

Catalyzed Olefin Isomerization Leading to Highly Stereoselective Claisen Rearrangements of Aliphatic Allyl Vinyl Ethers

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Supporting Information

General Information: Unless otherwise stated, all reactions were performed in dry glassware under an atmosphere of oxygen-free nitrogen using standard inert atmosphere techniques for the manipulation of solvents and reagents. Anhydrous solvents were obtained by passage through successive alumina- and Q5 reactant-packed columns on a solvent purification system. Acetone was used as purchased. Sodium hydride (60 % dispersion in mineral oil) was washed with hexanes (3x) and dried under vacuum before use. Crotyl bromide, allyl bromide and allyl acetate were distilled from CaH_2 . $[(^{\text{C}}\text{C}_8\text{H}_{14})_2\text{IrCl}]_2$ ¹ and PCy_3 were stored and weighed out in a nitrogen-filled glove box. Proton NMR spectra were recorded on a Bruker Avance-300 (300 MHz) spectrometer with chemical shifts reported relative to residual CHCl_3 (7.26 ppm) for ^1H and CDCl_3 (77.0 ppm) for ^{13}C NMR spectra. Flash chromatography was performed as previously described on EM silica gel 60 (230-240 mesh).² Analytical high performance liquid chromatography (HPLC) was performed on a Hewlett Packard 1100 liquid chromatograph equipped with a variable wavelength UV detector (deuterium lamp, 190-600 nm), using a Daicel ChiracelTM OD-H column (250 x 4.6 mm) (Daicel Inc.). HPLC grade isopropanol and hexanes were used as the eluting solvents. Analytical gas liquid chromatography (GLC) was performed on a Varian 3900 gas chromatograph with a flame ionization detector and split mode capillary injection system using a Varian CP Wax 52CB column (30 m x 0.25 mm).

Compound Characterization and Determination of Diastereomer Ratios: The α -chiral aldehyde Claisen products **2** were subject to significant epimerization of the α -stereocenter during attempted chromatographic purification. As a result, diastereomer ratios were determined for the crude aldehydes **2a-h, j-l** by integrating the aldehyde CHO resonances in the ^1H NMR; these resonances for the diastereomeric aldehydes were well resolved and readily integrated. The assignment of these resonances as belonging to the diastereomeric aldehydes differing in configuration at the α -stereocenter was confirmed by stirring a solution of the crude aldehyde with DBU and observing the increase in the minor aldehyde resonance. Diastereomer ratios for **2i** were determined by GC of the corresponding primary alcohol; see experimental section for methods. Stereochemical assignment of the major aldehyde diastereomer as *syn* was made by comparing spectral data for **2j** with literature data;³ the stereochemical assignment of the remaining Claisen adducts **2** were made by analogy to this assignment. To avoid the need for fully characterizing the diastereomeric mixture of aldehydes that would result from chromatographic purification, full characterization of the Claisen rearrangement products **2** was obtained for the primary alcohols obtained by direct $^t\text{Bu}_2\text{AlH}$ reduction of the crude aldehyde products; see **General Procedure D** below.

General Procedure A for preparing of di(allyl)ethers 1a,c,d,h-l: A solution of the allylic alcohol (5.0 mmol) in THF (10 ml) was added to a suspension of pre-washed NaH (400 mg, 10.0 mmol) in THF (10 ml). The resulting suspension was heated at reflux for 30 min whereupon allyl bromide or crotyl bromide (15.0 mmol) was added and the resulting suspension heated at reflux for a further 2 h. The reaction mixture was then cooled to ambient temperature and poured into ice. The THF was evaporated *in vacuo* and the aqueous residue was extracted with Et_2O (3x) and the combined organic extracts were dried (MgSO_4). The solvent was removed *in vacuo* and the residue purified as indicated.

General Procedure B for preparing of di(allyl)ethers 1f,g:⁴ A hexanes solution of Et_2Zn (1 M in hexanes, 2.94 ml, 2.94 mmol) was added to a solution of the allylic alcohol (4.52 mmol) in anhydrous THF (2.5 ml) at ambient temperature. The resulting homogeneous solution was stirred for 30 min then added via syringe to a solution of

¹ Onderdelinden, A. L.; van der Ent, A. *Inorganica Chimica Acta* **1972**, 6, 420.

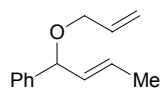
² Still, W. C.; Kahn, M.; Mitra, A. *J. Org. Chem.* **1978**, 43, 2923.

³ Nonoshita, K.; Maruoka, K.; Yamamoto, H. *B. Chem. Soc. Jpn.* **1992**, 65, 541.

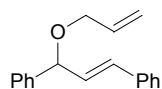
⁴ Kim, H.; Lee, C. *Org. Lett.* **2002**, 4, 4369.

$\text{Pd}(\text{PPh}_3)_4$ (5 mol %, 262 mg, 0.226 mmol) and allyl acetate (1.5 equiv, 732 μL , 6.78 mmol) in anhydrous THF (2.5 ml). The reaction was stirred for 2 days at ambient temperature whereupon the solvent was removed *in vacuo* and the residue purified as indicated.

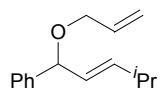
General Procedure C for preparing di(allyl)ethers 1b,e: Five drops of concentrated H_2SO_4 were added to a solution of (*E*)-1,3-diphenyl-2-propen-1-ol⁵ and allyl alcohol or crotyl alcohol (1.1 equiv) in anhydrous THF (10 ml). The resulting solution was stirred for 1 h at ambient temperature whereupon H_2O (10 ml) was added and the resulting mixture was extracted with Et_2O (3x). The combined organic extracts were washed with brine, dried (MgSO_4) and filtered. The solvent was removed *in vacuo* and the product mixture was purified as indicated.



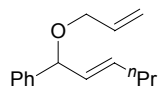
(*E*)-1-Allyloxy-1-phenyl-2-butene (1a): General Procedure A was followed employing 14.4 g of (*E*)-1-phenyl-2-buten-1-ol (97 mmol).⁶ Purification by vacuum distillation gave 16.6 g (91%) of the title compound as a colorless oil. ^1H NMR (300 MHz, CDCl_3): δ 1.64 (d, $J=5.6$ Hz, 3H), 3.88 (m, 2H), 4.68 (d, $J=6.7$ Hz, 1H), 5.10 (dd, $J=10, 1.4$ Hz, 1H), 5.20 (dd, $J=18, 1.6$ Hz, 1H), 5.49-5.68 (m, 2H), 5.80-5.93 (m, 1H), 7.16-7.27 (m, 5H); ^{13}C NMR (75 MHz, CDCl_3): δ 17.7, 68.9, 81.8, 116.6, 126.7, 127.3, 128.2, 128.3, 132.1, 134.9, 141.6; MS (EI, 70 eV): m/z 187 ($\text{M}^+ - \text{H}$), 147, 131, 115, 105, 91, 77, 69; HRMS m/z calcd for $\text{C}_{13}\text{H}_{16}\text{O}$: 188.1201; found 188.1197.



(*E*)-3-Allyloxy-1,3-diphenyl-2-propene (1b): General Procedure C was followed employing 3.67 g of (*E*)-1,3-diphenyl-2-propen-1-ol (17.5 mmol).⁴ Purification by flash chromatography (5% EtOAc/hexanes) gave 3.65 g (84%) of the title compound as a colorless oil. ^1H NMR (300 MHz, CDCl_3): δ 4.00 (ddt, $J=12.8, 5.6, 1.4$ Hz, 1H), 4.06 (ddt, $J=12.8, 5.4, 1.3$ Hz, 1H), 4.97 (d, $J=7.0$ Hz, 1H), 5.20 (dq, $J=10.5, 1.3$ Hz, 1H), 5.31 (dq, $J=17.2, 1.6$ Hz, 1H), 5.97 (ddt, $J=17.1, 10.4, 5.5$ Hz, 1H), 6.30 (dd, $J=15.9, 7.0$ Hz, 1H), 6.61 (d, $J=15.9$ Hz, 1H), 7.41-7.20 (m, 10H); ^{13}C NMR (75 MHz, CDCl_3): δ 69.0, 81.5, 116.7, 126.4, 126.7, 127.5, 128.3, 130.1, 131.2, 134.7, 136.4, 141.0; MS (EI, 70 eV): m/z 250 (M^+), 220, 207, 193, 181, 165, 145, 131, 115, 105, 91, 77, 65; HRMS m/z calcd for $\text{C}_{18}\text{H}_{18}\text{O}$: 250.1358; found 250.1368.



(*E*)-1-Allyloxy-4-methyl-1-phenyl-2-pentene (1c): General Procedure A was followed employing 1.75 g of (*E*)-1-phenyl-4-methyl-2-penten-1-ol (10 mmol).⁷ Purification by flash chromatography (2% EtOAc/hexanes) gave 1.99 g (92%) of the title compound as a colorless oil. ^1H NMR (300 MHz, CDCl_3): δ 0.89 (d, $J=6.7$ Hz, 3H), 0.91 (d, $J=6.7$ Hz, 3H), 2.25-2.18 (m, 1H), 3.84 (ddt, $J=12.8, 5.5, 1.5$ Hz, 1H), 3.90 (ddt, $J=12.8, 5.5, 1.5$ Hz, 1H), 4.67 (d, $J=7.2$ Hz, 1H), 5.09 (dq, $J=10.4, 1.5$ Hz, 1H), 5.20 (dq, $J=17.2, 1.7$ Hz, 1H), 5.45 (ddd, $J=15.5, 7.2, 1.0$ Hz, 1H), 5.59 (dd, $J=15.5, 6.3$ Hz, 1H), 5.92-5.79 (m, 1H), 7.26-7.16 (m, 5H); ^{13}C NMR (75 MHz, CDCl_3): δ 22.2, 22.3, 30.7, 68.9, 81.9, 116.7, 126.7, 127.3, 127.7, 128.3, 135.0, 140.6, 141.8; MS (EI, 70 eV): m/z 216 (M^+), 173, 159, 143, 131, 117, 105, 97, 91, 77; HRMS m/z calcd for $\text{C}_{15}\text{H}_{20}\text{O}$: 216.1514; found 216.1507.



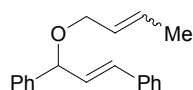
(*E*)-1-Allyloxy-1-phenyl-2-hexene (1d): General Procedure A was followed employing 5.54 g of (*E*)-1-phenyl-2-hexen-1-ol (31 mmol).⁸ Purification by flash chromatography (2% EtOAc/hexanes) gave 5.96 g (90%) of the title compound as a colorless oil. ^1H NMR (300 MHz, CDCl_3): δ 0.81 (t, $J=7.4$ Hz, 3H), 1.33 (qt, $J=7.4, 7.4$ Hz, 2H), 1.95 (q, $J=6.8$ Hz, 2H), 3.86 (ddt, $J=12.8, 5.5, 1.4$ Hz, 1H), 3.92 (ddt, $J=12.8, 5.5, 1.4$ Hz, 1H), 4.68 (d, $J=7.1$ Hz, 1H), 5.09 (dq, $J=10.4, 1.4$ Hz, 1H), 5.20 (dq, $J=17.2, 1.7$ Hz, 1H), 5.48 (ddt, $J=15.4, 7.0, 0.9$ Hz, 1H), 5.61 (dt, $J=15.4, 6.4$ Hz, 1H), 5.93-5.79 (m, 1H), 7.27-7.16 (m, 5H); ^{13}C NMR (75 MHz, CDCl_3): δ 13.6, 22.1, 34.2, 68.8, 81.7, 116.5, 126.6, 127.2, 128.2, 130.8, 133.3, 134.9, 141.7; MS (EI, 70 eV): m/z 216 (M^+), 173, 159, 145, 129, 117, 105, 91, 84, 77, 71; HRMS m/z calcd for $\text{C}_{15}\text{H}_{20}\text{O}$: 216.1514; found 216.1518.

⁵ Stoner, E. J.; Cothron, D. A.; Balmer, M. K.; Roden, B. A. *Tetrahedron* **1995**, *51*, 11043.

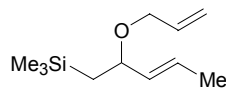
⁶ Pocker, Y.; Hill, M. J. *J. Am. Chem. Soc.* **1969**, *91*, 3243.

⁷ Prepared in quantitative yield by addition of phenyllithium to 4-methyl-2-pentenal.

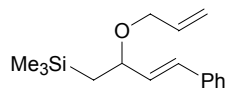
⁸ Wang, D.; Chen, D.; Haberman, J. X.; Li, C. *Tetrahedron* **1988**, *54*, 5129.



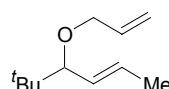
1-(2-Butenyloxy)-1,3-diphenyl-2E-propene (1e): General Procedure C was followed employing 2.10 g of (*E*)-1,3-diphenyl-2-propen-1-ol (10 mmol).⁴ Purification by flash chromatography (5% EtOAc/hexanes) gave 2.24 g (85%) of the title compound as a colorless oil. ¹H NMR (300 MHz, CDCl₃): δ 1.75 (dd, *J* = 5.9, 1.0 Hz, 3H), 3.99 (m, 2H), 5.00 (d, *J* = 7.0 Hz, 1H), 5.62-5.82 (m, 1H), 6.34 (dd, *J* = 16, 7.0 Hz, 1H), 6.63(d, *J* = 16 Hz, 1H), 7.22-7.48 (m, 10H); ¹³C NMR (75 MHz, CDCl₃): δ 17.8, 70.0, 81.5, 126.5, 126.9, 127.5, 128.5, 129.4, 130.4, 131.2, 136.5, 141.2; MS (EI, 70 eV): *m/z* 264 (M⁺), 234, 209, 181, 115, 105, 77; HRMS *m/z* calcd for C₁₉H₂₀O: 264.1514; found 264.1522.



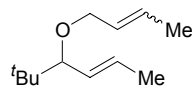
(*E*)-2-Allyloxy-1-trimethylsilanyl-3-pentene (1f): General Procedure B was followed employing 716 mg of (*E*)-1-trimethylsilanyl-3-penten-2-ol (4.52 mmol).⁹ Purification by flash chromatography (3% Et₂O/hexanes) gave 530 mg (59%) of the title compound as a colorless oil. ¹H NMR (300 MHz, CDCl₃): δ 0.014 (s, 9H), 0.85 (dd, *J* = 14, 8.0 Hz, 1H), 1.06 (dd, *J* = 14, 6.7 Hz, 1H), 1.70 (dd, *J* = 6.5, 1.5 Hz, 1H), 3.70-3.80 (m, 2H), 3.97 (ddt, *J* = 13, 5.3, 1.5 Hz, 1H), 5.12 (dq, *J* = 10, 1.3 Hz, 1H), 5.23 (dq, *J* = 17, 1.7 Hz, 1H), 5.28 (ddq, *J* = 15, 8.5, 1.6 Hz, 1H), 5.55 (dq, 15, 6.4 Hz, 1H), 5.84-5.96 (m, 1H); ¹³C NMR (75 MHz, CDCl₃): δ -0.77, 17.5, 24.9, 68.5, 78.4, 116.2, 127.4, 134.0, 135.4; MS (EI, 70 eV): *m/z* 183 (M⁺-Me), 155, 115, 73, 68, 59; HRMS *m/z* calcd for C₁₀H₁₉OSi (M⁺-Me): 183.1205; found 183.1213.



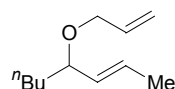
(*E*)-2-Allyloxy-4-phenyl-1-trimethylsilanyl-3-butene (1g): General Procedure B was followed employing 2.91 g of (*E*)-4-phenyl-1-trimethylsilanyl-3-buten-2-ol (13.2 mmol).⁷ Purification by flash chromatography (2.5% Et₂O/hexanes) gave 1.85 g (54%) of the title compound as a colorless oil. ¹H NMR (300 MHz, CDCl₃): δ 0.28 (s, 9H), 0.96 (dd, *J* = 14, 7.5 Hz, 1H), 1.17 (dd, *J* = 14, 7.2 Hz, 1H), 3.83 (ddt, *J* = 13, 5.9, 1.4 Hz, 1H), 3.95-4.10 (m, 2H), 5.15 (ddd, *J* = 10, 3.2, 1.3 Hz, 1H), 5.26 (ddd, *J* = 17, 3.5, 1.6 Hz, 1H), 5.92 (m, 1H), 6.04 (dd, *J* = 16, 8.3 Hz, 1H), 7.24-7.61 (m, 5H); ¹³C NMR (75 MHz, CDCl₃): δ -0.70, 25.1, 69.0, 78.5, 116.5, 126.4, 127.6, 128.6, 131.1, 132.4, 135.2, 136.7; MS (EI, 70 eV): *m/z* 260 (M⁺), 203, 130, 115, 73, 59; HRMS *m/z* calcd for C₁₆H₂₄OSi: 260.1596; found 260.1593.



(*E*)-3-Allyloxy-2,2-dimethyl-4-hexene (1h): General Procedure A was followed employing 3.56 g of (*E*)-2,2-dimethylhex-4-en-3-ol (27.8 mmol).¹⁰ Purification by vacuum distillation gave 3.48 g (75%) of the title compound as a colorless oil. ¹H NMR (300 MHz, CDCl₃): δ 0.88 (m, 9H), 1.73 (dd, *J* = 6.4, 1.5 Hz, 3H), 3.20 (d, *J* = 8.5 Hz, 1H), 3.73 (ddt, *J* = 13, 5.9, 1.5 Hz, 1H), 4.02 (ddt, *J* = 13, 4.8, 1.6 Hz, 1H), 5.11 (ddd, *J* = 8.7, 3.4, 1.4 Hz, 1H), 5.24 (dq, *J* = 17, 1.8 Hz, 1H), 5.35 (ddq, *J* = 15, 8.5, 1.5 Hz, 1H), 5.55 (dq, 15, 6.3 Hz, 1H), 5.89 (m, 1H); ¹³C NMR (75 MHz, CDCl₃): δ 17.7, 26.2, 34.5, 69.0, 88.0, 115.6, 129.0, 129.5, 135.7; MS (EI, 70 eV): *m/z* 127 (M⁺-C₃H₅), 111, 57; HRMS *m/z* calcd for C₇H₁₁O (M⁺-C₄H₉): 111.0810; found 111.0805.



3-(2-Butenyloxy)-2,2-dimethyl-4E-hexene (1i): General Procedure A was followed employing 1.28 g of (*E*)-5,5-dimethyl-2-hexen-4-ol (10 mmol). Purification by flash chromatography (2 % Et₂O/hexanes) gave 1.66 g (91 %) of the title compound as an *E/Z* mixture of butenyl group isomers. ¹H NMR (300 MHz, CDCl₃): δ 0.88 (s, 9H), 1.63-1.76 (m, 6H), 3.19 (d, *J* = 8.4Hz, 1H), 3.67 (dd, *J* = 12.2, 6.2 Hz, 1H), 4.06-3.83 (m, 1H), 5.34 (dd, *J* = 15.3, 8.4 Hz, 1H), 5.73-5.49 (m, 3H); ¹³C NMR (75 MHz, CDCl₃): δ ; MS (EI, 70 eV): *m/z* 125 (M⁺-C₄H₉), 111, 95, 71, 55; HRMS *m/z* calcd for C₈H₁₃O (M⁺-C₄H₉): 125.0966; found 125.0967.



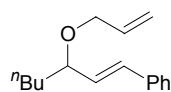
(*E*)-4-Allyloxy-2-octene (1j): General Procedure A was followed employing 6.40 g of (*E*)-2-octen-4-ol (50 mmol).¹¹ Purification by vacuum distillation gave 7.86 g (94 %) of the title compound as a colorless oil. ¹H NMR (300 MHz, CDCl₃): δ 0.89 (t, *J* = 7.0 Hz, 3H), 1.23-1.35 (m, 4H), 1.40-1.63 (m, 2H), 1.71(dd, *J* = 6.4, 1.6 Hz, 3H), 3.61 (dd, *J* = 15, 6.5 Hz, 1H), 3.79 (dd, *J* = 13, 6.0 Hz, 1H), 3.81 (ddt, *J* = 13, 6.0, 1.4 Hz, 1H), 4.03 (ddt, *J* = 13, 5.2, 1.5 Hz, 1H), 5.13 (ddd, *J* = 10, 3.1, 1.3 Hz, 1H), 5.24 (dq, *J* = 17, 1.7 Hz, 1H), 5.30 (ddq, *J* = 15, 8.2, 1.6 Hz, 1H), 5.59 (dq, *J* = 15, 6.4 Hz, 1H), 5.90 (m, 1H); ¹³C

⁹ Taylor, R. T.; Galloway, J. G. *J. Organomet. Chem.* **1981**, 220, 295.

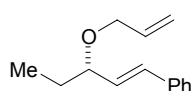
¹⁰ Oare, D. A.; Henderson, M. A.; Sanner, M. A.; Heathcock, C. A. *J. Org. Chem.* **1990**, 55, 132.

¹¹ Chamberlin, A. R.; Mulholland, R. L. Jr. *Tetrahedron* **1984**, 40, 2297.

NMR (75 MHz, CDCl_3): δ 14.0, 17.6, 22.6, 27.6, 35.4, 68.7, 80.3, 116.3, 128.3, 132.2, 135.4; MS (EI, 70 eV): m/z 168 (M^+), 153, 139, 125, 111, 84, 69, 55; HRMS m/z calcd for $\text{C}_{11}\text{H}_{20}\text{O}$: 168.1514; found 168.1510.

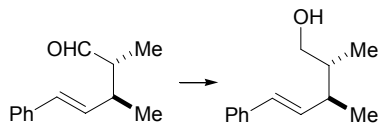


(E)-3-Allyloxy-1-phenyl-1-heptene (1k): General Procedure A was followed employing 5.13 g of (E)-1-phenyl-1-hepten-3-ol (27 mmol). Purification by flash chromatography (2% EtOAc/hexanes) gave 5.41 g (87%) of the title compound as colorless oil. ^1H NMR (300 MHz, CDCl_3): δ 0.94 (t, J = 7.0 Hz, 3H), 1.36-1.82 (m, 6H), 3.74-3.84 (m, 2H), 4.13 (ddt, J = 12.8, 5.2, 1.5 Hz, 1H), 5.20 (dm, J = 17.2 Hz, 1H), 5.31 (dq, J = 17.2, 1.6 Hz, 1H), 5.90-6.04 (m, 1H), 6.11 (dd, J = 16.0, 8.0 Hz, 1H), 6.54 (d, J = 16.0 Hz, 1H), 7.27-7.45 (m, 5H); ^{13}C NMR (75 MHz, CDCl_3): δ 14.0, 22.6, 27.6, 35.5, 69.1, 80.2, 116.5, 126.4, 127.5, 128.5, 130.7, 131.9, 135.2, 136.6; MS (EI, 70 eV): m/z 230 (M^+), 189, 173, 145, 131, 117, 91, 85, 57; HRMS m/z calcd for $\text{C}_{16}\text{H}_{22}\text{O}$: 230.1671; found 230.1670.



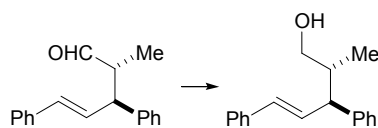
(E)-(S)-3-Allyloxy-phenyl-1-pentene (1l): General Procedure A was followed employing 551 mg of (E)-(S)-1-phenyl-1-penten-3-ol (3.40 mmol).¹² Purification by flash chromatography (5% EtOAc/hexanes) gave 658 mg (96%) of the title compound as a colorless oil. Separation of the enantiomers by chiral HPLC (Daicel ChiracelTM OD-H column, flow rate 0.5 ml/min, 0.5% *i*-PrOH, 95.5% hexanes, T_r 13.4 (*R*) and 16.3 (*S*) provided the enantiomer ratio: **1l**(*S*):**1l**(*R*) 92:8 (84% ee). $[\alpha]_D = -66.1^\circ$ (c 1.89, CHCl_3); ^1H NMR (300 MHz, CDCl_3): δ 0.96 (t, J = 7.5 Hz, 9H), 1.55-1.83 (m, 2H), 3.81 (dd, J = 14, 6.7 Hz, 1H), 3.90 (dd, J = 13, 5.9 Hz, 1H), 4.11 (dd, J = 13, 5.1 Hz, 1H), 5.18 (d, J = 10 Hz, 1H), 5.29 (dd, J = 17, 1.1 Hz, 1H), 5.88-6.03 (m, 1H), 6.08 (dd, J = 16, 8.0 Hz, 1H), 7.26-7.43 (m, 5H); ^{13}C NMR (75 MHz, CDCl_3): δ 9.86, 28.6, 69.2, 81.6, 116.6, 126.4, 127.6, 128.5, 130.4, 132.2, 135.2, 136.6; MS (EI, 70 eV): m/z 202 (M^+), 173, 161, 145, 131, 117, 103, 91, 77, 57; HRMS m/z calcd for $\text{C}_{14}\text{H}_{18}\text{O}$: 202.1358; found 202.1366.

General Procedure D for ICR reactions: A solution of $[(\text{C}_8\text{H}_{14})_2\text{IrCl}]_2$ (0.05 mol%, 0.01 equiv Ir) and PCy_3 (1.5 mol%, 0.03 equiv) in anhydrous CH_2Cl_2 or 1,2-dichloroethane (1,2-DCE) (1.5 ml) was added to a solution of NaBPh_4 (0.01 mol%, 0.01 equiv) in CH_2Cl_2 /acetone (25:1) or 1,2-DCE/acetone (25:1) (1.5 ml, 0.67M final concentration in substrate **1**) and the resulting yellow solution stirred for 5 min at ambient temperature. Di(allyl)ether **1** (2.0 mmol) was added and the reaction stirred for 30 min at ambient temperature whereupon PPh_3 (15.7 mg, 0.06 mmol) was added and the resulting solution heated at reflux (39 or 80 $^\circ\text{C}$) for the indicated time. The solvent was removed *in vacuo* and the diastereomer ratio of the aldehyde products **2** was determined by integration of the aldehyde proton resonances ($-\text{CHO}$) in the ^1H NMR spectrum of the crude product mixture. The crude product mixture was dissolved in anhydrous CH_2Cl_2 and cooled to -78°C and a 1M hexanes solution of $i\text{Bu}_2\text{AlH}$ (3.0 ml, 3.0 mmol) was added dropwise via syringe and the resulting solution was stirred for 5 min at -78°C . The reaction mixture was warmed to ambient temperature and poured into H_2O . This mixture was diluted with EtOAc and 1M HCl, the layers were shaken and separated and the aqueous portion was extracted with EtOAc(3x). The combined organic extracts were dried (MgSO_4), filtered and the solvent removed *in vacuo*. The resulting residue was purified by flash chromatography on silica gel using the solvents indicated.

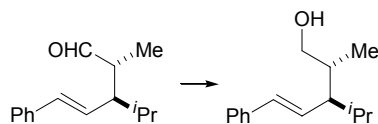


(E)-syn-2,3-Dimethyl-5-phenylpent-4-en-1-ol: General Procedure D (CH_2Cl_2) was followed employing 515 mg of ether **1a** (2.74 mmol) and a reaction time of 6 h to afford aldehyde (**2a**) (*syn:anti* = 94:6). Diisobutylaluminum hydride reduction of **2a** followed by purification by flash chromatography (25% EtOAc/hexanes) gave 415 mg (80%) of the title compound as a colorless oil. ^1H NMR (300 MHz, CDCl_3): δ 0.98 (d, J = 6.9 Hz, 3H), 1.10 (d, J = 6.8 Hz, 3H), 1.72 (m, 1H), 2.39 (m, 1H), 3.52 (dd, J = 11, 6.4 Hz, 1H), 3.67 (dd, J = 11, 5.7 Hz, 1H), 6.18 (dd, J = 16, 8.1 Hz, 1H), 6.41 (d, J = 16 Hz, 1H), 7.20-7.40 (m, 5H); ^{13}C NMR (75 MHz, CDCl_3): δ 13.7, 16.6, 39.1, 40.8, 66.5, 125.9, 126.9, 128.4, 128.8, 135.3, 137.6; MS (EI, 70 eV): m/z 190 (M^+), 131, 91; HRMS m/z calcd for $\text{C}_{13}\text{H}_{18}\text{O}$: 190.1358; found 190.1363.

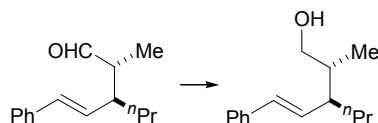
¹² Soai, K.; Ookawa, A.; Kaba, T.; Ogawa, K. *J. Am. Chem. Soc.* **1987**, *109*, 7111.



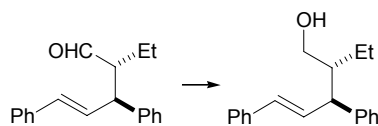
(E)-syn-2-Methyl-3,5-diphenylpent-4-en-1-ol: A modification of General Procedure D (CH_2Cl_2) was followed employing 500 mg of ether **1b** (2 mmol) and the reaction was stirred 12 h at ambient temperature (instead of reflux) to afford the aldehyde **2b** (*syn:anti* = 98:2). Diisobutylaluminum hydride reduction of **2b** followed by purification by flash chromatography (20% EtOAc/hexanes) gave 461 mg (92%) of the title compound as colorless oil. ^1H NMR (300 MHz, CDCl_3): δ 0.87 (d, J = 6.8 Hz, 3H), 1.92 (s, 1H), 2.10-2.20 (m, 1H), 3.36 (dd, J = 8.3, 7.9 Hz, 1H), 3.59 (dd, J = 9.5, 4.9 Hz, 1H), 3.73 (dd, J = 10.4, 4.2 Hz, 1H), 6.40-6.52 (m, 2H), 7.23-7.38 (m, 10H); ^{13}C NMR (75 MHz, CDCl_3): δ 15.1, 40.4, 52.8, 66.2, 126.1, 126.2, 127.1, 128.0, 128.4, 128.5, 130.2, 132.7, 137.2, 142.9; MS (EI, 70 eV): m/z 252 (M^+), 193, 178, 165, 115, 91, 77, 65; HRMS m/z calcd for $\text{C}_{18}\text{H}_{20}\text{O}$: 252.1514; found 252.1514.



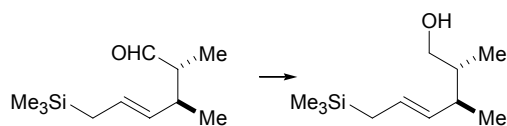
(E)-syn-2-Methyl-3-(1-methylethyl)-5-phenylpent-4-en-1-ol: General Procedure D (CH_2Cl_2) was followed employing 216 mg of ether **1c** (1 mmol) and a reaction time of 12 h to afford aldehyde **2c** (*syn:anti* = 95:5). Diisobutylaluminum hydride reduction of **2c** followed by purification by flash chromatography (20% EtOAc/hexanes) gave 201 mg (93%) of the title compound as colorless oil. ^1H NMR (300 MHz, CDCl_3): δ 0.90 (d, J = 6.8 Hz, 3H), 0.96 (d, J = 6.7 Hz, 3H), 1.06 (d, J = 6.8 Hz, 3H), 1.78 (m, 1H), 1.86-2.08 (m, 3H), 3.46 (dd, J = 10.7, 6.1 Hz, 1H), 3.71 (dd, J = 10.7, 3.3 Hz, 1H), 6.06 (dd, J = 15.7, 9.4 Hz, 1H), 6.38 (d, J = 15.8 Hz, 1H), 7.22-7.47 (m, 5H); ^{13}C NMR (75 MHz, CDCl_3): δ 15.6, 17.4, 21.9, 28.2, 37.0, 52.7, 66.6, 126.0, 126.9, 128.4, 130.3, 132.0, 137.5; MS (EI, 70 eV): m/z 218 (M^+), 175, 157, 129, 117, 104, 91; HRMS m/z calcd for $\text{C}_{15}\text{H}_{22}\text{O}$: 218.1671; found 218.1673.



(E)-syn-2-Methyl-3-propyl-5-phenylpent-4-en-1-ol: A modification of General Procedure D (CH_2Cl_2) was followed employing 216 mg of ether **1d** (1 mmol) and an initial reaction time of 10 min (instead of 30 min) prior to heating the reaction at reflux (CH_2Cl_2) for 12 h to afford aldehyde **2d** (*syn:anti* = 97:3). Diisobutylaluminum hydride reduction of **2d** followed by purification by flash chromatography (20% EtOAc/hexanes) gave 152 mg (70%) of the title compound as colorless oil. ^1H NMR (300 MHz, CDCl_3): δ 0.92 (t, J = 7.0 Hz, 3H), 1.01 (d, J = 6.8 Hz, 3H), 1.25-1.39 (m, 4H), 1.52-1.75 (m, 1H), 1.93 (s, 1H), 2.09-2.19 (m, 1H), 3.46 (dd, J = 10.7, 6.8 Hz, 1H), 3.67 (dd, J = 10.7, 5.1 Hz, 1H), 6.04 (dd, J = 15.8, 9.5 Hz, 1H), 6.38 (d, J = 15.8 Hz, 1H), 7.20-7.39 (m, 5H); ^{13}C NMR (75 MHz, CDCl_3): δ 14.1, 14.7, 20.6, 33.8, 40.1, 45.9, 66.2, 125.9, 126.8, 128.4, 130.4, 133.5, 137.5; MS (EI, 70 eV): m/z 218 (M^+), 159, 143, 129, 117, 104, 91; HRMS m/z calcd for $\text{C}_{15}\text{H}_{22}\text{O}$: 218.1671; found 218.1670.

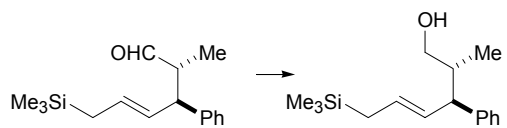


(E)-syn-2-Ethyl-3,5-diphenylpent-4-en-1-ol: A modification of General Procedure D (CH_2Cl_2) was followed using 2 mol % catalyst **5a** prepared using $[(\text{C}_8\text{H}_{14})_2\text{IrCl}]_2$ (0.02 equiv), PCy_3 (0.06 equiv) and NaBPh_4 (0.02 equiv). The reaction employing 496 mg of ether **1e** (1.88 mmol) and stirring the reaction for 18 h at ambient temperature (instead of reflux) afforded aldehyde **2e** (*syn:anti* = 95:5). Diisobutylaluminum hydride reduction of **2e** followed by purification by flash chromatography (15% EtOAc/hexanes) gave 422 mg (84 %) of the title compound as a colorless viscous oil. ^1H NMR (300 MHz, CDCl_3): δ 0.88 (t, J = 7.4 Hz, 3H), 1.19-1.43 (m, 2H), 1.90 (m, 1H), 3.47 (m, 1H), 3.77 (m, 2H), 6.37-6.51 (m, 2H), 7.15-7.38 (m, 10H); ^{13}C NMR (75 MHz, CDCl_3): δ 11.3, 21.2, 46.8, 51.5, 62.4, 126.1, 126.3, 127.2, 127.9, 128.4, 128.6, 130.2, 132.7, 137.2, 143.3; MS (EI, 70 eV): m/z 266 (M^+), 193, 178, 115, 91; HRMS m/z calcd for $\text{C}_{19}\text{H}_{22}\text{O}$: 266.1671; found 266.1682.



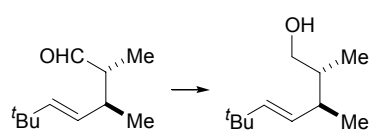
(E)-syn-2,3-Dimethyl-6-trimethylsilylhex-4-en-1-ol: General Procedure D (CH_2Cl_2) was followed employing 475 mg of ether **1f** (2.51 mmol) and a reaction time of 14 h to afford aldehyde **2f** (*syn:anti* = 93:7). Diisobutylaluminum hydride reduction of **2f** followed by purification by flash chromatography (15% EtOAc/hexanes) gave 423 mg (84%) of the title compound as a colorless oil. ^1H NMR (300 MHz, CDCl_3): δ -0.01 (s, 9H), 0.89 (d, J = 6.9 Hz, 3H), 0.95 (d, J = 6.9 Hz, 3H), 1.41 (dd, J = 7.9, 0.9 Hz, 2H), 1.53 (m, 1H), 2.09 (m, 1H), 3.44 (m, 1H), 3.58 (m, 1H), 5.19 (ddt, J =

15, 8.1, 1.2 Hz, 1H), 5.39 (dtd, $J = 15, 7.9, 0.8$, 1H); ^{13}C NMR (75 MHz, CDCl_3): δ -1.89, 14.0, 17.6, 22.6, 39.4, 41.0, 66.8, 125.5, 133.4; MS (EI, 70 eV): m/z 200 (M^+), 95, 84, 73, 68; HRMS m/z calcd for $\text{C}_{11}\text{H}_{24}\text{OSi}$ (M^+): 200.1596. Found: 200.1603.



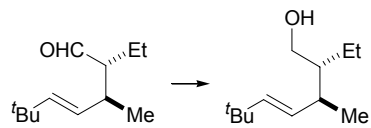
(E)-syn-2-Methyl-3-phenyl-6-trimethylsilylhex-4-en-1-ol:

General Procedure **D** (CH_2Cl_2) was followed employing 498 mg of ether **1g** (1.82 mmol) and a reaction time of 4 h to afford aldehyde **2g** (*syn:anti* = 96:4). Diisobutylaluminum hydride reduction of **2g** followed by purification by flash chromatography (15% EtOAc/hexanes) gave 442 mg (93%) of the title compound as a colorless oil. ^1H NMR (300 MHz, CDCl_3): δ -0.039 (s, 9H), 0.79 (d, $J = 6.8$ Hz, 3H), 1.42 (m, 2H), 2.00 (m, 1H), 3.10 (m, 1H), 3.56 (dd, $J = 11, 5.8$ Hz, 1H), 3.56 (dd, $J = 11, 5.8$ Hz, 1H), 3.69 (dd, $J = 11, 4.9$ Hz, 1H), 5.44-5.52 (m, 2H), 7.14-7.31 (m, 5H); ^{13}C NMR (75 MHz, CDCl_3): δ -1.94, 15.3, 22.8, 40.4, 53.1, 66.7, 125.9, 127.5, 127.8, 128.3, 131.0, 144.3; MS (EI, 70 eV): m/z 262 (M^+), 247, 203, 73; HRMS m/z calcd for $\text{C}_{16}\text{H}_{26}\text{OSi}$: 262.1753; found 262.1761.



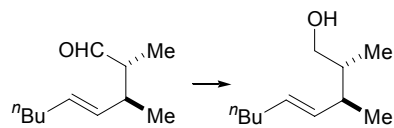
(E)-syn-2,3,6,6-Tetramethylhept-4-en-1-ol:

General Procedure **D** (1,2-DCE) was followed employing 504 mg of ether **1h** (3.4 mmol) and a reaction time of 18 h to afford aldehyde **2h** (*syn:anti* = 92:8). Diisobutylaluminum hydride reduction of **2h** followed by purification by flash chromatography (20% EtOAc/hexanes) gave 331 mg (69 %) of the title compound as a colorless oil. ^1H NMR (300 MHz, CDCl_3): δ 0.90 (d, $J = 6.8$ Hz, 3H), 0.96 (d, $J = 6.8$ Hz, 3H), 0.99 (s, 9H), 1.34 (t, $J = 5.5$ Hz, OH), 1.53 (m, 1H), 2.05 (m, 1H), 3.43 (m, 1H), 3.58 (m, 1H), 5.24 (dd, $J = 16, 8.2$ Hz, 1H), 5.47 (dd, $J = 16, 0.8$ Hz, 1H); ^{13}C NMR (75 MHz, CDCl_3): δ 14.0, 17.4, 29.8, 32.7, 39.3, 40.9, 66.8, 129.4, 140.7; MS (EI, 70 eV): m/z 170 (M^+), 137, 111, 95, 83, 69, 57; HRMS m/z calcd for $\text{C}_{11}\text{H}_{22}\text{O}$: 170.1671; found 170.1672.



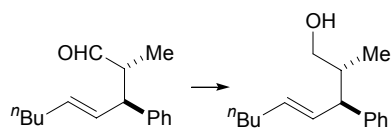
(E)-syn-2-Ethyl-3,6,6-trimethylhept-4-en-1-ol:

A modification of General Procedure **D** (1,2-DCE) was followed using 2 mol % catalyst **5a** prepared using $[(^{\text{C}}\text{H}_8\text{H}_{14})_2\text{IrCl}]_2$ (0.02 equiv), PCy_3 (0.06 equiv) and NaBPh_4 (0.02 equiv). The reaction employing 127 mg of ethyl **1i** (0.70 mmol) and stirring the reaction for 14 h at 80 °C afforded aldehyde **2i**. Diisobutylaluminum hydride reduction of **2i** followed by purification by flash chromatography (15 % EtOAc/hexanes) gave 80 mg (62 %) of the title compound as a colorless viscous oil. Separation of the diastereomers by GLC [Varian CP Wax 52CB column (30 m x 0.25 mm), flow rate 0.6 mL/min, method: 80 °C for 2.00 min, ramp @ 5.00 °C/min to 250 °C, hold for 20.00 min, $T_r = 21.0$ (2,3 *syn*, 4*E*) and 21.3 (2,3 *anti*, 4*E*) min] provided the diastereomer ratio: 93:7. ^1H NMR (300 MHz, CDCl_3): δ 0.92 (t, $J = 7.2$ Hz, 3H), 1.00 (d, $J = 6.8$ Hz, 3H), 1.00 (s, 9H), 1.26-1.49 (m, 3H), 1.61 (s, 1H), 2.19 (s, 1H), 3.60 (m, 2H), 5.28 (dd, $J = 15.7, 8.1$ Hz, 1H), 5.47 (dd, $J = 15.7, 0.6$ Hz, 1H); ^{13}C NMR (75 MHz, CDCl_3): δ 11.6, 18.2, 21.1, 29.8, 31.6, 37.6, 47.7, 63.5, 129.1, 140.9; MS (EI, 70 eV): m/z 184 (M^+), 151, 128, 111, 97, 84, 69, 58; HRMS m/z calcd for $\text{C}_{12}\text{H}_{24}\text{O}$: 184.1827; found 184.1829.

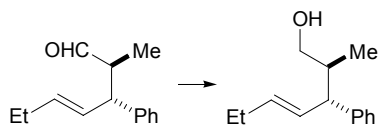


(E)-syn-2,3-Dimethylnon-4-en-1-ol:

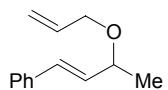
A modification of General Procedure **D** (1,2-DCE) was followed employing 500 mg of ether **1j** (2.97 mmol) and a reaction time of 14 h to afford aldehyde **2j**. Diisobutylaluminum hydride reduction of **2j** followed by purification by flash chromatography (15% EtOAc/hexanes) gave 430 mg (85%) of the title compound as a colorless oil. Separation of the diastereomers by GLC [Varian CP Wax 52CB column (30 m x 0.25 mm), flow rate 0.6 mL/min, method: 80 °C for 2.00 min, ramp @ 5.00 °C/min to 250 °C, hold for 20.00 min, $T_r = 23.4$ (2,3 *anti*, 4*E*), 23.7 (2,3 *syn*, 4*E*) and 23.8 (2,3 *syn*, 4*Z*) min] provided the diastereomer ratio: 8:86:6. ^1H NMR (300 MHz, CDCl_3): δ 0.89 (d, $J = 6.8$ Hz, 3H), 0.89 (m, 3H), 0.95 (d, $J = 6.8$ Hz, 3H), 1.31 (m, 4H), 1.53 (m, 1H), 1.99 (m, 2H), 2.07 (m, 1H), 3.44 (dd, $J = 11, 6.3$ Hz, 1H), 3.58 (dd, $J = 11, 5.7$ Hz, 1H), 5.30-5.46 (m, 2H); ^{13}C NMR (75 MHz, CDCl_3): δ 13.8, 13.9, 17.1, 22.2, 31.8, 32.2, 39.0, 40.8, 66.7, 129.6, 134.8; MS (EI, 70 eV): m/z 170 (M^+), 152, 139, 123, 111, 95, 83, 69, 55; HRMS m/z calcd for $\text{C}_{11}\text{H}_{22}\text{O}$: 170.1671; found 170.1672.



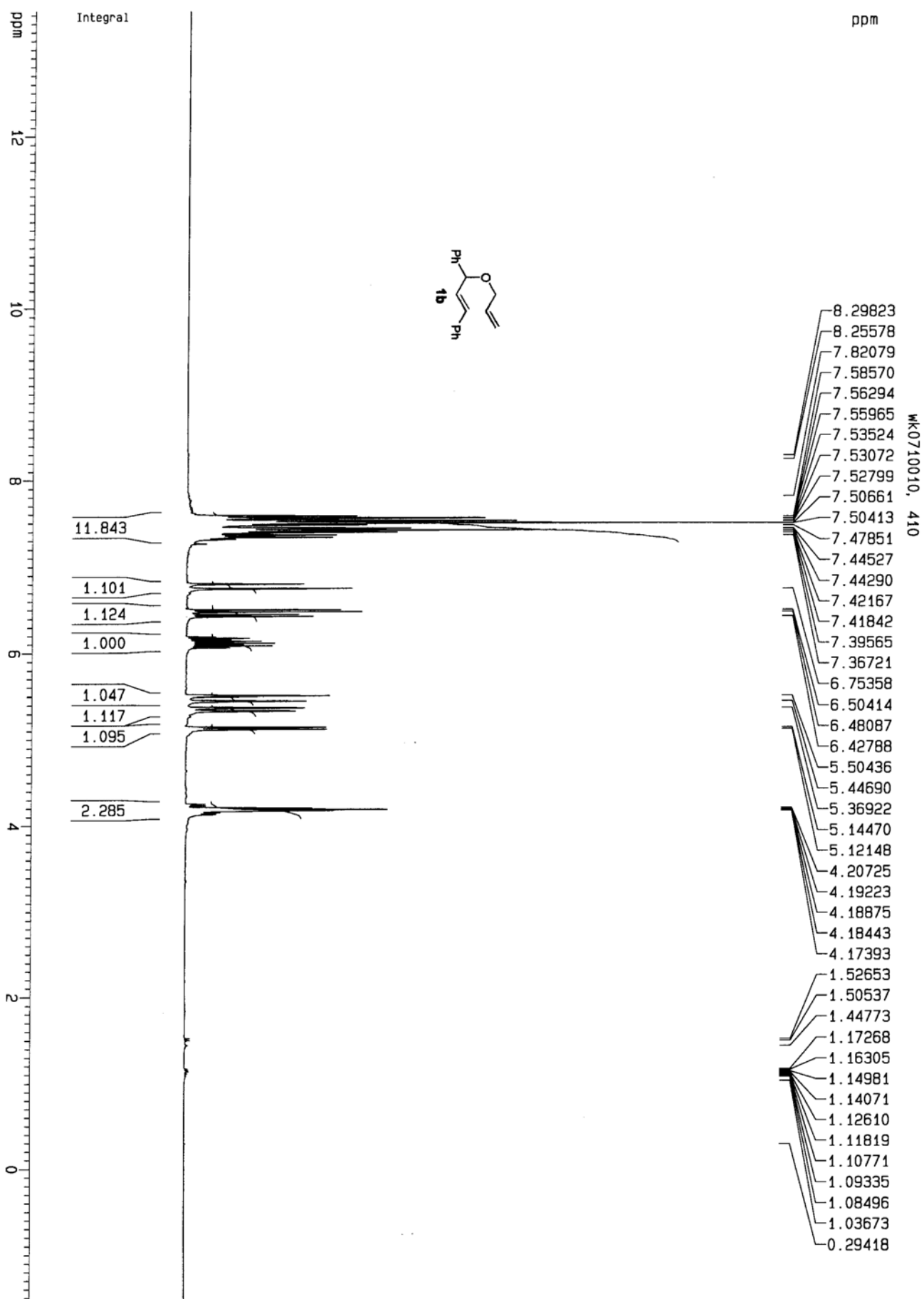
(E)-syn-2-Methyl-3-phenylnon-4-en-1-ol: General Procedure **D** (1,2-DCE) was followed employing 460 mg of ether **1k** (2 mmol) and a reaction time of 14 h to afford aldehyde **2k** (*syn:anti* = 96:4). Diisobutylaluminum hydride reduction of **2k** followed by purification by flash chromatography (20% EtOAc/hexanes) gave 284 mg (62%) of the title compound as a colorless oil. ^1H NMR (300 MHz, CDCl_3): δ 0.79 (d, J = 6.9 Hz, 3H), 0.89 (t, J = 7.0 Hz, 3H), 1.26-1.40 (m, 4H), 1.63 (s, 1H), 1.94-2.08 (m, 3H), 3.11 (t, J = 9.1 Hz, 1H), 3.57 (dd, J = 10.9, 5.8 Hz, 2H), 3.70 (dd, J = 10.9, 5.0 Hz, 1H), 5.54 (dt, J = 15.2, 6.3 Hz), 5.68 (ddt, J = 15.2, 9.0, 1.1 Hz), 7.17-7.34 (m, 5H); ^{13}C NMR (75 MHz, CDCl_3): δ 13.9, 15.3, 22.2, 31.5, 32.2, 40.5, 53.1, 66.7, 126.0, 127.8, 128.4, 131.4, 132.6, 143.9; MS (EI, 70 eV): m/z 232 (M^+), 173, 131, 117, 105, 91, 69, 55; HRMS m/z calcd for $\text{C}_{16}\text{H}_{24}\text{O}$: 232.1827; found 232.1833.

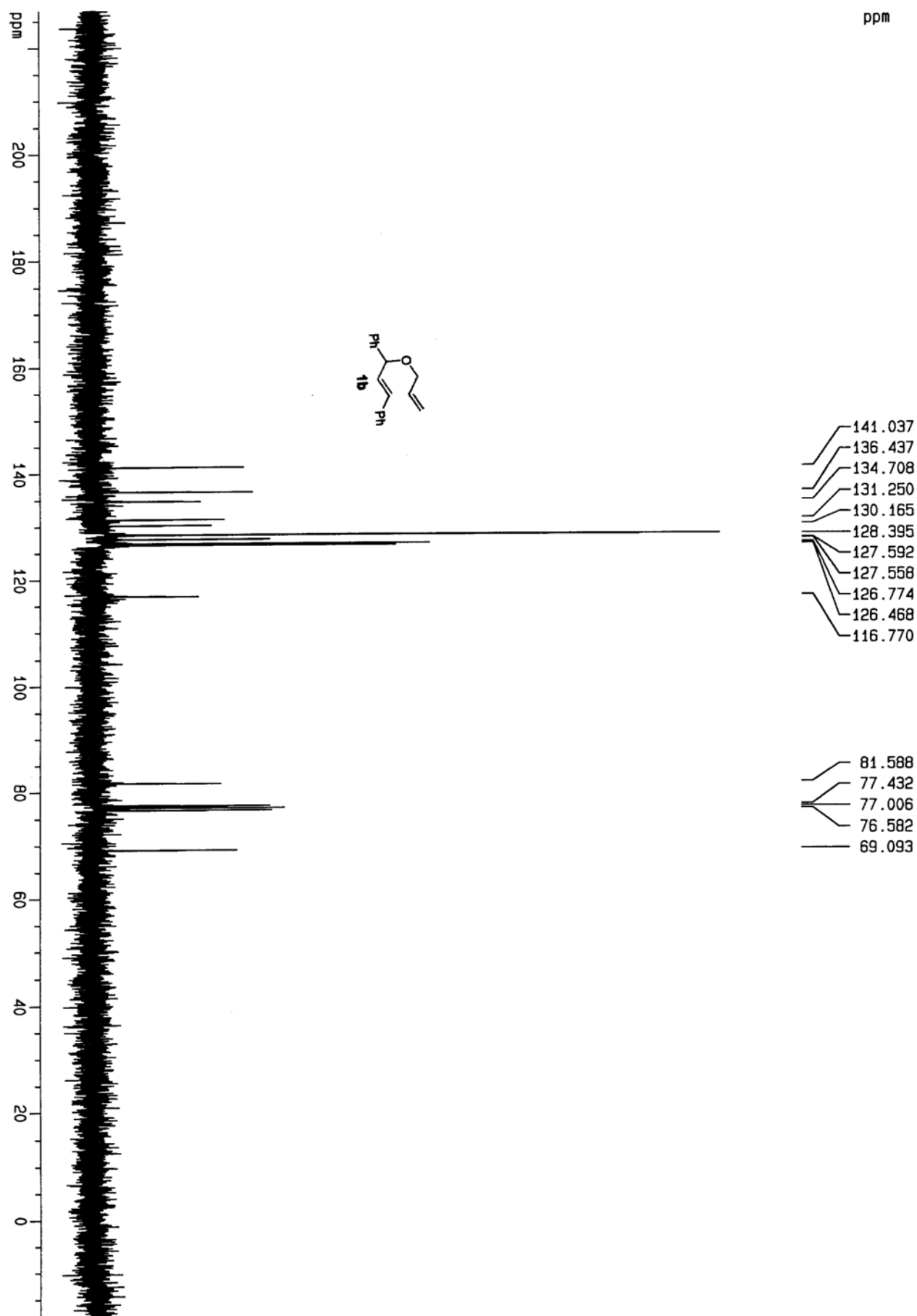


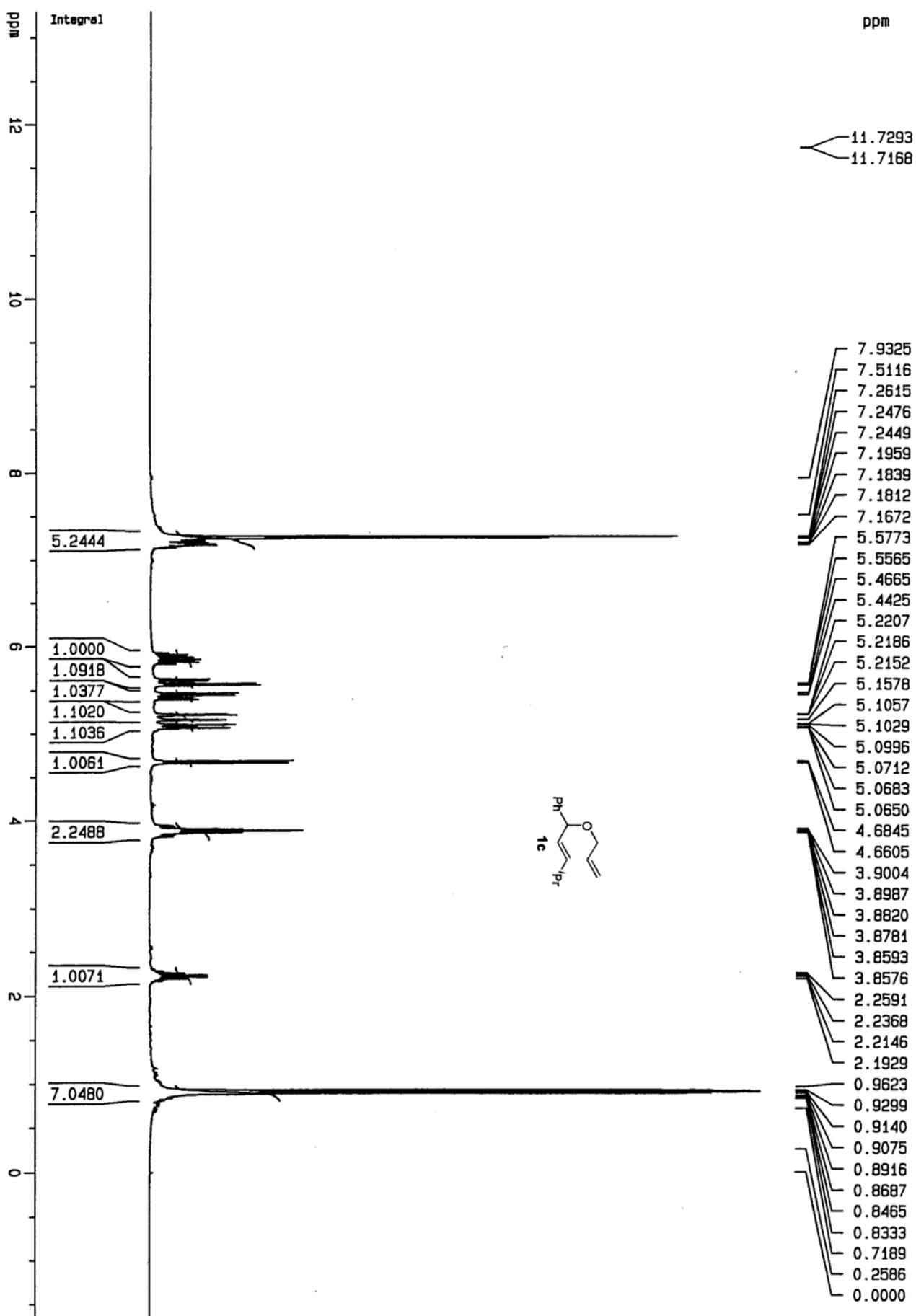
(E)-(2S,3R)-2-Methyl-3-phenylhept-4-en-1-ol: General Procedure **D** (1,2-DCE) was followed employing 498 mg of ether **1l** (2.46 mmol, 84 % ee) and a reaction time of 9 h to afford aldehyde **2l** (*syn:anti* = 95:5). Diisobutylaluminum hydride reduction of **2l** followed by purification by flash chromatography (20% EtOAc/hexanes) gave 467 mg (93%) of the title compound as a colorless oil. Separation of the enantiomers by chiral HPLC (Daicel ChiracelTM OD-H column, flow rate 0.5 ml/min, 5 % *i*-PrOH, 95 % hexanes, T_r 7.72 (2*S*,3*R*) and 14.9 (2*R*,3*S*) provided the enantiomer ratio: **1l** (2*S*,3*R*):**1l** (2*R*, 3*S*) 92:8 (84 % ee). $[\alpha]_D = +66.1^\circ$ (c 2.45, CHCl_3); ^1H NMR (300 MHz, CDCl_3): δ 0.77 (d, J = 6.8 Hz, 3H), 0.96 (t, J = 7.4 Hz, 3H), 2.02 (m, 1H), 3.09 (t, J = 8.9 Hz, 1H), 3.56 (dd, J = 11, 5.7, 1H), 3.69 (dd, J = 11, 4.9 Hz, 1H), 5.52-5.70 (m, 2H), 7.16-7.36 (m, 5H); ^{13}C NMR (75 MHz, CDCl_3): δ 13.7, 15.3, 25.5, 40.5, 53.1, 66.8, 126.0, 127.8, 128.4, 131.7, 132.9, 143.9; MS (EI, 70 eV): m/z 204 (M^+), 145, 129, 117, 105, 91, 77, 65, 55; HRMS m/z calcd for $\text{C}_{14}\text{H}_{20}\text{O}$: 204.1514; found 204.1515.

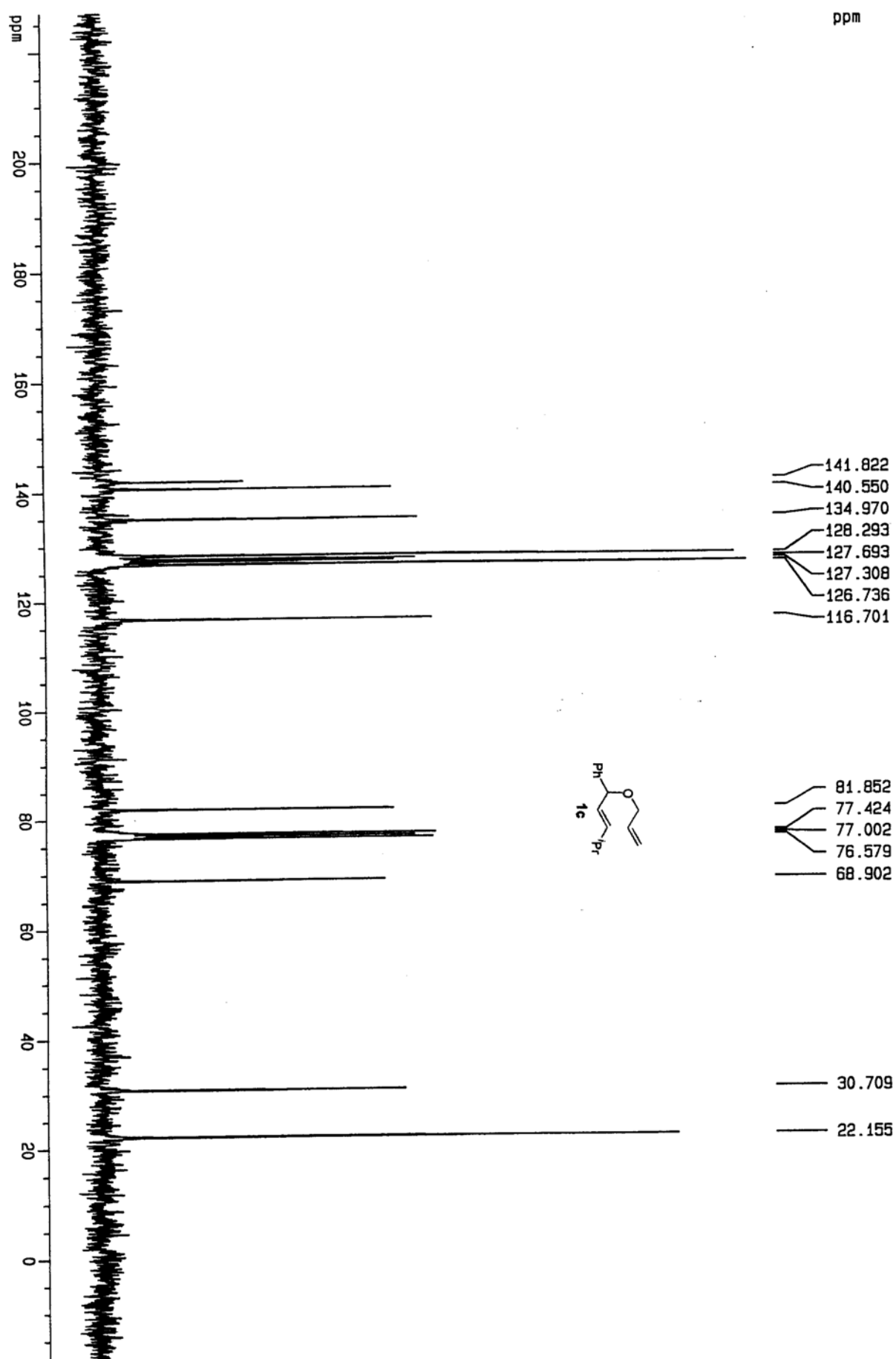


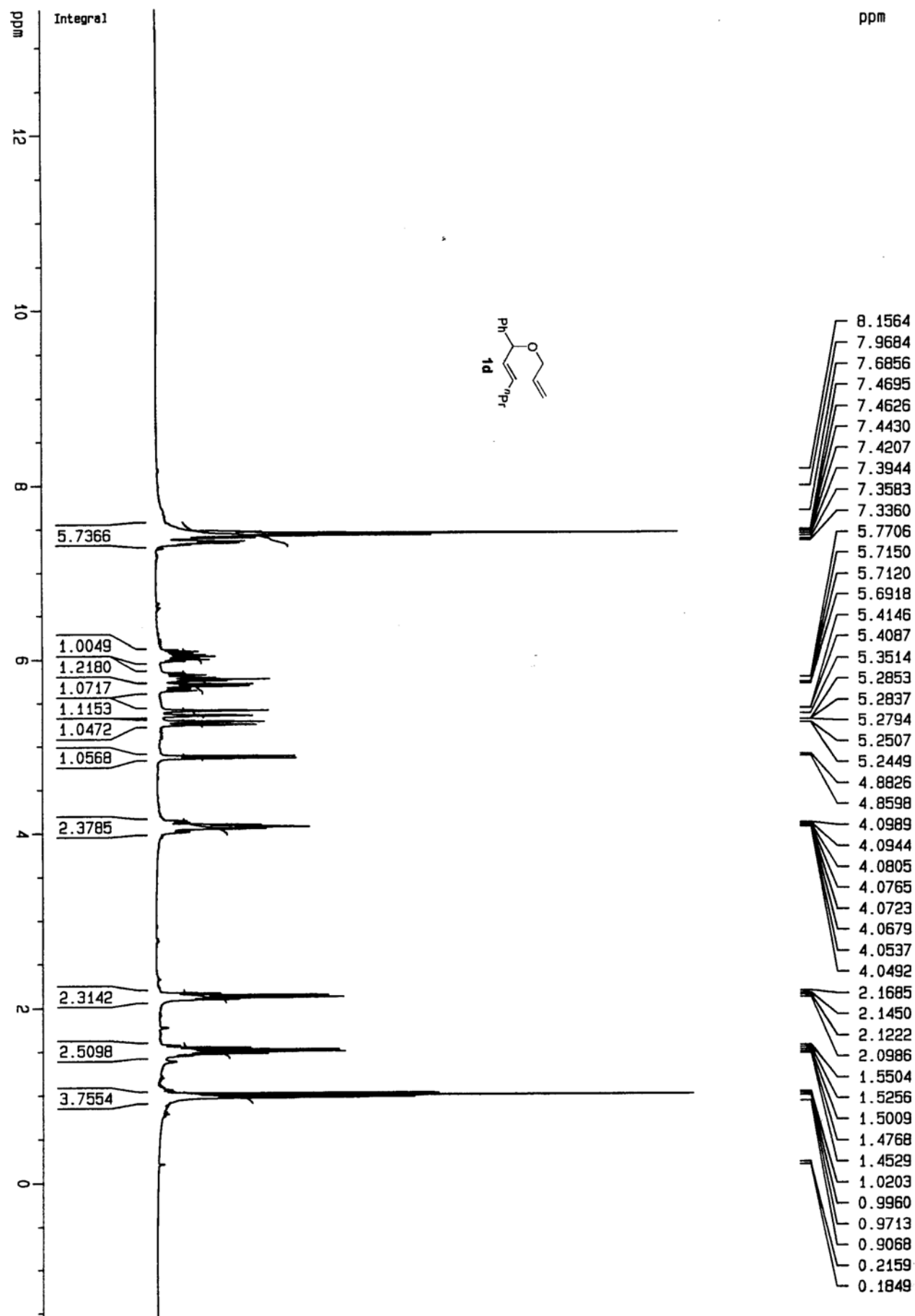
(E)-3-Allyloxy-1-phenyl-1-butene (8) (Ether Migration Product): The title compound was isolated from the attempted isomerization of ether **1a** by flash chromatography (5% EtOAc/hexanes). ^1H NMR (300 MHz, CDCl_3): δ 1.34 (d, J = 6.4 Hz, 3H), 3.90 (ddt, J = 13, 5.9, 1.4, 1H), 4.05 (m, 2H), 5.16 (ddd, 9.7, 3.1, 1.3 Hz, 1H), 5.25 (dq, J = 17, 1.7 Hz, 1H), 5.86-5.99 (m, 1H), 6.10 (dd, J = 16, 7.7 Hz, 1H), 6.51 (d, J = 16 Hz, 1H), 7.18-7.40 (m, 5H); ^{13}C NMR (75 MHz, CDCl_3): δ 21.7, 69.1, 75.9, 116.7, 126.4, 127.6, 128.5, 131.2, 131.6, 135.1, 136.5; MS (EI, 70 eV): m/z 188 (M^+), 173, 147, 131, 115, 103, 91, 77; HRMS m/z calcd for $\text{C}_{13}\text{H}_{16}\text{O}$: 188.1201; found 188.1205.



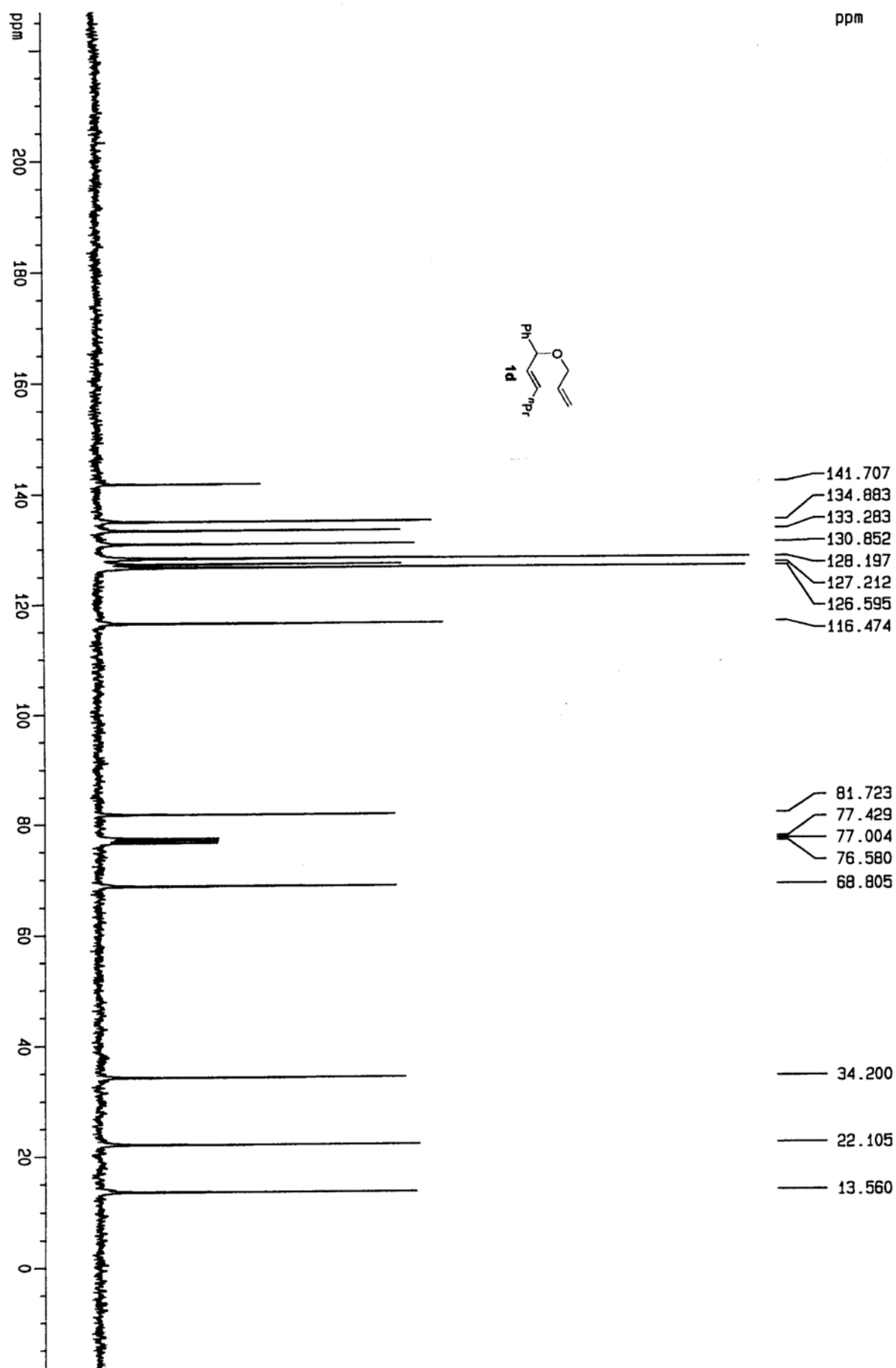


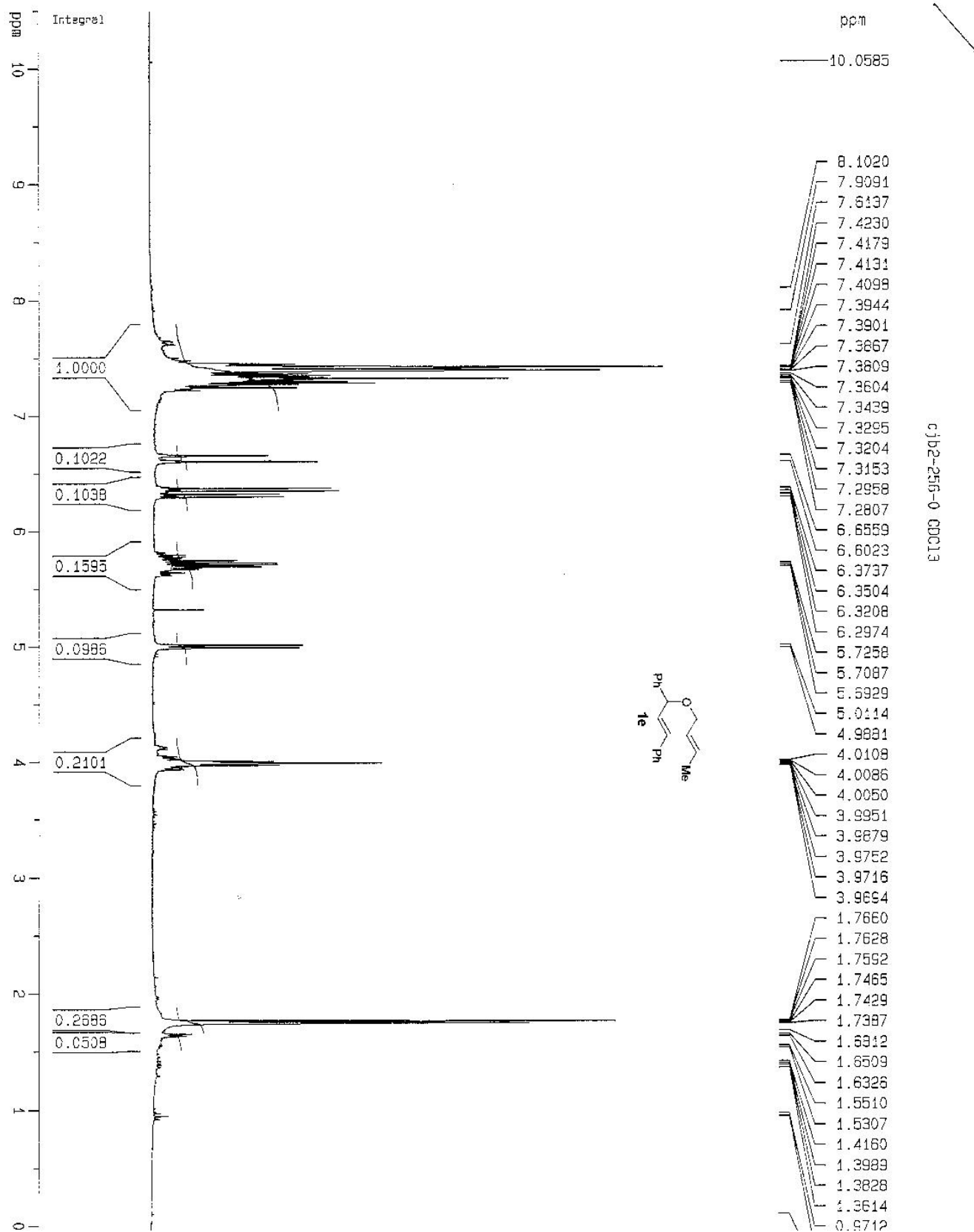


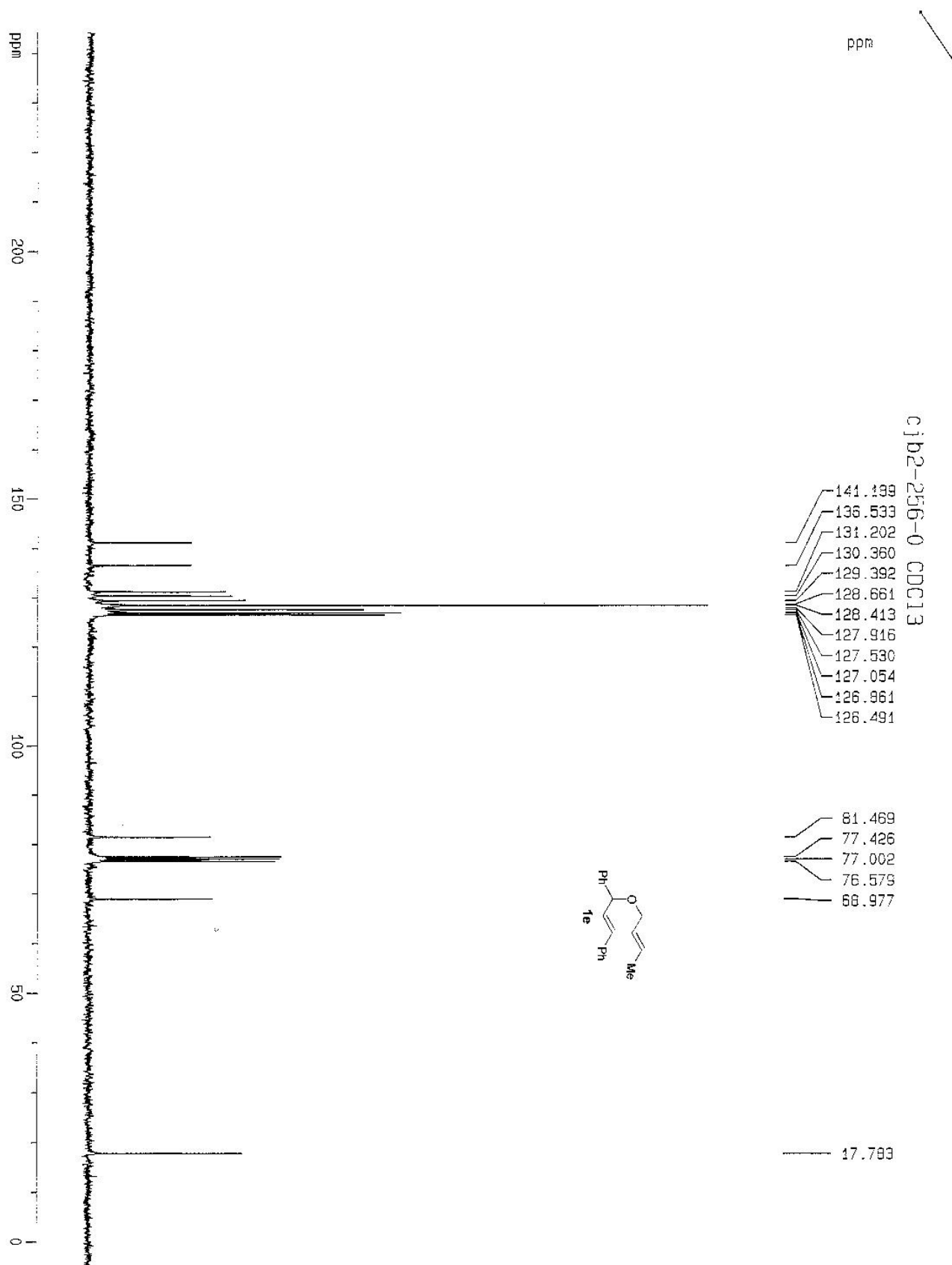


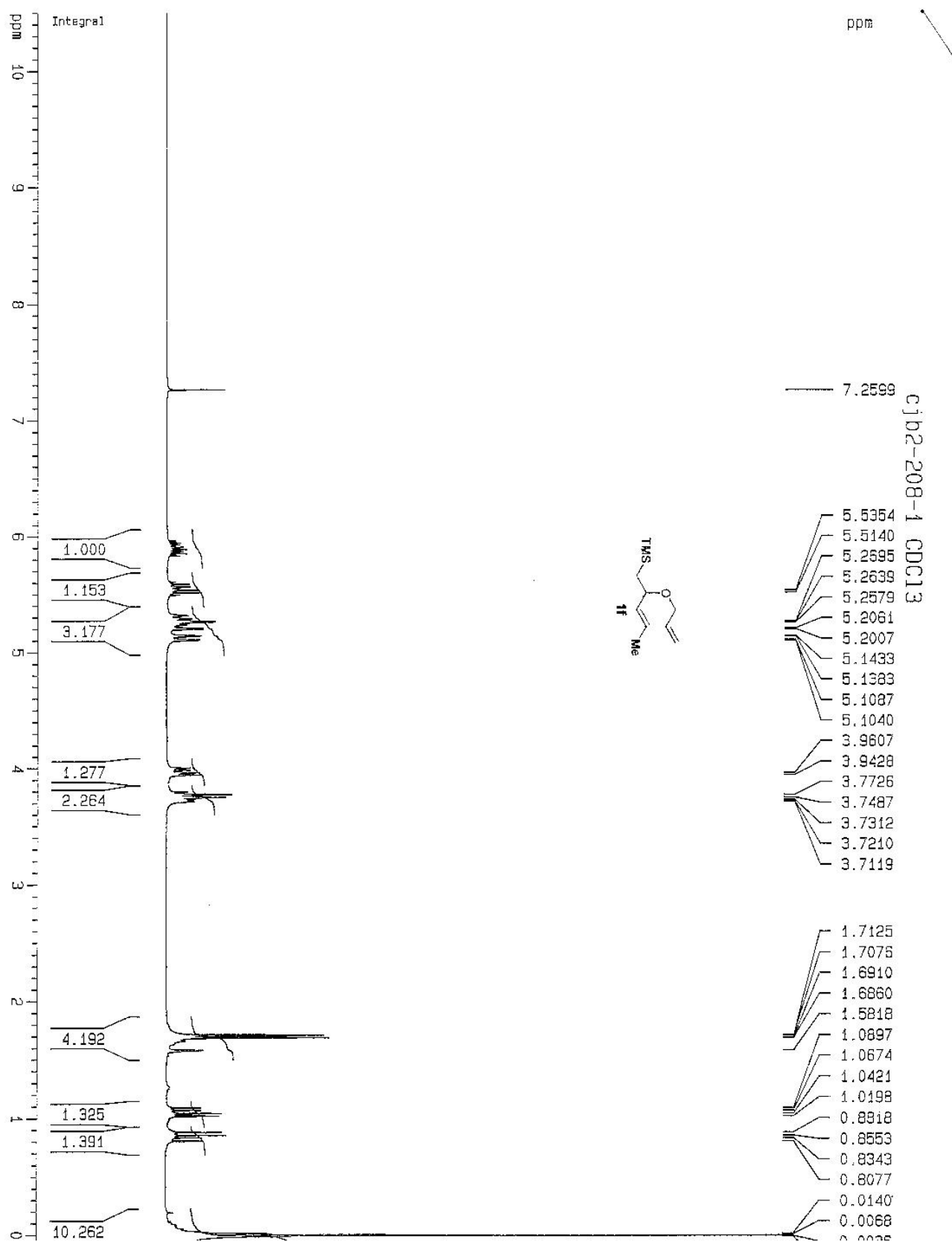


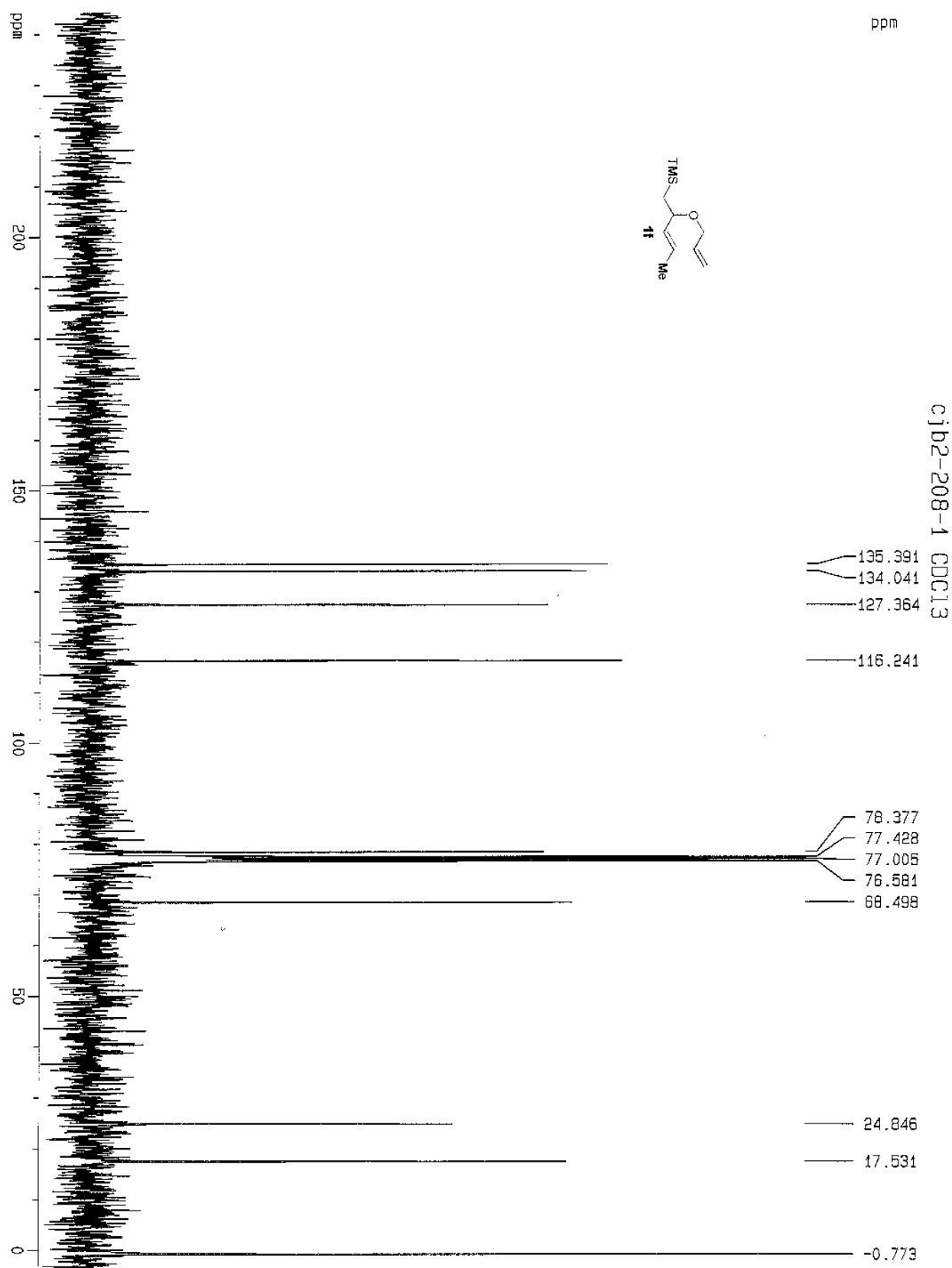
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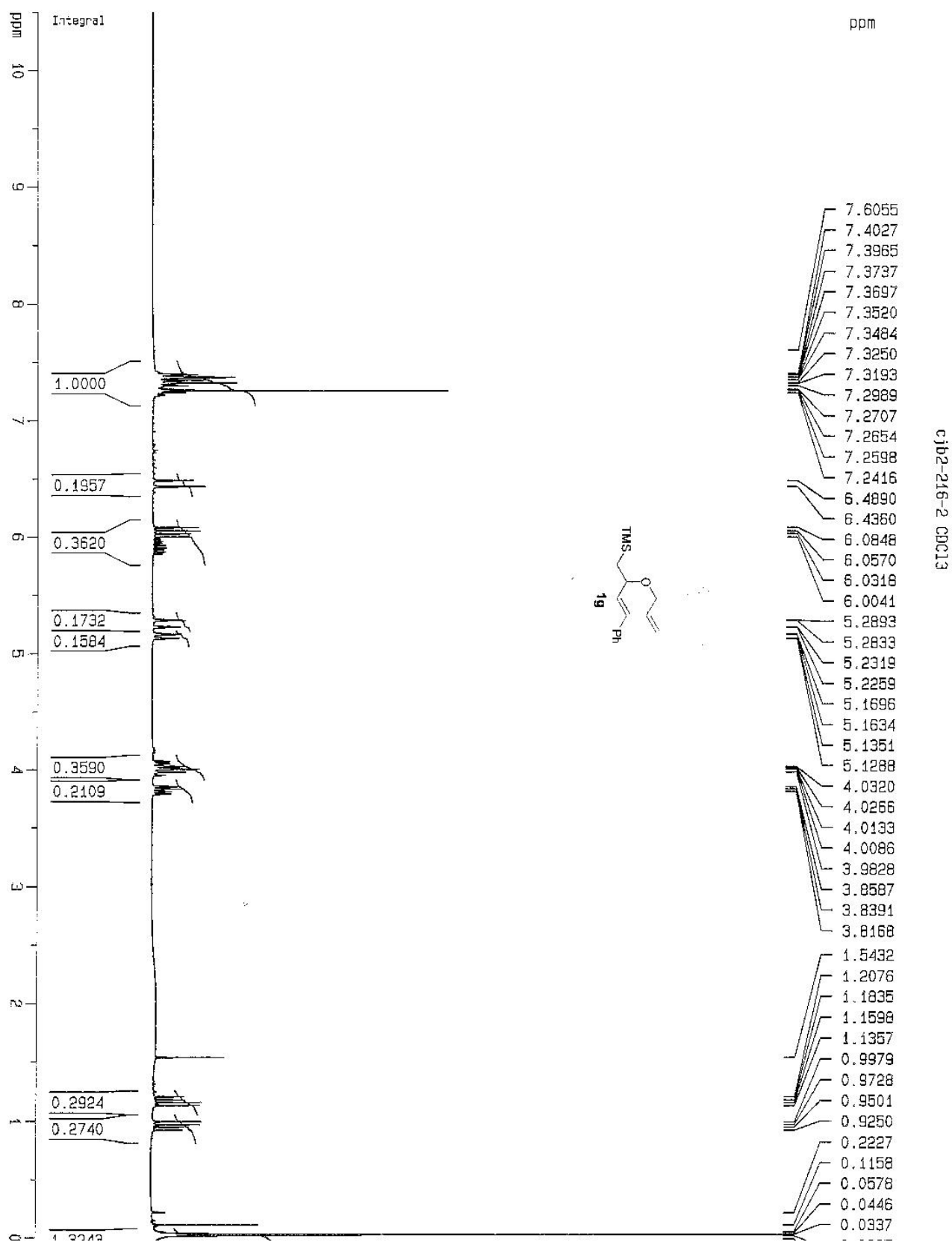


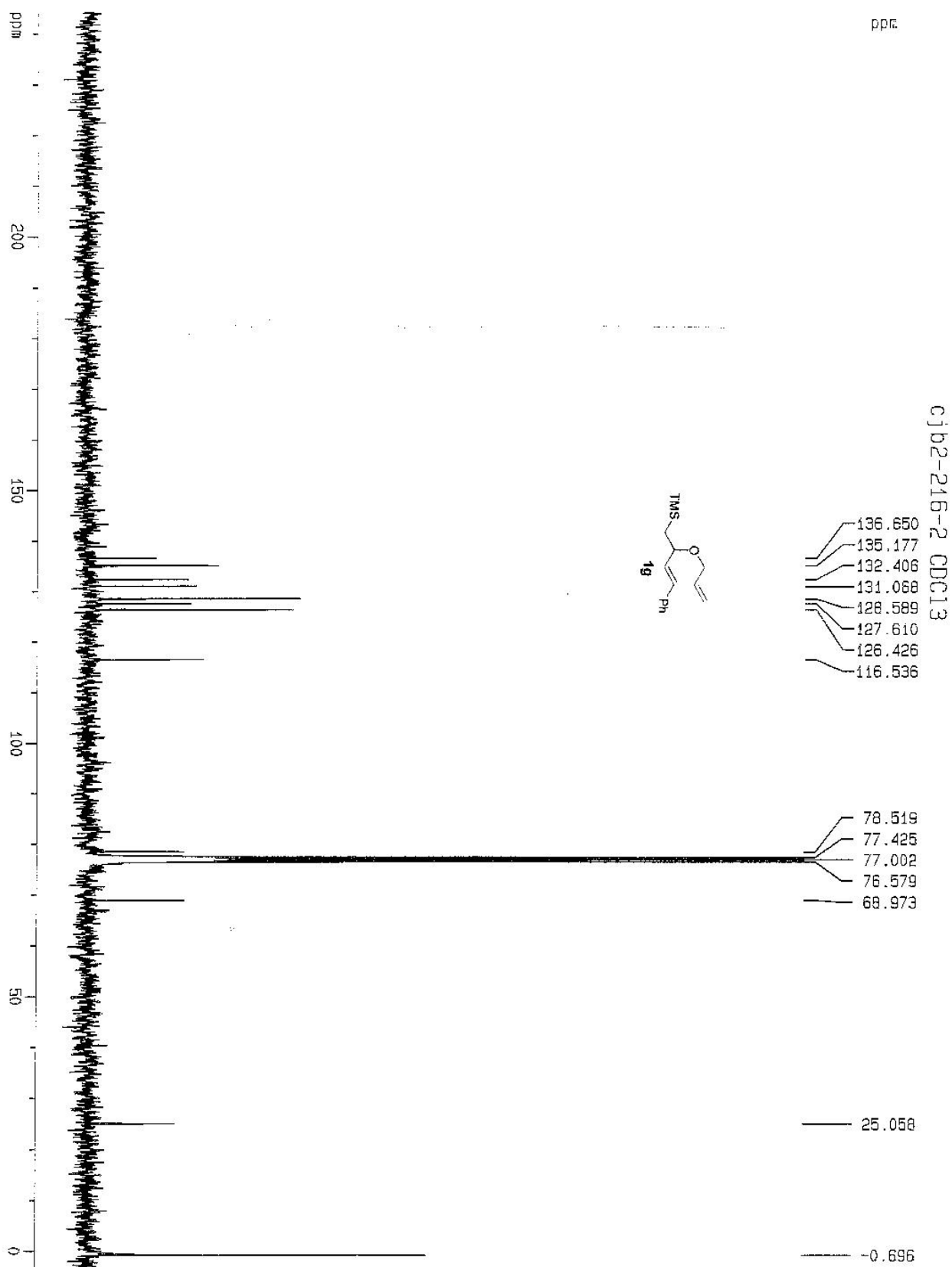


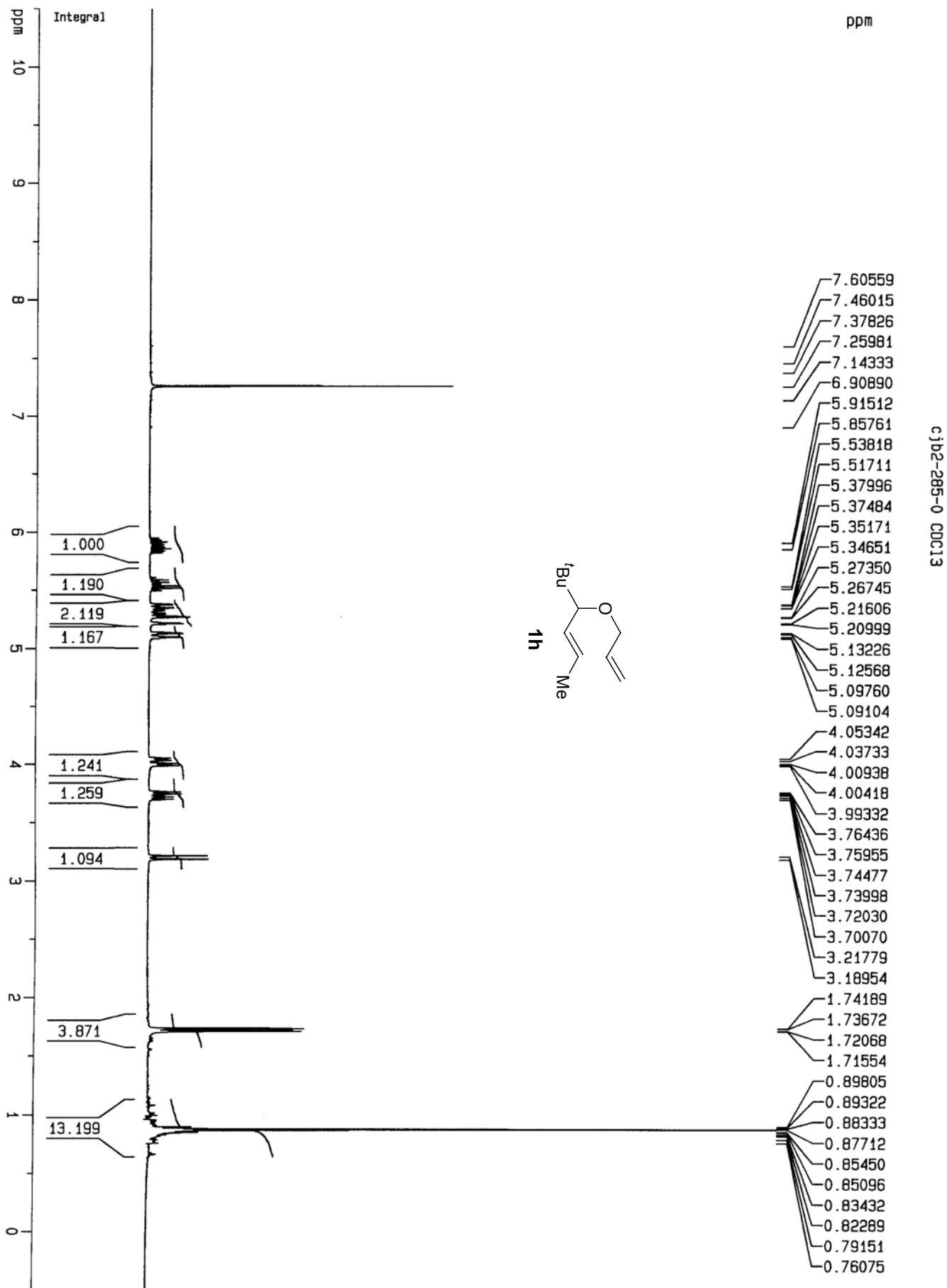


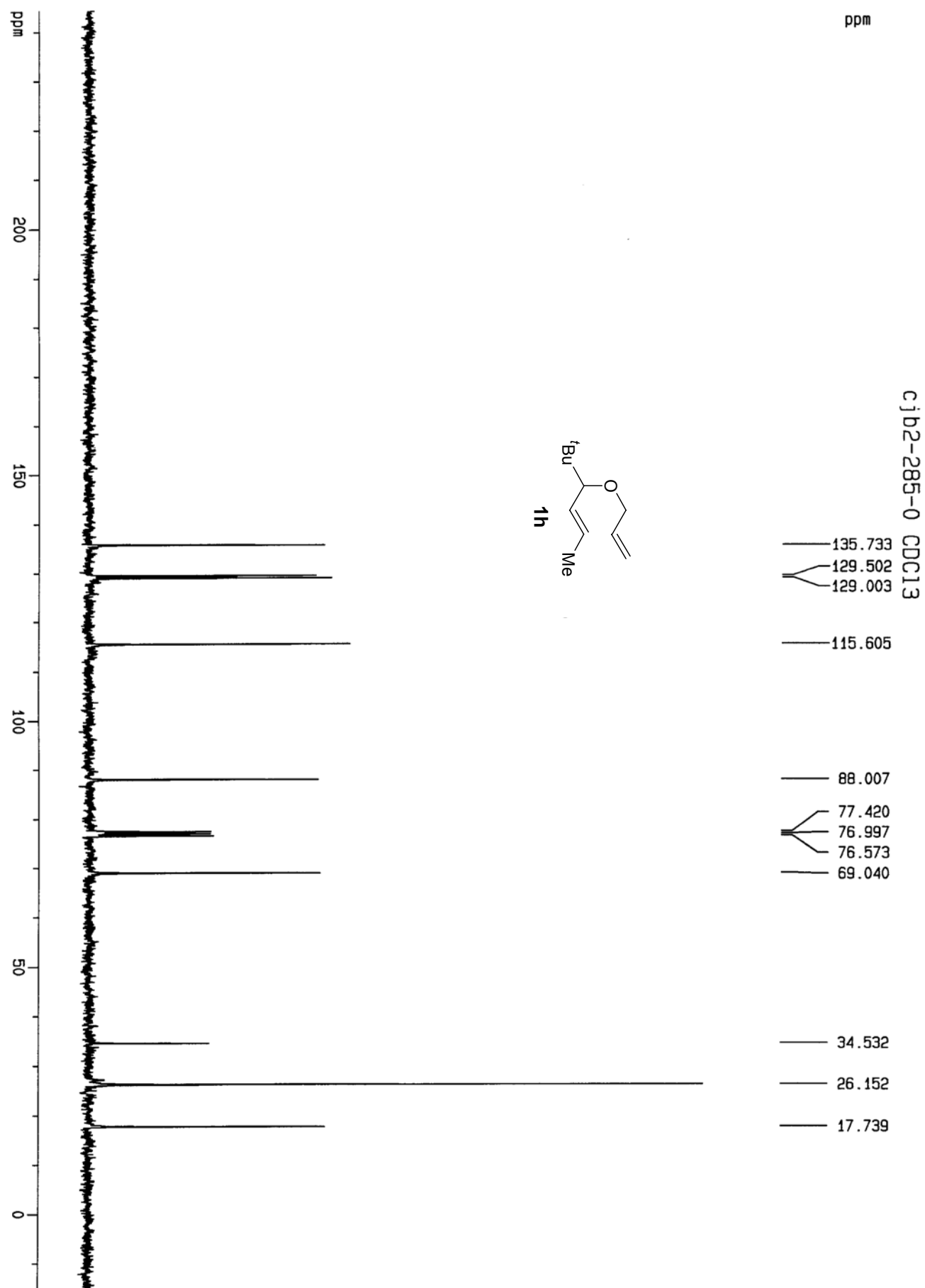


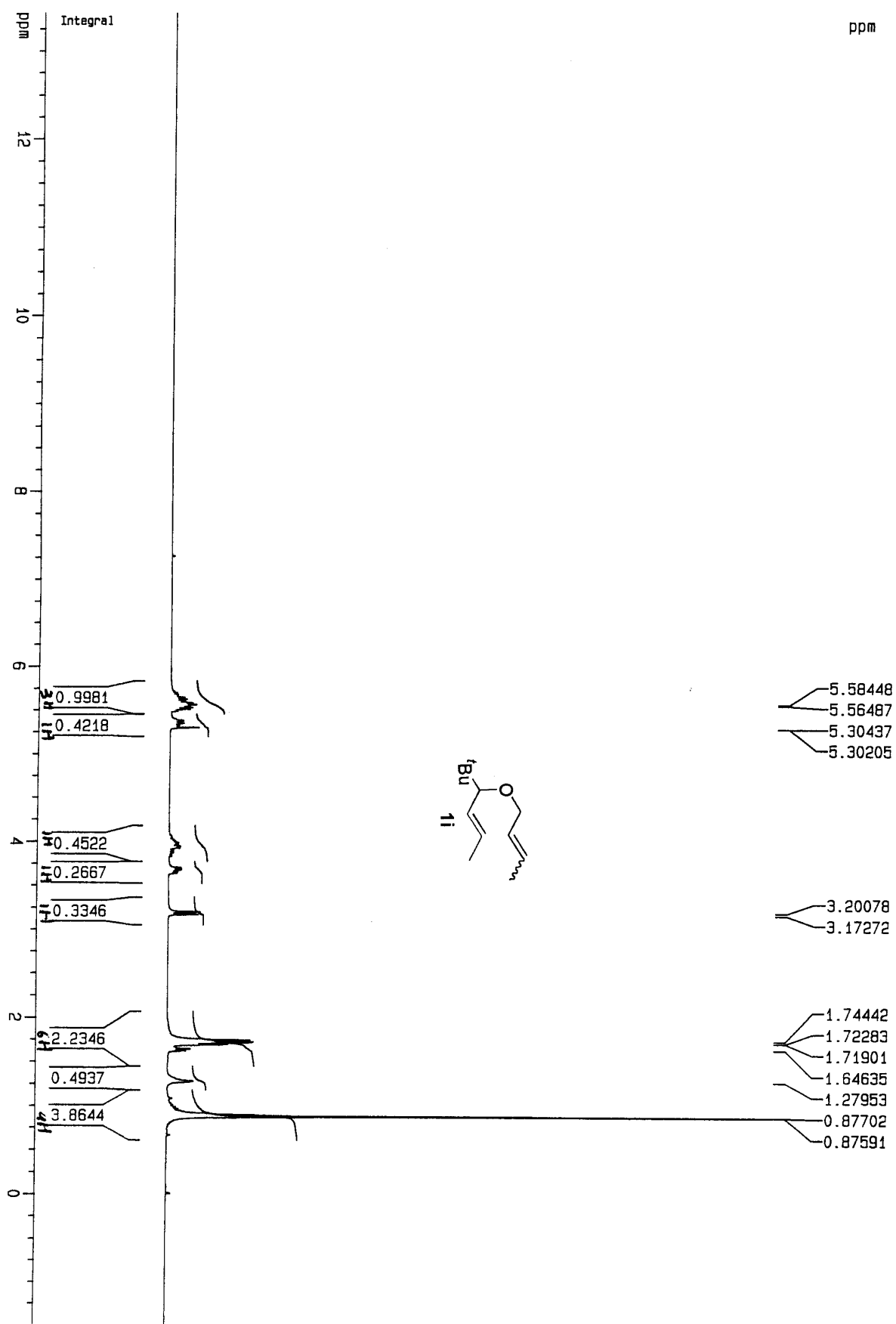




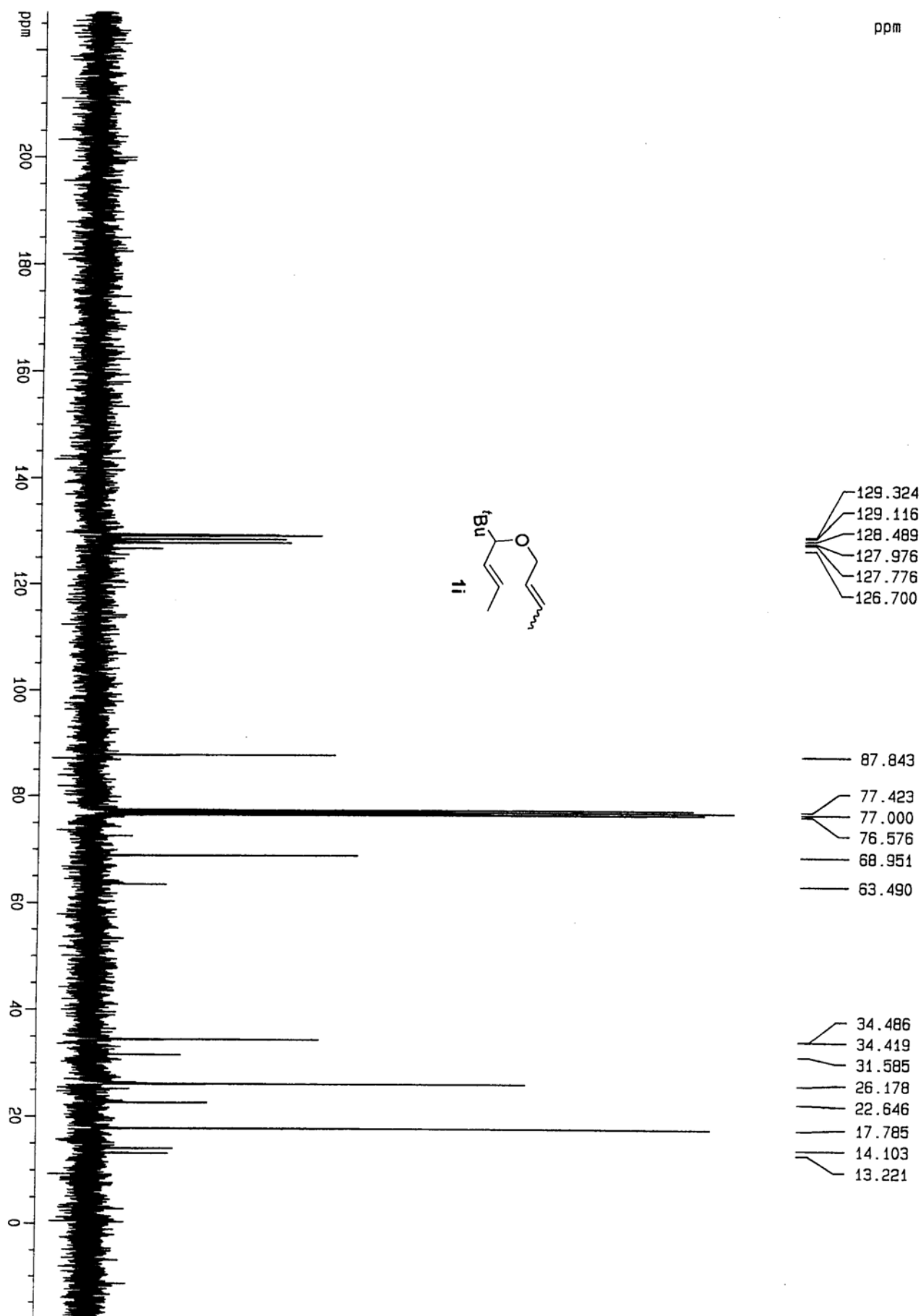


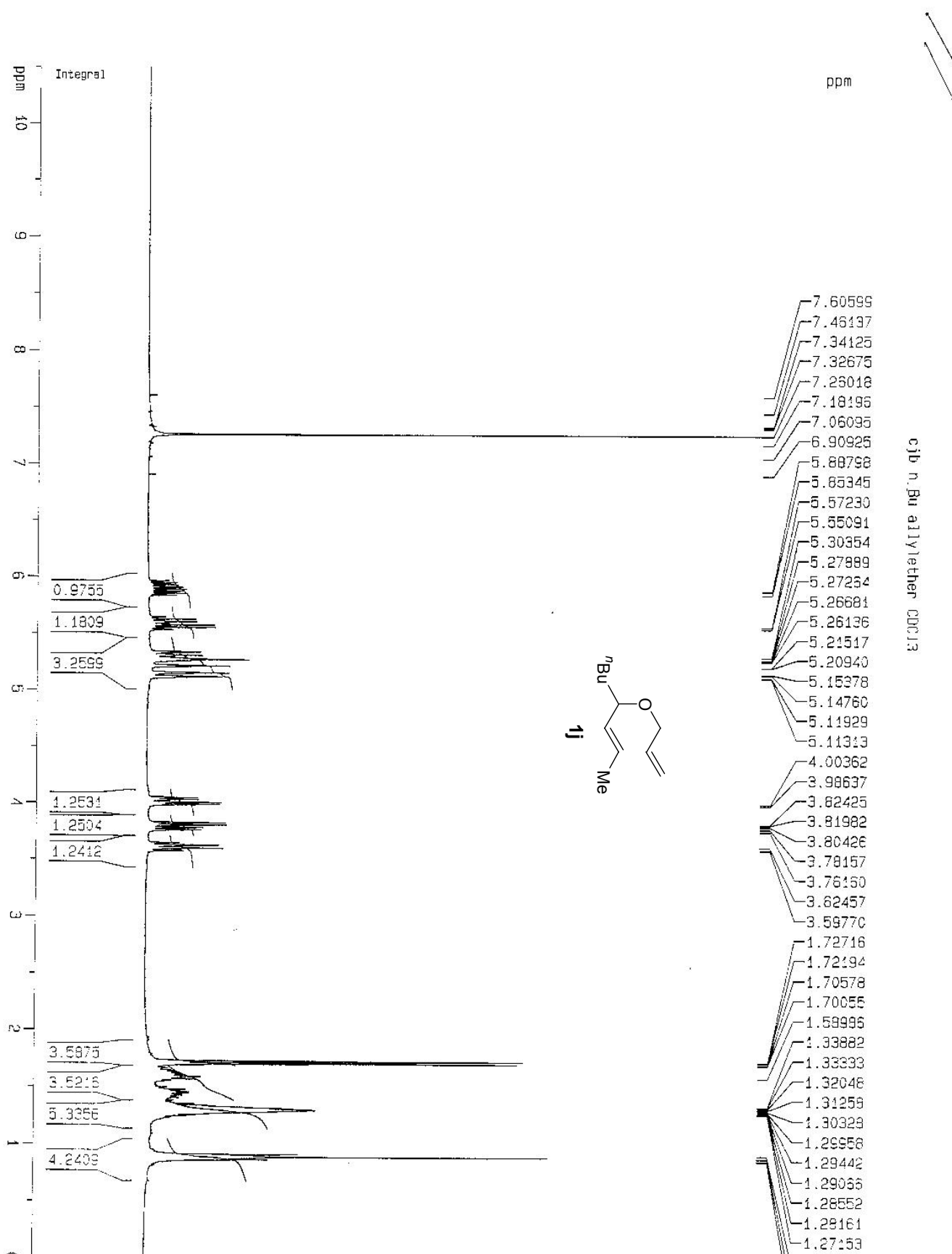


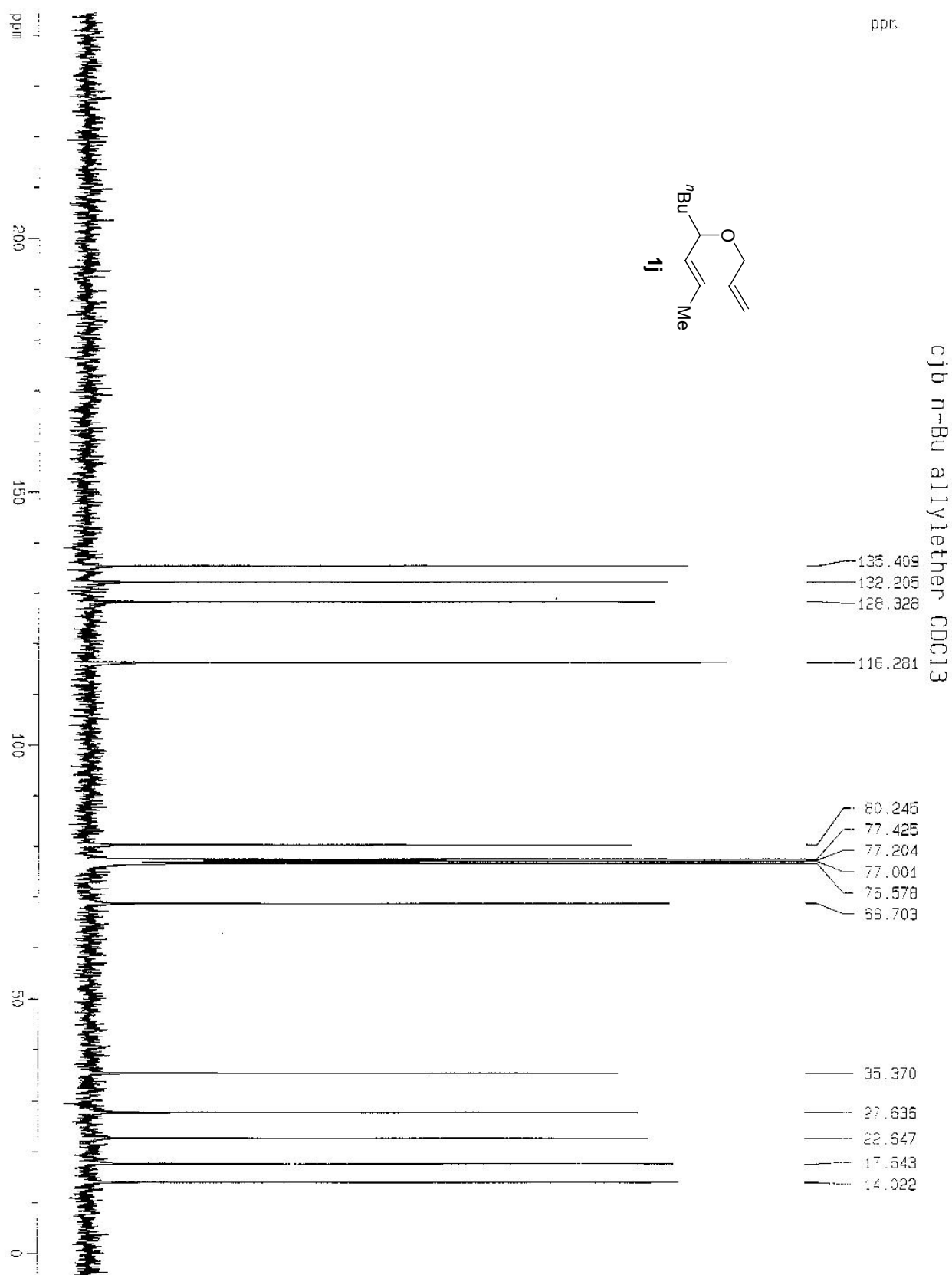


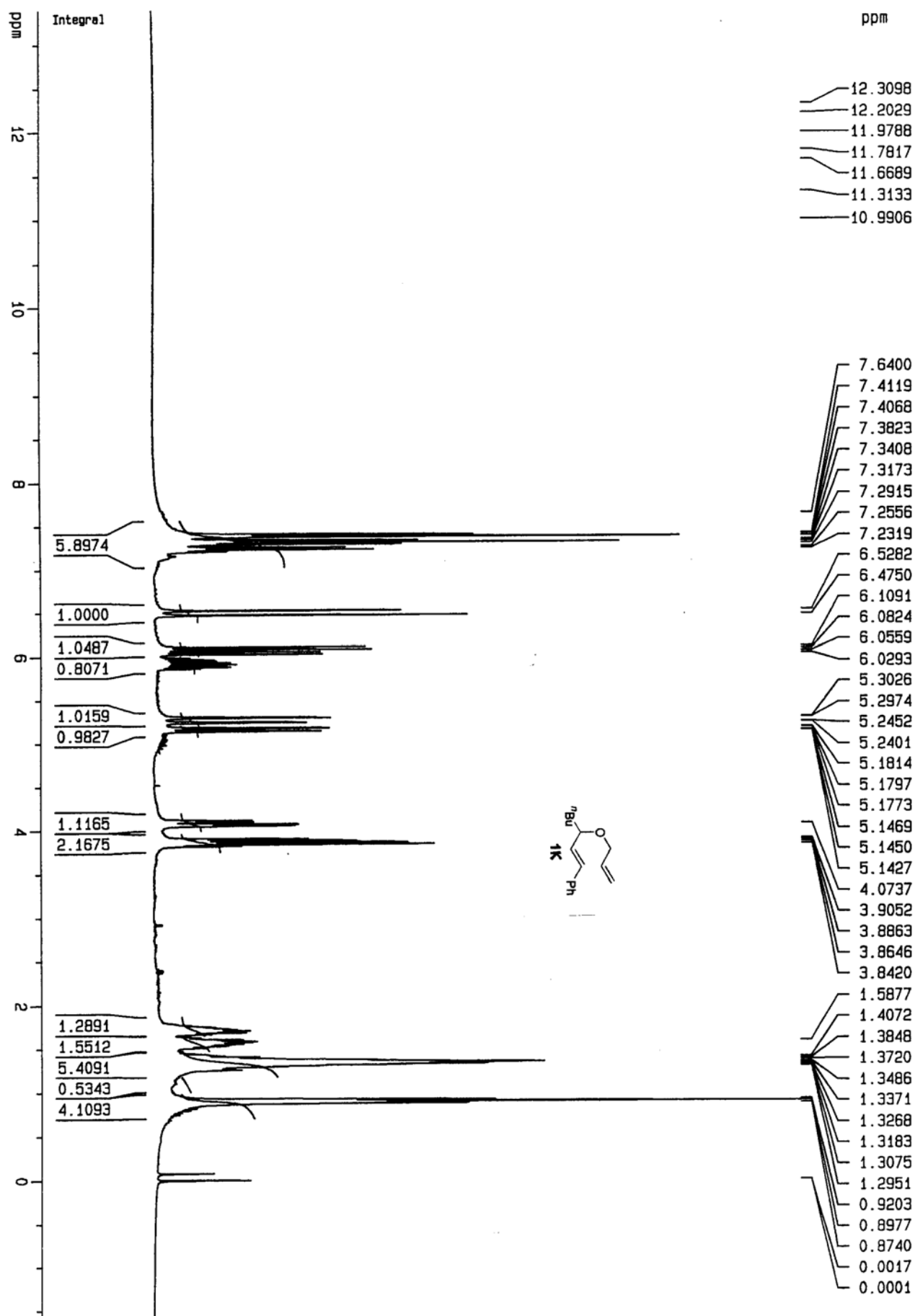


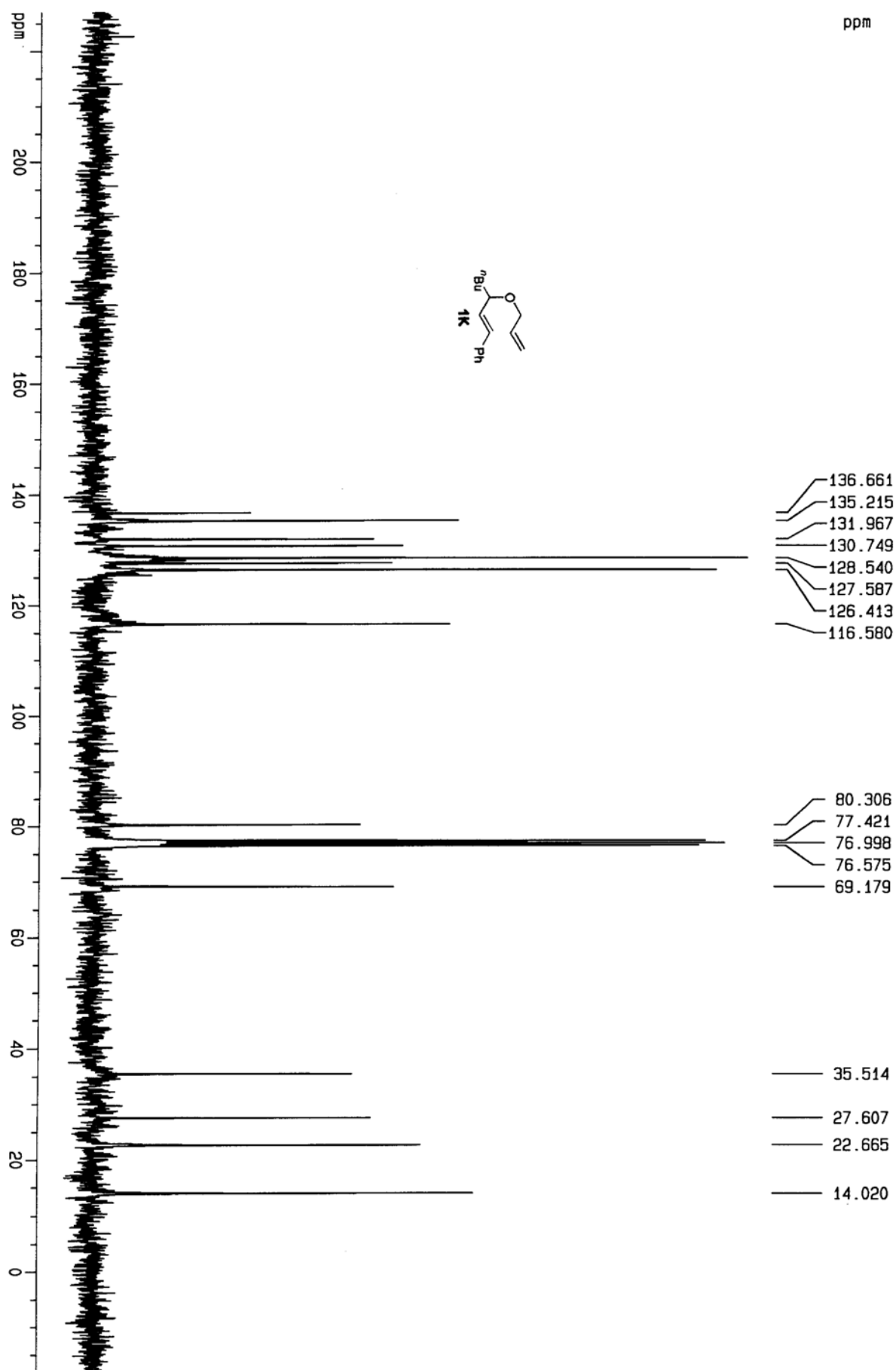
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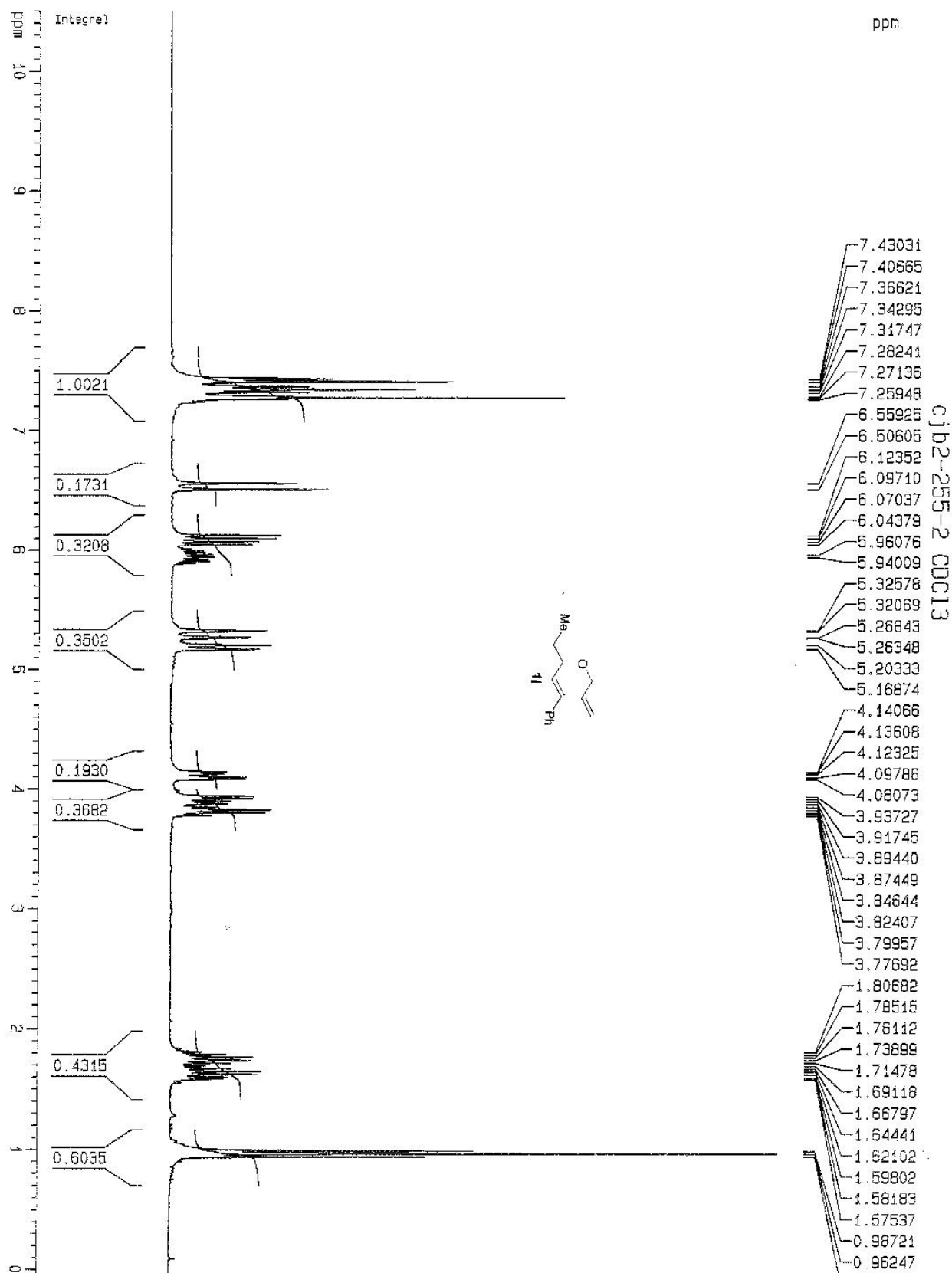


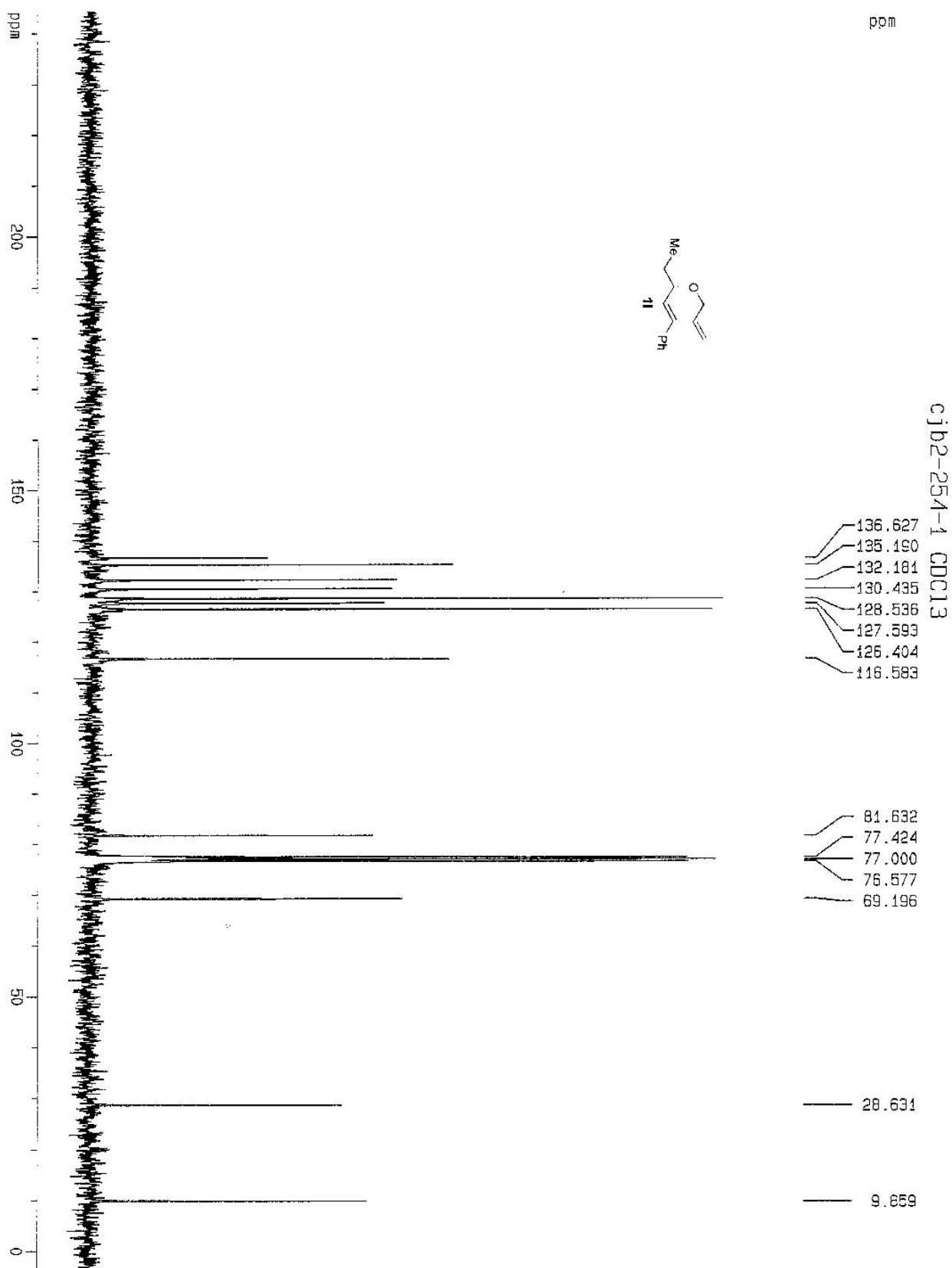


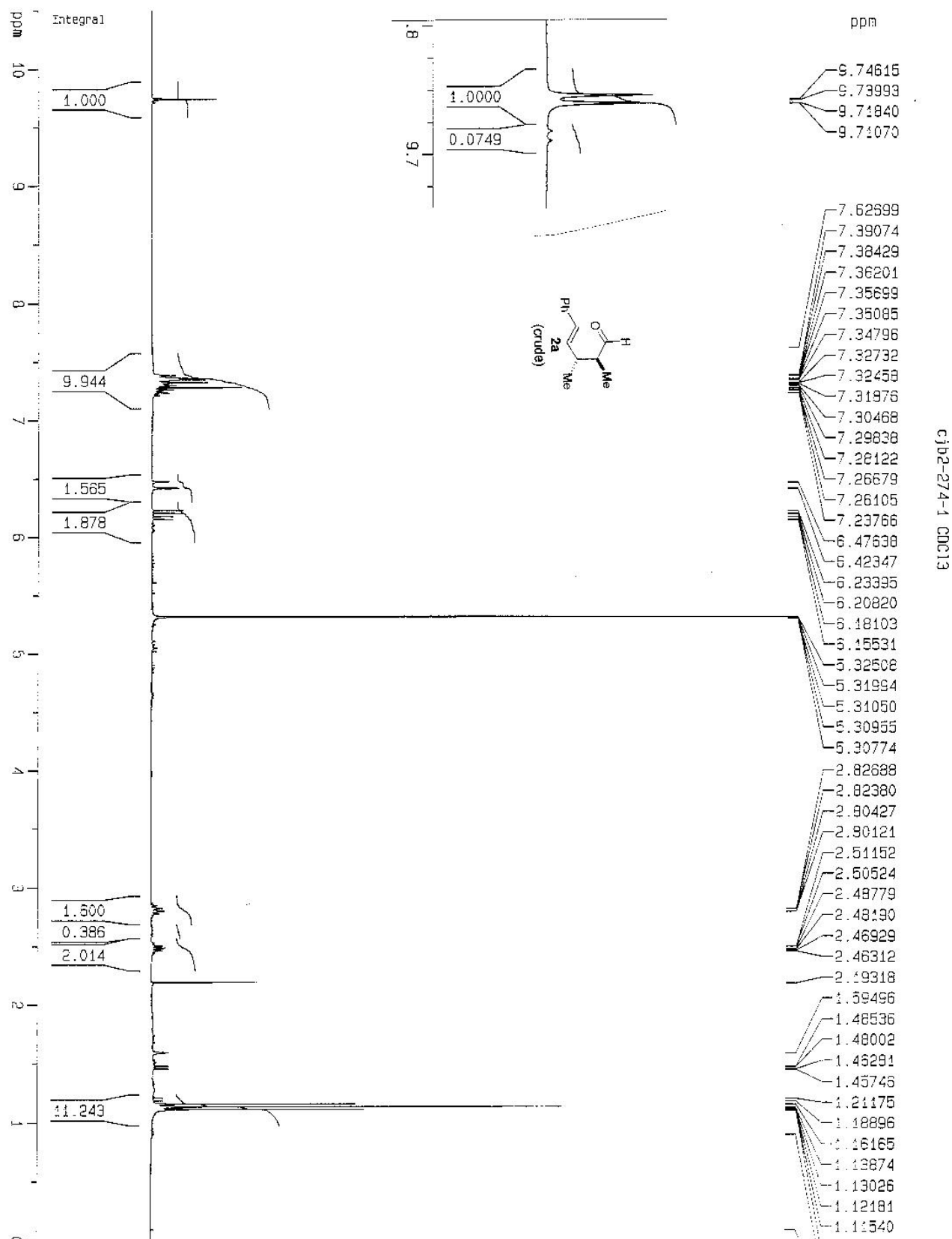


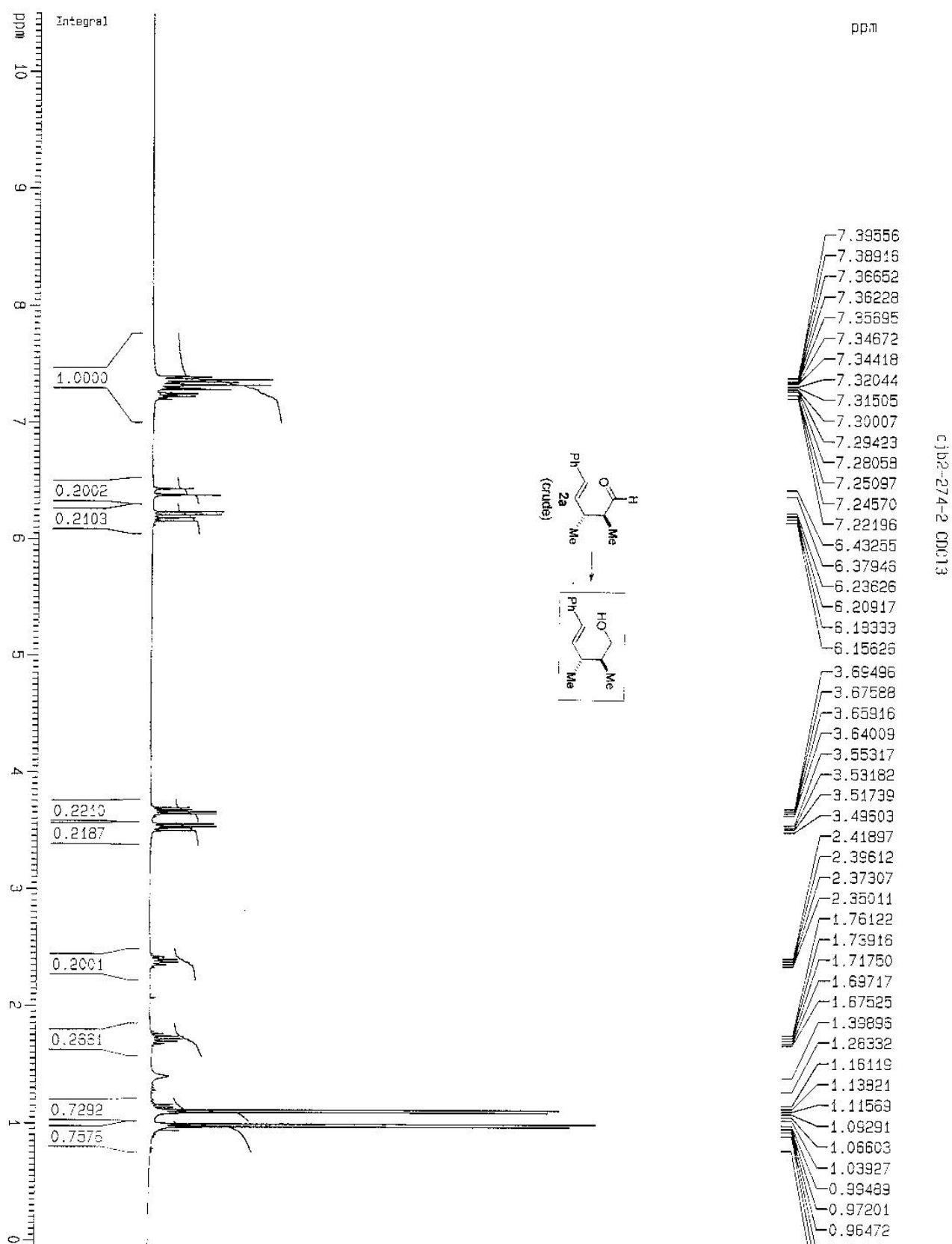


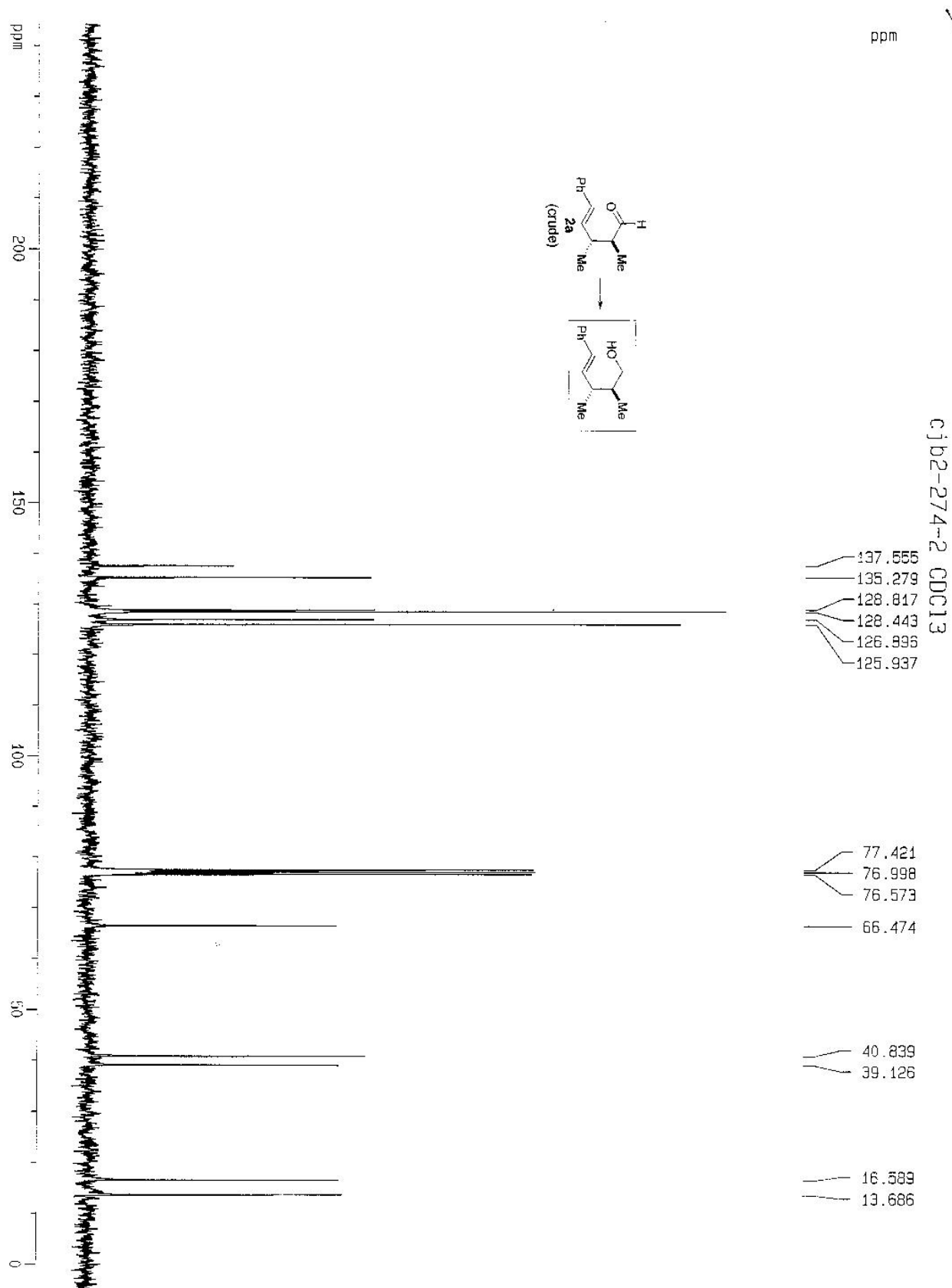
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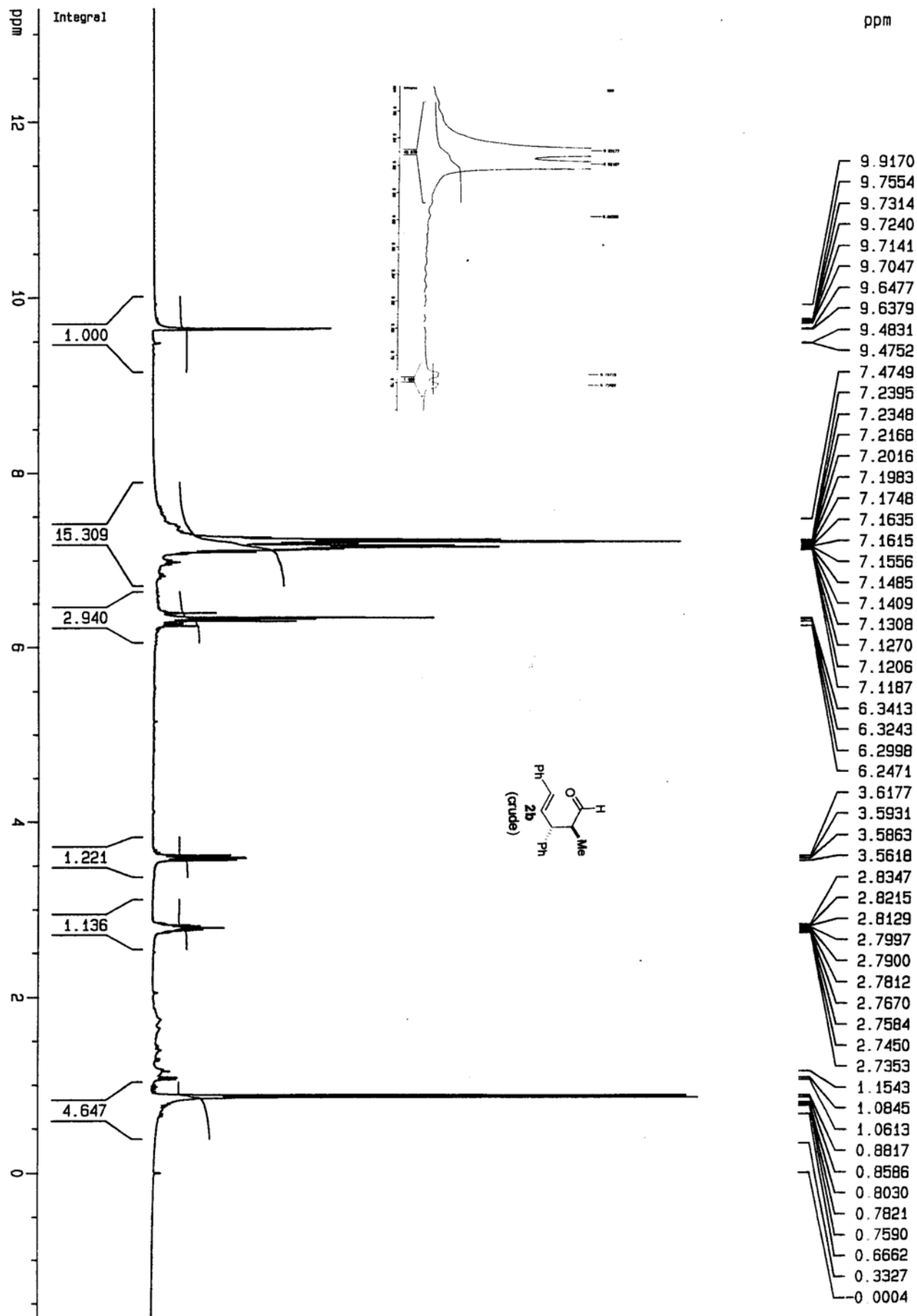


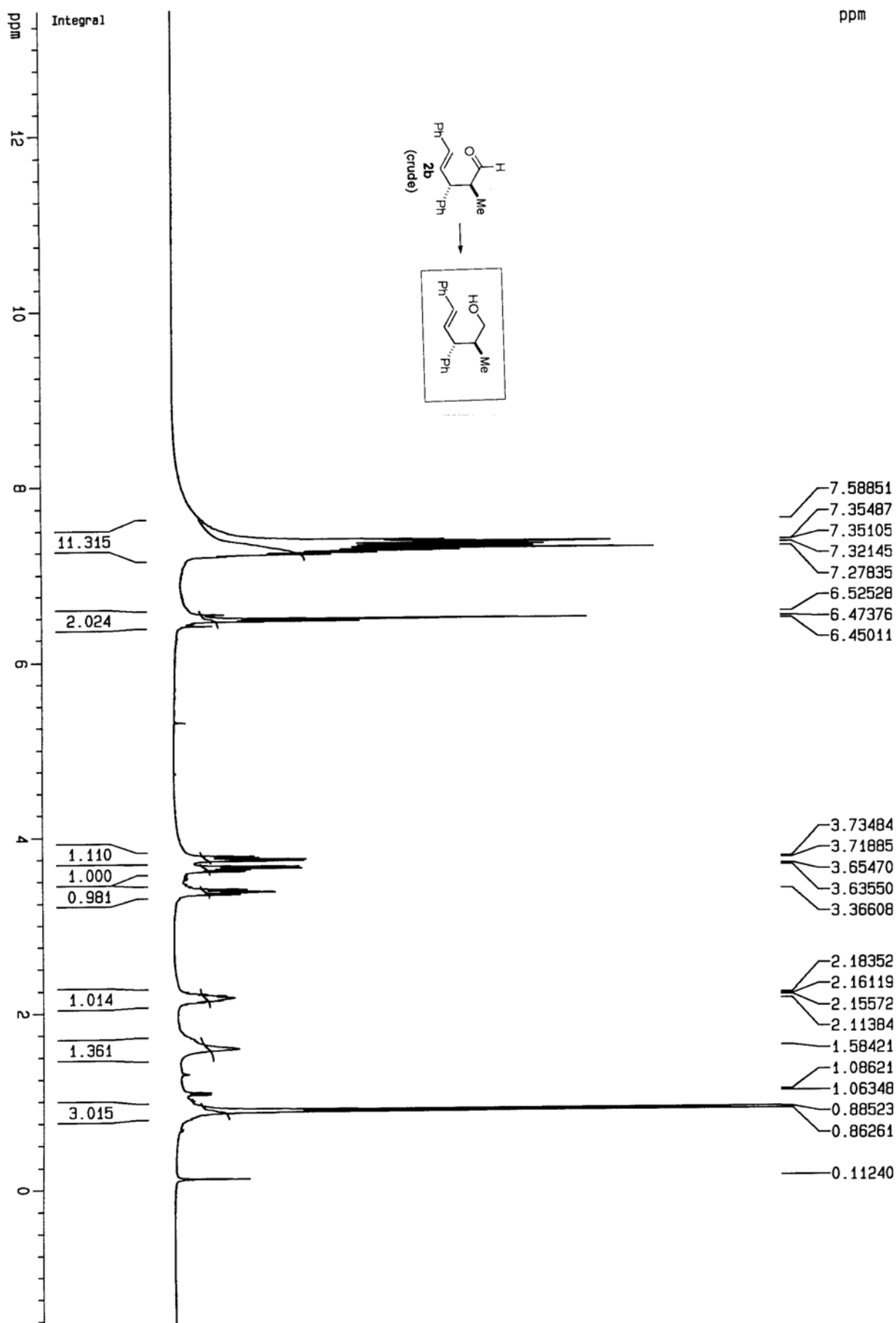




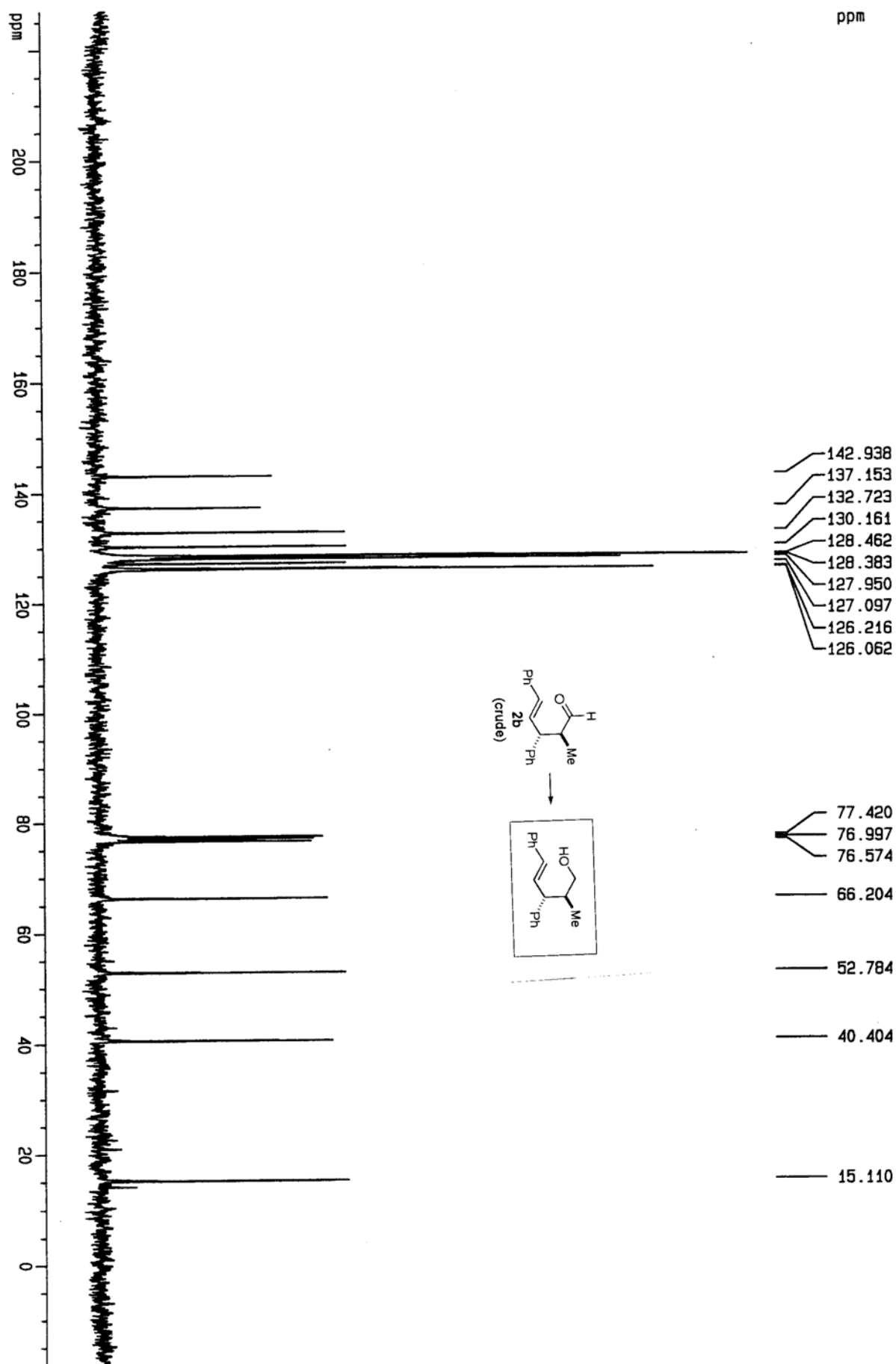


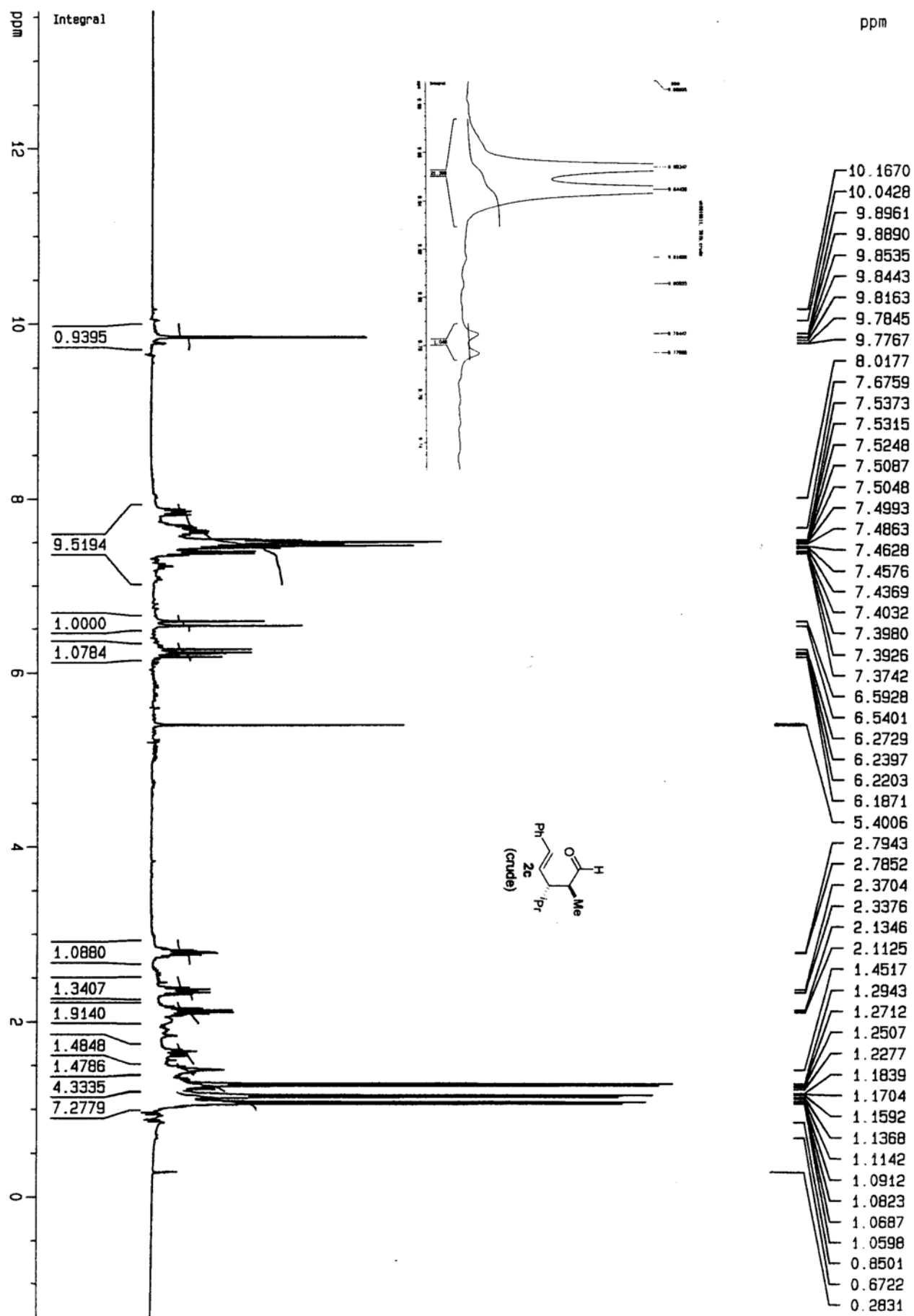


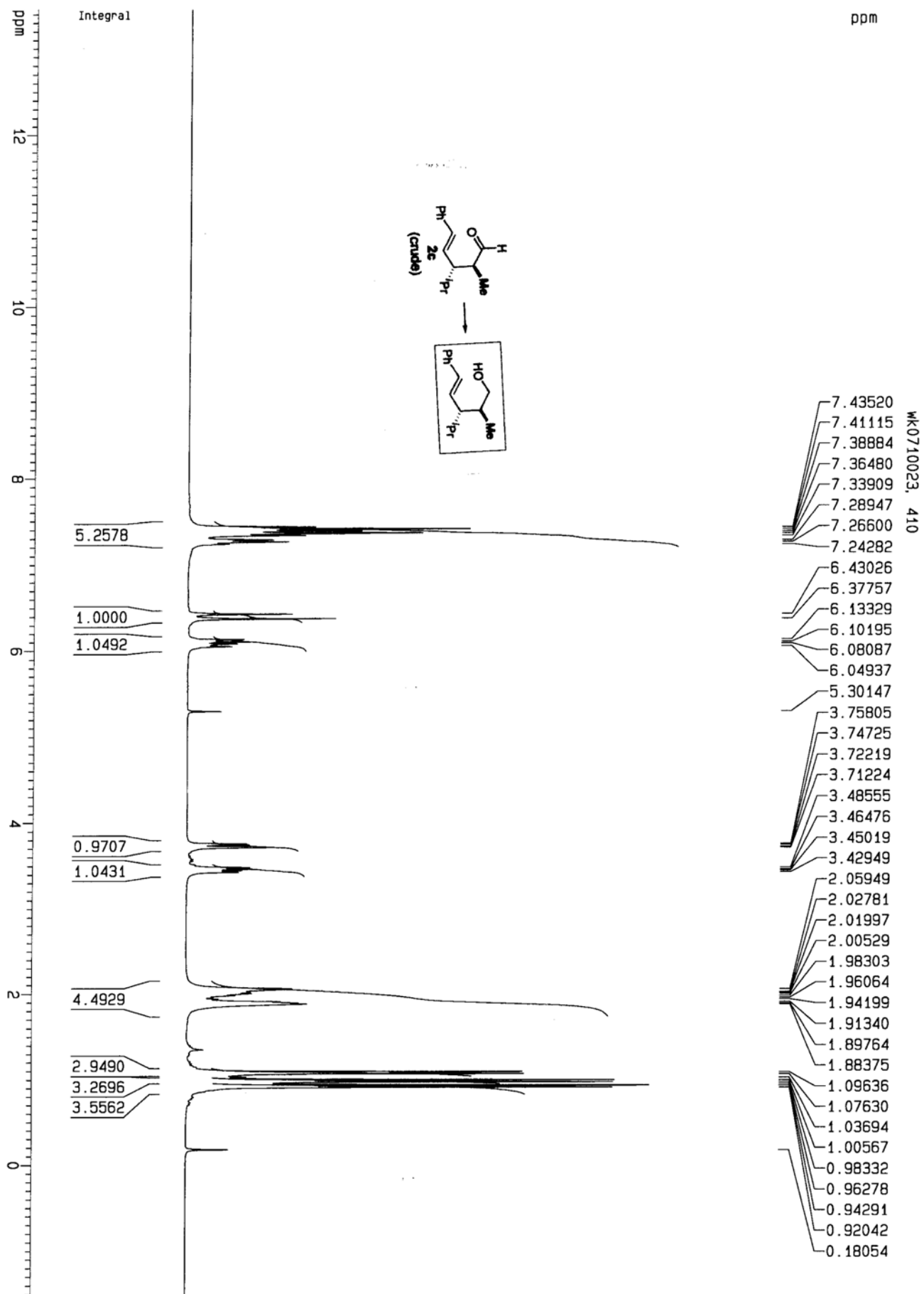


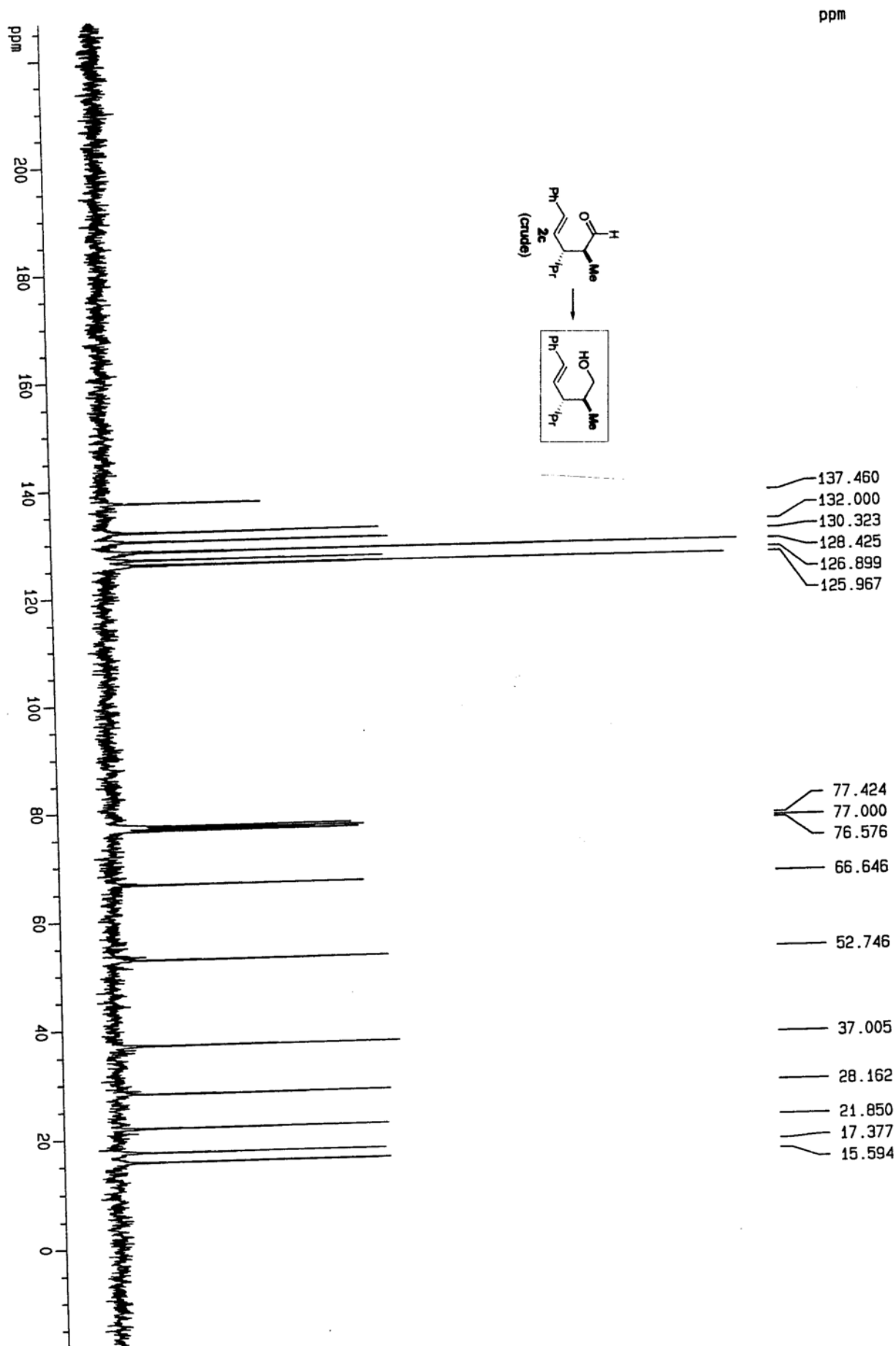


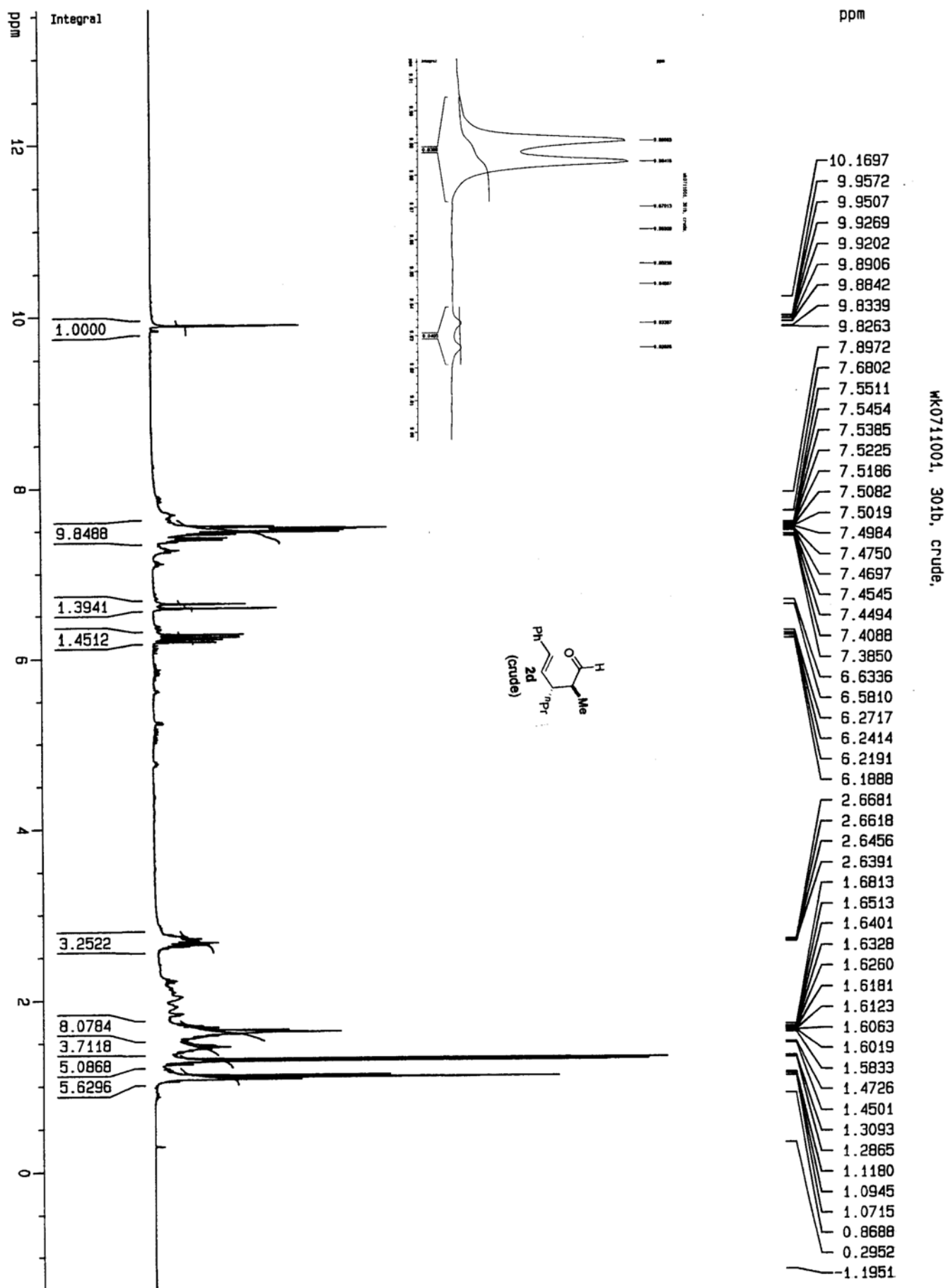
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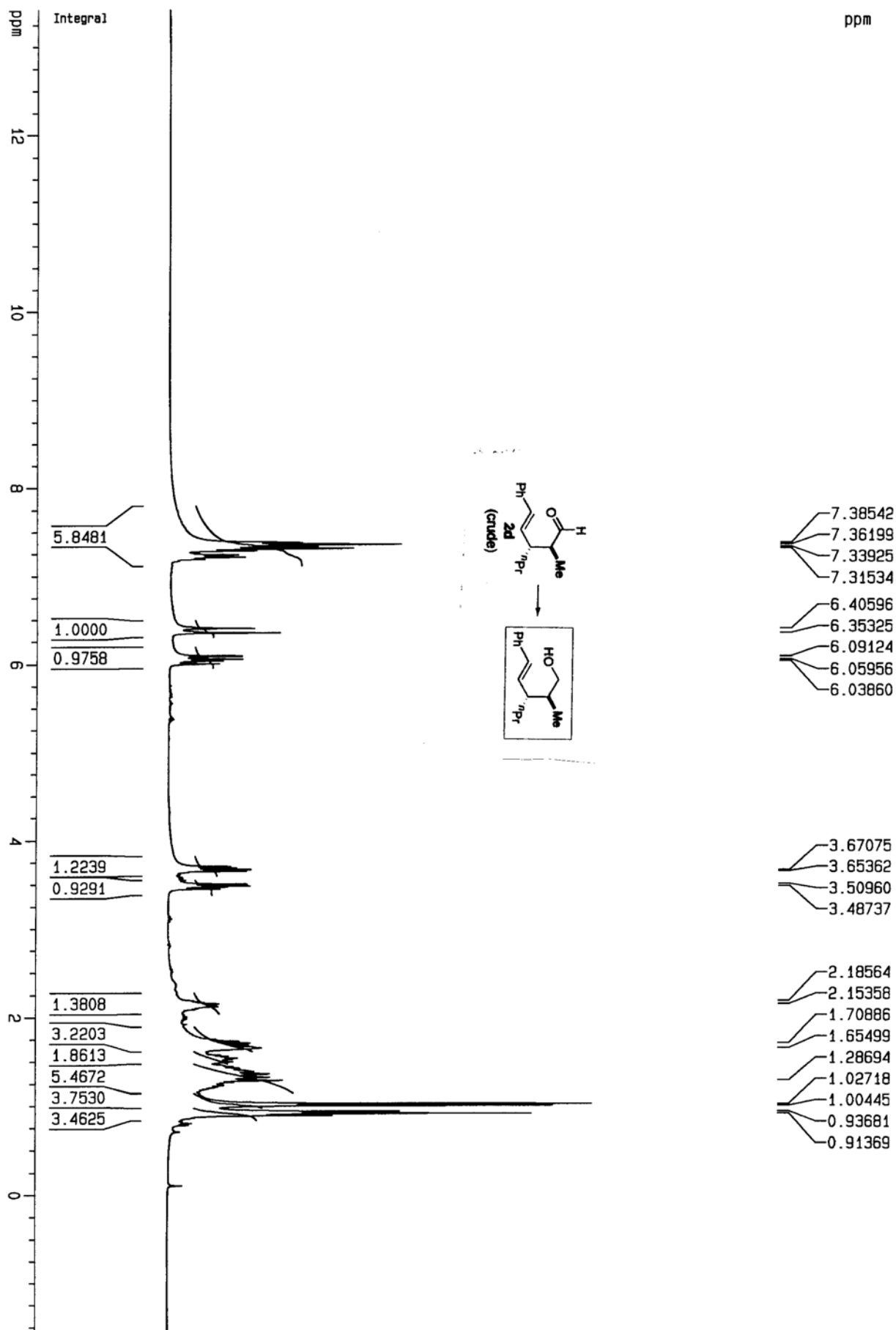


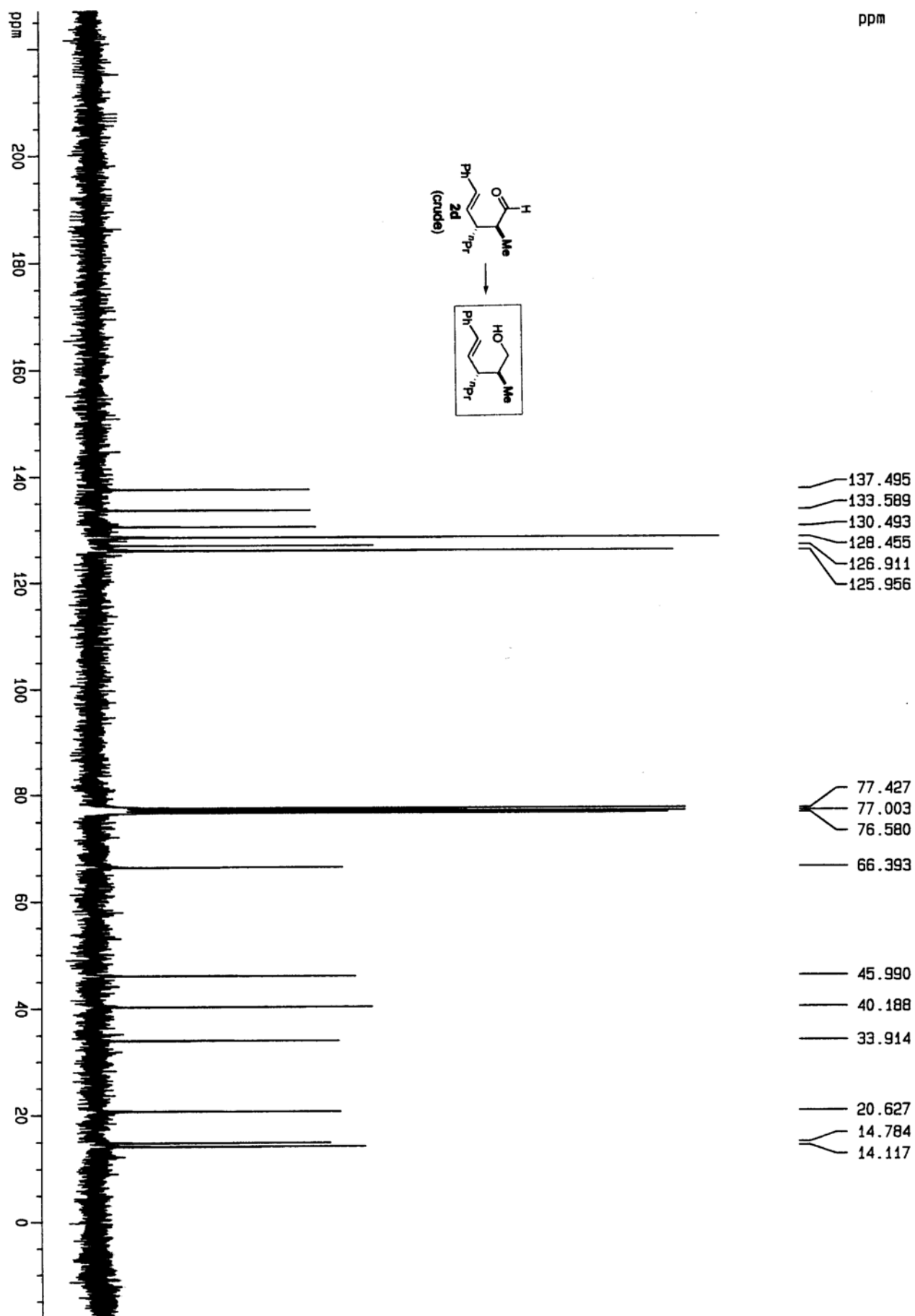


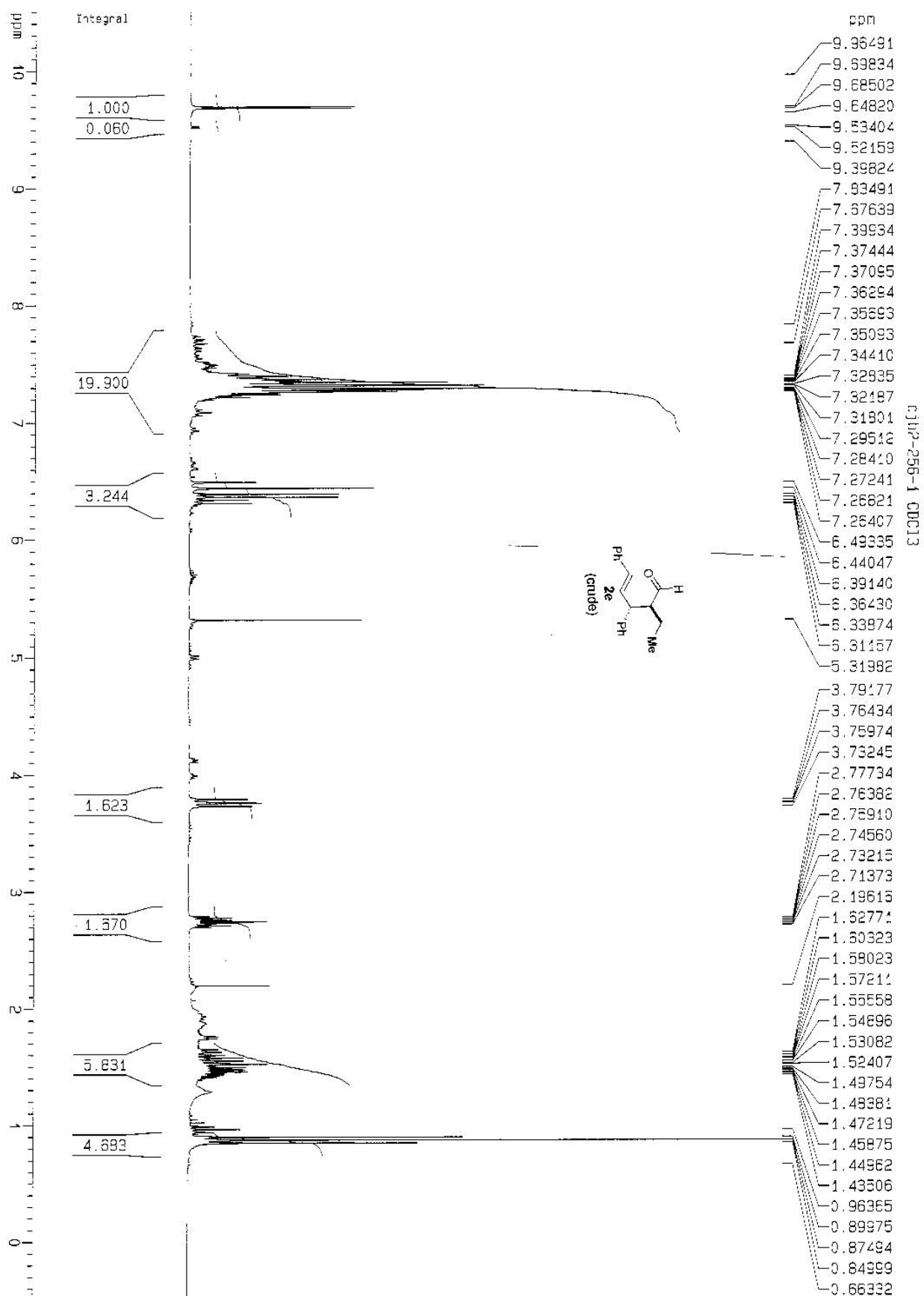


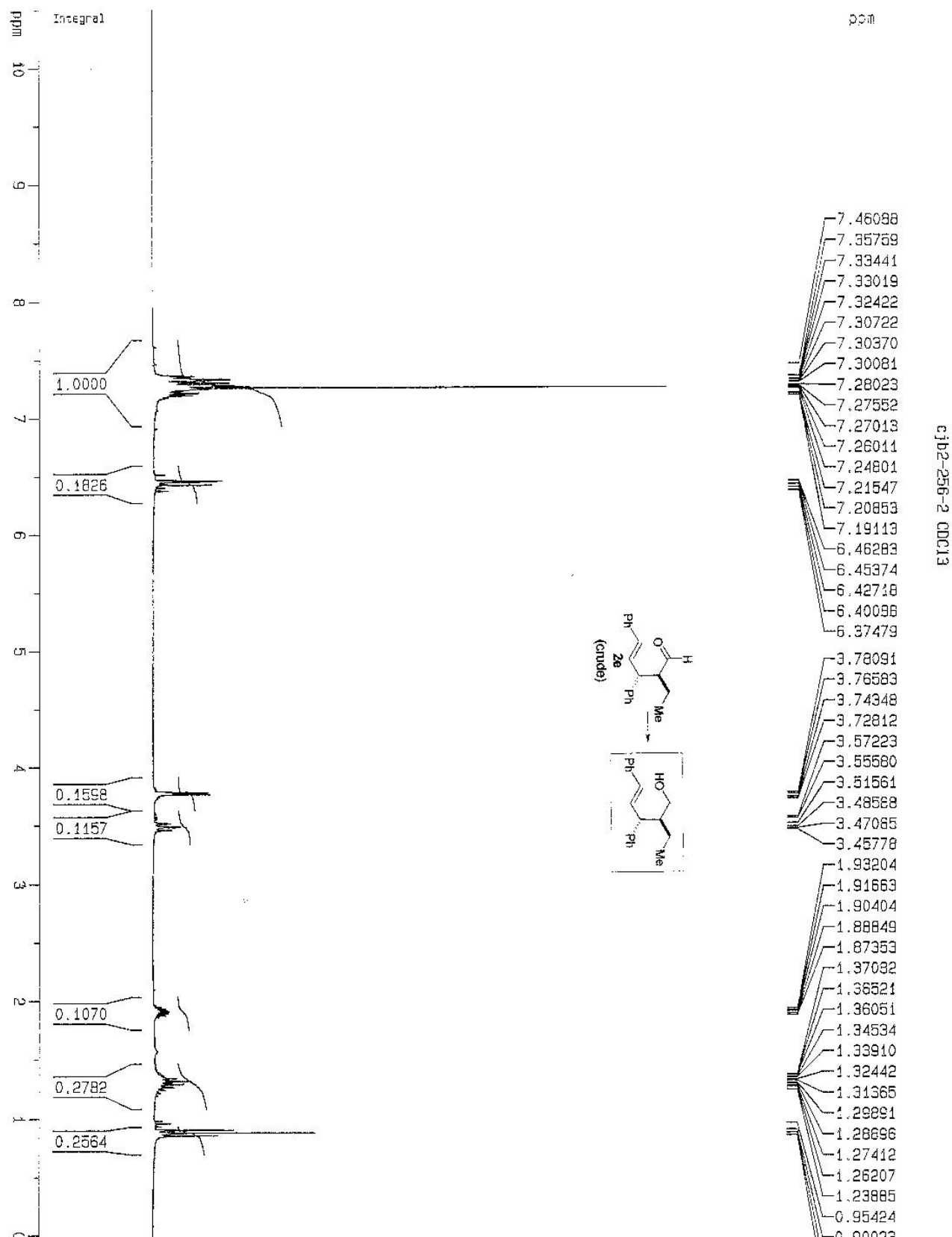


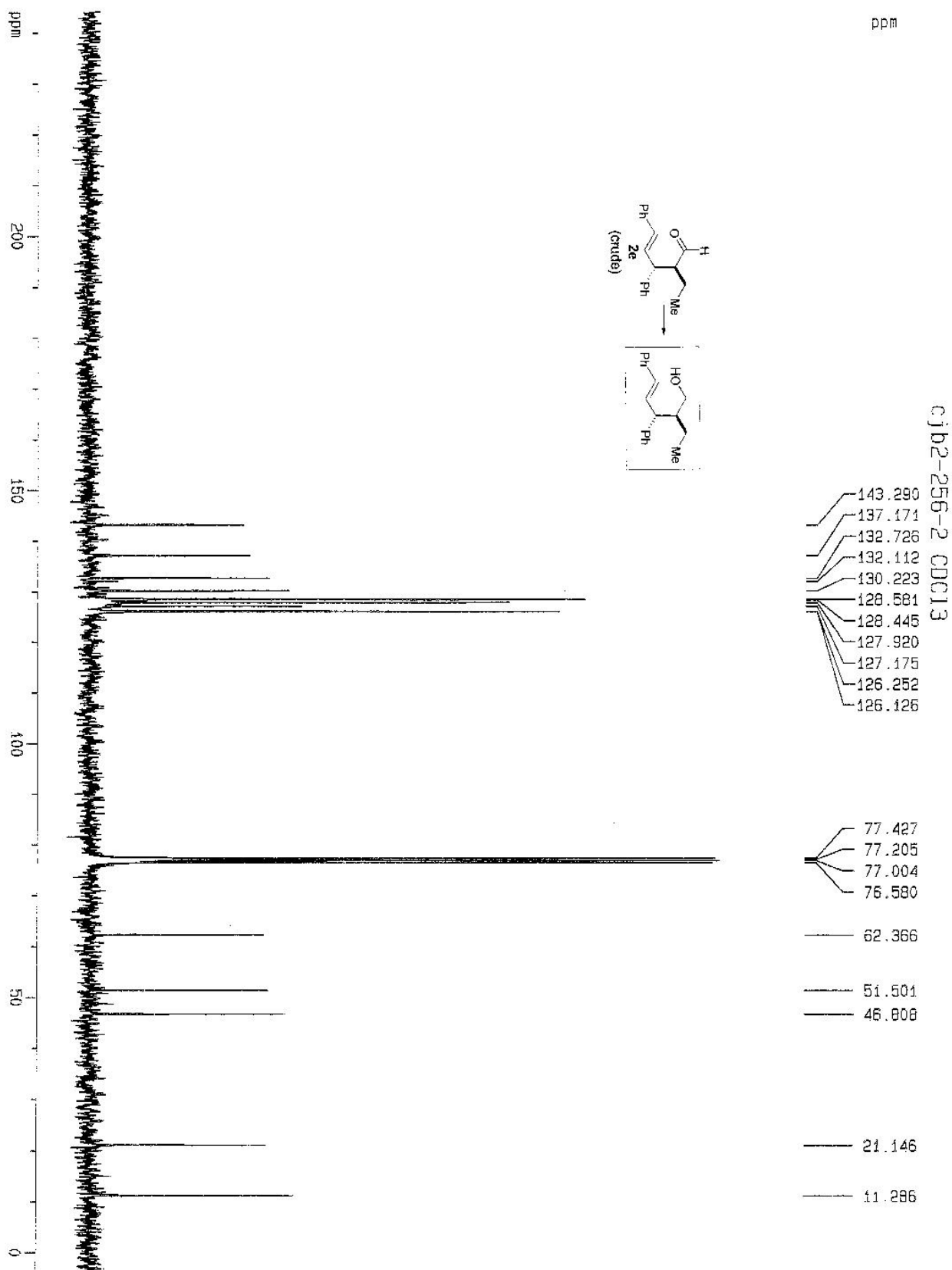
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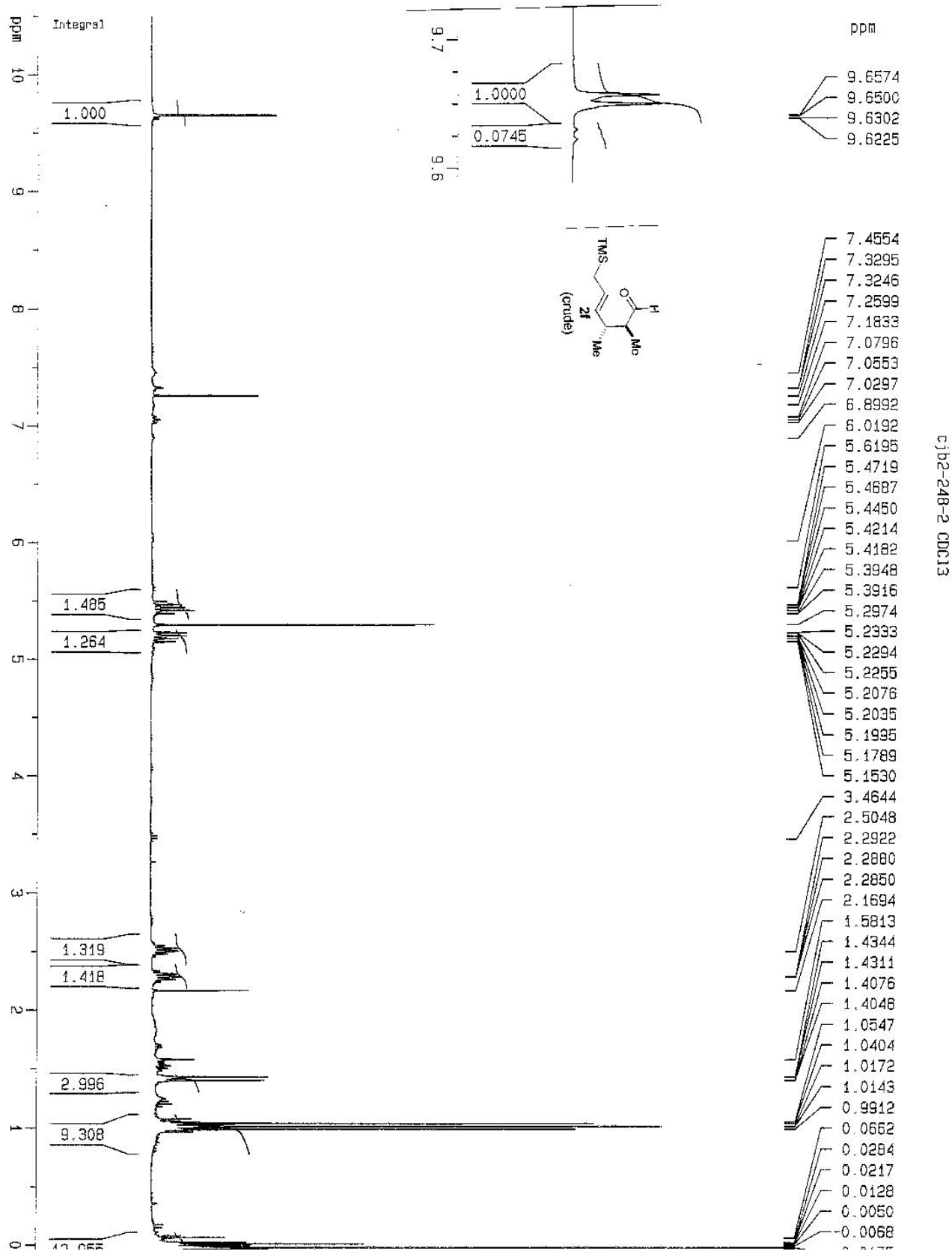


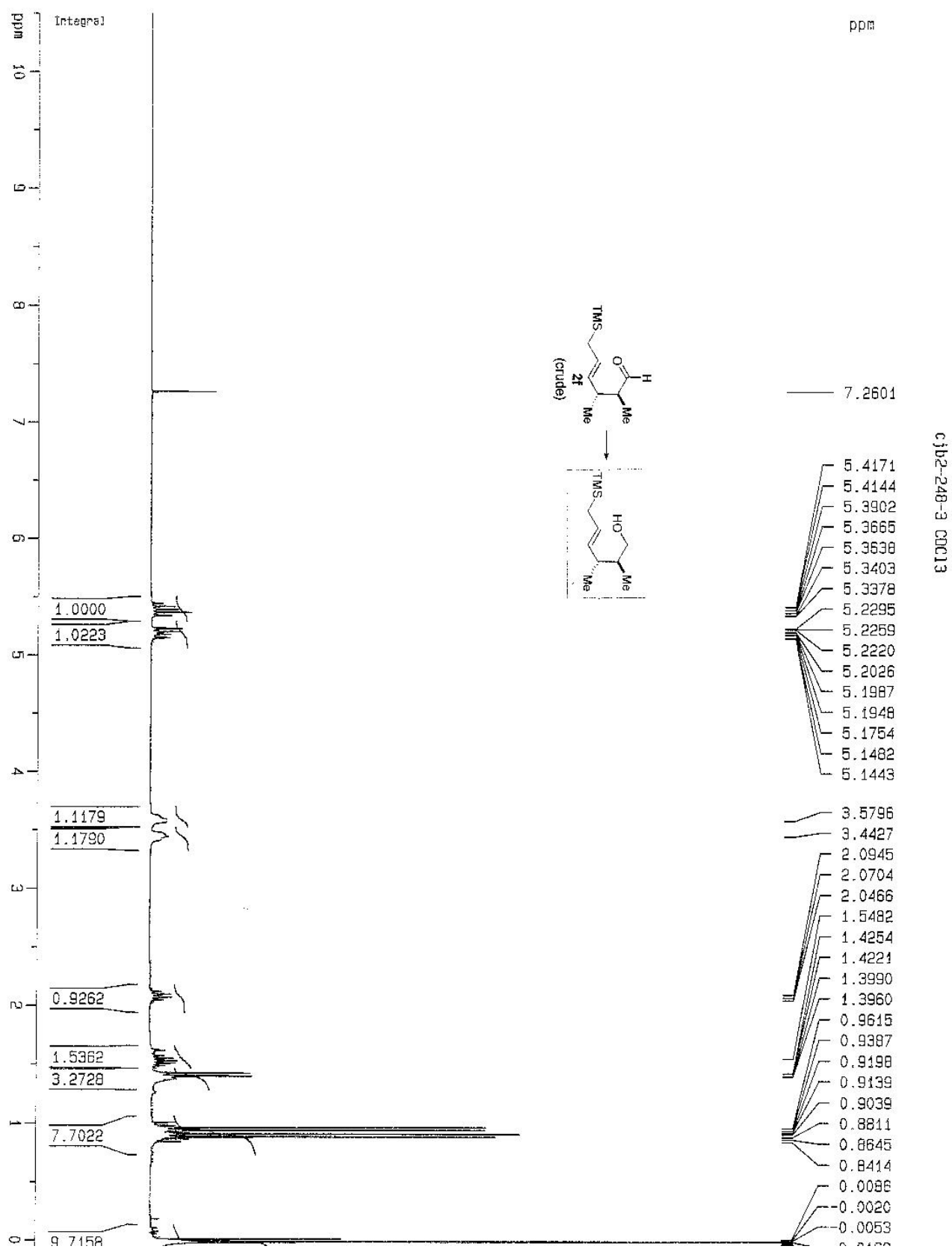


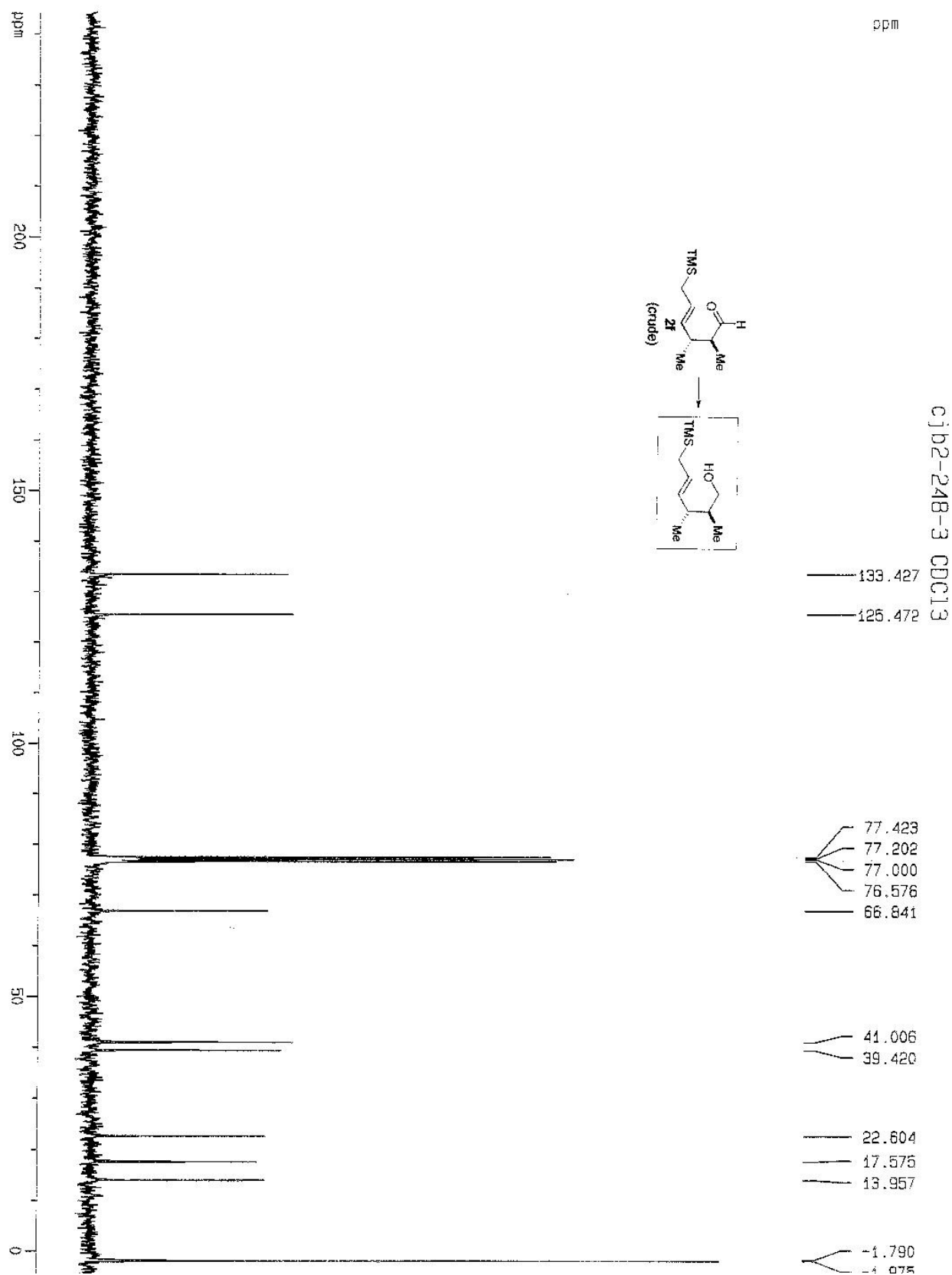


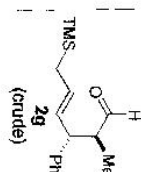


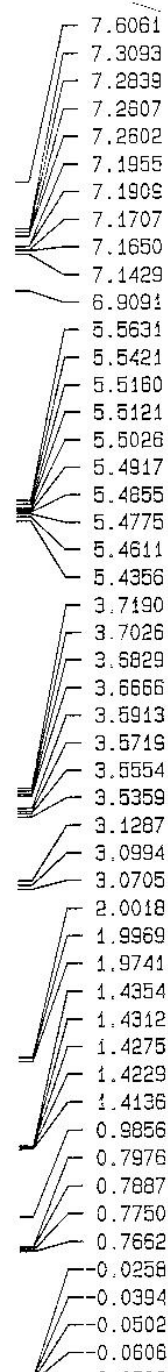
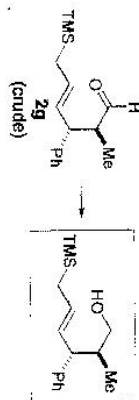




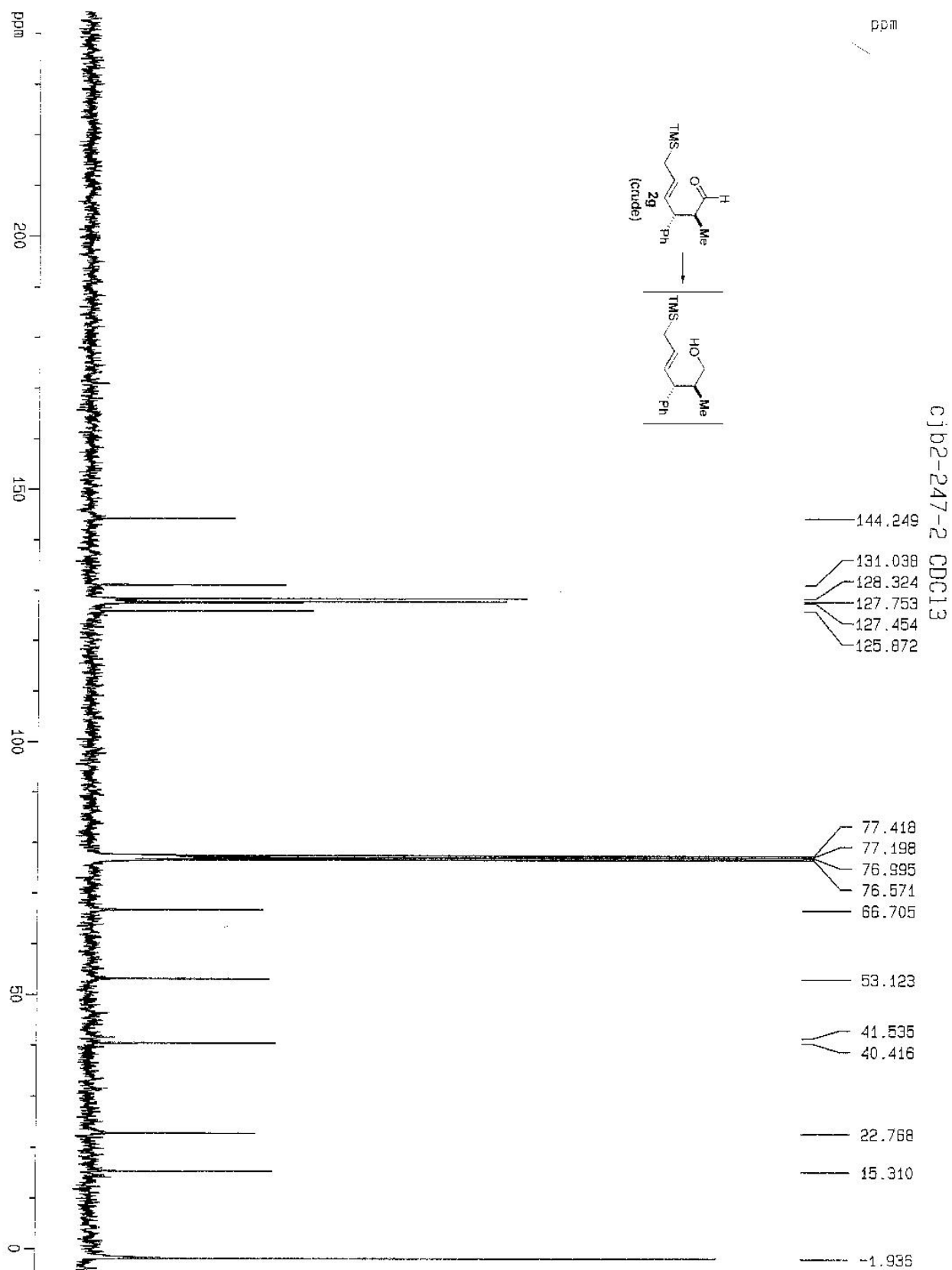


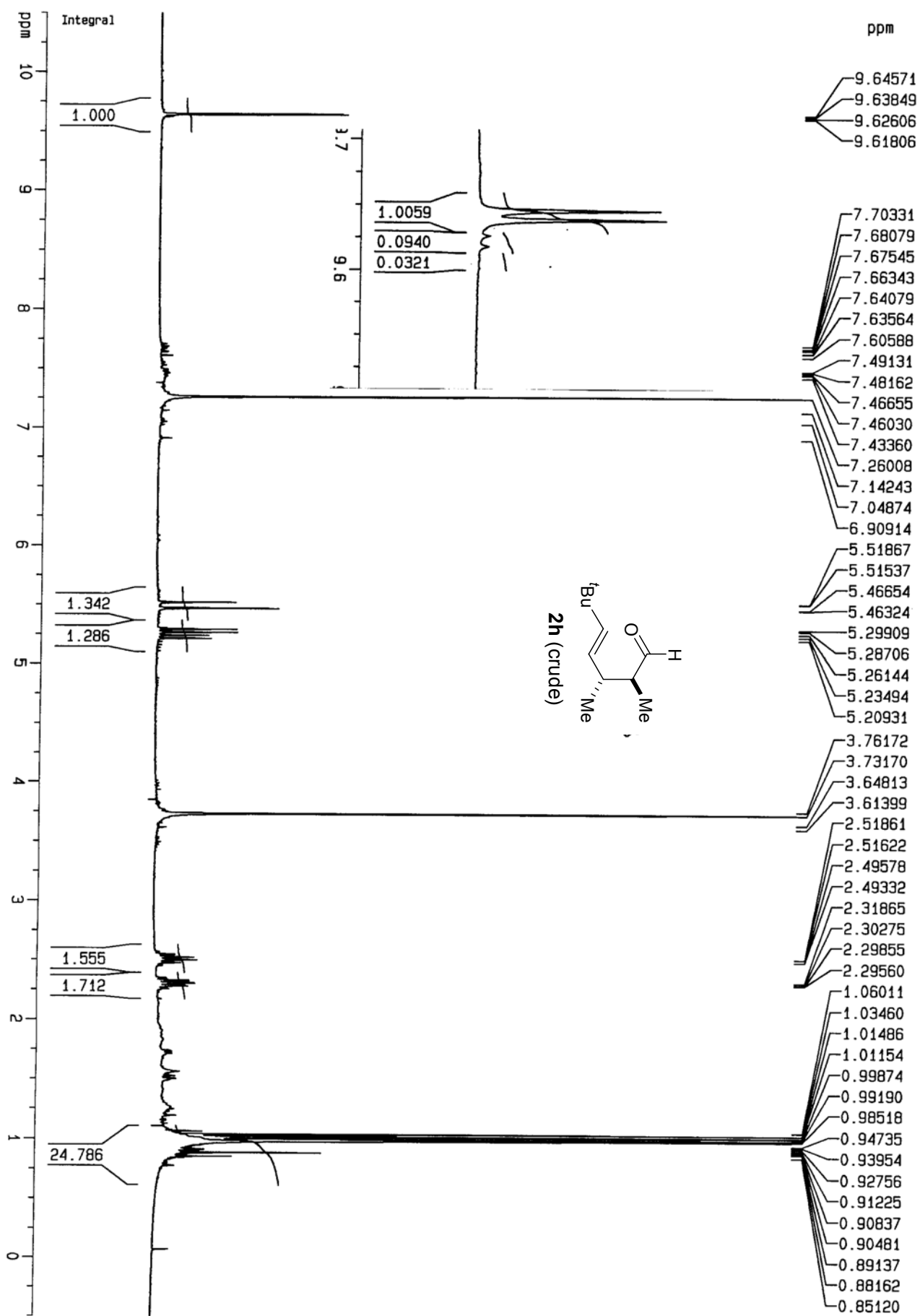


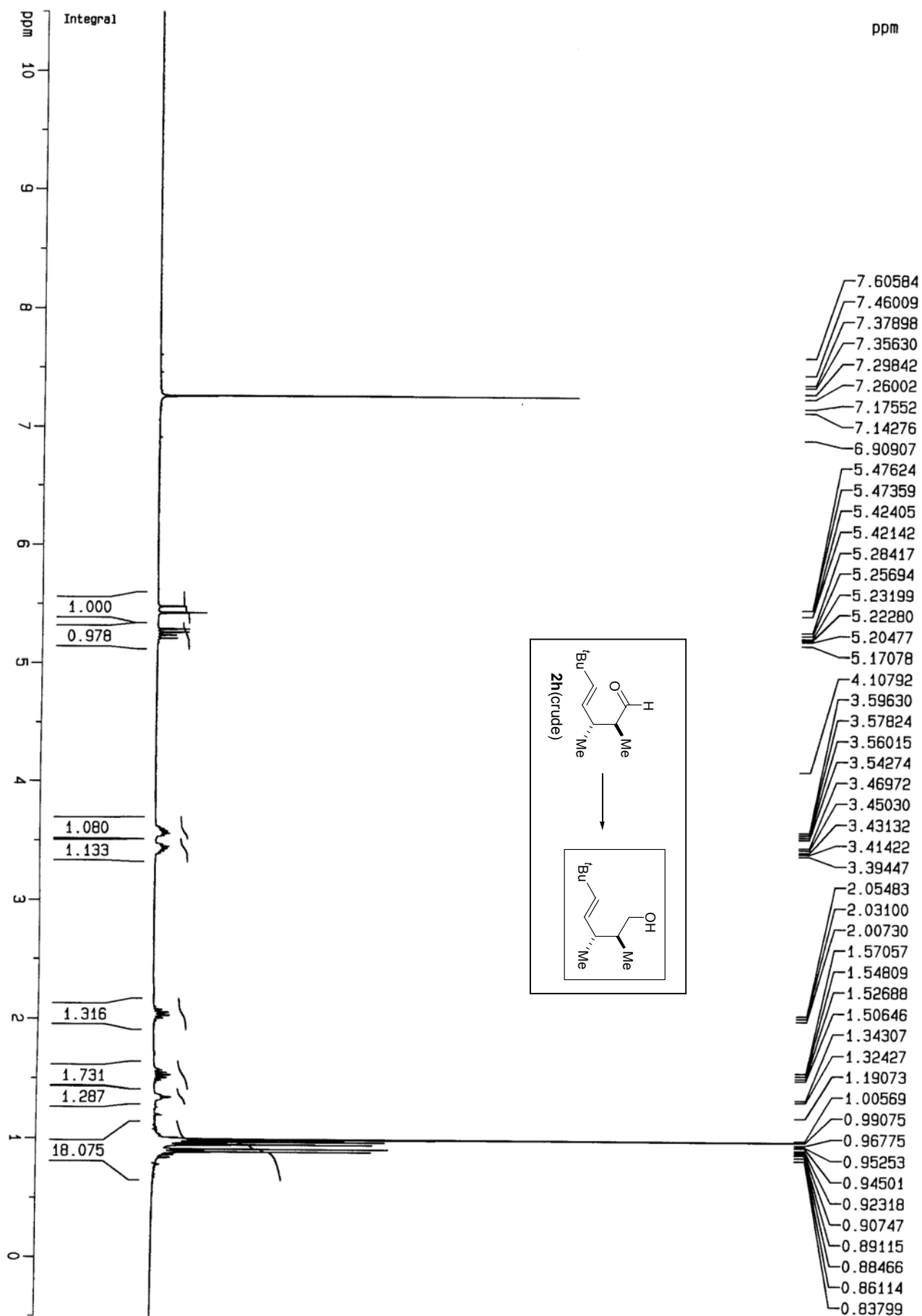


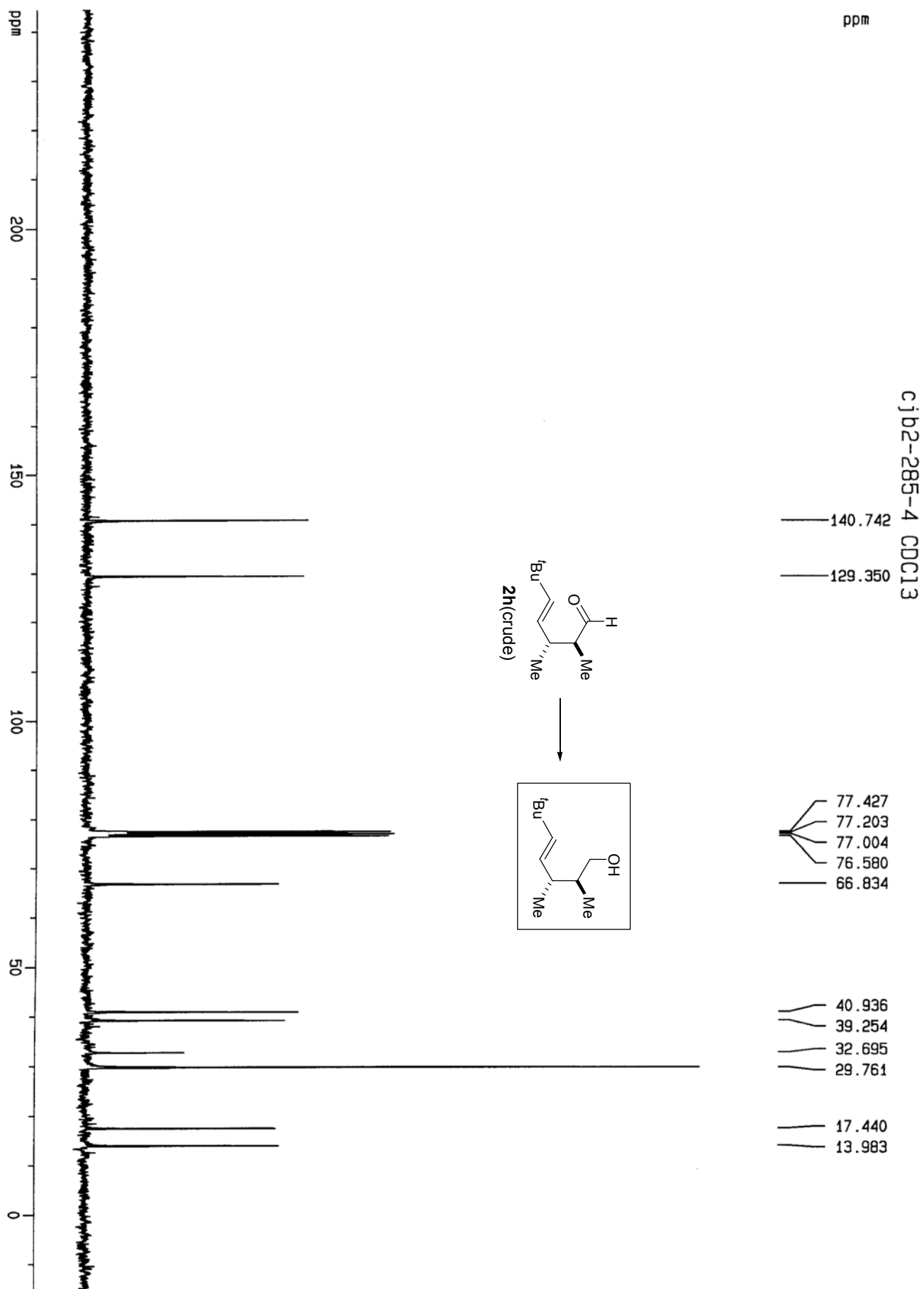


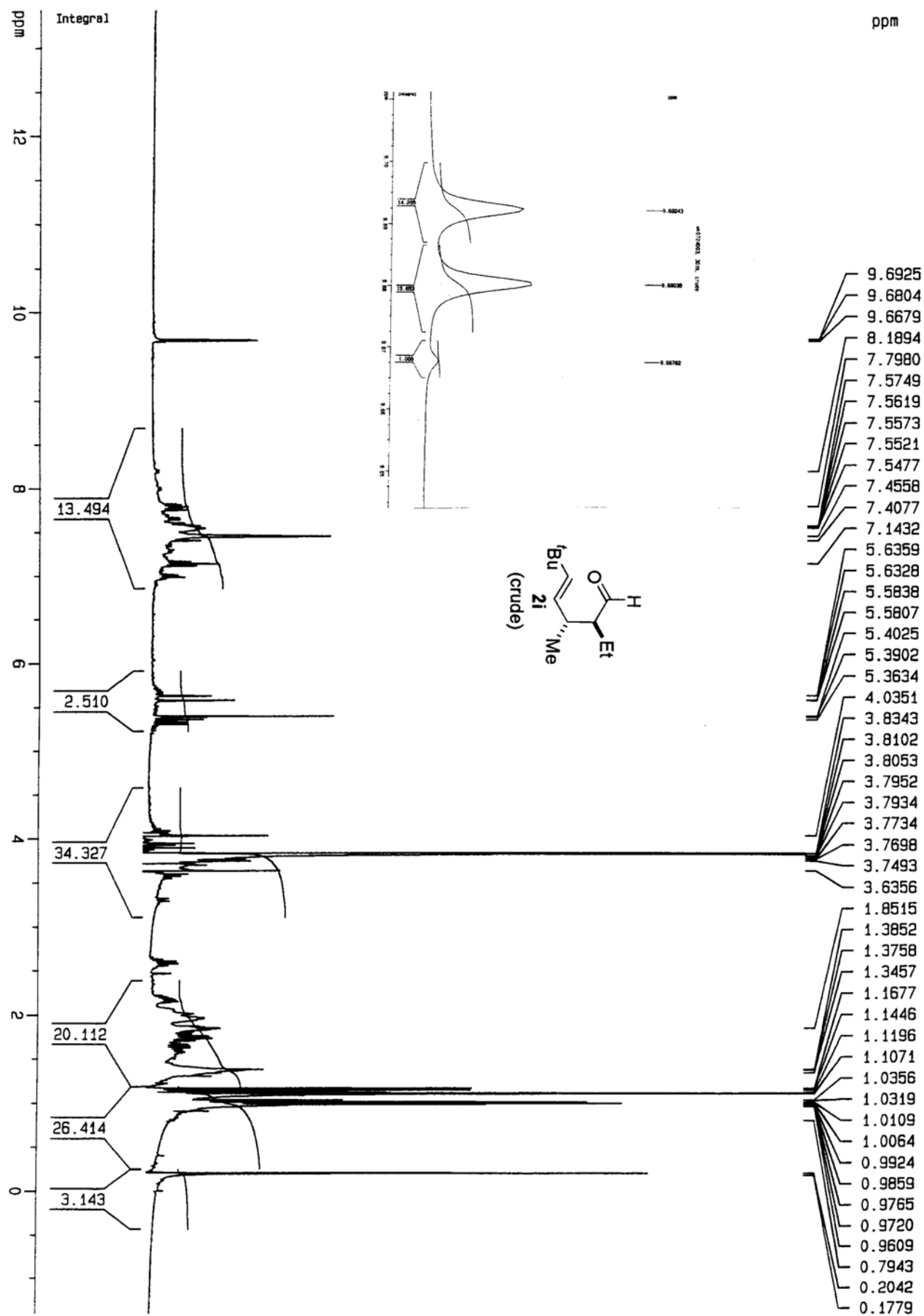
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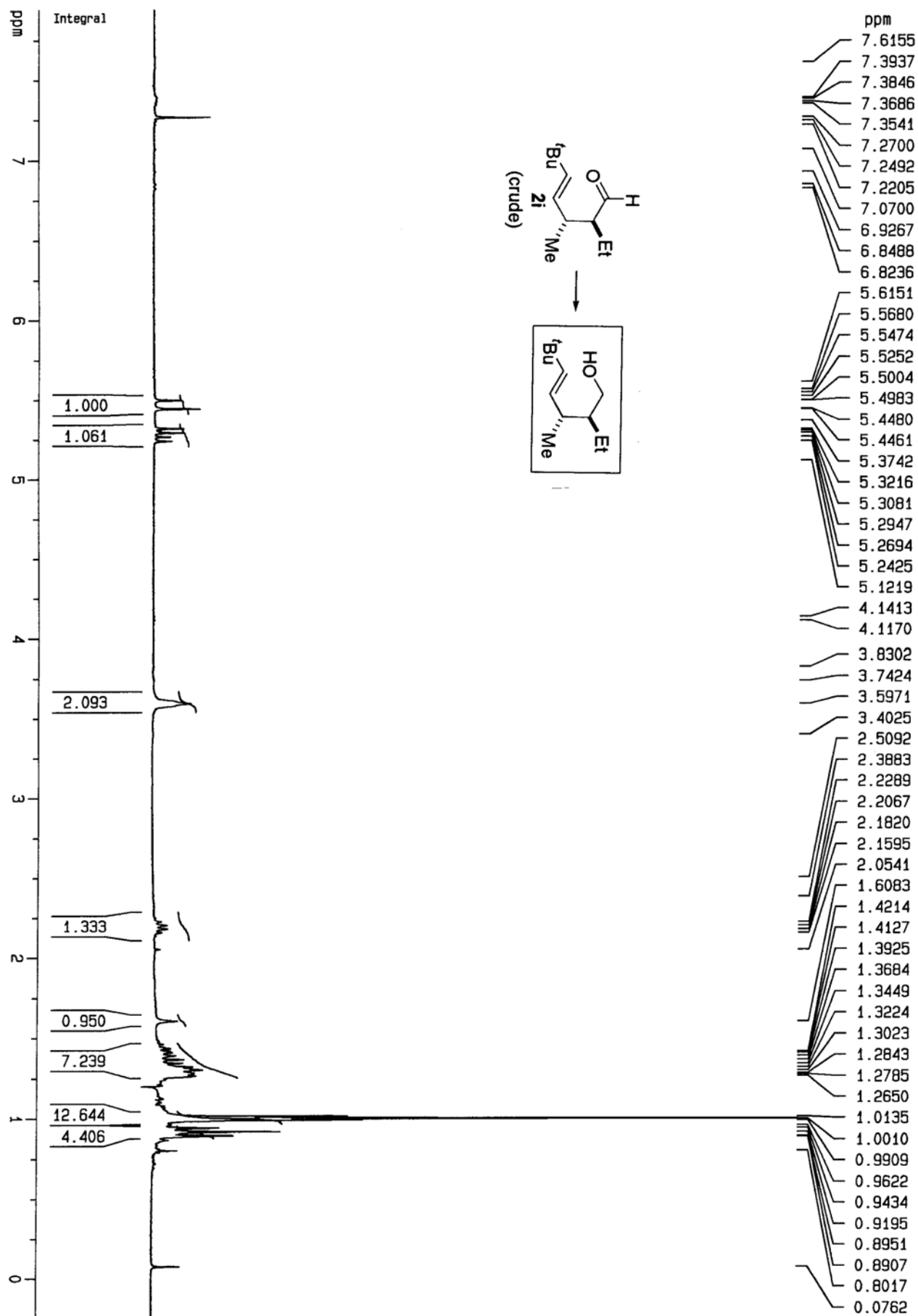


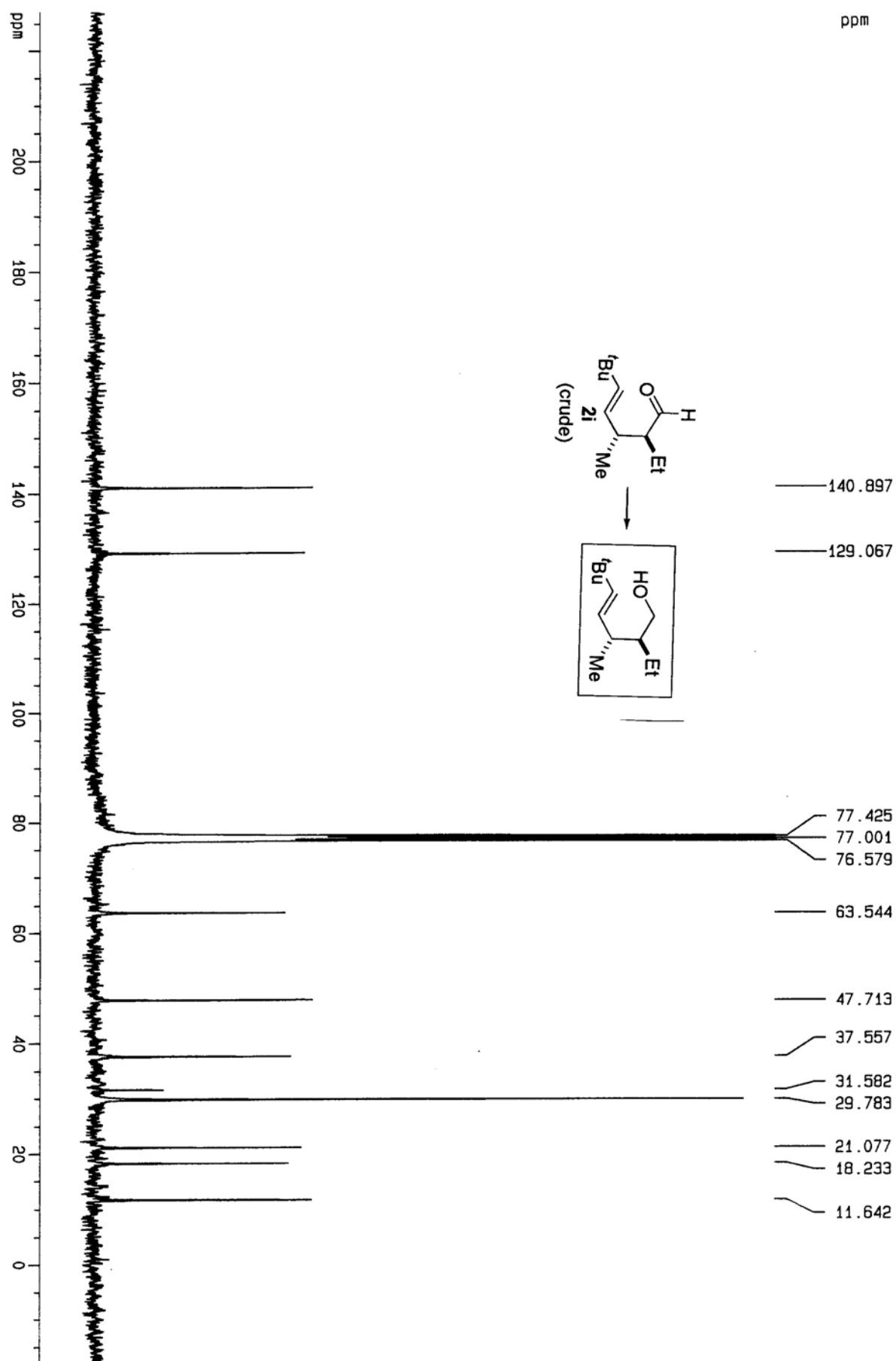


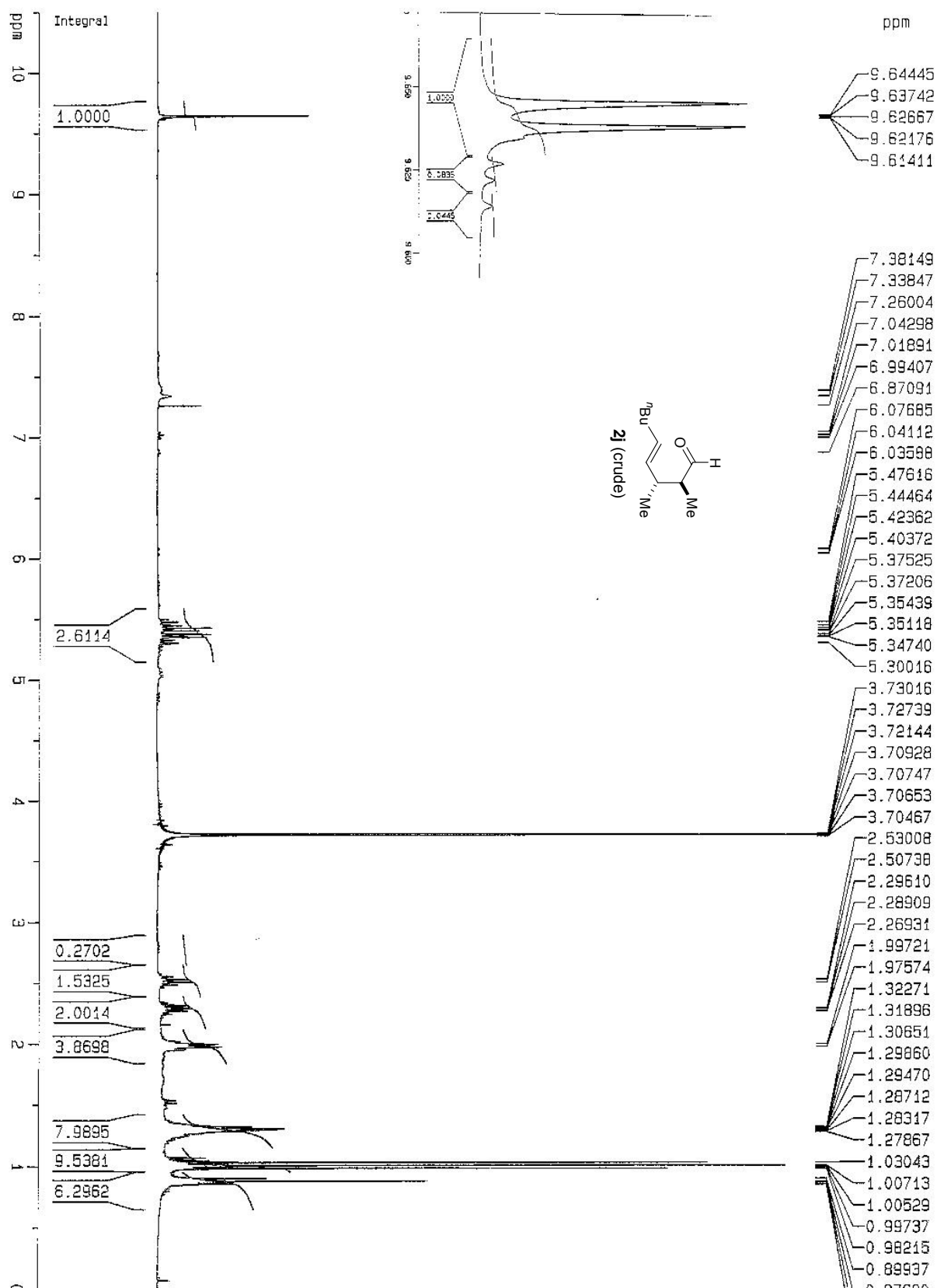


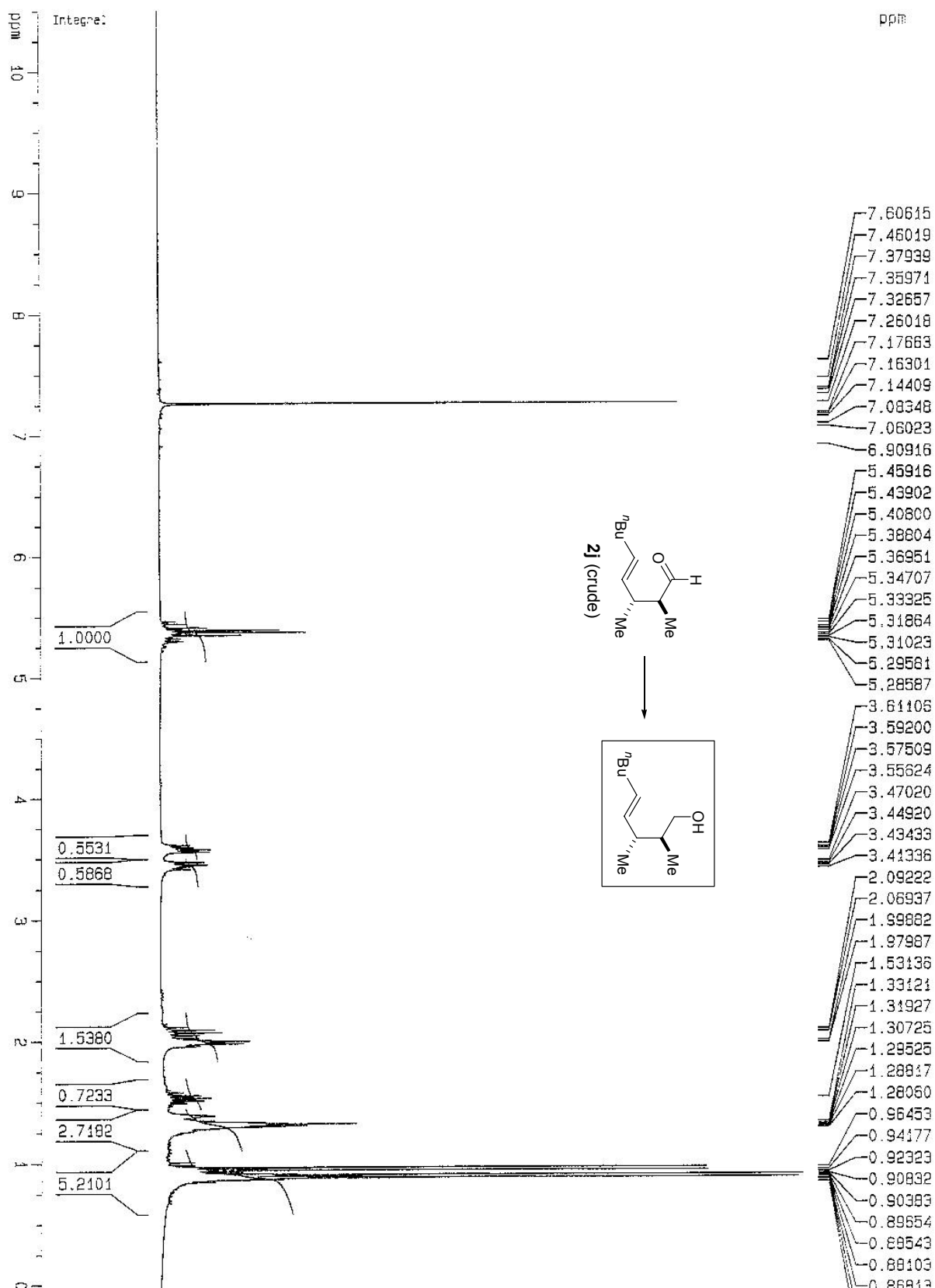


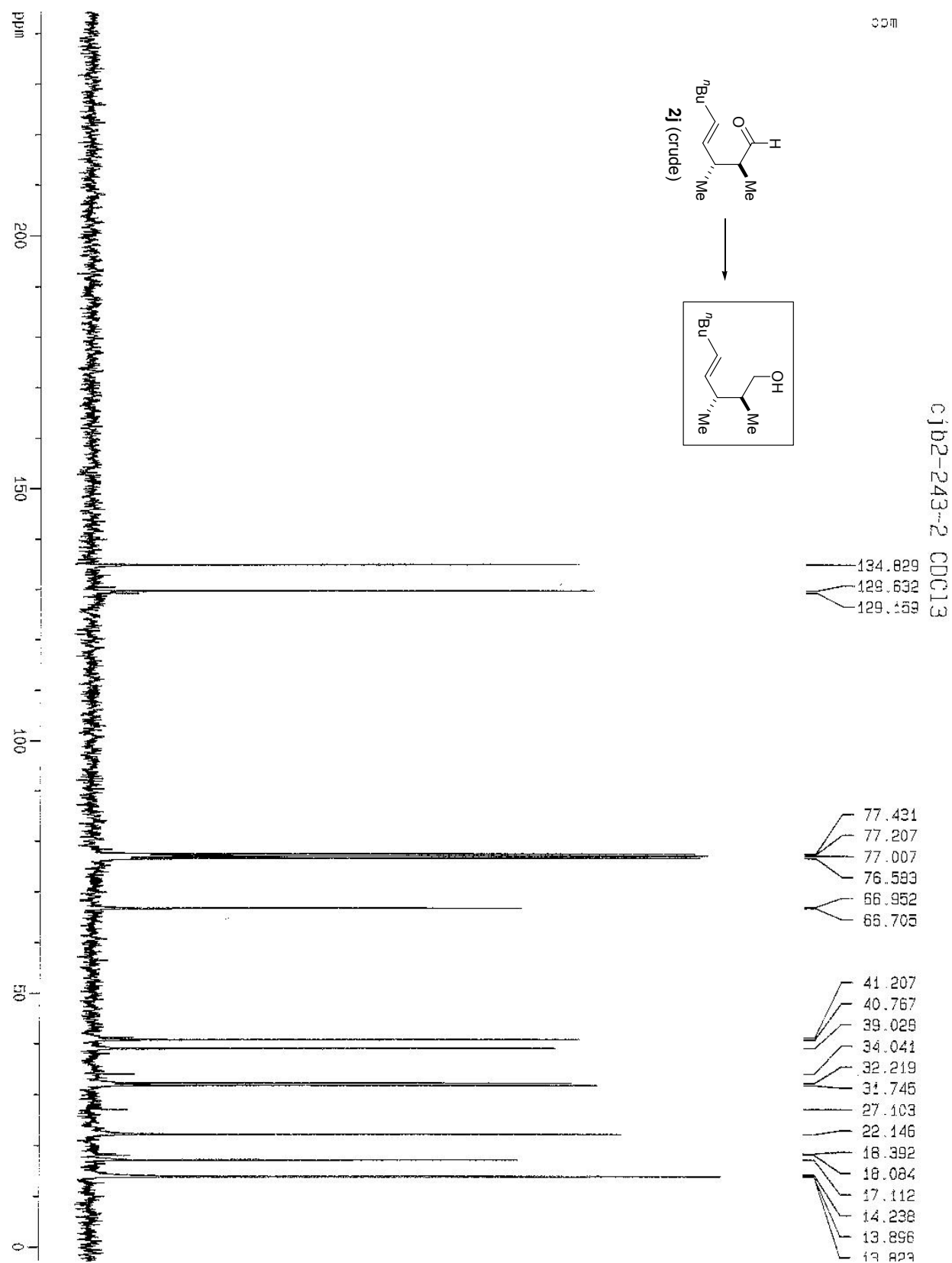


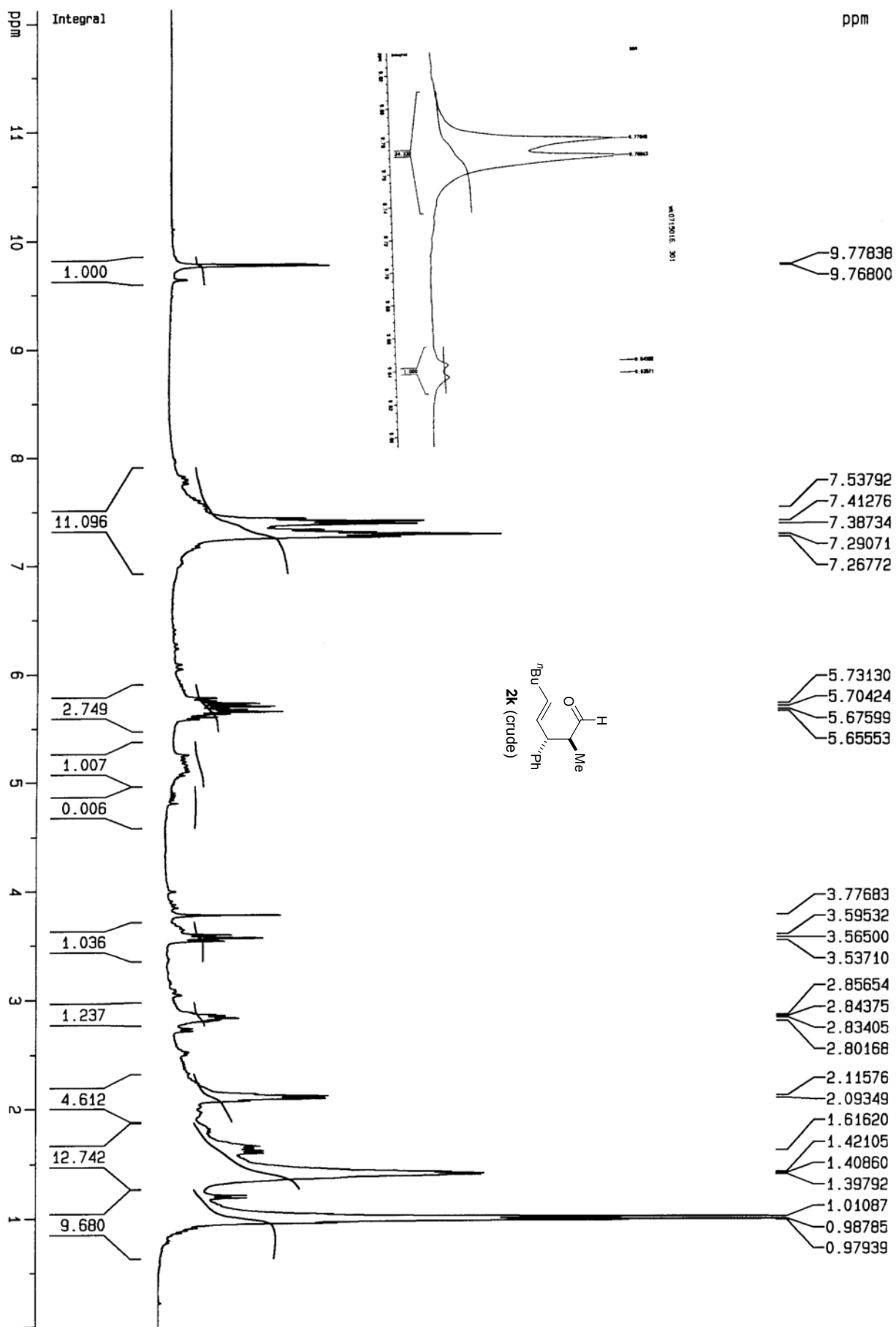




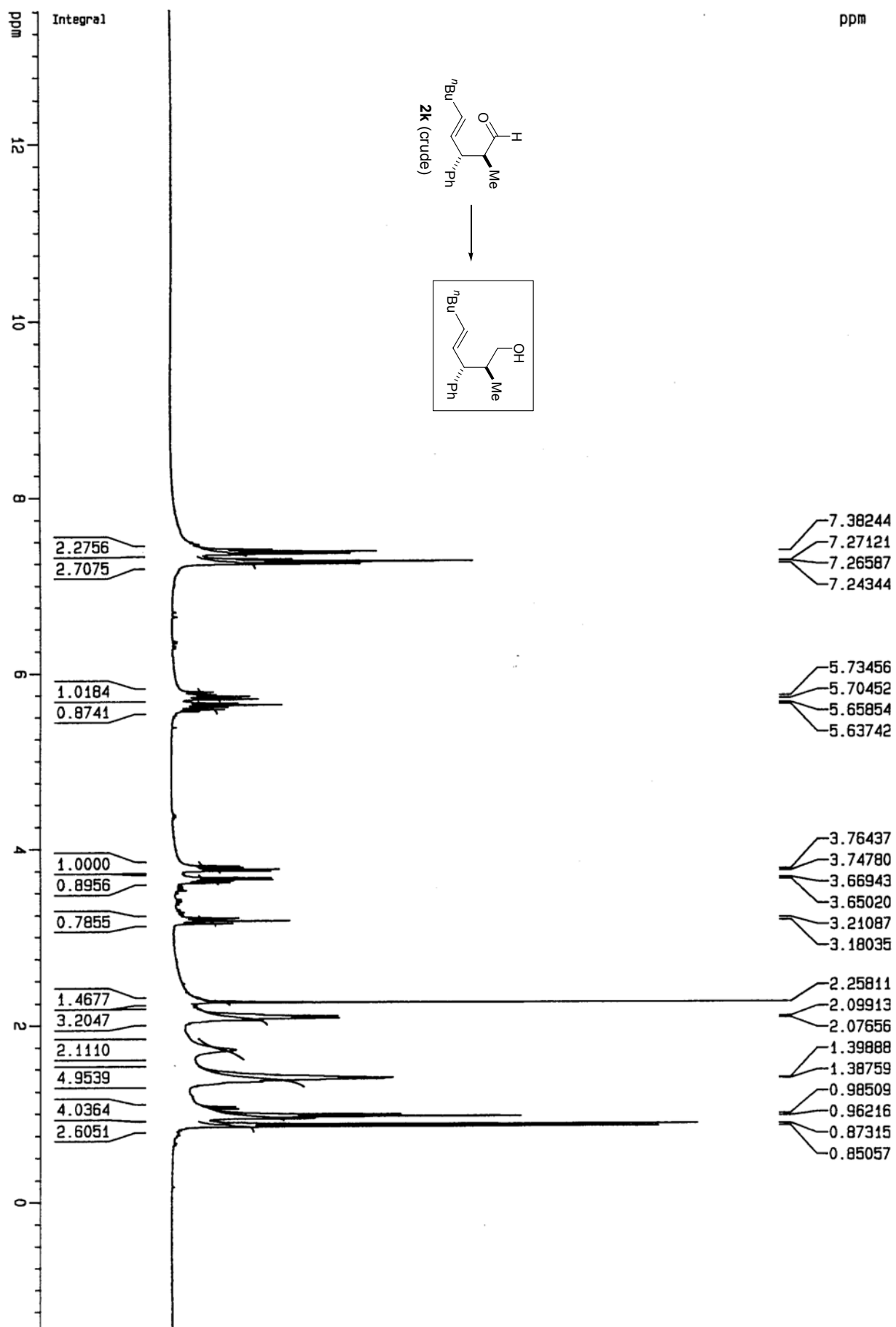








W0715016, 301



WK0711003, 301.

