Synthesis of the Multisubstituted Halogenated Olefins via Cross-Coupling of Dihaloalkenes with Alkylzinc Bromides

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SUPPORTING INFORMATION

CONTENTS

Experimental Part.

^{1}H (Me_4Si) NMR spectra were determined with solutions in $CDCl_3$ at 400 or 600 MHz, ^{13}C (Me_4Si) at 100.6 MHz and ^{19}F (CCl_3F) at 376.4 MHz. Mass spectra (MS) were obtained by atmospheric pressure chemical ionization (APCI) technique and HRMS using AP-ESI mode unless otherwise noted. Reagent grade chemicals were used and solvents were dried by reflux over and distillation from CaH_2 (except THF//Na/benzophenone) under an argon atmosphere. Selectfluor™ fluorinating reagent (>95% active [F^+]) and alkylzinc bromide reagents were purchased from Aldrich. TLC was performed on Merck kieselgel 60-F_{254} and products were detected with 254 nm light or by development of color with I_2. Merck kieselgel 60 (230-400 mesh) was used for column chromatography. Purity and identity of the products (crude and/or purified) were also established using a GC/MS (EI) system with a mass selective detector [capillary column (30 m × 0.25 mm × 25 μm)].

Diethyl fluoro(phenylsulfonyl)methylphosphonate. *Step a*: *Oxidation***.** A solution of oxone (20.1 g, 32.7 mmol, 50% reagent) in deionized-H_2O (150 mL) was added slowly to diethyl (phenylthiomethyl)phosphonate (2.00 g, 7.9 mmol) dissolved in MeOH (40 mL) at 0 ^{0}C. A white precipitate was formed immediately and the heterogeneous reaction was left stirring at ambient temperature for 4 h. The volatiles were evaporated and the residue was partitioned (H_2O/$CHCl_3$). Organic layer was separated and evaporated to give diethyl (phenylsulfonyl)methylphosphonate (2.10 g, 92%). *Step b: Fluorination.* LHMDS (1.0 M/THF, 9.16 mL, 9.16 mmol) was added dropwise to a stirred solution of diethyl (phenylsulfonyl)methylphosphonate (2.10 g, 7.32 mmol) in dried THF (25 mL) under N_2 at –78 ^{0}C. After 30 min Selectfluor (3.90 g, 11.0 mmol) was added and the heterogeneous reaction mixture was stirred for 5 min. DMF (15 mL) was added and the resulting yellow solution was allowed to warm to 0 ^{0}C and stirring was continued for 3 h. $CHCl_3$ (10 mL) and saturated NH_4Cl/H_2O (10 mL) were added and the volatiles were evaporated. The residue was partitioned ($NaHCO_3$/H_2O//$CHCl_3$) and the organic layer was washed (brine), dried (Na_2SO_4), evaporated and chromatographed (90:10 EtOAc/hexanes) to give diethyl fluoro(phenylsulfonyl)methylphosphonate[16] (1.9 g, 85%).

(*E/Z*)-1-Fluoro-2-phenyl-1-(phenylsulfonyl)ethene (2a). Procedure A. LHMDS (1.0 M/THF, 2.0 mL, 2.0 mmol) was added dropwise to a stirred solution of diethyl fluoro(phenylsulfonyl)methylphosphonate (0.50 g, 1.61 mmol) in dried THF (8 mL) under N_2 at –78 ^{0}C. After 30 min, **1a** (0.18 mL, 0.19 g, 1.77 mmol) was added and the resulting yellow solution was allowed to warm to -30 ^{0}C over 1.5 h. Saturated NH_4Cl/H_2O (~1 mL) was added, volatiles were evaporated and the residue was partitioned ($NaHCO_3$/H_2O//$CHCl_3$). The organic layer was washed (brine), dried (Na_2SO_4), evaporated and chromatographed ($CHCl_3$) to give **2a**[9b] (*E/Z,* 95:5; 0.36 g, 85%). Crystallization of the crude product (without chromatography) from MeOH also afforded **2a** (*E/Z*, 95:5).

(*E/Z*)-1-Fluoro-4-(phenylsulfonyl)-1-butene (2b). Subjection of **1b** (0.23 mL, 0.24 g, 1.77 mmol) to procedure A gave **2b**[11] (*E/Z*, 68:32; 0.42 g, 90%).

(*E/Z*)-1-Fluoro-3-benzyloxy-1-(phenylsulfonyl)-1-propene (2c). Subjection of **1c** (0.1 mL, 0.10 g, 0.71 mmol) to procedure A, gave **2c** (*E/Z*, 63:37; 0.18 g, 92%): ^{1}H NMR δ 4.24-4.28 (m, 1.26H, *E*), 4.54 (s, 1.26H, *E*), 4.60 (s, 0.74H, *Z*), 4.68-4.73 (m, 0.74H, *Z*), 6.07 (dt, *J* = 21.9, 4.9 Hz, 0.37H, *Z*), 6.46 (dt, *J* = 34.1, 5.0 Hz, 0.63H, *E*), 7.30-7.45 (m, 5H), 7.58 (t, *J* = 7.5 Hz, 2H), 7.76 (d, *J* = 7.4 Hz, 2H), 7.95 (t, *J* = 7.8 Hz, 1H); ^{13}C NMR δ 62.8 (d, $^3J_{C\text{-}F}$ = 3.1 Hz, *Z*), 63.4 (d, $^3J_{C\text{-}F}$ = 6.1 Hz, *E*), 73.3, 73.7, 115.3 (d, $^2J_{C\text{-}F}$ = 4.9 Hz, *E*), 118.3 (d, $^2J_{C\text{-}F}$ = 12.9 Hz, *Z*), 128.3, 128.4, 128.5, 128.8, 128.9, 128.9, 129.2, 129.9, 135.1, 135.2, 137.4, 137.7, 137.9, 138.1, 153.0 (d, $^1J_{C\text{-}F}$ = 292.7 Hz, *Z*), 155.4 (d, $^1J_{C\text{-}F}$ = 299.7 Hz, *E*); ^{19}F NMR δ -114.91 (d, *J* = 22.6 Hz, 0.37F, *Z*), -123.42 (d, *J* = 33.9 Hz, 0.63F, *E*); GC-MS *m/z* 306 [2%, M^+; t_R = 25.27 min (*Z*) and 25.86 min (*E*)]. HRMS Calcd for $C_{16}H_{15}FO_3S$ ($M+H^+$): 307.0804; Found: 307.0801.

(*E/Z*)-1-Fluoro-2-phenyl-1-(phenylsulfonyl)-1-propene (2d). Subjection of **1d** (0.21 mL, 0.21 g, 1.77 mmol) to procedure A gave **2d**[9b] (*E/Z*, 42:58; 0.37 g, 90%). Column chromatography with slow elution (hexane/EtOAc, 85:15) gave fractions enriched in each isomer.

(*E/Z*)-1-Fluoro-2-phenyl-1-(tributyltin)ethene (3a). Procedure B. Argon was bubbled through a solution of **2a** (*E/Z,* 95:5; 490 mg, 1.87 mmol) in anhydrous benzene (10 mL) for 15 min. Bu_3SnH (0.5 mL, 544 mg, 1.87 mmol) and AIBN (76.7 mg, 0.46 mmol) were added and degassing of oxygen was continued for another 10 min. The solution was then heated (85 ^{0}C, oil bath) for 2 h. Additional AIBN (38 mg, 0.23 mmol) and Bu_3SnH (1.87 mmol, 0.5 mL) in degassed benzene (2 mL) were then injected through a septum via a precision syringe pump or periodically by manual injection over a 1 h period and heating was continued for a total of 4 h. The volatiles were evaporated and the residue was chromatographed (hexane) to give **3a**[9b] (*E/Z*, 95:5; 740 mg, 96%).

(*E/Z*)-1-Fluoro-4-phenyl-1-(tributyltin)-1-butene (3b). Treatment of **2b** (*E/Z*, 68:32; 690 mg, 2.37 mmol) with Bu_3SnH (0.636 mL, 689 mg, 2.37 mmol) and AIBN (97 mg, 0.59 mmol) by procedure B gave **3b**[11] (*E/Z*, 78:22; 976 mg, 93%): ^{19}F NMR δ -99.33 (d, *J* = 37.6 Hz, 84% of 0.22F, *Z*), (dd, $J_{Sn\text{-}F}$ = 259.7, 37.6 Hz, 16% of 0.22F, *Z*), -102.90 (d, *J* = 52.7 Hz, 84% of 0.78F, *E*), (dd, $J_{Sn\text{-}F}$ = 248.4, 52.7 Hz, 16% of 0.78F, *E*).

Note: Careful separation on column chromatography (hexane) gave pure isomer **3b**(*E*) (792 mg, 76%) followed by **3b** (*E/Z*, 15:85; 184 mg, 17%).

***(E/Z)*-1-Fluoro-3-benzyloxy-1-(tributyltin)-1-propene (3c).** Treatment of **2c** (*E/Z*, 63:37; 252 mg, 0.87 mmol) with Bu_3SnH (0.23 mL, 252 mg, 0.87 mmol) and AIBN (71 mg, 0.43 mmol) by procedure B gave **3c** (*E/Z*, 77:23; 352 mg, 92%): ^{1}H NMR δ 0.90-0.97 (m, 9H), 1.00-1.06 (m, 6H), 1.30-1.41 (m, 6H), 1.50-1.61 (m, 6H, Bu), 3.93 ("d", *J* = 7.5 Hz, 0.46H, *Z*), 4.25 ("d", *J* = 6.6 Hz, 1.54H, *E*), 4.50 (s, 2H, *E/Z*), 5.12 (dt, *J* = 53.5 Hz, 6.8 Hz, 0.77H, *E*), 6.05 (dt, *J* = 39.5, 7.5 Hz, 0.23H, *Z*), 7.30-7.40 (m, 5, Ph); ^{19}F NMR δ -93.03 (d, *J* = 35.4 Hz, 84% of 0.23F, *Z*), (dd, $J_{Sn\text{-}F}$ = 240.9, 35.4 Hz, 16% of 0.23F, *Z*), -98.25

(d, J = 53.5 Hz, 84% of 0.77F, *E*), (dd, $J_{Sn\text{-}F}$ = 233.4, 53.5 Hz, 16% of 0.77F, *E*); GC-MS *m/z* 399 [18%, M^+-Bu [^{120}Sn]; t_R = 25.59 min (*Z*) and 26.18 min (*E*)]. HRMS Calcd for $C_{22}H_{37}FO^{120}Sn$ ($M+Na^+$): 479.1748; Found: 479.1747.

(*E/Z*)-1-Fluoro-2-phenyl-1-(tributyltin)-1-propene (3d). Treatment of **2d** (*E/Z*, 42:58; 380 mg, 1.38 mmol) with Bu_3SnH (0.37 mL, 400 mg, 1.38 mmol) and AIBN (56 mg, 0.34 mmol) by procedure B gave **3d**[9b] (*E/Z*, 45:55; 555 mg, 95%).

(*E/Z*)-1-Fluoro-1-iodo-2-phenylethene (4a). Procedure C. A solution of NIS (273 mg, 1.22 mmol) in CH_2Cl_2 (5 mL) was added to **3a** (*E/Z*, 95:5; 400 mg, 0.97 mmol) dissolved in CH_2Cl_2 (5 mL) at -20 ^{0}C. The reaction mixture was allowed to warm to 0 ^{0}C over 30 min and $NaHSO_3$ (~0.5 mL) was added to decolorize the reaction mixture. Volatiles were evaporated and the residue was partitioned ($NaHCO_3/H_2O//CH_2Cl_2$). The organic layer was washed (brine), dried (Na_2SO_4), evaporated and chromatographed (hexane → 15% EtOAc/hexane) to give **4a**[17] (*E/Z*, 95:5; 229 mg, 95%): ^{19}F NMR δ -60.02 (d, J = 18.4 Hz, 0.05F, *Z*), -62.90 (d, J = 36.9 Hz, 0.95F, *E*).

(*E/Z*)-1-Fluoro-1-iodo-4-phenyl-1-butene (4b). Treatment of **3b** (*E/Z*, 78:22; 380 mg, 0.87 mmol) with NIS (0.25 g, 1.10 mmol) by procedure C gave **4b**[17] (*E/Z*, 78:22; 221 mg, 94%): ^{19}F NMR δ -66.26 (d, J = 16.9 Hz, 0.22F, *Z*), -70.21 (d, J = 34.6 Hz, 0.78F, *E*).

Analogous treatment of **3b**(*E*) (792 mg, 1.8 mmol) with NIS gave **4b**(*E*) (442 mg, 91%).

Treatment of **3b** (*E/Z*, 15:85; 184 mg, 0.41 mmol) with NIS gave **4b** (*E/Z*, 15:85; 102 mg, 92%).

***(E/Z*)-3-Benzyloxy-1-fluoro-1-iodo-1-propene (4c).** Treatment of **3c** (*E/Z*, 77:23; 400 mg, 0.88 mmol) with NIS (246 mg, 1.09 mmol) by procedure C gave **4c** (*E/Z*, 67:33; 236 mg, 0.80 mmol, 92%): ^{1}H NMR δ 3.93 (dd, J = 7.1, 1.9 Hz, 0.66H, *Z*), 4.03 (dd, J = 7.1, 2.9 Hz, 1.34H, *E*), 4.42 (s, 1.34H, *E*), 4.43 (s, 0.66H, *Z*), 5.50 (dt, J = 34.0, 7.1 Hz, 0.67H, *E*), 5.71 (dt, J = 16.1, 7.1 Hz, 0.33H, *Z*), 7.21-7.30 (m, 5H, Ph). ^{13}C NMR δ 63.6 (d, $^3J_{C\text{-}F}$ = 4.8 Hz, *E*), 68.8 (d, $^3J_{C\text{-}F}$ = 7.1 Hz, *Z*), 72.3, 105.5 (d, $^1J_{C\text{-}F}$ = 335.4 Hz, *E*), 112.8 (d, $^1J_{C\text{-}F}$ = 331.2 Hz, *Z*), 115.2 (d, $^2J_{C\text{-}F}$ = 12.4 Hz, *Z*), 120.2 (d, $^2J_{C\text{-}F}$ = 7.5 Hz, *E*), 127.8, 128.5, 137.71, 137.75; ^{19}F NMR δ - 59.92 (dt, J = 16.3, 2.1 Hz, 0.33F, *Z*), -65.18 (dt, J = 33.9, 2.7 Hz, 0.67F, *E*); GC-MS *m/z* 292 [2%, M^+; t_R = 15.09 min (*Z*) and 15.48 min (*E*)]. Anal. Calcd. for $C_{10}H_{10}FIO$ (291.97): C, 41.12; H, 3.45; Found: C, 41.56; H, 3.87.

(*E/Z*)-1-Fluoro-1-iodo-2-phenyl-1-propene (4d). Treatment of **3d** (*E/Z*, 45:55; 450 mg, 1.06 mmol) with NIS (300 mg, 1.32 mmol) by procedure C gave **4d** (*E/Z*, 49:51; 263 mg, 95%): ^{1}H NMR δ 2.15 (d, J = 3.7 Hz, 1.47H, *E*), 2.18 (d, J = 4.6 Hz, 1.53H, *Z*), 7.28-7.45 (m, 5H, Ph); ^{19}F NMR δ - 68.27 Hz (s, 0.49F, *E*), -68.81 (s, 0.51F, *Z*); GC-MS *m/z* 262 [100%, M^+; t_R = 10.96 min (*Z*) and 12.31 min (*E*)]. HRMS Calcd for C_9H_8FI (M^+): 261.9655; Found: 261.9662.

(*E/Z*)-1-Bromo-1-fluoro-2-phenylethene (5a). Treatment of **3a** (*E/Z,* 95:5; 800 mg, 1.95 mmol) with NBS (430 mg, 2.43 mmol) by procedure C (using NBS instead of NIS) gave **5a**[8b,18] (*E/Z*, 93:7; 378 mg, 97%): ^{1}H NMR δ 6.05 (d, J = 32.9 Hz, 0.93H, *E*), 6.72 (d, J = 15.1 Hz, 0.07H, *Z*), 7.20 (t, J = 7.3 Hz,

2H), 7.30 (t, J = 7.8 Hz, 1H), 7.45 (d, J = 7.4 Hz, 2H); ^{19}F NMR δ -65.50 (d, J = 15.1 Hz, 0.07F, *Z*), -69.50 (d, J = 32.7 Hz; 0.93F, *E*).

***(E/Z)*-1-Fluoro-1-bromo-3-benzyloxy-1-propene (5c).** Treatment of **3c** (*E/Z*, 77:23; 250 mg, 0.55 mmol) with NBS (122 mg, 0.68 mmol) by procedure C (using NBS instead of NIS) gave **5c** (*E/Z*, 77:23; 125 mg, 93%): ^{1}H NMR δ 4.08 (dd, J = 7.1, 1.7 Hz, 0.46H, *Z*), 4.12 (dd, J = 7.3, 2.6 Hz, 1.54H, *E*), 4.55 (s, 1.54H, *E*), 4.57 (s, 0.46H, *Z*), 5.35 (dt, J = 30.5, 7.3 Hz, 0.77H, *E*), 5.78 (dt, J = 12.2, 7.1 Hz, 0.23H, *Z*), 7.23-7.28 (m, 5H); ^{13}C NMR δ 63.2 (d, $^3J_{C\text{-}F}$ = 3.0 Hz, *E*), 66.3 (d, $^3J_{C\text{-}F}$ = 6.8 Hz, *Z*), 72.3, 107.4 (d, $^2J_{C\text{-}F}$ = 15.5 Hz, *Z*), 109.9 (d, $^2J_{C\text{-}F}$ = 11.0 Hz, *E*), 127.8, 128.5, 135.0 (d, $^1J_{C\text{-}F}$ = 323.2 Hz, *E*), 138.0 (d, $^1J_{C\text{-}F}$ = 319.8 Hz, *Z*), 137.7, 137.7; ^{19}F NMR δ -66.46 (d, J = 12.4 Hz, 0.23F, *Z*), -70.80 (dt, J = 30.9, 2.3 Hz, 0.77F, *E*); GC-MS *m/z* 245 [2%, M^+; t_R = 13.11 min (*Z*) and 13.43 min (*E*). HRMS Calcd for $C_{10}H_{10}{}^{79}BrFO$ ($M+H^+$): 244.9977; Found: 244.9970.

(*E/Z*)-1-Chloro-1-fluoro-2-phenylethene (6a). Compound **3a** (*E/Z,* 95:5; 50 mg, 0.12 mmol) was dissolved in dried CH_2Cl_2 (5 mL) and the temperature was adjusted to -50 ^{0}C. Chlorine gas was bubbled through the solution over 5 min. until a light yellow solution was obtained and the reaction mixture was allowed to warm to 0 ^{0}C. Volatiles were evaporated and the residue was chromatographed (hexane → 5% EtOAc/hexane) to give **6a**[19] (*E/Z*, 93:7; 13 mg, 70%): ^{1}H NMR δ 5.80 (d, J = 31.0 Hz, 0.93H, *E*), 6.30 (d, J = 12.8 Hz, 0.07H, *Z*), 7.20 (t, J = 7.3 Hz, 2H), 7.30 (t, J = 7.8 Hz, 1H), 7.45 (d, J = 7.3 Hz, 2H); ^{19}F NMR δ -74.0 (d, J = 30.5 Hz, 0.93F, *E*), -71.5 (d, J = 12.8 Hz, 0.07F, *Z*).

Ethyl 5-Fluoro-6-phenyl-5(*Z*)-hexenoate (7a). Procedure D. 4-Ethoxy-4-oxobutylzinc bromide (0.5 M/THF; 0.60 mL, 0.30 mmol) was added *via* syringe to a stirring solution of **4a** (*E/Z*, 95:5; 50 mg, 0.20 mmol) in dried benzene (5 mL) containing $Pd(PPh_3)_4$ (7 mg, 0.006 mmol) under N_2. The resulting mixture was heated at 65 ^{0}C for 5 h. Additional $Pd(PPh_3)_4$ (4.5 mg, 0.004 mmol) and 4-ethoxy-4-oxobutylzinc bromide (0.20 mL, 0.10 mmol) were then added and heating was continued for an extra 5 h. Volatiles were evaporated and the residue was partitioned ($NaHCO_3/H_2O$//EtOAc). The organic layer was washed (brine), dried (Na_2SO_4), evaporated and chromatographed (hexane → 15% EtOAc/hexane) to give **7a**(*Z*) (33 mg, 70%; 74% based on the conversion of the *E* isomer only): ^{1}H NMR δ 1.26 (t, J = 7.1 Hz, 3H), 1.95 (quint, J = 7.3 Hz, 2H), 2.39-2.48 (m, 4H), 4.15 (q, J = 7.1 Hz, 2H), 5.50 (d, J = 39.4 Hz, 1H), 7.15 (t, J = 7.2 Hz, 1H), 7.30 (t, J = 7.4 Hz, 2H), 7.45 (d, J = 7.4 Hz, 2H); ^{13}C NMR δ 14.6, 22.0, 32.7 (d, $^2J_{C\text{-}F}$ = 26.9 Hz), 33.5, 60.82, 106.9 (d, $^2J_{C\text{-}F}$ = 8.5 Hz), 127.2, 128.7, 128.9, 133.9, 160.2 (d, $^1J_{C\text{-}F}$ = 266.7 Hz), 173.5; ^{19}F NMR δ -102.20 (dt, J = 39.8, 19.7 Hz); MS *m/z* 237 (100%, MH^+). Anal. Calcd. for $C_{14}H_{17}FO_2$ (236.12): C, 71.16; H, 7.25; Found: C, 70.80; H, 7.16.

Treatment (2 h) of **4a** (*E/Z*, 95:5; 50 mg, 0.20 mmol) with $PdCl_2$(dppb) (6.0 mg, 0.01 mmol) and 4-ethoxy-4-oxobutylzinc bromide (0.5 M; 0.74 mL, 0.37 mmol) as described in procedure D gave **7a**(*Z*) (44 mg, 93%; 97% based on the conversion of *E* isomer).

Treatment of **5a** (*E/Z*, 93:7; 50 mg, 0.25 mmol) with $Pd(PPh_3)_4$ (5% molar) and 4-ethoxy-4-oxobutylzinc bromide (0.5 M; 0.74 mL, 0.37 mmol) as described in procedure D gave **7a**(*Z*) (41 mg, 70%; 75% based on *E* isomer).

Treatment of **6a** (*E/Z*, 93:7; 120 mg, 0.77 mmol) with $Pd(PPh_3)_4$ (5% molar) and 4-ethoxy-4-oxobutylzinc bromide (0.5 M; 2.30 mL, 1.15 mmol) as described in procedure D gave **7a**(*Z*) (145 mg, 80%; 86% based on *E* isomer).

Ethyl 5-Fluoro-8-phenyl-5(*Z*)-octenoate (7b). Treatment of **4b** (*E/Z*, 78:22; 50 mg, 0.18 mmol) with $Pd(PPh_3)_4$ (10 mg, 0.009 mmol) and 4-ethoxy-4-oxobutylzinc bromide (0.5 M; 0.72 mL, 0.36 mmol) in dried benzene (5 mL) as described in procedure D [24 h; second portions of $Pd(PPh_3)_4$ and 4-ethoxy-4-oxobutylzinc bromide were added after 10 h.] gave **7b**(*Z*) (29 mg, 60%; 78% based on *E* isomer only): ^{1}H NMR δ 1.25 (t, *J* = 7.3 Hz, 3H), 1.79 (quint, *J* = 7.3 Hz, 2H), 2.20 (dt, *J* = 18.2, 7.2 Hz, 2H), 2.28 (t, *J* = 7.5 Hz, 2H), 2.39-2.50 (m, 2H), 2.65 (t, *J* = 7.8 Hz, 2H), 4.13 (q, *J* = 7.1 Hz, 2H), 4.55 (dt, *J* = 37.7, 7.3 Hz, 1H), 7.20 (t, *J* = 7.3 Hz, 1H), 7.30 (t, *J* = 7.9 Hz, 2H), 7.45 (d, *J* = 7.4 Hz, 2H); ^{13}C NMR δ 14.6, 21.9, 25.6 (d, $^3J_{C\text{-}F}$ = 4.7 Hz), 31.6 (d, $^2J_{C\text{-}F}$ =28.2 Hz), 33.5, 36.1, 60.7, 105.3 (d, $^2J_{C\text{-}F}$ = 15.5 Hz), 126.3, 128.7, 128.8, 142.1, 157.9 (d, $^1J_{C\text{-}F}$ = 253.7 Hz), 173.6; ^{19}F NMR δ -109.89 (dt, *J* = 37.6, 17.9 Hz); MS *m/z* 265 (100%, MH^+); GC-MS *m/z* 264 [1%, M^+; t_R = 19.86 min (*Z*)]. HRMS Calcd for $C_{16}H_{21}FO_2$ ($M+Li^+$): 271.1686; Found: 271.1701.

Analogous treatment (12 h) of **4b** (*E*, 15 mg, 0.054 mmol) produced only **7b**(*Z*) (11.9 mg, 88%; 96% based on GC/MS).

Analogous treatment (24 h) of **4b** (*E/Z*, 15:85; 15 mg, 0.054 mmol) showed (GC/MS, ^{19}F NMR) a conversion of the *E* isomer into **7b**(*Z*) (2 mg, 0.007 mmol, 14%) and slow decomposition of **4b**(*Z*) but no formation of **7b**(*E*) was detected.

Analogous treatment (8 h) of **4b** (*E/Z*, 84:16; 25 mg, 0.09 mmol) with $PdCl_2$(dppb) (5% molar) and 4-ethoxy-4-oxobutylzinc bromide (0.5 M; 0.28 mL, 0.14 mmol) gave **7b**(*Z*) (19.5 mg, 82%; 98% based on *E* isomer).

Ethyl 5-Fluoro-6-phenyl-5(*Z*)-heptenoate (7d). Treatment of **4d** (*E/Z*, 49:51; 55 mg, 0.21 mmol) with $Pd(PPh_3)_4$ (5% molar) and 4-ethoxy-4-oxobutylzinc bromide (0.5 M; 0.63 mL, 0.315 mmol) as described in procedure D (60 ^{0}C, 24 h) gave **7d**(*Z*) (23 mg, 45%; 94% based on *E* isomer): ^{1}H NMR δ 1.26 (t, *J* = 7.1 Hz, 3H), 1.56 (s, 3H), 1.92-2.10 (m, 2H), 2.45 (dt, *J* = 23.5, 7.1 Hz, 2H), 2.50 (t, *J* = 7.2 Hz, 2H), 4.17 (q, *J* = 7.1 Hz, 2H), 7.25-7.35 (m, 3H), 7.36-7.45 (m, 2H); ^{13}C NMR δ 14.6, 17.6 (d, $^3J_{C\text{-}F}$ = 4.5 Hz), 22.2, 28.8 (d, $^2J_{C\text{-}F}$ = 29.1 Hz), 33.6, 60.7, 113.5 (d, $^2J_{C\text{-}F}$ = 25.5 Hz), 127.1, 128.4, 128.5, 138.8, 154.5 (d, $^1J_{C\text{-}F}$ = 253.5 Hz), 173.6; ^{19}F NMR δ -107.82 ("tq", *J* = 22.6, 2.1 Hz). HRMS Calcd. for $C_{15}H_{19}FO_2$ ($M+Na^+$): 273.1267; Found: 273.1293.

Analogous treatment (8 h) of **4d** (*E/Z*, 49:51; 15 mg, 0.06 mmol) with $PdCl_2$(dppb) (5% molar) and 4-ethoxy-4-oxobutylzinc bromide (0.5 M; 0.18 mL, 0.09 mmol) gave in addition to **7d**(*Z*) a new product

tentatively assigned as **7d**(*E*): ^{19}F NMR δ -107.82 ("tq", *J* = 22.6, 2.1 Hz, 0.84F), -109.91 ("tq", *J* = 22.5, 3.4 Hz, 0.16F); GC-MS *m/z* 250 [8%, M^+; t_R = 17.20 min (*E*) and 18.74 min (*Z*)].

***(Z)*-2-Fluoro-1-phenyl-1,6-heptadiene (8a).** Treatment of **4a** (*E/Z*, 95:5; 75 mg, 0.30 mmol) with $Pd(PPh_3)_4$ (17 mg, 0.015 mmol) and 4-pentenylzinc bromide (0.5 M; 0.9 mL, 0.45 mmol) as described in procedure D gave **8a**(*Z*) (37 mg, 65%; 69% based on *E* isomer) and slightly more polar (*Z,Z)*-2,3-difluoro-1,4-diphenyl-1,3-butadiene[9b] [**12**; 6 mg, 8%, e.g. 16% consumption of **4a**; ^{19}F NMR δ –127.95 ("dd", *J* = 28.6, 14.6 Hz); GC-MS *m/z* 242 (100%, M^+; t_R = 21.46 min)]. Compound **8a** had: ^{1}H NMR δ 1.75 (quint, *J* = 7.5 Hz, 2H), 2.15 (q, *J* = 6.8 Hz, 2H), 2.35 (dt, *J* = 18.4, 7.7 Hz, 2H), 5.03 (dd, *J* = 10.2, 1.3 Hz, 1H), 5.08 (dd, *J* = 17.3, 1.7 Hz, 1H), 5.51 (d, *J* = 39.5 Hz, 1H), 5.85 (ddt, *J* = 17.0, 10.2, 7.1 Hz, 1H), 7.25 (t, *J* = 7.8 Hz, 1H), 7.35 (t, *J* = 7.3 Hz, 2H), 7.55 (d, *J* = 8.2 Hz, 2H); ^{13}C NMR δ 25.9, 32.8 (d, $^2J_{C\text{-}F}$ = 26.5 Hz), 33.3, 106.2 (d, $^2J_{C\text{-}F}$ = 28.6 Hz), 115.7, 127.1, 128.6, 129.7, 134.3, 138.4, 159.9 (d, $^1J_{C\text{-}F}$ = 266.6 Hz); ^{19}F NMR δ -101.45 (dt, *J* = 39.8, 18.8 Hz); GC-MS *m/z* 190 [25%, M^+; t_R = 13.97 min (*Z*)]. Anal. Calcd. for $C_{13}H_{15}F$ (190.26): C, 82.07, H, 7.95. Found: C, 82.41, H, 8.15.

(*Z*)-6-Fluoro-9-phenyl-1,6-nondiene (8b). Treatment of **4b** (*E/Z*, 78:22; 70 mg, 0.26 mmol) with $Pd(PPh_3)_4$ (5% molar) and 4-pentenylzinc bromide (0.5 M; 1.04 mL, 0.52 mmol) in dried benzene (5 mL) as described in procedure D [20 h; second portions of $Pd(PPh_3)_4$ mmol) and 4-pentenylzinc bromide were added after 10 h] gave **8b**(*Z*) (37 mg, 66%; 85% based on *E* isomer): ^{1}H NMR δ 1.56 (quint, *J* = 7.7 Hz, 2H), 2.04 (q, *J* = 7.2 Hz, 2H), 2.18 (dt, *J* = 17.8, 7.6 Hz, 2H), 2.39 (q, *J* = 7.6 Hz, 2H), 2.70 (t, *J* = 7.3 Hz, 2H), 4.50 (dt, *J* = 37.9, 7.4 Hz, 1H), 4.98-5.05 (m, 2H), 5.75-5.85 (m, 1H), 7.18-7.25 (m, 3H), 7.30-7.35 (m, 2H); ^{13}C NMR δ 23.1, 25.7 (d, $^3J_{C\text{-}F}$ = 4.8 Hz), 31.7 (d, $^2J_{C\text{-}F}$ = 27.9 Hz), 33.2, 36.2, 104.7 (d, $^2J_{C\text{-}F}$ = 15.6 Hz), 115.4, 126.3, 128.7, 128.8, 138.6, 142.2, 160.1 (d, $^1J_{C\text{-}F}$ = 253.7 Hz); ^{19}F NMR δ -109.65 (dt, *J* = 38.7, 17.9 Hz); MS *m/z* 219 (100%, MH^+). Anal. Calcd. for $C_{15}H_{19}F$ (218.15): C, 82.53, H, 8.77. Found: C, 82.33, H, 9.15.

The ^{19}F NMR of the crude reaction mixture in addition to **8b**(*Z*) (0.74F) showed the presence of other products tentatively assigned as *E*-isomer of **8b** [-104.81 ppm ("q", *J* = 16.9 Hz, 0.12F)], (*Z*)-1-fluoro-4-phenyl-1-butene[11] [-130.33 ppm (dd, *J* = 41.4, 82.8 Hz, 0.03F) and (*Z,Z*)-4,5-difluoro-1,8-diphenyl-3,5-octadiene[9f] [-132.34 ppm ("dd", *J* = 13.2, 26.3 Hz, 0.10F)].

(*E/Z*)- 6-Fluoro-8-benzyloxy-1,6-octadiene (8c). Treatment of **4c** (*E/Z*, 67:33; 63 mg, 0.215 mmol) with $PdCl_2$(dppb) (5% molar) and 4-pentenylzinc bromide (0.5 M; 0.86 mL, 0.43 mmol) as described in procedure D [55 ^{o}C, 4 h] gave **8c** (*E/Z*, 20:80, 46 mg, 86%): ^{1}H NMR δ 1.55 (quint, *J* = 7.4 Hz, 2H), 1.98-2.05 (m, 2H), 2.08-2.19 (m, 2H), 3.88 (d, *J* = 7.8 Hz, 0.4H, *E*), 4.04 (d, *J* = 7.1 Hz, 1.6H, *Z*), 4.41 (s, 2H), 4.73 (dt, *J* = 36.7, 7.2 Hz, 0.8H, *Z*), 4.88-4.97 (m, 2H), 5.22 (dt, *J* = 20.5, 7.8 Hz, 0.2H, *E*), 5.65-5.75 (m, 1H), 7.20-7.27 (m, 5H); ^{13}C NMR δ 25.1, 25.4, 27.6 (d, ^2J = 27.6 Hz, *E*), 31.3 (d, ^2J = 26.8 Hz, *Z*), 32.8, 62.7 (d, $^3J_{C\text{-}F}$ = 6.9 Hz, *Z*), 64.5 (d, $^3J_{C\text{-}F}$ = 14.2 Hz, *E*), 71.9, 72.1, 102.4 (d, $^2J_{C\text{-}F}$ = 13.8 Hz, *Z*), 102.9 (d, $^2J_{C\text{-}F}$ = 22.8 Hz, *E*), 115.2, 127.6, 127.8, 128.4, 137.8, 138.3, 162.2 (d, $^1J_{C\text{-}F}$ = 259.1 Hz,

Z), 163.9 (d, $^{1}J_{C\text{-}F}$ = 254.8 Hz, *E*); ^{19}F NMR δ -98.05 (q, *J* = 22.4 Hz, 0.20F, *E*), -104.21 (dt, *J* = 36.7, 17.3 Hz, 0.80F, *Z*); GC-MS *m/z* 233 [1%, M^+; t_R = 16.95 min (*Z*) and 17.57 min (*E*)]. HRMS Calcd. for $C_{15}H_{19}FO$ ($M+H^+$) 235.1498; Found: 235.1490.

Treatment of **4c** (*E/Z*, 75:25; 20 mg, 0.07 mmol) with $Pd(PPh_3)_4$ (5% molar) and 4-pentenylzinc bromide (0.5 M; 0.28 mL, 0.14 mmol) as described in procedure D (48 h) gave **8c**(*Z*) [56%; ^{19}F NMR δ -104.26 (dt, *J* = 37.6, 17.1 Hz) in addition to unchanged **4c** (44%, *E/Z,* 44:56).

Treatment of **5c** (*E/Z*, 77/23; 45 mg, 0.18 mmol) with $PdCl_2$(dppb) (5% molar) and 4-pentenylzinc bromide (0.5 M; 0.7 mL, 0.36 mmol) as described in procedure D [55 ^{0}C, 6 h] gave **8c** (*E/Z*, 20:80; 36 mg, 84%).

(*Z*)-6-Fluoro-7-phenyl-1,6-octadiene (8d). Treatment of **4d** (*E/Z*, 49:51; 65 mg, 0.25 mmol) with $Pd(PPh_3)_4$ (14.3 mg, 0.012 mmol) and 4-pentenylzinc bromide (0.5 M; 0.75 mL, 0.38 mmol) as described in procedure D [55 ^{0}C, 24 h] gave **8d**(*Z*) (23 mg, 45%; 92% based on *E* isomer): ^{1}H NMR δ 1.71 (quint, *J* = 7.9 Hz, 2H), 1.59 (s, 3H), 2.12-2.20 (m, 2H), 2.41 (dt, *J* = 23.6, 7.1 Hz, 2H), 5.02 (d, *J* = 10.2 Hz, 1H), 5.07 (d, *J* = 18.1 Hz, 1H), 5.78-5.90 (m, 1H), 7.15-7.38 (m, 5H); ^{13}C NMR δ 17.7 (d, $^{3}J_{C\text{-}F}$ = 4.9 Hz), 26.2, 29.2 (d, $^{2}J_{C\text{-}F}$ = 29.2 Hz), 33.4, 110.1 (d, $^{2}J_{C\text{-}F}$ = 26.7 Hz), 115.5, 127.0, 128.4, 128.5, 138.6, 139.0, 154.8 (d, $^{1}J_{C\text{-}F}$ = 255.6 Hz); ^{19}F NMR δ -108.10 (t, *J* = 23.1 Hz); GC-MS *m/z* 204 [5%, M^+; t_R = 14.59 min, *Z*]. Anal. Calcd. for $C_{14}H_{17}F$ (204.28): C, 82.31; H, 8.39. Found: C, 82.56; H, 8.78.

Assessment of the reaction progress by GC-MS and ^{19}F NMR showed the gradual conversion of the **4d**(*E)* isomer into **8d**(*Z*) [2 h (6%), 8 h (35%), 16 h (60%), 24 h (92%)] while **4d**(Z) isomer remained unchanged.

2-Fluoro-1-phenyl-4-[2-(1,3-dioxolanyl)]-1(*Z*)-butene (9a). Treatment of **4a** (*E/Z*, 95:5; 25 mg, 0.10 mmol) with $Pd(PPh_3)_4$ (5 mg, 0.005 mmol) and 2-[2-(1,3-dioxolanyl]ethylzinc bromide (0.5 M; 0.6 mL, 0.3 mmol) as described in procedure D [12 h; second portions of $Pd(PPh_3)_4$ and 2-[2-(1,3-dioxolanyl]ethylzinc bromide were added after 6 h] gave **9a**(*Z*) (20 mg, 90%; 94% based on *E* isomer): ^{1}H NMR δ 1.98-2.03 (m, 2H), 2.50 (dt, *J* = 17.8, 7.6 Hz, 2H), 3.82-3.91 (m, 2H) 3.96-4.08 (m, 2H), 4.95 (t, *J* = 4.5 Hz, 1H), 5.50 (d, *J* = 39.3 Hz, 1H), 7.20 (t, *J* = 7.4 Hz, 1H), 7.30 (t, *J* = 7.8 Hz, 2H), 7.45 (d, *J* = 7.3 Hz, 2H); ^{13}C NMR δ 27.8 (d, $^{2}J_{C\text{-}F}$ = 27.8 Hz), 31.0, 65.4, 103.7, 106.4 (d, ^{2}J = 8.5 Hz), 127.2, 128.7, 128.8, 134.1, 160.6 (d, $^{1}J_{C\text{-}F}$ = 266.2 Hz); ^{19}F NMR δ -101.78 (dt, *J* = 39.3, 17.9 Hz); GC-MS *m/z* 222 [10%, M^+; t_R = 18.19 min, *Z*]. HRMS Calcd for $C_{13}H_{15}FO_2$ ($M+Li^+$): 229.1216. Found: 229.1207.

Effect of the Pd catalysts on the efficiency of coupling: Progress of the reactions was monitored by ^{19}F NMR and GC-MS and yields are based on ^{19}F NMR and GC-MS of the crude reaction mixtures.

Treatment of **4a** (*E/Z*, 95:5, 25 mg, 0.10 mmol) with $Pd(Ph_3P)_4$ (5% molar) and 2-[2-(1,3-dioxolanyl]ethylzinc bromide (0.5 M; 0.4 mL, 0.2 mmol) as described in procedure D [2h, 50 ^{0}C] gave **9a** (11%) and unchanged **4a** (*E/Z*, 95:5, 85%).

Treatment of **4a** (*E/Z*, 95:5, 25 mg, 0.10 mmol) with $PdCl_2$(dppf) (5% molar) and 2-[2-(1,3-

dioxolanyl]ethylzinc bromide (0.5 M; 0.4 mL, 0.2 mmol) as described in procedure D [2h, 50 ^{0}C] gave **9a** (8%) plus unchanged **4a** (*E/Z*, 95:5, 85%).

Treatment of **4a** (*E/Z*, 95:5, 25 mg, 0.10 mmol) with $Pd(OAc)_2$ (5% molar) and 2-[2-(1,3-dioxolanyl]ethylzinc bromide (0.5 M; 0.4 mL, 0.2 mmol) as described in procedure D [2h, 50 ^{0}C] gave **9a** (75%). Reaction was completed in 95% after 3.5 h.

Treatment of **4a** (*E/Z*, 95:5, 25 mg, 0.10 mmol) with $Pd_2(dba)_3$ (5% molar) and 2-[2-(1,3-dioxolanyl]ethylzinc bromide (0.5 M; 0.4 mL, 0.2 mmol) as described in procedure D [2h, 50 ^{0}C] gave **9a** (93%). Isolated yield 92% (96% based on the *E* isomer).

Treatment of **4a** (*E/Z*, 95:5, 25 mg, 0.10 mmol) with $PdCl_2$(dppb) (5% molar) and 2-[2-(1,3-dioxolanyl]ethylzinc bromide (0.5 M; 0.4 mL, 0.2 mmol) as described in procedure D [2h, 50 ^{0}C] gave **9a** (95%). Isolated yield 94% (98% based on the *E* isomer).

4-Fluoro-1-phenyl-6-[2-(1,3-dioxolanyl)]-3(*Z*)-hexene (9b). Treatment of **4b** (*E/Z*, 78:22; 30 mg, 0.11 mmol) with $Pd(PPh_3)_4$ (7 mg, 0.006 mmol) and 2-[2-(1,3-dioxolanyl)]ethylzinc bromide (0.5 M; 0.66 mL, 0.33 mmol) in dried benzene (5 mL) as described in procedure D [20 h; second portions of $Pd(PPh_3)_4$ and 2-[2-(1,3-dioxolanyl)]ethylzinc bromide were added after 8 h] gave **9b**(*Z*) (20 mg, 74%; 94% based on *E* isomer): ^{1}H NMR δ 1.80-1.91 (m, 2H), 2.22 (dt, J = 16.7, 8.4 Hz, 2H), 2.40 (q, J = 7.5 Hz, 2H), 2.63 (t, J = 7.9 Hz, 2H), 3.86-3.90 (m, 2H), 3.96-4.02 (m, 2H), 4.55 (dt, J = 37.6, 7.4 Hz, 1H), 4.86 (t, J = 4.6 Hz, 1H), 7.18-7.25 (m, 3H), 7.28-7.35 (m, 2H); ^{13}C NMR δ 25.6 (d, $^3J_{C\text{-}F}$ = 4.9 Hz), 26.8 (d, $^2J_{C\text{-}F}$ = 28.8 Hz) 31.0, 36.1, 65.3, 103.9, 104.8 (d, $^2J_{C\text{-}F}$ = 15.5 Hz), 126.2, 128.7, 128.8, 142.1, 159.5 (d, $^1J_{C\text{-}F}$ = 253.2 Hz); ^{19}F NMR δ -109.37 (dt, J = 37.6, 16.4 Hz); GC-MS *m/z* 250 [1%, M^+; t_R = 17.74 min, *Z*]. FAB-HRMS Calcd for $C_{15}H_{19}FO_2$ ($M+H^+$): 251.1448; Found: 251.1455.

Treatment (12 h) of **4b**(*E*) (15 mg, 0.054 mmol) with $Pd(PPh_3)_4$ (5% molar) and 2-[2-(1,3-dioxolanyl)]ethylzinc bromide (0.5 M; 0.21 mL; 0.10 mmol) produced only **9b**(*Z*) (12 mg, 89%; 98% based on GC/MS).

Analogous treatment (24 h) of **4b** (*E/Z*, 15:85; 15 mg, 0.055 mmol) showed a conversion of the *E* isomer into **9b**(*Z*) (14%) and disappearance of **4b**(*Z*) but no formation of **9b**(*E*) was detected (GC/MS, ^{19}F NMR).

3-Fluoro-2-phenyl-5-[2-(1,3-dioxolanyl)]-2(*Z*)-pentene (9d). Treatment of **4d** (*E/Z*, 49:51; 30 mg, 0.11 mmol) with $Pd(PPh_3)_4$ (5% molar) and 2-[2-(1,3-dioxolanyl]ethylzinc bromide (0.5 M; 0.66 mL, 0.33 mmol) as described in procedure D [60^0 C, 24 h; a second portion of $Pd(PPh_3)_4$ and 2-[2-(1,3-dioxolanyl]ethylzinc bromide were added after 12 h] gave **9d**(*Z*) (12 mg, 46%; 90% based on *E* isomer): ^{1}H NMR δ 1.30 (s, 3H), 1.94-2.03 (m, 2H), 2.55 (dt, J = 23.1, 8.1 Hz, 2H), 3.89-3.94 (m, 2H), 3.95-4.05 (m, 2H), 4.95 (t, J = 4.5 Hz, 1H), 7.20-7.38 (m, 5H); ^{13}C NMR δ 17.6, 24.2 (d, $^2J_{C\text{-}F}$ = 29.2 Hz), 30.1, 65.4, 103.9, 112.8 (d, $^2J_{C\text{-}F}$ = 26.8 Hz) 127.0, 128.4, 128.6, 138.9, 153.8 (d, $^1J_{C\text{-}F}$ = 255.8 Hz); ^{19}F NMR δ -108.77 (t, J = 22.9 Hz). HRMS Calcd for $C_{14}H_{17}FO_2$ ($M+Li^+$): 243.1373; Found: 243.1361.

3,3-Dimethyl-2-Fluoro-1-phenyl-1-butene (11a). Treatment of **4a** (*E/Z*, 95:5, 40 mg, 0.16 mmol) with $PdCl_2$(dppb) (5% molar) and *tert*-butylzinc bromide (0.5 M; 0.6 mL, 0.32 mmol) as described in procedure D [3 h, 50 ^{0}C] gave **11a** (23 mg, 80%; 95% based on GC-MS and ^{19}F NMR): ^{1}H NMR δ 1.15 (s, 9H), 5.40 (d, J = 40.7 Hz, 1H), 7.17-7.41 (m, 5H); ^{19}F NMR δ -109.47 (d, J = 40.7 Hz); GC-MS *m/z* 178 [80%, M^+; t_R = 10.78 min]. HRMS Calcd. for $C_{12}H_{15}F$ ($M+H^+$) 179.1237; Found: 179.1246

Treatment of **4a** (*E/Z*, 95:5, 32 mg, 0.12 mmol) with *tert*-butylzinc bromide (0.5 M; 0.48 mL, 0.24 mmol) in the presence of $Pd(Ph_3P)_4$ (5% molar) as described in procedure D [24 h, 65 ^{0}C] gave **11a** (60%) and **12**[9b] (20%, 40% consumption of **4a**): ^{19}F NMR δ -109.47 (d, J = 40.7 Hz, 0.60F), -127.95 ("dd", J = 28.6, 14.6 Hz, 0.40F).

Treatment of **4a** (*E/Z*, 95:5, 40 mg, 0.16 mmol) with *tert*-butylzinc bromide (0.5 M, 0.6 mL, 0.32 mmol) in the presence of $Pd_2(dba)_3$ (5 % molar) as described in procedure D [12 h, 50 ^{0}C] gave **12**[9b] (35 mg, 45%, 90% consumption of **4a**) based on ^{19}F NMR.

Attempted coupling with secondary alkylzinc bromides:

Treatment of **4a** (*E/Z*, 95:5; 18 mg, 0.07 mmol) with $Pd_2(dba)_3$ (5% molar) and 1-methylbutylzinc bromide (0.5 M, 0.29 mL, 0.14 mmol) as described in procedure D [3h, 50 ^{0}C] gave a mixture of **11b** (50%) and **12** (12%) in addition to *Z*-β-fluorostyrene[20] (26%): ^{19}F NMR δ -109.34 (dd, J = 40.2, 22.9 Hz, 0.50F, **11b**), -122.49 (dd, J = 82.5, 44.6 Hz, 0.26F, *Z*-β-fluorostyrene), -127.95 ("dd", J = 28.6, 14.6 Hz, 0.24F, **12**); GC-MS for **11b**/**12** had *m/z* 192 (65%, M^+; t_R = 14.08 min; **11b**), 242 (100%, M^+; t_R = 21.46 min; **12**).

Treatment (18 h, 65 ^{0}C) of **4a** (*E/Z*, 95:5; 22 mg, 0.088 mmol) with 1-methylbutylzinc bromide (0.5 M, 0.35 mL, 0.17 mmol) in the presence of $Pd(Ph_3P)_4$ (5% molar) produced **11d** [37%; ^{19}F NMR δ -101.01 (dt, J = 40.3, 18.8 Hz)], **11b** (21%), **12** (19%) and *Z*-β-fluorostyrene (4%) as estimated based on the ^{19}F NMR and GC-MS of the crude reaction mixture.

Treatment of **4a** (*E/Z*, 95:5, 50 mg, 0.20 mmol) and 3-pentylzinc bromide (0.5 M; 0.60 mL, 0.30 mmol) in the presence of $Pd(Ph_3P)_4$ (5% molar) as described in procedure D gave a mixture of **11c** and **11d** (30/70): GC-MS *m/z* 192 (85%, M^+; t_R = 11.67 min; **11c**), 192 (60%, M^+; t_R = 12.55 min; **11d**). HRMS (AP-ESI) Calcd for $C_{13}H_{17}F$ ($M+Li^+$): 199.1474; Found: 199.1478.

(*Z*)-Ethyl 5-Chloro-6-phenyl-5-hexenoate (15). Procedure E. 4-Ethoxy-4-oxobutylzinc bromide (0.5 M; 1.45 mL, 0.72 mmol) was added *via* syringe to a stirring solution of **13**[21] (50 mg, 0.29 mmol) in dried THF (3 mL) containing $PdCl_2$(dppf) (24 mg, 0.029 mmol) under N_2. The resulting mixture was heated at 65 ^{0}C overnight. Volatiles were evaporated and the residue was partitioned ($NaHCO_3$/H_2O//EtOAc). The organic layer was washed (brine), dried (Na_2SO_4), evaporated and chromatographed (hexane → 10% EtOAc/hexane) to give **15** (47 mg, 65%) and **18**[22] (14 mg, 22%). Compound **15** had: ^{1}H NMR δ 1.19 (t, J = 7.1 Hz, 3H), 1.94 (quint, J = 7.1 Hz, 2H), 2.30 (t, J = 7.4 Hz, 2H), 2.47 (t, J = 7.1 Hz, 2H), 4.08 (q, J = 7.1 Hz, 2H), 6.40 (s, 1H), 7.28-7.52 (m, 5H); ^{13}C NMR δ 14.2,

22.8, 32.9, 40.3, 60.3, 125.2, 127.5, 128.1, 129.0, 133.6, 135.0, 173.2; GC-MS *m/z* 252 (30%, M^+ [^{35}Cl]; t_R = 20.00 min). HRMS Calcd for $C_{14}H_{17}{}^{35}ClO_2$ ($M+H^+$): 253.0995; Found: 253.0989.

Analogous treatment (65 ^{0}C, 2h) of **13** (50 mg, 0.29 mmol) with 4-ethoxy-4-oxobutylzinc bromide (0.5 M; 1.45 mL, 0.72 mmol) in dried THF (5 mL) in the presence of $PdCl_2$(dppb) (5% molar) gave **15** (39 mg, 53%), **17** (26 mg, 27%) and **18** (10 mg, 15%).

Treatment (65 ^{o}C, overnight) of **13** (70 mg, 0.40 mmol) with 4-ethoxy-4-oxobutylzinc bromide (0.5 M; 2 mL, 1.01 mmol) [$Pd(Ph_3P)_4$ (32 mg, 0.028 mmol)] gave **17** (67 mg, 50%) and **18** (27 mg, 30%).

Ethyl 6-phenyl-5-[(3-ethoxycarbonyl)propyl]hexenoate (17). Treatment of **14**[23] (50 mg, 0.19 mmol) with $PdCl_2$(dppf) (21 mg, 0.025 mmol) and 4-ethoxy-4-oxobutylzinc bromide (0.5 M, 0.57 mL, 0.28 mmol) in dried THF (5 mL) as described in procedure E gave **17** (43 mg, 69%) and **18**[22] (12 mg, 28%). Compound **17** had: ^{1}H NMR δ 1.15 (t, *J* = 7.1 Hz, 3H), 1.19 (t, *J* = 7.1 Hz, 3H), 1.66-1.82 (m, 4H), 2.10-2.22 (m, 6H), 2.27 (t, *J* = 7.4 Hz, 2H), 4.01 (q, *J* = 7.2 Hz, 2H), 4.07 (q, *J* = 7.1 Hz, 2H), 6.25 (s, 1H), 7.09-7.23 (m, 5H); ^{13}C NMR δ 14.6, 14.6, 23.7, 23.8, 30.1, 34.2, 34.5, 36.5, 60.6, 60.6, 126.5, 127.1, 128.5 129.0, 138.5, 141.4, 173.7, 173.9; GC-MS *m/z* 332 [35%, M^+; t_R = 25.36 min]. Anal. Calcd. for $C_{20}H_{28}O_4$ (332.20): C, 72.26; H, 8.49. Found: C, 71.92; H, 8.59.

Analogous treatment of **14** (50 mg, 0.19 mmol) with 4-ethoxy-4-oxobutylzinc bromide (0.5 M, 0.57 mL, 0.28 mmol) in dried THF (5 mL) in the presence of $PdCl_2$(dppb) (5% molar) as described in procedure E gave **17** (36 mg, 57%) and **18** (10 mg, 24%).

Analogous treatment of **14** (50 mg, 0.19 mmol) with 4-ethoxy-4-oxobutylzinc bromide (0.5 M, 0.57 mL, 0.28 mmol) in dried THF (5 mL) in the presence of $Pd(Ph_3P)_4$ (29 mg, 0.025 mmol) mmol) or $Pd[P(tBu_3)_3]_2$ (5% molar) or $Pd_2(dba)_3$ (5% molar) as described in procedure E gave **18** (36 mg, 87%).

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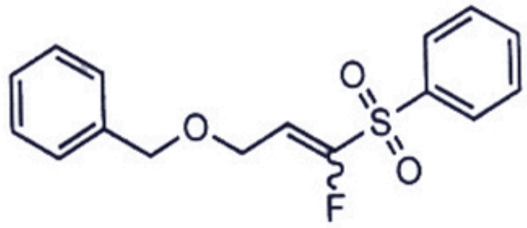
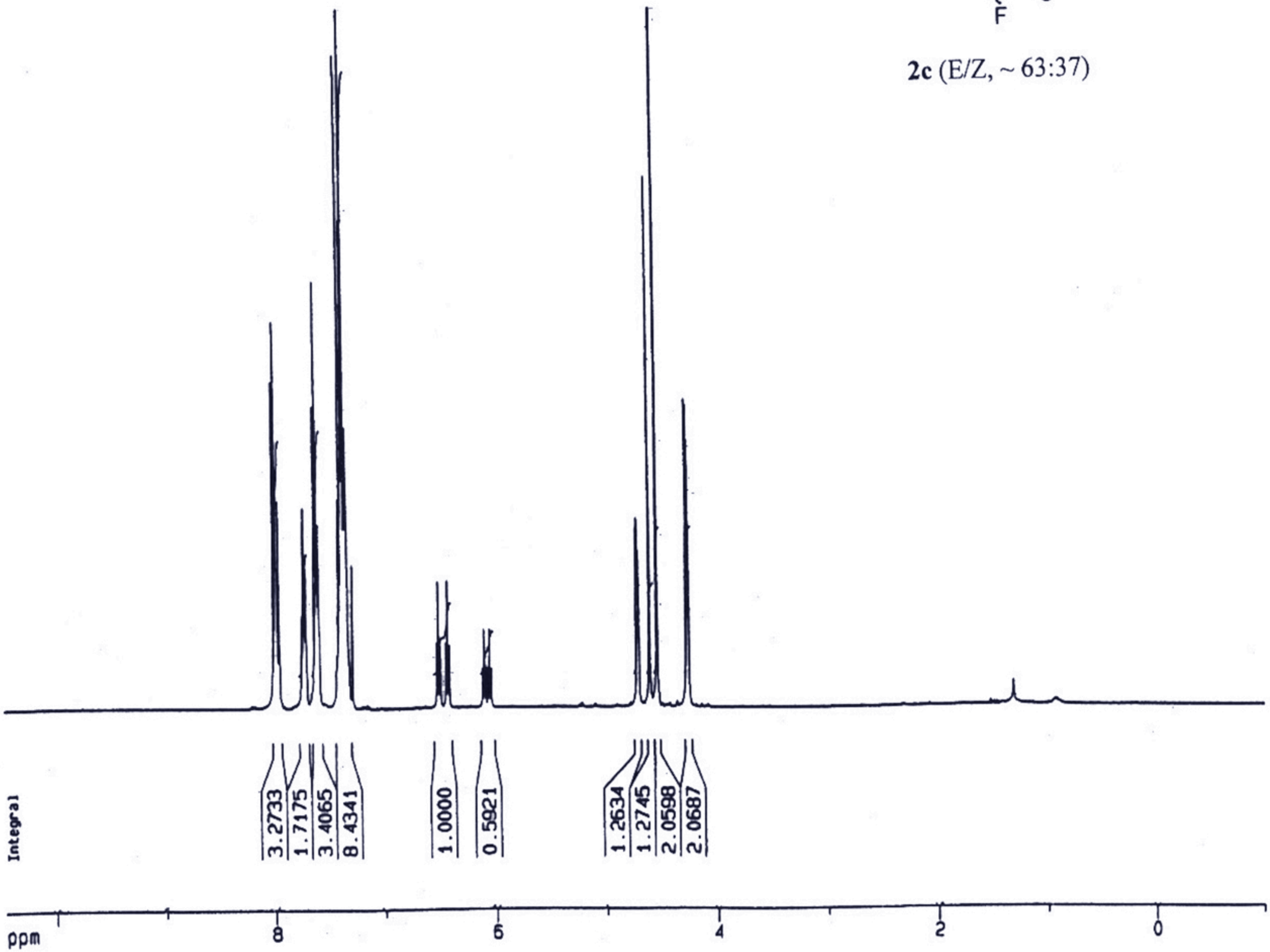
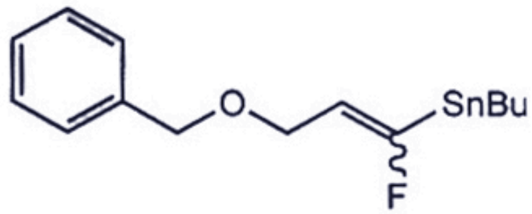


2c (E/Z, ~ 63:37)

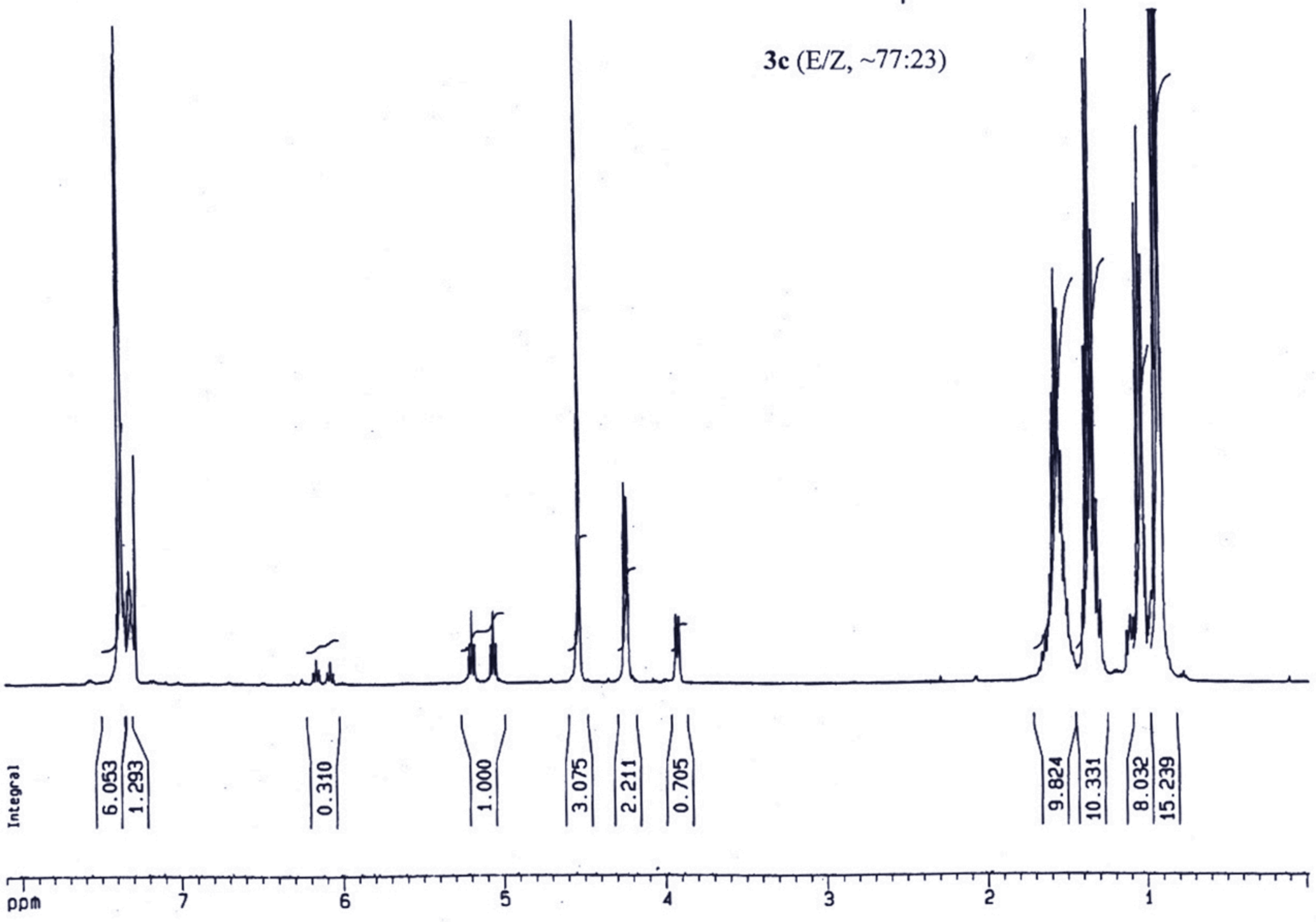
^{1}HNMR
$CDCl_3$
400 MHz



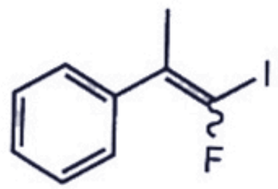
^{1}HNMR
$CDCl_3$
400 MHz



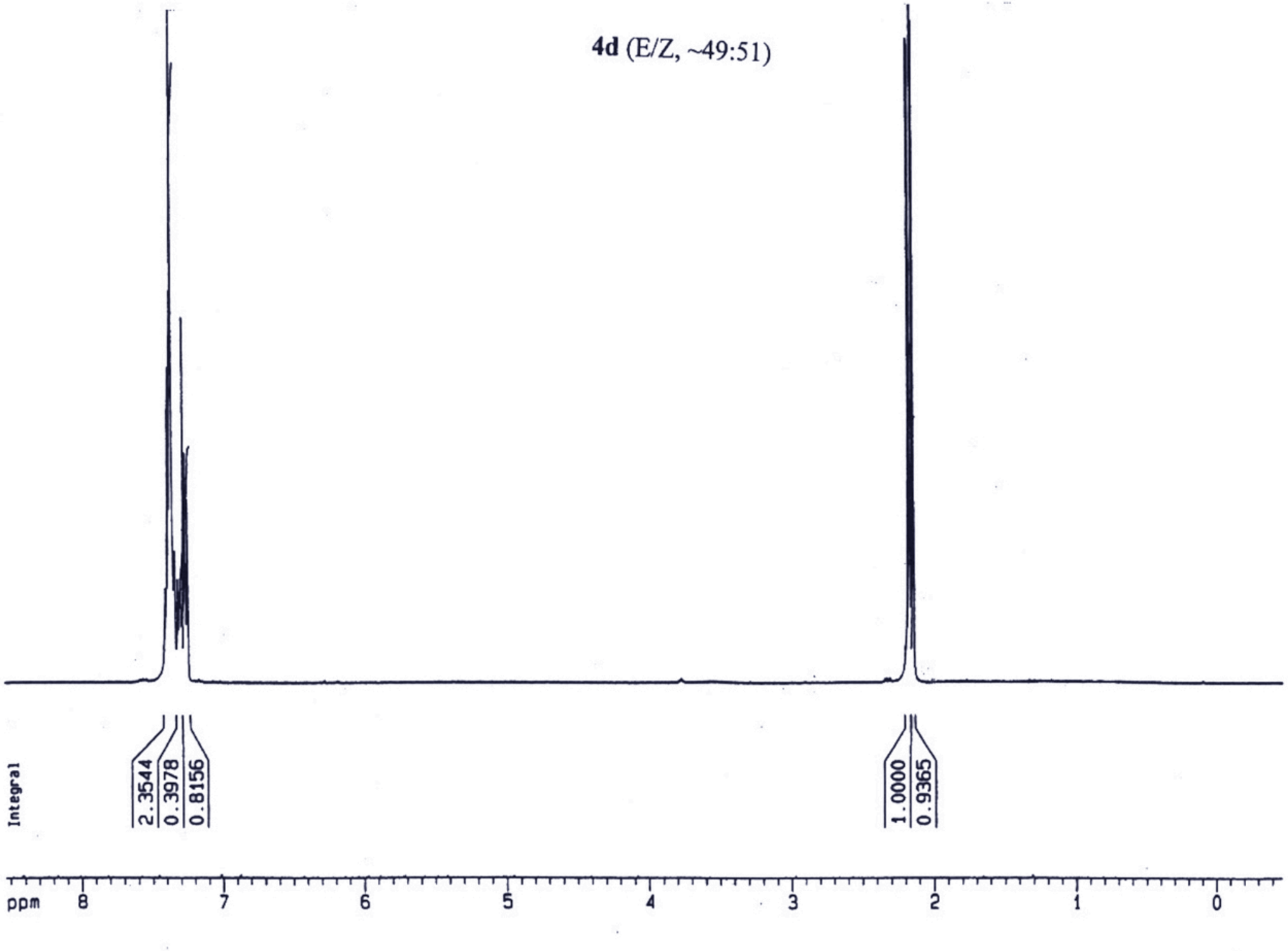
3c (E/Z, ~77:23)



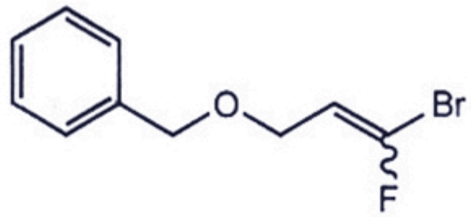
^{1}HNMR
$CDCl_3$
400 MHz



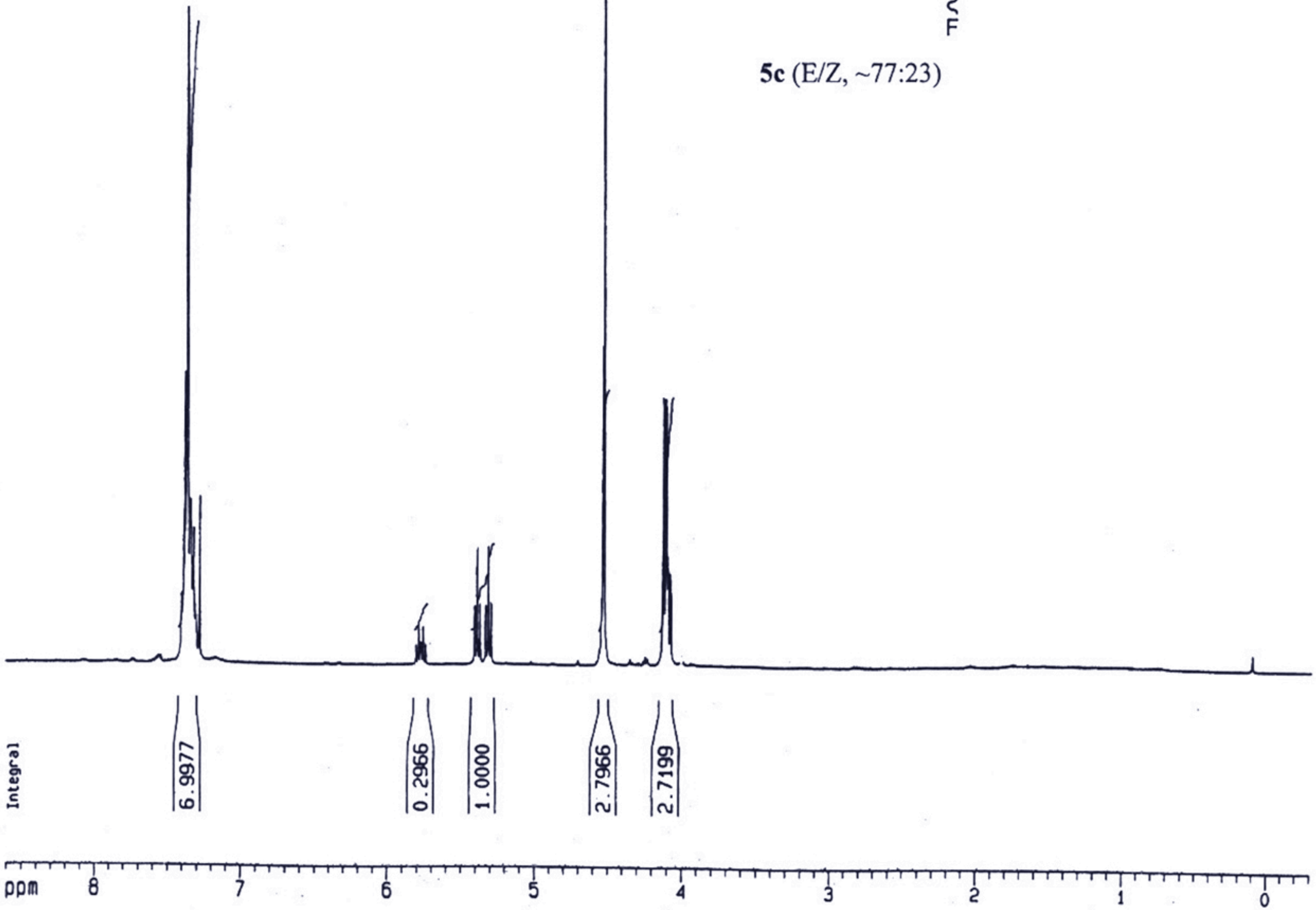
4d (E/Z, ~49:51)



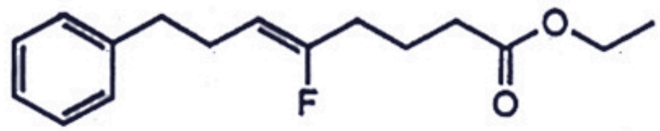
^{1}HNMR
$CDCl_3$
400 MHz



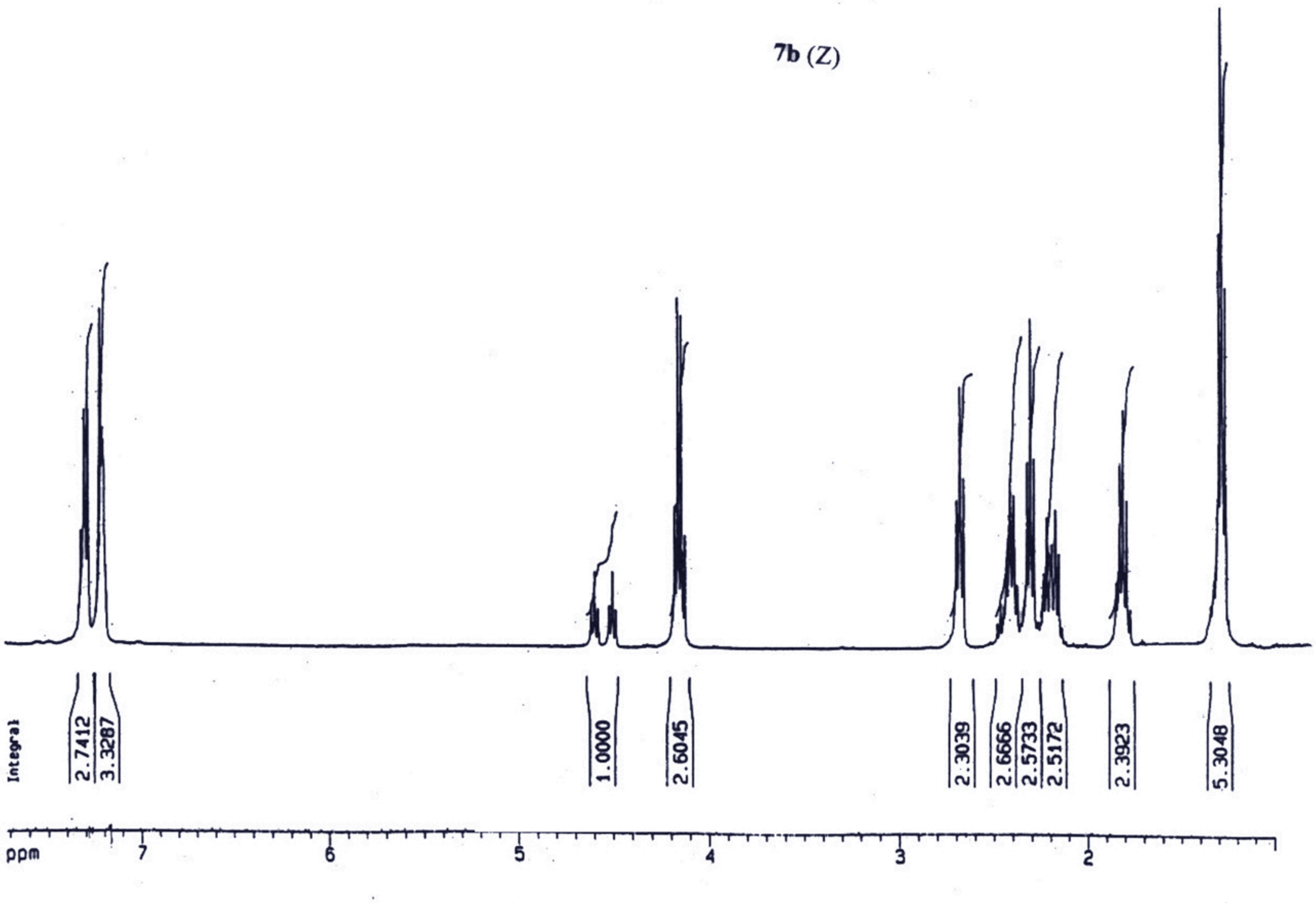
5c (E/Z, ~77:23)



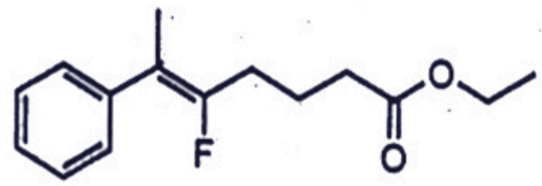
^{1}HNMR
$CDCl_3$
400 MHz



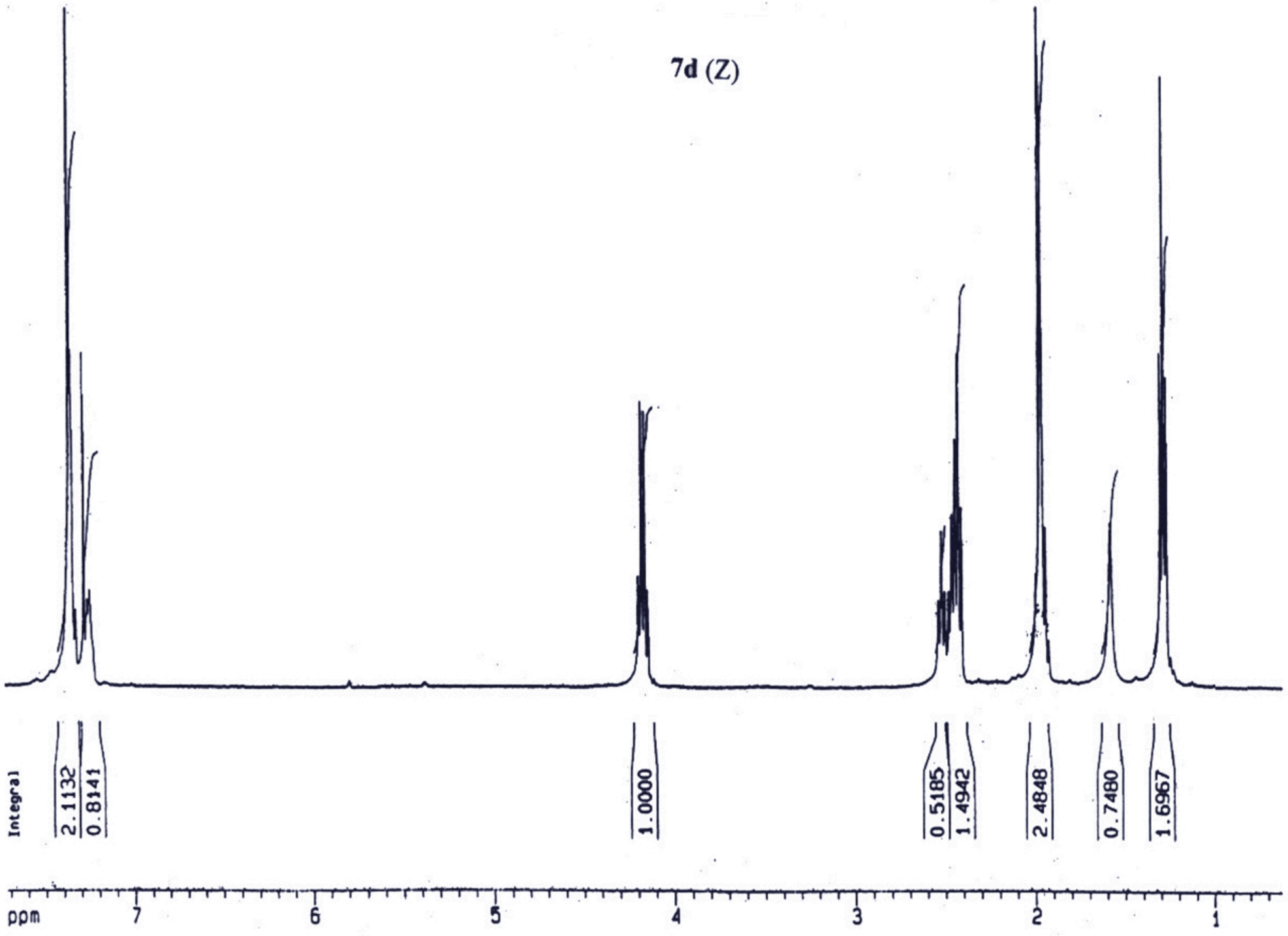
7b (Z)

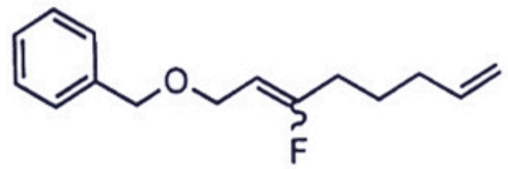


^{1}HNMR
$CDCl_3$
400 MHz



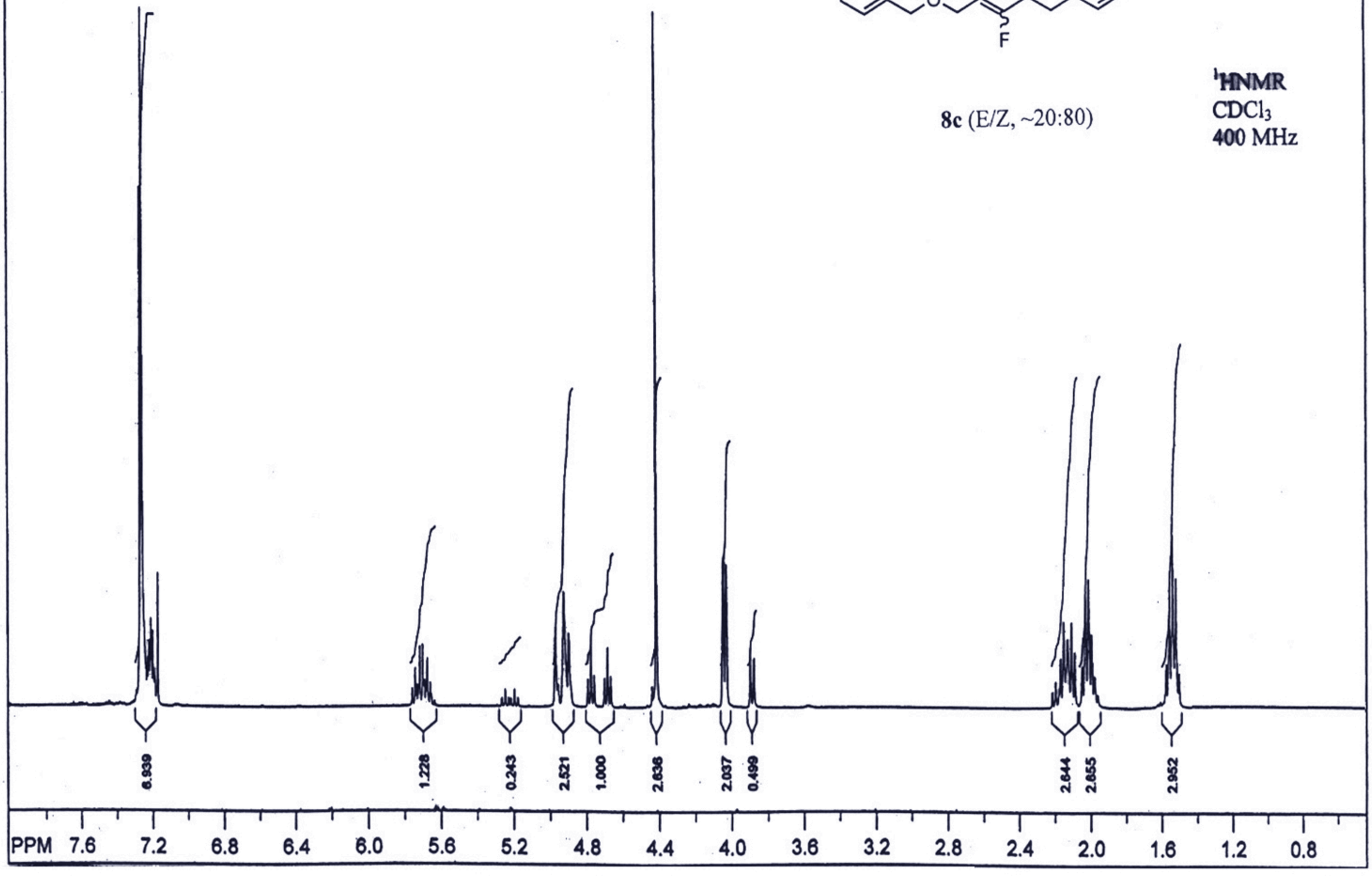
7d (Z)



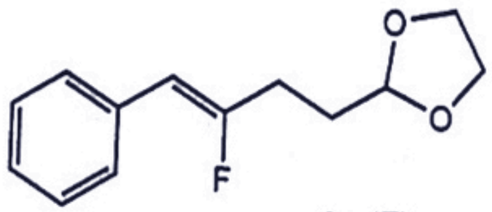


8c (E/Z, ~20:80)

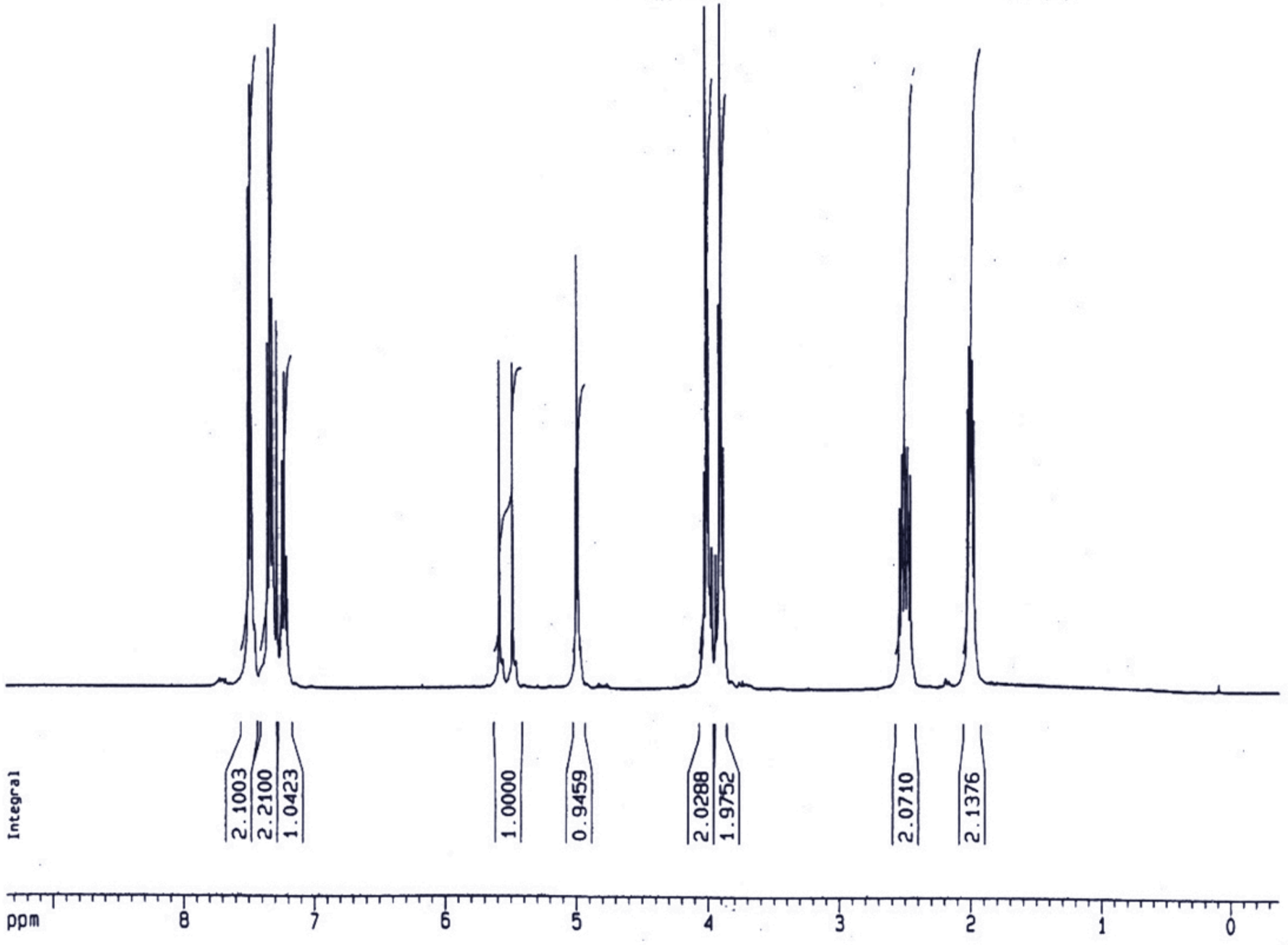
^{1}HNMR
$CDCl_3$
400 MHz



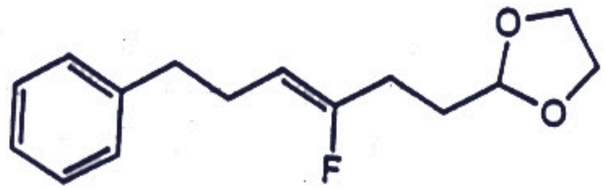
^{1}HNMR
$CDCl_3$
400 MHz



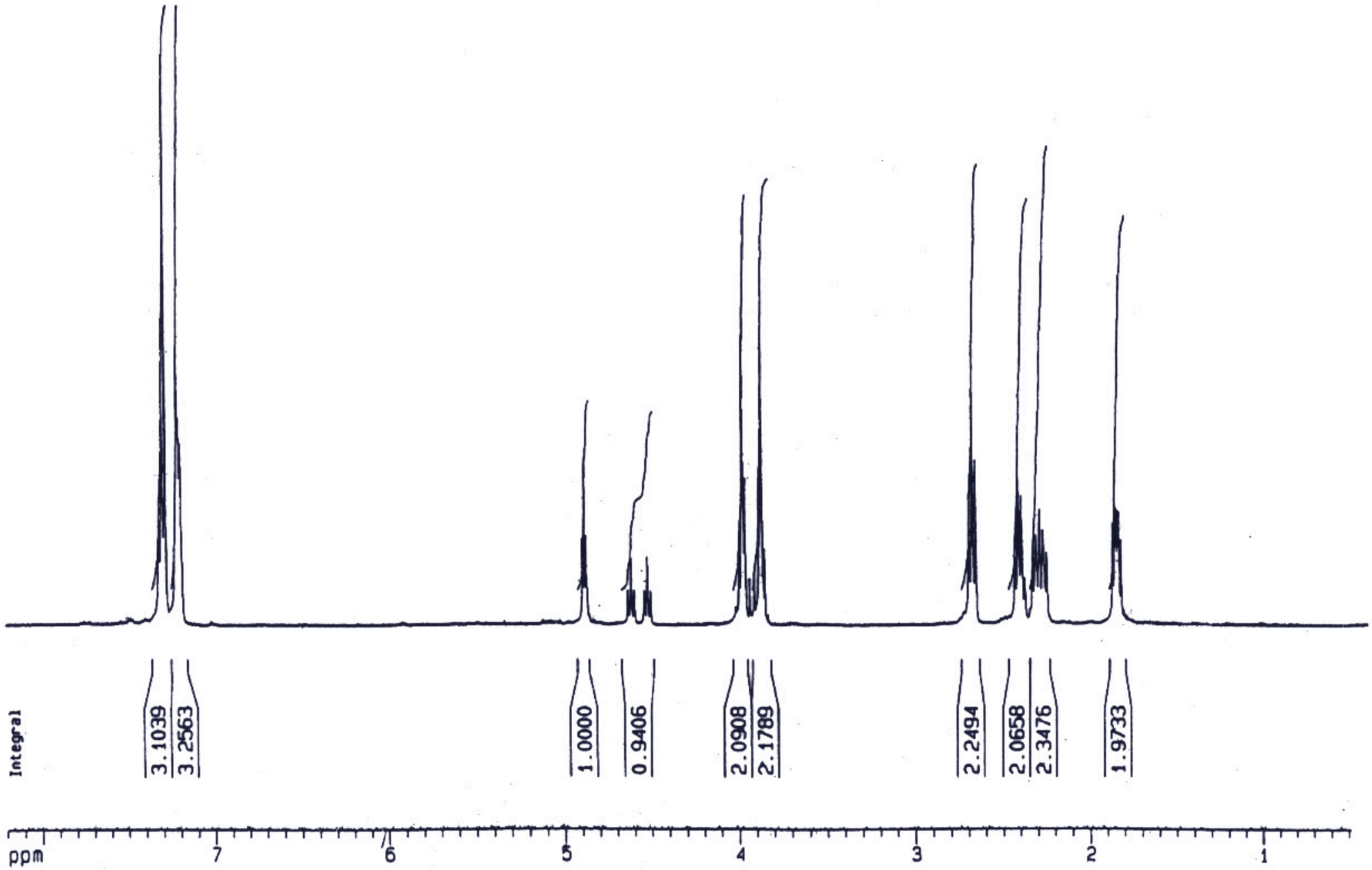
9a (Z)

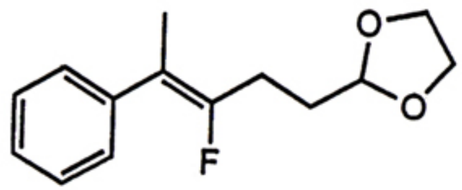


^{1}HNMR
$CDCl_3$
400 MHz



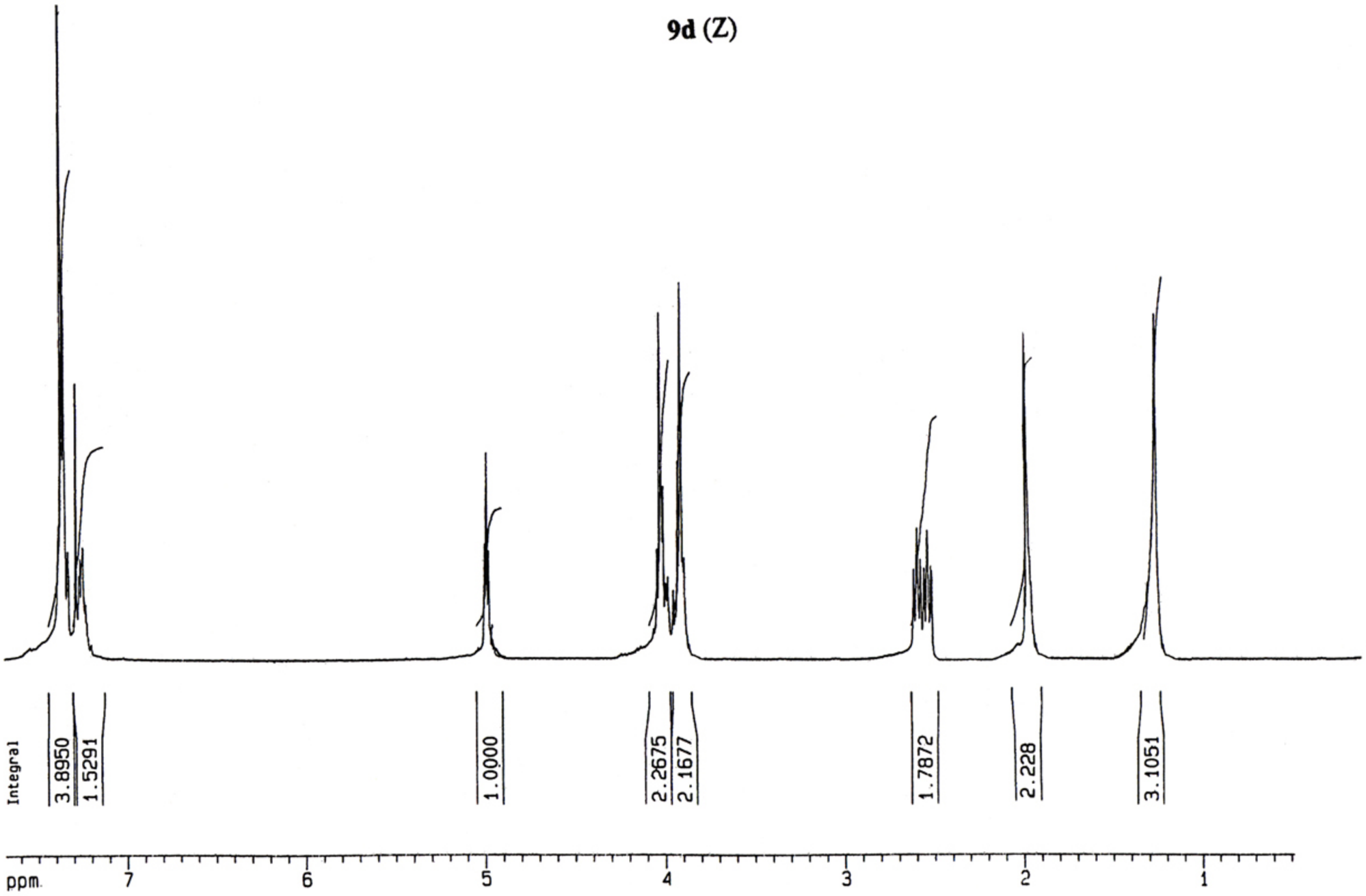
9b (Z)

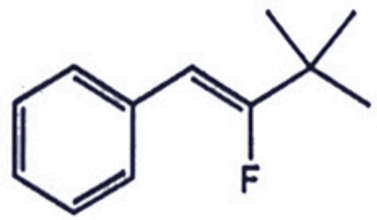




9d (Z)

^{1}HNMR
$CDCl_3$
400 MHz

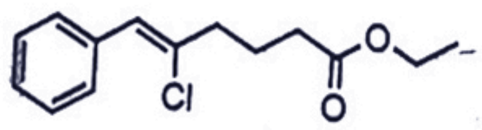




^{1}HNMR
$CDCl_3$
400 MHz

11a (Z)

^{1}HNMR
$CDCl_3$
400 MHz



15 (Z)