Supporting Information

A New Look at Boron Enolate Chemistry: Aminative C-C Bond Formation Using Diaminoboron enolate with Aldehyde

Michinori Suginome,* Lars Uehlin, Akihiko Yamamoto, and Masahiro Murakami*

Department of Synthetic Chemistry and Biological Chemistry, Graduate School of Engineering, Kyoto University, and PRESTO, Japan Science and Technology Corporation (JST), Sakyo-ku, Kyoto 606-8501, Japan

Contents

1. General

All reactions were performed in drybox or using Schlenk technique under a nitrogen atmosphere with magnetic stirring. ^{1}H NMR spectra were recorded on a Varian Mercury-400 (400 MHz) or Varian GEMINI-2000 (300 MHz) spectrometer using $CDCl_3$ as solvent and tetramethylsilane as internal standard or using C_6D_6 as solvent and internal standard. ^{13}C NMR spectra were recorded on a Varian GEMINI-2000 spectrometer at 75.45 MHz with $CDCl_3$ as solvent. Chemical shifts of the ^{13}C NMR spectra were measured relative to $CDCl_3$ (77.0 ppm). ^{11}B NMR spectra were recorded on a Varian Mercury-400 spectrometer at 128.48 MHz with C_6D_6 as solvent. Chemical shifts of the ^{11}B NMR spectra were measured relative to $BF_3 \bullet Et_2O$ (0 ppm). High resolution mass (FAB) spectra were recorded on a JEOL JMS-700 spectrometer.

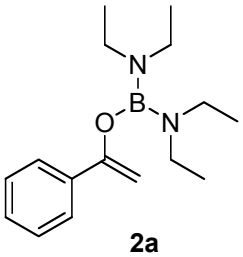
Anhydrous solvents were purchased from Kanto Chemical Co. Aldehydes and ketones were dried over CaH and distilled under Ar. Bis(diamino)chloroboranes were

synthesized according to the literature method. [1]

2. Preparation of boron enolates 2a –2e

2.1. *General procedure.*

To a solution of diisopropylamine (10 mmol) in THF (10 mL) was added *n*-butyllithium (1.6 M in hexane, 6.3 mL, 10 mmol) dropwise at 0 °C. Stiring was continued for 30 min. at 0 °C. To the reaction mixture cooled to -78 °C was added dropwise a solution of ketone (10 mmol) in THF (10 mL). After stirring for 15 min., chlorobis(dialkylamino)borane (10 mmol) was added slowly at –78 °C. The reaction mixture was allowed to warm up to room temperature and stirred further for 3 h. Evaporation of the volatile material followed by addition of hexane (20 mL) to the residue resulted in precipitation of LiCl, which was filtered off. Evaporation of hexane gave essentially pure boron enolate, which can be purified by distillation. Obtained yields varied between 82% and 97%.



2a

1-(1-bis(diethylamino)boryloxyvinyl)benzene (2a) (b.p. 90 °C/ 0.3 mmHg)

^{1}H NMR (C_6D_6): δ 0.97 (t, J = 7.2 Hz, 12H), 2.90 (q, J = 7.2 Hz, 8H), 4.42 (d, J = 1.2 Hz, 1H), 4.85 (d, J = 1.2 Hz, 1H), 7.05-7.18 (m, 3H) 7.77 (dd, J = 7.2 Hz, J = 1.2 Hz, 2H). ^{13}C NMR (C_6D_6): δ 15.6, 41.1, 87.8, 125.5, 127.9, 128.5, 137.8 , 156.9. ^{11}B NMR (C_6D_6): δ = 24.4.

3. Aminative alkylation of aldehydes

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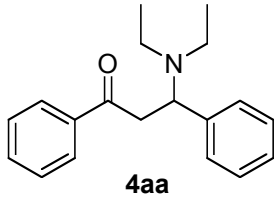
[1]Chavant, P. Y.; Vaultier M. *J. Organomet. Chem.* **1993**, 455, 37-46. Gerrard, W.; Lappert, M. F.; Pearce, C.A. *J. Chem Soc.* **1957**, 381-386.

3.1. ***General procedure.***

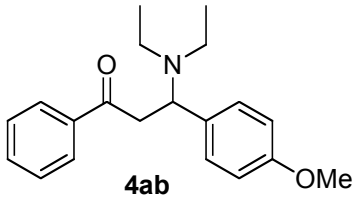
Boron enolate **2** (0.25 mmol) was dissolved in THF or DMF (0.5 mL). Aldehyde (0,50 mmol) was then added, and the mixture was stirred at 50 °C for 5 h in THF or for 1.5 to 2 h in DMF. To the reaction mixture were added ice water and, subsequently, *tert*-butyl methyl ether (15 mL). Basic components were extracted three times with hydrochloric acid (0.5 M, 5 mL × 3). The combined acid layers were washed with *tert*-butyl methyl ether (10 ml) and cooled to 0 °C. The pH of the solution was brought to 8 by addition of conc. ammonia solution. The organic material was extracted with *tert*-butyl methyl ether and washed with water (10 mL). Removal of the solvent in vacuo at 0 °C afforded the products as colorless or pale yellow oil.



4aa

3-Diethylamino-1,3-diphenyl-propan-1-one (4aa)[2]

^{1}H NMR (C_6D_6): δ = 0.90 (t, J = 7.2 Hz, 6H), 2.22 (dq, J = 13.2, 6.8 Hz, 2H), 2.42 (dq, J = 13.2, 7.2 Hz, 2H), 3.11 (dd, J = 15.6 Hz, J = 7.6 Hz, 1H), 3.26 (dd, J = 15.6 Hz, J = 6.4 Hz, 1H), 4.70 (t, J = 7.0 Hz, 1H), 6.98-7.24 (m, 8H), 7.78 (dd, J = 6.8, 1.6 Hz, 2H). ^{13}C NMR (C_6D_6): δ = 13.9, 41.2, 44.0, 60.5, 127.5, 128.9, 129.0, 130.6, 132.9, 141.8, 199.6.



4ab

3-Diethylamino-3-(4-methoxy-phenyl)-1-phenyl-propan-1-one (4ab)

^{1}H NMR (C_6D_6): δ 0.98 (t, J = 7.2 Hz, 6H), 2.31 (dq, J = 13.2, 6.8 Hz, 2H), 2.58 (dq, J =

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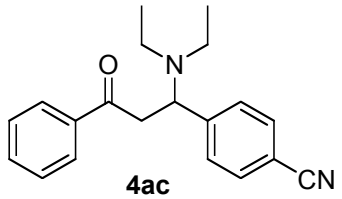
[2]Hosomi, A.; Yanagi, T.; Hojo, M.; *Tetrahedron Lett.* **1991**, 32, 2371-2374; Clark, J. H.; Cork, D. G.; Gibbs, H. W.; *Perkin Trans. 1* **1983**, 9, 2253-2258; Clark, J. H.; Cork, D. G.; *Chem. Commun.* **1982,** 11, 935-936.

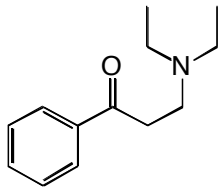
13.2, 7.2 Hz, 2H), 3.38 – 3.50 (m, 2H), 3.76 (s, 3H), 4.52 (t, J = 7.0 Hz, 1H), 6.81 (d, J = 8.8 Hz, 2H), 7.21 (d, J = 8.8 Hz, 2H), 7.45 (t, J = 8.0 Hz, 2H), 7.55 (δ, J = 6.8 Hz, 1H), 7.91 (dd, J = 8.4, 1.6 Hz, 2H). ^{13}C NMR (C_6D_6): δ 13.0, 41.3, 43.2, 55.1, 59.2, 113.3, 128.1, 128.4, 129.4, 130.3, 132.8, 137.5, 158.5, 199.4. IR (neat): 2970, 2834, 1683, 1609, 1511, 1447, 1246, 1179, 1036, 831, 708 cm^{-1}. MS (FAB): *m/z* (%) 312 (12) [M+H$^+$], 289 (19), 239 (37), 192 (11), 154 (100), 136 (66), 119 (10), 107 (18), 89 (14), 77 (12), 65 (5). HRMS for $C_{20}H_{25}O_2N$•H$^+$: calcd.: 312.1964, found: 312.1964.



4ac

4-(3-Diethylamino-3-phenyl-propionyl)-benzonitrile (4ac)

^{1}H NMR ($CDCl_3$): δ 0.89 (t, J = 7.2 Hz, 6H), 2.36 (dq, J = 13.2 Hz, J = 6.8 Hz, 2H), 2.52 (dq, J = 13.2 Hz, J = 6.8 Hz, 2H), 3.41-3.61(m, 2H), 4.60 (dd, J = 8.0, 5.6 Hz, 1H), 7.41-7.57 (m, 8H) 7.89 (dd, J = 7.2, 1.6 Hz, 2H). ^{13}C NMR ($CDCl_3$): δ 13.0, 39.7, 43.4, 59.3, 110.6, 118.9, 127.9, 128.7, 129.0, 131.9, 133.3, 136.9, 147.2, 198.5. IR (neat): 2970, 2811, 2229, 1683, 1607, 1385, 1206, 1065, 841, 691 cm^{-1}. MS (FAB): *m/z* (%) 307 (31) [M+H$^+$], 277 (5), 234 (5), 187 (100), 159 (4), 135 (4), 105 (39), 89 (6), 77 (8). HRMS for $C_{20}H_{23}ON_2$•H$^+$: calcd.: 307.1810, found: 307.1810.



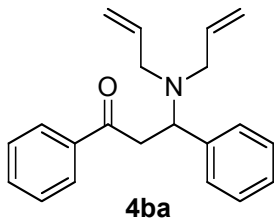
4ad

3-(Diethylamino)-1-phenylpropan-1-one (4ad)[3]

^{1}H NMR (C_6D_6): δ 1.05 (t, J = 7.2 Hz, 6H), 2.57 (q, J = 7.2 Hz, 2H), 2.91 (dd, J = 8.4 Hz, J = 6.4 Hz, 2H), 3.14 (dd, J = 8.0, 6.8 Hz, 2H), 7.45 (dt, J = 6.8, 1.2 Hz, 2H), 7.53 (t, J = 6.0

[3] Rochin, C.; Babot, O.; Dunogues, J.; Duboudin, F. *Synthesis* **1986**, 8, 667-668.

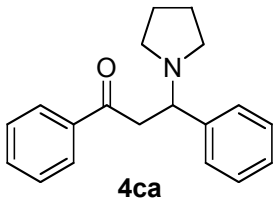
Hz, 1H), 7.96 (dt, J = 6.8, 1.2 Hz, 2H). ^{13}C NMR (C_6D_6): δ 11.7, 36.3, 46.9, 47.8, 128.1, 128.6, 133.8, 137.1, 199.9.



4ba

3-Diallylamino-1,3-diphenyl-propan-1-one (4ba)

^{1}H NMR (C_6D_6): δ 2.73 (dd, J = 14.4 Hz, J = 7.6 Hz, 2H), 3.09 (dd, J = 15.6 Hz, J = 7.2 Hz, 1H), 3.15 – 3.20 (m, 2H), 3.31 (dd, J = 15.6 Hz, J = 7.6 Hz, 1H), 4.77 (t, J = 7.2 Hz, 1H), 4.93 – 5.10 (m, 4H), 5.67 – 5.76 (m, 2H), 6.99-7.18 (m, 7H), 7.34 (d, J = 7.6 Hz, 1H), 7.77 (dd, J = 6.8 Hz, J = 1.8 Hz, 2H). ^{13}C NMR (C_6D_6): δ = 42.7, 54.7, 61.2, 118.3, 128.9, 129.9, 130.0, 130.1, 130.3, 138.0, 138.9, 141.2, 199.2. IR (film): 3080, 2813, 1686, 1580, 1493, 1449, 1285, 996, 919, 702 cm^{-1}. MS (FAB): *m/z* (%) 306 (89) [M+H$^+$], 289 (17), 264 (20), 186 (100), 154 (92), 136 (54), 105 (52), 96 (39), 89 (10). HRMS for $C_{21}H_{24}ON\bullet H^+$: calcd.: 306.1858, found: 306.1856.

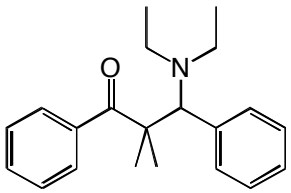


4ca

1,3-Diphenyl-3-pyrrolidin-1-yl-propan-1-one (4ca)[4]

^{1}H NMR (C_6D_6): δ 1.47 (brm, 4H), 2.34 (brm, 4H), 3.12 (dd, J = 16.0, 6.8 Hz, 1H), 3.35 (dd, J = 16.0, 6.0 Hz, 1H), 4.13 (t, J = 6.4 Hz, 1H), 6.91-7.12 (m, 6H), 7.41 (d, J = 8.0 Hz, 1H), 7.77 (dd, J = 6.8, 1.8 Hz, 2H). ^{13}C NMR (C_6D_6): δ 24.0, 46.2, 52.7, 65.9, 127.7, 128.7, 128.9, 132.9, 138.3, 144.2, 197.8.

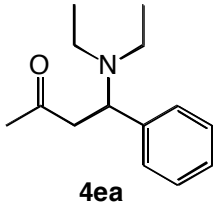
[4]Kinastowski, S.; Grabarkiewicz-Szczesna, J.; Kostecki, M.; *Pol. J. Chem*. **1980**, 9, 1697-1706.



4da

3-Diethylamino-2,2-dimethyl-1,3-diphenyl-propan-1-one (4da)

^{1}H NMR ($CDCl_3$): δ 0.82 (t, J = 7.2 Hz, 6H), 1.05 (s, 3H), 1.38 (s, 3H), 2.21 (dq, J = 13.2, 6.8 Hz, 2H), 2.61 (dq, J = 13.2, 7.2 Hz, 2H), 4.33 (s, 1H), 7.17-7.33 (m, 8H), 7.51 (dd, J = 6.8, 1.6 Hz, 2H) . ^{13}C NMR ($CDCl_3$): δ 12.5, 22.9, 27.1, 45.2, 52.8, 71.2 110.9 118.8 , 127.0, 127.7, 127.8, 130.1, 130.6, 138.8, 199.2. IR (neat): 2968, 2931, 2815, 1697, 1493, 1468, 1382, 1057, 756, 700 cm^{-1}. MS (FAB): *m/z* (%) 310 (43) [M+H$^+$], 289 (17), 188 (6), 163 (48), 154 (100), 136 (58), 105 (18), 89 (10), 77 (9). HRMS for $C_{21}H_{28}ON \bullet H^+$: calcd.: 310.2171, found: 310.2171.

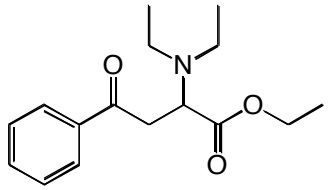


4ea

4-(diethylamino)-4-phenylbutan-2-one (4ea)[5]

^{1}H NMR ($CDCl_3$): δ 1.01 (t, J = 6.9 Hz, 6H), 2.10 (s, 3H), 2.26 (dq, J = 13.2, 7.2 Hz, 2H), 2.60 (dq, J = 14.7, 7.2 Hz, 2H), 2.79 (dd, J = 15.0, 7.5 Hz, 1H), 3.01 (dd, J = 15.0, 6.9 Hz, 1H), 4.33 (t, J = 7.5 Hz, 1H), 7.23 – 7.33 (m, 5H). ^{13}C NMR ($CDCl_3$): δ 13.1, 30.4, 43.2, 46.5, 59.6, 127.1, 128.1, 128.3, 139.9, 207.9.

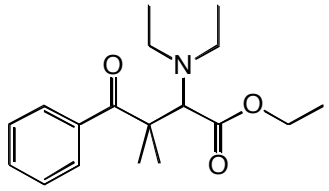
[5] Clark, J. H.; Cork, D. G., *Chem. Commun.* **1982**, 11, 635-636.



4ae

Ethyl 2-(diethylamino)-4-oxo-4-phenylbutanoate (4ae)

^{1}H NMR (C_6D_6): δ 1.05 (t, J = 7.2 Hz, 6H), 1.28 (t, J = 7.2 Hz, 3H), 2.56 (dq, J = 12.8, 6.8 Hz, 2H), 2.67 (dq, J = 12.8, 7.2 Hz, 2H), 3.31 (dd, J = 17.6, 4.8 Hz, 1H), 3.57 (dd, J = 17.6, 8.4 Hz, 1H), 4.15-4.19 (m, 3H), 7.47 (t, J = 8.0 Hz, 2H), 7.53-7.59 (m, 1H), 7.97 (dd, J = 8.8, 1.6 Hz, 2H). ^{13}C NMR (C_6D_6): δ 13.9, 14.3, 38.7, 45.1, 58.7, 60.4, 128.1, 128.6, 133.1, 137.0, 172.4, 199.6. IR (neat): 2964, 2858, 1698, 1636, 1470, 1397, 1260, 1065, 801, 699 cm^{-1}. MS (FAB): *m/z* (%) 278 (90) [M+H$^+$], 204 (100), 158 (46), 154 (29), 136 (19), 105 (28), 77 (8), 56 (7). HRMS for $C_{16}H_{24}O_3N\bullet H^+$: calcd.: 278.1756, found: 278.1749.



4de

Ethyl 2-(diethylamino)-3,3-dimethyl-4-oxo-4-phenylbutanoate (4de)

^{1}H NMR (C_6D_6): δ 1.05 (t, J = 7.2 Hz, 6H), 1.25 (t, J = 7.2 Hz, 3H), 1.34 (s, 6H), 2.57 (dq, J = 13.2, 7.2 Hz, 2H), 2.68 (dq, J = 13.2, 6.8 Hz, 2H), 4.06 (s, 1H), 4.09-4.20 (m, 2H), 7.37-7.40 (m, 3H), 7.53 (dd, J = 7.6 Hz, J = 1.6 Hz, 2H). ^{13}C NMR (C_6D_6): δ 14.1, 14.4, 20.8, 26.2, 47.4, 60.1, 69.3 127.1, 127.9, 129.9, 140.6, 172.4, 197.8. IR (film): 2971, 2933, 1723, 1679, 1466, 1382, 1198, 1069, 963, 758, 700 cm^{-1}. MS (FAB): *m/z* (%) 306 (20) [M+H$^+$], 289 (9), 232 (12), 158 (100), 154 (48), 136 (37), 120 (6), 105 (18), 89 (7), 73 (34), 56 (5). HRMS for $C_{18}H_{28}O_3N\bullet H^+$: calcd.: 306.2069, found: 306.207.

Reaction of boron enolate 5 with benzaldehyde. (Table 2)

Reactions were carried out according to the general procedure. The compounds **7a** and **7b**

were reported in the literature.[6]

Crossover experiment using boron enolate 2b and 2e. (Scheme 2)

Boron enolate **2b** (40.0 mg, 0.125 mmol) was dissolved in DMF-d^7 (0.6 mL). Boron enolate **2e** (26.5 mg, 0.125 mmol) was added and the mixture was heated for 2 h at 50 °C. ^{1}H NMR data showed no formation of boron enolates other than **2b** and **2e**. Benzaldehyde (52 μl, 0.5 mmol) was added and the mixture was stirred for 2 h at 50 °C. To the yellow solution cooled to room temperature were added ice water (3 ml) and *t*-butyl methyl ether (15 ml). Basic substances were extracted three times with 5 ml 0.5 N hydrochloric acid. The combined acidic aqueous layers were washed with 10 ml *t*-butyl methyl ether, cooled to 0 °C, and adjusted to pH 9 by addition of conc. ammonia solution. Organic material was extracted with *t*-butyl methyl ether and washed with 10 ml water. Removal of the solvent in vacuo at 0 °C yielded 51 mg of a product mixture containing **4aa** and **4ea** in a ratio of 1:1.38. Yield: **4aa**: 69 %, **4ea**: 95 % .

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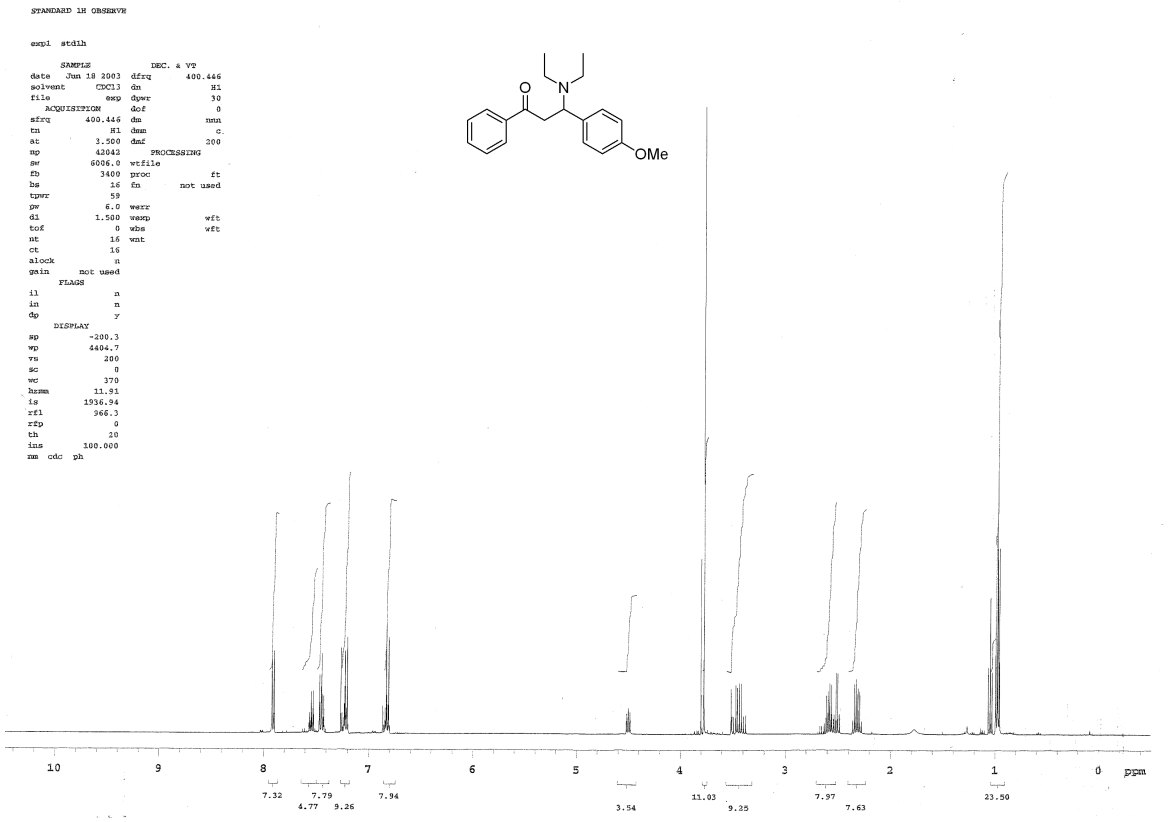
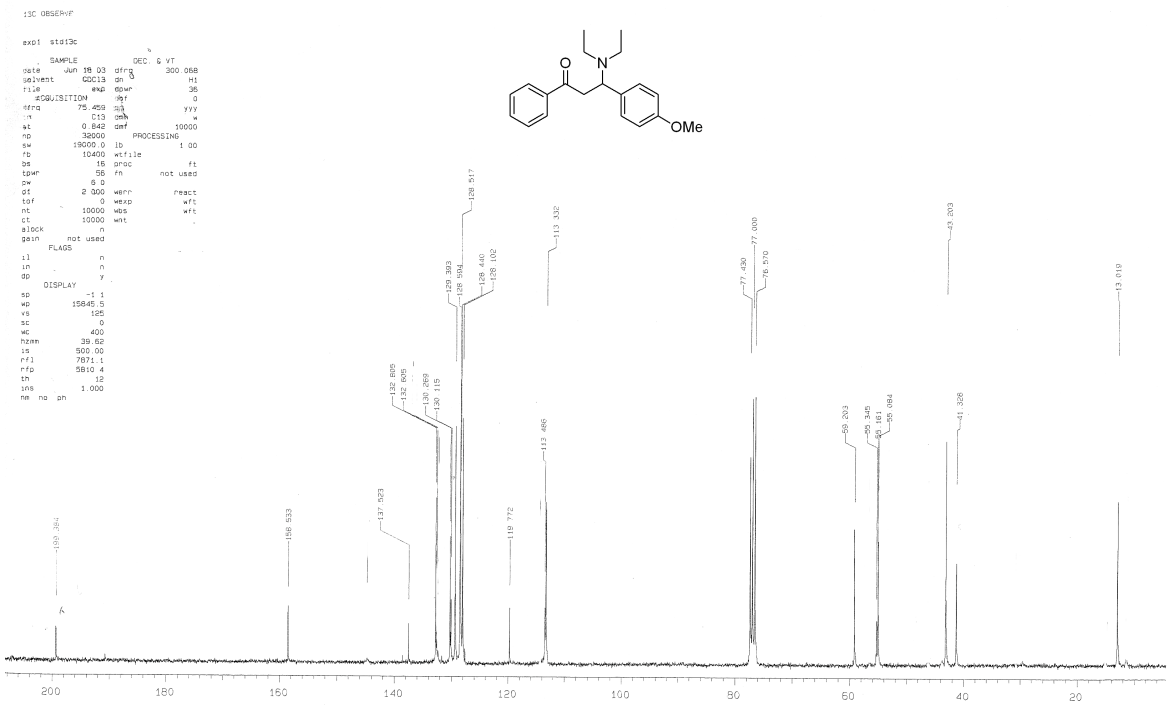
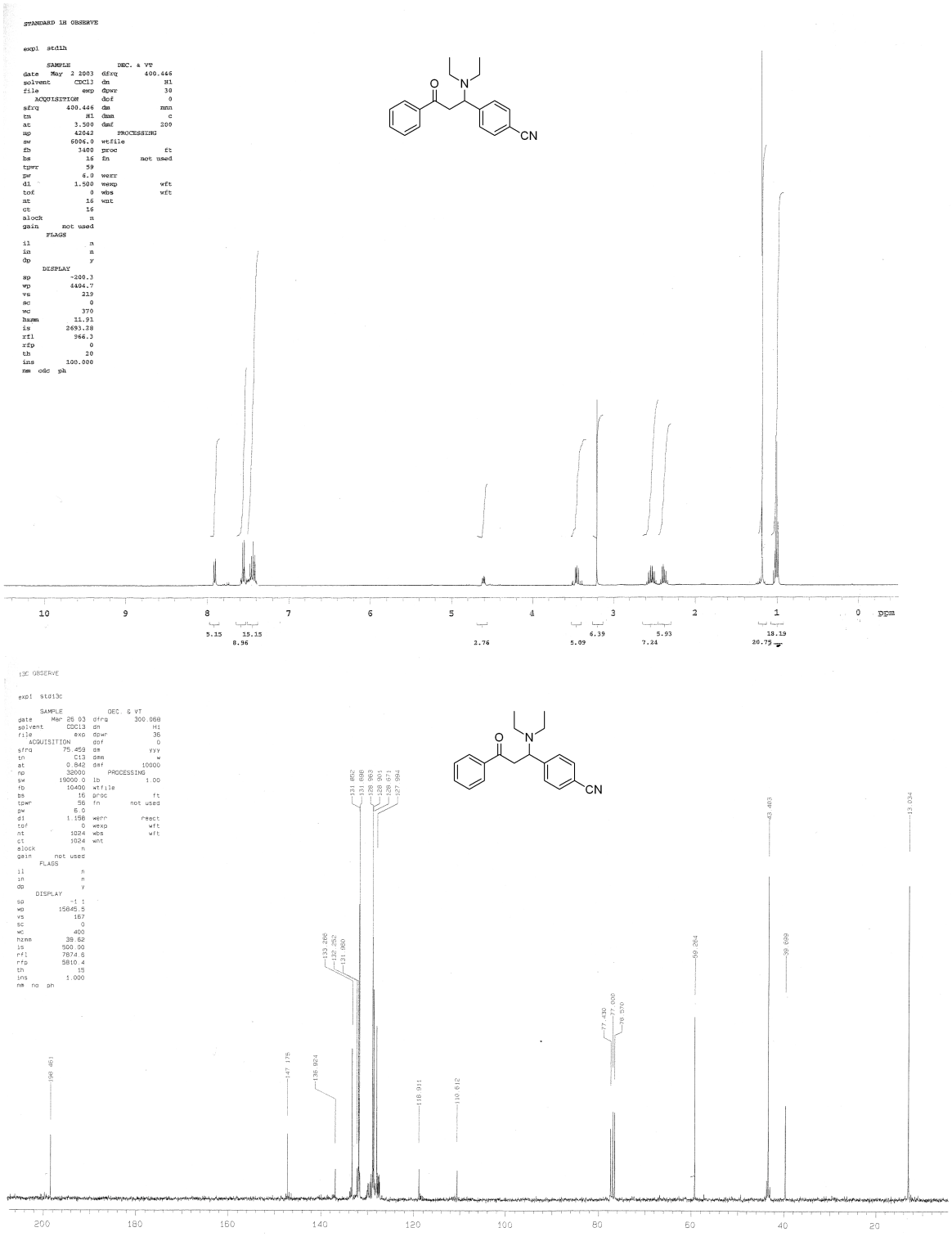
[6] **7a**: Arend, M.; Nikolaus, R. *Angew. Chem*. **1995**, *107*, 2861. **7b**: Seebach, D.; C. Betschart; M. Schiess, *Helv. Chim. Acta*. **1984**, *67*, 1593.

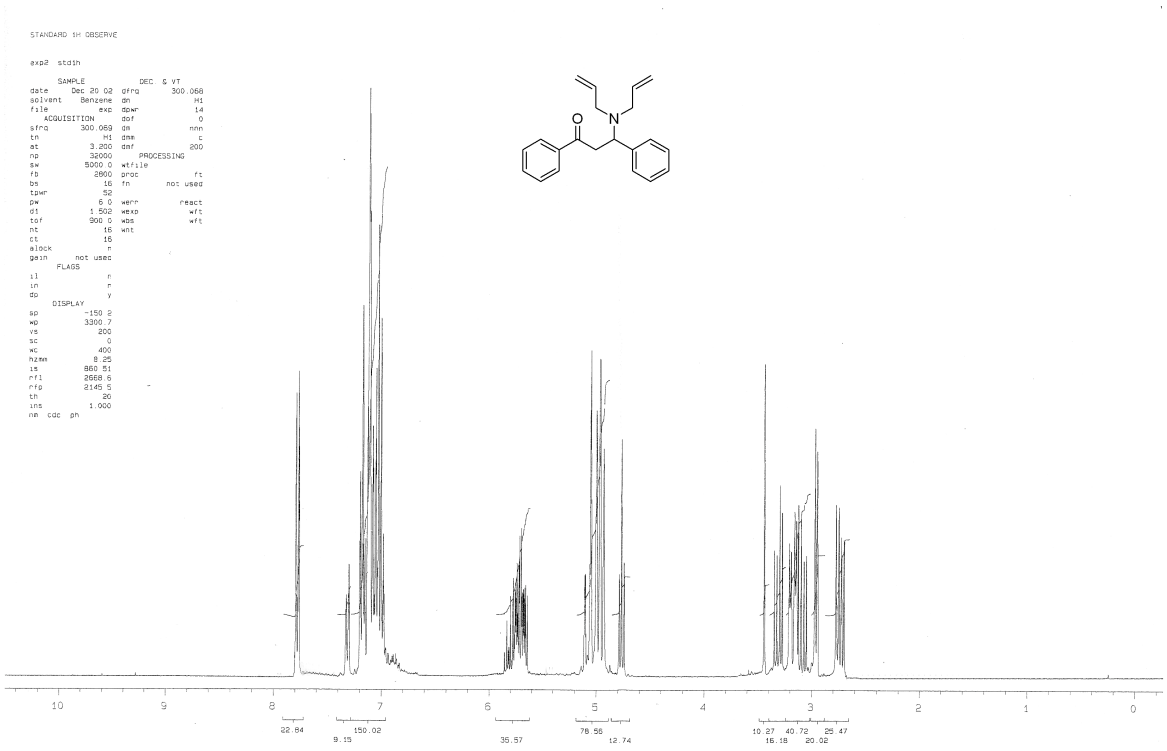


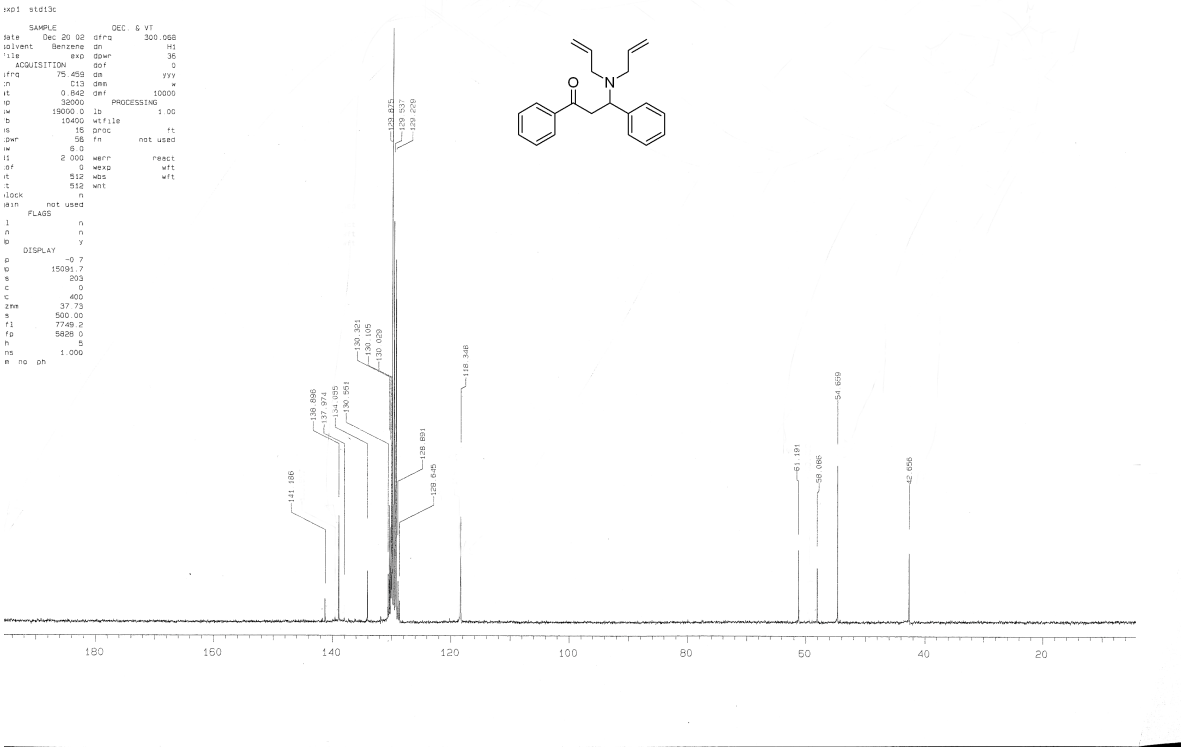


^{1}H and ^{13}C NMR spectra of **4ab**

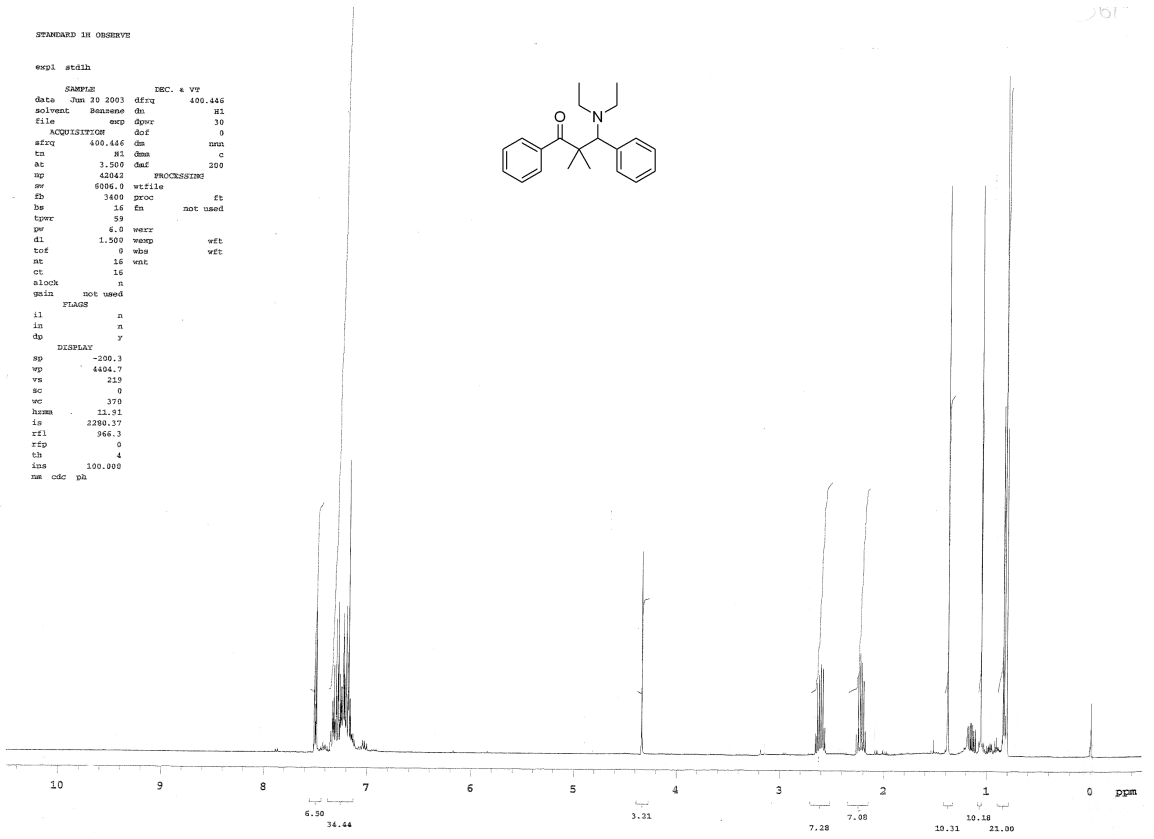


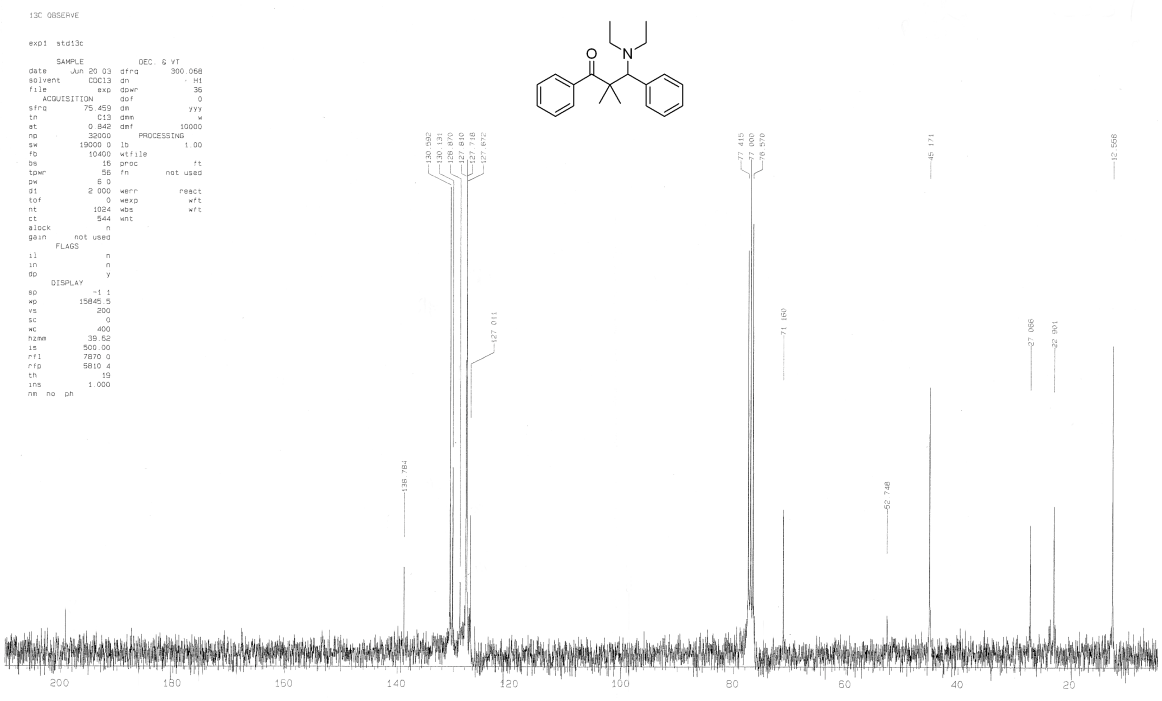
^{1}H and ^{13}C NMR spectra of **4ac**



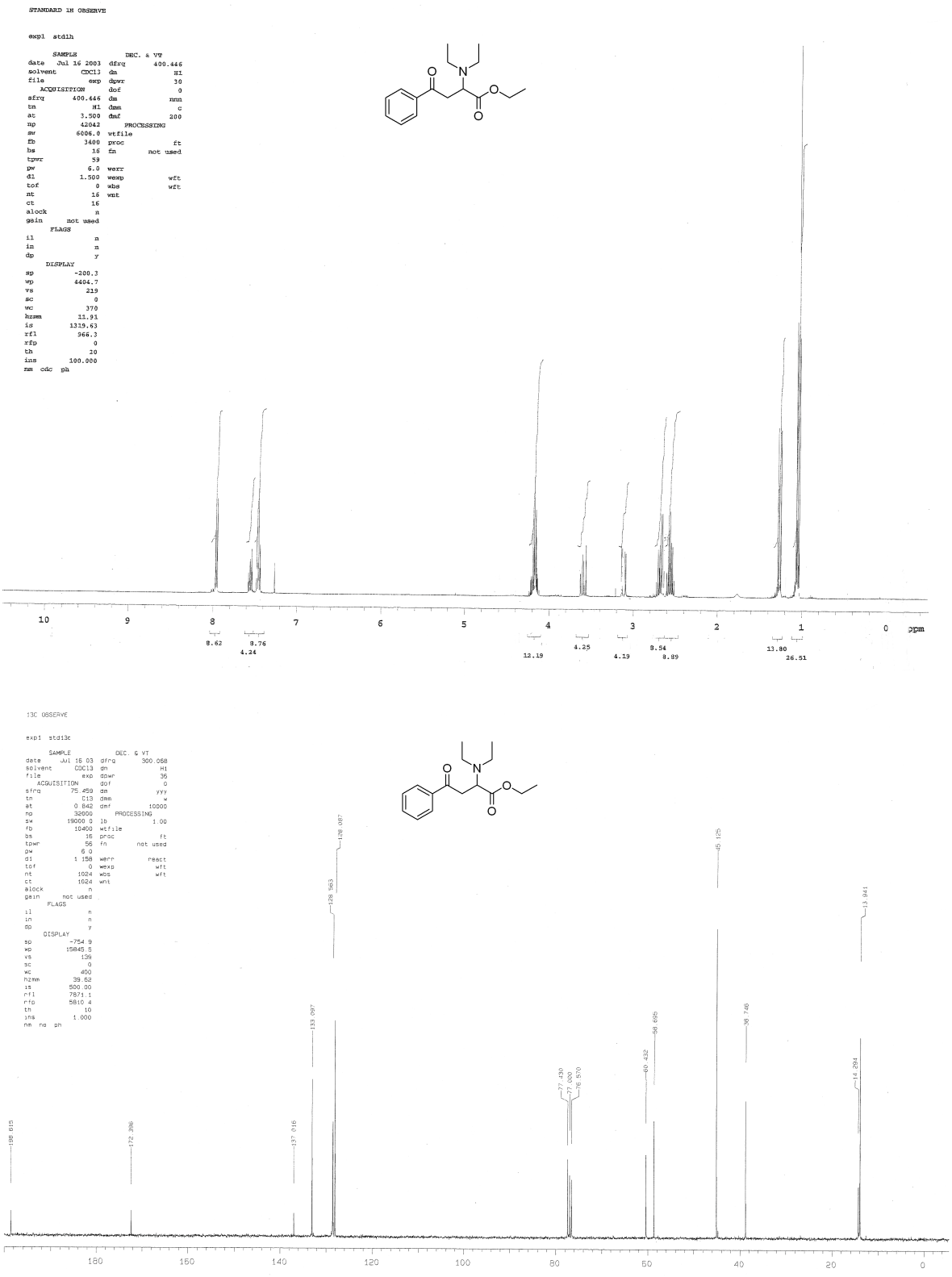


^{1}H and ^{13}C NMR spectra of **4ba**

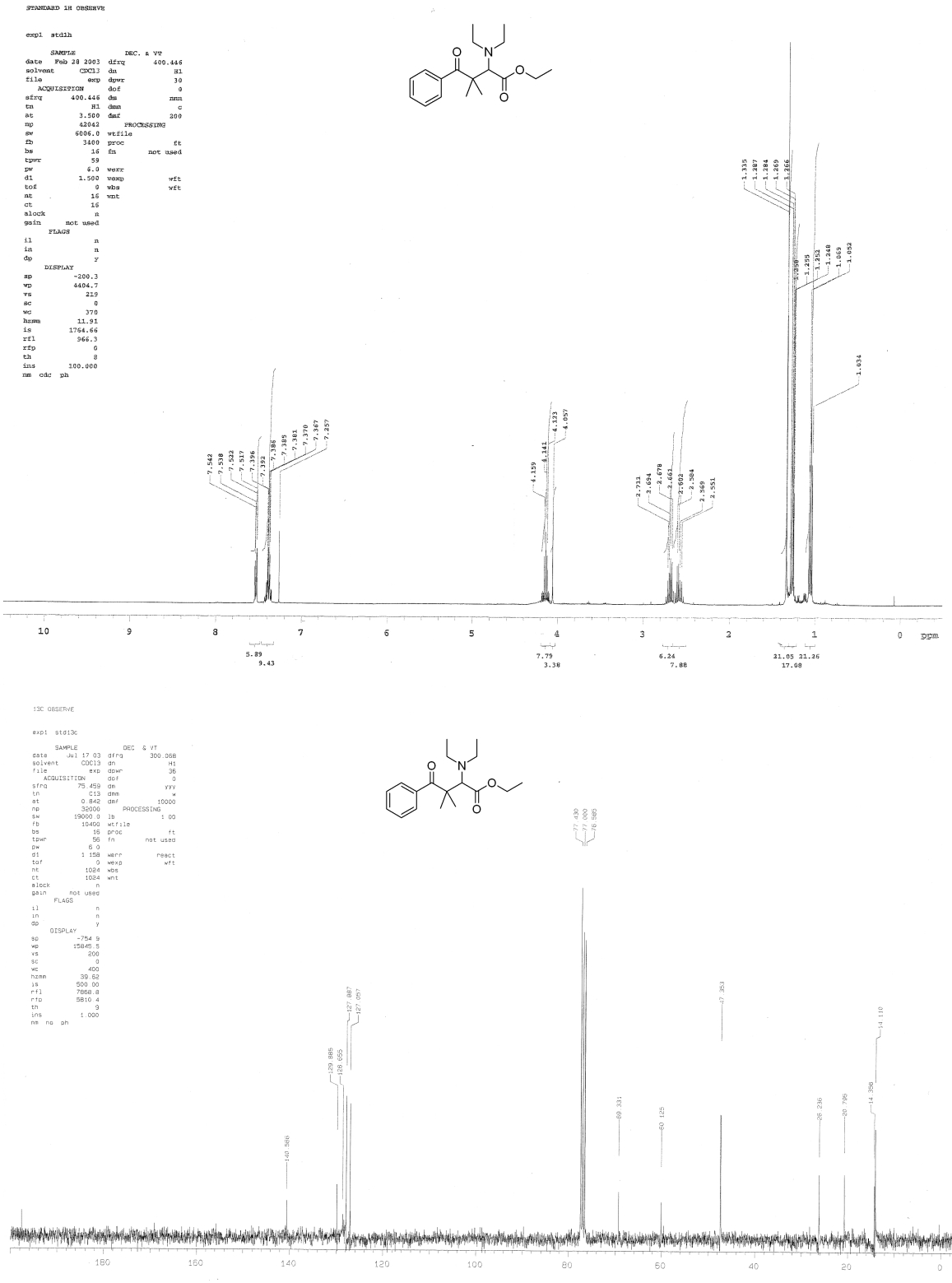




^{1}H and ^{13}C NMR spectra of **4da**



^{1}H and ^{13}C NMR spectra of **4ae**



^{1}H and ^{13}C NMR spectra of **4de**