

## Catalytic and Regioselective Ring Expansion of Arylcyclobutanones with Trimethylsilyldiazomethane. Ligand-Dependant Entry to $\beta$ -Ketosilane or Enolsilane Adducts.

Jennifer A. Dabrowski, David C. Moebius, Andrew J. Wommack, Anne F. Kornahrens, and  
Jason S. Kingsbury\*

*Department of Chemistry, Merkert Chemistry Center, Boston College, Chestnut Hill, Massachusetts 02467*

### SUPPORTING INFORMATION

**General.** Infrared spectra were recorded on a Bruker FTIR Alpha (ATR mode) spectrophotometer,  $\nu_{\max}$  in  $\text{cm}^{-1}$ . Bands are reported as strong (s), medium (m), weak (w), and broad (br).  $^1\text{H}$  NMR spectra were recorded on a Varian Gemini 2000 (400 MHz) spectrometer and processed with MestReNova v5.3.1-4825. Chemical shifts are reported in ppm from tetramethylsilane with the solvent resonance as the internal standard ( $\text{CHCl}_3$ ;  $\delta$  7.26). Data are reported as follows: chemical shift, multiplicity (s = singlet, d = doublet, t = triplet, q = quartet, br = broad, m = multiplet), coupling constants (Hz), and integration.  $^{13}\text{C}$  NMR spectra were recorded on a Varian Gemini 2000 (100 MHz) spectrometer with complete proton decoupling. Chemical shifts are reported in ppm from tetramethylsilane with the solvent as the internal reference ( $\text{CDCl}_3$ ;  $\delta$  77.16). High-resolution mass spectra were obtained at the Boston College Mass Spectrometry Facility.

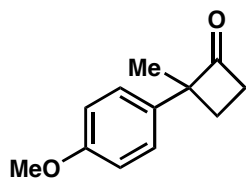
Unless stated otherwise, all reactions were carried out in flame-dried glassware under an atmosphere of nitrogen in dry, degassed solvent with standard Schlenk or vacuum-line techniques. Toluene,  $\text{CH}_2\text{Cl}_2$ , THF,  $\text{Et}_2\text{O}$ , and hexanes were dispensed from a Glass Contour solvent purification system custom manufactured by SG Waters, LLC (Nashua, NH). Many of the electronically-modified 2-arylcyclobutyl ketone starting materials reported herein are new compounds, and we have explored traditional methods for their preparation. The procedures recommended here represent adaptation of those described in the references found in footnote 9 of the manuscript. Scandium triflate (Aldrich, 99%) was dried under high vacuum (0.4 torr) for 12 h in an Abderhalden pistol at 120 °C in the presence of  $\text{P}_2\text{O}_5$ . Scandium tris(hexafluoroacetylacetonate) was purchased from Sol Tech Ventures, Inc. or Aldrich and used as received. Cyclopropyl phenyl sulfide<sup>1</sup> and cyclopropyldiphenylsulfonium tetrafluoroborate<sup>2</sup> were prepared according to literature procedures. *p*-Toluenesulfonic acid, after drying by dissolution in benzene and azeotropic distillation, was recrystallized from chloroform as off-white needles. Dimethyl sulfoxide was passed through flame-dried alumina and vacuum distilled from calcium hydride. All other materials were purchased commercially and used as received.

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(1) Angelaud, R.; Landais, Y. *Tetrahedron* **2000**, 56, 2025-2036.

(2) Bogdanowicz, M. J.; Trost, B. M. *Organic Syntheses* **1988**, Collect. Vol. 6, 364-368.

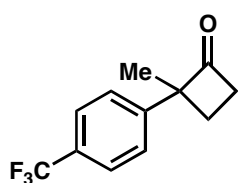
## Representative Procedure for Cyclobutanone Synthesis:



**2-(4-Methoxyphenyl)-2-methylcyclobutanone (1b).** To a flame-dried 25 mL round bottom flask equipped with a magnetic stir bar, cyclopropyl phenyl sulfide (475  $\mu\text{L}$ , 3.27 mmol, 1.1 equiv) and THF (13.1 mL) were added under nitrogen.

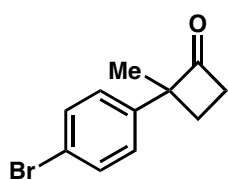
The solution was cooled to 0  $^{\circ}\text{C}$  and *n*-butyllithium (1.91 mL of 1.74 M in hexanes, 3.32 mmol, 1.1 equiv) was added by syringe. After 1 h of stirring, 4'-methoxyacetophenone (409  $\mu\text{L}$ , 2.97 mmol) was added by syringe. After 4 h of additional stirring at 0  $^{\circ}\text{C}$ , the reaction was quenched with water (1.0 mL) and transferred to a separation funnel containing 30 mL of water and 20 mL of  $\text{Et}_2\text{O}$ . After agitation and removal of the extract, the water layer was washed with two more 10 mL volumes of  $\text{Et}_2\text{O}$ . The combined organic layers were dried over magnesium sulfate and filtered. Concentration and purification by silica gel chromatography (TLC  $R_f = 0.36$  in 5:1 hexanes:ethyl acetate) afforded 1-(4-methoxyphenyl)-1-(1-(phenylthio)cyclopropyl)ethanol (741 mg, 2.47 mmol, 83% yield) as a colorless oil. IR (thin film): 3486 (b), 3059 (w), 2972 (w), 2934 (w), 2835 (w), 1610 (m), 1583 (m), 1510 (s), 1478 (m), 1463 (w), 1439 (m), 1333 (m), 1248 (s), 1178 (s), 1131 (w), 1084 (m), 1029 (s), 933 (w), 829 (m), 739 (m), 692 (m), 574 (w), 518 (w).  $^1\text{H}$  NMR (400 MHz,  $\text{CDCl}_3$ ):  $\delta$  7.44 (ddd,  $J = 3.1, 5.3, 6.8$  Hz, 2H), 7.29-7.26 (m, 2H), 7.21-7.17 (m, 2H), 7.14-7.10 (m, 1H), 6.81 (ddd,  $J = 3.1, 5.3, 6.8$  Hz, 2H), 3.79 (s, 3H), 2.50 (s, 1H), 1.63 (s, 3H), 1.28-1.19 (m, 1H), 1.14 (ddd,  $J = 4.4, 6.0, 10.8$  Hz, 1H), 1.04 (ddd,  $J = 4.6, 6.0, 9.7$  Hz, 1H), 0.96 (ddd,  $J = 4.4, 6.0, 9.7$  Hz, 1H). HRMS (ESI $^+$ ) Calcd for  $\text{C}_{18}\text{H}_{19}\text{OS}$  [M-OH] $^+$ : 283.1157; Found: 283.1156.

A flame-dried 25 mL round bottom flask containing a magnetic stir bar was then charged with 1-(4-methoxyphenyl)-1-(1-(phenylthio)cyclopropyl)ethanol (741 mg, 2.47 mmol), *p*-toluenesulfonic acid (425 mg, 2.47 mmol, 1.0 equiv), and benzene (9.9 mL). The resulting homogeneous solution was heated at 80  $^{\circ}\text{C}$  for 5 h. The solution was diluted with 20 mL of  $\text{Et}_2\text{O}$  and in a separation funnel, washed with saturated solutions of sodium bicarbonate (30 mL) and sodium chloride (30 mL). The organic layer was dried over magnesium sulfate, filtered, and concentrated to a yellow oil. Purification by Kugelrohr distillation provided **1b** (188 mg, 0.988 mmol, 40% yield) as a colorless oil. IR (thin film): 2994 (w), 2958 (w), 2863 (w), 2835 (w), 1774 (s), 1610 (w), 1579 (w), 1512 (s), 1464 (w), 1444 (w), 1393 (w), 1370 (w), 1249 (s), 1180 (m), 1095 (w), 1057 (m), 1032 (m), 831 (m), 788 (w), 556 (w).  $^1\text{H}$  NMR (400 MHz,  $\text{CDCl}_3$ ):  $\delta$  7.28 (ddd,  $J = 2.4, 2.8, 9.2$  Hz, 2H), 6.88 (ddd,  $J = 2.4, 2.8, 9.2$  Hz, 2H), 3.79 (s, 3H), 3.16 (ddd,  $J = 6.8, 10.8, 17.6$  Hz, 1H), 3.04 (ddd,  $J = 6.8, 10.8, 17.6$  Hz, 1H), 2.48 (ddd,  $J = 6.8, 10.6, 11.0$  Hz, 1H), 2.16-2.09 (m, 1H), 1.51 (s, 3H).  $^{13}\text{C}$  NMR (100 MHz,  $\text{CDCl}_3$ ):  $\delta$  212.41, 158.42, 134.60, 126.78, 114.11, 67.55, 55.41, 42.75, 26.36, 25.80. HRMS (ESI $^+$ ) Calcd for  $\text{C}_{12}\text{H}_{15}\text{O}_2$  [M+H] $^+$ : 191.1072; Found: 191.1067.



**2-(4-Trifluoromethylphenyl)-2-methylcyclobutanone (1c).** Prepared by the general procedure from 475  $\mu\text{L}$  of cyclopropyl phenyl sulfide (3.27 mmol, 1.1 equiv) in 13.1 mL THF, 3.32 mmol of *n*-butyllithium (1.91 mL of 1.74 M in hexanes, 1.1 equiv), and 556 mg 4-(trifluoromethyl)acetophenone (2.96 mmol). (1-

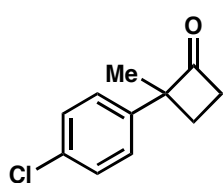
(Phenylthio)cyclopropyl)-1-(4-(trifluoromethyl)phenyl)ethanol (721 mg, 2.13 mmol, 72% yield) was recovered as an oil after passage through a pad of silica gel (TLC  $R_f$  = 0.33 in 5:1 hexanes:ethyl acetate). IR (thin film): 3485 (b), 3061 (w), 2983 (w), 1618 (w), 1583 (w), 1479 (w), 1439 (w), 1409 (w), 1327 (s), 1165 (m), 1124 (m), 1103 (m), 1074 (m), 1016 (w), 852 (w), 740 (w), 692 (w), 613 (w).  $^1\text{H}$  NMR (400 MHz,  $\text{CDCl}_3$ ):  $\delta$  7.62 (d,  $J$  = 8.2 Hz, 2H), 7.48 (d,  $J$  = 8.2 Hz, 2H), 7.17-7.11 (m, 5H), 2.62 (s, 1H), 1.58 (s, 3H), 1.37-1.32 (m, 1H), 1.26-1.17 (m, 2H), 1.05-1.00 (m, 1H). HRMS Calcd for  $\text{C}_{18}\text{H}_{17}\text{F}_3\text{OS}$ : 338.0952; Found: 338.0961. Rearrangement involved 488 mg of (1-(phenylthio)cyclopropyl)-1-(4-(trifluoromethyl)phenyl)ethanol (1.44 mmol), 248 mg *p*-toluenesulfonic acid (1.44 mmol, 1.0 equiv), and 5.8 mL of benzene, giving 169 mg of **1c** (0.740 mmol, 51% yield) as a colorless oil after Kugelrohr distillation. IR (thin film): 2966 (w), 2928 (w), 2869 (w), 1779 (s), 1616 (m), 1449 (w), 1411 (m), 1323 (s), 1164 (m), 1119 (s), 1065 (s), 1016 (m), 873 (m), 606 (m).  $^1\text{H}$  NMR (400 MHz,  $\text{CDCl}_3$ ):  $\delta$  7.59 (d,  $J$  = 8.6 Hz, 2H), 7.48 (d,  $J$  = 8.6 Hz, 2H), 3.24 (ddd,  $J$  = 7.1, 10.2, 17.9 Hz, 1H), 3.05 (ddd,  $J$  = 6.2, 10.6, 17.9 Hz, 1H), 2.52 (ddd,  $J$  = 7.1, 10.6, 17.6 Hz, 1H), 2.22 (ddd,  $J$  = 6.2, 10.2, 17.6 Hz, 1H), 1.56 (s, 3H).  $^{13}\text{C}$  NMR (100 MHz,  $\text{CDCl}_3$ ):  $\delta$  210.96, 146.44, 129.11 ( $J$  = 32.1 Hz), 126.12, 125.64, 124.24 ( $J$  = 270.8 Hz), 67.93, 42.80, 26.63, 25.50. HRMS Calcd for  $\text{C}_{12}\text{H}_{11}\text{F}_3\text{O}$ : 228.0762; Found: 228.0758.



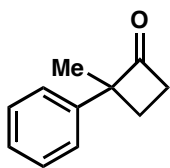
**2-(4-Bromophenyl)-2-methylcyclobutanone (1d).** Prepared by the general procedure from 475  $\mu\text{L}$  of cyclopropyl phenyl sulfide (3.27 mmol, 1.1 equiv) in 13.1 mL THF, 3.32 mmol of *n*-butyllithium (1.91 mL of 1.74 M in hexanes, 1.1 equiv), and 591 mg of 4'-bromoacetophenone (2.97 mmol, 1.0 equiv). 1-(4-Bromophenyl)-

1-(1-(phenylthio)cyclopropyl)ethanol (489 mg, 1.40 mmol, 47% yield) was obtained as an oil after filtration through silica gel (TLC  $R_f$  = 0.38 in 5:1 hexanes:ethyl acetate). IR (thin film): 3481 (b), 3059 (w), 2982 (w), 2927 (w), 1678 (w), 1585 (m), 1480 (s), 1439 (m), 1395 (m), 1371 (w), 1330 (w), 1270 (w), 1079 (s), 1026 (m), 1009 (s), 785 (m), 739 (s), 692 (m).  $^1\text{H}$  NMR (400 MHz,  $\text{CDCl}_3$ ):  $\delta$  7.40-7.35 (m, 4H), 7.24-7.14 (m, 5H), 2.59 (s, 1H), 1.57 (s, 3H), 1.28 (ddd,  $J$  = 11.5, 6.6, 4.9 Hz, 1H), 1.23-1.10 (m, 2H), 1.00 (ddd,  $J$  = 11.2, 6.6, 4.8 Hz, 1H). HRMS Calcd for  $\text{C}_{17}\text{H}_{17}\text{BrOS}$ : 348.0183; Found: 348.0184. Rearrangement of 185 mg of 1-(4-bromophenyl)-1-(1-(phenylthio)cyclopropyl)ethanol with 91.3 mg of *p*-toluenesulfonic acid (0.530 mmol, 1.0 equiv) and 2.1 mL benzene gave 56.7 mg of **1d** (0.237 mmol, 45% yield) as a clear oil after Kugelrohr distillation. Spectral data has been recorded.<sup>3</sup>

(3) Shao, L.; Shi, M. *Eur. J. Org. Chem.* **2004**, 426-430.



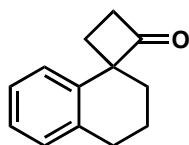
**2-(4-Chlorophenyl)-2-methylcyclobutanone (1e).** Prepared by the general procedure above from 475  $\mu$ L cyclopropyl phenyl sulfide (3.27 mmol, 1.1 equiv) in 13.1 mL THF, 3.32 mmol of *n*-butyllithium (1.91 mL of 1.74 M in hexanes, 1.1 equiv), and 459 mg of 4'-chloroacetophenone (2.97 mmol). 524 mg of 1-(4-chlorophenyl)-1-(1-(phenylthio)cyclopropyl)ethanol (1.72 mmol, 58% yield) was isolated as an oil after passage through a plug of silica gel (TLC  $R_f$  = 0.37 in 5:1 hexanes:ethyl acetate). IR (thin film): 3587 (w), 3469 (b), 3061 (w), 2981 (w), 1680 (w), 1584 (m), 1490 (m), 1479 (m), 1439 (w), 1419 (w), 1399 (w), 1371 (w), 1331 (w), 1214 (w), 1175 (w), 1130 (w), 1094 (s), 1027 (w), 1013 (m), 826 (w), 739 (m), 692 (m).  $^1$ H NMR (400 MHz,  $CDCl_3$ ):  $\delta$  7.46-7.43 (m, 2H), 7.26-7.14 (m, 7H), 2.55 (s, 1H), 1.58 (s, 3H), 1.27 (ddd,  $J$  = 11.2, 6.2, 4.6 Hz, 1H), 1.28-1.09 (m, 2H), 1.00 (ddd,  $J$  = 11.2, 6.2, 4.6 Hz, 1H). HRMS Calcd for  $C_{17}H_{16}ClS$  [ $M-OH$ ] $^+$ : 287.0661; Found: 287.0675. Rearrangement of 467 mg of 1-(4-chlorophenyl)-1-(1-(phenylthio)cyclopropyl)ethanol (1.53 mmol) with 257 mg *p*-toluenesulfonic acid (1.51 mmol, 0.98 equiv) and 6.1 mL benzene provided **1e** (127 mg, 0.652 mmol, 43% yield) as a clear oil after Kugelrohr distillation. IR (neat): 2962 (w), 2924 (w), 2864 (w), 1773 (s), 1595 (w), 1492 (s), 1446 (w), 1399 (m), 1371 (w), 1281 (w), 1189 (w), 1091 (m), 1055 (s), 1013 (s), 869 (w), 826 (s), 732 (m), 717 (w), 570 (w), 505 (w).  $^1$ H NMR (400 MHz,  $CDCl_3$ ):  $\delta$  7.29 (s, 4H), 3.20 (ddd,  $J$  = 17.0, 10.1, 7.0 Hz, 1H), 3.03 (ddd,  $J$  = 17.0, 10.6, 6.4 Hz, 1H), 2.46 (ddd,  $J$  = 17.8, 10.6, 7.0 Hz, 1H), 2.16 (ddd,  $J$  = 17.8, 10.1, 6.4 Hz, 1H), 1.52 (s, 3H).  $^{13}C$  NMR (100 MHz,  $CDCl_3$ ):  $\delta$  211.49, 141.92, 132.59, 128.77, 127.11, 67.52, 42.77, 26.53, 25.58. HRMS Calcd for  $C_{11}H_{12}ClO$  [ $M+H$ ] $^+$ : 195.0571; Found: 195.0583. 127.11, 67.52, 42.77, 26.53, 25.58. HRMS Calcd for  $C_{11}H_{12}ClO$  [ $M+H$ ] $^+$ : 195.0571; Found: 195.0583.



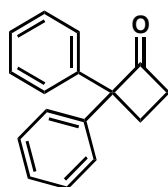
**2-Phenyl-2-methylcyclobutanone (1a).** Prepared by the procedure of Bogdanowicz and Trost.<sup>4</sup> A flame-dried 10-mL round bottom flask with a magnetic stir bar was charged with 299 mg of cyclopropyldiphenylsulfonium tetrafluoroborate (0.952 mmol, 1.34 equiv), 3 mL of dimethyl sulfoxide, and 85 mg of powdered potassium hydroxide (1.51 mmol, 2.0 equiv). At 0  $^{\circ}C$ , 83.0  $\mu$ L of acetophenone (0.712 mmol, 1.0 equiv) was added by syringe and the reaction mixture was slowly warmed to 23  $^{\circ}C$  for 12 h of rapid stirring. The mixture was then poured into a separation funnel containing 25 mL of saturated sodium bicarbonate solution, and the product was extracted with three 30 mL volumes of hexanes. The organic layers were pooled, dried over magnesium sulfate, filtered, and concentrated to a yellow oil that was used directly as the Lewis acid-catalyzed rearrangement. Thus, a solution of the unpurified oxaspiropentane (155 mg in 3.5 mL benzene) was treated with 15.0 mg of lithium perchlorate (0.145 mmol, 0.15 equiv) as a solid and heated at 80  $^{\circ}C$  for 12 h. Upon cooling to 23  $^{\circ}C$ , the reaction mixture was filtered through celite with two 5 mL

(4) Bogdanowicz, M. J.; Trost, B. M. *J. Am. Chem. Soc.* **1973**, *95*, 5321-5334.

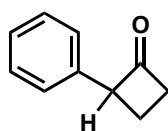
hexane rinses and concentrated at reduced pressure. Purification by column chromatography (TLC  $R_f$  = 0.35 in 12:1 hexanes:ethyl acetate) gave **1a** in 82% yield over two steps (94.1 mg, 0.584 mmol). Characterization data for this compound has been reported.<sup>5</sup>



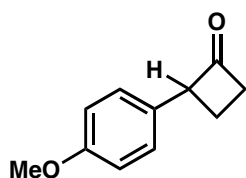
**3',4'-Dihydro-2'H-spiro[cyclobutane-1,1'-naphthalen]-2-one (3).** Prepared by the procedure of Bogdanowicz and Trost<sup>4</sup> on a scale involving 95.0  $\mu$ L of  $\alpha$ -tetralone (0.712 mmol), 299 mg of cyclopropyldiphenylsulfonium tetrafluoroborate (0.952 mmol, 1.34 equiv), 3 mL of dimethyl sulfoxide, and 85 mg of potassium hydroxide (1.51 mmol, 2.0 equiv). The impure oxaspiropentane, a yellow oil, was then subjected to 15.0 mg of lithium perchlorate (0.145 mmol, 0.15 equiv) in 3.5 mL of hot benzene, affording 94.0 mg of **3** (0.504 mmol, 70 % yield) after purification by silica gel chromatography (TLC  $R_f$  = 0.35 in 15:1 hexanes:ethyl acetate). Characterization data for this spirocycle has been reported.<sup>4</sup>



**2,2-Diphenylcyclobutanone (5).** Prepared by the procedure of Bogdanowicz and Trost<sup>4</sup> from 0.238 g (1.31 mmol) of benzophenone, 0.409 g cyclopropyldiphenylsulfonium tetrafluoroborate (1.30 mmol, 1.0 equiv), 7.0 mL of dimethyl sulfoxide, and 0.147 g of potassium hydroxide (2.61 mmol, 2.0 equiv). The crude oxaspiropentane, a pale yellow oil, was then subjected to 20 mg of lithium perchlorate (0.188 mmol, 0.14 equiv) in 4.5 mL of benzene to afford 172 mg of **5** (0.774 mmol, 59% yield) after purification by column chromatography (TLC  $R_f$  = 0.35 in 10:1 hexanes:ethyl acetate). Characterization data for **5** has been reported.<sup>4</sup>



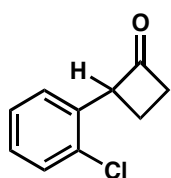
**2-Phenylcyclobutanone (7a).** Prepared by the procedure of Bogdanowicz and Trost<sup>4</sup> from 0.200 mL benzaldehyde (1.96 mmol), 0.650 g of cyclopropyldiphenylsulfonium tetrafluoroborate (2.07 mmol, 1.1 equiv), 9.0 mL of dimethyl sulfoxide, and 0.220 g of potassium hydroxide (3.93 mmol, 2.0 equiv). The impure oxaspiropentane, a clear oil, was then subjected to 25.0 mg of lithium perchlorate (0.235 mmol, 0.12 equiv) in 5.0 mL of benzene to give 0.207 g of **7a** (1.42 mmol, 72% yield) following purification by column chromatography ( $R_f$  = 0.30 in 25:1 hexanes:ethyl acetate). Characterization data for **7a** has been reported.<sup>4</sup>



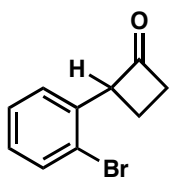
**2-(4-Methoxyphenyl)cyclobutanone (7b).** Prepared by the general procedure above on a scale involving 475  $\mu$ L of cyclopropyl phenyl sulfide (3.27 mmol, 1.1 equiv) in 13.1 mL of THF, 3.32 mmol of *n*-butyllithium (1.91 mL of 1.74 M in hexanes, 1.1 equiv), and 355  $\mu$ L of 4-methoxybenzaldehyde (2.97 mmol, 1.0 equiv). (4-Methoxyphenyl)(1-(phenylthio)cyclopropyl)methanol (684 mg, 2.39 mmol, 80% yield) was recovered as a colorless oil after filtration through a pad of silica gel (TLC  $R_f$  = 0.35 in 5:1 hexanes:ethyl acetate). IR (thin film): 3462 (b), 3059 (w), 3003 (w), 2956 (w), 2932 (w), 2835 (w),

(5) Nemoto, H.; Miyata, J.; Hakamata, H.; Nagamochi, M.; Fukumoto, K. *Tetrahedron* **1995**, *51*, 5511-5522.

1611 (m), 1584 (w), 1512 (s), 1479 (m), 1463 (w), 1439 (m), 1421 (w), 1381 (w), 1303 (w), 1248 (s), 1174 (m), 1111 (w), 1089 (w), 1034 (s), 833 (m), 740 (m), 692 (m).  $^1\text{H}$  NMR (400 MHz,  $\text{CDCl}_3$ ):  $\delta$  7.41 (d,  $J = 7.3$  Hz, 2H), 7.30-7.17 (m, 5H), 6.84 (d,  $J = 8.2$  Hz, 2H), 4.79 (d,  $J = 3.8$  Hz, 1H), 3.79 (s, 3H), 2.53 (dd,  $J = 3.7, 1.3$ , Hz, 1H), 1.09-1.03 (m, 2H), 0.99-0.91 (m, 1H). HRMS Calcd for  $\text{C}_{17}\text{H}_{17}\text{OS}$   $[\text{M}-\text{OH}]^+$ : 269.1000; Found: 269.0986. Rearrangement was effected on a scale involving 609 mg of (4-methoxyphenyl)(1-(phenylthio)cyclopropyl)methanol (2.13 mmol) and 367 mg *p*-toluenesulfonic acid (2.13 mmol, 1.0 equiv) in 8.5 mL of benzene, affording **7b** (33.0 mg, 0.187 mmol, 9% yield) as an oil after a purification by Kugelrohr distillation. Characterization data for this material has been reported.<sup>6</sup>



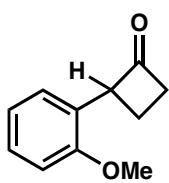
**2-(2-Chlorophenyl)cyclobutanone (9a)**. Prepared according to the general procedure on a scale involving 475  $\mu\text{L}$  cyclopropyl phenyl sulfide (3.27 mmol, 1.1 equiv) in 13.1 mL of THF, 3.32 mmol of *n*-butyllithium (1.91 mL of 1.74 M in hexanes, 1.1 equiv), and 335  $\mu\text{L}$  2-chlorobenzaldehyde (2.97 mmol, 1.0 equiv). 614 mg of (2-chlorophenyl)(1-(phenylthio)cyclopropyl)methanol (2.11 mmol, 71% yield) was isolated as a colorless oil after passage through a plug of silica gel (TLC  $R_f = 0.35$  in 5:1 hexanes:ethyl acetate). IR (thin film): 3442 (b), 3060 (w), 3009 (w), 2916 (w), 1583 (w), 1478 (m), 1439 (m), 1419 (w), 1386 (w), 1303 (w), 1270 (w), 1234 (w), 1189 (w), 1158 (w), 1125 (w), 1088 (w), 1057 (w), 1027 (s), 947 (w), 753 (s), 738 (s), 705 (m), 691 (m), 664 (w), 462 (w).  $^1\text{H}$  NMR (400 MHz,  $\text{CDCl}_3$ ):  $\delta$  7.63 (dd,  $J = 7.7, 1.6$  Hz, 1H), 7.53-7.50 (m, 2H), 7.31-7.16 (m, 6H), 5.40 (d,  $J = 2.8$  Hz, 1H), 2.83 (d,  $J = 2.8$  Hz, 1H), 1.21-1.14 (m, 1H), 1.02 (ddd,  $J = 9.5, 6.6, 5.1$  Hz, 1H), 0.90 (ddd,  $J = 11.5, 9.5, 5.1$  Hz, 1H), 0.79 (ddd,  $J = 9.5, 6.4, 5.1$  Hz, 1H). HRMS Calcd for  $\text{C}_{16}\text{H}_{15}\text{ClOS}$ : 290.0532; Found: 290.0521. Rearrangement was effected on a scale involving 586 mg of (2-chlorophenyl)(1-(phenylthio)cyclopropyl)methanol (2.01 mmol) and 351 mg of *p*-toluenesulfonic acid (2.04 mmol, 1.0 equiv) in 8.0 mL benzene delivering **9a** (72.9 mg, 0.200 mmol, 20% yield) as a colorless oil after Kugelrohr distillation. IR (thin film): 3064 (w), 2966 (w), 2929 (w), 1782 (s), 1593 (w), 1570 (w), 1474 (m), 1395 (w), 1070 (m), 1039 (m), 750 (m).  $^1\text{H}$  NMR (400 MHz,  $\text{CDCl}_3$ ):  $\delta$  7.40 (ddd,  $J = 12.8, 7.1, 1.8$  Hz, 2H), 7.31 (s, 1H), 7.26 (ddd,  $J = 11.8, 7.1, 1.8$  Hz, 1H), 4.86 (ddd,  $J = 10.6, 4.6, 2.2$  Hz, 1H), 3.29 (dddd,  $J = 18.8, 12.6, 8.4, 2.2$  Hz, 1H), 3.13 (dddd,  $J = 14.5, 9.7, 4.8, 2.4$  Hz, 1H), 2.68 (ddd,  $J = 21.5, 10.6, 4.8$  Hz, 1H), 2.26-2.16 (m, 1H).  $^{13}\text{C}$  NMR (100 MHz,  $\text{CDCl}_3$ ):  $\delta$  207.05, 135.00, 133.58, 129.81, 128.59, 128.59, 127.06, 62.52, 45.12, 18.86. HRMS Calcd for  $\text{C}_{10}\text{H}_9\text{ClO}$ : 180.0342; Found: 180.0345.



**2-(2-Bromophenyl)cyclobutanone (9b)**. Prepared by the general procedure from 475  $\mu\text{L}$  of cyclopropyl phenyl sulfide (3.27 mmol, 1.1 equiv), 3.32 mmol of *n*-butyllithium (1.91 mL of 1.74 M in hexanes, 1.1 equiv), and 347  $\mu\text{L}$  of 2-bromobenzaldehyde (2.97

(6) Cohen, T.; Brockunier, L. *Tetrahedron* **1989**, *45*, 2917-2924.

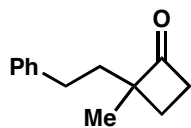
mmol) in 13.1 mL of THF. (2-Bromophenyl)(1-(phenylthio)cyclopropyl)methanol (647 mg, 1.93 mmol, 65% yield) was recovered as a colorless oil after passage through a short column of silica gel (TLC  $R_f$  = 0.37 in 5:1 hexanes:ethyl acetate). IR (thin film): 3416 (b), 3060 (w), 3006 (w), 2955 (w), 2926 (w), 2855 (w), 1584 (w), 1568 (w), 1478 (m), 1468 (w), 1380 (w), 1192 (w), 1158 (w), 1121 (w), 1089 (w), 1040 (m), 1018 (s), 752 (s), 739 (m), 691 (m).  $^1\text{H}$  NMR (400 MHz,  $\text{CDCl}_3$ ):  $\delta$  7.61 (dd,  $J$  = 7.9, 1.6 Hz, 1H), 7.56-7.54 (m, 2H), 7.46 (dd,  $J$  = 8.1, 1.3 Hz, 1H), 7.32-7.22 (m, 4H), 7.13-7.09 (m, 1H), 3.52 (d,  $J$  = 2.2 Hz, 1H), 2.88 (d,  $J$  = 2.7 Hz, 1H), 1.21-1.15 (m, 1H), 1.05-0.99 (m, 1H), 0.92-0.86 (m, 1H), 0.79-0.73 (m, 1H). HRMS Calcd for  $\text{C}_{16}\text{H}_{14}\text{BrS}$   $[\text{M}-\text{OH}]^+$ : 316.9994; Found: 317.0041. Rearrangement of 345 mg (2-bromophenyl)(1-(phenylthio)cyclopropyl)methanol (1.03 mmol) with 177 mg of *p*-toluenesulfonic acid (1.03 mmol, 1.0 equiv) and 4.1 mL of benzene gave **9b** (66.6 mg, 0.296 mmol, 29% yield) as a colorless oil after Kugelrohr distillation. IR (thin film): 3060 (w), 3003 (w), 2964 (w), 2927 (w), 1778 (s), 1471 (m), 1437 (m), 1391 (w), 1201 (w), 1072 (m), 1025 (m), 748 (s).  $^1\text{H}$  NMR (400 MHz,  $\text{CDCl}_3$ ):  $\delta$  7.56 (dd,  $J$  = 8.0, 1.3 Hz, 1H), 7.34-7.24 (m, 2H), 7.11 (ddd,  $J$  = 9.2, 8.0, 1.8 Hz, 1H), 4.82 (ddd,  $J$  = 10.8, 4.8, 2.2 Hz, 1H), 3.23 (dddd,  $J$  = 17.8, 12.6, 7.9, 2.2 Hz, 1H), 3.04 (dddd,  $J$  = 14.5, 9.7, 4.8, 2.4 Hz, 1H), 2.65 (ddd,  $J$  = 21.4, 10.8, 4.8 Hz, 1H), 2.10 (dddd, 17.0, 10.8, 9.7, 8.6 Hz, 1H).  $^{13}\text{C}$  NMR (100 MHz,  $\text{CDCl}_3$ ):  $\delta$  206.93, 136.82, 133.07, 127.70, 123.92, 64.57, 45.04, 19.25. HRMS Calcd for  $\text{C}_{10}\text{H}_{10}\text{BrO}$   $[\text{M}+\text{H}]^+$ : 224.9910; Found: 224.9915.



**2-(2-Methoxyphenyl)cyclobutanone (9c)**. Prepared by the general procedure from 475  $\mu\text{L}$  cyclopropylphenylsulfide (3.27 mmol, 1.1 equiv), 3.32 mmol of *n*-butyllithium (1.91 mL of 1.74 M in hexanes, 1.1 equiv), and 359  $\mu\text{L}$  of *o*-anisaldehyde (2.97 mmol) in 13.1 mL of THF. 579 mg of (2-methoxyphenyl)(1-(phenylthio)cyclopropyl)methanol (2.02

mmol, 68% yield) was recovered as an oil after filtration through silica gel (TLC  $R_f$  = 0.32 in 5:1 hexanes:ethyl acetate). IR (thin film): 3513 (b), 3059 (w), 3004 (w), 2938 (w), 2907 (w), 2836 (w), 1601 (w), 1585 (m), 1490 (s), 1463 (m), 1439 (m), 1419 (w), 1388 (w), 1288 (w), 1242 (s), 1187 (w), 1161 (w), 1038 (s), 1027 (s), 755 (s), 739 (s), 692 (m).  $^1\text{H}$  NMR (400 MHz,  $\text{CDCl}_3$ ):  $\delta$  7.50-7.44 (m, 3H), 7.30-7.22 (m, 3H), 7.16 (t,  $J$  = 7.1, 14.7 Hz, 1H), 6.94 (t,  $J$  = 7.1, 14.3 Hz, 1H), 6.84 (d,  $J$  = 7.9 Hz, 1H), 5.35 (d,  $J$  = 4.2 Hz, 1H), 3.83 (s, 3H), 2.88 (d,  $J$  = 4.2 Hz, 1H), 1.06-1.02 (m, 2H), 0.89-0.80 (m, 2H). HRMS Calcd for  $\text{C}_{17}\text{H}_{17}\text{OS}$   $[\text{M}-\text{OH}]^+$ : 269.1000; Found: 269.1006. Rearrangement of 514 mg of (2-methoxyphenyl)(1-(phenylthio)cyclopropyl)methanol (1.79 mmol) with 308 mg of *p*-toluenesulfonic acid (1.79 mmol, 1.0 equiv) and 7.2 mL of benzene gave **9c** (101 mg, 0.573 mmol, 32% yield) as an oil after Kugelrohr distillation. IR (thin film): 3005 (w), 2963 (w), 1782 (s), 1560 (w), 1586 (w), 1493 (m), 1462 (w), 1438 (w), 1389 (w), 1262 (w), 1243 (m), 1178 (w), 1073 (m), 1051 (w), 1027 (m), 793 (m).  $^1\text{H}$  NMR (400 MHz,  $\text{CDCl}_3$ ):  $\delta$  7.23 (ddd,  $J$  = 1.6, 7.5, 9.2 Hz, 1H), 7.12 (dd,  $J$  = 1.6, 7.3 Hz, 1H), 6.92-

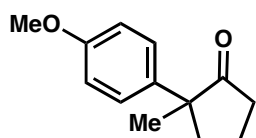
6.86 (m, 2H), 4.50 (dd,  $J = 8.2, 10.4$  Hz, 1H), 3.81 (s, 3H), 3.16-3.12 (m, 2H), 2.47-2.38 (m, 1H), 2.27-2.17 (m, 1H).  $^{13}\text{C}$  NMR (100 MHz,  $\text{CDCl}_3$ ):  $\delta$  209.17, 157.40, 129.25, 128.65, 126.24, 120.79, 111.06, 61.82, 55.63, 45.03, 18.46. HRMS Calcd for  $\text{C}_{11}\text{H}_{13}\text{O}_2$  [ $\text{M}+\text{H}$ ] $^+$ : 177.0910; Found: 177.0919.



**2-Methyl-2-phenethylcyclobutanone (11).** This material is readily accessed by the procedure of Bogdanowicz and Trost,<sup>4</sup> but it was synthesized here by Kulinkovich ethylenation of the corresponding tertiary  $\alpha$ -(thiomethyl)methoxy methyl ester. The

requisite hydroxyester was prepared by catalytic cyanosilylation<sup>7</sup> of dihydrocinnamyl methyl ketone and acidic hydrolysis.<sup>8</sup> Protection as the thiomethyl methyl ether followed standard conditions.<sup>9</sup>  $\text{EtMgBr}$  was freshly prepared in THF with Mg turnings and distilled ethyl bromide. The Grignard reagent (8.0 mL of a 1.25 M solution, 10 mmol, 3.0 equiv) was added dropwise at 0 °C over 30 min to a solution of the  $\alpha$ -(thiomethyl)methoxy methyl ester (885 mg, 3.30 mmol) and  $\text{ClTi}(\text{O}i\text{-Pr})_3$  (1.33 g, 5.12 mmol, 1.56 equiv) in THF (25 mL), causing black discoloration of the reaction mixture. The ice bath was removed, and the mixture was stirred for 48 h at 23 °C. The reaction was then quenched with 1.0 mL of saturated ammonium chloride and diluted with  $\text{Et}_2\text{O}$  (100 mL) and ice-cold 10%  $\text{H}_2\text{SO}_4$  (100 mL). After partitioning of the layers in a separatory funnel, the aqueous portion was washed with two additional volumes of  $\text{Et}_2\text{O}$  (50 mL). Combined organic layers were washed with one volume each of saturated sodium bicarbonate and sodium chloride. The extract was dried over magnesium sulfate, filtered, concentrated, and purified by column chromatography. Characterization data for **11** has been reported.<sup>10</sup>

*Representative Procedure for Catalytic Homologation with in situ Hydrolysis:*



**2-Methyl-2-(4-methoxyphenyl)cyclopentanone (2b).** In a glovebox, a 2-dram vial (8 mL, 17 x 60 mm) with a magnetic stir bar was charged with  $\text{Sc}(\text{OTf})_3$  (5.2 mg, 0.011 mmol, 0.11 equiv) and sealed with a rubber septum. In a fume hood,

the vial was cooled to 0 °C and a 0.40 M solution of 2-methyl-2-(4-methoxyphenyl)cyclobutanone (**1b**) in  $\text{CH}_2\text{Cl}_2$  (20 mg, 0.11 mmol in 0.25 mL, 1.0 equiv) was added through a steel cannula followed by one  $\text{CH}_2\text{Cl}_2$  rinse of the substrate vial (0.25 mL). Trimethylsilyldiazomethane (95  $\mu\text{L}$  of a 1.33 M solution in hexane, 0.13 mmol, 1.2 equiv) was then added to the solution by syringe in one portion, resulting in nitrogen evolution. After 1 h of stirring at 0 °C, the reaction mixture was quenched with 1.0 mL of a 1 N hydrochloric acid solution, stirred vigorously for 30 min, and then transferred to a small separation funnel for extraction. After dilution with 10 mL of water and 10 mL of  $\text{CH}_2\text{Cl}_2$ , the mixture was agitated and the organic layer was removed. The aqueous layer was then extracted two more times with

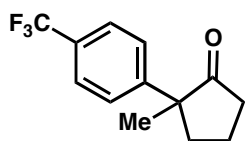
(7) Evans, D. A.; Truesdale, L. K. *Tetrahedron Lett.* **1973**, 4929-4923.

(8) Deng, H.; Isler, M. P.; Snapper, M. L.; Hoveyda, A. H. *Angew. Chem. Int. Ed.* **2002**, *41*, 1009-1012.

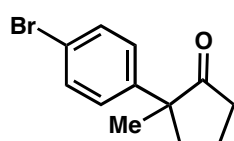
(9) Kingsbury, J. S.; Corey, E. J. *J. Am. Chem. Soc.* **2005**, *127*, 13813-13815.

(10) Bernard, A. M.; Cadoni, E.; Frongia, A.; Piras, P. P.; Secci, F. *Org. Lett.* **2002**, *4*, 2565-2567.

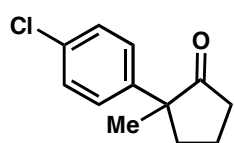
10 mL of  $\text{CH}_2\text{Cl}_2$ . The combined organic layers were dried over magnesium sulfate, filtered, and concentrated.  $^1\text{H}$  NMR analysis of the extract showed 8:1 selectivity in favor of **2b** based on integration. Purification by column chromatography (TLC  $R_f$  of **2b** = 0.30 in 20:1 hexanes:ethyl acetate) gave the product as a clear viscous oil in 83% yield (17.9 mg, 0.0872 mmol). 10% of the isomeric  $\beta$ -quaternary cyclopentanone was also recovered. Characterization data for **2b** has been previously reported.<sup>11</sup>



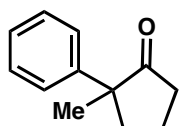
**2-Methyl-2-(4-trifluoromethylphenyl)cyclopentanone (2c).** Prepared according to the procedure above from 16.0 mg of 2-methyl-2-(4-trifluoromethylphenyl)cyclobutanone (**1c**, 0.0701 mmol), 0.0841 mmol of trimethylsilyldiazomethane (63.2  $\mu\text{L}$  of a 1.33 M solution in hexane, 1.2 equiv), and 0.0070 mmol of  $\text{Sc}(\text{OTf})_3$  (4.1 mg, 0.10 equiv) in a 4:1 regioisomer ratio and 91% combined yield (12.4 mg, 0.0512 mmol, 73% of **2c**) after chromatographic purification (TLC  $R_f$  of **2c** = 0.30 in 20:1 hexanes:ethyl acetate). IR (thin film): 2968 (w), 1737 (s), 1410 (w), 1327 (s), 1165 (m), 1070 (m), 1016 (w), 844 (w), 691 (w), 607 (w), 535 (w).  $^1\text{H}$  NMR (400 MHz,  $\text{CDCl}_3$ ):  $\delta$  7.58 (d,  $J$  = 8.2 Hz, 2H), 7.49 (d,  $J$  = 8.2 Hz, 2H), 2.56-2.50 (m, 1H), 2.46-2.30 (m, 2H), 2.12-1.87 (m, 3H), 1.41 (s, 3H).  $^{13}\text{C}$  NMR (100 MHz,  $\text{CDCl}_3$ ):  $\delta$  219.85, 146.99, 129.10 (q,  $J$  = 32.5 Hz), 126.90, 125.58 (q,  $J$  = 3.8 Hz), 122.92, 53.12, 38.10, 37.81, 25.16, 18.91. HRMS Calcd for  $\text{C}_{13}\text{H}_{14}\text{F}_3\text{O}$   $[\text{M}+\text{H}]^+$ : 243.0997; Found: 243.1007.



**2-Methyl-2-(4-bromophenyl)cyclopentanone (2d).** Prepared according to the procedure above from 32.2 mg of 2-methyl-2-(4-bromophenyl)cyclobutanone (**1d**, 0.135 mmol), 0.162 mmol of trimethylsilyldiazomethane (122  $\mu\text{L}$  of a 1.33 M solution in hexane, 1.2 equiv), and 0.015 mmol of  $\text{Sc}(\text{OTf})_3$  (7.6 mg, 0.11 equiv) in 6:1 regioselectivity and 77% combined yield (22.5 mg, 0.0888 mmol, 66% of **2d**) after chromatographic purification (TLC  $R_f$  of **2d** = 0.30 in 7:1 hexanes:ethyl acetate). Characterization data for **2d** has been reported.<sup>11</sup>



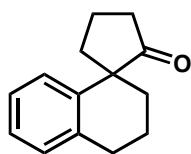
**2-Methyl-2-(4-chlorophenyl)cyclopentanone (2e).** Prepared according to the procedure above from 33.8 mg of 2-methyl-2-(4-chlorophenyl)cyclobutanone (**1e**, 0.174 mmol), 0.209 mmol of trimethylsilyldiazomethane (157  $\mu\text{L}$  of a 1.33 M solution in hexane, 1.2 equiv), and 0.017 mmol of  $\text{Sc}(\text{OTf})_3$  (8.8 mg, 0.10 equiv) in a 6:1 regioisomer ratio and 85% combined yield (26.9 mg, 0.129 mmol, 74% of **2e**) after chromatographic purification (TLC  $R_f$  of **2e** = 0.30 in 7:1 hexanes:ethyl acetate). Characterization data for **2e** has been reported.<sup>11</sup>



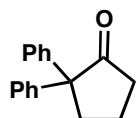
**2-Methyl-2-phenylcyclopentanone (2a).** Prepared according to the procedure above from 20.0 mg of 2-methyl-2-phenylcyclobutanone (**1a**, 0.125 mmol), 0.150 mmol of trimethylsilyldiazomethane (113  $\mu\text{L}$  of a 1.33 M solution in hexane, 1.2 equiv), and 0.013 mmol of  $\text{Sc}(\text{OTf})_3$  (6.2 mg, 0.10 equiv) in a 9:1 regioisomer ratio and 94% combined yield (18.5

(11) Shen, Y.; Wang, B.; Shi, Y. *Tetrahedron Lett.* **2006**, *47*, 5455-5458.

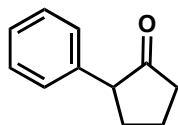
mg, 0.106 mmol, 85% of **2a**) after chromatographic purification (TLC  $R_f$  of **2a** = 0.30 in 10:1 hexanes:ethyl acetate). Characterization data for **2a** has been reported.<sup>12</sup>



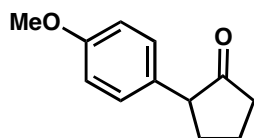
**3',4'-Dihydro-2'H-spiro[cyclopentane-1,1'-naphthalen]-2-one (4)**. Prepared by the procedure above from 25.0 mg of 3',4'-dihydro-2'H-spiro[cyclobutane-1,1'-naphthalen]-2-one (**3**, 0.134 mmol), 0.161 mmol of trimethylsilyldiazomethane (121  $\mu$ L of a 1.33 M solution in hexane, 1.2 equiv), and 0.013 mmol of Sc(OTf)<sub>3</sub> (6.6 mg, 0.10 equiv) in a 9:1 regioisomer ratio and 67% combined yield (16.2 mg, 0.0809 mmol, 60% of **4**) after chromatographic purification (TLC  $R_f$  of **4** = 0.30 in 20:1 hexanes:ethyl acetate). Characterization data for **4** has been reported.<sup>12</sup>



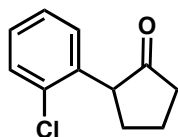
**2,2-Diphenylcyclopentanone (6)**. Prepared by the procedure above from 15.6 mg of 2,2-diphenylcyclobutanone (**5**, 0.0702 mmol), 0.0842 mmol of trimethylsilyldiazomethane (42.1  $\mu$ L of a 2.00 M solution in hexane, 1.2 equiv), and 0.0089 mmol of Sc(OTf)<sub>3</sub> (4.4 mg, 0.13 equiv) in a 7:1 regioisomer ratio and 84% combined yield (11.9 mg, 0.0504 mmol, 72% of **6**) after column chromatography (TLC  $R_f$  of **6** = 0.30 in 10:1 hexanes:ethyl acetate). Characterization data for **6** has been reported.<sup>12</sup>



**2-Phenylcyclopentanone (8a)**. Prepared by the procedure above from 35.1 mg of 2-phenylcyclobutanone (**7a**, 0.240 mmol), 0.287 mmol of trimethylsilyldiazomethane (216  $\mu$ L of a 1.33 M solution in hexane, 1.2 equiv), and 0.0239 mmol of Sc(OTf)<sub>3</sub> (11.7 mg, 0.10 equiv) in a 7:1 regioisomer ratio and 88% combined yield (29.3 mg, 0.183 mmol, 76% of **8a**) after chromatographic purification (TLC  $R_f$  of **8a** = 0.30 in 20:1 hexanes:ethyl acetate). Characterization data for **8a** has been reported.<sup>12</sup>



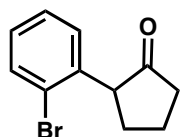
**2-(4-Methoxyphenyl)cyclopentanone (8b)**. Prepared according to the procedure above from 17.4 mg of 2-(4-methoxyphenyl)cyclobutanone (**7b**, 0.0987 mmol), 0.118 mmol of trimethylsilyldiazomethane (89.0  $\mu$ L of a 1.33 M solution in hexane, 1.2 equiv), and 0.0098 mmol of Sc(OTf)<sub>3</sub> (4.8 mg, 0.10 equiv) in a 10:1 regioisomer ratio and 87% combined yield (14.7 mg, 0.0773 mmol, 78% of **8b**) after chromatographic purification (TLC  $R_f$  of **8b** = 0.30 in 15:1 hexanes:ethyl acetate). Characterization data for **8b** has been reported.<sup>12</sup>



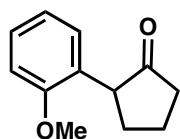
**2-(2-Chlorophenyl)cyclopentanone (10a)**. Prepared according to the procedure above from 20.0 mg of 2-(2-chlorophenyl)cyclobutanone (**9a**, 0.111 mmol), 0.133 mmol of trimethylsilyldiazomethane (0.100 mL of a 1.33 M solution in hexane, 1.2 equiv), and 0.011 mmol of Sc(OTf)<sub>3</sub> (5.5 mg, 0.10 equiv) in a 5:1 regioisomer ratio and 78% combined yield (13.7 mg, 0.0704 mmol, 63% of **10a**) after chromatographic purification (TLC  $R_f$  of **10a** = 0.30 in 20:1 hexanes:ethyl acetate). IR (thin film): 2964 (w), 2925 (w), 2881 (w), 1742 (s), 1478 (w), 1442 (w),

(12) Moebius, D. C.; Kingsbury, J. S. *J. Am. Chem. Soc.* **2009**, *131*, 878-879.

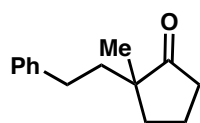
1405 (w), 1272 (w), 1147 (w), 1130 (w), 1039 (w), 1000 (w), 824 (w), 755 (m), 734 (m), 717 (w).  $^1\text{H}$  NMR (400 MHz,  $\text{CDCl}_3$ ):  $\delta$  7.38 (dd,  $J = 7.7, 1.7$  Hz, 1H), 7.21 (td,  $J = 7.3, 1.9$  Hz, 2H), 7.12-7.08 (m, 1H), 3.72 (dd,  $J = 11.4, 8.7$  Hz, 1H), 2.56-2.46 (m, 3H), 2.41 (dd,  $J = 11.2, 8.7$  Hz, 1H), 2.23-2.14 (m, 1H), 2.08 (dd,  $J = 12.0, 6.0$  Hz, 1H), 2.03-1.93 (m, 1H).  $^{13}\text{C}$  NMR (100 MHz,  $\text{CDCl}_3$ ):  $\delta$  217.61, 138.99, 133.29, 129.88, 128.75, 127.97, 125.31, 56.41, 38.83, 32.02, 21.12. HRMS Calcd for  $\text{C}_{11}\text{H}_{12}\text{ClO} [\text{M}+\text{H}]^+$ : 195.0571; Found: 195.0578.



**2-(2-Bromophenyl)cyclopentanone (10b).** Prepared according to the procedure above from 18.0 mg of 2-(2-bromophenyl)cyclobutanone (**9b**, 0.0800 mmol), 0.0960 mmol of trimethylsilyldiazomethane (72.2  $\mu\text{L}$  of a 1.33 M solution in hexane, 1.2 equiv), and 0.015 mmol of  $\text{Sc}(\text{OTf})_3$  (7.6 mg, 0.19 equiv) in a 6:1 regioisomer ratio and 82% combined yield (13.4 mg, 0.0560 mmol, 70% **10b**) after chromatographic purification (TLC  $R_f$  of **10b** = 0.30 in 20:1 hexanes:ethyl acetate). IR (thin film): 3058 (w), 2958 (w), 2924 (w), 2853 (w), 1741 (s), 1590 (w), 1566 (w), 1472 (m), 1438 (w), 1405 (w), 1378 (w), 1331 (w), 1272 (w), 1146 (w), 1126 (w), 1053 (m), 1022 (w), 824 (w), 753 (m), 730 (w), 673 (w), 597 (w), 545 (w), 489 (w), 443 (w).  $^1\text{H}$  NMR (400 MHz,  $\text{CDCl}_3$ ):  $\delta$  7.57 (dd,  $J = 8.0, 1.3$  Hz, 1H), 7.29-7.27 (m, 1H), 7.11 (ddd,  $J = 8.0, 7.4, 1.7$  Hz, 1H), 7.08-7.06 (m, 1H), 3.80-3.75 (m, 1H), 2.60-2.53 (m, 1H), 2.52-2.50 (m, 1H), 2.41-2.33 (m, 1H), 2.22-2.15 (m, 1H), 2.08-1.93 (m, 2H).  $^{13}\text{C}$  NMR (100 MHz,  $\text{CDCl}_3$ ):  $\delta$  217.53, 138.92, 133.22, 129.81, 128.68, 127.90, 125.24, 56.34, 38.76, 31.95, 21.05. HRMS Calcd for  $\text{C}_{11}\text{H}_{12}\text{BrO} [\text{M}+\text{H}]^+$ : 239.0066; Found: 239.0077.

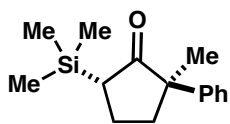


**2-(2-Methoxyphenyl)cyclopentanone (10c).** Prepared by the procedure above from 31.3 mg of 2-(2-methoxyphenyl)cyclobutanone (**9c**, 0.178 mmol), 0.214 mmol of trimethylsilyldiazomethane (161  $\mu\text{L}$  of a 1.33 M solution in hexane, 1.2 equiv), and 0.018 mmol of  $\text{Sc}(\text{OTf})_3$  (8.6 mg, 0.10 equiv) in a 5:1 regioisomer ratio and 88% combined yield (24.5 mg, 0.129 mmol, 72% **10c**) after chromatography (TLC  $R_f$  of **10c** = 0.30 in 20:1 hexanes:ethyl acetate). IR (thin film): 2960 (w), 2875 (w), 2835 (w), 1741 (s), 1600 (w), 1586 (w), 1494 (s), 1462 (m), 1439 (w), 1405 (w), 1244 (s), 1162 (w), 1142 (m), 1051 (m), 1026 (m), 1001 (w), 753 (s).  $^1\text{H}$  NMR (400 MHz,  $\text{CDCl}_3$ ):  $\delta$  7.25-7.21 (m, 1H), 7.09-7.06 (m, 1H), 6.94-6.89 (m, 1H), 6.89-6.86 (m, 1H), 3.77 (s, 3H), 3.40-3.33 (m, 1H), 2.43-2.39 (m, 2H), 2.37-2.32 (m, 1H), 2.19-2.09 (m, 2H), 1.93-1.83 (m, 1H).  $^{13}\text{C}$  NMR (100 MHz,  $\text{CDCl}_3$ ):  $\delta$  219.31, 156.96, 130.64, 128.48, 128.42, 120.93, 111.33, 55.41, 52.56, 38.36, 31.27, 21.67. HRMS Calcd for  $\text{C}_{12}\text{H}_{15}\text{O}_2 [\text{M}+\text{H}]^+$ : 191.1067; Found: 191.1072.



**2-Methyl-2-phenethylcyclopentanone (12).** Prepared according to the procedure above from 68.1 mg of 2-methyl-2-phenethylcyclobutanone (**11**, 0.358 mmol), 0.430 mmol of trimethylsilyldiazomethane (328  $\mu\text{L}$  of a 1.31 M solution in hexane, 1.2

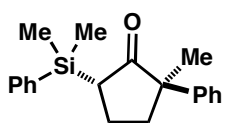
equiv), and 0.035 mmol of Sc(OTf)<sub>3</sub> (17.6 mg, 0.10 equiv) in a 3:1 regioisomer ratio and 92% combined yield (50.9 mg, 0.252 mmol, 70% **12**) after chromatographic purification (TLC R<sub>f</sub> of **12** = 0.30 in 20:1 hexanes:ethyl acetate). IR (thin film): 3061(w), 3025 (w), 2958 (m), 2867 (w), 1733 (s), 1495 (w), 1455 (w), 1405 (w), 1372 (w), 1161 (w), 1065 (w), 750 (w), 699 (m), 483 (w). <sup>1</sup>H NMR (400 MHz, CDCl<sub>3</sub>): δ 7.31-7.24 (m, 3H), 7.18 (dd, *J* = 9.2, 4.2 Hz, 2H), 2.69-2.59 (m, 1H), 2.53-2.43 (m, 1H), 2.38-2.18 (m, 2H), 2.06-1.85 (m, 3H), 1.84-1.64 (m, 3H), 1.08 (s, 3H). <sup>13</sup>C NMR (100 MHz, CDCl<sub>3</sub>): δ 223.34, 142.33, 128.53, 128.44, 125.98, 48.52, 38.82, 37.83, 35.96, 30.92, 21.91, 18.87. HRMS Calcd for C<sub>14</sub>H<sub>19</sub>O [M+H]<sup>+</sup>: 203.1436; Found 203.1443.



***trans*-5-Trimethylsilyl-2-methyl-2-phenylcyclopentanone (13)**. Prepared in the same manner as **15**, *vide infra*, from 21.6 mg of 2-methyl-2-phenylcyclobutanone (**1a**, 0.135 mmol), 0.162 mmol of trimethylsilyldiazomethane (121 μL of a 1.33 M

solution in hexane), and 0.014 mmol of Sc(hfac)<sub>3</sub> (6.2 mg, 0.10 equiv) with 12:1 regioselectivity and 8:1 diastereoselectivity. After chromatography (TLC R<sub>f</sub> of **13** = 0.30 in 20:1 pentane:Et<sub>2</sub>O), the product was obtained in isomerically pure form as a colorless oil (25.4 mg, 0.103 mmol, 76% yield). IR (thin film): 2957(m), 2876 (w), 1712 (s), 1495 (w), 1445 (w), 1370 (w), 1311 (w), 1249 (s), 1171 (m), 1035 (m), 986 (w), 838 (s), 758 (m), 698 (s). <sup>1</sup>H NMR (400 MHz, CDCl<sub>3</sub>): δ 7.37 (dd, *J* = 7.9, 1.4 Hz, 2H), 7.31 (dd, *J* = 7.9, 7.2 Hz, 2H), 7.21 (tt, *J* = 7.2, 1.4 Hz, 1H), 2.57-2.52 (m, 1H), 2.12-2.00 (m, 2H), 1.95-1.86 (m, 2H), 0.15 (s, 9H). <sup>13</sup>C NMR (100 MHz, CDCl<sub>3</sub>): δ 221.60, 143.22, 128.54, 126.61, 126.52, 54.03, 41.50, 38.18, 24.68, 21.72, -1.71. HRMS Calcd for C<sub>14</sub>H<sub>19</sub>O [M+H]<sup>+</sup>: 203.1436; Found 203.1443.

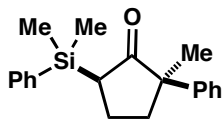
#### Representative Procedure for α-Silylcyclopentanone Synthesis:



***trans*-5-(Dimethyl(phenyl)silyl)-2-methyl-2-phenylcyclopentanone (15)**. In a glovebox, a 50 mL round bottom flask with a magnetic stir bar was charged with Sc(hfac)<sub>3</sub> (150 mg, 0.225 mmol, 0.10 equiv) and sealed with a rubber septum. In a

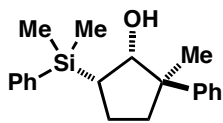
fume hood, the vial was charged with 12.0 mL of toluene and 361 mg 2-methyl-2-phenylcyclobutanone (**1a**, 2.25 mmol, 1.00 equiv) through a syringe. The reaction flask was covered with aluminum foil and (dimethylphenylsilyl)diazomethane (1.02 g, 4.95 mmol, 2.2 equiv) was slowly added to the solution by syringe pump at a rate of 1.00 mL/h. After 12 h of stirring, the reaction mixture was diluted with 25 mL of Et<sub>2</sub>O and transferred to a small separatory funnel for extraction. The organic layer was washed with 25 mL portions of saturated sodium bicarbonate, water, and saturated sodium chloride. The organic layer was dried over sodium sulfate, filtered, and concentrated under reduced pressure. <sup>1</sup>H NMR analysis of the extract showed 6:1 diastereoselectivity in favor of the *trans*-β-ketosilane (**15**). The crude oil was purified by silica gel chromatography (TLC R<sub>f</sub> of **15** = 0.30 in 19:1 hexanes:ethyl acetate), affording 550 mg (1.78 mmol, 79% yield) of **15** as a colorless oil. IR (thin film): 2959 (s), 1711 (s),

1427 (w), 1250 (m), 1168 (w), 1114 (m), 1033 (m), 834 (m), 810 (m), 699 (s), 471 (w).  $^1\text{H}$  NMR (400 MHz,  $\text{CDCl}_3$ ):  $\delta$  7.57-7.54 (m, 2H), 7.42-7.27 (m, 7H), 7.19 (tt,  $J = 7.0, 1.5$  Hz, 1H), 2.38 (dddd,  $J = 12.9, 6.4, 4.6, 1.4$  Hz, 1H), 2.04-1.95 (m, 1H), 1.89-1.82 (m, 1H), 1.64-1.57 (m, 1H), 1.55 (s, 3H), 0.50 (s, 3H), 0.46 (s, 3H).  $^{13}\text{C}$  NMR (100 MHz,  $\text{CDCl}_3$ ):  $\delta$  221.29, 143.09, 134.19, 129.71, 128.53, 128.04, 126.60, 126.49, 54.09, 41.24, 37.72, 24.29, 21.82,  $-3.11, -3.62$ . HRMS Calcd for  $\text{C}_{20}\text{H}_{28}\text{NOSi}$   $[\text{M}+\text{NH}_4]^+$ : 326.1940; Found 326.1938.



**cis-5-(Dimethyl(phenyl)silyl)-2-methyl-2-phenylcyclopentanone.** Recovered as a byproduct in the synthesis of **15** by silica gel chromatography (TLC  $R_f = 0.26$  in 19:1 hexanes:ethyl acetate). IR (thin film): 2959 (m), 1714 (s), 1427 (w), 1250 (m), 1156

(m), 1114 (m), 1025 (m), 831 (m), 731 (w), 699 (s).  $^1\text{H}$  NMR (400 MHz,  $\text{CDCl}_3$ ):  $\delta$  7.40-7.38 (m, 2H), 7.35-7.31 (m, 1H), 7.29-7.23 (m, 6H), 7.20-7.17 (m, 1H), 2.46-2.40 (m, 1H), 2.36-2.33 (m, 1H), 2.06-2.00 (m, 1H), 1.94-1.83 (m, 2H), 1.37 (s, 3H), 0.28 (s, 3H), 0.06 (s, 3H).  $^{13}\text{C}$  NMR (100 MHz,  $\text{CDCl}_3$ ):  $\delta$  220.55, 141.37, 136.96, 133.92, 129.46, 128.47, 127.94, 126.64, 126.64, 53.62, 41.29, 37.02, 26.58, 21.67, 10.70, 7.81,  $-3.30, -4.62$ . HRMS Calcd for  $\text{C}_{20}\text{H}_{28}\text{NOSi}$   $[\text{M}+\text{NH}_4]^+$ : 326.1940; Found 326.1949.

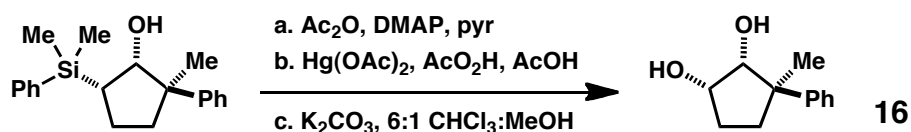


**5-(Dimethyl(phenyl)silyl)-2-methyl-2-phenylcyclopentanol.** A flame-dried 5 mL round bottom flask with a magnetic stir bar was charged with **15** (154 mg, 0.499 mmol, 1.0 equiv). The flask was flushed with nitrogen and sealed with a rubber

septum. 1.0 mL of  $\text{Et}_2\text{O}$  was added and the solution was cooled to  $-78$   $^\circ\text{C}$  with stirring. A separate flame-dried round bottom flask with a magnetic stir bar was charged with  $\text{Et}_2\text{O}$  (1.0 mL) and *t*-BuOH (94.1  $\mu\text{L}$ , 0.998 mmol, 2.0 equiv) under a nitrogen atmosphere. With stirring, the *t*-BuOH solution was cooled to  $-78$   $^\circ\text{C}$  and treated rapidly with LAH (499  $\mu\text{L}$  of a 1.0 M solution in  $\text{Et}_2\text{O}$ , 0.499 mmol, 1.0 equiv). After cessation of bubbling, the cold LAH solution was transferred to the flask containing **15** through a cannula, and 0.5 mL of  $\text{Et}_2\text{O}$  was used to rinse the flask containing residual reductant. The reaction mixture was stirred at  $-78$   $^\circ\text{C}$  until it was judged complete as indicated by TLC analysis (developed in 9:1 hexanes: $\text{Et}_2\text{O}$ ). The reaction was quenched by the addition of 1.0 mL of saturated sodium bicarbonate and slowly warmed to 23  $^\circ\text{C}$  with vigorous stirring. After 10 min, the bilayer was diluted with 20 mL of  $\text{Et}_2\text{O}$  and transferred to a separatory funnel. The organic layer was washed with equal portions of saturated sodium bicarbonate, water, and saturated sodium chloride. The organic layer was then dried over sodium sulfate, filtered, and concentrated under reduced pressure. The resulting oil was purified by silica gel chromatography (TLC  $R_f = 0.30$  in 9:1 hexanes: $\text{Et}_2\text{O}$ ) to provide 131 mg (0.425 mmol, 85% yield) of the major diastereomer<sup>13</sup> as a colorless oil. IR (thin film): 3370 (br), 2959

(13) Facile synthesis of the corresponding *p*-bromobenzylidene acetal (**1**) subsequent to Tamao-Fleming oxidation ultimately confirmed the *syn* relative configuration between silicon and oxygen in the major diastereomer; see below.

(s), 1643 (w), 1487 (m), 1470 (w), 1427 (w), 1381 (m), 1250 (m), 1110 (w), 1073 (m), 834 (m), 733 (w), 699 (m).  $^1\text{H}$  NMR (400 MHz,  $\text{CDCl}_3$ ):  $\delta$  7.56-7.53 (m, 1H), 7.35-7.28 (m, 8H), 7.19 (dt,  $J = 7.1, 1.5$  Hz, 1H), 4.34 (dd,  $J = 5.3, 5.0$  Hz, 1H), 2.32-2.25 (m, 1H), 1.95-1.80 (m, 3H), 1.52 (d,  $J = 5.0$  Hz, 1H), 1.46-1.40 (m, 1H), 1.30 (s, 3H), 0.37 (s, 3H), 0.31 (s, 3H).  $^{13}\text{C}$  NMR (100 MHz,  $\text{CDCl}_3$ ):  $\delta$  148.41, 139.88, 134.04, 128.91, 128.41, 127.89, 126.00, 125.94, 84.11, 53.13, 35.95, 31.57, 24.60, 24.18, -2.53, -2.93. HRMS Calcd for  $\text{C}_{20}\text{H}_{24} [\text{M}-\text{OH}]^+$ : 293.1726; Found: 293.1734.

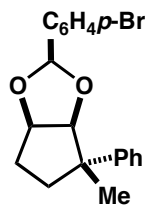


**3-Methyl-3-phenylcyclopentane-1,2-diol (16).** A 10 mL round bottom flask with a magnetic stir bar was charged with 5-(dimethyl(phenyl)silyl)-2-methyl-2-phenylcyclopentanol (138 mg, 0.444 mmol, 1.0 equiv), acetic anhydride (89.0  $\mu\text{L}$ , 0.889 mmol, 2.0 equiv), DMAP (10.9 mg, 0.0890 mmol, 0.20 equiv), and pyridine (2.2 mL). The reaction was heated to 35  $^\circ\text{C}$  for 14 h. After cooling the reaction mixture to 23  $^\circ\text{C}$ , it was diluted with 20 mL  $\text{Et}_2\text{O}$  and transferred to a separatory funnel. The organic layer was washed with 15 mL portions of 0.5 M HCl, 1.0 M  $\text{CuSO}_4$ , water, and saturated sodium chloride. The organic layer was dried over sodium sulfate, filtered, and concentrated under reduced pressure.

A portion of the unpurified acetate (54.4 mg, 0.154 mmol, 1.0 equiv) was dissolved in acetic acid (340  $\mu\text{L}$ ) and treated with 37 wt % peracetic acid (170  $\mu\text{L}$ , 2.52 mmol, 16.4 equiv) and mercuric acetate (54.1 mg, 0.154 mmol, 1.1 equiv). The reaction was stirred at 23  $^\circ\text{C}$  until the reaction was complete as indicated by TLC analysis (developed in 3:1 hexanes:ethyl acetate). The turbid mixture was then diluted with 20 mL of  $\text{Et}_2\text{O}$  and transferred to a separatory funnel where the organic layer was washed with two 25 mL portions of saturated sodium bicarbonate, 25 mL of saturated sodium thiosulfate, 20 of mL water, and 25 mL of saturated sodium chloride. The organic layer was dried over sodium sulfate, filtered, and concentrated under reduced pressure. The desired product of C–Si bond oxidation is subject to intramolecular transacylation on silica gel, and it was therefore immediately deprotected.

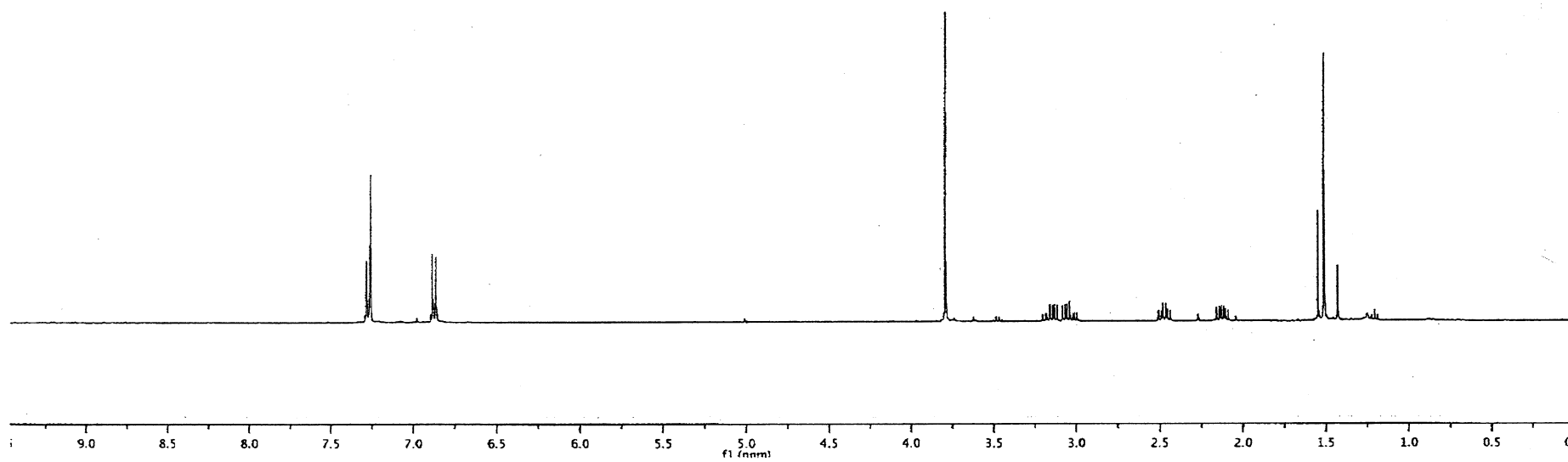
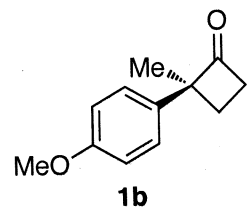
After dissolution in 1.0 mL of 6:1  $\text{CHCl}_3$ – $\text{MeOH}$ , potassium carbonate (245 mg, 1.78 mmol, 4.0 equiv) was added and the mixture was stirred at 23  $^\circ\text{C}$  until the reaction was complete as indicated by TLC analysis (developed in 1:1 hexanes:ethyl acetate). Direct concentration of the reaction mixture and purification by silica gel chromatography (TLC  $R_f$  of **16** = 0.30 in 1:1 hexanes:ethyl acetate) provided 18.4 mg (0.097 mmol, 63% yield over three steps) of **16** as a colorless oil. IR (thin film): 3389 (m), 2962 (m), 2926 (m), 2872 (w), 1496 (m), 1462 (m), 1444 (m), 1103 (m), 1053 (m), 1030 (m), 971 (w), 762 (m), 701 (s), 557 (w).  $^1\text{H}$  NMR (400 MHz,  $\text{CDCl}_3$ ):  $\delta$  7.44-7.42 (m, 2H), 7.34-7.30 (m, 2H), 7.20

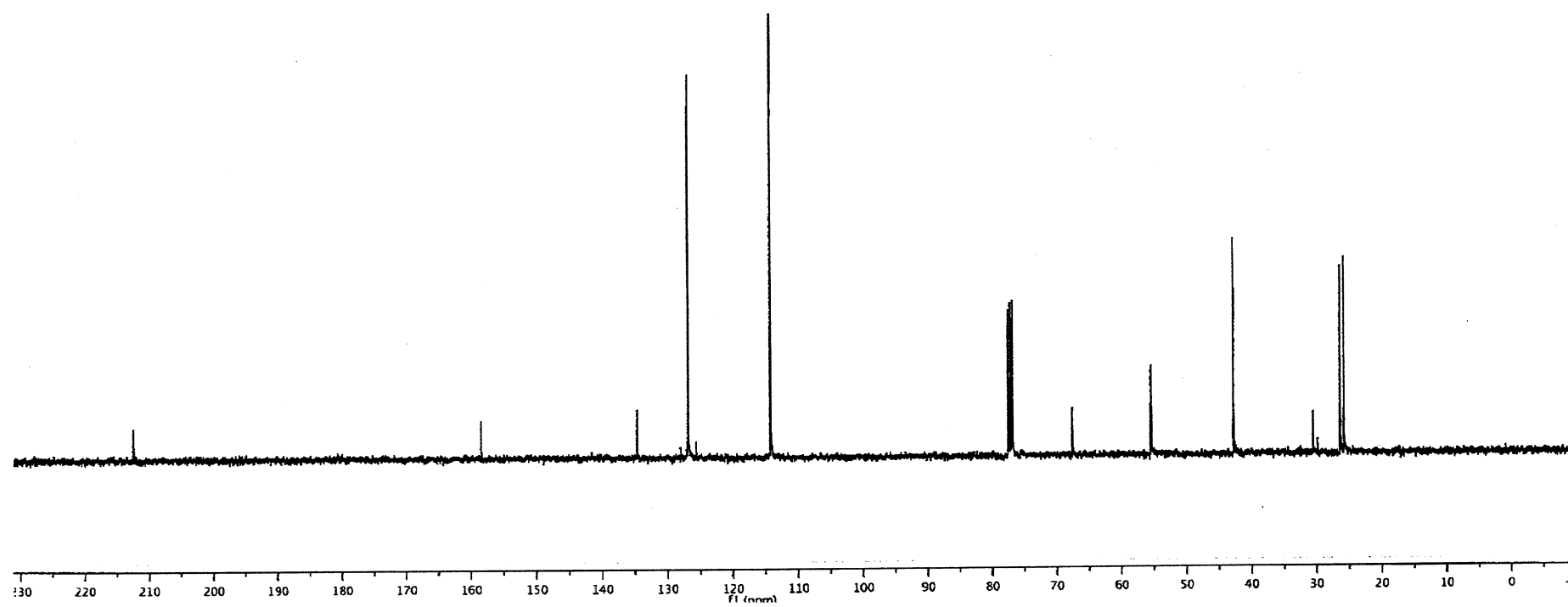
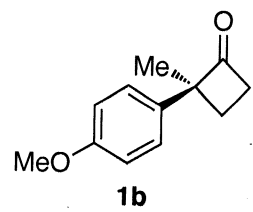
(tt,  $J = 7.3, 1.2$  Hz, 1H), 4.22 (dd,  $J = 12.6, 6.1$  Hz, 1H), 4.06 (d,  $J = 6.1$  Hz, 1H), 2.66 (br s, 1H), 2.24-2.17 (m, 2H), 2.05 (ddd,  $J = 13.3, 9.3, 4.1$  Hz, 1H), 1.95-1.89 (m, 1H), 1.83-1.76 (m, 1H), 1.34 (s, 3H), 1.25 (s, 1H).  $^{13}\text{C}$  NMR (100 MHz,  $\text{CDCl}_3$ ):  $\delta$  149.21, 128.47, 126.08, 126.01, 79.84, 72.41, 48.66, 34.11, 30.93, 23.36. HRMS Calcd for  $\text{C}_{12}\text{H}_{20}\text{NO}_2$   $[\text{M}+\text{NH}_4]^+$ : 210.1494; Found 210.1486.

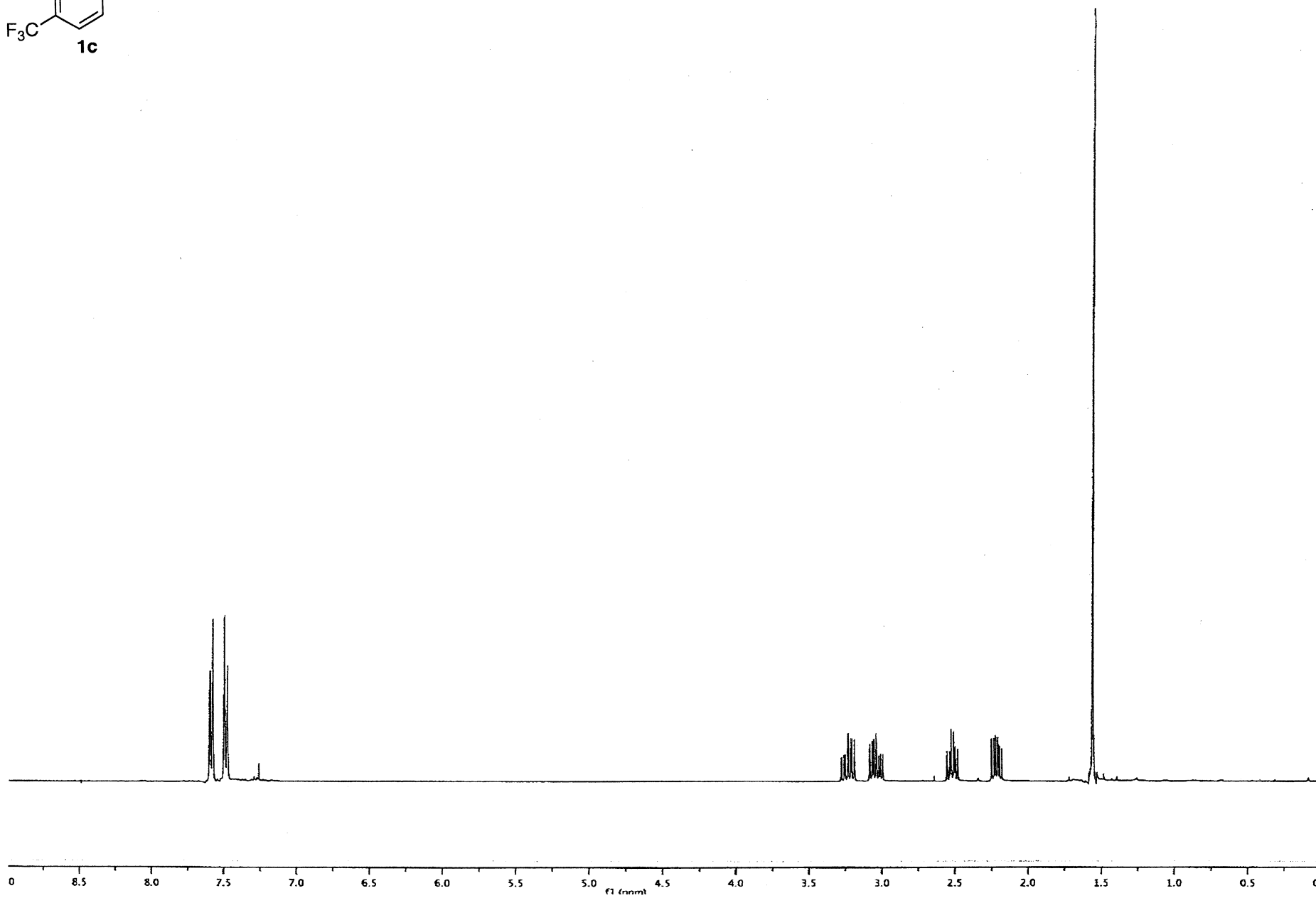
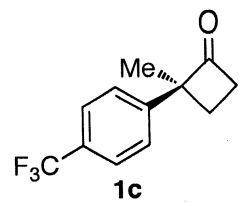


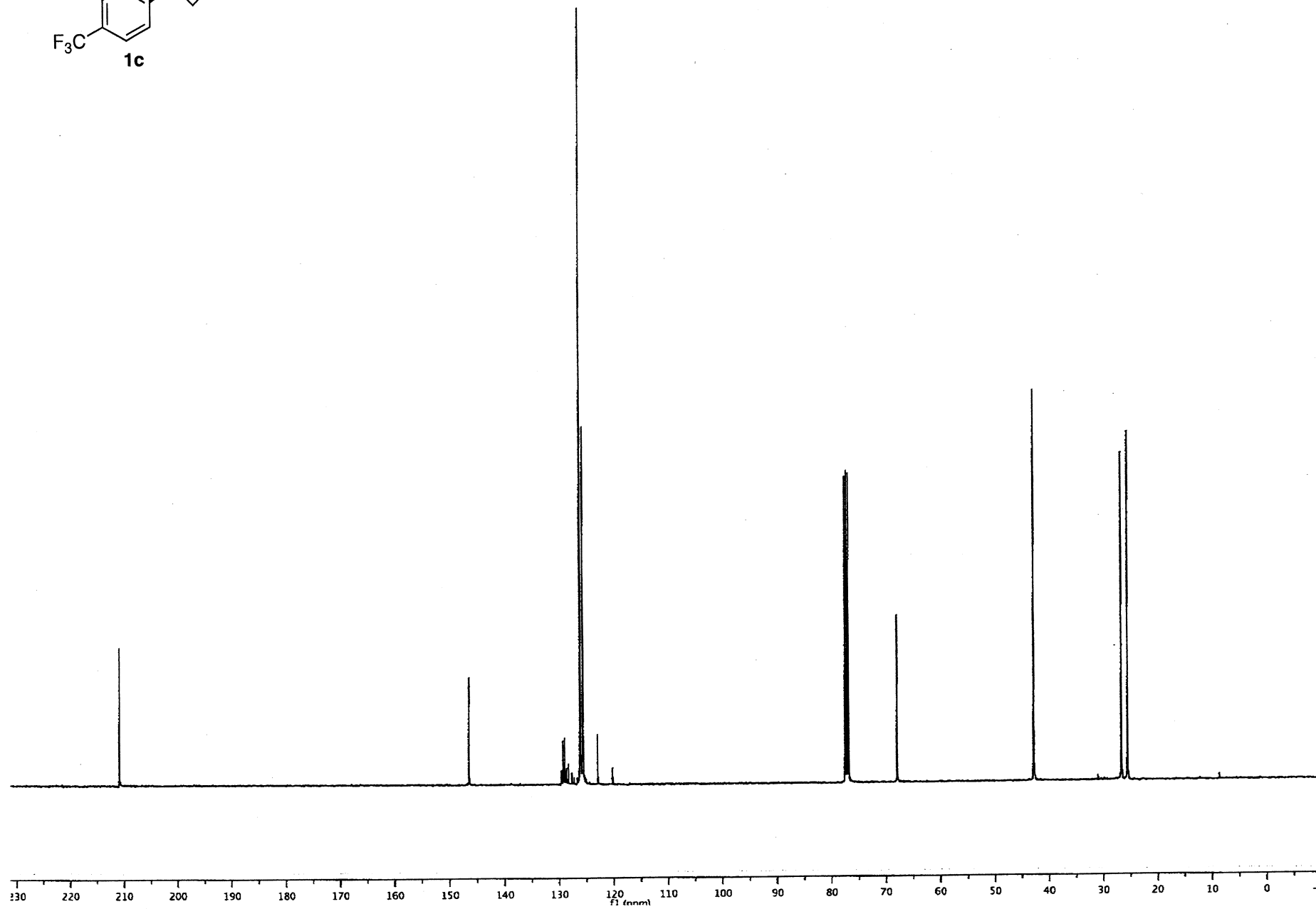
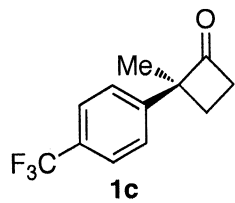
**2-(4-Bromophenyl)-4-methyl-4-phenyltetrahydro-3aH-cyclopenta[d][1,3]dioxole.** A

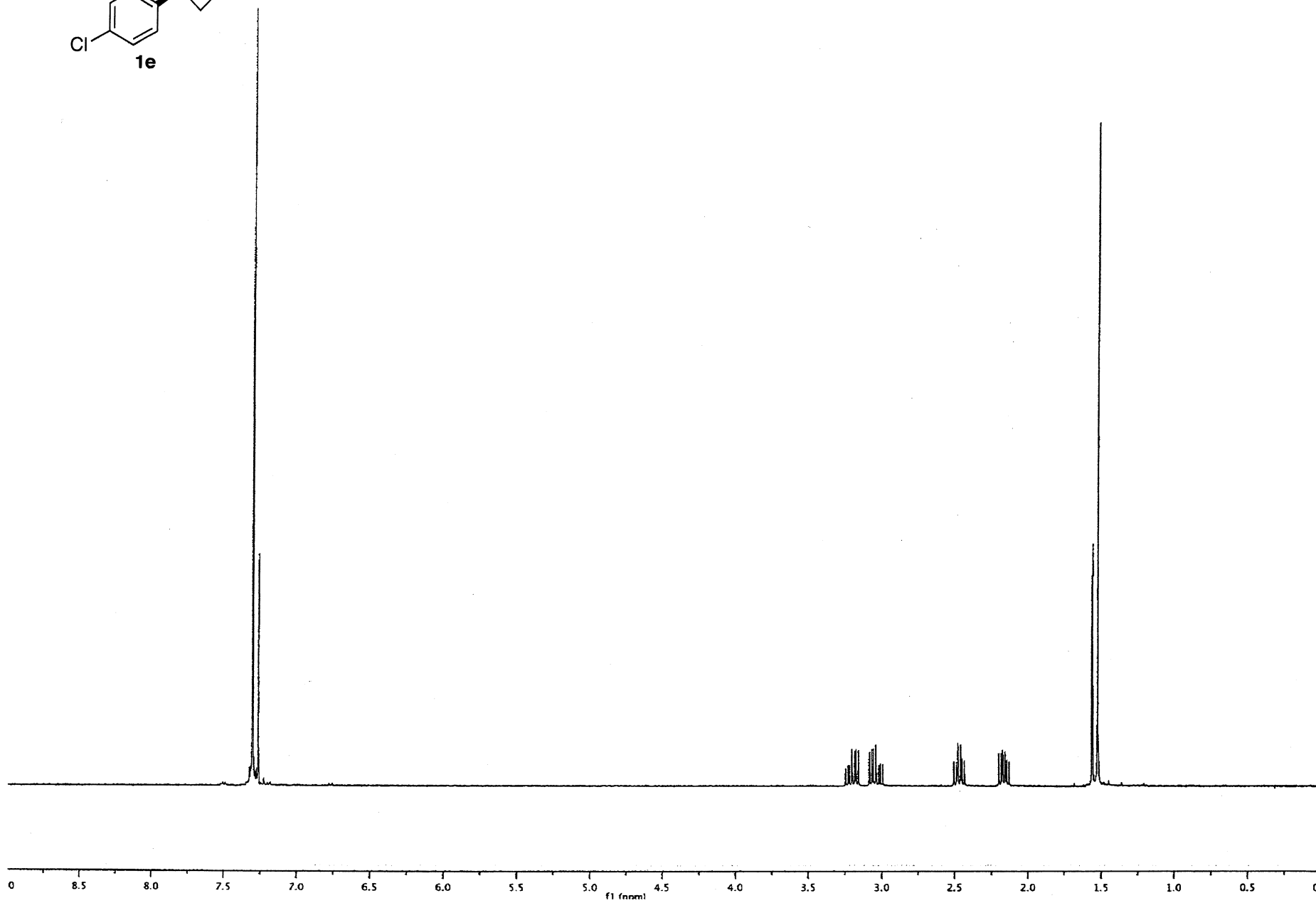
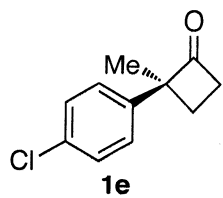
flame-dried 1 dram vial with a magnetic stir bar was charged with **16** (14.0 mg, 0.072 mmol), 4-bromobenzaldehyde (53.1 mg, 0.287 mmol, 4.0 equiv), ( $\pm$ )-camphorsulfonic acid (2.5 mg, 0.011 mmol, 0.15 equiv), a spatula tip full of 4 Å molecular sieves, and benzene (720  $\mu\text{L}$ ). The reaction vial was sealed with a Teflon-lined screw cap and heated to 80 °C for 2 h. After diluting the mixture with 10 mL of  $\text{Et}_2\text{O}$ , it was washed with 10 mL of saturated sodium chloride. The organic layer was then dried over magnesium sulfate, filtered, and concentrated under reduced pressure. The impure oil was purified by silica gel chromatography (TLC  $R_f = 0.30$  in 12:1 hexanes:ethyl acetate) to provide 25.1 mg (0.0690 mmol, 97% yield) as a clear oil. IR (thin film): 2965 (w), 2930 (w), 2873 (w), 1597 (w), 1491 (w), 1443 (w), 1296 (w), 1214 (w), 1070 (s), 1012 (s), 817 (m), 762 (m), 701 (m).  $^1\text{H}$  NMR (400 MHz,  $\text{CDCl}_3$ ):  $\delta$  7.54 (d,  $J = 8.5$  Hz, 2H), 7.45 (d,  $J = 8.5$  Hz, 2H), 7.35 (app d,  $J = 4.0$  Hz, 4H), 7.22 (tt,  $J = 4.5, 4.5$  Hz, 1H), 4.8 (app d,  $J = 4.8$  Hz, 1H), 4.66 (app t,  $J = 6.0$  Hz, 1H), 2.15-2.05 (m, 2H), 1.89 (dddd,  $J = 14.1, 6.5, 2.5, 1.0$ , 1H), 1.77-1.70 (m, 1H), 1.55 (s, 1H), 1.45 (s, 3H).  $^{13}\text{C}$  NMR (100 MHz,  $\text{CDCl}_3$ ):  $\delta$  146.13, 136.02, 131.72, 131.72, 128.61, 126.48, 126.37, 123.73, 103.51, 88.38, 82.35, 50.44, 35.22, 30.94, 25.21. HRMS Calcd for  $\text{C}_{19}\text{H}_{20}\text{BrO}_2$   $[\text{M}+\text{H}]^+$ : 361.0626; Found 361.0646.



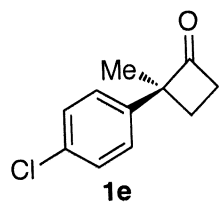








211.49



140.92

132.59

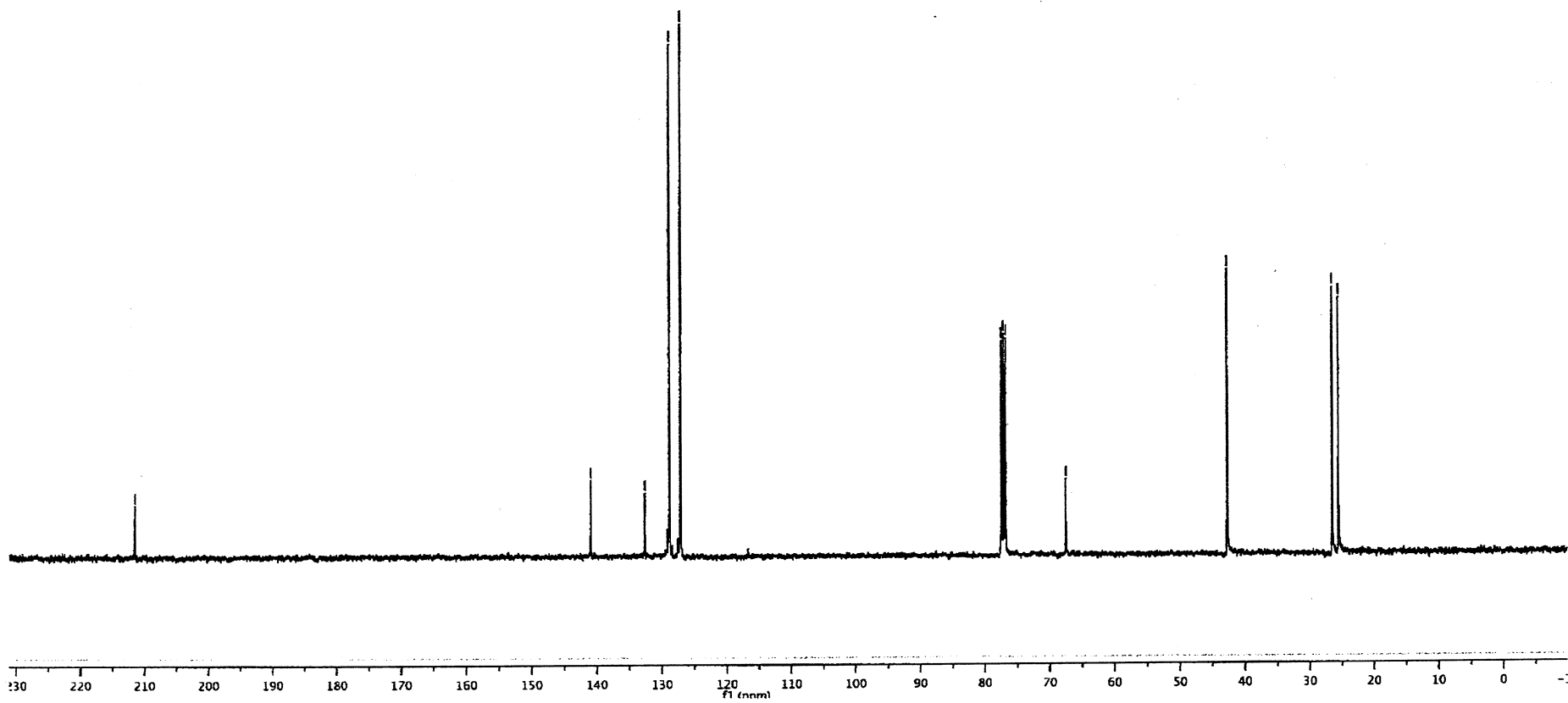
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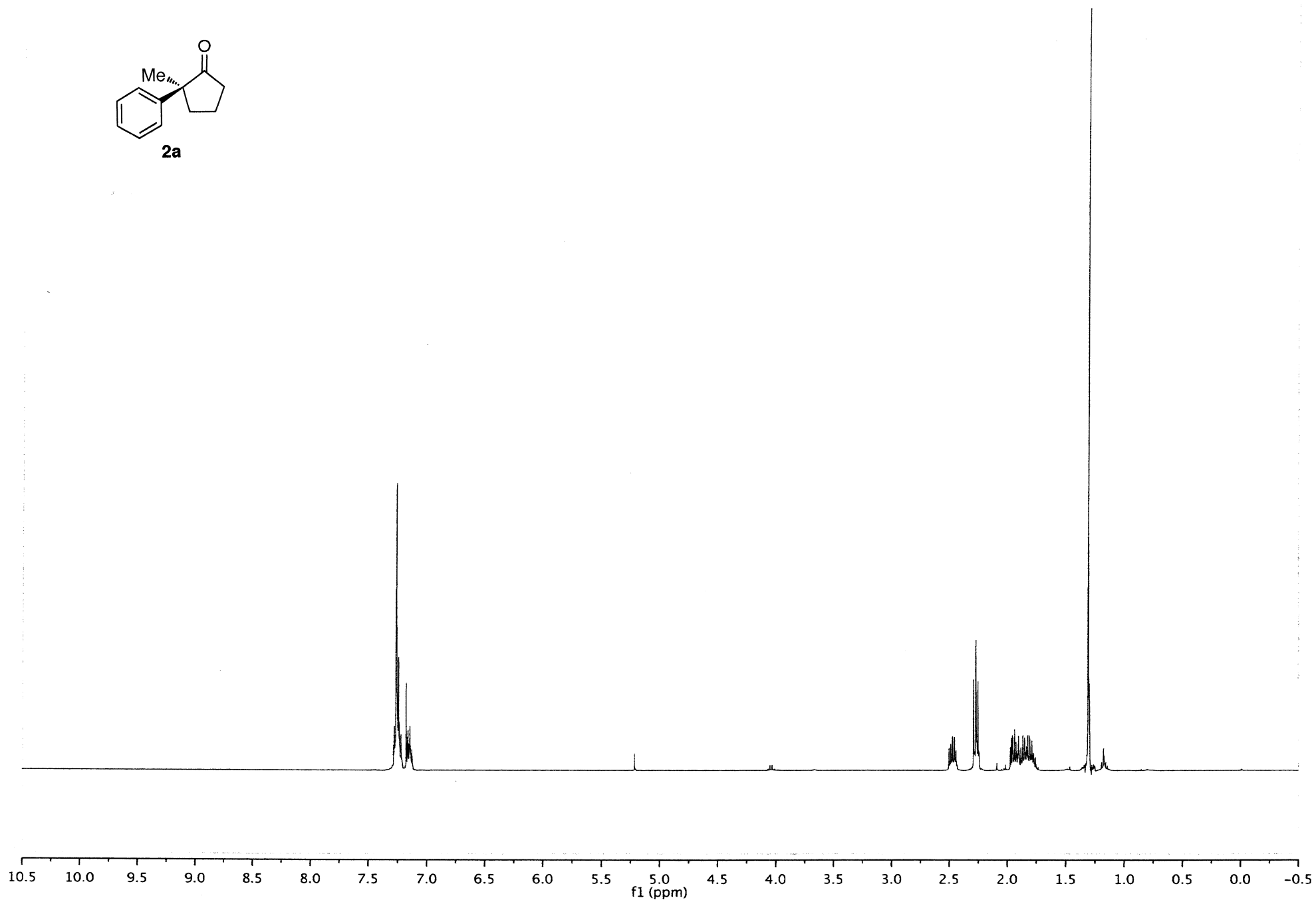
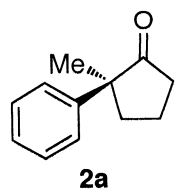
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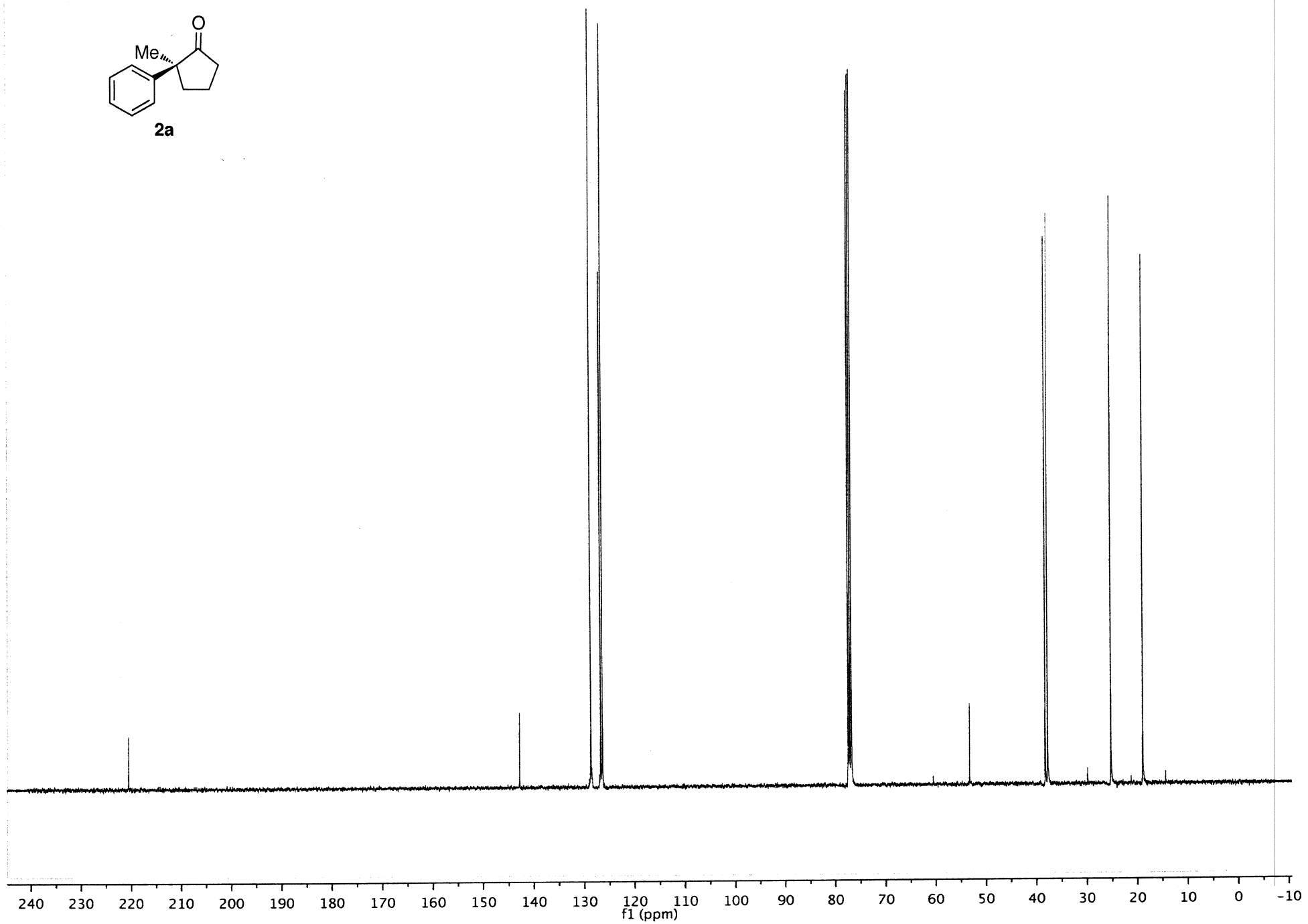
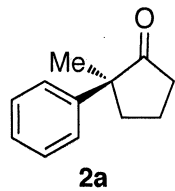
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76.84

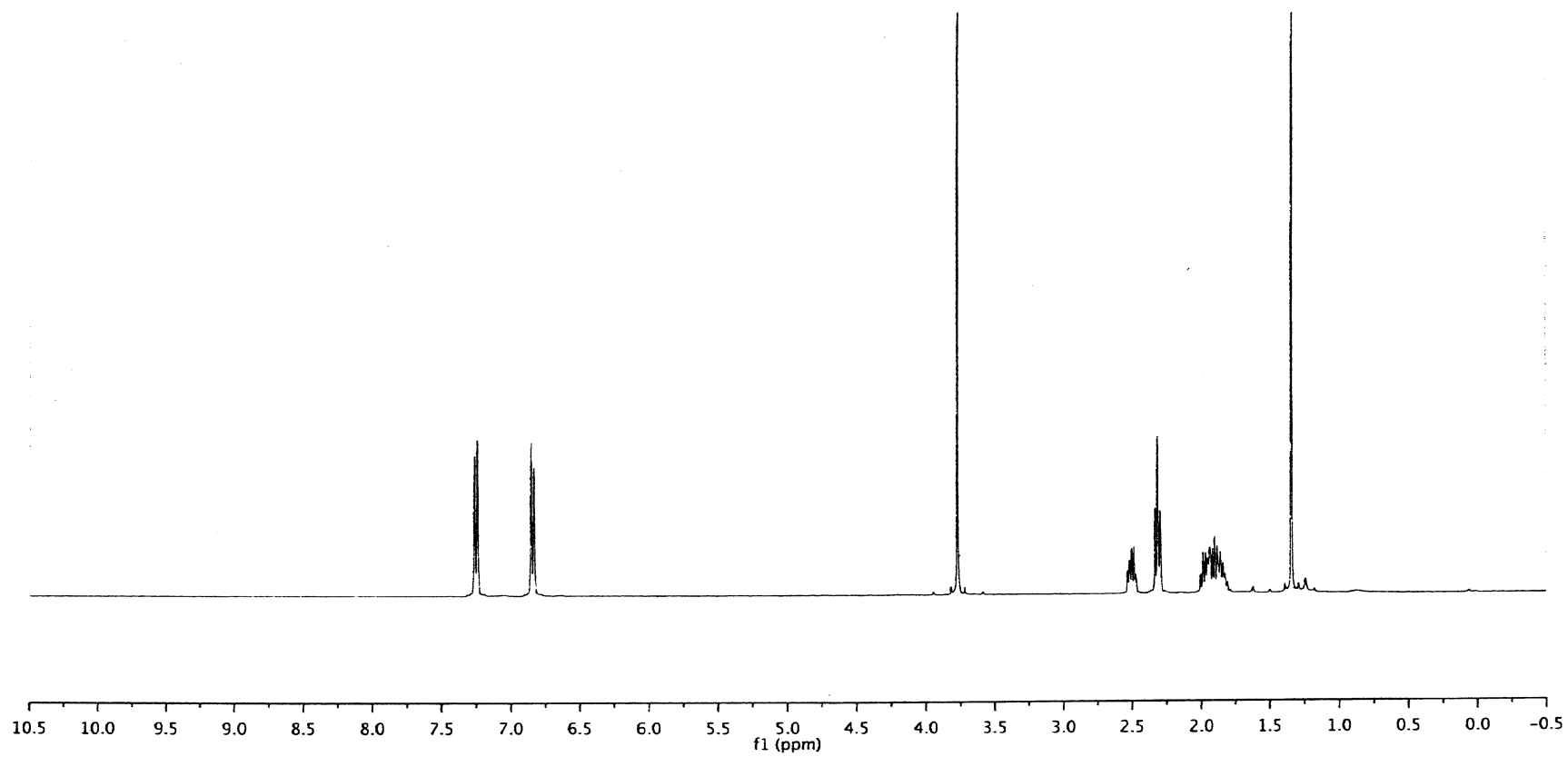
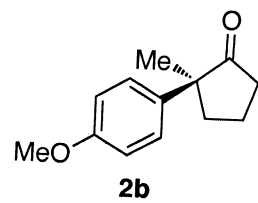
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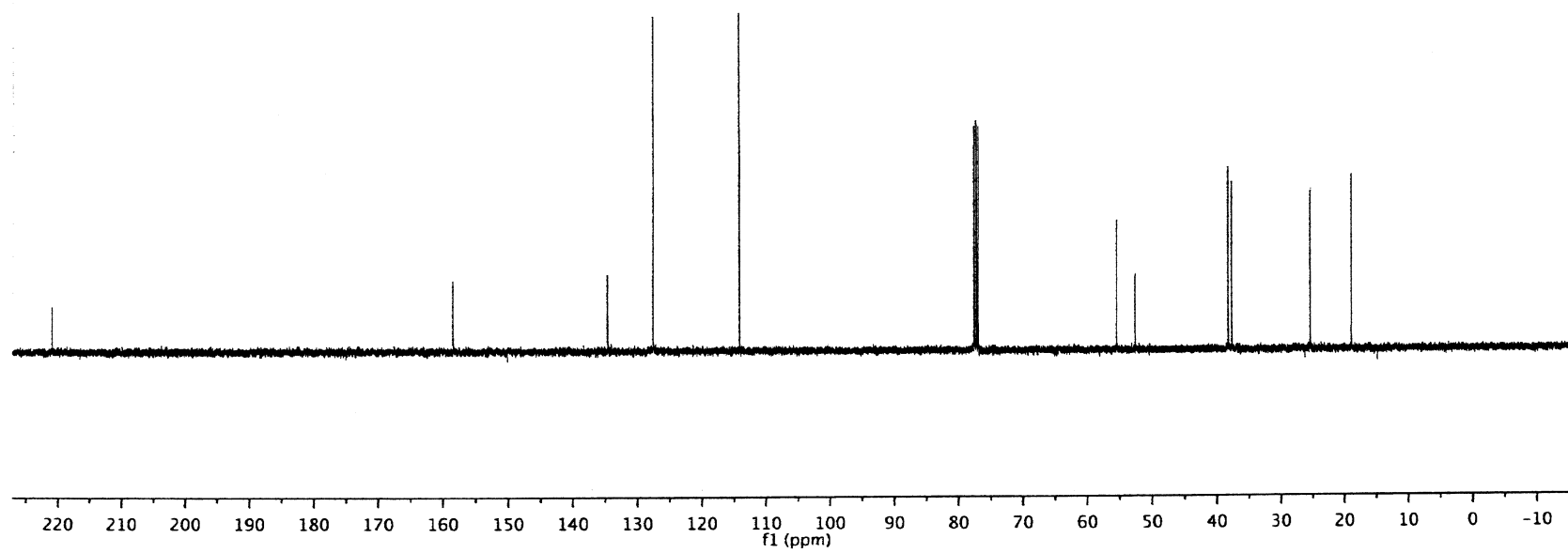
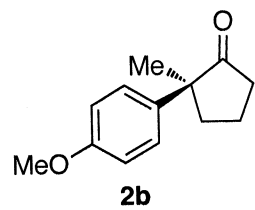
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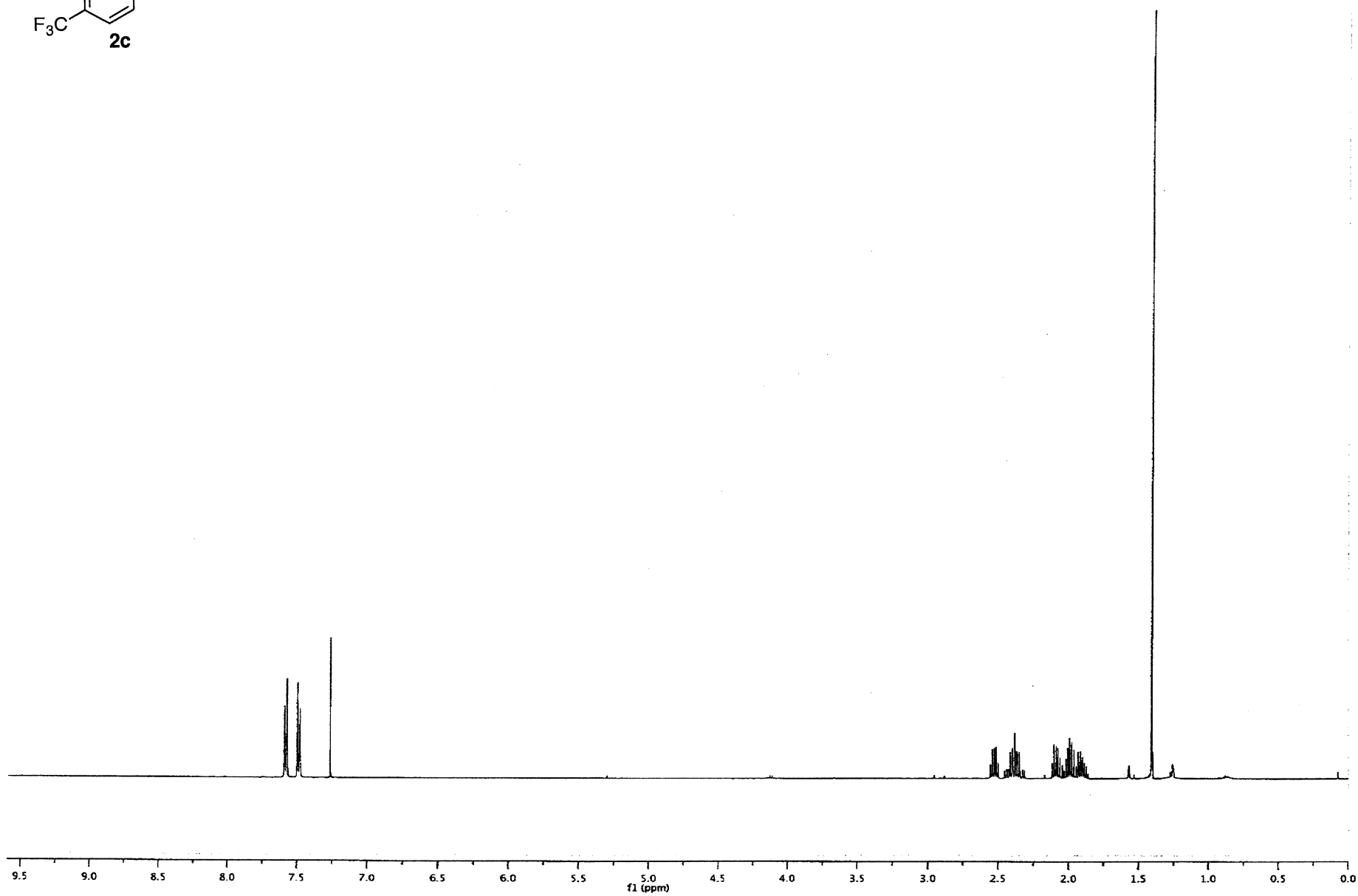
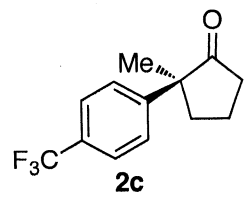
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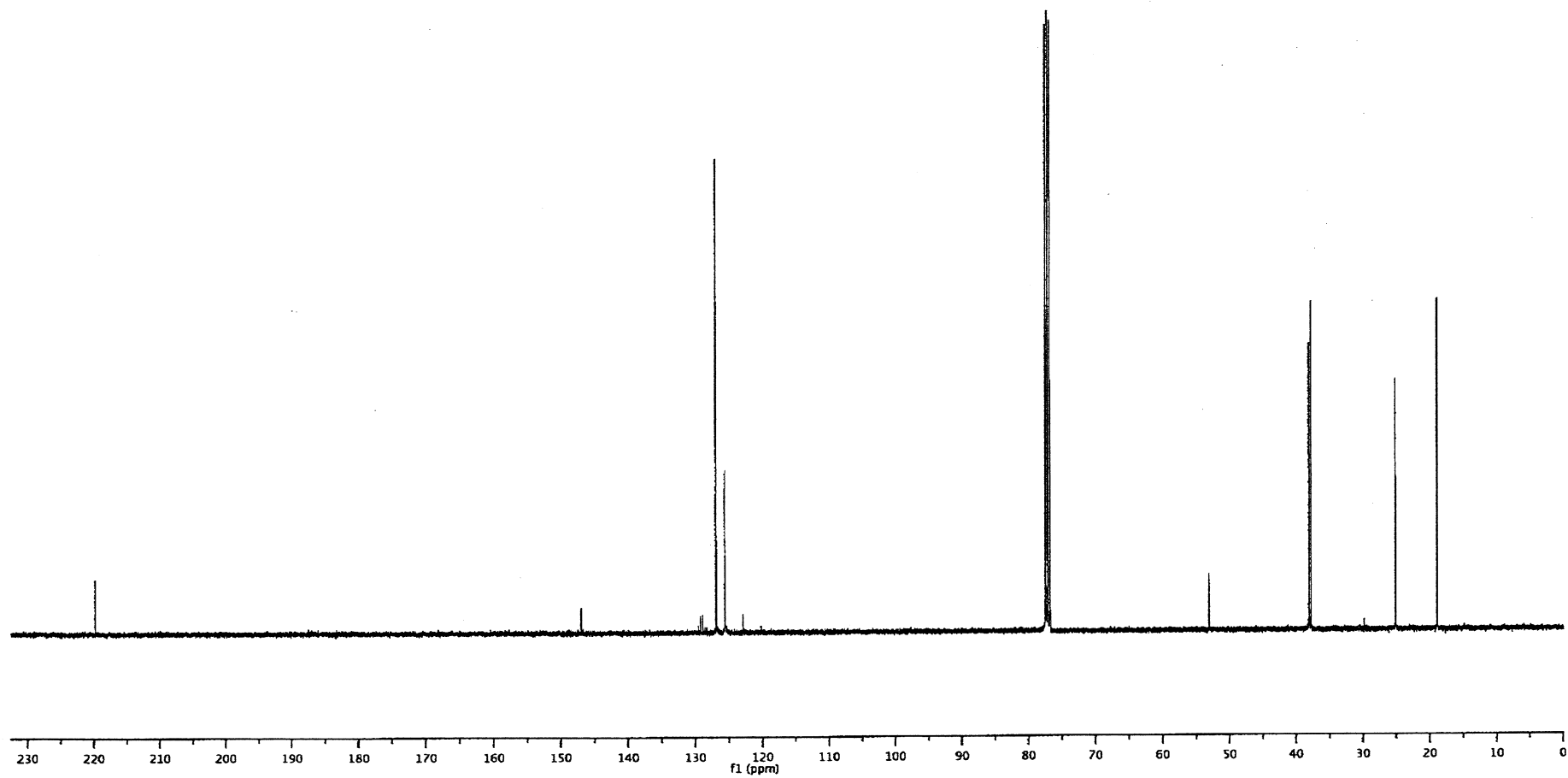
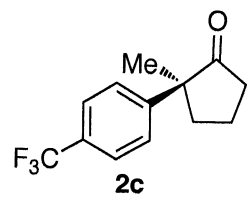


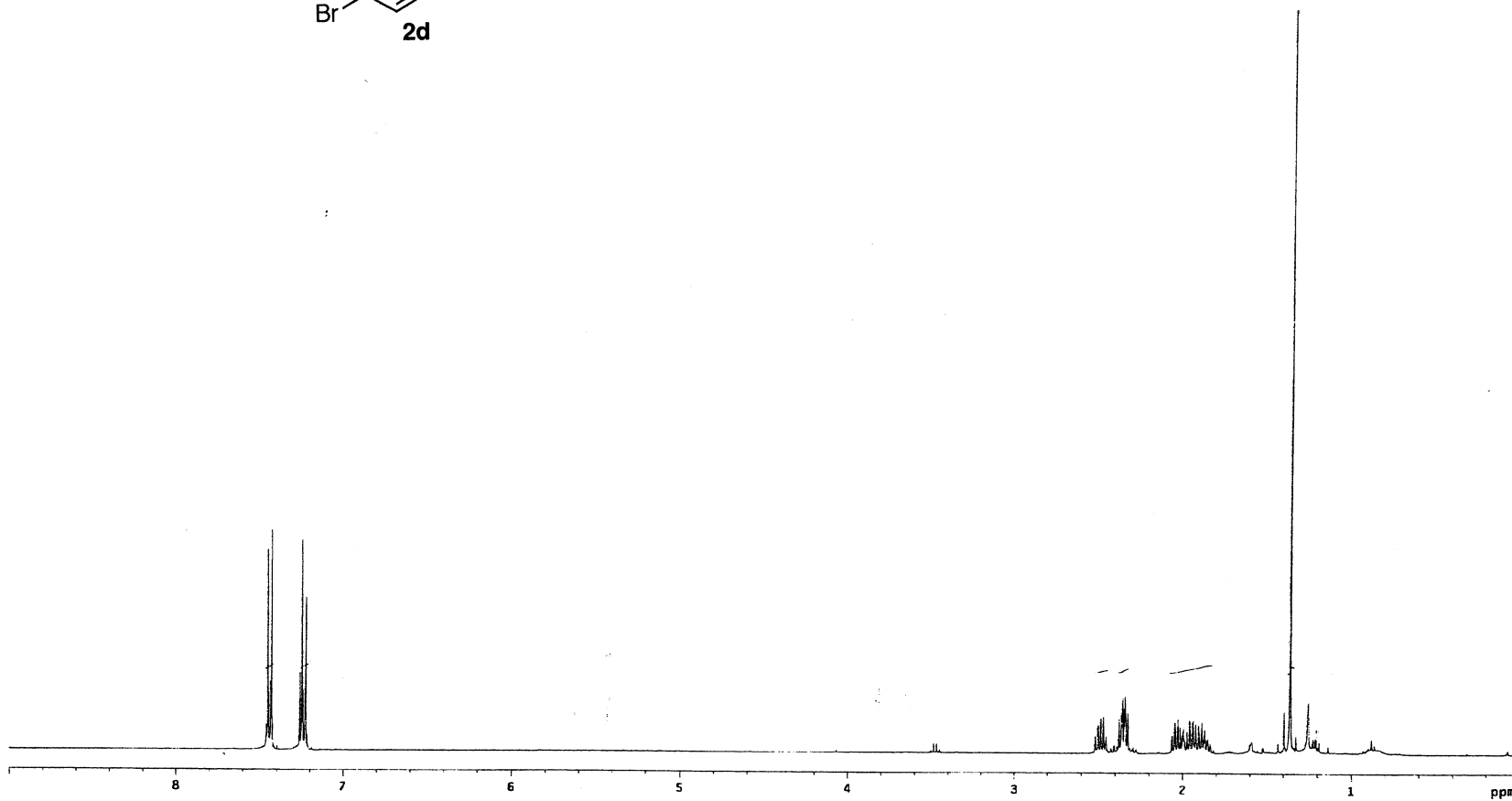
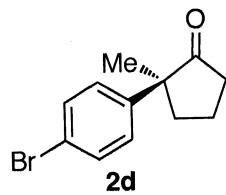


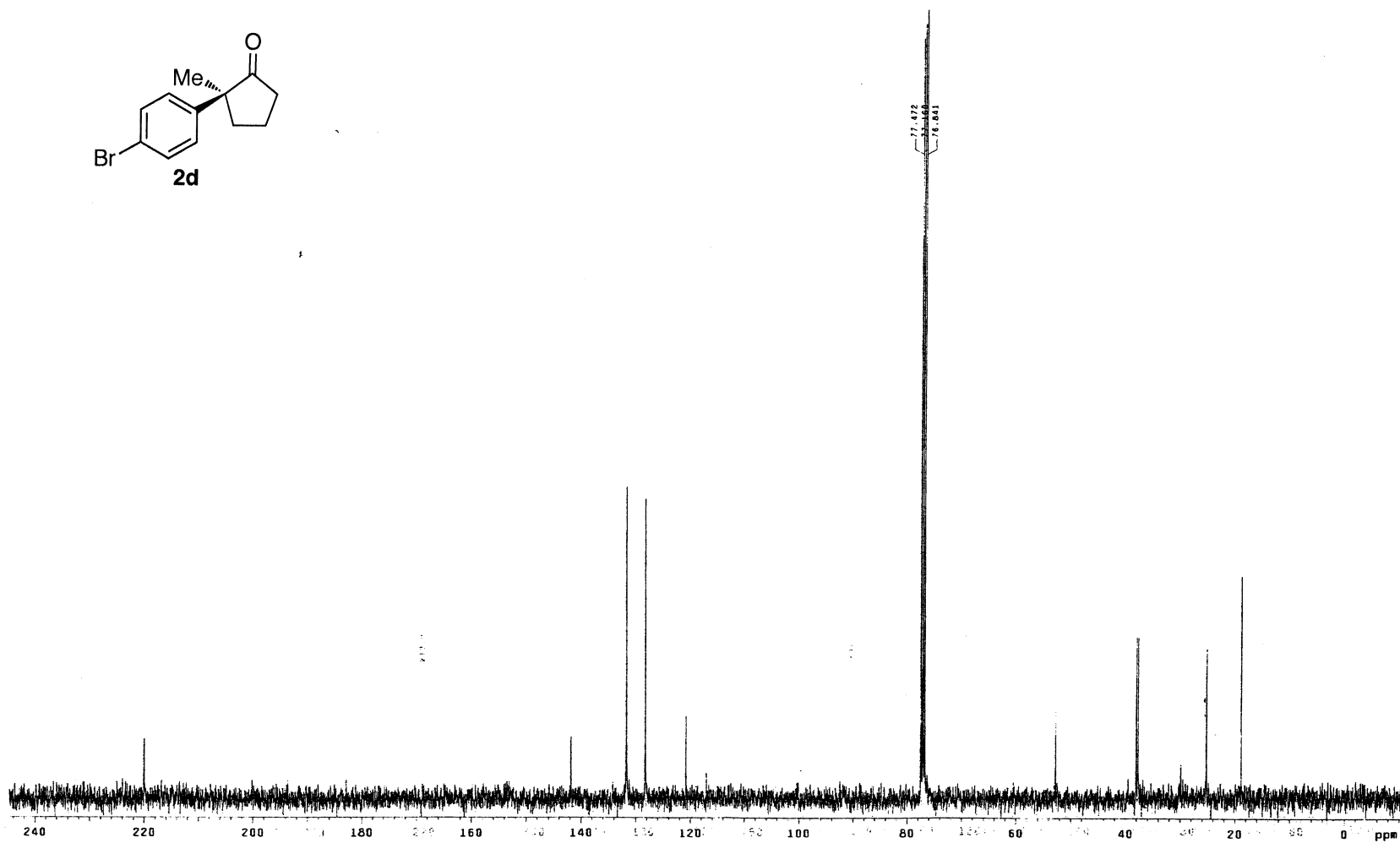
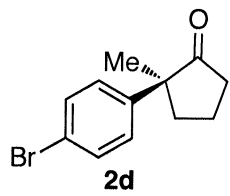


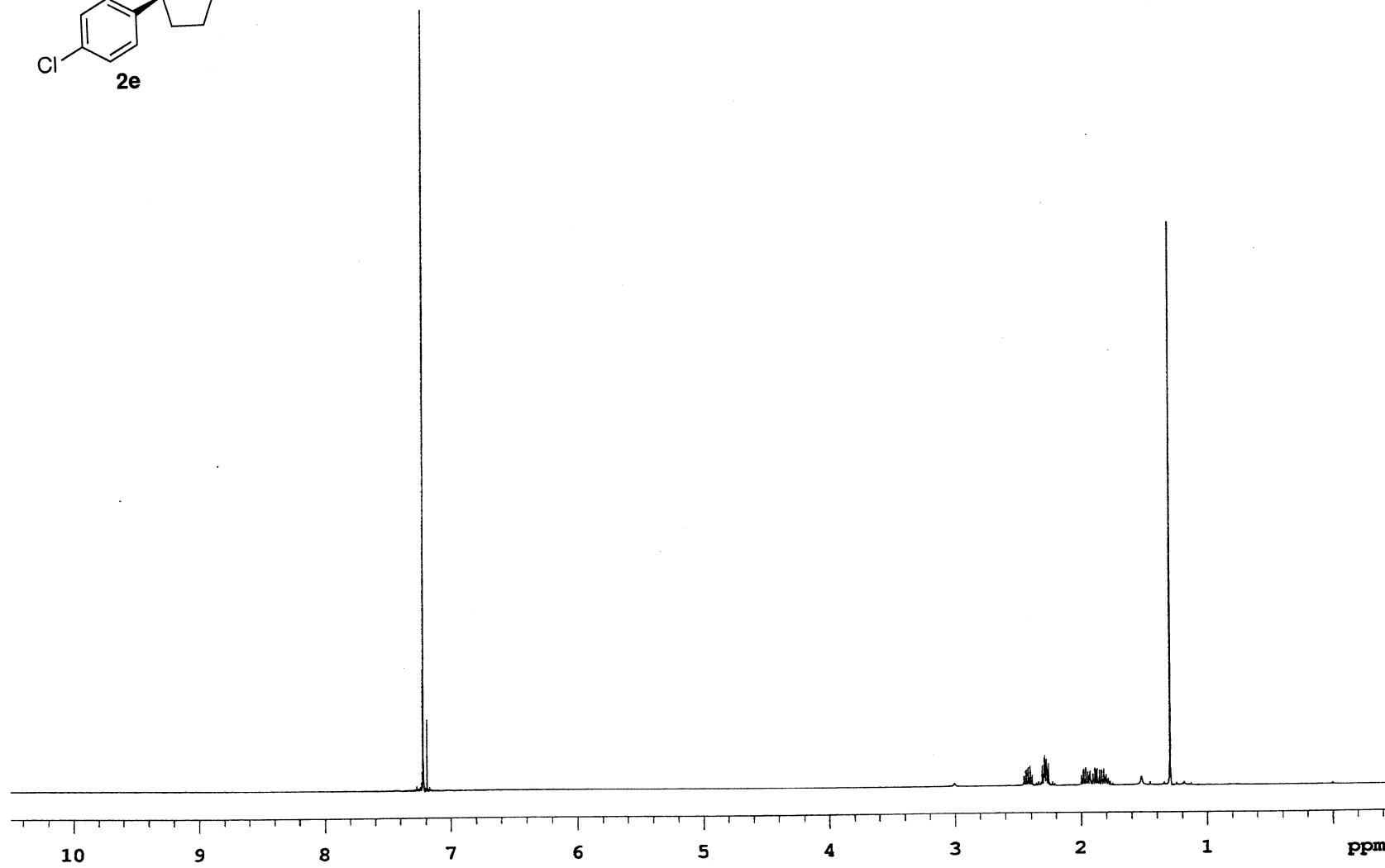
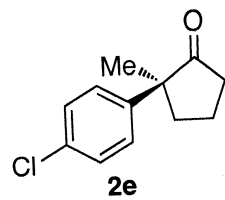


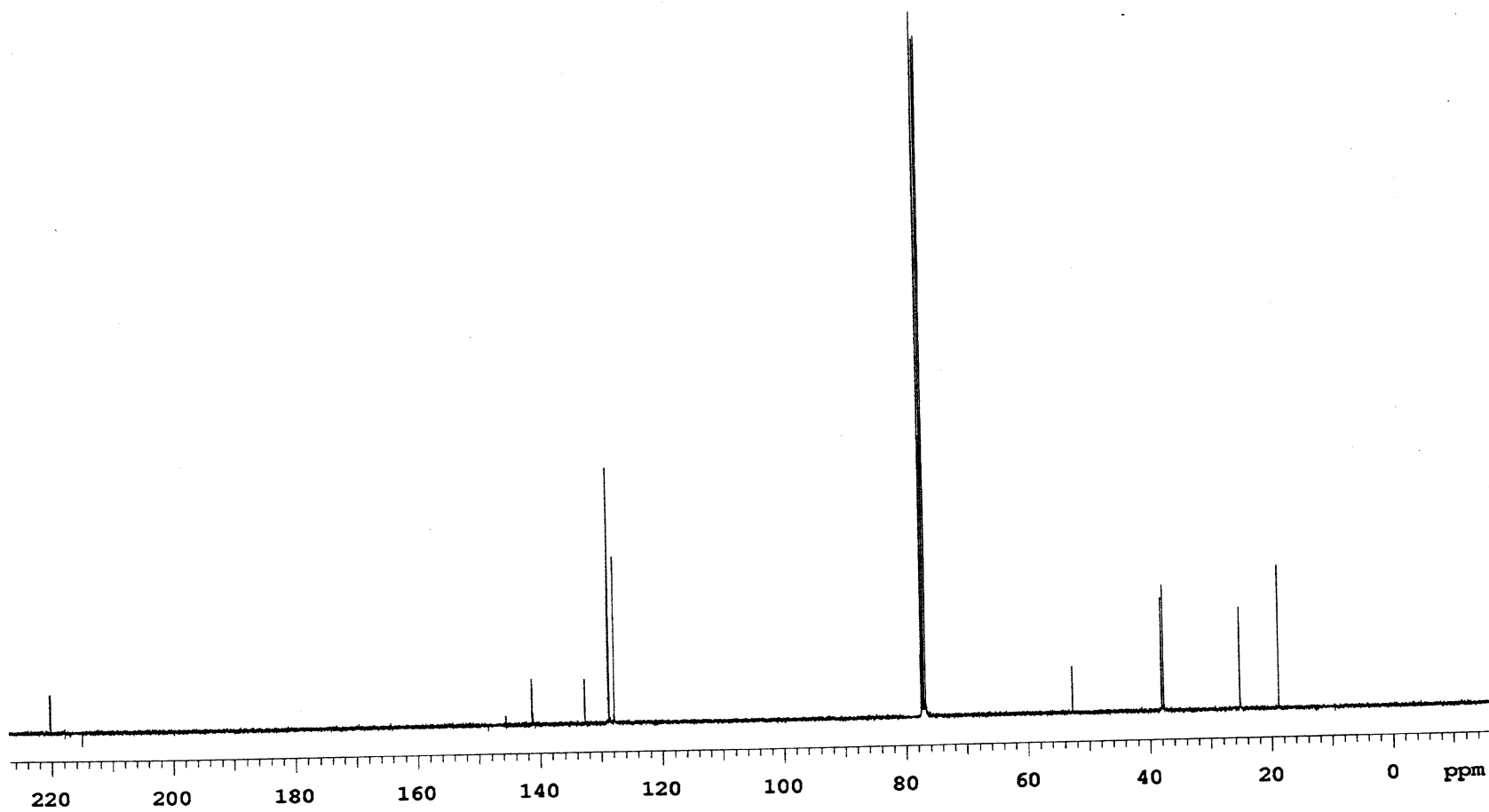
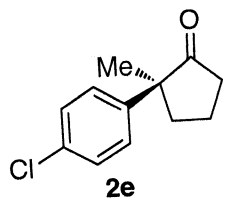


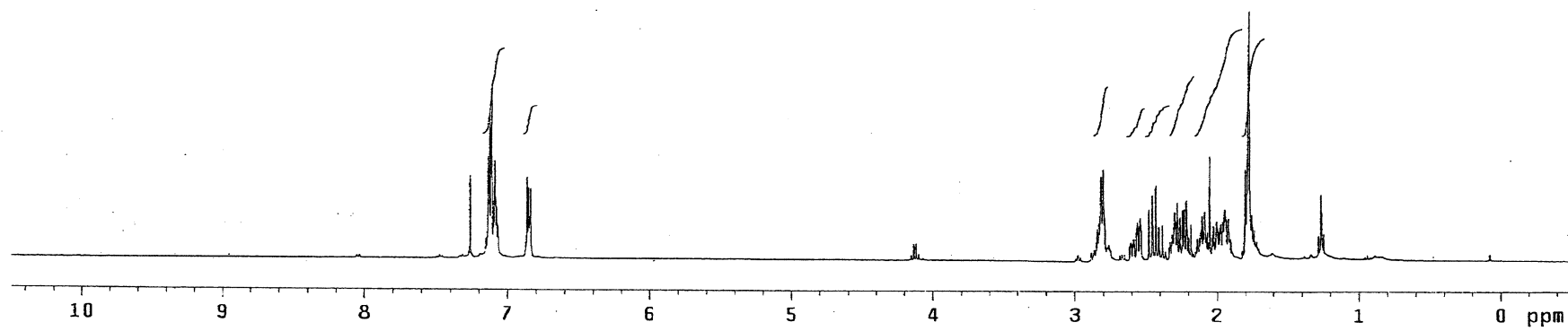
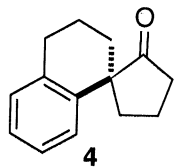


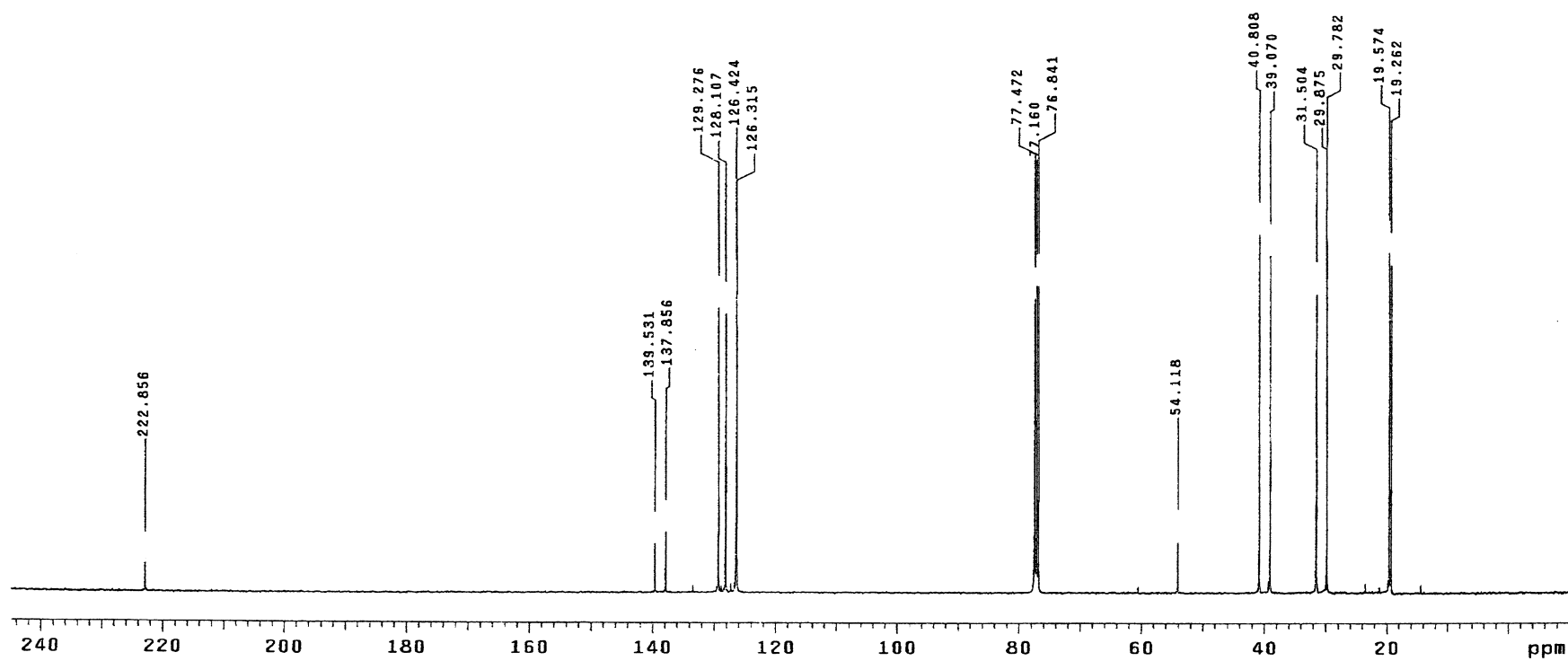
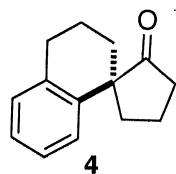


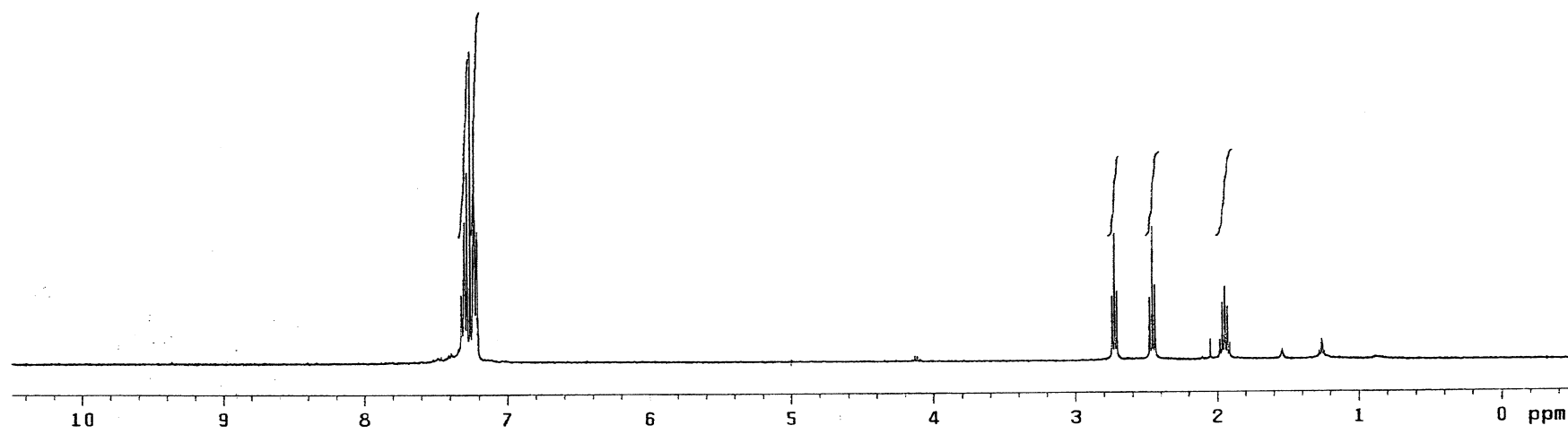
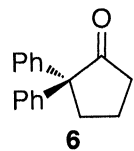


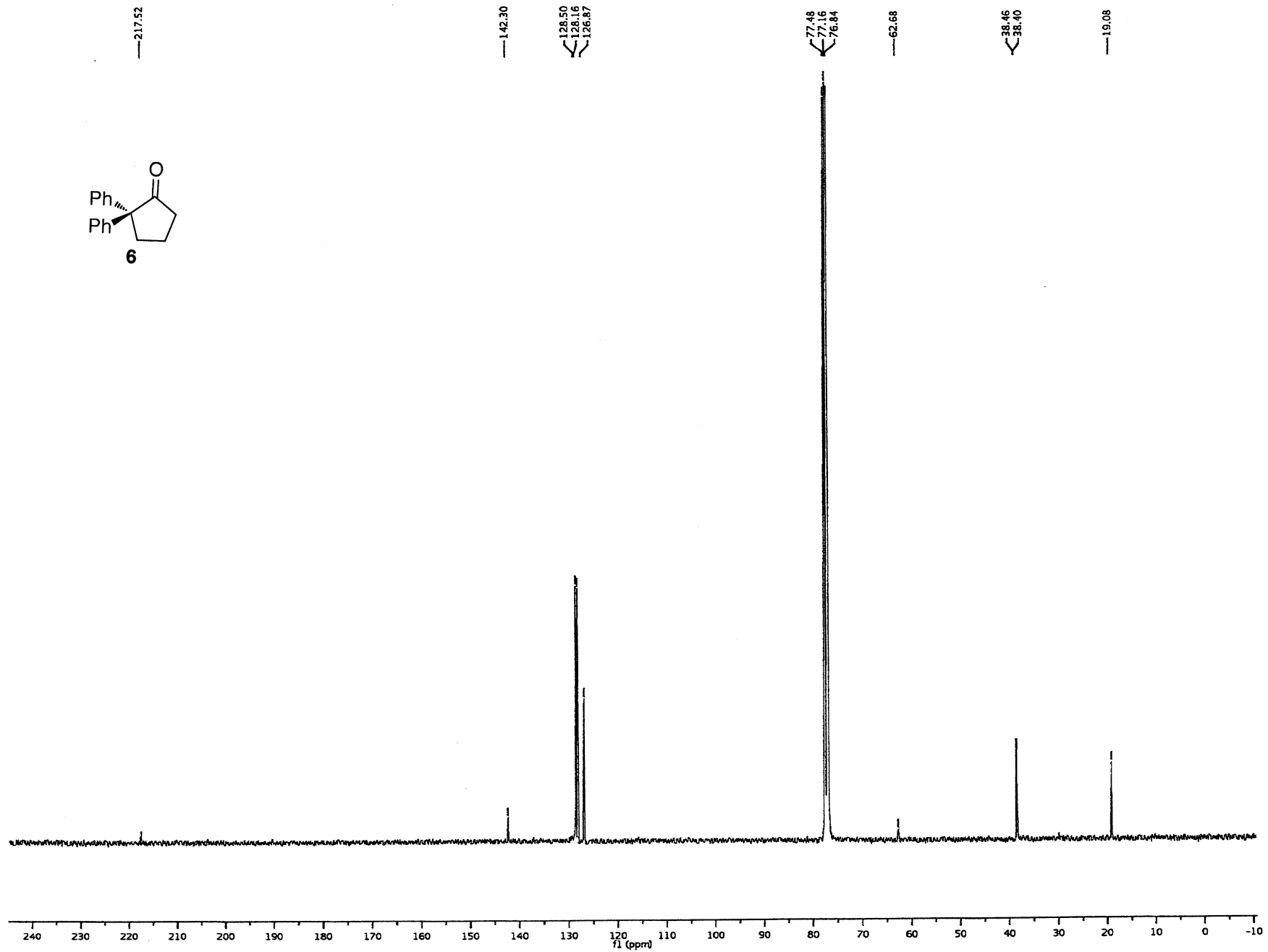
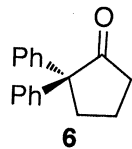


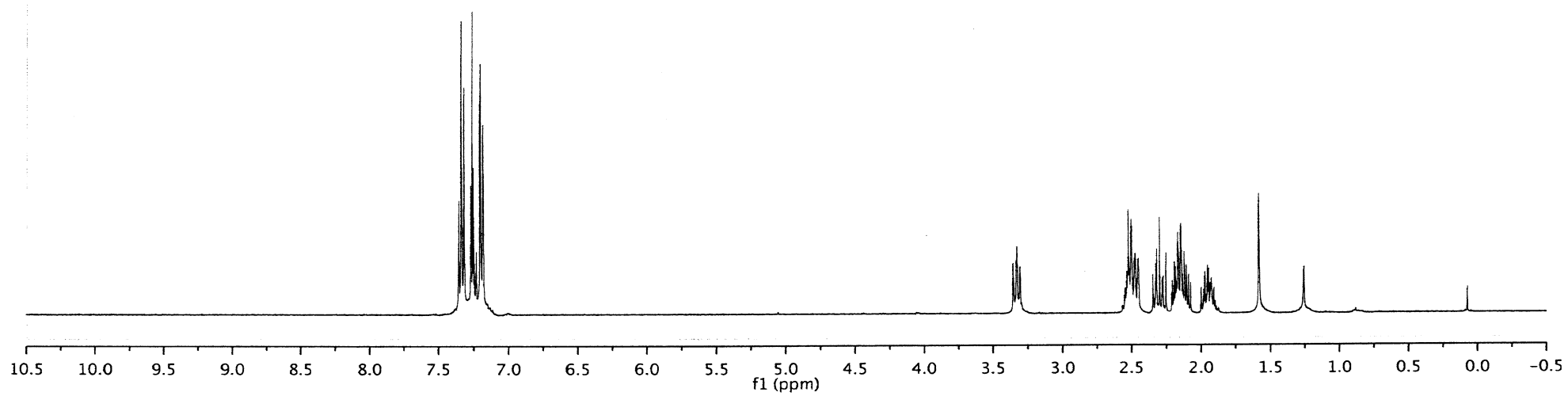
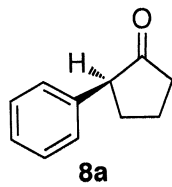


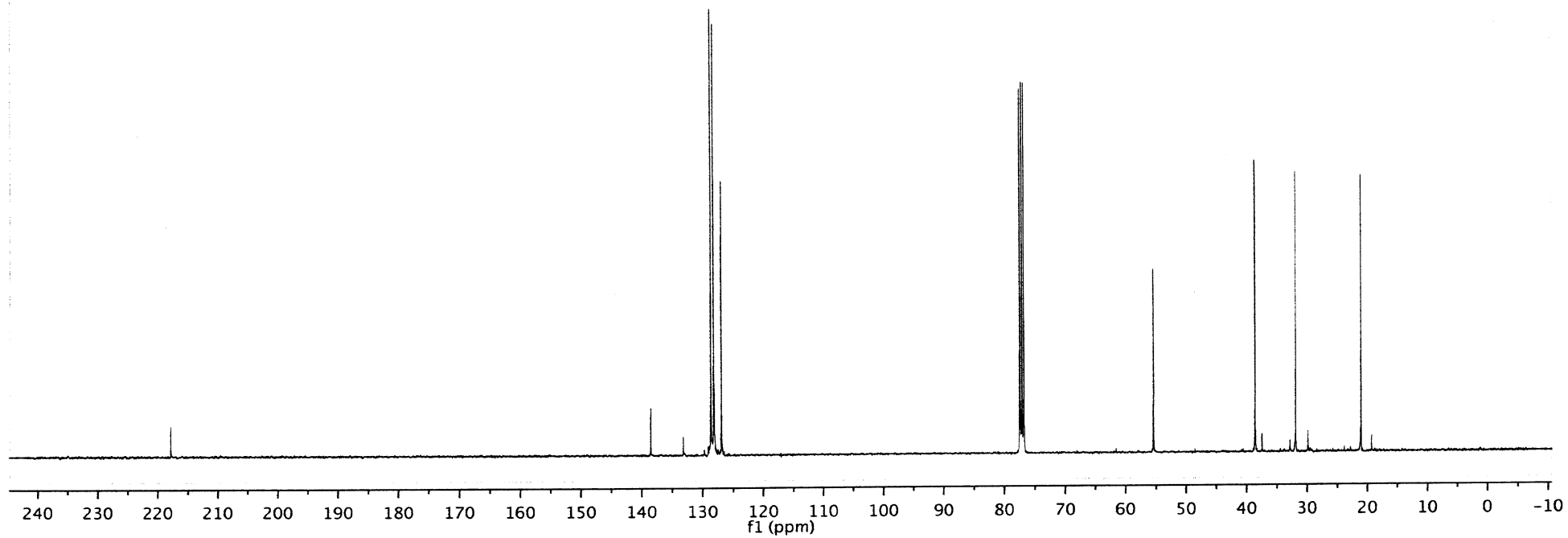
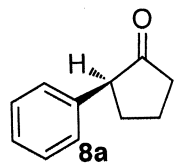


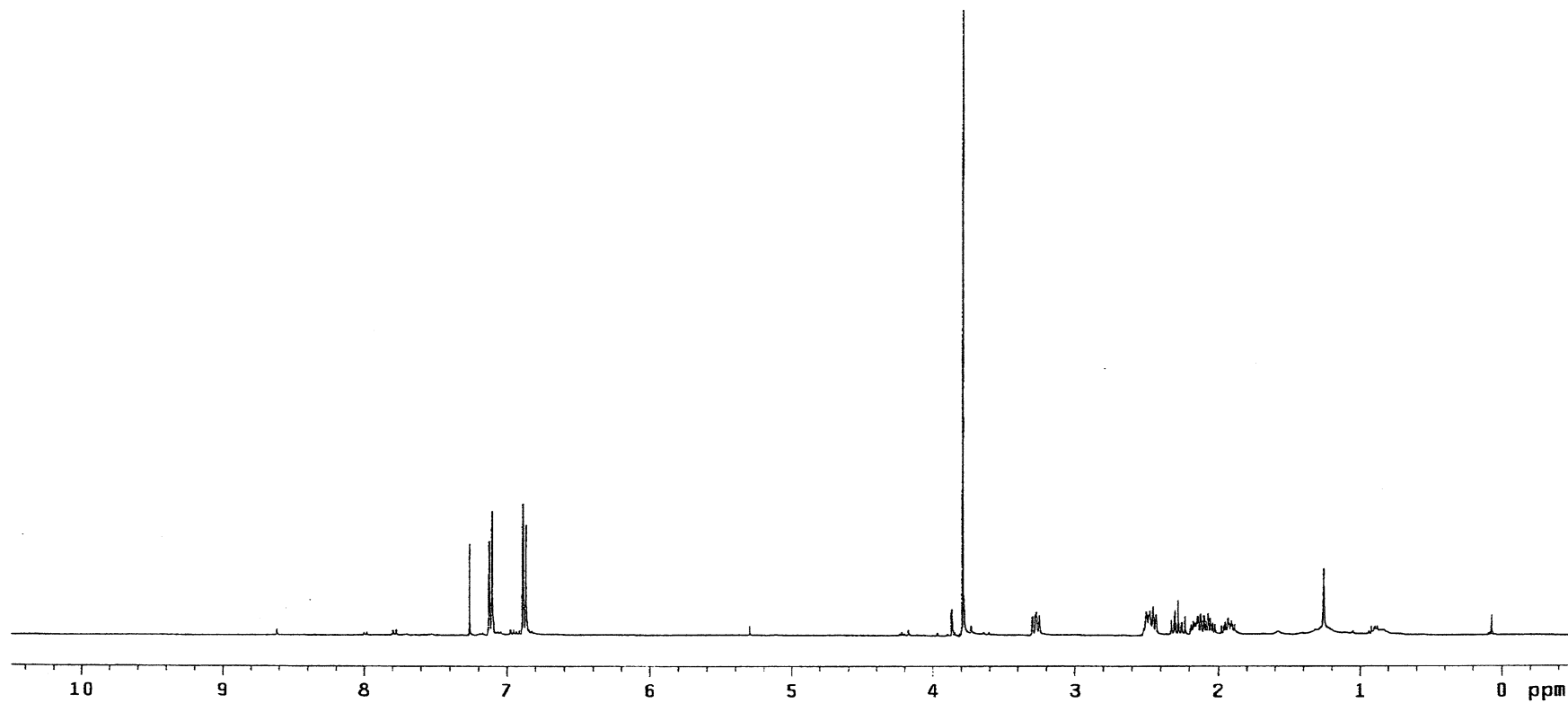
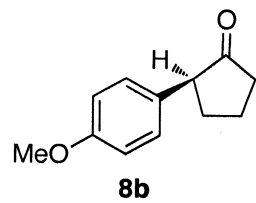


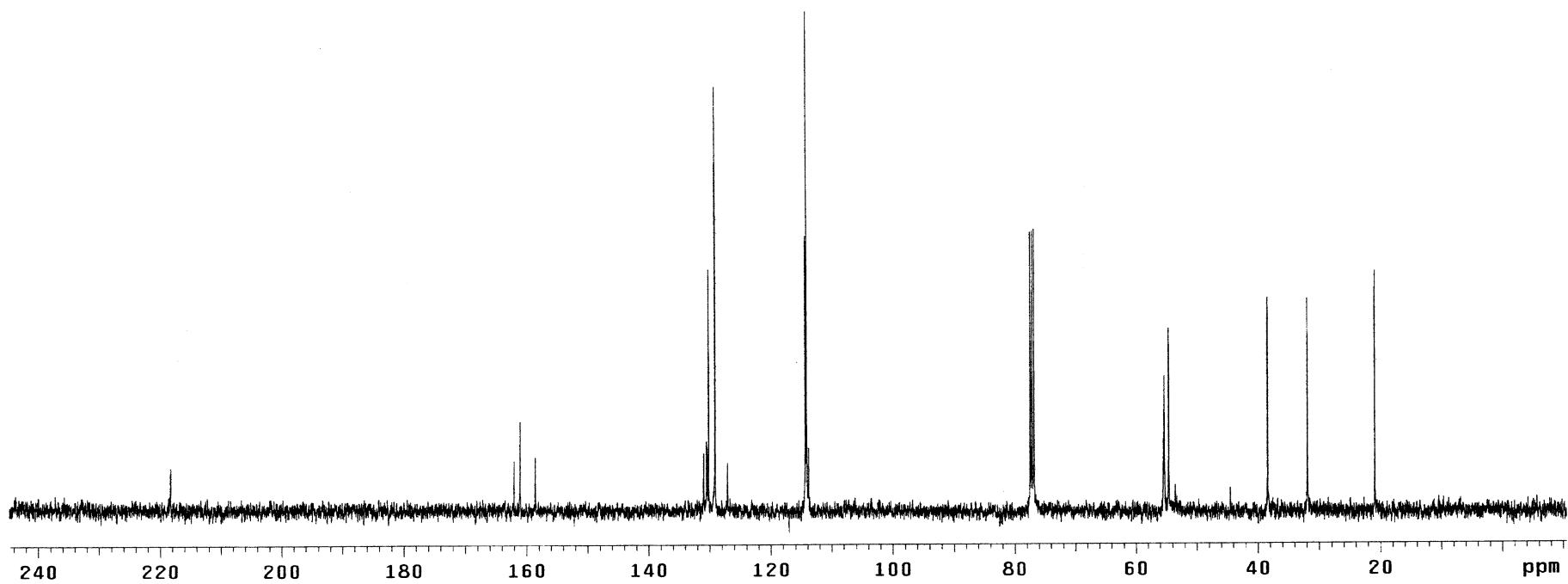
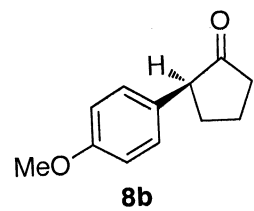


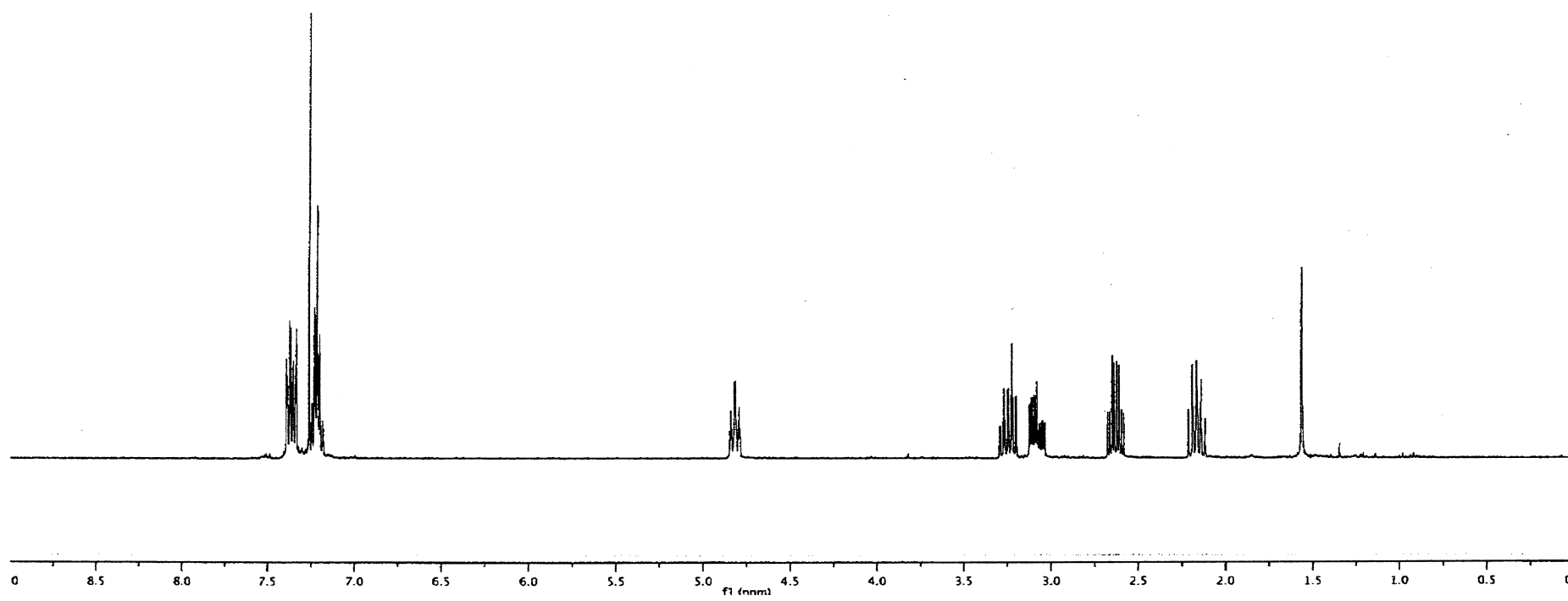
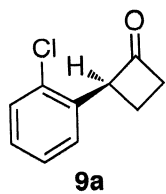


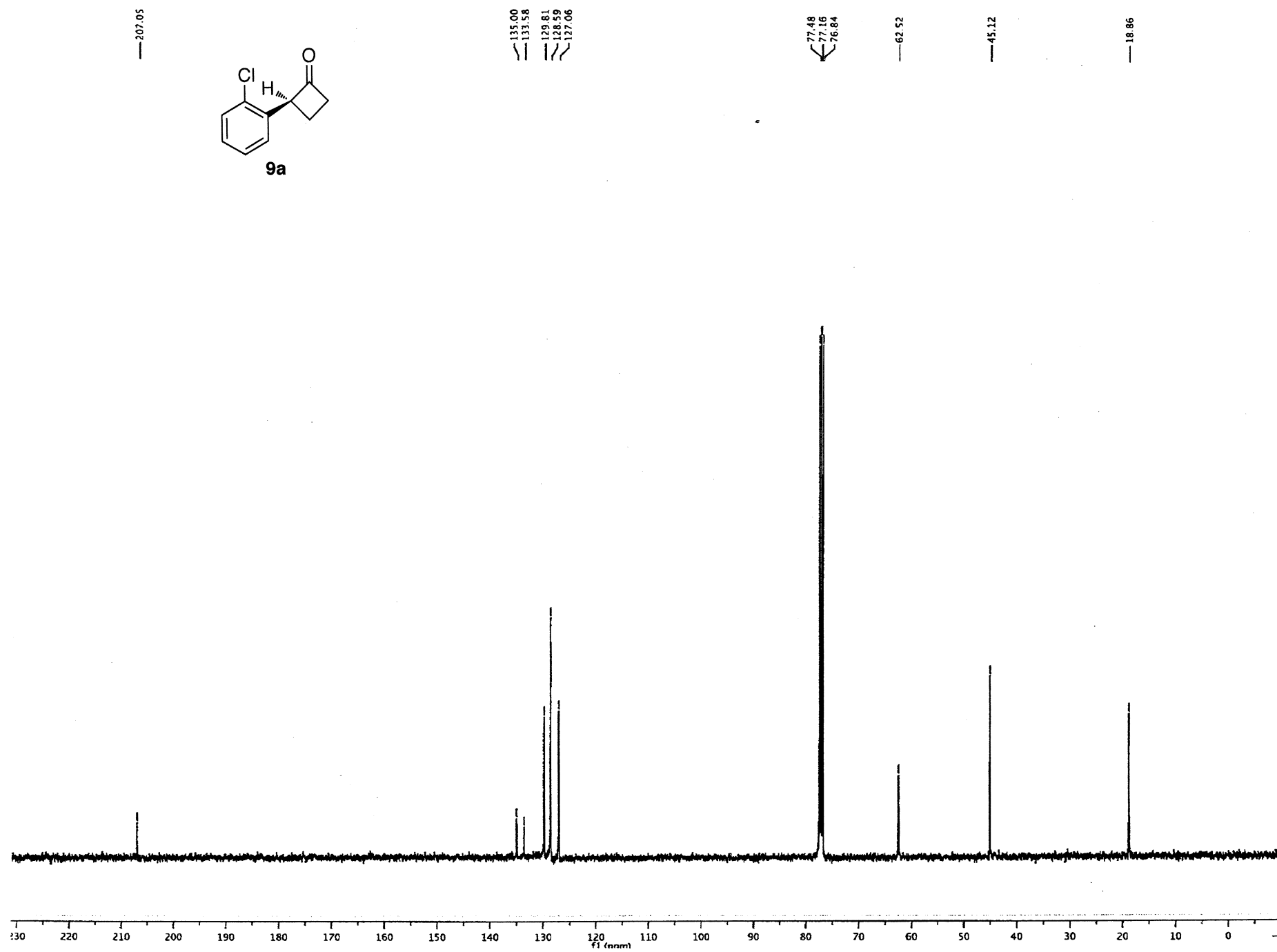
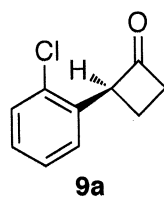


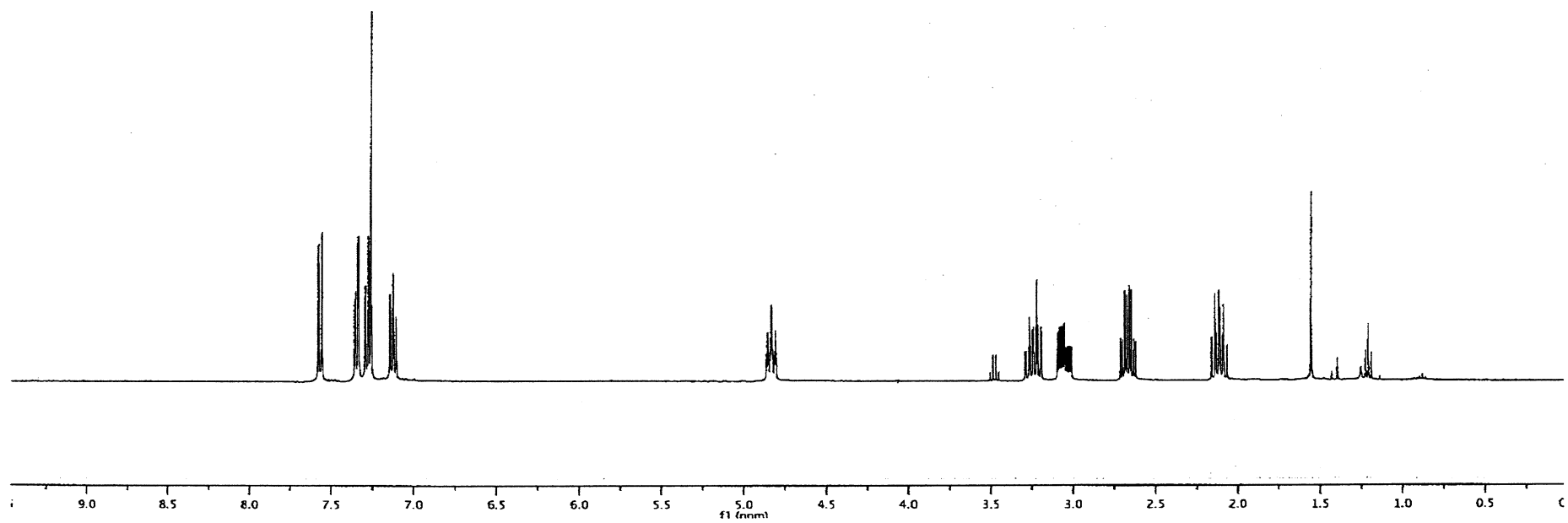
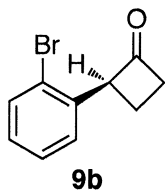




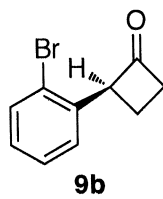








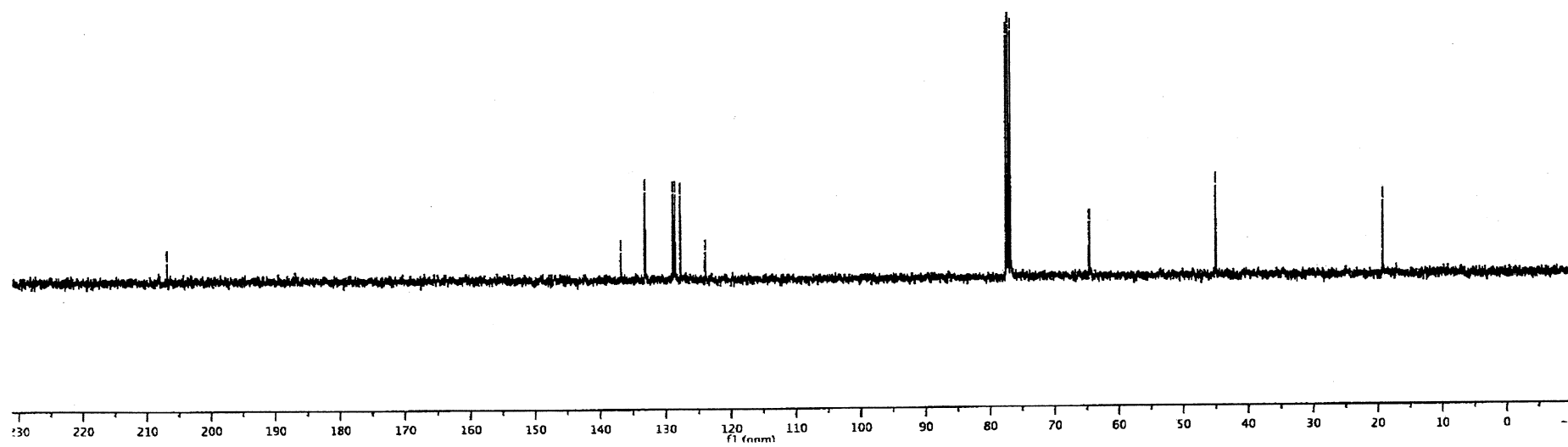
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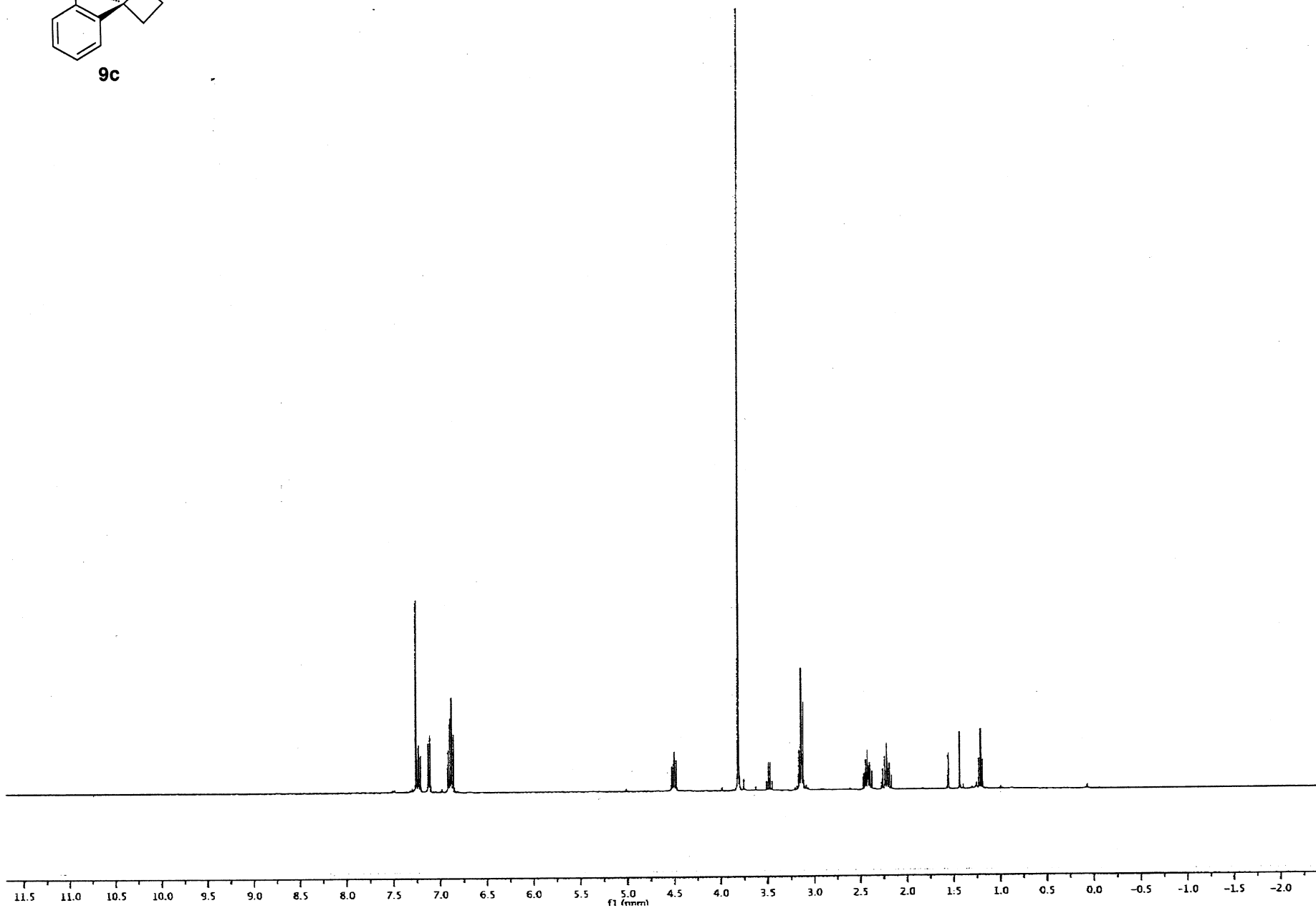
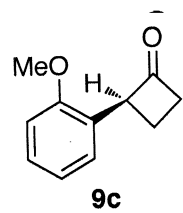
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76.84

64.57

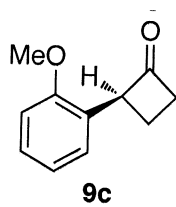
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19.25





— 209.17



— 157.40

— 129.25  
— 128.65

— 126.24

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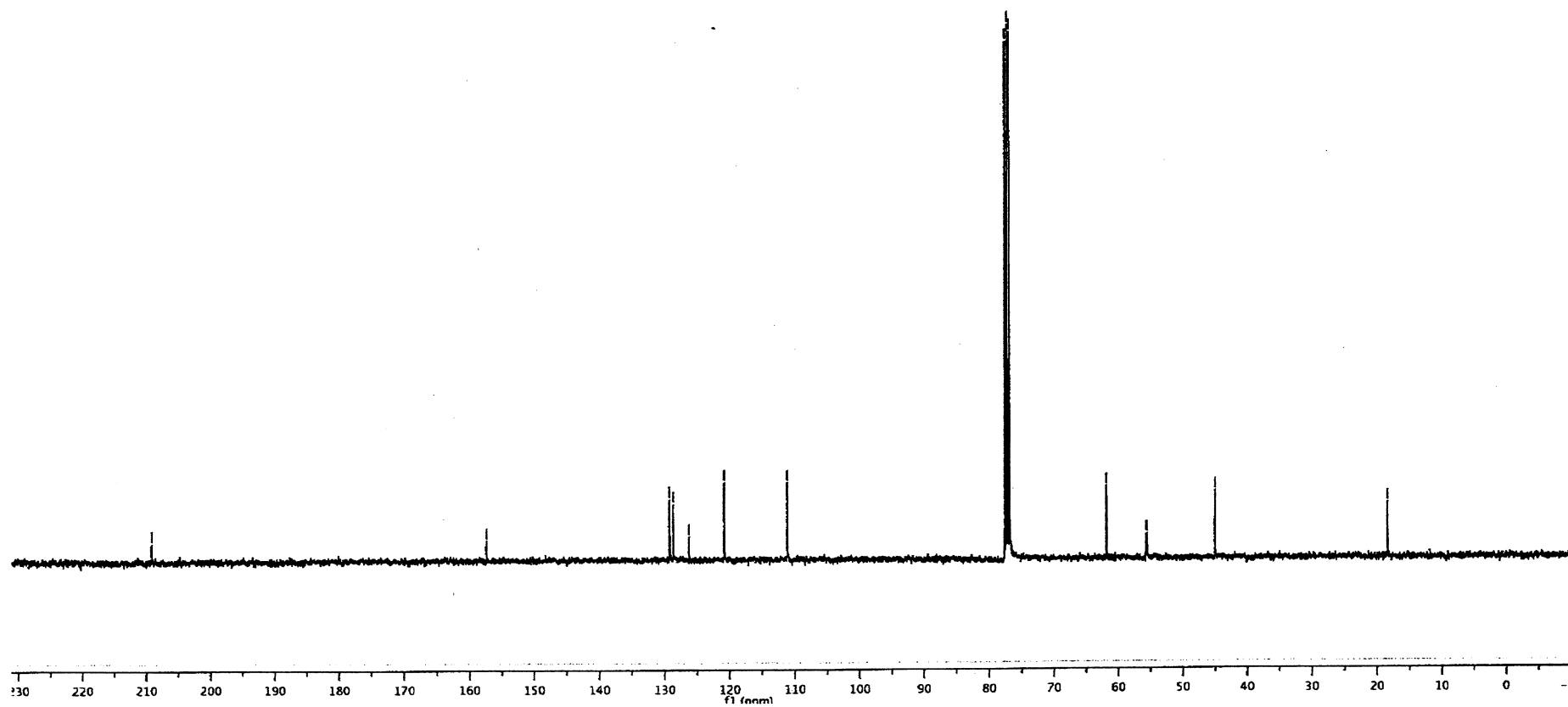
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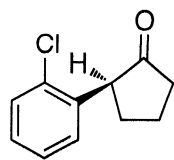
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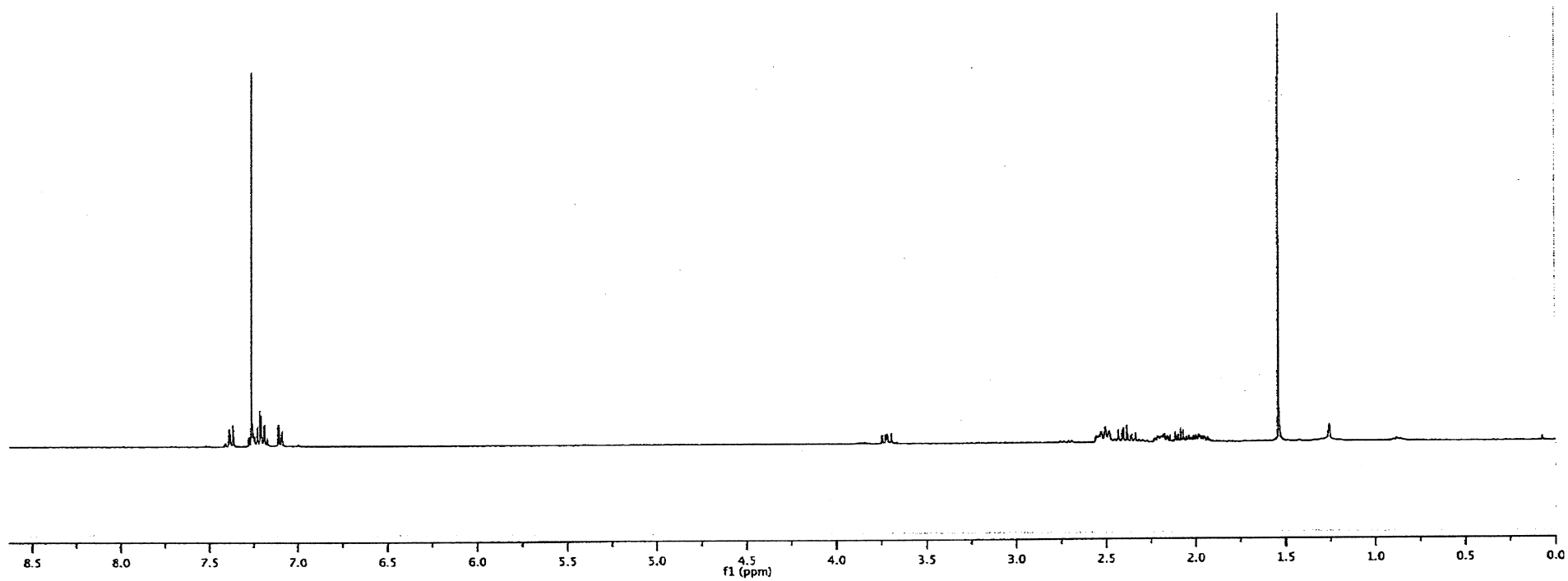
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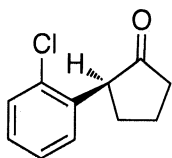




10a



—217.61



10a

—138.99

—133.29

—127.97

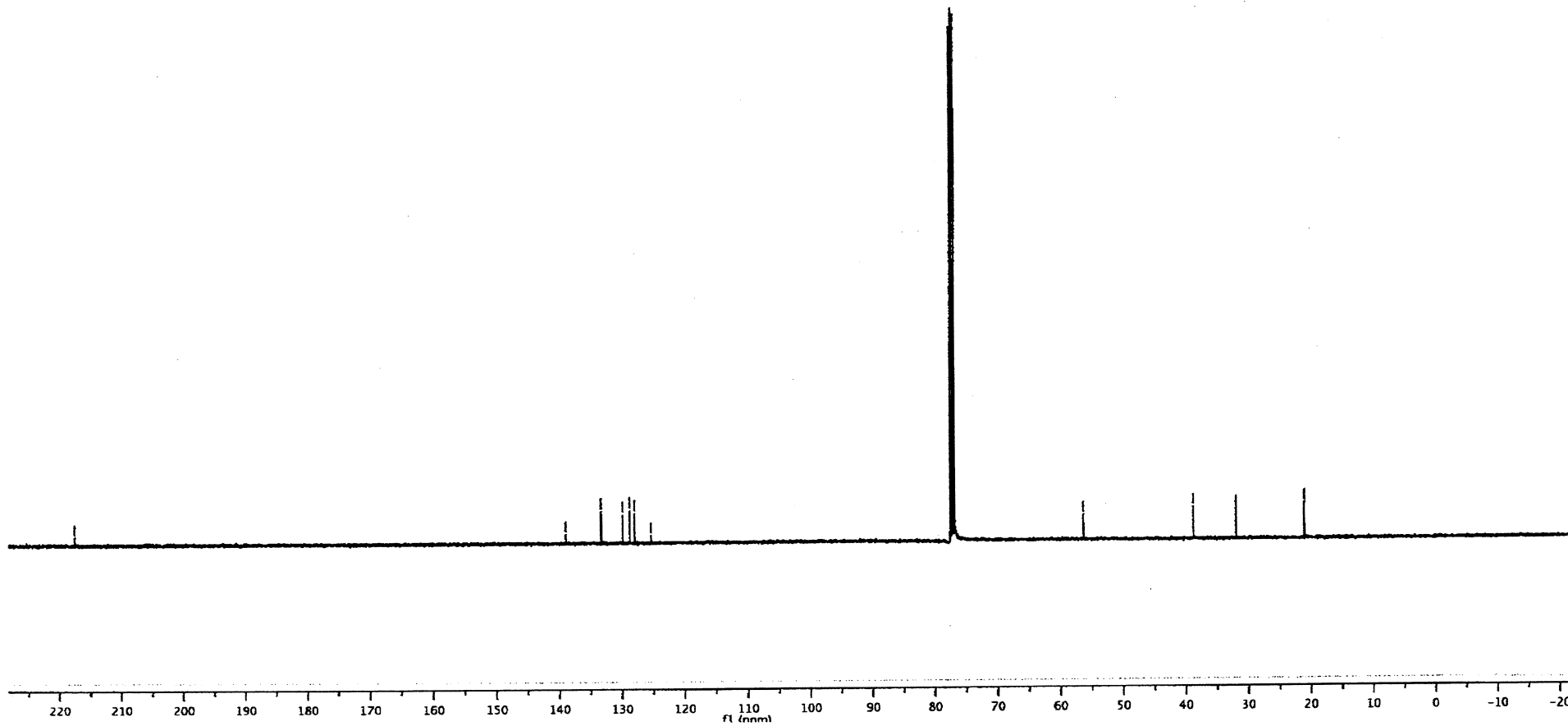
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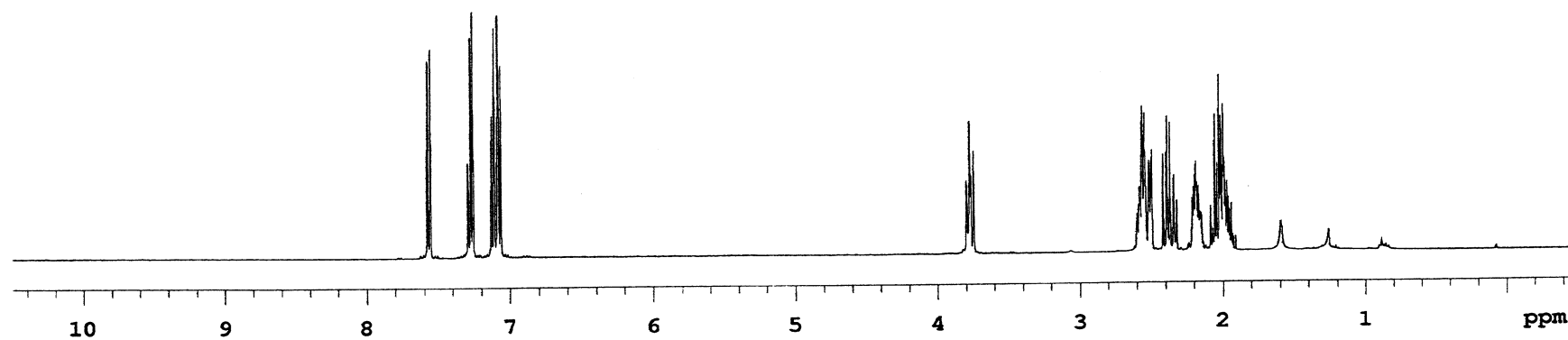
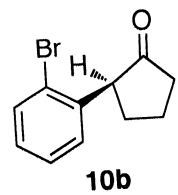
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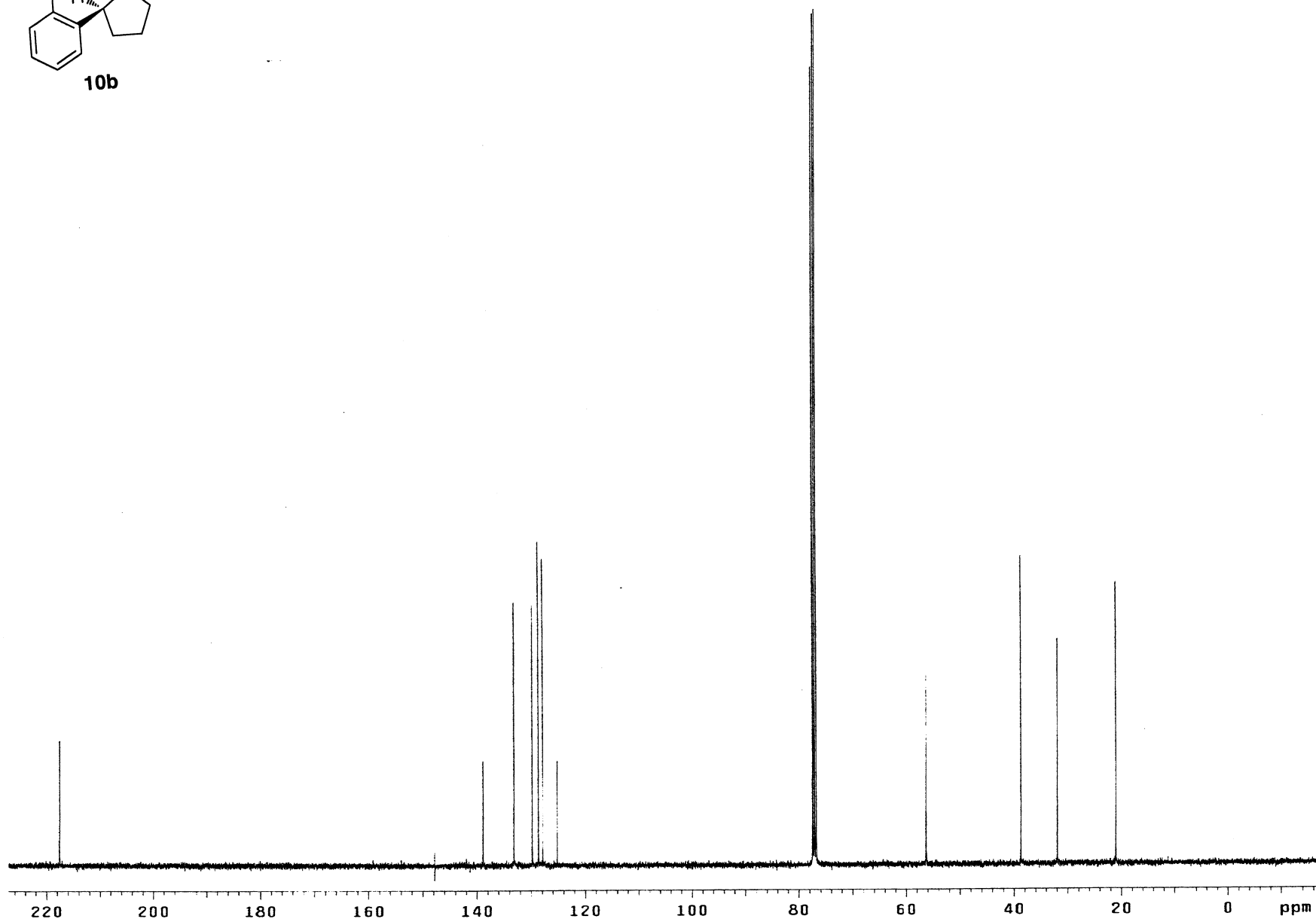
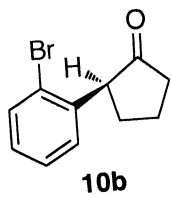
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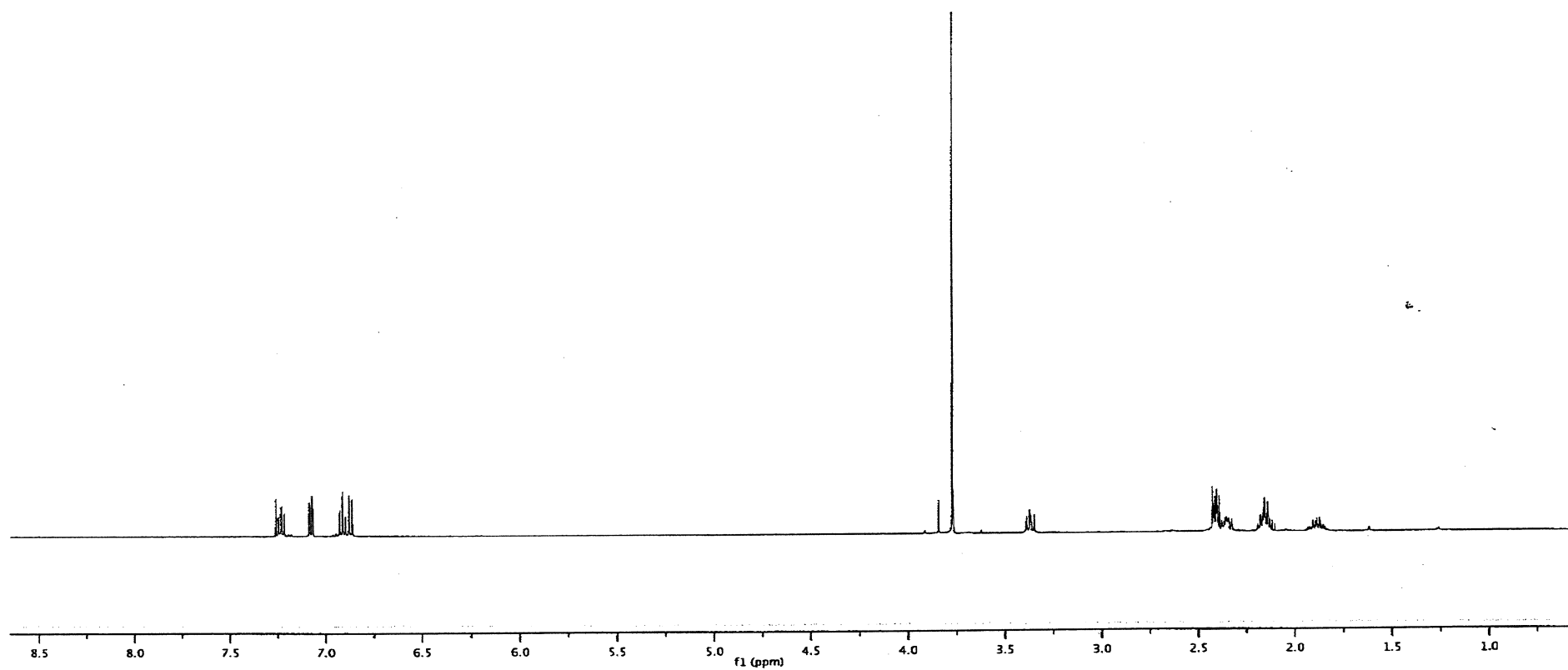
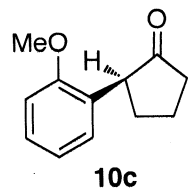
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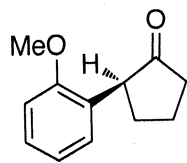








— 219.31



10c

— 156.96

— 130.64

— 128.48

— 128.42

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— 111.33

— 77.48

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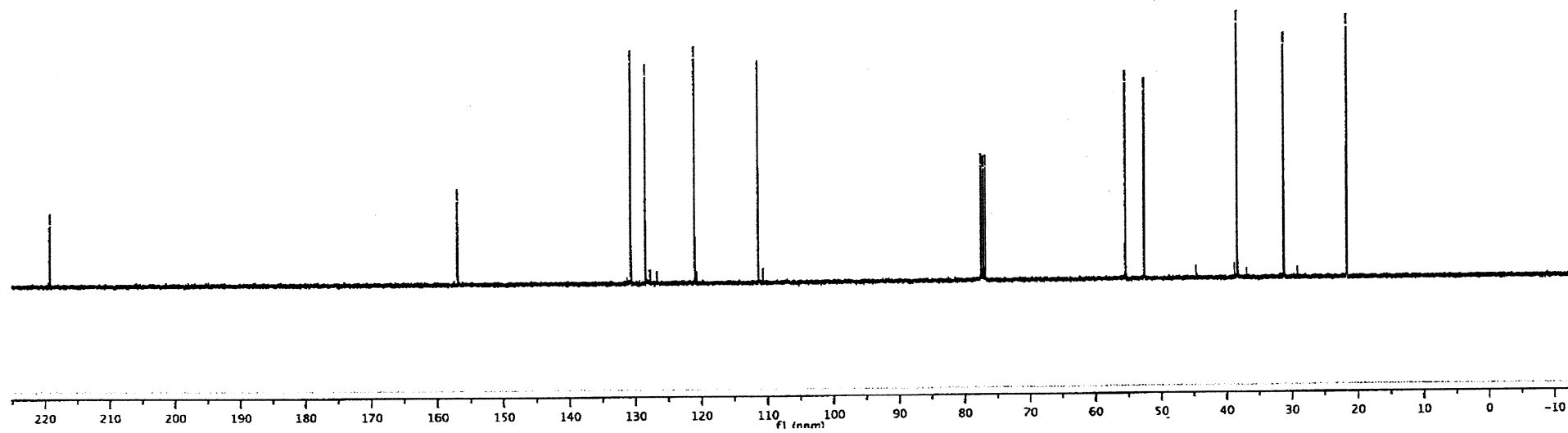
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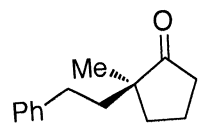
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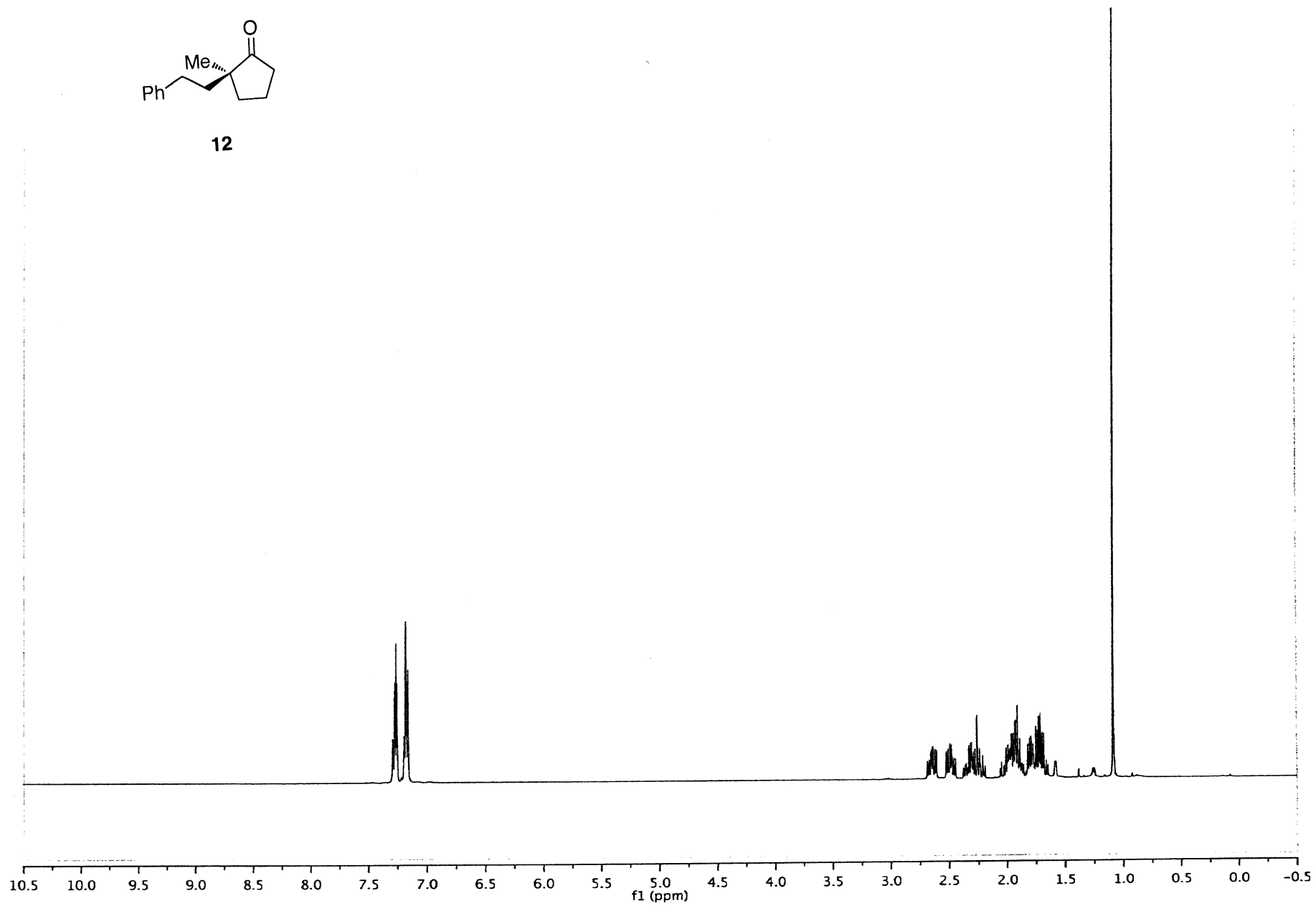
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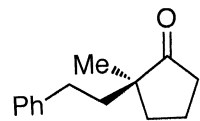
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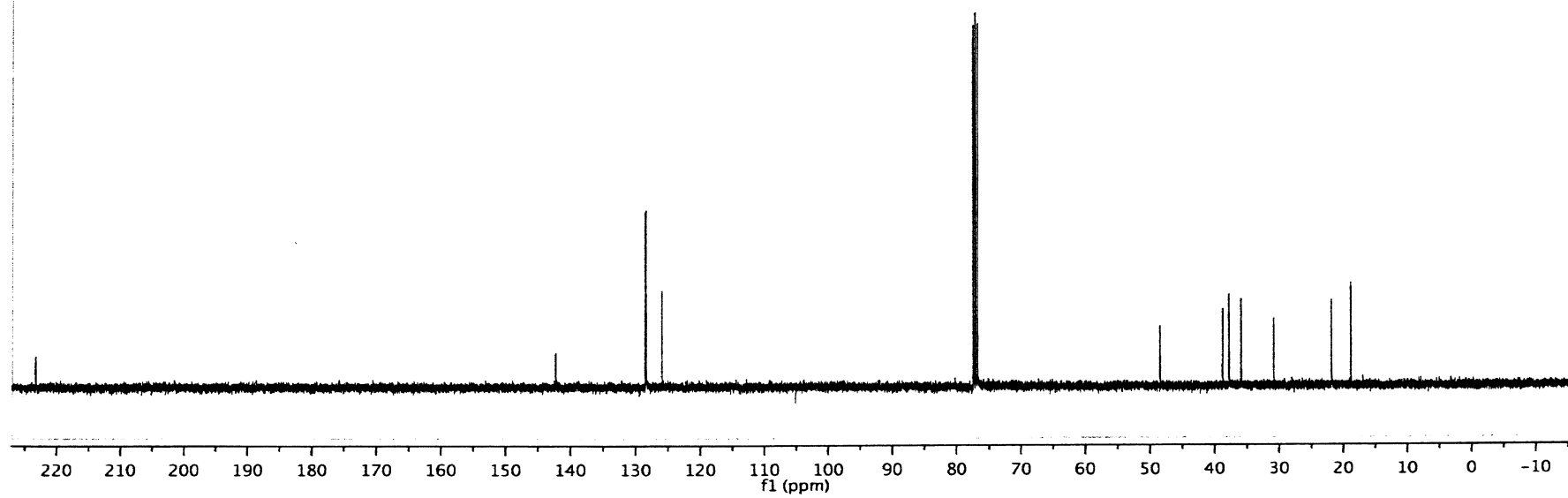


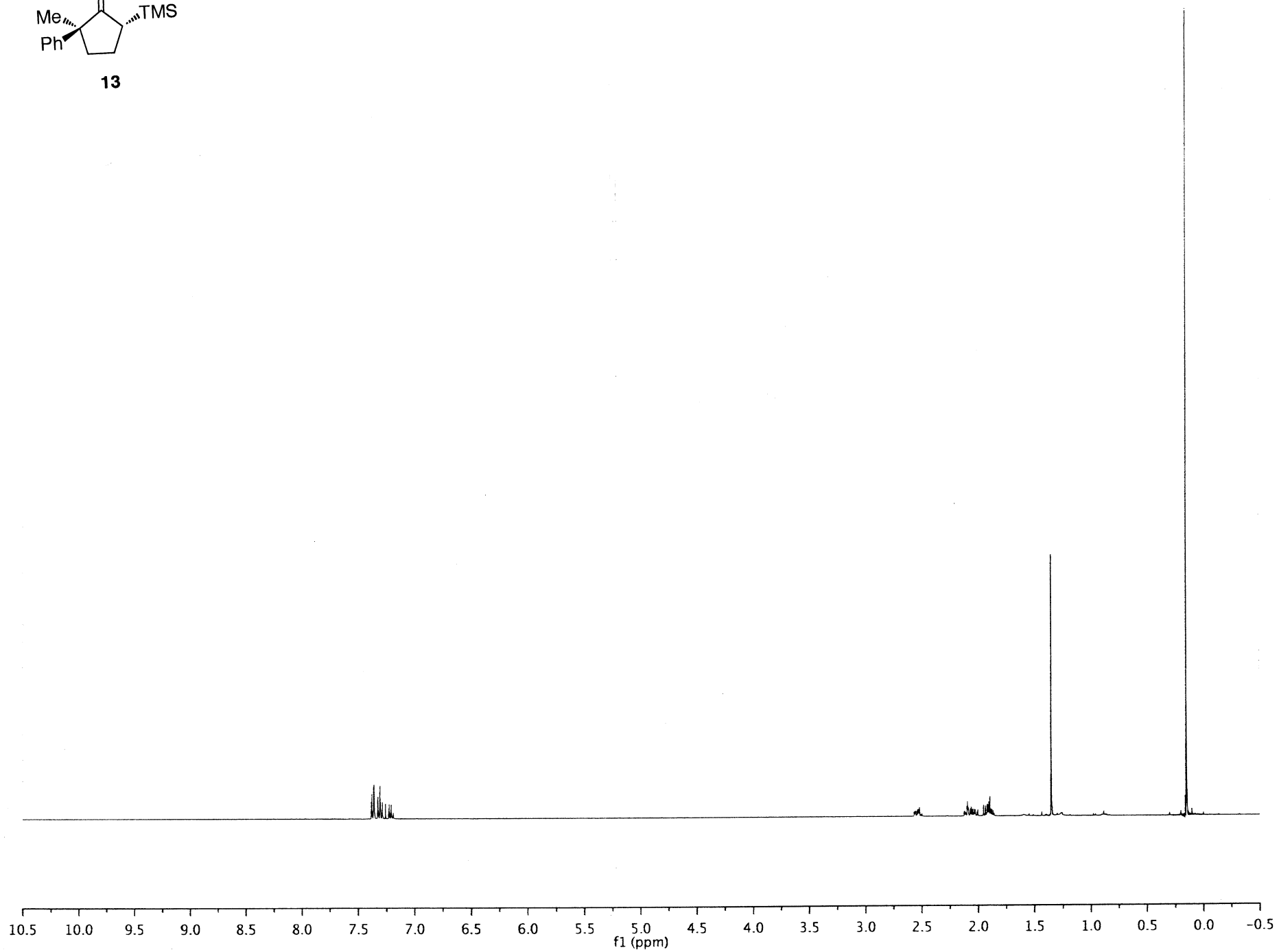
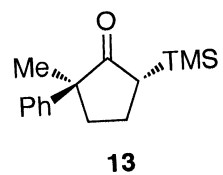
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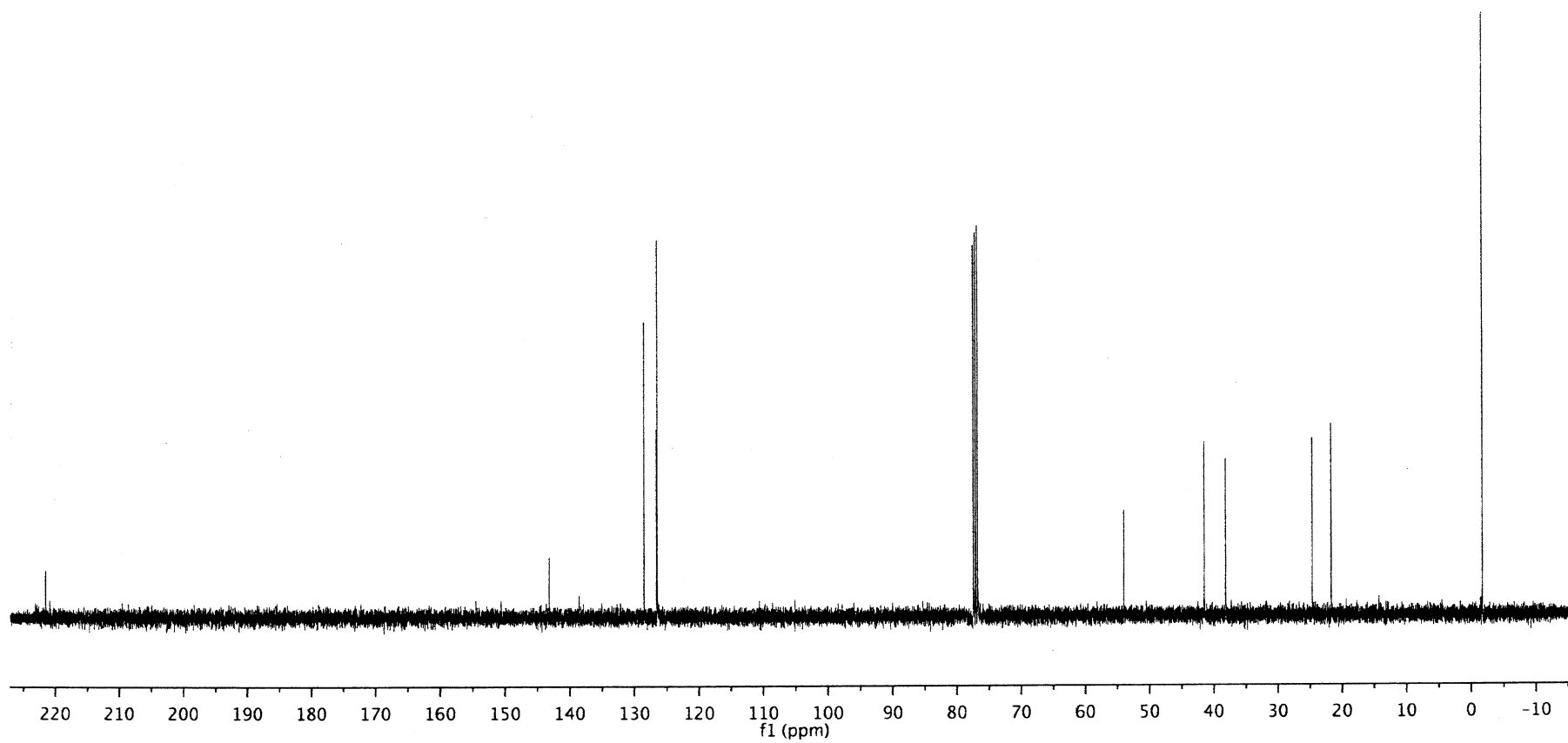
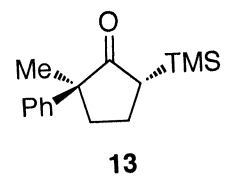


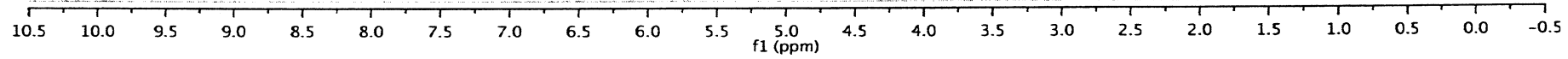
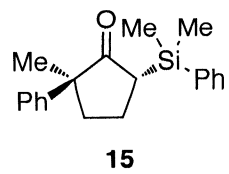


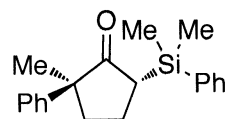
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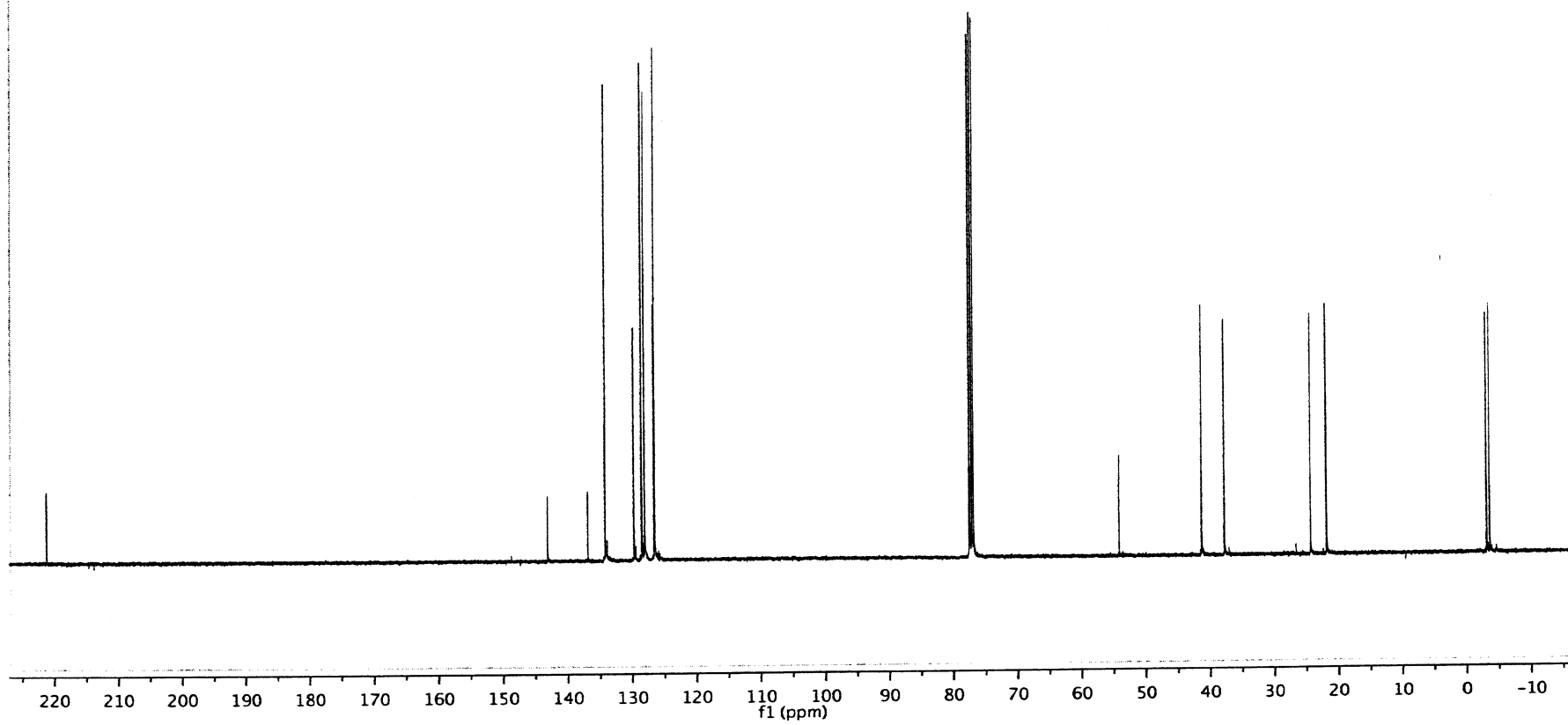


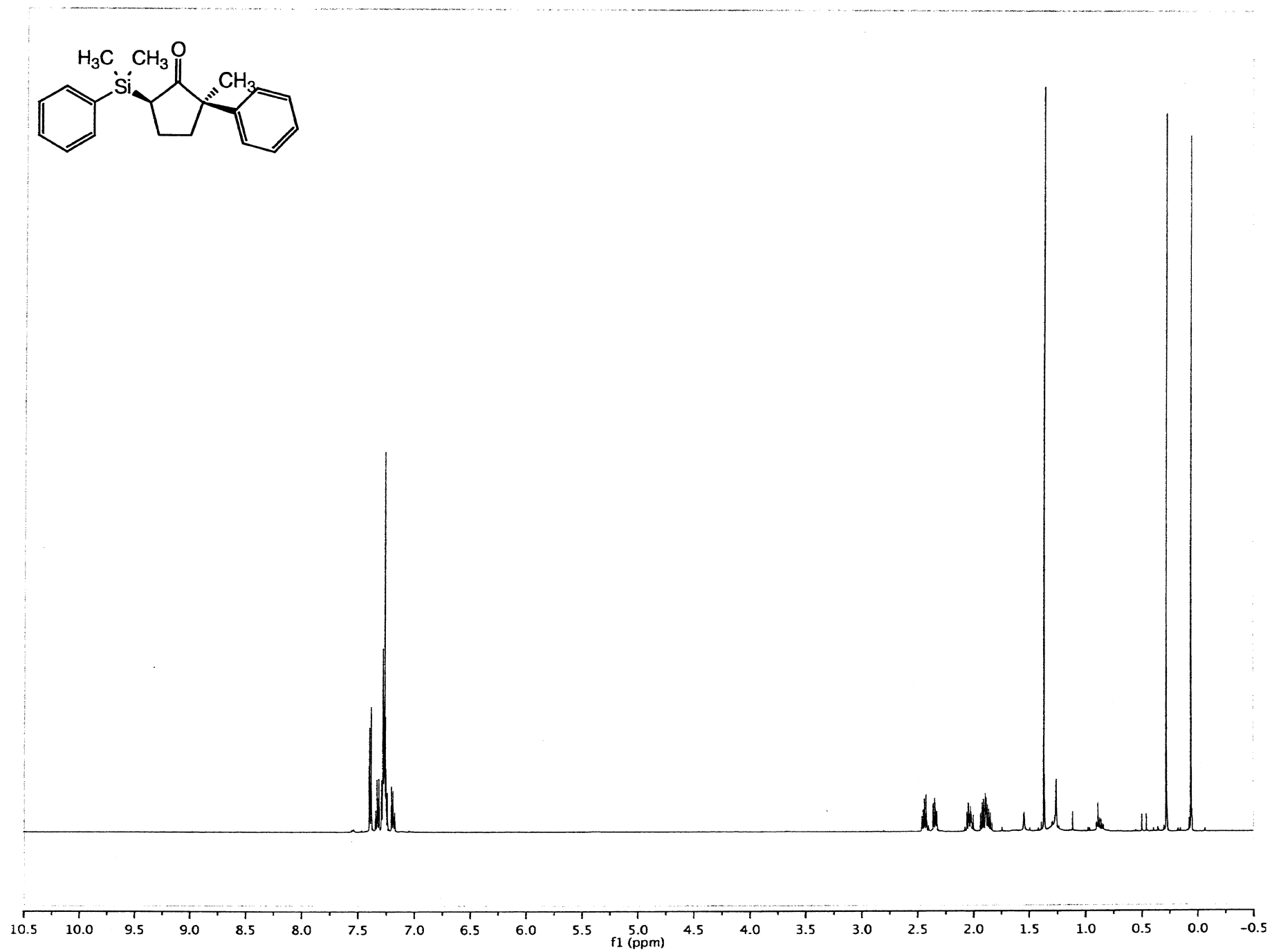


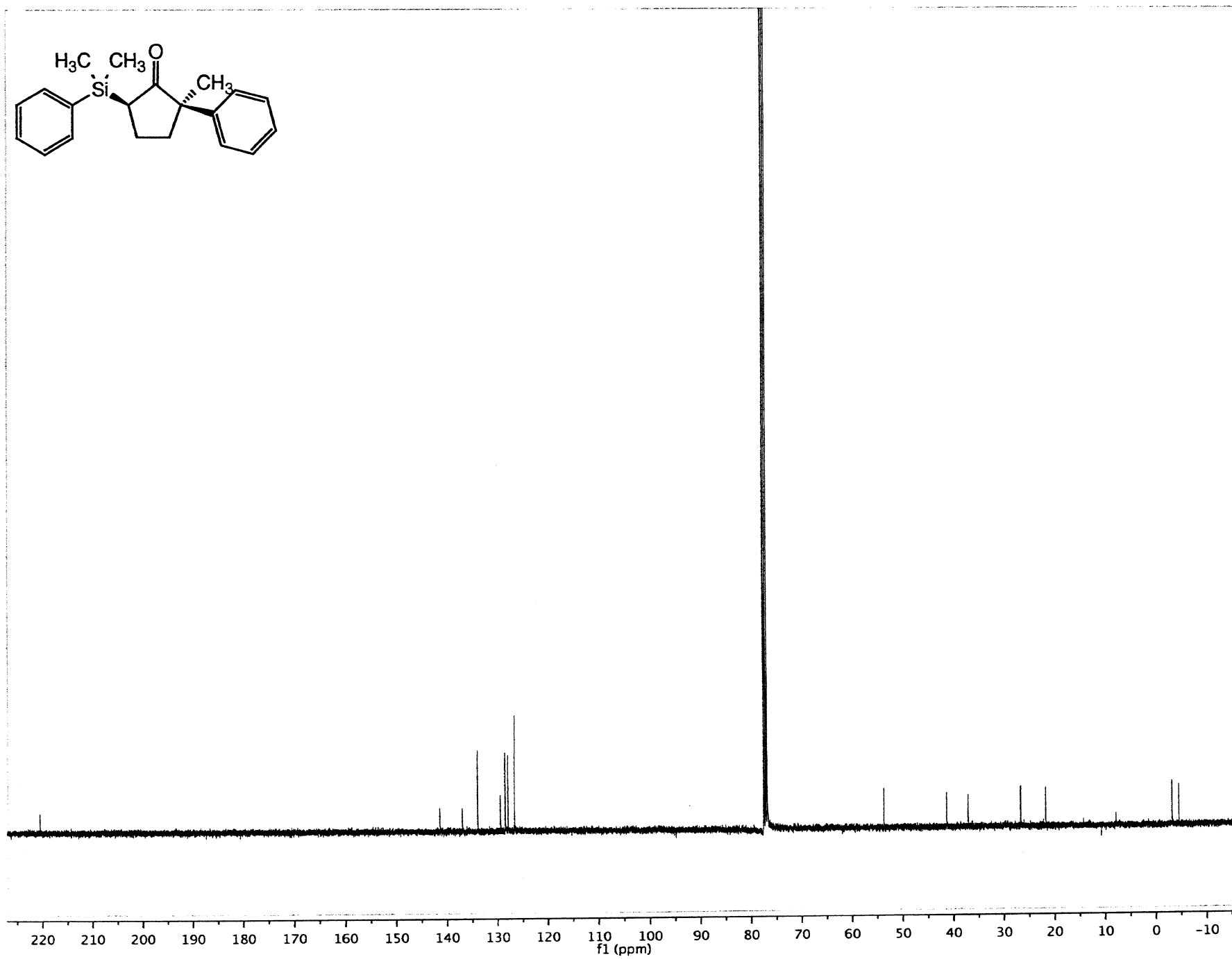


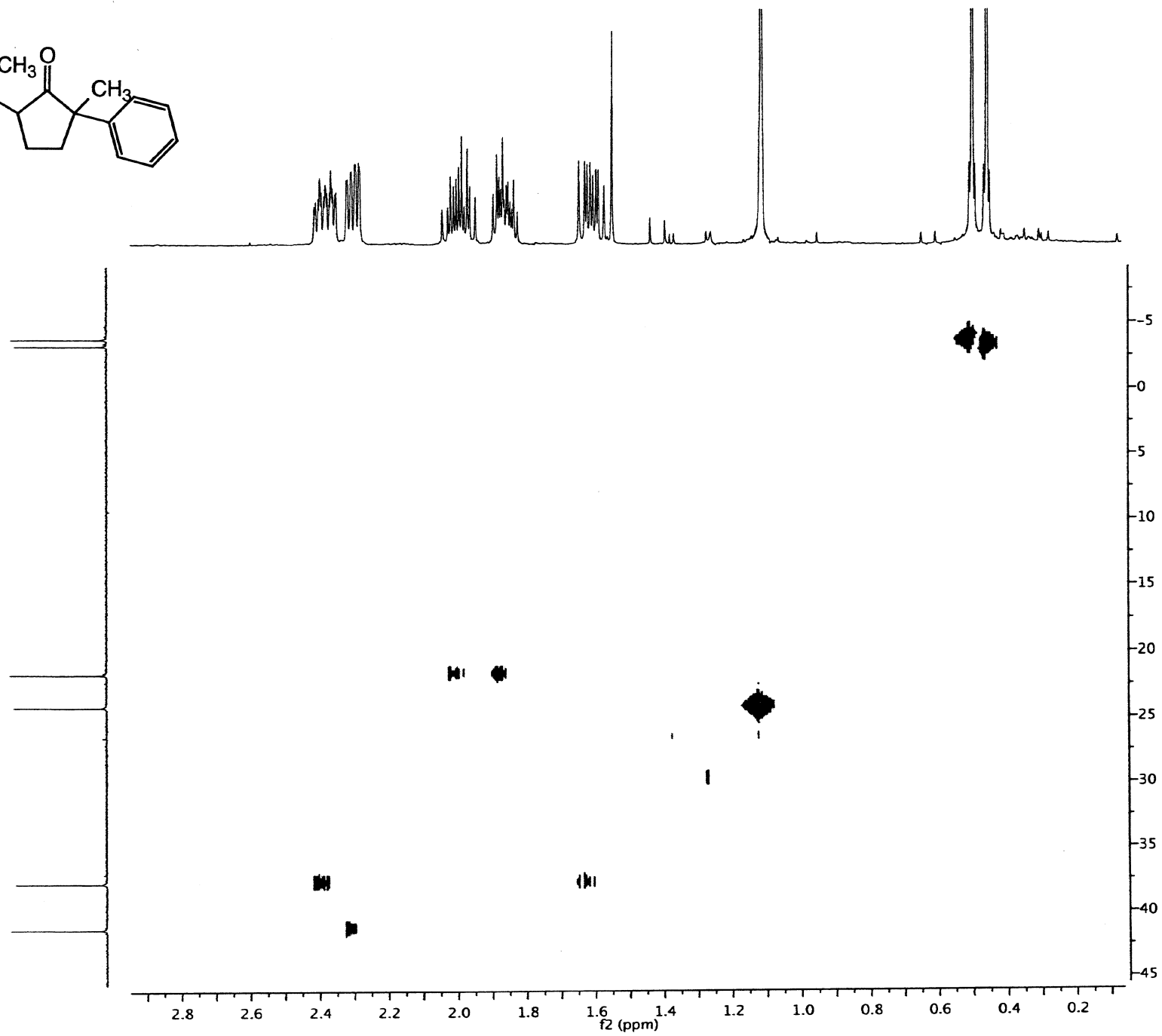
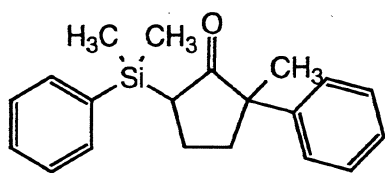


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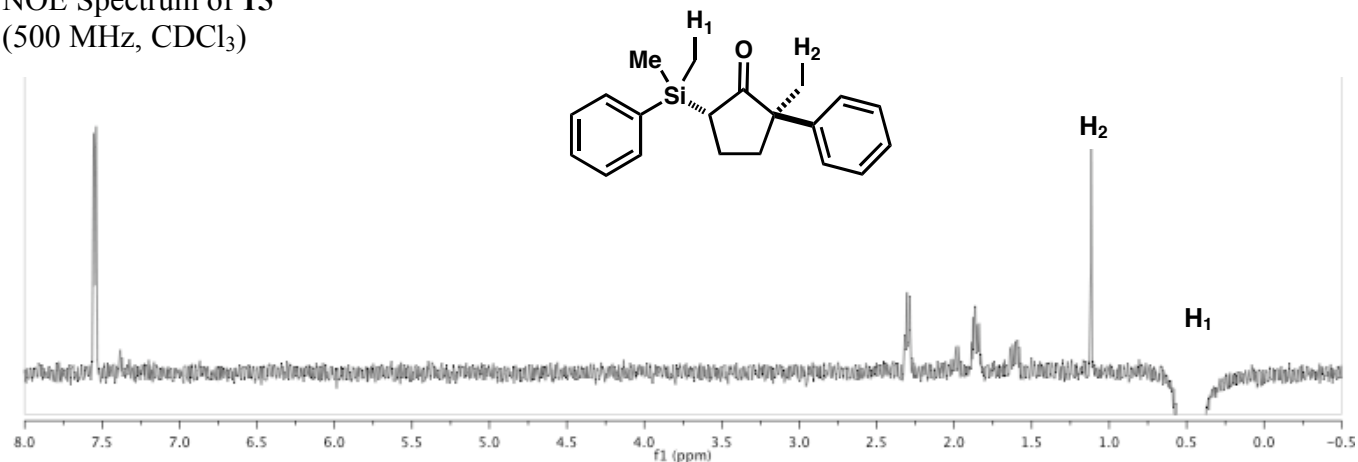






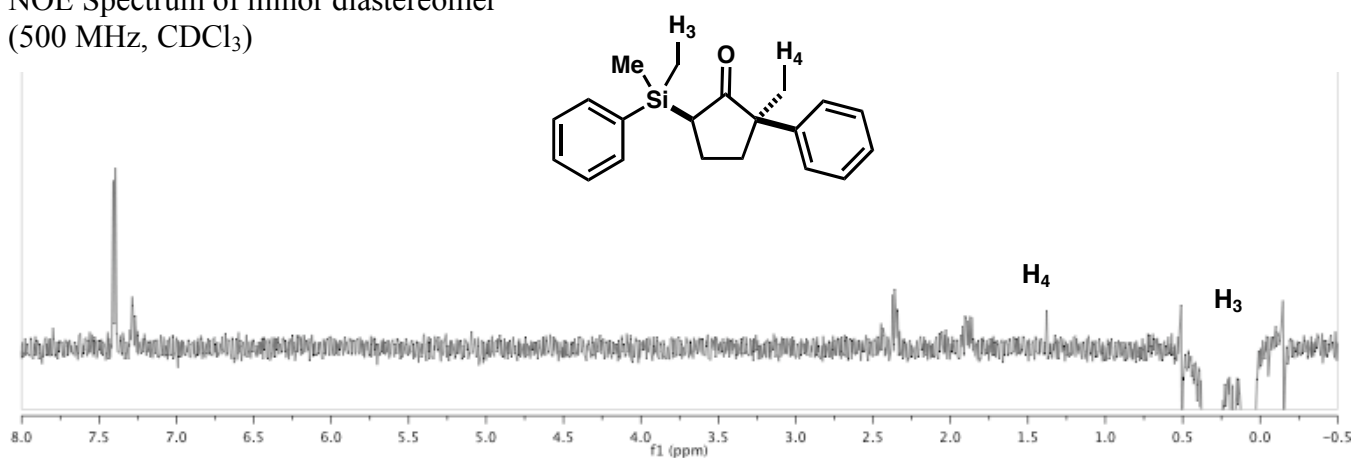


NOE Spectrum of **15**  
(500 MHz, CDCl<sub>3</sub>)



Irradiation of H<sub>1</sub> in **15** resulted in a strong NOE to H<sub>2</sub>.

NOE Spectrum of minor diastereomer  
(500 MHz, CDCl<sub>3</sub>)



Irradiation of H<sub>3</sub> shows a very weak NOE to H<sub>4</sub>.

