Supporting Information

Total Synthesis of Naturally Ocurring Diacetylenic Spiroacetal Enol Ethers

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General. Melting points are uncorrected. IR spectra were measured in $CHCl_3$. ^1H NMR spectra were taken in $CDCl_3$. $CHCl_3$ (7.26 ppm) for silyl compounds and tetramethylsilane (0.00 ppm) for compounds without a silyl group was used as an internal standard. ^{13}C NMR spectra were recorded in $CDCl_3$ with $CHCl_3$ (77.0 ppm) as an internal standard. All reaction were corried out under a nitrogen atmosphere unless otherwise stated. Silica gel (silica gel 60, 230-400 mesh) was used for chromatography. Organic extracts were dried over anhydrous Na_2SO_4.

6-[(*1R,2S*)-1-Benzyloxy-*2*-(*tert*-Butyldiphenylsiloxy)-but-3-ynyl]-3,4-dihydro-*2H*-pyran. (+)-24. According to the procedure described for the preparation of (-)-**22**, (-)-**20** (61.0 mg, 0.10 mmol) was converted to the corresponding alcohol. A solution of $PdCl_2(MeCN)_2$ (13.0 mg, 0.050 mmol) in MeOH (3.5 mL) was stirred under a CO atmosphere at room temperature for 10 min, to which a solution of the crude alcohol and benzoquinone (11.9 mg, 0.11 mmol) in MeOH (1.5 mL) was added. After being stirred for 30 min, MeOH was evaporated off and the residue was taken up in CH_2Cl_2, which was successively washed with saturated aqueous NaS_2O_3, saturated aqueous $NaHCO_3$, water, and brine, dried, and concentrated to dryness. The residue was passed through a short pad of silica gel with hexane-AcOEt (5:1) to afford the crude tetrahydropyran derivative. CSA (4.60 mg, 0.20 x 10^{-1} mmol) and Molecular sieves 4 A (50.0 mg) were added to a solution of the crude tetrahydropyran derivative and the reaction mixture was stirred for 4 h at room temperature, quenched by addition of Et_3N (1.0 mL), and solid was filtered off. The filtrate was concentrated to leave the residual oil, which was chromatographed with hexane-AcOEt (5:1) to afford (+)-**24** (29.0 mg, 59%) as a colorless oil: $[\alpha]^{24}_D$ +61.3 (*c* 0.72, $CHCl_3$); IR 3308, 1674 cm^{-1}; ^1H NMP δ 7.75-7.70 (m, 4H), 7.40-7.34 (m, 2H), 7.31-7.22 (m, 9H), 4.80 (t, 1H, *J* =3.5 Hz), 4.64(dd, 1H, *J* =7.3, 2.0 Hz), 4.64, 4.44 (AB-q, 2H, *J* =11.7 Hz), 3.91 (m, 2H), 3.75 (d, 1H, *J* =7.3 Hz), 2.21 (d, 1H, *J* =2.0 Hz), 2.02 (m, 2H), 1.76 (m, 2H), 1.07 (s, 9H); ^{13}C NMR δ 149.7, 138.3, 136.3, 136.1, 133.6, 133.5, 129.5, 128.1, 128.0, 127.3, 127.3, 127.2, 101.6, 83.7, 82.5, 73.8, 70.8, 66.1, 65.7, 26.9, 22.2, 20.1, 19.4; FABMS *m/z* 497 (M^++1, 2.0). FABHRMS calcd for $C_{32}H_{37}O_3Si$

497.2512, found 497.2518.

(*2E*,*3R*,*4R*,*5R*)-4-Benzyloxy-3-(*tert*-butyldiphenylsiloxy)-2-(2-hydroxyethylidene)-1,6-dioxaspiro[4.5]decane ((-)-25). DIBAL-H in hexane (1.00 M, 0.30 mL, 0.30 mmol) was added to a solution of (-)-**22** (16.0 mg, 0.28 x 10^{-1} mmol) in CH_2Cl_2 (3.0 mL) at –78 °C. The mixture was stirred for 30 min, quenched by addition of saturated aqueous Na_2SO_4, and the resulting solid was filtered off. The filtrate was concentrated to leave the residual oil, which was chromatographed with hexane-AcOEt (2:1) to afford (-)-**25** (14.0 mg, 92%) as a colorless oil: $[\alpha]^{24}_D$ –68.7 (*c* 0.77, $CHCl_3$); IR 3564, 1686 cm^{-1}; ^1H NMR δ 7.80-7.74 (4H, m) 7.48-7.41 (m, 6H), 5.25 (dt, 1H, *J* = 1.3, 7.9 Hz), 4.58 (br-s, 1H), 4.14-3.68(m, 5H), 1.85-1.60(m, 6H), 1.06 (s, 9H); ^{13}C NMR δ 158.5, 136.0, 136.0, 133.3, 132.9, 130.2, 130.0, 128.0, 127.8, 107.3, 102.0, 80.9, 62.2, 58.6, 28.2, 26.8, 24.9, 19.4, 19.0; MS *m*/*z* 454 (M^+, 0.1). HRMS calcd for $C_{26}H_{34}O_5Si$ 454.2175, found 454.2174. Anal. Calcd for $C_{33}H_{40}O_5Si$: C, 72.76; H, 7.40. Found: C, 72.70, H, 7.53.

(*2E*,*3R*,*4R*,*5R*)-4-Benzyloxy-3-(*tert*-butyldiphenylsiloxy)-2-propynylidene-1,6-dioxaspiro[4.5]decane ((-)-26). A suspension of (-)-**25** (7.00 mg, 0.12 x 10^{-1} mmol) and chemical manganese dioxide (18.3mg, 0.26 mmol) in CH_2Cl_2 (2.0 mL) was stirred at room temperature for 1 h. The mixture was filtered off and the filtrate was concentrated to leave the crude aldehyde. The crude aldehyde was converted to the title compound (5.80 mg, 0.11 x 10^{-1} mmol) by the procedure described for conversion of (-)-**17** into (-)-**18**. Compound (-)-**26** was a colorless plate: mp 130-131 °C (EtOH); $[\alpha]^{25}_D$ –68.5 (*c* 0.74, $CHCl_3$); IR 3308, 2110, 1655 cm^{-1}; ^1H NMR δ 7.83-7.80 (m, 4H), 7.44-7.35 (m, 6H), 7.22-7.20 (m, 3H), 6.96-6.94 (m, 2H), 5.08 (d, 1H, *J* = 3.0 Hz), 4.84 (s, 1H), 3.96 (dt, 1H, *J* = 3.0, 11.7 Hz), 3.75 (m, 1H), 3.71, 3.67 (AB-q, 2H, *J* = 11.7 Hz), 3.58 (s, 1H), 2.69 (d, 1H *J* = 3.0 Hz), 1.88-1.57 (m, 6H), 1.07 (s, 9H); ^{13}C NMR δ 169.8, 137.7, 136.5, 133.8, 133.2, 129.7, 128.1, 127.6, 127.4, 127.1, 110.3, 86.5, 82.5, 80.7, 79.9, 74.6, 71.2, 62.3, 28.8, 26.9, 24.9, 19.6, 19.1; Anal. Calcd for $C_{34}H_{38}O_2Si$: C, 75.80; H, 7.11. Found: C, 75.58, H, 7.20.

(*2E,3R,4R,5R*)-4-Benzyloxy-2-propynylidene-1,6-dioxaspiro[4.5]decan-3-ol ((-)-27). To a solution of (-)-**26** (10.0 mg, 0.18 x 10^{-1} mmol) in THF (2.0 mL) was added TBAF in THF (1.00 M, 0.1 mL, 0.1 mmol) and the reaction mixture was stirred for 4 h at room temperature, quenched by addition of water, and extracted with Et_2O. The extract was washed with water and brine, dried, and concentrated to dryness. Chromatography of the residue with hexane-AcOEt (4:1) afforded (-)-**27** (5.10 mg, 94%) as a colorless oil: $[\alpha]^{23}_D$ –106.9 (*c* 0.38, $CHCl_3$); IR 3693, 3306, 2106, 1655 cm^{-1}; ^1H NMR δ 7.37-7.28 (m, 5H), 5.14 (d, 1H, *J* = 2.4 Hz), 4.78 (d, 1H, *J* = 8.8 Hz), 4.74, 4.55 (AB-q, 2H, *J* = 11.7 Hz), 3.88 (dt, 1H, *J* = 2.9, 11.2 Hz), 3.73 (s, 1H), 3.72-3.69 (m, 1H), 3.04 (d, 1H, *J* = 2.4 Hz), 2.97 (d, 1H, *J* = 8.8 Hz), 2.06-2.01 (m, 1H), 1.85-1.58 (m, 5H); ^{13}C NMR δ 167.0, 128.5, 128.0, 127.7, 110.1, 85.5, 83.2, 80.0, 79.4, 73.4, 71.8, 62.6, 28.0, 24.7, 18.6; FABMS *m/z* 301 (M^++1, 12.0). FABHRMS calcd for $C_{18}H_{21}O_4$ 301.1440, found 301.1438.

(*2E,3R,4R,5R*)-3-(*tert*-Butyldiphenylsiloxy)-2-propynylidene-1,6-dioxaspiro[4.5]decan-4-ol ((-)-30). According to the procedure for the preparation of (-)-**26**, (-)-**29** was converted to the corresponding alkyne. The title compond was obtained in 84% yield as a colorless oil: $[\alpha]^{25}_D$ –80.7 (*c* 0.44, $CHCl_3$); IR 3568, 3308, 2110, 1655 cm^{-1}; ^1H NMR δ 7.82-7.78 (m, 4H), 7.46-7.37 (m, 6H), 5.18 (d, 1H, *J* = 3.0 Hz), 4.71 (s, 1H), 3.93 (dt, 1H, *J* = 3.4, 11.7 Hz), 3.75 (s, 1H), 3.73 (m, 1H), 2.77 (d, 1H *J* = 3.0 Hz), 1.82-1.48 (m, 6H), 1.10 (s, 9H); ^{13}C NMR δ 168.8, 136.3, 136.1, 134.0, 133.0, 129.9, 129.8, 127.6, 127.6, 109.5, 82.8, 80.5, 80.3, 80.2, 78.8, 62.5, 28.1, 26.9, 24.7, 19.6, 18.9; MS *m/z* 448 (M^+, 3.4). HRMS calcd for $C_{27}H_{32}O_4Si$ 448.2070, found 448.2073.

(*2E,3R,4R,5R*)-4-Benzoyloxy-2-(2,4-hexadiynylidene)-1,6-dioxaspiro[4.5]decan-3-ol ((+)-32). According to the procedure described for coupling reaction of (+)-**28**, (+)-**31** (5.90 mg, 0.19 x 10^{-1} mmol) was converted into (+)-**32** (4.00 mg, 60%) as a colorless oil: $[\alpha]^{26}_D$ +183.0 (*c*

0.092, $CHCl_3$); IR 3547, 2142, 1728, 1649 cm^{-1}; ^1H NMR δ 8.03-7.98 (m, 2H), 7.60 (m, 1H), 7.48-7.42 (m, 2H), 5.29 (s, 1H), 5.24 (d, 1H, *J* = 1.0 Hz), 4.76 (d, 1H, *J* = 9.9 Hz), 3.92 (dt, 1H, *J* = 3.3, 10.9 Hz), 3.80 (m, 1H), 2.98 (d, 1H, *J* = 9.9 Hz), 1.95 (d, 3H, *J* = 1.0 Hz), 1.92-1.58 (m, 6H); ^{13}C NMR δ 170.7, 164.9, 133.6, 129.9, 128.9, 128.6, 109.9, 84.1, 80.1, 79.7, 77.4, 74.6, 69.7, 68.0, 64.7, 62.8, 27.6, 24.4, 18.5, 4.6; MS *m/z* 352 (M^+, 14.5). HRMS calcd for $C_{21}H_{20}O_5$ 352.1311, found 352.1310.

(*2E,3S,4R,5S*)-3,4-Epoxy-2-propynylidene-1,6-dioxaspiro[4.5]decane (+)-36. MsCl (0.27 x 10^{-1} mL, 0.36 mmol) was added to a solution of (-)-**30** (16.0 mg, 0.36 x 10^{-1} mmol), Et_3N (0.10 mL, 0.72 mmol) in CH_2Cl_2 (1.0 mL) at 0 °C. After being stirred for 5 min, the reaction mixture was quenched by addition of water and extracted with CH_2Cl_2, which was washed with water and brine, dried, and concentrated to dryness. The residue was passed through a short pad of silica gel with hexane-AcOEt (5:1) to afford the crude mesylate. TBAF (1.0M solution of THF, 0.36 mL, 0.36 mmol) was added to a solution of the crude mesylate in THF (3.0 mL) and the reaction mixture was stirred for 1 h at room temperature, refluxed for 3h, quenched by addition of water, and extracted with Et_2O. The extract was washed with water and brine, dried, and concentrated to dryness. Chromatography of the residue with hexane-AcOEt (5:1) afforded (+)-**36** (6.90 mg, quant.) as a colorless oil: $[\alpha]^{28}_D$ +167.6 (*c* 0.10, $CHCl_3$); IR 3308, 2106, 1661 cm^{-1}; ^1H NMR δ 5.11 (d, 1H, *J*=2.4 Hz), 4.29 (d, 1H, *J*=2.9 Hz), 3.91-3.88 (m, 2H), 3.79 (d, 1H, *J*=2.9 Hz), 2.94 (d, 1H, *J*=2.4 Hz), 1.86-1.60 (m, 6H); ^{13}C NMR δ 162.2, 134.8, 129.7, 127.7, 105.7, 85.1, 79.0, 64.7, 58.8, 52.1, 30.6, 29.7, 26.6, 24.4, 18.0; MS *m/z* 192 (M^+, 9.0). HRMS calcd for $C_{21}H_{20}O_5$ 192.0786, found 192.0796.

(2*R*,3*R*)-3-Benzyloxy-4-(*tert*-butyldimethylsiloxy)-2-(*tert*-butyldiphenylsiloxy)butan-1-ol ((+)-17): colorless oil: $[\alpha]^{28}_D$ +15.1 (*c* 1.00, $CHCl_3$) Anal. Calcd for $C_{33}H_{48}O_4Si_2$: C, 70.16; H, 8.56. Found: C, 69.84, H, 8.57.

(3*R*,4*R*)-4-Benzyloxy-5-(*tert*-butyldimethylsiloxy)-3-(*tert*-butyldiphenylsiloxy)pent-1-yne ((+)-18): colorless oil: $[\alpha]^{30}_{D}$ +0.1 (*c* 0.93, $CHCl_3$); Anal. Calcd for $C_{34}H_{46}O_3Si_2$: C, 73.07; H, 8.30. Found: C, 72.78, H, 8.42.

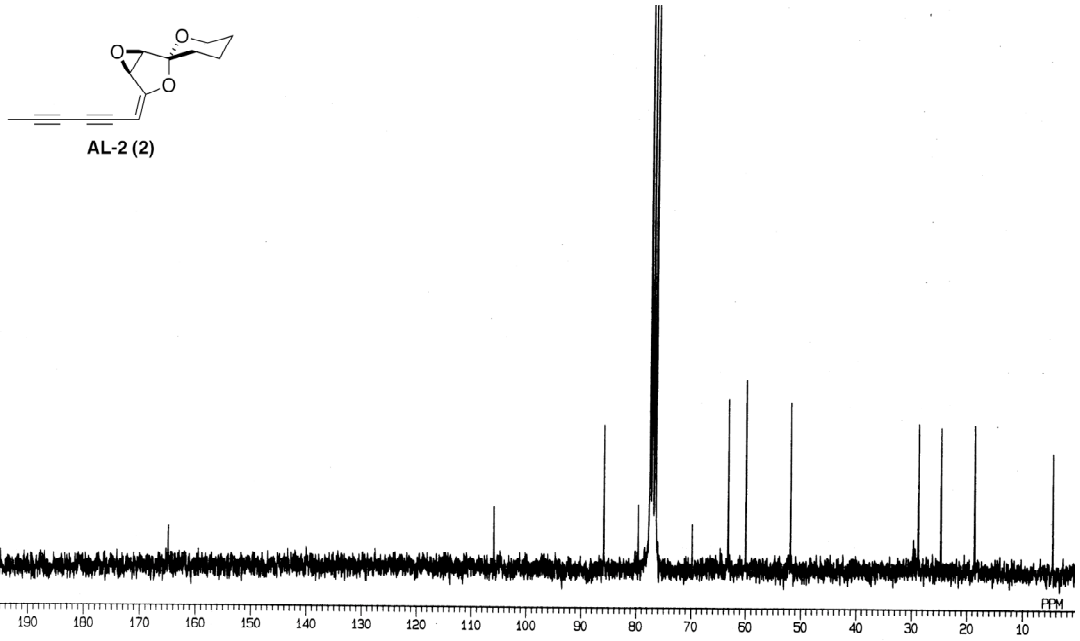
(2*R*,3*R*)-2-Benzyloxy-3-(*tert*-butyldiphenylsiloxy)-4-pentyn-1-ol ((+)-19): colorless oil: $[\alpha]^{26}_{D}$ +5.7 (*c* 1.00, $CHCl_3$); Anal. Calcd for $C_{28}H_{32}O_3Si$: C, 75.63; H, 7.25. Found: C, 75.51, H, 7.25.

(3*R*,4*S*)-4-Benzyloxy-9-(*tert*-butyldimethylsiloxy)-3-(*tert*-butyldiphenylsiloxy)-1-nonyn-5-one ((-)-20): colorless oil: $[\alpha]^{26}_{D}$ -39.8 (*c* 1.05, $CHCl_3$); Anal. Calcd for $C_{38}H_{52}O_4Si_2$: C, 72.56; H, 8.33. Found: C, 72.29, H, 8.58.

(*2E*,*3S*,*4S*,*5S*)-4-Benzyloxy-3-(*tert*-butyldiphenylsiloxy)-2-methoxycarbonylmethylidene-1,6-dioxaspiro[4.5]decane ((+)-22): $[\alpha]^{24}_{D}$ +75.6 (*c* 0.21, $CHCl_3$); FABMS *m*/*z* 573 (M^++1, 1.4). FABHRMS calcd for $C_{34}H_{41}O_6Si$ 573.2672, found 573.2640.

(*2E*,*3S*,*4S*,*5S*)-3-(*tert*-Butyldiphenylsiloxy)-2-(2-hydroxyethylidene)-1,6-dioxaspiro[4.5]decan-4-ol ((+)-29): colorless needles: mp. 168.5-169.5 °C (hexane-AcOEt); $[\alpha]^{25}_{D}$ +70.4 (*c* 0.19, THF); Anal. Calcd for $C_{26}H_{34}O_5Si$: C, 68.69; H, 7.54. Found: C, 68.62, H, 7.63.

(*2E*,*3S*,*4S*,*5S*)-3-(*tert*-Butyldiphenylsiloxy)-2-propynylidene-1,6-dioxaspiro[4.5]decan-4-ol ((+)-30): colorless oil: $[\alpha]^{25}_{D}$ +82.03 (*c* 0.27, $CHCl_3$); MS *m*/*z* 448 (M^+, 0.7). HRMS calcd for $C_{27}H_{32}O_4Si$ 448.2070, found 448.2073.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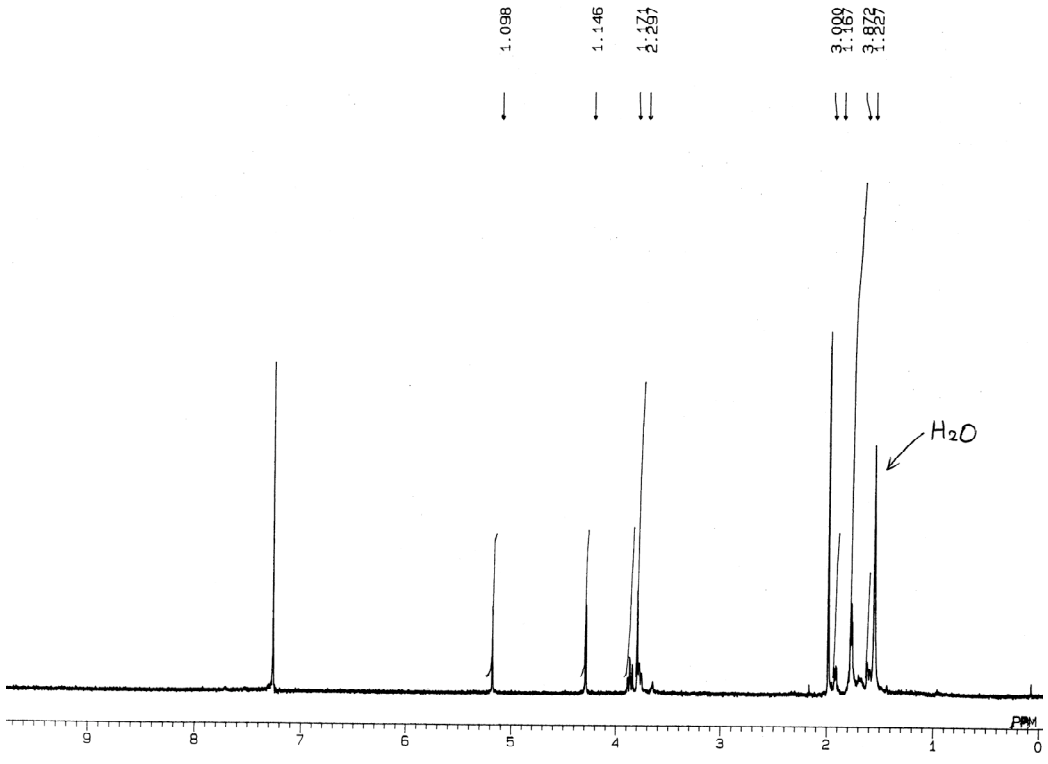
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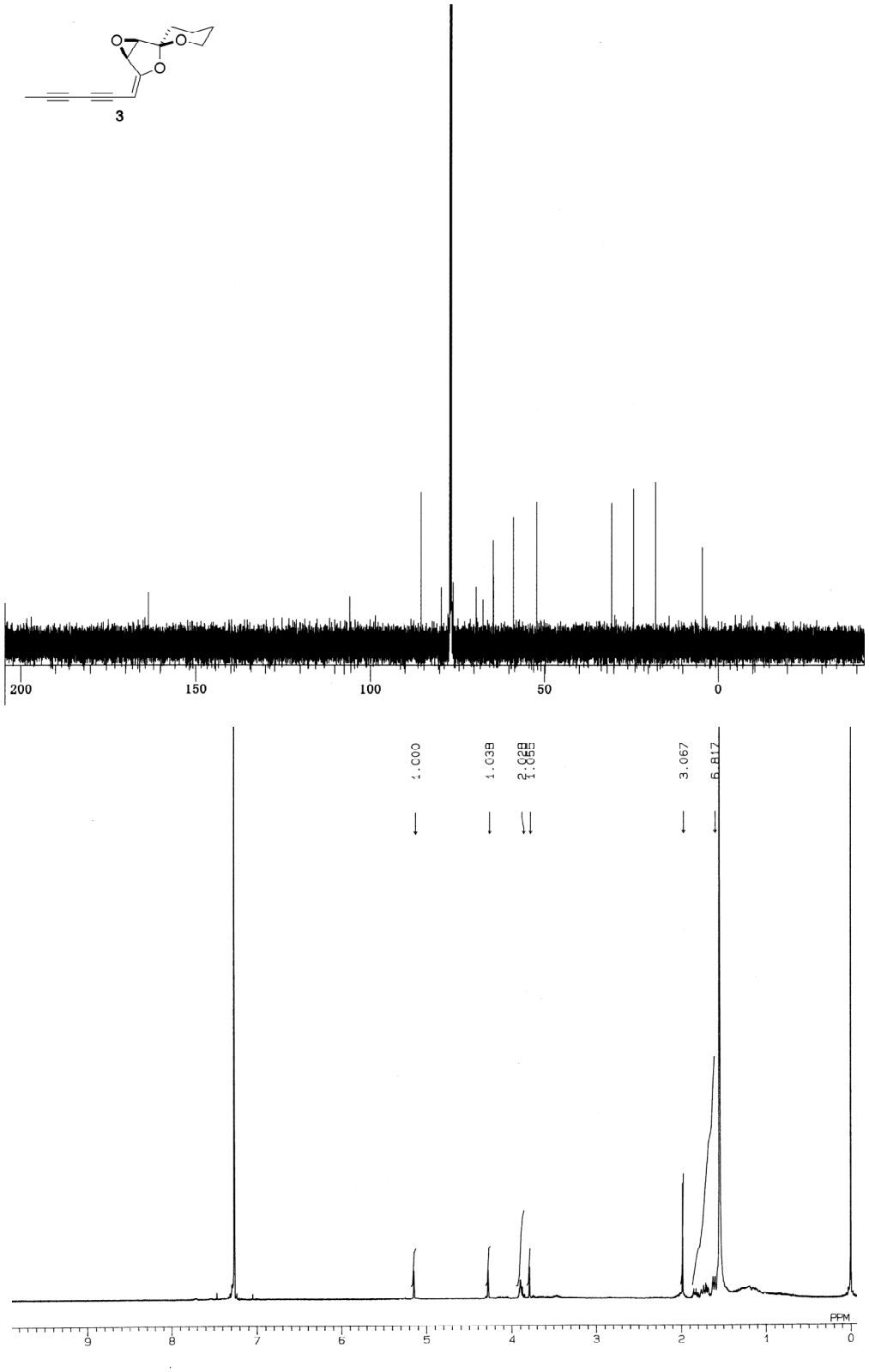
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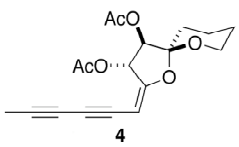
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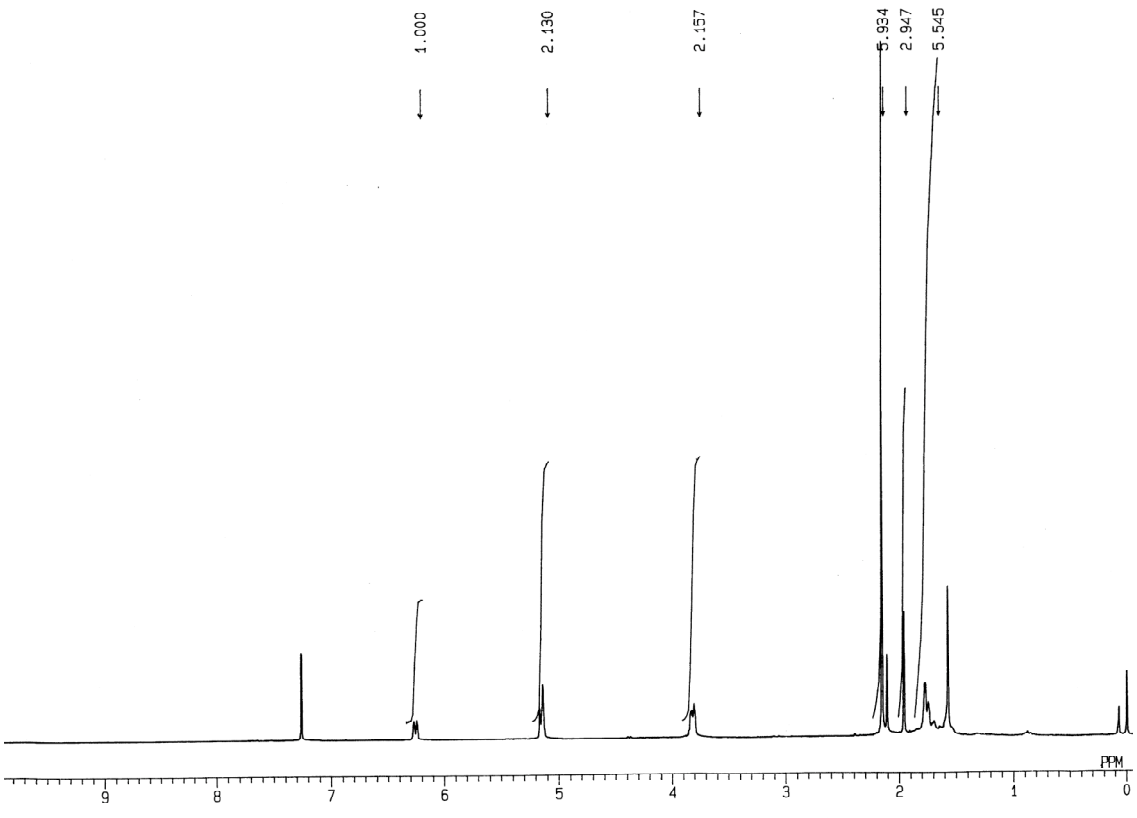
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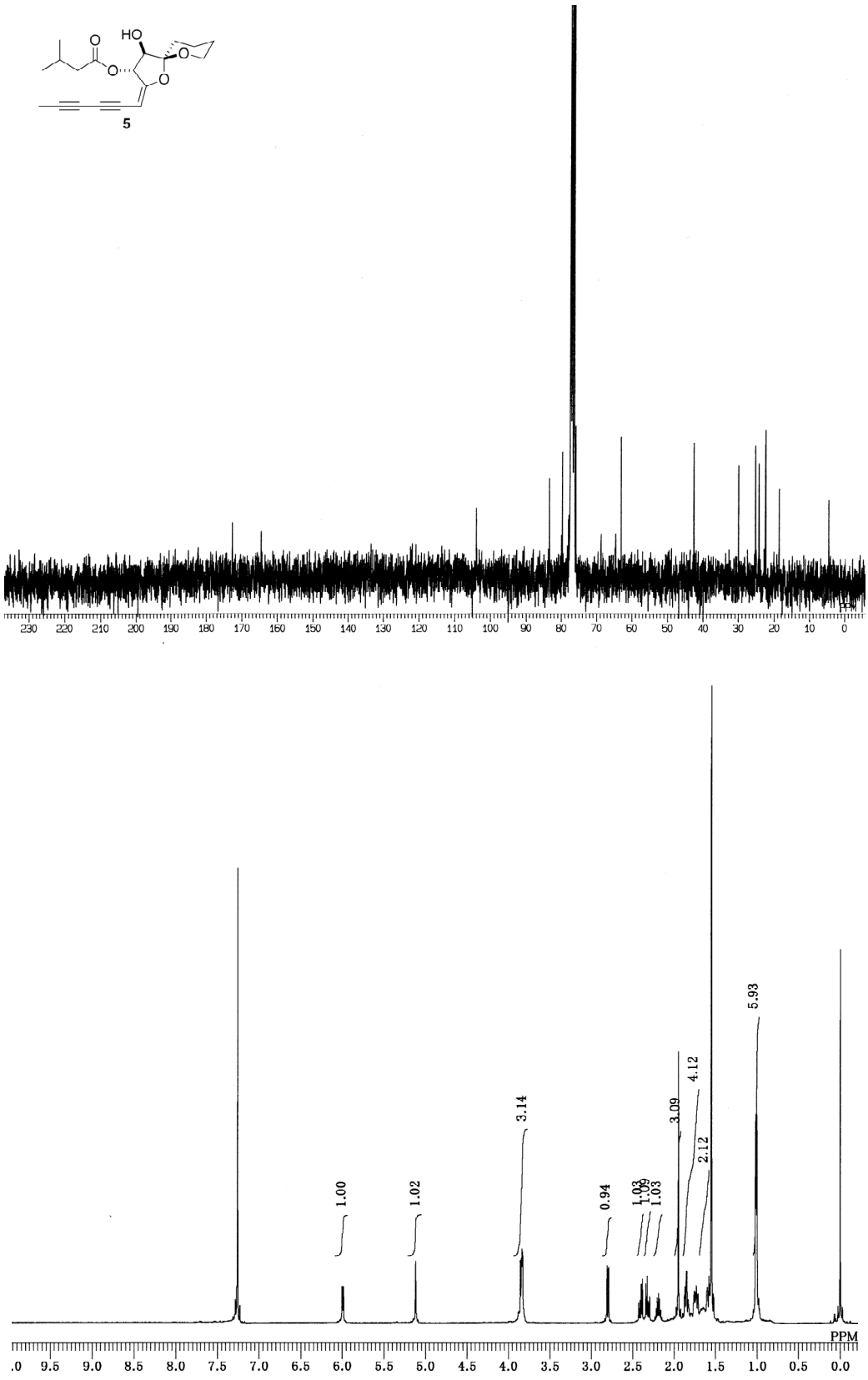
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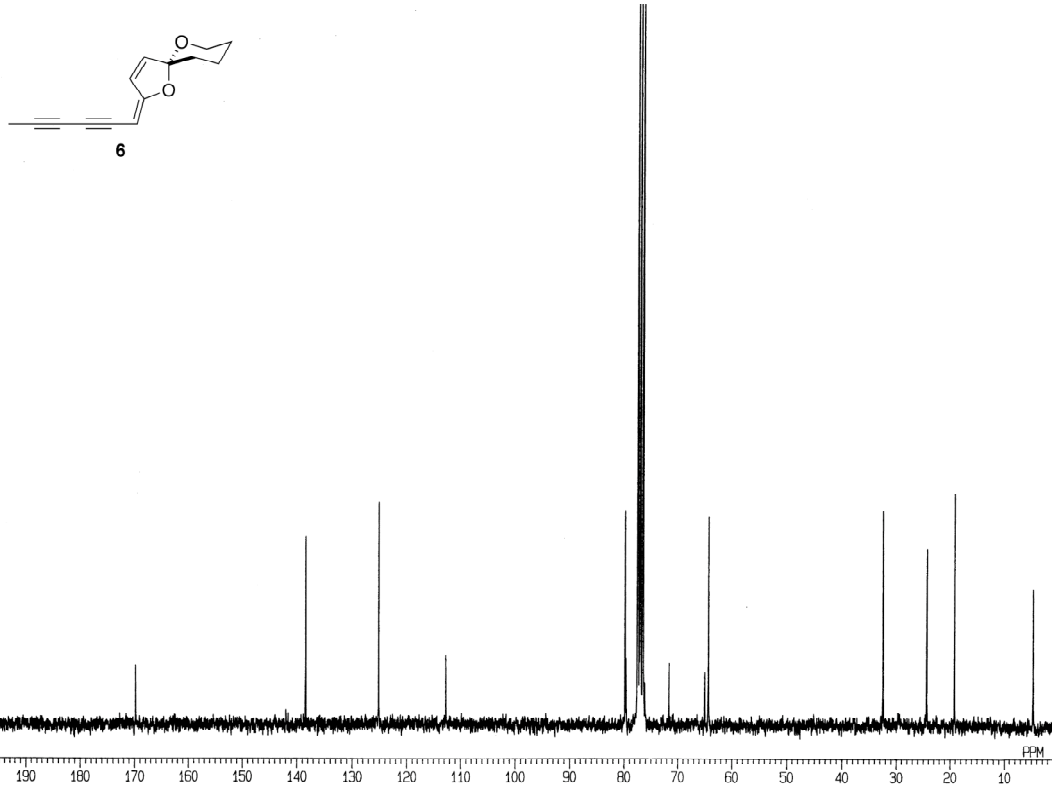
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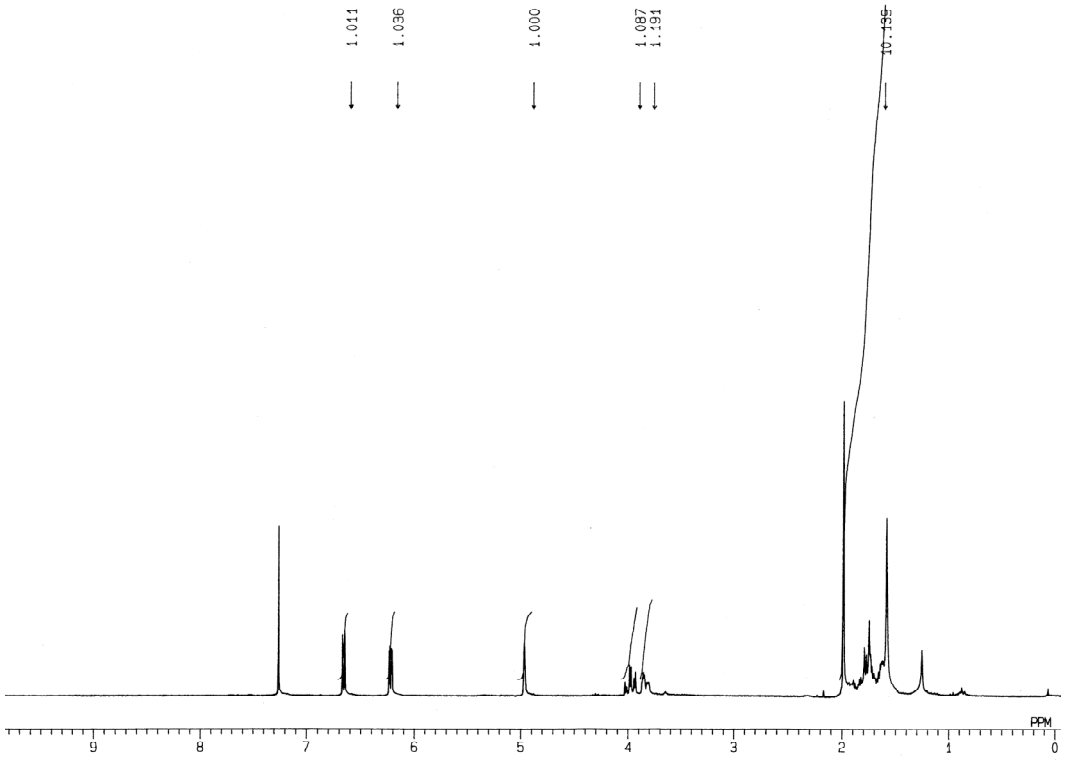
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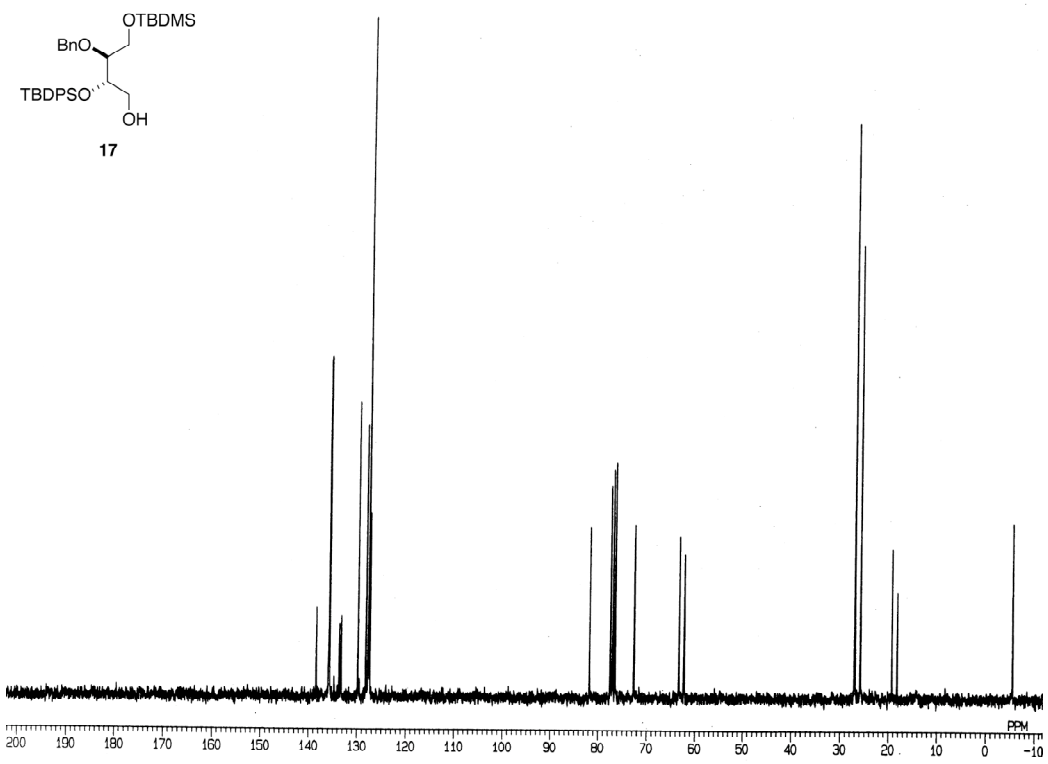
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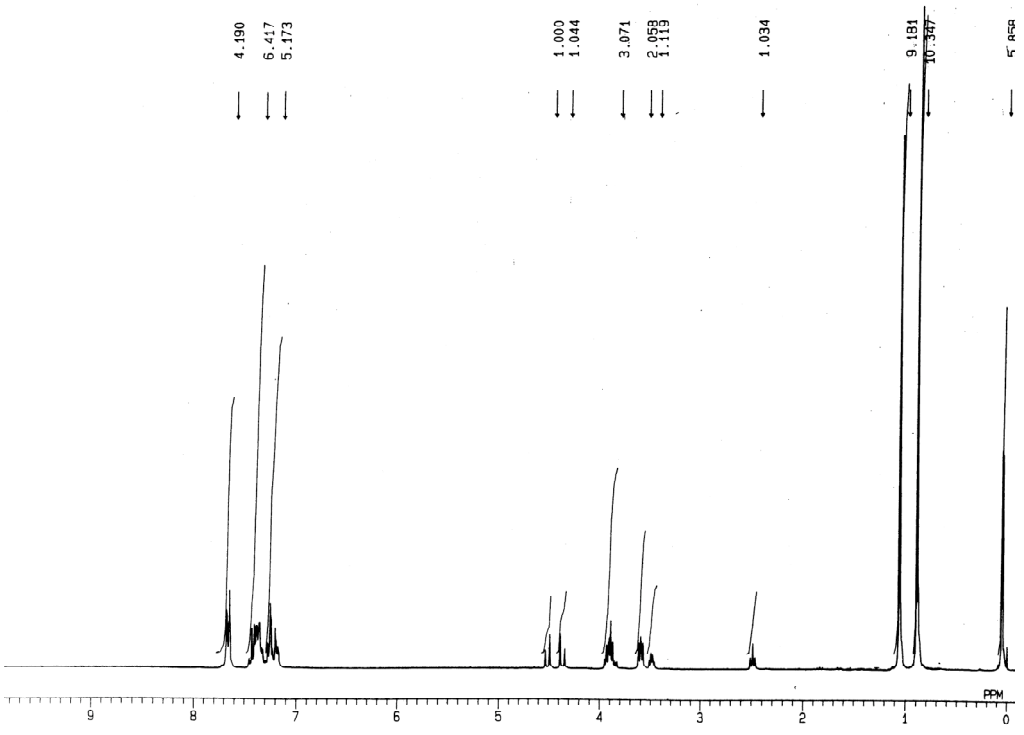
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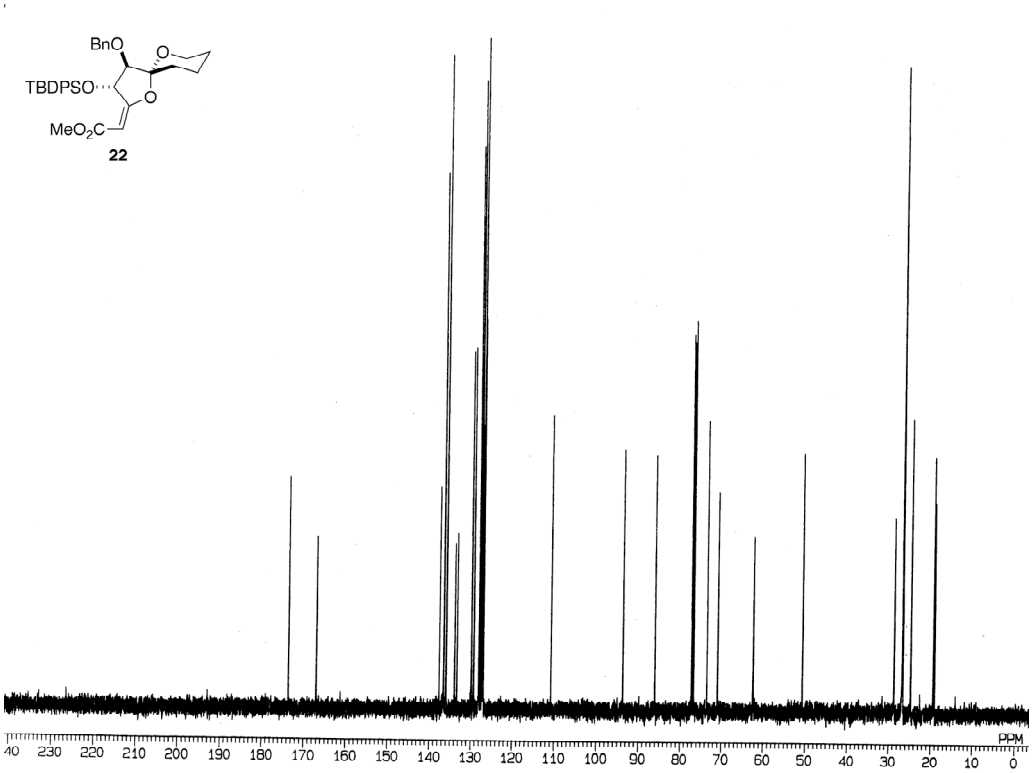
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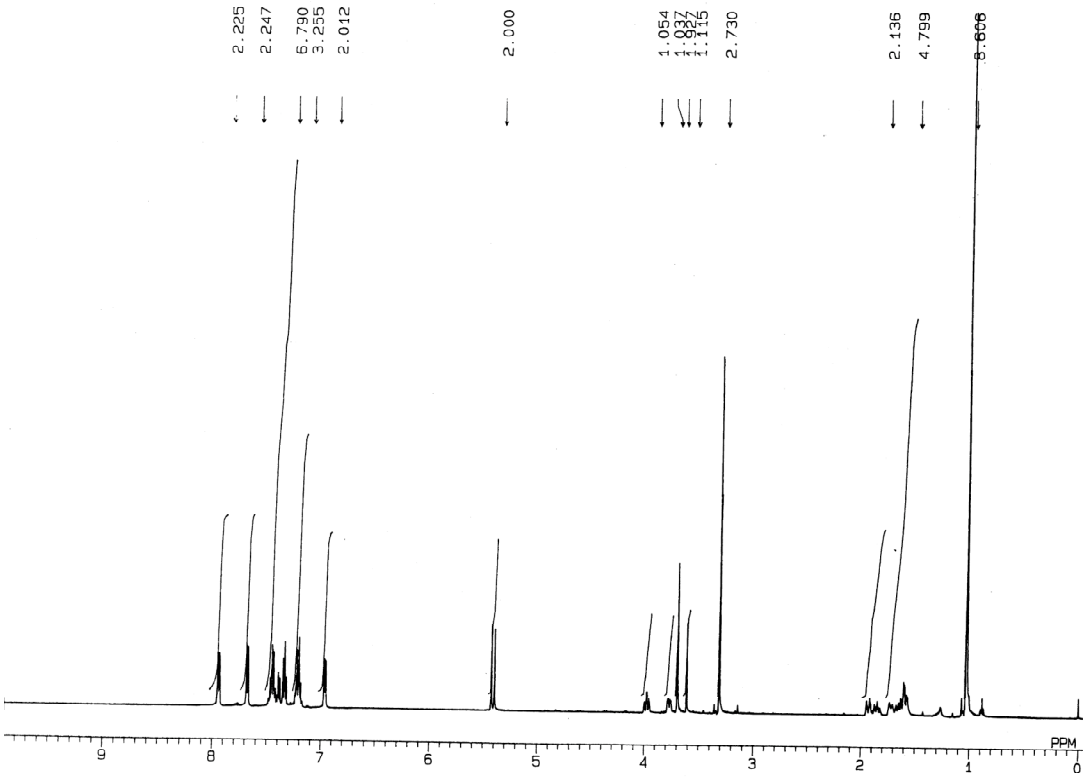
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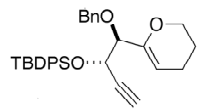
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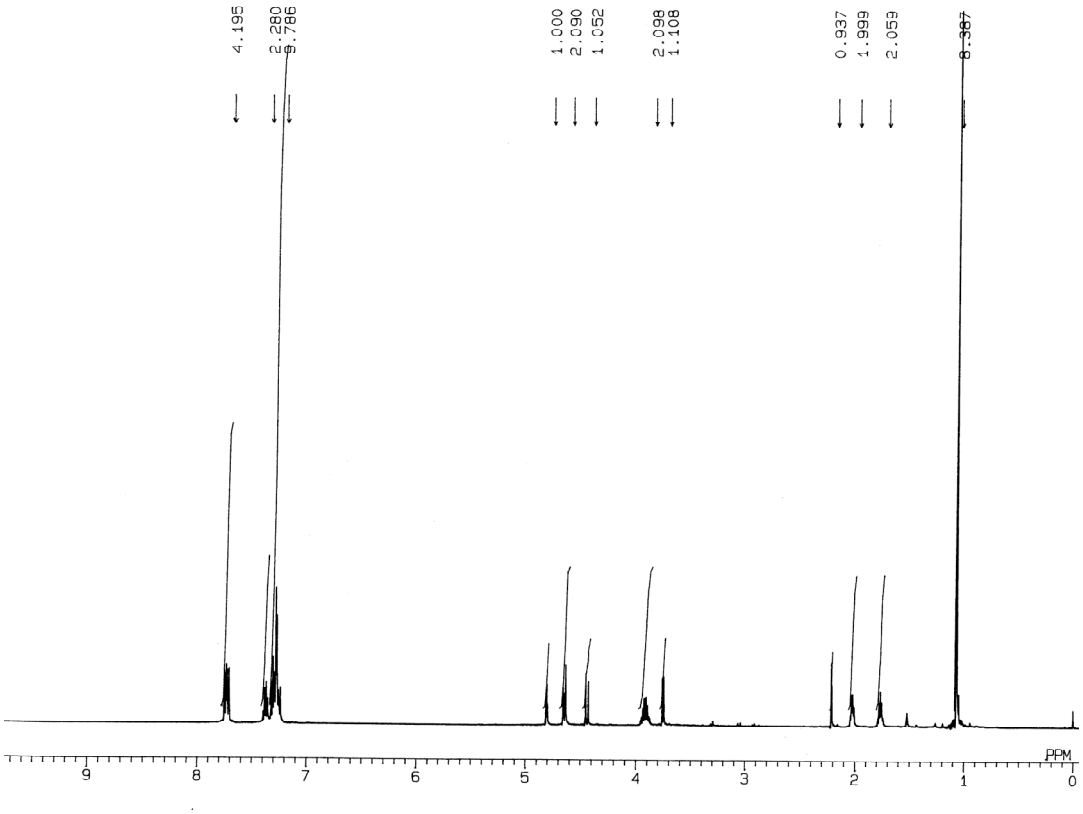
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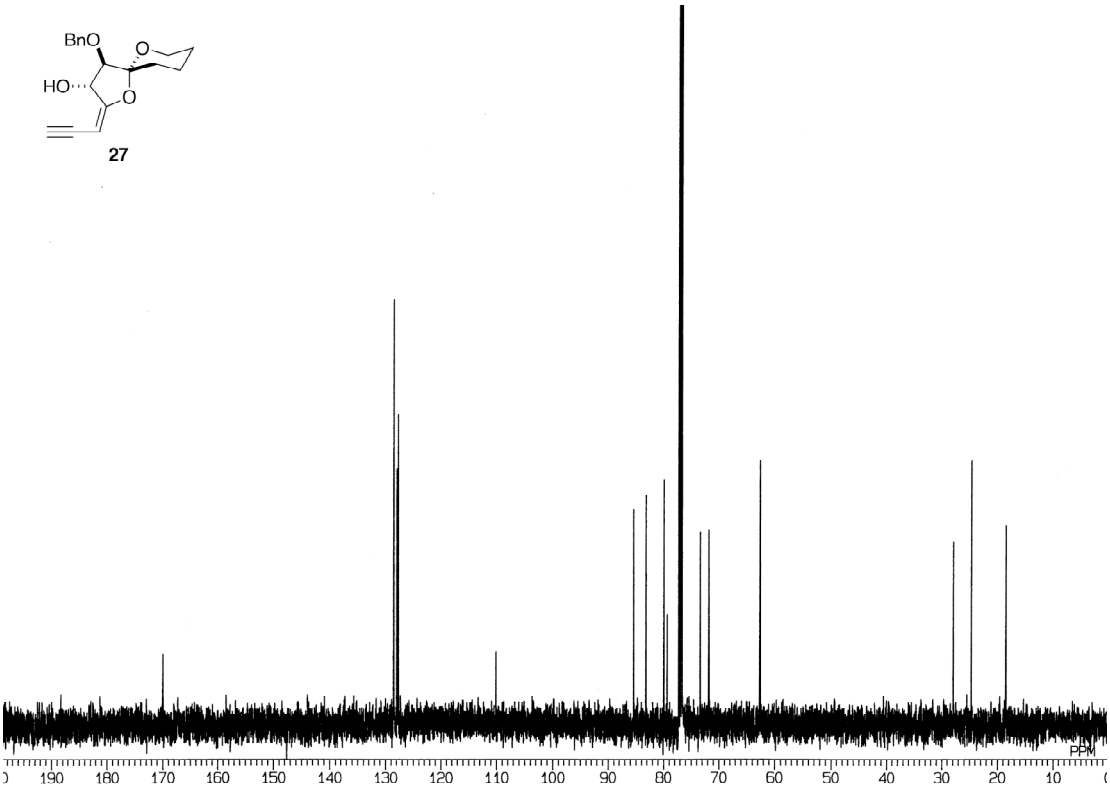
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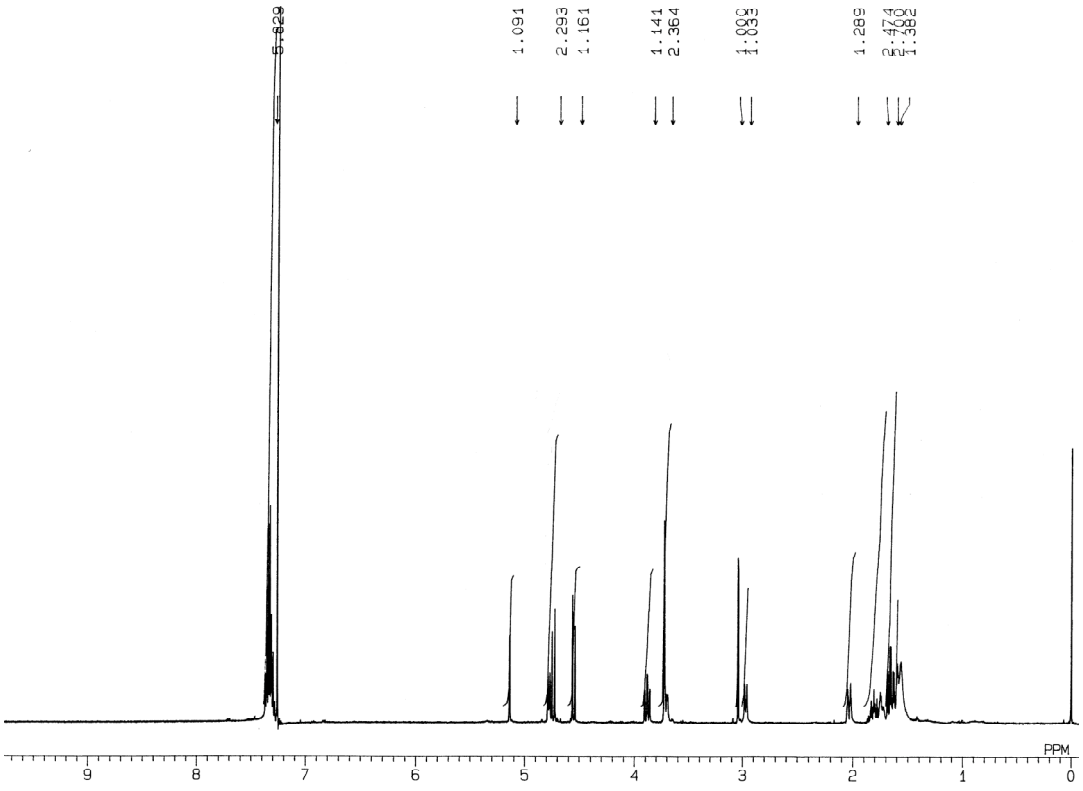
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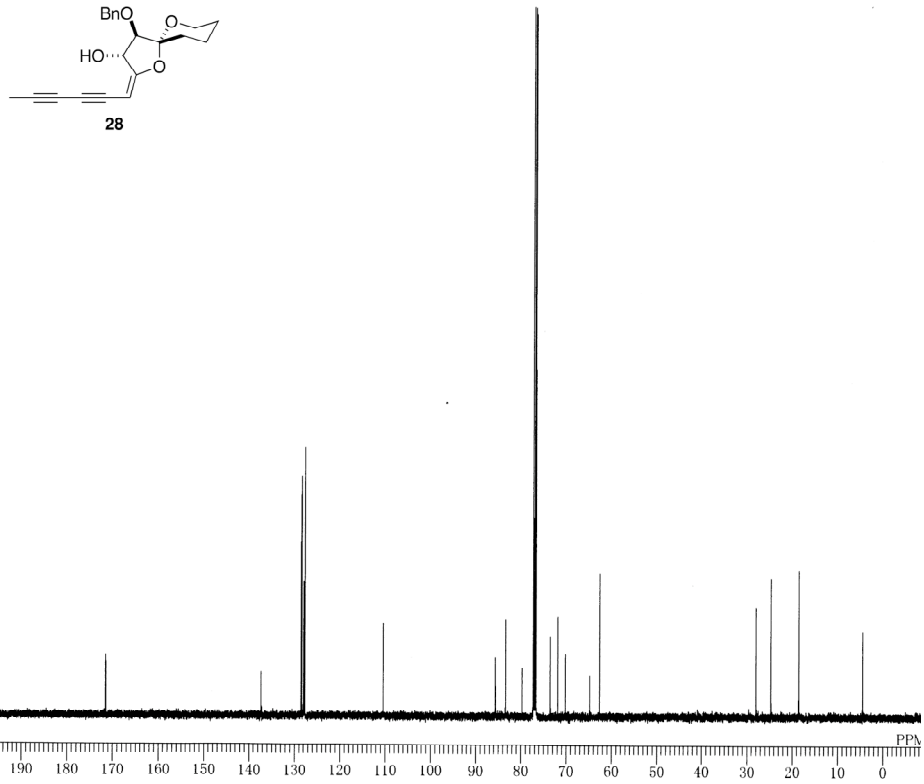
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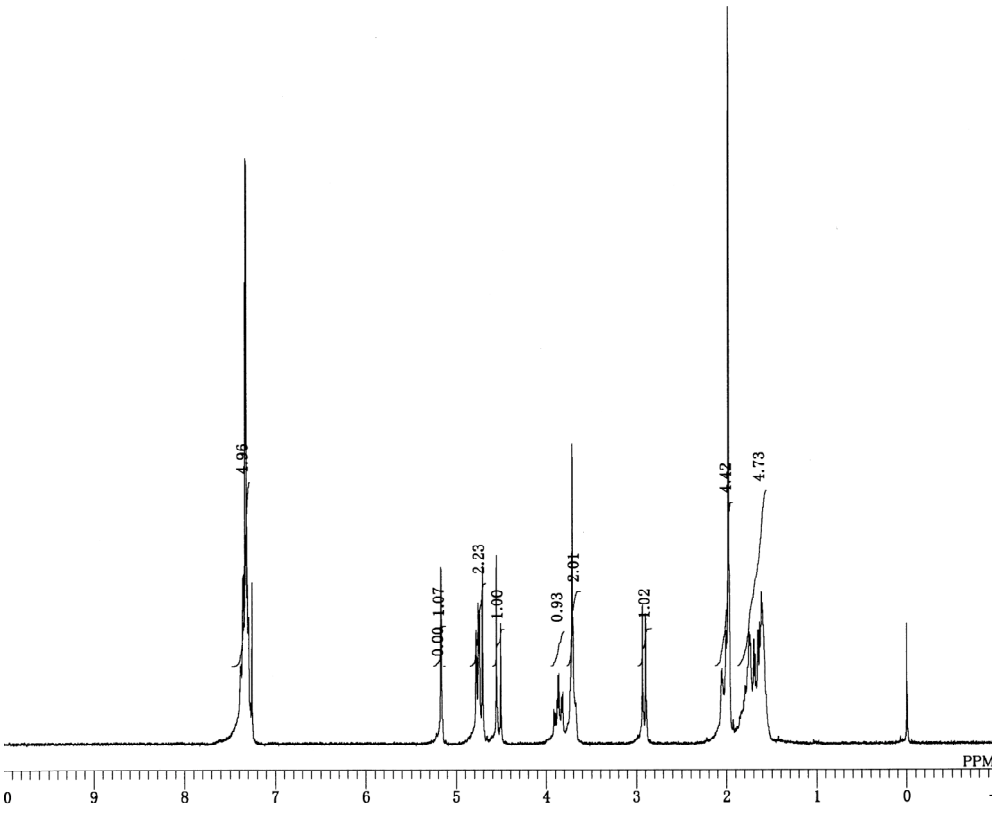
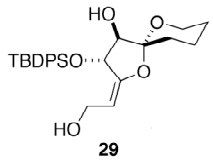
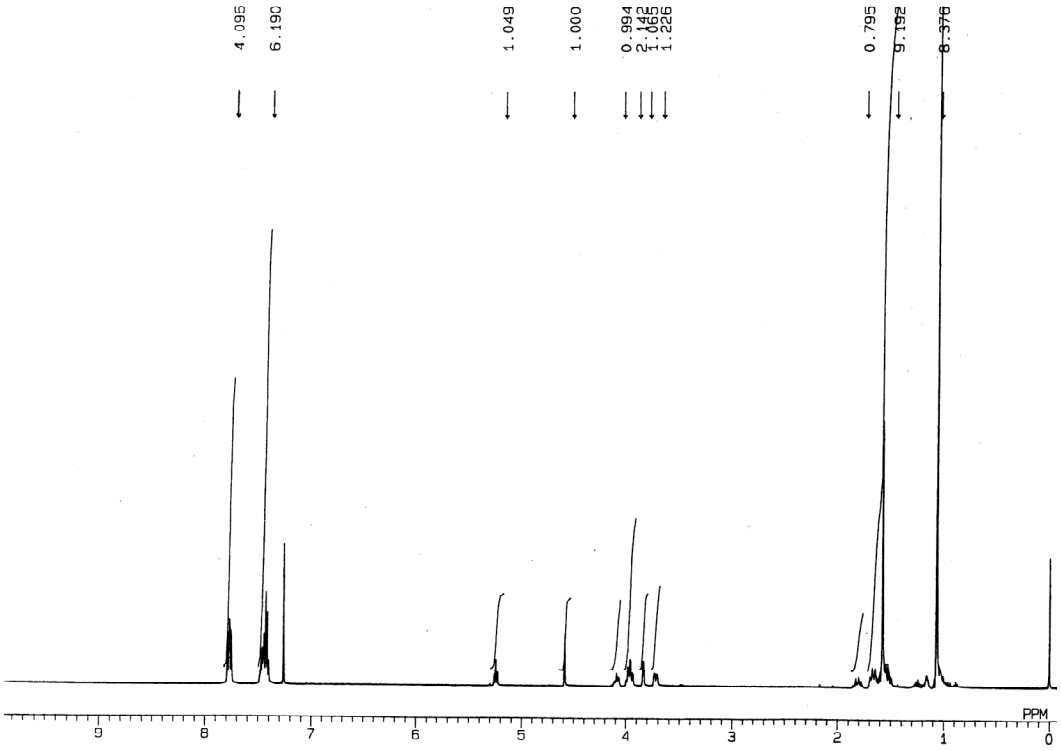

4.96
0.00
1.07
2.23
1.00
0.93
2.01
1.02
4.42
4.73
PPM
0 9 8 7 6 5 4 3 2 1 0


HO
TBDPSO
O
O
HO

29

PPM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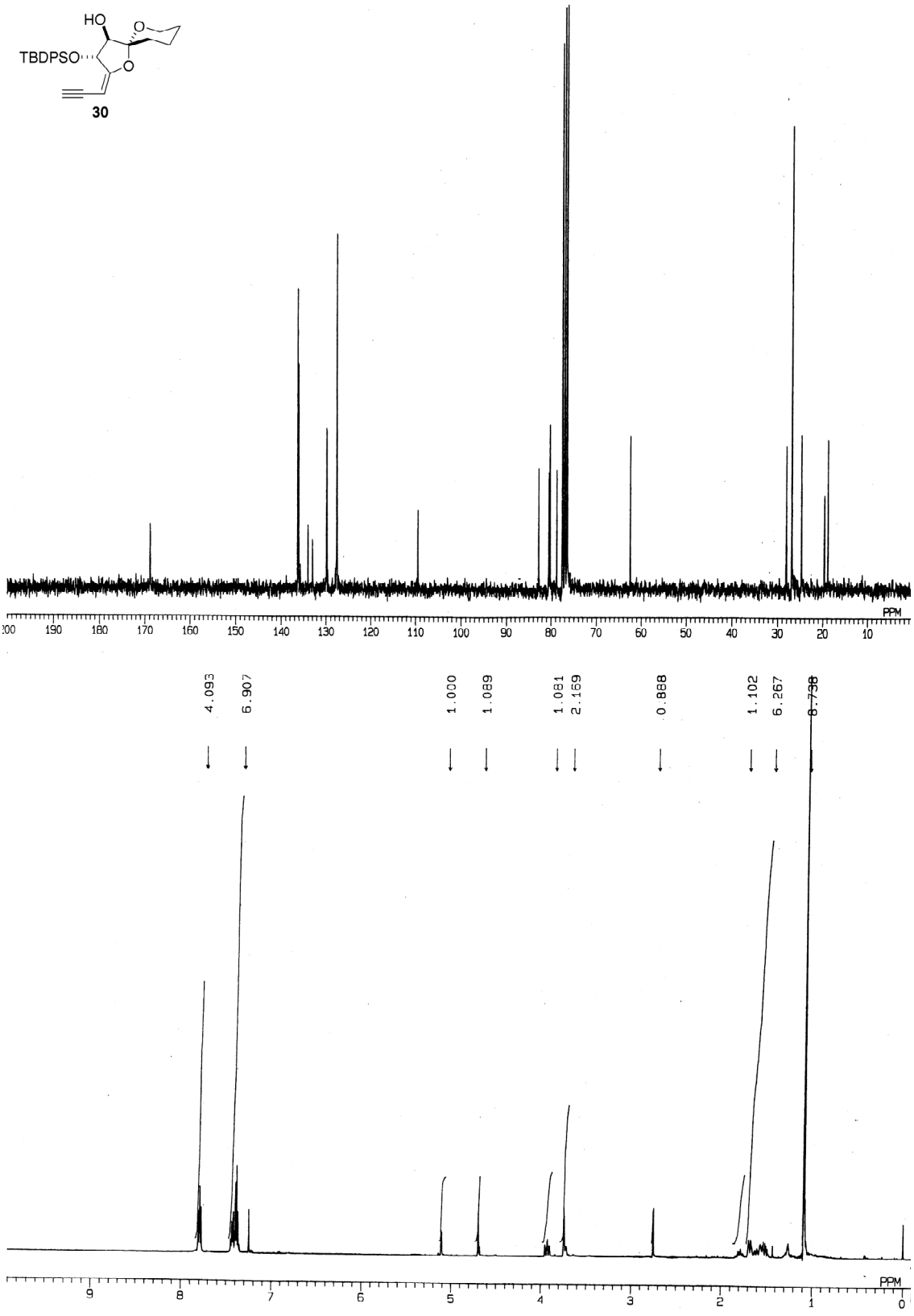
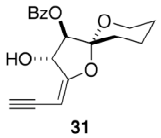
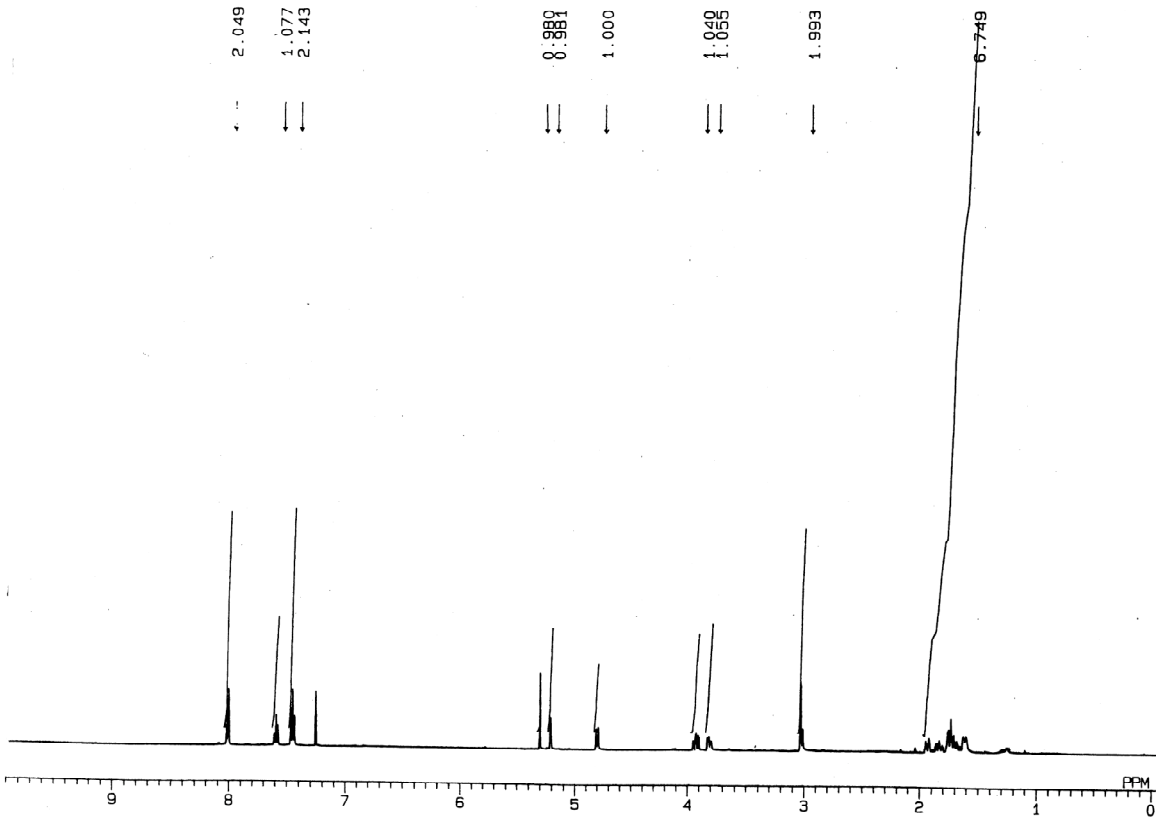
6.190
1.049
1.000
0.994
2.142
1.065
1.226
0.795
9.192
6.376
PPM


HO
TBDPSO
O
O
30
PPM
4.093
6.907
1.000
1.089
1.051
2.159
0.888
1.102
6.267
8.738
PPM


BzO
HO
O
O

31

PPM
00 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0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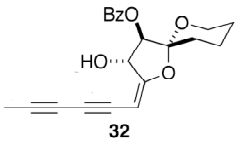
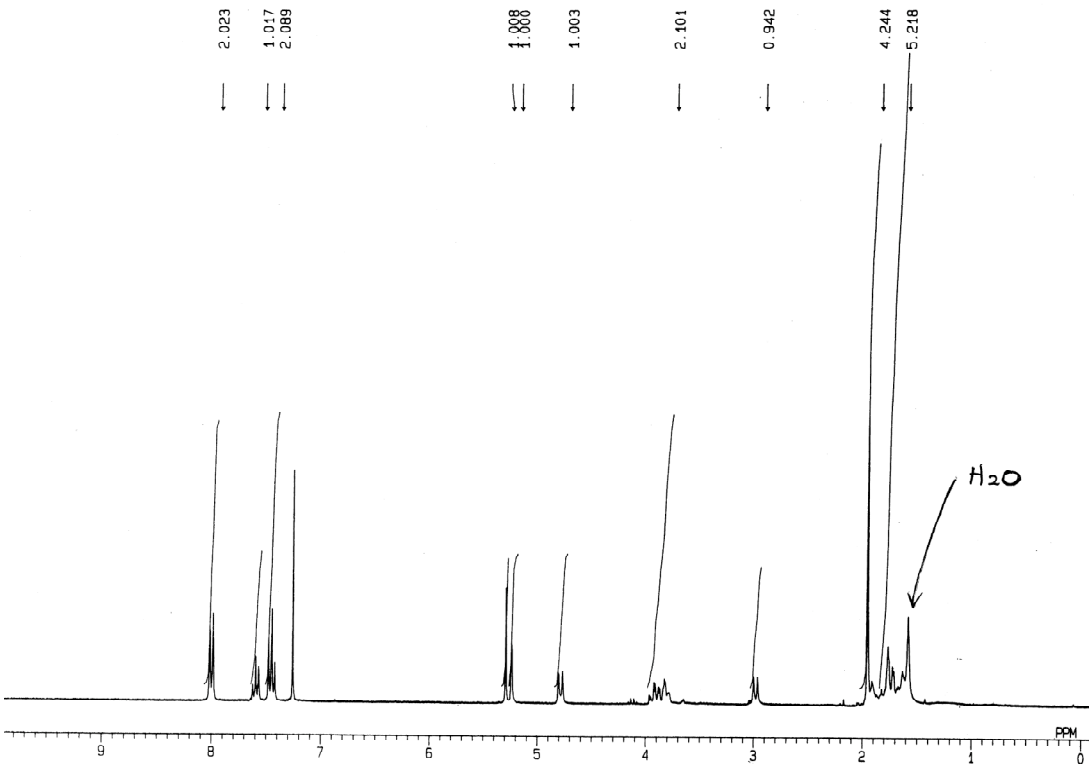
1.077
2.143
0.980
0.981
1.000
1.040
1.055
1.993
6.749
PPM
9 8 7 6 5 4 3 2 1 0


BzO
O
HO
O

32

190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
PPM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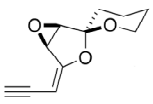
1.017
2.089
1.008
1.000
1.003
2.101
0.942
4.244
5.218
H2O
9
8
7
6
5
4
3
2
1
0
PPM



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