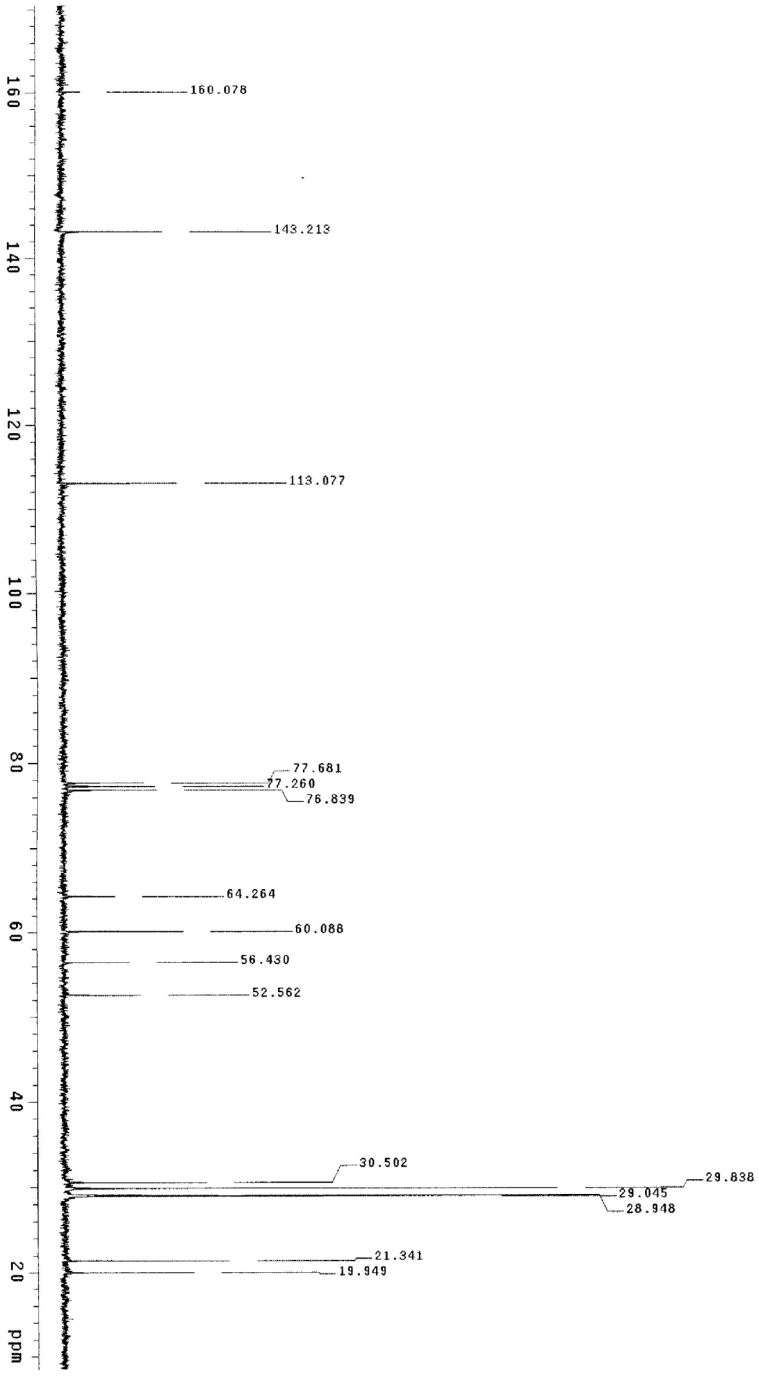
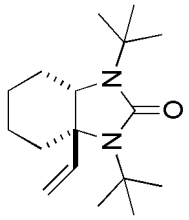


Table 2, entry 6



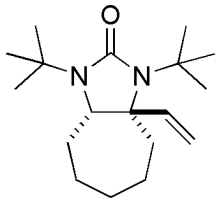


Table 2, entry 7

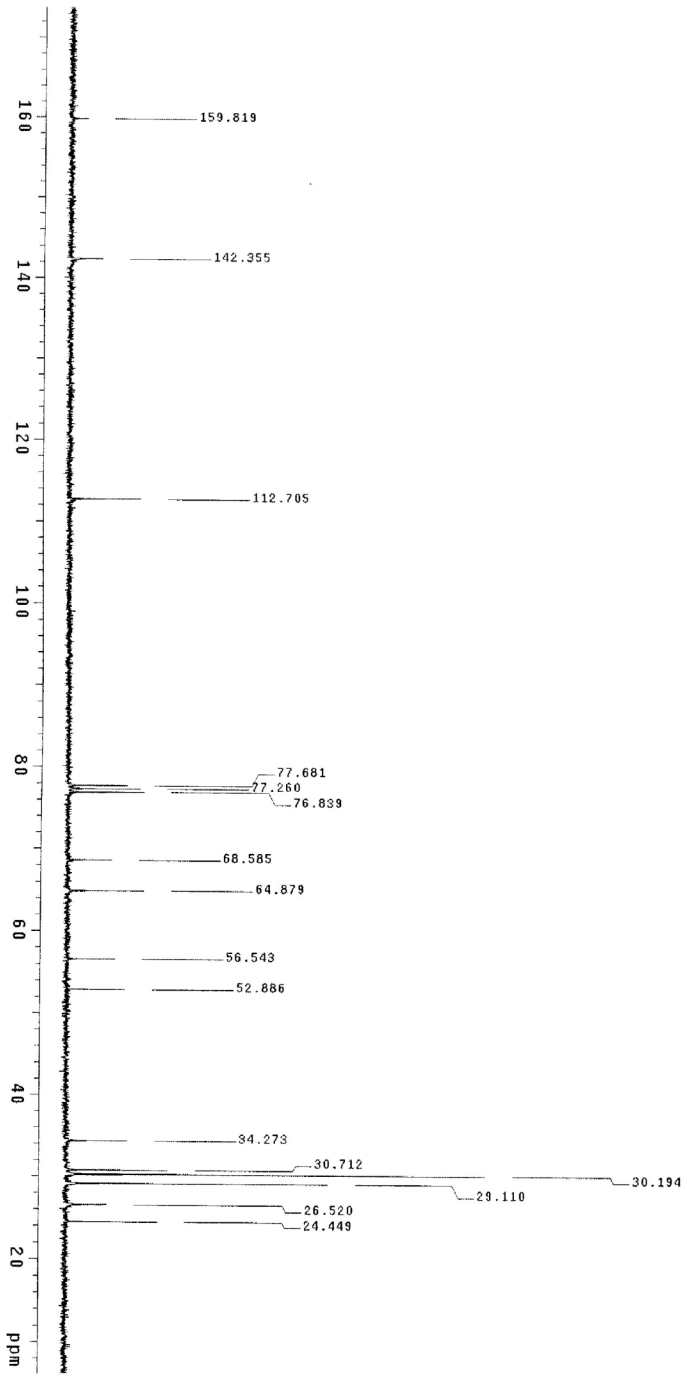
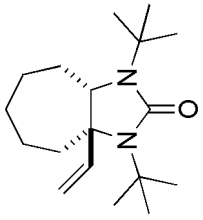


Table 2, entry 7



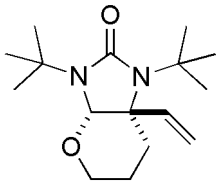
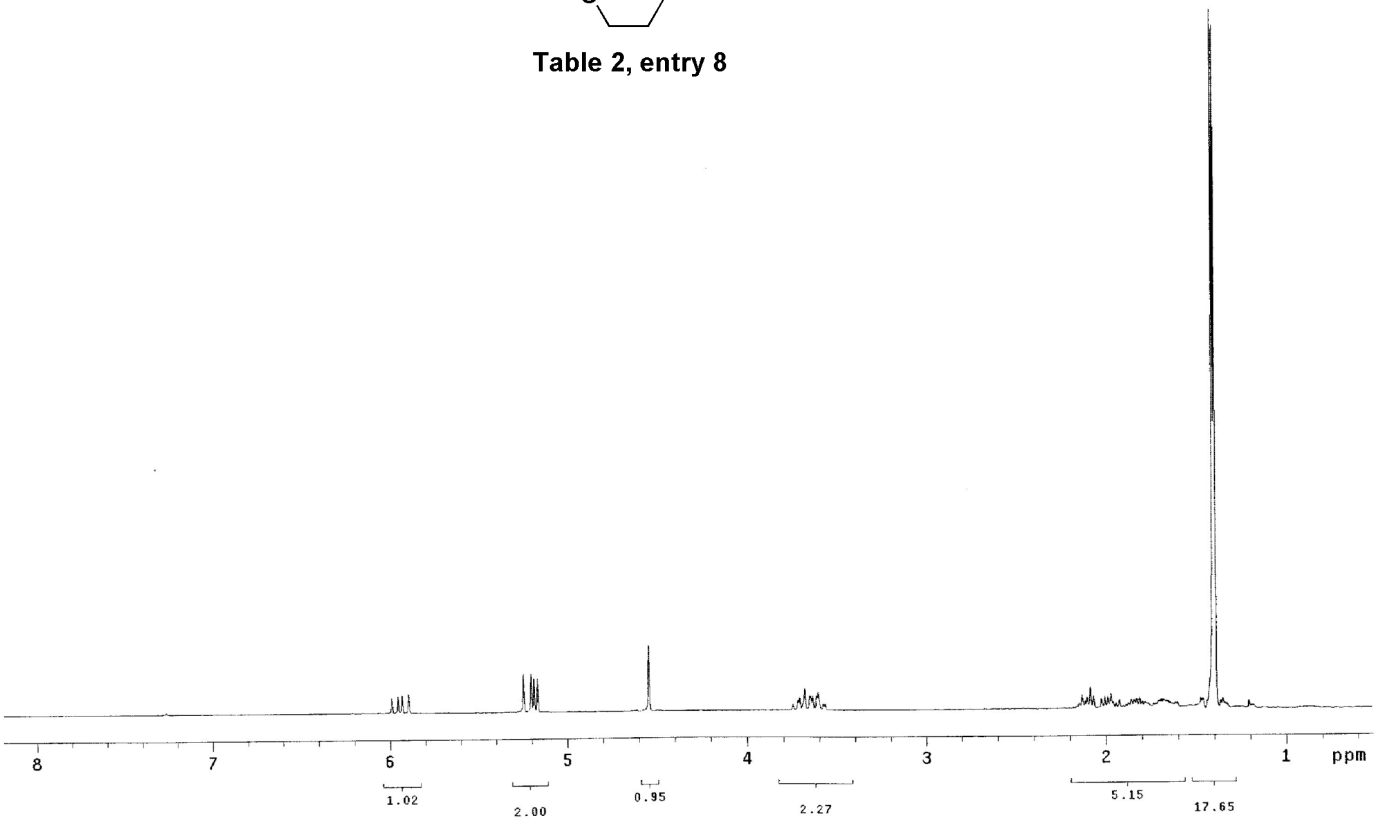


Table 2, entry 8



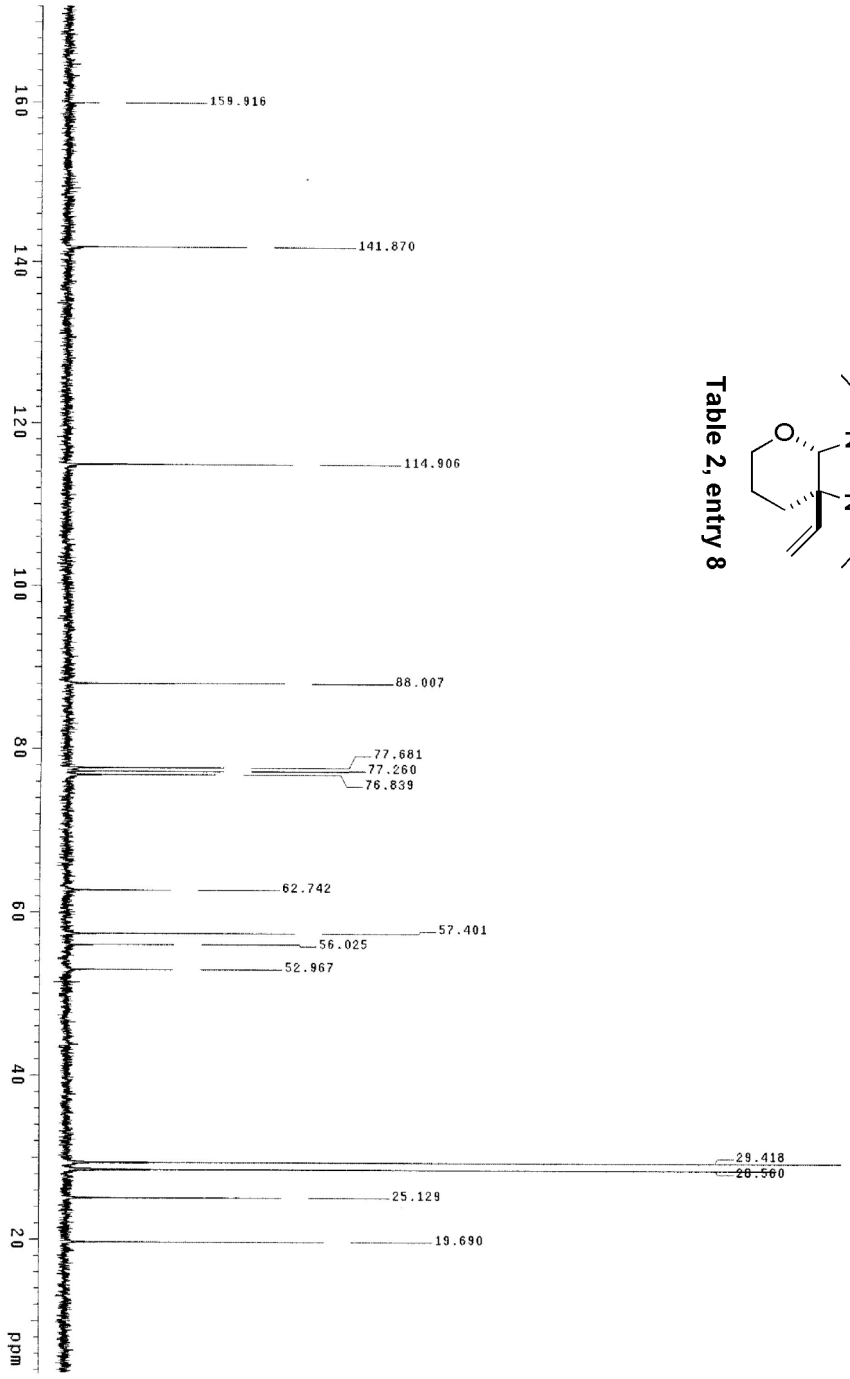


Table 2, entry 8

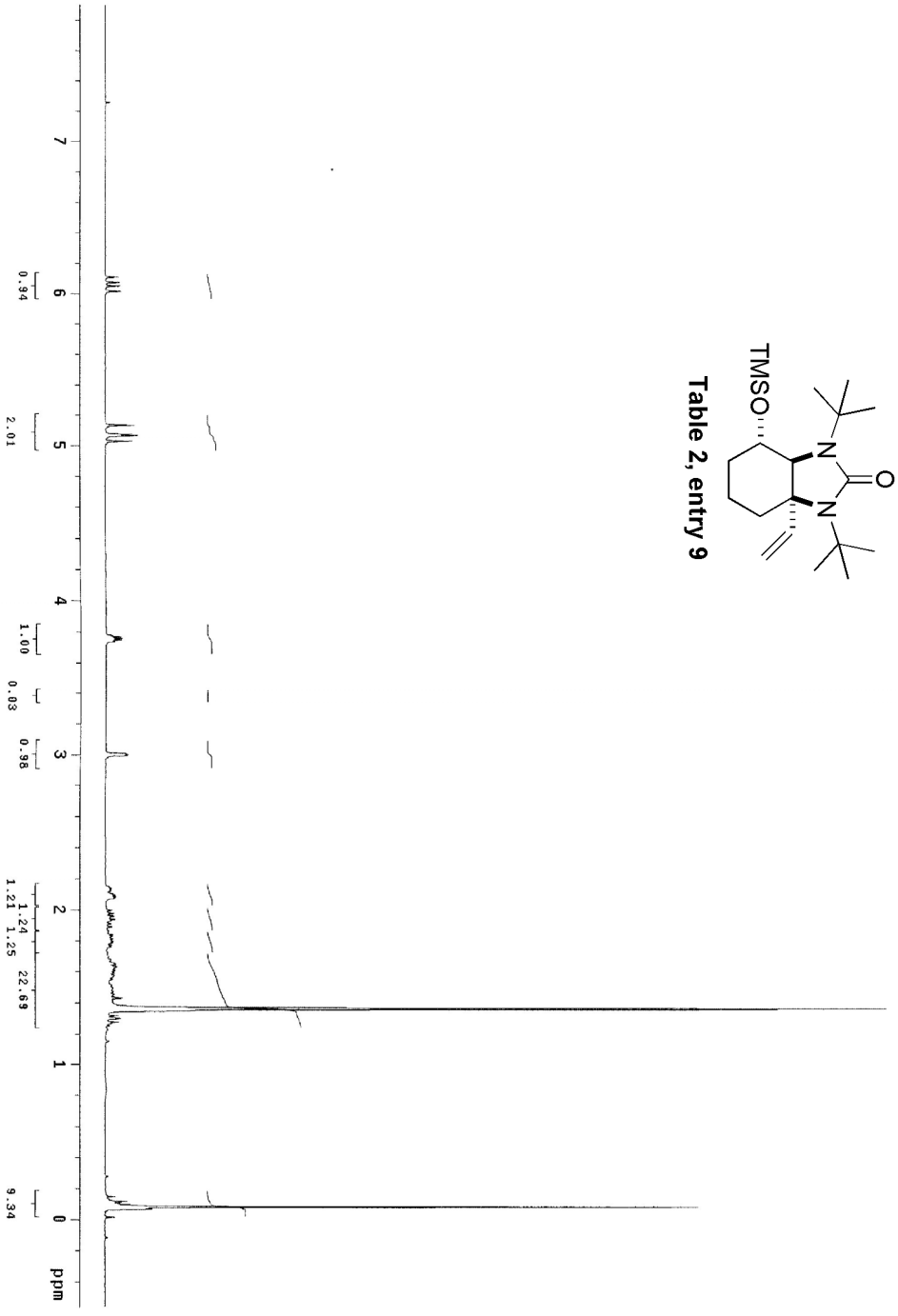
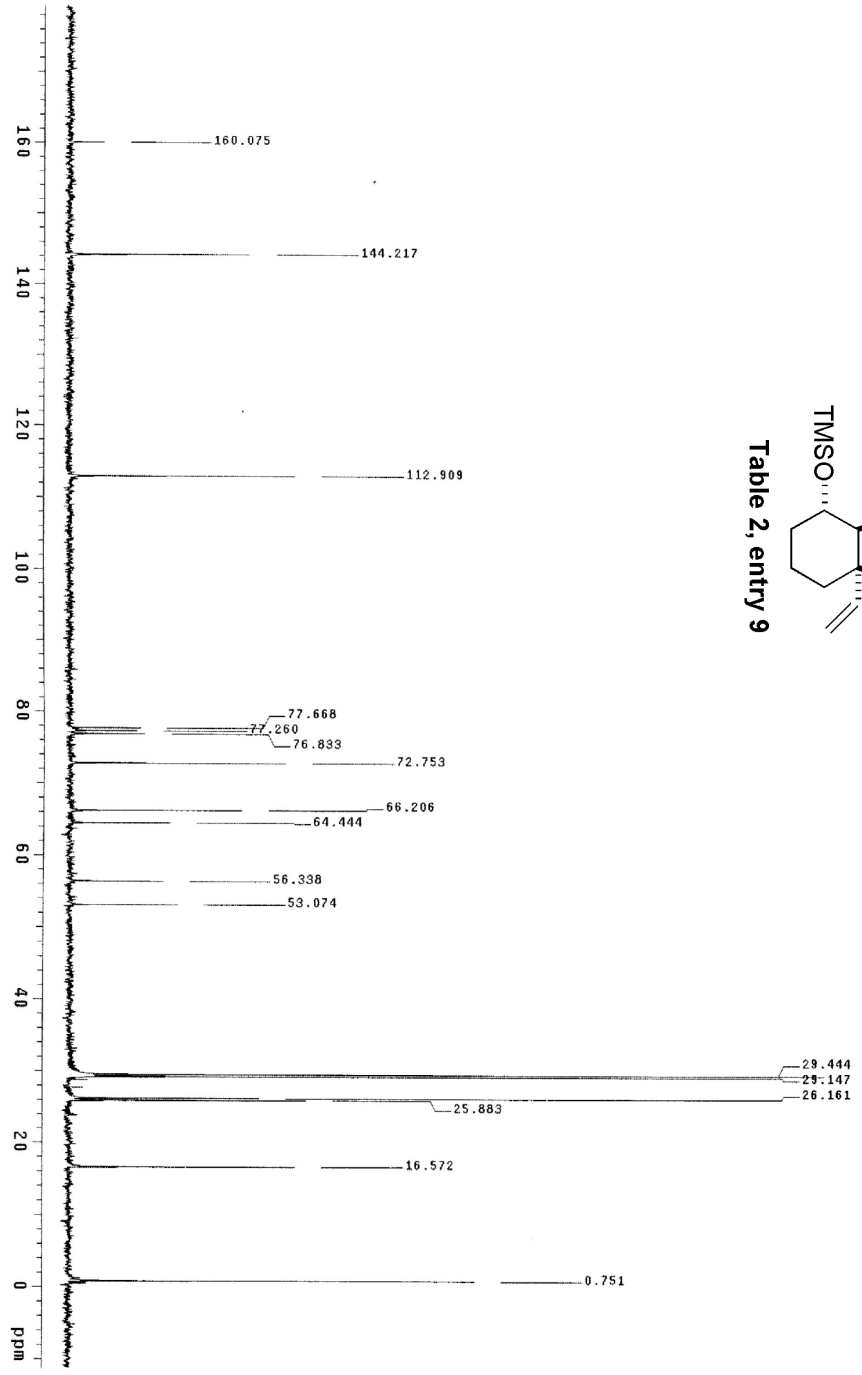


Table 2, entry 9



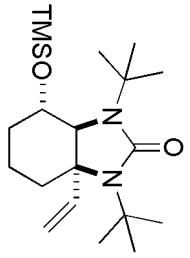


Table 2, entry 9

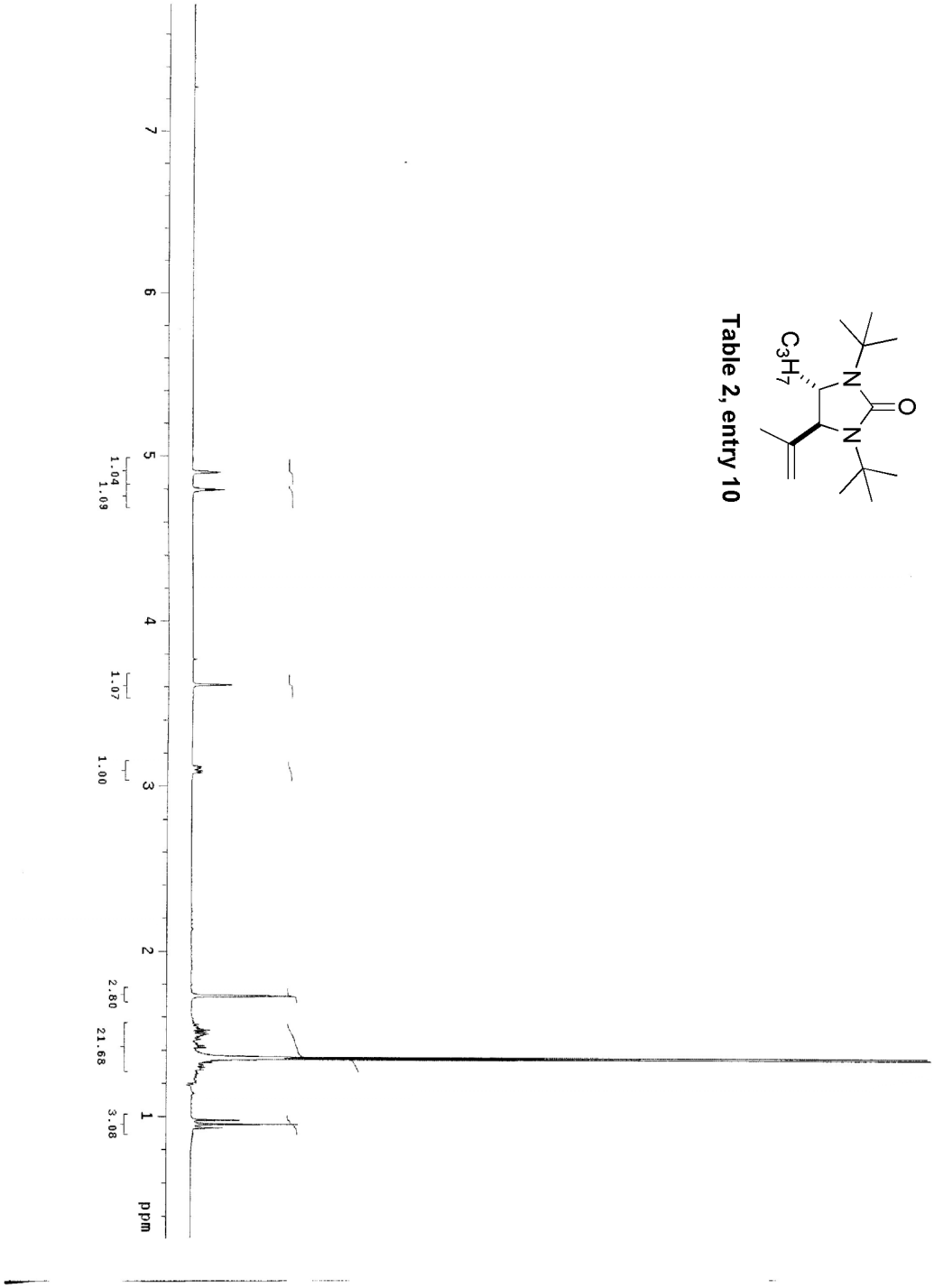


Table 2, entry 10
C3H7
N
O
N
7
6
5
4
3
2
1
ppm
1.04
1.09
1.07
1.00
2.80
21.68
3.08

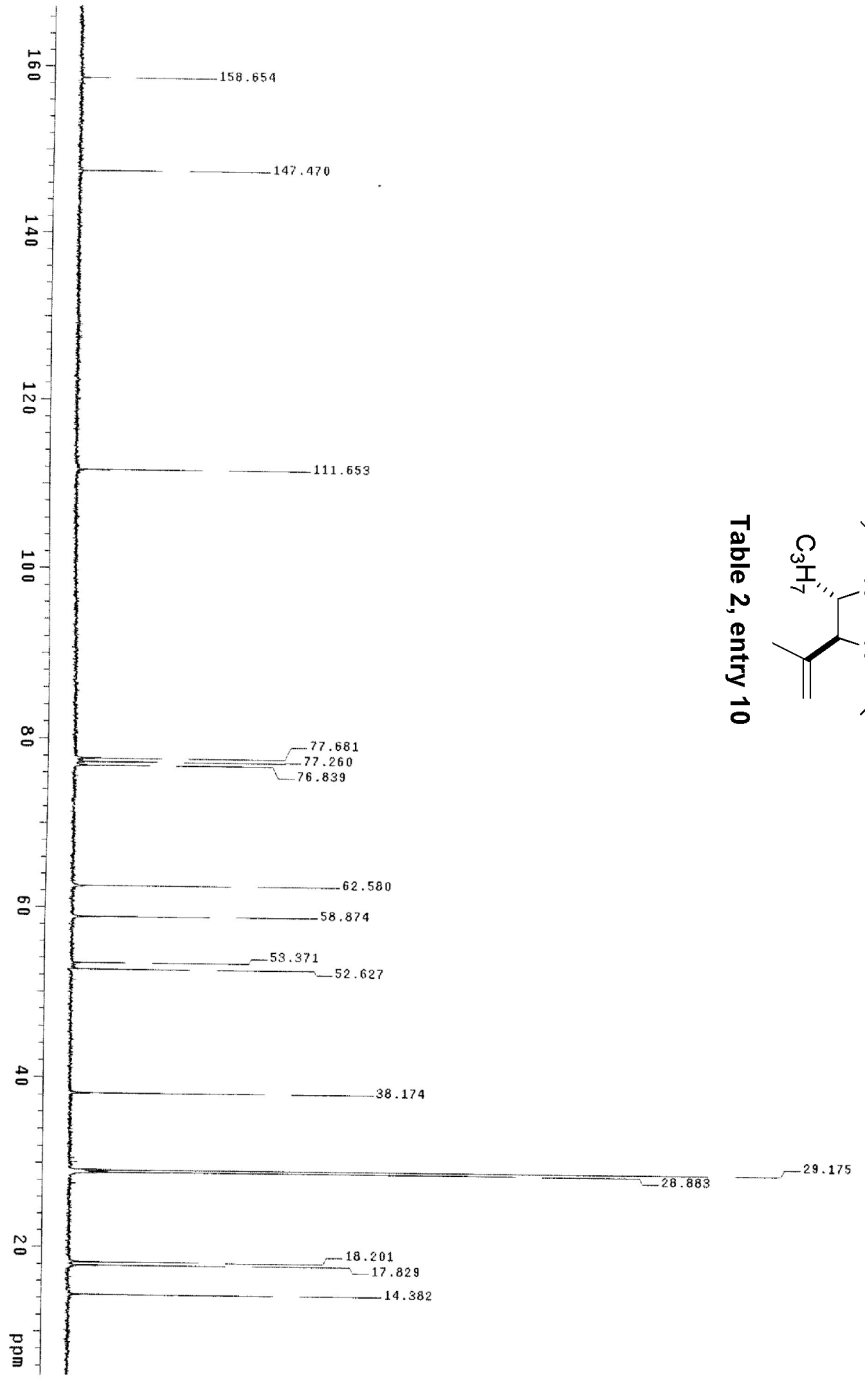
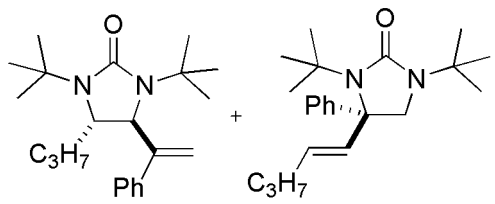
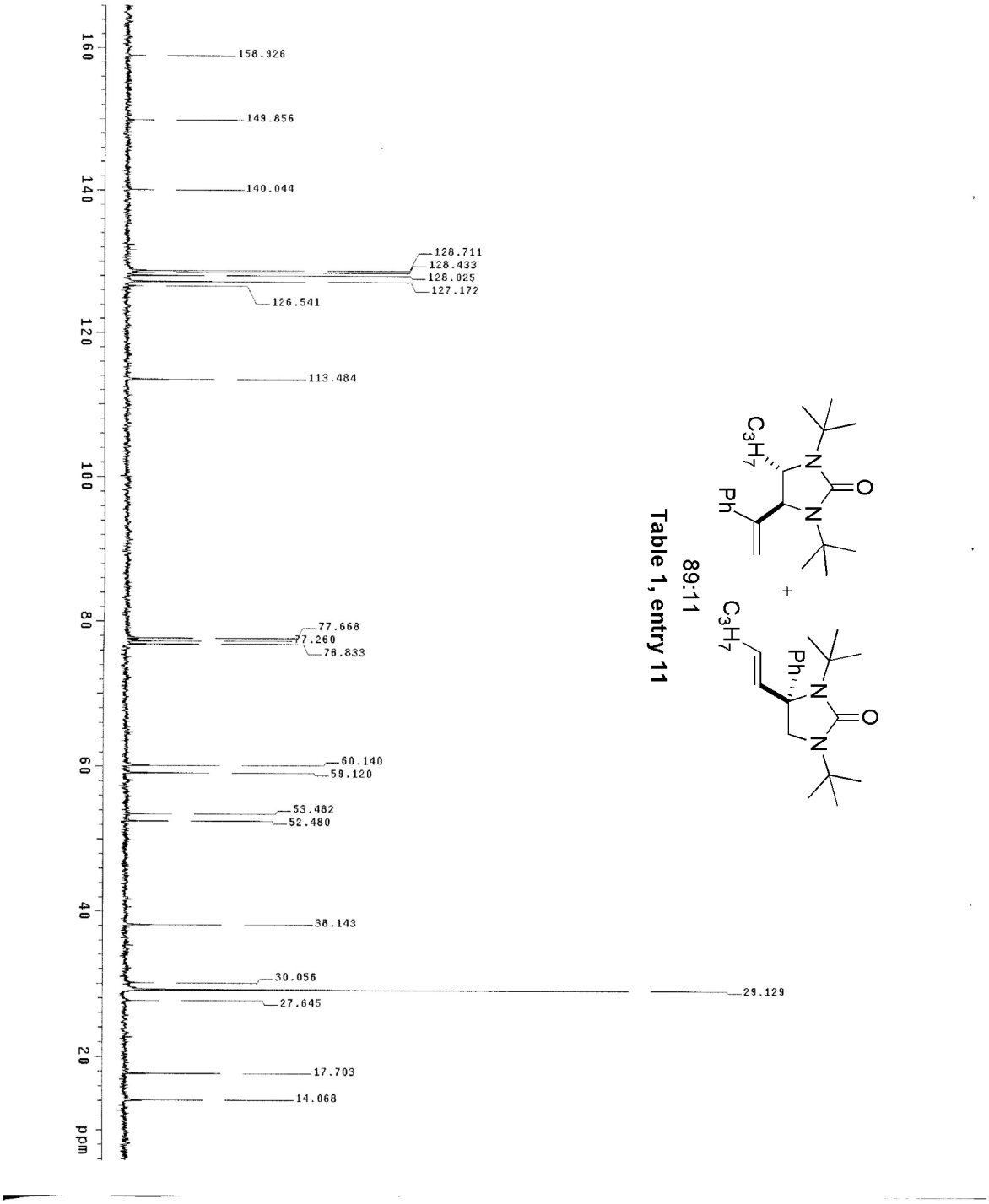


Table 2, entry 10



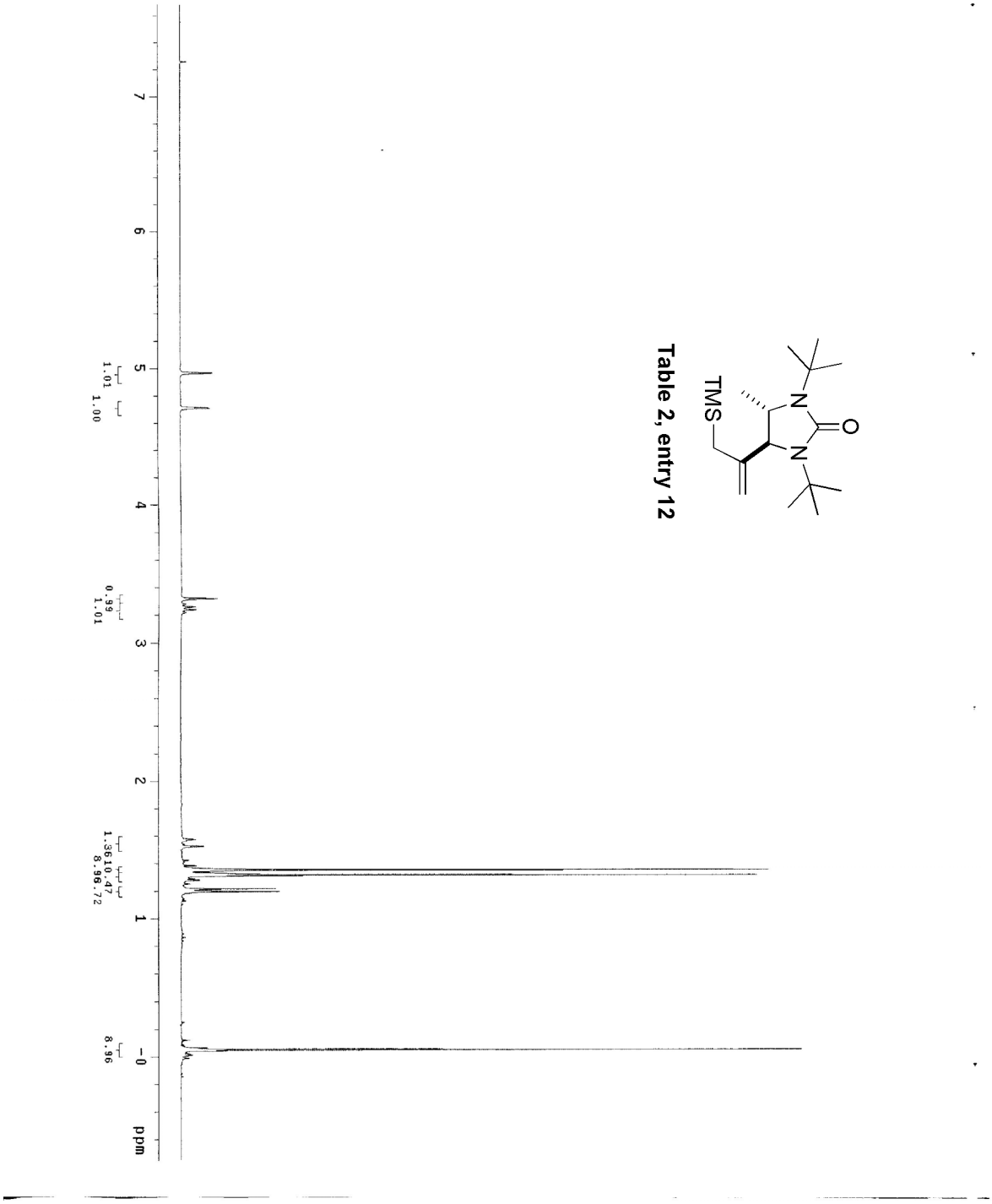
89:11

Table 1, entry 11



89:11

Table 1, entry 11


TMS
N
O
N
Table 2, entry 12
7
6
5
4
3
2
1
-0
ppm
1.01
1.00
0.99
1.01
1.36
10.47
8.96
72
8.96

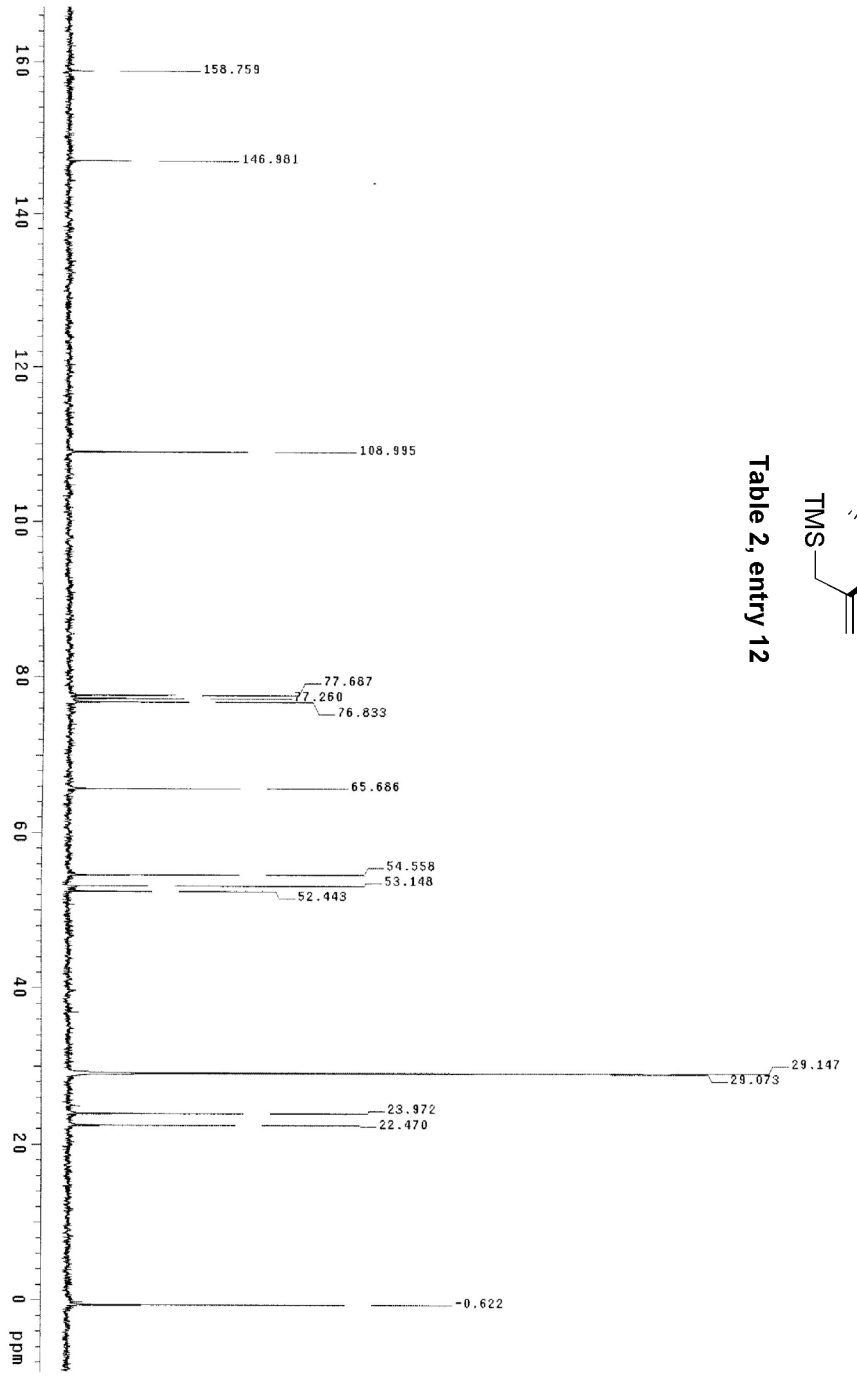


Table 2, entry 12

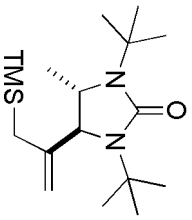
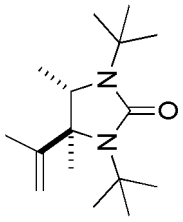


Table 2, entry 13



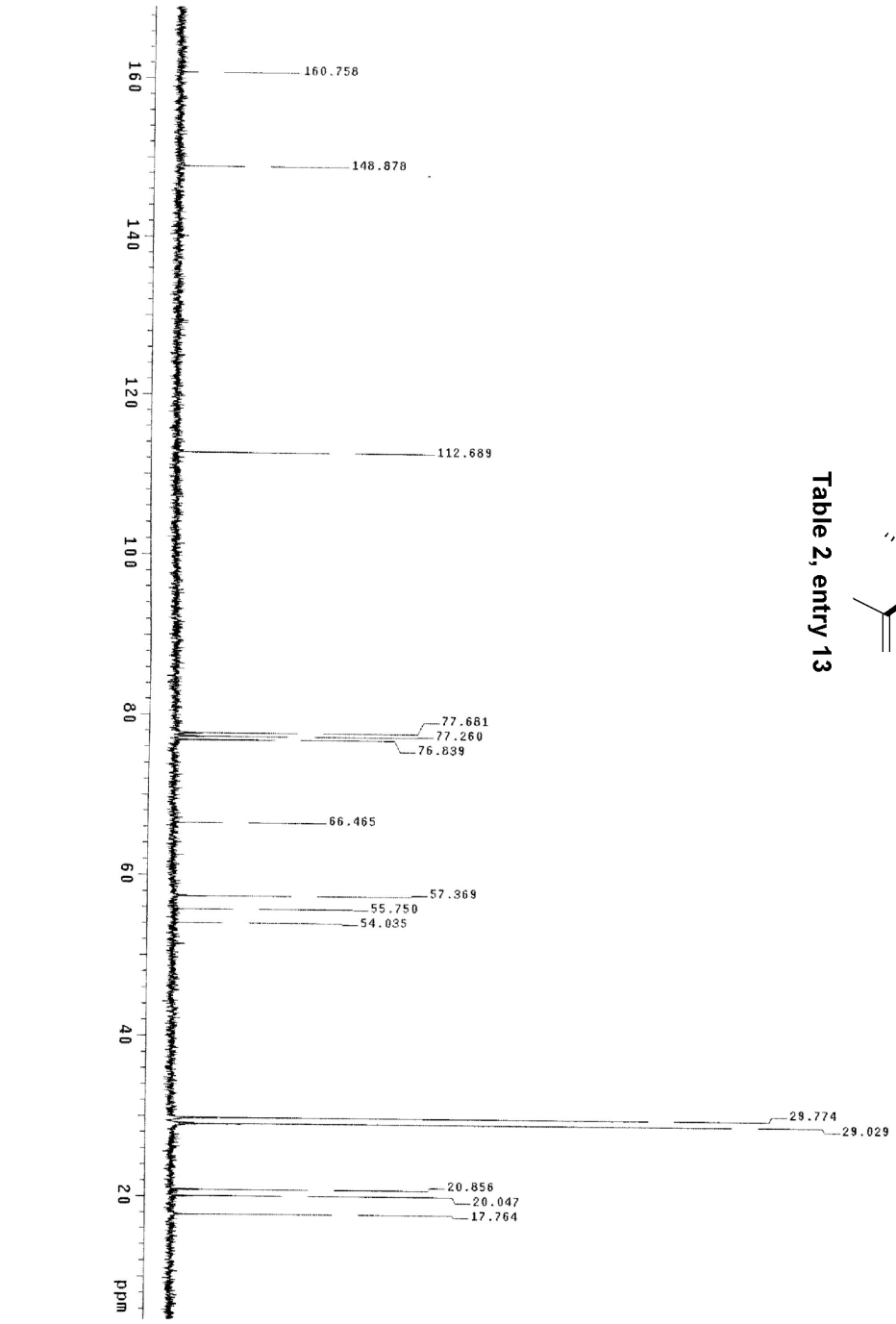
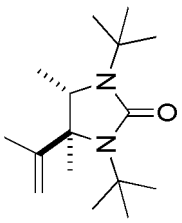


Table 2, entry 13



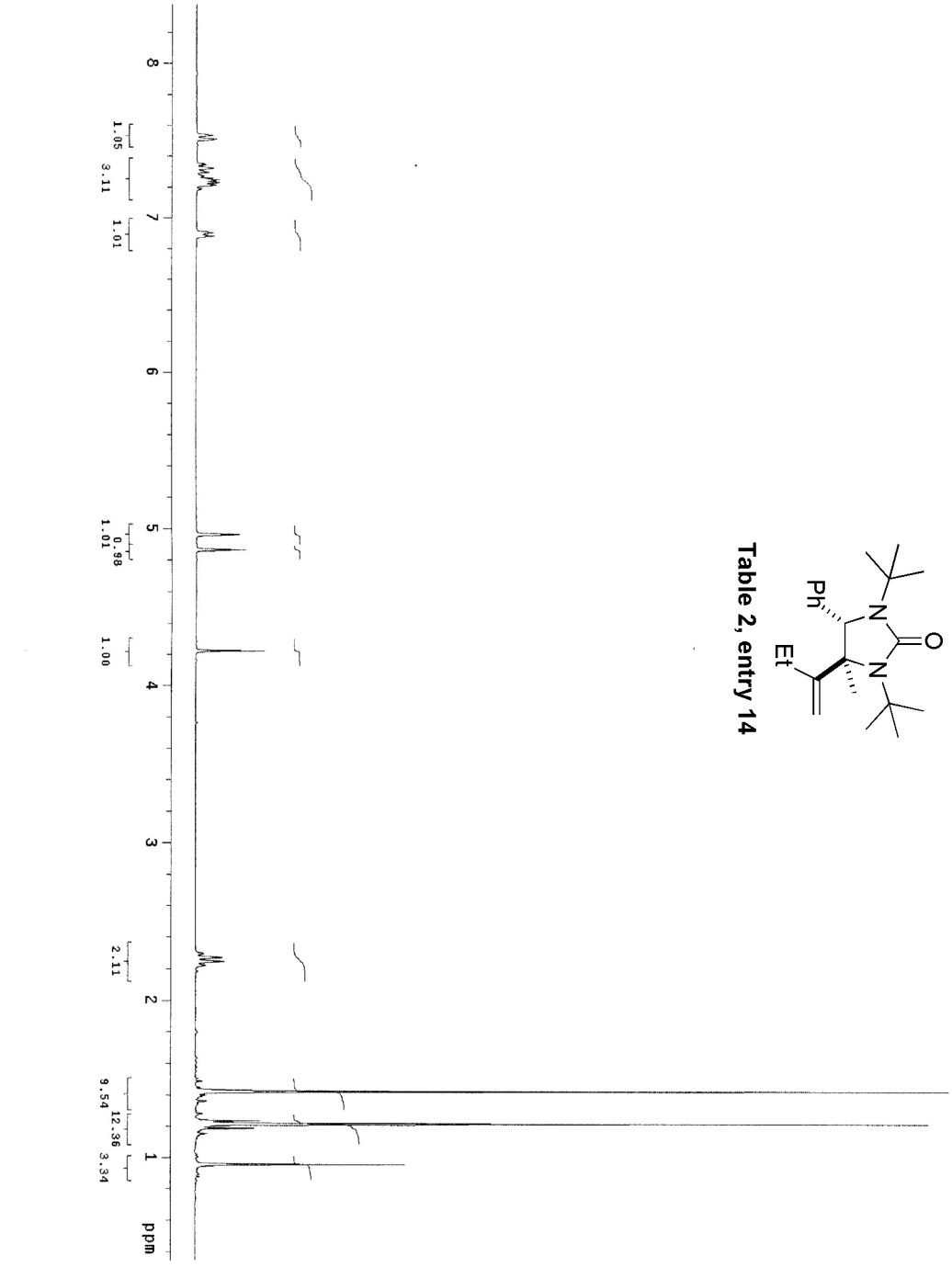


Table 2, entry 14

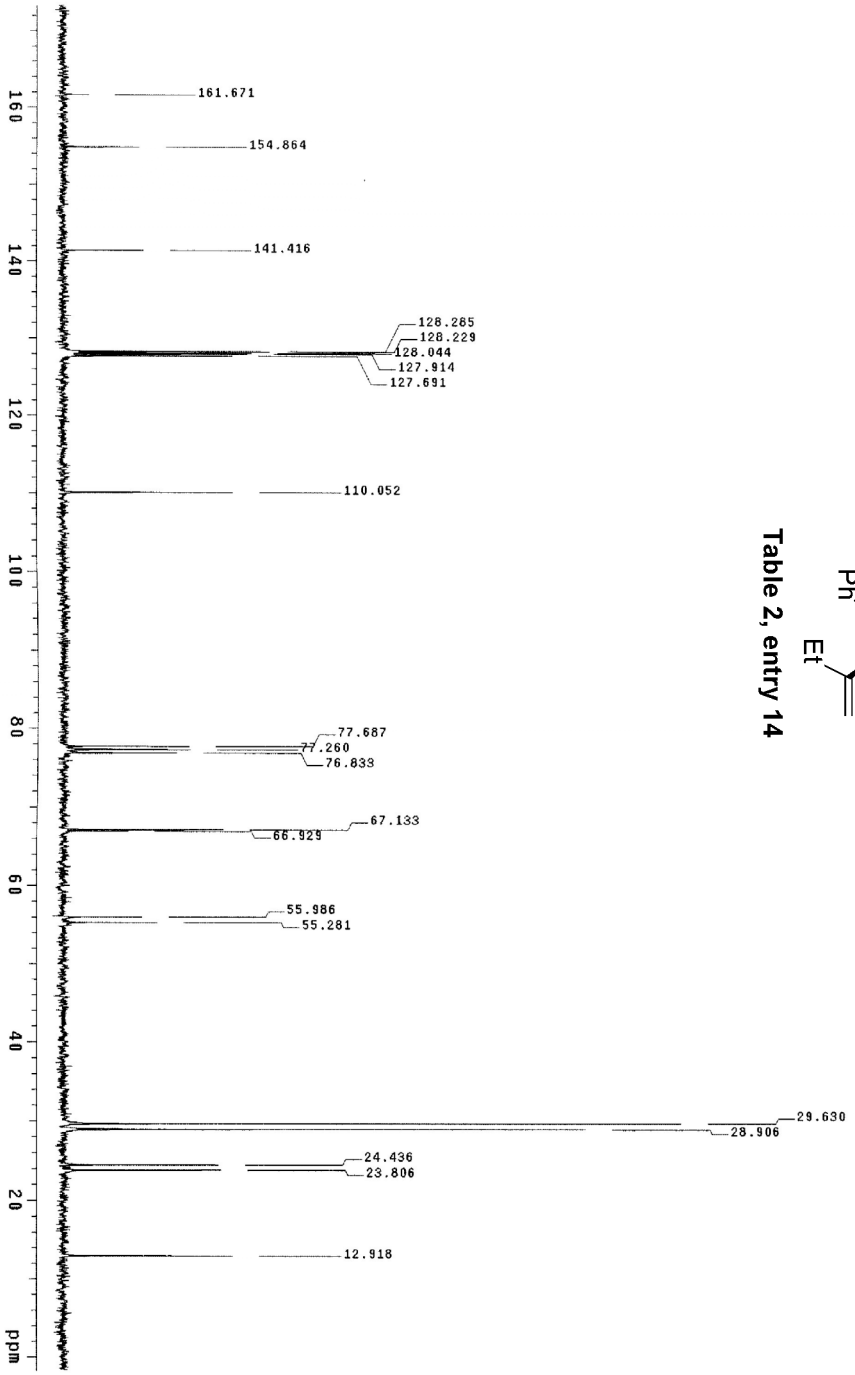
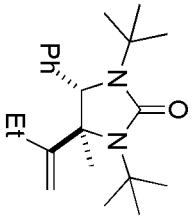
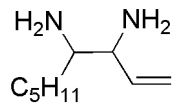
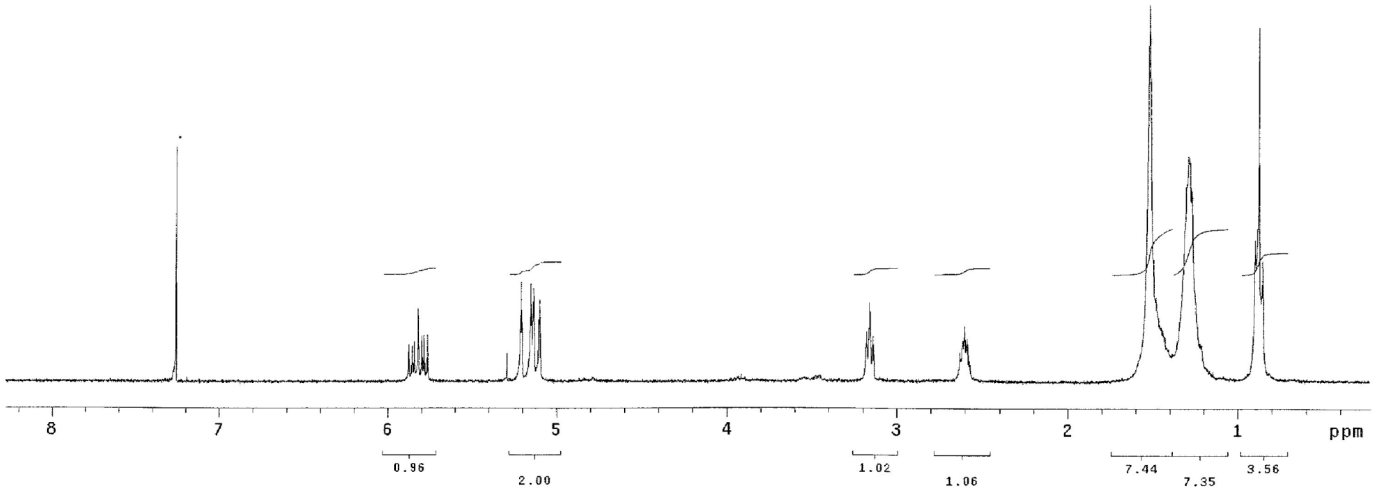


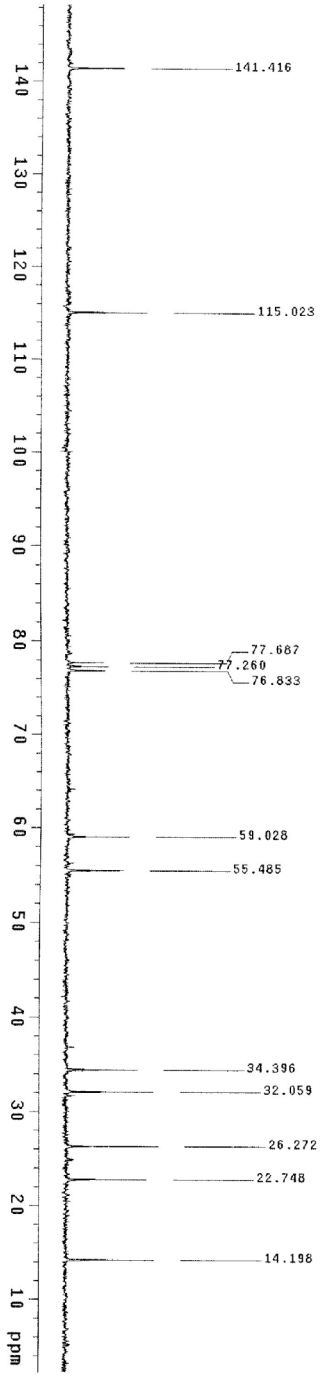
Table 2, entry 14

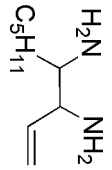




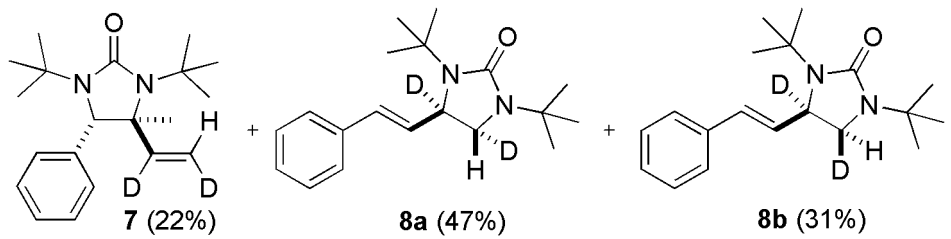
Scheme 2, (±)-5




141.416
115.023
77.687
77.260
76.833
59.028
55.485
34.396
32.059
26.272
22.748
14.198
140
130
120
110
100
90
80
70
60
50
40
30
20
10
ppm

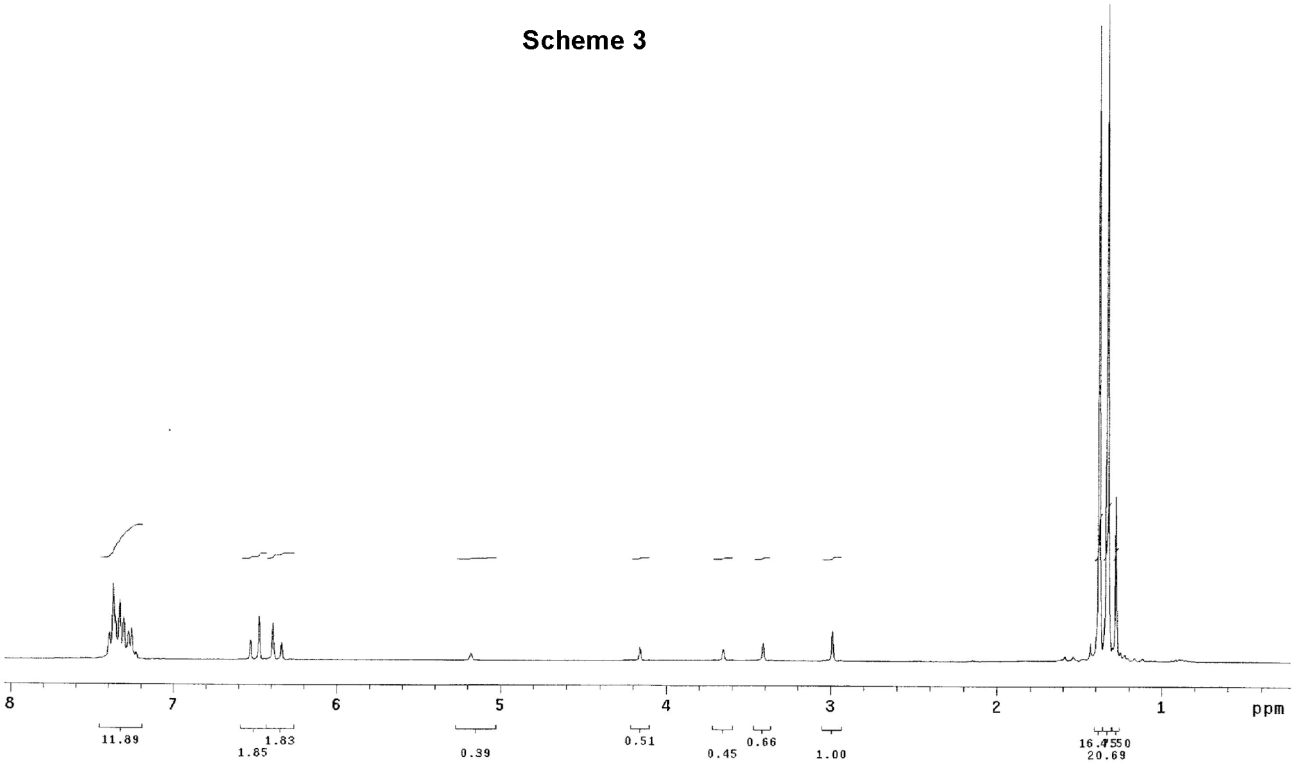

H2N
C5H11
NH2

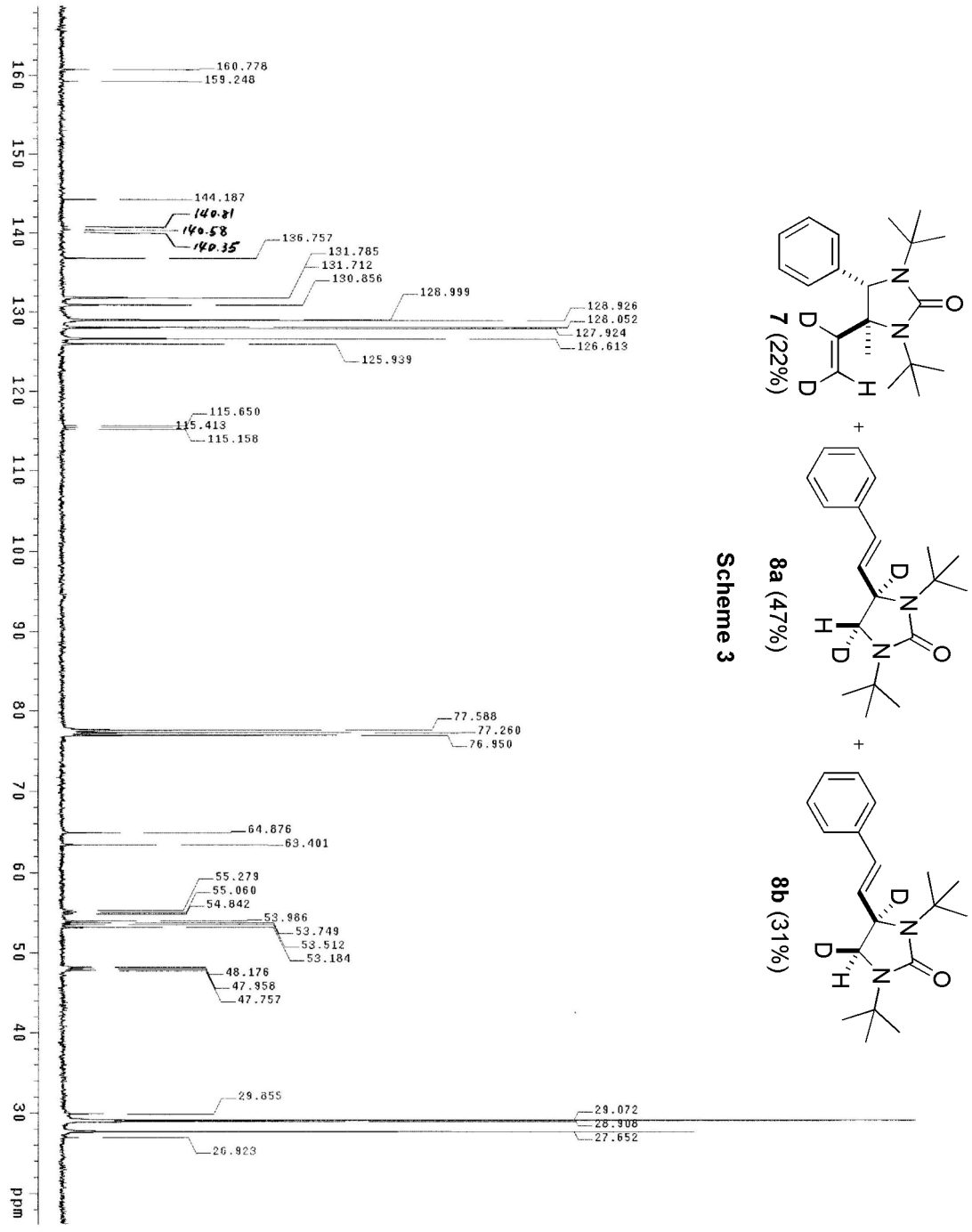
Scheme 2, (±)-5



7 (22%) + **8a** (47%) + **8b** (31%)

Scheme 3




160.778
159.248
144.187
140.81
140.58
140.35
136.757
131.785
131.712
130.856
128.999
128.926
128.052
127.924
126.613
125.939
115.650
115.413
115.158
77.588
77.260
76.950
64.876
63.401
55.279
55.060
54.842
53.986
53.749
53.512
53.184
48.176
47.958
47.757
29.855
29.072
28.908
27.652
26.923
ppm
7 (22%)
+
8a (47%)
+
8b (31%)

Scheme 3